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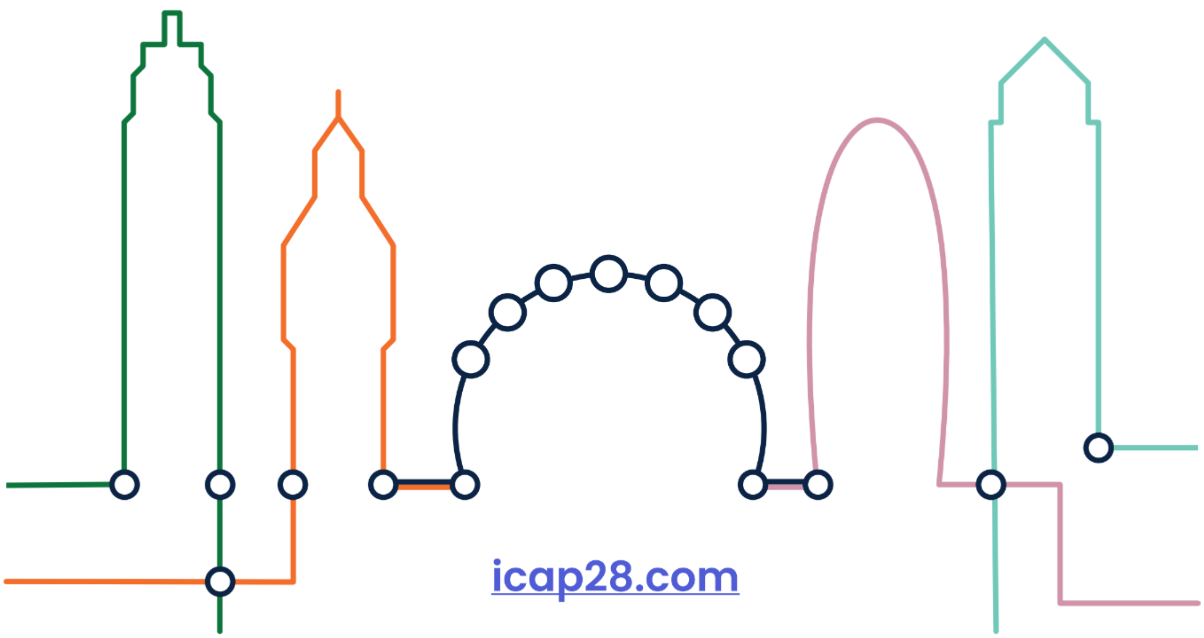

Book of Abstracts

Sorted by program code

A01

Highly Charged Ion Clocks to Test Fundamental Physics

Piet O. Schmidt

Physikalisch-Technische Bundesanstalt, Braunschweig, Germany. Leibniz Universität Hannover, Hannover, Germany

Abstract

The extreme electronic properties of highly charged ions (HCI) render them highly sensitive probes for testing fundamental physical theories. The same properties reduce systematic frequency shifts, making HCI excellent optical clock candidates [1]. The technical challenges that hindered the development of such clocks have now been overcome, starting with their extraction from a hot plasma and sympathetic cooling in a Paul trap [2], readout of their internal state via quantum logic spectroscopy [3], and finally the preparation of the HCI in the motional ground state of the trap [4]. Here, we present the first optical clock based on an HCI (Ar^{13+} in our case) and a full evaluation of systematic frequency shifts [5]. The achieved uncertainty is almost eight orders of magnitude lower than any previous frequency measurements using HCI and comparable to other optical clocks. By measuring the isotope shift between $^{36}Ar^{13+}$ and $^{40}Ar^{13+}$ the theoretically predicted QED nuclear recoil effect could be confirmed. Finally, first results on the search for a 5th force based on isotope shift spectroscopy of Ca^{+}/Ca^{14+} isotopes will be presented. This demonstrates the suitability of HCI as references for high-accuracy optical clocks and to probe for physics beyond the standard model.

References

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2. Schmöger, L. *et al.*, Science **347**, 1233 (2015).
3. Micke, P. *et al.*, Nature **578**, 60 (2020).
4. King, S. A. *et al.*, Phys. Rev. X **11**, 041049 (2021).
5. King, S. A. *et al.*, Nature **611**, 43 (2022).

Categories

Clocks and metrology

Presentation

Invited speaker

A02

Antihydrogen physics: spectroscopy to 13 significant figures and beyond

Claudio Lenz Cesar

UFRJ, Rio de Janeiro, Brazil

Abstract

I describe work with trapped antihydrogen at the ALPHA collaboration at CERN. The 1S-2S transition frequency measurement[1] used a 300 mK average energy sample. The resolution, lower than that of trapped H spectroscopy at MIT[2] and still far from the natural linewidth limit, allowed the most precise comparison of antimatter with matter[3]. With laser cooling[4], the ALPHA experiment data from 2023 (under blind analysis) points to a 13 significant figure absolute frequency measurement. A future comparison at 15 figures or more will be discussed in conjunction with techniques[5] to load hydrogen into the same antihydrogen trap and its detection independent of annihilation signal[6]. I also briefly describe results on the gravitational fall of antihydrogen[7,8].

[1] M. Ahmadi et al. Characterization of the 1S–2S transition in antihydrogen. Nature 557,71(2018)

[2] C.L.Cesar et al. Two-photon spectroscopy of trapped atomic hydrogen. Phys.Rev.Lett.77, 255(1996)

[3] C.G.Parthey et al. Improved measurement of the hydrogen 1S–2S transition frequency. Phys.Rev.Lett.107,203001(2011)

[4] C.J. Baker et al. Laser cooling of antihydrogen atoms. Nature 592,35(2021).

[5] L.O. Azevedo et al. Adaptable platform for trapped cold electrons, hydrogen and lithium anions and cations. Commun.Phys.6,112(2023)

[6] C.L. Cesar, A sensitive detection method for high resolution spectroscopy of trapped antihydrogen, hydrogen and other trapped species. J.Phys.B 49,074001(2016)

[7] E.K. Anderson et al., Observation of the effect of gravity on the motion of antimatter, Nature 621, 716(2023)

[8] C.L.Cesar, Trapping and spectroscopy of hydrogen. Hyp.Interact.109,293(1997)

Categories

Precision measurements

Presentation

Invited speaker

A03

Precision Spectroscopy with In+ and Yb+ Ions

Tanja Mehlstäubler

PTB, Braunschweig, Germany. Leibniz University Hannover, Hannover, Germany

Abstract

Trapped and laser-cooled ions allow for a high degree of control of atomic quantum systems. They are the basis for modern atomic clocks, quantum computers and quantum simulators. In our research we use ion Coulomb crystals, i.e. many-body systems with complex dynamics, for precision spectroscopy. Multi-ion clocks will not only improve the stability by exploiting the higher signal to noise of multiple ions or their uncertainty by allowing for sympathetic cooling of clock ions using a separate ion species but will be the basis for future entangled clocks and cascaded clocks.

This paves the way to novel optical frequency standards with ultra-high stability reaching 10^-19 relative accuracy and stability, and for applications such as relativistic geodesy and quantum simulators in which complex dynamics becomes accessible with atomic resolution. We will report on the first multi-ion clock operation and frequency comparisons.

Last but not least, I will briefly discuss new world-record limits we obtained in our work on an improved test of local Lorentz invariance using $^{172}Yb^{+}$ ions and the search for new bosons using clock spectroscopy on even Yb^{+} isotopes.

Categories

Precision measurements

Presentation

Invited speaker

A04

Quantum computing with neutral ytterbium atoms

Jeff Thompson

Princeton University, Princeton, USA

Abstract

Neutral atom quantum computing is a rapidly developing field. Exploring new atomic species, such as alkaline earth atoms, provides additional opportunities for cooling and trapping, measurement, qubit manipulation, high-fidelity gates and quantum error correction. In this talk, I will present recent results from our group on implementing high-fidelity gates on nuclear spins encoded in metastable ^{171}Yb atoms, including mid-circuit detection of gate errors that give rise to leakage out of the qubit space, using erasure conversion. I will conclude by discussing several new directions including spectroscopy and modeling of ^{171}Yb Rydberg states and interactions, which has led to improved two-qubit gate fidelities.

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

A05

Towards new frontiers of quantum science with dual-species atom arrays

Giulia Semeghini

Harvard University, Cambridge, USA

Abstract

In this talk, we will explore recent advancements in quantum science using Rydberg atom arrays and present future applications enabled by the use of a dual-species array based on a mixture of alkali and alkaline-earth atoms. Trapped arrays of interacting Rydberg atoms have become a leading platform for quantum information processing and quantum simulation due to their large system size and programmability. The use of two atomic species allows for the independent control of two different sets of qubits for quantum error correction, and selective tuning of inter- and intra-species interactions for more flexible Hamiltonian engineering. These new features enable more efficient protocols for quantum information processing and would allow to simulate a broader class of highly-entangled phases of matter. We will present the current development of a new experimental platform based on Yb and Rb atom arrays, leveraging the distinct characteristics of these two atomic species to create a versatile platform for quantum simulation and quantum information processing.

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

A06

Hilbert space fragmentation in a Rydberg atom array

Huanqian Loh

Duke University, Durham, USA. National University of Singapore, Singapore, Singapore

Abstract

Scalable and programmable Rydberg atom arrays offer a promising platform for exploring quantum science. When atoms undergo Rydberg blockade, the prevention of nearby atoms from being excited to the Rydberg state leads to constrained dynamics, such as that in the effective PXP model. Complementary to the Rydberg-blockade mechanism is facilitation, where a Rydberg atom must be present in order to drive other nearby atoms to the Rydberg state.

In this talk, I will present our results on combining both blockade and facilitation by invoking beyond-nearest-neighbor interactions. Our tools allow us to realize a broad class of models where the Hilbert space has been shattered into exponentially many disjointed subspaces. For strongly fragmented models, we uncover interesting dynamics such as Z_{2n} quantum many-body scarring, which generalizes beyond the Z_2 scars previously reported in cold-atom systems. When bringing multiple long-range interactions into resonance, we observe quantum thermalization restricted to Hilbert space fragments. Notably, thermalization between states belonging to different subspaces is forbidden, even when these states have the same energy, defying expectations from the eigenstate thermalization hypothesis.

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

A07

Quantum networking with photons and trapped ions

David Lucas

Department of Physics, Oxford University, Oxford, United Kingdom

Abstract

Trapped-ion qubits are one of the leading platforms for quantum computing. Combined with photonic interconnects, trapped-ion processors can form the basis of a quantum network. Our apparatus in Oxford consists of two independent ion traps, separated by about 2 metres, linked via a single-photon optical fibre interface [1]. It is capable of generating entangled pairs of ions, one in each trap, with high fidelity (94%) and at high rates (182/sec). We have previously used it to implement fully device-independent quantum key distribution [2] and entanglement-enhanced comparison of optical atomic clock transitions [3].

Recently we have added robust memory qubits to the nodes [4], enabling the quantum information to be preserved for around 10 seconds, much longer than the time taken to generate remote entanglement. I will present recent work on demonstrating "blind" quantum computing using this hybrid matter-photon system [5], and preliminary results on implementing distributed logic operations across the network link.

[1] L. J. Stephenson, D. P. Nadlinger *et al.*, Phys.Rev.Lett. **124**, 110501 (2020).
[2] D. P. Nadlinger, P. Drmota *et al.*, Nature **607**, 682 (2022).
[3] B. C. Nichol, R. Srinivas *et al.*, Nature **609**, 689 (2022).
[4] P. Drmota, D. Main *et al.*, Phys.Rev.Lett. **130**, 090803 (2023).
[5] P. Drmota, D. P. Nadlinger *et al.*, Phys.Rev.Lett. **132**, 150604 (2024).

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

A08

A two-dimensional trapped-ion quantum simulator with single-qubit control

Christian Roos

University of Innsbruck, Innsbruck, Austria

Abstract

Trapped ions illuminated with laser light constitute an engineered quantum system that enables the realization of spin-lattice models with long-range interactions. While linear ion strings of up to 50 ions have been used for this purpose for a long time, experiments with two-dimensional ion crystals held in radiofrequency traps started only recently.

I will present experiments demonstrating control over planar ion crystals with more than 100 ions [1]. After cooling all transverse motional modes of the crystal close to the ground state, long-range transverse field Ising models can be realized by Raman interactions that off-resonantly couple the Zeeman ground states of singly-charged calcium ions to crystal's motional modes. We demonstrate the creation of spin-squeezed states of up to 91 ions using an approach previously realized with long ion chains [2], characterize the spin-spin interactions and demonstrate single-qubit control over all ions in the crystal.

[1] D. Kiesenhofer, H. Hainzer et al, PRX Quantum **4**, 020317 (2023)

[2] J. Franke et al., Nature **621**, 740 (2023)

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

A09

Entangling Ultracold Molecules

Kang-Kuen Ni

Harvard University, Cambridge, USA

Abstract

Coherence and entanglement are key features of quantum mechanics, although they are susceptible to environmental perturbations. A conventional strategy to entangle qubits with high fidelity is to leverage precisely controlled interactions while keeping qubits from decohering. By leveraging electric dipolar interactions, I will report entangling individual trapped NaCs molecules in optical tweezers. Going beyond this paradigm, we explore and ask the question: Can coherence be preserved during chemical reactions and subsequently harnessed to produce entangled products? To address this question, we conduct investigations within the context of an atom-exchange chemical reaction (2KRb -> K2 + Rb2) at a temperature of 500nK. I will share our research findings including surprises and puzzles.

Categories

Molecules

Presentation

Invited speaker

A10

Ultracold RbCs molecules in magic-wavelength traps and optical tweezers

Simon Cornish

Durham University, Durham, United Kingdom

Abstract

Ultracold polar molecules are an exciting new platform for quantum science and technology. The combination of rich internal structure of vibration and rotation, controllable long-range dipole-dipole interactions and strong coupling to applied electric and microwave fields has inspired many applications. These include quantum simulation of strongly interacting many-body systems, the study of quantum magnetism, quantum metrology and molecular clocks, quantum computation, precision tests of fundamental physics and the exploration of ultracold chemistry. Many of these applications require full quantum control of both the internal and motional degrees of freedom at the level of single molecules, combined with traps that support long coherence times for rotational-state superpositions.

Using ultracold RbCs molecules assembled from ultracold atoms, we demonstrate all these requirements. We present a novel magic-wavelength trap that supports second-scale rotational coherences in a gas of molecules and gives access to controllable dipole-dipole interactions. We also report the efficient assembly of individual molecules in optical tweezers. Using mid-sequence detection of molecule formation errors, we demonstrate rearrangement to produce small defect-free arrays. By transferring the molecules into magic-wavelength tweezers, we demonstrate long-lived rotational coherences that will enable spin-exchange interactions between molecules.

Finally, as an outlook, we demonstrate a new hybrid platform that combines single ultracold molecules with single Rydberg atoms, opening up the prospect of non-destructive readout of the molecular state and fast entangling gates.

Categories

Molecules

Presentation

Invited speaker

A11

Fermion Pairs and Loners in an Attractive Hubbard Gas

Martin Zwierlein

Massachusetts Institute of Technology, Cambridge, USA

Abstract

The Hubbard model of attractively interacting fermions provides a paradigmatic setting for fermion pairing, featuring a crossover between Bose-Einstein condensation (BEC) of tightly bound pairs and Bardeen-Cooper-Schrieffer (BCS) superfluidity of long-range Cooper pairs, and a "pseudo-gap" region where pairs form already above the superfluid critical temperature. We directly observe the non-local nature of fermion pairing in a Hubbard lattice gas, employing spin- and density-resolved imaging of ∼1000 fermionic 40K atoms under a bilayer microscope. In the strongly correlated regime, the fermion pair size is found to be on the order of the average interparticle spacing.

When spins are imbalanced, not every fermion can find a partner, resulting in competition between pairing, charge order and magnetism. One candidate ground state in this regime is the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state, a spatially modulated superfluid hosting a crystal of excess spins. As a first hint at new order awaiting at lower temperatures, we find that excess spins become attracted by neighboring pairs beyond a critical spin imbalance.

Categories

Many body physics

Presentation

Invited speaker

A12

Observing the dynamics of long-range interacting Fermi gases in a high-finesse cavity

Jean-Philippe Brantut

EPFL, Lausanne, Switzerland

Abstract

Cavity quantum electrodynamics offers unique perspectives for quantum simulations. It allows for real-time, continuous, weakly destructive monitoring of the dynamics of atoms inside the cavity mode, as well as for photon-mediated long-range interactions.

In this talk, I will present the real-time observation of the dynamics of a Fermi gas undergoing a density-wave phase transition induced by cavity-mediated interactions. There, we track the exponential rise of the order over several orders of magnitude and connects its rate to the microscopic physics of the Fermi gas. We find that the growth rate is insensitive to the contact interaction strength from the ideal gas up to the unitary limit and can exceed the Fermi energy by an order of magnitude, in quantitative agreement with theory. Our results generalize to linear interaction ramps, where deviations from the adiabatic behavior are captured by a simple dynamical ansatz.

I will then present a new generation of observation methods that combine cavities with microscope techniques. I will first show that cavity-induced density wave order can be directly observed in-situ through high-resolution absorption imaging. Second, I will introduce and describe a new ‘cavity-microscope’ device that combines in a single device and a single optical axis a microscope and a cavity. This device allows for high resolution spatial control of light-matter interaction, opening the perspective of programing interactions in space and time to realize a quantum simulations of the Sachdev-Ye-Kiatev model.

Categories

Cavity QED

Presentation

Invited speaker

A13

Atomic Physics Approach to Quantum Critical States

Hui Zhai

Tsinghua University, Beijing, China

Abstract

Quantum critical states are manifestations of strong correlations in quantum many-body systems, usually occurring in low dimensions or nearby quantum critical points. Quantum critical states also widely exist in cold atom systems. Examples include one-dimensional cold atomic gases, quantum critical points in optical lattice and Rydberg atom arrays. In this talk, I will discuss several unique cold atom approaches to reveal novel properties of quantum critical states, such as their response to controlled dissipations and reconfigurable geometries and their connection to quantum many-body scars.

Categories

Many body physics

Presentation

Invited speaker

A14

A new land of microwave-shielded polar molecules

Xin-Yu Luo

Max-Planck-Institute of Quantum Optics, Garching, Germany

Abstract

Microwave-shielding has proven to be a powerful technique for producing degenerate quantum gases of polar molecules as well as assembling ultracold polyatomic molecules. Here, I will review our efforts in controlling the interactions of ultracold molecules using microwave fields, enabling us to stabilize the molecular gases and evaporate them to temperatures well below the Fermi temperature. The shape, symmetry, and depth of the intermolecular potential can be flexibly controlled by the polarization, strength, and frequency of the microwave field. This is a unique feature of microwave-shielded polar molecules that is distinguished from ultracold atoms. It allows us to observe field-linked resonances in collisions of polar molecules, providing a universal tool for independently controlling the dipolar and contact interactions of molecules, as well as creating exotic long-range tetratomic molecules. In the end, I will show our progress towards a *p*-wave superfluid of dimers and its crossover to a Bose-Einstein condensate of tetramers.

Categories

Molecules

Presentation

Invited speaker

A15

Creating and exploring Bose-Einstein condensates of dipolar molecules

Sebastian Will

Columbia University, New York, USA

Abstract

We have recently created the first Bose-Einstein condensate (BEC) of dipolar molecules [1-3]. We efficiently cool sodium-cesium molecules from 700 nK to less than 10 nK, deep into the quantum degenerate regime. The lifetime of the molecular BEC is longer than one second, reaching a level of stability similar to ultracold atomic gases. A cornerstone of this advance is double microwave shielding, a novel technique that gives us control over intermolecular interactions and reduces inelastic loss of molecules by four orders of magnitude. The creation of a BEC constitutes the first observation of a phase transition in an ultracold molecular gas.

In this talk, I will discuss our experimental approach, share latest insights, and give an outlook on opportunities with our system for many-body quantum physics, quantum simulation, and quantum information. Thanks to a large dipole moment, BECs of sodium-cesium molecules promise access to regimes of dipolar quantum matter that have been inaccessible so far.

References:

1. Bigagli, Yuan, Zhang, et al., Observation of Bose-Einstein condensation of dipolar molecules, arXiv:2312.10965 (2023) and Nature (2024)
2. Bigagli, et al., Collisionally stable gas of bosonic dipolar ground state molecules, Nature Physics, 19, 1579-1584 (2023)
3. Stevenson, et al., Ultracold gas of dipolar NaCs ground state molecules, Phys. Rev. Lett. 130, 113003 (2023

Categories

Molecules

Presentation

Invited speaker

A16

Microwave shielding of ultracold polar molecules

Tijs Karman

RU, Nijmegen, Netherlands

Abstract

Ultracold polar molecules have long been regarded as a powerful platform for quantum many-body physics and quantum simulation.
Realizing these applications however requires cooling to quantum degeneracy and simultaneously the ability to control interactions.

In this talk I will discuss how microwaves can be used to engineer repulsive interactions between molecules that ``shield'' them from collisional loss.
Controlling collisions between ultracold molecules has recently enabled their efficient evaporative cooling to Fermi[1] and Bose[2] degeneracy.
In addition, microwave shielding offers full control of the contact and dipole-dipole interactions, realizing a new platform for dipolar quantum matter.

[1] Schindewolf et al. Nature 607, 677–681 (2022)
[2] Bigagli et al. arXiv:2312.10965

Categories

Molecules

Presentation

Invited speaker

A17

Discovering new physics with quantum technologies in the lab and in space

Marianna Safronova

University of Delaware, Newark, USA

Abstract

The extraordinary advances in quantum control of matter and light have been transformative for atomic and molecular precision measurements enabling probes of the most basic laws of Nature to gain a fundamental understanding of the physical Universe. Exceptional versatility, inventiveness, and rapid development of precision experiments supported by continuous technological advances and improved atomic and molecular theory led to rapid development of many avenues to explore new physics. The development of high-precision optical atomic clocks enables searches for the variation of fundamental constants, dark matter, violations of Lorentz invariance, and tests of gravity. Deployment of high-precision clocks in space will open the door to new applications, including precision tests of gravity and relativity, searches for a dark-matter halo bound to the Sun, and gravitational wave detection in wavelength ranges inaccessible on Earth, and others.

I will give a broad overview of atomic clock applications on Earth and in space, focusing on searches for physics beyond the standard model of elementary particles. Several examples will be highlighted, including dark matter searches with atomic and nuclear clocks and new ideas for searches of physics beyond the standard model with quantum sensors in space. New ideas for detection of transient signals will be presented.

Categories

Clocks and metrology

Presentation

Invited speaker

A18

Robust optical lattice clock for time keeping and searching for ultralight dark matter

Takumi Kobayashi[1], Daisuke Akamatsu[2], Akifumi Takamizawa[1], Kazumoto Hosaka[1], Yusuke Hisai[2], Akiko Nishiyama[1], Akio Kawasaki[1], Masato Wada[1], Hajime Inaba[1], Takehiko Tanabe[1], Feng-Lei Hong[2], Masami Yasuda[1]

[1]National Metrology Institute of Japan, Ibaraki, Japan. [2]Yokohama National University, Kanagawa, Japan

Abstract

Optical clocks exhibit better performances in terms of frequency stability and accuracy compared with microwave Cs fountain clocks, and are considered as promising candidates for a redefinition of the SI second. However, the robustness of optical clocks has not generally reached to a level of Cs fountain clocks that are running nearly continuously for a long period. At National Metrology Institute of Japan (NMIJ), we have developed an Yb optical lattice clock NMIJ-Yb1 which can be operated for many months with an uptime of > 80 %. Our best operation records include uptimes of 80.3 % for half a year from October 2019 to March 2020, 94.5 % for 30 days in August 2021, and 97.0 % for 20 days in March 2022. We here present some technical details about the robustness of NMIJ-Yb1 and its applications to (i) the frequency calibration of International Atomic Time (TAI) with reduced link uncertainties, (ii) generation of a stable local time scale by steering a hydrogen maser with NMIJ-Yb1, and (iii) search for ultralight dark matter candidates by high uptime comparisons between NMIJ-Yb1 and our Cs fountain clock NMIJ-F2.

This work was supported by Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Number JP17H01151, JP17K14367, JP18K04989, JP22H01241, JST-Mirai Program Grant Number JPMJMI18A1, and JST Moonshot R&D Program Grant Number JPMJMS2268, Japan.

Categories

Clocks and metrology

Presentation

Invited speaker

A19

Exploring Itinerant Magnetism with Polar Molecules Confined in Optical Lattices

Ana Rey

JILA, Boulder, USA

Abstract

Dipolar interactions provide opportunities for the exploration of many-body phenomena that remain difficult to be seen in systems with just contact interactions. One such phenomenon falls under the general heading of itinerant quantum magnetism, where magnetic moments (spins) interact with one another with coupling strength J as they hop in a periodic potential at a rate t. Their dynamics is described by the so-called t-J model, a model originally emerging from the large interaction energy expansion of the Hubbard Model, which is believed to describe the fundamental physics behind high temperature superconductors. In this talk I plan to report on the first realization of a generalized t-J spin model with dipolar interactions using a system of ultracold KRb fermionic molecules with a spin-1/2 encoded in the two lowest rotational states. Our study paves the way for future explorations of itinerant spin dynamics and quantum magnetism with highly tunable molecular platforms in regimes challenging for existing numerical and analytical methods that could shed light on the complex behaviors in real materials.

Categories

Molecules

Presentation

Invited speaker

A20

Microscopic study on lattice gauge theory with quantum simulation

Zhen-Sheng Yuan

University of Science and Technology of China, Hefei, China

Abstract

Exploring the fundamental structure and basic laws of the universe constitutes an essential drive to physicists. The studies of ultracold atoms have built a bridge between the principles of microscopic world and condensed matter physics. One can build and manipulate synthetic quantum material to simulate strongly correlated quantum many-body system with microscopic techniques to solve formidable tasks for the state-of-the-art supercomputers. I will introduce our recent research on one of such synthetic quantum material, the lattice gauge theory (LGT). We implemented a U(1) LGT Hamiltonian with ultracold atoms trapped in optical lattices and studied the relevant properties of gauge invariance, thermalization dynamics and quantum criticality [1-6].

References

1. Han-Ning Dai et al. Four-body ring-exchange interactions and anyonic statistics within a minimal toric-code Hamiltonian. Nature Physics **13**, 1195 (2017).
2. Bing Yang et al. Observation of gauge invariance in a 71-site Bose-Hubbard quantum simulator. Nature **587**, 392 (2020).
3. Zhao-Yu Zhou et al. Thermalization dynamics of a gauge theory on a quantum simulator. Science **377**, 311 (2022).
4. Guo-Xian Su et al. Observation of many-body scarring in a Bose-Hubbard quantum simulator. Phys. Rev. Res. **5**, 023010 (2023).
5. Han-Yi Wang et al. Interrelated thermalization and quantum criticality in a lattice gauge simulator, Phys. Rev. Lett. **131**, 050401 (2023).
6. Wei-Yong Zhang et al. Observation of microscopic confinement dynamics by a tunable topological angle, arXiv:2306.11794.

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

A21

Precision measurements are having a moment: recent results in g-2 and electric dipoles of leptons

ERIC CORNELL

JILA, Boulder, USA

Abstract

The past three years have seen three dipole-moment measurements of record-breaking accuracy – the magnetic dipole moments (aka “g-2”) of the muon and of the electron, and the electric dipole moment (EDM) of the electron. I will focus in on the latter measurement, performed at JILA. Then I will compare and contrast the relative implications of all these three measurements for the search for Beyond Standard Model physics.

Categories

Precision measurements

Presentation

Invited speaker

A22

Tests of Fundamental Symmetries with Radioactive Molecules

RONALD GARCIA RUIZ

MIT, CAMBRIDGE, USA

Abstract

Rapid progress in the experimental control and interrogation of molecules is enabling new opportunities for investigating the fundamental laws of our universe. In particular, molecules containing heavy, octupole-deformed nuclei, such as radium, can offer enhanced sensitivity for measuring yet-to-be-discovered parity and time-reversal violating nuclear properties. This talk will present recent highlights and perspectives from laser spectroscopy experiments on these species, as well as discuss the relevance of these experiments in addressing open problems in nuclear and particle physics.

Categories

Precision measurements

Presentation

Invited speaker

A23

Precision measurement with ultracold ytterbium atoms in an optical lattice for new boson search

Yoshiro Takahashi[1], Koki Ono[1], Taiki Ishiyama[1], Hokuto Kawase[1], Tetsushi Takano[1,2], Ayaki Sunaga[3], Yasuhiro Yamamoto[4], Minoru Tanaka[5]

[1]Department of Physics, Graduate School of Science, Kyoto University, Kyoto, Japan. [2]JST-PRESTO, Tokyo, Japan. [3]Inst. of Chem. Eötvös Loránd University, Budapest, Hungary. [4]Accelerator Laboratory, High Energy Accelerator Research Organization (KEK), Tsukuba, Japan. [5]Department of Physics, Graduate School of Science, Osaka University, Osaka, Japan

Abstract

We report our recent study of the precision measurement towards new physics beyond the Standard Model. We perform precision isotope-shift measurements for ultra-narrow optical clock transitions of four bosonic isotope pairs of ytterbium atoms loaded in a three-dimensional magic wavelength lattice. For the $^1S_0$ and $^3P_0$ clock transition, we achieve the part-per-billion precision [1]. In addition, we observe a new clock transition between the $^1S_0$ and $4f^{13}5d6s^2(J=2)$ states [2], and determine the isotope shifts with less than 10 Hz precision. These results, combined with other precision data using ytterbium atoms and ions, show the significantly large non-linearity of the King relation, and will allow us to obtain a bound of the coupling strength of a new hypothetical particle mediating a force between electrons and neutrons with a generalized King plot approach [3].

[1] K. Ono, *et al.,* Phys. Rev. X **12**, 021033 (2022).

[2] T. Ishiyama *et al.*, Phys. Rev. Lett. **130**, 153402 (2023).

[3] K. Mikami, *et al.,* Eur. Phys. J. C **77**, 896 (2017).

Categories

Precision measurements

Presentation

Invited speaker

A24

Attosecond Clocking and Control of Recollision

Pierre Agostini

The Ohio State University, Columbus, USA

Abstract

Ionization of argon by an attosecond pulse train (APT) yields electron wavepackets (WP) which can be accelerated in the field of a NIR laser, return to the parent ion and extract a second electron by an e2e collision. The ionization time is controlled with attosecond precision and the doubly charged ion signal monitored as a function of the delay between the APT and the laser optical cycle. Considering the wavepacket spreading and the e2e dependence on the electron kinetic energy, allows to predict the time dependence of the doubly charged ion seen in the experiment. This is, I believe, the first application of an APT in the time domain. In addition, adjusting the release time of the WP allows to control the trajectory, while spectrally sculpting the APT allows to mimic a tunneling ionization, and improve our understanding of the strong field recollision physics.

Authors: Andrew J. Piper, Qiaoyi Liu, Abraham Camacho Garibay, Dietrich Kiesewetter, Vyacheslav Leshchenko, Jens E. Bækhøj, Pierre Agostini, Kenneth J. Schafer, Louis F. DiMauro, Yaguo Tang.

Categories

Ultrafast

Presentation

Invited speaker

A25

Ultrafast Kapitza Dirac Effect

Reinhard Doerner[1], Kang Lin[1,2], Maksim Kunitski[1], Doerte Blume[3], Sebastian Eckart[1], Till Jahnke[1], Alexander Hartung[1]

[1]University Frankfurt, Frankfurt, Germany. [2]Zhejiang University, Hangzhou, China. [3]University of Oklahoma, Norman, USA

Abstract

Combining ultrafast physics with matter wave diffraction, we demonstrate how electron wave packets from photoionization in an ultrashort laser pulse are diffracted by a time-delayed ultrashort pulsed standing light wave. This exploits the Kapitza-Dirac effect to create a movie of the phase evolution of a freely moving electron[1].

In another example we show the time evolution of the wavefunction of a free moving atom released from an ultracold He molecule[2] using multi coincidence detection with a COLTRIMS reaction microscope

[1] Lin et al Science 6690, 1467 (2024)

[2] Kunitiski et al Nat. Phys., 17, 174 (2021)

https://www.atom.uni-frankfurt.de/

Categories

Ultrafast

Presentation

Invited speaker

A26

Attosecond pump-probe spectroscopy: Theoretical methods for the description of correlated electron and nuclear dynamics

Alicia Palacios

Universidad Autonoma de Madrid, Madrid, Spain

Abstract

Monitoring electron dynamics in matter requires the use of coherent light sources that can offer attosecond resolution. For more than two decades, attosecond experiments have been mostly performed using table-top experimental set ups where trains of attosecond pulses are produced through high-harmonic generation (HHG). But the most recent technological developments at free electron lasers (introducing, for instance, self-amplified spontaneous emission schemes) also allows one nowadays to produce phase-controlled pulses that offer the necessary time resolution to access and steer electronic motion in matter. This talk presents our latest progresses on state-of-the-art ab initio theoretical methods that are employed to describe ongoing experiments and forthcoming applications of attosecond pump-probe spectroscopic techniques to investigate the ultrafast electron dynamics in gas phase atomic and molecular targets. In particular, we investigate, using nearly-exact calculations, the role of the electron-electron and electron-nuclear correlation terms in laser-induced excitation and single and multiple ionization events.

Categories

Ultrafast

Presentation

Invited speaker

A27

Ultrafast chiroptical switching

Francesca Calegari

DESY, Hamburg, Germany

Abstract

Attosecond science is nowadays a well-established research field, which offers formidable tools for the realtime investigation of electronic processes. In this context, we have demonstrated that attosecond pulses can initiate charge migration in aromatic amino-acids [1] as well as in the DNA nucleobase adenine [2]. These pioneering investigations have been done in ionized molecules and there is still a long path towards attochemistry and the control of the reactivity of neutral molecules via electronic coherences

Here, I will show our most recent work devoted to the investigation of charge migration in neutral molecules and its applications to manipulate the outcome of photochemical and photophysical processes. We exploited our new light source delivering few-femtosecond UV pulses [3] in order to photoexcite below the ionization threshold and trigger electronic dynamics in the chiral molecule methyl-lactate. We used time-resolved photoelectron circular dichroism (TR-PECD) to image charge migration and disclose - for the first time - its impact on the molecular chiral response. We show that charge migration enables an ultrafast chiroptical switching effect where the amplitude and direction of the photoelectron current generated by PECD can be controlled on a sub-10 fs timescale [4]. These results provide important perspectives to exploit charge-directed reactivity for controlling the chiral properties of matter at the electron time scale

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Categories

Ultrafast

Presentation

Invited speaker

A28

Atom interferometry: holding versus dropping atoms

Holger Mueller

UC Berkeley, Berkeley, USA

Abstract

Atom interferometers are versatile instruments, working as quantum sensors in the field and probing the laws of physics at the deepest level in the lab. Examples are testing the standard model by measuring the fine-structure constant and searching for quantum aspects of the gravitational field, such as superposition and entanglement.

In typical atom interferometers, the freely-falling motion of the atoms limits the free evolution to a few seconds. We will show that atoms trapped in optical lattices allow free evolution times as long as 70 seconds, during which small effects can generate large, measurable phase shifts. We use a system of signal inversions to suppress systematics caused by the trapping potential. This enables measuring the attractive force from a small tungsten mass with a precision that is five times improved over a previous measurement with freely falling atoms. The long-lasting coherence lends itself well to measuring the dynamic interactions between the atoms and a coherent mechanical system, such as a torsion pendulum. This may yield insights into the coherence of the gravitational field itself. A setup that is intended to take the first step is under construction.

Our measurement of the fine-structure constant uses atoms in free fall. This isolates the atoms strongly from environmental influences and minimizes systematic effects. It is favorable in applications that require long-term stability or absolute accuracy. Minimizing the leading systematic effects requires clean and well characterized laser wavefronts. This is hoped to improve the accuracy beyond current limitations and clarify the issues raised by the current, discrepant, measurements.

Categories

Matter wave interferometry

Presentation

Invited speaker

A29

Continuous quantum measurements and sensing with entangled spins in hot atomic vapor

Yanhong Xiao

Shanxi University, Taiyuan, China. Fudan University, Shanghai, China

Abstract

Continuous quantum measurement is an intriguing and challenging problem both theoretically and experimentally because it involves measurement backaction and quantum trajectories. Quantum enhanced sensing in the continuous regime is even more demanding with a requirement of sustained entanglement in the presence of unknown signal perturbations. In this talk, I will show how we perform continuous quantum nondemolition measurements for a hot atomic ensemble of more than 10^10 atoms, and achieve steady state spin squeezing lasting in the lab for over a day. Then, we demonstrate that the same measurement can be used to sense a time-varying magnetic field continuously with quantum enhancement, where deep learning model is employed for the inference process. Finally, I will discuss prospects of continuous measurements of non-commuting variables, and hybrid squeezing of different types of spins.

Categories

Clocks and metrology

Presentation

Invited speaker

A30

Creation of ultracold triatomic molecules

Bo Zhao

University of Science and Technology of China, Hefei, China

Abstract

Ultracold assembly of diatomic molecules has enabled great advances in controlled chemistry, ultracold chemical physics, and quantum simulation with molecules. Extending the ultracold association to triatomic molecules will offer many new research opportunities and challenges in these fields. A possible approach is to form triatomic molecules in a mixture of ultracold atoms and diatomic molecules. I will talk about our recent work on the creation of ultracold triatomic molecules near the Feshbach resonance between 23Na40K molecules in the rovibrational ground state and 40K atoms. We use radio-frequency association and magnetoassociation to form weakly bound triatomic Feshbach molecules. Moreover, we form deeply bound triatomic molecules in electronic excited states using Feshbach-enhanced photoassociation. Our work contributes to the understanding of the complex ultracold atom-molecule collisions and opens up an avenue toward bottom-up construction of ultracold polyatomic molecules.

Categories

Molecules

Presentation

Invited speaker

A31

Advances in Controlling Programmable Molecular Arrays for Quantum Science

Lawrence Cheuk

Princeton University, Princeton, NJ, USA

Abstract

Ultracold polar molecules, with their rich internal structure and tunable long-range interactions, have long been proposed as a platform for quantum science. In particular, programmable arrays of molecules individually trapped in optical tweezers promise to be a powerful new platform for quantum simulation and quantum information processing.

In this talk, I will report several advances from our group on the quantum control of laser-cooled molecules held in programmable optical tweezer traps. In the first part of the talk, I will report our demonstrations of creating defect-free molecular arrays, observing coherent interactions between molecules, deterministically entangling molecules, and controlling their motional states at the quantum level. These establish the basic building blocks for quantum simulation and information processing. In the second part of the talk, I will report on quantum measurement and feedback in molecules. In particular, I will report the first demonstration of classical and quantum erasure error detection in molecules, which are both important capabilities for quantum science with molecules. Our work on classical erasure error detection and their correction allows robust high-fidelity internal state preparation, which directly opens to preparation of large-scale systems needed for quantum simulation in the many-body regime. Our work on quantum erasure errors demonstrates a key capability for quantum error correction, as erasure conversion has recently been found to vastly increase fault-tolerant thresholds in quantum error correcting codes.

Categories

Molecules

Presentation

Invited speaker

A32

Cold molecules for clocks and precision measurements

Tanya Zelevinsky

Columbia University, New York, USA

Abstract

Precise atomic spectroscopy has played a pivotal role in advancing our knowledge of physics. With the emergence of laser cooling and trapping techniques alongside stable light sources, an exceedingly high level of spectroscopic precision has been attained. More recent developments have extended this ultrahigh precision, including atomic clock technologies, to more intricate quantum systems such as diatomic molecules. This extension enables the characterization of molecular degrees of freedom, such as vibrational motion, with a level of resolution approaching that of atomic clocks. Illuminating previously unknown molecular properties, this capability also suggests interesting avenues for exploring fundamental aspects of physical interactions, including the refinement of laboratory based tests probing Newtonian gravity at the nanometer scale.

Categories

Molecules

Presentation

Invited speaker

A33

Many-body physics with arrays of individual atoms and optical dipoles

Antoine Browaeys

Institut d'Optique, CNRS, Palaiseau, France

Abstract

This talk will present our recent work on the control of interactions between cold atoms to implement spin Hamiltonians useful for quantum simulation of many-body problems, or quantum optics situations. We rely on laser-cooled atomic ensembles of Rb, consisting either of individual atoms in tweezer arrays, or dense elongated atomic gases.

By exciting arrays of up to 100 atoms into Rydberg states, we make the atoms interact by the resonant dipole interaction. The system implements the XY spin ½ model. When the system is placed out of equilibrium, the interactions generate scalable spin squeezing [Bornet et al., Nature 2023]. Analyzing the spread of correlations across the system, we measure the dispersion relation and observe the predicted anomalous behavior in the ferromagnetic case, a consequence of the dipolar interactions [Chen et al., arXiv:2311.11726].

Using an elongated dense atomic ensemble driven on an optical transition, we rely on the collective coupling of many atoms to a single mode of the electromagnetic field to observe driven superradiance and demonstrate the generation of non-gaussian light [Ferioli et al., PRL 2024].

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

A34

An optical tweezer array in a cryogenic environment

Cindy Regal

University of Colorado, Boulder, USA

Abstract

Scalable Rydberg atom arrays are a fast evolving platform for programmable quantum computation and simulation. We present a new system for the control of 2D Rydberg atom arrays embedded in a cryogenic environment. Our high optical access system is compatible with long vacuum lifetime, high-fidelity atomic manipulation, and reduction of blackbody-driven Rydberg decay. I present measurements of ground-state and initial Rydberg manipulation in our cold box, as well as long-lived atoms in a cryopumped vacuum with which we study single-atom imaging of rubidium with high survival, an important component of high-fidelity atom rearrangement. I discuss plans to harness similar long-lived vacuum conditions for addressing one source of loss and heating in Fermi gases. I also outline our ongoing efforts in controlling external degrees of freedom in an optical tweezer traps in the context of cooling, light-assisted collisions, and non-classical motional states.

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

A35

Building macroscopic quantum systems, atom by atom

Selim Jochim

Heidelberg University, Heidelberg, Germany

Abstract

For many phenomena that occur in Nature, a successful description involves taking the limit of a continuum, i. e. an infinite system size.

It is our quest to understand how such a continuum emerges from a finite system size, where access to single particle resolved quantities is still available.

In terms of energy, this involves the competition of three scales:

a) The interaction strength between atoms, that can be tuned using a Feshbach resonance

b) The finite energy gap between single particle states or energy shells stemming from the confinement,

c) The Fermi energy, controlled by the number of fermionic atoms is the scale driving the convergence of observables to the continuum limit.

In our experiments we harmonically trap a fixed number of atoms in two dimensions, with the largest number to date being 42 fermionic atoms. This corresponds to six shells being filled, with the Fermi energy significantly surpassing the shell spacing.

Our tunable platform allows us to manipulate such quantum systems with an extreme fidelity. As one example we can control the (relative) angular momentum between two single atoms in such a configuration, allowing us to prepare a microscopic Laughlin wave function.

Categories

Many body physics

Presentation

Invited speaker

A36

Measuring the superfluid fraction of a dipolar supersolid via the Josephson effect

Giovanni Modugno

LENS, Sesto Fiorentino, Italy. University of Florence, Firenze, Italy. CNR-INO, Pisa, Italy

Abstract

Dipolar quantum gases are offering an unprecedented opportunity to explore the supersolid, a quantum phase intermediate between ordinary superfluids and crystals that might be present in many superfluids and superconductors. The main property characterizing supersolids, a sub-unity superfluid fraction, is still elusive fifty years after it was proposed by A. J. Leggett.

I will show how the superfluid fraction of a dipolar supersolid can be measured directly by exciting Josephson oscillations in the supersolid lattice, and measuring the corresponding tunnelling energy. The measured superfluid fraction spans a relative large range between one and zero by varying the interaction strengths, and is in agreement with the original theory predictions. The very existence of spontaneous Josephson oscillations confirms supersolids as a separate quantum phase of matter.

Categories

Quantum fluids

Presentation

Invited speaker

A37

A 10-Fold Rotation-Symmetric Quasicrystal Quantum Simulator

Charles Brown

Yale University, New Haven, USA

Abstract

Quasicrystals are aperiodic yet exhibit long-range order, without translation symmetry but with rotational symmetries that are mathematically forbidden in periodic lattices. In 1984, Shechtman performed X-ray diffraction measurements on a metallic alloy, revealing 10-fold rotational symmetry in the diffraction pattern. This work eventually led to the redefinition of what constitutes a crystal, and the recognition of the reality of aperiodic crystals. Shechtman was then awarded the 2011 Nobel prize in chemistry for the discovery of aperiodic crystals.

In recent decades, band structure and its interplay with topology has provided deep insight into intriguing behavior in periodic crystalline quantum materials. However, thirty years after the discovery of aperiodic crystals, the role of the energy spectrum and its interplay with topology is not well-understood for quasicrystals because standard theoretical methods used to study the energy spectrum of a crystal rely on translational symmetry. Quantum simulation of a quasicrystal would open a window into quasicrystalline “band structure” and topology that is difficult to access with theoretical and analytical methods alone.

This talk will describe the design of an experiment in which a quantum gas is confined within a 10-fold rotation-symmetric quasiperiodic optical lattice, which serves as a quasicrystal quantum simulator.

Categories

Many body physics

Presentation

Invited speaker

A38

Identifying Old Ice and Water with Single-Atom Counting

Zheng-Tian Lu

University of Science and Technology of China, Hefei, China

Abstract

The long-lived noble-gas isotope ^{81}Kr is the ideal tracer for old water and ice with ages of 0.1 – 1 million years, a range beyond the reach of ^{14}C. ^{81}Kr-dating, a concept pursued over the past six decades, is now available to the earth science community at large. This is made possible by the development of the Atom Trap Trace Analysis (ATTA) method, in which individual atoms of the desired isotope are captured and detected. ATTA possesses superior selectivity, and is thus far used to analyze the environmental radioactive isotopes ^{85}Kr, ^{39}Ar, ^{41}Ca, and ^{81}Kr, These isotopes have extremely low isotopic abundances in the range of 10^{-17} to 10^{-11}, and cover a wide range of ages and applications. In collaboration with earth scientists, we are dating groundwater and mapping its flow in major aquifers around the world, and dating old ice from the deep ice cores of Antarctica, Greenland, and the Tibetan Plateau. For an update on this worldwide effort, please google “ATTA Primer”.

Categories

Precision measurements

Presentation

Invited speaker

A39

Iterative Assembly, Mid-Circuit Measurement, and High-Fidelity Gates with Alkaline Earth Atoms

Matthew Norcia

Atom Computing, Inc., Boulder, USA

Abstract

A quantum computer capable of useful computation will likely require numbers of qubits beyond what is accessible today, a means of performing mid-circuit readout of a subset of those qubits, and the ability to perform high-fidelity gates. In this talk, I will present recent progress towards achieving these goals at Atom Computing Inc, using neutral ytterbium atoms confined within arrays of optical tweezers. This includes an iterative approach to assembling and maintaining arrays of atoms, a means of selective qubit readout through local light-shifts, and a demonstration of high-fidelity two-qubit gates using a protocol suited to the level structure of alkaline earth atoms.

Categories

Quantum computing, simulation & networks

Presentation

Invited speaker

B001

Collective Excitation of Shell-shaped Bose-Einstein condensate

Zerong HUANG, Chun Kit Wong, Bo Yang, Liyuan Qiu, Kai Yuen Lee, Yangqian Yan, Dajun Wang

The Chinese University of Hong Kong, Hong Kong, Hong Kong

Abstract

We investigate the hollowing transition of a shell-shaped Bose-Einstein condensate (BEC) with collective excitation. The shell is created using a double species BEC in the immiscible regime, with the hollowness of the shell BEC controlled by tuning the repulsive interspecies interaction by a Feshbach resonance. Our study reveals two distinct monopole modes in which the two condensates oscillate in-phase and out-of-phase relative to each other, respectively. While the frequency of the in-phase mode remains largely constant, the frequency of the out-of-phase mode changes significantly, providing a clear signature of the topology change from a filled to a hollow condensate. Furthermore, we observe a strong dependence of the critical point of the hollowing transition on the number ratio of the two species. Our findings offer a comprehensive understanding of the topology change in this curved quantum gas system and pave the way for future research into quantum many-body phenomena in curved spaces.

Categories

Many body physics

Presentation

Poster presentation

B002

A homogeneous Bose--Fermi mixture

Xing-Yan Chen[1,2], Shrestha Biswas[1,2], Sebastian Eppelt[1,2], Christine Frank[1,2], Andreas Schindewolf[1,2], Timon Hilker[1,2], Immanuel Bloch[1,2,3], Xin-Yu Luo[1,2]

[1]Max-Planck-Institut für Quantenoptik, Garching, Germany. [2]Munich Center for Quantum Science and Technology, München, Germany. [3]Fakultät für Physik, Ludwig-Maximilians-Universität, München, Germany

Abstract

Homogeneous quantum gases offer unique opportunities in many-body physics, especially in critical phenomena where the correlation length diverges. While homogeneous gases of single species have been extensively studied, extending it to dual-species had been a challenge. Here we report the creation of a homogeneous mixture of ^{23}Na and ^{40}K atoms in a three-dimensional optical box trap. Horizontal confinement is provided by a blue-detuned ring beam, while vertical confinement is generated by a red-detuned paint beam, manipulated by an acousto-optic deflector. By combining a linear optical potential with a magnetic field gradient along the vertical axis, we have achieved simultaneous levitation of both atomic species. The dual-species box trap allows us to match the densities of the Bose and Fermi gases across the trap, facilitating the formation of a significant number of fermionic Feshbach molecules. Our work opens up new avenues in many-body physics with Bose-Fermi mixtures, including the exploration of charge-density waves and unconventional boson-induced superconductivity.

Categories

Many body physics

Presentation

Poster presentation

B003

Measurement of Charge Exchange Cross Section for Highly Charged Ions Collision with Atom and Molecule

Baoren WEI

Fudan University, Shanghai, China

Abstract

The charge exchange (CX) process between ions and the neutral target is of great significance in explaining the X-ray emission spectrum of the solar system, which has been established as being responsible for the X-ray emissions from comets and the diffuse soft X-ray background. To investigate the CX process in the lab, an experimental instrument setup based on the 150 kV high-voltage platform with an electron cyclotron resonance (ECR) ion source at Fudan University was built. Recently, the absolute single- and double-electron capture cross sections and *nl*-resolved state-selective charge exchange cross sections between low-energy highly charged ions and neutral targets has been measured[1-4].

References

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Categories

Many body physics

Presentation

Poster presentation

B004

Measurement of the superfluid fraction of a supersolid by Josephson effect

Nicolò Antolini[1,2], Giulio Biagioni[3,2], Beatrice Donelli[1,4,5,6], Luca Pezzé[1,4,5], Augusto Smerzi[1,4,5], Marco Fattori[3,1,7], Andrea Fioretti[2], Carlo Gabbanini[2], Massimo Inguscio[1,8], Luca Tanzi[1,2], Giovanni Modugno[3,1,2]

[1]LENS, University of Florence, Florence, Italy. [2]INO-CNR, Pisa, Italy. [3]Dipartimento di Fisica e Astronomia, University of Florence, Florence, Italy. [4]INO-CNR, Florence, Italy. [5]QSTAR, Florence, Italy. [6]University of Naples, Naples, Italy. [7]INO-CNR, Sesto Fiorentino, Italy. [8]Dipartimento di Ingegneria, Università Campus Bio-Medico di Roma, Rome, Italy

Abstract

Many quantum materials in various systems, ranging from superconductors to superfluid helium, feature a spatially modulated macroscopic wavefunction resulting from spontaneous breaking of gauge and translational symmetries. Their connection with supersolids, so far observed in different quantum gases platforms, has only been traced in a few cases since a universal property able to quantify the differences between supersolids, superfluids/superconductors, and crystals has not been established. A key quantity, introduced by A. Leggett in the 1970s, is the superfluid fraction which measures the reduction of the superfluid stiffness due to spatial modulations. A reduced superfluid fraction leads to the non-standard superfluid dynamics of supersolids. We employ the Josephson effect to locally measure the superfluid fraction in a supersolid. Even without a physical barrier, the Josephson effect arises spontaneously in supersolids, and single lattice cells act as self-induced Josephson junctions. We study a cold-atom dipolar supersolid, revealing a significant sub-unity superfluid fraction. Our results point to new research directions, like the study of partially quantized vortices and supercurrents, and have an impact on the understanding of other supersolid-like systems.

Poster

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Categories

Many body physics

Presentation

Poster presentation

B005

Elastic electron scattering from alkali earth metals- analysis using MCDF approach

AISWARYA R[1], Jobin Jose[1], Hari R Varma[2]

[1]IIT Patna, Patna, India. [2]IIT Mandi, Mandi, India

Abstract

Modelling the interaction potential for projectile-target interactions has always been a difficulty for theorists to simulate scattering because of the complex interactions that exist between them. A simple and robust method is to use static interaction potential for the projectile-target combo. Numerous model potentials were employed for many atomic and molecular systems, and in most cases a reasonably good agreement was found between the model potential results and the experimental data. Another level of investigation is the molecular level calculations, involving the consideration of all symmetry elements present in the target, albeit at a higher computational expense and time. All the aforementioned methods do simulate the electronic density of the scatterer with required precision. In the present study, we go one step beyond by including the interaction among different electrons scattered into different channels. A multi-configurational treatment is employed to include the initial state correlation of the scatterer. Similarly, the final state correlation effects are also included by writing the outgoing electron in a linear combination of different states arising from different initial states. Modelling of the electron density of the targets is done using Multiconfiguration Dirac Fock (MCDF) method. The scattered electronic states are conceived employing Dirac partial wave analysis and further include coupling among different scattered states. Several degrees of correlation effects are considered. A comparison study with available experimental and theoretical results will be presented.

Poster

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Categories

Many body physics

Presentation

Poster presentation

B006

Quantum magnetism meets cavity QED

Krzysztof Jachymski[1], Joao Pedro Mendonca[1], Yao Wang[2]

[1]University of Warsaw, Warsaw, Poland. [2]Emory University, Atlanta, USA

Abstract

We consider a class of many-body problems consisting of an ensemble of spins coupled to a global bosonic field. Such systems are relevant for cavity QED as well as spin-phonon models in condensed matter physics. We introduce a numerical method suitable for large photon numbers in the strong coupling regime, general spin interactions as well as chain geometries. We present results for extensions of seminal spin models with Ising and XXZ- type interaction as an example, showing that even small coupling to light can destabilize the system close to phase transitions and instead enforce paramagnetic order. The method can also describe the system dynamics in addition to the ground state, making it especially useful for studying Hamiltonian engineering protocols beyond the adiabatic elimination regime.

Categories

Many body physics

Presentation

Poster presentation

B007

Collective excitations and nonequilibrium dynamical phase transition in dissipative fermionic superfluids

Kazuki Yamamoto

Tokyo Institute of Technology, Tokyo, Japan

Abstract

We predict a new mechanism to induce collective excitations and a nonequilibrium phase transition of fermionic superfluids via a sudden switch on of two-body loss, for which we extend the BCS theory to fully incorporate a change in particle number. We find that a sudden switch on of dissipation induces an amplitude oscillation of the superfluid order parameter accompanied by a chirped phase rotation as a consequence of particle loss. We demonstrate that when dissipation is introduced to one of the two superfluids coupled via a Josephson junction, it gives rise to a nonequilibrium dynamical phase transition characterized by the vanishing dc Josephson current. The dissipation-induced collective modes and nonequilibrium phase transition can be realized with ultracold fermionic atoms subject to inelastic collisions.

Poster

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Categories

Many body physics

Presentation

Poster presentation

B008

Observation of Ferrimagnetism in a Lieb Lattice Hubbard Model with Ultracold Fermions

Anant Kale, Martin Lebrat, Lev Kendrick, Muqing Xu, Youqi Gang, Alexander Nikolaenko, Subir Sachdev, Markus Greiner

Harvard University, Cambridge, USA

Abstract

Strongly correlated materials feature multiple electronic orbitals which are crucial to accurately understand their many-body properties, from cuprate materials to twisted bilayer graphene. In such multi-band models, quantum interference can lead to dispersionless energy bands (flat bands) whose large state degeneracy gives rise to itinerant magnetism even with weak interactions. For the case of the Lieb lattice, the ground state is expected to show unusual *ferrimagnetic* order, i.e. a macroscopic total spin along with long range antiferromagnetic order. Here we report on signatures of a ferrimagnetic state realized in an optical Lieb lattice at half-filling, characterized by antialigned magnetic moments with antiferromagnetic correlations, concomitant with a finite spin polarization. We demonstrate its robustness when increasing repulsive interactions from the non-interacting to the Heisenberg regime, and study its emergence when continuously tuning the lattice unit cell from a square to a Lieb geometry. Our work paves the way towards exploring exotic phases in related multi-orbital models such as quantum spin liquids in kagome lattices and heavy fermion behavior in Kondo models.

Poster

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Categories

Many body physics

Presentation

Poster presentation

B009

Shapiro steps in driven atomic Josephson junctions

Vijay Singh[1], Juan Polo[1], Ludwig Mathey[2], Luigi Amico[1]

[1]Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE. [2]Center for Optical Quantum Technologies and Institute for Laser Physics, University of Hamburg, Hamburg, Germany

Abstract

We study driven atomic Josephson junctions realized by coupling two two-dimensional atomic clouds with a tunneling barrier. By moving the barrier at a constant velocity, dc and ac Josephson regimes are characterized by a zero and nonzero atomic density difference across the junction, respectively. Here, we monitor the dynamics resulting in the system when, in addition to the above constant velocity protocol, the position of the barrier is periodically driven. We demonstrate that the time-averaged particle imbalance features a step-like behavior that is the analog of Shapiro steps observed in driven superconducting Josephson junctions.

The underlying dynamics reveals an intriguing interplay of the vortex and phonon excitations, where Shapiro steps are induced via suppression of vortex growth. We study the system with a classical-field dynamics method, and benchmark our findings with a driven circuit dynamics.

Categories

Many body physics

Presentation

Poster presentation

B010

Observation of the antiferromagnetic phase transition in the fermionic Hubbard model

Hou-Ji Shao, Yu-Xuan Wang, De-Zhi Zhu, Yan-Song Zhu, Hao-Nan Sun, Si-Yuan Chen, Chi Zhang, Zhi-Jie Fan, Youjin Deng, Xing-Can Yao, Yu-Ao Chen, Jian-Wei Pan

University of Science and Technology of China, Shanghai, China

Abstract

The fermionic Hubbard model (FHM) captures essential features of strongly correlated electron physics. Ultracold fermions in optical lattices provide a clean and well-controlled platform for simulating FHM. Doping its antiferromagnetic ground state at half filling, various exotic phases are expected to arise in the FHM simulator, offering valuable insights into high-temperature superconductivity. However, despite significant advances in quantum simulation of the FHM, realizing the low-temperature antiferromagnetic phase transition in a large-scale quantum simulator remains elusive. In this poster, I will present our recent progress on the realization of a low-temperature repulsive FH system in three dimensions, consisting of lithium-6 atoms in a uniform optical lattice with approximately 800,000 sites. Using spin-sensitive Bragg diffraction of light, we measure the spin structure factor (SSF) of the system. We observe divergences in the SSF by finely tuning the interaction strength, temperature, and doping concentration to approach their respective critical values for the phase transition, which are consistent with a power-law scaling in the Heisenberg universality class. Our results successfully demonstrate the antiferromagnetic phase transition in the FHM, paving the way for exploring the low-temperature phase diagram of the FHM.

Poster

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Categories

Many body physics

Presentation

Poster presentation

B011

Phase diagram of dissipative fermionic superfluids in non-Hermitian Hubbard model with complex-valued interaction and the effect of the asymmetric hopping

SOMA TAKEMORI

Tokyo Institute of Technology, Tokyo, Japan

Abstract

Recent experimental techniques in ultracold atoms have allowed us to realize the novel quantum many-body phenomena induced by dissipation. The non-Hermitian (NH) Hamiltonian effectively describes the conditional dynamics of the open systems. Notably, NH BCS theory has been established [1] and much research on the NH physics associated with exceptional manifolds has been conducted. However, it has not yet been obtained how exceptional manifolds affect conventional many-body physics.

In the poster session, we show that the unconventional phase transition occurs in the region where the normal state appears in the Hermitian system. Remarkably, the interplay between the exceptional lines and the van Hove singularity causes an anomalous cusp on the phase boundary, which results in the enlargement of the dissipation-induced superfluid state. Furthermore, we also show our recent results which include the phase diagram of the non-Hermitian superfluidity in the NH Hubbard model with asymmetric hopping [3].

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Categories

Many body physics

Presentation

Poster presentation

B012

Many body quantum chaos resonance in Floquet Rydberg atom arrays

Yunhui He[1], Yuechun Jiao[1], Jianming Zhao[1], Weibin Li[2]

[1]Shanxi University, Taiyuan, China. [2]University of Nottingham, Nottingham, United Kingdom

Abstract

Quantum chaos as a quantum counterpart of classical chaos in the many-body systems is related to thermalization and level repulsion. These features are generally absent in which integrable systems. We study the many-body quantum chaos enhancement of a one-dimensional array of Floquet Rydberg atoms driven by a laser field where dynamical phase transition periodically emerges between the chaotic and integrable phases. According to level statistics, we examine the dependence of the level spacing ratio on the laser detuning, laser pulse duration, and interatomic interaction by analyzing the phase diagrams and confirming it by probability distributions. The dynamical simulations demonstrate that the chaotic and integrable phases could be characterized by Loschmidt echo, entanglement entropy, and expectation values of Rydberg populations in the long time limit. Comparing the temporal evolution results of different initial states to the steady-state and thermal limit results shows a good agreement.

Categories

Many body physics

Presentation

Poster presentation

B013

Ultracold and Ultrafast: Creating and detecting matter made of electrons, ions and Rydberg atoms

Jette Heyer[1,2], Julian Fiedler[1,2], Mario Großmann[1,2], Lasse Paulsen[2], Marlon Hoffmann[2], Klaus Sengstock[1,2], Markus Drescher[1,2], Philipp Wessels-Staarmann[1,2], Juliette Simonet[1,2]

[1]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany. [2]Center for Optical Quantum Technologies, Hamburg, Germany

Abstract

Ultrashort laser pulses enable the local ionization of quantum gases on femtosecond timescales. By tuning the central wavelength of a single laser pulse of 166 fs duration across the two-photon ionization threshold of ^{87}Rb, we investigate the transition from ultracold plasma with ultrafast electron cooling to dense Rydberg gases.

A novel coincidence unit consists of a high-resolution ion microscope and a Velocity-Map-Imaging Spectrometer (VMIS) allowing for simultaneous detection of the spatial distribution of the ions and the momentum of the photoelectrons. The ion microscope has a simulated resolution in range of 100 nm and a tunable magnification, while the VMIS is designed to detect electrons with kinetic energies of 0.05 meV – 3.2 eV.

Additionally, a pulsed extraction on ns-timescales of the ions and electrons grants access to a coincidence detection for investigating correlations as well as the time-resolved dynamics of the many-body system.

Categories

Many body physics

Presentation

Poster presentation

B014

AC driving of a Fermi superfluid Josephson junction

Giulia Del Pace[1,2], Nicola Grani[1,3,2], Diego Hernandez-Rajkov[1,3,2], Giulio Nesti[1,2], Marcia Frometa Fernandez[1,3,2], Massimo Inguscio[1,3,4,2], Giacomo Roati[3,2]

[1]University of Florence, Florence, Italy. [2]LENS, Sesto Fiorentino, Italy. [3]CNR-INO, Sesto Fiorentino, Italy. [4]Campus Bio-Medico University of Rome, Roma, Italy

Abstract

The Josephson effect is one of the most striking manifestations of a macroscopic system phase coherence. Besides representing a powerful probe of phase coherence, Josephson junctions (JJ) are also fundamental building blocks for atomtronics circuits, thanks to their well defined current-chemical potential and current-phase characteristics.

In this poster, I will present our ongoing research on the response of an atomic JJ with Fermi superfluids of lithium-6 under an AC driving. To inject in the junction an alternate current, we modulate the position of the tunneling barrier at a given frequency and probe the chemical potential imbalance developed across the junction after a few modulation periods. The AC drive introduces in the current-chemical potential characteristic a number of plateaus at a chemical potential value that is an integer multiple of the driving frequency, closely resembling the Shapiro steps observed in superconducting JJ illuminated by an external electromagnetic field. We probe the AC response for a molecular BEC and a unitary Fermi gas junction, finding that in both cases the plateaus in the current-chemical potential characteristic coincides with the emission of a well-defined number of vortices, suggesting that the stabilization of the current in the plateaus is operated by phase slippage processes.

Categories

Many body physics

Presentation

Poster presentation

B015

Precise measurement of collision-induced atomic alignment and magnetic sub-state ionization

Xing Wang, Zhongfeng Xu

Xi'an Jiaotong University, Xi'an, China

Abstract

Many-body systems with excess internal energy relax towards states of lower energy by rearrangement of molecular, atomic or nuclear structure. Excitation of a strongly bound electron from an atomic inner shell is followed by an ultrafast rearrangement of the electronic system, resulting in a disappearance of the inner-shell vacancy. As is well known, atomic inner-shell spectroscopy can provide important information about the collision system.

Alignment property of electron vacancies produced in collision process has been investigated in low energy region. Characteristic L X-ray spectra are measured at different emission angles. Angular dependence of differential intensity ratios has been studied as a function of the second-order Legendre polynomial. This served to reduce the experimental uncertainties. Then the anisotropy parameter β is converted to alignment parameter A_{20} by considering CK correction coefficient and anisotropy coefficient. The measured results are compared with other measurements and theoretical calculations. Good agreement is found in general, and small discrepancy is attributed to the atomic parameters employed only for single ionization. In addition, it is demonstrated that the influence of CK transition is significant for large alignment parameters. The experimental results are compared to theoretical predictions within the framework of plane wave Born approximation and reasonable agreement is found in the energy range studied in the present work. The results of atomic alignment provide an important and fundamental testing ground for ionization models.

Poster

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B016

Towards low temperatures and modified Hubbard models in a cold atom quantum simulator

Muqing Xu, Lev Kendrick, Anant Kale, Youqi Gang, Aaron Young, Martin Lebrat, Markus Greiner

Harvard, Cambridge, USA

Abstract

Ultracold atoms in optical lattices can provide very clean realizations of quantum lattice models that are of interest in condensed matter physics. However, in the past, cold atom-based simulations of the Hubbard model have operated at temperatures that are higher than where most of the exotic and poorly understood phases of the Hubbard model reside (for example, the pseudogap and d-wave superconducting phases).

We report on recent progress simulating the Hubbard model, and variations thereof, in a cold atom quantum simulator using fermionic lithium atoms in an optical lattice. By taking advantage of a dynamically tunable lattice potential, we make progress on two fronts: first, we reach lower temperatures by exploring new schemes for entropy redistribution and adiabatic state preparation. Second, we augment the square lattice Hubbard model with additional terms that can lead to exotic behaviors at higher temperatures.

Categories

Many body physics

Presentation

Poster presentation

B017

Quantum gases in ultrastable magnetic fields: from False vacuum decay to zero magnetic field physics

Gabriele Ferrari[1], Chiara Rogora[1], Diego Andreoni[1], Cosetta Baroni[2], Riccardo Cominotti[2], Alessandro Zenesini[2], Giacomo Lamporesi[2]

[1]University of Trento, Trento, Italy. [2]Istituto Nazionale di Ottica - CNR, Trento, Italy

Abstract

Metastability stems from the finite lifetime of a state when a lower-energy configuration is available but only by tunneling through an energy barrier. In classical many-body systems, metastability naturally emerges in a first-order phase transition and a prototypical example is a supercooled vapor. The extension to quantum field theory and quantum many-body systems has attracted significant interest in the context of statistical physics, protein folding, and cosmology, for which thermal and quantum fluctuations are expected to trigger the transition from the metastable state (false vacuum) to the ground state (true vacuum) through the probabilistic nucleation of bubbles. However, the theoretical progress in estimating the relaxation rate of the metastable field through bubble nucleation has not been validated experimentally. Here, we experimentally observe bubble nucleation in isolated and coherently coupled atomic superfluids, and we support our observations with numerical simulations. More generally, we will discuss our experiments on magnetism based on superfluid multicomponent gases in an ultrastable magnetic field environment, which recently became available.

- Ferromagnetism in an extended coherently-coupled atomic superfluid, R. Cominotti et al., Phys. Rev. X. 13, 021037 (2023).
- False vacuum decay via bubble formation in ferromagnetic superfluids, A. Zenesini et al., Nat. Phys. 20, 558 (2024).
- Ultracold atomic spin mixtures in ultrastable magnetic field environments, R. Cominotti et al., Europhys. Lett. (2024), DOI 10.1209/0295-5075/ad4b9a
- Towards a zero magnetic field environment for ultracold atoms experiments, C. Rogora et al., (2024), arXiv:2404.19565

Categories

Many body physics

Presentation

Poster presentation

B018

Coherent evolution of superexchange interaction in seconds long optical clock spectroscopy

Stefan Lannig, William R. Milner, Mikhail Mamaev, Lingfeng Yan, Anjun Chu, Ben Lewis, Max N. Frankel, Ross B. Hutson, Ana Maria Rey, Jun Ye

JILA, Boulder, USA

Abstract

The scalability of optical clock precision rests strongly on increasing the number of coherently interrogated particles. A promising avenue of scaling up optical lattice clocks is by embedding atoms into a 3-dimensional lattice operating in the Mott-insulating regime where motion and interactions are controlled. In such a densely packed system, understanding the interactions between atoms and light poses a key challenge which will ultimately lead to improvements of clock accuracy and precision.

In this work we study Fermi-Hubbard interactions induced by the spin-orbit coupling of the clock laser. This leads to an XXZ-type spin anisotropy which is tunable by the external confinement of optical lattice and gravity. In our experiments on ^{87}Sr we find lattice regimes where s- and p-wave interactions lead to optimal coherence or where the dynamics is dominated by superexchange over a timescale of multiple seconds. Here, we further demonstrate the tunability of the seconds-scale superexchange dynamics by modifying the lattice power and displacement of the atoms.

Our investigations lay the groundwork for interaction-based coherence protection and additional quantum improvements of clock precision in the form of squeezing by carefully engineering collective interactions between the atoms. I will also give an outlook on promising avenues for optimizing clock performance with such techniques.

Categories

Many body physics

Presentation

Poster presentation

B019

Dissipative Phases of a Bose-Einstein Condensate of Photons

Fahri Öztürk[1], Niels Wolf[1], Tim Lappe[2], Göran Hellmann[1], Jan Klaers[3], Frank Vewinger[1], Johann Kroha[2], Julian Schmitt[1], Martin Weitz[1]

[1]Institut für Angewandte Physik, Universität Bonn, Bonn, Germany. [2]Physikalisches Institut, Universität Bonn, Bonn, Germany. [3]Complex Photonic Systems (COPS), MESA+ Institute for Nanotechnology, University of Twente, Twente, Netherlands

Abstract

Bose-Einstein condensation has been observed with cold atomic gases, exciton-polaritons, and more recently also with low-dimensional photon gases e.g. in a dye solution-filled optical microcavity [1]. We here report on experiments observing a non-Hermitian phase transition in a photon Bose-Einstein condensate realized in the dye-microcavity platform. The dissipative phase transition occurs due to an exceptional point in the condensate that is associated with the (small) system losses. While usually Bose-Einstein condensation is separated by a smooth crossover to lasing, the presence of the here observed phase transition reveals a state of the light field characterized by a bi-exponential second order coherence that is separated by a phase transition from lasing [2]. In more recent work, we have performed a critical test of the thermal nature of the photon condensate coupled to the reservoir of photo-excitable dye molecules by probing the fluctuation-dissipation theorem in this system [3].

References:

[1] See, e.g.: Novel superfluids, Vol. 1, K. H. Bennemann and J. B. Ketterson (eds.) (Oxford University Press, Oxford, 2013).

[2] F. Öztürk, T. Lappe, G. Hellmann, J. Schmitt, J. Klaers, F. Vewinger, J. Kroha, and M. Weitz, Science **372**, 6537 (2021).

[3] F. Öztürk, F. Vewinger, M. Weitz, and J. Schmitt, Phys. Rev. Lett. **130**, 033602 (2023).

Poster

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Many body physics

Presentation

Poster presentation

B020

Bose and Fermi Polarons in Atom-Ion Hybrid Systems

Luis Ardila[1], Renato Pessoa[2], Silvio vitiello[3]

[1]School of Science and Technology, Physics Division, University of Camerino, Camerino MC, Italy. [2]Instituto de Física, Universidade Federal de Goiás, Goiânia GO, Brazil. [3]Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas- UNICAMP, Campinas SP, Brazil

Abstract

Charged quasiparticles dressed by the low excitations of an electron gas constitute one of the fundamental pillars for understanding quantum many-body effects in some materials. Quantum simulation of quasiparticles arising from atom-ion hybrid systems may shed light on solid-state uncharted regimes. Here, we will discuss ionic polarons created as a result of charged dopants interacting with a Bose-Einstein condensate [1,2] and a polarized Fermi gas [3]. Here, we show that even in a comparatively simple setup consisting of charged impurities in a weakly interacting bosonic medium and an ideal Fermi gas with tunable atom-ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state in the bosonic case; in contrast, a molecular state appears in the Fermi case. We unravel their vastly different polaronic properties compared to neutral quantum impurities using quantum Monte Carlo simulations. Contrary to the case of neutral impurities, ionic polarons can bind many excitations, forming a nontrivial interplay between few and many-body physics, radically changing the ground-state properties of the polaron.

Categories

Many body physics

Presentation

Poster presentation

B021

Commensurate and incommensurate 1D interacting quantum systems

Andrea Di Carli, Christopher Parsonage, Arthur La Rooij, Lennart Koehn, Clemens Ulm, Callum W. Duncan, Andrew J. Daley, Elmar Haller, Stefan Kuhr

University of Strathclyde, Glasgow, United Kingdom

Abstract

Quantum-gas microscopes using ultra-cold atoms in optical lattices offer a powerful platform for quantum simulation with single-atom manipulation and detection capabilities. Key to single-site control are programmable light patterns from a digital micromirror device (DMD) that can create arbitrary potential landscapes. In our most recent study, we apply dynamically varying repulsive DMD potentials to create commensurate and incommensurate 1D systems of interacting bosonic Rb atoms [1].

Initially, a commensurate system with unit filling and fixed atom number is prepared between two potential barriers. We deterministically create an incommensurate system by dynamically changing the position of the barriers such that the number of available lattice sites is reduced while retaining the atom number. We study the spatial distribution of the (in)commensurate gases from the weakly interacting to the strongly interacting regime, as well as the atom number variance to characterise our 1D systems. Finally, we probe particle mobility by applying an external bias field.

[1] Di Carli, A., Parsonage, C., La Rooij, A. *et al.* Commensurate and incommensurate 1D interacting quantum systems. *Nat Commun* **15**, 474 (2024). https://doi.org/10.1038/s41467-023-44610-3

Categories

Many body physics

Presentation

Poster presentation

B022

Dark States, Scale Invariance, and Topological Fragmentation

Nathan Harshman

American University, Washington, DC, USA

Abstract

This poster presents several models for trapped ultracold atoms in one dimension that share a common feature. In all cases, the models have dark states, i.e., stationary states that are invariant as certain trap or interaction parameters are varied. These dark states occur when some subspace of the Hilbert space for the model possesses additional symmetries that preserve a form of scale invariance. These dark states also signify that these parameter-dependent models have scale-invariant limits described by topological defects that disrupt the connectivity or simple-connectivity of the configuration space of the model. This poster explains the phenomenological consequences of dark states, how they lead to fragmentation of the Hilbert space for these parameter-dependent models, their relation to anyon models in one dimension, and how breaking scale invariance can be exploited to produce exotic quantum holonomies under parameter variation.

Categories

Many body physics

Presentation

Poster presentation

B023

Quench-induced dynamics of bound impurities in a one-dimensional Bose lattice gas

Felipe Isaule[1], Abel Rojo-Francàs[2], Bruno Juliá-Díaz[2]

[1]Pontificia Universidad Católica de Chile, Santiago, Chile. [2]Universitat de Barcelona, Barcelona, Spain

Abstract

The progress in realising ultracold atomic mixtures has greatly revitalised the interest in studying impurities immersed in quantum mediums [1]. Of particular interest is the problem of two correlated mobile impurities, as these can form bound particles usually referred to as bipolarons [2]. In this direction, and motivated by studies of bipolarons in BECs [3], the study of bipolaron-like physics in optical lattices has appeared as a new platform to study highly imbalanced mixtures [4-6].

In our recent work [7], we study two mobile bosonic impurities immersed in a one-dimensional optical lattice and interacting with a bosonic bath. We examine the formation of bound dimers of impurities across superfluid and Mott bosonic baths and study the dynamics after a quench of the interactions. We reveal that after large interaction quenches from strong to weak interactions the system can show large oscillations over time with revivals of the dimer states. Moreover, we find that the periods depend strongly on the interaction quenches, resulting in distinct regions of oscillations.

[1] C. Baroni, G. Lamporesi, and M. Zaccanti, arxiv:2405.14562 (2024).

[2] A. S. Alexandrov and N. F. Mott, Rep. Prog. Phys. 57, 1197 (1994).

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[4] S. Dutta and E. J. Mueller, PRA 88, 053601 (2013).

[5] M. Pasek and G. Orso, PRB 100, 245419 (2019).

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[7] F. Isaule, A. Rojo-Francàs, and B. Juliá-Díaz, arXiv:2402.03070 (2024).

Categories

Many body physics

Presentation

Poster presentation

B024

Higgs oscillations in a strongly interacting Fermi gas

Paul Dyke[1], Silvia Musolino[2], Hadrien Kurkjian[3], Denise Ahmed-Braun[4], Allan Pennings[1], Ivan Herrera[1], Sascha Hoinka[1], Servaas Kokkelmans[4], Victor Colussi[5,6], Chris Vale[1,7]

[1]Optical Sciences Centre, ARC Centre of Excellence in Future Low-Energy Electronics Technologies, Swinburne University of Technology, Melbourne, Australia. [2]Université Côte d'Azur, CNRS, Institut de Physique de Nice, Nice, France. [3]Laboratoire de Physique Théorique, Université de Toulouse, Toulouse, France. [4]Eindhoven University of Technology, Eindhoven, Netherlands. [5]Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Universitá di Trento, Trento, Italy. [6]Infleqtion, Inc., Boulder, USA. [7]CSIRO, Clayton, Australia

Abstract

Ultracold Fermi gases with tunable interactions serve as a versatile platform for investigating quantum many-body phenomena, providing a defect-free environment ideal for studying condensed matter physics. In this work, we examine the dynamics of a two-component, strongly interacting Fermi gas following a sudden change in the inter-atomic interactions within the superfluid phase. This induces oscillations in the superfluid order parameter, known as Higgs oscillations. Utilizing two-photon Bragg spectroscopy, we directly observe these amplitude oscillations and measure the pairing gap and damping rate as functions of temperature and interaction strength. Our experimental results show strong qualitative agreement with time-dependent BCS theory.

Categories

Many body physics

Presentation

Poster presentation

B025

Bloch oscillations of a soliton in a 1D quantum fluid

Franco Rabec, Guillaume Chauveau, Guillaume Brochier, Sylvain Nascimbène, Jean Dalibard, Jérôme Beugnon

Laboratoire Kastler Brossel, Paris, France

Abstract

We experimentally study the dynamics of 1D **magnetic solitons** using an **ultracold mixture** of two internal states of ^{87}Rb. This **many-body quantum object**, under the action of a constant force, undergoes a **periodic motion** similar to that of a particle undergoing Bloch oscillations, despite the **absence of a periodic potential** in our system. This surprising motion is a **feature of 1D systems**. We also demonstrate, in our work, the key role of the **phase of the quantum fluid** to interpret our results.

Categories

Many body physics

Presentation

Poster presentation

B026

Halo trimers and dimer-trimer superpositions in ultracold Na-K mixtures

Arthur Christianen[1], Alexander Y. Chuang[2], Richard Schmidt[3], Martin W. Zwierlein[2]

[1]ETH Zürich, Zürich, Switzerland. [2]MIT, Boston, USA. [3]Heidelberg University, Heidelberg, Germany

Abstract

Radiofrequency (rf) association is a well-established tool to create Feshbach dimers starting from an ultracold mixture. In experiments using thermal Na-K mixtures we demonstrate that also halo trimers can directly be rf-associated. Moreover, when performing such experiments in a dense BEC of Na, not just dimers and trimers appear, but their superpositions! The trimers are of the Efimov-unfavorable type, consisting of a Na-atom very weakly bound to a Na-K Feshbach dimer. However, we find that they exist over a wide range of magnetic fields. We theoretically model the experimental observations, such as trimer energies and lineshapes, and the many-body dressed spectra, generally obtaining good agreement without fitting to the experimental data. Our study opens the door towards new universal few-body physics and its manifestation in a degenerate medium.

Categories

Many body physics

Presentation

Poster presentation

B027

Non-separability of phonon pairs in a time modulated Bose-Einstein condensate

Victor Gondret[1], Charlie Leprince[1], Clothilde Lamirault[1], Quentin Marolleau[2], Denis Boiron[1], Chris Westbrook[1]

[1]Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Palaiseau, France. [2]Onera, Palaiseau, France

Abstract

In standard cosmological models, inflation is driven by a quantum field known as the inflaton, whose constant energy density causes the universe to expand at superluminal speeds. When inflation ends, the universe has an extremely low density, but the inflaton field begins to oscillate around its energy minimum and decays into entangled pairs of particles. This phase is known as pre-heating. The particles then start to interact, leading to decoherence and thermalization, marking the re-heating stage. Although in situ observation of the inflaton particle creation process is impossible, this pair production through parametric amplification is analogous to the creation of phonon pairs in a Bose-Einstein condensate (BEC) with temporally modulated interaction strength. Modulating the stiffness of a dipole trap in a cigar-shaped BEC is equivalent to modulating the effective one-dimensional interaction strength in a BEC. Our work is both theoretical, introducing new criteria to probe non-separability, and experimental. We report the observation of entangled phonons with opposite momenta. The entanglement of the phonon pairs is observed to decrease as the excitation duration increases.

Categories

Many body physics

Presentation

Poster presentation

B028

Atomic Quantum Sensor using Rydberg EIT for Ultralow-Frequency Electric Field Measurements

Yi-Hsin Chen, Yu-Chi Chen, Shao-Cheng Fang

National Sun Yat-sen University, Kaohsiung, Taiwan

Abstract

Highly-excited Rydberg atoms hold great promise for quantum sensing applications. Rydberg-assisted atomic electrometry using thermal vapors is a feasible method for detecting external electric fields. However, challenges arise in low-frequency measurements due to metal-alkali atoms' absorption on the vacuum enclosure's interior surface. In this study, we utilize high-contrast Rydberg-electromagnetically-induced-transparency (EIT) spectroscopy to systematically address these challenges, investigating the effects of laser power and electric field variations. Our findings show significant advancements in enhancing frequency measurements below 10 Hz, thus improving the performance of Rydberg atomic electrometry. Moreover, we establish a standard quantum limit for data capacity and validate it experimentally across bandwidths ranging from 10 Hz to 1 MHz. Furthermore, we explore the potential to amplify the interaction strength between Rydberg atoms through Förster resonance, achievable by applying external fields based on the Stark effect. In addition to contributing valuable insights to field sensing, this study elucidates the potential for quantum information processing.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

B029

Fano spectroscopy and EIT based cooling of a neutral atom in an optical trap

Chang Hoong Chow[1], Boon Long Ng[1], Vindhiya Prakash[1], Christian Kurtsiefer[1,2]

[1]Centre for Quantum Technologies, Singapore, Singapore. [2]National University of Singapore, Singapore, Singapore

Abstract

It was predicted in the 90s that a three level atom probed in a Λ configuration reveals an asymmetric Fano-type excitation spectrum. This asymmetry is due to coherent population trapping in a dark state that is close in energy to a bright dressed state, causing the spectral profile of the bright state to truncate rapidly. We probe this excitation spectrum in a single ^{87}Rb atom optically trapped at the focus of two lenses with high numerical-aperture [1]. The large solid angle for fluorescence collection provided by the lenses helps resolve the Fano-profile.

We use the dark state to implement a cooling technique based on electromagnetically induced transparency (EIT). EIT can be used to cool an atom in a harmonic potential close to the ground state by suppressing diffusion from spontaneous emission and addressing several vibrational modes simultaneously. Previous efforts focus primarily on trapped ions. Here, we extend it to an atom in an optical trap where the trap frequencies are an order of magnitude smaller than in an ion trap and a standing-wave trap, which makes the vibrational modes harder to resolve. We also observe the Fano like profile in temperature measurements as a function of laser frequencies. A final temperature of ∼6 μK is achieved, a factor of two lower than the value obtained from polarisation gradient cooling. This extends the toolkit for increasing the coherence of atomic qubits.

[1] Chow et al., Fano Resonance in Excitation Spectroscopy and Cooling of an Optically Trapped Single Atom, arXiv:2312.06438v1

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

B030

A device for magnetic-field angle control in magneto-optical filters using a solenoid-permanent magnet pair.

Sharaa A Alqarni[1,2], Jack D Briscoe[1], Clare R Higgins[1], Fraser D Logue[1], Danielle Pizzey[1], Thomas G Robertson-Brown[3], Ifan G Hughes[1]

[1]Durham University, Durahm, United Kingdom. [2]Najran University, Najran, Saudi Arabia. [3]Swansea University, Swansea, United Kingdom

Abstract

Atomic bandpass filters have an extensive range of applications for their narrow bandwidths and efficient transmission at specific frequencies. In general, these filters are configured in the Faraday (Voigt) setup, employing a magnetic field applied axially (or transversely) with respect to the direction of laser propagation. In our study [1], we introduce an innovative approach to achieve magnetic fields at arbitrary angles. The method utilises a fixed pair of permanent magnets to generate a transverse B-field, coupled with a solenoid for a precise axial field control. By adjusting the current into the solenoid, the magnetic field angle can be rapidly reconfigured. We measure the magnetic fields produced by our method and an old method involving physically rotating permanent magnets with respect to the k-vector of the interrogating laser beam. We note that both methods work similarly across the vapor cell. We then compare the transmission profiles of filters produced using both methods, they are almost identical. Finally, we show how changing the magnetic field angle affects the filter's performance, which is easier to utilise due to our new design's flexibility and precise angle control. Additionally, our design allows for the utilisation of longer vapor cells-crucial for enhanced filters-across various field angles. This advantage stems from the significantly reduced drop-off in magnetic field uniformity as the angle increases, with the new method offering an order of magnitude improvement over the old method.

[1] A device for magnetic-field angle control in magneto-optical filters using a solenoid-permanent magnet pair.Rev. Sci. Instrum. 95, 035103 (2024)

Poster

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Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

B031

Interference of photons scattered from independent hot atoms

STUTI JOSHI[1], JAROMIR MIKA[1], ROBIN KAISER[2], Lukas Slodicka[1]

[1]Department of Optics, Palacky University, Olomouc, Czech Republic. [2]Universite Cote d'Azur, CNRS, INPHYNI,, Nice, France

Abstract

The interference of light emitted from independent ensembles of elementary atomic emitters plays a paramount role in diverse areas of modern classical and quantum optics. In the present work, we demonstrate an interference of light scattered from a two-level warm rubidium vapour in a counter-propagating excitation laser beam configuration. The method shows the existence of the finite coherence between photons elastically scattered by two different atomic velocity groups in a Doppler-broadened media. Although the random phase fluctuations from the independent atoms prevent any direct observable first-order interference effects, the stable frequency difference between the scattered photons gives rise to modulations in the second-order correlation function. We also demonstrate the direct applicability of the scheme to estimate the frequency detuning of the exciting laser from a two-level electronic transition which can find potential application in atomic or molecular spectroscopy.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

B032

Quantum scar and classical localisation affecting the motion of three interacting particles in a circular trap

David Papoular, Benoit Zumer

LPTM, UMR8089 CNRS and Univ. Cergy-Pontoise, Cergy-Pontoise 95302, France

Abstract

We theoretically analyse the system comprised of three interacting Rydberg atoms in a circular trap [1,2]. This system has a mixed classical phase space. In particular, it exhibits both stable and unstable classical periodic trajectories. We calculate the quantum energy eigenvalues and the corresponding eigenfunctions numerically using the finite element method. We find that the energy spectrum obeys Berry-Robnik statistics. We show that some eigenfunctions exhibit a quantum scar due to the classically unstable periodic trajectory, and identify towers of scarred quantum states which we fully explain semiclassically [1]. Other eigenfunctions are localised near the classically stable periodic trajectories: we characterise the energies of these states and construct their wavefunctions using the semiclassical Einstein-Brillouin-Keller approach, in excellent agreement with our full-fledged numerical solution [2]. We discuss the impact of discrete symmetries, including bosonic exchange symmetry, on these classically localised states. Quantum scarring and classical localisation occur within the same range of energies. The system we consider is within current experimental reach owing to recent advances in Rydberg atom trapping.

[1] D.J. Papoular and B. Zumer, Phys. Rev. A 107, 022217 (2023).
[2] D.J. Papoular and B. Zumer, arXiv:2404.18265 (April 2024).

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

B033

Highly Correlated Ultrabright Biphotons via Spontaneous Four-Wave Mixing

Jiun-Shiuan Shiu[1,2], Zi-Yu Liu[1,2], Chin-Yao Cheng[1,2], Yu-Chiao Huang[1,2], Ite A. Yu[3,4], Ying-Cheng Chen[5], Chih-Sung Chuu[3,4], Che-Ming Li[2,6], Shiang-Yu Wang[7], Yong-Fan Chen[1,2]

[1]Department of Physics, National Cheng Kung University, Tainan, Taiwan. [2]Center for Quantum Frontiers of Research & Technology, Tainan, Taiwan. [3]Center for Quantum Science and Technology, National Tsing Hua University, Hsinchu, Taiwan. [4]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan. [5]Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan. [6]Department of Engineering Science, National Cheng Kung University, Tainan, Taiwan. [7]Institute of Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan

Abstract

The pairing ratio, a metric quantifying a biphoton source's ability to generate correlated photon pairs, is crucial for assessing source quality. Despite theoretical predictions, the intrinsic characteristic of the pairing ratio has remained largely unexplored in experiments. In this study, we present experimental findings on the pairing ratio using a double-Λ spontaneous four-wave mixing biphoton source in cold atoms. At an optical depth (OD) of 20, we achieved an ultrahigh biphoton generation rate, reaching up to 1.3×10^7 per second, with a successful pairing ratio of 61%. Increasing the OD to 120 significantly improved the pairing ratio to 89%, while maintaining a consistent biphoton generation rate. This dual achievement, characterized by high generation rates and robust biphoton pairing, holds great promise for enhancing efficiency in quantum communication and information processing. Furthermore, in a scenario with a lower biphoton generation rate of 5.0×10^4 per second, we attained an impressive signal-to-background ratio of 241 for the biphoton wavepacket, surpassing the Cauchy-Schwarz criterion by approximately 1.5×10^4 times.

Poster

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Quantum optics and thermodynamics

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B034

Collective coupling of driven multilevel atoms and its effect on four-wave mixing

Pablo Yanes-Thomas[1], Ricardo Gutiérrez-Jáuregui[1], Pablo Barberis-Blostein[2], Daniel Sahagún Sánchez[1], Rocío Jáuregui[1], Alejandro Kunold[3]

[1]Instituto de Física, Universidad Nacional Autónoma de México, Ciudad de México, Mexico. [2]Instituto de Investigaciones en Matemáticas Aplicadas y en Sistemas, Universidad Nacional Autónoma de México, Ciudad de México, Mexico. [3]Área de Física Teórica y Materia Condensada, Universidad Autónoma Metropolitana Azcapotzalco, Ciudad de México, Mexico

Abstract

The design of protocols for achieving controlled quantum non-linear optical responses of atomic gases requires microscopic models involving multi-level atoms. Cooperative effects seem to be essential to understand experimental observed features. In this work, the collective effects that arise in a system of driven, multi-level atoms that all couple to a common electromagnetic environment were e carefully studied. A non trivial interplay between dressed states, photon exchanges between atoms and its collective decay channels was found. Explicit calculations are shown for four-wave-mixing in two four-level atoms in a diamond configuration under experimentally feasible conditions. The influence of the collective effects of both the inter-atomic correlations and the collective decay channels on the outgoing photons was worked out in terms of the $g^{(2)}$ function. It displays a prominent two-peak structure, in contrast with the Lorentzian shape that is expected for independent atoms. We related this two-peak structure to the combined influence of the dressed states and the collective decay channels. A similar two-peak structure for the correlation function has been observed in experimental implementations. The insights gained from this work can aid in finding relevant parameters that could be employed in quantum control protocols involving dispersive and dissipative collective effects in systems of multi-level atoms.

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Quantum optics and thermodynamics

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Poster presentation

B035

Tunable Einstein-Bohr recoiling-slit gedankenexperiment at the quantum limit

Yu-Chen Zhang[1,2,3], Hao-Wen Cheng[1,2,3], Xu-Zhao-Qiu Zeng[1,2,3], Zhan Wu[1,2,3], Ming-Cheng Chen[1,2,3], Jun Rui[1,2,3], Jin-Yi Zhang[1,2,3], Rui Lin[1,2,3], Yu-Cheng Duan[1,2,3], Hao-Nan Lin[1,2,3], Zhou-Chen Deng[1,2,3], Chao-Yang Lu[1,2,3], Jian-Wei Pan[1,2,3]

[1]Hefei National Research Center for Physical Sciences at the Microscale and School of Physical Sciences, University of Science and Technology of China, Hefei, China. [2]Shanghai Research Center for Quantum Science and CAS Center for Excellence in Quantum Information and Quantum Physics, University of Science and Technology of China, Shanghai, China. [3]Hefei National Laboratory, University of Science and Technology of China, Hefei, China

Abstract

In 1927, during the fifth Solvay Conference, Einstein and Bohr described a double-slit interferometer with a "movable slit" that can detect the momentum recoil of one photon. Their debate centered around this gedankenexperiment has provided profound insights into the central concepts of quantum mechanics. Despite many experimental efforts to realize this conceptual experiment, none has reproduced the original linear optical interferometer faithfully with pure one-photon momentum recoil and a full tunability. Here, we report a faithful realization of the Einstein-Bohr interferometer using a single atom in an optical tweezer, which is cooled to the motional ground state in three dimensions such that its momentum uncertainty is comparable to that of a single photon. We design an interferometric configuration where the single atom serves as an ultralight, quantum-limit beam-splitter that becomes momentum-entangled with the input photon. By varying the depth of the tweezer trap, we dynamically tune the atom's intrinsic momentum uncertainty, thus enabling the observation of a gradual shift in the visibility of single-photon interference. The interferometer also allows to distinguish the classical noise caused by atom heating from the quantum-limited noise due to the momentum transfer, illustrating a quantum-to-classical transition.

Poster

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B036

Manipulation of single photon with microwave field based on Rydberg polariton

Yuechun Jiao, Yunhui He, Jianming Zhao

Shanxi University, Taiyuan, China

Abstract

Rydberg atom are particularly attractive for quantum applications because they offer a unique combination of precision, scaling to three dimensions, direct photonic readout, and strong photon-photon interactions. Due to the strong nonlinearities in a Rydberg blockade region, a single photon can be stored in the formation of Rydberg polariton using electromagnetically induced transparency (EIT). Moreover, the energy level interval between two nearby Rydberg states is in the microwave frequency range, enabling coherent manipulation of Rydberg levels via microwaves. Firstly, we demonstrate a coherent microwave manipulation of a single optical photon based on a single Rydberg excitation in an atomic ensemble. A single photon is stored in the formation of Rydberg polariton using electromagnetically induced transparency (EIT) and the manipulation of the stored single photon is performed by applying a microwave field that resonantly couples the nS1/2 and nP3/2, while the coherent readout is performed by mapping the excitation into a single photon. Then, we demonstrate a robust single-photon stored-light Ramsey interferometer by applying Ramsey-like microwave sequences, which is robust to the decoherence induced by external perturbations. Our work provides a way to manipulate the stored photons by employing the microwave field, which is significant for developing quantum technologies.

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B037

Optical switching with nanofiber-trapped cold atoms

Mingxin Dong, Zhengze Li, Alban Urvoy, Julien Laurat

Laboratoire kastler Brossel, Paris, France

Abstract

Our research focuses on large Bragg reflections observed near one-dimensional nanoscale waveguides formed by cold atom arrays. By using an optical lattice in the evanescent field surrounding a nanofiber with a period nearly commensurate with the resonant wavelength, we observe a reflectance of up to 75% for the guided mode. Each atom behaves as a partially reflecting mirror and an ordered chain of about 2000 atoms is sufficient to realize an efficient Bragg mirror. By combining the EIT effect with a control light, we can achieve high contrast optical switching of such Bragg mirrors.

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B038

Towards high temperature solid state spin photon interfaces

Leeju Singh, Eilon Poem, Ofer Firstenberg

Weizmann Institute of Science, Rehovot, Israel

Abstract

We propose the use of nickel centers in diamond and magnesium oxide for the implementation of solid-state-based components of a quantum-optical network. We show that these centers have long lived spin states, and, due to the large spin-orbit coupling in nickel, also allow for fast and coherent coupling between the spins and telecom-band photons. We believe that this unique combination makes the study of these centers a very promising research direction towards their use in future quantum-optical network components such as quantum-optical memories and quantum-optical gates.

We study nickel related color centers in diamond towards their application in a solid state light spin interfaces. these centers have strong spin orbit interaction, thus are potentially suitable for high temperature operation. using polarized resonant excitation we observe signs of both spin and charge optical pumping at 10K.

Poster

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B039

Sub-hertz electric field sensing with rubidium $nF_{7/2}$ Rydberg states

Michael Lim

Rowan University, Glassboro, USA

Abstract

We demonstrate a Rydberg-atom sensor for sub-hertz electric fields based on three-photon excitation of $nF_{7/2}$ states in warm rubidium vapor. The effect is characterized in a vapor cell with internal parallel-plate electrodes to facilitate signal collection and modeling without the complication of Faraday screening by condensed alkali metal on the interior cell wall [1]. Three-photon cascade excitation to a Rydberg state produces an EIT response in the transmission of the weak probe beam tuned to the D2 line, similarly to Ref. [2]. Sinusoidal voltage modulation of one of the internal field plates generates time variation of the response, which is then demodulated using a lock-in amplifier. Demodulation at the driving frequency (and at certain harmonics) yields a signal that is highly sensitive to low frequency fields simultaneously incident on the atomic population; a hertz-scale test field is created by applying a weak, slowly varying voltage to the opposing internal field plate. To demonstrate detection of ambient electric fields, a second apparatus is configured with a single electrode outside a conventional quartz vapor cell (no internal electrodes). When the modulation voltage is applied to the external electrode and Rydberg states are excited in the same manner as described above, the demodulated signal remains sensitive to weak ambient fields near and below 1 Hz, despite Faraday screening of low frequencies due to the metallic rubidium layer inside the cell.

[1] M. J. Lim, et al., App. Phys. Lett. **123**, 051106 (2023).

[2] N. Thaicharoen, et al., Phys. Rev. A **100**, 063427 (2019).

Categories

Quantum optics and thermodynamics

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B040

Experimental realization of RF-dressed ultra-cold bubbles in microgravity: update on the Cold Atom Laboratory (CAL) mission.

Jean-Baptiste Gerent, Nathan Lundblad

Bates College, Lewiston, USA

Abstract

The atomic physics community utilizes ultra-cold atoms to explore the effects of geometry, topology, dimensionality, and interactions in purely quantum systems. While reduced dimensionality profoundly influences system properties, it remains a subject of theoretical debate. Field-induced adiabatic potentials offer a versatile alternative to optical lattices for manipulating ultra-cold atoms, enabling the creation of 2D traps where wave functions localize around spherical surfaces (shells). This would allows to extend the study of quantum gases and their many-body properties from flat to curved geometry. However, experimental realization of such traps faces challenges due to RF dressing hindering gravitational sag compensation using magnetic gradients. A solution lies in conducting experiments in sustained microgravity environments, such as the NASA Cold Atom Lab on the International Space Station. In this presentation, recent observations of trapped ultracold atom shells in various configurations will be discussed, alongside an exploration of their thermodynamics and ongoing investigations into open questions. We will especially focus on presenting recent modifications of the on-board experimental apparatus and it's next generation.

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Quantum optics and thermodynamics

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B041

Spectroscopy of Heteronuclear Xenon-Noble gas Dimers - Towards Bose-Einstein Condensation of Vacuum-UV Photons

Eric Boltersdorf, Thilo vom Hövel, Jeremy Andrew Morín Nenoff, Frank Vewinger, Martin Weitz

Institute of Applied Physics, Bonn, Germany

Abstract

Photons confined in a dye-filled optical microcavity can exhibit Bose-Einstein condensation upon thermalization through repeated absorption and (re-)emission processes by the dye molecules. This has been experimentally demonstrated for photons in the visible spectral regime in 2010. In this work, an experimental approach is investigated to realize Bose-Einstein condensation of vacuum-ultraviolet (100nm-200nm; *VUV*) photons via repeated absorption and (re-)emission cycles between two electronic state manifolds of xenon-noble gas excimer molecules in dense gaseous ensembles (pressure of up to 100bar). (Re-)emission and absorption to achieve thermalization are considered to occur between the quasi-molecular states associated with the xenon $5p^6(J = 0)$ and $5p^5 6s(J = 1)$ states, respectively. A Bose-Einstein condensate of VUV photons would serve as a coherent light source. We plan to pump the photon gas inside a high-pressure optical microcavity with light near 129nm wavelength, which can be generated by third-harmonic generation of near-ultraviolet light around 387nm. The pump drives the $5p^6(J = 0) \rightarrow 5p^5 6s'(J = 1)$ transition in xenon. We report on the results of spectroscopic measurements, indicating the formation of heteronuclear noble gas excimers. Also, the fulfillment of the thermodynamic Kennard-Stepanov relation, a fundamental prerequisite for a gas to serve as a thermalization medium, has been successfully investigated.

Poster

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B042

Efficient filling of long-lifetime, single-atom traps in the collisional blockade regime

Mark IJspeert, Isabel Parke, Naomi Holland, Axel Kuhn

University of Oxford, Oxford, United Kingdom

Abstract

Single trapped atoms at temperatures near absolute zero are ideal information carriers in quantum computing and simulation. The confinement of atoms is often achieved with focussed laser beams acting as optical dipole-force traps that allow for both static and dynamic positioning of atoms. Normally, the time-averaged probability of trapping a single atom in the collisional blockade regime is limited to 50% when loading directly from a magneto-optical trap, preventing deterministic filling of large arrays of cold atoms. Furthermore, when dynamic, holographic masks are used for simultaneous rearrangement of atoms, the intensity flicker that occurs as the spatial light modulator updates its holographic frame leads to undesirable loss during transport. In this work, we demonstrate that increasing the depth of a static, optical dipole trap enables the transition from fast loading (at a rate of 0.63 Hz) to long-lifetime trapping (average lifetime of 8.5 s). This translates to an achievable filling ratio of 84%. In addition, we simulate and experimentally realise techniques to suppress intensity-flicker in holographic traps generated with a liquid crystal spatial light modulator. This allows us to nearly preserve the trap depth during the transition between two static frames. Such a deterministic means of holding a single atom in place and suppressing its loss during transport are important factors for implementing large and scalable atomic networks for quantum processing. Reconfigurable arrays of cold atoms enable the simulation of many-body physics and the realisation of high-fidelity quantum gates.

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Quantum optics and thermodynamics

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B043

Engineering Effective Interactions for Bose-Einstein Condensates of Photons

Niels Wolf, Andreas Redmann, Christian Kurtscheid, Frank Vewinger, Julian Schmitt, Martin Weitz

University of Bonn, Bonn, Germany

Abstract

Bose-Einstein condensation can be observed with ultracold atomic gases, polaritons, and since about a decade ago also with low-dimensional photon gases. Bose-Einstein condensates of photons have been realized in dye-solution filled optical microcavities, where a wavelength-size small mirror spacing imprints a low-frequency cutoff with a spectrum of photon energies above the low-frequency cutoff and thermalization of photons being achieved by repeated absorption-reemission processes on the dye molecules [1]. In the presence of an effective photon interaction, the energetically driven optical state preparation method can in future in lattice potentials provide a route for exploring highly correlated and entangled states [2].

Here we report the generation of effective Interactions, which is a third order nonlinearity, by cascading second order nonlinearities in a double resonant setup (see [3] corresponding theory). Our demonstration experiment builds upon a triply resonant optical parametric oscillator setup, with independent control of the cavities for the pump and subharmonic wavelengths respectively. The achieved effective Kerr-nonlinearity of periodically poled lithium niobate (PPLN) of 4.2(3)e^{-11} cm^2/W is two orders of magnitude above the intrinsic Kerr-nonlinearity of the used PPLN crystal.

[1] J. Klaers, J. Schmitt, F. Vewinger, and M. Weitz, Nature 468, 545 (2010)

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Quantum optics and thermodynamics

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B044

A cryogenic neutral atom optical tweezer array

Ting You Tan[1,2], Ting-Wei Hsu[1,2], Zhenpu Zhang[1,2], Matteo Marinelli[1,2], Daniel Slichter[3], Cindy Regal[1,2], Adam Kaufman[1,2,3]

[1]University of Colorado, Boulder, Boulder, USA. [2]JILA, Boulder, USA. [3]National Institute of Standards and Technology, Boulder, USA

Abstract

Scalable ultracold Rydberg atom arrays provide an intriguing platform for programmable quantum computation and simulation. We present a new system for the control of 2D Rydberg qubit arrays of 87Rb atoms embedded in a cryogenic environment. The setup leverages two main features: a low-vibration cryostat and a high optical access vacuum chamber with a room temperature large-field-of-view objective. In our low vibration system, we observe single-atom vacuum lifetime above 2500 s due to cryopumping. Furthermore, a < 50 K cold box should extend the Rydberg lifetime to several times its value at room temperature when fully upgraded in the future. The high-optical access vacuum chamber will allow the creation and control of a large tweezer array or optical lattice with the site-resolved addressability and interaction control aided by optical tweezers. We report our results on trapping and rearranging atoms within the cryogenic environment, as well as results on Rydberg and qubit control.

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Quantum computing, simulation & networks

Presentation

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B045

Running benchmarking algorithms on 10-ququarts $^{171}Yb^{+}$ ions processor

Ilia Zalivako[1,2], Anastasiia Nikolaeva[1,2], Alexander Borisenko[1,2], Andrei Korolkov[1,2], Pavel Sidorov[1,2], Kristina Galstyan[1,2], Nikita Semenin[1,2], Vasilii Smirnov[1,2], Mikhail Aksenov[1], Konstantin Makushin[1], Evgeniy Kiktenko[1], Aleksey Fedorov[1,2], Ilya Semerikov[1,2], Ksenia Khabarova[1,2], Nikolay Kolachevsky[1,2]

[1]Russian Quantum Center, Moscow, Russian Federation. [2]P.N. Lebedev physical institute of RAS, Moscow, Russian Federation

Abstract

Multilevel quantum information carriers, qudits, is a prospective approach to quantum computing. Qudits not only provide more dense information encoding by incapsulating several qubits in only one particle, but also allow one to more efficiently implement quantum algorithms. For example, in some cases ancilla qubits can be replaced with auxiliary quantum states in the same particles. In this work we present a quantum processor based on optical ququarts encoded in $^{2}S_{1/2}$ (F=0) -> $^{2}D_{3/2}$(F=2) E2 transition in a chain of ten $^{171}Yb^{+}$ ions. We demonstrate a universal quantum gate set with single-qudit and two-qudit gates fidelities of 99.95% and 95%, respectively. We also present results of benchmarking algorithms including Bernstein-Vazirani and Grover search, quantum machine learning, quantum molecular simulations and others. We also show possibility of mid-circuit measurements in our system and illustrate it by implementation of CNOT gate teleportation protocol.

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B046

Floquet transverse-field Ising dynamics in a Rydberg-dressed optical tweezer array

Neomi Lewis[1], Shankari Rajagopal[1], Gabriel Moreau[1], Michael Wahrman[1], Nazli Köylüoğlu[2], Monika Schleier-Smith[1]

[1]Stanford University, Stanford, USA. [2]Harvard University, Cambridge, USA

Abstract

Using Rydberg dressing and microwaves, cold atoms allow for a natural implementation of transverse-field Ising dynamics - a paradigmatic model of quantum magnetism. Time-dependent control of these interactions can enhance entanglement generation, execute quantum optimization algorithms, emulate more complex spin models, and explore driven phases with no equilibrium analogue. Indeed, in previous experimental work in a bulk gas of cesium atoms, we demonstrated a Floquet implementation of the transverse-field Ising model, observing dynamical signatures of a mean-field paramagnet-ferromagnet phase transition. More recently, we optimized the Rydberg dressing pulse sequence to extend the coherence time of these interactions. This allowed us to observe the generation of spin squeezed states in a microtrap configuration, which can be used for quantum-enhanced sensing. In this poster, we present experimental upgrades going from microtraps to an array of single atoms in optical tweezers and discuss three future directions: (a) realization of Floquet symmetry-protected topological phases, (b) simulation of emergent black hole dynamics based on a Floquet conformal field theory, and (c) optimal control of entanglement for quantum metrology.

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Quantum computing, simulation & networks

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B047

A Dysprosium Quantum Gas Microscope

Fiona Hellstern[1], Kevin Ng[1], Paul Uerlings[1], Jens Hertkorn[1], Lucas Lavoine[1], Ralf Klemt[1], Tim Langen[1,2], Tilman Pfau[1]

[1]5th Institute of Physics, University of Stuttgart, Stuttgart, Germany. [2]Atominstitut, TU Wien, Vienna, Austria

Abstract

Quantum Gas Microscopy opens avenues for the microscopic study of dipole-dipole interactions in a lattice and thus the extended Hubbard models as well as a new platform for quantum simulations of long-range interacting models ranging from topological matter to lattice spin models.

We present the progress of our dipolar quantum gas microscope, which will enable in situ single atom and single site resolved detection of Dysprosium atoms in different types of two-dimensional optical UV lattice geometries.
We will utilise an objective with an extremely high numerical aperture (NA=0.9) and employ a spin- and energy-resolved super-resolution imaging technique, allowing us to achieve single-site and single atom detection with 180 nm resolution. Our single-particle detection scheme is complemented by the long-range and anisotropic interactions inherent in highly magnetic Dysprosium atoms.
The close spacing of the ultraviolet (360nm) optical lattice significantly amplifies the strength of nearest-neighbor dipolar interactions, reaching approximately 200 Hz (at 10 nK).
With our optical setup we are able to integrate both square and triangular lattice geometries, offering the capability to observe and manipulate diverse quantum phase transitions such as the (fractional) mott insulator to supersolid transitions.
This places us in the regime of strongly interacting Bose- and Fermi-Hubbard physics, where phases dependent on nearest and even next-nearest neighbor interactions becomes more accessible.

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B048

Calibrating qudits and holonomic gates in neutral atomic ensembles.

Arina Tashchilina[1], Logan Cooke[1], Joseph Lindon[1], Mason Protter[1], Tian Ooi[2], Joseph Maciejko[1], Frank Marsiglio[1], Lindsay LeBlanc[1]

[1]University of Alberta, Edmonton, Canada. [2]University of Colorado, Boulder, USA

Abstract

We have prepared and benchmarked novel single qubit-gates within our ultracold atomic ensemble. In one work [1], we have created a qudit and a universal set of single qudit gates to operate with it. Recently qudits have gained a lot of attention as a promising platform for performing computation for lattice-gauge fields. Therefore, we are hopeful to make our platform useful for quantum computation for quantum electrodynamics and quantum chromodynamics.

One aspect, which could bring the 'useful' quantum computation closer is an improvement in gate fidelity. Thus in our work we explored holonomic gates [2], which are known to be robust against certain noise sources. We study the holonomic transformations of spin eigenstates in the presence of a background magnetic field, characterizing the fidelity of these gate operations. In order to induce degeneracies in our non-degenerate system, we use Floquet engineering. Through a periodic driving of a nondegenerate Hamiltonian degenerate Floquet bands appear, leading to non-Abelian phases and gauge structures.

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Quantum computing, simulation & networks

Presentation

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B049

Scalable graph states generation using state carving in an atom-nanophotonic interface

C.-H. Chien[1,2], S. Goswami[2], C.-C. Wu[2], W.-S. Hiew[1,2], Y.-C. Chen[2], H. H. Jen[2]

[1]Department of Physics, National Taiwan University, Taipei, Taiwan. [2]Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan

Abstract

Scalable graph states are crucial for measurement-based quantum computation and many entanglement-assisted applications in quantum technologies. Generation of these multipartite entangled states requires a controllable and efficient quantum device with delicate design of generation protocol. Here we propose to use an atom-nanophotonic cavity which provides a high-fidelity generation of scalable graph states. We present a general recipe to weave graph states in one and two dimensions, where a multiqubit state carving is utilized for linear and two-dimensional graph states at arbitrary sizes. We further propose an exquisite and systematic design protocol which relies on the feature of contrasted single-photon reflection spectra allowed by the critical coupling regime in the interface. Via the state-carving technique, we are able to project the system into the target graph states with high fidelity. A sequence of single-photon probes further enhances the graph state probability, which is especially useful for large-size graph states and promises a near-term application in quantum engineering of multipartite entangled states. Our results showcase the capability and the potential of an atom-nanophotonic cavity for generating linear and high-dimensional graph states, which sets the foundation for measurement-based quantum computation and paves the way toward novel problem-specific applications using scalable high-dimensional graph states with stationary qubits.

Poster

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B050

Noise Analysis of Quantum Singular Value Transformation Algorithm

Muhammad Ijaz[1], Muhammad Faryad[2]

[1]Lahore, Lahore, Pakistan. [2]Lahore University of Management Sciences, Lahore, Pakistan

Abstract

The quantum singular value transformation algorithm (QSVT) is a recently proposed algorithm that generalizes many fundamental quantum algorithms such as the Grover search and quantum phase estimation (QPE) algorithms. The major challenge in running these quantum algorithms is the noise in quantum computers. This noise is due to the interactions of qubits with the environment and faulty gate operations. Here, we present the impact of incoherent noise on the QSVT algorithm when implemented as the Grover search and QPE algorithm. The noise impact is modeled as trace-preserving and completely positive quantum channels. Different noise models such as depolarizing, phase flip, bit flip, and bit-phase flip are taken to understand the performance of these algorithms in the presence of noise. The simulation results indicate that the probability of success of the Grover algorithm and the standard deviation of the eigenvalue of the unitary operator have strong exponential dependence upon the error probability of individual qubits. Furthermore, the original formulation is compared with the QSVT implementation for the noise resilience of these algorithms.

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B051

Realising fast readout for Rydberg arrays

Balázs Dura-Kovács[1,2], Mehmet Öncü[1,2,3], Jacopo De Santis[1,2,3], Sebastian Ruffert[1,2,4], Adrien Bouscal[1,2], Johannes Zeiher[1,2,3]

[1]Max-Planck Institute for Quantum Optics, Garching, Germany. [2]Munich Center for Quantum Science and Technology, Munich, Germany. [3]Ludwig-Maximilians-Universität, Munich, Germany. [4]Technische Universität München, Garching, Germany

Abstract

Ordered arrays of neutral atoms provide an appealing platform for quantum simulation and quantum computation. Laser-cooled atomic gases allow for simulating quantum many-body systems with unprecedented control over microscopic degrees of freedom. The recent progress on tweezer-based atom arrays and quantum gas microscopes has enabled microscopic detection and manipulation of such systems down to the level of single atoms. Here, we present our progress on an experimental platform aimed at achieving cavity-assisted, non-destructive, local readout of dual species of atoms in a tweezer array. Long-range and tunable interactions between highly-excited Rydberg states make the platform suited to simulate spin models and – together with the fast cavity-based readout – form the architectural basis for the realisation of a scalable error-corrected quantum computing platform.

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B052

NISQy Business: A Full Stack Quantum Computer for Near-Term Quantum Chemistry

Max Festenstein[1,2], Marijn Venderbosch[1,2], Rik van Herk[1,2], Zhichao Guo[1,2], Jesús del Pozo Mellado[1,2], Ricky Teunissen[1,2], Carolus Hamers[1,2], Yuri van der Werf[1,2], Deon Janse van Rensburg[1,2], Rianne Lous[1,2], Edgar Vredenbregt[1,2], Servaas Kokkelmans[1,2]

[1]Department of Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands.
[2]Centre for Quantum Materials and Technology, Hendrik Casimir Institute, Eindhoven, Netherlands

Abstract

Though myriad algorithms exist for quantum computation, the Noisy Intermediate Scale Quantum (NISQ) era makes it challenging to use them on state-of-the-art quantum hardware. Within the Neutral Atom Kat-1 Collaboration at the Eindhoven University of Technology, we are constructing a neutral-atom digital quantum computer to dedicatedly run hybrid Variational Quantum Eigensolver (VQE) algorithms for the purpose of finding the ground state energy of molecules. The VQE algorithm makes use of classical computers to reduce the required coherence times of our qubits to within feasible limits. Our experiment will utilise Strontium atoms in a re-configurable optical tweezer array as our qubit register, with the ground and clock states of the Sr atoms acting as the qubit states. Entangling gates are mediated by long-range Rydberg interactions. Single qubit rotations will be performed via direct coherent addressing of the Sr clock transition, with operand qubits individually addressed via an acousto-optic deflector, whilst the Rydberg transition will be addressed globally with a broad light-sheet beam. This work illustrates the hardware and techniques being employed to progress toward running VQE algorithms, as well as the software infrastructure being developed to turn our platform into a full-stack, web-addressable quantum computer.

Poster

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B053

Microwave- and Optical-Matter Interactions for Microwave Transduction Applications in Quantum Networks

Ujjwal Gautam[1,2], Nasser Gohari Kamel[1,2], Sourabh Kumar[1,2], Daniel Oblak[1,2]

[1]Institute for Quantum Science and Technology, Calgary, Canada. [2]Department of Physics and Astronomy, University of Calgary, Calgary, Canada

Abstract

Quantum technologies, operating on disparate platforms, require quantum transducers as interfaces. A microwave-to-optical transducer is one such device that will facilitate communication between microwave-driven devices, such as superconducting quantum circuits, and optical-photon mediated quantum networks. The rare-earth ion Yb3+ doped in yttrium-orthosilicate (YSO) crystals possess intriguing properties for transduction-based applications, thanks to its clock transitions and long spin coherence times at zero magnetic field. We utilize loop-gap microwave resonators to coherently drive microwave-matter interactions. Loop-gap resonators specialize in providing a homogeneous and focused magnetic field mode in the sample region, enhancing the mode overlap between the magnetic field mode, the optical mode, and the ions in the sample region. Rabi oscillations are optically observed with intense microwave pulses. The oscillation period is used to determine the microwave pi-pulse for subsequent experiments. Optically detected microwave spin echo measurements are conducted using 1-us long microwave pi-pulses, through a beat note with a local oscillator 3 MHz detuned from the expected output optical echo signal. The intensity decay curve of the echo measurements is fitted to obtain the spin coherence time (T2) at a temperature <50mK. The simultaneous coherent interaction of microwave-matter and optical-matter will be utilized to demonstrate the up-conversion of coherent microwave signals to optical signals. Achieving efficient transduction will necessitate higher quality-factor loop-gap resonators and employing a Fabry-Perot resonator for the optical mode in future stages of the experiments.

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Presentation

Poster presentation

B054

Quantum Correlated Probes for Weak Field Sensing

Timothy Leese, Siobhan Patrick, Silvia Bergamini, Calum MacCormick

The Open University, Milton Keynes, United Kingdom

Abstract

Cold atoms offer a promising platform for quantum computing, employing optical tweezers to hold atoms while lasers control the qubit states for quantum logic gates. One suitable protocol for cold atoms is deterministic quantum computation with one clean qubit (DQC1). This method can be adapted into a phase estimation scheme [1] for quantum sensing, improving on a standard atom interferometer by using entanglement to surpass the shot noise limit.

This poster presents our progress toward implementing DQC1. We have made improvements in our experiment based around a mesoscopic dipole trap with a waist of ≈ 2 μm holding ≈ 50 atoms at a temperature ~ 120 μK. For coherent control of qubits, we are developing a noise-tolerant laser system that drives Raman transitions between two hyperfine ground states via an excited state in a λ-configuration. Two lasers excite a narrow ~ 700 kHz FWHM spectral feature from electromagnetically induced transparency (EIT). By stabilising one laser to a saturation absorption spectrum and the other to the EIT signal, we minimise relative frequency noise. In addition, we present modelling of λ-enhanced grey molasses which other work has shown cooling to ~ 4 μK in ^{87}Rb. We will implement grey molasses by adapting our laser system. This temperature reduction is necessary to minimise atomic thermal motion, which we expect will decrease decoherence in quantum gates and enhance our ability to initialise and readout quantum states.

[1] Calum MacCormick et al. Phys. Rev. A 93, 023805 (2016).

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B055

Design and Fabrication of an 8-Qubit Multi-layer Surface Electrode Ion Trap Quantum Processor Chip

Nila Krishnakumar[1,2], Eike Iseke[1,2], Jacob Stupp[2,3], Konstantin Thronberens[1], Nora D. Stahr[2,3], Rodrigo Munoz[2], Teresa Meiners[2], Brigitte Kaune[2], Ludwig Krinner[1,2], Friederike Giebel[1,2], Christian Ospelkaus[1,2,3]

[1]Physikalisch-Technische Bundesanstalt, QUEST institute, Braunschweig, Germany. [2]Leibniz University Hannover, Institute for Quantum Optics, Hannover, Germany. [3]Laboratory for Nano and Quantum Engineering (LNQE), Hannover, Germany

Abstract

Quantum Computing is a developing field characterized by numerous potential systems, each aiming to achieve scalability and ultimately provide solutions to intricate problems. Multi-layer surface-electrode ion traps [1] provide a promising platform for this. Offering geometries unattainable with single-layer traps these feature thick and planarized dielectric-metal layers allowing signal routing flexibility.

We present a demonstrator chip as part of the German Federal Ministry of Education and Research (BMBF) project ATIQ, designed and simulated to achieve all-to-all connectivity and high 2-qubit fidelity. The chip attains this through storage, reliable ion transport, and manipulation of eight trapped Beryllium ions. The 2-layer micro-fabricated ion trap with two storage registers and a gate zone has a size of 5 mm x 10 mm. The computational zone facilitates merging, splitting, and swapping of ions. The buried first layer consists of the microwave line and control electrodes. The embedded single microwave conductor as a bi-layer meander is intrinsically amplitude and phase stable [2]. This layer is then connected through metallised vias to the second layer which carries the segmented DC electrodes and the radio frequency line.

Chip fabrication involves processes like UV-lithography, reactive ion etching, electroplating and chemical mechanical polishing. To enable hybrid integration in the next iteration of chip with integrated photonics, we explore the application of interposer technology, through substrate vias, and packaging technologies like flip-chip bonding.

[1] A. Bautista-Salvador et al., New J. Phys. 21, 043011, Patent DE10 2018 111 220 (2019).

[2] G. Zarantonello et al., Phys. Rev. Lett. 123, 260503 (2019).

Poster

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Presentation

Poster presentation

B056

Strongly interacting dynamics in Rydberg synthetic dimensions

Chenxi Huang[1], Tao Chen[1], Jacob Covey[1], Bryce Gadway[2]

[1]University of Illinois Urbana-Champaign, Champaign, USA. [2]The Pennsylvania State University, State College, USA

Abstract

Synthetic dimensions, formed by coupling suitable degrees of freedom, provide ways to investigate structures that are hard to achieve in real space and nontrivial gauge fields in a highly controllable manner. While the concept were mostly explored in the non-interacting or weakly interacting regimes, we extend the synthetic dimensions playbook to strongly interacting systems of Rydberg atoms prepared in optical tweezer arrays. We use precise control over driving microwave fields to create indented synthetic lattice structures, and separation of atoms in real space to vary the strength of interactions. Here we present our studies of strongly interacting dynamics in both 1D and 2D synthetic lattices.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B057

High-fidelity gates with mid-circuit erasure conversion in a metastable neutral atom qubit

Genyue Liu[1], Shuo Ma[1], Pai Peng[1], Bichen Zhang[1], Sven Jandura[2], Jahan Claes[3], Alex Burgers[1], Sebastian Horvath[1], Michael Peper[1], Yiyi Li[1], Guido Pupillo[2], Shruti Puri[3], Jeff Thompson[1]

[1]Princeton University, Princeton, USA. [2]University of Strasbourg, Strasbourg, France. [3]Yale University, New Haven, USA

Abstract

Neutral atom quantum computing has progressed rapidly in recent years. New atomic species, such as alkaline earth atoms, can enable new capabilities for improving coherence, control, and scalability. One example of this are qubits dominated by erasure errors, which are advantageous for realizing more favorable error models [1]. We demonstrate a new neutral atom qubit, using the nuclear spin of a long-lived metastable state in 171Yb. The long coherence time and fast excitation to the Rydberg state allow one- and two-qubit gates with fidelities of 0.9990(1) and 0.980(1), respectively [2]. Importantly, a significant fraction of all gate errors result in decays out of the qubit subspace to the ground state. By performing fast, mid-circuit detection of these errors, we convert them into erasure errors; during detection, the induced error probability on qubits remaining in the computational space is less than 10-5. We will also discuss ongoing experiments that aim to improve two-qubit gate fidelities by implementing complex quantum circuits that leverage erasure conversion.

[1] Wu, Y., Kolkowitz, S., Puri, S., Thompson, J. D. Erasure Conversion for Fault-Tolerant Quantum Computing in Alkaline Earth Rydberg Atom Arrays. Nat Commun 2022, 13 (1), 4657.

[2] Ma, S. et al., High-Fidelity Gates and Mid-Circuit Erasure Conversion in an Atomic Qubit. Nature 2023, 622 (7982), 279-284.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B058

Do qubits like Metalicca?: Stochastic Schrödinger Equations for qubit evolution

Robert de Keijzer, Luke Visser, Oliver Tse, Servaas Kokkelmans

Eindhoven University of Technology, Eindhoven, Netherlands

Abstract

Environmental noise affecting controlled quantum systems is commonly represented by a dissipative Lindblad equation, capturing the system's average state through the density matrix ρ. While one approach to deriving this equation involves a stochastic operator evolving under white noise in the Schrödinger equation, white noise doesn't reflect real-world noise profiles, where lower frequencies often dominate. In this study, we propose a method to determine the full distribution of qubit fidelities in significant stochastic Schrödinger equation scenarios, where qubits evolve amidst more realistic noise profiles like Ornstein-Uhlenbeck noise. This approach enables the prediction of mean, variance, and higher-order moments of qubit fidelities, offering insights crucial for assessing permissible noise levels in prospective quantum computing systems, thereby aiding decisions on control system quality procurement. Additionally, these methodologies are pivotal for optimizing qubit state control amidst classical control system noise

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B059

Rydberg excitation from a linear array of trapped atoms at the interface of an optical nanofibre

Aswathy Raj[1], Veronika Lidia Giricz[1,2], Alexey Vylegzhanin[1], Dylan Brown[1], Síle Nic Chormaic[1]

[1]Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan. [2]University of Stuttgart, Stuttgart, Germany

Abstract

Rydberg atoms are very promising candidates for quantum technologies. We have realised Rydberg excitation of cold ^{87}Rb atoms using the evanescent light field of an optical nanofibre (ONF). Our system consists of an ONF overlapped with a cloud of laser-cooled Rubidium-87 atoms confined in a magneto-optical trap (MOT). Atoms from the MOT are excited to the Rydberg state via a two-photon process, where the first photon is from the cooling beams, and the second photon is guided through the ONF. When atoms undergo Rydberg excitation, they are lost from the MOT, resulting in the reduction of fluorescence, giving us an indirect measurement of the excitation rate. We have achieved Rydberg excitations from the MOT for principal quantum number n = 24 up to n = 68. To further explore the Rydberg blockade mechanism and the effect of surface-atom interactions, we have realised a two-colour fibre-based optical dipole trap mediated via the evanescent fields. We have optimised the trap using a machine learning algorithm. Currently, we are using this linear chain of atoms to explore Rydberg excitation from the dipole trap and further study the properties of Rydberg excitation at the interface of an ONF. Moreover, these Rydberg atom arrays should prove useful for studies of quantum many-body physics and have potential applications in quantum simulations.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B060

Investigation of ^{171}Yb - ^{87}Rb Rydberg pair interactions and progress toward dual-element atom arrays

Franklin J. Vivanco[1,2], Tao Alex Zheng[1,2], Fangde Liu[1,2], Zihua Wang[2,1], Tao Chen[2,1], Majid Zahedian[2,1], Luis Fernandez Martinez[2,1], Jeth Arunseangroj[2], Liyang Zhang[2], Zhanchuan Zhang[2,1], Wenchao Xu[2,1]

[1]Paul Scherrer Institut, Villigen, Switzerland. [2]ETH Zürich, Zürich, Switzerland

Abstract

Rydberg atoms are central to the current quantum technology revolution, from quantum sensing and metrology to quantum information processing with atom-array-based architectures [1]. Recent breakthroughs have demonstrated the execution of an error-detectable complex sampling circuit with 48 logic qubits [2]. Despite this rapid progress, several key challenges remain, such as performing rapid repetitive error syndrome detection and reusing atoms after an experimental run. Overcoming these difficulties is essential for the efficient implementation of fault-tolerant quantum protocols.

Our group aims to advance quantum technology by using dual-element atom arrays that combine two-electron valence atoms (^{171}Yb) with alkali species (^{87}Rb). We report on the ongoing development of an experimental system combining these two types of atoms. Our research focuses on studying and calibrating the heteronuclear dipole-dipole interactions and identifying Förster resonances between ^{171}Yb-^{87}Rb Rydberg pairs through spectroscopic techniques. By leveraging these heteronuclear interactions, novel gate and measurement schemes developed in our group, we aim to demonstrate efficient, high-fidelity multi-quit gate operations and repetitive stabilizer measurements, paving the way for efficient fault-tolerant quantum computation.

[1] Adams, C. S. et al. J.Phys.B 53 1, 012002 (2019)
[2] Bluvstein D. et al. Nature 626 58-65 (2024)

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B061

Deterministic entanglement sources compatible with absorptive quantum memories

Jun Hu, Xue Li, Zong-Quan Zhou, Chuan-Feng Li, Guang-Can Guo

USTC, HEFEI, China

Abstract

Constructing a large-scale quantum network based on the quantum repeater is essential in the quantum field. Using absorptive quantum memory, the quantum repeater scheme can support external deterministic quantum sources and multi-mode storage simultaneously, which can effectively increase the communication rate. For quantum sources, the deterministic entanglement source can increase the success rate of establishing entanglement between nodes and further increase the communication rate. However, due to the difference in wavelength and bandwidth, the interface between deterministic entanglement sources and quantum memories is still challenging. This work intends to develop a suitable deterministic entanglement source based on quantum dots. Such quantum dots potentially serve as an entanglement source for absorptive quantum memories by optimizing the fidelity and tuning the wavelength. This work will lay a solid foundation for applying quantum repeaters and a large-scale quantum network.

Poster

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B062

Deployable Quantum Network Node Based on Trapped $^{40}Ca^{+}$ Ions Coupled to an Optical Cavity

Moming Jia[1], Pascal Wintermeyer[1], Josef Schupp[2], Maria Galli[1], Viktor Krutianskii[1], Armin Winkler[1], Benjamin Lanyon[1], Tracy Northup[1]

[1]University of Innsbruck, Institute for Experimental Physics, Innsbruck, Austria. [2]Alpine Quantum Technologies GmbH, Innsbruck, Austria

Abstract

With the increasing need for secure information transmission, a quantum version of internet connectivity is a significant technological milestone we have yet to achieve. Unlike classical bits, quantum bits (qubits) require the development of new technologies to transmit information efficiently in metropolitan-scale networks. As part of the Quantum Internet Alliance Consortium within the EU's Quantum Flagship, my project focuses on advancing quantum nodes capable of preparing and/or measuring qubits within the network – the end nodes. Specifically, we aim to develop and characterise a compact and portable trapped-ion quantum node. In this rack-mounted setup, trapped 40Ca+ ions will be coupled to the mode of a high-finesse optical cavity, providing an interface between the qubits and the travelling photons for information transmission. With the goal of deploying these nodes to data centres in the future, the key challenge lies in adapting the design to be compact and robust without compromising its performance as an ion-photon interface.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B063

Amorphous quantum magnets in a two-dimensional Rydberg atom array

Sergi Julià-Farré, Joseph Vovrosh, Alexandre Dauphin

PASQAL, Paris, France

Abstract

Amorphous solids, i.e., systems which feature well-defined short-range properties but lack long-range order, constitute an important research topic in condensed matter. While their microscopic structure is known to differ from their crystalline counterpart, there are still many open questions concerning the emergent collective behavior in amorphous materials. This is particularly the case in the quantum regime, where the numerical simulations are extremely challenging. In this article, we instead propose to explore amorphous quantum magnets with an analog quantum simulator. To this end, we first present an algorithm to generate amorphous quantum magnets, suitable for Rydberg simulators of the Ising model. Subsequently, we use semiclassical approaches to get a preliminary insight of the physics of the model. In particular, for ferromagnetic interactions, we calculate mean-field phase diagrams, and use the linear-spin-wave theory to study localization properties and dynamical structure factors of the excitations. For antiferromagnetic interactions, we show that amorphous magnets exhibit a complex classical energy landscape by means of simulated annealing. Finally, we outline an experimental proposal based on Rydberg atoms in programmable tweezer arrays, thus opening the road towards the study of amorphous quantum magnets in regimes difficult to simulate classically.

Categories

Quantum computing, simulation & networks

Presentation

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B064

Systematic Characterisation of Calcium-Rich Targets using Nanosecond Pulsed-Laser Ablation

Roland Habluetzel, Silpa Muralidharan, Klara Burlamaqui, Alexander Owens, Scott Thomas, Georgina Croft, Yashna Lekhai, Cameron Deans

NQCC, Didcot, United Kingdom

Abstract

Trapped-ion quantum technologies aim for scalability. Thus, ion traps are evolving towards a planar geometry and a cryogenic environment. The cryogenic temperatures allow a short duty cycle between testing iterations of ion-trap models, by avoiding the time-consuming task of baking the vacuum system each time. These traps need to be loaded from ionising the neutral atoms crossing the trapping volume. Laser ablation provides a thermally efficient method for neutral atom generation in cryogenics. But planar surface traps suffer from a weak trapping region, capturing only some of those ions coming from the slowest atoms in the ablation plume. Which material makes for the best target, in terms of high atomic fluence and low atomic speed? Isotopically-pure calcium is not ideal because it is expensive and oxidises within an hour, which is not suitable for multiple iterations of ion traps, thus compound targets were studied here. We present our progress towards the characterisation of the ablation plume from different calcium-rich targets with natural abundance, comparing their suitability for cryogenic surface traps.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B065

Graph Optimisation On Neutral Atom Arrays With Local Addressing

Elliot Diamond-Hitchcock[1], Andre de Oliveira[1], Daniel Walker[1], Maximillian Wells-Pestell[1], Gerard Pelegri[1], Craig Picken[2], Graeme Malcolm[2], Andrew Daley[1], Jonathan Bass[1], Jonathan Pritchard[1]

[1]University of Strathclyde, Glasgow, United Kingdom. [2]M Squared Lasers, Glasgow, United Kingdom

Abstract

Neutral atoms have emerged as a powerful and scalable platform for quantum computing, offering the ability to generate large numbers of identical and high-quality qubits in reconfigurable arrays. By coupling atoms to highly excited Rydberg states with strong, long-range dipole-dipole interactions this system can natively implement Maximum Independent Set (MIS) graph problems on a unit disk graph, providing a route to performing analogue optimisation of real problems however with large systems required to reach a regime competitive against current classical optimisation protocols.

With the use of locally addressed light shifts, this implementation can be extended to a wider class of problems, including Maximum Weighted Independent Set (MWIS) and Quadratic unconstrained Binary Optimisation (QuBO). This method introduces a weighting to graph nodes with at worst a quadratic resource overhead, providing a route to scalable quantum simulation of classically hard problems.

In this poster we present work to develop a large-scale system for quantum computing and annealing and show preliminary results highlighting our ability to implement small-scale demonstrations of weighted graph optimisation using programmable local light-shifts across an atom array. We introduce a hybrid annealing process combining global addressing with ramped light shifts, and outline prospects for scaling this approach to larger graph problems as a potential pathway to quantum utility.

Funding: This work is supported by the EPSRC Prosperity Partnership SQuAre (Grant No. EP/T005386/1) with funding from M Squared Lasers Ltd.

Categories

Quantum computing, simulation & networks

Presentation

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B066

Stimulated Raman 2-qubit logic gates in metastable trapped-ion qubits

Sean Brudney, Alexander Quinn, Gabriel J. Gregory, Isam Daniel Moore, Jeremy Metzner, Evan R. Ritchie, Jameson O'Reilly, David Wineland, David Allcock

University of Oregon, Eugene, USA

Abstract

A proposed scheme for implementing trapped-ion quantum computing encodes qubits in different types of electronic levels where logic gates can be implemented with low cross-talk, know as the *omg* architecture [1]. One type of qubit this scheme employs is the metastable (*m*) qubit, which has not been widely studied. We have implemented *m* qubits in the $D_{5/2}$ manifold of $^{40}Ca^{+}$ and performed one- and two-qubit stimulated Raman gates, one of the first entangling gates performed in *m* qubits. We perform these gates using laser beams tuned 44 THz red of the 854 nm $D_{5/2}$ to $P_{3/2}$ transition with increased power using a fiberized injection-locked 976 nm diode laser system. The injection-locked scheme allowed for a three-fold increase in gate speed compared to using a single free-space laser diode setup by increasing the power in each of the two beams from 80 mW to 250 mW. We have measured the spontaneous Raman scattering rate from these beams, and comparing these results to scattering models we have developed that account for effects relevant at large detunings [2], we find that spontaneous Raman scattering error rates at this wavelength can be made low enough that they are no longer a limiting factor in achieving fidelities needed for fault-tolerance.

[1] D. T. C. Allcock et al., Appl. Phys. Lett. 119, 214002 (2021)

[2] I. D. Moore et al., Phys. Rev. A 107, 032413 (2023)

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B067

Simulation of Kibble-Zurek behaviour across topological transitions of a Chern band

Huan Yuan[1,2,3], Chang-Rui Yi[1,2,3], Jia-Yu Guo[1,2,3], Xiang-Can Cheng[1,2,3], Rui-Heng Jiao[1,2,3], Jinyi Zhang[1,2,3], Shuai Chen[1,2,3], Jian-Wei Pan[1,2,3]

[1]Hefei National Research Center for Physical Sciences at the Microscale and School of Physical Sciences, University of Science and Technology of China, Hefei, China. [2]Shanghai Research Center for Quantum Science and CAS Center for Excellence in Quantum Information and Quantum Physics, University of Science and Technology of China, Shanghai, China. [3]Hefei National Laboratory, University of Science and Technology of China, Hefei, China

Abstract

The Kibble-Zurek (KZ) mechanism renders a theoretical framework for elucidating the formation of topological defects across continuous phase transitions. Nevertheless, it is not immediately clear whether the KZ mechanism applies to topological phase transitions. The direct experimental study for such topic is hindered by quenching a certain parameter over orders of magnitude in topological materials. Instead, we simulate the KZ behaviour across topological transitions of a Chern band in two dimensional (2D) optical Raman lattices with quantum gases. Defined as the defects, excitation density is reconstructed via measuring the spin wavefunctions, with which the power-law scaling of total excitation density is extracted and such scaling could be interpreted within the KZ framework. Our work has heralded the commencement of experimentally exploring the KZ mechanism of the topological phase transitions.

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Presentation

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B068

Tweezer array for Sr with multi-reservoir enhanced loading

Chengdong He[1], Xu Yan[1], Kai Wen[2], Zejian Ren[2], Huijin Chen[1], Elnur Hajiyev[1], Tsz Fung Wong[1], Gyu-boong Jo[1]

[1]Hong Kong University of Science and Technology, Hong Kong, Hong Kong. [2]Hong Kong University of Science and Technology (Guangzhou), Guangzhou, China

Abstract

A neutral-atom-based tweezer array has been a versatile platform for metrology, quantum simulation and computation. Especially, alkaline-earth atoms with two valence electrons offer extra controllability and high-sensitivity detection schemes. Here, we report the efficient creation of single atom arrays of ^{88}Sr with enhanced-loading method based on iterative reloading from multiple reservoir tweezers. We achieve a 96% loading rate after four reload cycles. Our method could work as a strong booster of existing tweezers rearrangement protocols, significantly reducing the rearranging iteration time and optical power consumption to achieve larger site numbers in a quantum logic device.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B069

Efficient learning of mixed states for photonic quantum walk

Qin-Qin Wang[1,2], Xiao-Ye Xu[1,2], Chuan-Feng Li[1,2]

[1]University of Science and Technology of China, Hefei, China. [2]CAS Key Laboratory of Quantum Information, Hefei, China

Abstract

Noise-enhanced applications in open quantum walk (QW) have recently seen a surge due to their ability to improve performance. However, verifying the success of open QW is challenging, as mixed-state tomography is a resource-intensive process, and implementing all required measurements is almost impossible due to various physical constraints. To address this challenge, we present a neural-network–based method for reconstructing mixed states with a high fidelity (~97.5%) while costing only 50% of the number of measurements typically required for open discrete-time QW in one dimension. Our method uses a neural density operator that models the system and environment, followed by a generalized natural gradient descent procedure that significantly speeds up the training process. Moreover, we introduce a compact interferometric measurement device, improving the scalability of our photonic QW setup that enables experimental learning of mixed states. Our results demonstrate that highly expressive neural networks can serve as powerful alternatives to traditional state tomography.

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Presentation

Poster presentation

B070

Disentanglement Provide a Unified Estimation for Quantum Entropies and Distance Measures

Myeongjin Shin[1], Seungwoo Lee[1], Kabgyun Jeong[2]

[1]KAIST, Daejeon, Korea, Republic of. [2]Seoul National University, Seoul, Korea, Republic of

Abstract

The estimation of quantum entropies and distance measures, including von Neumann entropy, Rényi entropy, Tsallis entropy, trace distance, fidelity induced distance such as bures distance and bures angle has received significant attention. While various algorithms exist for individual estimation, a unified approach is lacking. This paper proposes a unified methodology using disentangling quantum neural networks(DEQNN). Recent studies exploring parameterized quantum circuits for quantum entropies and distances estimation face challenges such as barren plateaus and complexity issues in large qubit states. In contrast, our work overcomes these challenges, avoiding barren plateaus and providing a practical solution for large qubit states. Our contribution offers a mathematical proof that disentangling quantum states with low error preserves the quantum entropies and distances. This implies that DEQNN preserves the quantum entropies and distances.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B071

Fast, robust and laser-free universal entangling gates for trapped-ion quantum computing

Markus Nünnerich[1], Daniel Cohen[2], Patrick Barthel[1], Patrick Huber[1], Dorna Niroomand[1], Alex Retzker[2], Christof Wunderlich[1]

[1]University of Siegen, Siegen, Germany. [2]Hebrew University, Jerusalem, Israel

Abstract

Trapped atomic ions are well suited to investigate fundamental questions of quantum physics that require access to and detailed control of individual quantum systems. In addition, this physical platform has set the standard for quantum information processing for decades. Laser light has long been the tool of choice for coherently controlling individual ions and making them interact in a deterministic way. In suitably modified ion traps, radiofrequency (RF) radiation is used instead for coherent control of internal states and motion states, drastically reducing the technological overhead for scaling up quantum processors, and providing alternative interaction mechanisms.

Here, a novel two-qubit entangling gate for RF-controlled trapped-ion quantum processors is proposed theoretically and demonstrated experimentally. The speed of this gate is an order of magnitude higher than that of previously demonstrated two-qubit entangling gates in static magnetic field gradients. At the same time, the phase-modulated field driving the gate, dynamically decouples the qubits from amplitude and frequency noise, increasing the qubits' coherence time by two orders of magnitude. The gate requires only a single continuous RF field per qubit, making it well suited for scaling a quantum processor to large numbers of qubits. Implementing this entangling gate, we generate the Bell states $|\Phi+\rangle$ and $|\Psi+\rangle$ in ≤ 313 µs with fidelities up to 98+2 −3 % in a static magnetic gradient of only 19.09 T/m. At higher magnetic field gradients, the entangling gate speed can be further improved to match that of laser-based counterparts.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B072

Optical Memory in a Microfabricated Rubidium Vapor Cell

Suyash Gaikwad, Roberto Mottola, Gianni Buser, Philipp Treutlein

Univeristy of Basel, Basel, Switzerland

Abstract

Quantum memories based on various atomic and solid state systems have promising applications in quantum networks, photonic synchronization, and photonic quantum computation. In the present work we realize for the first time a room temperature quantum memory in a MEMS-compatible microfabricated vapor cell paving a way towards realizing scalable quantum networks whilst keeping the experimental complexity low [1]. The memory scheme is based on an atomic lambda system which is "cleanly" engineered to operate in the Paschen-Back regime using tesla-order magnetic fields allowing for a low noise ground state storage of light [2]. The broadband memory demonstrates the storage of light pulses attenuated to a single photon level and are hundreds of MHz broad, hence showing compatibility with deterministic quantum dot sources available at the Rb D2 wavelength.

1. Mottola, R., Buser, G., & Treutlein, P. (2023). Optical Memory in a Microfabricated Rubidium Vapor Cell. Phys. Rev. Lett., 131, 260801.

2. Mottola, R., Buser, G., & Treutlein, P. (2023). Electromagnetically induced transparency and optical pumping in the hyperfine Paschen-Back regime. Phys. Rev. A, 108, 062820.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B073

Strong Spin-Motion Coupling in the Ultrafast Quantum Many-body Dynamics of Rydberg Atoms in a Mott-insulator Lattice

Vineet Bharti[1], Seiji Sugawa[1,2,3], Masaya Kunimi[4], Vikas Singh Chauhan[1], Tirumalasetty Panduranga Mahesh[1,2], Michiteru Mizoguchi[1], Takuya Matsubara[1], Takafumi Tomita[1,2], Sylvain de Léséleuc[1,2], Kenji Ohmori[1,2]

[1]Institute for Molecular Science, National Institutes of Natural Sciences, Okazaki, Japan. [2]SOKENDAI (The Graduate University for Advanced Studies), Okazaki, Japan. [3]The University of Tokyo, Tokyo, Japan. [4]Tokyo University of Science, Tokyo, Japan

Abstract

Rydberg atoms in optical lattices and tweezers is now a well established platform for simulating quantum spin systems. However, the role of the atoms' spatial wavefunction has not been examined in detail experimentally. Here, we show a strong spin-motion coupling emerging from the large variation of the interaction potential over the wavefunction spread. We observe its clear signature on the ultrafast, out-of-equilibrium, many-body dynamics of atoms excited to a Rydberg S state from an unity-filling atomic Mott-insulator. We also propose a novel approach to tune arbitrarily the strength of the spin-motion coupling relative to the motional energy scale set by trapping potentials. Our work provides a new direction for exploring the dynamics of strongly-correlated quantum systems by adding the motional degree of freedom to the Rydberg simulation toolbox.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B074

Probing the topological phase transition present in the SSH Hamiltonian with Rydberg-atom synthetic dimensions

Y. Lu, C. Wang, S. K. Kanungo, F. B. Dunning, T. C. Killian

Rice University, Houston, USA

Abstract

The Su-Schrieffer-Heeger (SSH) model, which describes a particle hopping on a one-dimensional lattice with alternating strong and weak tunneling rates, is simulated using Rydberg- atom synthetic dimensions formed using six neighboring n3S1 Rydberg states created in a single atom, by coupling adjacent states using microwave radiation. The tunneling rates are controlled by varying the microwave powers, allowing the study of the "trivial" to "topological" phase transition that occurs as the ratio of the tunneling rates is changed. For each ratio, quench dynamics experiments are undertaken. The system is initially prepared in a single Rydberg state within the lattice and then subjected to the microwave fields for a pre-selected time, which is varied. Measurement of the distribution of final Rydberg states is then used to monitor the time evolution of the system dynamics. The dynamics measurements are used to extract the mean chiral displacement and verify that its long-term average value converges toward the system winding number. The phase transition is also examined in a separate series of experiments by probing the energy spectrum of the system in a steady state and observing the disappearance of the zero-energy edge states. The measurements agree well with theoretical predictions and show that even a system of only six levels can demonstrate the essential features of the SSH Hamiltonian.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B075

On-demand random-access multimode optical memory based on adiabatic phase imprinting

Nasser Gohari Kamel[1], Sourabh Kumar[1], Ujjwal Gautam[1], Farhad Rasekh[1], Erhan Saglamyurek[2], Vahid Salari[1], Daniel Oblak[1]

[1]University of Calgary, Calgary, Canada. [2]Lawrence Berkeley National Laboratory, Berkeley, USA

Abstract

Quantum memories are an essential constituent for quantum information processing and long-distance quantum networks. Rare-earth-ion-doped crystals (REDCs) have been demonstrated to serve as excellent optical quantum memories at cryogenic temperatures owing to their long coherence times and wide inhomogeneous broadenings. In our work, we implement a novel optical quantum memory protocol based on adiabatically imprinting frequency-dependent phases on an ensemble of atoms in a promising REDC, ytterbium-doped-yttrium-orthosilicate (Yb:YSO). Compared to other well-known optical quantum memory protocols, for example, Atomic Frequency Comb (AFC), and Controlled Reversible Inhomogeneous Broadening (CRIB), ours requires no prior manipulation of the atomic absorption profile or strong control-pump lasers, which relaxes the requirement for high optical depths and introduces less noise. In a dilution refrigerator, we demonstrate long storage times (140 µs) with high efficiency (28%) for coherent input pulses. We store multiple temporal and spectral modes and can retrieve these modes in a random-access fashion – individually and on-demand. We develop a theoretical model of the memory protocol and find a close agreement with the experimental results. Our model additionally confirms the protocol's suitability as a quantum memory with high fidelity. Given our relatively simple protocol, this can be employed in other ensemble-based systems. Moreover, integrating our Yb:YSO optical memory with superconducting qubits in a microwave resonator and addressing the spin transitions in Yb:YSO can provide a convenient approach for microwave-to-optical transduction, useful for interconnecting superconducting quantum computers over long distances, bringing us a step closer to the realization of the quantum internet.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

B076

Generating soliton trains through Floquet engineering

Charles Creffield, Pablo Blanco-Mas

Complutense University, Madrid, Spain

Abstract

We study a gas of interacting ultracold bosons held in a parabolic trap in the presence of an optical lattice potential. By treating the system as a discretised Gross-Pitaevskii model, we show how the sign of the hopping parameter can be inverted by means of Floquet engineering by rapidly ``shaking'' the lattice. Using this technique we are able to convert the ground state of the undriven system into a train of bright solitons. We go on to demonstrate how the number of solitons produced depends on the system's nonlinearity and the curvature of the trap, how the method can be applied both in the high and low driving-frequency regimes, and finally demonstrate the phenomenon's stability against noise. We conclude that the Floquet approach is a useful and highly controllable method of preparing solitons in cold atom systems.

Categories

Quantum fluids

Presentation

Poster presentation

B077

Stability of superfluids in tilted optical lattices with periodic driving

Elmar Haller

University of Strathclyde, Glasgow, United Kingdom

Abstract

Tilted lattice potentials with periodic driving play a crucial role in the study of artificial gauge fields and topological phases with ultracold quantum gases. However, driving-induced heating and the growth of phonon modes restrict their use for probing interacting many-body states. By experimentally investigating phonon modes and interaction-driven instabilities of superfluids in the lowest band of a shaken optical lattice, we identified stable and unstable parameter regions and provided a general resonance condition. In contrast to the high-frequency approximation of a Floquet description, we directly used the superfluids' micromotion to analyze the growth of phonon modes from slow to fast driving frequencies. Our observations enable the prediction of stable parameter regimes for quantum-simulation experiments aimed at studying driven systems with strong interactions over extended time scales.

Categories

Quantum fluids

Presentation

Poster presentation

B078

Sounds waves and fluctuations in dipolar supersolids

Blair Blakie

University of Otago, Dunedin, New Zealand

Abstract

We examine the low-energy excitations of a dilute supersolid state of matter with a one-dimensional crystal structure. A hydrodynamic description is developed based on a quadratic Lagrangian, incorporating generalized elastic parameters derived from ground state calculations. The predictions of the hydrodynamic theory are validated against solutions of the Bogoliubov-de Gennes equations, by comparing the speeds of sound, density fluctuations, and phase fluctuations of the two gapless bands. Our results are presented for two distinct supersolid models: a dipolar Bose-Einstein condensate in an infinite tube and a dilute Bose gas of atoms with soft-core interactions. Characteristic energy scales are identified, highlighting that these two models approximately realize the bulk incompressible and rigid lattice supersolid limits.

Categories

Quantum fluids

Presentation

Poster presentation

B079

Vortex Dynamics in Ultracold Quantum Mixtures

Omar Moutamani, Ilian Despard, Kali Wilson

University of Strathclyde, Glasgow, United Kingdom

Abstract

Vortices play a significant role in the internal mechanisms of neutron stars, black holes, superconducting materials, and dilute-gas superfluids [1]. The comprehensive study of vortices in these systems could explain phenomena like energy transfer and dissipation [2]. The exceptional level of control attainable in ultracold atomic quantum gases provides an ideal environment to explore the fundamental behaviour of vortices under diverse conditions within the ultracold regime. In particular, the utilization of ultracold mixtures enables precise adjustment of interparticle interactions. Manipulation of intra- and interspecies interactions will facilitate the attainment of regimes where quantum fluctuations dominate over mean-field effects [3], regimes where exotic phenomena like entrainment might manifest, and regimes where mutual friction has a significant impact on the dissipation of the system.

We report progress towards the construction of an ultracold rubidium-potassium experimental apparatus designed to study the dynamics of vortices and supercurrents in a binary superfluid. We will discuss potential applications of this apparatus to study the interactions between two superflows, such as dissipationless drag and mutual friction.

[1] E. B. Sonin, Dynamics of quantized vortices in superfluids (2016).

[2] J. H. Kim, et al., Phys. Rev. Lett. 127, 095302 (2021).

[3] D. S. Petrov and G. E. Astrakharchik, Phys. Rev. Lett. 117, 100401 (2016).

Categories

Quantum fluids

Presentation

Poster presentation

B080

Odd-frequency superfluidity from a particle-number-conserving perspective

Joachim Brand[1,2], Kadin Thompson[3,4,5], Uli Zülicke[3,2,4], Michele Governale[3,4]

[1]Massey University, Auckland, New Zealand. [2]Dodd-Walls Centre for Photonic and Quantum Technologies, Dunedin, New Zealand. [3]Victoria University of Wellington, Wellington, New Zealand. [4]MacDiarmid Institute, Wellington, New Zealand. [5]University of Cambridge, Cambridge, United Kingdom

Abstract

We investigate odd-in-time—or odd-frequency—pairing of fermions in equilibrium systems within the particle-number-conserving framework of Penrose, Onsager and Yang, where superfluid order is defined by macroscopic eigenvalues of reduced density matrices. We show that odd-frequency pair correlations are synonymous with even fermion-exchange symmetry in a time-dependent correlation function that generalises the two-body reduced density matrix. Macroscopic even-under fermion-exchange pairing is found to emerge from conventional Penrose-Onsager-Yang condensation in two-body or higher-order reduced density matrices through the symmetry-mixing properties of the Hamiltonian. We identify and characterise a transformer matrix responsible for producing macroscopic even fermion-exchange correlations that coexist with a conventional Cooper-pair condensate, while a generator matrix is shown to be responsible for creating macroscopic even fermion-exchange correlations from hidden orders such as a multi-particle condensate. The transformer scenario is illustrated using the spin-imbalanced Fermi superfluid as an example. The generator scenario is demonstrated by the composite-boson condensate arising for itinerant electrons coupled to magnetic excitations. Structural analysis of the transformer and generator matrices is shown to provide general conditions for odd-frequency pairing order to arise in a given system.

Categories

Quantum fluids

Presentation

Poster presentation

B081

Emergent Universal Drag Law in a Model of Superflow

Maarten Christenhusz[1], Arghavan Safavi-Naini[2], Halina Rubinsztein-Dunlop[1], Tyler Neely[1], Matt Reeves[1]

[1]University of Queensland, Brisbane, Australia. [2]University of Amsterdam, Amsterdam, Australia

Abstract

Despite the fundamentally different dissipation mechanisms, many laws and phenomena of classical turbulence equivalently manifest in quantum turbulence. The Reynolds law of dynamical similarity states that two objects of same geometry across different length scales are hydrodynamically equivalent under the same Reynolds number, leading to a universal drag coefficient law. We confirm the existence of a universal drag law in a superfluid wake, facilitated by the nucleation of quantized vortices. We study superfluid flow across a range of Reynolds numbers for the paradigmatic classical hard-wall and the Gaussian obstacle, popular in experimental quantum hydrodynamics. In addition, we provide a feasible method for measuring superfluid drag forces in an experimental environment using control volumes.

Poster

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Categories

Quantum fluids

Presentation

Poster presentation

B082

Universal coarsening in a homogeneous two-dimensional Bose gas

Martin Gazo[1], Andrey Karailiev[1], Tanish Satoor[1], Christoph Eigen[1], Maciej Gałka[1,2], Zoran Hadzibabic[1]

[1]University of Cambridge, Cambridge, United Kingdom. [2]Universität Heidelberg, Heidelberg, Germany

Abstract

Coarsening of an isolated far-from-equilibrium quantum system is a paradigmatic many-body phenomenon, relevant from subnuclear to cosmological lengthscales, and predicted to feature universal dynamic scaling. Here, we observe universal scaling in the coarsening of a homogeneous two-dimensional Bose gas, with exponents that match analytical predictions. For different initial states, we reveal universal scaling in the experimentally accessible finite-time dynamics by elucidating and accounting for the initial-state-dependent prescaling effects. The methods we introduce establish direct comparison between cold-atom experiments and non-equilibrium field theory, and are applicable to any study of universality far from equilibrium.

Categories

Quantum fluids

Presentation

Poster presentation

B083

Defects and universal scaling in dynamic supersolid formation

Wyatt Kirkby[1,2], Lauriane Chomaz[2], Thomas Gasenzer[1], Hayder Salman[3]

[1]Kirchhoff-Institut fur Physik, University of Heidelberg, Heidelberg, Germany. [2]Physikalisches Institut, University of Heidelberg, Heidelberg, Germany. [3]Centre for Photonics and Quantum Science, University of East Anglia, Norwich, United Kingdom

Abstract

We numerically study the formation of linear dipolar supersolids via a scattering length quench. We probe the proliferation of defects in the droplet crystal, which take the form of incommensurate domains resulting from the Kibble-Zurek mechanism, for a variety of quench rates across the second-order superfluid-supersolid phase transition. Critical exponents corresponding to the diverging correlation length and correlation times, driven by a roton instability, are calculated.

Categories

Quantum fluids

Presentation

Poster presentation

B084

Study of quantum thermalization in a lattice dipolar system from collective and bipartite measurements of quantum correlations

Laurent Vernac[1], Youssef Aziz Alaoui[1], Sean R. Muleady[2], Edwin Chaparro[2], Youssef Trifa[3], Tommaso Roscilde[3], Ana Maria Rey[2], Bruno Laburthe-Tolra[1]

[1]Laboratoire de Physique des Lasers, Villetaneuse, France. [2]JILA, NIST and Department of Physics, University of Colorado, Boulder, USA. [3]Univ Lyon, Ens de Lyon, CNRS, Laboratoire de Physique, Lyon, France

Abstract

We measure the dynamical growing of quantum correlations of a large ensemble of dipolar chromium atoms, during an out-of-equilibrium dynamic, taking place in 3D deep optical lattice. Two-point correlators associated with the magnetization are measured from ensemble measurements, assuming homogeneity. While collective measurements show that globally anti-correlations develop in our system, the implementation of a bipartite protocol allows to investigate the correlation landscape, and to demonstrate a strong anisotropy of correlations, linked to the anisotropic nature of the dipolar interaction. Our various theoretical models offer a description of the system throughout the dynamics. In particular, at long time, where quantum thermalization leads to a stationary state with thermal properties, we can point thermalization at a high negative spin temperature.

Categories

Quantum fluids

Presentation

Poster presentation

B085

Selective Persistent Currents in Anti-Dipolar Bose-Einstein Condensates

Tiziano Arnone Cardinale, Koushik Mukherjee, Stephanie Reimann

Lund University, Lund, Sweden

Abstract

Bose-Einstein condensates of particles with a permanent dipole moment form an excellent platform for studying the phenomenon of supersolidity, as well as persistent currents in annular geometries. In this work, we show that for an anti-dipolar condensate in a ring geometry, where the translational symmetry is broken along the azimuthal axis, the energy-angular momentum curve takes a particular shape compared to that of a regular dipolar supersolid, resulting in a different rotational response. In particular, by dynamical simulations, we show that an asymmetric weak link can induce a persistent current in selected layers of the system, while maintaining rigid-body motion in the others.

Categories

Quantum fluids

Presentation

Poster presentation

B086

Observation of Universal Kibble-Zurek Scaling in the Superfluid Phase Transition induced by an Interaction quench

Taehoon Kim, Kyuhwan Lee, Sol Kim, Yong-il Shin

Seoul National University, Seoul, Korea, Republic of

Abstract

The Kibble–Zurek mechanism (KZM) is a universal phenomenon that governs the formation of topological defects during continuous phase transitions. It predicts a robust power-law relationship between the density of defects and the rate of change of control parameters that induce phase transitions. Central to this striking phenomenon are the critical scaling behaviors near the phase transition, which are determined by the underlying symmetries and dimensions of the system. However, experimental verification of this universal scaling law has been challenging in ultracold atomic gases due to sample inhomogeneity. Here, we observe the scaling law in the superfluid phase transition of a strongly interacting Fermi gas of ^{6}Li. We develop a large and homogeneous sample using a spatial light modulator (SLM) and investigate the transition dynamics using two distinct variables: temperature and interaction strength. Regardless of the phase transition protocol, we obtain an identical scaling exponent of approximately 0.68, which shows good agreement with theoretical predictions. Our results demonstrate that despite the different approaches to inducing phase transitions, the Kibble–Zurek exponent remains consistent when the system is within the same universality class. The tunability of interaction opens a new avenue for studying superfluid phase transition dynamics. Owing to the ability to swiftly tune the interaction, it is possible to regulate the nature of superfluidity. This could serve as a starting point to study not only the onset of superfluidity but also the disappearance of condensation after crossing the critical point.

Categories

Quantum fluids

Presentation

Poster presentation

B087

Quench Dynamics of Two-Dimensional Superfluids in Bilayer Traps

Abel Beregi, En Chang, Erik Rydow, Charu Mishra, Shinichi Sunami, Christopher Foot

University of Oxford, Oxford, United Kingdom

Abstract

Coherent and controllable coupling of multiple many-body quantum systems result in rich emergent behaviour with numerous applications. Of particular interest is a bilayer junction of two-dimensional (2D) systems, which also provides us with a very useful control parameter, the inter-well coupling, for probing non-equilibrium dynamics.

In this presentation, we introduce our experiments to create and probe highly controllable bilayer 2D systems of ultracold atoms, generated by the multiple-RF dressing technique for precision control of the trap geometry. We probe the phase fluctuation of the bilayer system in symmetric and antisymmetric modes by using matter-wave interferometry and spatial noise correlation measurements, obtaining information on second-order correlation functions [1]. Combined with full-counting probe for higher-order correlations, these techniques allow detailed understanding of novel many-body states [2].

Using this toolset, we investigate the coupling-induced Berezinskii-Kosterlitz-Thouless (BKT) phase of the bilayer system and map out the phase diagram. Furthermore, dynamical control of the trap geometry allows the preparation of unique non-equilibrium initial state by quenching the bilayer. As an example, we perform coherent splitting of a single 2D system into two copies, which serves as clean and repeatable superfluid-to-normal quench. We probe universal relaxation dynamics using matter-wave interferometry and interpret the two-step decoherence dynamics using real-time renormalization-group theory [3].

[1] S. Sunami *et al.*, Phys. Rev. Lett. **128**, 250402 (2022)

[2] A. Beregi *et al.*, *in preparation*.

[3] S. Sunami *et al.*, Science 382, 443 (2023).

Categories

Quantum fluids

Presentation

Poster presentation

B088

Trapped-condensate interferometer in microgravity

Shuyu Zhou, Angang Liang, Bowen Xu, Chen Chen, Bin Wang

Shanghai Institute of Optics and Fine Mechanics, The Chinese Academy of Sciences, Shanghai, China

Abstract

Bose-Einstein condensates (BECs) with kinetic energy equivalent temperatures on the order of picokelvin can be obtained by deep cooling in a microgravity environment, with significantly reduced interatomic interactions and deformations of the trap potential due to gravity. These factors, ultra-low kinetic energy, weak interatomic interactions, and the absence of distortions in the trap potential, are useful for the study of interferometry based on trapped-condensates and the realization of free oscillation atom interferometers. Here we discuss applications of trapped-condensate interferometry, including measurements of the momentum width of BECs in traps, the removal of uncondensed cold atoms, and the study of the evolution of matter-wave coherence and microgravity measurements. Using ground-based cold atom experiments and optical simulations, we have verified the feasibility of the interferometric approach to measure the kinetic energy equivalent temperature of BECs in traps. Numerical simulations have shown that the sensitivity of free oscillation atom interferometers in measuring microgravity is on the order of 10^{-8} g. The experiments are expected to be carried out on the Chinese space station's Cold Atom Physics Rack.

Categories

Matter wave interferometry

Presentation

Poster presentation

B089

Fast quantum gas formation via electromagnetically induced transparency cooling

Wui Seng Leong[1], Mingjie Xin[2], Zilong Chen[2], Yu Wang[2], Shau-Yu Lan[1]

[1]National Taiwan University, Taipei, Taiwan. [2]Nanyang Technological University, Singapore, Singapore

Abstract

Ultracold quantum gases play a pivotal role as essential states of matter in many-body physics, quantum sensing, and quantum simulation. However, the constrution of quantum gas requires time-consuming evaporative cooling in bulk ensembles, which takes generally from seconds to minutes. Here, we report the creation of a ^{85}Rb quantum gas by simply cooling individual atoms pinned in a three-dimensional optical lattice using electromagnetically induced transparency and adiabatic expansion. We demonstrate the generation of quantum gas through 10 ms time-scale cooling. This significant reduction in preparation time holds great potential for enhancing quantum gas applications.

Poster

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Categories

Matter wave interferometry

Presentation

Poster presentation

B090

Rotating atom interferometer for onboard quantum inertial sensing

Quentin d'Armagnac de Castanet[1], Vincent Jarlaud[2], Cyrille Des Cognets[1], Vincent Ménoret[2], Philippe Bouyer[3], Baptiste Battelier[1]

[1]LP2N - U. Bordeaux, IOGS, CNRS, Talence, France. [2]Exail, Talence, France. [3]University of Amsterdam, Amsterdam, Netherlands

Abstract

The exquisite precision of atom interferometers has sparked the interest of a large community for use cases ranging from fundamental physics to geodesy and inertial navigation. However, their practical use for onboard applications is still limited, not least because rotation and acceleration are intertwined in a single phase shift in free-fall atom interferometers, which makes the extraction of a useful signal more challenging. Moreover, the spatial separation of the wave packets due to rotations leads to a loss of signal.

Here we present an atom interferometer operating over a large range of random angles, rotation rates and accelerations. An accurate model of the expected phase shift allows us to untangle the rotation and acceleration signals. We also implement a real-time compensation system using two fibre-optic gyroscopes and a tip-tilt platform to rotate the reference mirror and maintain the full contrast of the atom interferometer.

Using these theoretical and practical tools, we reconstruct the fringes and demonstrate a single-shot sensitivity to acceleration of 24 µg, for a total interrogation time of 2T = 20 ms, for angles and rotation rates reaching 30° and 14°/s respectively. Our hybrid rotating atom interferometer unlocks the full potential of quantum inertial sensors for onboard applications, such as autonomous navigation or gravity mapping.

Poster

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Matter wave interferometry

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Poster presentation

B091

Differential Mach-Zehnder Interferometry With TrappedBECs

Andrea Santoni[1], Tommaso Petrucciani[2], Chiara Mazzinghi[3], Marco Fattori[4]

[1]Università degli Studi di Napoli “Federico II”, Naples, Italy. [2]CNR_INO, firenze, Italy. [3]CNR_INO, Firenze, Italy. [4]Physics and Astronomy Department,, firenze, Italy

Abstract

. Here we report on the realization of Mach-Zehnder interferometers with Bose-Einstein condensates of 39K optically trapped in an horizzontal array of double-well potentials. Each DW represents an independent MZI which can work simultaneously with the other ones. Having more than one correlated interferometer is useful, since it’s possible to cancel out the effect of common sources of noise acting on the system via differential analysis and realize a trapped atom gradiometer. This allows to measure differential forces acting on the two sensors with high spatial resolution even inn presence of strong noise. In our system we can load the BEC in up to three DWs spatially separated by 10µm and 5µm spacing between left and right modes. To demonstrate the functioning of our sensor, we impose a well known harmonic potential on the system and we show that the interferometric differential phase evolves linearly as a function of the interrogation time as expected. We can finely tune the two body scattering length to zero and cancel two body interactions, reaching coherence time of few hundreds ms. In the future we will investigate the possibility to operate several interferometers simultaneously and measure higher orders of the Taylor expansion of the external potential acting on the atoms. In addition we are planning to generate number squeezed states in our system introducing repulsive interactions. Exploiting non classic states at the interferometer’s input will allow us to enhance the sensitivity of our sensor beyond the standard quantum limit.

Poster

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B092

INTENTAS (INTerferometry with ENTangled Atoms in Space)

Alexander Fieguth[1], INTENTAS Collaboration[2,3,4,5,6]

[1]Deutsches Zentrum für Luft- und Raumfahrt, Institute for Satellite Geodesy and Inertial Sensing, Hanover, Germany. [2]Leibnitz Universität Hannover, Hanover, Germany. [3]Ferdinand-Braun-Institut, Berlin, Germany. [4]Humboldt-Universität, Berlin, Germany. [5]TU Darmstadt, Darmstadt, Germany. [6]Universität Ulm, Ulm, Germany

Abstract

The INTENTAS (INTerferometry with ENTangled Atoms in Space) project aims to provide the first source of entangled atoms for experiments in micro-gravity. Employing an innovative all-optical approach, the project seeks to generate atomic Bose-Einstein condensates at short generation times.These Bose-Einstein condensates will be employed as a coherent source for the generation of squeezing and entanglement via spin-changing collisions. However, the micro-gravity conditions, facilitated by the Einstein Elevator in Hanover, present unique challenges related to robustness, compactness, the management of heat and power, as well as to the experimental control. A successful operation of the INTENTAS project will provide crucial progress towards long interrogation atomic interferometers deploying squeezed states. This poster will provide an overview of the setup, as well as first results from on-ground testing, an update on the micro-gravity operation and an outlook on future plans.

Categories

Matter wave interferometry

Presentation

Poster presentation

B093

Preparing for a next-generation measurement of the fine-structure constant

Jack Roth, Madeline Bernstein, Yair Segev, Zack Pagel, Andrew Christensen, Holger Müller

UC Berkeley, Berkeley, USA

Abstract

Using Bragg diffraction and Bloch oscillations a simultaneous conjugate Ramsey-Bordé matterwave interferometer is implemented to measure the fine-structure constant. This experiment improves on prior work by reducing systematic effects related to the beam mode of the laser responsible for implementing Bragg diffraction and Bloch oscillations. A simulation is robustly compared with experimental data, allowing a precise understanding of how beam imperfections lead to systematic shifts.

Categories

Matter wave interferometry

Presentation

Poster presentation

B094

A Hybrid Cold Atom Accelerometer for Space Gravimetry Missions

Noémie Marquet[1], Nassim Zahzam[1], Yannick Bidel[1], Sylvain Schwartz[1], Alexis Bonnin[1], Alexandre Bresson[1], Malo Cadoret[2], Antoine Godard[3]

[1]DPHY, ONERA-The French Aerospace Lab, Palaiseau, France. [2]LCM-CNAM, La Plaine Saint-Denis, France. [3]DSG, ONERA-The French Aerospace Lab, Palaiseau, France

Abstract

Space gravimetry missions such as GRACE or GOCE determined the Earth gravity field with great accuracy. The data gathered was very useful in the sciences of climatology, hydrology or geophysics and to understand global climate change. These missions boarded state-of-the-art space electrostatic accelerometers displaying a very good sensitivity but also a long-term drift. By combining an electrostatic accelerometer with a very stable cold atom accelerometer, it is possible to correct this drift. To this day, no acceleration measurements with a cold atom accelerometer has been performed in space, mostly because of the harmful effect of the satellite's rotation on the interferometer output.

In this paper, we present our experimental work concerning the development of a hybridised electrostatic/atomic accelerometer. In particular, we addressed the problematic of satellite's rotation and its detrimental effect on the cold atom accelerometer. The hybrid lab prototype is made of an electrostatic accelerometer and a cold atom interferometer (operated as an accelerometer). The test mass of the electrostatic accelerometer, very well controlled in angle and position, is employed as the retro-reflection mirror of the interferometer. By rotating the whole sensor, we studied the impact of inertial accelerations on the contrast and phase shift of the atomic interferometer. Moreover, we were able to implement and characterise a method to compensate the rotation of the sensor. The test mass acting as a mirror is rotated in the opposite way to limit the impact of the rotation of the whole instrument.

Categories

Matter wave interferometry

Presentation

Poster presentation

B095

Performance evaluation of high-sensitivity absolute and differential quantum gravimeters

Laura Antoni-Micollier[1], Maxime Arnal[1], Romain Gautier[1], Camille Janvier[1], Vincent Jarlaud[1,2], Vincent Ménoret[1,2], Jérémie Richard[1], Pierre Vermeulen[1], Peter Rosenbusch[1], Cédric Majek[1], Bruno Desruelle[3]

[1]Exail Quantum Systems, Talence, France. [2]Laboratoire Photonique, Numérique et Nanosciences (LP2N), Université de Bordeaux - IOGS - CNRS, Talence, France. [3]Exail, Saint Germain-en-Laye, France

Abstract

We demonstrate the metrological assessment of Exail's high performance Absolute and Differential Quantum Gravimeters (AQG and DQG). These instruments are designed to be used in field conditions and operated by non-specialists while maintaining a level of performance close to the one obtained in the best academic laboratories. They are based on a compact architecture where all operations are performed with a single laser beam, using pyramid reflectors to trap ^{87}Rb atoms. The 780 nm fibered laser system itself is very compact and robust, based on a frequency-doubled telecom architecture.

For all 16 AQGs manufactured to date, we obtain reproducible signal-to-noise and short-term sensitivity performance, reaching 10 $nm.s^{-2}$ in 2 hours of measurement or less (< 40 min on quiet site) [1]. Ongoing research aims at characterizing systematic effects to the level of a few tens of $nm.s^{-2}$. A significant challenge is to understand and evaluate these effects with the same level of performance on all the instruments.

The DQG is a novel instrument capable of measuring both gravity and its vertical gradient simultaneously. Having demonstrated quantum projection noise limited measurements, we have further improved the performance of the device, now achieving a sensitivity of 30 $E/\sqrt{\tau}$ and a long-term stability of 0.1 E, which is the state of art for this type of instrument. We also describe a "long gravimeter" operation, where we achieve longer interrogation times and increased sensitivity.

[1] L. Antoni-Micollier *et al.*, Absolute quantum gravimeters and gradiometers for field measurements, http://arxiv.org/abs/2405.10844 (accepted IEEE Inst. Meas. Mag.)

Categories

Matter wave interferometry

Presentation

Poster presentation

B096

Space-deployed magnetic curvature sensing with differential matter-wave interferometry

Matthias Meister[1], Naceur Gaaloul[2], Nicholas P. Bigelow[3], the CUAS team[1,2,3,4]

[1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany. [2]Leibniz University Hannover, Institute of Quantum Optics, QUESTLeibniz Research School, Hannover, Germany. [3]Department of Physics and Astronomy, University of Rochester, Rochester, USA. [4]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQST, Ulm University, Ulm, Germany

Abstract

Matter-wave interferometers in space are excellent tools for high precision measurements, relativistic geodesy, or Earth observation. In particular, differential interferometric setups feature common-mode noise suppression and enable reliable measurements of magnetic field curvatures or gravity gradients even under harsh environmental conditions.

Here we report on a series of experiments performed with NASA's Cold Atom Lab aboard the International Space Station demonstrating atom interferometers with differential geometries in orbit. By comparing measurements with atoms in magnetic sensitive and insensitive states we have realized atomic magnetometers mapping the residual magnetic field background of the apparatus. Our results pave the way towards future quantum sensing missions with cold atoms in space.

This work is supported by NASA/JPL through RSA No. 1616833 and the DLR Space Administration with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers 50WM1861-2 and 50WM2245-A/B.

Categories

Matter wave interferometry

Presentation

Poster presentation

B097

Matter-wave collimation to picokelvin energies with scattering length and potential shape control

Timothé Estrampes[1,2], Alexander Herbst[1], Robin Corgier[3], Éric Charon[2], Ernst M. Rasel[1], Dennis Schlippert[1], Naceur Gaaloul[1]

[1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany. [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, Orsay, France. [3]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Paris, France

Abstract

In atom interferometers, achieving long pulse separation times and minimizing contrast loss are critical for enhancing sensitivity. In this work, we investigate the impact of atomic interactions on collimation using a lensing protocol with a ^{39}K Bose-Einstein condensate at varying scattering lengths. By manipulating interactions, we measure energies of (340 ± 12) pK in one direction. The associated value is confirmed by numerical simulations which also predict a 2D ballistic expansion energy of (438 ± 77) pK. Based on these findings, we suggest a protocol for achieving 3D expansion energies below 16 pK by introducing an additional pulsed delta-kick. This advanced scenario opens avenues for realizing ensembles exceeding 1 x 10^5 atoms with 3D energies in the double-digit pK range in typical dipole trap setups, eliminating the need for microgravity environment.

Categories

Matter wave interferometry

Presentation

Poster presentation

B098

Dark-Matter Searches with Quantum Sensors

Daniel Derr, Enno Giese

TU Darmstadt, Darmstadt, Germany

Abstract

As an emerging high-precision tool for inertial forces, atom interferometers can complement the ongoing search for dark matter (DM). Compared to optical interferometers, atom interferometers benefit from the additional internal atomic structure that could be sensitive to DM.

Thus, propagating matter waves manipulated by light in a superposition of two trajectories through space-time serves as a platform for DM detection and for testing violations of the Einstein equivalence principle (EEP). The combination of internal degrees of freedom (clock properties of the atom) and external degrees of freedom (centre-of-mass motion) allows for both state-preserving (Bragg) and state-changing diffraction mechanisms. Even in the case of Bragg diffraction, DM has an influence on the centre-of-mass motion.

We present a unified treatment [1] of internal and centre-of-mass dynamics for atom interferometers, taking into account relativistic effects, mass defects, and violation parameters introduced by DM and the EEP. Based on this approach, we investigate the leading-order effects for atom interferometers with and without internal transitions. Overall, we identify the effects of DM in atom interferometers and discuss the difference between those induced by the atom's clock properties and the centre-of-mass effects.

[1] AVS Quantum Sci. 5, 044404 (2023)

Categories

Matter wave interferometry

Presentation

Poster presentation

B099

Spin- and Momentum-Correlated Atom Pairs Mediated by Photon Exchange and Seeded by Vacuum Fluctuations

Fabian Finger, Rodrigo Rosa-Medina, Nicola Reiter, Panagiotis Christodoulou, Tobias Donner, Tilman Esslinger

ETH, Zurich, Switzerland

Abstract

Engineering pairs of massive particles that are simultaneously correlated in their external and internal degrees of freedom is a major challenge, yet essential for advancing fundamental tests of physics and quantum technologies. We experimentally demonstrate a mechanism for generating pairs of atoms in well-defined spin and momentum modes. This mechanism couples atoms from a degenerate Bose gas via a superradiant photon-exchange process in an optical cavity, producing pairs via a single channel or two discernible channels. The scheme is independent of collisional interactions, fast and tunable. We observe a collectively enhanced production of pairs and probe interspin correlations in momentum space. We characterize the emergent pair statistics and find that the observed dynamics is consistent with being primarily seeded by vacuum fluctuations in the corresponding atomic modes. Together with our observations of coherent many-body oscillations involving well-defined momentum modes, our results offer promising prospects for quantum-enhanced interferometry and quantum simulation experiments using entangled matter waves.

Categories

Cavity QED

Presentation

Poster presentation

B100

Cavity-based non-destructive detection in ultracold gases

Gokul V I, Arun Bahuleyan, S P Dinesh, V R Thakar, Raghuveer Singh, S A Rangwala

Raman Research Institute, Bengaluru, India

Abstract

Cavity quantum electrodynamics studies the interaction of atoms with the electromagnetic mode of an optical cavity. Placing an atom within a cavity modifies its emission properties either by changing the spontaneous emission rates (weak coupling regime) or by coherent exchange of energy between atom and cavity mode (strong coupling regime). When there are multiple atoms (N_c) inside the cavity mode volume, collective effects emerge. As a result, the atom-cavity system shows vacuum Rabi splitting (VRS), which directly depends on the $\sqrt{N_c}$ (collective strong coupling regime). This makes the cavity a frequency-sensitive detection tool for measuring state-dependent interactions.

To demonstrate rapid, continuous cavity-based measurement, we experimentally measure population dynamics in a multilevel system that mimics an open transition and show the potential of cavity-based measurements for state detection, even when there are many participating energy levels. We then explores the possibility of cavity detection to cold molecules that do not have a closed transition. To illustrate the range of applications of the cavity-based detection scheme, we also use the cavity to detect photoassociation of Rb_2 in a dark MOT, where a direct fluorescence measurement is not possible, using free atoms coupled to a cavity and use this to determine PA rates in the system.

Categories

Cavity QED

Presentation

Poster presentation

B101

Atom-photon interface based on nanofiber cavity QED

Hideki Konishi[1], Kenichi N. Komagata[1], Shanjou Yang[1,2], Ryotaro Inoue[1], Shinya Kato[1], Shinichi Sunami[1,3], Takao Aoki[1,2], Akihisa Goban[1]

[1]Nanofiber Quantum Technologies, Inc., Tokyo, Japan. [2]Waseda University, Tokyo, Japan. [3]University of Oxford, Oxford, United Kingdom

Abstract

Cavity QED is a promising approach to interface atomic and photonic qubits, leading to various applications such as single photon generation, quantum repeaters and distributed quantum computing. While its basic operations as an atom-photon interface have been performed mainly with free-space optical cavities, optical waveguide cavities have a potential for better connectivity to optical fiber networks and larger atom capacity.

Our cavity QED system features an optical nanofiber cavity fabricated from a single-mode optical fiber. It consists of two Bragg gratings serving as end mirrors and a nanofiber region with a diameter smaller than the wavelength of the guided light. Thanks to its fiber-based structure, the cavity is seamlessly integrable to a standard optical fiber network. Single atoms are trapped and aligned in the vicinity of the nanofiber surface by using optical tweezers and interact with the cavity photons through the evanescent field. The nanofiber region is capable of accommodating >100 atoms as it has a millimeter length scale.

Here we present our recent experimental development using Cs atoms for the proof-of-concept demonstration of atom-photon gate operations on a high-finesse nanofiber cavity. We also show our blueprint towards atom-photon interface with Yb atoms, which is more suitable for modular quantum communication and computing thanks to Yb's robustness as atomic qubit and its rich energy structure allowing for cavity QED at telecom-band wavelengths.

Categories

Cavity QED

Presentation

Poster presentation

B102

Modelling simultaneous strong coupling of an atom to two nanofibre cavity modes

Thomas Clarkson[1,2], Scott Parkins[1,2]

[1]The University of Auckland, Auckland, New Zealand. [2]Dodd-Walls Centre for Quantum and Photonic Technologies, Dunedin, New Zealand

Abstract

Traditionally strong-coupling cavity quantum electrodynamics involves a small, short cavity with a large free spectral range (FSR), such that an atom couples resonantly to just one cavity mode. However, experiments with nanofiber cavities have demonstrated strong coupling with much longer cavities, where the smaller FSR enables the possibility of simultaneous strong coupling to multiple cavity modes.

We model one such setup, where two cavity modes of distinct frequencies couple strongly to a pair of transitions within a single D-line of a caesium atom. These modes, in combination with a pair of laser fields, are used to drive Raman transitions in a cyclic manner between the two atomic hyperfine ground states, thereby producing a continuous source of highly (quantum) correlated photons in the output fields of the two modes.

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Cavity QED

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B103

A cavity-microscope for micrometer-scale control of atom-photon interactions

Rohit Prasad Bhatt[1], Francesca Orsi[1], Nick Sauerwein[1], Jonas Faltinath[1], Ekaterina Fedotova[1], Nicola Reiter[2], Tigrane Cantat-Moltrecht[3], Jean-Philippe Brantut[1]

[1]Institute of Physics and Center for Quantum Science and Engineering, EPFL, Lausanne, Switzerland. [2]Institute for Quantum Electronics, ETH, Zürich, Switzerland. [3]Univ. Grenoble-Alpes, CEA, Leti, Grenoble, France

Abstract

Cavity quantum electrodynamics offers the possibility to observe and control the motion of few or individual atoms, enabling the realization of various quantum technological tasks such as quantum-enhanced metrology or quantum simulation of strongly-correlated matter. A core limitation of these experiments lies in the mode structure of the cavity field, which is hard-coded in the shape and geometry of the mirrors. As a result, most applications of cavity QED trade spatial resolution for enhanced sensitivity.

In this poster, I will present our cavity-microscope device capable of controlling in space and time the coupling between atoms and light in a single-mode high-finesse cavity, reaching a spatial resolution an order-of-magnitude lower than the cavity mode waist. This is achieved through local Floquet engineering of the atomic level structure, imprinting a corresponding atom-field coupling. We illustrate this capability by engineering micrometer-scale coupling, using cavity-assisted atomic measurements and optimization. Our system forms an optical device with a single optical axis and has the same footprint and complexity as a standard Fabry-Perot cavity or confocal lens pair, and can be used for any atomic species. This technique opens a wide range of perspectives from ultra-fast, cavity-enhanced mid-circuit readout to the quantum simulation of fully connected models of quantum matter such as the Sachdev-Ye-Kitaev model.

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Cavity QED

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B104

Towards a cw superradiant laser.

Bruno Laburthe-Tolra, Yannis Pargoire, Benjamin Pasquiou, Martin Robert-de-Saint-Vincent

CNRS, Paris North University, Villetaneuse, France

Abstract

The prospect for a continuous superradiant laser has attracted attention because of the fundamental interest in cavity quantum electrodynamics and because of potential metrological applications [1]. Indeed, these lasers will operate deep in the bad-cavity limit, such that their frequency is weakly sensitive to mirror vibrations, and is instead mainly set by the atomic transition. In addition, the laser's linewidth can even reach values below the natural linewidth of the transition [1,2].

At the moment, super-radiant bursts have been observed with ultra-cold atoms inside a high-finesse Fabry Perot cavity [3]. However, it has up to now been impossible to reach the cw regime because atoms are unavoidably lost at some rate due to spontaneous emission and heating. I will describe our strategy to reach the cw regime. Our architecture is based on a simple continuous beam of thermal strontium atoms which is slowed down in a Zeeman slower, and deflected towards a high-finesse (F =10 000) Fabry-Perot cavity. Our first experimental results indicate that the steady-state atom number inside the cavity surpasses the critical number to reach collective emission. I will also describe our proposed strategy to obtain the necessary population inversion for the $^1S_0$ - $^3P_1$ transition.

[1] J. Chen, Sci. Bull. 54, 348 (2009), D. Meiser et al, PRL. 102, 163601 (2009)

[2] Bruno Laburthe-Tolra et al., SciPost Phys. Core 6, 015 (2023)

[3] M. Norcia et al., Science Advances , Vol. 2, No. 10 (2016), Sofus Laguna Kristensen et al., PRL. 130, 223402 (2023)

Categories

Cavity QED

Presentation

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B105

Theoretical study of electron-induced vibrational excitation of H_2O

Mehdi Ayouz[1], Alexandre Faure[2], Viatcheslav Kokoouline[3]

[1]CentraleSupélec, Paris, France. [2]Université Grenoble Alpes, Grenoble, France. [3]University of Central Florida, Florida, USA

Abstract

The study presents calculations of cross sections for vibrational excitation of $H_2O(X^1A_1)$ by electron impact. The employed theoretical approach is based on first principles only, combining electron-scattering calculations performed using the UK R-matrix codes for several geometries of the target molecule, three-dimensional vibrational states of H$_2$O, and three-dimensional vibrational frame transformation to represent the scattering matrix for the electron incident of the molecule. The vibrational wave functions are obtained numerically, without the normal-mode approximation, so that the interaction and transitions between vibrational states, assigned to different normal modes, are accounted for. Thermally-averaged rate coefficients are derived from the calculated cross sections for temperatures in the 10-10000 K interval and analytical fits for rate coefficients are provided. Uncertainty estimations of the obtained data are assessed for a further use of the rate coefficients in modelling non-LTE spectra of water in various astrophysical environments.

Categories

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B106

Study of low-energy collisions between atoms and ions in a hybrid apparatus

Bubai Rahaman, Satyabrata Baidya, Sourav Dutta

Tata Institute of Fundamental Research, Mumbai, India

Abstract

The collisions between particles at ultra-low temperatures exhibit their quantum nature. A hybrid experimental apparatus enables the study of ultracold collisions between polar molecules (via $\pm C_3/r^3$ potential), trapped atoms and ions (via $-C_4/r^4$ potential), etc. However, it can be challenging to switch between species due to the limited versatility of the apparatus.

We have built an experimental apparatus capable of trapping and overlapping many species (Li, K, Rb, Cs, Sr) of ultracold atoms and ions simultaneously [1]. We demonstrated the versatility of our apparatus by trapping ^{7}Li and ^{133}Cs atoms in a three-dimensional (3D) magneto-optical trap (MOT) and $^{7}Li^{+}$ and $^{133}Cs^{+}$ ions in a linear Paul trap. This enabled the study of low-energy collisions between atoms (^{7}Li – ^{7}Li, ^{133}Cs – ^{133}Cs, and ^{7}Li – ^{133}Cs) also between atoms and ions (^{7}Li – $^{7}Li^{+}$ and ^{133}Cs – $^{133}Cs^{+}$).

We studied the low-energy collisions between atoms and ions by observing the fluorescence from the atoms and determined the collision rate coefficients ($\beta_{Cs,Li}$, β_{Cs,Cs^+}, β_{Li,Li^+}). Furthermore, we demonstrated the signature of sympathetic cooling of $^{7}Li^{+}$ ($^{133}Cs^{+}$) due to collisions with ultracold ^{7}Li (^{133}Cs) by measuring the increased lifetime of the ions in the Paul trap.

We will present our hybrid experimental apparatus and the low-energy collisions performed in that apparatus as a poster.

References:

1) B. Rahaman, S. Baidya, and S. Dutta, *A versatile apparatus for simultaneous trapping of multiple species of ultracold atoms and ions to enable studies of low energy collisions and cold chemistry*, J. Chem. Phys. 160, 064201 (2024).

Categories

Molecules

Presentation

Poster presentation

B107

Towards a buffer-gas-loaded, multi-species optical trap for molecules

Ashwin Singh, Lothar Maisenbacher, Junqi Xie, Stefan Straßer, Jack Mango, Holger Müller

University of California, Berkeley, Berkeley, USA

Abstract

Despite much interest in studying cold molecules, access to cold, trapped molecules has been limited to only a few select species. We here present progress towards trapping a variety of small, chemically stable molecules, such as N_2, CO, O_2, and HCl [1]. The molecules will be trapped at cryogenic temperatures by buffer-gas loading a deep optical dipole trap. The ~10 K trap depth is produced by a tightly-focused, 1064-nm cavity capable of reaching intensities of hundreds of GW/cm^2. Molecules will be directly buffer-gas loaded into the trap using a helium buffer gas at 1.5 K. Both buffer-gas cooling and the very far-off-resonant, quasi-electrostatic trapping mechanism are insensitive to a molecule's energy level structure and dipole moments, allowing for co-trapping of multiple species. Our trap would open new possibilities in molecular spectroscopy, studies of cold chemical reactions, and precision measurement, amongst other fields of physics. This work showcases our design of a cryogenic apparatus that incorporates both the cavity and the buffer-gas source required for trapping. We show robust operation of the high-intensity, near-concentric cavity, and show our simulations of the novel buffer-gas cell geometry suited for loading the trap.

[1]: Ashwin Singh, Lothar Maisenbacher, Ziguang Lin, Jeremy J. Axelrod, Cristian D. Panda, and Holger Müller. Dynamics of a buffer-gas-loaded, deep optical trap for molecules. Phys. Rev. Research 5, 033008 – Published 5 July 2023

Categories

Molecules

Presentation

Poster presentation

B108

Isotopologue-selective laser cooling of barium monofluoride molecules

Tim Langen

TU Wien, Vienna, Austria

Abstract

We demonstrate laser cooling of barium monofluoride (BaF) molecules, which are highly sought after for precision measurement applications. We synthesize time-sequenced optical spectra that can be precisely tailored to the hyperfine structure of this previously uncooled molecular species. Optimization of the optical spectra allows us to realize strong Sisyphus laser cooling forces that can efficiently collimate a molecular beam. Moreover, by carefully choosing the transitions involved in the cooling, we also demonstrate the first isotopologue-selective laser cooling of molecules, selectively addressing both the 138BaF and 136BaF isotopologues in the same molecular beam. Our results are an important step towards slowing and trapping of BaF molecules, and will also be useful for cooling other molecular species with complex level structure.

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B109

Ultracold LiK Molecules through Direct Association from Fermi-Fermi Mixtures in 3D Optical Lattices

Xiaoyu Nie[1], Canming He[1], Anbang Yang[1], Victor Avalos[1], Jacek Klos[2], Svetlana Kotochigova[2], Kai Dieckmann[1,3]

[1]Center for Quantum Technologies, National University of Singapore, Singapore, Singapore. [2]Department of Physics, Temple University, Philadelphia, USA. [3]Department of Physics, National University of Singapore, Singapore, Singapore

Abstract

We propose a direct association of ultracold $^{6}Li^{40}K$ molecules from Fermi-Fermi mixtures of ^{6}Li and ^{40}K atom in 3D optical lattices, aimed at enhancing Feshbach association efficiency and extending lifetime and coherence time.

We first show the calibration on 3D lattices with Rb atoms via superfluidity to Mott insulator transitions, Kapitza-Dirac scattering, and Brillouin zones. Subsequently, we delve into an ongoing investigation concerning the behavior of a mixture comprising ^{40}K and ^{6}Li atoms within lattices. By excluding Bosons, the mixture can be loaded into 3D lattices with at most one particle occupancy per site for each species. Unlike Bose-Fermi mixtures, spin-polarized Fermi-Fermi mixtures exhibit favorable density matching properties. Through tuning of the Feshbach field towards strong interacting regime, enhanced interspecies overlap can be tuned, and the Feshbach molecules association efficiency is explored. From the theoretical calculations, we employ self-consistent mean field theory to predict the density distributions of mass-imbalanced interacting Fermions within lattices. The presence of heavier and denser ^{40}K atoms induces a mean field effect that compresses ^{6}Li cloud, thereby promoting dual-species doublon occupancy.

Additionally, frequency-dependent polarizability calculations for the ground and first rotational excited states of $^{6}Li^{40}K$ are conducted. It indicates favorable features in the polarizability spectra, particularly in the vicinity of a broad and far-detuned magic wavelength where the differential light shift remains negligible across the trap. Building upon these predictions, a 3D magic lattice configuration is designed, comprising retro-reflected beams at 1064 nm and a magic wavelength, with appropriate polarization alignment relative to the Feshbach field.

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B110

Quantum Logic via Electric-field Gradient Gates on Molecular Ion Qubits

Grant Mitts, Clayton Ho, Joshua Rabinowitz, Hao Wu, Eric Hudson

UCLA, Los Angeles, USA

Abstract

Molecular ions possess a myriad of electric dipole transitions, many of which exist in the microwave and RF regime. These transitions allow for strong, laser-free coupling between long-lived energy states, making them favorable quantum logic candidates. Previously described in (PhysRevA. 2021, 104, 042605), applying an oscillating voltage to a linear ion trap will produce an electric gradient to address these splittings, allowing for the application of electric-field gradient gates (EGGs). Presented is a description of our cryogenic dual species ion trap employing co-trapped HCl^+ and Ca^+ in addition to the current progress towards using EGGs to perform hyperfine spectroscopy of the ground lambda-doublet states of HCl^+.

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B111

Towards Quantum Simulation with Ultrapolar KAg Molecules

Zoe Yan

University of Chicago, Chicago, USA

Abstract

Ultracold polar molecules are emerging as a prominent platform for quantum simulation by facilitating tunable, long-range interactions while retaining long coherence times similar to ultracold atoms. We present progress toward creating ultracold potassium silver (KAg) molecules with a record 8.5 Debye dipole moment that enables large interaction strengths, comparable to those employed in existing Rydberg atom platforms. The production of KAg begins with the preparation of ultracold K and Ag. Subsequently, the molecules will be associated into dimers via magnetic Feshbach resonance and transferred to the molecular ground state via stimulated Raman adiabatic passage (STIRAP), following a path previously demonstrated with ultracold bialkali molecules. We discuss advancements in our vacuum design, electric field control, Zeeman slowing, and MOT of Ag atoms. This platform will provide an opportunity to explore topological superfluidity and investigate lattice spin models relevant to quantum magnetism.

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B112

Making molecules by mergoassociation

Robert Bird, Ruth Le Sueur, Jeremy Hutson

Durham University, Durham, United Kingdom

Abstract

An enormous number of experiments exploring quantum simulation, quantum computation, and different tests of fundamental physics use ultracold molecules. The molecules used in these experiments are now, almost exclusively, produced via magnetoassociation or direct laser cooling. The former requires magnetically tuneable zero-energy Feshbach resonances to exist in collisions between the molecules' constituent atoms. The latter requires a molecule to have diagonal Frank-Condon factors. Researchers are therefore limited in the number of molecular systems available to them. Mergoassociation is a new way to produce ultracold molecules. The mergoassociation of two ultracold atoms to form a weakly bound molecule can occur when two optical traps, each containing a single atom, are merged. We have developed the theory of mergoassociation for pairs of nonidentical nonspherical traps and have illuminated the effects of trap length and aspect ratio on the mergoassociation process.

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B113

Formation of rotationally-excited ultralong-range Rydberg molecules: Role of photon momentum transfer, sample temperature, and ground-state atom-atom interactions.

Chuanyu Wang[1], Yi Lu[1], Soumya Kanungo[1], Thomas Killian[1], F Barry Dunning[1], Shuhei Yoshida[2]

[1]Rice University, Houston, USA. [2]TUWein, Vienna, Austria

Abstract

Ultralong-range Rydberg molecules (ULRRMs) comprise a Rydberg atom in whose electron cloud is embedded one, or more, ground-state atoms weakly bound through scattering of the Rydberg electron. Here we examine the factors that govern ULRRM formation, with emphasis on the production of rotationally-excited dimers. Strontium 5sns $^1S_0$ dimers are created in a cold gas, ~1mK, by two-photon excitation using lasers operating at 412 and 461 nm. The important role played by photon momentum transfer during excitation of one of the atoms in the initial atom pair to a high Rydberg state is examined through measurements using co- and counter-propagating laser beams. (For counter-propagating beams the net photon momentum transfer is near-zero providing a valuable benchmark against which to look for such effects.) The role of atom-atom interactions in the parent cold gas is explored through comparative studies with ^{84}Sr and ^{86}Sr which have very different *s*-wave scattering lengths, a_s, of 123 and 811 a_0, respectively. For ^{86}Sr, a_s is comparable to the size of an n~25 Rydberg atom which suppresses, for nearby values of n, the formation of dimers in the N=0 ground rotational state, reducing the dimer production rate and allowing the effects of higher-wave scattering, which leads to the production of rotationally-exited states, to be observed. Measurements also show that increases in sample temperature lead to increased relative production of rotationally-excited states. The results are in good agreement with the predictions of a model that includes all these factors.

Poster

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B114

Direct laser cooling of He_2^*

Maximilian Beyer

VU Amsterdam, Netherlands, Netherlands

Abstract

I will discuss direct laser cooling of the lightest and first homonuclear molecule He_2^*. The light mass of the molecule, absence of hyperfine structure, and a restricted set of rotational states due to the Pauli principle, drastically reduce the level density and facilitate laser and evaporative cooling.

He_2^* can be categorized as a Rydberg Molecule. The Rydberg electron doesn't contribute significantly to the chemical bond, resulting in diagonal Franck-Condon factors of electronic transitions and making them suitable for laser cooling. Three laser cooling transitions - in the UV, NIR and IR - were identified in He_2^*.

This project aims to provide a controllable, simple 4-electron system at record low temperature, allowing quantum sensing and precision measurements to test quantum physics and the quantum nature of collisions with unprecedented accuracy - while being accessible to highly accurate ab initio computational methods.

Applications involve a measurement of the atomic polarizability of He ground-state atoms, being accessed via the long-range part of the molecular potential of He_2^+. Using Rydberg series extrapolation, intervals between excited vibrational levels in the cation, which are particularly sensitive to the static polarizability, are measured. Accurate measuring methods for the polarizability of helium and other rare gases are of utmost importance for paving the way for new quantum pressure standards. The pressure is related via the gas law to the particle density, which can be measured via monitoring a change in the dielectric constant of a capacitor or the refractive index of light inside a cavity - if an accurate polarizability is known.

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B115

Advancing Photoemission Orbital Tomography Towards Absolute Electron Density Reconstruction

Hans Kirschner, Hendrik Kaser, Alexander Gottwald, Mathias Richter

Physikalisch-Technische Bundesanstalt, Berlin, Germany

Abstract

Photoemission orbital tomography (POT) is a technique based on angle-resolved photoemission spectroscopy (ARPES) that links photoemission intensity distributions measured in momentum space to real-space electron densities, such as molecular orbitals (MOs) of adsorbed molecules. POT approximates the emission of photoelectrons by a transition from an initial MO to a plane wave final state. The MO can thus be reconstructed by a formalism based on an inverse Fourier transfromation. Despite its success, POT faces criticism for its simplistic plane wave approximation, which neglects final state scattering and the spherical symmetry of photoelectron emission, leading to inaccuracies, particularly along the energy-dependent k_z axis.

This work aims to advance POT by addressing these limitations and promoting it as a metrological method capable of providing absolute scale results with associated uncertainties. We adapt the POT formalism to reconstruct atomic orbitals using absolute photoemission data from neon. The methodology is then extended to methane, chosen for its similar electron structure to neon and practical application as a monolayer on surfaces. By employing monochromatized synchrotron radiation and photoelectron spectroscopy, we obtained reliable absolute photoemission data for methane and used these to test the reconstruction method.

Poster

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B116

Fast and robust molecular MOT compression using conveyor belt cooling and trapping

Grace Li, Christian Hallas, Nathaniel Vilas, Paige Robichaud, Loic Anderegg, John Doyle

Harvard University, Cambridge, USA

Abstract

A challenge faced by molecular magneto-optical traps (MOTs) is the relatively inefficient cooling and trapping due to the type-II nature of the optical cycling transition, compared to type-I transitions in atomic MOTs. To achieve higher density in phase space, a second-stage blue-detuned MOT has been proposed and recently achieved in many molecular laser-cooling experiments [Burau (2023), Jurapur (2024), Li (2024)]. Here, we demonstrate a novel blue-detuned scheme, "conveyor belt" MOT, that achieves fast and robust compression: in our experiment, we compress a cloud of Calcium Monohydroxide (CaOH) molecules from 0.6 mm to 59(5) µm within 5 ms, reaching a peak density of 8(2) $\times 10^{8}$ cm^{-3}, the highest reported density for a molecular MOT to date.

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B117

Suppression of 3-body decay in a resonantly interacting Rubidium-Strontium mixture via dimensional effects

D Digvijay, Premjith Thekkeppat, Mateusz Borkowski, N.J van Druten, Florian Schreck

Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam, Amsterdam, Netherlands

Abstract

The rich internal structure of ultracold molecules allows the study of many-body physics, quantum simulation and information, precision measurements, and quantum-controlled chemistry. Here we aim to create open-shell ^{87}Rb^{87}Sr molecules which, unlike bi-alkali molecules, would have both an electric and a magnetic dipole moment. These molecules can in principle be created from a resonantly interacting mixture of ^{87}Rb (bosonic) and ^{87}Sr (fermionic) atoms, but this mixture suffers from significant three-body decay. Here, we suppress this three-body decay using a 1-D optical lattice putting the system in a quasi-2D regime. We increase the mixture's lifetime to several hundreds of milliseconds without substantial heating. In the future, this will allow us to first sweep across a confinement-induced resonance by ramping up the lattice depth to transfer ^{87}Rb-^{87}Sr atom pairs into a near-threshold molecular state, and then to use STIRAP to transfer them into the rovibrational ground state.

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B118

Towards the creation of NaK dipolar molecules in their absolute ground state

Sungjun Lee, Jaeryeong Chang, Yoonsoo Kim, Seokmin Jang, Sooshin Kim, Younghoon Lim, Jee Woo Park

Pohang University of Science and Technology, Pohang, Korea, Republic of

Abstract

Ultracold polar molecules possessing rich internal structures provide a fascinating platform that gives access to the quantum simulation of strongly dipolar many-body physics, state-controlled quantum chemistry, and quantum information processing based on molecular qubits. In this poster, we present our progress towards creating ground-state bosonic $Na^{41}K$ and fermionic $Na^{40}K$ molecules. Degenerate gases of both Bose-Bose and Bose-Fermi mixtures are prepared by sympathetic cooling with Na as a coolant. Specifically, 7-interspecies Feshbach resonances of the Bose-Bose mixture in various spin combinations are located using atom loss spectroscopy. Based on the investigation, we create weakly bound Feshbach molecules of $Na^{41}K$ and $Na^{40}K$, which serve as a stepping stone for the creation of NaK ground-state molecules. Additionally, we present our characterization of efficient Feshbach association and our efforts to find a suitable two-photon pathway down to the absolute ground state.

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B119

A programmable hybrid system of ultracold molecules and Rydberg atoms

Alexander Guttridge[1], Daniel Ruttley[1], Thomas Hepworth[1], Rosario Gonzalez-Ferez[2], Hossein Sadeghpour[3], Stuart Adams[1], Simon Cornish[1]

[1]Department of Physics, Durham University, Durham, United Kingdom. [2]Universidad de Granada, Granada, Spain. [3]Center for Astrophysics, Harvard & Smithsonian, Cambridge, USA

Abstract

Ultracold dipolar systems, like atoms excited to Rydberg states and polar molecules, hold great potential for quantum simulation and computation. Rydberg atoms offer strong, long-range interactions, facilitating the engineering of quantum entanglement and multi-qubit gates through the Rydberg blockade mechanism. Similarly, polar molecules exhibit long-range interactions but also possess numerous long-lived internal states. These states can be effectively coupled using microwave fields and can exhibit long coherence times for robust storage of quantum information. Programmable arrays of optical tweezers have enabled flexible trapping of both these systems, creating the possibility of a hybrid system that combines the advantages of both platforms.

In this presentation, I will present our hybrid system consisting of ultracold RbCs molecules in their rovibrational ground state and Rb atoms trapped in species-specific optical tweezers. I will demonstrate how Rydberg blockade due to the charge-dipole interaction with a RbCs molecule facilitates the detection of individual molecules. Furthermore, I will describe the toolbox of techniques we have developed for the control and readout of individually trapped polar molecules in optical tweezers. Finally, I will highlight some recent results on the production of heteronuclear Rydberg molecules in separate optical tweezers and the observation of resonant dipole-dipole interactions between a Rydberg atom and a polar molecule. These results lay the foundation for future explorations of quantum computation and precision measurements utilising this hybrid platform.

Categories

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B120

Progress on Zeeman slowing and trapping CaF

Timo Poll, Julius Niederstucke, Paul Kaebert, Supeng Xu, Mirco Siercke, Silke Ospelkaus

Leibniz University Hannover, Hannover, Germany

Abstract

Recently, great progress has been made in direct laser cooling of molecules to temperatures close to absolute zero [1,2]. However, experiments are limited by the number of molecules that can be captured from molecular beams using typical laser-based trapping methods [3,4]. Here we discuss our approaches to increase the number of molecules in the experiments. We show our experimental results on the Zeeman slower for directly laser-coolable molecules proposed by our group [5] as well as schemes and first experimental steps towards the realisation of a sub-Doppler cooling magneto-optical trap [6,7].

[1] J. F. Barry et al. 2012
[2] Y. Wu et al. 2021
[3] S. Truppe et al. 2017
[4] L. Anderegg et al. 2017
[5] M. Petzold et al. 2018
[6] S. Xu et al. 2021
[7] S. Xu et al. 2022

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B121

Direct laser cooling and trapping of bosonic CaH and fermionic CaD molecules

Debayan Mitra, Qi Sun, Jinyu Dai, Benjamin Riley, Tanya Zelevinsky

Columbia University, New York, USA

Abstract

Recent advances in the field of direct laser cooling and trapping of molecules have led to new candidate platforms for quantum computing, quantum simulation, precision measurement and metrology. One such platform consists of molecular hydrides. Here we present our progress towards laser cooling and trapping of CaH. We describe how predissociative decay pathways that are inherent to many molecular species can be leveraged for quantum state controlled dissociation into atomic fragments. We also describe a new chemical production method for obtaining a higher and more consistent CaH yield from a cryogenic buffer gas source. Finally, we will present our work on successfully laser cooling the isotopologue CaD, which is the first fermionic molecule to be directly laser cooled. Cold and trapped gases of CaH and CaD will serve as sources of ultracold and trapped hydrogen and deuterium atoms for future studies of beyond standard model physics.

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B122

1S-3S CW spectroscopy of Deuterium atoms

Pauline YZOMBARD[1], Simon Thomas[1,2], Lucile Julien[1], François Biraben[1], François Nez[1]

[1]Laboratoire Kastler Brossel, Paris, France. [2]Laboratoire de physique des Lasers, Villetaneuse, France

Abstract

In this poster, I will first briefly present some of the main motivations for the spectroscopic study of hydrogen-like atoms, which are perfect tools for testing and challenging the most accurate theory in physics: Quantum Electrodynamics (QED) [1]

I will then present the basics and status the latest result on CW 1S-3S spectroscopy on Deuterium atoms, conducted during the measurement campaign of winter 2020. This discussion will encompass an analysis of the principal systematic effects encountered and outline plans for the next generation of experiments aimed at mitigating some of the primary limitations.

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B123

The Lepton Symmetry Experiment: LSym

Sangeetha Sasidharan, Maria Pasinetti, Fabian Raab, Lukas Holtmann, Andreas Thoma, Sven Sturm

Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Abstract

One of the prevailing enigmas in contemporary physics is the observed disparity between the abundance of matter and antimatter in the universe, posing a fundamental challenge to the principles of the Standard Model of particle physics.

In the LSym experiment we plan to compare the fundamental properties, specifically the charge-to-mass ratios and the *g*-factors, of the electron and the positron in a cryogenic Penning trap to 14 digits precision and thereby performing a highly sensitive test of matter-antimatter symmetry in the lepton sector [1]. The key to this precision is in the simultaneous trapping of both particles in the same trap. Once the positron is cooled to the ground state of motion in a millikelvin-cooled Penning trap that forms a custom-tailored millimeter-wave cavity, we can measure the coherent difference of the spin precession frequencies of the matter- and antimatter particles [2].

In the contribution, the experimental setup, techniques and challenges will be presented.

References:

[1] E. Widmann *et al.*, Hyperfine Interact **240**, 5 (2019)

[2] Tim Sailer *et al.*, Nature **606**, 479–483 (2022)

Categories

Precision measurements

Presentation

Poster presentation

B124

Atomic Magnetometry with Kalman Filters

Klaudia Dilcher, Jan Kolodynski

University of Warsaw, Warsaw, Poland

Abstract

Kalman Filter constitutes a way to construct an estimator that allows one to optimally extract the signal encoded in the system dynamics by minimizing the average mean-squared-error, despite the dynamics and measurement all undergoing uncontrolled independent stochastic fluctuations. In contrast to previously known algorithms, Kalman Filters do not require a full history of all previous computational steps, and so this technique is suitable for real-time data analysis and has proven to be very successful in many applications, including navigation systems, robotics, image processing and many more.

In this work, we applied Kalman Filters for magnetic field inference from an atomic sensor with optical read-out. Such sensors are widely used in magnetometry both within and beyond the classical limit, achieving precision comparable to cryogenic methods. Kalman Filter has been applied to such systems before [1, 2], however the usability of this technique is very limited, as the magnetic field obeys highly non-linear dynamics in most regimes. This suggests that using the Extended Kalman Filter can greatly improve the estimator beyond the linear regime. In this work, we simulate, for relevant experimental parameters, an output of such a sensor and show that in fact the magnetic field can be successfully estimated in real-time with the Extended Kalman Filter.

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[2] Jia Kong et. all Measurement-induced, spatially-extended entanglement in a hot, strongly-interacting atomic system, Nature Communications vol. 11, Article number: 2415, 2020.

Categories

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B125

Nuclear and Particle Physics with Precision Spectroscopy of a New Clock Transition in Ytterbium

Akio Kawasaki, Takumi Kobayashi, Akiko Nishiyama, Takehiko Tanabe, Masami Yasuda

NMIJ/AIST, Tsukuba, Japan

Abstract

Laser spectroscopy has reached remarkable accuracy up to 18 digits, enabling the investigation of high-energy physics in low-energy systems such as atoms. This approach has paved new paths for investigating nuclear and particle physics that were conventionally conducted with high-energy accelerators. Motivated by this, we are performing precision spectroscopy of ytterbium. The recently-observed $6s^2\ {}^1S_0$ - $4f^{13}5d6s^2$ (J=2) transition at 431 nm offers properties suitable for fundamental physics searches. We performed absolute frequency measurements for multiple isotopes, completing the full table of isotope shifts for stable isotopes. Combining these data with previously reported isotope shift data for other transitions, we conducted various analyses, including determination of hyperfine constants for ^{173}Yb, assessment of nuclear charge radii, analyses on King plots, and a search for new bosons mediating the force between an electron and a neutron. We present our latest results and prospects.

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B126

Theoretical calculations for isotope shifts of $^{7,9,10,11,12,14}Be^{2+}$ ions

Zong-Chao Yan[1], Xiao-Qiu Qi[2], Pei-Pei Zhang[3], G. W. F. Drake[4], Ai-Xi Chen[2], Zhen-Xiang Zhong[5], Ting-Yun Shi[3]

[1]University of New Brunswick, Fredericton, Canada. [2]Zhejiang Sci-Tech University, Hangzhou, China. [3]Wuhan Institute of Physics and Mathematics, Wuhan, China. [4]University of Windsor, Windsor, Canada. [5]Hainan University, Haikou, China

Abstract

Standard perturbation theory in quantum mechanics is employed to calculate the mass shifts of 2^1S_0–2^3S_1 and 2^3S_1–2^3P_J transitions in $^{7,9,10,11,12,14}Be^{2+}$ ions. These mass shifts are determined with high precision, typically having uncertainties of 1-2 parts per million. The sensitivity of the isotope shifts between $^{7,10,11,12,14}Be^{2+}$ and $^{9}Be^{2+}$ to differences in nuclear charge radii is examined. Moreover, we present the fine-structure splitting isotope shifts, which serve as valuable tools for testing the consistency of experimental results. The study presented here will provide valuable insights for future measurements aimed at extracting atomic physics values of Be nuclear charge radii with an accuracy of 5% or higher.

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B127

Polarization-selective four-wave mixing in a degenerate multi-level system

Sanghyun Park[1,2], Jaeuk Baek[1,2], Min-Hwan Lee[1,2], Heung-Ryoul Noh[1,2], Geol Moon[1,2]

[1]Department of Physics, Chonnam National University, Gwangju, Korea, Republic of. [2]Center for Quantum Technologies, Chonnam National University, Gwangju, Korea, Republic of

Abstract

This paper presents the first observation of polarization-selective four-wave mixing (FWM) signals within traditional coupling-probe spectroscopy, specifically within saturation absorption spectroscopy conducted on ^{85}Rb atoms. The FWM signal arises from the interaction of two counter-propagating laser beams within a degenerate multi-level atomic system, exploiting transitions of the ^{85}Rb D2 line. Consequently, FWM signals co-propagating with the probe beam induce polarization rotation in a linearly polarized probe beam. To differentiate these FWM signals from the resultant probe beam, we detect the polarization components perpendicular to the input probe beam's polarization direction, varying with linear polarization angles between the probe and coupling beams. Experimental results exhibit strong agreement with theoretical predictions. Moreover, FWM signals must adhere to phase-matching criteria, including polarization, frequency, and propagation direction, making them responsive to external magnetic fields that cause shifts in Zeeman magnetic sublevels. This finding holds potential applications in magnetic sensing.

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B128

Spin noise spectroscopy of an alignment-based atomic magnetometer

Marcin Koźbiał[1], Lucy Elson[2], Lucas M. Rushton[3], Ali Akbar[2], Adil Meraki[2], Kasper Jensen[2], Jan Kołodyński[1]

[1]University of Warsaw, Warsaw, Poland. [2]University of Nottingham, Nottingham, United Kingdom. [3]National Physics Laboratory, London, United Kingdom

Abstract

Optically pumped magnetometers (OPMs) are revolutionising the task of magnetic-field sensing due to their extremely high sensitivity combined with technological improvements in miniaturisation which have led to compact and portable devices. OPMs can be based on spin-oriented or spin-aligned atomic ensembles which are spin-polarized through optical pumping with circular or linear polarized light, respectively. Characterisation of OPMs and the dynamical properties of their noise is important for applications in real-time sensing tasks. In our work, we experimentally perform spin noise spectroscopy of an alignment-based magnetometer. Moreover, we propose a stochastic model that predicts the noise power spectra exhibited by the device when, apart from the strong magnetic field responsible for the Larmor precession of the spin, white noise is applied in the perpendicular direction aligned with the pumping-probing beam. By varying the strength of the noise applied as well as the linear-polarisation angle of incoming light, we verify the model to accurately predict the heights of the Larmor-induced spectral peaks and their corresponding line-widths. Our work paves the way for alignment-based magnetometers to become operational in real-time sensing tasks.

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B129

Gravity-aided navigation based on cold-atom gravimetry

Wenjun Kuang[1,2], Fubin Wan[1], Yaoyu Zhong[1], Qingqing Hu[1], Yansong Fan[1], Fufang Xu[1,2], Chengcheng Li[1], Yukun Luo[1,2]

[1]National Innovation Institute of Defense Technology, Beijing, China. [2]Hefei National Laboratory, Hefei, China

Abstract

Gravity anomaly generated by terrain variations can be potentially exploited for navigation, where vehicles are positioned and guided by referring the real-time measured gravity to a pre-stored local gravity map. Gravity-aided navigation provides an effective solution in cases where GPS signals are not accessible, such as underwater. Recently, quantum gravimetry based on cold atom interferometers has seen great improvement in both precision of gravity measurement and mobility, endowing exciting prospects in its use for gravity-aided navigation. Here we performed a simulation study on gravity-aided navigation based on the state-of-art characteristics of cold-atom gravimeters. A gravity map with precision <0.1 mGal and a resolution of 500 m was constructed directly from the bathymetric data of an ocean area. Then, an iterative closest contour point algorithm was employed for the gravity-aided vehicle trace matching. Our simulation based on cold-atom gravimetry has demonstrated the feasibility of narrowing the navigation error from an initial value of 4 km down to 400 m. Moreover, the algorithm shows an exponential convergence with iteration times, giving an averaged converging iteration of 44 and converging time of 600 ms for a typical error threshold of 10^{-6}. Strategies of performing gravity-based trace matching for practical underwater navigation were also discussed. Our study could advise the design and development of practical quantum gravimetry systems for their application in high-precision gravity-aided navigation.

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B130

In-beam hyperfine spectroscopy of antihydrogen, hydrogen, and deuterium for tests of CPT and Lorentz invariance

Eberhard Widmann

Stefan Meyer Institute, Vienna, Austria

Abstract

Cold antihydrogen, the bound state of an antiproton and a positron, is an ideal laboratory to test the fundamental CPT symmetry, one of the cornerstones of the Standard Model of particle physics, by comparing its energy levels to ordinary hydrogen. Hydrogen is one of the best studied atoms experimentally, among the two best-known transitions is the ground-state hyperfine transition f_{HF} with a relative precision of better than 10^{-12}.

The ASACUSA collaboration has proposed a measurement of $\mathrm{nu}_{\mathrm{HF}}$ in a beam, which allows to perform the experiment in a region far away from the strong magnetic fields needed for antihydrogen creation. Recent improvements of the temperature and density of the positron plasma resulted in a strong increase in formed antihydrogen atoms. The next step remaining is to form a beam from the created antiatoms to achieve the initial goal of a precision of 1 ppm for f_{HF}.

Within the Standard Model Extension (SME) framework, which describes potential Lorentz invariance and CPT violation scenarios, also measurements using ordinary atoms can be used to constrain symmetry-violating SME coefficients [1]. Recently first results have been obtained on the orientation dependence of an external static magnetic field for hydrogen hyperfine measurements [2], and on siderial variations of transitions in the hyperfine structure of deuterium, putting limits of the order of 10^{-21} GeV onto various coefficients [3].

References

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2. L. Nowak et al., arXiv:2403.17763 [hep-ex]
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B131

CeNTREX : A Search for Time Reversal Symmetry Violation using ^{205}TlF molecules

Olivier Grasdijk[1], David DeMille[2,1], David Kawall[3], Jakob Kastellic[4], Jianhui Li[5], Tristan Winick[3], Yuanhang Yang[2], Tanya Zelevinsky[6], Perry Zhou[5]

[1]Argonne National Laboratory, Lemont, USA. [2]University of Chicago, Chicago, USA. [3]University of Massachusetts Amherst, Amherst, USA. [4]Yale University, New Haven, USA. [5]Columbia University, New York, USA. [6]University of Columbia, New York, USA

Abstract

The Cold molecule Nuclear Time-Reversal EXperiment (CeNTREX) aims to search for the fundamental time-reversal symmetry (T) and parity (P) violation in the hadronic sector. The Standard Model provides for T (and hence CP) symmetry violation in the quark mixing (CKM) matrix, but this is not sufficient to generate the magnitude of the baryon asymmetry observed in the universe. Many Standard Model extensions propose additional sources of T-violation, and Schiff moments and electric dipole moments (EDMs) are excellent probes free of Standard Model backgrounds. CeNTREX utilizes shifts in nuclear magnetic resonance frequencies of the ^{205}Tl nucleus in highly polarized thallium fluoride (TlF) molecules to search for these T violating interactions. With the expected experimental sensitivity, we would be able to set competitive bounds on θ_{QCD}, quark chromo electric dipole moments (cEDMs), and the proton EDM. CeNTREX uses modern methods including a cryogenic molecular beam source, optical state preparation and detection, and coherent quantum state manipulation. This poster provides an overview of the experiment and the techniques involved, its current status and recent progress, as well as the upcoming developments and anticipated timeline for a nuclear Schiff moment measurement.

This work is funded by the Heising-Simons Foundation, NSF and the U.S. DOE, Office of Science, Office of Nuclear Physics, under contract DE-AC02-06CH11357.

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B132

Sympathetic cooling of ions using electron cyclotron radiation

Jost Herkenhoff, Klaus Blaum

Max-Planck Institute for Nuclear Physics, Heidelberg, Germany

Abstract

The rapid increase of precision in recent Penning-trap experiments is driving the need for ever-improving cooling techniques. This poster presents the prospect of a new sympathetic cooling technique using an electron-plasma coupled to a single ion. The cyclotron motion of electrons in a strong magnetic field and cryogenic environment decays to very low quantum numbers by emission of cyclotron radiation, which can be used to sympathetically cool all motional degrees of a single ion stored in a spatially distant trap. The extremely low expected temperatures in the millikelvin range open up an exciting new frontier of measurements in Penning traps like atomic masses or g-factors of highly charged ions or antimatter. The first implementation of this technique is currently being realized at the dedicated ELCOTRAP experiment at the Max-Planck Institute for Nuclear Physics in Heidelberg, Germany, whose current status will be presented on this poster.

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B133

Implementing a Josephson Voltage Standard for the Nuclear Magnetic Moment Measurement of ^{2}D, ^{3}He and ^{7}Li in a Penning Trap

Annabelle Kaiser[1], Ralf Behr[2], Ute Beutel[1], Stefan Dickopf[1], Menno Door[1], Sergey Eliseev[1], Ankush Kaushik[1], Kathrin Kromer[1], Marius Müller[1], Luis Palafox[2], Stefan Ulmer[3,4], Andreas Mooser[1], Klaus Blaum[1]

[1]MPIK, Heidelberg, Germany. [2]PTB, Braunschweig, Germany. [3]RIKEN, Wako, Japan. [4]HHU, Düsseldorf, Germany

Abstract

Penning traps are versatile tools for high-precision measurements on single, trapped ions of e.g. their mass or their hyperfine structure, from which electron binding energies, diamagnetic shielding coefficients and electron as well as nuclear magnetic moments can be extracted. For the latter, a spin-flip needs to be resolved with a change in signal that is barely detectable before the background noise, using methods described in [1]. This requires an ultra-stable trapping environment and extremely cold ion temperatures. A new technique will be presented, which reduces the noise originating from the voltage sources generating the electrostatic trapping potential: By implementing a tunable 20V Josephson voltage standard, the stability of the ion's axial frequency was measured to be twice as stable (10ppb over 8 minutes, at 800kHz absolute frequency) as with the typical low-noise voltage sources UM1-14.

An environment this stable enables the direct high-precision measurement of the nuclear magnetic moment of ^{2}D, ^{3}He and ^{7}Li. To tackle the mandatory cold ion temperatures of a few hundred mK, a sympathetic laser cooling scheme between the ion of interest and 9Be+ can be used [2,3]. First results of the frequency stability improvement will be presented [4], along with the status of the project.

[1] A. Mooser *et al.*, J. Phys.: Conf. Ser. 1138 012004 (2018)
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Poster

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B134

Adaptable platform for trapped cold electrons, hydrogen and lithium anions and cations

Levi Azevedo[1], Rodolfo Costa[1], Wania Wolf[1], Alvaro Oliveira[2,3], Rodrigo Sacramento[1], Daniel Silveira[1], Claudio Cesar[1]

[1]UFRJ, Rio de Janeiro, Brazil. [2]Aarhus University, Aarhus, Denmark. [3]INMETRO, Xerem, Brazil

Abstract

Cold-charged particles play an essential role in interstellar molecular formation, are present in many high-precision experiments, antimatter physics, and chemistry, and are also relevant for studies on the origin of biological homochirality. I will describe here a system based on the Matrix Isolation Sublimation (MISu) technique to generate and trap these species in the laboratory. After growing a thin film of Neon upon a cold (4 K) sapphire subtract, we implant different species inside this film via laser ablation of a solid target. With a heat pulse to the sapphire surface, we sublimate the solid neon at low temperatures, and the inert gas carries the particles that were confined inside the solid, producing a beam at low energies. We guide the charged particles using a weak magnetic field and trap them in a Penning-Malmberg trap using low voltages (~1 V) and weak magnetic fields (~0.1 T).

We have measured energy distribution for positive and negative trapped charge particles whose peak was below 25 meV. Using an on-trap-time-of-flight scheme, we demonstrate the presence of electrons, hydrogen anions, protons, lithium cations and anions, and light molecular ions.

The hydrogen anions can be used to produce a cold sample of neutral trappable hydrogen by near-threshold photodetachment. These cold H can be loaded into the ALPHA antihydrogen trap, at CERN, toward direct spectroscopic comparison of both conjugated species beyond 13 significant figures. The production is scalable and adaptable to different species, including deuterium and tritium, which is relevant for neutrino mass and fusion research.

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B135

Precise microwave spectroscopy of cesium Rydberg atom and molecules

Jianming Zhao[1], Yuechun Jiao[1], Yunhui He[1], Georg Raithel[2]

[1]Shanxi University, Taiyuan, China. [2]University of Michigan, Michigan, USA

Abstract

Rydberg atoms with large principal quantum numbers, n, exhibit many exotic properties related to the fact that energy differences between neighboring Rydberg levels are in the THz and microwave frequency ranges. THz and microwave transitions between Rydberg are employed in narrow-linewidth spectroscopy, which has applications in both precision measurement of Rydberg-atom properties as well as in field metrology. Here, we perform precise microwave spectroscopy of cesium Rydberg atoms, where the microwave field drives (n+2)D-nF transitions, and state-selective field ionization is employed to measure transition probabilities. Microwave spectra with a resolution in the range of tens of kHz are obtained over a range of dc electric and magnetic fields, Rydberg atom densities etc. As a first topic, we investigate the Stark and Zeeman effect of (n+2)D-nF transitions and precisely determine the quantum defects of nF (n=45-50) states of non-interacting Cs Rydberg atoms prepared at low density. In the second topic, we increase the atom density to observe fine-structure-mixed $(n+2)D_{5/2}nF_J$ Rydberg macro-dimer molecules, which are bound by dipolar interactions. In our microwave photo-association scheme, the microwave field drives a transition from an optically prepared $[(n+2)D_{5/2}]_2$ Rydberg-pair state, which is relatively weakly-interacting, into a more strongly interacting $(n+2)D_{5/2}\ nF_J$ macro-dimer state. We provide spectroscopic evidence for the fine-structure-mixed DF macro-dimer molecules, explain their formation mechanism, and investigate their Stark effect and Stark broadening.

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B136

Searching for new physics by testing the Standard Model: The anomaly in the electron orbital g-factor

Ayodeji Awobode

University of Massachusetts Boston, Department of Physics, Boston, USA

Abstract

A high precision measurement of the electron orbital g-factor is a good complement to the atomic/molecular experiments which test QED, search for a permanent electric dipole moment, investigate the CPT theorem or study the Lorentz symmetry. We shall discuss evidence from available experimental data and the results of recent calculations concerning a probable anomaly in the electron orbital g-factor. Further evidence for such an anomaly provides a stringent test of QED (and by extension, the Standard Model), in which it is currently assumed that the electron orbital g-factor is unaffected by radiative or other interactions, and hence not anomalous; in contrast, the anomaly in the spin g-factor, (g_S – 2), is commonly attributed to radiative interactions. Furthermore, it is currently believed that because the orbital g-factor is assumed exactly equal to 1, the electron must have a uniform distribution of mass-to-charge and thus behave like a point particle. However, preliminary determinations from the measurement of the ratio of g_J values in In, Ga, Na, Ar and Ne, indicate that the anomaly in the electron orbital g-factor is of the order of 10^{-3} or 10^{-4} to a precision of about 4 parts in $10^{\wedge 5}$. Hence, a search for an anomaly in the electron orbital g-factor (g_L – 1), or, alternatively, high-precision measurements of the electron orbital g-factor, also provides a means of elucidating the nature or structure of the electron, as well as constituting a useful guide in the search for new physics beyond the Standard Model.

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B137

Precision measurement of the n=2 triplet P J=1-to-J=0 fine structure of atomic helium using frequency-offset separated oscillatory fields

Farshad Heydarizadmotlagh[1], Taylor D Skinner[1], Kosuke Kato[2], Matthew C George[1], Eric A Hessels[1]

[1]York University, Toronto, Canada. [2]National Research Council Canada, Ottawa, Canada

Abstract

Increasing accuracy of the theory and experiment of the n=2 ^{3}P fine structure of helium has allowed for increasingly-precise tests of quantum electrodynamics (QED), determinations of the fine-structure constant α, and limitations on possible beyond-the-Standard-Model physics. Here we present a 2-part-per-billion (ppb) measurement of the J=1-to-J=0 interval. A helium beam is produced using a liquid-nitrogen-cooled dc-discharge source, and is intensified using a two-dimensional magneto-optical trap. The microwave measurement is performed using frequency-offset separated oscillatory fields (FOSOF) [1]. Laser excitation to a Rydberg state, followed by Stark ionization allows for efficient detection. Our result of 29,616,955,018(60) Hz [2] represents a landmark for helium fine-structure measurements, and, for the first time, will allow for a 1-ppb determination of the fine-structure constant when QED theory for the interval is improved.

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B138

Two-Photon Direct Frequency Comb Spectroscopy of atomic Hydrogen

Derya Taray[1], Vitaly Wirthl[1], Vincent Weis[1], Omer Amit[1], Alexey Grinin[1,2], Theodor W. Hänsch[1,3], Thomas Udem[1,3]

[1]Max Planck Institute of Quantum Optics, Garching, Germany. [2]Center for Fundamental Phyiscs, Northwestern University, Chicago, USA. [3]LMU, Munich, Germany

Abstract

The energy levels of hydrogen-like systems can be both calculated and measured very precisely. Precision spectroscopy of two transitions at the current level of accuracy allows the determination of the Rydberg constant and the proton charge radius [4]. Comparison with additional transitions is a consistency check for the theory of quantum electrodynamics. Improvements in these measurements in the last years, revealed discrepancies, which are not yet fully resolved [1]. I will present the last measurement of the 1S-3S transition in hydrogen, using two photon direct frequency comb spectroscopy and explain the experimental technique along with our setup. The obtained result (f_{1S-3S} = 2,922,743,278,665.79(72) kHz, [3]) supports the value of the proton charge radius, first obtained from muonic hydrogen. The value differs by 2.1 standard deviations from the second laser measurement of the same transition obtained at Laboratoire Kastler Brossel [2] suggesting, that the discrepancies in these precision measurements probably arise due to yet unknown experimental issues. Therefore, we hope that further investigation of the experiments will resolve this deviation. We will give an update on the status of the experiment, the next intermediate results and the anticipated improvements for the next measurement campaign.

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B139

A recoil measurement scheme in intermediate-scale atom interferometers for determining fundamental constants

Jesse Schelfhout, Thomas Hird, Kenneth Hughes, Christopher Foot

University of Oxford, Oxford, United Kingdom

Abstract

Atom-interferometric recoil measurements currently limit the precision of many of the fundamental constants, including the fine-structure constant, the atomic mass constant (and hence the masses in kilograms of many particles), the vacuum magnetic permeability and electric permittivity, and the Bohr magneton [1]. Very-long-baseline atom interferometry (of order 100m-1km) presents an interesting science case for gravitational wave detection and dark matter investigations. Intermediate-scale instruments (of order 10m) are under development as technology pathfinders, bridging the gap between laboratory-scale and very-long-baseline instruments. We have devised a scheme for photon-recoil measurement in these intermediate-scale atom interferometers [2], whereby the recoil phase can be optimised through strategic use of large momentum transfer and the gravity-gradient phase can be mitigated by crossing the spatial trajectories of two Ramsey-Bordé interferometers. We find that, using existing atom-interferometry techniques, our scheme implemented in a 10-metre instrument operating on the clock transition in Sr or Yb is more than sufficient to increase the precision of the fine-structure constant by an order of magnitude. These measurements find application in testing the Standard Model of particle physics to the highest precision using the magnetic moment of the electron [3].

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B140

Probing the interaction energy of two ^{85}Rb atoms in an optical tweezer via spin-motion coupling

Jun Zhuang[1,2], Kun-Peng Wang[1], Peng-Xiang Wang[1,2], Ming-Rui Wei[1,2], Bahtiyar Mamat[1,2], Cheng Sheng[1], Peng Xu[1], Min Liu[1], Jin Wang[1], Xiao-Dong He[1], Ming-Sheng Zhan[1]

[1]Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan 430071, China. [2]School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

The inherent polarization gradients in tight optical tweezers can be used to couple the atomic spins to the two-body motion under the action of a microwave spin-flip transition, so that such a spin-motion coupling offers an important control knob on the motional states of optically trapped two colliding atoms. Here, after preparing two elastically scattering 85Rb atoms in the three-dimensional ground-state in the optical tweezer, we employed this control in order to probe the colliding energies of elastic and inelastic channels. The combination of microwave spectra and corresponding s-wave pseudopotential model allows us to infer the effect of the state-dependent trapping potentials on the elastic colliding energies, as well as to reveal how the presence of inelastic interactions affects elastic part of the relative potential. Our work shows that the spin-motion coupling in a tight optical tweezer expand the experimental toolbox for fundamental studies of ultracold collisions in the two body systems with reactive collisions, and potentially for that of more complex interactions, such as optically trapped atom-molecule and molecule-molecule interactions.

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B141

Neutron electric dipole moment measurement result and new experiment design

Georg Bison

Paul Scherrer Institut, Villigen, Switzerland

Abstract

We report on the results of the neutron electric dipole moment (EDM) search, which collected data in 2015 and 2016 using the ultracold neutron source at the Paul Scherrer Institut. The neutron EDM is considered one of the most sensitive probes for physics beyond the Standard Model. To improve upon the current result of $d_n < 1.8\ 10^{-26}$ e cm [1], the nEDM collaboration is currently commissioning a new apparatus, n2EDM, which provides one of the world's most uniform and stable magnetic fields, along with updated neutron handling. Systematic and statistical uncertainties in n2EDM critically depend on the performance of the magnetic field monitoring systems. Here, we utilize atomic magnetometers based on Cs and ^{199}Hg atoms, which will be presented in detail.

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B142

Hydrogen lattice clocks and bounds on physics beyond the standard model

Joseph Scott, Adair Nicolson, David Carty, Matthew Jones, Robert Potvliege, Michael Spannowsky

Department of Physics, Durham University, Durham, United Kingdom

Abstract

We consider precision spectroscopy of hydrogen and deuterium in the search for physics beyond the standard model, as well as the use of optical traps in future experiments. Specifically we consider the wide class of models that can be described by an effective Yukawa-type interaction between the nucleus and the electron (or the muon for the muonic species). We find that it is possible to set bounds on new light-mass bosons that are orders of magnitude more sensitive than those set using a single isotope only provided the interaction couples differently to the deuteron and proton. Further enhancements of these bounds by an order of magnitude or more would be made possible by extending the current set of data to measurements of a transition between the 2s state and a Rydberg s-state with an experimental error of 100 Hz or better [1]. In terms of prospects for achieving this, we find that a hydrogen optical lattice clock could operate with an intrinsic linewidth of the order of 1 kHz, which would provide an independent measurement of the 1s-2s interval free from motional systematics, and that trap induced losses do not limit measurements on other transitions [2].

[1] R M Potvliege, A Nicolson, M P A Jones and M Spannowsky, Phys. Rev. 108, 052825 (2023)

[2] J P Scott, R M Potvliege, D Carty and M P A Jones, Metrologia 61, 025001 (2024)

Categories

Precision measurements

Presentation

Poster presentation

B143

Cs in cryogenic Ar matrix as a platform to measure P and T violations

Sebastian Lahs, Hemanth Dinesan, Daniel Comparat

Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton, Orsay, France

Abstract

To answer the open questions in the fundaments of physics, new theories that reach beyond the standard model of particle physics are needed. Many of these predict Violations of the fundamental symmetries of Parity P and Time reversal T. While over the last decades, measurements in atomic and molecular beams, and more recently in ion traps, provided the most successful tests of these symmetries, only quite recently did the method of matrix isolation spectroscopy arise. It has the potential advantage of performing spectroscopy on unprecedented numbers of atoms/molecules. To perform such a measurement in the future, it is necessary first to understand how the trapping of atoms inside the cryogenic matrix looks in detail.

In this contribution, I present what we learned so far through experiments and simulations of cesium trapped in an inert argon matrix and which future steps we are planning to take toward a measurement of the electron EDM and other beyond standard model effects.

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B144

Observation of quantum interference in Doppler-free two-photon spectroscopy and its implications for precision measurements

Bubai Rahaman[1], Sid C. Wright[2], Sourav Dutta[1]

[1]Tata Institute of Fundamental Research, Mumbai, India. [2]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany

Abstract

Doppler-free two-photon spectroscopy is a standard technique for precision measurement of transition frequencies of dipole forbidden transitions, e.g. the s-s and s-d transitions in atoms. The accuracy of such measurements depends critically on accurate fitting of the spectrum to a model lineshape and on proper estimation of systematic effects. We observe, for the first time, a subtle systematic effect arising from quantum interference of optical transition pathways in Doppler-free two-photon spectroscopy [1]. The interference manifests itself as asymmetric lineshapes of the hyperfine lines of the cesium 7d states, observed through spontaneous emission following excitation by a narrow-linewidth cw laser. The interference arises because there are two or more allowed optical pathways that connect the initial quantum state to the final quantum state. Neglecting the effect and fitting the spectrum to a Lorentzian or Voigt lineshape results in apparent line-shifts of several 10 kHz in the cesium 6s-7d transition. On the other hand, on calculating the lineshape including the effect of quantum interference and fitting to the spectrum to the quantum interference lineshape resolves the apparent line-shift. Additionally, we show that the quantum interference vanishes at a particular “magic angle” 54.7° between the laser polarization and the detection axis, providing an experimental alternative to full modeling of the quantum interference lineshape. The results have implications for optical clocks, measurement of hydrogen 1s-2s and 1s-3s transition frequencies and isotope shifts and hyperfine splittings of any element.

[1] Bubai Rahaman, Sid C. Wright, and Sourav Dutta, Phys. Rev. A 109, 042820 (2024).

Categories

Precision measurements

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B145

Search for P- and T-Violating Dipole Moments of Atoms

Z.-L. Ba, Z.-T. Lu, D. Sheng, Z.-J. Tao, S.-B. Wang, S.-Z. Wang, T. Xia, S.-B. Zhang, T. A. Zheng

Hefei National Laboratory, University of Science and Technology of China, Hefei, China

Abstract

Electric dipole moment of ^{171}Yb [1] – The EDM of ^{171}Yb is measured with atoms held in an optical dipole trap. By enabling a cycling transition that is simultaneously spin-selective and spin-preserving, a quantum nondemolition measurement with a spin-detection efficiency of 50% is realized. A systematic effect due to parity mixing induced by a static E field is observed, and is suppressed by averaging between measurements with optical traps in opposite directions. The EDM is determined to have an upper limit at 10^{-27} e-cm. These measurement techniques can be adapted to search for the EDM of ^{225}Ra.

Gravitational dipole moments of ^{129}Xe and ^{131}Xe [2] – The gravitational dipole moments of odd-isotopes of xenon are searched using an atomic gas comagnetometer to measure the nuclear spin-precession frequencies of ^{129}Xe and ^{131}Xe. No changes of the ratio between the two frequencies have been observed to the precision of 10^{-9} as the sensor is flipped in Earth's gravitational field, leading to an upper limit on the coupling energy between the neutron spin and the gravity on the ground at 10^{-22} eV. The results can also be used to constrain the coupling strength of axion-mediated monopole-dipole interactions at the range of Earth's radius.

Works are supported by the Chinese National Science Foundation, Ministry of Science and Technology, and Chinese Academy of Sciences.

[1] T. A. Zheng *et al.*, PRL 129, 083001 (2022).

[2] S.-B. Zhang *et al.*, PRL 130, 201401 (2023).

Categories

Precision measurements

Presentation

Poster presentation

B146

High precision theory for the Rydberg states of helium up to n = 24

Gordon Drake[1], Aaron Bondy[1], Eric Ene[1], Evan Petrimoulx[1], Lamies Sati[2]

[1]University of Windsor, Windsor, Canada. [2]Western University, London, Canada

Abstract

Variational calculations readily produce high precision energies and wave functions for the ground state of helium, but typically the accuracy rapidly deteriorates with increasing principal quantum number n. The current limit is n = 10, except for S-states up to n = 24. We report the results of new variational calculations based on the use of triple basis sets in Hylleraas coordinates (see E.M.R. Petrimoulx et al., Can. J. Phys. DOI: 10.1139/cjp-2023-0277). The basis sets are "tripled" in that each combination of powers *i, j, k* in basis functions of the form $r_1^i\, r_2^j\, r_{12}^k \exp(-\alpha r_1 - \beta r_2)$ is repeated three times with different nonlinear parameters α and β that are separately optimized on the energy surface to span different distance scales. Relativistic and quantum electrodynamic (QED) corrections are calculated, and results reported for the S- and P-states up to n = 24, including a comparison with high precision measurements for n = 24 (G. Clausen et al., Phys. Rev. Lett. **127**, 093001 (2021) .

Poster

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B147

Quantum-logic based search techniques for narrow transitions in highly charged ions

Shuying Chen[1], Lukas J. Spieß[1], Alexander Wilzewski[1], Malte Wehrheim[1], Kai Dietze[1], Ivan Vybornyi[2], Klemens Hammerer[2], José R. Crespo López-Urrutia[3], Piet O. Schmidt[1,4]

[1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany. [2]Institute of Theoretical Physics, Leibniz Universität Hannover, Hannover, Germany. [3]Max-Planck-Institut für Kernphysik, Heidelberg, Germany. [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

Abstract

Optical clocks are the most precise measurement devices, finding rich applications in frequency metrology and fundamental physics. Highly charged ions (HCI) are promising candidates as references for optical clocks, benefiting from the tightly bound valence electrons, leading to reduced sensitivity to external fields while featuring enhanced relativistic and QED contributions. The first HCI clock was demonstrated in Ar^{13+} with statistical uncertainty of 10^{-16}, which was predominantly limited by the excited state lifetime of 10 ms [1]. The precise measurement of isotope shifts to mHz uncertainty in five even, stable isotopes of Ca^{14+} (^{40}Ca, ^{42}Ca, ^{44}Ca, ^{46}Ca, ^{48}Ca) was also used for constructing a King plot for search for the 5th force in our group. To establish a next-generation HCI optical clock at the state-of-the-art precision, an HCI possessing a sub-Hz natural linewidth transition is required. Numerous candidate systems have been explored theoretically, but experimental challenges remain due to the considerable uncertainty of the transition frequencies. In this work, we investigated experimentally and theoretically three search techniques for such ultra-narrow transitions based on quantum logic spectroscopy in a two-ion crystal system. These techniques include blue sideband Rabi excitation, optical dipole force [2] and a linear continuous sweep of the laser frequency.

[1] S. A. King, L. J. Spieß, et al., Nature 611, 43-47 (2022)

[2] F. Wolf, et al., Nature 530, 457–460 (2016).

Categories

Clocks and metrology

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Poster presentation

B148

Dynamically-decoupled hyper-Ramsey spectroscopy of clock transitions

Thomas Zanon[1,2], David Wilkowski[3], Nikolay V. Vitanov[4]

[1]Sorbonne University, Paris, France. [2]MONARIS, Paris, France. [3]MajuLab, International Research Laboratory IRL 3654, Centre for Quantum Technologies, National University of Singapore, 117543 Singapore, Singapore, Singapore. [4]Centre for Quantum Technologies, Department of Physics, Sofia University, Sofia, Bulgaria

Abstract

We present hyper-clocks that are designed to simultaneously eliminate probe-induced frequency-shifts and frequency-drifts for robust quantum sensing and frequency metrology, opening fault-tolerant laser spectroscopy for fundamental physics tests. Hyper-Ramsey spectroscopy is modified by inserting, halfway in between Ramsey pulses, a phase-shifted refocusing Hahn-echo pulse alternating frequency detunings with opposite signs during inter-pulse delays. Quantum interferences are shielded against light-shifts associated to a drastic reduction of a detrimental probe-laser frequency-drift.

Ultra-robust frequency error correction protocols can be also achieved by combining dispersive interferometric signals eliminating residual frequency-drifts and frequency-shifts connected to a laser decoherence rate and slow intensity probe fluctuations.

Dynamically-decoupled hyper-Ramsey spectroscopy with phase-alternating composite pulses can be finally designed to operate within various experimental quantum simulation platforms suffering from noisy environment and technical distortions synchronized with electromagnetic pulses.

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Poster

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Clocks and metrology

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B149

Laser Excitation of the Th-229 Nucleus in Calcium Fluoride

Fabian Schaden[1], Thomas Pronebner[1], Ira Morawetz[1], Luca Toscani De Col[1], Adrian Leitner[1], Michael Bartokos[1], Georgy Kazakov[1], Kjeld Beeks[1], Tomas Sikorsky[1], Thorsten Schumm[1], Johannes Tiedau[2], Maksim Okhapkin[2], Ke Zhang[2], Johannes Thielking[2], Gregor Zitzer[2], Ekkehard Peik[2]

[1]TU Wien, Vienna, Austria. [2]PTB, Braunschweig, Germany

Abstract

We report on resonant excitation of the Th-229 isomeric state at 8.4 eV using a tabletop experimental apparatus and vacuum ultraviolet (VUV) laser. Th-229 doped Calcium Fluoride (CaF_2) crystals, central to our experimental setup, are grown using a specially modified vertical gradient freeze method, enabling high thorium concentrations up to $5\times10^{18}/cm^3$. Furthermore, we enhance the optical transmission of Th-229 doped crystals via superionic fluoride transfer. The laser excitation enables us to achieve the most precise measurement of the Th-229 isomer's resonance energy and its radiative lifetime to date. We observe the isomer signal in two different crystals with different doping concentrations, but it is absent in the control experiment with a Th-232 doped crystal. Furthermore, we report a quenching effect that allows for ondemand depopulation of the isomer state. This quenching effect, possible because the Th^{4+} ions are in a solid-state environment, is key for speeding up the interrogation cycle in the development of future nuclear clocks. Additionally, we are developing a state read-out scheme for solid-state nuclear clocks based on nuclear quadrupole spectroscopy. These results pave the way for Th-229 nuclear laser spectroscopy with a hertz-level resolution, similar to what has been achieved in the most advanced optical atomic clocks.

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B150

Quenching of Thorium-229 nuclear isomeric state using X-ray beam

Takahiro Hiraki[1], Michael Bartokos[2], Kjeld Beeks[3], Hiromitsu Haba[4], Yoshitaka Kasamatsu[5], Shinji Kitao[6], Adrian Leitner[2], Takahiko Masuda[1], Guan Ming[1], Nobumoto Nagasawa[7], Ryoichiro Ogake[1], Koichi Okai[1], Martin Pimon[2], Martin Pressler[2], Noboru Sasao[1], Fabian Schaden[2], Thorsten Schumm[2], Makoto Seto[6], Yudai Shigekawa[4], Koutaro Shimizu[1], Tomas Sikorsky[2], Kenji Tamasaku[8], Sayuri Takatori[1], Tsukasa Watanabe[9], Atsushi Yamaguchi[4], Yoshitaka Yoda[7], Akihiro Yoshimi[1], Koji Yoshimura[1]

[1]Okayama University, Okayama, Japan. [2]TU Wien, Vienna, Austria. [3]EPFL, Lausanne, Switzerland. [4]RIKEN, Wako, Japan. [5]Osaka University, Osaka, Japan. [6]Kyoto University, Sennan, Japan. [7]JASRI, Sayo, Japan. [8]RIKEN SPring-8, Sayo, Japan. [9]AIST, Tsukuba, Japan

Abstract

^{229}Th has a first excited state with an unusually low nuclear excitation energy of about 8.4 eV. Therefore, it can be excited by a vacuum ultraviolet laser and various applications using atomic physics techniques such as atomic clocks (nuclear clocks) are expected. Our group irradiated ^{229}Th-doped CaF_2 crystals with the X-ray beam available at synchrotron radiation facility SPring-8, located in Japan. The isomeric state of ^{229}Th is produced if X-ray beam energy coincides with its second excitation energy. Because these crystal targets emit numerous scintillation photons due to nuclear decay and X-ray beam irradiation, detectors are required to significantly reduce these backgrounds. We developed an apparatus with efficient signal detection and strong background rejection, which can be used as a detection system of future solid-state nuclear clocks. In the beamtime of 2023, We observed the vacuum ultraviolet light by the de-excitation of the isomeric state and measured its lifetime and wavelength. We also found that the isomeric lifetime is shortened during X-ray beam irradiation. This quenching effect has a possibility to manipulate the interrogation time when operating solid-state nuclear clocks. In this poster, we will present an overview of the experiments at SPring-8 and the dependence of the quenching effect on the beam intensity and crystal temperature.

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B151

Compact structures for single-beam magneto-optical trapping of ytterbium

Julian Pick[1], Roman Schwarz[1], Jens Kruse[1], Christian Lisdat[2], Carsten Klempt[1]

[1]German Aerospace Center (DLR), Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany. [2]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

Abstract

The ongoing improvement of measurement resolution and measurement capabilities in metrology, including frequency metrology, inertial sensing, and gravimetry, enables applications that require field deployable systems operating reliably outside of a well-controlled environment of a laboratory. Transportable systems demand a miniaturization of key components, including magneto-optical traps (MOTs). Such a miniaturization can be achieved by substituting the standard six-beam MOT configuration with in-vacuum optics that reflect or diffract a single incident beam into multiple beams that provide trapping and cooling forces along all spatial directions.

Here, we report a direct comparison between a quasi-monolithic pyramid-shaped reflector and an achromatic Fresnel reflector that are suitable to generate a MOT with a single-beam input. Both reflectors rely on aluminum mirror surfaces to generate secondary beams for three-dimensional trapping and cooling. The use of reflective elements provides achromaticity, preventing a beam overlapping mismatch that arises in diffractive grating structures. We investigate the properties of the corresponding MOT platform by trapping and cooling various isotopes of neutral ytterbium. The comparison encompasses the structures' performance in loading atoms into a first MOT stage operating on the $^1S_0$-$^1P_1$ transition. Furthermore, we investigate the transfer efficiency of bosonic ^{174}Yb and fermionic ^{171}Yb into the second MOT stage operating on the narrow $^1S_0$-$^3P_1$ transition. The demonstrated trapping and cooling geometries are compact and robust, and provide a reliable atom source for future compact and spaceborne optical lattice clocks.

Poster

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B152

Development of Strontium Optical Lattice Clock at University of Birmingham

Jordan Wayland, Abhilash Jha, Yogeshwar Kale, Yuheng Huyan, Anurag Borah

University of Birmingham, Birmingham, United Kingdom

Abstract

We present our work towards realising a stationary strontium optical lattice clock. When operational, the clock will feature in clock comparison campaigns with the rest of Europe via an optical fibre network between Birmingham and the National Physical Laboratory (NPL) in London. The clock will also serve as an ultra-low phase noise oscillator for our quantum-enabled radar testbed. As of writing, we have successfully confined strontium (Sr-88) atoms into an optical lattice with a lifetime of 4.45 s and an observed Rabi spectroscopic linewidth of 65 Hz for the 698 nm $^1\boldsymbol{S}_0$- $^3\boldsymbol{P}_0$ clock transition. The ultra-stable laser used for clock spectroscopy is stabilised to a 10cm ULE cavity with a measured modified Allan deviation, mod σ_y = ~2.5 × 10 $^{-15}$ at 1 s and a linewidth of ~1 Hz. We are gearing towards locking the ultra-stable laser to the atomic transition, establishing the system as a fully operational strontium optical lattice clock.

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B153

Progress Towards the Transportable Strontium Optical Lattice Clock

Yuheng Huyan, Anurag Borah

University of Birmingham, Birmingham, United Kingdom

Abstract

This abstract reports on our progression towards the transportable optical lattice clock (OLC) with strontium atoms. We target to achieve a fully functioning strontium 88 OLC and shift to strontium 87 isotope for better accuracy for the clock comparison in the National Physical Laboratory (NPL) in London. The OLC being built is highly compact with a physics package and light distribution unit together in a box with a volume under 100L, with the rest of the system including the computer control module, lasers, laser controllers and frequency comb will be transported together via two 19-inch racks.

Within the physics package, we have successfully realised the first-stage cooling at 1s0-1p1 461 nm transition with 11.38 x 10^6 strontium 88 atoms trapped, as well as the broadband second-stage cooling 1s0-3p1 689 nm transition with a good transfer rate of 46%. The entire system is controlled by Advanced Real-Time Infrastructure for Quantum Physics (ARTIQ).

Our control system comprises TTL, Analog and RF generators with a 16-bit data acquisition system. All the experimental milestones until broadband second-stage cooling have been orchestrated completely by ARTIQ. The flexible and open-source programming interface of ARTIQ empowers us to implement custom experimental sequences tailored towards a transportable OLC with a higher degree of freedom.

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B154

Einstein-Podolsky-Rosen Experiment with spatially separated entangled Bose Einstein Condensates

Lex Joosten, Paolo Colciaghi, Yifan Li, Tilman Zibold, Philipp Treutlein

Universität Basel, Basel, Switzerland

Abstract

In 1935, Einstein, Podolsky, and Rosen (EPR) conceived a Gedankenexperiment which became a cornerstone of quantum technology and still challenges our understanding of reality and locality today. While this experiment has been realized with smaller quantum systems, a demonstration of the EPR paradox with macroscopic many-particle systems remains an important challenge, as such systems are particularly closely tied to the concept of local realism in our everyday experience and may serve as probes for new physics at the quantum-classical transition. Here we report an EPR experiment with two spatially separated Bose-Einstein condensates, each containing about 700 Rubidium atoms. Entanglement between the condensates results in strong correlations of their collective spins, allowing us to demonstrate the EPR paradox between them. Our results represent the first observation of the EPR paradox with spatially separated, massive many-particle systems. They show that the conflict between quantum mechanics and local realism does not disappear as the system size increases to more than a thousand massive particles. Furthermore, EPR entanglement in conjunction with individual manipulation of the two condensates on the quantum level, as demonstrated here, constitutes an important resource for quantum metrology with many-particle systems. Our system is particularly well tuned for experiments in multi-parameter quantum sensing.

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B155

Metrology of microwave fields with cold Rydberg atoms

Romain Granier, Romain Duverger, Alexis Bonnin, Quentin Marolleau, Cédric Blanchard, Nassim Zahzam, Yannick Bidel, Malo Cadoret, Alexandre Bresson, Sylvain Schwartz

DPHY, ONERA, Université Paris-Saclay, Palaiseau, France

Abstract

Rydberg atoms hold great promise for microwave electric field sensing owing to their large dipole matrix elements. While most experimental developments have focused on room-temperature vapors so far, utilizing cold atoms in this context could enable new applications where accuracy, long term stability and high-resolution at large integration times are required, such as calibrating blackbody shifts in state-of-the-art optical clocks or measuring the cosmic MW background. Moreover, this paves the way for the hybridization of different sensors to harness the various advantages of cold atom sensors and mitigate their limitations.

Here, we demonstrate a novel approach for the metrology of microwave fields with cold 87 Rubidium Rydberg atoms based on trap-loss-spectroscopy in a magneto-optical trap (MOT). This new method is particularly simple as it relies on fluorescence measurements only. By using a two-photon transition highly-detuned from the intermediate state, we realize a situation where the frequencies of the spectral lines are well-described by a coupled two-level system, which is particularly favorable for the linearity of the sensor in the resonant case. Moreover, we show that it leads to a quasi-ideal Autler-Townes configuration, allowing in principle to reconstruct the amplitude and the frequency of the microwave field simultaneously without the need for an external reference field. With a scale factor linearity at the 1% level and a long-term frequency stability equivalent to a resolution of 5 µV/cm at 2500s and no noticeable drift over this time period, this new measurement technique appears to be particularly well-suited for metrology experiment.

Poster

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B156

First observation of the bosonic ^{198}Hg clock transition in an optical lattice clock

Clara Zyskind, Benjamin Pointard, Rodolphe Le Targat, Sebastien Bize

LNE-SYRTE, Observatoire de Paris-PSL, CNRS, Sorbonne Université, Paris, France

Abstract

Mercury exhibits promising properties for an optical lattice clock, including a low sensitivity to blackbody radiation (16 times lower than Yb and 30 times lower than Sr). Historically, the ^{199}Hg fermionic isotope was the only isotope used in mercury clocks. However, its limited excited state lifetime restricts the full utilization of upcoming ultrastable lasers. Using bosonic isotopes, which can potentially have unlimited lifetimes, circumvents this issue.

We present the first observation of the ^{198}Hg bosonic transition in an optical lattice clock, achieved through significant experimental advancements and a meticulous search for a narrow transition within a broad uncertainty range. The bosonic clock transition is forbidden and requires a high magnetic field to induce it via the quenching method, which hence allows for longer probing times.

A critical step was creating a setup producing a sufficiently large magnetic field to induce the transition. Another challenge was developing a widely tunable probe laser with ultra-low noise properties, essential for probing any mercury isotopes without additional noise. Increasing the deep UV ultrastable light power was also crucial for optimizing the coupling.

Our efforts led to the successful observation of the ^{198}Hg transition, enabling an operational optical lattice clock with ^{198}Hg, reaching a stability of 10^{-15} at 1 second. We measured the quadratic Zeeman shift coefficient with an uncertainty allowing control to 10^{-17} and began examining other systematic effects such as the probe light shift and measure the magic wavelength. Additionally, we aim to measure the ^{198}Hg/^{87}Sr optical frequency ratio for the first time.

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B157

An end-cap 3D Paul trap towards precision spectroscopy

Akhil Ayyadevara[1], Anand Prakash[1], Subodh Vashist[1], Mohamed Ibrahim[1], Yatheendran K. M.[1], Subhadeep De[2], E. Krishnakumar[1], S. A. Rangwala[1]

[1]Raman Research Institute, Bengaluru, India. [2]Inter-University Center for Astronomy and Astrophysics, Pune, India

Abstract

Trapped ions in radio-frequency Paul traps are one of the leading candidates for precision metrology at optical frequencies[1]. Ions can be confined and laser-cooled to their motional ground state, which minimizes the systematic shifts in the transition spectra. Current engineering challenges call for traps that improve the isolation of trapped ions from the environment and reach fractional uncertainties below 10^{-18}[2][3].

Here we present our design and characterization of an end-cap Paul trap with reduced an-harmonicity in the trapping potential. The optimization of the trap parameters is done with COMSOL, with an emphasis on electrode dimensions while considering the achievable machining and alignment tolerances. We have developed a low-divergence oven to minimize the coating of the trap electrodes and successfully loaded a cloud of calcium ions into the trap[4]. With the custom-built diffraction-limited imaging system, we observe exotic morphologies of 4-ion Coulomb crystals, which closely match the theoretical predictions[5].

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Clocks and metrology

Presentation

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B158

Three-dimensional Rydberg atom rf polarimeter

Peter Elgee, Kevin Cox, Joshua Hill, Paul Kunz, David Meyer

DEVCOM Army Research Laboratory, Adelphi, USA

Abstract

Radio frequency (rf) receivers using Rydberg atoms and their broadband sensitivity to electric fields offer unique advantages over classical sensors, such as their size, extreme tunability, and lack of field absorption. However, so far their ability to measure the polarization of a signal has been limited. In this work we present a Rydberg atom rf polarimeter taking advantage of current rf heterodyne techniques. Using three independent local oscillators, one for each cardinal axis, we are able to fully measure the polarization of an incoming field through each heterodyne beat. In contrast to previous work, we use the phase relationship between these beats to extract the polarization ellipticity, not just the amplitude of polarization projections. We demonstrate this polarization measurement for a signal with a fixed k-vector, and for incoming fields at different angles around the sensor. Our measurement of polarization, and specifically ellipticity, provides limited k-vector information without requiring a sensor on the scale of the wavelength. Lastly, we investigate the reception of symbols encoded in the polarization angle, ellipticity and signal amplitude.

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B159

A Phase Frequency Detector (PFD) for spectral purity transfer with offset frequencies up to 10 GHz

Pierre Thoumany, Dewni Pathegama, Rudolph Neuhaus, Steffen Schmidt-Eberle, Heather Partner, Manfred Hager

TOPTICA Photonics AG, Munich, Germany

Abstract

The realization of ultra-stable lasers is both a technically challenging and costly endeavour. Implementing more than one laser with such stability is a prerequisite for a large number of experiments.

Here we present a phase detector module (PFD) allowing the spectral purity transfer from an ultra-stable laser stabilized to a very high finesse cavity to both a Difference Frequency Comb (DFC) and directly to a second CW laser with offset frequencies in the range of 5 MHz to 10 GHz.

Using a PFD provides the advantage that the resulting error signal is both proportional to the phase discrepancy for small phase deviations and indicates the sign of the frequency error for larger frequency deviations, thus enabling a very stable phase lock with large capture range. This allows to implement fast offset frequency changes through frequency jumps or ramps.

We demonstrate the performance of our module by realizing the spectral purity transfer of an ultra-stable laser to both a DFC with 200 MHz repetition rate and a CW laser. The transfer is demonstrated by comparing the instability of the frequency comb and the phase locked CW laser to a second ultra stable laser.

With an ultimate instability at the level of 3×10^{-18} at 1s, this module can sustain spectral purity transfer at the level required by many quantum applications, including the best contemporary optical clocks.

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B160

Optical clock spectroscopy with Sr ensembles in reconfigurable tweezer arrays

Mitch Walker, Ryuji Moriya, Liam Gallagher, Matthew Hill, C. Stuart Adams, Matthew Jones

Durham University, Durham, United Kingdom

Abstract

We report on progress towards implementing Rydberg-based spin squeezing protocols [1] using small (N < 10) ensembles of ^{88}Sr atoms in magic-wavelength optical tweezers. Highly-excited Rydberg states provide new ways to engineer entanglement in optical frequency standards such as Sr and Yb atomic clocks, with the first results using single atoms in tweezer arrays appearing last year [2, 3]. A similar protocol was implemented using a 1D array of ensembles of Cs atoms [4]: our current goal is to examine whether a similar approach using smaller ensembles could be used in Sr tweezer experiments.

We will describe our experiments with ensembles of ^{88}Sr atoms trapped in long working distance optical tweezers [5] at the 813 nm magic wavelength. Our larger tweezer waist (2 microns) allows the collisional blockade to be circumvented such that we can load small ensembles into each site of a 2D reconfigurable array (site spacing ~6 microns). We will present results on site-resolved spectroscopy of the $^1S_0$-$^3P_0$ clock transition as a function of the number of atoms per tweezer site, alongside interpretation in terms of density-dependent collisions. As outlook, we intend to perform precision Rydberg spectroscopy from the ^3P_J states in individual tweezers.

[1] L. I. R. Gil *et al*., PRL **112** (2014)
[2] G. Bornet *et al*., Nature **621** (2023)
[3] W. J. Eckner *et al.*, Nature **621** (2023)
[4] J. A. Hines *et al.*, PRL **131** (2023)
[5] N. C. Jackson *et al.*, SciPost Phys. **8** (2020)

Categories

Clocks and metrology

Presentation

Poster presentation

B161

Towards an isotope shift measurement with Sr_2 to search for new physics

Brandon Iritani[1], Mateusz Borkowski[2], Wenwei Xu[1], Debayan Mitra[1], Tanya Zelevinsky[1]

[1]Columbia University, New York, USA. [2]University of Amsterdam, Amsterdam, Netherlands

Abstract

Optical atomic clocks represent the state of the art for precision measurement, reaching 10^{-21} fractional frequency uncertainty and enabling the measurement of gravitational redshift below the cm scale[1]. Molecular clocks are complementary platforms for performing tests of fundamental physics, such as constraining new forces. We have characterized a vibrational transition in $^{88}Sr_2$ molecules to the 10^{-14} level[2]. In this study we present a methodology aimed at constraining mass-dependent Yukawa forces through the measurement of the isotope shift of vibrational levels within the $X0_g^+$ ground state potential in Sr_2. Looking ahead, we outline the progress towards measuring the vibrational isotope shift between $^{88}Sr_2$ and $^{86}Sr_2$ through trapping and cooling their corresponding atomic isotopes in an interleaved fashion. Additionally, we present a second-generation apparatus designed to improve coherence time and mitigate the limiting systematic effects. This will be achieved through the implementation of an in-vacuum buildup cavity, enabling the utilization of a larger lattice waist and reduced trap depths.

[1]T. Bothwell, C. J. Kennedy, A. Aeppli, D. Kedar, J. M. Robinson, E. Oelker, A. Staron, and J. Ye, Resolving the Gravitational Redshift across a Millimetre-Scale Atomic Sample, Nature (London) 602, 420 (2022).

[2]K. H. Leung, B. Iritani, E. Tiberi, I. Majewska, M. Borkowski, R. Moszynski, and T. Zelevinsky, Terahertz vibrational molecular clock with systematic uncertainty at the 10−14 level, Phys. Rev. X 13, 011047 (2023).

Categories

Clocks and metrology

Presentation

Poster presentation

B162

Transportable optical lattice clock with uncertainty below $5*10^{-18}$

Ingo Nosske, Chetan Vishwakarma, Tim Lücke, Sofia Herbers, Christian Lisdat

Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

Abstract

Transportable high-performance optical atomic clocks are being designed and constructed worldwide, as they will enable beyond-state-of-the-art geodetic measurements on the centimeter level as well as accurate inter-institute frequency comparisons, paving the way towards the redefinition of the SI second.

Here we describe the current evaluation status of the second-generation transportable optical lattice clock based on ^{87}Sr atoms at PTB, which is operational since early 2023. In this setup the atoms are cooled to a few µK in a single-beam pyramid magneto-optical trap, moved into a blackbody radiation (BBR) shield at -50 °C where they are held in an optical lattice, and interrogated on the $^1S_0 \rightarrow {}^3P_0$ clock transition. With an ultrastable transportable laser we achieve a fractional clock frequency instability of about $4*10^{-16}$ $(\tau/s)^{-1/2}$ after an averaging time τ, corresponding to a height measurement resolution of about 6 cm $(\tau/hour)^{-1/2}$ utilizing the gravitational redshift.

Due to the carefully machined BBR shield the atomic blackbody radiation shift uncertainty is reduced to less than $1*10^{-18}$. The system has a ≥15 s vacuum-limited lifetime, leading to a reduced background gas collision shift, and a mu-metal shield for a stable magnetic field environment. Taking all frequency shifts into account, we evaluate the clock uncertainty to be below $5*10^{-18}$. The apparatus is installed in an air-conditioned car trailer and already operated after transportations over distances of 100s of km. We review previous and future off-campus measurements involving this clock.

Categories

Clocks and metrology

Presentation

Poster presentation

B163

Uncertainty evaluation of the atomic gravimeter KRISS-AG-1 and toward improving the uncertainty

Sang-Bum Lee, Taeg Yong Kwon, Sang Eon Park, Sangwon Seo, Sanglok Lee, Hyun-Gue Hong, Jae Hoon Lee, Young-Ho Park, Seji Kang

Korea Research Institute of Standard and Science, Dajeon, Korea, Republic of

Abstract

An absolute atomic gravimeter based on an atom interferometer has surpassed the sensitivity of its classical counterpart, FG5X, by about an order of magnitude, but its accuracy in absolute terms is comparable. The most dominant limit in the accuracy is due to the wavefront distortion of the Raman laser, which imprints its phase on the phase factor of the atomic wavepackets while manipulating them to constitute an atom interferometer. This effect is related to the ballistic expansion of the atomic source through its motion described by atomic temperature and does not occur at atomic temperature of zero. Here, we report an uncertainty evaluation of the Rb atomic gravimeter KRISS-AG-1 developed at KRISS (Korea Reasearch Institute of Standard and Science), with a total uncertainty of less than 30 nm/s^2, mainly limited by a wavefront distortion. We then present the way to improve the uncertainty by introducing a new physical package using Cs atoms and by compensating for bias by directly measuring the wavefront distortions induced by all optical elements.

Categories

Clocks and metrology

Presentation

Poster presentation

B164

Status report and relativistic redshift evaluation of Yb optical lattice clocks at KRISS

Won-Kyu Lee[1], Huidong Kim[1], Chang Yong Park[1], Myoung-Sun Heo[1], Dai-Hyuk Yu[1], SungNam Park[1], Dohyeon Kwon[1], Jisun Lee[2], Jay Hyoun Kwon[2]

[1]KRISS, Daejeon, Korea, Republic of. [2]University of Seoul, Seoul, Korea, Republic of

Abstract

We report the status of the Yb optical lattice clocks developed at KRISS (Korea Research Institute of Standards and Science). The absolute frequency of KRISS-Yb1 contributed to the determination of the BIPM recommendation values of the Yb standard frequency. KRISS-Yb1 has contributed to the steering of the International Atomic time (TAI) since 2021, and was the most frequently contributing optical clock in 2023. The systematic uncertainty of KRISS-Yb1 was limited to $1.7x10^{-17}$ mainly due to the blackbody radiation (BBR) shift uncertainty. The second Yb optical lattice clock (KRISS-Yb2) was developed to reach the 10^{-18} uncertainty level overcoming this BBR shift uncertainty. The total uncertainty of the BBR shift including the atomic response was evaluated as $9.5x10^{-19}$ and six electrodes were installed to evaluate the DC Stark shift along three axes. We expect that the total systematic uncertainty of KRISS-Yb2 would be improved to be less than $5x10^{-18}$ with these upgrades. We should accurately evaluate the relativistic redshift to compare with the remote frequency standards or to participate in the calibration of TAI. We evaluated the relativistic redshift of KRISS-Yb1 to be $8.193(4)x10^{-15}$, which will be presented at the conference.

Categories

Clocks and metrology

Presentation

Poster presentation

B165

Observation of buffer gas cooling of carbon atoms

Takashi Sakamoto[1], Kohei Suzuki[1], Kosuke Yoshioka[1,2]

[1]Department of Applied Physics, School of Engineering, The University of Tokyo, Tokyo, Japan.
[2]Photon Science Center, Tokyo, Japan

Abstract

Laser-cooled atoms at ultralow temperatures provided platforms for exploring science in diverse fields such as observation of quantum degeneracy, frequency standards, quantum simulations, and cold collision studies. These applications have been a great success for alkali and alkaline earth atoms with strong and closed electronic transitions easily accessible with current laser technology, motivating the community to extend laser-coolable atomic species.

Nevertheless, non-metallic atoms of chemical or biological interest including carbon have not been laser-cooled. This is primarily due to optically allowed electronic transitions lying in the vacuum ultraviolet region. Moreover, in the case of carbon, the extremely low vapor pressure makes it difficult to prepare atomic gas for laser cooling. Coupled with the difficulty in spectroscopic observation, production methods of ground-state carbon atoms have not been well investigated until recently.

In the previous study, we demonstrated gas production of carbon atoms in the ground state using laser ablation of graphite in vacuum via two-photon excitation-induced fluorescence [1]. We also proposed a realistic cooling scheme of carbon that employs buffer gas cooling and subsequent two-photon laser cooling with a microsecond pulsed light source.

Here, we demonstrate buffer gas cooling of carbon atoms. Specifically, we observed the thermalization process of carbon atoms with buffer gas atoms via time-resolved spectroscopic measurements in the buffer gas cell using two-photon excitation by broadband nanosecond pulses. We also compare the results with Monte Carlo simulations and estimate the achieved temperature.

[1] T. Sakamoto and K. Yoshioka, Phys. Rev. A 106, 052808 (2022)

Categories

New directions

Presentation

Poster presentation

B166

Transverse Field Zeeman Slower for ^{7}Li from Permanent Magnetic Dipoles

Roy Elbaz, Fatema Gzal, Majdi Gzal, Neta Priel, Lev Khaykovich

Bar Ilan university, Ramat Gan, Israel

Abstract

In the field of ultracold atoms Zeeman slowers are commonly used for slowing down atomic beams. The conventional method typically involves electromagnets with high current which require water cooling and introduce further complications to the system. Here we present our design of a Zeeman slower made from an array of individual magnetic dipoles in a cylindrical Halbach configuration. This alternative method creates a stable and robust uniform transverse field while allowing high tunability of the spatial dependence of that field along the symmetry axis. Due to some details of lithium energy spectrum, a zero-crossing transverse field configuration poses unique challenges to its characterization. We present experimental result of its performance, together with theoretical description of interesting features found in this device.

Poster

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Categories

Quantum optomechanics

Presentation

Poster presentation

B167

Wideband Vector Signal Analysis on Quantum Harmonic Oscillator Platforms

Clayton Ho, Grant Mitts, Hao Wu, Josh Rabinowitz, Eric Hudson

University of California, Los Angeles, Los Angeles, USA

Abstract

Despite unprecedented control over Quantum HarmonicOscillators (QHOs) and their ubiquity in precision metrology, field sensing onQHO platforms has heretofore been limited to narrowband measurements about astatic secular frequency.

Using a single trapped 40Ca+ ion, we demonstrate a novel technique (arXiv:2311.12263) that allows for wideband amplitude, frequency, and phase sensing of a field while retaining leading-edge sensitivities.

By applying quadrupole microwave fields about a dipole field of interest, we engineer a motional Raman transition that results in a phase-sensitive displacement.

As a proof-of-concept, we demonstrate commercial network analysis by reproducing the known transfer function of a filter element. We then showcase the potential for challenging in situ measurements by using our scheme to calibrate qubit control lines.

Benchmarking of our scheme further confirms the achievement of precisions and sensitivities beyond the standard quantum limit.

Our scheme is general and requires no apparatus beyond the addressing infrastructure of the QHO, and is thus easily extendable to other QHO platforms.

This research was supported by the National Science Foundation (Grants No. 2110421 and No. CHE-1900555), the Army Research Office (Grant No. W911NF-19-1-0297) and the Air Force Office of Surface Research (Grant No. FA9550- 20-1-0323). We acknowledge support from the NSF QLCI program through Grant No. OMA-2016245.

Categories

New directions

Presentation

Poster presentation

B168

Self-aligning Crossed Optical Dipole Trap and Multi-region Trap for ^{6}Li Atoms

Ariel Sommer, Maximillian Mrozek-McCourt, Ming Lian, Zachary Blogg, Nikolas Cruz, Loghan Michell

Lehigh University, Bethlehem, PA, USA

Abstract

We demonstrate a novel crossed optical dipole trap (ODT) design that features inherent stability of the beam crossing, allowing the trap to move and remain aligned. The trap consists of a single high-power laser beam, imaged back onto itself at an angle to form a crossed trap. Self-aligning behavior results from employing an imaging system with positive magnification tuned precisely to unity (M=1.000(5)). We employ laser-cooled samples of ^{6}Li atoms to demonstrate that the trap remains well-aligned over a 4.3 mm travel range perpendicular to the crossing plane. Performance is demonstrated by measurements of loading efficiency and transverse trapping frequency versus trap location. Real-time tuning of the trap along the out-of-plane axis can allow bringing an atomic gas close to an opaque or light sensitive surface without directly subjecting the surface to the trapping beams. Our technique therefore has potential applications in quantum sensing, such as atomic magnetometry of materials, and in the production of strong RF magnetic fields for cold atoms. We implement the self-aligning crossed ODT as part of a new apparatus for studying non-equilibrium physics of strongly interacting fermions in a multi-region box trap. Our multi-region trap design is based on programmable light sheet barriers generated from four beams of blue-detuned light, focused to sheets by a cylindrical lens, and controlled with a DMD.

Supported by the US NSF (2110483) and Lehigh University (FIGAWD274).

Categories

New directions

Presentation

Poster presentation

B169

Applications of Time Crystals Based on Ultracold Atoms

Krzysztof Giergiel[1,2], Ali Zaheer[1], Arpana Singh[1], Chamali Gunawardana[1], Mohammed Bouras[1], Satoshi Tojo[3], Andrei Sidorov[1], Krzysztof Sacha[2], Peter Hannaford[1]

[1]Swinburne University of Technology, Melbourne, Australia. [2]Jagiellonian University, Krakow, Poland. [3]Chuo University, Tokyo, Japan

Abstract

We report on the application of discrete time crystals, created by periodically driven ultracold atoms, to condensed matter physics in the time domain [1]. For interaction strengths greater than a critical value, such a system can exhibit dramatic spontaneous breaking of time-translation symmetry, allowing the formation of big time crystals having many tens of temporal lattice sites. In our experiment currently under construction, such a system takes the form of a Bose-Einstein condensate of potassium-39 atoms bouncing resonantly on an oscillating atom mirror [2]. Predicted condensed matter phenomena in the time domain include Anderson and many-body localization due to temporal disorder; Mott insulator phases in time; topologically protected time crystals; and quasi-crystalline structures in time [1].

Other potential applications of time crystals include **‘**time-tronics’ – a temporal analogue of electronics. For example, ultracold atoms moving in a driven 1D box lattice potential can be used to create temporal crystalline structures that behave like a temporal printed circuit board, in which the various elements on the board can be arbitrarily connected through controlled Bragg scattering-induced tunnelling of atoms between pairs of crossing wave-packets [3]. This may allow the design and realisation of a broad range of quantum devices, such as quantum gates that can be performed between all possible qubit pairs within the device, and a universal quantum computer.

1. P. Hannaford and K. Sacha, *AAPPS Bulletin* **32**, 12 (2022).
2. K. Giergiel et al., *New J. Phys*. **22**, 085004 (2020).
3. G. Zlabys et al., *Phys. Rev. B* **103**, 100301 (2021).

Categories

New directions

Presentation

Poster presentation

B170

Spin-squeezing and entanglement generation under the influence of holes

Tanausú Hernández Yanes[1,2], Youcef Baamara[3], Artur Niezgoda[4], Alice Sinatra[3], Emilia Witkowska[1]

[1]Institute of Physics PAS, Warszawa, Poland. [2]Universität Innsbruck, Innsbruck, Austria. [3]LKB, Paris, France. [4]ICFP, Barcelona, Spain

Abstract

Spin-squeezing in systems with single-particle control is a well-established resource of modern quantum technology. Applied in an optical lattice clock it can reduce the statistical uncertainty of spectroscopic measurements. Here, we consider the dynamic generation of spin-squeezing with ultra-cold bosonic atoms with two internal states loaded into an optical lattice in the strongly interacting regime. We show that anisotropic interactions and inhomogeneous magnetic fields generate scalable spin-squeezing if their magnitudes are sufficiently small, but not negligible. The effect of non-uniform filling caused by hole doping is studied at a microscopic level. We derive analytical models for the limiting cases of zero and infinite effective tunnelling to approximately bound the corresponding t-J models. We also analyse entanglement generation under the influence of holes, based on a Bell inequality derived for collective measurements.

Categories

Many body physics

Presentation

Poster presentation

B171

Coherent Three-Photon Excitation of the Strontium Clock Transition

Junyu He[1], Benjamin Pasquiou[1,2,3,4], Rodrigo González Escudero[1], Sheng Zhou[1], Mateusz Borkowski[1], Florian Schreck[1,2]

[1]University of Amsterdam, Amsterdam, Netherlands. [2]QuSoft, Amsterdam, Netherlands. [3]CNRS, Villetaneuse, France. [4]Université Sorbonne Paris Nord, Villetaneuse, France

Abstract

We recently demonstrated a steady-state Bose-Einstein condensate of strontium atoms [1]. We could turn this into a perpetual atom laser if an efficient outcoupling mechanism is found. Here we show a coherent three-photon excitation of the clock transition in a strontium BEC with contrast of 44.5(3.5)% [2]. We follow it up with a demonstration of three-photon STIRAP-like transfer. Our work constitutes an essential step towards the outcoupling of a continuous atom laser beam and provides a robust excitation mechanism for quantum simulation.

[1] C.-C. Chen, *et al.*, *Nature* **606**, 683–687 (2022)

[2] J. He, *et al.*, arXiv: 2406.07530 (2024)

Categories

Quantum fluids

Presentation

Poster presentation

B172

Pushing single atoms into an optical resonator

Dowon Lee[1], Taegyu Ha[1], Donggeon Kim[1], Keumhyun Kim[1], Kyungwon An[2], Moonjoo Lee[1]

[1]Department of Electrical Engineering, Pohang University of Science and Technology (POSTECH), Pohang, Korea, Republic of. [2]Department of Physics and Astronomy & Institute of Applied Physics, Seoul National University, Seoul, Korea, Republic of

Abstract

We make use of an optical scattering force to reduce an atomic loading time to a high-finesse cavity mode [1]. After releasing a cold 87Rb atomic ensemble above the resonator, a push beam is illuminated along the direction of gravity, resulting in fast atomic transport with narrow velocity distribution. We also monitor in real time that, when the push beam is shined upward, single atoms slow down and even turn around in the mode, via the cavity-transmission measurement. Our experimental results are understood with a theoretical model that considers mechanical effects of both the push beam and cavity photons. We also discuss the progress in constructing a remote atom-cavity system for the generation of a cavity-based quantum network.

[1] D. Lee, T. Ha, D. Kim, K. Kim, K. An, and M. Lee, arXiv:2403.03019 (2024)

Categories

Cavity QED

Presentation

Poster presentation

B173

A new generation $^{27}Al^+$ optical clock

Daniel Rodriguez Castillo[1,2], Willa Dworschack[1,2], Mason Marshall[2], David Hume[2]

[1]University of Colorado - Boulder, Boulder, USA. [2]National Institute of Standards and Technology, Boulder, USA

Abstract

The $^1S_0$ to $^3P_0$ transition of $^{27}Al^+$ has been shown to be an excellent frequency standard due to its narrow intrinsic linewidth and low sensitivity to external fields. At NIST, the previous generation of this Al^+ clock was shown to have systematic uncertainty below $1x10^{-18}$. A network of optical clocks in Boulder including $^{27}Al^+$, ^{171}Yb and ^{87}Sr has measured frequency ratios with a total uncertainty between $6x10^{-18}$ and $8x10^{-18}$.

The next generation $^{27}Al^+$ clock is under evaluation at NIST and is expected to improve on both these results. The new design facilitates trapping multiple Al+ ions and taking advantage of the improved projection noise. Improvements include reduced excess micromotion and lower background gas pressure. The two-ion crystal reordering rate was measured to be ~1 event/hour, and is consistent with an upper bound for background pressure of $5x10^{-12}$ Torr, a factor of 30 lower than the previous generation.

Progress towards a multi-ion clock as well as towards a full systematic characterization of the single ion apparatus will be presented, the latter done with the goal of repeating the clock network measurement campaign.

Categories

Clocks and metrology

Presentation

Poster presentation

B174

Compact Vertical-External-Cavity Surface-Emitting Laser (VECSEL) for AMO physics

Jussi-Pekka Penttinen, Emmi Kantola, Topi Uusitalo, Sanna Ranta, Arttu Hietalahti, Mircea Guina

Vexlum, Tampere, Finland

Abstract

VECSELs are considered a key enabling laser platform with an excellent technological match for quantum technology applications using ion, atoms, or molecules. Our commercial VECSEL platform called "VALO" has enabled a large number of scientific experiments, delivering an unmatched combination of high power, narrow-linewidth, low-noise, and low-cost performance. At the same time the need for further reducing the size, weight, power consumption, and cost has become obvious in order to enable the field deployment of industrial-grade quantum technology systems. To this end, we are reporting on a compact VECSEL platform, called VXL™. The platform has an equally broad wavelength coverage from 350 nm to 2150 nm as its predecessor VALO but has a significantly reduced volume of ~1 litre. The sealed and rugged VECSEL cavity is reducing the susceptibility of the laser to external noise sources making it suitable for field deployment, and the modular design enables flexible system integration and more practical servicing with spares. The system can cover all the wavelengths needed for e.g. an optical lattice clock or a quantum computing system, including the clock/qubit transitions. Sub-Hz linewidths can be reached by utilizing an intracavity electro-optical modulator for high phase locking bandwidth. As a performance reference, we report operation at the 729 nm Ca+ ion clock transition, with more than 600 mW of output power in a beam with excellent transverse beam quality (TEM_{00}, $M^2 < 1.1$).

Categories

Exhibitor

Presentation

Invited speaker

C001

Exploring fermionic superfluidity in an optical kagome lattice

Rowan Duim[1,2], Shao-Wen Chang[1,2], Malte Schwarz[1,2], Dan Stamper-Kurn[1,2,3]

[1]University of California, Berkeley, Berkeley, USA. [2]Challenge Institute for Quantum Computation, Berkeley, USA. [3]Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, USA

Abstract

We use a bichromatic triangular superlattice to generate an optical kagome lattice, in which geometrical frustration leads to a flat band in the lowest manifold. In the band theory of solids, the curvature of a band is related to the density of states and the effective mass of electrons. Bands with extremely low dispersion – 'flat bands' – enhance the effects of interactions and can lead to correlated electronic states such as superconductivity, or, in a neutral atom system, fermionic superfluidity. Fermionic superfluidity across the BEC-BCS crossover was observed in early studies of bulk Fermi gases, but has not yet been observed in optical lattices in the tight-binding regime due to the high temperature of the gas with respect to the Fermi temperature. One pathway to achieving fermionic superfluidity in an optical lattice is to use a lattice geometry in which the critical temperature is increased due to a high density of states: BCS theory suggests that the critical temperature for superfluidity in a flat band will be enhanced, and there is experimental evidence that flat bands may be crucial to high-temperature unconventional superconductivity. We propose to search for fermionic superfluidity of a potassium-40 Fermi gas in the flat band of the kagome lattice. The tunability of our system allows us to test the dependence of the critical temperature on the curvature of the band and the interaction strength. In addition, we describe progress towards introducing the fermionic species 40K into the optical Kagome lattice and additional upgrades to our setup.

Categories

Many body physics

Presentation

Poster presentation

C002

Observation of the Einstein–de Haas effect in europium Bose–Einstein condensate

Hiroki Matsui[1], Ryoto Goto[2], Chihiro Nakano[2], Yuki Miyazawa[1], Yuki Kawaguchi[3], Masahito Ueda[4], Mikio Kozuma[1,2]

[1]Institute of Innovative Research, Tokyo Institute of Technology, Kanagawa, Japan. [2]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan. [3]Department of Applied Physics, Nagoya University, Nagoya, Japan. [4]Department of Physics, The University of Tokyo, Tokyo, Japan

Abstract

The magnetic dipole-dipole interaction in an atomic Bose–Einstein condensate (BEC) couples the atomic spin to the orbital degree of freedom due to its anisotropy. Combined with its long-range nature, quantized vortices can appear in an initially spin-polarized BEC in conjunction with the atomic spin relaxation, thereby conserving the total angular momentum, which is interpreted as an experimental evidence of the Einstein–de Haas effect. Theoretically, this effect is predicted to occur in BECs for atomic species with large magnetic dipole moments such as Cr, Er, and Dy; however, the emergence of circulation accompanying spin relaxation has not been reported yet. Here, we have successfully observed this effect in a Eu atomic BEC. We prepared a BEC in the spin-polarized state ($m=-6$) along an external magnetic field and quenched the magnetic field to below 100 μG. We let the system evolve and then projected the spins by suddenly increasing the magnetic field. We then performed a Stern–Gerlach experiment and observed spin relaxation in the BEC and a ring-shaped spatial structure in the $m=-5$ spin component in the absorption image. We confirmed the presence of a quantized mass current in the ring-shaped component through matter-wave interference. The spinor dynamics also exhibited temporal oscillations indicating that the dynamics is driven by the Larmor precession around magnetic fields created by the BEC. The observed dynamics can also be interpreted as the Barnett effect occurring following the Einstein de–Haas effect.

Categories

Many body physics

Presentation

Poster presentation

C003

Explorations with Erbium

Robert Smith

University of Oxford, Oxford, United Kingdom

Abstract

My poster will consist of two parts.

First, I will present our measurements of the modification of transition temperature for Bose Einstein Condensation (BEC) due to dipole-dipole interactions. The effect of dipolar interactions on harmonically trapped BECs has been the subject of intense and fruitful research over recent years, but despite being theoretically calculated over 15 years ago the modification of the BEC transition temperature due to dipole-dipole interactions has, up to now, not been experimentally observed. We use an ultracold erbium gas confined in a highly prolate trap to directly observe the dependence of the critical temperature on the orientation of the dipoles relative to the trap and compare the results with theoretical expectations.

Second, I will discuss the challenges and progress towards, the realization of a box-trapped dipolar gas.

Categories

Many body physics

Presentation

Poster presentation

C004

Bose polarons in a box

Jiri Etrych[1], Gevorg Martirosyan[1], Alec Cao[2], Seb Morris[1], Simon Fischer[1], Christopher Ho[1], Zoran Hadzibabic[1], Christoph Eigen[1]

[1]University of Cambridge, Cambridge, United Kingdom. [2]JILA, Colorado, USA

Abstract

We measure the spectral properties and real-time dynamics of mobile impurities injected into a homogeneous Bose-Einstein condensate, using two Feshbach resonances to tune both the impurity-bath and the intrabath interactions. We map out both attractive and repulsive branches of polaron quasiparticles, resolving the repulsive polaron and the molecular state associated with the Feshbach resonance in the strongly interacting regime, and show that the latter also has a many-body character. Our measurements reveal remarkably universal behavior, controlled by the bath density and a single dimensionless interaction parameter; for near-resonant interactions the polarons are no longer well defined, but the universality still holds. Finally, we study the fate of the quasiparticle branches as we heat the system and cross the BEC transition temperature of the bath.

Categories

Many body physics

Presentation

Poster presentation

C005

Emergent Physics with Cold Atoms in a Hollow-Core Fiber

Luisa Loranca Cruz, Andrea Bertoldi

LP2N, Bordeaux, France

Abstract

CRYST³ is a project that seeks to build on state-of-the-art research at the frontier of quantum many-body physics of atoms and photons, fiber photonics and ultracold atoms. The objective is to cool (at temperatures of the order of the microkelvin) and load Rubidium 87 atoms into a hollow core photonic crystal fiber (HCPCF) hermetically sealed, using a protocol relying on dark-states and gray molasses in the presence of a large differential light shift [1]. Once the atoms will be in the fiber we expect to observe and characterize the emergence of spontaneous crystallization of the atoms and the photons, caused by scattering of light by long-range interactions between the atoms mediated by the light field and at the same time by the scattering of light in a collective way that results in a superradiant emission, breaking the translation symmetry, as theoretically foreseen in [2]. The absence of boundaries in the direction of the fiber enables us to use the continuum of electromagnetic modes of the light in free space, unlike a cavity that sets a specific mode. This promises the rise of new technologies and numerous research lines.

[1]Naik, D. S., Eneriz-Imaz, H., Carey, M., Freegarde, T., Minardi, F., Battelier, B., & Bertoldi, A. (2020). Loading and cooling in an optical trap via hyperfine dark states. Physical Review Research, 2(1), 013212.
[2]Ostermann, S., Piazza, F., & Ritsch, H. (2016). Spontaneous crystallization of light and ultracold atoms. Physical Review X, 6(2), 021026.

Categories

Many body physics

Presentation

Poster presentation

C006

Measuring the Saturation of Mass-Current Dissipation in a 3D Optical Lattice

Frank Corapi[1], Robyn Learn[1], Benjamin Driesen[1], Pushkar Sharma[2], Frédéric Chevy[2], Xavier Leyronas[2], Cora Fujiwara[1], Joseph Thywissen[1]

[1]University of Toronto, Toronto, Canada. [2]Laboratoire de physique de l'Ecole normale supérieure, Paris, France

Abstract

We present our observation of the saturation of mass-current dissipation via measurements of the AC conductivity spectra of ultracold fermionic 40K in a single-band 3D Fermi-Hubbard model. By oscillating the displacement of an external optical potential, an oscillatory force is applied to the system. The atomic response is then measured in-situ using a quantum gas microscope with single atom resolution. In an optical lattice system, where phonons and impurities are absent, current dissipation is mainly caused by atom-atom collisions, which manifests as a broadening of the conductivity spectra. We tune the rate of these collisions by varying the inter-particle s-wave interaction strength via a magnetic Feshbach resonance and observe a spectral broadening that saturates as we approach unitarity. These measurements explore a high-temperature and defect-free regime inaccessible to conventional materials.

Categories

Many body physics

Presentation

Poster presentation

C007

Probing topological phase transition and critical physics in an ultracold quantum Hall system

Nehal Mittal, Quentin Redon, Evgenii Gadylshin, Raphael Lopes, Sylvain Nascimbene

LKB, ENS, Paris, France

Abstract

Topological phase transitions (TPTs) differ from the conventional Landau-Ginzburg theory of phase transitions due to their lack of explicit symmetry breaking. These transitions are characterized by a change of topological invariants, exhibiting discontinuous behaviour across the transition, in contrast to the continuous change of local order parameters in conventional second-order phase transitions. Nonetheless, scale invariance emerges at the quantum critical point (QCP) due to the divergence of penetration length of edge modes, facilitating the identification of critical exponents and universality classes.

In this study, we investigate a quantum Hall ribbon in one real and one synthetic dimension encoded in the spin of Dysprosium atoms through a 2-photon Raman process. By introducing an additional optical lattice, we induce a TPT between the topological and trivial insulator phases. The critical physics of this transition is dominated by a parity-symmetric Dirac point, resulting in a half-quantized Hall effect with C = ½ at gap closing. This robust “topological” state at the TPT prompts intriguing questions for the theoretical understanding of topological phenomena, especially the bulk-edge correspondence.

Poster

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Categories

Many body physics

Presentation

Poster presentation

C008

Spontaneously sliding multipole spin waves in cold atoms

Guillaume Labeyrie[1], Gordon R. M. Robb[2], Joshua Walker[2], Robin Kaiser[1], Thorsten Ackemann[2]

[1]Institut de Physique de Nice, Universite Cote d'Azur and CNRS, Nice, France. [2]SUPA and Department of Physics, University of Strathclyde, Glasgow, United Kingdom

Abstract

We report on the observation of a spontaneously sliding combined dipolar and quadrupolar spin density wave in the ground state of Rb atoms, where spontaneous magnetic ordering is obtained via light mediated interactions [1]. Although spin density waves and quadrupolar charge density waves in condensed matter systems have translation as a (soft) Goldstone mode, in real materials they are pinned by inhomogeneities and a finite amplitude parity breaking is needed for depinning. The observation of spontaneous drift in a non-equilibrium version of magnetic ordering is expected to provide also insight in the question of (dissipative) time crystals as ground state of many-body systems in general.

A laser-cooled atomic cloud is irradiated by a linearly polarized laser beam detuned to the F=2®F'=3-line of the ^{87}Rb D_2-line. Most of the light is retro-reflected by a plane feedback mirror. A striped magnetic structure emerges beyond a pump threshold. Analyzing the contrast of the transmitted light vs integration time of the camera shows a behaviour consistent with a drifting structure. For a stripe period of 78 mm and magnetic fields between 0.1 and 0.7 G, drift velocities are between 8 and 70 m/s.

Numerical simulations show that there is spontaneous symmetry breaking for the drift direction and the chirality. The magnetization vectors form a left-handed screw in space, if magnetic field and drift direction are parallel to each other, and a right-handed screw, if they are anti-parallel.

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C009

Towards ultracold fermions in an optical kagome lattice

Shao-Wen Chang[1,2], Rowan Duim[1,2], Malte Schwarz[1,2], Erin Moloney[1,2], John Ciavarra[1,2], Nikhil Maserang[1,2], Kylie Aboukhalil[1,2], Casey Lin[1,2], Dan Stamper-Kurn[1,2]

[1]University of California, Berkeley, Berkeley, USA. [2]Challenge Institute for Quantum Computation, Berkeley, USA

Abstract

The optical kagome lattice experiment in Berkeley has explored properties of degenerate bosons loaded into lattices with interesting band structures, such as the modification of group velocity in the flat band due to mean-field interaction between bosons, and measuring the topological winding number around a Dirac point by translating a honeycomb lattice. I will give an overview of our ongoing efforts to trap fermionic potassium in the new generation of the experiment, and future research directions we will pursue, including flat band magnetism and enhanced superconductivity. I will also present the phase lock setup that allows us to extend the lattice translation technique to bichromatic lattices, and how it can potentially be used to change the lattice geometry in real time, or to perform Floquet engineering in a kagome lattice.

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C010

Ytterbium optical tweezers for single-atom resolved many-body physics

Alessandro Muzi Falconi[1], Omar Abdel Karim[2,3], Riccardo Panza[1], Sara Sbernadori[1], Antonino Vardè[1], Riccardo Forti[1], Wenlianf Liu[3], Francesco Scazza[1,3]

[1]University of Trieste, Trieste, Italy. [2]University of Naples, Napoli, Italy. [3]CNR-INO, Trieste, Italy

Abstract

Understanding the nonequilibrium dynamics of fermionic systems is one of the major challenges of contemporary physics. Owing to their control on both motional and internal atomic states, optical tweezers provide a unique tool for investigating the build-up of correlations in many paradigmatic scenarios. Here I will report on the first results of a new experimental apparatus where we employ optical tweezers to manipulate and detect individual ytterbium atoms. Exploiting additional slowing beams after the Zeeman slower, we prepare a narrow-line MOT from which we directly load an optical tweezer array. We achieve single atom imaging with >99.99% fidelity by detecting fluorescence photons from a broad optical transition while simultaneously cooling with a narrow-line transition. As a complementary imaging scheme, we avoid cooling and apply high-intensity fluorescence pulses to collect many photons in a short time, at the cost of losing the atoms from the traps. This fast imaging presents various advantages over traditional imaging and cooling schemes, including reduced sensitivity to trapping wavelength. This scheme can also be employed to image single atoms in free-space, allowing to measure their momentum after being released from the tweezers and to avoid parity projection due to in-trap pairwise losses, a fundamental requirement for investigating systems in which tweezers are filled with more than one particle. Following pioneering works with lithium atoms, we will develop schemes for deterministically loading few-fermions in each tweezer and we will investigate few-body out-of-equilibrium dynamics by addressing phenomena such as spin equilibration and fermionic dynamics in SU(N) systems

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C011

Formation of the stationary dark-state polaritons dressed by dipole-dipole interaction toward the realization of dark-state polariton Bose-Einstein condensation

Bongjune Kim[1], Ko-Tang Chen[1], Kuei-You Chen[1], Yu-Shan Chiu[1], Chia-Yu Hsu[1], Yi-Hsin Chen[2], Ite A. Yu[1,3]

[1]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan. [2]Department of Physics, National Sun Yat-sen University, Kaohsiung, Taiwan. [3]Center for Quantum Science and Technology, National Tsing Hua University, Hsinchu, Taiwan

Abstract

A Bose-Einstein condensation (BEC) of dark-state polaritons (DSPs) was proposed in 2008. The DSP describes a propagating probe field in an electromagnetically induced transparency (EIT) media as the superpositions of probe photons and atomic ground-state coherences. According to the proposal, the effective mass of DSP can be expected to have higher critical temperature than atomic BEC. A longer lifetime than the exciton-polariton BEC is also expected. Furthermore, a three-dimensional DSP-BEC system is achievable without the cavity.

The reduction of the transverse direction of Rydberg polariton momentum distribution with increasing dipole-dipole interaction (DDI) strength in a Rydberg EIT system was demonstrated. To achieve the BEC, the longitudinal momentum distribution of DSP also must be cooled down. Therefore, the DSPs need to be stationary.

In this study, we propose a platform of stationary DSPs dressed by DDI to achieve BEC of DSP and experimentally demonstrate the formation of the scheme. The scheme consists of the Λ-type EIT system and the two-photon transition to drive a Rabi oscillation between a ground state and a Rydberg state. The scheme can overcome the large phase mismatch problem in the direct formation of the stationary Rydberg polaritons. The formation of the stationary-DSP dressed by DDI was verified by the measurement of attenuation coefficients and phase shift with various input probe Rabi frequencies which can control the strength of DDI. The estimated stationary-DSP temperature was well below the BEC transition temperature.

Poster

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C012

Towards ultracold Rb-Yb mixtures in an optical lattice

Myeonghyeon Kim, Dalmin Bae, Yangheon Lee, Junyoung Park, Junhwan Kwon, Tenzin Rabga, Yong-il Shin

Seoul National University, Seoul, Korea, Republic of

Abstract

We aim to generate a mixture of alkali rubidium atoms and alkaline-earth-like ytterbium atoms and study the mixture physics in an optical lattice. The distinct properties of these two atoms allow for the engineering of species-selective potentials, enabling the independent control of the different atomic species. This independent controllability provides us with the ability to manipulate the density and momentum of the two atoms in mixture experiments. By adjusting the mixture imbalance and interactions, we intend to explore new phases induced by mixture behaviors and study exotic phenomena that arise in this system, such as polaronic physics and phase separation. We have apparatuses capable of generating ultracold atomic gas samples for both Rb and Yb, and we are combining these two machines to create a mixture apparatus. We will present our design of the Rb-Yb mixture apparatus and the progress in building it.

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C013

Dimensional Crossover for Critical exponents of Quantum Phase Transition in Optical Lattice Measured with Kibble Zurek Mechanism

Xuzong Chen[1], Qinpei Zheng[1], Qi Huang[1], Wenlan Chen[2], Jiazhong Hu[2]

[1]School of Electronics, Peking University,, Beijing 100871, China. [2]Department of Physics,Tsinghua University,, Beijing, 100084,, China

Abstract

We reported that the recent experiment for mearing the critical exponents of quantum phase transition from three to two dimension in optical lattice. We improved the band-mapping method to investigate the quantum phase transition from superfluid to Mott insulators, and we measured critical exponents of quantum phase transitions from 3D to 2D crossover in optical lattice with Kibble-Zurek mechanism. Beside the measurement of critical exponents of quantum phase transitions, we demonstrate the critical dynamics under dimensional crossover involving many-body phase transitions by continuously suppressing correlations and tunnelings along one direction of bulk materials. This provides a smooth connection from higher dimensions to lower dimensions based on intrinsic correlations instead of geometry tailoring. By measuring the non-adiabatic excitations, both critical scaling laws in 3D and 2D are observed and consistent with predictions. Besides, we find new scaling behaviors for intermediate regimes with non-integer dimensions. This provides new insights to extend critical exponents descriptions into more general or complex scenarios.

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C014

Polaron dynamics in a superfluid quantized vortex

Kazunari Ochi[1], Junichi Takahashi[2], Hiroyuki Tajima[3], Kei Iida[1], Eiji Nakano[1]

[1]Kochi University, Kochi, Japan. [2]Asia University, Tokyo, Japan. [3]The University of Tokyo, Tokyo, Japan

Abstract

An impurity atom immersed in a Bose superfluid, which interacts with surrounding elementary excitations, forms a quasiparticle known as a Bose polaron. Recently, the static and dynamic properties of the polaron have been actively investigated in both the cold-atom experiments and theoretical studies [1]. On the other hand, a quantized vortex, a kind of topological soliton having the line defect structure of condensate, has been also realized in early cold atom experiments [2], where two kinds of low-energy elementary excitations exist as Nambu-Goldstone bosons: The first one is the superfluid phonon that originates from U(1) symmetry breaking and the other is the Kelvon (Kelvin mode) associated with translation symmetry breaking, which propagates along the vortex line. The vortex provides effective trap potentials for the impurity atom (if introduced) and the elementary excitations.

In the present study, we apply the polaron concept to the impurity atom trapped in a rectilinear quantum vortex. We use the variational method that includes the contribution of single elementary excitations in the medium, a la Chevy [3]. Our numerical results show that the polaron energy splits with respect to angular momentum reflecting the vortex circulation. Furthermore, within the same framework we have evaluated the decay process of an excited polaron with Kelvon production.

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Presentation

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C015

Rapid Fermionic Quantum Simulator for Random Unitary Observables

Naman Jain[1], Jin Zhang[1], Marcus Culemann[1], Xinyi Huang[1], Kirill Khoruzhii[1], Pragya Sharma[1], Philipp Preiss[1,2]

[1]Max Planck Institute of Quantum Optics, Garching, Germany. [2]Munich Centre for Quantum Science and Technology, Munich, Germany

Abstract

Ultracold atoms in optical lattices provide an experimental platform to perform controlled single-particle operations in many-body systems. The UniRand experiment aims to leverage this control to study physics at the interface between condensed matter physics and quantum information science. One exciting avenue towards this goal are measurements in random bases using so-called random unitary protocols. They are predicted to give access to global density matrix properties and provide a general way of characterizing many-body systems in and out of equilibrium.

We report on the progress of building a fermionic quantum simulator capable of realizing random unitaries with high repetition rates and a high-fidelity readout process. At present, the experiment demonstrates the use of 2D-MOT as a cold atom source, capable of loading with high rates into the 3D-MOT, atom counting capability with single atom resolution, realisation of a molecular BEC of $^6Li_2$, and deterministic few-atom state preparation inside a single tweezer. The envisaged system combines evaporative cooling in optical tweezer arrays followed by quantum state assembly in a tunable optical lattice. The readout process aims to reach single site resolution by using matter wave magnification and spin-resolved free-space imaging. The poster will summarize the current status and future prospects of the experiment.

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C016

Non-equilibrium dynamics of long-range interacting Fermions

Timo Zwettler[1], Giulia Del Pace[1], Filip Marijanovic[2], Sambuddha Chattopadhyay[2,3], Tabea Bühler[1], Catalin-Mihai Halati[4], Luka Skolc[2], Luisa Tolle[5,4], Victor Helson[1], Gaia Bolognini[1], Aurélien Fabre[1], Shun Uchino[6], Thierry Giamarchi[4], Eugene Demler[2], Jean-Philippe Brantut[1]

[1]Institute of Physics and Center for Quantum Science and Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland. [2]Institute for Theoretical Physics, ETH Zürich, Zürich, Switzerland. [3]Lyman Laboratory, Department of Physics, Harvard University, Cambridge, USA. [4]Department of Quantum Matter Physics, University of Geneva, Geneva, Switzerland. [5]Physikalisches Institut, University of Bonn, Bonn, Germany. [6]Faculty of Science and Engineering, Waseda University, Tokyo, Japan

Abstract

Non-equilibrium dynamics through phase transitions remain an open problem in strongly-interacting quantum systems. While phase transitions with local interactions have been largely studied both theoretically and experimentally, little is known about instabilities in Fermi gases originating from long-range interactions, which compete with Pauli exclusion principle and short-range contact interactions. Here we investigate the dynamics of a unitary Fermi gas undergoing a phase transition with density-wave ordering induced by long-range photon-mediated interactions in a high-finesse optical cavity. We observe in real-time the exponential rise of the order parameter following an instantaneous quench and track the evolution of its time scale over three orders of magnitude as the system is quenched deeper above the critical point. Remarkably, this time scale is independent of the strength of contact interactions from the ideal up to the unitary limit, and can be orders of magnitude faster than the Fermi time, which we attribute to sum-rules constraints on the response function of the system. We also show that the universal character further extends to the response to linear ramps of finite speeds.
Our study establishes the specificity of dynamical instabilities in long-range interacting Fermi gases and provides a striking example of simple, universal dynamics emerging in far from equilibrium, strongly-interacting systems.

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C017

Observation of microscopic confinement dynamics by a tunable topological θ-angle

Wei-Yong Zhang[1], Ying Liu[1], Yanting Cheng[2], Ming-Gen He[1], Han-Yi Wang[1], Tian-Yi Wang[1], Zi-Hang Zhu[1], Guo-Xian Su[1], Zhao-Yu Zhou[1], Yong-Guang Zheng[1], Hui Sun[1], Bing Yang[3], Philipp Hauke[4], Wei Zheng[1,5], Jad C. Halimeh[6,7], Zhen-Sheng Yuan[1,5], Jian-Wei Pan[1,5]

[1]University of Science and Technology of China, Hefei, China. [2]University of Science and Technology Beijing, Beijing, China. [3]Southern University of Science and Technology, Shenzhen, China. [4]University of Trento, Trento, Italy. [5]Hefei National Laboratory, Hefei, China. [6]Ludwig-Maximilians-Universität München, München, Germany. [7]Munich Center for Quantum Science and Technology, München, Germany

Abstract

The topological ϑ-angle is central to the understanding of a plethora of phenomena in condensed matter and high-energy physics such as the strong CP problem, dynamical quantum topological phase transitions, and the confinement–deconfinement transition. Difficulties arise when probing the effects of the topological ϑ-angle using classical methods, in particular through the appearance of a sign problem in numerical simulations. Quantum simulators offer a powerful alternate venue for realizing the ϑ-angle, which has hitherto remained an outstanding challenge due to the difficulty of introducing a dynamical electric field in the experiment. Here, we report on the experimental realization of a tunable topological ϑ-angle in a Bose–Hubbard gauge-theory quantum simulator, implemented through a tilted superlattice potential that induces an effective background electric field. We demonstrate the rich physics due to this angle by the direct observation of the confinement–deconfinement transition of (1+1)-dimensional quantum electrodynamics. Using an atomic-precision quantum gas microscope, we distinguish between the confined and deconfined phases by monitoring the real-time evolution of particle–antiparticle pairs, which exhibit constrained (ballistic) propagation for a finite (vanishing) deviation of the ϑ-angle from π. Our work provides a major step forward in the realization of topological terms on modern quantum simulators, and the exploration of rich physics they have been theorized to entail.

Poster

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C018

All Optical Formation of High Phase-Space Density Atoms near Glass Surface

HAYATO KAWAMURA, Yukari Maruyama, Ryota Hashimoto, Satoshi Tojo

Chuo Univerasity, Tokyo, Japan

Abstract

Precise manipulation of laser-cooled atoms is a powerful technique for investigation of atom surface interactions owing to neutral atoms having high handling abilities caused by high-sensitive to electromagnetic fields such as van der Waals and Casimir-Polder potentials [1]. In the vicinity of dielectric surfaces, particularly in the evanescent field region, theoretical models suggest that transition probabilities of optical forbidden transitions are enhanced more than several orders [2].

We have experimentally investigated atom-surface interactions using ultracold ^{87}**Rb** atoms. Pre-cooled atoms are loaded into an optical dipole trap and transferred to a glass surface region. A far-off-resonant dipole force trap is used for a main optical trap to be manipulated for atoms into the surface. In addition, a near-resonant dipole force trap to assist for the far-off resonant trap in order to generate a deep trapping potential even at its low power [3]. For transportation to the glass surface, we adjust the position of the focal point of the trapping light onto the surface controlling a lens position on a linear motion stage. At the focus point on a glass surface, the trapping light is reflected and generating standing waves near the surface region.

We evaluate the motion associated with transporting the ultracold atoms and report on the behavior of high phase-space-density ensembles near the surface.

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Many body physics

Presentation

Poster presentation

C019

A Rydberg quantum simulator for the study of the dipolar XY model

Guillaume Bornet

Institut d'optique (LCF), Palaiseau, France

Abstract

This talk will present our implementation and study of the dipolar XY spin model using a Rydberg simulator where the atoms are coupled by resonant dipole-dipole interactions. We use our ability to address individual atoms in the arrays to first adiabatically prepare and study the properties of the 2D square dipolar XY ground state (known as the antiferromagnetic state, AFM) and the highest energy state (ferromagnetic state, FM).

We continue this analysis by performing quench spectroscopy experiments to probe the dispersion relation of the XY magnets in both the AFM and FM states. Our studies can be generalized to any system exhibiting dipolar interactions, such as ultra-cold molecules, magnetic atoms, or solid-state spin defects.

Finally, I will present our ongoing work on extending the range of spin models simulated by our platform using non-diagonal second-order Rydberg-Rydberg interactions. For example, the so-called *t-J* model, which describes antiferromagnetic insulators doped with holes, could be simulated using this approach.

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C020

Influence of non-trivial geometry in a magnetic field and finite temperature on phase transitions of the Bose Hubbard model

Miguel Rodríguez Martín, T. A. Zaleski

Institute of Low Temperature and Structure Research, Polish Academy of Sciences, Wroclaw, Poland

Abstract

We study the properties of the Bose Hubbard model, of great relevance in the analysis of ultracold atoms in optical lattices, making use of the quantum rotor approach, which has the advantage of carefully including the spatial correlations. This allows us to investigate a complicated form of the system: three-dimensional lattice under a uniform synthetic magnetic field with reduced dimensionality, i.e. with finite thickness in the direction perpendicular to the field. This opens up new possibilities, e.g. to analyze the correlations between strongly interacting bosons under the influence of a magnetic field in terms of the distance to the system's edge, visualizing effects of non-trivial topology of the band structure, or discovering parallels between finite and infinite systems in certain conditions. Furthermore, we are able to improve the accuracy on the account of the thermal fluctuations, which allows us to properly describe the state of the system at non-zero temperature. These elements allow further development of the quantum rotor method as one of the most versatile analytical methods for analyzing complex interacting systems in solid-state physics.

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C021

Interferometric sensing with multiple nuclear spin states of strontium 87

Pauline Guesdon[1], Husain Ahmed[1], Andrea Litvinov[2], Martin Robert de Saint Vincent[1], Bruno Laburthe-Tolra[1], Benjamin Pasquiou[1]

[1]sorbonne paris nord, villetaneuse, France. [2]Österreichischen Akademie der Wissenschaften, Wien, Austria

Abstract

Strontium-87 is an alkaline-earth atom with a nuclear spin of I=9/2, that exhibits SU(N) symmetric spin interactions. This type of magnetic interaction leads to exotic physics in strongly correlated systems, like antiferromagnets. To engineer such a system, we need to find a method to control the atoms' spin state. We implement a tensor light shift (TLS) to remove the spin degeneracy and isolate a pair of spin states, thus facilitating a coherent, spin-selective, two-photon Raman transition relying on the 1S0-3P1 intercombination line. We can thus perform spin qubit rotations within the SU(N) manifold.

As examples of this new method of manipulation, we implement several schemes of Ramsey interferometers. First, we measure the phase evolution of a qubit consisting of two spin components and observe how it is affected by the mean-field interaction from a third component, with a precision on the interaction better than one hertz. With this, we are currently conducting tests to assess the quality of SU(N) symmetry.

Second, thanks to the large number of spin states in ^{87}Sr, we build two simultaneous parallel interferometers, with which we measure together two physical quantities, such as the quadratic part of the TLS and the magnetic field. We can also measure in the same shot two non-commuting observables (e.g. <Sz> and <Sx,y>) to characterize the state of an assembly of qubits.

These methods can extend to other alkaline-earth-like species like Yb and can find applications for metrology and the study of SU(N) quantum magnetism.

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C022

Does a disordered Heisenberg spin system exhibit features of localization?

Gerhard Zürn[1], Titus Franz[1,2], Sebastian Geier[1], Eduard Braun[1], Valentina Salazar Silva[1], Clément Hainaut[1,3], Moritz Hornung[1,4], Adrian Brämer[1,5], Martin Gärttner[1,5,6], Matthias Weidemüller[1]

[1]Physikalisches Institut, Universität Heidelberg, Heidelberg, Germany. [2]Max-Planck-Institut für Quantenoptik, Garching, Germany. [3]Université de Lille, Lille, France. [4]Ludwig-Maximilians-Universität, München, Germany. [5]Institut für Theoretische Physik, Universität Heidelberg, Heidelberg, Germany. [6]Universität Jena, Jena, Germany

Abstract

Strongly disordered systems can retain retrievable memory of their initial state for arbitrarily long times, leading to a rich phenomenology ranging from glassy dynamics to many-body localization. We experimentally probe the relaxation dynamics of the magnetisation in an isolated spin system realised by a frozen gas of Rydberg atoms [1]. Our findings reveal an anomalously slow dynamics that is independent of the specific type of Heisenberg Hamiltonian ranging from XX, XXZ to Ising Hamiltonians [2]. Remarkably, the observed dynamics can be captured by theoretical models that only consider localized pairs of spins. These pairs constitute approximate local integrals of motion [3] which remain partially conserved on a timescale exceeding the duration of the relaxation dynamics pointing towards the emergence of localization in spin systems with off-diagonal disorder.
In order to further experimentally investigate this phenomenon we envisage to measure out-of-time-order correlations in Rydberg spin systems. Therefore we have implemented a time-reversal protocol that changes the states encoding the spin in order to flip the sign of the interaction Hamiltonian [4]. We demonstrate the reversal by letting a demagnetised many-body state evolve back-in-time into a magnetised state. By combining the approach with Floquet engineering [5], we demonstrate time-reversal for a large family of spin models with different symmetries.

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C023

Probing the local rapidity distribution of a 1D Bose gas.

Léa Dubois, Guillaume Thémèze, Florence Nogrette, Jérôme Dubail, Isabelle Bouchoule

Laboratoire Charles Fabry (LCF), Palaiseau, France

Abstract

One-dimensional Bose gases with contact repulsive interactions are characterized by the presence of infinite-lifetime quasiparticles whose momenta are called the rapidities. Here we develop a probe of the local rapidity distribution, based on the fact that rapidities are the asymptotic momenta of the particles after a long one-dimensional expansion. This is done by performing an expansion of a selected slice of the gas. We first apply this idea to a cloud in the quasi-condensate regime at equilibrium in a trap. We obtain an experimental picture of the position-dependent rapidity distribution which is in fair agreement with the theory prediction. The asymptotic regime is barely reached, but we show that finite expansion time can be taken into account using the Generalized Hydrodynamics theory. We then apply this local probe to an out-of-equilibrium situation where the local rapidity distribution is expected to be doubly peaked -- a hallmark of a non-thermal state -- even though the global rapidity distribution would possess no such distinctive feature. We observe the doubly-peaked local rapidity distribution.

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C024

Non-polar to strongly polar atom-ion collision dynamics via a pulsed ion microscope

Moritz Berngruber[1], Dan J. Bosworth[2,3], Viraatt S.V. Anasuri[1], Jennifer Krauter[1], Ruven Conrad[1], Raphael Benz[1], Ole Einar Prochnow[1], Oscar Andrey Herrera-Sancho[1,4,5,6], Florian Meinert[1], Robert Löw[1], Peter Schmelcher[2,3], Tilman Pfau[1]

[1]5. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany. [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Hamburg, Germany. [3]Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany. [4]Escuela de Física, Universidad de Costa Rica, San José, Costa Rica. [5]Instituto de Investigaciones en Arte, Universidad de Costa Rica, San José, Costa Rica. [6]Centro de Investigación en Ciencias Atómicas, Nucleares y Moleculares, San José, Germany

Abstract

The immense variety of interactions found in nature consists of atoms combining with each other to form molecules and complex structures. Nowadays, an ideal platform to study this environment is realized by laser-engineering a so-called giant of the atomic world, i.e. a Rydberg atom, and therefore observe the phenomena that arise from its interplay in the tunable long range within this exotic system. Hence, we explored the interactions of those collisional channels as part of the dynamical process caused by an ion's electric field and the numerous potential energy curves split by the Stark effect of the highly excited Rydberg atom by means of our pulsed ion microscope. It is worth mentioning that due to the large spatial gradient of these Stark states, the collision dynamics in those channels happen on a much faster time scale, which are particularly observed in our apparatus. Interestingly, this leads to a counterintuitive behavior for the overall dynamics: if a cold, low kinetic energy system follows the potential energy curve adiabatically, it will ultimately reach the steep strongly polar potential and thus rapidly accelerate. The experimental realization allows a precise control of the speed of the collisional dynamics, allowing for tuning the occupation of the collision channels. The experimental observations are supported by semi-classical simulations, which model the pair state evolution and provide evidence for tunable non-adiabatic dynamics. The semi-classical model using the Landau-Zener approximation is efficiently employed to estimate the probability for an adiabatic transition to a strongly polar state at each crossing.

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C025

Rydberg Spin Glas

Gerhard Zürn[1], Titus Franz[2,3], Sebastian Geier[2], Eduard Braun[2], Valentina Salazar Silva[2], Clément Hainaut[4], Moritz Hornung[2,5], Adrian Braemer[2], Martin Gärttner[6], Matthias Weidemüller[2]

[1]Physikalisches Institut, Heidelberg, Germany. [2]Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany. [3]Max-Planck-Institut für Quantenoptik, Garching, Germany. [4]Université de Lille, Lille, France. [5]Ludwig-Maximilians-Universität, München, Germany. [6]Universität Jena, Jena, Germany

Abstract

Using our Rydberg platform as a quantum simulator for disordered Heisenberg systems [1], we have found signatures indicating that an isolated frozen gas of quantum spins under dipolar interactions shows similar features as a "classical" spin glass [2]. The relaxation of the magnetization after a quench follows a stretched-exponential function, which appears to be universal in the sense that it is independent on the degree of disorder [3] and the symmetries of the underlying Heisenberg Hamiltonian [4]. We observe a drastic change in the late-time magnetization when increasing disorder strength. The data is well described by models based on pairs of strongly interacting spins, indicating a crossover into a pair-localized prethermal regime [5]. Most recently, we observed linear response to an external magnetic field signaling non-thermal behavior. Measurements of the magnetic susceptibilities as a function of the energy show the existence of two regimes with different magnetic behavior. The lower energy regime exhibits pronounced hysteresis, which might indicate the existence of a glas-phase transition [6].

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Categories

Many body physics

Presentation

Poster presentation

C026

In-situ Imaging of a Single-Atom Wave Packet in Continuous Space.

Joris Verstraten[1], Kunlun Dai[1], Maxime Dixmerias[1], Bruno Peaudecerf[2], Tim de Jongh[1], Tarik Yefsah[1]

[1]Laboratoire Kastler Brossel, Paris, France. [2]Laboratoire Collisions Agrégats Réactivité, Toulouse, France

Abstract

The wave nature of matter remains one of the most striking aspects of quantum mechanics and has been observed with an increasing level of control and resolution in recent years. Here, we prepare single atoms near the ground state of harmonic oscillator wells and probe the associated Gaussian wave packets in-situ by following their dynamics upon release from the trap as they expand in a plane. By varying the initial momentum spread of the single-atom wave packets, we observe dynamics that is in quantitative agreement with the prediction from the Schrödinger equation. Our measurement represents a pristine observation of the textbook ballistic expansion of a single-atom Gaussian wave packet in real space. This is realized by performing quantum gas microscopy after projecting the wavefunction freely expanding in space onto a deep optical lattice. Using the known single-particle wave packet expansion, we quantitatively determine a protocol for controlled projection of a wavefunction evolving in continuous space and reliable pinning of the corresponding atom for imaging. With this, we achieve a crucial pre-requisite to extend the use of quantum gas microscopy to interacting many-body systems in continuous space, offering direct access to spatially-resolved correlation functions up to high order and at large distances.

Categories

Many body physics

Presentation

Poster presentation

C027

Fluctuations and correlations in a far-from-equilibrium steady state

Christopher Ho, Gevorg Martirosyan, Simon Fischer, Seb Morris, Jiri Etrych, Christoph Eigen, Zoran Hadzibabic

University of Cambridge, Cambridge, United Kingdom

Abstract

Fluctuation-dissipation relations are central to equilibrium thermodynamics, linking equilibrium concepts of linear response and temperature to the microscopic fluctuations. Here we study the fluctuations and correlations of momentum-space densities of a paradigmatic far-from-equilibrium state, a turbulent-wave cascade. We create these cascades by large-scale forcing of a box-trapped Bose gas, where the resultant far-from-equilibrium steady state is described by a power-law momentum distribution and sustained by a constant particle and energy flux in momentum space [1-3]. We map out the dependence of these momentum-space fluctuations of the turbulent cascade on the microscopic interactions in the system. Our measurements offer a promising testbed for theories of far-from-equilibrium thermodynamics.

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Categories

Many body physics

Presentation

Poster presentation

C028

Magnetic imaging of carbon nanotubes using Bose-Einstein condensates

Poppy Joshi, Julia Fekete, Thomas J Barrett, Fedja Orucevic, Peter Kruger

University of Sussex, Brighton, United Kingdom

Abstract

A key property of Bose-Einstein condensates (BECs) is their sensitivity to small (~pT) magnetic fields. This property of BECs can be exploited to address the longstanding problem of imaging active current flow in 2D materials. In our BEC microscope experiment we have been able to create a map of the current flow in a sample where 100 (50) mA of current is passing through a bundle of carbon nanotubes. This 40 um x 200 um map is produced by bringing BECs close to the surface where the atomic distribution is affected by the fields emanating from the sample and scanning the BEC position across the sample surface. From the magnetic field map the current density distribution in the sample can be reconstructed. Such 2D current density maps enable the identification of individual current pathways in nanotubes and nanowires.

The observation of current pathway reconfiguration and the formation of hotspots in random electrically percolating nanowire networks is in high demand for the development of novel materials such as transparent electrodes for next generation touchscreens. Further applications of the BEC microscope include studying the response of biological cells (heart, skin, stem cells) to electrical stimulation on carbon nanotube scaffolds.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

C029

Thermal Radiation from an Optically-Levitated Metallic Microparticle

Shun Takeuchi, Taiyo Nagaoka, Hitoshi Odashima, Maki Tachikawa

Meiji University, Kawasaki, Japan

Abstract

Although Planck's law of blackbody radiation well describes spectral profiles of thermal radiation from macroscopic objects, it is not straightforwardly applicable to an object of size comparable or smaller than thermal wavelengths. Limitation of Planck's law is a fundamental problem in quantum optics, and also important in micro-thermometry. Nonetheless, clear experimental evidence of the size effects in thermal radiation is sparse because spatial and thermal isolation of a hot single microparticle has been an experimental challenge.

Our CO_2 laser trap levitates a high-temperature microparticle in air and enables its emission spectroscopy. We previously reported that thermal radiation spectrum from a dielectric microsphere exhibits regularly spaced sharp resonances with whispering gallery modes of the spherical resonator caused by spontaneous emission enhanced through the cavity-QED effect [1].

In this paper, we analyze thermal radiation from a metallic microparticle levitated and heated above the melting point by the infrared radiation. In contract to the dielectric cases, the observed spectrum of a 10-micron gold particle resembles the Planck function, but there is a definite deviation due to dispersion of the optical constants. Spectral profiles are reproducible with the Mie scattering theory, and this leads to a precise determination of optical constants of such extremely hot materials. The Mie theory predicts that resonance structure may appear in the emission spectrum of a metallic microsphere, which is attributed to the surface plasmon modes localized around the sphere.

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Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

C030

Complete control of the quantum state with oscillating magnetic field

Arash Dezhang Fard, Marek Kopciuch, Yujie Sun, Szymon Pustelny

Jagiellonian University, Krakow, Poland

Abstract

Quantum-state engineering involves the deliberate manipulation and control over quantum-states to generate systems with specific quantum properties. However, in order to develop robust schemes of the manipulations, one must gain precise knowledge about the states. In this task, quantum-state tomography plays a key role [1,2].

Here, we present our experimental studies on the reconstruction of the collective density matrix of the ground-state of ^{87}Rb. The heart of our experimental setup is the room-temperature atomic vapor, which has two hyperfine ground states with $F = 1$,2 (F is total angular momentum). Reconstruction of the state in the $F = 2$ manifold is one of challenges due to the energy degeneracy of the magnetic sublevels splitting. However, to address this issue we propose an oscillating magnetic field inducing both linear and and quadratic Zeeman effect at not-too strong fields (B<5 Gauss). Interestingly, application of oscillating magnetic field allows us to cancel the linear effect contribution inducing only quadratic coupling. We demonstrate the conversion from orientation of the atomic polarization to alignment, which indicates the ability to fully control the ground state of atoms.

The oscillating magnetic field enables us to perform quantum tomography of $F = 2$ and quantum process tomography.

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Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

C031

Trapped ions in an ultracold gas: chemical reactions and experimental upgrades

Eleanor Trimby[1], Henrik Hirzler[1], Rianne Lous[1], Egor Kovlakov[1], Jesus Perez-Rios[2,3,4], Arghavan Safavi-Naini[1,5], Rene Gerritsma[1,5]

[1]University of Amsterdam, Amsterdam, Netherlands. [2]Stony Brook University, New York, USA. [3]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany. [4]Radboud University, Nijmegen, Netherlands. [5]QuSoft, Amsterdam, Netherlands

Abstract

Hybrid ion-atom systems combine the benefits of a single, well-controlled ion with those of a many-body quantum gas, offering prospects for quantum simulation, ultracold chemistry, and charged impurity physics [1, 2]. In this poster, I will present recent observations of chemical reactions between a single Yb^+ ion and Li_2 dimers in an ultracold cloud, leading to the formation of a $LiYb^+$ molecular ion [3]. We find that we can use the ion as a probe of the surrounding atom cloud to detect trace quantities of dimers.

Furthermore, I will outline recent and future experimental upgrades and their predicted effects on the atom-ion collision behaviour. Numerical simulations indicate that optimization of our ion trap parameters should allow buffer gas cooling to 0.6 times the atom-ion *s*-wave collision energy limit [4]. This is twice as cold as our previous best experimental observations, in which we reached sufficiently low energies to observe quantum effects in the atom-ion collision statistics [5]. Meanwhile an additional optical potential, used to increase the density of our atom cloud, will enhance the dimer formation and atom-ion collision rates in our system.

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Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

C032

Quantum Interface for Telecom Frequency Conversion Based on Diamond-Type Atomic Ensembles

Po-Han Tseng[1], Ling-Chun Chen[1,2], Jiun-Shiuan Shiu[1,2], Yong-Fan Chen[1,2]

[1]Department of Physics, National Cheng Kung University, Tainan, Taiwan. [2]Center for Quantum Frontiers of Research & Technology, Tainan, Taiwan

Abstract

In a fiber-based quantum network, quantum frequency conversion (QFC) serves as a pivotal quantum interface for efficiently bridging the frequency gap between atomic quantum devices and telecom fibers. In this study, we explore an efficient telecom-band QFC mechanism based on diamond-type four-wave mixing (FWM) with rubidium energy levels. The mechanism enables the conversion of photons between the near-infrared wavelength of 795 nm and the telecom band of 1367 or 1529 nm. Using the Heisenberg-Langevin approach, we optimize conversion efficiency (CE) across varying optical depths while addressing the applied field absorption loss and present corresponding experimental parameters. Moreover, by employing the reduced-density-operator theory to construct a theoretical framework, we demonstrate that this diamond-type FWM scheme can maintain the quantum characteristics of input photons with high fidelity, such as quadrature variances and photon statistics. Importantly, these properties remain unaffected by vacuum field noise, enabling the system to achieve high-purity QFC. Another significant contribution lies in examining how this scheme impacts quantum information (QI) encoded in photon-number, path, and polarization degrees of freedom (DOFs). These encoded qubits exhibit remarkable entanglement retention under sufficiently high CE and achieve unity fidelity for perfect CE. This comprehensive exploration establishes a theoretical foundation for the application of the diamond-type QFC scheme based on atomic ensembles in quantum networks, laying essential groundwork for advancing the scheme in distributed quantum computing and long-distance quantum communication.

Poster

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C033

Transport of ultracold atoms in an accelerated optical lattice

Zhongcheng Yu, Xiaoji Zhou

Peking University, Beijing, China

Abstract

The ultracold atoms in optical lattices due to high controllability are widely applied to simulating the physics of condensed matter. For instance, the optimal lattice depth on lifetime of D-band ultracold atoms is researched in triangular optical lattice [1] and atomic Ramsey interferometry is achieved with S- and D-band atoms [2].

The transport phenomenon has been attracting tremendous efforts in recent years. The accelerated optical lattice has emerged as a valuable technique for the investigation of quantum transport physics. In our work, by our proposed shortcut method [3], we load atoms from a harmonic trap into the optical lattice. Then, we perform the transport process in the moving optical lattice. By measuring the group velocity and band distribution of atoms, the time bound of adiabatic evolution of ultracold atoms within an accelerated optical lattice is researched [4]. Moreover, we perform transport of superposition states with different superposition weights of S-band and D-band atoms [5].

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Quantum optics and thermodynamics

Presentation

Poster presentation

C034

Quantum precision measurement of two-dimensional forces with 10^{-28}-Newton stability

Xiaoji Zhou, Zhongcheng Yu

Peking University, Beijing, China

Abstract

The system of ultracold neutral atoms confined in optical lattices has a large degree of controllability, and is widely applied to quantum simulation and quantum precision measurements. For instance, novel physical phases and dynamical mechanisms of higher orbital atomic are observed [1,2], many body phenomenon of atoms in optical lattice is researched [3,4].

High-precision sensing of vectorial forces has a broad impact on fundamental research and technological applications, such as examining vacuum fluctuations and detecting surface roughness of nanostructures.

Based on the BEC in a triangular optical lattice, we perform a precision force sensor by imaging coherent wave mechanics in the quasi-momentum space [5]. With that we achieve a state-of-the-art sensitivity of $2.30(8)\times10^{-26}$ N/√Hz. Long-term stabilities on the order of 10^{-28} N are observed in the two spatial components of a force.

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Quantum optics and thermodynamics

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Poster presentation

C035

Experimental results from a cascaded system for optical resonance fluorescence based on an optical nanofibre

Maarten Hoogerland, Mohammad Sadeghi, Wayne Crump, Scott Parkins

University of Auckland, Auckland, New Zealand

Abstract

The interaction of resonance fluorescence with another ensemble of atoms has been the subject of significant research over the past years [1].

Experimentally, we form a magneto-optical trap (MOT) of caesium atoms around the waist of an optical nanofibre (diameter ~400 nm). One end of the nanofibre terminates in a single-photon detector module (SPCM) and the other end is connected to a 250 m length of normal optical fibre and terminated with a Fibre Bragg Grating (FBG).

We observe photons emitted directly towards the SPCM, but also photons that have been emitted towards the FBG, are reflected back, interact with the atoms again and arrive at the detector after a time delay. The delayed photons are partially absorbed by the MOT atoms, thereby creating a system of atoms interacting with a distant mirror image. This is more accurately described as two distant collections of atomic ensembles.

We present an investigation into this interaction, changing the pump laser power, polarisation and detuning, as well as the atom number in the MOT. We compare our experimental results with the results of calculations based on a transfer-matrix approach.

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Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

C036

Composite Acousto-Optical Diffraction with Efficiency Exceeding 99%

Yuxiang Zhao[1], Jiangyong Hu[1], Ruijuan Liu[1], Ruochen Gao[2], Saijun Wu[1]

[1]Fudan University, Shanghai, China. [2]Tsinghua University, Beijing, China

Abstract

Acousto-optical modulation (AOM) is a powerful, widely applied technique for rapidly controlling frequency, phase, intensity and direction of light. Based on Bragg diffraction by sound, AOM is not known for its moderate diffraction efficiency, typically about 90% at best. In this work, we demonstrate beyond 99% efficiency in a composite-modulation (CPM) setup. The high efficiency 1st-order diffraction is accompanied by more than 30 dB single-mode suppression of the 0th–order beam. We discuss the underlying physics for the exceptional performance associated with optical rephasing. The two effects, referred to as “momentum echo” and “high-order rephasing” respectively, can be optimized almost simultaneously by tuning the relative distance between the two daughter-AOMs in the CP-AOM setup. We in addition demonstrate the highly efficient CP-AOM with a single AOM, using a Sagnac interferometer with a suitable round-trip optical delay. The exceptional performance enables CP-AOM as a high-contrast beam splitter with rapidly tunable splitting amplitude and phase. The device may find novel applications at the frontiers of laser physics and quantum optics.

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C037

A picosecond pulse array synthesizer for precise quantum control of atomic dipoles

Yiming Li, Yuxiang Zhao, Jiangyong Hu, Ruijuan Liu, Lingjing Ji, Saijun Wu

Fudan University, Shanghai, China

Abstract

We develop a picosecond pulse array synthesizer that converts a mode-locked laser pulse into array of sub-pulses with precisely programmable amplitude an phase. The technique is based linear optical filtering, using a "Direct reciprocal-space to time pulse shaping" method [1] where the amplitudes and phases of multiple delayed pulses are programmed by multi-tone acousto-optical modulations (AOM). Starting from our previous effort [1], a composite AOM system is installed to substantially suppress the nonlinear parameter-crosstalk, thereby supporting efficient sub-pulse generation. The systhesizer output is monitored by a high-resolution VIPA spectrometer, with which we are able to recover the $\Delta\omega\sim$ 30GHz, $\tau_c\sim$200ps optical waveforms. Using a mode-locked picosecond laser pulse as input, we achieve pulse array with a peak power approaching 10W. The pulse array is shape-stable and powerful enough, with which we are working toward quantum control on optical dipole transitions of laser-cooled Rb87 atoms [2] with an fidelity approaching F=99%.

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Quantum optics and thermodynamics

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Poster presentation

C038

Probing cold-atom-optical-nanofiber interface with frequency-jump atomic spectroscopy

Jinggu Wu, Ruijuan Liu, Saijun Wu

Fudan University, Shanghai, China

Abstract

Optical nanofiber (ONF) supports strong, evanescent coupling between guided photons with near-field atoms over macroscopic distances. At the ONF interface, response of individual atoms to light is modified by the nanoscale atom-surface interaction, by the strong coupling to the waveguide, and by distant interaction with other atoms through exchange of guided photons. Precise characterization of the optical response of the ONF-coupled atoms is not only important for understanding the interactions, but also crucial for achieving precise quantum control with the nanophotonic quantum optical platform. In this work, we demonstrate a frequency-jump approach for simultaneous retrieving the absorption (OD) and phase-shift (ϕ) spectrum of atoms at the ONF interface. In particular, after the light-atom interaction reaches its steady state, the frequency of the guided resonant probe is shifted out of atomic resonance to serve as a reference field. By demodulating the beat signal, the time-dependent amplitude and phase of the atomic forward emission is reconstructed, from which the complex-valued atomic spectroscopy can be retrieved with simple Fourier transform. The accuracy of our single-mode coherent spectroscopy is supported by the excellent coupling efficiency of the tapered ONF. Comparing to traditional absorption or fluorescence methods, the transient spectroscopy does not require laser frequency scan and is therefore substantially more data-efficient. Furthermore, the simultaneous OD and ϕ retrieval supports self-calibration of atom numbers participating the interaction. The coherent technique is therefore helpful for suppressing atom-number drifts in the nanoscopic atomic spectroscopy.

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C039

Room-temperature quantum optomechanics using an ultra-low noise cavity

Nils Johan Engelsen[1,2,3], Guanhao Huang[2,3], Alberto Beccari[2,3], Tobias Jan Kippenberg[2,3]

[1]Chalmers University of Technology, Gothenburg, Sweden. [2]Institute of Physics, Swiss Federal University of Technology (EPFL), Lausanne, Switzerland. [3]Center for Quantum Science and Engineering, EPFL, Lausanne, Switzerland

Abstract

Over the last two decades, there has been a revolution in the quantum control of mechanical oscillators with light. Cryogenic pre-cooling has usually been required, as the thermal decoherence rate of the mechanical oscillator depends on the bath temperature and mechanical dissipation rate. This has inspired efforts reduce the coupling to the environment by creating mechanical resonators with lower dissipation, specifically exploiting the effect known as dissipation dilution. However, until now, dissipation-diluted resonators have not reached the regime where the quantum backaction dominates thermal motion at room temperature.

We demonstrate optomechanical squeezing of light at room temperature using a membrane-in-the-middle system with an ultracoherent silicon nitride membrane. We also show a measurement of mechanical motion strong enough to project the mechanical mode to a displaced thermal state with approximately one phonon occupancy, showing that ground state cooling can potentially be achieved. These results are enabled by phononic engineering of both the mirror and the membrane: Firstly, we employ the recently developed phononic density modulation technique to realize a soft-clamped membrane with ultrahigh quality factor and excellent optical power handling. Secondly, we developed cavity mirrors with phononic crystal patterning to eliminate vibrational modes of the mirror that would otherwise prevent the observation of squeezing and limit the mechanical motion measurement efficiency. We also implement a single-port homodyne scheme that cancels thermal intermodulation noise in detection. This is the first optomechanical system operating in the quantum backaction-dominated regime at room temperature without an external optical potential.

Poster

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Quantum optomechanics

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C040

Direct Laser Cooling of Rydberg Atoms with an Isolated-Core Transition

Alisée Bouillon, Eduardo Marin-Bujedo, Matthieu Génévriez

Université Catholique de Louvain, Louvain-la-Neuve, Belgium

Abstract

Whereas ground-state atoms and small molecules have already been laser-cooled, direct laser cooling of Rydberg atoms has never been achieved. This is explained by the absence of a suitable cooling cycle for the Rydberg electron. Instead, we theoretically propose to laser cool the ion within the Rydberg electron orbit, motivated by the fact that the ion core can be, to a good approximation, isolated from the Rydberg electron. In the upper state of the cooling cycle, the ion core of the Rydberg atom is excited and the atom can rapidly autoionize. For sufficiently high orbital-angular-momentum quantum numbers of the Rydberg electron (l >10), it is however possible to suppress autoionization far below the radiative lifetime of both the ion core and the Rydberg electron. In this case, the lifetime of the states reaches > 100 µs, which permits realizing many isolated-ion-core cooling cycles.

To demonstrate the feasibility of our scheme, we first calculate the energy-level structure of the states involved in the cooling cycle. Their number is largely increased and their energies split, compared to the isolated ion, by the residual Coulomb interaction between the ion-core and the Rydberg electrons. We then examine population dynamics over the 200 states of the cooling cycle and demonstrate that an important ion-core photon scattering rate can be achieved, and, in the presence of a small magnetic field, maintained over > 100 µs. Our Rydberg-atom laser cooling scheme paves the way to explore the properties of cold Rydberg gases as a function of temperature.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

C041

Geometric control of optical dipoles at a cold atom--nanofiber interface

Ruijuan Liu[1], Jinggu Wu[1], Yudi Ma[1], Yanting Zhao[2], Saijun Wu[1]

[1]State Key Laboratory of Surface Physics and Department of Physics, Fudan University, Shanghai, China. [2]State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Laser Spectroscopy, Shanxi University, Taiyuan, China

Abstract

Photons guided through an optical nanofiber (ONF) excite surrounding atoms in the near field. The atomic dipoles take the form of optical spin-wave, with a k-vector matching the propagation constant, $k=\beta$. The collective forward emission interferes with the probe. Owning to strong light-atom interaction over exceptionally long distances, the seemingly simple setup may already lead to nontrivial quantum optical dynamics [1]. For optical spin wave with $k\neq\beta$, the associated quantum dynamics can be even more exotic [2]. To access the subradiant manifold at the ONF interface, one may phase-pattern the atomic dipoles for coherent conversion between the phase-matched and mismatched spin-waves [3]. This work takes the first step toward the goal, by demonstrating geometric phase control at an ^{87}Rb-ONF interface. After laser-cooling, an ONF-guided probe establishes the phase-matched spin-wave excitation. Two sub-nanosecond control pulses are then fired to cyclically drive the D1 population inversion in the near field. A geometric phase $\gamma=\pi+\phi_2-\phi_1$ is written to the atomic dipoles. Using a phase-jump transmission spectroscopy, the geometric phase control efficiency is found to be ~50%, agreeable with numerical model based on uniform ensemble in the inhomogeneous evanescent field. Aided by the full-level simulations, we find our setup to support a spin-wave control fidelity F>90% for near-field lattice-confined atoms [4]. We outline next steps, and discuss possibilities opened by our technique.

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Poster

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Quantum optics and thermodynamics

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Poster presentation

C042

Comb-Like Time-Frequency Entanglement via Two-Photon Interference and Distribution

Sheng-Hung Wang[1], Po-Han Chen[1], Yen-Hung Chen[2], Pin-Ju Tsai[2]

[1]Department of Physics, National Central University, Taoyuan City, Taiwan. [2]Department of Optics and Photonics, National Central University, Taoyuan City, Taiwan

Abstract

Quantum entanglement is crucial in quantum technologies, encompassing quantum communication and quantum computing. The exploration of time-frequency entanglement (TFE) with a comb-like structure has been quite discussed, owing to its high-dimensional entanglement and inherent robustness for propagation in long-distance fiber networks. Therefore, the generation and verification of the time-frequency comb feature in photon pairs become crucial tasks for time-frequency quantum information processing. In this study, we investigate the use of an unbalanced polarization-based Michelson interferometer composed of the Hong-Ou-Mandel (HOM) effect and Franson interference. By leveraging the distinctive effects in a single interferometer, this setup allows us to generate and verify comb-like time-frequency entanglement in photon pairs simultaneously. The developed method offers a compact solution for quantum information processing encoded in frequency, contributing to the broader landscape of quantum technologies and their potential applications in the real world.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

C043

Superradiant bursts of light from cascaded quantum emitters: Experiment on photon-photon correlations

Constanze Bach, Felix Tebbenjohanns, Christian Liedl, Philipp Schneeweiss, Arno Rauschenbeutel

Humboldt-Universität zu Berlin, Berlin, Germany

Abstract

We experimentally investigate the second-order quantum coherence function of a superradiant burst in a cascaded quantum system. We chirally (i.e. direction-dependently) couple roughly 900 cesium atoms to the forward propagating mode of an optical nanofiber. We then coherently optically excite a large fraction of the atoms and observe that second-order coherence emerges in the subsequent transient collective emission. This is a clear feature of the underlying collective dynamics that is also at the origin of the occurrence of the superradiant burst itself. We furthermore study the dynamics of the second-order coherence function of the superradiant burst in dependence on the initial collective dipole moment of the ensemble. Our findings shed light on the emission of coherent light from initially independent emitters

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

C044

Port-Based Teleportation with Noisy Resource State

Ha Eum Kim[1], Kabgyun Jeong[2]

[1]Department of Physics, Korea University, Seoul, Korea, Republic of. [2]Research Institute of Mathematics, Seoul National University, Seoul, Korea, Republic of

Abstract

Port-based teleportation (PBT)represents a variation of the standard quantum teleportation and is currently being employed and explored within the field of quantum information processing owing to its various applications. In this study, we focus on PBT protocol when the resource state is disrupted by local Pauli noises. Here, we fully characterise the channel of the noisy PBT protocol using Krauss representation. Especially, by exploiting the application of PBT for entanglement distribution necessary in realizing quantum networks, we investigate entanglement transmission through this protocol for each qubit considering noisy resource states, denoted as port-based entanglement teleportation (PBET). Finally, we derive upper and lower bounds for the teleported entanglement as a function of the initial entanglement and the noises. Our study demonstrates that quantum entanglement can be efficiently distributed by protocols utilizing large-sized resource states in the presence of noise and is expected to serve as a reliable guide for developing optimized PBET protocols.

Poster

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Quantum computing, simulation & networks

Presentation

Poster presentation

C045

Simultaneous Trapping of Two Optical Pulses in an Atomic Ensemble as Stationary Light Pulses

U-Shin Kim, Yoon-Ho Kim

Pohang University of Science and Technology, Pohang, Korea, Republic of

Abstract

The stationary light pulse (SLP) refers to a zero-group-velocity optical pulse in an atomic ensemble prepared by two counterpropagating driving fields. Despite the uniqueness of an optical pulse trapped within an atomic medium without a cavity, observations of SLP so far have been limited to trapping a single optical pulse due to the stringent SLP phase-matching condition, and this has severely hindered the development of SLP-based applications. In this Letter, we first show theoretically that the SLP process in fact supports two phase-matching conditions and we then utilize the result to experimentally demonstrate simultaneous SLP trapping of two optical pulses for the duration from 0.8 to 2.0 μs. The characteristic dissipation time, obtained by the release efficiency measurement from the SLP trapping state, is 1.22 μs, which corresponds to an effective Q factor of 2.9×10^9. Our Letter is expected to bring forth interesting SLP-based applications, such as, efficient photon-photon interaction, spatially multimode coherent quantum memory, creation of exotic photonic gas states, etc.

Poster

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Presentation

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C046

Direct Observation of Coherent Back and Forward Scattering Peaks in a Shaken Bose Gas

Floriane Arrouas[1], Julien Hebraud[2], Nicolas Ombredane[1], Eloi Flament[1], Dominique Ronco[1], Nathan Dupont[3], Juliette Billy[1], Gabriel Lemarie[2], Christian Miniatura[4], Bertrand Georgeot[2], Bruno Peaudecerf[1], David Guery-Odelin[1]

[1]Laboratoire Collisions Agrégats Réactivité, Université Toulouse III/CNRS, Toulouse, France. [2]Laboratoire de Physique Théorique, Université Toulouse III/CNRS, Toulouse, France. [3]Center for Nonlinear Phenomena and Complex Systems, ULB, Brussels, Belgium. [4]Institut de Physique de Nice, Nice, France

Abstract

The quantum kicked rotor is a paradigmatic model of quantum chaotic dynamics in which dynamical localization - the equivalent, in momentum space, of Anderson localization - occurs. In the presence of symmetries, weak localization, a precursor of Anderson localization, can also be present.

Both these localization effects are associated with two distinct peak signatures in the reciprocal (position) space: the Coherent Back-Scattering (CBS) peak, linked specifically to weak localization, and the recently predicted Coherent Forward Scattering (CFS) peak, a hallmark of strong (Anderson) localization, which has only been observed indirectly so far.

Inspired by a recent proposal, we use Bose-Einstein condensates placed in a time-modulated 1D-optical lattice to simulate an equivalent of the kicked-rotor with matter waves, in which we make the first direct experimental observation of the CFS peak.

After preparing a peaked distribution at an initial position within the lattice cells, we induce chaotic dynamics through strong modulation of the lattice amplitude, using several modulation functions corresponding to as many disorder configurations. We then perform a rotation in phase space, transferring information on the spatial distribution onto the momentum distribution, which we measure after a long free expansion. By averaging the signal for multiple modulations, we are able to measure the presence or absence of the scattering peaks in position space.

Our ability to tailor the modulation function allows us to investigate these localization signatures with or without various symmetries of the dynamics. This versatility opens perspectives for the deeper study of localization effects in unusual symmetry regimes.

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Presentation

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C047

An apparatus for millimeter-wave-mediated quantum gates between Rydberg atoms

Tony Zhang[1], Michelle Wu[1], Nolan Peard[1], Lin Xin[1], Sam Cohen[1], Kevin Multani[1], Debadri Das[1], Emilio Nanni[2], Amir Safavi-Naeini[1], Paul Welander[2], Monika Schleier-Smith[1]

[1]Stanford University, Stanford, USA. [2]SLAC National Accelerator Laboratory, Menlo Park, USA

Abstract

Rydberg atom arrays have become a leading platform for quantum computing and simulation. However, the power-law decay of the interaction strength in Rydberg systems poses a limitation to efficient generation of long-range entanglement, as compared to the non-local interactions achievable between trapped ions or cold atoms in optical cavities. We propose to trap Rydberg atoms in a millimeter (mm)-wave Fabry-Perot cavity to enable high-fidelity non-local entangling gates. Coupling a transition between circular Rydberg states to a cavity mode will enable atoms to interact with each other regardless of their locations, by emitting and reabsorbing photons to and from the cavity mode. We are developing a high-finesse superconducting cavity with optical access for atom trapping and single-atom detection in a cryogenic apparatus. This new platform will enable entangling gates between atom pairs separated by mm-scale distances, as well as scalable preparation of many-body entangled states. The platform also offers opportunities in quantum simulation, with the interplay of local dipolar and global cavity-mediated interactions raising prospects for accessing novel strongly correlated states.

Categories

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Presentation

Poster presentation

C048

Rydberg Blockade Revisited

Lucia Valor, Natalie Pearson, Elie Bermot, Wesley Coelho, Louis-Paul Henry

Pasqal, Massy, France

Abstract

In Rydberg atom quantum computation, the well known blockade effect is a crucial phenomenon where an atom in the Rydberg state prevents the excitation of any other nearby atom. Despite its importance, analysis of this mechanism is usually simplistic. We extend this analysis to better quantify the blockade phenomenon. Using these insights, we explore ways of embedding graphs in Rydberg atom quantum computers by means of register arrangement and pulse sequence design, to extend our capabilities for graph-based computation using this hardware.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C049

Quantum computing with trapped ions and the optical magnus effect.

Louis Gallagher[1], Zeger Ackerman[2], Matteo Mazzanti[1], Nella Diepeveen[1], Clara Pereira[2], Rima Schuessler[1], Arghavan Safavi-Naini[1], Robert Spreeuw[1], Rene Gerritsma[1]

[1]University of Amsterdam, Amsterdam, Netherlands. [2]Amsterdam, Amsterdam, Netherlands

Abstract

Optical tweezers offer new opportunities to control and manipulate trapped ions with applications in quantum information processing. Beyond the paraxial approximation, strong polarization gradients in the tweezer waist give rise to a transverse force on trapped ions [1]. A quantum logic gate using this 'optical magnus effect' to excite an ion chain's vibrational modes has been theoretically developed in our group [2]. The proposed gate may offer key benefits such as infrastructural simplification – the light only has to be supplied from one direction - and enhanced long-ranged interactions between the ion qubits.

We also explore the effects of the breakdown of the paraxial approximation in single qubit operations with tightly focused laser beams and see an unexpected dependence on ion motion which can cause errors when the ions are not ground state cooled. We give strategies to avoid these effects.

We present the ongoing development to implement this quantum gate in the lab. Specifically, the design and construction of a microfabricated ion trap and UHV setup, and the optimization of a programmable UV tweezer array. We aim to supress off-resonant scattering using an array of Laguerre-Gaussian tweezer modes generated by a spatial light modulator.

[1] R.J.C. Spreeuw. Physical Review Letters 125, 233201 (2020).

[2] M. Mazzanti et al. Physical Review Research 5 (3), 033036 (2023).

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C050

Towards measurement-enhanced and adiabatic preparations of many-body entangled states in ^{171}Yb tweezer arrays

Joanna Lis, Aruku Senoo, Gaurav Vaidya, Alexander Baumgartner, Adam Kaufman

JILA, Boulder, USA

Abstract

Fault-tolerant quantum computing and quantum simulation benefit from a combination of high-fidelity single-qubit operations, programmable interactions, low-entropy state preparation and midcircuit operations. Among quantum science platforms, ytterbium 171 atoms in optical tweezers emerged as a promising candidate for realizing these capabilities efficiently. Here, the quantum information, encoded in either the ground, metastable or optical state, is manipulated with high-fidelity within each qubit manifold and site-selectively shuffled between them [1]. Strengthened by the decoherence robustness of the nuclear qubit, motional ground-state cooling and fast non-destructive imaging, the platform realizes midcircuit readout and reset as well as local feed-forward [1]. Building on our previous work [1,2], we expand our toolbox by high-fidelity two qubit gates and tunable interactions via Rydberg states. We report on the progress towards pairing the unitary and projective operations in an effort to measurement-enhance entanglement generation; and towards utilizing long coherences on the Rydberg transition to adiabatically prepare ground-states of many-body hamiltonians.

[1] J. W. Lis, A. Senoo, W. F. McGrew, F.Rönchen, A. Jenkins, and A. M. Kaufman. “Midcircuit Operations Using the omg Architecture in Neutral Atom Arrays”. Phys. Rev. X 13, 041035 (2023).

[2] A. Jenkins*, J. W. Lis*, A. Senoo, W. F. McGrew, and A. M. Kaufman. “Ytterbium Nuclear-Spin Qubits in an Optical Tweezer Array”. Phys. Rev. X 12, 021027 (2022).

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C051

Advances in the control of $^{133}Ba^{+}$ Qubits

Zach Wall, Sam Vizvary, Eric Hudson, Wesley Campbell

University of California, Los Angeles, Los Angeles, USA

Abstract

This poster highlights key advancements in controlling $^{133}Ba^{+}$ (Barium-133) ion qubits, a promising candidate for quantum computing. We focus on innovative methods for initializing, manipulating, and reading out the quantum states of $^{133}Ba^{+}$ qubits, utilizing the single species approach of the omg protocol. Our research explores improved coherence times and reduced error rates through microwave and Raman gates. We address the use of $^{133}Ba^{+}$ ions in scalable quantum architectures, such as integrated photonics and demonstrate its advantages over other ion species in operational stability and decoherence minimization. This work represents a significant step towards realizing efficient and scalable quantum computers, leveraging the unique properties of $^{133}Ba^{+}$.

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C052

Optical Superoscillatory Techniques for Quantum Gas

Kelvin Lim[1], Vincent Mancois[1], Haijun Wu[1], Yijie Shen[1], Nikolay Zheludev[1,2], David Wilkowski[3,1,4]

[1]Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore, Singapore. [2]Optoelectronics Research Centre, University of Southampton, Southampton, United Kingdom. [3]Centre for Quantum Technologies, National University of Singapore, Singapore, Singapore. [4]MajuLab, International Research Laboratory, IRL 3654, CNRS, Université Cote d'Azur, Sorbonne Université, National University of Singapore, Nanyang Technological University, Singapore, Singapore

Abstract

The trapping of single 133Cs atom in a superoscillatory hotspot smaller than the Abbe's diffraction limit has been demonstrated experimentally [1]. Using the optical superoscillatory technique, we plan on extending the applications of superoscillatory fields for quantum gases. The superoscillatory trap should provide a way to realize arrays of traps in which the spot size and separation distance can be tuned below the standard diffraction limit. This control over the spot size and separation distance with subwavelength accuracy is essential for quantum simulation and quantum information processing.

[1] H. M. Rivy, S. A. Aljunid, E. Lasalle, N. I. Zheludev, D. Wilkowski. Single atom in a superoscillatory optical trap. *Commun Phys.*, 6:155, 2023.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C053

Slow-mode nanophotonics and cold atoms: towards a versatile Waveguide QED platform

Anaïs Chochon[1], Adrien Bouscal[1], Malik Kemiche[2,3], Sukanya Mahapatra[2], Nikos Fayard[4,5], Jérémy Berroir[1], Tridib Ray[1], Jean-Jacques Greffet[4], Fabrice Raineri[2,6], Ariel Levenson[2], Kamel Bencheikh[2], Christophe Sauvan[4], Alban Urvoy[1], Julien Laurat[1]

[1]LaboratoireLaboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, 75005 Paris, France. [2]Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Saclay, 91120 Palaiseau, France. [3]MEP-LAHC, Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, Grenoble INP, 38000 Grenoble, France. [4]Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, 91127 Palaiseau, France. [5]Université Paris-Saclay, CNRS, Ecole Normale Supérieure Paris-Saclay, CentraleSupélec, LuMIn, Orsay 91190, France. [6]Universiteé Côte d'Azur, Institut de Physique de Nice, CNRS-UMR 7010, Nice 06200, France

Abstract

The emerging field of Waveguide Quantum Electrodynamics (WQED) focuses on the interaction of quantum emitters with guided light in nanoscopic waveguides. In our group, we are developing a new platform to interface cold Rubidium atoms with slow-mode nanophotonic crystals (PCWs). These novel light-matter interfaces commonly rely on high confinement and low group velocities of the PCWs-guided modes to reach strong atom-photon coupling in single pass, and are a promising route to implement quantum non-linear optics and quantum simulation protocols.

Interfacing cold atoms with nanophotonic devices raises many technical challenges from the design and nanofabrication of the waveguide to its integration in the cold atom set-up. I will first present our design of a slow-mode nanophotonic waveguide reaching light and matter interaction up to *β = 0.47* [1], with a design optimized for robustness to inherent nanofabrication imperfections. The next challenge is the deterministic loading of atoms in the dipole traps in the vicinity of the waveguide surface. I will present our progress on generating optical tweezers with radial Laguerre-Gauss modes to ensure efficient delivery of single atoms close to the nanophotonic device.

[1] Adrien Bouscal *et al, New J. Phys.* **26** 023026 (2024)

Categories

Quantum computing, simulation & networks

Presentation

C054

Adaptive estimation of qudit quantum observables with Bayesian statistics

Rick Simon[1], Andrew Jena[2], Luca Dellantonio[1]

[1]University of Exeter, Exeter, United Kingdom. [2]University of Waterloo, Waterloo, Canada

Abstract

The accurate estimation of quantum observables is a crucial task in quantum computing. One advancement on the hardware level is the development of qudit-based devices; however, currently, no protocols exist for estimating quantum observables on these new systems. Here, we present the first protocol that can accurately estimate both the mean and the error of an observable on qudit-based quantum computers. Our protocol achieves this by constructing a Bayesian model to accommodate generalized Pauli operators. It is designed to continuously monitor the estimated average and the associated error of the observable, dynamically adjusting the subsequent measurement based on this real-time information. Being able to exploit general commutation relations and overlap grouping measurements our protocol is state-of-the art when restricted to qubit-based quantum computers and brings this advantage to the qudit case.

Categories

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Presentation

Poster presentation

C055

Qubit Fidelity of CSS Codes under General Neutral Atom Noise

Jasper Postema, Servaas Kokkelmans

TU Eindhoven, Eindhoven, Netherlands

Abstract

Storing quantum information in a quantum error correction (QEC) code enhances protection against errors. Imperfection of quantum devices due to decoherence effects will limit the fidelity of quantum gate operations. In particular, neutral atom quantum computers will suffer from correlated errors because of the fragility of the Rydberg states that facilitate entanglement. Predicting the impact of such errors on the performance of topological QEC codes is important in understanding and characterising the fidelity limitations of a real quantum device. Mapping a QEC code to a Z2 lattice gauge theory with disorder allows us to use Monte Carlo to calculate upper bounds on error rates without resorting to a decoder. In this Poster, we adopt this statistical mapping to predict error rate thresholds for neutral atom architecture, assuming radiative decay to the computational basis and leakage as the sole error sources. We show that radiative decay will lower the threshold while leakage will benefit the error rate because of the favourability of erasure, and quantify the interplay between these noise parameters.

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C056

Spatial light potentials for quantum simulation experiments

Arthur La Rooij, Paul Schroff, Elmar Haller, Stefan Kuhr

University of Strathclyde, Glasgow, United Kingdom

Abstract

Arbitrary light potentials have proven to be a valuable and versatile tool in many quantum information and quantum simulation experiments with ultracold atoms. I will report on our recent progress in generating high quality holographic light potentials using a phase-modulating spatial light modulator (SLM). We employ conjugate gradient minimisation to calculate the SLM phase pattern for a given target light potential after measuring the intensity and phase-front at the SLM. Using a camera feedback routine and by modelling the pixel crosstalk on the SLM we further reduce experimental errors. This way we are able to generate light potentials with measured efficiencies between 15 and 40% and an accuracy of <2% root-mean-squared error [1]. Secondly, I will report on a newly developed method to calibrate a SLM for holography. By using a stochastic approach, we are able to drastically reduce the calibration time that is required to measure the phase-front and intensity of a laser beam at the SLM. We use the same method to optimise more elaborate pixel crosstalk models and demonstrate how this advancement leads to even more accurate light potentials.

[1] P. Schroff et al., Sci. Rep. 13, 3252 (2023)

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C057

Towards quantum simulation with programmable optical lattices

Sarah Waddington, Isabelle Safa, Tom Schubert, Marvin Holten, Rodrigo Rosa-Medina, Julian Léonard

Atominstitut TU Wien, Vienna, Austria

Abstract

Ultracold atoms in optical lattices provide a highly versatile platform for exploring strongly correlated quantum matter and out-of-equilibrium many-body dynamics. Although quantum gas microscopy has significantly advanced the field by achieving single-site resolution, experiments often face limitations due to restricted single-atom control and rigid lattice configurations.

In this poster, we describe the ongoing design and development of a next-generation quantum gas microscope for fermionic and bosonic lithium isotopes. Our approach relies on a reconfigurable lattice potential, combining site-resolved state preparation, evolution, and readout by leveraging auxiliary optical tweezers. The setup is optimized to reach sub-second cycle times by eliminating the transport stage and incorporating all-optical cooling techniques.

Our platform opens various research avenues, including quantum simulation of strongly correlated matter within and beyond the Fermi-Hubbard model, fractional quantum Hall states, and frustrated phases with unconventional geometries.

Categories

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Presentation

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C058

Progress towards a network of quantum registers with neutral Rb atoms

Preston Huft[1], Akbar Safari[1], Eunji Oh[1], Gavin Chase[1], Jacob Uribe[1], Mark Saffman[1,2]

[1]University of Wisconsin - Madison, Madison, USA. [2]Infleqtion Inc., Madison, USA

Abstract

We report on progress towards a rudimentary network of quantum registers with neutral atoms. While quantum computing has the potential to out-perform classical computers for certain classes of problems, scaling these platforms to the number of qubits necessary for useful quantum advantage is an outstanding challenge for all architectures. A modular approach based on quantum processors connected by photonic links is one pathway to surmounting this challenge. Here we show experimental progress towards a two-node network of quantum registers using a novel quantum node architecture based on centimeter scale optics in vacuo, which reduces the experimental footprint. Moreover, we demonstrate the first use of a parabolic mirror with neutral atoms, used for trapping of and photon collection from the communication qubits. Memory qubits are held in projected tweezer arrays formed with a passive Fourier filtering technique, where Rydberg gates can be performed both within the memory register and between memory and communication qubits. This work was supported by NSF Award 2016136 for the QLCI Hybrid Quantum Architectures and Networks, the U.S. Department of Energy Office of Science National Quantum Information Science Research Centers as part of the Q-NEXT center, and NSF Award 2228725.

Categories

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Presentation

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C059

Realizing exotic dynamical phenomena with ultracold strontium

Anna Dardia, Toshi Shimasaki, Yifei Bai, Peter Dotti, David Weld

UCSB, Santa Barbara, USA

Abstract

Ultracold atoms in 1D bichromatic optical lattices realize the Aubry-André-Harper model, enabling the study of localization in quasiperiodic systems as well as topological properties inherited from higher dimensions. Dipolar modulation, which mimics an oscillating force, can induce dynamic localization, while modulation of the phasonic degree of freedom tunes the effective strength of the quasi-periodic disorder. We present the results of experiments exploring the effects of dipolar and phasonic modulation and their interplay, and discuss a mapping to 2D quantum Hall matter in which the relative phase between the two modulations emerges as the polarization of an optical driving field. By tuning this polarization we can change the topological properties of the undriven system and Floquet engineer an extended critical phase. Separately, we discuss ongoing developments in the use of structured light fields to generate an oscillating linear gradient force, and resultant experimental possibilities such as quantum simulation of high harmonic generation and ultrafast phenomena.

Categories

Quantum computing, simulation & networks

Presentation

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C060

Development of a cesium array platform for quantum computing and simulation

Tsai-Ni Wang[1,2], I-Chia Huang[1,2], Fang-Yu Lee[1,2], Yu-Ju Lin[2], Ying-Cheng Chen[2]

[1]Department of Physics, National Taiwan University, Taipei, Taiwan. [2]Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan

Abstract

We report our development of a cesium atom array platform for the study of quantum computing and simulation. We implement the L-enhanced grey molasses cooling at cesium D_1 transition to cool atoms to sub-mK. Using a modified beam splitting algorithm to calculate the phase hologram for a spatial light modulator, we generate arbitrary two-dimensional tweezer arrays of Gaussian beams, as well as defect-free bottle-beam arrays. We demonstrate a simple scheme to use an electro-optic modulator to realize the stimulated Raman transition for quantum control of the hyperfine atomic qubits. We excite cesium atoms to the Rydberg state via the $6S_{1/2}$ to $7P_{1/2}$ transition at 459 nm and the $7P_{1/2}$ to 81 $S_{1/2}$ transition at 1039 nm. The two Rydberg excitation lasers have been locked to a high-finesse Fabry-Perot cavity to reduce their phase noises. Sub-kHz linewidth and a cavity drift of less than 7 kHz per day have been characterized. To conduct the background-free qubit detection by exciting the $6S_{1/2}$ to $5D_{5/2}$ electric-quadrupole transition at 685 nm and measuring the fluorescence at D_2 transition of 852 nm, we develop a high-power laser system including an external cavity diode laser (ECDL), two slave lasers and one tampered amplifier. The ECDL is locked to a molecular iodine spectral line nearby the transition at 685 nm. We are currently working on loading single atoms to the tweezer arrays. The results will be reported.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C061

Quantum simulation with circular Rydberg atoms of strontium

Baptiste Muraz, Léa Lachaud, Mathis Pepin, Jean-Michel Raimond, Michel Brune, Sébastien Gleyzes

Laboratoire Kastler Brossel, Paris, France

Abstract

One of the promising platforms for Quantum simulation is Rydberg atoms trapped in optical tweezers, where the transition between the ground state and the Rydberg state is used as a two level system to study many-body phenomena.

In our group, we instead use Circular Rydberg atoms, which are states with maximum angular momentum. When placed in a cryogenic environment they exhibit a very long lifetime, up to tens of milliseconds. Those states could thus open the way to study dynamics over a longer timescale.

For my project in particular, I am using Strontium atoms that offer many advantages over more commonly used alkali atoms like Rubidium. First, it is possible to trap the atom in the circular states using Gaussian tweezers thanks to the polarizability of the Sr+ ionic core. We can also excite the ionic core without autoionization allowing detecting the Rydberg atoms by fluorescence imaging on the broad transition of the Sr+ ion.

We showed that the coupling between the two electrons while one of them is in the circular states shifts the energy levels of the states with a non-zero electric quadrupole moment. For strontium, in particular, it is the case for the two clock states of the ion; these transitions are narrow enough to resolve this energy shift. It is then possible to selectively excite to the clock state the core with the Rydberg electron in a specific n, and perform QND measurement of the qubit made of two circular states.

Poster

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C062

A strontium quantum-gas microscope for Bose- and Fermi-Hubbard quantum simulation

Sandra Buob[1], Jonatan Höschele[1], Vasiliy Makhalov[1], Antonio Rubio-Abadal[1], Leticia Tarruell[1,2]

[1]ICFO—Institut de Ciencies Fotoniques, Castelldefels (Barcelona), Spain. [2]ICREA, Barcelona, Spain

Abstract

Quantum-gas microscopes represent an outstanding tool for quantum simulations in optical lattices. Adding strontium with its rich energy level structure to these systems opens access to a vast field of research topics. On the one hand, strong cooperative effects in atom-photon scattering can be realized with bosonic strontium in sub-wavelength atomic arrays. On the other hand, the fermionic isotope allows the study of exotic magnetic phases in the SU(N) symmetric Fermi-Hubbard model with up to N=10 spin states. Furthermore, the ultra-narrow clock transition fundamental in the most precise atomic clocks, provides a useful tool to probe the prepared quantum many-body systems.

Here, we present a quantum-gas microscope for bosonic and fermionic isotopes of strontium. In our experiment, we routinely load Bose-Einstein condensates of strontium into a two-dimensional optical lattice potential which is formed by a four-fold interfering laser beam combined with a light sheet for vertical confinement. Both are operating at the magic wavelength 813nm of the clock transition. Our quantum-gas microscope enables probing these Hubbard systems with single-site resolution. To this end, a high-NA objective collects the photons scattered on the broad transition at 461nm. To counteract the heating, we perform attractive Sisyphus cooling driving the narrow-linewidth transition at 689nm. Apart from the bosonic isotope, we load the fermionic isotope with its 10 nuclear spin states into the lattice and demonstrate single atom detection. We also plan to implement spin-resolved detection, which paves the way to investigating SU(N) Fermi-Hubbard physics with full single-site and spin resolution.

Categories

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Presentation

Poster presentation

C063

Single-atoms optical trap array using silicon metasurface optics

Feng Zhou

Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan, China

Abstract

Metasurfaces made of subwavelength silicon nanopillars provide unparalleled capacities to manipulate light, which have emerged as one of the leading platforms for developing integrated photonic devices. Here, we present a unique, passive optical configuration to generate single-atom dipole trap arrays using dielectric metasurface optics. Precisely controlling light propagation and wavefront manipulation are obtained by spatially varying the geometry of the silicon nanopillars in a designed pattern without any active devices. This work highlights a compact, stable, and scalable trap array platform well-suitable for Rydberg-state mediated quantum gate operations, which will further facilitate advances in neutral atom quantum computing. Compared to traditional active optoelectronic devices, our metasurface design offers advantages of simplicity, scalability, and low manufacturing cost, making it well-suitable for Rydberg-state mediated quantum gate operations. It is expected to provide a new platform for integrated quantum systems with neutral-atom arrays in near the future.

Key words: Optical trap array; Meta-hologram; Metalens; Single atoms

Reference: Huang, R. T.; Zhou, F.; Li, X.; Xu, P.; Wang, Y. and Zhan, M. S.: “Metasurface optical trap array for single atoms” Opt. Exp., **32**(12), 21293-21303 (2024).

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C064

Photon-atom interfaces at telecom wavelengths

Natalia Bruno

CNR-INO, Firenze, Italy. LENS, Sesto Fiorentino, Italy

Abstract

Enabling communication between quantum devices, such as clocks, computers, and simulators has the potential to significantly enhance the capabilities of their applications, such as quantum sensing and computing. The key to achieving this lies in establishing efficient communication channels among these quantum devices even over a long distance, which involves the exchange of qubits encoded in light at telecom wavelengths through optical fibers. In this context, I will present an overview of the new experiment that we are building in Florence, which focuses on interfacing single photons at telecom wavelengths with individual neutral ytterbium atoms trapped in optical tweezers. By leveraging the unique properties of the ytterbium clock state and its telecom transitions, our objective is to interface a long-lived "matter" qubit and resonant light, including heralded single photons or photons forming entangled pairs. I will discuss the motivation for exploring this research line and its impact as a crucial foundation for distributing entanglement between light and matter.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C065

Mid-circuit measurements of optical qubits in $^{171}Yb^+$ ions using auxiliary Zeeman sublevels

Kristina Galstyan[1,2], Ilia Zalivako[1,2], Alexander Borisenko[1,2], Ilia Semerikov[1,2], Andrey Korolkov[1,2], Nikita Semenin[1,2], Ksenia Khabarova[1,2], Nikolay Kolachevsky[1,2]

[1]Russian Quantum Center, Skolkovo, Moscow, Russian Federation. [2]P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russian Federation

Abstract

Mid-circuit measurement is one of the key elements required to implement error correction protocols. In some cases, such operations can also significantly reduce amount of resources required for implementation of quantum algorithms. In this poster we present a protocol for a mid-circuit measurement of a subset of ion qubits, encoded in a $^2S_{1/2}(F=0, m_F=0) \rightarrow {}^2D_{3/2}(F=2, m_F=0)$ transition in $^{171}Yb^+$ ions. The protocol includes usage of auxiliary Zeeman sublevels of the $^2D_{3/2}(F=2)$ state as well as spin-echo technique to prevent decoherence of the spectator qubits. The protocol also does not require individual ion addressing with an electron shelving beam. We also experimentally demonstrate the proposed method by performing a CNOT gate teleportation.

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Quantum computing, simulation & networks

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C066

Trapped Ions Quantum Computing with Penning Traps

Yingying Cui[1], Tobias Saegesser[1], Shreyans Jain[1], Matteo Simoni[1], Kilian Hanke[1,2], Pavel Hrmo[1], Daniel Kienzler[1], Jonathan Home[1]

[1]ETH Zürich, Zürich, Switzerland. [2]Infineon, Villach, Austria

Abstract

Trapped-ion quantum computing offers high-fidelity gates and long coherence times. Current implementations mainly use Paul traps where ions are trapped by DC and RF electric fields. The high-voltage RF drive can lead to significant power dissipation and limitations on ion placement and transport. In contrast, Penning traps provide confinement using only static electric fields and a global magnetic field. We have demonstrated a microfabricated Penning trap, showcasing exceptionally low heating rates and arbitrary transport. We present our latest measurements of stray electric field and heating rate in all three dimensions. Additionally, we outline plans for upgrading our apparatus with a new multi-zone trap chip, enabling trapping and entangling up to four ions, as well as a more robust Raman phase lock for qubit manipulations.

Categories

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C067

Optimal probe states for single-mode quantum target detection in arbitrary object reflectivity

Wei-Ming Chen[1], Pin-Ju Tsai[2]

[1]Department of Physics, National Central University, Taoyuan, Taiwan. [2]Department of Optics and Photonics, National Central University, Taoyuan, Taiwan

Abstract

Quantum target detection (QTD) utilizes nonclassical resources to enable radar-like detection for identifying reflecting objects in lossy and noisy environments, surpassing the detection performance achieved by classical methods. To fully exploit the quantum advantage in QTD, determining the optimal probe states (OPSs) across various detection parameters and gaining a deeper understanding of their characteristics are crucial. In this study, we employ optimization algorithms to identify the single-mode continuous-variable OPSs for entire range of target reflectivity. Our findings suggest that OPSs are non-Gaussian states in most reflectivity scenarios, with exceptions under specific conditions. Furthermore, we provide a comprehensive physical interpretation of the observed phenomena. This study offers a tool for identifying OPSs along with a clear physical interpretation. It also contributes to further advancements towards optimal multi-mode QTD, which holds the potential for broad applications in quantum sensing and metrology.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C068

Theoretical proposal for studying topologically robust edge-states in a harmonic synthetic dimension.

David Reid[1], Chris Oliver[2], Thomas Easton[3], Aaron Smith[1], Grazia Salerno[4], Vera Guarrera[1], Nathan Goldman[5], Giovanni Barontini[1], Hannah Price[1]

[1]University of Birmingham, Birmingham, United Kingdom. [2]National Quantum Computing Centre, Oxford, United Kingdom. [3]National Physical Laboratory, London, United Kingdom. [4]Aalto University, Espoo, Finland. [5]Universite libre de bruxelles, Brussels, Belgium

Abstract

Given the broad interest in topological physics [1] many powerful tools have been developed to induce such effects in a plethora of platforms, including cold atoms [2]. One tool used are “synthetic dimensions”, in which a set of states are coupled to engineer an effective spatial dimension [3]. This approach is tailored for investigating topological systems as the external coupling can imprint a desired artificial magnetic field, inducing quantum Hall-like models. In Birmingham, we have been developing a type of synthetic dimension that is based on coupling the harmonic trap states associated with cold atomic clouds [4]. This experimental set-up recently demonstrated 1D Bloch oscillations along the synthetic dimension [5]. We now theoretically propose how to realise a 2D quantum Hall system in this set-up by combining the synthetic dimension with a real spatial dimension and an artificial magnetic field. We demonstrate how to induce topological one-way chiral orbits with experimentally realistic parameters. When this platform when combined with a Digital Mircro-mirror Device we can vary the length of and add impurities to the synthetic dimension. This opens the way for future experiments on topological physics with atomic trap states.

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[2] J. Dalibard et al. Rev. Mod. Phys. 83 1523, (2011).

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[4] H. M. Price et al., Phys. Rev. A. 95 023607, (2017).

[5] C. Oliver et al.,Phys. Rev. Res., 5 , 033001, (2023).

Poster

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Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C069

A stand-alone mobile quantum memory system

Martin Jutisz[1], Alexander Erl[2,3], Elisa Da Ros[1], Janik Wolters[3,2], Mustafa Gündoğan[1], Markus Krutzik[1,4]

[1]Humboldt-Universität zu Berlin, Berlin, Germany. [2]Technische Universität Berlin, Berlin, Germany. [3]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany. [4]Ferdinand-Braun-Institut, Berlin, Germany

Abstract

Quantum memories (QMs) are central to many applications in quantum information science. To date, many realisations of QMs have been demonstrated with different physical systems, ranging from cold atomic ensembles to solid-state systems. As a necessary element of quantum repeaters, these devices should be able to operate in non-laboratory environments, and as such their future deployment in space could advance global quantum communication networks [1]. In this context, warm-vapour QMs are particularly promising due to their low complexity and small size, weight and power. Unlike many other systems, they do not require laser or cryogenic cooling, which would make them attractive for practical applications.

We will present the implementation and performance analysis of a portable, rack-mounted stand-alone warm vapour QM system [2], that also includes the laser package and control electronics. The optical memory is based on long-lived hyperfine ground states of Cesium which are connected to an excited state via the D1 line at 895 nm in a lambda-configuration. The memory is operated with weak coherent pulses containing on average <1 photons per pulse. The long-term stability of the memory efficiency and storage fidelity is demonstrated at the single photon level together with operation in a non-laboratory environment. As an outlook, we will also discuss storage of non-classical states and different methods to micro-integrate this platform.

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)
[2] M. Jutisz et. al., in preparation (2024)

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C070

Local control and mixed dimensions: Exploring high-temperature superconductivity in optical lattices

Henning Schlömer[1,2], Hannah Lange[1,2,3], Titus Franz[2,3], Thomas Chalopin[4], Petar Bojović[2,3], Si Wang[2,3], Immanuel Bloch[1,2,3], Timon Hilker[2,3], Fabian Grusdt[1,2], Annabelle Bohrdt[2,5]

[1]Ludwig-Maximilians-Universität München, Munich, Germany. [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany. [3]Max-Planck-Institute for Quantum Optics, Garching, Germany. [4]Institut d'Optique Graduate School, CNRS, Université Paris-Saclay, Palaiseau, France. [5]Universität Regensburg, Regensburg, Germany

Abstract

The simulation of high-temperature superconducting materials by implementing strongly correlated fermionic models in optical lattices is one of the major objectives in the field of analog quantum simulation. Here, we show that local control and optical bilayer capabilities create a versatile toolbox to study both cuprate and nickelate high-temperature superconductors. Specifically, we suggest three distinct experimental setups: *(i)* On the one hand, we present a scheme to implement a mixed-dimensional (mixD) bilayer model that has been proposed to capture the essential pairing physics of pressurized bilayer nickelates. This allows for the long-sought realization of a state with long-range superconducting order in current lattice quantum simulation machines. In particular, we show how coherent pairing correlations can be accessed in a partially particle-hole transformed and rotated basis. *(ii)* On the other hand, we demonstrate that control of local gates enables the observation of *d*-wave pairing order in the two-dimensional (single-layer) repulsive Fermi-Hubbard model through the simulation of a system with attractive interactions. *(iii)* Lastly, we introduce a scheme to measure momentum-resolved dopant densities, which provides access to observables complementary to solid-state experiments, which is of particular interest for future studies of the enigmatic pseudogap phase appearing in cuprates.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C071

In situ subwavelength quantum gas microscopy : control and measurement of dense ensemble

Simon Bernon[1], Ruiyang HUANG[1], Eliott Beraud[1], Romain Veyron[2], Jean-Baptiste Gerent[3]

[1]LP2N, IOGS, Univ. Bordeaux, Talence, France. [2]ICFO, Barcelona, Spain. [3]LP2N, IOGS, Univ. Bordeaux, talence, France

Abstract

Quantum gas microscopes have become a major element for quantum simulations using ultra-cold atoms in optical lattices. They are for example used to observe long-range order such as anti-ferromagnetic correlations in far field optical lattices using density and spin resolved microscopy. Decreasing the period of such lattice offer interesting perspective to increase atom-atom interaction energies and engineer atom-light coupling that our group tackles via the hybridization of cold atoms and nano-structured surfaces.

In this poster, we will present how such type of sub-wavelength lattice potentials can be generated by trapping atoms in proximity (tens to hundreds of nanometers) of a nano-structured surface. At such atom to surface distance, the attractive Casimir-Polder force can be compensated by a doubly dressed state trapping method that I will discuss. Such method additionally offers solutions to overcome the diffraction limit of conventional imaging that become critical for sub-wavelength lattices. In this work, I will present the experimental characterization of a sub-wavelength resolution absorption imaging applicable to quantum gas detection. This method requires a quantitative determination of the atom number of dense clouds which has been experimentally characterized. In this work we demonstrate that the scattering cross section reduces linearly with the optical density. Modelling the propagation of light in dense cloud we show that this reduction can be attributed to re-scattering of the incoherent part of the resonant fluorescence spectrum.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C072

Towards quantum simulations with strontium atoms

Thies Plaßmann[1,2], Meny Menashes[1], Leon Schäfer[1], Guillaume Salomon[1,2]

[1]Institute for Quantum Physics, Hamburg University, Luruper Chaussee 149, 22761, Hamburg, Germany. [2]The Hamburg Center for Ultrafast Imaging, Hamburg University, Luruper Chaussee 149, 22761, Hamburg, Germany

Abstract

Cold atom platforms with single particle/spin detection and control offer fascinating opportunities for studying quantum many-body systems. Atoms trapped in programmable optical tweezer arrays and excited to Rydberg states are nearly ideal systems to engineer quantum spin models and to detect orders beyond Landau paradigm. Quantum gas microscopy of lattice fermions is also shedding new light on the interplay between doping and magnetism relevant to high-Tc superconductivity.
We report here on the development of a novel quantum simulator with single particle and spin resolution operating with strontium atoms with which we aim to study the SU(*N*) Fermi-Hubbard model and highly frustrated quantum magnetism.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C073

Passive dynamical decoupling of trapped-ion qubits and qudits

Tyler Sutherland

Oxford Ionics, Kidlington, United Kingdom

Abstract

We propose a method to dynamically decouple every magnetically sensitive hyperfine sublevel of a trapped ion from magnetic field noise, simultaneously using integrated circuits to adiabatically rotate its local quantization field. These integrated circuits allow passive adjustment of the effective polarization of any external (control or noise) field. By rotating the ion's quantization direction *relative* to this field's polarization, we can perform "passive" dynamical decoupling (PDD), inverting the linear Zeeman sensitivity of every hyperfine sublevel. This dynamically decouples the entire ion, rather than just a qubit subspace. Fundamentally, PDD drives the transition $m_F \rightarrow -m_F$ for every magnetic quantum number m_F in the system—with only one operation—indicating it applies to qudits with constant overhead in the dimensionality of the qudit. We show how to perform pulsed and continuous PDD, weighing each technique's insensitivity to external magnetic fields versus their sensitivity to diabaticity and control errors. Finally, we show that we can tune the sinusoidal oscillation of the quantization axis to a motional mode of the crystal in order to perform a laser-free two-qubit gate that is insensitive to magnetic field noise.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C074

A tweezer array with 6100 highly coherent atomic qubits

Hannah Manetsch, Gyohei Nomura, Elie Bataille, Kon Leung, Xudong Lv, Manuel Endres

California Institute of Technology, Pasadena, USA

Abstract

Optical tweezer arrays have had a transformative impact on atomic and molecular physics over the past years, and they now form the backbone for a wide range of leading experiments in quantum computing, simulation, and metrology. Typical experiments trap tens to hundreds of atomic qubits, and very recently systems with around one thousand atoms were realized without defining qubits or demonstrating coherent control. However, scaling to thousands of atomic qubits with long coherence times and low-loss, high-fidelity imaging is an outstanding challenge and critical for progress in quantum computing, simulation, and metrology, in particular, towards applications with quantum error correction. Here, we experimentally realize an array of optical tweezers trapping over 6,100 neutral atoms in around 12,000 sites while simultaneously surpassing state-of-the-art performance for several key metrics associated with fundamental limitations of the platform. While scaling to such a large number of atoms, we also demonstrate a coherence time of 12.6(1) seconds, a record for hyperfine qubits in an optical tweezer array. Further, we show trapping lifetimes close to 23 minutes in a room-temperature apparatus, enabling record-high imaging survival of 99.98952(1)% in combination with an imaging fidelity of over 99.99%. Our results, together with other recent developments, indicate that universal quantum computing with ten thousand atomic qubits could be a near-term prospect. Furthermore, our work could pave the way for quantum simulation and metrology experiments with inherent single particle readout and positioning capabilities at a similar scale.

Poster

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Poster presentation

C075

Towards Scalable Networking of Neutral-Atom Processors with Nanophotonic Optical Cavities

Shinichi Sunami[1,2], Shinya Kato[1], Seitaro Horikawa[1,3], Masafumi Shimasaki[1], Shiro Tamiya[1], Hayata Yamasaki[1,4], Akihisa Goban[1]

[1]Nanofiber Quantum Technologies, Inc, Tokyo, Japan. [2]University of Oxford, Oxford, United Kingdom. [3]Waseda University, Tokyo, Japan. [4]The University of Tokyo, Tokyo, Japan

Abstract

A high-bandwidth atom-photon interface is a key technological milestone to realize the multiprocessor operation of neutral-atom quantum processing units (QPUs). The tweezer-array systems are scalable thanks to highly parallel operations, however, photonic networking channels are inherently sequential and are expected to become a significant bottleneck for multiprocessor operations involving code blocks of hundreds of atoms or more.

In this presentation, we propose nanofiber optical cavities as a scalable interconnect for atom array and discuss their prospect as a networking module for multiprocessor logical quantum processing with high-rate concatenated code. Tapered nanofiber with a pair of fiber Bragg grating (FBG) mirrors features fiber-coupled, low-profile waveguide optical cavities with low and length-independent loss, crucial characteristics to achieve efficient time and channel multiplexing to scale the remote entanglement generation. We report on our recent development of nanofiber cavity QED systems with low-loss FBG mirrors and their interfacing with optical tweezer array for stable atom-photon coupling. Further, we provide an outlook for wavelength-multiplexed nanofiber cavities with multiple FBG pairs around the nanofiber region, for both high-bandwidth entanglement generation and continuous operation with multiple species or alkaline-earth atoms.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

C076

Thermal Decay of Planar Jones-Roberts Solitons: from Vortex Dipole to Rarefaction pulse

Nils Krause[1,2], Ashton Bradley[1,2]

[1]University of Otago, Dunedin, New Zealand. [2]Dodd-Walls Centre for Photonic and Quantum Technologies, Dunedin, New Zealand

Abstract

Planar Jones-Roberts solitons, which include vortex dipoles and rarefaction pulses, are excitations of two-dimensional Bose-Einstein condensates described by the Gross-Pitaevskii equation. They are stable nonlinear eigenstates in a translating frame of reference. We examine how these solitons decay due to thermal effects using the stochastic projected Gross-Pitaevskii theory of reservoir interactions. In particular, we examine the two distinct damping terms arising in the theory: number damping, responsible for the formation and growth of the condensate, and energy damping, arising from number conserving interactions between reservoir and condensate. Our main finding is that energy damping is the primary decay mechanism; we identify conditions for the dominance of either mechanism, finding that energy damping is dominant at high phase space density. Analytical results for the momentum decay are derived and supported by numerical studies spanning the range from vortex dipole to rarefaction pulse. We identify the interaction energy as a good parameter for experimental characterisation of rarefaction pulses, analogous to the distance between vortices for vortex dipoles. It is robust and sensitive to soliton velocity changes, and can be directly measured. As its decay proves to be qualitatively different for the two damping mechanisms, a testbed for current finite temperature theory of Bose-Einstein condensates is provided.

Poster

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Quantum fluids

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C077

Probing early phase coarsening in a rapidly quenched Bose gas using off-resonant matter-wave interferometry

Tenzin Rabga, Yangheon Lee, Yong-il Shin

Seoul National University, Seoul, Korea, Republic of

Abstract

We investigate the evolution of spatial phase correlations using off-resonant matter-wave interferometry in an inhomogeneous Bose gas of rubidium. We observe that the phase coherence length *l* increases during the early stage of condensate growth, especially before vortices are stably formed, and once they are formed, the measured value of *l* is found to be linearly proportional to the mean distance between vortices. This observation confirms the presence of early-time coarsening of phase correlations, preceding the formation of vortices, and leading to the suppression of vortex density in the fast quench regime. Currently, we are working on applying this method to a homogeneous sample to quantitatively investigate the vortex number suppression in the rapid-quench regime due to this early-time coarsening effect, which lies beyond the standard Kibble-Zurek description of second-order phase transitions.

Categories

Quantum fluids

Presentation

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C078

Chaos-assisted turbulence in spinor Bose-Einstein condensates

Jongmin Kim, Jongheum Jung, Junghoon Lee, Deokhwa Hong, Yong-il Shin

Seoul National University, Seoul, Korea, Republic of

Abstract

Turbulence, a ubiquitous phenomenon in fluids, poses a major challenge in physics owing to its complexity. While various methods exist to generate turbulence in a controlled manner, most of them are based on external forces and inertial energy cascades, which might limit the possibilities of exploring novel properties of turbulent states. In this talk, we propose an alternative approach to generate turbulence by harnessing the intrinsic chaos within the fluid itself. Specifically, we present numerical and experimental verification of the turbulence-sustaining mechanism in a spinor Bose-Einstein condensate, which is based on the chaotic nature of internal spin dynamics under magnetic driving. This chaos-assisted turbulence establishes the spinor condensate as an intriguing platform for exploring chaos and related superfluid turbulence phenomena.

Categories

Quantum fluids

Presentation

Poster presentation

C079

Energy-space random walk in a driven disordered Bose gas

Yansheng Zhang, Gevorg Martirosyan, Christopher Ho, Jiri Etrych, Zoran Hadzibabic, Christoph Eigen

University of Cambridge, Cambridge, United Kingdom

Abstract

Motivated by our experimental observation [1] that driving a non-interacting Bose gas in a 3D box with weak disorder leads to power-law energy growth, $E \sim t^{\eta}$ with $\eta = 0.46(2)$, and compressed-exponential momentum distributions that exhibit dynamic scaling, we perform a systematic theoretical study of this system [2]. Schrödinger-equation simulations reveal a crossover from $\eta \approx 0.5$ to $\eta \approx 0.4$ with increasing disorder strength, hinting at the existence of two distinct dynamical regimes. We formulate a semi-classical model that analytically captures the crossover between the two regimes and explains the dynamics in terms of an energy-space random walk. We also extend our study to explore the interplay of interparticle interactions and disorder in driven Bose gases, mapping out the dynamical phase diagram, which exhibits a crossover from the energy-space random walk to wave turbulence, characterized by a power-law momentum distribution.

[1] Martirosyan, G., Ho, C. J., Etrych, J., Zhang, Y., Cao, A., Hadzibabic, Z., & Eigen, C. (2024). Observation of subdiffusive dynamic scaling in a driven and disordered Bose gas. Physical Review Letters, 132(11), 113401.

[2] Zhang, Y., Martirosyan, G., Ho, C. J., Etrych, J., Eigen, C., & Hadzibabic, Z. (2024). Energy-space random walk in a driven disordered Bose gas. *C. R. Phys.* 24, Online first.

Categories

Quantum fluids

Presentation

Poster presentation

C080

Observation of vortices in dipolar supersolids

Thomas Bland[1], Eva Casotti[2,1], Elena Poli[1], Lauritz Klaus[2,1], Andrea Litvinov[2], Clemens Ulm[2], Claudia Politi[2,1], Manfred Mark[1,2], Francesca Ferlaino[1,2]

[1]University of Innsbruck, Innsbruck, Austria. [2]IQOQI, Innsbruck, Austria

Abstract

Supersolids are an exotic state of matter that spontaneously break two symmetries: gauge invariance by phase-locking of single-particle wavefunctions and translational symmetry due to the emergence of a crystalline structure. First predicted in solid helium, ultracold atoms have provided the necessary platform to observe this state, most successfully so far with dipolar atoms. The crystalline structure can be probed directly by observing the density modulation of the gas, and phase-locking of the single-particle wavefunction emerges from self-interference. What has not yet been observed are quantized vortices, a hallmark of superfluidity. Bolstered by the recent realization of two-dimensional supersolids, we report on the theoretical study and experimental observation of vortices in a dipolar supersolid of dysprosium. Our work shows how supersolids, exhibiting both crystalline and superfluid properties, show a mixture of rigid-body and irrotational behavior, revealing a fundamental difference between modulated and unmodulated quantum fluids. These observations open the way to study the peculiar properties of vortices in supersolids: their reduced angular momentum, the effect of the crystalline structure on their dynamics, and further applications to the study of other systems with multiple spontaneously broken symmetries, such as neutron stars.

Categories

Quantum fluids

Presentation

Poster presentation

C081

Binding and vortices in squeezed Bose-Bose droplets

Leandra Vranjes Markic[1], Ares Sanuy[2], Rocco Barač[1], Ivan Poparić[1,2], Petar Stipanović[1], Jordi Boronat[2]

[1]University of Split, Faculty of Science, Split, Croatia. [2]Departament de Fisica, Universitat Politecnica de Catalunya, Barcelona, Spain

Abstract

We present the study of ultradilute Bose-Bose liquid droplets in an external harmonic potential that squeezes them in one spatial direction, partially published in [1]. Our theoretical approach is based on a functional that incorporates quantum Monte Carlo (QMC) results of the bulk phase and finite-range effects. Lee-Huang-Yang (LHY) functional is used for comparison in reference cases.

First, we examine the critical atom number N_c, the minimum number of particles required for a many-body bound state. We investigate how N_c for different magnetic fields vary with confinement strengths, approaching a quasi-two-dimensional setup. Our results indicate that N_c decreases linearly with the harmonic oscillator length as the confinement strength increases. Under the strongest interparticle interaction and maximum squeezing, we predict stable droplets with about 1000 atoms. Deviations from the linear behaviour which appear for the larger magnetic fields (lower attractive interaction) and the strongest squeezing suggest approach to 3D-2D crossover, where local density approximation may require correction. To evaluate this effect, we perform QMC calculations of the bulk phase and report first results.

Next, we analyse how droplet size and shape change with the magnetic field and the confinement strength. Near N_c, droplets become less flat with increased squeezing, attributed to confinement-induced increase of interaction strength. For atom numbers significantly above N_c, droplets exhibit saturation and extend perpendicularly to the squeezing direction, similarly to helium droplets.

Finally, we present unpublished results on vortex formation in droplets under varying squeezing strengths.

References

[1] A. Sanuy, et al., PRA **109**, 013313 (2024).

Categories

Quantum fluids

Presentation

C082

Density dependence of the EIT bandwidth in an ultra-cold rubidium cloud.

Ilja Zebergs, Rasmus Malthe Fiil Andersen, Laurits Nikolaj Stokholm, Toke Vibel, Adam Simon Chatterley, Jan Joachim Arlt

Aarhus University, Aarhus, Denmark

Abstract

The poster gives an overview of the ongoing study of electromagnetically induced transparency (EIT) in a rubidium Bose-Einstein condensate (BEC) at the Ultracold Quantum Gases Group at Aarhus University. EIT is a quantum interference phenomenon which manifests in a narrow frequency window of transparency in an otherwise opaque medium. It gives rise to exotic light pulse propagation at extremely low group velocity and very low absorption rate. This also entails the possibility to capture a light pulse as an atomic excitation and release it at a later time, as well as enhanced non-linear phenomena at relatively low light intensity.

Current experiments intend to characterize the dependence of the EIT bandwidth, i.e the transparency window width in the absorption spectrum, on the density of the medium. Specifically, we aim to capture the effect of the collective interactions (collective Lamb shift) on the bandwidth predicted by the theory. According to simulations, the bandwidth should transition from a single-atom description limit (inversely proportional to the square-root of density) to a high-density limit (inversely proportional to the density). Using a BEC allows us to achieve relatively high densities while avoiding thermal broadening effects. To the date we have upgraded our setup to allow for few photon detection, developed a suitable experimental scheme, and started first measurements. The poster presents our experimental setup as well as the current progress towards measuring the EIT bandwith scaling.

Categories

Quantum fluids

Presentation

Poster presentation

C083

Two-component fluids of light in a Rubidium vapor

Clara Piekarski[1], Tangui Aladjidi[2], Nicolas Cherroret[1], Alberto Bramati[1], Quentin Glorieux[1]

[1]Laboratoire Kastler-Brossel, Sorbonne Université, Paris, France. [2]ssel, Sorbonne Université, Paris, France

Abstract

Quantum fluids of light are based on the mathematical analogy between the Gross-Pitaevskii equation (GPE), which describes Bose-Einstein condensates, and the propagation of a laser through a nonlinear Kerr medium – in our case a Rubidium vapor. The work presented here focuses on how this analogy can be pushed to the realization of a two-component fluid. The two-component GPE naturally arises when considering the propagation of the field's circular polarization components. We can then define intra- and inter-component interaction terms, of which the signs and relative weights determine whether the mixture is stable or unstable, miscible or immiscible. I will present different measurements to establish which regimes can be achieved in our system. In particular, I will show experimental results on the measurement of the density and spin dispersion branches in the miscible case, and numerical results on domain formation dynamics in the immiscible case.

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Quantum fluids

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C084

Observation of a microwave-induced Feshbach resonance for sodium atoms

Manon Ballu, Bastien Mirmand, Zhibin Yao, Thomas Badr, Hélène Perrin, Aurélien Perrin

LPL - CNRS - Univ. Sorbonne Paris Nord, Villetaneuse, France

Abstract

Controlling the interactions in a quantum gas is a fascinating feature that allows to explore phase diagrams of quantum systems. Tuning the interactions requires in general the use of a magnetic Feshbach resonance, which requires to confine the atoms in an optical trap in order to control independently the magnetic field and hence the interactions. Feshbach resonances also exist in the optical or in the microwave range, where an oscillating field is required to dress a molecular state near a molecular resonance. In this work, we investigate a microwave Feshbach resonance predicted for alkali, in a degenerate Bose gas of magnetically trapped sodium atoms.

On our experimental setup the quantum gas is trapped beneath an atom chip. Relying on a microwave waveguide located on the same chip, we are able to induce a large amplitude microwave field (several gauss) at the position of the atoms. This allows us to realize a complete spectroscopy of the hyperfine structure of the closest molecular bound state to the sodium atoms ground state with a resolution of the order of 10 kHz.

Near the most favorable resonance, located around 1562 MHz, we investigate its effect on the interatomic interactions. Preliminary observations are compatible with a significant modification of the scattering length of sodium atoms.

Poster

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Poster presentation

C085

Entropy transport between fermionic superfluids

Meng-Zi Huang, Jeffrey Mohan, Philipp Fabritius, Mohsen Talebi, Simon Wili, Tilman Esslinger

ETH Zurich, Zurich, Switzerland

Abstract

The transport properties of strongly interacting fermionic systems can reveal exotic states of matter, but experiments and theories have mostly focused on bulk systems in the hydrodynamic and linear response limit. However, a ballistic channel connecting two superfluid reservoirs of unitary Fermi gases can reach a far-from-equilibrium regime where particle and entropy currents respond nonlinearly to biases of chemical potential and temperature. Here, we explore the coupled transport of particles and entropy, varying the channel geometry and interparticle interaction across the BCS-BEC crossover. Surprisingly, the entropy advectively transported per particle is much larger than the prediction in the hydrodynamic limit and depends only on the interactions and reservoir degeneracy but not on the details of the channel. In our setting, superfluidity counterintuitively increases the speed of entropy transport. The observations suggest that the non-equilibrium entropy transport inherits properties from the universal equilibrium properties of the reservoirs, raising fundamental questions on transport phenomena and universalities in strongly correlated systems far from equilibrium.

Categories

Quantum fluids

Presentation

Poster presentation

C086

Joule expansion of a homogeneous interacting Bose gas

Simon Fischer, Christopher Ho, Sebastian Morris, Jirka Etrych, Gevorg Martirosyan, Christoph Eigen, Zoran Hadzibabic

University of Cambridge, Cambridge, United Kingdom

Abstract

An ideal Bose gas, when allowed to freely expand into a larger volume, is expected to cool due to bosonic statistics, in contrast to a classical ideal gas which remains at the same temperature. We experimentally demonstrate this Joule cooling effect by releasing a box-trapped Bose gas of 39K atoms into a larger box. For negligible interparticle interactions, we observe stronger cooling with increasing quantum degeneracy, which saturates when the gas remains Bose-condensed after expansion. For increasing repulsive interactions, we observe that the quantum cooling effect reduces, as interaction energy is converted into kinetic energy during expansion. Moreover, we find that this reduction in cooling is greater for higher condensed fractions, owing to the different quantum correlations of condensed and thermal bosons.

Categories

Quantum fluids

Presentation

Poster presentation

C087

Interactions and Reconnections of Extra-Dimensional Quantum Vortices

Holly Alice Jess Middleton-Spencer[1], Ben McCanna[1], Davide Proment[2], Hannah Price[1]

[1]University of Birmingham, Birmingham, United Kingdom. [2]University of East Anglia, Norwich, United Kingdom

Abstract

Interactions and reconnections of vortices are fundamental in many areas of physics, including in both classical and quantum fluids. The reconnection procedure provides the mechanism for the distribution of energy to multiple length-scales throughout the system. This has been studied and observed in three-dimensional quantum fluids, resulting in the reporting of universal scaling laws [1]. We generalise this to a four-dimensional system to study how two vortices in a four-dimensional quantum fluids interact.

Recent rapid experimental progress in the creation of synthetic dimensions in ultra-cold atoms and molecules [2] and the recent achievement of a molecular Bose-Einstein condensate [3] provides ample reasoning to explore these extra-dimensional dynamics of topological defects in condensates, with a view of testing and exploring the current laws of universality in vortex reconnections [4]

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Poster

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Categories

Quantum fluids

Presentation

Poster presentation

C088

Searching for chameleon fields using atom interferometry

Bryony Lanigan, Guanchen Peng, Robert Shah, Aisha Kaushik, Joseph Cotter, Ben Sauer, Ed Hinds

Imperial College London, London, United Kingdom

Abstract

There are a number of models that aim to reconcile the observed accelerating expansion of the universe with our current understanding of general relativity. One interesting model proposes the existence of a scalar field that is screened in regions of high matter density and can therefore go unnoticed in experiments performed on Earth – colloquially referred to as the 'chameleon field'.

In 2015 Burrage et al showed that atoms inside a vacuum chamber are too small to screen the chameleon field and could therefore be used as a probe to measure it. Since then a number of experimental searches have been undertaken using cold atoms, but have so far failed to observe its existence.

Here, we describe a number of upgrades to our experiment at Imperial College that improve our precision and reduce systematic sources of errors. We are now planning a series of experiments that will probe the remaining region in parameter space where a signature of the elusive chameleon field may exist.

Poster

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Categories

Matter wave interferometry

Presentation

Poster presentation

C089

Analyzing the sensitivity of an atom interferometer with a phase modulation readout scheme

Takuya Kawasaki[1,2], Sotatsu Otabe[3], Tomoya Sato[3], Martin Miranda[3], Nobuyuki Takei[3], Mikio Kozuma[3,4]

[1]Institute of Innovative Research, Tokyo Institute of Technology, Kanagawa, Japan. [2]Current address: Department of Physics, University of Tokyo, Tokyo, Japan. [3]Institute of Innovative Research, Kanagawa, Japan. [4]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan

Abstract

Atom interferometers are widely used for precise and accurate measurements. As for the sensitivity, the readout scheme of an interferometer is essential since the sensitivity of the interferometer depends on it; the readout scheme determines how the interferometer phase is extracted from the output of the interferometer. However, less attention has been paid to readout schemes in terms of sensitivity in atom interferometers. Since there was no general framework to calculate sensitivity for arbitrary readout schemes, it was not possible to compare and optimize readout schemes.

In this study, we establish a method for calculating sensitivity according to typical readout schemes by applying the two-photon formalism to an atom interferometer; the two-photon formalism was developed to calculate quantum noises in optical interferometers. Based on the calculated results, we find that the readout scheme using phase modulation can reach better sensitivity than the conventional readout scheme with phase sweeping. Our calculation includes not only shot noise but also atom-flux fluctuation. Furthermore, we discuss sensitivities for both a cold atomic beam and a thermal atomic beam. For both cases, the phase modulation readout scheme is advantageous with the optimized parameter of the modulation index. Our work provides a calculation method for atom interferometers' sensitivity and identifies the advantageous readout scheme, including schemes that may be proposed in the future.

This work was supported by JST, Japan Grant Numbers JPMJMI17A3 and JPMJPF2015.

Categories

Matter wave interferometry

Presentation

Poster presentation

C090

Compact Vacuum Chamber for an Earth Gravity Gradiometer

Anna Marchant, Victoria Henderson, Jorge Ferreras, Cameron Deans, Tristan Valenzuela

RAL Space, UKRI STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, OX11 0QX, United Kingdom

Abstract

Atomic quantum sensors offer levels of accuracy and precision unmatched by their classical counterparts, opening up new possibilities in applications such as fundamental physics, navigation and Earth observation. The sensitivity of atom interferometers to inertial forces makes them particularly well suited to Earth observation missions, with this sensitivity further enhanced by the extended free-fall times afforded by the low-gravity conditions in space. In addition, unlike classical accelerometers which suffer from noise at low frequencies, atomic interferometers maintain high accuracy over the entire frequency range.

The fundamental technology associated with cold atom interferometry has been previously flown on the Chinese Space Station [1], the International Space Station [2] and in sounding rockets [3], however, it has not yet been used as the fundamental sensor technology in a free flight space mission. Due to the extended free-fall times associated with these interferometry schemes, it is crucial that the atomic samples used do not expand significantly over the course of the experimental cycle. To achieve this, ultracold clouds, typically Bose-Einstein condensates, are needed. Here we present work characterising a compact vacuum chamber designed to produce Bose-Einstein condensates of ^{87}Rb atoms for use in a cold atom interferometer in future free flight space missions.

ESA project: ‘Compact vacuum chamber for an Earth gravity gradiometer based on laser-cooled atom interferometry’

[1] L. Liu, *et al*., Nat. Commun. 9, 2760 (2018).

[2] D.C. Aveline, *et al*., Nature 582, 193–197 (2020).

[3] D. Becker, *et al*., Nature 562, 391–395 (2018).

Categories

Matter wave interferometry

Presentation

Poster presentation

C091

Bragg interferometer using cold ytterbium atomic beam with sub-recoil momentum width

Toshiyuki Hosoya[1], Tomoya Sato[2], Ryotaro Inoue[2], Atsushi Kira[1], Mikio Kozuma[2,3]

[1]Product Development Center, Japan Aviation Electronics Industry, Ltd., Tokyo, Japan. [2]Institute of Innovative Research, Tokyo Institute of Technology, Kanagawa, Japan. [3]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan

Abstract

Atom interferometry has a variety of potential applications, such as developing a gyroscope for reliable inertial navigation and measuring geodetic and general relativistic effects. One critical issue in improving measurement stability is increasing the tolerance to magnetic fields. A Bragg interferometer using the ground state of two-electron atoms is a promising candidate for a method robust to magnetic disturbance. Given that Bragg diffraction preserves the atomic internal state, the output of the interferometer must be discerned using momentum states. Therefore, a high-flux atomic source with sub-recoil momentum width is crucial for Bragg interferometry.

In this study, we generated a cold ytterbium atomic beam with high flux and sub-recoil momentum width using three optical transitions for a continuous Bragg interferometer. Firstly, a slow atomic beam with a momentum width approximately 50 times that of the recoil momentum and a flux of $3*10^8$ atoms/s was generated using the dipole-allowed $^1S_0$–$^1P_1$ transition. The transverse momentum width was narrowed down to four times the recoil momentum while maintaining the atomic flux using two-dimensional cooling with the $^1S_0$–$^3P_1$ intercombination transition. Finally, we further narrowed the transverse momentum width to a quarter of the recoil momentum with a flux of 10^7 atoms/s using the momentum-selective optical transition between the ground state and the long-lived $^3P_2$ metastable state. In addition, we successfully constructed the Bragg interferometer with the obtained continuous atomic beam. This work was supported by JST, Japan Grant Numbers JPMJMI17A3 and JPMJPF2015.

Categories

Matter wave interferometry

Presentation

Poster presentation

C092

Closed-loop atom interferometer gyroscope with velocity-dependent phase dispersion compensation

Tomoya Sato[1], Naoki Nishimura[2], Naoki Kaku[2], Sotatsu Otabe[1], Takuya Kawasaki[1,3], Toshiyuki Hosoya[4], Mikio Kozuma[1,2]

[1]Institute of Innovative Research, Tokyo Institute of Technology, Kanagawa, Japan. [2]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan. [3]Current address: Department of Physics, University of Tokyo, Tokyo, Japan. [4]Product Development Center, Japan Aviation Electronics Industry, Ltd., Tokyo, Japan

Abstract

A wide dynamic range of measurement is essential for inertial sensors for field applications, such as inertial navigation. Although atom interferometer gyroscopes are potentially more sensitive than conventional optical gyroscopes, their dynamic range is limited by the velocity distribution of atoms. Since the Sagnac phase shift induced by rotation is velocity-dependent, the velocity distribution diminishes the interference contrast at high angular velocities. While several methods have been demonstrated, such as three-dimensional cooling that narrows the velocity distribution of atoms, a simpler and more robust method may improve stability.

We have studied a method of introducing phase shift depending on the atom's velocity using only the two-photon detuning of Raman lights composing Mach-Zehnder atom interferometers to compensate for the dephasing. We found that the dephasing vanishes by performing a closed-loop measurement with two interferometers composed of counterpropagating atomic beams so that the difference between their interference phase is zero by adjusting two-photon detunings. In addition, the angular velocity can be obtained from two-photon detunings satisfying closed-loop conditions, independent of the atom's velocity.

We have validated our proposed method using the atom interferometer gyroscope of Rb thermal atomic beams on a three-axis rotating stage. We confirmed that the interference contrast was maintained with our closed-loop method even with the rotation rate of 1deg/s, whereas the contrast dropped to 1/5 at the rotation rate of 0.6deg/s in the conventional open-loop measurement. Our measurement was robust to equipment tilting, demonstrating the possibility for real-world applications. This work was supported by JST, JPMJMI17A3 and JPMJPF2015.

Categories

Matter wave interferometry

Presentation

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C093

Optimal control pulse design for Raman light-pulse atom interferometry

Tim Freegarde[1], Nikolaos Dedes[1], Jack Saywell[1,2], Max Carey[1,3], Ilya Kuprov[1]

[1]University of Southampton, Southampton, United Kingdom. [2]Now at Q_CTRL, Sydney, Australia. [3]Now at Aquark Technologies, Fareham, United Kingdom

Abstract

The fidelity of atom interferometers that use laser pulses as their mirrors and beam-splitters can be severely limited by experimental realities. Doppler shifts, intensity inhomogeneities and stray fields can affect each atom's Rabi frequency and/or detuning from resonance. The resulting reduction in fringe visibility can limit read-out precision and preclude extended pulse sequences needed for large momentum transfer. Happily, analagous problems have been solved by NMR spectroscopists through the use of composite pulses and optimal control, and experimental investigations have demonstrated their utility.

We have designed a range of high fidelity pulses for atom interferometry, validating them using an atom interferometer based upon Raman transitions between ^{85}Rb hyperfine states. Using gradient-based techniques, we have optimized π (mirror) and π/2 (beam-splitter) pulses for transfer efficiency and phase fidelity; designed pulses that track the separated velocity classes during large momentum transfer; optimized complete interferometer sequences for fringe visibility and scale-factor stability; and investigated the dependence of the optimal solutions upon the target and optimization parameters. We have developed a perturbation theory method linking optimization to the interferometer sensitivity function; and shown that mirrors and beam-splitters can be optimized for interferometers whose 'arms' share the same electronic state. For a 35 µK cloud, we have experimentally demonstrated a transfer efficiency increase from 75% to 99.8%, and shown that 90% transfer can be achieved for detunings at which conventional pulses transfer only 20%. Close agreement between experimental and simulated results has allowed us to identify, characterize and correct modulation nonlinearities within our apparatus.

Categories

Matter wave interferometry

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C094

A cold atom gyroscope for inertial navigation

Keyu He, Alessia Cimbri, Robert Shah, Teodor Krastev, Aisha Kaushik, Edward Hinds, Joseph Cotter

Imperial College London, London, United Kingdom

Abstract

Global navigation satellite systems (GNSS) are used widely in our daily life, yet they are vulnerable to signal obstructions, interference, and cannot operate underground or underwater.

Inertial navigation systems (INS) are a compelling alternative when GNSS is unavailable or unreliable. By measuring the acceleration and rotation of a vehicle, INS can calculate changes in position relative to a known starting point within the map frame. Quantum-enhanced inertial sensors offer improvements in bias and scale-factor stability over classical sensors, potentially leading to more accurate inertial navigation systems in the future.

We present a laboratory-based multi-axis atom interferometer, functioning as both an accelerometer and a gyroscope. The apparatus is mounted on a dynamic platform, allowing us to study cross coupling between accelerations and rotations along different sensing axes. Preliminary results of rotation measurements using this apparatus will be discussed.

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Matter wave interferometry

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C095

Proposal for measuring the optical version of the He-McKellar-Wilkens phase using an atom interferometer, and its connection to the Abraham-Minkowski controversy

Duncan O'Dell, Josh Hainge

McMaster University, Hamilton, Canada

Abstract

An electric dipole moving in a magnetic field acquires a geometric phase known as the He-McKellar-Wilkens (HMW) phase, which is the electromagnetic dual of the Aharanov-Casher phase. The HMW phase was first measured in 2012 using an atom interferometer [1]. In that experiment the electric and magnetic fields were static. We propose a modification where these fields are generated by laser beams. The significance of the optical HMW phase is that it can be connected to the Abraham-Minkowski controversy.

[1] Lepoutre et al, PRL 109, 120404 (2012)

Categories

Matter wave interferometry

Presentation

Poster presentation

C096

Quantum state engineering with dynamic optical potentials: from sensing applications to factorization of integers

Renzo Testa[1], Karen Craigie[1], Daisy Matthews[1], Andrea Trombettoni[2,3], Giuseppe Mussardo[3], Donatella Cassettari[1]

[1]SUPA School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews KY16 9SS, United Kingdom. [2]Department of Physics, University of Trieste, Strada Costiera 11, I-34151 Trieste, Italy. [3]SISSA and INFN, Sezione di Trieste, Via Bonomea 265, I-34136 Trieste, Italy

Abstract

Precise and flexible manipulation of quantum states by means of dynamic optical potentials is a fundamental enabling technology for diverse applications aiming to exploit the unique characteristics of quantum systems. A matter wave interferometry application based on the Sagnac effect for a Bose-Einstein condensate in a ring shaped trap offers a powerful example of a compact geometry for a rotational sensor prototype. We propose a combination of time-varying optical potentials and phase imprint as a way to generate superpositions of persistent currents in the ring trap. Simulations show very high fidelity between the state we generate and the ideal current superposition state, including in presence of self-interactions. The versatile nature of optical potentials is demonstrated by another different and intriguing application, showing the possibility to control the vibrational state of an atom in a 1D potential, in view of performing purely mathematical operations. Potentials having arbitrary sequences of integers as energy levels, such as the first N prime numbers, can been realized using holographic techniques. Even without error-correction algorithms, the experimental eigenvalues reproduce the target sequence with high accuracy. Finer resolution and correction methods of the holographic potential promise better accuracy and the possibility to realize more complex spatial structures. Such remarkable techniques open the way to use quantum physical experiments for addressing important problems such as integer factorization.

Categories

Matter wave interferometry

Presentation

Poster presentation

C097

Ytterbium atom interferometry for dark matter searches

Yifan Zhou, Rowan Ranson, Michalis Panagiotou, Chris Overstreet

Johns Hopkins University, Baltimore, USA

Abstract

We analyze the sensitivity of a laboratory-scale ytterbium atom interferometer to scalar, vector, and axion dark matter signals. A frequency ratio measurement between two transitions in ^{171}Yb enables a search for variations of the fine-structure constant that could surpass existing limits by a factor of 100 in the mass range 10^{-22} eV to 10^{-15} eV. Differential accelerometry between Yb isotopes yields projected sensitivities to scalar and vector dark matter couplings that are stronger than the limits set by the MICROSCOPE equivalence principle test, and an analogous measurement in the MAGIS-100 long-baseline interferometer would be more sensitive than previous bounds by factors of 10 or more. A search for anomalous spin torque in MAGIS-100 is projected to reach similar sensitivity to atomic magnetometry experiments. We discuss strategies for mitigating the main systematic effects in each measurement. These results indicate that improved dark matter searches with Yb atom interferometry are technically feasible.

Categories

Matter wave interferometry

Presentation

Poster presentation

C098

Robust Bragg diffraction for atom interferometers using optimal control theory

Víctor José Martínez Lahuerta[1], Rui Li[1], Jan-Niclas Kirsten-Siemß[1], Klemens Hammerer[2], Naceur Gaaloul[1]

[1]Institute of Quantum Optics, Leibniz University, Hannover, Germany. [2]Institute for Theoretical Physics, Leibniz University, Hannover, Germany

Abstract

Algorithms from the field of artificial intelligence (AI) and machine learning have been used in recent years to efficiently solve multidimensional problems. In physics, these algorithms are applied with increasing success, e.g., to solve the Schrödinger equation for many-body problems, or used experimentally to generate ultracold atoms and control lasers. In this project, we aim to work on three fundamental pillars of AI in atom interferomtry: theory modelling, operation of experiments, and measurement data extraction. We report on our results obtained optimizing Bragg diffraction for atom interferometers towards robust operation with ensembles featuring finite velocity uncertainties (of up to 30% of the laser recoil velocity). In the case of high-order Bragg pulses, we focus on minimizing diffraction phase shifts by suppressing scattering to off-resonant momentum states. For double Bragg pulses, we optimize the beam splitting efficiencies and make the diffraction robust against polarization imperfections of the coupling light fields.

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Matter wave interferometry

Presentation

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C099

Purcell-modified Doppler cooling of quantum emitters inside optical cavities

Julian Lyne[1,2], Nico Baßler[2,1], Seong eun Park[3], Guido Pupillo[4], Claudiu Genes[1]

[1]Max Planck Institute for the Science of Light, Erlangen, Germany. [2]FAU Erlangen Nürnberg, Erlangen, Germany. [3]Daegu Gyeongbuk Institute of Science and Technology, Daegu, Korea, Republic of. [4]University of Strasbourg, Strasbourg, France

Abstract

Standard cavity cooling of atoms or dielectric particles is based on the action of dispersive optical forces in high-finesse cavities. We investigate here a complementary regime characterized by large cavity losses, resembling the standard Doppler cooling technique. For a single two-level emitter a modification of the cooling rate is obtained from the Purcell enhancement of spontaneous emission in the large cooperativity limit. This mechanism is aimed at cooling quantum emitters without closed transitions, which is the case for molecular systems, where the Purcell effect can mitigate the loss of population from the cooling cycle. We extend our analytical formulation to the many-particle case governed by small individual coupling but exhibiting large collective coupling.

Categories

Cavity QED

Presentation

Poster presentation

C100

Deterministic freely propagating photonic qubits with negative Wigner functions

Valentin Magro, Julien Vaneecloo, Sébastien Garcia, Alexei Ourjoumtsev

JEIP, Collège de France, Paris, France

Abstract

For quantum simulations and quantum computing applications, scalability is paramount. Achieving scalability in quantum optics hinges on the development of photon gates or photon sources capable of deterministic behavior.

Here, we will present the first fully-deterministic preparation of non-GaussianWigner-negative free-propagating optical quantum states. In our setup, a small atomic cloud, placed inside a medium finesse optical cavity and driven to a highly-excited Rydberg state acts as a single two-level collective "superatom". We coherently control its internal state, then map it onto a free-propagating light mode to produce an optical qubit encoded as a quantum superposition of 0 and 1 photons. Its single-photon character is revealed by photon-correlation measurements showing strong antibunching. The photonics states are generated in the desired spatio-temporal mode with a high 60% efficiency. In agreement with theoretical predictions, reconstructed Wigner functions are quadrature-squeezed for small qubit rotation angles and develop a negative region when angle approaches π and the one-photon component becomes dominant.

We will also investigate the limits of the perfect superatom model. Indeed, the two-level behaviour of our atomic ensemble relies on the strong interactions betweens Rydberg-state atoms. We will introduce a new model describing efficiently an imperfect Rydberg blockade in a small atomic cloud. We will perform coherent Rabi oscillations on our ”superatom” for three Rydberg states n = 80, 95, 109 and measure Rydberg residual population as well as photon number extracted from the cavity of differents qubit rotation angle.

Categories

Cavity QED

Presentation

Poster presentation

C101

Observation of a phase transition from a continuous to a discrete time crystal

Hans Keßler[1,2], Phatthamon Kongkhambut[1], Jayson G. Cosme[3], Anton Bölian[1], Jim Skulte[1], Michelle A. Moreno Armijos[4], Ludwig Mathey[1], Andreas Hemmerich[1]

[1]University of Hamburg, Hamburg, Germany. [2]University of Bonn, Bonn, Germany. [3]University of the Philippinesines, Diliman, Philippines. [4]University of São Paulo, São Carlos, Brazil

Abstract

Discrete (DTCs) and continuous time crystals (CTCs) are novel dynamical many-body states, that are characterized by robust self-sustained oscillations, emerging via spontaneous breaking of discrete or continuous time translation symmetry. DTCs are periodically driven systems that oscillate with a subharmonic of the drive, while CTCs are driven continuously and oscillate with a system's inherent frequency. Here, we explore a phase transition from a continuous time crystal to a discrete time crystal [1]. A CTC with a characteristic oscillation frequency ω_{CTC} is prepared in a continuously pumped atom-cavity system. Modulating the pump intensity of the CTC with a frequency ω_{dr} close to $2\omega_{CTC}$ leads to robust locking of ω_{CTC} to $\omega_{dr}/2$, and hence a DTC arises. This phase transition in a quantum many-body system is related to subharmonic injection locking of non-linear mechanical and electronic oscillators or lasers.

[1] P. Kongkhambut, et al., arxiv.org/abs/2402.12378v1

Categories

Cavity QED

Presentation

Poster presentation

C102

Multicritical dissipative phase transitions in the anisotropic open quantum Rabi model

Guitao Lyu[1], Korbinian Kottmann[2], Martin Plenio[3], Myung-Joong Hwang[1]

[1]Duke Kunshan University, Kunshan, China. [2]The Barcelona Institute of Science and Technology, Barcelona, Spain. [3]Ulm University, Ulm, Germany

Abstract

We investigate the nonequilibrium steady state of the anisotropic open quantum Rabi model, which exhibits first-order and second-order dissipative phase transitions upon varying the degree of anisotropy between the coupling strengths of rotating and counterrotating terms. Using both semiclassical and quantum approaches, we find a rich phase diagram resulting from the interplay between the anisotropy and the dissipation. First, there exists a bistable phase where both the normal and superradiant phases are stable. Second, there are multicritical points where the phase boundaries for the first- and second-order phase transitions meet. We show that a new set of critical exponents governs the scaling of the multicritical points. Finally, we discuss the feasibility of observing the multicritical transitions and bistability using a pair of trapped ions where the anisotropy can be tuned by the controlling the intensity of the Raman transitions. Our study enlarges the scope of critical phenomena that may occur in finite-component quantum systems, which could be useful for the applications in the critical quantum sensing.

Poster

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Presentation

Poster presentation

C103

Progress towards a continuous wave superradiant Calcium Laser

David Nak, Andreas Hemmerich

Institute for Quantum Physics, University of Hamburg, Hamburg, Germany

Abstract

Superradiant Lasers are suitable as light sources with ultralow bandwidth, as their emission frequency is only weakly dependent on an eigenfrequency of the laser cavity. They can be used as a read-out tool for precise optical atomic clocks. Currently, our experiment loads cold Calcium-40 atoms from a magneto optical trap into a one-dimensional optical lattice prepared inside a cavity. By incoherent population of the metastable triplet state, pulsed superradiant emission on the intercombination line was realized [1]. We will present our progress with the advancement of our bichromatic MOT and our incoherent repumping protocol, which will enable us to maintain the superradiant state for an extended period of time.

[1] T. Laske, H. Winter, and A. Hemmerich, Pulse Delay Time Statistics in a Superradiant Laser with Calcium Atoms, Phys. Rev. Lett. 123, 103601 (2019).

Categories

Cavity QED

Presentation

Poster presentation

C104

Unlocking ultra-short time-scale many-body entanglement generation through atom-pair coupling to cavity photons

Sankalp Sharma[1], Jan Chwedeńczuk[2], Tomasz Wasak[1]

[1]Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Toruń, Poland. [2]Faculty of Physics, University of Warsaw, Warsaw, Poland

Abstract

The process of generation of many-body entangled states in atomic samples should be fast, because it is always a subtle interplay between desired quantum effects and unwanted decoherence. Here, we identify a powerful, controllable and scalable catalyst for this process, allowing to create metrologically useful entangled states at an unprecedented pace. This is achieved by immersing a collection of bosonic atoms, trapped in a double-well potential, into an optical cavity. In our protocol, the cavity photons couple pairs of atoms in a ground state to molecular state in a dispersive regime, effectively, as we show, generating photon-number-dependent atom-atom interaction. This allows to entangle atoms at a rate that scales with the photon number, a pace that is much faster than that related to the atom-atom interactions. We demostrate that the proposed approach is very robust to the main source of decoherence, coming from the photon losses. We also identify the characteristic time-scales of the entanglement build-up in this setup, which set the benchmark for the acceptable loss rates. Moreover, the control over the entanglement-generation rate does not require any use of Feshbach resonances, where the fluctuations of the magnetic field may contribute to decoherence. Our protocol may find applications in future quantum sensors or any other setups where controllable and scalable many-body entanglement is desired.

Poster

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C105

Three-dimensional Magneto-optical Trapping of Barium Monofluoride

Zixuan Zeng, Bo Yan

Zhejiang University, Hangzhou, China

Abstract

As a heavy molecule, barium monofluoride (BaF) presents itself as a promising candidate for measuring permanent electric dipole moment. The precision of such measurements can be significantly enhanced by utilizing a cold molecular sample. Here we report the realization of three-dimensional magneto-optical trapping (MOT) of BaF molecules. Through the repumping of all the vibrational states up to v = 3, and rotational states up to N = 3, we effectively close the transition to a leakage level lower than 10^{-5}. This approach enables molecules to scatter a sufficient number of photons required for laser cooling and trapping. By chirped slowing, BaF molecules are decelerated to near-zero velocity, resulting in the capture of approximately 3×10^3 molecules in a dual-frequency MOT setup. Our findings represent a significant step towards the realization of ultracold BaF molecules and the conduct of precision measurements with cold molecules.

Categories

Molecules

Presentation

Poster presentation

C106

A new apparatus for investigating collisions and chemical processes with ultracold NaK molecules

Jakob Stalmann[1], Sebastian Anskeit[1], Fritz von Gierke[1], Kai Voges[2], Silke Ospelkaus[1]

[1]Institute of Quantum Optics, Hannover, Germany. [2]Centre for Cold Matter, Blackett Laboratory, Imperial College, London, United Kingdom

Abstract

Ultracold molecular collisions feature many highly complex and still not understood phenomena, such as formation and loss
of long-lived collisional complexes, molecular Feshbach resonances and chemical reactions.

Here, we present our efforts for the construction of a new experimental setup for the investigation of such collisional phenomena with ultracold $^{23}Na^{39}K$ ground-state molecules.

For ground-state molecule creation, we first produce optically trapped ultracold atomic ensembles from a dual-species Zeeman slower and MOT setup. The atoms are optically transported to a science chamber, where molecule preparation takes place by first creating weakly bound Feshbach molecules and subsequently transfering them into their ground state by a coherent Raman process.
For detection of all educt and product particles of molecular collisions, our setup comprises a time of flight-velocity map imaging mass spectrometer in the science chamber. In combination with a state-selective pulsed laser ionization and fragmentation scheme this will allow us to resolve chemical reaction pathways, explore ultracold reaction dynamics and develop new quantum control techniques for chemical reaction steering.

Categories

Molecules

Presentation

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C107

Towards a MOT of AlF molecules: testing deep ultraviolet laser cooling of cadmium atoms

J. Eduardo Padilla-Castillo[1], Simon Hofsäss[1], Jionghao Cai[1], Lajos Palanki[2], Russell S. Thomas[1], Sebastian Kray[1], Boris Sartakov[1], Gerard Meijer[1], Stefan Truppe[1,2], Sidney C. Wright[1]

[1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany. [2]Centre for Cold Matter, Imperial College London, SW7 2AZ London, United Kingdom

Abstract

Aluminium monofluoride (AlF) is a promising candidate for laser cooling and trapping at high densities. The primary laser cooling transition at 227.5 nm is extremely strong, highly vibrationally diagonal, and it is feasible to slow a molecular beam from 200 m/s to rest in around 1 cm. This offers the potential to greatly increase the number and density of molecules available for ultracold experiments.

As a useful first step towards a magneto-optical trap (MOT) of AlF, we tested our experimental system on cadmium atoms. The $^1P_1$-$^1S_0$ transition in Cd at 229 nm lies conveniently near the laser cooling transition in AlF, with an almost identical radiative lifetime. However, the simple structure of atomic Cd enables slowing and trapping with a single laser, with far fewer loss channels than for AlF. Moreover, the narrow $^3P_1$-$^1S_0$ intercombination line in Cd permits straightforward velocity resolved measurements at the level of 1 m/s, via Doppler-sensitive laser-induced fluorescence.

We demonstrate rapid loading of a high density Cd MOT on the $^1P_1$-$^1S_0$ transition with a cold atomic beam of Cd. Using the intercombination line, we measure the velocity distribution directly in front of the trap location and compare Zeeman, crossed beam and chirped frequency laser slowing. As an outlook, we show chirped frequency slowing laser slowing applied to AlF molecules, decelerating from 160 m/s to 80 m/s. Our experiments illustrate the power of deep ultraviolet laser slowing, providing useful guidance and a pathway towards a future MOT of AlF.

Categories

Molecules

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C108

Direct Cooling of Dipolar Molecules Towards Bose-Einstein Condensation

Claudia Volk, Arijit Chakraborty, Jing Wu, Ben E. Sauer, Stefan Truppe, Michael R. Tarbutt

Centre for Cold Matter, Imperial College London, London, United Kingdom

Abstract

Bose-Einstein condensates (BECs) have been and continue to be extensively studied in atoms, with molecules being a logical next step. Molecules can have large, tunable electric dipole moments so a molecular BEC forms a strongly dipolar quantum fluid and can be used to study many-body physics and for quantum simulations. However, the production of such molecular BECs, either through association of ultracold atoms or direct cooling of the molecules, is very challenging.

In our experiment we produce, cool down, and trap CaF molecules in several steps. The molecules are generated in a cryogenic buffer gas source such that they form a cold molecular beam, then decelerated to rest using frequency-chirped slowing, are finally trapped in a magneto-optical trap (MOT). To reach the lower temperatures and higher densities necessary for the phase transition to a BEC, the molecules need to be cooled further in an optical molasses and compressed using either magnetic compression or the blue-detuned MOT method. Afterwards, the molecules will be loaded into a crossed-dipole trap for evaporative cooling until they form a BEC. Two-body losses can be controlled and suppressed by applying an electric field, which will also improve the elastic scattering rate.

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Molecules

Presentation

Poster presentation

C109

Progress on the laser cooling and frequency-chirped magneto-optical trapping of MgF

Nickolas Pilgram, Stephen Eckel, Eric Norrgard

NIST, Gaithersburg, USA

Abstract

Magnesium monofluoride (MgF) is an ideal candidate for laser cooling and magneto-optical trapping due to its light mass, fast scattering rate, and low wavelength cycling transition. Under ideal conditions, a typical cryogenic buffer gas beam of MgF can be stopped in a few centimeters. In principle, this short stopping distance allows a magneto-optical trap (MOT) of MgF to be directly loaded from a beam without additional slowing. MOT capture efficiency can be improved by a combination of frequency-chirped magneto-optical trapping, a two-stage cryogenic buffer gas beam source, and modest laser slowing. We report on the application of these three techniques toward the laser cooling and magneto-optical trapping of MgF, including high resolution spectroscopy of vibrational repumping transitions.

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Molecules

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C110

Ultracold LiCr and the quest for quantum gases of doubly-polar molecules

Alessio Ciamei[1], Stefano Finelli[2], Beatrice Restivo[1], Maximilian Schemmer[1], Antonio Cosco[2], Massimo Inguscio[3], Andreas Trenkwalder[1], Klaudia Zaremba-Kopczyk[4], Marcin Gronowski[4], Michal Tomza[4], Matteo Zaccanti[1]

[1]INO-CNR, Sesto Fiorentino, Italy. [2]Dipartimento di Fisica e Astronomia, Università di Firenze, Firenze, Italy. [3]LENS, Sesto Fiorentino, Italy. [4]Department of Physics, University of Warsaw, Warsaw, Poland

Abstract

Quantum gases of doubly polar molecules, possessing both an electric and a magnetic dipole moment, have been proposed for a number of cross-disciplinary applications, ranging from precision measurements to quantum simulation and ultracold chemistry. Here, we report on a joint experimental-theory work, in which we explore a novel system composed of alkali metal (lithium) and transition metal (chromium) atoms. Thanks to a suitable set of FRs and the favorable stability of the ^{6}Li-^{53}Cr Fermi mixture, we produce up to 50x10^3 molecules at phase-space densities exceeding 0.1. These Feshbach dimers conveniently populate the least bound vibrational level of the electronic sextet ground state. We show the paramagnetic nature of our Feshbach dimers and demonstrate quantum state control over them via novel probing methods. We investigate the dominant loss processes and achieve lifetimes in excess of 0.2 s for pure LiCr samples. Our theory collaborators, led by Prof. M. Tomza, carry out state-of-the art quantum chemical calculations to predict properties of the electronic ground and low-lying excited states, identifying favorable transitions for the coherent optical transfer to the rovibrational ground-state. This is predicted to feature both large electric (3.3D) and magnetic ($5\mu_B$) dipole moments.

Categories

Molecules

Presentation

Poster presentation

C111

Collisions in a quantum gas of bosonic $^{23}Na^{39}K$ molecules

Mara Meyer zum Alten Borgloh[1], Jule Heier[1], Philipp Gersema[1], Kai Konrad Voges[2], Charbel Karam[3], Leon Karpa[1], Olivier Dulieu[3], Silke Ospelkaus[1]

[1]Leibniz Universität Hannover, Institut für Quantenoptik, Hanover, Germany. [2]Centre for Cold Matter, Blackett Laboratory, Imperial College London, London, United Kingdom. [3]Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton, Paris, France

Abstract

We report on our experiments with quantum gases of polar $^{23}Na^{39}K$ molecules. We discuss both atom-molecule and molecule-molecule collisions including the origin of loss processes in a cloud of chemically stable molecules. Furthermore, we discuss a method for suppressing molecular loss using a coherent two-photon transition to induce a potential barrier that protects the colliding molecules from reaching the short range.

Categories

Molecules

Presentation

Poster presentation

C112

Ultracold SrOH for EDM and Dark Matter Searches

Abdullah Nasir[1], Mingda Li[2], Annika Lunstad[1], Hiromitsu Sawaoka[1], Alex Frenett[1], Zack Lasner[1], Loic Anderegg[1], Rachel Fields[1], Jack Mango[1], John Doyle[1]

[1]Harvard University, Cambridge, USA. [2]Harvard University, Camridge, USA

Abstract

Laser-coolable polyatomic molecules containing heavy nuclei are a promising platform for probes of fundamental physics, e.g. searches for the electron electric dipole moment (eEDM) and temporal variation of fundamental constants. Their advantages over simpler systems stem from structural complexity. However, these structures also make laser cooling and trapping the molecules difficult. To date, only one other polyatomic molecule, CaOH, has been laser-cooled and trapped in a magneto-optical trap (MOT). SrOH, which has many of the same characteristics that made it possible to laser-cool CaOH (1, 2) has much greater sensitivity to physics beyond the Standard Model. We report a MOT of SrOH containing >10^3 molecules. We will also discuss our next steps towards precision measurements using SrOH, including high resolution spectroscopy of additional vibrational repumping transitions, sub-doppler cooling, and loading of SrOH into an optical dipole trap.

1: Kozyryev et al., PRL, 2017

2: Lasner et al., PRA, 2022

Categories

Molecules

Presentation

Poster presentation

C113

Optical Tweezer Arrays and Ultracold Collisions of Polyatomic Molecules

Paige Robichaud[1,2], Nathaniel Vilas[1,2], Christian Hallas[1,2], Grace Li[1,2], Loïc Anderegg[1,2], John M. Doyle[1,2]

[1]Harvard University, Cambridge, USA. [2]Harvard-MIT Center for Ultracold Atoms (CUA), Cambridge, USA

Abstract

Ultracold polyatomic molecules are a promising platform for pursuing quantum science and for studies of novel ultracold collisions and chemistry. Polyatomic molecules generically possess closely-spaced parity doublet states which allow the molecule to be polarized at low electric fields and generate an advantageous stark level structure for both precision measurement and quantum information processing. Here, we present work on direct laser cooling of calcium monohydroxide (CaOH) and the loading of optical tweezer arrays with single CaOH molecules. We demonstrate coherent quantum control of parity doublet states in a single vibrational bending mode. In addition, due to the high densities achievable with our recent conveyor-belt magneto-optical trap, we study collisions between molecules in an optical dipole trap. We compare the inelastic collision rate in different quantum states of the molecule (including the parity doublets) at various electric field strengths, exploring both van der Waals and dipolar interactions and collisional shielding.

Categories

Molecules

Presentation

Poster presentation

C114

High-Resolution Spectroscopy of Radioactive Molecules for Fundamental Physics

Chandler Conn[1], Phelan Yu[1], Madison Howard[1], Yuxi Yang[1], Chaoqun Zhang[2], Lan Cheng[2], Nicholas Hutzler[1]

[1]Caltech, Pasadena, USA. [2]Johns Hopkins, Baltimore, USA

Abstract

Radioactive molecules containing octupole-deformed nuclei are highly sensitive platforms for probing symmetry-violating physics beyond the Standard Model. Limited radioisotope abundances and handling hazards, however, pose challenges to their study. Here, we discuss the construction of a cryogenic buffer gas spectrometer designed for radioactive molecule spectroscopy. We discuss the first synthesis, detection, and high-resolution laser spectroscopy of neutral polyatomic radium monohydroxide (RaOH) from microgram-scale quantities of source material. Due to favorable relativistic effects, radium pseudo-fluoride systems such as RaOH are anticipated to possess unusually diagonal optical cycling transitions which -- combined with the large static octupole deformation of Ra -- makes them promising platforms for next-generation molecular nuclear Schiff moment (NSM) experiments.

Categories

Molecules

Presentation

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C115

Hyperfine-resolved spectroscopy of the X $^1\Sigma_+$ - b $^3\Pi_0$ transitions in ultracold $^{87}Rb^{133}Cs$ molecules

Arpita Das[1], Albert Li Tao[1], Luke M. Fernley[1], Fritz Von-Gierke[2], Philip D. Gregory[1], Simon L. Cornish[3]

[1]Department of Physics and Joint Quantum Centre (JQC) Durham-Newcastle, Durham University, Durham DH1 3LE, United Kingdom. [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany. [3]Department of Physics and Joint Quantum Centre (JQC) Durham-Newcastle, Durham University, Durham DH1~3LE, United Kingdom

Abstract

Long rotational coherence times of ultracold polar molecules are required for many proposed applications, including quantum computation and quantum simulation. In our previous work, we have demonstrated a rotationally magic trap for ultracold $^{87}Rb^{133}Cs$ molecules at a detuning of 185 GHz from the transition at 1146.1 nm from the rovibrational ground state of the X $^1\Sigma_+$ potential to the lowest vibrational level of the b $^3\Pi_0$ potential. We have observed second-scale rotational coherence and detected the dipolar interactions in a dilute gas of molecules through the loss of contrast in a Ramsey sequence. Here, we report hyperfine-resolved spectroscopy of the relevant transitions needed to develop an improved model of the magic conditions. We resolve rotational and hyperfine structures associated with the three lowest vibrational levels of the b $^3\Pi_0$ potential. From the spectroscopy, we extract the anharmonicity parameter of $^{87}Rb^{133}Cs$ molecules in the b $^3\Pi_0$ state. Linear Zeeman shifts of the hyperfine states are measured across magnetic fields ranging from 181.5 G to 210.4 G, from which the associated magnetic moments are derived. We determine the transition dipole moments to the lowest two vibrational levels by directly driving the Rabi oscillations. The results indicate partial transition linewidths of 4.7(1) kHz and 2.7(1) kHz, respectively. We also measure excited state lifetimes of 12.3(1) μs and 7.20(4) μs, corresponding to natural linewidths of 13.0(9) kHz and 22.1(8) kHz. As an outlook, we report ongoing work to load the molecules into a magic wavelength optical lattice.

Categories

Molecules

Presentation

Poster presentation

C116

Mercury Rydberg molecules

Agata Wojciechowska[1], Michał Tomza[1], Matthew Eiles[2]

[1]University of Warsaw, Warsaw, Poland. [2]Max-Planck-Institut fur Physik komplexer Systeme, Dresden, Germany

Abstract

The discovery of Rydberg matter empowers prospects in ultracold science. In recent times, physicists direct their attention to giant and polarizable ultralong-range Rydberg molecules, composed of an excited Rydberg atom and a ground-state atom bound through electron scattering. In both theoretical and experimental studies, people predominantly utilize alkali atoms like Rb. We propose a model to describe the Rydberg molecules composed of Hg atoms, which are effectively two valence electron atoms. The generalized frame transformation paves the path towards more complex multielectron Rydberg molecules. We provide the energy spectrum of hetero- and homonuclear molecules -- Hg*Rb and Hg*Hg, unraveling compelling peculiarities of Hg*Rb potential energy curves. We propose the realization of long-range spin entanglement and remote spin flip in this molecule. Finally, we discuss the Hg*Hg spectrum with the Hg scattering data incorporated.

Categories

Molecules

Presentation

Poster presentation

C117

Elastic scattering of metastable positronium from antihydrogen

Yi Zhang[1], Guo-An Y[2], Kalman Varga[3], Jun-Yi Zhang[4]

[1]Center for Theoretical Physics, Hainan University, Haikou, China. [2]School of Physics and Physical Engineering, Qufu Normal University, Qufu, China. [3]Department of Physics and Astronomy, Vanderbilt University, Nashville, USA. [4]State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan, China

Abstract

Collisions between metastable positronium (Ps) and antihydrogen ($\bar{H}$) are pivotal in antihydrogen experiment series. This study improves the analysis of elastic scattering between $\bar{H}$ and Ps(2s) by integrating the confined variational method with the projection method, targeting scattering energies from 0.0245 eV to 0.068 eV. The projection method elucidates the wavefunction of the excited Ps(2s) state, while the confined variational method is employed to calculate scattering phase shifts. Our findings provide accurate phase shifts and partial scattering cross-sections for the ^{1,3}S- and ^{1,3}P-wave interactions between $\bar{H}$ and Ps(2s). The pronounced increase in the total scattering cross-section near the bound threshold suggests possible P-wave resonance effects. Moreover, we determined the scattering lengths to be 9.28 a_0 for singlet and 5.77 a_0 for triplet scattering between $\bar{H}$ and Ps(2s).

Categories

Molecules

Presentation

Poster presentation

C118

Optical cycling of MgF molecules

Seunghwan Roh, Kikyeong Kwon, Youngju Cho, Dongkyu Lim, Giseok Lee, Youngwoong Lee, Hyunjun Jang, Eunmi Chae

Korea University, Seoul, Korea, Republic of

Abstract

Diatomic molecules are emerging as an innovative platform for quantum simulation and quantum computing. Their complex internal structures allow for the definition of stable qubit states within the electronic ground state of these molecules. Moreover, their large electric dipole moment has enabled the demonstration of entanglement between two molecular qubits. The Magneto-Optical Trap (MOT) is the initial step required to cool molecules to ultracold temperatures, which is essential for various quantum research applications. Numerous diatomic molecules, such as CaF, SrF, and YO, have been successfully trapped in MOTs.

MgF molecule is a promising candidate for laser cooling due to its light mass, strong UV transition, and highly diagonal Franck-Condon Factor. Moreover, MgF has bosonic and fermionic isotopologues, which enables quantum techniques using both Bose/Fermi statistics with laser-cooled molecules.

In this poster, we report optical cycling, which is the first-step of laser-cooling, of 24MgF within the hyperfine states of the ground state. A two-fold increase in fluorescence was achieved by forming closed-cycling transitions using an electro-optic modulated laser. The poster will provide detailed information about the overall experiment and the performance of the optical cycling, as well as the on-going efforts on laser-slowing of MgF molecules.

Categories

Molecules

Presentation

Poster presentation

C119

Zeeman-Sisyphus deceleration of CaF molecules

Bethan Humphreys, Archie Baldock, Alex Matthies, David Carty, Hannah Williams

Durham University, Durham, United Kingdom

Abstract

The complex internal structure of ultracold molecules offers exciting possibilities for quantum technology, cold chemistry and fundamental physics. However, this complexity comes with additional challenges for reaching low temperatures.
As a step in producing molecules in the ultracold regime, direct laser slowing has proved to be a hugely successful technique, decelerating fast molecular beams to below the capture velocity of a magneto-optical trap ($\sim$20 m/s). This process requires $\sim 10^4$ photons to be scattered however, so is impractical for the vast majority of molecular species, particularly those with unfavourable branching ratios, long wavelength transitions or large masses.

Zeeman-Sisyphus deceleration (1) presents a novel way to address these concerns, reducing the number of photon scatters required by at least two orders of magnitude compared to laser slowing. Molecules travel through a spatially varying magnetic field and are optically pumped between high and low field seeking substates to ensure they are continually climbing a potential hill. This technique has previously been demonstrated for polyatomic molecules (2, 3), using two cryogenically cooled superconducting magnets.

Here, we present our current progress in building upon this work. We produce CaF molecules using a cryogenic buffer gas source (4) and use a series of permanent magnets which can be extended to many hundreds of deceleration stages.

(1) Fitch N.J. et al *ChemPhysChem* **17** 22 (2016)
(2) Augenbraun B.L. et al *Phys. Rev. Lett.* **127** 263002 (2021)
(3) Sawaoka H. et al *Phys. Rev. A* **107** 022810 (2023)
(4) Truppe S. et al *J. Mod. Opt.* **65**:5-6 (2018)

Categories

Molecules

Presentation

Poster presentation

C120

Bialkali and Beyond: Experiments with ultracold RbCs molecules and a future Ag-Cs mixture

Philip Gregory

Durham University, Durham, United Kingdom

Abstract

Ultracold polar molecules uniquely combine a rich structure of long-lived internal states with access to controllable long-range anisotropic dipole-dipole interactions. One class of molecules currently available in experiments are bialkali molecules that are produced at ultracold temperatures by association from a pre-cooled mixture of atoms. In Durham, we routinely produce ultracold gases of RbCs molecules and have recently developed a rotationally-magic trap that supports second-scale coherence times [1]. In this poster, we report on new directions for our experiments with RbCs, including plans to directly detect the molecules using either absorption imaging [2] or dispersive imaging [3]. Both imaging schemes probe transitions between the $X^1\Sigma+ \rightarrow A^1\Sigma^{+}+b^3\Pi_0$ potentials with 935nm light. We also present plans for a new project underway in Durham to produce an ultracold mixture of Ag and Cs atoms with the aim of creating ultracold polar molecules with dipole moments in the $^1\Sigma$ ground state of around 10 Debye [4].

[1] P. D. Gregory *et al.*, Nature Physics **20**, 415-421 (2024).

[2] D. Wang *et al.*, Physical Review A **81**, 061404(R) (2010).

[3] Q. Guan *et al.*, Physical Chemistry Chemical Physics **22**, 20531-20544 (2020).

[4] M. Śmiałowski and M. Tomza, Physical Review A **103**, 022802 (2021).

Categories

Molecules

Presentation

Poster presentation

C121

Fast entanglement between molecular qubits

Gabriel Patenotte, Annie Park, Lewis Picard, Samuel Gebretsadkan, Kang-Kuen Ni

Harvard University, Cambridge, USA

Abstract

Individual trapping of polar molecules enables precise control of their rich rotational-hyperfine structure and their long range anisotropic electric dipole-dipole interactions. We report ten exchanges of rotational energy between two NaCs molecules at the ms-scale. By interrupting the interaction at a quarter-cycle we verify production of a maximally entangled Bell state with a fidelity of 0.94(3) in trials where both molecules are present. Furthermore, we tune the interaction rate with the tweezer polarization and turn it off by changing the hyperfine state of the molecule. The latter technique enables the realization of a molecular iSWAP gate for which a truth table has been verified. Control over the dipolar interaction paves the way for universal quantum computing and quantum simulation with polar molecules.

Categories

Molecules

Presentation

Poster presentation

C122

Probing the nuclear magnetic octupole moment of trapped Sr ions

Julien Grondin, Pierre Lassegues, Philip Imgram, Stefanos Pelonis, Ruben de Groote

KULeuven, Leuven, Belgium

Abstract

Nuclear multipole moments inform us on the charge distribution of the nucleus, as well as the nuclear configuration and wavefunctions. This has made these nuclear observables frequently beneficial for testing nuclear theory models. Typically, and especially for short-lived radioactive atoms, only the two lowest-order moments, the magnetic dipole and electric quadrupole moment, are experimentally accessible. The nuclear magnetic octupole moment stands out as a so far underexplored observable, which may be key to exploring the inhomogeneities in magnetization currents and neutron distributions within nuclei. The small magnitude of the experimental signature of this moment, typically on the order of 100 Hz or less, poses challenges for current in-flight laser spectroscopy techniques to precisely measure the octupole-induced shift in hyperfine structure.

In this study, we introduce a novel approach using ion trap technology coupled with radiofrequency spectroscopy to address this limitation. We aim to measure the nuclear magnetic octupole moment of stable singly ionized trapped strontium. This work covers the theoretical framework for investigating octupole moments, delves into our measurement techniques, and updates on the project's progress.

Categories

Precision measurements

Presentation

Poster presentation

C123

Shipborne absolute gravity surveys based on cold atom gravimeter

Can Zhang[1], Yin Zhou[1], Qianlong Chen[1], Peng Yuan[1], Zhongkun Qiao[1], Bing Cheng[1], Bin Wu[1], Xiaolong Wang[1], Qiang Lin[1,2]

[1]Zhejiang University of Technology, Hangzhou, China. [2]Zhejiang University, Hangzhou, China

Abstract

Dynamic precision measurement of gravity field is of great importance to the fields of geological surveying, resource exploration, etc. Current shipborne dynamic gravity survey is mainly relative measurement, thereby facing the drawbacks of accuracy calibration and zero-point drift of instruments. Operation of the atomic gravimeters in dynamic measurement could solve these problems. Whereas, during the measurement of absolute gravity in a dynamic environment, the interference and coupling of the dynamic environment is an important issue to be solved urgently.

The new progress on the dynamic precision measurement of gravity field in our group is presented in this poster. Experiments of marine gravity surveys are carried out in the Chinese Yellow Sea. The cross and repeat survey lines are designed in order to evaluate the performance. The internal consistency accuracy of our marine survey system is estimated to be less than 1 mGal. The results are also in good agreement with the data measured by the relative gravimeter. The comparison between the gravity data measured by our dynamic atom gravimeter with the satellite gravity data shows that they are in good agreement.

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Precision measurements

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C124

Bose-Einstein condensation of dipolar molecules with double microwave shielding

Ian Stevenson[1], Niccolò Bigagli[1], Weijun Yuan[1], Siwei Zhang[1], Boris Bulatovic[1], Haneul Kwak[1], Tijs Karman[2], Sebastian Will[1]

[1]Columbia University, New York, USA. [2]Radboud University, Nijmegen, Netherlands

Abstract

We report on the realization of a BEC of dipolar molecules [1, 2]. For the past two decades a BEC of dipolar molecules has been sought after, but severe collisional losses have prevented efficient cooling. We developed double microwave shielding to suppress the collisional loss, enabling efficient evaporation of sodium-cesium (NaCs) molecules. We observe the emergence of a bimodal distribution in time of flight when the phase space density exceeds one. We achieve a condensate with a 60 % of BEC fraction at 6(2) nK with a lifetime of two seconds. We also report on recent improvements to our technique that allows us to reach a BECs with 800 molecules, up by a factor of 4 over the initial realization.

Funding:

We acknowledge funding support from NSF, ONR, and the Moore Foundation.

Reference:

We acknowledge funding support from NSF, ONR, and the Moore Foundation.

[1] “Observation of Bose-Einstein condensation in a gas of dipolar molecules,” Bigagli, N., Yuan, W., Zhang, S., Bulatovic, B., Karman, T., Stevenson, I., Will, S., https://arxiv.org/abs/2312.10965

[2] “Collisionally stable gas of bosonic dipolar ground state molecules,” Bigagli, N., Warner, C., Yuan, W., Zhang, S., Stevenson, I., Karman, T., Will, S., Nature Phys., 19, 1579-1584 (2023).

Categories

Molecules

Presentation

Poster presentation

C125

High-precision measurements of transition amplitudes and scalar polarizabilities in Lead and other multi-valence atomic systems using vapor-cell and atomic-beam spectroscopy

Protik Majumder, John Lacy, Abby Kinney, Robin Wang

Williams College, Williamstown, MA, USA

Abstract

Heavy, multi-valence atomic systems present a challenge for state-of-the-art *ab initio* atomic wavefunction calculations. Yet many of these same high-Z atomic systems have historically provided a testbed for important experimental tests of physics of and beyond the standard model. We have pursued a series of experimental benchmark measurements in 3- and 4-valence systems thallium, indium[1] and lead[2], providing tests of new calculations.

In one set of experiments, we use Faraday rotation spectroscopy to compare the strength of two different Pb transitions using a heated quartz vapor cell. Here, an infrared laser scans a 'reference' <M1> ground state transition while another laser scans across an excited-state <E1> transition. Using a polarization modulation / lock-in detection technique, we measure optical rotation signals with microradian noise levels for both lasers. Analysis of these spectra at precisely-known temperatures allows determination of absolute <E1> amplitudes at the 1% level. In a separate experiment, we use these same two Pb transitions to perform two-step excitation in a high-flux atomic beam apparatus where transverse spectroscopy allows 20-fold Doppler narrowing. By applying carefully-calibrated electric fields (10-20 kV/cm) to the atoms we measure the Stark shift and thus the transition polarizability. This exacting test of the atomic structure calculations is a follow up to a long series of such polarizability measurements in tri-valent thallium and indium. Current results will be presented.

[1] N.B. Vilas, *et al.* *Phys. Rev. A* **97**, 022507 (2018).
[2] D.L. Maser, *et al.* *Phys. Rev. A* **100**, 052506 (2019)

Categories

Precision measurements

Presentation

Poster presentation

C126

Stringent QED tests via bound electron *g* factors in the ALPHATRAP experiment

Fabian Heisse[1], Matthew Bohman[1], Athulya Kulangara Thottungal George[1], Charlotte M. Konig[1], Jonathan Morgner[1], Tim Sailer[1], Bingsheng Tu[1], Stephan Schiller[2], Sven Sturm[1], Klaus Blaum[1]

[1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany. [2]Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

Abstract

Quantum electrodynamics (QED) is considered to be the most successful quantum field theory in the Standard Model. Its most precise confirmation is conducted via the comparison of QED calculations with the measurement of the free electron *g* factor. However, there is a tension in the muon *g* factor. Furthermore, both tests are restricted to low electrical field strengths. Consequently, it is of utmost importance to perform similar tests at high field strengths.

The ALPHATRAP experiment is a dedicated cryogenic Penning-trap setup to measure the *g* factor of bound electrons in highly charged ions using single ion spectroscopy [1]. Our latest measurements of the bound electron *g* factor in H-like, Li-like, and B-like tin ions (Z=50) are presented. There, extreme electric field strength up to 10^{15} V/cm act on the electron, magnifying QED effects and allowing to test them to highest precision via the comparison with theory calculation [2]. Furthermore, by co-trapping two hydrogenlike neon ions ($^{20}Ne^{9+}$ and $^{22}Ne^{9+}$) we have directly measured their isotope bound electron *g*-factor difference with 13 digits precision in respect to *g*. This allows to test the QED recoil contribution to highest precision and set limits on hypothetical new physics beyond the standard model [3]. Finally, an overview on the recent measurement of the hyperfine structure of HD^+ will be presented together with plans for high-precision rovibrational laser spectroscopy.

[1] Sturm *et al.* Eur. Phys. J. Spec. Top. 227, 1425 (2019).
[2] Morgner *et al.* Nature 622, 5357 (2023).
[3] Sailer *et al.* Nature 606, 479483 (2022).

Categories

Precision measurements

Presentation

Poster presentation

C127

Measuring accurate atomic parameters of astrophysical importance using emission spectroscopy

Maria Teresa Belmonte, Pratyush Ranjan Sen Sarma, Santiago Mar, Sara Llorente

Universidad de Valladolid, Valladolid, Spain

Abstract

Accurate atomic parameters (wavelengths, transition probabilities, hyperfine and isotope structure constants) are essential in very different fields, from lighting industry to plasma diagnostics for fusion science. In astronomy, these parameters are crucial for the correct analysis of complex astrophysical spectra which hold the key to answering some of the most puzzling questions about our cosmos. Experimental atomic parameters are also indispensable as a benchmark for theoretical atomic data, leading to improvements in theoretical and semi-empirical calculations. However, despite their undeniable importance, there is still a great need for atomic data for thousands of transitions across the periodic table.

Atomic spectroscopy has always played a major role in the measurement of accurate atomic parameters. Improvements in light sources and detectors (increased quantum efficiency and smaller pixel size) contribute to an increase in resolution and accuracy. At the Atomic Spectroscopy Laboratory of the University of Valladolid (Spain), we have more than 40 years of experience in the measurement of accurate atomic parameters. Our current focus is on measuring parameters for the rare earths, urgently needed by astronomers to study neutron star mergers. Our experiment has been upgraded with a new detector and a Fabry-Pérot interferometer, allowing resolving powers of up to 10^8.

In this poster, we will give a comprehensive explanation of our experimental setup and current measurements. The ultimate goal of this contribution is to foster collaborations with other groups in need of accurate atomic data and to explore new ways in which to improve the capabilities of our experimental setup.

Categories

Precision measurements

Presentation

Poster presentation

C128

Recent progress in the measurement of the rubidium recoil using atom interferometry

Saïda Guellati-Khelifa[1,2], Clément Debavelaere[1], Pierre Cladé[1], Cyrille Solaro[1], Oscar Boucher[1], Samuel Gaudout[1]

[1]Laboratoire Kastler Brossel, Paris, France. [2]National Conservatory of Arts and Crafts, Paris, France

Abstract

Light-pulse atom interferometry allows for high precision measurements of a variety of physical quantities. This method offers exciting prospects for testing the fundamental laws of physics using low-energy experiments. Notably, the measurement by atom interferometry of the recoil velocity of an atom that absorbs or emits a photon leads to the most accurate determination of the fine structure constant α. This constant is crucial for quantum electrodynamics calculations and for testing certain predictions of the Standard Model of particle physics.

Our experiment measures the recoil velocity of a rubidium atom. In 2020, we obtained a value of α with a record relative uncertainty of 8.1×10^{-11} : α^{-1}=137.035999206 (11). However, this value differs by 5.4 σ from the value deduced from the caesium recoil measurement. To clarify the origin of this discrepancy, we have made several improvements to reduce and refine the control of systematic effects, in particular the effect related to laser wavefront distortions. This poster will present recent work on this experiment.

Categories

Precision measurements

Presentation

Poster presentation

C129

Precision spectroscopy of the magnetic moments and hyperfine splitting of $^{9}Be^{3+}$ at µTEx

Stefan Dickopf[1], Bastian Sikora[1], Annabelle Kaiser[1], Marius Müller[1], Stefan Ulmer[2,3], Vladimir A. Yerokhin[1], Zoltan Harman[1], Christoph H. Keitel[1], Andreas Mooser[1], Klaus Blaum[1]

[1]Max-Planck-Insitut für Kernphysik, Heidelberg, Germany. [2]Institute for Experimental Physics, Heinrich-Heine-Universität, Düsseldorf, Germany. [3]Ulmer Fundamental Symmetries Laboratory, Saitama, Japan

Abstract

Measurements of the Zeeman and hyperfine splitting of atoms or ions can be used to infer the shielded nuclear and the bound electron g-factors, as well as the zero-field hyperfine splitting [1]. In our Penning-trap apparatus, we performed such a measurement in the ground state of $^{9}Be^{3+}$ to determine its nuclear magnetic moment and Zemach radius with 0.6 ppb and 500 ppm uncertainty, respectively. By comparing to measurements on $^{9}Be^{+}$ [2] we can, for the first time, test the theory of the diamagnetic shielding factor [3] at the parts per billion level. Additionally, we compare our measured zero-field splitting with the value obtained in $^{9}Be^{+}$ via the so-called hyperfine specific difference to cancel theoretically intractable nuclear structure contributions. Recent progress and the latest results will be presented.

[1] A. Schneider et al, Nature 606, 878-883 (2022)
[2] D. J. Wineland, J. J. Bollinger, and Wayne M. Itano, Phys. Rev. Lett. 50, 628-631 (1983)
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Categories

Precision measurements

Presentation

Poster presentation

C130

Quantum Logic Spectroscopy of the Hydrogen Molecular Ion

Fabian Schmid, David Holzapfel, Nick Schwegler, Oliver Stadler, Martin Stadler, Alexander Ferk, Jonathan Home, Daniel Kienzler

ETH Zurich, Zurich, Switzerland

Abstract

I will present our latest results, implementing pure quantum state preparation, coherent manipulation, and non-destructive state readout of the hydrogen molecular ion H_2^+. The hydrogen molecular ion H_2^+ is the simplest stable molecule, and its structure can be calculated ab-initio with high precision. By comparing the calculations with experimental data, fundamental constants can be determined, and the validity of the theory itself can be tested. However, challenging properties such as high reactivity, low mass, and the absence of rovibrational dipole transitions have thus far strongly limited spectroscopic studies of H_2^+. We trap a single H_2^+ molecule together with a single beryllium ion using a cryogenic Paul trap apparatus, achieving trapping lifetimes of 11 h and ground-state cooling of the shared axial motion [1]. With this platform we have recently implemented quantum logic spectroscopy of H_2^+. We utilize helium buffer gas cooling to prepare the lowest rovibrational state of ortho-H_2^+ (rotation $L = 1$, vibration $v = 0$). We combine this with quantum logic operations between the molecule and the beryllium ion for the preparation of single hyperfine states and non-destructive state readout and demonstrate Rabi flopping on several hyperfine transitions. Our results pave the way for high precision spectroscopy of H_2^+ which will enable tests of theory, measurements of fundamental constants, and an optical molecular clock.

[1] N. Schwegler, D. Holzapfel, M. Stadler, A. Mitjans, I. Sergachev, J. P. Home, and D. Kienzler, Phys. Rev. Lett. 131, 133003 (2023)

Categories

Precision measurements

Presentation

Poster presentation

C131

In Situ Transfer of BEC from Optical Trap to Magnetic Quadrupole Trap

Yaoyuan Fan, Xiaoji Zhou

Peking University, Beijing, China

Abstract

A typical device suitable for a waveguide Sagnac interferometer needs to satisfy three conditions simultaneously: (I) be able to produce BEC; (II) be able to construct a cylindrical symmetric trap to guide the atoms; (III) be large enough to contain an effective Sagnac area [1].

As a mature technology for preparing BEC, crossed optical dipole trap has the advantages of a simple structure and rapid preparation process[2]. However, its effective volume is small.

In contrast, a quadrupole magnetic trap has a large effective volume and cylindrical symmetry. However, due to the Majorana transition loss effect at its zero point, it cannot be used to generate BEC directly.

Thus, we study BEC's in situ transfer scheme from an optical trap to a quadrupole magnetic trap. By carefully adjusting three key parameters, we achieved a BEC transfer efficiency of more than 95% [3]. The BEC's temperature after the transfer is below 50nK.

Our scheme effectively reduces the size and complexity of equipment. It is helpful to introduce a new practical ultracold atom interference gyroscope in the future.

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Poster

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Categories

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Poster presentation

C132

Towards laser cooling of Actinium

Benjamin Fox, Luke Caldwell

University College London, London, United Kingdom

Abstract

This poster presents our work towards laser cooling of actinium. Actinium is a heavy radioactive element (Ac-227 has half-life of 22 years) with a wide range of applications, from cancer therapy to studies of fluid movements in the ocean. The primary motivation for cooling actinium in this research is to facilitate future measurements of its electric dipole moment (EDM) to search for beyond-Standard-Model CP violation, which goes towards explaining the Baryon Asymmetry. For given new physics, the octupole deformed nucleus of Actinium-227 greatly enhances the measurable EDM relative to comparable measurements using isotopes with spherical nuclei. We simulate the cooling process using rate equations in Python and report progress towards an experimental implementation.

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C133

Antihydrogen production rate enhancement with sympathetically cooled positrons

Maria Beatriz Gomes Goncalves, Niels Madsen, Kurt Thompson

Swansea University, Swansea, United Kingdom

Abstract

The ALPHA experiment at CERN studies fundamental properties of antihydrogen, for example, its interaction with gravity, intending to compare it to its matter counterpart, hydrogen. Antihydrogen is formed by slowly merging cold plasmas of antiprotons and positrons in a Penning-Malmberg trap. The magnetic minimum trap where antihydrogen is stored has a well depth of about 0.5K, therefore, the produced antihydrogen must be as cold as possible to optimise the trapping rate. To increase the data-taking rate as well as decrease statistical errors, it is necessary to accumulate thousands of atoms. Thus, increasing the amount of antihydrogen available for experimentation is key to improving our studies of fundamental symmetries.

Years of studying antihydrogen production and trapping have demonstrated that one of the key parameters for increasing trapping rate is the positron temperature. The colder the positrons the higher the trapping rate. Under the 3T region of our trap, these particles reach a minimum temperature of about 15K. This temperature yielded a trapping rate of about 20 antihydrogen atoms every 4 minutes.

9Be+ can be laser-cooled down to cryogenic temperatures in a very controlled way. By sympathetically cooling the positron plasma with this laser-cooled ion cloud, the temperature of the mixture can be reproducibly brought to <10K. This technique was integrated in the antihydrogen production scheme at ALPHA and resulted in a near 5-fold increase in stacking rate. In this work, we present the details of this technique as well as a controlled study of antihydrogen production rate depending on positron temperature.

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C134

Measurement of the g factor of ground-state ^{87}Sr at the parts-per-million level using co-trapped ultracold atoms

Premjith Thekkeppatt, D Digvijay, Klaasjan van Druten, Florian Schreck

University of Amsterdam, Amsterdam, Netherlands

Abstract

We demonstrate nuclear magnetic resonance of optically trapped ground-state ultracold ^{87}Sr atoms. Using a scheme where a cloud of ultracold ^{87}Rb is co-trapped nearby, we obtain a 400-fold improvement in the determination of the nuclear g-factor, g_I, of atomic ^{87}Sr, reaching accuracy at the part-per-million level. We achieve similar accuracy in the ratio of relevant g-factors between Rb and Sr. This establishes ultracold ^{87}Sr as an excellent in-vacuum magnetometer. These results are relevant for ongoing efforts towards quantum simulation, quantum computation and optical atomic clocks employing ^{87}Sr. The employed methods can be extended to other alkaline-earth and alkaline-earth-like atoms.

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C135

Improvements on direct-bonded copper, atom chips used for Cold-Atom Atomic Interferometry.

Johnathan White[1], Franscisco Fonta[1], Joshua Wilson[1], Matthew Squires[2], Spencer Olson[2], Brian Kasch[2], James Stickney[1]

[1]Space Dynamics laboratory, Logan, USA. [2]Air Force Research Laboratory, Kirtland AFB, USA

Abstract

The Air Force Research Laboratory (AFRL) has been developing atom chips for use with cold-atom sensing and atom interferometry. We detail numerous advances in processing and fabrication techniques. Design improvements support tighter traps and rapid prototyping. Development of vias allow atom chips to serve as vacuum-chamber walls, decreasing current demands. Fabrication innovations that improve planarization support the integration of micro-features on single chips and chip-based assemblies.

Categories

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C136

Towards an improved precision measurement of the 1S-2S transition in Antihydrogen

Edward Thorpe-Woods

Swansea University, Swansea, United Kingdom. ALPHA, CERN, Geneva, Switzerland

Abstract

Antihydrogen, a simple and pure antimatter atom, can be synthesised and confined for extended periods in the ALPHA experiment at CERN [1]. As a consequence of the CPT invariance theorem, the antihydrogen is predicted to exhibit an energy spectrum identical to that of hydrogen. Consequently, a precise comparison of antihydrogen and hydrogen spectra constitutes a direct test of CPT invariance. The ALPHA collaboration has measured the frequency of transitions in antihydrogen as a direct test of this fundamental symmetry [2][3][4].

The narrow 1S-2S two-photon transition serves as the gold standard for precision spectroscopy, and has been determined with a precision of two parts per trillion [5] in antihydrogen. To improve the laser frequency stability during spectroscopy the metrology suite has been upgraded by integrating a caesium fountain clock and a hydrogen maser. The most recent measurement of the 1S-2S transition, employing laser-cooled antihydrogen [6], has yielded the narrowest spectrum observed in antihydrogen to date, which is anticipated to substantially enhance the precision in measuring the 1S-2S antihydrogen transition frequency. Here, we present our latest progress.

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Categories

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C137

Sub-kHz level mid-infrared saturation spectroscopy of complex molecules and its applications to fundamental physics

Yuhao LIU[1], Nicolas CAHUZAC[1], Etienne CANTIN[1], Olivier LOPEZ[1], Dang Bao An TRAN[1], Rosa SANTAGATA[1], Anne AMY-KLEIN[1], Mathieu MANCEAU[1], Benoit DARQUIE[1], Mads TONNES[2], Benjamin POINTARD[2], Michel ABGRALL[2], Luca LORINI[2], Yann LE COQ[2], Rodolphe LE TARGAT[2], Dan XU[2], Paul-Eric POTTIE[2], Héctor ALVAREZ-MARTINEZ[2,3]

[1]Laboratoire de Physique des Lasers, Université Sorbonne Paris Nord, CNRS, Villetaneuse, France. [2]LNE-SYRTE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Université, Paris, France. [3]Real Instituto y Observatorio de la Armada (ROA), Cádiz, Spain

Abstract

Molecular systems, owing to their numerous degrees of freedom, offer promising perspectives for improving spectroscopic tests of fundamental physics and precision measurements in general1,2. Ultra-stable lasers are required for precision spectroscopic measurements. Using a near infrared optical frequency comb, we stabilized a 10 µm quantum cascade laser (QCL) to an ultra-stable near infrared reference signal operated at the French metrology institute via a fiber cable of the REFIMEVE infrastructure3. This results in a record relative frequency uncertainty of 10^{-14} and a 0.1 Hz QCL linewidth4.

We have used this laser to perform high resolution spectroscopy on various molecular species of fundamental, atmospheric and astrophysics interest, by realizing cavity enhanced saturated absorption measurements. I will show results on osmium tetroxide, methanol and ethylene achieving a few hundred hertz uncertainties on molecular frequencies and present investigations of various noise sources currently limiting our signal-to-noise ratio as well as perspectives for improvements.

These results enhance our ability to meet the needs for our ongoing efforts towards studying the variation of fundamental constants2 or testing fundamental symmetries, eg by measuring the tiny parity-violating energy difference between enantiomers of a chiral molecule1. Furthermore, it can contribute to the enrichment and refinement of the HITRAN database, which can be highly beneficial for the fields of astronomy and atmospheric physics, providing valuable data for accurate modeling and analysis.

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Categories

Precision measurements

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C138

A Spin-interferometer to Measure the Electron's Electric Dipole Moment Using an Ultracold Beam of YbF Molecules

Michael Ziemba, Shirley Zheng, Freddie Collings, Rhys Jenkins, Jongseok Lim, Ben Sauer, Mike Tarbutt

Imperial College, London, United Kingdom

Abstract

The fact that more matter than antimatter has been produced in the early stages of the universe is unexplained [1]. One precondition is the combined violation of charge conjugation and parity (CP-violation) which is too small in the Standard Model. In almost all its extensions, CP-violation is also a prerequisite for the electron to have an electric dipole moment (d_e). In this respect, a measurement of d_e may act as a test of theories beyond the Standard Model.

The value of d_e can be determined by measuring the precession rate of the electron spin in a strong electric field. Heavy polarized molecules with their high intra-molecular fields have already set a limit of $|d_e| < 4.1\times10^{-30}$ e cm [3]. To improve on this, we create a collimated, bright beam of laser cooled YbF molecules [4] and have built an experiment to measure d_e with it [2]. I will report the successful transfer to the spin-superposition state using Stimulated Raman Adiabatic Passage (STIRAP) for the first time in this system and first interferometer fringes recorded on a transversally cold beam of YbF molecules. Moreover, I present the experiment's key features which allow us to determine d_e with a projected uncertainty of 5×10^{-30} e cm per day [4].

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C139

Quantum magnetometry at the spatial resolution extremes

Dominic Hunter[1], Stuart Ingleby[1], Marcin Mrozowski[1], Allan McWilliam[1], Chris Perrella[2], James McGilligan[1], David Burt[3], Angus Bell[1], Ciaran Beggan[4], Paul Griffin[1], Erling Riis[1]

[1]University of Strathclyde, Glasgow, United Kingdom. [2]University of Adelaide, Adelaide, Australia. [3]Kelvin Nanotechnology, Glasgow, United Kingdom. [4]British Geological Survey, Edinburgh, United Kingdom

Abstract

This work showcases the development and application of robust, scalable, and highly precise quantum magnetometers known as optically pumped magnetometers (OPMs), which offer effective magnetic imaging solutions across a wide spatial range, from high-resolution (micrometre) to long-baseline (kilometre) extremes.

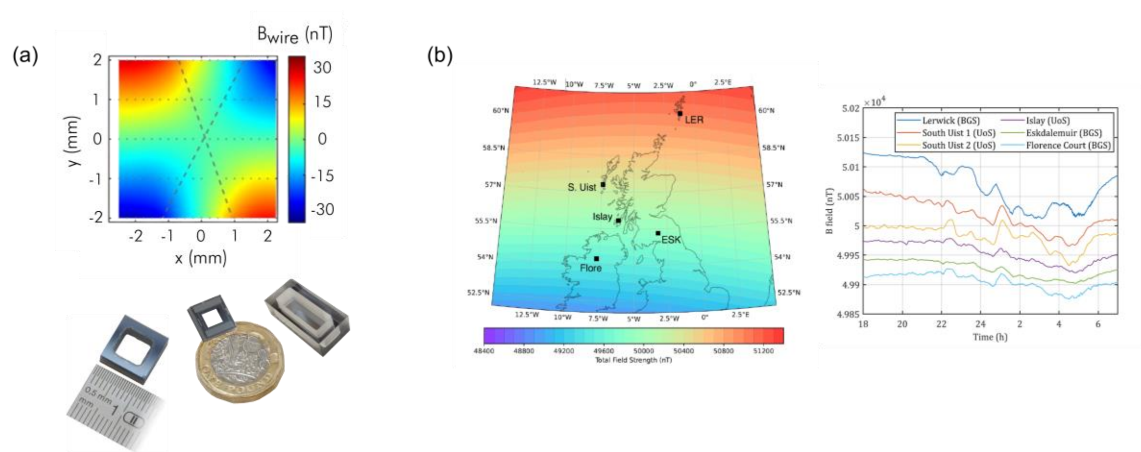

Figure 1: (a) High spatial resolution magnetic imaging (top) of a wire current distribution using a micro-machined vapour cell (bottom). (b) Low spatial resolution measurements performed using a distributed network of OPMs and classical sensors.

We utilize various OPM strategies including a double-resonance approach, and an intrinsically calibrated method based on free-induction-decay (FID). This involves two main stages: first, optical pumping orientates the atomic spins coherently along the beam direction using intense resonant laser light; second, detection occurs after the light is turned off, allowing the atomic spins to rotate freely in the presence of external magnetic fields, a process known as Larmor precession. This is detected using weak off-resonant light, ensuring high accuracy and minimizing systematic shifts in the measured magnetic field. Enhanced optical pumping strategies provide high spin coherence and consistent sensitivity across a broad dynamic range, enabling precision sensing at parts-per-billion levels in challenging Earth's field (~ 50-μT) environments.

Classical magnetic sensors operating under typical environmental conditions suffer from drifts and require frequent calibration. For example, the British Geological Survey (BGS) currently uses fluxgates and Overhauser magnetometers, calibrated with weekly manual measurements, for full field geophysical monitoring. We demonstrate the utility of OPMs which offer a compact single-sensor with important applications in space weather, situational awareness, surveying and navigation.

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C140

The Trade-off Between Precision and Accuracy in Quantum Metrology with Finite Resoures

Conggang Song[1], Qingyu Cai[2]

[1]APM, Chinese Academy of Sciences, Wuhan, China. [2]Hainan University, Haikou, China

Abstract

We propose an alternative definition of precision based on the signal-to-noise ratio (SNR) and sensitivity metrics, introducing a parameter α to quantify accuracy. Our findings reveal a fundamental incompatibility between high precision and high accuracy with finite resources. High accuracy is analogous to using a ruler with a larger scale, providing an accurate estimate despite lower precision levels. Conversely, tightening the estimation range increases precision but diminishes the probability of capturing the true value, thereby reducing accuracy.

Key results include the derivation of precision limits:

\begin{equation}

\delta \phi \geq \phi_{\min} = \arccos \left(\frac{n-1}{n+1} \right) \approx \frac{2}{\sqrt{n}},

\end{equation}

where $\delta \phi$ is the minimum detectable signal.

Further, we introduce the relationship between precision and accuracy:

\begin{equation}

|p - p'| \geq \alpha (\Delta p + \Delta p'),

\end{equation}

where α ranges from 0 to ∞, influencing the trade-off between precision and accuracy.

We demonstrate that multiple quantum states, whether independently or as a combined system, significantly enhance measurement precision. Specifically, the precision is governed by:

\begin{equation}

\delta \phi \geq 2 \arccos \left(\sqrt{\frac{F_0}{2M}} \right) \approx \frac{2}{\sqrt{MN}},

\end{equation}

where $F_0 = \frac{N}{N+1}$ denotes the critical fidelity, M represents the number of quantum states, and N the number of repeated measurements.

Quantum entanglement further accelerates state evolution, significantly improving precision:

\begin{equation}

\delta \phi \geq \frac{2}{M} \arccos (\sqrt{F_0}) \approx \frac{2}{M\sqrt{N}}.

\end{equation}

Categories

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C141

High-precision study of E1 transition amplitudes for single-valence atoms and ions

Benjamin Roberts, Jacinda Ginges, Carter Fairhall

University of Queensland, Brisbane, Australia

Abstract

Motivated by recent measurements of several properties of alkali metal atoms and alkali-like ions, we perform a detailed study of electric dipole transition amplitudes in K, Ca^+, Rb, Sr^+, Cs, Ba^+, Fr, and Ra^+, which are of interest for studies of atomic parity violation, electric dipole moments, polarisabilities, the development of atomic clocks, and for testing atomic structure theory. We perform high-precision calculations of E1 amplitudes between s, p, and d states of the above systems, perform a robust error analysis, and compare our calculations to ~50 amplitudes which have high-precision experimental determinations. We find excellent agreement at the level of 0.1% or better.

Half our calculated amplitudes are *within the experimental uncertainties*, demonstrating unprecedented theoretical accuracy for many-body atoms. Further, 95% of our calculated amplitudes are within 1σ combined (theory + experimental) uncertainties, better than statistically expected, demonstrating our theory uncertainties are conservative. In several cases, the radiative QED corrections are larger than the discrepancy between theory and experiment.

We also compare our results to other theoretical evaluations, and discuss the implications for uncertainty analyses of theoretical methods. In particular, we observed that in many cases there is a large discrepancy between various calculations using coupled-cluster methods, possibly indicative of the sensitivity of such methods to basis choices and the details of the inclusion of triple excitations. Our method does not suffer from these issues.

Roberts et al, Phys. Rev. A **107**, 052812 (2023)

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Precision measurements

Presentation

C142

Cold Atom Interferometry Thermosphere Drag Measurement (CAITDM)

Victoria Anne Henderson[1], Anna Marchant[1], Mike Salter[1], Ashish Srivastava[1], Laurence Coles[2], Manolis Papastavrou[2], Peter Hobson[3], Alister Davis[3], Mark Fromhold[3], Tristan Valenzuela[1]

[1]RAL Space, UKRI-STFC Rutherford Appleton Laboratory, Didcot, United Kingdom. [2]Metamorphic Additive Manufacturing Ltd, Derby, United Kingdom. [3]School of Physics & Astronomy, University of Nottingham, Nottingham, United Kingdom

Abstract

To resolve knowledge gaps in our understanding of the upper atmosphere, improved measurements of mass density and its spatial and temporal fluctuations are necessary. These measurements of atmospheric drag in Low Earth Orbit can be used to inform climate modelling, weather forecasting, and satellite orbit prediction. The highly accurate and drift-free nature of a cold atom interferometer makes it well suited to this accelerometery [1].

CAITDM is a technology demonstrator project for cold atom interferometry-based drag measurements on a 16U CubeSat with the goal of addressing some of the engineering challenges associated with space qualification and miniaturisation. The project is supported by the UK Centre for Earth Observation Instrumentation (CEOI) and is a collaboration between RAL Space, Metamorphic Additive Manufacturing, and University of Nottingham. We aim to build a fully functional breadboard model combining a lightweight additively manufactured vacuum chamber, bi-planar magnetic coils [2], custom optics delivery systems, and low-noise coil current drivers. This poster will give an overview of the project and its constituent parts.

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Precision measurements

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Poster presentation

C143

Quantum Magnetometry for Space Weather Monitoring

Mark Bason[1], Mike Salter[1], Adam Filip[1], Stuart Ingleby[2], Dominic Hunter[2], Ciaran Beggan[3], Christopher Turbitt[3], Hugo Shelley[4]

[1]Rutherford Appleton Laboratory, Didcot, Oxfordshire, United Kingdom. [2]University of Strathclyde, Glasgow, United Kingdom. [3]British Geological Survey, Edinburgh, United Kingdom. [4]Iota Technology, Oxford, United Kingdom

Abstract

Space weather concerns the highly variable conditions generated by the Sun's output, primarily carried by the solar wind plasma and energetic particles. The impacts are felt in near-Earth space and in-ground responses, such as geomagnetically-induced currents. For spaceborne measurements, the focus has centred on neutral densities and total electron content from GPS, plasma composition and energetic particles, and changes in the magnetic field.

Innovations in magnetic field sensing help to improve our present measurement capabilities for Earth-core field and space weather monitoring. Specifically, we focus on optically-pumped magnetometers (OPMs), the most sensitive and accurate magnetic sensors available. Quantum magnetic sensing offers advantages over the combination of triaxial fluxgates and proton-precession magnetometers. Advances in quantum technology, have enabled full field, high frequency, and temperature insensitive measurements of the natural field (0-60μT). The low-noise, high-bandwidth OPMs can detect variations in the Earth's magnetic field arising from space weather activity.

Here, we report on the progress of a programme to build and deploy five ground-based OPMs and work towards deploying such OPMs in orbit. As part of this work, we are developing high-frequency vectorised scalar magnetometers (UoS) combined with custom electronics (RAL). A BGS-run geomagnetic observatory at Eskdalemuir will allow the OPM systems to be compared to the highest scientific standards. The sensors will be deployed to locations around Britain to reduce the spacing between UK observatories <200 km. This will provide one of the densest magnetic networks in the world, meeting the World Meteorological Office's breakthrough goal for space weather monitoring.

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C144

First observation of Muonium 1S-2S F=0→F'=0 transition at J-PARC

Shinsuke Yamamoto[1], Hideaki Hara[1], Takahiro Hiraki[1], Yasutaka Imai[1], Takahiko Masuda[1], Yuki Miyamoto[1], Wataru Saga[1], Satoshi Uetake[1], Koji Yoshimura[1], Taihei Adachi[2], Yutaka Ikedo[2], Shusei Kamioka[2], Naritoshi Kawamura[2], Akihiro Koda[2], Tsutomu Mibe[2], Yasuhiro Miyake[2], Yu Oishi[2], Masashi Otani[2], Strasser Patrick[2], Koichiro Shimomura[2], Takayuki Yamazaki[2], Mitsuhiro Yoshida[2], Toru Iijima[3], Kazuhito Suzuki[3], Mai Yotsuzuka[3], Katsuhiko Ishida[4], Yajun Mao[5], Ce Zhang[5], Saeid Kamal[6]

[1]Okayama Univesity, Okayama, Japan. [2]KEK, Tsukuba, Japan. [3]Nagoya University, Nagoya, Japan. [4]RIKEN, Wako, Japan. [5]Peking University, Peking, China. [6]University of British Colombia, Vancouver, Canada

Abstract

To explore physics beyond the Standard Model of particle physics (BSM) is quite important because the SM is incomplete. One of the most intriguing approach for search of the BSM is precision measurement of energy interval in Muonium. Muonium is an exotic hydrogen-like atom consists of a positive muon and an electron. This purely leptonic system enables a precise calculation of the energy interval based on the SM, without ambiguity of the charge radius of the nucleus, unlike hydrogen atoms. Thus comparing theoretical prediction and precise measurements of the energy interval provides a precision test of the Standard Model. In order for this, it is quite important to improve accuracy of the muon mass. This is because the present uncertainty in the theoretical prediction of the energy interval is limited by muon mass uncertainty. The muon mass is precisely determined from the 1S-2S energy interval of Muonium. Thus we focused on measuring the 1S-2S transition frequency of Muonium by Doppler-free two-photon laser spectroscopy.

We report the first observation of the 1S-2S (F=0→F'=0) transition in Muonium. Since the signal rate of this transition is one third of F=1→F'=1 transition, it was difficult to observe. By continuous improvement of measuring apparatus, the signal rate of 1S-2S (F=1→F'=1) transition is >60 times higher than the previous experiment[1]. Such high signal rate enables us to observe the transition between singlet states.

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Categories

Precision measurements

Presentation

C145

Hybrid quantum squeezing of spins with different nature in an atomic vapor

Youwei Zhang[1], Shenchao Jin[1], Junlei Duan[1], Heng Shen[2], Liantuan Xiao[2], Suotang Jia[2], Mingfeng Wang[3], Yanhong Xiao[2,1]

[1]Fudan University, Shanghai, China. [2]Shanxi University, Taiyuan, China. [3]Wenzhou University, Wenzhou, China

Abstract

Squeezed spin states and squeezed light are both key resources for quantum metrology and quantum information science, but have largely been separately investigated in experiments so far. Meanwhile, spin squeezing can be produced in different ways. For instance, entanglement between atoms can be generated by quantum non-demolition measurement (QND), or by nonlinear dynamics such as one-axis twisting (OAT), two-axis twisting (TAT) or two-mode squeezing (TMS) etc., and internal spin squeezing was also achieved, but these have mainly been implemented separately. Simultaneous generation of spin and light squeezed states, or combining multiple spin squeezing processes in one experiment setup are intriguing due to potentially improved performance and new opportunities for applications. Here we report experimental demonstrations of hybrid quantum squeezing in a hot atomic ensemble. By engineering the atom-light interaction Hamiltonian, we can concurrently produce spin squeezing and light squeezing (polarization squeezing) in one vapor cell. By designing a sequence of optical pulses each inducing different types of spin squeezing (TAT, TMS and QND) and optimizing their cooperative behavior, we have obtained enhanced total spin squeezing.

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C146

Single photon counting for axion detection with a trapped electron

Marko Wojtkowiak, Kitty Zhang, Jiacheng Shi, Kanika Kanika, Richard Thompson, Jack Devlin

Imperial College London, London, United Kingdom

Abstract

The Quantum enhanced particle astrophysics (QuEPA) project plans to use an electron Penning trap as one part of a detector for axion dark matter with mass between 125 and 250 µeV. Axions emerged as a dark matter candidate after initially being proposed to resolve the observed lack of charge parity (CP) violation by the strong interaction. In the presence of a strong magnetic field, axions can transform into microwave photons. These photons can then be detected through excitation of the motion of an electron in a Penning trap, serving as a single-photon counter.

To cover a range of potential axion masses, a Penning trap that can control the electron microwave photon interaction at different frequencies is needed. A novel adjustable endcap Penning trap will therefore be constructed in this project, allowing for the trapped electron to variably interact with photons between 30-60 GHz.

In this session, an update on the progress of the design and construction of the trap will be presented, as well as the upcoming roadmap for the project including other applications of the trapped electron quantum sensor.

Categories

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C147

Progress of ytterbium optical clocks at ECNU

Taoyun Jin[1], Changyue Sun[1], Chengquan Peng[1], Qichao Qi[1], Tao Zhang[1], Shuai Lei[1], Chengcheng Zhao[1], Yan Xia[1], Suzhen Feng[1], Xinye Xu[1,2,3]

[1]East China Normal University, Shanghai, China. [2]2. Shanghai Research Center for Quantum Sciences, Shanghai, China. [3]3. Shanghai Branch, Hefei National Laboratory, Shanghai, China

Abstract

We have carried out some experiments to improve the performance of ^{171}Yb optical clocks with 578-nm transition. The comparison experiment of five evaluation schemes of blackbody radiation (BBR) frequency shift and uncertainty in the same optical clock was completed [1], which not only clearly shows the advantages and disadvantages of each method, but also puts forward an optimal evaluation method under normal temperature environment. By further using the built-in cryochamber, one of the best results of the BBR-frequency-shift uncertainty with E-19 level was obtained. In order to make a lattice site occupy at most one atom in subsequent optical clock experiments, we have conducted the photoassociation experiment of cold ^{171}Yb atoms, and successfully observed a series of photoassociation spectra corresponding to the 556-nm transition [2]. In addition, we have also experimentally observed the 1695-nm clock transition resulted from the inner shell transition of electrons for the first time [3], found the magic wavelength of the optical lattice, and accurately measured some important physical quantities related to the 1695-nm transition, such as the hyperpolarizability, the tensor polarizability and the magnetic dipole coefficient of the hyperfine structure energy levels, which provides valuable experimental data for further improvement of theoretical model; the closed-loop locking of ^{171}Yb optical clock with 1695-nm transition was realized, and the inner-shell-type ytterbium optical clock was preliminarily developed, which lays a foundation for the development of a new type of optical clock, and also provides a new way to precisely measure the fine-structure constant changing with time.

References

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Categories

Clocks and metrology

Presentation

C148

A continuously operating optical clock based on Ramsey-Bordé interferometry with a thermal strontium beam

Ingmari C. Tietje[1], Oliver Fartmann[1], Amir Mahdian[1], Martin Jutisz[1], Conrad L. Zimmermann[1], Vladimir Schkolnik[1], Ullrich Schwanke[1], Steven Worm[1,2], Markus Krutzik[1,3]

[1]Institute of Physics, Humboldt University of Berlin, Berlin, Germany. [2]DESY Zeuthen, Zeuthen, Germany. [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Abstract

Atomic clocks in their function as time keepers and quantum sensors have evolved from the microwave regime to the optical – greatly facilitated by the advent and commercial availability of frequency combs. While the most accurate and stable clocks to date are optical lattice or ion clocks, smaller, less complex systems can be advantageous. Ramsey-Bordé interferometry (RBI) based interrogation schemes of atomic beams allow for continuous operation with only two lasers. Our optical RBI clock uses the $^1S_0 \rightarrow {}^3P_1$ strontium intercombination line aiming at a stability of 10^{-15}. We will present some preliminary results of the Allan deviation of the clock, the measured noise contributions, systematic shifts of the transition frequency, cover our compact and high-flux atomic oven and the cavity-stabilised laser system at 689nm.
Its comparably low complexity and development roadmap, along with the possibility of a micro-integration of the atom interferometer, pave the way for the operation of the clock as a candidate for next generation Global Navigation Satellite Systems and for fundamental research. In searches for ultra-light dark matter the continuous clock readout opens the possibility to establish bounds on “heavier” dark matter particles ($m>10^{-14}$ eV/c^2) compared to the most accurate and stable clocks in the world, which are read out roughly once per second. These bounds could be complementary and competitive to the different methods employed in bosonic dark matter searches, e.g. bounds deduced from the Eötvös parameter.

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Clocks and metrology

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C149

Ultrastable lasers based on crystalline AlGaAs mirror coatings at room temperature

Chun Yu Ma[1], Jialiang Yu[1], Thomas Legero[1], Sofia Herbers[1], Daniele Nicolodi[1], Mona Kempkes[1], Fritz Riehle[1], Dhruv Kedar[2], Jun Ye[2], Uwe Sterr[1]

[1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany. [2]JILA, National Institute of Standards and Technology and University of Colorado, Boulder, USA

Abstract

Ultrastable lasers locked to Fabry-Perot resonators are an important part of optical clocks, providing narrow bandwidth radiation for exciting clock transitions and acting as flywheel during deadtimes. The best systems are limited to fractional frequency instabilities of 4×10^{-17} by Brownian thermal noise of the dielectric mirror coatings.

Crystalline AlGaAs mirror coatings due to their low mechanical loss reduce this noise. However, with optical silicon resonators using these coatings at cryogenic temperature we observed photo-modified birefringence and unexpected novel noise contributions above the Brownian noise [J. Yu et al., Phys. Rev. X, 13, 041002 (2023) and D. Kedar et al., Optica, 10, 464 (2023)].

To investigate these coatings at room temperature, we lock two lasers to fast and slow polarization eigenmodes of a 48 cm long ULE cavity respectively. A step in intracavity power modifies the static birefringence of the mirror coatings on timescales of a second. On the fast axis this photo-modified birefringence induces an optical length change opposite to the one from the temperature change, minimizing laser-power induced frequency noise. We also investigate the modification of the coating birefringence from illumination by LED light at different photon energies. From our results we can give an upper limit of the spontaneous birefringent noise at room temperature. Our findings help to understand the physical mechanism of the novel effects and noise found in these crystalline coatings.

Categories

Clocks and metrology

Presentation

Poster presentation

C150

Optimal states for quantum sensing using neutral atoms in sparse coupling graphs

Sridevi Kuriyattil[1], Pablo Poggi[1], Johannes Kombe[1], Andrew Daley[2,1]

[1]Strathclyde University, Glasgow, United Kingdom. [2]Oxford University, Oxford, United Kingdom

Abstract

Quantum states featuring extensive multipartite entanglement are a resource for quantum-enhanced metrology, allowing to reach the maximum sensitivity set by the Heisenberg limit. Generating these type of states, however, often requires all-to-all interactions among particles. Here we show that optimal states for quantum sensing can be generated with sparse interaction graphs featuring only a logarithmic number of couplings, which can be efficiently generated in neutral atoms arrays via dynamical shuffling of the atoms. We numerically demonstrate that specific sparse graphs featuring long-range interactions approximate the dynamics of all-to-all spin models like the one-axis-twisting accurately up to large system sizes using tensor network methods. Furthermore, we provide analytical arguments for the optimality of these sparse coupling graphs in mimicking the dynamics of densely connected systems, and show how these interactions could be readily implemented in systems of neutral atoms in optical tweezers.

Categories

Clocks and metrology

Presentation

Poster presentation

C151

Single-beam grating-chip 3D and 1D optical lattices

Alan Bregazzi, James McGilligan, Paul Griffin, Erling Riis, Aidan Arnold

University of Strathclyde, Glasgow, United Kingdom

Abstract

Ultracold atoms are crucial for unlocking truly precise and accurate quantum metrology, and provide an essential platform for quantum computing, communication and memories. One of the largest ongoing challenges is the miniaturization of these quantum devices. Here, we show that the typically macroscopic optical lattice architecture at the heart of many ultra-precise quantum technologies can be realized with a single input laser beam on the same diffractive chip already used to create the ultracold atoms. Moreover, this inherently ultra-stable platform enables access to a plethora of new lattice dimensionalities and geometries, ideally suited for the design of high-accuracy, portable quantum devices.

Categories

Clocks and metrology

Presentation

Poster presentation

C152

Polarization and Remote Sensing in Rydberg Electrometry

Matthew Chilcott, Matthew Cloutman, J. Susanne Otto, Niels Kjaergaard

University of Otago, Dunedin, New Zealand

Abstract

We report on Rydberg-atomic sensing of electric fields ranging from gigahertz to terahertz. These highly-excited atoms are a promising platform for calibration-free field measurements.

We find that the measurements can be polarization-insensitive [1], or strongly polarization sensitive, depending on the quantum numbers of the Rydberg states involved. Using the polarization-insensitive scheme, we demonstrate the recording of high-resolution emission patterns of a THz antenna without influence from local variations of the output polarization.

Accurate field measurements also require the sensor to have minimal influence on the field under test, while a complete Rydberg-atomic sensor includes electronics and metallic components which perturb the field under test. To minimize this impact, we study an atomic probe---a vapour cell and glass retro-reflector---distant from electrical and metallic components [2]. Via a free-space optical link, the field at the probe is interrogated 30 m from any metal components. Such a system is also well suited for sensing in environments which are hostile to metal.

[1] M. Cloutman, *et al*. Phys. Rev. Applied **21**, 044025 (2024)

[2] J. S. Otto, *et al*. Appl. Phys. Lett. **123**, 144003 (2023)

Categories

Clocks and metrology

Presentation

Poster presentation

C153

Compact laser system with Doppler-free frequency locked to a micro-fabricated Rubidium vapor cell

Seji Kang, Taeg Yong Kwon, Sang Eon Park, Sang Bum Lee, Jae Hoon Lee, Sangwon Seo, Young-Ho Park, Hyun-Gue Hong

KOREA RESEARCH INSTITUTE OF STANDARDS AND SCIENCE, Daejeon, Korea, Republic of

Abstract

We present a compact laser system with a micro-fabricated Rubidium (Rb) vapor cell designed for frequency locking based on Doppler-free saturated absorption spectroscopy. Rb vapor cells incorporate three lithographically patterned chambers: two for obtaining Doppler-broadened background and saturated absorption spectrum, and one for deriving a frequency-locked laser beam for practical use. The two spectroscopy chambers are linked to an atomic source, in which the vacuum is maintained with non-evaporable getters. A laser beam spatially splits into three paths after traversing the micro-fabricated Rb vapor cell. We can get saturated absorption lines on a flat background by utilizing the beams passing through the spectroscopy chambers. We discuss the design, characteristics, and stability of the laser system, highlighting its potential for miniaturizing atomic devices such as atomic clocks and magnetometers.

Categories

Clocks and metrology

Presentation

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C154

Vacuum-Ultraviolet Laser Excitation of the Thorium-229 nucleus in Th:CaF2 Crystals

Johannes Tiedau[1], Maksim Okhapkin[1], Ke Zhang[1], Johannes Thielking[1], Gregor Zitzer[1], Ekkehard Peik[1], Fabian Schaden[2], Thomas Pronebner[2], Ira Morawetz[2], Luca Toscani De Col[2], Felix Schneider[2], Adrian Leitner[2], Martin Pressler[2], Georgy Kazakov[2], Kjeld Beeks[2], Tomas Sikorsky[2], Thorsten Schumm[2]

[1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany. [2]Vienna Center for Quantum Science and Technology, Atominstitut, Vienna, Austria

Abstract

The thorium-229 nucleus has a unique, low-lying isometric state allowing for laser spectroscopic investigations that are otherwise only accessible in electronic transitions. Here, we report on the first resonant laser excitation of the Th-229 nucleus with a tabletop tunable laser system. The laser system consists of two seeded dye amplifiers that are frequency-converted via four-wave mixing in Xenon to the vacuum-ultraviolet (VUV) region. Using this light source with Th-229 doped calciumfluoride crystals we were able to determine the center frequency of 2020.409(7) THz corresponding to 148.3821(5) nm of the nuclear transition. The fluorescence lifetime in the crystal is 630(15) s, corresponding to an isomer half-life of 1740(50) s for a nucleus isolated in vacuum. These results pave the way towards high-resolution nuclear laser spectroscopy of Th-229 and an optical nuclear clock with high sensitivity in fundamental tests.

Categories

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Presentation

Poster presentation

C155

Limitation of single-laser repumping schemes for laser cooling of Sr atoms

Naohiro Okamoto, Takatoshi Aoki, Yoshio Torii

The University of Tokyo, Tokyo, Japan

Abstract

We investigate the performance of a magneto-optical trap (MOT) of Sr atoms for two single-repumping schemes: 5s5p $^3P_2$ - 5p^2 $^3P_2$ (481 nm) and 5s5p $^3P_2$ - 5s5d $^3D_2$ (497 nm), revealing that the dominant decay path from the 5s5p $^1P_1$ state to the 5s5p $^3P_0$ state is via the 5s4d $^3D_1$ state, not via the upper states accessed by the single-repumping lasers. Due to this decay path, the enhancement in the lifetime of the MOT is limited to 25.9(2) for any single-repumping schemes. For the first time, we determined that the branching ratio of the 5s5p $^1P_1$ → 5s4d $^3D_1$ → 5s5p $^3P_0$ decay path is 1:3.9×10^6 and the decay rate from the 5s5p $^1P_1$ state to the 5s4d $^3D_1$ state is 83(32) s^{-1}. This result shows the atom number in the MOT is significantly limited for a single-repumping scheme when a long loading time ($\gtrsim$ 1 s) is required. This finding will contribute to the construction of field-deployable optical lattice clocks.

Poster

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Clocks and metrology

Presentation

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C156

Developments for a continuous superradiant laser on ytterbium (171Yb) clock transition

Jana El Badawi[1,2], Martina Matusko[1], Martin Hauden[1], Francisco Sebastian Ponciano-Ojeda[1], Bruno Bellomo[2], Marion Delehaye[1]

[1]FEMTO-ST, CNRS UMR 6174, UFC, Besançon, France. [2]UTINAM, CNRS UMR 6213, UFC, OSU THETA, Besançon, France

Abstract

Superradiant lasers operating on atomic clock transitions are promising candidates for the next generation of optical frequency references. Superradiance refers to the collective emission of an ensemble of atoms producing a short and intense radiation pulse. It can occur when atoms interact within a common electromagnetic field, typically provided by a Fabry-Perot cavity in the optical domain. In several recent experiments, pulsed optical superradiant emission was observed and characterized in terms of time and frequency metrology. The next objective is to reach a steady state of continuous emission. Here, we present our experimental and theoretical developments on continuous superradiance of the ytterbium (^{171}Yb) associated to the optical clock transition $^1S_0$-$^3P_0$. Experimentally, we plan to achieve continuous emission through a constant multi-step repumping of the clock transition with a sequential transport of atoms into two sites of the cavity. We plan to utilize an optical conveyor belt to transport the atoms across a distance of approximately 30 cm, from a Magneto-Optical Trap (MOT) containing more than 10^7 atoms at temperature below 100 µK, to the cavity where the atoms will generate superradiant emission on the narrow (Γ = 7 mHz) $^1S_0 \rightarrow {}^3P_0$ clock transition at 578 nm. Using a theoretical model of such an open quantum system, we are able to perform numerical simulations of the systems dynamics to study the characteristics of this superradiant laser.

Categories

Clocks and metrology

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C157

Raman-Ramsey CPT in a grating magneto-optical trap for compact microwave clock applications

Umakanth Dammalapati, Paul Griffin, Erling Riis

University of Strathclyde, Glasgow, United Kingdom

Abstract

Atomic clocks based on microwave transitions employ the coherent population trapping (CPT) technique making use of Raman transitions [1,2]. These provide a compact solution for applications where size, weight, power and cost (SWaP-C) are a limitation. The CPT method has been in use both in atomic vapour cells and atoms cooled and trapped in a magneto-optical trap (MOT) for clock applications [3,4]. Laser cooled atoms offer advantages in terms of frequency stability and accuracy. In this work, status of our experiment is presented that makes use of a single input laser beam and a grating chip for a MOT for microwave atomic clock application using CPT method [5,6]. Raman-Ramsey spectroscopy is performed on ^{87}Rb atoms cooled to few microkelvin temperatures. Initial results of the measurement of ac-Stark shifts in the grating MOT will be reported along with other measurements. In addition, an experimental technique to reject unwanted sidebands/frequencies produced during the generation of Raman beams is also presented. This method has applications in atomic clocks, atom interferometry, gravimetry and other fields of interest.

[1] J. Kitching, et al., Appl. Phys. Lett. 81, 553 (2002).

[2] J. Vanier, Appl. Phys. B 81, 421 (2005).

[3] M. Abdel Hafiz, et al., J. Appl. Phys. 121, 104903 (2017).

[4] F.-X. Esnault, et al., Phys. Rev. A 88, 042120 (2013).

[5] C. Nshii, et al., Nat. Nanotechnol. 8, 321 (2013).

[6] R. Elvin, et al., Opt. Express 27, 38359 (2019).

Categories

Clocks and metrology

Presentation

Poster presentation

C158

Precision microwave and optical manipulation of atomic states in thulium optical clock

Dmitry Tregubov[1,2], Artem Golovizin[1,2], Denis Mishin[1], Daniil Provorchenko[1], Mikhail Yaushev[1,2], Nikolay Kolachevsky[1,2]

[1]Lebedev Physical Institute, Moscow, Russian Federation. [2]Russian Quantum Center, Moscow, Russian Federation

Abstract

In our recent experiments, we demonstrated that a clock transition in thulium is insensitive to external electric and magnetic fields. Low polarisability of the transition provides low sensitivity to blackbody radiation and through our use of two components of the clock transition we form a synthetic frequency insensitive to magnetic field. This setup requires careful preparation of the initial states, ground state cooling in the lattice potential, and simultaneous clock transition spectroscopy.

In order to achieve it we employ several techniques. First, we populate the outermost magnetic sublevel of the ground state using optical pumping with narrow-line transition. The same transition is used for the sideband cooling to the ground state. With a radiofrequency we transfer the atomic population to the central magnetic sublevel. A microwave pulse is used to redistribute the population equally between the two initial states before the clock transition spectroscopy. A simultaneous interrogation of the two clock transitions is performed which negates the influence of magnetic field and its fluctuations on the synthetic clock frequency. This is done synchronous in two separate thulium optical lattice clocks for comparison.

We characterize experimentally every step of the preparation process and the spectroscopy. Properties of the clock transition in thulium and precision control of the atomic states allow us to create a robust and compact optical clock with the total systematic frequency shift at or below 10^{-17} in relative units.

Categories

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C159

$^{171}Yb^{+}$ ion optical clock at NPL: frequency metrology and fundamental physics

E. Anne Curtis, Alexandra Tofful, Patrick Regan, Rachel M. Godun

National Physical Laboratory (NPL), Teddington, United Kingdom

Abstract

The accuracy and stability of ion-based optical frequency standards make them ideal metrological tools, with applications in myriad areas requiring precise timing. Practical implementation of these complex systems requires improvements in reliability and robustness of operation over extended periods of time. We have addressed this in the ytterbium ion optical clock system at the National Physical Laboratory (NPL) by implementing automated system-recovery algorithms utilising ARTIQ infrastructure [1], as well as applying on-the-fly data validation and systematic corrections. A recent full evaluation of the uncertainty budget was performed for the electric octupole (E3) $^2S_{1/2} \rightarrow {}^2F_{7/2}$ transition of $^{171}Yb^{+}$ in our laboratory. This included an in-depth assessment of the RF-trap-drive-induced AC Zeeman effect, resulting in a fractional frequency shift contribution $\lesssim 1\times10^{-20}$. The total E3 systematic frequency shift was measured with a fractional standard systematic uncertainty of 2.2×10^{-18} [2].

These system advances and state-of-the-art uncertainty budget enable us to provide improved contributions to the international efforts in the redefinition of the SI second [3], which would allow the realisation of the new definition at the level of 10^{-18} fractional frequency uncertainty, and other applications such as tests of fundamental physics. We report how our analysis of atomic clock data is used to constrain variations of fundamental constants over time, contributing to the effort to understand dark matter in the universe [4].

[1] https://m-labs.hk/experiment-control/artiq/

[2] A. Tofful, *et al.*, arXiv:2403.14423.

[3] N. Dimarcq, *et al.*, Metrologia, 61(1):012001, 2024.

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Categories

Clocks and metrology

Presentation

Poster presentation

C160

Comparison of Rb vapour lamps for optically pumped Rb atomic clocks

Ulas Gokay, Nitika Gupta, Rabia Ince, Hugh Klein, Guilong Huang, Mohsin Haji

National Physical Laboratory (NPL), London, United Kingdom

Abstract

Rubidium (Rb) lamp-based frequency standards exhibit frequency fluctuations through lamp intensity jumps due to the light shift effect [1]. To investigate this further, we have characterised two different types of Rb lamps containing bulbs with and without Xenon (Xe) buffer gas.

Vapour contents of the two types of the lamps were characterised through optical spectroscopy. All tested lamps exhibited characteristic Rb-87 excitation lines, whereas the lamps with bulbs containing Xe showed additional Xe-associated spectral lines. The optical power, electrical power, and temperature of the lamps were monitored for several months during operation. Results show that the group of lamps containing bulbs with Xe buffer gas exhibited sudden intensity jumps, whereas the lamps with pure Rb-87 exhibited continuous stationary noise without the intensity jumps. All lamps exhibited slow varying changes in intensity which correlated with electrical current fluctuations.

Further data is being collected to better understand these intensity jumps along with the failure modes of the Rb lamps. A statistical analysis of the intensity jumps relating to the ac-Stark shift is also under development [2].

Authors acknowledge funding from Innovate UK.

[1] C. H. Volk and R. P. Frueholz. “The role of long-term lamp fluctuations in the random walk of frequency behavior of the rubidium frequency standard: A case study”, Journal of Applied Physics vol. 57.3, p. 980-983, 1985.

[2] Formichella, V., Camparo, J., Sesia, I., Signorile, G., Galleani, L., Huang, M., & Tavella, P. (2016). The ac Stark shift and space-borne rubidium atomic clocks. Journal of Applied Physics, 120(19).

Categories

Clocks and metrology

Presentation

Poster presentation

C161

795 nm VCSEL characterisation for rubidium based miniature atomic clocks

Peter Read, Duncan Spence, Hugh Klein, Nitika Gupta, Mohsin Haji

National Physical Laboratory, London, United Kingdom

Abstract

Vertical cavity surface emitting lasers (VCSELs) are useful for certain miniature atomic clocks. When a VCSEL is frequency locked to a rubidium spectral line, ambient thermal changes can cause intensity variations that lead to light (ac Stark) shifts. To alleviate this, intensity locking can be implemented by stabilising the thermal actuator (in this case, a thermoelectric cooler), although the bandwidth of this type of servo is typically much slower (several seconds), leading to residual intensity noise in the short term.

The VCSEL operating temperature and thermal stability plays an important role in determining the optical frequency and intensity stability performance of these clocks. Commercial rubidium-based miniature atomic clocks contain physics packages that tend to operate above 70°C. it is therefore important to understand the temperature and bias current tuning coefficients, along with the spectral purity of the lasers over a range of temperatures close to this operating temperature.

795 nm VCSELs have been tested for potential use in a miniature rubidium clocks. The temperature and current tuning factors were measured to tune the laser to the correct transition. An optical emission power of 300 µW was obtained, suitable to feed into the physics package of the clock. Due to the device's current limitations (damage threshold limits > 2 mA), the temperature tuning coefficient was seen as the dominant tuning parameter. Further results will be presented at the conference.

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C162

Optimised atomic interrogation for reduced instability in optical clocks

Filip Butuc-Mayer[1,2], Chen-Hao Feng[1], Matthew Johnson[1], Ian Hill[1]

[1]National Physical Laboratory, Teddington, United Kingdom. [2]University of Oxford, Oxford, United Kingdom

Abstract

The rate at which an optical clock's frequency fluctuations average down is limited by its frequency instability, which arises from errors in the frequency measurements used to steer the local oscillator to the atomic reference. We have developed numerical simulations and statistical models to characterise the frequency instability of different clocks, extended to include mixed noise types, dead-time, and short probe times. We use these to explore the contribution of three main sources of error: the Dick effect, quantum projection noise (QPN), and coherence time limit (CTL).

We identify potential improvements to the limiting instability at the optimal probe time using a dynamically decoupled probe scheme, which allows for modification of the duty cycle through engineering of the probe sensitivity level. This has an advantage in optical lattice clocks as it trades only a marginal increase in QPN and CTL for a significant reduction in the dominant Dick effect noise. We present experimental implementations of such a probe scheme in a Sr optical lattice clock and estimate its effect on clock instability. We also use this method to extend the duty cycle of two Sr optical lattice clocks to implement a zero deadtime composite clock with extremely low Dick noise and the ability to track local oscillator phase continuously. Finally, we show how phase tracking can enhance the local oscillator in a hybrid composite clock setup, offering improved stability in systems which are limited by QPN and CTL, such as single-ion clocks.

Categories

Clocks and metrology

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C163

Cold thulium atomic beam for continuous loading of the narrow line MOT

Mikhail Yaushev[1,2], Denis Mishin[1,2], Dmitriy Tregubov[1,2], Provorchenko Daniil[1,2], Nikolay Kolachevsky[1,2], Artem Golovizin[1,2]

[1]The Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russian Federation.
[2]Russian Quantum Center, Moscow, Russian Federation

Abstract

Ensembles of neutral atoms are widely used as a platform for various experiments. Recently, there has been an increased interest in using an additional two-dimensional magneto-optical trap (2D MOT) which is located in separate vacuum chamber as a source of cold atomic flux. This approach provides a number of benefits in comparison with the classical Zeeman slower including compactness which is essential for transportable systems (e.g., optical clocks) and absence of hot atoms from the atomic oven or dispenser in the main ("science") vacuum chamber, which simplifies achieving ultrahigh vacuum.

Furthermore, the possibility of operation of MOT with deep laser cooling in continuous mode opens new pathways for realization of optical clocks with continuous interrogation of the clock transition and experiments with continuous BEC.

Here we discuss the design of a source of cold thulium atoms based on a two-dimensional magneto-optical trap on a broad transition at a wavelength 410 nm alongside numerical simulation of its performance. Based on theoretical predictions the cold atomic beam has narrow longitudinal velocity distribution with center at v=8 m/s and FWHM of 1 m/s. The angular spread of the atomic beam is less than 50 mrad. Such beam characteristics should allow direct capturing of almost all atoms in the secondary MOT on the narrow transition at 530 nm. Our design could be modified for experiments with other rare-earth atoms, namely our new ytterbium tweezer project will be based on aforementioned scheme.

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C164

Black-body radiation shifts of ion-based optical clocks

Martin Steinel[1], Thomas Lindvall[2], Melina Filzinger[1], Jian Jiang[1], Saaswath J. K.[1], Ekkehard Peik[1], Nils Huntemann[1]

[1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany. [2]VTT Technical Research Centre of Finland, National Metrology Institute VTT MIKES, Espoo, Finland

Abstract

Ion-based optical clocks realize transition frequencies with small uncertainty. The shifts from thermal radiation perturbing the ions limit the accuracy of optical clocks operated at room temperature. Particular challenges result from the temperature rise of the ion trap assembly from radiofrequency losses during operation. For $^{88}Sr^+$ the sensitivity Δα to infrared radiation has been measured with small uncertainty [1]. Consequently, it can be used to determine the intensity of black-body radiation (BBR).

We follow this idea by measuring the rise of the effective temperature of BBR above ambient temperature via the corresponding frequency shift of $^{88}Sr^+$. Measurements with different rf powers allow us to extrapolate the BBR shift to zero heating. Using an independent $^{171}Yb^+$ optical clock as a reference, we find their frequency ratio with 2.3×10^{-17} uncertainty [2]. This result helps with tension found between previous determinations of the $^{88}Sr^+$ clock frequency and supports an improved recommended standard value [3].

We also use $^{88}Sr^+$ to obtain the local intensity of an infrared laser at the ion position. Placing an $^{171}Yb^+$ ion at the same position, allows us to calculate Δα from the induced frequency shift. This allows us to determine Δα for the $^{171}Yb^+$ clock transitions more accurately, enabling clock operation with 10^{-19} uncertainty.

[1] P. Dubé, et al., Phys. Rev. Lett. 112, 173002 (2014)

[2] M. Steinel, et al., Phys. Rev. Lett. 131, 083002 (2023)

[3] H. S. Margolis, et al., Metrologia 61, 035005 (2024)

Categories

Clocks and metrology

Presentation

Poster presentation

C165

Resonance states in exotic helium-like atoms

Jean Servais, Jérémy Dohet-Eraly

Université libre de Bruxelles, Brussels, Belgium

Abstract

In the last decades, exotic few-body atoms, in which an electron is replaced by an exotic particle, have attracted great scientific interest. These systems are indeed useful to determine accurately the properties of their constituting exotic particles.

For instance, an antiproton can be captured by a helium atom in a high orbital momentum state (L = 30 to 35) to form the so-called antiprotonic helium. This atom lies in a high-L quasibound resonant state with long lifetime. The radiative transitions between these quasibound states enable to study these systems experimentally, and the recent study of antiprotonic helium has led to the up-to-now most precise value of the antiproton mass. Similar studies have been conducted with other exotic atoms, such as pionic helium.

In order to give a quantitative understanding of those systems, I will present a method for computing non-relativistic resonance energies and widths of three-body exotic atoms, for a wide range of the total orbital momentum L.

I developed an approach combining the Lagrange-mesh method and the complex Kohn variational principle to obtain the S-matrix related to the emission of the electron from the three-body system. By approximating the S-matrix in the complex plane from the real axis, the widths of the states are determined.

I will show that this approach is suited for studying very accurately the resonances of these systems for a wide range of the orbital momentum L. In addition, I will show how to evaluate the leading-order relativistic corrections to the energies of these systems.

Categories

New directions

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Poster presentation

C166

The MOT revisited: can order-of-magnitude increase in atom loading open up new possibilities for cold atoms?

Nathan Cooper, David Johnson, Ben Hopton, Lucia Hackermuller

University of Nottingham, Nottingham, United Kingdom

Abstract

Cold atoms underpin our most advanced quantum sensors and many proposed tests of fundamental physics; these include searches for dark matter, tests of wave function collapse and the equivalence principle, gravitational wave detection and even experimental measurement of quantum gravity. The performance of these sensors and experiments scales favourably with the number of atoms used – at least as the square root of the atom number from signal-to-noise considerations, but sometimes linearly or even quadratically. Cold atom experiments are already a competitive approach in these areas, so any major improvement in atom capture efficiency would push the boundaries of our abilities to test fundamental physics far beyond their current level.

We are constructing an experiment that will use multiple optical frequencies to address a wide range of velocity classes of atom simultaneously, allowing a dramatic improvement in the rate at which atoms can be captured. This approach was briefly investigated in the early 1990s and a number of seemingly unavoidable pitfalls were identified. Exploiting subsequent advances in experimental hardware, we have updated the multi-frequency approach to circumvent these problems; by combining this with methods to reduce density-dependent losses, we aim to drastically break existing records for atom capture efficiency.

Our long-term goal is to experimentally probe quantum gravity – something not feasible without major experimental advances. However, the development of improved atom trapping techniques is potentially more important than any single application; if sufficiently effective, these could have a transformative effect within many areas of research, both applied and fundamental.

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New directions

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C167

Terahertz and Radio-Frequency Sensing and Imaging using Caesium Rydberg Atoms

Gianluca Allinson, Matthew J. Jamieson, Lucy Downes, Andrew MacKellar, Kevin J. Weatherill, C. Stuart Adams

Department of Physics, Durham University, Durham, United Kingdom

Abstract

Rydberg atoms, those with electrons excited to very high principal quantum numbers, exhibit exaggerated properties that render them superb quantum sensors. Employing a hot caesium (Cs) Rydberg-atom receiver, we demonstrate the simultaneous detection of radio-frequency (RF) fields from the very high-frequency (VHF) band at 128 MHz to terahertz frequencies at 0.61 THz. These RF fields are concurrently applied to a sequence of high-orbital-angular-momentum states, enabling access to progressively higher L states with diminishing energy separations, thus covering a broad spectrum of radio frequencies. Consequently, a series of amplitude-modulated tones can be detected across a vast range of carrier frequencies. This paves the way for Rydberg receivers to access low-frequency RF bands at lower principal quantum numbers and facilitates communication across multiple bands simultaneously with a singular optical receiver. Additionally, the experimental approach described permits high-resolution spectroscopy of these states. We also outline our THz full-field imager that utilizes hot Rydberg atoms as THz-to-optical converters.

Poster

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New directions

Presentation

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C168

Transfer of an optical skyrmion to matter

Chirantan Mitra[1,2], Chetan Sriram Madasu[3,2], Lucas Gabardos[1,2], Chang Chi Kwong[1,2], Yijie Shen[1], David Wilkowski[1,3,2], Janne Ruostekoski[4]

[1]Nanyang Technological University, Singapore, Singapore. [2]MajuLab, International Joint Research Unit, CNRS-UCA-SU-NUS-NTU, Singapore, Singapore. [3]Centre for Quantum Technologies, Singapore, Singapore. [4]Lancaster University, Lancaster, United Kingdom

Abstract

The recent advances in the engineering of structured light have allowed for the creation of optical beams having non-trivial topologies [1]. Notably, paraxial beams of light can carry a topological charge if the Stokes vector field has a spatially winding pattern, similar to the spin profile of a skyrmion [2]. In this experiment, we create such a skyrmionic beam of light that coherently excites a gas of ultracold strontium atoms. The optical spin texture is mapped on the atomic dark state via adiabatic passage and the transferred topological charge is subsequently detected. This work could find potential applications in topological photonics for information storage.

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New directions

Presentation

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C169

Third-order exceptional point in an ion-cavity setting

Taegyu Ha[1], Jinuk Kim[2], Donggeon Kim[1], Dowon Lee[1], Jongcheol Won[1], Youngil Moon[1], Moonjoo Lee[1]

[1]Department of Electrical Engineering, Pohang University of Science and Technology (POSTECH), Pohang, Korea, Republic of. [2]Quantum Technology Institute, Korea Research Institute of Standards and Science (KRISS), Daejeon, Korea, Republic of

Abstract

We theoretically explore the non-Hermitian physics and a higher-order exceptional point (EP) with trapped ions in an optical cavity [1]. In the lambda-type level configuration, the ion is driven by a pump laser field, and the resonator is probed with a low-intensity laser field. By using the high asymmetric branching ratio of an ion's excited state, the system is in the weak-excitation limit and thus we can neglect a quantum jump operator, in order to obtain the non-Hermitian Hamiltonian (H_{nH}). We can extract the eigenvalues of the H_{nH} by fitting the cavity-transmission spectrum. The EP3 appears at a point where the Rabi frequency of the pump laser and the atom-cavity coupling constant balance the loss rates of the system. We provide feasible experimental parameters for $^{40}Ca^{+}$. This exceptional point would be equivalent to a crossover point between cavity electromagnetically induced transparency and Autler-Townes splitting.

[1] J. Kim*, T. Ha*, D. Kim, D. Lee, K.-S. Lee, J. Won, Y. Moon, and M. Lee, Appl. Phys. Lett. 123, 161104 (2023)

Categories

Cavity QED

Presentation

Poster presentation

C170

Towards a 1D Periodic Trap

Omar Hussein, Forouzan Forouzan Forouharmanesh, Paul del Franco, Megan Byres, Andrew Lagno, Alan Jamison

University of Waterloo, Waterloo, Canada

Abstract

We report our progress toward building a 1D periodic trap for bosons. The trap will help us experimentally realize the Lieb-Liniger model under a periodic boundary condition. We also plan to explore non-equilibrium physics in the range between the two limits of a weakly interacting bose gas to a strongly interacting one.

Categories

Many body physics

Presentation

Poster presentation

C171

Towards superfluid flow experiments with periodic boundary conditions

Forouzan Forouharmanesh, Omar Hussein, Paul Del Franco, Megan Byres, Andrew Lagno, Alan Jamison

University of Waterloo, Waterloo, Canada

Abstract

We report progress toward exploring the dynamic of superfluids in a strongly correlated Li Fermi gas by utilizing a novel trap geometry, the two dimensional surface of a cylinder. This cylindrical trap provides the required periodic boundary condition to sustain the persistent flow. It will allow us to make long-time measurements near the critical velocity of the superfluid. Employing dynamically tunable barriers, we will study the breakdown of superfluidity. A well-controlled study of the superfluid breakdown in a strongly correlated superfluid, like a unitary Fermi gas below the critical temperature, provides insights into the overall dynamics with strong correlations and high levels of entanglement.

Categories

Quantum fluids

Presentation

Poster presentation

C172

Optimized detection modality for double resonance alignment based optical magnetometer

ali akbar[1], marcin kozbial[2], Lucy Elson[1], Adil Meraki[1], janek Kolodynski[2], kasper jensen[1]

[1]University of Nottingham, Nottingham, United Kingdom. [2]University of Warsaw, Poland, Poland

Abstract

We present a comprehensive and comparative analysis of two detection modalities, i.e., polarization rotation and absorption measurement of light, for a double resonance alignment based optical magnetometer (DRAM). We derive algebraic expressions for magnetometry signals based on multipole moments description. Experiments are carried out using a room-temperature paraffin-coated Caesium vapour cell and measuring either the polarization rotation or absorption of the transmitted laser light. A detailed experimental analysis of the resonance spectra is performed to validate the theoretical findings for various input parameters. The results signify the use of a single isotropic relaxation rate thus simplifying the data analysis for optimization of the DRAM. The sensitivity measurements are performed and reveal that the polarization rotation detection mode yields larger signals and better sensitivity than absorption measurement of light.

Poster

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Categories

Precision measurements

Presentation

Poster presentation

C173

GHZ protocols enhance frequency metrology despite spontaneous decay

Timm Kielinski, Klemens Hammerer

Leibniz University, Hannover, Germany

Abstract

The use of correlated states and measurements promises improvements in the accuracy of frequency metrology and the stability of atomic clocks. However, developing strategies robust against dominant noise processes remains challenging. We address the issue of decoherence due to spontaneous decay and show that GHZ states, for ensembles of up to 40 atoms, achieve gains comparable to those of a hypothetical optimal quantum interferometer, except for a constant offset. This result is surprising since GHZ states do not provide any gain under dephasing noise compared to the standard quantum limit of uncorrelated states. We calculate the corresponding Cramér-Rao bound under spontaneous emission and identify a correlated measurement and a nonlinear estimation strategy that saturate this bound. The gain from GHZ states arises from a veto signal in the nonlinear estimator, which allows for the detection and exclusion of errors caused by spontaneous emission events. Through comprehensive Monte-Carlo simulations of atomic clocks, we demonstrate the robustness of the GHZ protocol. All necessary entangling and disentangling operations can be performed using single one-axis-twisting operations, making this scheme well-suited for atomic clocks based on trapped ions or neutral atoms in tweezer arrays.

Poster

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Categories

Clocks and metrology

Presentation

Poster presentation

C174

Observation and Characterization of the Low-Energy Isomeric Transition in ^{229}Th-Doped Crystals and Thin Films

Ricky Elwell[1], Christian Schneider[2], Justin Jeet[3], James E Terhune[1], Chuankun Zhang[4], Tian Ooi[4], Jake Higgins[4], Jun Ye[4], Harry Morgan[1], Anastassia Alexandrova[1], Hoang Bao Tran Tan[5], Andrei P Derevianko[6], Eric R Hudson[1]

[1]University of California, Los Angeles, USA. [2]NASA Jet Propulsion Laboratory, Flintridge, USA. [3]Lawrence Livermore National Lab, Livermore, USA. [4]CU Boulder/JILA, Boulder, USA. [5]Los Alamos National Laboratory, Los Alamos, USA. [6]University of Nevada, Reno, USA

Abstract

The nucleus of ^{229}Th has an exceptionally low-energy isomeric transition in the vacuum-ultraviolet (VUV) spectrum that holds much promise for future timekeeping and quantum logic operations [1]. Our group has recently measured a laser-linewidth-limited feature in ^{229}Th-doped $LiSrAlF_6$ crystals at $148.38219(4)_{stat}(20)_{sys}$ nm ($2020407.3(5)_{stat}(30)_{sys}$ GHz) that decays with a lifetime of $568(13)_{stat}(20)_{sys}$ s [2]. This feature is assigned to the excitation of the ^{229}Th nuclear isomeric state, whose energy is found to be $8.355733(2)_{stat}(10)_{sys}$ eV in ^{229}Th:$LiSrAlF_6$. In addition, our group has managed to find a similar feature in $^{229}ThF_4$ thin films that is characteristic of the excitation of the isomeric state. These $^{229}ThF_4$ films have the potential to greatly simplify the construction of a solid state nuclear clock. Our ongoing efforts to understand the coupling of this nuclear transition to the local environment in these systems will be discussed.

[1] Campbell, C. J., et. al. Phys. Rev. Lett. 108, 120802 (2012)
[2] Elwell, R., et. al. Phys. Rev. Lett. (accepted), arXiv:2404.12311

Categories

Clocks and metrology

Presentation

Poster presentation

C175

Measurements of optical transitions of highly charged ions suitable for frequency metrology and probing variation of fundamental constants

Nils-Holger Rehbehn[1], Lakshmi Priya Kozhiparambil Sajith[1,2], Michael Karl Rosner[1], Steven Worm[2], Dmitry Budker[3,4,5], Thomas Pfeifer[1], José Ramon Crespo López-Urrutia[1], Hendrik Bekker[4]

[1]Max-Planck-Institut fuer Kernphysik, Heidelberg, Germany. [2]DESY, Zeuthen, Germany. [3]Johannes Gutenberg-University, Mainz, Germany. [4]Helmholtz Institute Mainz, Mainz, Germany. [5]University of California, Berkeley, USA

Abstract

Atomic theorists have identified dozens of highly charged ions (HCI) with optical transitions suitable for frequency metrology and tests of fundamental physics, but only limited experimental data are available. Most of the transitions of interest are found near level crossings, where the filling order of atomic shells changes over from the Aufbau principle to Coulomb order. There, the electronic structure of these systems becomes very complex, making theoretical predictions difficult and far from sufficiently accurate to allow for directly finding transitions using laser spectroscopy. We present our methods to measure and subsequently identify the sought-after transitions, which were applied to discover the *4f-5p* level crossing in Pr^{9+} . We also show the latest results from our search for the *4f-5s* one in Ir^{17+} or Os^{16+} , in which transitions with a very high sensitivity to variation of the fine-structure constant can be found. This is a vital first step in developing new clocks based on HCI, and serves as crucial input for improving atomic theory codes. Finally, exciting prospects for fundamental studies based on radioisotopes and nuclear transitions such as in ^{229}Th will be discussed.

Categories

Precision measurements

Presentation

Poster presentation

D001

Kapitza-Dirac scattering of strongly interacting Fermi gases

Max Hachmann[1], Yann Kiefer[2], Andreas Hemmerich[1]

[1]Institute for Quantum Physics, University of Hamburg, Hamburg, Germany. [2]ETH Zürich, Zürich, Switzerland

Abstract

We experimentally probe properties of interacting spin-mixtures of fermionic (^{40}K) atoms by studying their interaction with light. An elementary scattering scenario is resonant Bragg diffraction, also referred to as Bragg spectroscopy, where matter is diffracted from a onedimensional (1D) optical standing wave. A Feshbach resonance is used to tune the interactions across the entire BEC-BCS crossover regime, including the point of unitarity. With the preparation schemes available in our experiment, the scattering lengths can be dynamically tuned, such that either repulsively bound molecular dimers (Feshbach molecules) or pairs of unbound fermions can be studied. To benchmark our scattering protocol, we apply it to a sample of spin-polarized non-interacting fermionic atoms and study the dynamical behaviour. In this case, a simple model using a time-dependent Schrödinger equation yields surprisingly accurate results, well matching the experimental observations. For spin-mixtures in the unitarity regime, the higher order diffraction peaks are observed to disappear with no conclusive theoretical description presently available.

Categories

Many body physics

Presentation

Poster presentation

D002

Bragg spectroscopy of a dissipation-induced instability in an atom-cavity system

Alexander Baumgärtner, Gabriele Natale, Justyna Stefaniak, Simon Hertlein, David Baur, Dalila Rivero, Tobias Donner, Tilman Esslinger

ETH Zürich, Zürich, Switzerland

Abstract

In recent years, ultra-cold atom research has driven significant advancements in quantum optics, condensed matter physics, and quantum information processing, leading to the discovery of novel states of matter and new quantum simulation platforms. While many studies have focused on weakly interacting, short-range systems, there is a growing interest in systems with long-range interactions, especially those involving dissipation, which leads to complex dynamics. Understanding these systems can reveal new quantum phenomena and advance both quantum technology and fundamental physics.

Our experiment investigates the collective phenomena of a Bose-Einstein Condensate (BEC) of rubidium atoms trapped in two crossed high-finesse cavities. The coupling between the BEC and the cavity produces long-range interactions, resulting in two roton-like excitation modes corresponding to exotic superradiant phases [1,2]. The tunability of our system allows us to examine a parameter regime where the energy of these two modes would cross in a closed system. However, the inherent dissipation makes the fate of these two modes less trivial. To reveal the evolution of these modes, we performed Bragg spectroscopy measurements. We observed the coalescence of the two modes when their energies are close, leading to a dissipation-induced instability. Moreover, we studied the individual softening of the modes as they approach their respective phases, along with a diverging susceptibility.

[1] L. Xiangliang et al., Phys. Rev. Res. 3, L012024 (2021).

[2] D. Dreon et al., Nature 608, 494–498 (2022).

Categories

Many body physics

Presentation

Poster presentation

D003

Quantum Gas Microscopy of a Continuous Fermi Gas at Zero Temperature

Tim de Jongh[1], Maxime Dixmerias[1], Joris Verstraten[1], Cyprien Daix[1], Bruno Peaudecerf[2], Tarik Yefsah[1]

[1]Laboratoire Kastler Brossel, Paris, France. [2]Laboratoire Collisions Agrégats Réactivité, Toulouse, France

Abstract

Fermionic systems adhere to Pauli exclusion, one of the most fundamental principles of quantum mechanics, that prevents identical fermions from occupying the same quantum state. This leads to an antibunching of particles which manifests itself in the systems' density-density correlations. Here we present the direct, *in-situ* observation of antibunching at the single-atom level. Using a quantum gas microscope devoted to the study of continuous many-body systems, we probe both the density correlations in a two-dimensional, non-interacting Fermi Gas. At zero temperature, we observe distinct antibunching behavior in both the two- and three-body density correlations. We cross-validate our measurement protocol by relating these correlation functions through a Wick-decomposition, obtaining an excellent agreement between the two measured quantities. These results represent the first application of a quantum gas microscope to a many-body system in continuous space and offer the perspective to probe strongly-interacting Fermi gases in free space at an unprecedented length scale.

Categories

Many body physics

Presentation

Poster presentation

D004

Topological pumping in optical lattices: interactions and edge modes

Konrad Viebahn[1], Zijie Zhu[1], Anne-Sophie Walter[1], Marius Gächter[1], Stephan Roschinski[1], Joaquin Minguzzi[1], Samuel Jele[1], Giacomo Bisson[1], Yann Kiefer[1], Eric Bertok[2], Armando A. Aligia[3], Fabian Heidrich-Meisner[2], Tilman Esslinger[1]

[1]ETH Zurich, Zurich, Switzerland. [2]Georg-August-Universität Göttingen, Göttingen, Germany. [3]Centro Atomico, Bariloche, Argentina

Abstract

A topological Thouless pump represents the quantised motion of atoms, electrons or, in general, quantum many-body states. This directional transport is enabled by a slow, cyclic modulation of external control parameters. Traditionally, Thouless pumping has been described in the language of free fermions, exhibiting non-trivial single-particle Chern numbers. In our lab, we have recently been able to engineer many-body pumps by combining a dynamical, single-wavelength optical lattice with tuneable interactions between fermionic potassium-40 atoms.

This poster presents three phenomena that arise from the combination of quantised pumping with strong interparticle interactions. First, we show that pumping remains robust to weak and moderate interactions. However, strong interactions cause an asymmetric response in the sign of the interaction strength, in which pumping breaks down for repulsive interactions, while it remains quantised for attractive interactions [1]. Second, we demonstrate a purely interaction-induced pump for a modified trajectory of external driving parameters [2]. Finally, when taking into account the confining potentials, the pump exhibits two distinct reversals of quantised drift, which manifest themselves as individual topological edge modes in the non-interacting and interacting cases, respectively [3]. Our results demonstrate the ability of topological pumps to probe the interplay between topology and strong interactions.

[1] Walter et al., Nature Physics 19, 1417 (2023)

[2] Viebahn et al. PRX (in press)

[3] Zhu et al. Science 384, 317 (2024)

Categories

Many body physics

Presentation

D005

A quantum gas microscope for Rubidium-87

Enid Cruz Colón[1], Candice Chua[2], Jinggang Xiang[1], Wolfgang Ketterle[1]

[1]Massachusetts Institute of Technology, Cambridge, USA. [2]Harvard University, Cambridge, USA

Abstract

We present recent experimental progress to realize a quantum gas microscope for site-resolved imaging of Rb-87. Our imaging system features a high numerical aperture objective (NA = 0.8) with a long working distance. The atoms are trapped in a combination of two orthogonal lattices with a spacing of 532 nm and a highly elliptical light sheet which confines the atoms within the depth of field of the objective. Polarization gradient cooling at 780 nm is employed to keep the atoms confined while also generating fluorescence photons. We have achieved to image single atoms with a full width at half maximum of 640 nm which allows for reconstruction of lattice occupation. A future addition of a digital micromirror device (DMD) will enable for single-site manipulation of the atoms. One possible direction for science under the microscope could be the study of emission of matter waves in-situ [1].

[1] Krinner, L., Stewart, M., Pazmiño, A. et al. Spontaneous emission of matter waves from a tunable open quantum system. Nature 559, 589–592 (2018). https://doi.org/10.1038/s41586-018-0348-z

Categories

Many body physics

Presentation

Poster presentation

D006

Exploring supersolidity with spin-orbit coupled Bose-Einstein condensates

Sarah Hirthe[1], Rémy Vatré[1], Vasiliy Makhalov[1], Craig Chisholm[1], Ramón Ramos[1], Leticia Tarruell[1,2]

[1]ICFO - The Institute of Photonic Sciences, Barcelona, Spain. [2]ICREA, Barcelona, Spain

Abstract

Spin-orbit coupled Bose-Einstein condensates, where the internal state of the atoms is linked to their momentum through optical coupling, are a flexible experimental platform to engineer synthetic quantum many body systems. In my poster, I will present recent work where we have exploited the interplay of spin-orbit coupling and tunable interactions in potassium BECs to observe and characterize the supersolid stripe phase. Supersolidity is a counter-intuitive phase of matter that combines the frictionless flow of a superfluid and the crystalline structure of a solid. While this has been observed on several cold atom platforms, realizations based on spin-orbit coupling have so far been very fragile, and could only be probed indirectly. This led to contradictory opinions concerning the properties of their modulated density profile, also known as the stripe pattern, and of their collective excitations. Here, we have achieved a robust regime of supersolidity in spin-orbit coupled BECs, which enables us to observe their modulated density profiles in situ. We demonstrate that the stripe spacing is not fixed, but varies with the spin-orbit coupling strength. Moreover, the system hosts a crystal compression mode which dynamically changes the spacing. We measure the softening of the compression mode frequency with increasing spin-orbit coupling strength, thus revealing the supersolid phase transition. Our experiments establish spin-orbit coupled BECs as a powerful platform to investigate supersolidity, and provide an excellent starting point to explore its interplay with quantum fluctuations and external lattice potentials.

Categories

Many body physics

Presentation

Poster presentation

D007

Progress towards long-range interactions study using lattice trapped ultracold Sr atoms

Balsant Shivanand Tiwari, Sandhya Ganesh, Ceren Yuce, Yeshpal Singh

School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

Abstract

Our research explores fundamental physics using ultracold strontium (Sr) atoms. In particular, we aim to study long-range dipole-dipole interactions by observing the collective properties of scattered light from lattice-trapped Sr atoms. We've successfully completed the first-stage cooling (Blue MOT), and measured the $^3P_2$ magnetic trap lifetime. We're currently implementing the second-stage cooling, aiming for Bose-Einstein Condensation (BEC). Achieving these milestones relies heavily on the innovative tools we have developed. Our innovations include a suite of systems based on Red Pitaya STEMlab, utilizing Python and C programming. This includes a laser frequency stabilization system that employs a scanning transfer cavity—a cost-effective method for stabilizing a slave laser to a master using a Fabry-Perot cavity. The master laser operates at 698 nm with a 200 Hz linewidth, while the slave operates at 679 nm. Additionally, our control system, enhanced with Redpitaya, expands our capabilities by adding digital and analog channels. This setup supports data acquisition from devices like photomultiplier tubes and photodiodes, enabling real-time, data-driven optimization. Moreover, we developed a frequency modulation system that controls and modulates the 689 nm laser, aiding the transition from a Broadband Red MOT to a Single Frequency Red MOT for more efficient second-stage cooling.

Categories

Many body physics

Presentation

Poster presentation

D008

Melting of a vortex lattice in a fast rotating Bose gas

Rishabh Sharma[1], David Rey[2], Thomas Badr[2], Aurélien Perrin[2], Laurent Longchambon[2], Hélène Perrin[3], Romain Dubessy[2]

[1]Laboratoire de physique des lasers - Université Sorbonne Paris Nord - CNRS, Villetaneuse, France. [2]LPL-USPN-CNRS, Villetaneuse, France. [3]LPL-CNRS-USPN, Villetaneuse, France

Abstract

Weakly interacting quantum gases offer a very convenient platform for the study of superfluid dynamics. One of the many interesting properties of superfluids is their behaviour when put in rotation. The ground state of the rotating gas supports a triangular vortex lattice at zero temperature. The vortex density is set by the rotation frequency. As temperature increases, the triangular lattice is expected to be gradually destroyed, by displacement of the vortex centers and eventually strong phase fluctuations. In the poster, I will present our experimental observations as we put in rotation the rubidium quantum gas in a bubble shaped trap made up of magnetic and the radio-frequency (rf) field, by rotating the trap anisotropy. At large rotation frequency and finite temperature, we observe the progressive melting of the vortex lattice. We compare our findings to theoretical predictions by Gifford and Baym.

Categories

Many body physics

Presentation

Poster presentation

D009

Directional superradiance in a driven ultracold atomic gas in free-space

Sanaa Agarwal[1,2], Edwin Chaparro[1,2], Diego Barberena[1,2], Asier Pineiro Orioli[3,4], Giovanni Ferioli[5], Sara Pancaldi[5], Igor Ferrier-Barbut[5], Antoine Browaeys[5], Ana Maria Rey[1,2]

[1]JILA, NIST, Department of Physics, University of Colorado, Boulder, USA. [2]Center for Theory of Quantum Matter, University of Colorado, Boulder, USA. [3]QPerfect, Strasbourg, France. [4]University of Strasbourg and CNRS, CESQ and ISIS (UMR 7006), Strasbourg, France. [5]Universite Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, Palaiseau, France

Abstract

Ultra-cold atomic systems are among the most promising platforms that have the potential to shed light on the complex behavior of many-body quantum systems. One prominent example is the case of a dense ensemble illuminated by a strong coherent drive while interacting via dipole-dipole interactions. Despite being subjected to intense investigations, this system retains many open questions. A recent experiment carried out in a pencil-shaped geometry reported measurements that seemed consistent with the emergence of strong collective effects in the form of a "superradiant'' phase transition in free space, when looking at the light emission properties in the forward direction.

Motivated by the experimental observations, we carry out a systematic theoretical analysis of the system's steady-state properties as a function of the driving strength and atom number, *N*. We observe signatures of collective effects in the weak drive regime, which disappear with increasing drive strength as the system evolves into a single-particle-like mixed state comprised of randomly aligned dipoles. Although the steady-state features some similarities to the reported superradiant to normal non-equilibrium transition, also known as cooperative resonance fluorescence, we observe significant qualitative and quantitative differences, including a different *N*-scaling of the critical drive parameter. We validate the applicability of a mean-field treatment to capture the steady-state dynamics under currently accessible conditions. Furthermore, we develop a simple theoretical model that explains the scaling properties by accounting for interaction-induced inhomogeneous effects and spontaneous emission, which are intrinsic features of interacting disordered arrays in free space.

Categories

Many body physics

Presentation

Poster presentation

D010

Floquet transverse-field Ising dynamics in a Rydberg-dressed optical tweezer array

Neomi Lewis, Shankari Rajagopal, Gabriel Moreau, Michael Wahrman, Monika Schleier-Smith

Stanford University, Stanford, USA

Abstract

Ising dynamics are a paradigmatic model of quantum magnetism, and can be implemented in cold atoms using Rydberg interactions. By using Rydberg dressing with microwaves, we have shown a natural implementation of transverse-field Ising dynamics. Neutral atom tweezer arrays have proven to be valuable testbeds for quantum simulation, computation, and metrology. Using Rydberg dressing and microwaves, cold atoms allow for a natural implementation of transverse-field Ising dynamics - a paradigmatic model of quantum magnetism. Time-dependent control of these interactions can enhance entanglement generation, execute quantum optimization algorithms, emulate more complex spin models, and explore driven phases with no equilibrium analogue. In previous experimental work in a bulk gas of cesium atoms, we demonstrated such a Floquet implementation of the transverse-field Ising model, observing dynamical signatures of a mean-field paramagnet-ferromagnet phase transition. More recently, we optimized the Rydberg dressing pulse sequence, thus extending the coherence time of the interactions to generate squeezed spin states for quantum-enhanced sensing. In this poster, we present experimental upgrades to an array of single atoms in optical tweezers and discuss three directions enabled by the optical control of Ising interactions afforded by Rydberg dressing: (a) Realization of Floquet symmetry-protected topological phases, (b) simulation of emergent black hole dynamics based on a Floquet conformal field theory, and (c) optimal control of entanglement for quantum metrology.

Categories

Many body physics

Presentation

Poster presentation

D011

Non-equilibrium molecule association in lithium-6 revealing emerging coherence and enabling shortcuts to adiabaticity

Lucia Hackermueller, Nathan Cooper, David Johnson, Daniele Baldolini, Matthew Overton, Benjamin Hopton

University of Nottingham, Nottingham, United Kingdom

Abstract

We study non-equilibrium association of Li_2 Feshbach molecules over a range of temperatures $T>>T_F$ to $T<<T_F$. We observe an enhancement of the atom–molecule coupling efficiency as the fermionic atoms reach degeneracy demonstrating the importance of many-body coherence [1]. Our theoretical model can explain the temperature dependence of the atom–molecule coupling and we use it to demonstrate a shortcut to adiabaticity in molecular association efficiency.

We will also present recent results of a new type of microscopic atom-photon interface [2]. Hybrid quantum devices, incorporating both atoms and photons, are able to exploit the benefits of both systems. In our system, cold atoms are transferred to an optical dipole trap and positioned inside a transverse, 30 µm diameter through-hole in an optical waveguide, created via laser micromachining. We discuss precise atom number detection exploiting and adaptive Bayesian optimisation method, precision spectroscopy and photon storage.

For portable quantum technologies additive manufacturing or 3D-printing offers unique advantages. We have demonstrated a full magneto-optical trapping setup based on 3D-printing techniques including a 3D-printed ultra-high vacuum chamber with remarkably compactness weight reduction of more than 70%. [3] We have extended this method to transparent elements and will report on the first 3D-printed vapour cells. 3D-printed vacuum chambers can also be used for an experiment to detect the effect of dark walls.[4]

References:

[1] New J. Phys. 24 113005 (2022).

[2] Phys. Rev. Res. 2, 033098 (2020).

[3] PRX Quantum 2, 030326 (2021).

[4] arxiv:2308.01179 (2024).

Categories

Many body physics

Presentation

Poster presentation

D012

Universal Scaling Laws in the Weak Collapse of a BEC

Sebastian Cargan-Morris, Jiri Etrych, Simon Fischer, Gevorg Martirosyan, Christopher Ho, Zoran Hadzibabic, Christoph Eigen

University of Cambridge, Cambridge, United Kingdom

Abstract

Attractive box-trapped Bose-Einstein condensates exhibit weak collapse, where an unstable system evolves self-similarly towards a singularity, until three-body interactions regularize the otherwise diverging density. Counterintuitively, as the singularity is approached, the atom number in the shrinking collapse region decreases, and, consequently, more unstable systems exhibit smaller particle loss. Here, we extend measurements of the weak-collapse scaling laws, reproduce them using numerical simulations of the extended Gross-Pitaevskii equation, and reconcile them with analytical predictions for small dissipation. Finally, we explore the structure of the collapse remnants, finding rich variety in their momentum distributions, including striking power-law tails.

Categories

Many body physics

Presentation

Poster presentation

D013

Site-resolved imaging of ytterbium atoms in optical lattices

Jeong Ho Han[1], Haejun Jung[2], Yunheung Song[1], Jae-yoon Choi[2], Jongchul Mun[1]

[1]KRISS, Daejeon, Korea, Republic of. [2]KAIST, Daejeon, Korea, Republic of

Abstract

Ultracold gases of alkaline-earth-like atoms in optical lattices present a unique platform for quantum simulation of the SU(N) Fermi-Hubbard model and the Kondo problem, leveraging their large nuclear spins and metastable clock states. To explore the many-body states that arise in these systems, quantum gas microscopy is essential for probing correlations in the exotic interacting regime. Here, we demonstrate site-resolved imaging of ytterbium atoms in optical lattices without cooling. The atoms are confined in two-dimensional optical lattices and a single layer of an accordion lattice, and imaged using the deep potential method. In this approach, the light shift from the optical lattice beam provides deeper confinement for the excited state atoms, preventing their escape from the system. The fluorescence photons are collected with a high numerical aperture (NA=0.6) objective lens with a long working distance. We highlight short exposure time (~100us), which helps overcome possible errors during imaging. Additionally, we discuss key aspects of our experiment, including technical improvements to reduce lattice noise and achieve low heating rates. Our future plans include realizing the Mott insulating phase with low entropy and extending the system to fermionic ytterbium isotopes.

Categories

Many body physics

Presentation

Poster presentation

D014

Ultracold bosons in frustrated optical lattices

Mehedi Hasan, Luca Donini, Sompob Shanokprasith, Daniel Braund, Tobias Marozsak, Tim Rein, Liam Crane, Max Melchner von Dydiowa, Daniel Reed, Tiffany Harte, Ulrich Schneider

University of Cambridge, Cambridge, United Kingdom

Abstract

Frustrated lattices provide unique opportunities to investigate novel complex quantum phases and transitions, as they can suppress the emergence of conventional long-range order. Here, we employ bosonic K(39) atoms in optical lattices as an analog quantum simulator for the Bose-Hubbard model on the triangular and Kagome lattices.

Since these lattices are non-bipartite, they exhibit geometric frustration. In the triangular lattice, this gives rise to two inequivalent band maxima. For the kagome lattice, the frustration results in a totally flat band. Since the effects of frustration are only seen at the top of the lowest set of touching bands, we utilise negative absolute temperatures where these highest energy states are preferentially occupied.

In the triangular lattice we have studied the superfluid to Mott insulator phase transition at negative absolute temperature. We observed a marked difference in the critical interaction strength of the transition between the frustrated system and the unfrustrated (positive temperature) system – highlighting how frustration can suppress long-range order. Furthermore, by studying the emergence of coherence at the phase transition, we address a long-standing question on the order of SF-MI phase transition in this system. Our data suggest a continuous SF-MI transition for the frustrated system, similar to the unfrustrated case.

In the kagome lattice we were able to stabilise the atoms in the flat band using negative absolute temperatures and to study the melting of the Mott insulator into the flat band.

Poster

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Categories

Many body physics

Presentation

Poster presentation

D015

Spin squeezing with contact interactions in quenched Heisenberg magnets

Yoo Kyung Lee[1,2,3], Hanzhen Lin[1,2,3], Vitaly Fedoseev[1,2,3], Maxwell Block[4,3], Philip Crowley[4,3], Wolfgang Ketterle[1,2,3]

[1]Massachusetts Institute of Technology, Cambridge, USA. [2]Research Laboratory of Electronics at MIT, Cambridge, USA. [3]MIT-Harvard Center for Ultracold Atoms, Cambridge, USA. [4]Harvard University, Cambridge, USA

Abstract

Entanglement is a unique trait of quantum systems and provides a crucial resource for quantum-enhanced capabilities in metrology, computing, and beyond. One celebrated example of an entangled and metrologically useful state is a spin-squeezed state, in which entanglement leads to lower variance in a global spin operator than the standard quantum limit. Spin squeezing has previously been realized only with long-range (all-to-all or dipolar) interactions. For the first time, using singly occupied Mott insulators of 30,000 lithium-7 atoms, we demonstrate spin squeezing in one-dimensional (1D) geometries with only contact interactions. Our system achieves 1.9 dB of squeezing, in quantitative agreement with theory. We also observe the onset of spin squeezing in three dimensions (3D). It is predicted that continuous symmetry breaking order in 3D enables scalable spin squeezing, where the optimal projection noise decreases with larger system sizes. However, experimentally we observe that the spin length decays to zero instead of equilibrating to a constant, signifying the absence of ordering in our system. Simulations indicate that this decay arises primarily from holes, suggesting that scalable squeezing in 3D is possible with the preparation of defect-free Mott insulators.

Poster

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Poster presentation

D016

Quantum gas microscopy of a frustrated XY model in shaken triangular lattices

Hideki Ozawa, Ryuta Yamamoto, Takeshi Fukuhara

RIKEN Center for Quantum Computing, Wako, Japan

Abstract

Magnetic frustration is an intriguing issue in condensed matter physics. Even in the case of the simplest geometrical spin frustration that occurs in the triangular structure with antiferromagnetic interactions, competition between the interactions and the lattice geometry brings about various phases and phenomena. We have developed an experimental apparatus of a Bose gas of rubidium atoms in an optical triangular lattice combined with a quantum gas microscope, which provides high spatial resolution and high sensitivity. By using a Bose-Einstein condensate in a shaken optical lattice, we investigated the relaxation and excitation in a frustrated XY model. We revealed that the two spiral phases with chiral modes show significant differences in relaxation time from the initial ferromagnetic phase. With a fast ramp, simultaneous occupation of two ground states often occurs, which can be attributed to the domain formation of the chiral modes. We have detected the interference of the spatially separated chiral modes (chiral-mode domains), using the quantum gas microscope [1].

[1] H. Ozawa *et al*., "Observation of chiral-mode domains in a frustrated XY model on optical triangular lattices," Phys. Rev. Res. 5, L042026 (2023).

Categories

Many body physics

Presentation

Poster presentation

D017

Fluctuation-thermometry of a Fermi gas via single-atom counting statistics

Maxime Dixmerias[1], Cyprien Daix[1], Joris Verstraten[1], Tim de Jongh[1], Bruno Peaudecerf[2], Tarik Yefsah[1]

[1]Laboratoire Kastler Brossel, Paris, France. [2]Laboratoire Collisions Agrégats Réactivité, Toulouse, France

Abstract

We report on a thermometry method based on local number fluctuations in a quasi-two-dimensional ideal Fermi gas in continuous space through quantum gas microscopy. In degenerate fermionic systems, quantum statistics lead to a suppression of density fluctuations and to a Pauli hole. We measure the local number statistics of a non-interacting Fermi gas *in situ* at the single-atom level and relate these to the temperature of the gas. In the thermodynamic limit, this relation is directly given by the fluctuation-dissipation theorem. For small subsystems, nonlocal correlations lead to a deviation from this behavior. By accounting for these finite-size effects, we are able to perform accurate fluctuation thermometry over a large dynamic range, from the classical limit down to the deeply degenerate regime. We verify the consistency of our analysis by measuring the two-body correlation function of our Fermi gas which we find to be in remarkable agreement with finite-temperature predictions, without any free parameter. This general method, based on the fluctuation-dissipation theorem, offers the perspective to accurately measure temperatures in ultra-dilute many-body quantum systems without relying on any theoretical model beyond basic thermodynamic principles.

Categories

Many body physics

Presentation

Poster presentation

D018

Antiferromagnetic bosonic t-J models and their quantum simulation in tweezer arrays

Lukas Homeier[1,2], Timothy Harris[1,2], Tizian Blatz[1], Ulrich Schollwöck[1], Fabian Grusdt[1,2], Annabelle Bohrdt[3], Sebastian Geier[4], Simon Hollerith[5], Neng-Chun Chiu[5], Cheng Chen[6], Mu Qiao[6], Gabriel Emperauger[6], Guillaume Bornet[6], Bastien Gely[6], Lukas Klein[6], Thierry Lahaye[6], Antoine Browaeys[6]

[1]LMU, Munich, Germany. [2]MCQST, Munich, Germany. [3]University of Regensburg, Regensburg, Germany. [4]Universtiy of Heidelberg, Heidelberg, Germany. [5]Harvard University, Cambridge (MA), USA. [6]Universite Paris-Saclay, Palaiseau Cedex, France

Abstract

The combination of optical tweezer arrays with strong interactions - via dipole-exchange of molecules and van-der-Waals interactions of Rydberg atoms - has opened the door for the exploration of a wide variety of quantum spin models. A next significant step is the combination of such settings with mobile dopants: This enables to simulate the physics believed to underlie many strongly correlated quantum materials. By engineering antiferromagnetic (AFM) couplings between spins, competition between charge motion and magnetic order similar to that in high-Tc cuprates can be realized. Here we propose an experimental scheme to realize bosonic t-J models via encoding the local Hilbert space in a set of three internal atomic or molecular states and present first preliminary experimental results in Rydberg tweezer arrays. The dipolar origin of the spin interaction allows us to explore regimes previously inaccessible in optical lattice experiments. Further, we give an outlook how bosonic t-J models enable us to realize non-Abelian SU(2) lattice gauge theories with dynamical matter.

Categories

Many body physics

Presentation

Poster presentation

D019

Ultracold bosons in quasiperiodic 2D lattices

Lee Reeve[1], Jr-Chiun Yu[2], Qijun Wu[1], David Gröters[1], Zhuoxian Ou[1], Emmanuel Gottlob[1], Yong-Guang Zheng[1], Bo Song[3], Ulrich Schneider[1]

[1]University of Cambridge, Cambridge, United Kingdom. [2]Industrial Technology Research Institute, Hsinchu, Taiwan. [3]Peking University, Beijing, China

Abstract

Ultracold atoms in optical lattices form powerful quantum simulators to study the many-body physics of (strongly) interacting particles in lattices. After originally focussing on periodic potentials, these methods have been extended to 1D quasiperiodic models such as the Aubry-Andre model, mostly to study Anderson and Many-Body localisation.

We have now generalized these techniques to an 8-fold rotationally symmetric 2D quasicrystal that is realized using four independent 1D lattices overlapped in a plane. We characterized the optical quasicrystal using matter-wave (Kapitza-Dirac) diffraction and directly observed its self-similarity in momentum space.

We furthermore report on the experimental realisation of the 2D Bose glass – a disorder-induced localised but compressible phase of interacting bosons. By probing the coherence properties of the system, we observe the superfluid to Bose glass transition and map out the phase diagram. Moreover, we study the crossover from Bose glass to Mott insulator and the dynamics of quenches across the superfluid-Bose glass transition.
Finally we compare the full quasicrystal to the 2D Aubry-Andre lattice.

Categories

Many body physics

Presentation

Poster presentation

D020

Suppression of polaron self-localization by correlations

Lilith Zschetzsche, Robert Zillich

Johannes Kepler University, Linz, Austria

Abstract

We investigate self-localization of a polaron in a homogeneous Bose-Einstein condensate. This effect, where an impurity is trapped by the deformation that it causes in the surrounding Bose gas, has been first predicted by mean-field calculations [1,2], but has not been seen in experiments. We first study polarons in one dimension, where, according to the mean-field approximation, the self-localization effect is particularly robust and present for arbitrarily weak impurity-boson interactions [3]. We address the question whether self-localization is a real effect by developing a variational method which incorporates impurity-boson correlations nonperturbatively and solving the resulting inhomogeneous correlated polaron equations. Correlations indeed inhibit self-localization except for very strongly repulsive or attractive impurity-boson interactions where we do find polarons which are significantly larger than predicted in mean field calculations [4]. Our prediction for the critical interaction strength for self-localization agrees with a sharp drop of the inverse effective mass found in quantum Monte Carlo simulations of polarons in one dimension [5]. We extend our study to polarons to higher dimensions and discuss how robust self-localization is when correlations are taken into account.

[1] F. M. Cucchietti and E. Timmermans, Phys. Rev. Lett. 96, 210401 (2006).

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[5] L. Parisi and S. Giorgini, Phys. Rev. A 95, 023619 (2017).

Categories

Many body physics

Presentation

Poster presentation

D021

Anomalous quantum transport in fractal lattices and possibles applications

Abel Rojo-Francàs[1,2,3], Priyanshu Pansari[4], Utso Bhattacharya[5,6], Bruno Juliá-Díaz[1,2], Tobias Grass[3,7]

[1]Departament de Física Quàntica i Astrofísica, Facultat de Física, Universitat de Barcelona, Barcelona, Spain. [2]Institut de Ciències del Cosmos, Universitat de Barcelona, ICCUB, Barcelona, Spain. [3]DIPC - Donostia International Physics Center, San Sebastián, Spain. [4]ndian Institute of Technology, Roorkee, India. [5]ICFO - Institut de Ci` encies Fot` oniques, The Barcelona Institute of Science and Technology, Castelldefels (Barcelona), Spain. [6]Institute for Theoretical Physics, ETH Zurich,, Zurich, Switzerland. [7]KERBASQUE, Basque Foundation for Science, Bilbao, Spain

Abstract

Recent advances in the engineering of quantum systems have spurred quantum technology applications, including the vast field of quantum simulation. Recent examples of a simulation setup exploring the laws of quantum physics beyond standard geometries are quantum particles in fractal lattices, including electronic systems generated by molecular assembly [1] or using scanning tunneling microscopy [2], photonic systems of coupled optical fibers [3,4], or cold atoms in optical tweezers [5].

Here, we study the dynamical properties of a fractal lattice, the Sierpiński gasket that exhibits an inverse power-law behavior of the level spacing distribution and can be related to the transport exponent. As a possible technological application, we discuss a memory effect in the Sierpiński gasket which allows the reading of the phase information of an initial state from the spatial distribution after long evolution times, which may be exploited as a quantum memory.

[1] J. Shang, et al., Nature Chemistry 7, 389 (2015).

[2] S. N. Kempkes, et al., Nat. Phys. 15, 127 (2019).

[3] X.-Y. Xu, et al., Nature Photonics 15, 703 (2021).

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Categories

Many body physics

Presentation

Poster presentation

D022

Kinetic magnetism and hole pairing in the doped bosonic t-J model

Timothy J. Harris[1,2], Ulrich Schollwöck[1,2], Annabelle Bohrdt[2,3], Fabian Grusdt[1,2]

[1]Ludwig-Maximilians-Universität München, Munich, Germany. [2]Munich Center for Quantum Science & Technology (MCQST), Munich, Germany. [3]Universität Regensburg, Regensburg, Germany

Abstract

Developing a precise theoretical description of the interplay between spin and charge degrees-of-freedom in doped Mott insulators is a central challenge at the heart of strongly correlated many-body physics. Here we outline a new research direction that we are currently pursuing, exploring the strong coupling limit of doped bosonic quantum magnets, i.e. the bosonic t-J model [1]. We present recent numerical results from large-scale density-matrix renormalization group (DMRG) calculations investigating the phase diagram of the two-dimensional antiferromagnetic (AFM) bosonic t-J model at finite doping. In the case of only a few holes–the simplest instance in which the underlying bosonic statistics plays a role–our results indicate a strong tendency for holes to form stripe or pair-density wave (PDW) like structures with predominantly AFM character, similar to those observed in high-Tc cuprate materials. As doping increases beyond a critical value, we observe clear signatures of an interaction-dependent crossover to itinerant ferromagnetism. Our results can be realised in state-of-the-art quantum simulation platforms–such as ultracold atoms trapped in optical lattices or tweezer arrays–paving the way for future studies to probe the exotic phases of doped bosonic quantum magnets in microscopic detail.

[1] L. Homeier et al., accepted in PRL. (2024) [arXiv:2305.02322]

Categories

Many body physics

Presentation

Poster presentation

D023

Universal scaling laws for correlated decay of many-body quantum systems

Wai-Keong Mok[1], Avishi Poddar[2], Eric Sierra[2], Cosimo C. Rusconi[2], John Preskill[1,3], Ana Asenjo-Garcia[2]

[1]Caltech, Pasadena, USA. [2]Columbia University, New York City, USA. [3]AWS Center for Quantum Computing, Pasadena, USA

Abstract

What is the maximal decay rate of a large quantum system, and how does it scale with its size? In this work, we address these issues by reformulating the problem into finding the ground state energy of a generic spin Hamiltonian. Inspired by recent work in Hamiltonian complexity theory, we establish rigorous and general upper and lower bounds on the maximal decay rate. These bounds are universal, as they hold for a broad class of Markovian many-body quantum systems. For many physically-relevant systems, the bounds are asymptotically tight, resulting in exact scaling laws with system size. Specifically, for large atomic arrays in free space, these scalings depend only on the arrays' dimensionality and are insensitive to details at short length-scales. The scaling laws establish fundamental limits on the decay rates of quantum states and offer valuable insights for research in many-body quantum dynamics, metrology, and fault tolerant quantum computation.

http://arxiv.org/abs/2406.00722

Categories

Many body physics

Presentation

Poster presentation

D024

Density-engineered Bose-Einstein Condensate for Long-Lived Quantum Memory

Elisa Da Ros[1], Simon Kanthak[1], Erhan Sağlamyürek[2,3], Mustafa Gündoğan[1], Markus Krutzik[1,4]

[1]Humboldt-Universität zu Berlin, Berlin, Germany. [2]University of Calgary, Calgary, Canada.
[3]University of Alberta, Alberta, Canada. [4]Ferdinand-Braun Institut (FBH), Berlin, Germany

Abstract

Long-lived quantum memories (QMs) are required in numerous tasks in space-based quantum information experiments. As such, Bose-Einstein condensates (BECs) are ideal candidates for implementing such QMs: not only have they been successfully produced in space, but their ultralow temperature also enables high-performance operation in terms of noise and efficiency. However, due to density-dependent interatomic collisions, the same high density required for efficient operation causes decoherence, limiting the achievable storage time in a trapped BEC to ~100 ms timescales.

Here, we propose a novel protocol [1] that leverages matter-wave optics techniques to minimize such density-dependent effects. Optical atom lenses are employed to first collimate and then refocus an initially expanding BEC, enabling high-density write-in and read-out operations, while reducing the collision rate and the consequent decoherence in the expanded quantum gas during the storage period. Implementing this protocol in a microgravity environment, as found in space applications, prevents the fall of the BEC's center of mass during the storage. This, then, eliminates the requirement for any inhomogeneous field to suspend the atoms, which would otherwise introduce further decoherence mechanisms.

Using this method, we demonstrate a potential improvement in expected memory lifetime by many orders of magnitude compared to ground-based experiments that haven't implemented it, and we found that the memory lifetime would be ultimately limited by the background vacuum quality. We will also present the experimental efforts in our lab to implement a ground-based version of this protocol.

[1] E. Da Ros et al., Phys. Rev. Research **5**, 033003 (2023)

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D025

Non-Gaussian Correlation in the steady state of a superradiant cloud

Giovanni Ferioli[1], Sara Pancaldi[2], Antoine Glicenstein[2], David Clement[3], Antoine Browaeys[2], Igor Ferrier-Barbut[2]

[1]Florence University, Florence, Italy. [2]Institut d'Optique Graduate School, Palaiseau, France. [3]Palaiseau, Palaiseau, France

Abstract

We experimentally measure the second-order coherence function of the light emitted by a laser-driven dense ensemble of atoms, dyspling strong superradiant correlations[1,2]. We observe a clear departure from the Siegert relation valid for Gaussian chaotic light. Measuring intensity and first-order coherence, we conclude that the violation is not due to the emergence of a coherent field. This indicates that the light obeys non-Gaussian statistics, stemming from non-Gaussian correlations in the atomic medium [3].

[1] Ferioli et al., Physical Review Letters 127 (24), 243602 (2021)
[2] Ferioli et al., Nature Physics 19 (9), 1345-1349 (2023)
[3] Ferioli et al., Physical Review Letters 132 (13), 133601 (2024)

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D026

Leveraging quantum statistics to enhance quantum engines

Thomás Fogarty, Keerthy Menon, Thomas Busch

Okinawa Institute of Science and Technology Graduate University, Onna-son, Japan

Abstract

Quantum heat engines are an ideal testbed for investigating the thermodynamics of quantum systems and any potential advantage that can be gained from genuine quantum effects. For instance, the emergence of quantum statistics at low temperatures leads to distinct particle distributions if atoms are bosonic or fermionic, and switching between these statistics can lead to large energy changes that are non-classical in nature. This has been recently exploited to create a unique quantum engine that is driven by changes in quantum statistics across the BEC-BCS crossover, realising a fully unitary cycle without any coupling to external heat baths. Therefore, an open question is how changes in statistics can effect typical quantum heat engines, where useful work can be outputted from the heat flow between two thermal reservoirs. In this work we explore a related system that can also display different statistics owing to changes in the interaction strength, namely the 1D Lieb-Liniger model. For vanishing interactions the system has bosonic statistics, while in the strong interaction limit it obeys fermionic statistics. We show how changing the interactions, and therefore the statistics, during an Otto-like cycle can result in increased efficiency and work output when compared to purely bosonic or purely fermionic cycles. Interestingly, we find that depending on where the statistics change is implemented during the cycle the Carnot bound can be reached, while at large bath temperatures all statistical effects are lost and the usual Otto efficiency is regained.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D027

A theoretical model for an Electromagnetically-Induced Transparency (EIT)-based quantum memory in a solid

Sara Moezzi, Chitra Rangan

Department of Physics, University of Windsor, Windsor, ON, Canada

Abstract

Solids that support Electromagnetically Induced Transparency (EIT) are an attractive platform for quantum memories. Early experiments indicate that the decoherence of the active centres can be tuned by changing the doping concentration and hence the density of the active centres. We present a theoretical model of EIT in a solid by considering an ensemble of three-level atoms that are driven by a probe and a control field. The fields create a lambda configuration in each active centre. The whole ensemble is modelled by a single 5-level quantum system with the mean-field interactions between atoms modelled by decoherence terms. In addition, we use a three-dimensional Maxwell-Lindblad model to describe the propagation of an electromagnetic pulse in an EIT medium. A strong dependence on number density indicates limits on the type of solids that can be used in quantum memories.

Poster

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Poster presentation

D028

Unconditional Wigner function negativity in the emission from a two-level atom driven with squeezed light

Scott Parkins[1,2], Miriam Leonhardt[1,2], Rory Robertson[1,2]

[1]The Dodd-Walls Centre for Photonic and Quantum Technologies, Auckland, New Zealand.
[2]Department of Physics, University of Auckland, Auckland, New Zealand

Abstract

Propagating modes of light with negative-valued Wigner functions are of fundamental interest in quantum optics and represent a key resource in the pursuit of optics-based quantum information technologies. Most schemes proposed or implemented for the generation of such modes are probabilistic in nature and rely on heralding by detection of a photon or photons separated from the original field mode by a beamsplitter. In this theoretical work we demonstrate, using a cascaded-quantum-systems model, the possibility of unconditional generation of Wigner function negativity in appropriately defined temporal modes of the backwards (or reflected) emission of a two-level atom driven by finite-bandwidth quadrature-squeezed light. The driving can be either continuous or pulsed, and optimal negativity is obtained for a squeezing bandwidth similar to the linewidth of the atomic transition. While the Wigner function associated with the incident squeezed light is Gaussian and everywhere positive, the Wigner functions of the outgoing temporal modes show distinct similarities and overlap with a squeezed coherent-state superposition.

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Quantum optics and thermodynamics

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Poster presentation

D029

Conformal duality of the nonlinear Schrödinger equation: Theory and applications to parameter estimation

David B. Reinhardt[1], Dean Lee[2], Wolfgang P. Schleich[3,4], Matthias Meister[1]

[1]German Aerospace Center (DLR), Institute of Quantum Technologies, D-89081 Ulm, Germany. [2]Facility for Rare Isotope Beams and Department of Physics and Astronomy, Michigan State University, MI 48824, USA. [3]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, D-89069 Ulm, Germany. [4]Hagler Institute for Advanced Study at Texas A&M University, Texas A&M AgriLife Research, Institute for Quantum Science and Engineering (IQSE), and Department of Physics and Astronomy, Texas A&M University, College Station, Texas 77843-4242, USA

Abstract

The nonlinear Schrödinger equation (NLSE) is a rich and versatile model, which in one spatial dimension has stationary solutions similar to those of the linear Schrödinger equation as well as more exotic solutions such as solitary waves and quantum droplets. We present a unified theory of the NLSE [1], showing that all stationary solutions of the cubic-quintic NLSE can be classified according to a single number called the cross-ratio. Any two solutions with the same cross-ratio can be converted into one another using a conformal transformation. Our framework thus provides a deeper understanding of the connections between the physics of the NLSE and the mathematics of algebraic curves and conformal symmetry. Further, we show that NLSE parameter estimation from noisy empirical data is substantially improved through the use of an optimization afterburner that relies on this conformal symmetry. The new method therefore has far reaching practical applications for nonlinear physical systems.

[1] Reinhardt et al., arXiv:2306.17720 (2023)

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D030

Arrays of single dysprosium atoms in optical tweezers to study collective light scattering

Damien BLOCH, Britton Hofer, Antoine Browaeys, Igor Ferrier-Barbut

Laboratoire Charles Fabry, Palaiseau, France

Abstract

This poster presents a new cold atom experiment using arrays of single dysprosium atoms to study collective light scattering.

It first presents the techniques developped to trap and image single dysprosium atoms in optical tweezers. In particular, we found a magic trapping polarization on the intercombination line of dysprosium at 532 nm that allows to achieve high fidelity imaging of single atoms.

We then build on this result to construct defect-free arrays of dysprosium atoms with small interparticle spacing, of the order of a few wavelengths of an optical transition of the atoms.

We investigate the effect of collective light scattering and collective dissipation in such dense and ordered ensembles.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D031

Joint spectral intensity measurement of time-frequency entangled photon pair with high-resolution time-of-flight spectrometer

Yen-Cheng Shih[1], Wei-Po Chiu[1], Yen-Hung Chen[2], Pin-Ju Tsai[2]

[1]Department of Physics, National Central University, Taoyuan, Taiwan. [2]Department of Optics and Photonics, National Central University, Taoyuan, Taiwan

Abstract

Pairs of photons entangled in the time-frequency mode (TFM) play a significant role in quantum communication due to their high information capacity and adaptability in fiber networks. To further advance the application of TFM quantum information in quantum technology, a crucial technical task is the reconstruction of TFM quantum information, including the joint spectral intensity (JSI) of entangled photon pairs. In this work, we developed a fiber-based time-of-flight spectrometer (ToFS) using a single photon detector and an optical fiber to introduce group delay dispersion (GDD). This ToFS utilizes the frequency-to-time mapping technique to convert the frequency information of single photons into arrival time at the single photon detector, thereby reconstructing the frequency distribution of single photons in this compact experimental setup. To demonstrate the performance of our developed ToFS, we used it to experimentally measure the JSI of telecom C-band photon pairs generated through spontaneous parametric down-conversion (SPDC). Our results indicate that the developed ToFS efficiently captures the frequency correlation of photon pairs, with a wavelength resolution estimated at 2.5 nm. This work showcases a critical technique for measuring TFM quantum information. We believe this technique holds immense potential for applications in quantum technology, including TMF quantum key distribution, high-dimensional TMF quantum computing, and quantum sensing.

Poster

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Poster presentation

D032

Grating Magneto-Optical Trap Enabled Compact Cold-Atom Platforms

Oliver Burrow, Paul Griffin, Aidan Arnold, Erling Riis

University of Strathclyde, Glasgow, United Kingdom

Abstract

Laser-cooled atoms are an exemplar platform for precision quantum measurements. Over the past decade, there has been a concerted effort in the UK and internationally to develop quantum technologies for real-world applications. At the University of Strathclyde, we are developing key technologies to enable compact cold-atom platforms, aiming to simplify and standardise cold-atom sources.

Central to our research are two key innovations for laser cooling rubidium (Rb): the grating magneto-optical trap (gMOT) [1] and a compact vacuum system [2]. The gMOT technology streamlines laser cooling by using a single laser beam to illuminate a diffractive optic, creating the optical geometry required for laser cooling. These optics offer simplified solutions for various applications, with a high degree of optical access. Our compact vacuum system further advances this field by enabling cold-atom sources with significantly smaller SWAP (Size, Weight, and Power). These technologies have been developed to be commercially available, and we are now beginning to use these compact vacuum systems as the atomic source in quantum sensors.

This poster will discuss developments in gMOT techniques[3][4], advances in the compact vacuum system technology, and the exciting possibilities they hold for future quantum sensing and beyond.

[1] Nshii, C. et al. Nature Nanotech 8, 321–324 (2013). DOI: https://doi.org/10.1038/nnano.2013.47
[2] Burrow, O. S. et al. Appl. Phys. Lett. 119, 124002 (2021). DOI: https://doi.org/10.1063/5.0061010
[3] Lewis, B. et al. Appl. Phys. Lett. 121, 164001 (2022). DOI: https://doi.org/10.1063/5.0115382
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Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D034

A high Quality factor dielectric Fabry-Perot cavity for detecting dark matter axions

Jiacheng Shi, Marko Wojtkowiak, Kitty Zhang, Kanika Kanika, Richard Thompson, Devlin Jack

Imperial College London, London, United Kingdom

Abstract

The axion is a type of pseudoscalar (spin-0, odd parity) particle initially proposed as a solution to strong CP problem as well as being a theoretically well-motivated dark matter candidate [1]. One part of the Quantum enhanced Particle Astrophysics (QuEPA) project at Imperial College focuses on developing a Fabry-Perot cavity as a dark matter haloscope to convert axions in the 125-250 μeV mass range into microwave photons. The cavity, designed using multilayer Bragg mirrors, consists of interleaved layers of PTFE and sapphire, with a plano-convex quartz lens at its centre. According to axion-modified electrodynamics [2], axions can be converted to microwave photons between 30-60 GHz when this cavity is placed in a strong, homogeneous magnetic field. Compared to other haloscope geometries operating at this frequency, the Fabry Perot cavity is relatively compact, it has a large effective mode volume, it can be easily tuned, it has a quality factor above 100,000, and its performance should not be degraded when placed in a strong magnetic field. In this session, I will describe the anatomy of our Fabry-Perot cavity, explain why the Fabry-Perot is well suited for high frequency axion searches and provide updates on our project's progress.

References

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[2] I. G. Irastorza and J. Redondo, Progress in Particle and Nuclear Physics 102 (2018) DOI: 10.1016/j.ppnp.2018.05.003.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D035

Orientational melting of a two-dimensional ensemble of charged particles

Naoto Mizukami[1,2], Gabriele Gatta[3], Lucia Duca[1,4], Carlo Sias[1,4]

[1]INRIM, Torino, Italy. [2]Politecnico di Torino, Torino, Italy. [3]University of Florence, Sesto Fiorentino, Italy. [4]LENS, Sesto Fiorentino, Italy

Abstract

A system of confined charged particles undergoes crystallization at a sufficiently low temperature. However, when particles in a two-dimensional plane are confined in an almost isotropic potential, thermal fluctuations lead to the delocalization of particles in circular trajectories, a phenomenon known as orientational melting. Orientational melting of a mesoscopic crystal is a change of configuration that is similar to a phase transition in a macroscopic system, but it is not universal as it depends on the exact number of particles.

We report on the experimental observation and characterization of orientational melting in a two-dimensional crystal of trapped Ba^+ ions[1].

The specific geometry of our trap[2] makes it possible to continuously change the arrangement of the ions from a one-dimensional string to a two-dimensional crystal. We observe that orientational melting occurs under conditions that strongly depend on the number of particles, and find excellent agreement with the results of a Monte Carlo simulation, which we use to estimate the temperature of the ions at which melting occurs. Additionally, we are able to locally inhibit melting by adding a single impurity with a different mass. Interestingly, for a sufficiently large number of ions two or more concentric rings are populated, and the rings can exhibit independent dynamics.

Our experiment paves the way to accessing new quantum regimes for delocalized strongly-interacting particles, and for the coherent control of their rotational state.

[1] L. Duca, et. al. Phys. Rev. Lett. 131, 083602 (2023)

[2] E. Perego, et al. Appl. Sci. 10, 2222 (2020)

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D036

Towards a Next-generation Setup for Box-trapped 2D Quantum Gases with High-Resolution Imaging

Feiyang Wang, Konstantinos Konstantinou, Paul Wong, Yansheng Zhang, Nishant Dogra, Christoph Eigen, Tanish Satoor, Zoran Hadzibabic

University of Cambridge, Cambridge, United Kingdom

Abstract

Uniform 2D quantum gases of K39 offer a distinctive platform to study low-dimensional quantum phenomena. The tunability of interatomic interactions via Feshbach resonances along with the stable coherent coupling between different spin states offers the possibility of experimentally implementing various model systems including quantum simulation of false vacuum decay, which is domain nucleation across a first-order phase transition. The homogeneity of our system will be crucial in this case, allowing the study of random generation and collision dynamics of vacuum bubbles. Here, we present our experimental progress toward Uniform 2D quantum gases of K39. A quasi-2D confinement is realised by strong vertical confinement in a single node of an optical lattice generated holographically via a Digital Micromirror Device (DMD) in the Fourier space, combined with an in-plane box trap projected by another DMD in the real space. Finally, high-resolution microscopy will be implemented in the 2D system to enable in-situ detection at the single-vortex level.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D037

Optical Tweezer Arrays via Holographic Metasurfaces for Super- and Subradiance Studies with Strontium

Aaron Holman, Ximo Sun, Kevin Wang, Bojeong Seo, Sebastian Will

Columbia University, New York, USA

Abstract

We report our progress towards exploring super- and subradiance in optical tweezer arrays. Using holographic metasurfaces, we generate optical tweezer arrays that allow us to realize large, tightly packed atomic arrays with µm spacing. The metasurfaces feature high power resilience and the resulting optical tweezer arrays show high intensity, trap frequency, and positional uniformity. With such arrays, we have trapped single Sr atoms, achieving single-atom imaging fidelities >99%. In order to pursue super- and subradiance studies, we utilize the Sr $^3P_2$-$^3D_3$ transition in the mid-infrared at 2.9 µm. We demonstrate state preparation into the $^3P_2$ state and drive the 2.9 µm transition in our atomic tweezer array. Our work paves the way for a new platform to study quantum electrodynamics, with potential applications including atomic waveguides, novel atom-photon interfaces, and quantum memories.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D038

Diffusion of light in a cold atomic cloud of Yb

Apoorva Apoorva, Antoine Glicenstein, Raphaël Saint-Jalm, Daniel Benedicto Orenes, Robin Kaiser

INPHYNI, CNRS, Université Côte d'Azur, Nice, France

Abstract

Our new experimental setup aims to study 3D Anderson localization of light using large clouds of ^{174}Yb cold atoms. We have two stages of MOT loading. In the first stage, we trap the atoms operating on the broad linewidth transition $^1S_0$-$^1P_1$. In the second stage, we transfer the atoms in a MOT on the narrow transition $^1S_0$ to $^3P_1$. We obtain a cold cloud containing up to $1*10^9$ atoms with rms radius 0.5 mm and optical thickness up to 70 on the narrow transition. I will present an experimental study of the diffusive propagation of light in such a cloud. We first induce a local light shift in the $^3P_1$-$^3D_1$ transition using 1539 nm light. We send green light resonant with the light-shifted transition to create an excitation at the center of the atomic cloud. We monitor the population in the ground state using the absorption imaging of the atomic cloud on the broad transition. This allows us to study the spatial and temporal propagation of the light in this cold atom ensemble. We measure the diffusion coefficient and transport velocity as a function of the optical density and compare our results to previous measurements. The prominent feature of this new technique is that it allows us to excite atoms in the middle of an optically dense sample and temporally follow its spatial profile. This constitutes a promising tool to study light propagation in a disordered cloud when adding random light shifts to the atomic transition.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D039

Towards light scattering experiments in dense dipolar gases

Ishan Varma, Marvin Proske, Rhutwik Sriranga, Patrick Windpassinger

JGU, Mainz, Germany

Abstract

This poster reports on the progress made in generating dense samples of ultracold dysprosium atoms. We plan to optically transport atoms into a home-built science cell with high optical access. The creation and imaging of dense atomic samples inside the science cell is achieved using high NA custom objectives, designed and assembled in-house. We present the performance characterization and discuss the development of these objectives in our experimental system. Further, an outlook is given on future measurements exploring collective and cooperative effects in the generated sample.

A high NA custom objective, designed and assembled in-house, will then be used to create dense atomic samples inside this cell. We evaluate the performance and discuss the installation of the custom objective in our experimental system. Further, an outlook is given on future measurements exploring collective and cooperative effects in the generated sample.

Poster

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Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D040

Nanophotonic devices for trapping neutral atoms in MOTs and dipole traps

Sanket Deshpande, Chengyu Fang, Minjeong Kim, Hongyan Mei, Mark Saffman, Jennifer Choy, Mikhail Kats

University of Wisconsin-Madison, Madison, USA

Abstract

Magneto-optical traps (MOTs) and dipole traps are essential for several applications involving neutral atoms, such as quantum computing, inertial sensing, networking and clocks. Conventional 6-beam MOTs and dipole traps require large, complicated and often power inefficient experimental setups. Nanophotonic devices can significantly reduce the size of neutral atom experiments by manipulating light at the nanoscale, allowing for precise control over atom-light interactions. In this work, we present progress on developing the following nanophotonic devices: a two-dimensional reflective diffraction grating chip for trapping Rb-87 and Cs-133 atoms simultaneously in a MOT, a two-dimensional optical intensity mask for trapping Rb-87 and Cs-133 atoms in dipole traps, and a metasurface for generating bottle-beam traps of Rb-87 atoms.

The grating chip has been designed using our simulation framework which optimizes the fabrication parameters, experiment conditions and geometry to maximize the atom number. The optical intensity mask is developed on a fused silica substrate has been demonstrated to trap Cs-133 and Rb-87 atoms in bright and dark traps respectively using an 810 nm laser source. The metasurface uses sub-wavelength structures created on a silicon-on-insulator substrate to produce an array of bottle beam traps with an incident gaussian beam. These devices will help improve experimental efficiency, reduce system complexity, and enable field deployment of quantum technologies.

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D041

Bosonic enhancement of light scattering in a homogeneous Bose gas

Konstantinos Konstantinou[1], Yansheng Zhang[1], Paul Wong[1], Feiyang Wang[1], Yukun Lu[2], Christoph Eigen[1], Tanish Satoor[1], Nishant Dogra[1], Wolfgang Ketterle[2], Zoran Hadzibabic[1]

[1]University of Cambridge, Cambridge, United Kingdom. [2]Massachusetts Institute of Technology, Cambridge, USA

Abstract

Off-resonant light scattering can provide a powerful probe of fluctuations and correlations in an atomic gas. The long-predicted bosonic enhancement of scattering close to the BEC transition was recently observed in harmonically trapped 3D gases [1]. Here we present first results on such enhancement in box-trapped Bose gases; in this textbook setting the effect is even more dramatic, since the whole homogeneous cloud exhibits critical fluctuations near the condensation temperature.

[1] Lu, YK., Margalit, Y. & Ketterle, W. Bosonic stimulation of atom–light scattering in an ultracold gas. *Nat. Phys.* **19**, 210–214 (2023).

Categories

Quantum optics and thermodynamics

Presentation

Poster presentation

D042

Interplay between topology and disorder in driven honeycomb lattices

Alexander Hesse[1,2,3], Johannes Arceri[1,2,3], Christoph Braun[1,2,3], Moritz Hornung[1,2,3], Immanuel Bloch[1,2,3], Monika Aidelsburger[1,2,3]

[1]Ludwig Maximilian University, Munich, Germany. [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany. [3]Max Planck Institute for Quantum Optics, Garching, Germany

Abstract

Floquet engineering, i.e., periodic modulation of a Hamiltonian's parameters, has proven as a powerful tool for the realization of quantum systems with exotic properties that have no static analog. Notably, so-called anomalous Floquet topological systems exhibit gapless edge states in spite of vanishing Chern numbers in the bulk, which calls for a modified bulk-edge correspondence for driven systems. We study this physics with ultracold bosonic atoms in a driven optical honeycomb lattice, where Floquet engineering is performed via continuous, periodic modulation of the laser intensities. Depending on the modulation parameters, several topological regimes of ultracold bosons are within reach, including the conventional Haldane and the anomalous Floquet topological regime.

A key ingredient to reveal the non-trivial properties of anomalous Floquet topological systems is the study of topological edge states. To this end, we developed a protocol to probe real-space dynamics of chiral edge modes by preparing tightly-confined atomic wavepackets that we release in the proximity of a tunable potential step projected by a digital micromirror device. Moreover, adding an optical speckle potential paves the way for the investigation of the rich interplay between topology and disorder, which is expected to support novel phases of matter without any static analog, such as the anomalous Floquet Anderson insulator. We benchmark the robustness of chiral transport to disorder and observe a disorder-driven transition from the Haldane into the anomalous Floquet topological regime.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D043

Progress on ytterbium tweezer array at KRISS

Yunheung Song[1], Seungtaek Oh[2,1], Jeong Ho Han[1], Jaewook Ahn[2], Jongchul Mun[1]

[1]KRISS, Daejeon, Korea, Republic of. [2]KAIST, Daejeon, Korea, Republic of

Abstract

171-Yb has a rich structure of energy levels including ground nuclear spin-1/2 states, metastable clock states, and Rydberg states, which makes an Yb tweezer system a versatile platform for quantum computation and metrology. To leverage these advantages, we build 171-Yb single atom array trapped in clock-magic-wavelength tweezers, and report its progress in this presentation. In our setup, atoms are transferred from the oven to a glass cell using a 2D magneto-optical trap (MOT) and a pushing beam. Subsequently, we collect and cool the atoms with a 3D MOT, and trap them using 759 nm magic-wavelength tweezers shaped by a spatial light modulator (SLM). After trapping, we utilize narrow 556 nm $^1S_0 - {}^3P_1$ transitions to load, image, and cool the single atoms. We achieve imaging survival probability over 99.5% by applying magic-angle B field and dual-tone addressing of $m_F=\pm 1/2$ transitions. We also present our progress towards clock transitions and Rydberg transitions which will be used for implementing analog-digital quantum computation and entanglement-enhanced metrology.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D044

Interacting laser-trapped circular Rydberg atoms

Paul Méhaignerie, Yohann Machu, Andrés Durán Hernández, Gautier Creutzer, Aurore Young, Jean-Michel Raimond, Clément Sayrin, Michel Brune

Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-Université PSL, Sorbonne Université, Paris, France

Abstract

Rydberg atoms are particularly well suited for quantum simulation, thanks to their strong dipole-dipole interactions even at a few microns. Circular Rydberg atoms, the natural lifetime of which reaches several 10 ms, hundred times longer than laser-accessible Rydberg states, offer the perspective to run quantum simulation over unprecedented timescales [1]. .

Here, I will report on the first experimental study of the dipole-dipole interaction between two Circular Rydberg atoms. We laser trap individual Circular Rydberg atoms using holographic arrays of bottle beams [2]. We prepare independent pairs of laser-trapped circular Rydberg atoms with different geometries. We characterize the dipole-dipole interaction between n = 52 and n = 51 atoms through microwave spectroscopy, and measure its spatial dependency.

We use this method to probe the relative oscillation of the atoms in a pair. This oscillation is induced by the interaction between Rydberg levels with static electric dipole, transiently populated during the circularization process. This is a signature of spin-motion coupling in a Rydberg-atom platform.

[1] T. L. Nguyen *et al.*, Phys. Rev. X **8**,011032 (2018)

[2] B. Ravon *et al.*, Phys. Rev. Lett. **131**, 093401 (2023)

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D045

Dissipative coupling of atomic spin waves for topology and arrays of quantum light beams

Dongdong Hao[1], Lin Wang[1], Ying Hu[2], Yanhong Xiao[2,1]

[1]fudan university, shanghai, China. [2]shanxi university, taiyuan, China

Abstract

We show that thermal motion of hot atoms in a vapor cell can create dissipative couplings between spatial lattice sites (separated optical channels) of atomic spin waves, which provides a new platform for exploring topological physics and constructing large-scale quantum light beam arrays. In a vacuum vapor cell without coherence-preserving wall coating, where dissipative couplings arise from free flight of atoms and thus nearest-neighbor-couplings can be approximately engineered, we experimentally realized a dissipative version of the Su-Schrieffer-Heeger (SSH) model. We construct the dissipation spectrum of the topological or trivial lattices via electromagnetically-induced-transparency spectroscopy. The topological dissipation spectrum is found to exhibit edge modes within a dissipative gap. On the other hand, in wall coated Rb cells, ground state atomic coherence has an extended lifetime, and is shared across all optical channels. This allows mutually enhanced light squeezing among all channels via coherence enhanced nonlinear process. Consequently, an array containing about 30 beams of polarization squeezed light is created with relatively low laser power, much lower than that in an uncoated vapor cell. In the future, we aim to control the couplings to manipulate the topology and arrays of quantum light sources, such as by integrating an optical resonator and spatial light modulator.

Poster

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Presentation

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D046

Scalable Multipartite Entanglement Created by Spin Exchange in an Optical Lattice

Wei-Yong Zhang[1,2], Ming-Gen He[1,2], Hui Sun[1,2], Yong-Guang Zheng[1,2], Ying Liu[1,2], An Luo[1,2], Han-Yi Wang[1,2], Zi-Hang Zhu[1,2], Pei-Yue Qiu[1,2], Ying-Chao Shen[1,2], Xuan-Kai Wang[1,2], Wan Lin[1,2], Song-Tao Yu[1,2], Bin-Chen Li[1,2], Bo Xiao[1,2], Meng-Da Li[1,2], Yu-Meng Yang[1,2], Xiao Jiang[1,2], Han-Ning Dai[1,2], You Zhou[1,3], Xiongfeng Ma[4], Zhen-Sheng Yuan[1,2,5], Jian-Wei Pan[1,2,5]

[1]Hefei National Research Center for Physical Sciences at the Microscale and School of Physical Sciences, University of Science and Technology of China, Hefei 230026, China. [2]CAS Center for Excellence in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei 230026, China. [3]Key Laboratory for Information Science of Electromagnetic Waves (Ministry of Education), Fudan University, Shanghai 200433, China. [4]Center for Quantum Information, Institute for Interdisciplinary Information Sciences, Tsinghua University, Beijing 100084, China. [5]Hefei National Laboratory, University of Science and Technology of China, Hefei 230088, China

Abstract

Ultracold atoms in optical lattices form a competitive candidate for quantum computation owing to the excellent coherence properties, the highly parallel operations over spins, and the ultralow entropy achieved in qubit arrays. For this, a massive number of parallel entangled atom pairs have been realized in superlattices. However, the more formidable challenge is to scale up and detect multipartite entanglement, the basic resource for quantum computation, due to the lack of manipulations over local atomic spins in retroreflected bichromatic superlattices. In this Letter, we realize the functional building blocks in quantum-gate-based architecture by developing a cross-angle spin-dependent optical superlattice for implementing layers of quantum gates over moderately separated atoms incorporated with a quantum gas microscope for single-atom manipulation and detection. Bell states with a fidelity of 95.6(5)% and a lifetime of 2.20 ± 0.13 s are prepared in parallel, and then connected to multipartite entangled states of one-dimensional ten-atom chains and two-dimensional plaquettes of 2 × 4 atoms. The multipartite entanglement is further verified with full bipartite nonseparability criteria. This offers a new platform toward scalable quantum computation and simulation.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D047

Entanglement Distribution – Towards a Suburban Quantum Network Link

Yiru Zhou[1,2], Florian Fertig[1,2], Pooja Malik[1,2], Tommy Block[1,2], Chengfeng Xu[1,2], Tim van Leent[1,2], Matthias Bock[3], Christoph Becher[3], Harald Weinfurter[1,2,4]

[1]Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany. [2]Munich Center for Quantum Science and Technology, München, Germany. [3]Fachrichtung Physik, Universität des Saarlandes, Saarbrücken, Germany. [4]Max-Planck Institut für Quantenoptik, Garching, Germany

Abstract

Distributing quantum entanglement between distant nodes is crucial for future quantum networks, enabling applications such as secure communication and distributed quantum computing. For that, quantum nodes are required to provide an efficient light-matter interface for entanglement generation, serve as a quantum memory allowing long-lived storage of quantum states, and have the possibility to connect to low-loss quantum channels.

Here we present a neutral atom-based quantum node capable of sharing entanglement over long distances [1-2]. Our setup consists of single Rb-87 atoms trapped in optical dipole trap. First, entanglement is generated between the polarization of the photon and the Zeeman state of the atom. Then a state-selective Raman transfer changes the encoding of the atomic qubit in a combination of F=1 & F=2 hyperfine states [3]. The reduced sensitivity to magnetic fields in the new basis increases the coherence time to 10 ms.

With a polarization-preserving quantum frequency conversion to telecom wavelengths minimizing the photon loss along optical fibers, we achieve the distribution of atom-photon entanglement over 101 km of spooled fibers with a fidelity of >= 70.8% [2]. This crucial step of analyzing and evaluating our node paves the way for realizing city-to-city scale quantum network links by incorporating another Rb-87 atom node at a 14 km distance [1, 2, 4].

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Poster

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Quantum computing, simulation & networks

Presentation

Poster presentation

D048

Towards a neutral atom quantum computation and simulation platform

Yaoting Zhou[1,2], Shaoxiong Wang[1,2], Changtao Zhao[1,2], Zhongxiao Xu[1,2], Heng Shen[1,2]

[1]State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Opto-electronics, Shanxi, China. [2]Collaborative Innovation Center of Extreme Optics, Shanxi, China

Abstract

The defect-free neutral atom array has emerged as an ideal platform to investigate complex many-body physics of interacting quantum particles, offering the opportunities for quantum simulation and quantum-enhanced metrology [1-4]. We have started the plan to build such a platform since May 2022. Here we present some results and progress of our platform. Including intensity equalization & sorting algorithm [5], metasurface atomic array, transportable super-stable laser reference system, and some other results.

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Categories

Quantum computing, simulation & networks

Presentation

D049

Photoionization of metastable barium for quantum technologies

Steven Olmschenk, Erich Wette

Denison University, Granville, USA

Abstract

Trapped atomic ions are a leading candidate for emerging quantum technologies. One challenge in developing quantum devices based on trapped ions is the integration of all required laser light, including that used to produce the atomic ions. Here we investigate an all-optical method for producing barium ions that may improve system integration. Neutral barium atoms are produced by pulsed laser ablation of a target near the ion trap. We photoionize these atoms using a two-step process that requires only the primary cooling light for barium ions and one additional visible-wavelength laser near the standard repump wavelength by making use of a metastable level populated during ablation. This all-optical method for producing barium ions should be suitable for cryogenic chambers, is expected to be isotope selective, and might ease the integration of photoionization light in ion trap systems.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D050

The road from the Hall effect to chiral currents in strongly interacting fermions.

Jorge Mellado-Muñoz[1], Tianwei Zhou[2], Giacomo Cappellini[1,3], Thomas Beller[1,2], Gianmarco Masini[1,3], Jacopo Parravicini[1,2,3], Cécile Repellin[4], Massimo Inguscio[5], Thierry Giamarchi[6], Michele Filippone[7], Jacopo Catani[1,3], Leonardo Fallani[1,2,3]

[1]Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO), Sezione di Sesto Fiorentino, 50019, Sesto Fiorentino, Italy. [2]Department of Physics and Astronomy, University of Florence, 50019, Sesto Fiorentino, Italy. [3]European Laboratory for Non-Linear Spectroscopy (LENS), 50019, Sesto Fiorentino, Italy. [4]Université Grenoble Alpes, CNRS, LPMMC, 38000, Grenoble, France. [5]Department of Engineering, Campus Bio-Medico University of Rome, 00128, Rome, Italy. [6]Department of Quantum Matter Physics, University of Geneva, 1211, Geneva, Switzerland. [7]Université Grenoble Alpes, CEA, IRIG-MEM-L SIM, 38000, Grenoble, France

Abstract

We will report on recent experimental progress in the investigation of quantum systems made by ultracold ^{173}Yb lattice fermions, where a controllable Raman coupling between different spin states realizes a synthetic-dimensional lattice, which is suited for the quantum simulation of the Hall effect under the influence of a synthetic magnetic field.

Following the first quantum simulation of the Hall effect for strongly interacting fermions in an optical lattice with a potential gradient along the real dimension [1], we report the first measurement of the Hall voltage [2] in the very same system by further applying an additional potential gradient along the synthetic dimension, which also provides a direct measurement of the Hall resistance. The systematic study of the Hall voltage shows a strong dependence of the voltage on particle fillings while being robust to the changes in ladder geometries, enabling future research of the exotic transport properties in the strongly correlated regime.

We will discuss future perspectives, including current experimental work aimed at the investigation of the fate of chiral edge currents [3] in the strongly interacting regime, where an enhancement close to the metallic-to-insulating phase transition has been recently predicted [4].

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Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D051

Integrated quantum memory of time-bin qubits for 1 ms

Yuping Liu[1,2], Zhongwen Ou[1], Tianxiang Zhu[1], Zongquan Zhou[1,2], Chuanfeng Li[1,2], Guangcan Guo[1,2]

[1]University of Science and Technology of China, Hefei, China. [2]Hefei National Laboratory, Hefei, China

Abstract

Photonic integrated quantum memories are crucial for building scalable quantum repeaters.Long-duration quantum memories are vital for establishing long-distance quantum networks.However, implementing integrated long-time memory remains challenging.In this experiment, we combined a laser-written optical waveguide with a dynamical decoupling electrical waveguide on a $^{151}Eu^{3+}:Y_2SiO_5$ crystal. Using noiseless photon echo protocol, we stored single-photon level time-bin qubits for 1 ms with a fidelity of 89.7±1.5%. This device is compatible with magnetic fields. Considering coherent lifetime can reach hours at zero first-order Zeeman point, the device shows strong potential for practical, large-scale, long-distance quantum networks.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D052

Variational data encoding and correlations in quantum-enhanced machine learning

Minghao Wang[1], Hua Lu[2]

[1]Hubei University, Wuhan, China. [2]Hubei University of Technology, Wuhan, China

Abstract

With the help of extraordinary phenomena such as quantum superposition and quantum correlation, quantum computing offers unprecedented potential to solve difficult problems that are intractable for classical computers. This paper focuses on two key challenges in the field of quantum computing: first, developing an effective encoding protocol to convert classical data into quantum states, which is an important step for any quantum computation. Different encoding strategies can significantly affect the performance of quantum computers. Second, we focus on counteracting the interference of inevitable noise on quantum speedup. Our main contribution is the introduction of a new variational data encoding method based on the quantum regression algorithm model. By borrowing the concept of learning from machine learning, we make data encoding a learnable process. Through numerical simulations of various regression tasks, we demonstrate the effectiveness of variational data encoding after learning instruction data. In addition, we deeply explore the role of quantum correlation in improving task performance, especially in noisy environments. Our results highlight the key role of quantum correlation in improving performance and mitigating noise interference, thus pushing the frontier of quantum computing.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D053

Coherent control of strontium atoms trapped in an optical lattice and applications for quantum simulations

Felix Spriestersbach[1,2], Valentin Klüsener[1,2], Sebastian Pucher[1,2], Jan Geiger[1,2], Andreas Schindewolf[1,2,3], Immanuel Bloch[1,2,3], Sebastian Blatt[1,2,3]

[1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany. [2]Munich Center for Quantum Science and Technology, 80799 München, Germany. [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Abstract

The coherent excitation of ultra-narrow optical transitions between long-lived atomic states is fundamental for optical atomic clocks, quantum information processing, and quantum simulation.

We present our results on the coherent excitation of the ultranarrow $^1S_0$–$^3P_2$ magnetic quadrupole (M2) transition in ^{88}Sr. By confining atoms in a state-insensitive optical lattice, we achieve excitation fractions of 97(1) % and observe linewidths as narrow as 58(1) Hz. We determine the decay rate of the M2 transition to $154(32) \times 10^{-6}\ s^{-1}$ in agreement with longstanding theoretical predictions.

Building on these results, we demonstrate coherent control of a new THz qubit encoded in the metastable $^3P_2$ and $^3P_0$ states, which are coupled by a Raman transition. We use the $^1S_0$-$^3P_2$ M2 transition for coherent state-initialization and read-out. We demonstrate Rabi oscillations with more than 60 coherent cycles and single-qubit rotations on the μs scale. Our results pave the way for fast quantum information processors and highly tunable quantum simulators with two-electron atoms.

Poster

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Quantum computing, simulation & networks

Presentation

Poster presentation

D054

Selective and non-destructive readout of bits in an atomic register using an optical cavity

Edita Bytyqi, Beili Hu, Michelle Chong, Josiah Sinclair, Vladan Vuletic

Massachusetts Institute of Technology, Cambridge, USA

Abstract

Optical cavities have been used for the fast and non-destructive readout of atomic hyperfine states, however the innately global atom-cavity coupling limits the usefulness of this readout method for quantum error correction. We demonstrate the first cavity-mediated selective readout of atoms. An optical cavity strongly coupled to Rb-87 atoms trapped in optical tweezers is used to measure fluorescence on the 5S1/2 → 5P3/2 transition resonant at 780 nm. Individual addressing beams at 1529.42nm, acting on the 5P3/2 → 4D3/2, 4D5/2 transitions, are used to Stark-shift the 5P3/2 state down by 2GHz pushing it off-resonance. When paired with a global readout beam at 780 nm, this allows for the selective coupling of atoms to the readout beam, effectively hiding the Stark-shifted atoms. We demonstrate selective and sequential readout of N = 5 atoms in a 1D array while physically maintaining the atoms in the cavity mode. We measure atom presence and hyperfine state with a fidelity of F > 99% in 100us readout intervals. This scheme provides fast selection for reading out syndrome qubits and diagnosing errors, paving the way towards repeated rounds of quantum error correction in neutral atom arrays.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D055

Towards circular Rydberg qubits of calcium atoms

Claudia Politi, Wojciech Adamczyk, Silvan Koch, Pavel Filippov, Qianlong He, Daniel Kienzler, Jonathan Home

ETH, Zurich, Switzerland

Abstract

Recently, neutral atoms excited to Rydberg states have emerged as a promising platform for quantum simulation and computation, owing to the high control and scalability of the system. Experiments mostly focused on excitations to low-angular momentum Rydberg states, which sets limits on achievable gate fidelities due to the short lifetime of these states. The lifetime can be extended up to several minutes for atoms excited to circular Rydberg states in a cryogenic environment with spontaneous-emission inhibition.

Our experiment focuses on trapping single alkaline-earth calcium atoms excited to circular Rydberg states. The primary objective of the experiment is to perform QND (Quantum Non-Demolition) readout of the qubit, employing the narrow-line transitions available in calcium for state-dependent shelving of the core electron [2,3]. We plan to cool and trap calcium atoms in an array of optical tweezers generated by a spatial light modulator. Following Rydberg excitation and circularization, the atoms will be transferred to an array of hollow bottle-beam traps, where control of the core electron will aid in the cooling, manipulation, and non-destructive readout of the circular qubit.

In this work, we present the latest results from our room-temperature experiment, including the implementation of sub-Doppler cooling of calcium atoms, and our steps towards trapping single atoms in optical tweezers. Finally, we outline our progress in the design of a cryogenic chamber, essential for preserving the extended lifetimes of circular Rydberg atoms.

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Categories

Quantum computing, simulation & networks

Presentation

D056

Sub-Doppler cooling of calcium atoms using two-photon resonance

Wojciech Adamczyk, Silvan Koch, Claudia Politi, Pavel Filippov, Daniel Kienzler, Jonathan Home

ETH, Zurich, Switzerland

Abstract

Our experiment aims to trap individual calcium atoms excited to circular Rydberg states and perform Quantum Non-Demolition (QND) readout of the qubit state, as proposed in Refs. [1, 2]. To achieve this, the first step is to cool and trap calcium atoms in optical tweezers.

Efficient cooling of neutral alkaline-earth atoms typically requires two Magneto-Optical Traps (MOTs). The initial broadband MOT is followed by a second MOT operating on a narrower transition. However, for certain atoms, such as magnesium and calcium, this transition is impractically narrow, requiring additional quenching. To overcome this challenge, the initial cooling transition can be dressed with a high-intensity control beam, thereby altering the absorption spectrum of the initial cooling light [3, 4].

In our experiment, we implement this two-photon cooling technique on calcium atoms. The atoms are initially cooled in a MOT operating on the 423-nm 1S0 -> 1P1 transition. We subsequently switch on a single 1034-nm control beam, tuned to the 1P1 -> 4a5s 1S0 transition. This cooling forms a closed cycle, limiting losses due to decay channels, and could lead to temperatures as low as 150 μK.

[1] C. Fischer, Quantum non-demolition readout for optically trapped alkaline-earth Rydberg atoms, PhD Thesis, ETH Zürich (2022)
[2] A. Muni et al., Optical coherent manipulation of alkaline-earth circular Rydberg states, Nat.Phys.18,502 (2022)
[3] T. Mehstaubler et al., Observation of sub-Doppler temperatures in bosonic magnesium, PhysRev. A 77, (2008)
[4] W. Magno et al., Two-photon Doppler cooling of alkaline-earth-metal and ytterbium atoms, PhysRev. A 67, (2003)

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D057

Learning experimental noise from universal many-body behavior

Adam Shaw[1,2], Daniel Mark[3], Joonhee Choi[2], Soonwon Choi[3], Manuel Endres[1]

[1]Caltech, Pasadena, USA. [2]Stanford, Stanford, USA. [3]MIT, Cambridge, USA

Abstract

Understanding the behavior of quantum systems interacting with their environment is a long-standing problem of interest, but only recently have experiments attained a level of control required to study it microscopically. Here we use a Rydberg atom array to study this process for both coherent and incoherent couplings to the environment. For the coherent case, we observe a smooth transition in the statistics of measurement probabilities from anti-concentrated to concentrated behavior as a function of the environment dimension. Remarkably, we numerically find this observation is universal amongst a wide range of systems, including those at finite temperature, those with itinerant particles, and random circuits. We then generalize this observation to the incoherent case, developing a simple but comprehensive framework for predicting the effect of largely arbitrary noise channels on experimental many-body measurements. We demonstrate that this allows for clear discrimination between candidate error models both with numerical simulations of digital quantum circuits and experimentally with our analog quantum simulator.

Poster

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Presentation

Poster presentation

D058

Developing a Hybrid Tweezer Array of Rydberg Atoms and Polar Molecules

Daniel Hoare, Kai Voges, Qinshu Lyu, Jonas Rodewald, Yuchen Zhang, Stefan Truppe, Ben Sauer, Michael Tarbutt

Imperial College London, London, United Kingdom

Abstract

Hybrid tweezer arrays of atoms and molecules are a new and innovative tool for quantum science and technology. Tweezer arrays allow for flexible and dynamical trap scenarios. With their rich level structures and long rotational state coherence times, molecules are ideal for storing quantum information and make excellent qubits. Their interactions can be enhanced enormously by using Rydberg atoms to mediate long-range dipole-dipole interactions. This platform presents an interesting approach to quantum simulation [1] and computing [2,3]. In this poster, we present our efforts to build such a hybrid tweezer array using ultracold Rb atoms and CaF molecules. We discuss the advantages and challenges of multispecies hybrid systems and present our schemes for preparing ultracold Rb atoms and CaF molecules. We further show our recent progress in atom cooling, trap loading, imaging and trap characterisation. Cooling and loading of optical traps can be performed using the Rb D1 transition, where we can reach temperatures in free-space molasses in the low uK regime. Finally, we present our ideas for loading both species into separate tweezer arrays using a dual-color tweezer approach.

[1] J. Dobrzyniecki *et al*., PRA 108, 052618 (2023)
[2] C. Zhang et al., PRX Quantum 3, 030340 (2022)
[3] K. Wang et al., PRX Quantum 3, 030339 (2022)

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D059

Construction and frequency stabilisation of a compact, mid-IR external-cavity diode laser at 2.6 µm wavelength for quantum many-body experimental studies with neutral strontium atoms

Sandhya Ganesh, Balsant Tiwari, Ceren Yuce, Yeshpal Singh

University of Birmingham, Birmingham, United Kingdom

Abstract

Mid-infrared lasers that fall under the spectral region of 2-12 µm have traditionally found their applications in fields such as molecular spectroscopy and environmental studies. In quantum many-body physics experiments, particularly with strontium atoms, the available low-lying transitions on the $5s5p^3P_{0,1,2}$ - $5s4d^3D_{1,2,3}$ states, operating at the mid-infrared wavelengths of 2.6-3 µm are of great interest as they form a suitable platform to study black-body radiation shift corrections in optical lattice clocks, and emerging studies such as entanglement generation in structured atomic arrays mediated by dipolar interactions. Such studies often employ complex laser systems with differential frequency generation and optical parametric amplification. In this work, we present a simple method to build an external-cavity diode laser system at 2.6 µm and its frequency stabilisation with a scanning Fabry-Perot cavity using Pound-Drever-Hall method. We also employ the constructed laser system for spectroscopy on the $5s5p^3P_0$ - $5s4d^3D_1$ transition with the ^{88}Sr atoms trapped in a magneto-optical trap, where we have observed the repumping effect of the transition with enhancement in the trapped atom number.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D060

Quantum error correction and digital quantum simulation with reconfigurable atom arrays

Simon Evered[1], Dolev Bluvstein[1], Alexandra Geim[1], Sophie Li[1], Hengyun Zhou[1,2], Tom Manovitz[1], Sepehr Ebadi[1], Madelyn Cain[1], Marcin Kalinowski[1], Dominik Hangleiter[3], J. Pablo Bonilla Ataides[1], Nishad Maskara[1], Iris Cong[1], Xun Gao[1], Pedro Sales Rodriguez[2], Thomas Karolyshyn[2], Giulia Semeghini[1], Michael Gullans[3], Markus Greiner[1], Vladan Vuletić[4], Mikhail Lukin[1]

[1]Harvard University, Cambridge, USA. [2]QuEra Computing Inc., Boston, USA. [3]Joint Center for Quantum Information and Computer Science, NIST/University of Maryland, College Park, USA. [4]Massachusetts Institute of Technology, Cambridge, USA

Abstract

Suppressing errors is one of the central challenges for useful quantum computing, requiring quantum error correction for large-scale processing. However, the overhead in the realization of error-corrected "logical" qubits, where information is encoded across many physical qubits for redundancy, poses significant challenges to large-scale logical quantum computing. Here we will discuss recent advances in quantum information processing using dynamically reconfigurable arrays of neutral atoms, where physical qubits are encoded in long-lived hyperfine states and entangling operations are realized by coherent excitation into Rydberg states. With this platform we have realized programmable quantum processing with encoded logical qubits, combining the use of 280 physical qubits, high two-qubit gate fidelities, arbitrary connectivity, and mid-circuit readout and feedforward. Using this logical processor with various types of error-correcting codes, we demonstrate that we can improve logical two-qubit gates by increasing code size, outperform physical qubit fidelities, create logical GHZ states, and perform computationally complex scrambling circuits using 48 logical qubits and hundreds of logical gates. Finally, we demonstrate how the same architecture can be used for gate-based quantum simulations, by realizing tunable Floquet Hamiltonians through a periodic sequence of quantum gates and atom rearrangement. Together, these results chart a path toward future large-scale quantum processors and highlight unique near-term opportunities for gate-based quantum simulation.

[1] S. Evered*, D. Bluvstein*, M. Kalinowski* et al. Nature 622, 268-272 (2023)

[2] D. Bluvstein, S. Evered et al. Nature 626, 58-65 (2023)

Categories

Quantum computing, simulation & networks

Presentation

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D061

Potassium condensates in optical tweezers

Madeleine Bow Jun Leibovitch, Jared E Pagett, Jeremy Estes, Samyuktha Ramanan, Jack Kingdon, Andrew Jayich, David M Weld

University of California Santa Barbara, Santa Barbara, USA

Abstract

We present progress on a compact optical tweezer apparatus featuring multiple Bose-Einstein condensates (BECs) of potassium 39. The experiment aims to study systems whose evolution is governed by an interplay between measurement, feedback, and unitary evolution: a regime sometimes called quantum interactive dynamics. Additional scientific goals include the study of quantum thermodynamic engines. Relevant experimental capabilities include non-destructive phase-contrast imaging, Feshbach-tuned contact interactions, and Rydberg interactions.

We acknowledge support from the Gordon and Betty Moore Foundation (grant DOI 10.37807/gbmf12239), the Air Force Office of Scientific Research (DURIP FA9550-22-1-0489), the W.M. Keck foundation, and the Eddleman Center for Quantum Innovation.

Categories

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D062

Parallel addressing of arbitrary single atoms in two-dimensional fiber array optical tweezers

Xiao Li[1], Jiayi Hou[1,2], Guangwei Wang[1,2], Jiachao Wang[1,2], Xiaodong He[1,3], Yibo Wang[1], Min Liu[1], Jin Wang[1,3], Peng Xu[1,3], Mingsheng Zhan[1,3]

[1]Innovation Academy for Precision Measurement Science and Technology, CAS, Wuhan, China. [2]School of Physical Sciences, University of Chinese Academy of Sciences, Beijing, China. [3]Wuhan Institute of Quantum Technology, Wuhan, China

Abstract

In recent years, programmable quantum simulations and quantum computing have given us a new way to process information and explore the world. Arrays of atoms trapped in optical tweezers is one of the most powerful platform for realization of universal quantum computers due to its advantageous scalability and reconfigurability of qubits. Individual and parallel addressing of specified target qubits in an atomic qubit array is a building block of universal quantum computer.

Here, we present a novel architecture for atom array trapping and manipulation basing on an optical fiber array. The trapping laser and the addressed laser are combined into a single-mode optical fiber, achieving advanced addressing control with beam pointing noise common mode suppression. All parameters of the addressing laser can be adjusted independently, enabling precise and arbitrary parallel manipulation across the entire array. We experimentally demonstrate trapping and addressing of ten single atoms in a fiber array generated tweezers. The average fidelity of our addressed single-qubit gates is above 0.995, with the Rabi rate crosstalk between the targeted qubit and its nearest-neighbor qubits below 0.1%. In addition, we demonstrate the capability of this architecture to parallelly address and manipulate arbitrary single atoms within the array. Based on this architecture, we will next extend our experimental efforts to the addressing two-qubit gates, advancing our foundational technology for constructing a universal quantum computer.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D063

Shuttle and gate operations on fermionic quantum states enabled by topological pumping in an optical lattice

Yann Kiefer, Konrad Viebahn, Zijie Zhu, Marius Gächter, Samuel Jele, Giacomo Bisson, Tilman Esslinger

ETH Zürich, Zürich, Switzerland

Abstract

The transport of atoms, electrons or entanglement in general in large many-body systems is becoming an increasingly important target for quantum applications. Often, long-distance qubit connectivity relies on the transport of particles, which leads to unwanted excitations and heating. To circumvent this, we present a ground-state preserving transportation scheme based on periodic modulation of an optical lattice potential.

In detail, we leverage topological pumping in a periodically modulated one-dimensional optical superlattice to realise the transport of coherent fermionic two-particle states over large distances. Furthermore, we use the macroscopic access of the optical lattice potential to implement gate operations by engineering the local superexchange coupling J_{ex}. More specifically, when two particles meet in a double well of the optical lattice, we can control J_{ex} using two different methods, such that two-particle $(SWAP)^n$ gates are implemented while preserving the motional many-body ground state of the system. We reveal the successful implementation of such gates by observing multifrequency singlet-triplet oscillations as a direct signature of entanglement between fermions distributed over tens of lattice sites.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D064

Probing ergodic breaking dynamics in one dimensional Rydberg atom arrays

Tianyi Yan, Weibin Li

University of Nottingham, Nottingham, United Kingdom

Abstract

Rydberg atoms have strong and long-range two-body interactions and long lifetimes. Rydberg atoms trapped in tweezer arrays provide a versatile quantum simulator to emulate novel phases and dynamics of lattice models. In this work, we study a one dimensional spin model with cluster interactions that is realized with a chain of Rydberg atoms. The cluster interaction is achieved through using the blockade effects between Rydberg states. This model can be mapped to the PXP model in the weak interacting limit, where ergodic breaking has been predicted and experimentally demonstrated. We identify an ergodic breaking regime that results from dynamical constraints induced by the long-range cluster interaction. We show that thermalisation and ergodic breaking dynamics can be witnessed by the Rydberg population and entropy dynamics. We furthermore discuss parameters to realise such model and dynamics with the Rydberg atom quantum simulator.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D065

A Race-Track Trapped-Ion Quantum Processor: Applications, Benchmarks and Laser Cooling

John Bartolotta, Brian Estey, Michael Foss-Feig, David Hayes, Christopher Gilbreth

Quantinuum, Broomfield, USA

Abstract

We showcase the latest applications and performance benchmarks of our quantum charge-coupled device (QCCD) trapped-ion quantum computer, H2 (Phys. Rev. X 13, 041052). Based on a linear trap with periodic boundary conditions, which resembles a race track, H2 successfully incorporates several technologies crucial to future scalability while maintaining, and in some cases exceeding, the gate fidelities of previous QCCD systems. We discuss primitive and system-level performance benchmarks, such as average two-qubit gate infidelity and quantum volume, and we present evidence for random circuit sampling at unprecedented fidelities on a scale that is beyond the capabilities of state-of-the-art classical simulation algorithms. We also focus on recent advances in modeling the laser cooling of trapped-ion crystals with potentially many internal levels and motional modes, which has led to significant reductions in ground-state cooling times that enable the high fidelity achieved on H2.

Categories

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Presentation

Poster presentation

D066

A dual-species optical tweezer array of Na and Cs atoms

Ryan Cimmino, Kenneth Wang, Yu Wang, Kang-Kuen Ni

Harvard University, Cambridge, USA

Abstract

Optical tweezer arrays of neutral atoms interacting via Rydberg states are a promising platform for realizing quantum computation. A necessary component of a functional quantum computer is the implementation of quantum error correction, which involves building redundancy of quantum information into a larger set of physical qubits (data qubits) that comprise a single logical qubit. Successful detection and subsequent correction of errors involves entangling ancillary qubits with the data qubits and performing mid-circuit measurements of these ancillary qubits. A dual-species atom array naturally eliminates crosstalk when performing measurements of the ancilla qubits. Selective addressing of ancilla qubits also allows for multi-qubit gates between nearby data qubits. We present our progress towards realizing a dual species tweezer array of Na and Cs atoms. We create arbitrary-geometry 2D arrays of both species in tandem and excite them to Rydberg states.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D067

Distributed Quantum Computing across a Two-Node Network

Peter Drmota, David Nadlinger, Dougal Main, Gabriel Araneda, Bethan Nichol, Raghavendra Srinivas, Ellis Ainley, Ayush Agrawal, David Lucas

University of Oxford, Oxford, United Kingdom

Abstract

Building a large-scale quantum computer may only be feasible by combining the computing power of networked quantum processing modules. In this architecture, all-to-all connectivity can be established by quantum gate teleportation.

On our poster, we describe the first distributed quantum computation between two photonically networked trapped-ion quantum processors, using heralded shared entanglement to deterministically teleport quantum gates between distant "circuit qubits". We showcase the ability to execute multiple consecutive teleported controlled-Z gates and report benchmarks for the performance of the iSWAP and SWAP circuits, comprising 2 and 3 instances of gate teleportation, respectively. Furthermore, we present results of Grover's search algorithm on a distributed two-qubit register - the first demonstration of a distributed quantum algorithm containing more than one non-local two-qubit gate.

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D068

Room temperature probabilistic CNOT gate with synchronized photons.

Tanim Firdoshi, Haim Nakav, Ofer Firstenberg

Department of Physics of Complex Systems, Weizmann Institute of Science, Rehovot 7610001, Israel, Rehovot, Israel

Abstract

Quantum information processing necessitates the coherent synchronization of photons generated by probabilistic quantum sources. This synchronization can be achieved through the utilization of advanced quantum memories. Photon sources and quantum memories leveraging room temperature technology are rapidly emerging as leading candidates for the next generation of quantum technology. Our work demonstrates a room temperature probabilistic entangling gate using synchronized photons pairs. The performance of the gate is investigated with single photon pairs synchronized using quantum memory in contrast to the gate performance with accidental photon pairs from the single photon source only. Photon synchronization results in an enhancement of photon pair coincidence rate and hence improves the performance of the gate. Our research advances the frontier of scalable photonic quantum technologies, contributing to their development and implementation.

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D069

Background Free Detection and Light Shift Gate in an Ion Trap with Integrated Photonics

Alexander Ferk, Gillenhal Beck, Alfredo Ricci Vásquez, Henrik Hirzler, Daniel Kienzler, Jonathan Home

ETH Zürich, Zürich, Switzerland

Abstract

Surface-electrode ion traps with integrated photonics offer advantages in scalability for quantum computing as well as increased capabilities for exploring light-matter interaction physics. In this poster, we present a multi zone ion trap with integrated SiN and AlO waveguides as well as grating outcouplers enabling light delivery to the ion(s) for wavelengths ranging between 375 nm and 866 nm. The first two trap zones feature outcouplers delivering tightly focused light at 732 nm used for a two photon background-free state-detection scheme. The other two zones feature grating outcouplers at 532 nm, which will be used for high-fidelty two qubit gates in axial and radial modes.

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Quantum computing, simulation & networks

Presentation

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D070

Towards Realizing Single-Spin Excitation Transport in Rydberg Chains

Anastasiia Mashko, Artem Zhutov, Soroush Khoubyarian, Kent Ueno, Christopher Wyenberg, Alexandre Cooper-Roy

Department of Physics and Astronomy, Institute for Quantum Computing, University of Waterloo, Waterloo, Canada

Abstract

Quantum materials have the potential to enhance devices with greater sensitivity, efficiency, and performance. Typically, the discovery of such materials requires a fundamental understanding of the quantum phenomena governing them. Since quantum simulators can access properties in regimes inaccessible to classical simulators, they can help accelerate the design, characterization, and transformation of these materials into practical devices. Towards this goal, we seek to realize one-dimensional single-spin excitation transport in a Rydberg Atom Array Quantum Simulator.

We propose an approach to realize the spin exchange Hamiltonians in Rydberg chains. We present a hierarchy of approximations, starting from an analytically solvable effective Hamiltonian down to the Rydberg Hamiltonian directly given by experimental parameters, and provide a set of parameters satisfying perfect spin transport conditions. Moreover, we introduce a novel quantum channel for modeling the effect of spin-motion dephasing, in which the spread of atomic spatial wavefunctions may reduce the fidelity of internal spin dynamics. Finally, we present the unique features of our apparatus and current results towards the experimental realization of perfect spin transport. These include assembling microscope objectives in a cross-configuration, stochastic loading of the array of single atoms, deterministic imaging of single atoms, and reconfiguring atoms in defect-free chains.

By moving from theoretical ideal conditions to experimentally accessible ones, experimental spin transport studies bring us closer to real-world applications of quantum materials, such as information transport using spin degrees of freedom. Additionally, the experimental realization of an analytically solvable perfect spin transport model allows benchmarking the performance of quantum simulators.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D071

Photon-mediated entanglement generation in a mixed-species ion trap network

David P. Nadlinger, Peter Drmota, Ellis M. Ainley, Ayush Agrawal, Bethan C. Nichol, Raghavendra Srinivas, Gabriel Araneda, David M. Lucas

Department of Physics, University of Oxford, Oxford, United Kingdom

Abstract

Modular hybrid quantum systems, where matter qubits are linked using photonic interconnects, hold promise across a broad gamut of applications. Trapped ions are well-suited for the role of the matter qubit platform; in our elementary network of two nodes hosting $^{88}Sr^{+}$ and $^{43}Ca^{+}$ ions, we achieve state-of-the-art remote Bell pair generation performance, with fidelities exceeding 96.0% at rates around 100 s^{-1}. This has recently enabled first demonstrations of device-independent quantum cryptography [1] and entanglement-enhanced metrology [2]. In this poster, we present a detailed study of the spontaneous-emission-based remote entanglement generation process – including limitations to rates and fidelity in different protocols due to atomic motion in the quantum regime, and the impact of imperfect optical elements –, as well the mixed-species interaction with co-trapped $^{43}Ca^{+}$ ions, which allows for the creation of distributed 3- and 4-qubit GHZ states with fidelities larger than 90%. $^{43}Ca^{+}$ also acts as a long-lived memory well-decoupled from any network activity; we achieve remote Bell state coherence times of more than 10 s, greatly exceeding the average duration of the Bell state generation process. This enables the deterministic execution of protocols requiring multiple interactions, such as in client–server [3] and distributed computing, as well as entanglement distillation.

[1] Nadlinger et al., Nature 607, 682-686 (2022)
[2] Nichol, Srinivas et al., Nature 609, 689–694 (2022)
[3] Drmota et al., Phys. Rev. Lett. 130, 150604 (2023)

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D072

On the integration of miniature optical Cavities with a linear ion trap for quantum networking

Ezra Kassa, Soon Teh, Shaobo Gao, Diptaranjan Das, Shuma Oya, Hiroki Takahashi

OIST, Okinawa, Japan

Abstract

Trapped atomic ions have been shown to be excellent qubit candidates for quantum information processing. However, due to scaling constraints, the number of qubits that can be reliably controlled has been limited to a few tens, whereas thousands more are required for harnessing the potential of quantum processors. To this end, optical cavity mediated photonic interconnects have been pursued as promising candidates[1–3]. However, optical cavities have been found to be inherently incompatible with ion trap because (a) charges can accumulate on the dielectric cavity surfaces which distort the trapping potential[4], and (b) the dielectric material near the ions causes a significant motional heating[5]. For these reasons, efficient coupling between ions in a linear trap and an optical cavity has yet to be demonstrated. In addition, we have found that the conventional integration of optical cavities with linear ion traps can lead to significant distortion of the trapping field; for example the rf-null line could be converted to a deep potential well. We present configurations of cavity designs and rf-drives that are compatible for integration. The small cavity mode volumes that are required for efficient interfaces necessitate miniature ion traps. We have developed and characterised blade-type ion traps with low defects using selective laser etching. Another challenge that has limited the efficiency of ion-cavity interfaces is the degradation of high finesse ultra-violet band cavities designed to couple to the stronger dipole transitions in ions such as Ca^+ and Yb^+ [6–8]. We consider Ba^+ ions as alternatives which offer a strong dipole transition outside the UV band at 493 nm. We have measured a stable finesse of a high finesse cavity at this wavelength at a pressure of $\sim 10^{-8}$ mbar for moderate injection powers. This offers a route for cavity-QED with trapped ions in the strong coupling regime with much less stringent geometric limitations.

This work was supported by JST Moonshot R&D Grant No. JPMJMS2063 and MEXT

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[7] M. Cetina, et al. One-dimensional array of ion chains coupled to an optical cavity. New J. Phys., 15(5):053001, 2013.

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Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D073

Experimental Realization of a Quantum Router Using Single-Photon-Raman Interaction for QRAM Applications (dummy title until we get the real one)

Shonfeld Assaf, Aqua Ziv, Korn Dor, Ohana Tal, Garti Dror, Dayan Barak

Weizmann Institute of Science, Rehovot, Israel

Abstract

One requirement for the attainment of useful universal quantum computing is the ability to perform the equivalent of Random Access Memory (RAM), which allows efficient routing of data for storage in or retrieval from memory cells.

The quantum equivalent of RAM - the QRAM [1] - relies on the ability to route target qubits according to an address that is also quantum address, and is indicated by the control qubits. This process of quantum routing should be resilient to noise, as shown by Hann, et al. [2].

Here we are presenting the experimental ongoing realization of a basic building block of the QRAM - quantum router, for the first time. In this protocol, photonic time-bin qubits control the routing of target photonic time-bin qubits.

Based on Single-Photon-Raman Interaction (SPRINT, [3,4]), our realization involves single \$^{87}Rb\$ atoms coupled to a chip-based high-Q whispering-gallery-mode resonator, which in essence performs a photon-atom SWAP gate [5] that ends up either in reflection or transmission of the target time-bin qubit. After the routing the atomic state always ends up back in the same initial state, thereby keeping it non-entangled with any of the control or target photonic qubits.

This proof-of-principle demonstration lays the basis for the further development of the quantum information protocols that are necessary for the realization of full-scale universal quantum computation.

Citations:

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Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D074

Modelling Isentropic Quantum Engine Cycles in an Atomic Superfluid

Henry Harper-Gardner[1], Søren Balling[2], Jan Arlt[2], Nikolaos Proukakis[1]

[1]Newcastle University, Newcastle Upon Tyne, United Kingdom. [2]Aarhus University, Aarhus, Denmark

Abstract

Recently there has been a surge of activity in relation to quantum thermodynamics in coherent atomic superfluids. In addition to the usual quantum Otto cycle, experimental work has recently addressed isentropic cycles, through a combination of potential- and interaction-energy exchange cycles. Our investigation is motivated by the experiment of Simmons et al. (PRR 5, L042009 (2023)), in which they study a high purity trapped quantum gas of ^{7}Li atoms subjected to an Otto cycle. This cycle pumps energy between the magnetic and optical fields by alternately varying the scattering length and trapping frequency. Here we present our preliminary results on isentropic quantum engine efficiency and power within an atomic condensate based on mean-field calculations: in particular, we focus on the inter-dependence of the behaviour of such parameters on the underlying collective excitations induced by non-adiabatic processes in the various engine strokes – an important question to achieving maximal performance within a minimal evolution timescale. Our preliminary findings are discussed in the context of the broader literature and provide a first step towards a fully self-consistent analysis in a closed partially-condensed system, based on more advanced finite-temperature techniques.

Categories

Quantum fluids

Presentation

Poster presentation

D075

Controllable Quantum Vortex Dynamics, Dissipation and Quantum Sensing in Double-Ring Atomtronic Circuits

Tom Bland[1,2], Ihor Yatsuta[3,4], Andrii Chaika[3], Artem Oliinyk[3], Oksana Chelpanova[5], Yelyzaveta Nikolaieva[3,6], Mark Edwards[7], Alex Yakimenko[3,8], Nick Proukakis[1]

[1]Newcastle University, Newcastle upon Tyne, United Kingdom. [2]University of Innsbruck, Innsbruck, Austria. [3]Taras Shevchenko National University of Kyiv, Kyiv, Ukraine. [4]Weizmann Institute of Science, Rehovot, Israel. [5]Johannes Gutenberg University of Mainz, Mainz, Germany. [6]TU Wien, Vienna, Austria. [7]Georgia Southern University, Statesboro, USA. [8]University of Padova, Padova, Italy

Abstract

We study the dynamics of quantized vortices between density-coupled ring-shaped atomic Bose-Einstein condensates in experimentally accessible regimes, based on a quasi-2D double-ring configuration with a tuneable weak link. Remarkably, in the absence of external rotation or acceleration, we find that two density-connected rings can in fact support stable, long-lived, persistent currents with distinct winding numbers in each ring: such a scenario can, for example, be generated through the dynamical crossing of the BEC phase transition (Bland et al., JPB 53, 115301). For any given initial configuration, the addition of a tuneable weak link enables us to demonstrate and characterize the emergence of controllable periodic transfer of the current across the two rings. This can be vizualised as the periodic transfer of a centrally-located vortex along the line connecting the centres of the two co-planar rings. Interestingly, the co-existence of a thermal cloud can suppress (or randomize) such oscillations, an effect thoroughly characterized here by extending the usual mean-field Gross-Pitaevskii equation both through the coupling to a static heat bath introducing stochastic noise, and through the dynamical self-consistent monitoring of the thermal cloud through a quantum Boltzmann equation (Bland et al., PRR 4, 043171). The presence of external acceleration or rotation introduces a notable bias in the vortex transitions, due to the redistribution of phase and density, and this becomes particularly pronounced under strong dissipation, which can, e.g., restrict the dynamics to unilateral transfer. Our findings are thus directly relevant to precise local acceleration and rotation measurements.

Categories

Quantum fluids

Presentation

Poster presentation

D076

Temperature and Chemical Potential Characterisation of Bose-Einstein Condensates through Image Recognition

Jack Griffiths, Steven Wrathmall, Simon Gardiner

Department of Physics, Durham University, Durham, United Kingdom

Abstract

Temperature, together with the chemical potential, are two parameters which in principle completely characterise an atomic Bose gas (given a well characterised trapping potential) at thermal equilibrium in the grand canonical ensemble. In an experiment, however, temperature characterisation of atomic Bose-Einstein condensates is typically an imprecise process, which is also commonly the case for number counting (effectively equivalent to knowing the chemical potential for a known scattering length). We explore the possibility of training a machine learning model on images of the atomic cloud, comparable to those that would commonly be produced experimentally, arising from stochastic Gross-Pitaeveskii equation calculations for specified values of the temperature and chemical potential. The intention is that this methodology would be used to produce a tool that would give optimised estimates of the temperature and chemical potential (or equivalently, the mean particle number for a known scattering length) associated with a single-shot image of a Bose-condensed cloud of atoms, which could in principle be either time-of-flight or in-situ density. This would in turn lead to improved, or at least more straightforward theoretical modelling of BEC experiments. We describe some preliminary explorations, using a simplified two-dimensional model in a specified trapping configuration.

Categories

Quantum fluids

Presentation

Poster presentation

D077

Exploring dipolar quantum phases with a dipolar BEC of NaCs molecules

Weijun Yuan[1], Siwei Zhang[1], Niccolò Bigagli[1], Boris Bulatovic[1], Haneul Kwak[1], Ian Stevenson[1], Tijs Karman[2], Sebastian Will[1]

[1]Columbia University, New York, USA. [2]Radboud University, Nijmegen, Netherlands

Abstract

Following the realization of a BEC of dipolar molecules [1], we report on current efforts to explore dipolar quantum phases using this novel platform. The NaCs BECs are produced with the 'double microwave shielding' technique, where the molecules are dressed by a linearly and circularly polarized microwave field simultaneously. This technique both suppresses collisional loss and serves as a versatile tool for tuning dipolar and contact interactions. Utilizing this tool, we observe electrostriction of the BEC for small dipole-dipole interactions. For larger interactions, we observe the formation of quantum macro droplets and droplet arrays. Our results show the richness of dipolar quantum physics in degenerate molecular gases.

Funding:

We acknowledge funding support from NSF, ONR, and the Moore Foundation.

References:

[1] "Observation of Bose-Einstein condensation in a gas of dipolar molecules," Bigagli, N., Yuan, W., Zhang, S., Bulatovic, B., Karman, T., Stevenson, I., Will, S., arXiv:2312.10965 (2023).

Categories

Quantum fluids

Presentation

Poster presentation

D078

Realization of a Laughlin state of two rapidly rotating fermions

Maciej Galka[1], Philipp Lunt[1], Paul Hill[1], Johannes Reiter[1], Philipp Preiss[2,3], Selim Jochim[1]

[1]Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany. [2]Max Planck Institute of Quantum Optics, Munich, Germany. [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Abstract

The fractional quantum Hall (FQH) effect is a paradigmatic phenomenon in the interplay of strong magnetic fields and interparticle interactions. Its understanding arises from considering the Laughlin trial wavefunction, which describes a strongly correlated state in which the interaction energy is minimised by incorporating the relative angular momentum between all constituents. While initially the FQH effect was observed in electron systems, the progress with engineered quantum systems in synthetic magnetic fields allows new ways to explore quantum Hall physics by enabling an unprecedented level of microscopic control and detection. However, reaching the strongly correlated (FQH) regime still remains a challenge, with only a few recent exceptions.

Here, using our newly established experimental tools to precisely shape and modulate optical potentials we realise the Laughlin state of two rapidly rotating fermionic atoms in an optical tweezer [1]. By utilizing a single atom and spin resolved imaging technique we sample the Laughlin wavefunction and reveal its distinctive features: a ground state distribution in the centre-of-mass motion, a vortex distribution in the relative motion, correlations in the relative angle of the two particles, and the suppression of interparticle interactions.

Our work lays the foundation for atom-by-atom assembly of fermionic fractional quantum Hall states in quantum simulators.

[1] P. Lunt, P. Hill, J. Reiter, P. M. Preiss, M. Galka, S. Jochim, arXiv:2402.14814 (2024)

Categories

Quantum fluids

Presentation

Poster presentation

D079

Stabilizing persistent currents in an atomtronic Josephson junction necklace

Klejdja Xhani[1], Luca Pezze[2,3,4], Cyprien Daix[3,5], Nicola Grani[3,2,5], Beatrice Donelli[3,6,2], Francesco Scazza[3,7,2], Diego Hernandez-Rajkov[3,2], Woo Jin Kwon[8], Giulia Del Pace[2,5], Giacomo Roati[2,3]

[1]Dipartimento di Fisica e Astronomia "Augusto Righi", Bologna, Italy. [2]CNR-INO, Firenze, Italy. [3]LENS, Firenze, Italy. [4]QSTAR, Firenze, Italy. [5]University of Florence, Firenze, Italy. [6]University of Naples, Napoli, Italy. [7]University of Trieste, Trieste, Italy. [8]Department of Physics, Ulsan National Institute of Science and Technology (UNIST), Ulsan, Korea, Republic of

Abstract

Josephson junction arrays are at the forefront of research in quantum computing and simulation. These arrays serve as a platform for investigating a range of fundamental physical phenomena where macroscopic phase coherence, nonlinearities, and dissipative mechanisms compete. In this study, we examine finite-circulation states in an atomtronic Josephson junction necklace, which consists of a configurable array of tunneling links arranged in a ring-shaped superfluid. By adjusting both the imprinted circulation state and the number of junctions, we explore the stability diagram of the atomic flow.

Our theoretical predictions suggest that increasing the number of Josephson links enhances the circuit's ability to sustain higher circulations (which correspond to higher critical currents). This effect arises directly from the single-valued nature of the order parameter, reflecting the macroscopic phase coherence of the superfluid state. Adding more Josephson links reduces the superfluid speed across each junction, thereby increasing the global maximum (critical) current in the ring.

This enhanced stability contrasts with the trend observed in the superfluid fraction, as quantified by Leggett's criterion, which decreases with an increasing number of junctions and the associated density depletion. Our theoretical predictions of increased stability with more junctions are supported by experimental measurements conducted on a Bose-Einstein condensate (BEC) of 6Li molecules in an annular trap equipped with up to 16 static planar junctions.

Categories

Quantum fluids

Presentation

Poster presentation

D080

Energy damping and diffusion of quantum vortices in Bose-Einstein condensates

Zain Mehdi[1], Joseph Hope[1], Stuart Szigeti[1], Ashton Bradley[2]

[1]Australian National University, Canberra, Australia. [2]University of Otago, Dunedin, New Zealand

Abstract

Dissipation mechanisms play an important role in superfluid dynamics, and a central role in the dynamics of high energy turbulent superfluids. While the need to understand condensate formation stimulated a solid foundation for reservoir theory of matter wave Bose-Einstein condensates, its standard incarnation - a damped Gross-Pitaevskii equation closely related to the imaginary time treatment of nonlinear ground states - fails spectacularly to describe the damping timescales of quantum vortices in experiments. We describe an effective point vortex theory of 2D matter waves at finite temperature derived from open systems (c-field) theory in which number-conserving energy exchange with the reservoir determines the mutual friction coefficient, in agreement with experiments, and in stark contrast to the standard damped Gross-Pitaevskii treatment. Our results indicate the general significance of energy damping in cold quantum gases and we briefly mention implications for other systems where energy damping may be important.

Categories

Quantum fluids

Presentation

Poster presentation

D081

Observation of an inverse turbulent-wave cascade in a driven quantum gas

Andrey Karailiev[1], Martin Gazo[1], Maciej Gałka[1,2], Christoph Eigen[1], Tanish Satoor[1], Zoran Hadzibabic[1]

[1]University of Cambridge, Cambridge, United Kingdom. [2]Heidelberg University, Heidelberg, Germany

Abstract

We observe an inverse turbulent-wave cascade, from small to large lengthscales, in a driven homogeneous 2D Bose gas. Starting with an equilibrium condensate, we drive the gas isotropically on a lengthscale much smaller than its size, and observe a nonthermal population of modes with wavelengths larger than the drive one. At long drive times, the gas exhibits a steady nonthermal momentum distribution. At lengthscales increasing from the drive one to the system size, this distribition features in turn: (i) a power-law spectrum, with an exponent close to the analytical result for a particle cascade in weak-wave turbulence, and (ii) a spectrum intriguingly reminiscent of a nonthermal fixed point associated with universal coarsening in an isolated 2D gas. In further experiments, based on anisotropic driving, we reveal the complete qualitative picture of how the steady-state cascade forms.

Categories

Quantum fluids

Presentation

Poster presentation

D082

Universal speed limit in non-equilibrium Bose-Einstein condensation

Gevorg Martirosyan, Martin Gazo, Jiri Etrych, Simon Fisher, Seb Morris, Christopher Ho, Christoph Eigen, Zoran Hadzibabic

University of Cambridge, Cambridge, United Kingdom

Abstract

Thermalization of closed quantum systems is a fundamental problem in many-body physics that can feature universality akin to equilibrium systems. Here, we investigate the thermalization of a box-trapped Bose gas starting from a far-from-equilibrium momentum distribution. We observe that the condensation dynamics takes place in two stages: an initial transport of particles towards low momenta followed by self-similar coarsening dynamics until a Bose-Einstein condensate is formed. The initial transport is well described by weak-wave turbulence theory and the characteristic thermalization rate is quadratic in interaction strength. During the coarsening stage the coherence length grows algebraically in time with a timescale that is interaction-independent for sufficiently strong interactions.

Categories

Quantum fluids

Presentation

Poster presentation

D083

Towards quantum droplets and CsYb molecules: Quantum degenerate mixtures and Feshbach resonances

Tobias Franzen[1], Jack Segal[1], Kali E WIlson[2], Joe T Bloomer[1], Simon L Cornish[1]

[1]Durham University, Durham, United Kingdom. [2]University of Strathclyde, Glasgow, United Kingdom

Abstract

Ultracold mixtures of alkali metals such as Cs and closed shell atoms like Yb provide an exciting experimental platform for the study of quantum degenerate mixtures as well as the formation of doubly polar molecules.

The choice of the Yb isotope provides access to a wide range of interspecies scattering length through mass tuning as well as Bose-Bose and Bose-Fermi mixtures. For example we have demonstrated the production of a dual BEC of Cs and ^{174}Yb, which will allow investigations of a heteronuclear quantum droplets near a Cs Feshbach resonance.

Heteronuclear $^{2}\Sigma$ molecules such as CsYb have both an electric and a magnetic dipole moment in the electronic ground state. Combined with the long-range dipole-dipole interactions, the magnetic dipole moment makes CsYb a promising environment for quantum simulations of lattice spin models.

Here we present recent experimental upgrades and progress on our CsYb experiment. The production of a dual degenerate gas of Cs and Yb atoms in a bichromatic optical dipole trap lays the groundwork for mixture experiments, while the recent observation of magnetic Feshbach resonances in this system is a crucial step on the way towards the production of CsYb molecules.

In preparation for the observation of quantum droplets and production of molecules we are currently implementing optical transport to a glass cell, high-field magnetic coils and high-resolution imaging.

Categories

Quantum fluids

Presentation

Poster presentation

D084

3D-2D size-energy universality of self-bound van der Waals systems

Petar Stipanović[1], Leandra Vranješ Markić[1], Ana Ćavar[1], Jordi Boronat[2]

[1]University of Split, Faculty of Science, Split, Croatia. [2]Departament de Física, Universitat Politècnica de Catalunya, Barcelona, Spain

Abstract

Energy-size relationship was explored for few-body quantum systems in 2D and 3D. The self-binding ground-state energies, determined by the diffusion Monte Carlo method, follow generalized Tjon lines. Structural properties were extracted by pure estimators, which proved successful in evaluating theoretical predictions of distribution functions compared to the experimental results of Coulomb explosion imaging results. A universal size-energy law was found for homogeneous van der Waals systems in which the interaction pair potentials predominantly decrease with r^{-6}. The law extends from classical systems to quantum systems. The law is also valid for mixed systems with homogeneous-like structure.

Categories

Quantum fluids

Presentation

Poster presentation

D085

Thermal atomic beam gyroscope using phase modulation scheme

Naoki Kaku[1], Sotatsu Otabe[2], Tomoya Sato[2], Takuya Kawasaki[2,3], Naoki Nishimura[1], Toshiyuki Hosoya[4], Mikio Kozuma[2,1]

[1]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan. [2]Institute of Innovative Research, Tokyo Institute of Technology, Kanagawa, Japan. [3]Current address: Department of Physics, University of Tokyo, Tokyo, Japan. [4]Product Development Center, Japan Aviation Electronics Industry, Ltd., Tokyo, Japan

Abstract

The accuracy of inertial navigation, a method of estimating self-position using accelerometers and gyroscopes, is currently limited by the performance of gyroscopes. In optical interferometer gyroscopes, conventionally used for inertial navigation, angular velocity is estimated from the Sagnac phase shift induced by rotation. Since the de Broglie wavelength and velocity of atoms are much smaller than those of light, an atom interferometer has the potential to significantly increase the Sagnac phase shift and improve the performance of the gyroscope. As shot noise, which determines the sensitivity limit, depends on the phase detection scheme, the choice of the scheme plays an important role. The typical readout scheme involves linearly sweeping the phase of the atoms and detecting the Sagnac phase shift through lock-in detection of the interferometer output.

As we have recently proposed, the phase modulation technique has the advantage of improving shot noise-limited sensitivity compared to the conventional phase sweep method. We generated a thermal atomic beam from a Rb oven and constructed a $\pi/2$–π–$\pi/2$ Raman-type Mach–Zehnder interferometer. By modulating the phase of the Raman beams, we achieved phase modulation of the atoms and successfully extracted the interferometer phase through lock-in detection. In this poster, we will discuss the relationship between the demodulated signal and the modulation index, as well as the implementation of a gyroscope using this phase modulation technique. This work was supported by JST, JPMJMI17A3 and JPMJPF2015.

Categories

Matter wave interferometry

Presentation

Poster presentation

D086

Progress towards commissioning a Strontium High Flux Atomic Interferometry Source

Hamza Labiad[1], Anna Marchant[1], Mark Bason[1], Tristan Valenzuela-Salazar[1], Richard Hobson[2], Charles Baynham[2], Thomas Walker[2], Kenneth Hughes[3], Christopher Foot[3]

[1]STFC Rutherford Appleton Laboratory, Didcot, Oxfordshire, United Kingdom. [2]Blackett Laboratory, Imperial College, London, United Kingdom. [3]Clarendon Laboratory, University of Oxford, Oxford, United Kingdom

Abstract

We present an improved design for a compact cold atom source with high atomic flux, aimed at enhancing atom interferometry sensitivity for fundamental physics research and quantum sensing applications. The core of this work focuses on optimized design of 2D and 3D magneto-optical trap (MOT) chambers, Zeeman slowing beam and efficient high power laser cooling. This design minimizes size, weight and power consumption while maintaining high atom flux for optimal sensitivity. The project benefits from a collaborative effort between leading UK institutions (RAL Space, University of Oxford and Imperial College London) and Stanford University, US, leveraging each institution's expertise in quantum technologies.

Furthermore, we present a new version of a compact, fibre-based, and free-space high-power, beam-shaped 461 nm laser source for 2D MOT cooling able to deliver high 2D MOT loading rates. This development signifies a critical step forward not only for large-scale ground-based atom interferometry experiments but also for enabling compact, space-compatible quantum sensors.

This optimized cold atom source, with its high compactness and high atomic flux, opens exciting possibilities for advancements in fundamental physics research, including the detection of gravitational waves and ultralight dark matter candidates. Additionally, it paves the way for the development of smaller, more portable cold-atom interferometers and space-ready quantum sensors with a wide range of potential applications.

Categories

Matter wave interferometry

Presentation

Poster presentation

D087

Status of the Laser System for Cold Atom Experiments in BECCAL onboard the ISS

Hamish Beck[1], Hrudya Thaivalappil Sunilkumar[1], Marc Kitzmann[1], Matthias Schoch[1], Christoph Weise[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Jakob Pohl[1], Achim Peters[1], BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10]

[1]Humboldt University of Berlin, Berlin, Germany. [2]FBH, Berlin, Germany. [3]JGU, Mainz, Germany. [4]LUH, Hanover, Germany. [5]DLR-SI, Hanover, Germany. [6]DLR-QT, Ulm, Germany. [7]UULM, Ulm, Germany. [8]ZARM, Bremen, Germany. [9]DLR, Bremen, Germany. [10]DLR-SC, Braunschweig, Germany

Abstract

The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is designed for operation onboard the International Space Station (ISS). This multi-user facility will enable experiments with K and Rb ultra-cold atoms and BECs in mircogravity. Fundamental physics will be explored at longer time- and lower energy-scales compared to those achievable on earth.

The BECCAL laser system is comprised of micro-integrated diode lasers, miniaturized free-space optics on Zerodur boards, and a system of fibred components to bring light to the physics package. The design is subject to strict Size, Weight, and Power (SWaP) constraints, and the operation of the system is supported by extensive ground-based systems. An update on the progress of the laser system is presented, showing the flight model design and the status of ground-based systems built from commercial components.

This work is supported by the DLR with funds provided by the BMWK under grant number 50WP2102.

Categories

Matter wave interferometry

Presentation

Poster presentation

D088

Progress towards the creation of spin-squeezed states of 87Sr for the Atom Interferometer Observatory and Network

Alice Josset, Richard Hobson, Charles Baynham, Thomas Walker, Leonie Hawkins, Ludovico Iannizzotto Venezze, Elizabeth Pasatembou

Imperial College, London, United Kingdom

Abstract

Current progress on atom interferometers and atomic clocks makes these techniques suitable for Gravitational Waves (GW) detection and Dark Matter searches. However, these experiments are subject to a Standard Quantum Limit (SQL) on their resolution due to quantum projection noise at the measurement stage. GW and DM exploration with reasonable atomic cloud sizes require these instruments to have a sensitivity below the SQL, bringing the need for quantum correlations in the atom cloud.

Squeezed states of the atomic ensemble can be generated by performing a quantum non-demolition measurement of the atom number in each state. At Imperial College, we are working towards an 87Sr atom-cavity system where the 1S0-3P1 atomic transition is strongly coupled to a high-finesse cavity mode. Homogeneous coupling will be achieved by trapping the atoms in an optical lattice formed by a cavity mode at twice the wavelength of the probe. An entangled state will be created by taking non-destructive measurements of the atom number with a sweep of the probe field over the vacuum Rabi splitting of the system.

In this poster, we present experimental progress towards the creation of an atom-cavity system for the Atom Interferometer Observatory and Network (AION) detector. This instrument based on differential atom interferometry will aim for DM searches in the eV mass range and GW detection with frequencies within 0.01 Hz to a few Hz.

Categories

Matter wave interferometry

Presentation

Poster presentation

D089

Optical Clock Interferometry with 87Sr for the AION Project

Thomas Walker, Alice Josset, Ludovico Iannizzotto Venezze, Elizabeth Pasatembou, Leonie Hawkins, Charles Baynham, Richard Hobson

Imperial College, London, United Kingdom

Abstract

Atom interferometers (AIs) can be used to detect mid-frequency gravitational waves, and ultra-light dark matter candidates. In analogy to light-based interferometers, optical pulses are used to split and recombine atomic wave packets, and differential effects long the two paths can be observed in the final excitation fraction of the atoms. By manipulating the atoms using ultra-narrow single-photon transitions, the unparalleled accuracy of optical atomic clocks can be utilised in AIs.

In this poster, we present the experimental design for, and progress towards, clock interferometry on the 698 nm 1S0-3P0 clock transition in 87Sr. Atoms are cooled and state prepared in a dipole trap, where they are released into freefall and addressed by the clock laser. A series of pulses from the clock laser forms a Mach-Zehnder-type atom interferometer: first the momentum transfer from a $\pi/2$ pulse splits the atomic wave packet in space, then a π pulse acts as a mirror to bring the two paths back together, and finally a second $\pi/2$ pulse erases the which-way information and allows the paths to interfere. The implementation of the process can be verified by measuring the final atom state populations as a function of relative phase between the pulses.

This experiment is part of the development of the Atom Interferometer Observatory Network (AION), which will use differential phase measurements between multiple AIs interacting with a single clock laser. This eventually kilometre-scale experiment will use atom sources and clock interferometry techniques like the ones presented here.

Categories

Matter wave interferometry

Presentation

Poster presentation

D090

A Cold Atom Gyroscope in Space

Xi Chen[1], Jinting Li[1,2], Jin Wang[1,3,4], Mingsheng Zhan[1,3,4]

[1]State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan, China. [2]School of Physical Sciences, University of Chinese Academy of Sciences, Beijing, China. [3]Hefei National Laboratory, Hefei, China. [4]Wuhan Institute of Quantum Technology, Wuhan, China

Abstract

High precision gyroscopes in space are important for sophisticated scientific experiments and deep space navigation. Microgravity in the space provides an ideal condition for operation of a cold atom gyroscope. To demonstrate this advantage, an atom interferometer (AI) was launched and installed in the China Space Station in 2022 [1]. Here we report a realization of the cold atom gyroscope with this AI. By applying point source interferometry, spatial fringes are obtained. Acceleration and rotation are extracted from the phase shift. The evaluated rotation measurement is $(-115.64 \pm 1.71)\times10^{-5}$ rad/s in space. Meanwhile an acceleration measurement resolution of 1.03×10^{-6} m/s^2 is also obtained for a single image.

[1] M. He, X. Chen, J. Fang, Q.F. Chen, H.Y. Sun, Y.B. Wang, J.Q. Zhong, L. Zhou, C. He, J.T. Li, D.F. Zhang, G.G. Ge, W.Z. Wang, Y. Zhou, X. Li, X.W. Zhang, L. Qin, Z.Y Chen, R.D. Xu, Y. Wang, Z.Y. Xiong, J.J. Jiang, Z.D. Cai, K. Li, G. Zheng, W.H. Peng, J. Wang, and M.S. Zhan*,* **The space cold atom interferometer for testing the equivalence principle in the China Space Station**. npj *Microgravity* **9**, 58 (2023) [arXiv: 2306.04097]

Categories

Matter wave interferometry

Presentation

Poster presentation

D091

Development of a compact, fibre-based atom interferometer for rotation sensing

Joel Abraham, Tim Freegarde

University of Southampton, Southampton, United Kingdom

Abstract

Atom interferometry involves splitting, redirecting and recombining of the atomic wavefunction to produce interference, where inertial effects contribute to the phase shifts of the interference fringes. In Point Source Atom Interferometry (PSI), the correlation between position and velocity of cold atoms in an expanding ball is used to produce a spatial interference pattern across the atomic cloud, where phase shifts due to rotations and accelerations can be distinguished using a single cloud of atoms. PSI is therefore a promising technique for performing gyroscopic measurements in inertial navigation applications. As a step towards this goal, we are developing a cold atom rotation sensor, featuring a compact, fibre-based Raman laser system, which will be mounted on a transportable rack. We describe the design, latest progress and future plans for our interferometer.

Categories

Matter wave interferometry

Presentation

Poster presentation

D092

Progress towards strontium atom interferometry at RAL Space

Mark Bason[1], Kamran Hussain[2,1], Hamza Labiad[1], Anna Marchant[1], Tristan Valenzuela-Salazar[1]

[1]RAL Space, Didcot, United Kingdom. [2]University of Liverpool, Liverpool, United Kingdom

Abstract

Atom interferometers are quantum sensors capable of precise measurements and are currently being developed as pathfinder tools for fundamental physics research. The Atom Interferometer Observatory and Network (AION) is a consortium of UK institutions aiming to utilise strontium atom interferometry for detecting gravitational waves in the deci-hertz range and probing for ultra-light dark matter candidates. Each institution is working on different subsystems of a shared 1 m prototype design, further developing the scalability of the cold atom systems for a 10 m baseline and ultimately a 1 km baseline for enhanced sensitivities. Rutherford Appleton Laboratory, in collaboration with the University of Liverpool, aims to test a novel imaging technique of the atomic clouds during the end of the interferometry cycle known as “phase shear”. This enables the simultaneous readout of the contrast and phase of the atomic fringes. The status of the RAL prototype is the formation of a 2D Magneto-Optical Trap (MOT), with progress towards setting up the next stage of cooling with a 3D MOT.

Categories

Matter wave interferometry

Presentation

Poster presentation

D093

Sculpted optical potentials for ultracold quantum sensors

Tiffany Harte

University of Cambridge, Cambridge, United Kingdom

Abstract

Optical potentials are a core component of the ultracold atom toolkit, and with the additional versatility offered by holographic beam shaping sculpted potentials will play an increasing role in the development of the next generation of ultracold quantum technologies. The capabilities of these techniques include the ability for simultaneous and precise control over different aspects of the laser field including amplitude and phase [1] that unlock new means of manipulating ultracold atom clouds.

I will present plans for an experimental programme using sculpted optical potentials to explore a new approach to adaptive atom-optics, including applications to matter-wave lensing and atom interferometry readout to maximise the sensitivity of atom-interferometric quantum sensors for fundamental physics [2,3], inertial sensing and metrology [4], and studies of earth science [5]. I will also discuss the applications of quantum sensors based on cold atoms in tailored optical potentials to characterising and verifying quantum devices, and exploring the intersection of many-body physics and metrology.

[1] D. Bowman, T.L. Harte *et al.*, *Opt. Express* **25**, 11692-11700 (2017).

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Categories

Matter wave interferometry

Presentation

Poster presentation

D094

Towards Magic-Trapped Atom Interferometry for Inertial Sensing and Gravimetry

Tahiyat Rahman, Emmett Hough, Aidan Kemper, Subhadeep Gupta

University of Washington, Seattle, USA

Abstract

Free-fall atom interferometers (AIs) are already an established platform for precision measurement and quantum sensing [1,2]. However, increasing the sensitivity of such AIs requires drop towers hundreds of meters long or operation in micro-gravity environments. Recently, a new paradigm of trapped atom interferometers has demonstrated up to 70 seconds of coherence for an AI held in an optical lattice [3]. Many challenges pertinent to the phase stability of lattice trapped atom interferometers limit the spatial separation of the two interferometer arms. Decreasing decoherence in trapped AIs may be possible by confining atoms in an excited band and operating the lattice at a "magic depth," where the band energy is insensitive to lattice depth fluctuations. This technique has already been shown to increase the visibility of a free-space Mach-Zehnder interferometer [4].

In recent work [5] we have investigated phases for many BOs for both the ground and first excited bands. Here we report on work towards ultracold Yb atom trapping in the excited bands of a vertically-oriented optical lattice, operated at a magic depth. We plan to use this to develop trapped AIs at magic depths. Such AIs can be used for precision gravimetry including measurement of g, gravity gradiometry, and equivalence principle tests (using two different Yb isotopes), as well as accelerometry and inertial sensing.

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Categories

Matter wave interferometry

Presentation

D095

Large-scale atom interferometry in AION

Kimberly Tkalcec, Chun Chuan Hsu, Mariame Karzazi, Yijun Tang, Jiajun Chen, Julian Scheper, Chen Lu, Bhavana Panchumarthi, Noam Mouelle, Jeremiah Mitchell, Shengnan Zhang, Tiffany Harte, Ulrich Schneider

University of Cambridge, Cambridge, United Kingdom

Abstract

The Atom Interferometry and Observational Network (AION) collaboration aims to develop and build large-scale atom interferometers to study gravitational waves in the deci-hertz frequency range and search for signs of scalar- and vector- ultra-light dark matter. These interferometers will furthermore enable tests of the Einstein equivalence principle and fifth-force searches and allow superpositions of massive particles (atoms) over unprecedented distances for macroscopic tests of quantum mechanics.

Each detector will be based on differential measurements between several atom interferometers using the clock transition in ultracold strontium. These interferometers will be separated by a vertical baseline within a single vacuum chamber and be interrogated by the same interferometer laser, such that laser phase noise becomes common-mode and is thus suppressed. Several such detectors can then be networked together within the UK and internationally to increase sensitivity and signal verification.

The Cambridge team is working towards the preparation of ultracold strontium for atom interferometry, including cooling techniques beyond the recoil limit, efficient transport into the interferometer tube, and vertical launch of the atoms. It furthermore contributes to the general high-level design for large-scale atom interferometers, studies of systematic effects, data analysis techniques, and the development of supporting simulations, benefitting AION and the complementary MAGIS-100 experiment.

AION: An Atom Interferometer Observatory and Network
AION Collab., J. Cosmol. Astropart. Phys, 05(2020),011 (2020)

Categories

Matter wave interferometry

Presentation

Poster presentation

D096

Spin- and momentum-correlated atom pairs mediated by photon exchange

Jacob Fricke, Fabian Finger, Rodrigo Rosa-Medina, Nicola Reiter, Panagiotis Christodoulou, Tobias Donner, Tilman Esslinger

Institute for Quantum Electronics, ETH Zurich, Zurich, Switzerland

Abstract

Quantum correlations among the constituents of many-body systems determine their fundamental properties. With their pristine control over external and internal degrees of freedom, Quantum gases offer a versatile platform to manipulate and detect such correlations at a microscopic level. Here, we report on observing correlated atomic pairs in specific spin and momentum modes. Our implementation relies on Raman scattering between different spin levels of a spinor Bose-Einstein condensate induced by the interplay of a running-wave transverse laser and the vacuum field of an optical cavity. Far-detuned from Raman resonance, a four-photon process gives rise to collectively-enhanced spin-mixing dynamics. We investigate the statistics of the produced pairs and explore their non-classical character through noise correlations in momentum space. Our results demonstrate a new platform for the fast generation of correlated pairs in a quantum gas and provide prospects for matter-wave interferometry using entangled motional states.

Categories

Cavity QED

Presentation

Poster presentation

D097

Dimensional Reduction in Quantum Optics

Jannik Ströhle[1], Richard Lopp[1], Wolfgang Schleich[1,2]

[1]Universität Ulm, Ulm, Germany. [2]Texas A&M University, College Station, USA

Abstract

One-dimensional quantum optical models usually rest on the intuition of large-scale separation or frozen dynamics associated with the different spatial dimensions, for example when studying quasi one-dimensional atomic dynamics, potentially resulting in the violation of (3+1)-dimensional Maxwell's theory.

Here, we provide a rigorous foundation for this approximation by means of the light-matter interaction. We show how the quantized electromagnetic field can be decomposed exactly into an infinite number of subfields living on a lower-dimensional subspace and containing the entirety of the spectrum when studying axially symmetric setups, such as with an optical fiber, a laser beam, or a waveguide. The dimensional reduction approximation then corresponds to a truncation in the number of such subfields that in turn, when considering the interaction with for instance an atom, corresponds to a modification to the atomic spatial profile. We explore under what conditions the standard approach is justified and when corrections are necessary in order to account for the dynamics due to the neglected spatial dimensions. In particular we examine what role vacuum fluctuations and structured laser modes play in the validity of the approximation.

Categories

Cavity QED

Presentation

Poster presentation

D098

Light-induced phase transitions in strongly interacting ultracold Fermions

Tabea Bühler[1], Timo Zwettler[1], Giulia Del Pace[1], Victor Helson[1], Filip Marijanovic[2], Sambuddha Chattopadhyay[2,3], Shun Uchino[4], Eugene Demler[2], Jean-Philippe Brantut[1]

[1]Institute of Physics and Center for Quantum Science and Engineering, Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland. [2]Institute for Theoretical Physics, ETH Zürich, CH-8093 Zürich, Switzerland. [3]Lyman Laboratory, Department of Physics, Harvard University, Cambridge, USA. [4]Faculty of Science and Engineering, Waseda University, Tokyo 169-8555, Japan

Abstract

We study a hybrid system of strongly correlated atoms in a high-finesse optical cavity, making it possible to control simultaneously short-range and long-range interaction strength. For strong long-range interactions, this gives rise to a density-wave ordering transition [1].

In this poster I demonstrate the control of long-range three-body interactions induced by photons in this system, in addition to two-body short and long-range interactions. The three-body interactions arise through dispersive coupling of the cavity mode to a photoassociation transition and manifest in a shift of the phase boundary of the density-wave ordering transition. We track the change in strength and sign of this shift as a function of experimental parameters, demonstrating independent control over strength and sign of the three-body long-range interactions in our experiment. The presented setup offers a promising starting point for the generation and study of many-body states with non-trivial pair-density modulation.

Furthermore the poster presents in-situ imaging of the density-wave ordered state of the ultracold gas. A high numerical aperture objective allows to extract spatial information about the atomic state from a single shot via performing resonant, high saturation absorption imaging and opens the way towards the projection of arbitrary potentials on the atomic cloud.

[1]: Helson, V., Zwettler, T., Mivehvar, F. *et al.* Density-wave ordering in a unitary Fermi gas with photon-mediated interactions. *Nature* **618**, 716–720 (2023).

Categories

Cavity QED

Presentation

Poster presentation

D099

Towards cavity QED in a tweezers array of strontium atoms

Simone Colombo

Department of Physics, University of Connecticut, Storrs, USA

Abstract

State-of-the-art quantum sensors operate at the standard quantum limit (SQL), where the device is solely limited by quantum noise. The SQL is not a fundamental limit and can be overcome by engineering entanglement within the sensing elements. Quantum Metrology aims at pushing sensors beyond the SQL and, ideally, reaching the Heisenberg Limit (HL); a true fundamental limit to linear detection. While many proof of principle experiments have demonstrated operations beyond the SQL, the HL has been approached only in systems deploying a limited number of atoms. Indeed, operation near HL in large atomic systems is challenging, both because of the fragility of these states and limitations in state detection; to detect a maximally entangled state, one needs to resolve the collective atomic state with a single-atom resolution.

We present our work towards developing a platform that combines cavity quantum electrodynamics (QED) with an array of ultra-cold strontium atoms held/trapped by optical tweezers. Combining these two emerging quantum technologies offers the necessary level of quantum control for operations near the HL. The cavity QED provides high-fidelity all-to-all connection between the atoms. At the same time, the tweezer array furnishes single atom control and detection.

We present a method for operating a state-of-the-art optical clock near the HL. Thanks to the promised control offered by our system, this goal is within reach: optical cavities can reach single-atom cooperativity exceeding ~100, which allows for the generation of a maximally entangled state of up to 100 atoms.

Categories

Cavity QED

Presentation

Poster presentation

D100

Cavity-Mediated Entanglement Generation with Error Detection

Brandon Grinkemeyer[1], Elmer Guardado-Sanchez[1], Ivana Dimitrova[1], Danilo Shchepanovich[1], Eirini Mandopoulou[1], Vladan Vuletic [2], Mikhail Lukin[1]

[1]Harvard University, Cambridge, USA. [2]MIT, Cambridge, USA

Abstract

Neutral atom quantum processors are a leading platform for large-scale quantum computing. Coupling them to an optical cavity enables fast mid-circuit readout of atomic qubits and opens a pathway towards distributed quantum computing via quantum networks. Additionally, the cavity provides a channel for long-range coupling of atoms placed inside the cavity. Here we present a platform that couples single atoms in optical tweezers to a fiber Fabry-Perot optical cavity. Leveraging the strong atom-cavity coupling, we demonstrate qubit state readout with 99.95% fidelity in less than 5us and two novel methods for cavity-mediated entanglement generation. A key feature of our protocols is the use of error detection to improve entanglement fidelity. The cavity acts as a biased error channel, resulting in predominantly detectable errors. Specifically, we demonstrate Bell-state generation via cavity-carving with fidelity 91(3)% and via a photon-mediated gate with 60(2)% uncorrected fidelity and 76(2)% fidelity using error detection.

Poster

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Cavity QED

Presentation

Poster presentation

D101

Multimode Quantum-Enhanced Sensing using Cavity-Mediated Entanglement

Eric Cooper, Ocean Zhou, Philipp Kunkel, Avikar Periwal, Jonathan Jeffrey, Merrick Ho, Monika Schleier-Smith

Stanford University, Stanford, USA

Abstract

Entanglement is a powerful resource for improving the precision of quantum measurements beyond the standard quantum limit. Spatial control of entanglement extends this advantage to complex sensing tasks such as imaging spatially varying fields. Further, multimode entanglement between a sensing region and an ancillary quantum memory can be leveraged to sidestep local Heisenberg uncertainty relations and simultaneously sense displacements of conjugate variables. In our experiment, we generate and spatially structure multimode entanglement by combining all-to-all interactions mediated by an optical cavity with local control of atomic ensembles. Using an echo-based scheme, in which interactions are used both to prepare an initial state and to amplify measured displacements before readout, we achieve sensitivities beyond the SQL to spatially structured signals. To simultaneously sense displacements of conjugate variables, we further implement the echo-based protocol using a two-mode squeezed state with Einstein-Podolsky-Rosen type entanglement between a sensing region and an ancilla region. Our method is scalable to many modes, facilitating exponential advantage in sensing distributions of displacements and other advanced quantum metrology protocols.

Categories

Cavity QED

Presentation

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D102

Towards Multiplexed Photonic Interfaces for Neutral Atom Quantum Computers

Brandon Grinkemeyer[1], Sophie Ding[1], Eirini Mandopoulou[1], Andrei Ruskoc[1], Alexander Zibrov[1], Vladan Vuletic[2], Kiyoul Yang[1], Marko Loncar[1], Mikhail Lukin[1]

[1]Harvard University, Cambridge, USA. [2]Massachusetts Institute of Technology, Cambridge, USA

Abstract

Neutral atoms coupled to optical cavities is a well-developed platform for quantum networking. Combined with advances in neutral atom quantum computers, this approach promises significant progress toward distributed quantum computing. The effectiveness of these platforms hinges on the geometry and construction of the optical interface. Here, we present the fabrication of optical microcavities compatible with neutral atom quantum computers. Our micromirrors are produced through a two-step etching process followed by thermal smoothing. This method yields micromirrors with low radii of curvature (ROC), on the order of 100 µm, and sub-angstrom surface roughness, allowing for small mode volumes and high quality factors. Importantly, hundreds can be produced on a single structure with little variation in depth and ROC. This scalability enables a multiplexed architecture in which tens of cavities can operate in parallel within a single quantum node. Moreover, these cavities offer opportunities for high-efficiency photon collection and atom-photon entanglement at telecom wavelengths.

Categories

Cavity QED

Presentation

Poster presentation

D103

Engineering Topological Spin Models with Photon-Mediated Interactions

Avikar Periwal, Jonathan Jeffrey, Merrick Ho, Philipp Kunkel, Eric Cooper, Ocean Zhou, Monika Schleier-Smith

Stanford University, Stanford, USA

Abstract

Interactions between quantum degrees of freedom provide the foundational tools for generating entanglement, the bedrock for novel quantum technologies and exotic phases of quantum matter. Experimental platforms typically feature spatially local interactions, restricting the ability to generate highly-nonlocal entangled states of matter based on the underlying geometry. By contrast, cavity QED platforms have distance independent all-to-all interactions, enabling the generation of entanglement with exotic spatial structures. By combining the nonlocal cavity-mediated interactions with single-site rotations we are able to generate and characterize continuous-variable graph states of ensembles of atoms on arbitrary graphs. These two ingredients can be further harnessed to generate XY Hamiltonians with programmable couplings. As a demonstration we implement the Su–Schrieffer–Heeger (SSH) model and directly measure the Zak phase, before extending to more complicated models. By dynamically changing the Hamiltonian we implement a nonlocal interaction-based Ramsey interferometer, which we use to probe the symmetry-protected edge states of the SSH model. These methods of dynamically programming interactions and entanglement structure open prospects in simulating models of quantum magnetism, quantum-enhanced multiparameter estimation, and quantum computation.

Categories

Cavity QED

Presentation

Poster presentation

D104

Vibrational Branching in the Nonlinear Molecules $SrOCH_3$, $SrNH_2$, and SrSH

Alexander Frenett[1,2], Zack Lasner[1,2], Lan Cheng[3], John Doyle[1,2]

[1]Harvard University, Cambridge, MA, USA. [2]Center for Ultracold Atoms, Cambridge, MA, USA.
[3]Johns Hopkins University, Baltimore, MD, USA

Abstract

Symmetric and asymmetric top molecules are of interest for precision measurement due to their long-lived (>10 s) parity doublets in the vibronic ground state [1,2]. To best use these states for envisioned measurements, the molecules need to be cooled to sub-mK temperatures and held in conservative traps. Laser deceleration and cooling are conceptually simple methods of doing so, but require ~10^4 scattered photons to remove sufficient momentum for magneto-optical trapping. To scatter this many photons in a molecule, it is necessary to identify vibrational leakage out of the main vibronic optical transition and close these channels using narrowband lasers. To identify these loss channels, we here measure the vibrational branching ratios of $SrOCH_3$, $SrNH_2$ and SrSH at the 0.01-0.1% level. We complement our measurements with state-of-the-art calculations to compare with the data and to identify the states most likely to be populated at higher sensitivity. We further investigate rotational state closure for laser cooling in the three symmetry species represented by these molecules, identifying the features that differentiate the point groups. We find that $SrNH_2$ has the best combination of controlled vibrational branching and rotational closure, making it a good choice for a future measurement of the electron's permanent electric dipole moment. This also implies that its heavier analog, $RaNH_2$, may be a valuable platform for future Schiff moment searches for hadronic CP-violating physics beyond the Standard Model. The next steps toward full laser cooling and control of $SrNH_2$ are also discussed.

[1] Kozyryev, Hutzler, PRL **119** 2017

[2] Albert et al, PRX **10** 2020

Categories

Molecules

Presentation

Poster presentation

D105

Individually assembled triatomic molecules as sensors for nuclear CP violation

Luke Caldwell

UCL, London, United Kingdom

Abstract

We are developing a new experimental platform to search for CP violation in nuclei. Such CP violation is predicted by beyond-Standard-Model theories which seek to explain the matter-antimatter asymmetry of the universe. The new platform consists of arrays of triatomic molecules, assembled in optical tweezer traps from laser-cooled CaF molecules and Yb atoms with deformed nuclei. These designer molecules will: (i) have raw sensitivity enhanced by 4–6 orders of magnitude relative to the current state of the art, (ii) be produced at ultracold temperatures, ideally suited to high-precision measurements, and (iii) have structural features which enable powerful techniques to reject some of the most important systematic errors in similar experiments. This poster details our experimental plans.

Categories

Molecules

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D106

Polyatomic ultralong range Rydberg molecules

Juan Jose García-Garrido[1], David Mellado-Alcedo[2], Pablo Fernández-Mayo[1], Rosario González-Ferez[1]

[1]Universidad de Granada, Granada, Spain. [2]Universidad Loyola Andalucía,, Sevilla, Spain

Abstract

In cold and ultracold mixtures of atoms and molecules, Rydberg interactions with surrounding atoms or molecules may, under certain conditions, lead to the formation of special long-range Rydberg molecules. These exotic molecules provide an excellent toolkit for manipulation and control of interatomic and atom-molecule interactions, with applications in ultracold chemistry, quantum information processing and many-body quantum physics. We discuss ultralong-range polyatomic Rydberg molecules formed when a heteronuclear diatomic molecule is bound to a Rydberg atom or molecule. The binding mechanism appears due to anisotropic scattering of the Rydberg electron from the permanent electric dipole moment of the polar molecule. For the molecule Cs-RbCs, we explore the regime where the charge-dipole interaction due to the Rydberg electron with the diatomic polar molecule induces a coupling between the quantum defect Rydberg states Cs(ns) and the nearest degenerate hydrogenic manifold. We consider Rydberg states which are amenable to tweezer experimental production and study the influence of nonadiabatic coupling on the formation of such polyatomic Rydberg molecules. For the combination Rb-RbCs, we explore the pair of states that could induce a resonant coupling, analyzing the long-range behaviour of the potential energy curves. We also consider the He-ND_3, and explore its electronic structure, the vibrational bound states and the impact of an external electric field. Finally, we consider the Rydberg bimolecules NO-NO, assuming that the ground state molecule is in a thermal sample, and analyze the impact of the rotational temperature on the electronic structure and vibrational

bound states.

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Molecules

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D107

Laser cooling and spectroscopy of the AlF molecule

Sid Wright[1], J. Eduardo Padilla-Castillo[1], Jionghao Cai[1], Pulkit Kukreja[1], Priyansh Agarwal[1], Xiangyue Liu[1], Russell Thomas[1], Boris Sartakov[1], Stefan Truppe[1,2], Gerard Meijer[1]

[1]Fritz Haber Institute, Berlin, Germany. [2]Imperial College London, London, United Kingdom

Abstract

Aluminium monofluoride (AlF), a longstanding molecule of interest to spectroscopists, has recently been the subject of laser cooling efforts. The intense $X^1\Sigma^+ \rightarrow A^1\Pi$ transition at 227.5 nm enables the generation of enormous optical scattering forces and is promising for magneto-optical trapping at high densities. Analogous to the alkaline-earth elements, the spin-forbidden $X^1\Sigma^+ \rightarrow a^3\Pi$ transition provides an excellent toolbox for precision measurement, molecular control and detection.

Here, we present the first chirped-frequency laser slowing measurements on a buffer gas cooled AlF molecular beam, a key step towards magneto-optical trapping. We experimentally measure the loss probability to the $X^1\Sigma^+$, $v = 2$ state in the laser cooling cycle, showing that, whilst small, it is necessary to address this loss in a magneto-optical trap. Molecules in the second rotationally excited state are laser slowed from 160 m/s to 80 m/s, and slowing to the capture velocity of a magneto-optical trap is feasible.

Alongside these measurements, we continue to improve the available spectroscopic information about AlF, in particular with regard to highly excited states within the spin-triplet manifold. AlF molecules can be made efficiently at ~900K in a thermochemical source, and we have developed an intense, continuous molecular beam in our laboratory. We use this source to study high-lying rovibrational levels of the $c^3\Sigma^+$ state and show our progress towards a cryogenically cooled continuous AlF source.

Categories

Molecules

Presentation

Poster presentation

D108

Deep ultraviolet lasers to cool Cd atoms and AlF molecules

Lajos Palanki[1], Jionghao Cai[2], Carlos Alarcon Robledo[1], Russell Thomas[2], Sid Wright[2], Caleb Rich[1], Stefan Truppe[1]

[1]Imperial College London, London, United Kingdom. [2]Fritz Haber Institute of the Max Planck Society, Berlin, Germany

Abstract

We present our progress towards stable production of high-power deep ultraviolet (DUV) for laser cooling Cd atoms (229 nm) and AlF molecules (227.5 nm).

The strong transition in the DUV allows for rapid slowing and loading of large magento-optical traps (MOTs). This opens a new route to increase the number of molecules captured in the MOT significantly. These species also have a spin-forbidden transition in the UV enabling laser cooling to µK temperatures.

Our DUV laser systems are based on new Vertical External Cavity Surface Emitting Laser technology and produce up to 250 mW in the DUV. To evaluate the suitability of these systems for laser cooling applications, we have loaded and characterized MOTs of Cd atoms. We also outline our plan for loading substantial MOTs of AlF molecules.

Categories

Molecules

Presentation

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D109

New methods for quantum control of polar molecules using Rydberg atoms

Chi Zhang, Chandler Conn, Yuiki Takahashi, Ashay Patel, Harish Ramachandran, Phelan Yu, Yi Zeng, Nicholas Hutzler

California Institute of Technology, Pasadena, USA

Abstract

Polar molecules are one of the most rapidly developing platforms in quantum science and technology, offering great potential for diverse applications from quantum sensing for fundamental physics to quantum information processing. I will present our recent proposals for advancing the quantum control of molecules using Rydberg atoms. These new methods include Rydberg atom-assisted sympathetic slowing and cooling, Rydberg atom-assisted quantum logic control and entangling gates, as well as a new quantum-enhanced metrology protocol for precision measurements. These methods are generically applicable to any polar molecules and will vastly expand the scientific scope of experiments with quantum-controlled molecules.

Categories

Molecules

Presentation

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D110

Ultracold field-linked tetratomic molecules

Shrestha Biswas[1,2], Xing-Yan Chen[1,2], Sebastian Eppelt[3,2], Andreas Schindewolf[1,2], Fulin Deng[4,5], Tao Shi[4,6,7], Su Yi[4,8,7], Timon A. Hilker[1,2], Immanuel Bloch[1,9,2], Xin-Yu Luo[1,2]

[1]Max Planck Institute of Quantum Optics, 85748, Garching, Germany. [2]Munich Center for Quantum Science and Technology, 80799 München, Germany. [3]stitute of Quantum Optics, 85748, Garching, Germany. [4]Chinese Academy of Science, 100190 Beijing, China. [5]School of Physics and Technology, Wuhan University, Wuhan, Hubei 430072, China. [6]University of Chinese Academy of Sciences, 100190 Beijing, China. [7]Peng Huanwu Collaborative Center for Research and Education, Beijing 100191, China. [8]University of Chinese Academy of Sciences, Beijing 100049, China. [9]udwig-Maximilians-Universität, 80799 München, Germany

Abstract

We introduce a novel technique to generate ultracold tetratomic (NaK)2 molecules via electroassociation in a microwave-dressed fermionic polar molecule gas, achieving temperatures of 134 nK—over 3,000 times colder than previously reported polyatomic molecules. This approach yields approximately 1,100 molecules with a phase space density of 0.040. Evidenced by a maximum lifetime of 8 ms, these molecules show collisional stability both in free space and in an optical dipole trap.

Our findings, aligning well with theoretical predictions, paves the way for Bose–Einstein condensate (BEC) of tetratomic molecules and the exploration of an anticipated crossover between dipolar p-wave superfluid and Bose–Einstein condensate. It also sets the stage for deterministic optical transfer to more deeply bound tetramer states, and providing a robust foundation for advancements in cold chemistry, precision measurements, and quantum information processing.

Categories

Molecules

Presentation

Poster presentation

D111

Tweezer Arrays of CaF Molecules for Many-Body Quantum Simulation

Connor Holland, Yukai Lu, Samuel Li, Callum Welsh, Lawrence Cheuk

Princeton University, Princeton, USA

Abstract

Programmable optical tweezer arrays of ultracold molecules are a promising platform for quantum science. They combine the rich internal structure and long-lived interacting states of molecules with the microscopic control and detection capabilities of programmable tweezer arrays, thereby enabling applications in quantum information processing, quantum simulation of novel many-body Hamiltonians, and quantum-enhanced metrology. Nevertheless, initializing and controlling molecular arrays with high fidelity, which is desired in many applications, remains an ongoing challenge. In this poster, we report recent work from our group on new solutions to this challenge. We present work on 1) producing cold and dense molecular samples via a Blue Detuned MOT (BDM), 2) realizing mid-circuit erasure conversion and detection, which has allowed us to achieve record-level tweezer preparation fidelities and to mitigate blackbody-induced leakage errors, and 3) simulating small defect-free quantum spin chains.

Categories

Molecules

Presentation

Poster presentation

D112

Towards extended interrogation times for a trapped molecular ion

Baruch Margulis[1,2], Dalton Chaffee[1,3], Julian Schmidt[1,3,4], April Reisenfeld[1,3], David Leibrandt[5], Didi Leibfried[1,3], Chin-wen Chou[1,3]

[1]NIST, Boulder, USA. [2]JILA, Boulder, USA. [3]University of Colorado, Boulder, USA. [4]Paul Scherrer Institute, Villigen, Switzerland. [5]UCLA, Los Angeles, USA

Abstract

Over the last decade molecules have emerged as a platform for endeavors such as search of new physics, quantum information and simulation applications, and control of chemical reactions. However, unlike atoms, molecules vibrate and rotate, which makes them harder to cool and control at the single quantum-state level. For a trapped polar molecular ion such as $^{40}CaH^+$, the extent of the populated state space is determined by the black body radiation induced by the environment. This results in a vast number of occupied states in a room temperature environment. Here, we present a new experiment, where a molecular ion is trapped in a cryogenic environment at 15K. We plan to use quantum-logic-spectroscopy on a $^{40}Ca^+$-$^{40}CaH^+$ crystal to interrogate the molecular rotational states. We expect an increase in rotational lifetimes, relative to room-temperature operation, by two orders of magnitude. Prolonged state lifetimes will enable extended probe times and improve spectroscopic precision.

Categories

Molecules

Presentation

Poster presentation

D113

Applications of shielded ultracold molecules: From ultracold complexes to quantum magnetism

Bijit Mukherjee[1], Jeremy Hutson[2], Kaden Hazzard[3]

[1]University of Warsaw, Warsaw, Poland. [2]Durham University, Durham, United Kingdom. [3]Rice University, Houston, USA

Abstract

Trapped samples of ultracold polar molecules offer opportunities to study important physical phenomena that range from quantum simulation to quantum magnetism. To produce a stable ultracold gas in an optical trap, it is necessary to *shield* pairs of molecules from close collisions that otherwise cause trap loss. Shielding can be achieved by various methods, most notably with static electric and microwave fields. We show that using static electric fields we can gain substantial control over the scattering length a [1]. Furthermore, we show how we can tune the electric field to change a and create tetramer molecular bound states. This opens up the door to study ultracold complexes.

In a recent proposal, we show that shielded ultracold molecules can also exhibit many-body properties associated with SU(N) magnetism, where N is the number of available spin states [2]. Until now, SU(N) symmetry has been predicted and realized with nuclear spin states of alkaline-earth-like atoms, which allow N up to 10. However, they have important limitations: they are all fermionic and have repulsive interactions, i.e., their a is positive. Shielded molecules, on the other hand, can be either bosonic or fermionic, with much greater tunability of a. We show that experimentally accessible alkali dimers might exhibit SU(N) with N as large as 36. All these features open up exciting possibilities for studying novel aspects of quantum magnetism.

[1] B. Mukherjee and J. M. Hutson, Phys. Rev. Res. 6, 013145 (2024).

[2] B. Mukherjee et. al, arXiv:2404.15957 (2024).

Categories

Molecules

Presentation

Poster presentation

D114

Optical Tweezer Array of Ultracold CaF Molecular Qubits for Quantum Computation and Simulations

Scarlett Yu[1], Yicheng Bao[1], Jiaqi You[1], Loïc Anderegg[1], Eunmi Chae[2], Wolfgang Ketterle[3], Kang-Kuen Ni[1], John Doyle[1]

[1]Harvard University, Cambridge, USA. [2]Korea University, Seoul, Korea, Republic of. [3]MIT, Cambridge, USA

Abstract

Ultracold polar molecules trapped in tweezer arrays are promising candidate qubits for quantum information processing and quantum simulations. The long-lived molecular rotational states form robust qubits, the long-range dipolar interaction between molecules provides quantum entanglement, and the tweezer platform provides single-site addressability. In this work, we first show dipolar spin-exchange interactions between single calcium monofluoride (CaF) molecules trapped in tweezers. This allowed us to encode an effective spin-½ system into the rotational states of the molecules and use it to generate a Bell state through an iSWAP operation, achieving a measurement error-corrected Bell state fidelity of 0.89(6). To reduce the decoherence caused by thermal motion of the molecules in the tweezer, we then successfully applied Raman sideband cooling technique to CaF molecules in the optical tweezer array, cooling the molecules to near their motional ground state, with a 3-D motional ground state probability of 54(18)%. Furthermore, we report enhancement of molecular density through the implementation of a “conveyor-belt” MOT, as well as improvement on coherence time and prospects towards using ultracold molecules for robust quantum computation and simulation applications.

Categories

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Presentation

Poster presentation

D115

A molecular beam-loaded cryogenic ion trap for quantum-logic spectroscopy of single molecular ions

Dalton Chaffee[1,2], Baruch Margulis[1,2], Julian Schmidt[1,2,3], April Reisenfeld[1,2], David Leibrandt[4], Dietrich Leibfried[1,2], Chin-wen Chou[1,2]

[1]NIST, Boulder, USA. [2]University of Colorado, Boulder, USA. [3]PSI, Villigen, Switzerland. [4]UCLA, Los Angeles, USA

Abstract

Quantum state control of molecules has applications in precision measurement and quantum information processing. Compared to atoms, however, molecules' additional rotational and vibrational degrees of freedom make such control more challenging. In our group, the application of quantum-logic spectroscopy (QLS) in an ion trap has enabled preparation and coherent manipulation of pure molecular quantum states of a single CaH^+ ion [1]. Here, we present development of a new cryogenic ion trap apparatus capable of loading a broad range of molecular ions in an environment with low blackbody radiation for increased rotational-state lifetimes. We demonstrate REMPI of a molecular beam passing through the trap to co-trap a molecular ion with an atomic ion for QLS. Finally, we discuss first molecular ion operations and progress towards enhanced quantum state control.

[1] C.-W. Chou et al., Nature **545,** 203 (2017).

This work was supported by the Army Research Office and the National Science Foundation.

Categories

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Presentation

Poster presentation

D116

Towards Enhanced Loading of NaCs Molecules with Electric Field Shielding

Christian H. Nunez, Conner Williams, Yu Wang, Annie J. Park, Kang-Kuen Ni

Harvard University, Cambridge, MA, USA

Abstract

To harness the potential of ultracold polar molecules for both quantum computation and quantum simulation, we propose a programmable optical tweezer array with hundreds of individually-addressable molecules in precisely-controlled electric fields. As the foundation for this effort, our group has achieved the assembly of single ground-state NaCs molecules in optical tweezers, the creation of a rich set of tools for state preparation and measurement, and the observation of dipolar interactions between molecules in adjacent tweezers. One challenge for molecular tweezer arrays is scaling to large system sizes, which is primarily limited by ground-state molecule preparation efficiency. In pursuit of a unity-filled array, we propose a new method for obtaining single ground-state molecules in tweezers. Starting from an ensemble of molecules in each tweezer, we plan to leverage electric field shielding to suppress inelastic collisions and create interaction shifts to deterministically isolate a single molecule. Here, we detail features of our apparatus designed for this new direction including an in-vacuum electrode system, a dual-species 2D MOT, and dynamically-shaped tweezer arrays.

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D117

Towards Realization of a Quantum Degenerate Gas of Laser-Cooled SrF Molecules

Geoffrey Zheng[1], Qian Wang[1], Varun Jorapur[2], Thomas Langin[1], David DeMille[1,2]

[1]University of Chicago, Chicago, USA. [2]Argonne National Laboratory, Lemont, USA

Abstract

Ultracold quantum gases of dipolar molecules have recently emerged as a promising platform for quantum simulation, quantum chemistry, and probes of physics beyond the Standard Model. Tremendous progress has been made in direct laser cooling and trapping of dipolar molecules, putting the prospect of reaching quantum degeneracy in laser-cooled molecules within reach. We recently demonstrated optical trapping of a bulk gas of SrF molecules in the N=1 state (where N denotes rotational quantum number) at sufficient density to observe inelastic collisional loss from the trap. We measured a two-body loss rate coefficient $\beta \approx 2.7 \times 10^{-10}$ cm^3 s^{-1}, commensurate with the universal loss rate. Following up on this work, we describe our current efforts towards preparation of SrF molecules in the absolute rovibrational ground state (N=0) for single quantum state collision measurements. We also discuss upgrades to our apparatus designed to help increase the phase-space density of our bulk gas, including reduced source slowing length and a fully integrated rubidium magneto-optical trap for sympathetic cooling. Finally, we describe our plan for implementing microwave shielding in order to suppress inelastic collisional loss and enhance the elastic collision rate, which is ideal for evaporative cooling to quantum degeneracy.

Categories

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Presentation

Poster presentation

D118

Spectroscopy of RbYb molecular states - towards transfer into the absolute ground state

Axel Görlitz, Christian Sillus, Arne Kallweit, Celine Castor

University of Düsseldorf, Düsseldorf, Germany

Abstract

Here we report on our ongoing efforts to produce ultracold RbYb ground state molecules. Our current approach is to use the intercombination line of Yb for photoassociation spectroscopy and ultimately photoassociative association.

In our apparatus, we use optical tweezers to transport individually cooled samples of Rb and Yb from their separate production chambers to a dedicated science chamber. In the science chamber, the two species are combined in a common crossed optical dipole trap. In this setup we have already succeeded in performing 1- and 2-photon photoassociation spectroscopy using the intercombination line of Yb. However, only very weakly bound molecular levels have been studied. The next step will be to search for suitable molecular transitions involving more deeply bound levels for the transfer of the molecules to the absolute rovibrational ground state.

Categories

Molecules

Presentation

Poster presentation

D119

Progress towards a magneto-optical trap of AlCl molecules*

William Wortley, Mark Semco, Daniel McCarron

University of Connecticut, Storrs, USA

Abstract

Laser-cooled molecules promise access to a diverse range of research directions including quantum simulation, ultracold organic chemistry and improved precision measurements. Molecules, such as AlCl, appear particularly versatile by combining favorable properties for optical cycling and a sizable electric dipole moment (~1 D) with an electronic structure analogous to that of alkaline earth atoms. This structure provides both strong optical transitions for efficient laser-cooling and trapping and narrow optical transitions with the potential for manipulating quantum states and detecting interactions. This versatility comes at the expense of technical complexity as (similar to alkaline earth atoms) the strong optical cycling transition in AlCl demands energetic photons at 261 nm and has a high saturation intensity. Fortunately, recent progress by our group [1] and others has realized watt-level lasers in the deep UV and made the realization of large, trapped samples of laser-cooled AlCl a possibility. Here we will present an update on our experimental progress working towards laser-slowing and magneto-optically trapping AlCl molecules.

*This work is supported by the NSF (CAREER Award No. 1848435) and the University of Connecticut, including a Research Excellence Award from the Office of the Vice President for Research.

[1] J. C. Shaw, S. Hannig and D. J. McCarron, Opt. Express 29, 37140 (2021).

Categories

Molecules

Presentation

Poster presentation

D120

Towards highly polar CsAg and KAg ground state molecules

Om Tripathi, Jakub Pawlak, Jakub Dobosz, Mateusz Bocheński, Mariusz Semczuk

Institute of Experimental Physics, University of Warsaw, Warsaw, Poland

Abstract

The creation of ultracold polar molecules has been actively pursued by many research groups. Up to now, these molecules have mainly been alkali dimers, limiting the maximum achievable permanent electric dipole moment to approximately 5.5 D (using LiCs). However, fully polarizing these molecular samples requires substantial electric fields of several kV/cm, presenting a technical challenge.

Here, we introduce initial steps towards the production of highly polar, ultracold CsAg and KAg, which can achieve electric dipole moments nearing 10 D in the absolute ro-vibrational ground state. For CsAg, dipole moments exceeding 13 D can be attained in higher vibrational levels of the ground state potential, requiring only 0.3 kV/cm to fully polarize the sample.

Potassium and cesium are loaded into 3D magneto-optical traps from a shared 2D MOT, while a separate 2D MOT is used for pre-cooling silver. This setup avoids technical issues with coating the window opposite the atomic beam generated by the Zeeman slower and results in a particularly compact vacuum system. The main experimental chamber is constructed from titanium, with broadband AR-coated windows ensuring over 99% light transmission for all species.

With enriched potassium dispensers and a versatile potassium laser system we have constructed, we can switch between ^{39}K, ^{40}K, and ^{41}K, facilitating studies of both bosonic and fermionic KAg molecules. Our initial investigations will concentrate on photoassociation spectroscopy of KAg and CsAg to identify molecular levels suitable for efficient STIRAP.

Categories

Molecules

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D121

Ultracold CaF+Yb collisions: bound states, electric-field resonances, and prospects for triatomic molecule formation

Matthew Frye, Marcin Gronowski, Michał Tomza

University of Warsaw, Warsaw, Poland

Abstract

There has been much recent progress in cooling molecules to ultracold temperatures, particularly laser cooling molecules like CaF. There is now interest in controlling collisions of such molecules with ultracold atoms, and using these to form triatomic molecules. Such molecules may have uses in precision spectroscopy, such as searches for beyond-standard-model physics or time variation of fundamental constants. Sensitivity in such experiments can be enhanced by level structures of polyatomic molecules, and also by heavy elements such as Yb.

We have calculated the interaction potential of the CaF-Yb complex. It is highly anisotropic, with its global minimum bound by 8000 cm^{-1} in a bent Ca-F-Yb configuration. In scattering, the anisotropy provides a strong coupling between rotational states of CaF, but is not likely to drive strong magnetic Feshbach resonances. Instead we focus on effects of electric fields, where resonant states can be coupled directly by the interaction anitsotropy. We have calculated bound states and scattering lengths as a function of electric field up to 20 kV/cm and find a rich spectrum of Feshbach resonances. There are typically several resonances with widths over 1 V/cm and up to 100 V/cm, together with a great many narrower resonances.

This method is completely general and does not rely on any internal spin structure or state, so is applicable to any combination of heteronuclear molecule and atom. These results pave the way for a new generation of experiments towards control of atom+molecule mixtures and novel electro-association into triatomic complexes.

Categories

Molecules

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D122

Laser cooling molecules with octupole-deformed nuclei for CP violation measurements

Arian Jadbabaie[1], Sepher Ebadi[1], Nicholas R. Hutzler[2], John M. Doyle[3], Ronald Fernando Garcia Ruiz[1]

[1]MIT, Cambridge, USA. [2]Caltech, Pasadena, USA. [3]Harvard, Cambridge, USA

Abstract

Radium-containing molecules can be powerful probes for physics beyond the Standard Model. New sources of CP violation could explain the matter/antimatter asymmetry of the universe and point to the existence of new particles and forces. Importantly, in certain isotopes of Ra, octupole deformation of the nucleus greatly amplifies parity (P) and time-reversal (T) violating effects by more than three orders of magnitude compared to spherical nuclei. Recent spectroscopy indicates that RaF and RaOH possess a relatively simple molecular structure that is favorable for laser cooling. This opens the door to trapping and long coherence times to maximize the sensitivity of searches for P,T violating nuclear effects, such as the nuclear Schiff moment. We have undertaken an experiment to laser cool radium-containing molecules*. Experimental work will begin with the long-lived radioactive isotope, 226-Ra (T1/2 = 1600 yr), enabling rapid prototyping at university laboratories. Development and design of a cold molecular beam source to produce both RaF and RaOH is underway. This source will be used to laser cool RaF, which has an ideal molecular structure for this purpose, and to explore optical cycling in RaOH, where the polyatomic structure offers even more advantages for precision measurements. We aim to establish a path to trapping radium-containing molecules at <mK temperatures in an optical dipole trap, laying the groundwork for eventual measurements of hadronic P,T violation with 225-Ra (T1/2 = 14.9 d) containing molecules at FRIB.

Categories

Molecules

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Poster presentation

D123

Searching for scalar dark matter using antiprotons at BASE

Elise Wursten[1,2,3], Yevgeny Stadnik[4], Matthias Borchert[1,5,6], Jack Devlin[1,2], Stefan Erlewein[1,2,3], Markus Fleck[1,7], James Harrington[1,3], Julia Jäger[2,3], Barbara Latacz[1,2], Gilbertas Umbrazunas[8], Bela Arndt[3,9], Klaus Blaum[3], Yasuyuki Matsuda[7], Andreas Mooser[3], Christian Ospelkaus[5,6], Wolfgang Quint[9], Christian Smorra[1,10], Anna Soter[8], Jochen Walz[11], Yasunori Yamazaki[1], Stefan Ulmer[1,10]

[1]RIKEN, Wako, Japan. [2]CERN, Meyrin, Switzerland. [3]Max-Planck-Institut für Kernphysik, Heidelberg, Germany. [4]University of Sydney, Sydney, Australia. [5]Leibniz Univeristät Hannover, Hannover, Germany. [6]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany. [7]University of Tokyo, Tokyo, Japan. [8]ETH Zürich, Zürich, Switzerland. [9]GSI-Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany. [10]Heinrich Heine University, Düsseldorf, Germany. [11]Johannes Gutenberg Universität, Mainz, Germany

Abstract

The Standard Model of Particle Physics has known many successes, but it is known to be incomplete. It does not provide an explanation for the striking imbalance of matter over antimatter observed in our Universe, nor does it account for dark matter which makes up 27% of the Universe's energy content. To investigate the cause of this matter-antimatter asymmetry, a diverse physics program was set up at CERN's Antiproton Decelerator (AD) facility to study baryonic antimatter. Comparisons of matter and antimatter conjugates provide sensitive probes for possible CPT and Lorentz violation in Nature, testing two cornerstones of the Standard Model.

The Baryon Antibaryon Symmetry Experiment (BASE) at the AD searches for physics beyond the Standard Model by comparing the fundamental properties of protons and antiprotons. Using single-particle multi-Penning-trap techniques, we compare their charge-to-mass ratios [1] and magnetic moments [2,3] with high precision. All results so far have been compatible with Lorentz and CPT invariance.

In this contribution I will present new results constraining the coupling of scalar dark matter to antiprotons. I will review the 16-parts-per-trillion charge-to-mass ratio measurement of 2022 [1] and detail its re-interpretation in the search for scalar-dark-matter-induced oscillating signatures.

[1] M. J. Borchert *et al.*, Nature **601**, 53 (2022).
[2] C. Smorra *et al.*, Nature **550**, 371 (2017).
[3] G. Schneider *et al.*, Science **358**, 1081 (2017).

Categories

Precision measurements

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D124

Quantum enhanced sensing with a hybrid squeezing and anti-squeezing protocol

Zhiwei Hu[1], Junlei Duan[1], Yanhong Xiao[2,1]

[1]Fudan University, Shanghai, China. [2]Shanxi University, Taiyuan, China

Abstract

We propose a novel protocol for quantum enhanced sensing. By combining a quantum nondemolition measurement (QND) for squeezing and a deterministic Hamiltonian evolution for anti-squeezing in a successive way, we can have both amplification of a classical signal (applied in between) and reduction of the quantum noises. In this poster, we will describe our proposal and report experiment progress of its implementation in an atomic vapor cell.

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D125

Magneto-optical Trapping of Silver Atoms

Mohit Verma[1], Shaozhen Yang[1], Rohan Kapur[1], Thomas Langin[1], Wesley Cassidy[1], Alan Jamison[2], David DeMille[1,3]

[1]University of Chicago, Chicago, USA. [2]University of Waterloo, Waterloo, Canada. [3]Argonne National Lab, Lemont, USA

Abstract

Alkali-silver molecules have exceptionally large electric dipole moments, making them attractive for precision measurements and quantum simulation [1,2]. Silver also has an alkali-like atomic structure, making it amenable to standard laser-cooling and trapping techniques as well as to methods routinely applied to assemble ground-state bialkali molecules. In our lab, we are particularly interested in binding silver with francium to form FrAg molecules, which can be used to search for physics beyond the Standard Model. FrAg molecules have unprecedented sensitivity to hadronic CP-violation due to both the strong ionic Fr-Ag bond [3] and the presence of static octupole deformation in the ^{223}Fr ($t_{1/2}$ = 22 min) nucleus [4]. Prior to our work, silver had only been laser-cooled once [5] due to the need for high-power UV light. We present results on magneto-optical trapping of Ag atoms, as well as progress towards determining its s-wave scattering lengths.

[1] Kłos, J., Li, H., Tiesinga, E., & Kotochigova, S. (2022). Prospects for assembling ultracold radioactive molecules from laser-cooled atoms. NJP, 24(2), 025005.

[2] Śmiałkowski, M., & Tomza, M. (2021). Highly polar molecules consisting of a copper or silver atom interacting with an alkali-metal or alkaline-earth-metal atom. PRA, 103(2), 022802.

[3] Fleig, T., & DeMille, D. (2021). Theoretical aspects of radium-containing molecules amenable to assembly from laser-cooled atoms for new physics searches. NJP, 23(11), 113039.

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[5] Uhlenberg, G., Dirscherl, J., & Walther, H. (2000). Magneto-optical trapping of silver atoms. PRA, 62(6), 063404.

Poster

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D126

First results from the Axion Dark-Matter Birefringent Cavity (ADBC) experiment

Swadha Pandey, Evan Hall, Matthew Evans

MIT, Cambridge, USA

Abstract

Axions and axion-like particles are strongly motivated dark matter candidates that are the subject of many current ground based dark matter searches. We present first results from the Axion Dark-Matter Birefringent Cavity (ADBC) experiment, which is an optical bow-tie cavity probing the axion-induced birefringence of electromagnetic waves. Our experiment is the first optical axion detector that is tunable and quantum noise limited, making it sensitive to a wide range of axion masses. We have iteratively probed the axion mass range around 40.9-56.7 neV, and found no dark matter signal. On average, we constrain the ALP-photon coupling at the level $g_{a\gamma\gamma} < 1.9\times10^{-8}$ GeV^{-1}. We also present prospects for future axion dark matter detection experiments using optical cavities.

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D127

Developments in ALPHA's antihydrogen spectroscopy programme

Joos Schoonwater[1], ALPHA Collaboration[2]

[1]Swansea University, Swansea, United Kingdom. [2]CERN, Geneva, Switzerland

Abstract

Antihydrogen atoms are routinely produced in the ALPHA experiment at CERN by recombining positrons and antiprotons in a Penning-Malmberg trap nested within an Ioffe-Pritchard style magnetic trap. Studies on the internal structure of these anti-atoms serve as a test of CPT invariance. ALPHA's spectroscopy program benefits from laser cooling with a pulsed Lyman-alpha laser, enhanced production rates using sympathetic cooling of positrons with beryllium ions, and an improved metrology system featuring an active hydrogen maser and a Cs fountain clock which enable more precise 1S-2S spectroscopy.

The ALPHA collaboration has achieved the first direct measurement of the 2S-2P transition in antihydrogen. This is the first demonstration of excited state spectroscopy of antihydrogen, paving the way for precision spectroscopy of transitions to excited states with higher principal quantum number, with the aim of determining the anti-Rydberg constant and the antiproton charge radius.

Current efforts include upgrading the central trapping structures to incorporate silicon photomultipliers for detecting antihydrogen fluorescence. The ability to collect fluorescence from excited antihydrogen atoms will complement existing annihilation-based detection methods, enabling non-destructive spectroscopy. Photon detection also works for hydrogen, allowing direct comparisons with antihydrogen in the same environment for better control of systematic effects.

In this poster presentation, the latest progress in the ALPHA experiment on excited state spectroscopy will be reviewed, along with an overview of the design challenges of integrating a photon detection system into ALPHA's cryogenic Penning-Malmberg trap.

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D128

Magnetic field production and shielding for ACME III

Maya Watts[1], Daniel Ang[2,1], Collin Diver[1], David DeMille[3], John Doyle[2], Xing Fan[1], Gerald Gabrielse[1], Ayami Hiramoto[4], Zhen Han[3], Peiran Hu[3], Nicholas Hutzler[5], Zack Lasner[2], Siyuan Liu[1], Takahiko Masuda[4], Cole Meisenhelder[2,1], Cristian Panda[6], Satoshi Uetake[4], Koji Yoshimura[4], Xing Wu[7]

[1]Northwestern University, Evanston, USA. [2]Harvard University, Cambridge, USA. [3]University of Chicago, Chicago, USA. [4]Okayama University, Okayama, Japan. [5]California Institute of Technology, Pasadena, USA. [6]University of California Berkeley, Berkeley, USA. [7]Michigan State University, East Lansing, USA

Abstract

The ACME experiment measures the electron EDM through the spin precession of Thorium Monoxide (ThO) molecules. A nonzero electron EDM would violate CP and imply physics beyond the standard model. ACME II set an upper limit of $\mid d_e\mid = 1.1 \times 10^{-29} e \cdot cm$ [1] and ACME III seeks to obtain a factor of 40 improvement through upgrades [2,3]. Improved precision in the EDM measurement requires a magnetic field that is uniform throughout the 1 meter spin precession region which was extended in ACME III after the lifetime of ThO was measured to be long. The ambient and applied fields in the region must be reduced to 10 μG to minimize velocity fluctuations in the beam.

A two layer actively shielded coil that provides minimal magnetization of three layers of surrounding mu-metal shields was successfully implemented. The magnetic field applied is perpendicular to the ThO beam and uniform. The shields reduce the ambient field by 10^5. Auxiliary coils for systematic checks and residual field cancellation and in-situ comagnetometry with ThO are in place. ACME III now has 1μG level control.

This work was supported by the National Science Foundation, the Gordon and Betty Moore Foundation, the Alfred P. Sloan Foundation, JSPS Kakenhi, and Okayama University RECTOR program.

[1] ACME Collaboration, Nature 562, 355-360 (2018).

[2] D. G. Ang et al, Measurement of the $H\,^3\Delta_1$ radiative lifetime in ThO, Phys. Rev. A 106, 022808 (2022)

[3] C D Panda et al 2019 J. Phys. B: At. Mol. Opt. Phys. 52 235003

Categories

Precision measurements

Presentation

D129

Precision spectroscopy of the 2S-6P transition in atomic hydrogen and deuterium

Vitaly Wirthl[1], Lothar Maisenbacher[2,1], Derya Taray[1], Omer Amit[1], Randolf Pohl[3], Theodor W. Hänsch[1], Thomas Udem[1]

[1]MPQ, Garching, Germany. [2]University of California, Berkeley, Berkeley, USA. [3]Johannes Gutenberg University, Mainz, Germany

Abstract

Both atomic hydrogen and deuterium can be used to determine physical constants and to test bound-state Quantum Electrodynamics (QED). By combining at least two transition frequency measurements in each isotope, the proton and deuteron radii, along with the Rydberg constant, can be determined independently [1]. This is particularly interesting because of the tensions within the recent hydrogen measurements [2], as well as because no recent deuterium measurements are available such that a discrepancy with muonic deuterium persists [3].

Using our improved active fiber-based retroreflector to suppress the Doppler shift [4], we recently measured the 2S-6P transition in hydrogen with a relative uncertainty below one part in 10^{12}, allowing one of the most stringent tests of bound-state QED. We also performed a preliminary measurement of the same transition in deuterium. In contrast to hydrogen, the 2S-6P measurement in deuterium is complicated by the simultaneous excitation of unresolved hyperfine components, possibly leading to quantum interference between unresolved lines [5]. Our detailed study of these and other effects in deuterium demonstrates the feasibility of determining the 2S-6P transition frequency with a similar precision as for hydrogen.

References:

[1] R. Pohl et al., Metrologia 54, L1 (2017)

[2] A. Brandt et al., Phys. Rev. Lett 128, 023001 (2022)

[3] R. Pohl et al., Science 353, 669–673 (2016)

[4] V. Wirthl et al., Opt. Express 29(5), 7024-7048 (2021)

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Precision measurements

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D130

Precisely Controlled Electric and Magnetic Field for Measuring the Electron's Electric Dipole Moment

F. J. Collings, X. S. Zheng, R. Jenkins, M. T. Ziemba, N. J. Fitch, J. Lim, B. E. Sauer, M. R. Tarbutt

Centre for Cold Matter, Blackett Laboratory, Imperial College London, London, United Kingdom

Abstract

We aim to use a slow molecular beam to measure the electron's electric dipole moment (eEDM) by measuring the spin precession of ultracold YbF molecules in applied electric and magnetic fields. These fields need to be precisely controlled to avoid systematic errors and ensure that magnetic noise does not limit the sensitivity.

We will discuss the design and performance of a four-layer magnetic shield with a shielding factor exceeding 10^5, along with the magnetometers used to measure the magnetic noise in the apparatus. We discuss systematic shifts arising from magnetic fields correlated with electric field reversal. We also present the performance of ceramic electric field plates designed to produce a uniform electric field of 20 kV/cm without introducing excessive magnetic Johnson noise. We assess the limits of eEDM sensitivity that can be reached in this apparatus [1].

[1] F. J. Collings, PhD Thesis, Imperial College London, (2024).

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D131

Progress on the measurement of CP violating electromagnetic moments in YbOH molecules

Yuiki Takahashi[1], Chandler Conn[1], Daniel Grass[1], Arian Jadbabaie[2], Harish Ramachandran[1], Yi Zeng[1], Chi Zhang[1], Nick Hutzler[1]

[1]Caltech, Pasadena, USA. [2]MIT, Cambridge, USA

Abstract

Precision measurements of molecules containing heavy elements have proven to be an effective method for investigating physics beyond the Standard Model due to their large sensitivity to charge parity (CP) violating electromagnetic moments. The polyatomic molecule YbOH offers a promising avenue for exploring such phenomena in both the leptonic and hadronic sectors. This can be achieved through the measurement of the electron's electric dipole moment (eEDM) in the 174YbOH isotopologue and the nuclear magnetic quadrupole moment (nMQM) in the 173YbOH isotopologue. The localized electron around the Yb nucleus provides photon cycling capabilities, and the mechanical bending mode of the molecule creates parity doublets in the electronic ground state, which facilitates full polarization and robust systematic error rejection. Additionally, it provides the ability to tune sensitivity to external electromagnetic fields. This poster will detail recent experimental advancements aimed at these measurements, including the construction of the apparatus, observation of state preparation and readout, and progress towards measuring the nMQM.

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D132

Towards a measurement of the electron's electric dipole moment with trapped YbF molecules

Stefan Popa[1], Andrew White[1], Jorge Mellado-Muñoz[2], Guanchen Peng[1], Simeng Li[1], Horacio Septien-Gonzalez[1], Michail Athanasakis-Kaklamanakis[1], Jongseok Lim[1], Ben Sauer[1], Michael Tarbutt[1]

[1]Imperial College London, London, United Kingdom. [2]Istituto Nazionale di Ottica, Firenze FI, Italy

Abstract

The Standard Model of particle physics cannot explain the observed antimatter-matter imbalance. This imbalance requires additional CP violation, one signature of which is the electron's electric dipole moment (eEDM) [1]. The eEDM is predicted to be approximately 10^{-35} e·cm in the Standard Model (SM), but larger than 10^{-31} e·cm in most theories Beyond the Standard Model (BSM). Therefore, eEDM measurements can decisively distinguish between SM and BSM physics.

We present our plan to measure the eEDM with YbF molecules trapped in an optical lattice and our progress towards this goal. We use a two-stage cryogenic buffer gas source [2] to produce a molecular beam whose velocity distribution peaks at 49 m/s [3]. We use radiation pressure slowing to decelerate this beam so that it can be captured in a magneto-optical trap, which we have built. We measure a leak out of the cooling cycle at a few parts in 10^4, which we attribute to decay to low-lying states arising from inner-shell excitation [4]. We will summarise our spectroscopic studies of these "4f hole" states [5].

[1] M. Pospelov and A. Ritz. Phys. Rev. D, 89:056006 (2014).

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[4] C. Zhang et al. J. Mol. Specrosc. 386, 111625 (2022).

[5] S. Popa et al. PRX 14, 021035 (2024)

Poster

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D133

Blackbody radiation and Rydberg atoms: diamagnetic shifts and candidate states for thermometry in Yb optical lattice clocks

Kyle Beloy[1], Benjamin Hunt[1,2], Roger Brown[1], Tobias Bothwell[1], Youssef Hassan[1,2], Jacob Siegel[1,2], Tanner Grogan[1,2], Andrew Ludlow[1]

[1]NIST, Boulder, USA. [2]University of Colorado, Boulder, USA

Abstract

Rydberg atoms possess unique properties that make them promising tools for a variety of applications, including quantum information processing, fundamental physics measurements, and field sensing. For instance, Rydberg atoms have been proposed for extracting the Rydberg constant independent of the proton charge radius and for characterizing the blackbody radiation (BBR) environment in optical lattice clocks.

Rydberg states are sensitive to BBR, experiencing level shifts of order kHz. The dominant shift is the BBR Stark shift, attributed to the BBR electric field. The BBR Stark shift is predicted to approach a constant value with increasing principal quantum number. Consequently, transitions between Rydberg states can be largely immune to the BBR Stark shift, due to significant cancelation between levels. We demonstrate that, for such transitions, the BBR Stark shift can be overshadowed by the BBR Zeeman shift, attributed to the BBR magnetic field. The BBR Zeeman shift itself is dominated by the so-called diamagnetic contribution. This can have consequences for experiments aiming to extract the Rydberg constant.

The BBR shift is the largest uncanceled frequency shift in optical lattice clocks and requires characterizing the BBR environment within the clock apparatus. A transition between a low-lying state and a Rydberg state can provide a measure of the BBR temperature. We consider states of Yb that could be favorable for this goal. In particular, the $6s^2\ {}^1S_0$ to $6s23s\ {}^1S_0$ transition accommodates two-photon Doppler-free spectroscopy with suppressed density shifts. Supporting atomic structure calculations will be presented.

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D134

EDM^3: Studies of barium monofluoride molecules embedded in a cryogenic neon solid: Steps towards a measurement of the electron electric dipole moment

ZA Corriveau, RL Lambo, D Heinrich, NT McCall, J Perez-Garcia, H-M Yau, T Chauhan, GK Koyanagi, MC George, A Marsman, M Horbatsch, CH Storry, EA Hessels

York University, Toronto, Canada

Abstract

Improved measurements of the electron electric dipole moment (eEDM) will strongly constrain the parameter space of new physics theories. Over the last decade, polar molecules have become established as the most promising systems for eEDM searches, due to the large internal electric fields experienced by an eEDM in these molecules. We report here on large samples of barium monofluoride (BaF) molecules embedded into a cryogenic (6 K) solid neon matrix. These samples have been extensively studied, including studies of laser-induced fluorescence, radiative and nonradiative lifetimes, optical pumping, rf transitions between hyperfine states, lineshapes, and Zeeman structure. Experiments using time sequences of laser and rf pulses allow for more detailed studies. This work sets up some of the crucial steps needed for a full time sequence [1] that would allow for a precision measurement of the electron electric dipole moment using these matrix-isolated polar molecules.

[1] A. C. Vutha, M. Horbatsch and E. A. Hessels, Phys. Rev. A 98, 032513 (2018).

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D135

Measurement of the hyperfine structure of antihydrogen with microwave spectroscopy

Alberto Jesus Uribe Jimenez[1], ALPHA Collaboration[2]

[1]University of Calgary, Calgary, Canada. [2]CERN, Geneva, Switzerland

Abstract

The alpha collaboration uses atoms of antihydrogen, the antimatter counterpart of hydrogen, as a sample to perform precision tests of CPT invariance.

The positron spin resonance (PSR) transition in antihydrogen, induced by flipping the spin of the positron with microwave radiation, was observed for the first time in the ALPHA collaboration in 2012 [1]. It was improved in 2017 showing no discrepancies with that of hydrogen at 4 parts in 10000 [2]. However, the nuclear magnetic resonant (NMR) transition has never been directly induced in antihydrogen.

I report on the improvements in the microwave spectroscopy techniques used to measure the PSR transition and the developments that will enable direct observation of the NMR transition.

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[2] Ahmadi, M., Alves, B., Baker, C. *et al.* Observation of the hyperfine spectrum of antihydrogen. *Nature* **548**, 66–69 (2017). https://doi.org/10.1038/nature23446

Categories

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D136

The Integration of Laser Cooled $^{9}Be^{+}$ Ions into the ALPHA-g Experiment

Thomas Robertson-Brown, Maria Gonçalves, Kurt Thompson, Nishant Bhatt, Niels Madsen

Swansea University, Swansea, United Kingdom

Abstract

In 2023, ALPHA-g released the world's first observation of the effect of gravity on the antihydrogen atom, the electrically neutral bound state of an antiproton and a positron. [1]

As a exotic system, antihydrogen must be synthesised and trapped before it can be studied. This is done by slowly merging plasmas of antiprotons (provided by CERN's ELENA facility) and positrons. In this process called "Mixing" most of the antiatoms produced have too much energy to be able to be trapped within the 0.5 K magnetic minimum trap and only a small fraction of the total atoms can be caught. Thankfully, this procedure called "stacking" can be repeated an arbitrary number of times until a sufficient number of atoms for the forseen experiment have been accumulated.

Recently, laser cooled Be+ ions have been introduced into the antihydrogen production cycle within the sister ALPHA-2 experiment. These ions provide sympathetic cooling to the positrons before they get mixed with the antiprotons. [2] The reduction in positron energy has greatly increased the antihydrogen trapping rate and thus the installation of the $^{9}Be^{+}$ system is now desired for ALPHA-g as it affords measurements with increased statistics and improved systematic studies.[1]

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D137

Continuous field tracking with machine learning and steady state spin squeezing

Junlei Duan[1], Zhiwei Hu[1], Xingda Lu[1], Liantuan Xiao[2], Suotang Jia[2], Klaus Mølmer[3], Yanhong Xiao[2,1]

[1]Fudan University, Shanghai, China. [2]Shanxi University, Taiyuan, China. [3]University of Copenhagen, Copenhagen, Denmark

Abstract

Steady state entanglement is the key resource for continuous quantum sensing, yet maintaining such entanglement in spin system remains a challenge. In this study, we integrate optical pumping with continuous quantum nondemolition measurements to achieve a sustained spin-squeezed state with 4×10^{10} hot atoms, and maintain a metrologically relevant squeezing of -3.23±0.24 dB using prediction and retrodiction for 26 hours. This sustained spin-squeezed state is used to monitor various continuous time-fluctuating magnetic fields, with deep learning models decoding measurement records from optical signals. These findings mark significant progress toward the generation and application of long-lived quantum entanglement resources in practical scenarios. In the future, we plan to track the quantum trajectory of the collective spin with steady-state entanglement and explore its further application in quantum metrology.

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Poster presentation

D138

Magnetic field studies for precision measurements on antihydrogen in ALPHA

Jaspal Singh[1,2], William Bertsche[1,2]

[1]University of Manchester, Manchester, United Kingdom. [2]ALPHA, CERN, Geneva, Switzerland

Abstract

Experiments on trapped antihydrogen atoms are often conducted in superimposed Penning-Malmberg (PM) and Ioffe-Pritchard (IP) traps. The PM trap manipulates the charged particles necessary for anti-atom synthesis, while the IP trap confines the neutral atoms produced. Tests of charge-parity-time symmetry through spectroscopy and the weak equivalence principle via controlled releases of anti-atoms in Earth's gravitational field are performed within the trapping magnetic field. Detailed knowledge of the B-field trapping potential is crucial for understanding and enhancing the precision of these measurements.

Currently, magnetometry techniques available to ALPHA experiments without invasive hardware within traps are limited to on-axis locations. Techniques include Electron Cyclotron Resonance (ECR) using microwave pulses to illuminate quickly prepared low-density electron plasmas carefully positioned along the PM trap axis [1, 2], or extrapolations of the magnetron frequency of these plasmas [3]. This study presents 3D magnetometry results with additional radial off-axis control of these plasmas under sectored cylindrical PM electrodes, extending over 70% of the trap diameter (29.6 mm). Far off-axis ECR is performed on these displaced plasmas within the superimposed traps. The plasmas can be reproducibly restored on-axis and diagnosed, maintaining acceptable plasma characteristics.

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Categories

Precision measurements

Presentation

Poster presentation

D139

Progress toward order of magnitude improved electron EDM measurement

Collin Diver[1], Daniel Ang[2], Dave DeMille[3], John Doyle[2], Xing Fan[1], Gerald Gabrielse[1], Ayami Hiramoto[1,2,4], Zhen Han[2,3], Peiran Hu[3], Nick Hutzler[5], Zack Lasner[2], Siyuan Liu[1], Takahiko Masuda[4], Cole Meisenhelder[1], Cris Panda[6], Satoshi Uetake[4], Koji Yoshimura[7], Maya Watts[1], Xing Wu[8]

[1]Northwestern University, Evanston, IL, USA. [2]Harvard University, Cambridge, MA, USA. [3]University of Chicago, Chicago, IL, USA. [4]Okayama University, Okayama, Japan. [5]Caltech, Pasadena, CA, USA. [6]UC Berkeley, Berkeley, CA, USA. [7]Okayama University, Okayama, USA. [8]Michigan State University, East Lansing, MI, USA

Abstract

Measuring the electron electric dipole moment (EDM) is a sensitive probe of CP-violating physics beyond the Standard Model. The third generation of the Advanced Cold Molecule Electron EDM (ACME) collaboration aims to measure the electron EDM with an order of magnitude improved precision over the current limit [1]. ACME detects the EDM by measuring the electron spin precession in a cryogenic beam of thorium monoxide. The internal effective electric field of ~80 GV/cm and Ω-doublet of a metastable state provide enormous enhancement of the EDM sensitivity in applied electric fields of ~100 V/cm.

Previous work by the ACME collaboration improved on the then-best limit on the electron EDM by two orders of magnitude [2,3]. A new experimental apparatus provides a 5x longer spin precession time [4], electrostatic lens [5], photodetectors with higher quantum efficiency [6], improved fluorescence collection optics, and in-situ target changes. Upgraded electric field plates and magnetic shielding will reduce the known systematic errors below our anticipated statistical sensitivity.

This work was supported by the National Science Foundation, the Gordon and Betty Moore Foundation, the Alfred P. Sloan Foundation, JSPS Kakenhi, and Okayama University RECTOR program.

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[2] ACME Collaboration, Science 343, 269 (2014).

[3] ACME Collaboration, Nature 562, 355-360 (2018).

[4] D. G. Ang et al, Phys. Rev. A 106, 022808 (2022).

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[6] A. Hiramoto et al, Nucl. Instrum. Methods Phys. Res., Sect. A, 1045 (2023)

Categories

Precision measurements

Presentation

Poster presentation

D140

Measurements of the hyperfine structure of nS Rydberg states by velocity selective saturated fluorescence spectroscopy.

Gersain Gabriel Quiroz-Sánchez, José Eduardo Navarro-Navarrete, Alejandra Estefanía Díaz-Calderón, Lina Marieth Hoyos Campo, Jesús Flores-Mijangos, Fernando Ramírez-Martínez, José Ignacio Jiménez-Mier

Instituto de Ciencias Nucleares, UNAM, Mexico City, Mexico

Abstract

Strongly interacting quantum systems, such as Rydberg atoms, are valuable for developing various applications, including quantum sensors. Rydberg atoms are useful for detecting electromagnetic fields across a broad spectrum, including the terahertz region, which has seen significant growth of interest due to its scientific and technological potential. Improved detectors and terahertz imaging techniques are among the key areas of impact.

This work uses velocity selective fluorescence spectroscopy to measure the hyperfine structure of the Rydberg nS states of rubidium with n=19, 20, and 21.

Measurements were conducted in an atomic Rb vapor cell at 100 °C. Rydberg states nS are prepared by the two-photon excitation scheme $5S_{1/2} \rightarrow 6P_{3/2}$ nS for ^{87}Rb. A 420 nm laser tuned to the hyperfine transition 5S, F=3(F=2) → $6P_{3/2}$, F=4(F=3) for ^{85}Rb (^{87}Rb) populates hyperfine levels F=3, 2 (F=2, 1). The second step uses a 1050 nm laser to record nS hyperfine resolved spectra. The 488 nm fluorescence emitted by nS decay to $5P_{3/2}$ is detected by a photomultiplier tube. The hyperfine structure of the intermediate $6P_{3/2}$ states is used for frequency calibration.

For ^{87}Rb, our measurements of the hyperfine structure of the n=20 and 21 states agree with previous reports [1]. This is the first report of the hyperfine structure of n=19 in ^{87}Rb and n=19−21 in ^{85}Rb.

Schemes using these states for terahertz imaging are discussed.

[1] A. Tauschinsky et al, Phys. Rev. A 87, 042522, 2013.

Categories

Precision measurements

Presentation

Poster presentation

D141

Progress Towards a Continuous Offline Source of Francium-223 Atoms for Magneto-Optical Trapping

Wesley Cassidy[1], Mohit Verma[1], Shaozhen Yang[1], Rachel Dey[1], Alan O. Jamison[2], David DeMille[1]

[1]University of Chicago, Chicago, USA. [2]University of Waterloo, Waterloo, Canada

Abstract

We are developing an experiment to measure the Nuclear Schiff Moment of ^{223}Fr to search for physics beyond the standard model. The nucleus of ^{223}Fr ($t_{1/2}$=22min) has a static octupole deformation [1] that makes it highly sensitive to CP-violating physics. By binding ^{223}Fr to Ag (silver) using standard bialkali molecule assembly techniques, we will assemble strongly ionic FrAg molecules [2] that offer unprecedented sensitivity to hadronic CP violation [3]. To produce sufficient flux of ^{223}Fr, we are developing a continuous offline source of ^{223}Fr, fed from the radioactive decay of long-lived ^{227}Ac ($t_{1/2}$=22yr). We will use a 700C oven to milk Fr atoms out of Ac, ionize ^{223}Fr and no other decay daughters of ^{227}Ac, transport the beam of Fr^+ ions to a trapping region, then neutralize the Fr^+ and create a vapor cell MOT of Fr atoms. Our protocol combines features from several established techniques [4]. We present progress towards tests of the system using Rb, and plans for the remainder of the offline francium source.

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[2] Fleig, & DeMille (2021). Theoretical aspects of radium-containing molecules amenable to assembly from laser-cooled atoms for new physics searches. *NJP*, 23(11), 113039.
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Categories

Precision measurements

Presentation

Poster presentation

D142

Zeeman effect in the 5S1/2 → 5P3/2 transition of atomic rubidium as a magnetometry tool.

José Roberto Alonso-Garduza, Jesús Flores-Mijangos, Fernando Ramírez-Martínez, José Jiménez-Mier

Instituto de Ciencias Nucleares, UNAM, Ciudad de Mexico, Mexico

Abstract

Several applications require accurate measurements of magnetic fields. The effect of a constant magnetic field B_0 on the D_2 line of ^{87}Rb is studied in this work. This investigation is conducted at room temperature using Doppler-free saturated fluorescence spectroscopy with a single narrow-bandwidth diode laser in two separate Rb vapor cells. In the first cell, an external magnetic field produced by a pair of Helmholtz coils is applied perpendicular to the light propagation and parallel to its linear polarization, allowing only transitions between states with the same m_F values. The second cell, without the magnetic field, works as a frequency reference signal.

A numerical calculation was developed to generate the Breit-Rabi diagrams for the multiplets involved in the interaction and to calculate the transition matrix elements. As a result, the positions and intensities of the saturated fluorescence spectra were obtained as functions of the applied external field B_0.

A region of magnetic fields where several transition probabilities exhibit very small values has been identified [1]. Our measurements confirm that this allows the isolation of the 5 $S_{1/2}$, F=2 → 5 $P_{3/2}$, F'=1 (m_F=−1) transition as a promising candidate for magnetic field calibration.

Additionally, it is demonstrated that the cyclic transition 5 $S_{1/2}$, F=2 → 5 $P_{3/2}$, F'=3 is highly sensitive to small magnetic fields (<5 Gauss).

Further consideration is given to utilising the second resonance transition in rubidium (5P → 6P) for the detection of even smaller fields.

[1] A. Aleksanyan et al., J. Opt. Soc. Am. B 37, 3504-3514, 2020.

Categories

Precision measurements

Presentation

Poster presentation

D143

Recent status of laser spectroscopy experiments of antiprotonic and pionic helium atoms at CERN and PSI

Masaki Hori

Imperial College London, London, United Kingdom. Max Planck Institute of Quantum Optics, Garching, Germany

Abstract

The ASACUSA collaboration carries out laser spectroscopy of metastable antiprotonic helium atoms at CERN's Antiproton Decelerator [1-3]. This is a half-matter, half-antimatter atom composed of a helium nucleus, an electron, and orbital antiproton. We will utilize the high-quality antiproton beam provided by CERN's new ELENA facility and the latest metrological techniques to carry out sub-Doppler two-photon laser spectroscopy with a far higher precision than before. These experiments allow the antiproton-to-electron mass ratio to be determined [3]. Limits may be established on exotic forces that may arise between the constituent particles.

The collaboration also carried out the first laser spectroscopy of these atoms embedded in superfluid helium [1] and observed a surprising narrowing of the atomic spectral lines despite the high rate of collisions with the surrounding helium atoms.

The PiHe collaboration at Paul Scherrer Institute's Ring Cyclotron facility carried out laser spectroscopy of pionic helium atoms composed of a helium nucleus, electron, and negative pion. The atoms were irradiated with infrared laser pulses that induced a pionic transition. This constitutes the first laser spectroscopy of an atom containing a meson.

[1] A. Sótér, H. Aghai-Khozani, D. Barna, A. Dax, L. Venturelli, M. Hori, "High-resolution laser resonances of antiprotonic helium in superfluid ^{4}He", *Nature* **603**, 411 (2022).

[2] M. Hori, H. Aghai-Khozani, A. Sótér, A. Dax, D. Barna, "Laser spectroscopy of pionic helium atoms", *Nature* **581**, 37 (2020).

[3] M. Hori *et al.*, "Buffer-gas cooling of antiprotonic helium to 1.5 to 1.7 K, and antiproton-to-electron mass ratio", *Science* **354**, 610 (2016).

Categories

Precision measurements

Presentation

Poster presentation

D144

High-accuracy laser spectroscopy of the simplest molecule (H_2^+) and implications for the metrology of fundamental constants

Stephan Schiller[1], Soroosh Alighanbari[1], Magnus Schenkel[1], Vladimir Korobov[2]

[1]Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany. [2]JINR, Dubna, Russian Federation

Abstract

Laser spectroscopy of H_2^+ is one of the outstanding challenges in AMOP. Only RF and microwave spectroscopy had been implemented, more than 20 years ago, and with limited accuracy. Laser spectroscopy of rovibrational transitions in trapped and sympathetically cooled H_2^+ offers exceptional potential. On the theoretical side, ab initio predictions of the vibrational energies with small quantum numbers have been performed with exquisite uncertainty, 8×10^{-12} [1].

We developed a project aiming at Doppler-free laser spectroscopy of H_2^+. First, we demonstrated that electric quadrupole spectroscopy with high line resolution and low transition frequency uncertainty is possible on diatomic molecular ions. We achieved unprecedented $(1 - 2) \times 10^{-12}$ uncertainty. The study was performed on HD^+, since it is experimentally simpler to prepare in the lower spectroscopy level than H_2^+ [2].

At this conference, we will report on a complete Doppler-free spectroscopy campaign of H_2^+. We measured the optical frequencies of two spin components of a first-overtone rovibrational transition with similar uncertainty as above. We determined the spin-averaged transition frequency and the spin-rotation coefficient, both with uncertainty substantially smaller than the theoretical prediction.

We will present the experimental results, the evaluation of the systematic shifts and the comparison with the predicted transition frequencies. We also show how a new, independent value of the proton-electron mass ratio can be obtained, compare it with previous results, and discuss the implications of the work.

[1] V.I. Korobov and J.-Ph. Karr, PRA 104, 032806 (2021)

[2] M.R. Schenkel, et al. Nat. Phys. 20, 383 (2024).

Categories

Precision measurements

Presentation

Poster presentation

D145

ZOMBIES: Towards measuring the parity-violating nuclear anapole moment of ^{137}Ba in BaF molecules

Mangesh Bhattarai[1], David DeMille[1,2]

[1]University of Chicago, Chicago, USA. [2]Argonne National Laboratory, Lemont, USA

Abstract

We describe progress towards measuring the parity-violating nuclear anapole moment of ^{137}Ba in barium monofluoride (BaF) molecules. We present our measurement scheme and discuss a proof of principle experiment with the ^{19}F nucleus in ^{138}Ba^{19}F. A sensitivity sufficient to measure the predicted effect in ^{137}BaF, at the 10% level, was achieved. We have since incorporated several improvements into our system, such as a cryogenic buffer gas beam source and an improved laser frequency locking scheme. The A $^2\Pi_{1/2}$ and D $^2\Sigma^+$ states of BaF are used for the quantum state preparation and detection needed to measure the anapole moment in ^{137}Ba. We present recent measurements of the hyperfine splittings of the A $^2\Pi_{1/2}$ state, and progress towards further spectroscopy of both this state and the D $^2\Sigma^+$ state. We also sketch new strategies to increase the flux of the low-abundance isotopologue ^{137}BaF in our experiment.

Categories

Precision measurements

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Poster presentation

D146

Precision Measurements and tests of fundamental physics with cold molecules

Agathe BONIFACIO, Marylise SAFFRE, Sean TOKUNAGA, Anne COURNOL, Mathieu GONÇALVES, Albert KALADJIAN, Mathieu MANCEAU, Benoît DARQUIÉ

Université Sorbonne Paris Nord, Paris, France

Abstract

High-precision spectroscopy of complex polyatomic molecules are of interest in various fields of physics ranging from the study of the atmosphere and astrophysics to fundamental tests. At Laboratoire de Physique des Lasers, we are currently developing a new high-precision, SI traceable, mid-infrared quantum cascade laser spectrometer to measure rovibrational frequencies of cold complex molecules with unprecedented accuracies. At room temperature, the spectra of polyatomic molecules are congested and cooling is needed to resolve individual absorption lines and maximize populations at low energy levels. In our setup, a gas of complex species at a few kelvin is produced through collisions with a buffer gas in a cryogenic cell [1], as we already demonstrated for an organo-metallic compound, methyltrioxorhenium [2]. I will present our efforts towards extending this technique to (i) polycyclic aromatic hydrocarbons (PAHs) like cyanonaphtalene present in both the atmosphere and interstellar gas cloud [3]; (ii) heavy chiral organo-metallic species such as ruthenium(iii)-tris-acetylacetonate [4], which are particularly promising for measuring the electroweak-interactions-induced tiny energy difference between enantiomers of a chiral molecule, a signature of parity violation, and a sensitive probe of dark matter.

References :

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[3] McGuire *et al*, Science, **371**, 6535, 1265-1269 (2021)

[4] Fiechter *et al*, *J.* Phys. Chem. Lett. **13**, 42, 10011–10017 (2022)

Categories

Precision measurements

Presentation

Poster presentation

D147

Optical clock spectroscopy with multiple $^{88}Sr^+$ ions

Melina Filzinger, Martin Steinel, Jian Jang, Saaswath J.K., Daniel Bennett, Tanja E. Mehlstäubler, Ekkehard Peik, Nils Huntemann

Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Abstract

Optical clocks based on single trapped ions have demonstrated low systematic uncertainties and robust operation. The instability of these clocks, however, is limited by quantum projection noise, making long averaging times necessary to obtain a small statistical uncertainty. One way to reduce the measurement time is to interrogate multiple ions simultaneously.

The $^2S_{1/2} \rightarrow {}^2D_{5/2}$ transition in $^{88}Sr^+$ is well-suited for optical clock operation with multiple ions: Its excited state lifetime of about 400 ms enables long coherent interrogation times, and shifts from excess micromotion cancel for a specific radiofrequency (RF) trap drive frequency. Furthermore, the transition's sensitivity to the ambient thermal radiation is well-known, enabling low systematic uncertainties even at room temperature.

We have previously reported on optical clock operation with $^{88}Sr^+$ and demonstrated an improved stability using three Sr^+ ions instead of a single one [1]. In both cases, the systematic uncertainty was limited to 2.3×10^{-17} by the properties of the prototype linear ion trap. Here, we report on a new experimental apparatus that features a high-performance ion trap made of laser-machined aluminum nitride wafers, following the design in [2]. The resulting low micromotion, reduced heating, and the integrated calibrated temperature sensors, pave the way for multi-ion Sr^+ clock operation with low-10^{-18} systematic uncertainty and further improved instability.

[1] Steinel et al., PRL **131** 083002 (2023)

[2] Nordmann et al., Rev. Sci. Instrum. **91**, 111301 (2020)

Categories

Clocks and metrology

Presentation

Poster presentation

D148

Towards Overcoming the Dick Effect in Yb Optical Lattice Clocks

Thomas Easton, Maxime Favier, Ben Allen, Max Tamussino, Cameron Church, Ian Hill

National Physical Laboratory, Teddington, United Kingdom

Abstract

One of the main limits on the stability of optical lattice clocks (OLCs) is the Dick effect. This refers to noise on the local oscillator being aliased by the clock due to its pulsed mode of operation. We are developing OLCs based on ytterbium with the aim of overcoming the Dick effect. In each of these new clocks, we aim for fractional frequency uncertainties at the 10^{-18} level and instability in the $10^{-16}\ \tau^{-½}$ region with quantum projection noise contributing at the low $10^{-17}\ \tau^{-½}$.

We begin with Yb1, a pulsed OLC with an emphasis on autonomous operation and robust design to support high uptime operation. This allows for its use as a frequency reference for a new quantum test and evaluation system based at NPL. The Yb1 system is already producing cold atoms, with the aim to observe clock spectroscopy in the coming months.

We will improve on our capabilities with Yb2, a second pulsed OLC. We will be able to overcome Dick noise by interleaving measurements of Yb1 and Yb2. Yb2 will also incorporate a ring cavity allowing for quantum non-demolition measurements and provide a mechanism by which atomic samples can be transported into shielded regions with low magnetic field noise and a well-defined black body radiation environment for improved accuracy and stability.

Finally, we will present our plans to create a conveyor belt lattice clock, which will allow continuous generation and interrogation of atomic samples, completely eliminating Dick noise by enabling uninterrupted local oscillator frequency measurement.

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Clocks and metrology

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D149

Universal quantum operations for tweezer clocks

Xiangkai Sun[1], Ran Finkelstein[1], Richard Tsai[1], Adam Shaw[1], Pascal Scholl[1], Joonhee Choi[2], Manuel Endres[1]

[1]Caltech, Pasadena, USA. [2]Stanford, Stanford, USA

Abstract

We demonstrate a fully programmable universal quantum processor using optical clock qubits based on strontium-88 atoms trapped in optical tweezers. We simultaneously realize several key tasks: motional ground state preparation, site-selective mid-circuit readout, and high-fidelity entanglement generation on optical qubits. As a first step, we implement a novel cooling method involving detection and correction of excited atomic motional states, reminiscent of Maxwell's demon thought experiment. Next, facilitated by the low-entropy initial state and motional state control, we demonstrate site-selective mid-circuit detection and hyper-entanglement of the motional and spin degrees of freedom. In parallel, we utilize high-fidelity entangling gates mediated by Rydberg interactions for preparation of metrologically useful states. Gaining access to this expanded toolbox, we implement ancilla-assisted algorithms designed to improve quantum metrology. Finally, we propose a hybrid platform that could potentially improve the performance of tweezer clocks.

Poster

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D150

Progress towards a molecular lattice clock to search for time-variation of the proton-to-electron mass ratio

Jonas Rodewald[1], Yixin Wang[1], Qinshu Lyu[1], Mathieu Manceau[2], Benoit Darquie[2], Ben Sauer[1], Mike Tarbutt[1]

[1]Imperial College, Centre For Cold Matter, London, United Kingdom. [2]Laboratoire de Physique des Lasers, CNRS, Université Sorbonne Paris Nord, Paris, France

Abstract

The search for time-variation of fundamental constants is a promising way to probe physics beyond the standard model. In the frame of the QSNET project, we are setting up a molecular lattice clock to test for time-variation of the proton-to-electron mass ratio. The clock will be based on the fundamental vibrational transition in Calcium Monofluoride (CaF) at a wavelength of around 17µm. The transition is expected to have a linewidth of a few Hz and be largely insensitive to systematic DC Stark or Zeeman shifts. Additionally, the AC Stark shifts of the ground and excited states of the clock transition are expected to cancel for several wavelengths, potentially facilitating the trapping of the molecules in a magic wavelength lattice. The frequency of the clock transition is currently known to several MHz. To narrow this down, we perform vibrational spectroscopy of magneto optically trapped CaF with a 17µm quantum cascade laser (QCL). The frequency of the QCL is referenced to absorption lines of the v2 fundamental vibration mode of N_2O in the 17µm region. We measure these, for the first time, with frequency modulation spectroscopy and linearize the QCL frequency scan with a cavity.

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D151

Dynamic cryogenic radiation shield for controlling blackbody radiation shift at the sub-10^{-19} level in optical lattice clocks.

Youssef Hassan[1,2], Kyle Beloy[1], Takumi Kobayashi[1,3], Tobias Bothwell[1], Jacob Seigel[1,2], Benjamin Hunt[1,2], Kurt Gibble[1,4], Tanner Grogan[1,2], Andrew Ludlow[1,2]

[1]National Institute of Standards and Technology (NIST), Boulder, CO, USA. [2]Department of Physics, University of Colorado, Boulder, CO, USA. [3]National Metrology Institute of Japan (NMIJ), AIST, Tsukuba, Japan. [4]Department of Physics, The Pennsylvania State University, University Park, PA, USA

Abstract

We report on efforts towards Ytterbium lattice clocks with systematic uncertainties in the 19th decade. First, we demonstrate the operation of an in-vacuum cryogenic radiation shield that enables controlling the blackbody radiation (BBR) uncertainty *below* the 10^{-19} fractional frequency level. The shield is equipped with a mechanical system that actuates its internal structure to completely enclose the atomic sample with highly emissive cryogenic surfaces during clock spectroscopy time, blocking the atoms' line of sight to the ambient environment. The shield is integrated into a Yb clock and is stabilized at 75K with measured effective thermal inhomogeneity below 100 mK. We report a comparison between two clocks: one utilizing the cryogenic shield and the other with a room temperature shield acting as a reference.

Second, we demonstrate a novel lattice loading technique, dubbed *ratchet loading*, which provides programmable control over the spatial distribution of ultra-cold atoms in an optical lattice. The technique utilizes spatial control of the magneto-optical trap and shelving to a metastable state. In one experiment, we demonstrate the high spectral homogeneity of an extended (5-mm) sample exhibiting *low uniform density*. We also demonstrate *independent addressability* with the clock laser of two ensembles prepared in opposite spin states in the same lattice, providing a platform for extended interrogation schemes for improved clock stability. In a separate experiment, we demonstrate low relative fractional frequency instability at one second of 2.4×10^{-17} between two identically prepared ensembles in the same lattice, presenting an appealing platform for rapid evaluation of clock systematics.

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D152

Initial Evaluation of the M1/E2 Contribution to the Lattice Light Shift in Ytterbium

Benjamin D. Hunt[1,2], Tobias Bothwell[2], Jacob Siegel[1,2], Youssef S. Hassan[1,2], Takumi Kobayashi[2,3], Mario Duenas[1,2], Tanner Grogan[1,2], Kyle Beloy[2], Roger C. Brown[2], Andrew Ludlow[1,2]

[1]University of Colorado at Boulder, Boulder, USA. [2]National Institute of Standards and Technology, Boulder, USA. [3]National Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tokyo, Japan

Abstract

Uncertainty in the lattice light shift remains a key effect impacting the total systematic uncertainty of the ytterbium lattice clock. Numerous groups have carried out precision measurement of the differential electric dipole (E1) polarizability, leaving the magnetic dipole and electric quadrupole (M1/E2) polarizabilities as important elements in the light shift determination of shallow lattices. A previous measurement of the M1/E2 coefficient has shown large discrepancies with theoretical predictions, in both sign and magnitude. To resolve these discrepancies, and further limit the uncertainty of the lattice light shift, we measure the M1/E2 coefficient in ytterbium via two distinct methodologies. Both involve synchronous interrogation of two co-trapped samples of ytterbium prepared to have different sensitives to the M1/E2 contribution of the light shift. The first method measures the frequency difference between the samples prepared in different longitudinal mode. The second measures the frequency difference between samples when one is exposed to an axial running wave near the magic frequency. These methods provide two independent determinations of the M1/E2 coefficient, offering a pathway to reduced uncertainty in the lattice light shift for ytterbium.

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Clocks and metrology

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D153

Double Resonance Optically Pumped (DROP) Rubidium Atomic Clocks Physics Packages

Hugh Klein, Nyra Ashraf, Ulas Gokay, Nitika Gupta, Guilong Huang, Rabia Ince, Laurence Nicholls, Mohsin Haji

National Physical Laboratory (NPL), Teddington, United Kingdom

Abstract

The development of a reconfigurable testbed designed for optimising rubidium vapour-cell double-resonance optically-pumped (DROP) atomic clocks will be reported [1]. The testbed enables easy substitution of core physics package components such as vapour cells, cavities, optical sources, and assessment of DROP signals. Manufactured batches of vapour cells have been assessed to determine their uniformity and consistency. Buffer gas frequency shifts were observed as the vapour-cell temperature was varied. The DROP signals' linewidth, signal contrast and noise were characterised against temperature, optical power, and magnetic field. These DROP signals were generated with different optical sources including vertical cavity surface emitting lasers (VCSELs), and Rb lamps. A commercial external cavity diode laser is the baseline against which the VCSELs and lamps were compared. Various microwave cavities can be tested in this setup; to date the performance of magnetron-type and cylindrical cavities were studied.

The extent of helium permeation in two commercial rubidium microwave clocks was studied by immersion for several days in an atmosphere of pure helium; a Hertz/day level shift was measured in one case. A variety of Rb-integrated and Rb-lamp cells were investigated using an NPL-designed gas analysis system capable of determining both total buffer-gas pressure and partial pressures strengths of constituent species for a variety of commercial, in-house, and prototype cells.

Funding from Innovate UK is acknowledged together with advice from collaborators and colleagues.

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Clocks and metrology

Presentation

Poster presentation

D154

Status of Strontium Optical Lattice Clock at INRIM

Matteo Barbiero[1], Juan Pablo Salvatierra[2,1], Davide Calonico[1], Filippo Levi[1], Marco G. Tarallo[1]

[1]Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135, Turin, Italy. [2]Politecnico di Torino, Corso Duca degli Abruzzi, 24 10129, Turin, Italy

Abstract

We present the status of the Strontium optical lattice clock apparatus developed at the Italian National Metrology Institute (INRIM).

This apparatus employs some technical innovations, such as a 2D-MOT based atomic source for a complete suppression of black body radiation emitted from the oven. A multiwavelength ultrastable reference cavity is used to stabilize all the lasers without the need for dedicated spectroscopic cells. Additionally, we have developed a novel spectral purity transfer technique enabled by serrodyne frequency shifting.

We report a preliminary analysis of the cold collisions' role in the bosonic Strontium optical clocks.

Using the interleaved clock operation, we measure the frequency shift of the system by interrogating the atomic sample at varying density and excitation fractions using the Rabi interrogation protocol.

These analyses aim to potentially enhance the accuracy of the bosonic optical frequency standard and improve the theoretical understanding of cold collisions and potential mitigation strategies.

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D155

Self-Synchronous Comparison in a Spin-squeezed Strontium Optical Lattice Clock

Yee Ming Tso, Maya Miklos, John Robinson, Joonseok Hur, Yang Yang, James Thompson, Jun Ye

JILA, University of Colorado Boulder, Boulder, USA

Abstract

Optical atomic clocks are exquisite probes of fundamental physics. As state-of-the-art atomic clocks are approaching the fundamental limit of precision set by quantum projection noise (QPN), it has motivated works that utilizes entanglement, such as spin squeezing, in atomic clocks to surpass this QPN limit. To realize this squeezing-enhanced stability, we have built a platform that integrates a strontium optical lattice clock with a high-finesse cavity that generates spin-squeezing via quantum non-demolition (QND) measurements. A movable optical lattice enables transportation of atoms in and out of the cavity, which allows us to prepare two independent spin-squeezed sub-ensembles. We perform direct self-synchronous comparison between two atomic sub-ensembles and realize squeezing-enhanced performance that averages down to the 10^{-17} level [1]. We also present our recent improvements made to the experiment, such as enhanced control of atomic motion, as a step towards achieving entanglement-enhanced clock performance at the state-of-the-art level.

1. J. M. Robinson et al., *Nature Physics,* 1-6 (2024).

Categories

Clocks and metrology

Presentation

Poster presentation

D156

Optical manipulation of spin diffusive modes in high pressure vapour cells

Joseph Nicholson[1], Charu Mishra[1], Vera Guarrera[1], Patrick Bevington[2], Jake Zipfel[2], Witold Chalupczak[2]

[1]University of Birmingham, Birmingham, United Kingdom. [2]National Physics Laboratory, Teddington, United Kingdom

Abstract

Gaseous mixtures of alkali-metal and noble gas atoms are widely used in quantum optics and sensing due to the long-lived collective spin states of such ensembles [1]. We have constructed co-magnetometers, both in Bell-Bloom and RF configurations, using a glass cell containing alkali vapour mixed with high pressure Neon buffer gas. In this setup, collisions between the alkali and the buffer gas have been observed to modify the thermal motion of the spins, establishing a diffusive regime where atoms arrange into distinct stable spatial modes within the cell [2, 3]. These spatial modes each contribute to the overall signal, and the collective spin dynamics are observed to be highly dependent on the overlap between the spatial modes and the pump/probe beams. We analyse these multi-mode dynamics, including the dependence on intensity and position of the pump/probe beams. We also examine the appearance of a coherent coupling regime between the modes, resulting in non-trivial spin dynamics [4] [5]. These results show that a multi-mode approach to the spin dynamics could be a powerful tool for enhancing the performance of sensing devices, and also opens new avenues in quantum information and imaging.

[1] D. Budker, M.V. Romalis *Nature Physics* **3**, 227 (2007).

[2] J. Skalla et al. *Phys. Lett. A* **226**, 69 (1997)

[3] S. Knappe et al. *New. J. Phys.* **12**, 065021 (2010)

[4] R. Shaham et al. *Phys. Lett. A* **102**, 012822 (2020)

[5] P. Bevington, J. Nicholson et al. *Phys. Rev. Res*. **6**, 023134 (2024)

Categories

Clocks and metrology

Presentation

Poster presentation

D157

Contribution of NPL-Sr1 Towards a Redefinition of the SI Second

Chen-Hao Feng[1], Matthew Johnson[1], Filip Butuc-Mayer[1,2], Jacob Tunesi[1], Xi Zhang[1], Marco Schioppo[1], Helen Margolis[1], Ian Hill[1]

[1]National Physical Laboratory, London, United Kingdom. [2]University of Oxford, Oxford, United Kingdom

Abstract

The extraordinary precision with which frequency can be measured underpins significant advancements in measurement science. The high level of performance achieved by atomic frequency standards based on optical transitions has prompted a plan to redefine the SI second which requires several mandatory criteria to be met before the target date of 2030. These include regular contributions to International Atomic Time (TAI), demonstrated agreement of frequency ratio measurements between optical frequency standards at the 5×10^{-18} fractional frequency uncertainty level, and estimated fractional systematic uncertainties for individual optical frequency standards below 2×10^{-18}.

To support these criteria, we have developed and operated a Sr optical lattice clock, NPL-Sr1, with emphasis on high-uptime operation and low systematic uncertainty. We will present details of the contribution of NPL-Sr1 to TAI, which includes several on-time submissions to the Bureau International des Poids et Mesures (BIPM). We tackle the leading systematic uncertainty in the clock, given by blackbody radiation, by developing in-situ thermometry, and present a total evaluation of the clock uncertainty at the low 10^{-18} level. Finally, we discuss a recent campaign where our stationary clock NPL-Sr1 was operated in an international and inter-continental comparison to characterise the agreement between several Sr optical clocks using transportable clock systems.

Categories

Clocks and metrology

Presentation

Poster presentation

D158

A CONTINUOUSLY-PROBED STRONTIUM OPTICAL LATTICE CLOCK FOR DARK MATTER SEARCHES

Ludovico Iannizzotto Venezze, Charles Baynham, Leonie Hawkins, Richard Hobson, Alice Josset, Elizabeth Pasatembou, Thomas Walker

Imperial College London, London, United Kingdom

Abstract

State of the art optical lattice clocks are the most stable and reproducible timekeepers available today and have a remarkable precision below 10-18. For these reasons, optical lattice clocks are good candidates for studies of fundamental constants. For example, they can be used to investigate the fine structure constant and the proton-mass ratio in the search for the nature of ultra-light dark matter.

Despite significant advancements, even the most advanced optical clocks are still hindered by the limitations of their sequential operation and the associated Dick noise. The Ultra-precise, Shock-resistant Optical Clock (USOC) project aims to address these issues by developing a new strontium-based ultra-cold atomic system that operates continuously, thereby eliminating the dead-time found in traditional optical clocks. This poster will present an overview of the technical challenges involved in the USOC project, particularly in maintaining a zero-dead-time operation of an optical lattice clock. We will discuss the implementation of a continuous state preparation, clock spectroscopy, normalized readout in a conveyor-belt moving optical lattice.

Categories

Clocks and metrology

Presentation

Poster presentation

D159

Long-term operation of Yb optical lattice clock at INRIM

Irene Goti, Stefano Condio, Filippo Levi, Davide Calonico, Marco Pizzocaro

INRIM, Torino, Italy

Abstract

The optical lattice clock IT-Yb1, developed and maintained by INRiM, is based on the $^1S_0 \rightarrow {}^3P_0$ transition of ^{171}Yb, one of the frequency standards indicated as a secondary representation of the second. The performance of IT-Yb1 has been characterized by an accuracy of 1.9×10^{-17} and a typical instability of $2 \times 10^{-15} (\tau/s)^{-1/2}$. We operated the clock for 16 consecutive months, from February 2022 to May 2023. During this period, we performed a local absolute frequency measurement against the Caesium fountain developed at INRIM. The result of this measurement is f(IT-Yb1) = 518 295 836 590 863.44(14) Hz with a fractional uncertainty of 2.7×10^{-16}. Additionally, the data collected have been utilized for the calibration of the International Atomic Time (TAI) and to generate a local time scale with sub-nanosecond accuracy over a month-long period. Finally, since December 2021, IT-Yb1 has participated in several international comparison campaigns in collaboration with other European and Asian Metrology Institutes. The results of these campaigns are under analysis and represent an important step towards the realization of a new definition of the second in the International System of Units.

In recent months, to improve the performance of the clock, the lattice laser has been replaced. The new laser, with its higher power, allows for an increased lattice waist while maintaining a high trap depth. The new atomic trapping conditions are currently under investigation through a new fit function we developed to analyze the sideband spectra.

Categories

Clocks and metrology

Presentation

Poster presentation

D160

Measurement of the velocity distribution of rubidium atoms scattered from a low temperature paraffin film

Yutaro Tanaka, Kanta Asakawa, Hiroaki Usui, Atsushi Hatakeyama

Tokyo University of Agriculture and Technology, Koganei, Japan

Abstract

Paraffin and other inert materials are used as anti-relaxation coatings (ARCs) for spin-polarised atoms in alkali-metal vapour cells. ARCs have been applied to precision measurements such as miniaturised atomic clocks and atomic magnetometers [1]. However, the details of the surface conditions that contribute to the high performance of ARCs have not been fully understood. We have studied the films of tetracontane (C40H82) using atomic beam scattering in conjunction with surface analysis to understand basic scattering processes, including adsorption, diffusion, spin-relaxation, and desorption [2, 3].

In this paper, we report the velocity distribution of rubidium atoms scattered from low-temperature tetracontane films. The films were formed by vapour deposition in a thickness of a few micrometres and characterised by atomic force microscope and X-ray photoelectron spectroscopy. As the temperature of the film decreased from room temperature down to 110 K, the number of scattered atoms gradually decreased and finally no scattered atoms were observed at 130 K. We found that the temperature of the scattered atoms followed the film temperature. This thermalisation with the film surface was previously reported for tetracontane films at room temperature [2], and confirmed for the first time at low temperatures (down to 160 K).

[1] C. Haotian et al., Appl. Surf. Sci. 501, 143897 (2020)

[2] N. Sekiguchi et al., Phys. Rev. A 98, 042709 (2018)

[3] K. Asakawa et al., Phys. Rev. A 104, 063106 (2021)

Categories

Clocks and metrology

Presentation

Poster presentation

D161

A continuous high-flux atomic source for strontium optical clocks and atom interferometers

Leonie Hawkins, Ludo Iannizzotto Venezze, Charles Baynham, Richard Hobson, Alice Josset, Elizabeth Pasatembou

Imperial College London, London, United Kingdom

Abstract

Atomic clocks suffer from the Dick effect, which is the noise arising from spurious drifts in the local oscillator frequency during the dead time in the clock sequence. Operating continuously, rather than in the pulsed manner of previous clocks, would eliminate this effect [1]. We present the design of a continuous ultracold strontium source, which aims to generate a high atomic flux for clocks and atom interferometers.

The system comprises two separate regions: one for Zeeman slowing atoms from a Sr oven and trapping in a 2D magneto-optical trap (MOT), and a second for trapping in a 3D MOT, with transport between the two via a moving optical molasses. The magnetic field required across the Zeeman slowing region will be provided by a combination of permanent magnets in Halbach configuration, with shim coils for fine-tuning the field. The second chamber will utilise mid-infrared 2923 nm light to realise a metastable MOT, addressing a cycling transition between the 5s5p 3P2 and 5s4d 3D3 states, which avoids ac Stark shifts of the clock transition [2]. It also relaxes laser frequency stabilisation requirements due to the broader transition linewidth compared to the 689 nm intercombination line, typically used for cooling Sr.

[1]: R. Takeuchi et al., Continuous outcoupling of ultracold strontium atoms combining three different traps, Applied physics express, 2023-04, Vol.16 (4), p.42003.

[2]: R. Hobson et al., Midinfrared magneto-optical trap of metastable strontium for an optical lattice clock, Physical review. A, 2020-01, Vol.101 (1), Article 013420.

Categories

Clocks and metrology

Presentation

Poster presentation

D162

High Performance Laser Systems for Optical Clocks and Quantum Sensors

Eduardo Oteiza, Nate Phillips, Evan Barnes, Cole Smith, Henry Timmers, Andrew Attar, Bennett Sodergren, Alina Spiess, Kurt Vogel, Kevin Knabe

Vescent, Golden, USA

Abstract

With inherent precision, sensitivity, and traceability afforded by the atomic systems at their heart, advanced quantum sensors are poised to become integral parts of otherwise everyday platforms. The full potential of state-of-the-art atomic clocks, magnetometers, electric field sensors, and inertial sensors will be realized when these technologies are advanced from their development in research labs to deployment in field applications on moving platforms. The size, weight, power, and cost (SWaP-C) of required laser systems must be reduced, and robustness to environmental perturbations must be improved to meet the challenging requirements of deployed applications. Vescent, being a lead manufacturer of systems for deployable quantum, is actively developing novel modular laser and control systems to enable terrestrial and space-based atom interferometer sensors. Optical frequency combs, MOT and Raman lasers, and ultranarrow linewidth lasers will be reviewed for performance in both laboratory and harsh environments. Vescent has developed these systems for fielded next-generation quantum applications, such as cold atom microwave and optical atomic clocks that are intended as improvements to existing GPS timing systems. Frequency instability, optical power, relative intensity noise, and overall power consumption will be reviewed. Discussions on the impact that these laser systems would have on real-world quantum applications will be estimated.

Poster

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Categories

Clocks and metrology

Presentation

Poster presentation

D163

haCC-M: a general purpose solver to study multiphoton processes in atoms and small molecules

Hareesh Chundayil[1], Armin Scrinzi[2], Vinay Majety[1]

[1]IIT Tirupati, Tirupati, India. [2]Ludwig Maximilians University, munich, Germany

Abstract

We present here the hybrid coupled channels approach - multicentered (haCC-M), a many body framework to study multiphoton processes in atoms and molecules. The haCC-M solves the time dependent Schrodinger equation using a coupled channels discretization of wavefunction. The channel functions are constructed as antisymmterized products of ionic states computed using quantum chemical techniques and a numerical one electron basis. The numerical one electron basis is composed of multicentered Gaussians and FE-DVR basis functions suitably orthogonalized. In addition, neutral states can be added to the basis. The basis includes necessary ingredients to study single ionization of multielectron systems in various regimes.

The method is implemented on tRecX which is a C++ platform for solving the time dependent Schrodinger equation with arbitrary discretizations of the wavefunction. It handles discretizations and operators using tree data structures that take into account sparsity of various operators.

In the poster, we will discuss the mathematical framework of haCC-M and its application to computation of channel resolved photo-electron spectra in the non-perturbative regime and computation of autoionizing states and their modification in the presence of streaking fields.

Categories

Ultrafast

Presentation

Poster presentation

D164

Influence of catastrophes and hidden dynamical symmetries on ultrafast backscattered photoelectrons

Thomas Rook, Lidice Cruz Rodriguez, Carla Figueira de Morisson Faria

University College London, London, United Kingdom

Abstract

In this work, we discuss the effect of using a soft-core Coulomb potential in the photoelectron momentum distribution (PMD) using the recently implemented hybrid forward-boundary CQSFA (H-CQSFA) [1]. The softening in the Coulomb interaction influences the ridges observed in the PMD. We show that for a hard-core Coulomb interaction, the re-scattering ridges close along the polarization axis (see panel (a) in the figure). Increasing the softening parameter interrupts them by caustics at ridge-specific angles (panels (b) and (c) in the figure). We analyze the momentum mapping of the different orbits leading to the ridges. For the hard-core potential, we have two types of orbits that can be classified in terms of the number of focal points. By increasing the softening, we show that two additional solutions emerge as the number of focal points along the trajectories is now insufficient to classify the solutions thoroughly. Finally, we use scattering theory to understand how the maximum scattering angle depends on the softening of the Coulomb potential.

Poster

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Categories

Ultrafast

Presentation

Poster presentation

D165

Environmental effects in the dynamics of organic systems irradiated by intense ultrashort X-ray pulses

Sourav Banerjee[1], Zoltan Jurek[1,2], Rui Jin[3], Benoît Richard[1,2,4], Malik Muhammad Abdullah[1], Ludger Inhester[1], Sang-Kil Son[1,2], Robin Santra[1,2,4]

[1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany. [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany. [3]Max-Planck-Institut für Kernphysik, Heidelberg, Germany. [4]Department of Physics, Universität Hamburg, Hamburg, Germany

Abstract

Intense ultrashort pulses generated using X-ray free-electron laser (XFEL) sources have opened up the scope to study various systems, ranging from atoms and molecules to clusters, bulk and plasmas, with atomic spatial resolution and femtosecond temporal resolution. The irradiated systems are charged up quickly through undergoing photoinduced processes such as photoionization, Auger-Meitner decay and collisional ionization.

The classical molecular dynamics-Monte Carlo based hybrid toolkit XMDYN [1], with the aid of the ab initio XATOM[1] code, has been used in simulating the dynamical evolution of various systems under intense irradiation over the past years.

We present here recent studies delineating the applicability of these toolkits in different situations. First, taking glycine as a prototypical example of a small organic molecule, we investigated [2] the effects of chemical bonds and charge transfer at different X-ray fluences by extending the XMDYN framework, so that it incorporates the reactive-force-field approach to describe the bonds. This extension has also been applied to describe the Coulomb explosion dynamics of 2-iodopydine molecules in a recent XFEL experiment [3]. Another example is the study of glycine crystals irradiated by XFEL pulses. During and after the interaction with intense X-ray pulses, the system turns into plasma. We investigate how the plasma environment influences the atomic electronic structure and how it feeds back into plasma dynamics.

[1] Z. Jurek et al., J. Appl. Crystallogr. 49, 1048–1056 (2016).

[2] S. Banerjee et al., Struct. Dyn. 9, 054101 (2022).

[3] R. Boll et al., Nat. Phys. 18(4), 423-428 (2022).

Categories

Ultrafast

Presentation

Poster presentation

D166

Double Rydberg states of the Sr atom

Matthieu Génévriez[1], Ulli Eichmann[2]

[1]Université catholique de Louvain, Louvain la Neuve, Belgium. [2]Max-Born Institute, Berlin, Germany

Abstract

The motion of two electrons excited far from the nucleus is the result of the subtle balance between their mutual Coulomb repulsion and the Coulomb attraction of the residual ionic core. In highly excited "double Rydberg" states (DRS), strong electronic correlations give rise to complex two-electron dynamics that range from chaotic motion to quasi-stable, long-lived orbits depending on the relative degree of excitation of the two electrons and on the details of electronic correlation.

Despite the importance of DRS as a fundamental quantum three-body system, a detailed theoretical description of their energies and dynamics, systematically compared against experimental data in the time- or frequency domains, has been lacking. This hampers our understanding of a seemingly simple problem, how two electrons move far away from the nucleus, and limits its potential use for applications in quantum simulation.

I will report on recent advances achieved with theory and experiment in the study of the DRS of the Sr atom. Such states are prepared through sequential, resonant, multiphoton excitation of the two valence electrons of Sr, which unlocks access to a broad range of DRS exhibiting vastly different electronic dynamics and lifetimes. Their signatures are ubiquitous in the dense and complex double-ionization spectra recorded experimentally, and are fully unravelled through extensive theoretical calculations using configuration interaction with exterior complex scaling. The calculations further provide a spectacular view of the correlated two-electron motion in DRS.

Categories

New directions

Presentation

Poster presentation

D167

Global Network of Optical Magnetometers for Exotic physics searches (GNOME)

Grzegorz Łukasiewicz, Szymon Pustelny

Jagiellonian University, Kraków, Poland

Abstract

We will present the current status of the GNOME network that aims to search for exotic spin couplings using optical magnetometers and comagnetometers.

Not only optical magnetometers are the most sensitive magnetic-field sensors, but they may also be used to search for non-magnetic spin couplings, including those associated with hypothetical dark-matter interactions. A recently constructed Advanced GNOME sensor is a K-3He comagnetomter operating in the so-called self-compensating regime [1] optimized for long-term synchronized measurements. The performance of the sensors will be discussed in the context of searches for exotic spin couplings using a network of synchronized magnetometers [2], which extends the searching possibilities to transient and spatially correlated perturbations. Search targets and developed dark-matter detection schemes [3] will be discussed.

1] T. W. Kornack and M. V. Romalis. “Dynamics of Two Overlapping Spin Ensembles Interacting by Spin Exchange”, Phys. Rev. Lett. 89 (25 2002), p. 253002.
[2] Szymon Pustelny et al. “The Global Network of Optical Magnetometers for Exotic physics (GNOME): A novel scheme to search for physics beyond the Standard Model”, Ann. der Physik 525.8-9 (2013), p. 659.
[3] Samer Afach et al. “What Can a GNOME Do? Search Targets for the Global Network of Optical Magnetometers for Exotic Physics Searches”, Ann. der Physik (2023), p. 2300083.

Categories

New directions

Presentation

Poster presentation

D168

Monochromatic source of ions and electrons for nanosciences based on correlated ion and electron

Daniel Comparat, Florent Vallee, Clelia Bestelica, Azer Trimèche, Yan Picard

Laboratoire Aimé Cotton, CNRS, Université Paris Saclay, Orsay, France

Abstract

Electron and ion beams have become indispensable tools in surface and materials science. Unlike standard sources, laser ionization of a neutral atomic species allows to produce both ions and electrons. Moreover, coincident ion/electron detection provides correlated information on both particles that can be used to improve beam properties, such as deterministic creation of charged particles and correction of their trajectories in real time. We will discuss the development of three innovative prototypes:

•A focused ion beam using feedback control to perform (sub-)nm scale semiconductor circuit editing in collaboration with Orsay Physics company.

•A deterministic source of (potentially) any type of ion for controlled implantation at the nm scale for on-demand doping of quantum devices.

•A high resolution electron energy loss microscope to perform both imaging and vibrational spectroscopy for surface analysis made in collaboration with ISMO and CEA at Paris Saclay University.

Poster

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Categories

New directions

Presentation

Poster presentation

D169

Magneto optical traps of Ti

Scott Eustice[1,2], Jack Schrott[1,2], Dan Stamper-Kurn[1,2,3]

[1]UC Berkeley, Berkeley, USA. [2]CIQC, Berkeley, USA. [3]Lawrence Berkeley National Lab, Berkeley, USA

Abstract

We present magneto optical traps (MOTs) of the 3 stable bosonic isotopes of Ti. We measure loading rates at a variety of experimental parameters, perform time of flight imaging to do thermometry, constrain the branching ratio of the laser cooling transition by measuring lifetimes, and provide an upper limit on the two body loss coefficient. We load MOTs directly from the emission of a titanium sublimation pump running between 1350-1600 K, which we optically pump into a meta-stable state that possesses a laser cooling transition. In this simple setup we find loading rates up to ~1x10^7 atoms/s and peak densities of ~1x10^{11} atoms/cm^3.

Poster

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Categories

New directions

Presentation

Poster presentation

D170

Atom Interferometery Driven by a Picosecond Frequency Comb

Saïda Guellati-Khelifa[1,2], Clément Debavelaere[1], Pierre Cladé[1], Cyrille Solaro[1], Oscar Boucher[1], Samuel Gaudout[1]

[1]Laboratoire Kastler Brossel, Paris, France. [2]National Conservatory of Arts and Crafts, Paris, France

Abstract

New concepts and innovative geometries are currently being investigated to push the sensitivity of atom interferometers to the extreme and broaden their applications. Efforts are focused on developing Very-Long-Baseline Atom Interferometry for testing the fundamental laws of physics, detecting low-frequency gravitational waves and hints of ultralight dark matter. They also aim to design compact and portable inertial sensors, to be deployed on earth and in space, notably for geodesy applications. All these experiments use continuous-wave (CW) lasers to manipulate matter waves.

In 2022, we realized an atom interferometer using an appropriate sequence of picosecond laser pulses. Each pair of counter-propagating picosecond laser pulses diffracts the atomic wave paquet via a stimulated Raman transition between the hyperfine level of the ^{87}Rb ground state. There are two main motivations for investigating this new approach to implement atomic beamsplitters. The first one, as for high-resolution spectroscopy, is to extend matter-wave interferometry to a wider spectral range and to more atomic species. The second reason lies in the fundamental difference between using a CW laser and a pulsed laser. In the former case, laser-atom interaction takes place at the atoms location and affects both atomic wave packets, whereas in the latter it is determined by the overlap region of the two laser pulses and targets a single atomic wave packet. This specificity is a priori a constraint that limits the interrogation time of free-falling atoms and therefore the sensitivity of the interferometer. It does, however, have the advantage of enabling original atom interferometer configurations.

Poster

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Categories

Matter wave interferometry

Presentation

Poster presentation

D171

Creating Quantum Anomalies by Tightly Confining Ultracold Atoms to One Dimension

Philip Johnson, Nathan Harshman

American University, Washington, DC, USA

Abstract

This poster presents models for scale-invariant, effective three- and four-body interactions of ultracold atoms confined to one dimension. The models exhibit quantum anomalies that break the scale invariance at a renormalization scale that is directly related to and controlled by the trapping potential. We describe how the direct connection between the tunable, trapping potential and the quantum symmetry breaking scale provides an avenue for probing the physics of quantum anomalies in systems of tightly confined ultracold atoms. We also discuss the direct connection in these models between the emergence of a quantum anomaly and the emergence of a topological defect, the latter of which could be exploited for generating a system with anyonic exchange statistics. Finally, we describe ideas and challenges for implementations of these models.

Poster

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Categories

Many body physics

Presentation

Poster presentation

D172

ORKA - Towards a cavity enhanced Optical Dipole Trap for a Rb^{87} BEC in Microgravity

Marius Prinz, Jan Eric Stiehler, Marian Woltmann, Sven Herrmann

University of Bremen, ZARM, Bremen, Germany

Abstract

Quantum gases have become a major research topic for space-based and microgravity platforms in recent years. These unique laboratories promise to enable sensitive atom interferometry on longest time-scales and quantum gases at the lowest temperatures.

Most such experiments employ a magnetic chip trap due to their favourable power budget and fast evaporation, but with limitations due to the chip surface in close proximity to the atoms. An alternative is to use a high-power laser for all-optical dipole trapping and cooling. But this puts a severe strain on the limited power-budget available on a microgravity platform.

To mitigate the power needs of all-optical evaporative cooling, we thus investigate the use of a resonantly enhanced optical dipole trap for Rb87. Based on heritage of an optical dipole trap already operating in microgravity we are currently setting up a low-power 1064 nm laser and a compact high-finesse bow-tie cavity for evaporative cooling to a BEC. This shall serve as a source for matterwave interferometry at the Bremen drop tower facilities.

Here we present the status of our experiment, which is under construction in a compact mobile drop capsule, as well as simulation results for the bow-tie cavity trap. We are aiming for a doubly resonant cavity with a finesse of >15k for both 780 nm and 1064 nm. In the long run, our setup shall also enable the study of near resonant atom-light interaction in the cavity, as another appealing prospect of this setup.

Poster

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Categories

Matter wave interferometry

Presentation

Poster presentation

D173

Quantum computing with neutral Rydberg atom registers

Rik van Herk, Marijn Venderbosch, Zhichao Guo, Max Festenstein, Jesus del Pozo Mellado, Ricky Teunissen, Carolus Hamers, Rianne Lous, Edgar Vredenbregt, Servaas Kokkelmans

University of Technology Eindhoven, Eindhoven, Netherlands

Abstract

Optical tweezer arrays for neutral atoms is a fast advancing platform for quantum simulation and computation. In the KAT-1 collaboration we are developing a full stack quantum computer that will be made available online, through the Quantum Inspire platform. The quantum computer will consist of neutral strontium atoms trapped in arbitrary geometries of optical tweezers, generated by a spatial light modulator. The ground and optical clock states of strontium will server as our qubit basis. To manipulate the qubits, we will implement local single qubit gates using a focused beam directed by a set of acousto-optic deflectors. In the future, we aim to improve on this by using an optical fibre array instead, allowing qubits to be addressed in parallel. Qubit entanglement will be achieved by applying a global UV pulse. Furthermore, we plan to achieve site selective entanglement by implementing coherent transport, enabling complete digital quantum computing.

With this poster, we will report on the progress we have made on cooling and trapping atoms in optical tweezer arrays and on the creation of intensity stabilized laser pulses for driving the clock transition.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation

D174

A+ Upgrade to Advanced LIGO

Mark Barton[1], Angus Bell[1], Giles Hammond[1], James Hough[1], Russell Jones[1], Sheila Rowan[1], Kenneth Strain[1], Stephen Webster[1], Denis Martynov[2], Alberton Vecchio[2], Joe O'Dell[3], Adam Huddart[3], Claire Robertson[3], Katherine Dooley[4], Hartmut Grote[4], Stuart Reid[5]

[1]University of Glasgow, Glasgow, United Kingdom. [2]University of Birmingham, Birmingham, United Kingdom. [3]STFC Rutherford Appleton Laboratory, Harwell, United Kingdom. [4]Cardiff University, Cardiff, United Kingdom. [5]Strathclyde University, Glasgow, United Kingdom

Abstract

Advanced LIGO (Laser Interferometer Gravitational-Wave Observatory) is designed to measure the quadrupolar strain of space itself arising from passing gravitational waves and in 2015 made the first observation of a binary black hole merger [Abbot et al, Phys Rev A, **116**, 061102 (2016)]. With subsequent improvements to the interferometer, detections of such events now occur at a rate of 2-3 per week, with sources located at distances of up to 3 billion light years.

The A+ upgrade to aLIGO aims to reduce the noise floor of the instrument and, so, to further extend its reach into the Universe. Improvements to large-scale optics (reduced coating thermal noise, increased aperture), active optics for optimizing mode-matching, and the implementation of a balanced homodyne detection scheme, to maximise the efficacy of frequency-dependent squeezing, are the primary features of the upgrade.

We will report on the UK's contribution to A+, in core optics, suspensions, and the optical design for the balanced homodyne detection scheme, together with future plans for improving the sensitivity of the interferometer.

Categories

Precision measurements

Presentation

Poster presentation

R01

Non-BO calculation of low energy Li-He and Li-H_2 scattering

Deng-Xin Zhao[1], Jun-Yi Zhang[1], Zong-Chao Yan[2]

[1]Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan, China. [2]Department of Physics, University of New Brunswick, Fredericton, Canada

Abstract

The development of high-precision cold-atom vacuum standard (CAVS) is a recently surged hot direction in the field of precision measurement. The core principle of CAVS is that the ultracold atoms (such as Li) escape from shallow magnetic traps or optical dipole traps due to low-energy collisions with the residual gases in ultra-high vacuum or extreme-high vacuum. The vacuum pressure is determined jointly by measured loss rate of ultracold Li, vacuum temperature and calculated scattering cross sections for collisions of Li with the residual gases. These residual gases are mainly He and H_2 while the collisions are dominated by the elastic scattering. Therefore, the accurate values of low energy elastic scattering cross sections for Li-He and Li-H_2 play a key role in the development of CAVS. In order to avoid the errors caused by the Born-Oppenheimer approximation, we will accurately calculate the low energy elastic scattering cross sections of Li-He and Li-H_2 using the confined variational method together with explicitly correlated Gaussians as the basis to treat electrons and atomic nuclei on an equal footing. The progress of this project will be reported at the conference.

Categories

Precision measurements

Presentation

Poster presentation

R02

Weak Superfluidity in Twisted Optical Potentials

Dean Johnstone[1], Shanya Mishra[1], Zhaoxuan Zhu[1], Hepeng Yao[2], Laurent Sanchez-Palencia[1]

[1]Ecole Polytechnique, Palaiseau, France. [2]University of Geneva, Geneva, Switzerland

Abstract

A twist between different systems allows one to study and interpolate across ordered and disordered matter, under a single, unified framework. Here, we use quantum Monte Carlo simulations to determine the unique phase diagrams of strongly-correlated ultracold bosons in twisted optical potentials. At magic twisting angles, spectral gaps govern the formation of periodic insulating patterns, separated by thin superfluid domains. The latter form weak superfluids, which are very sensitive to thermal fluctuations. On the other hand, non-magic angles destroy most spectral gaps, leaving behind a prominent Bose glass phase. Our results are directly applicable to current generation experiments that quantum simulate moiré physics, with the control over parameters allowing for the stabilisation of weak superfluids.

Categories

Many body physics

Presentation

Poster presentation (virtual)

R03

Elastic scattering of positive muon from ^3He and ^4He

MengShan Wu[1], Yi Zhang[1], GuoAn Yan[2], JunYi Zhang[3], Kalman Varga[4], ZongChao Yan[5]

[1]Center for Theoretical Physics, Hainan University, Haikou, China. [2]School of Physics and Physical Engineering, Qufu Normal University, Qufu, China. [3]Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan, China. [4]Department of Physics and Astronomy, Vanderbilt University, Nashville, USA. [5]Department of Physics, University of New Brunswick, Fredericton, Canada

Abstract

The study of positive muon μ^+-helium scattering plays an important role in precision experiments involving positive muons. In this study, the confined variational method, in combination with explicitly correlated Gaussian basis, was used to calculate the S-wave phase shifts and scattering lengths for low-energy elastic μ^+-^4He and μ^+-^3He scatterings without relying on the Born-Oppenheimer approximation. The S-wave phase shifts obtained through this method are converged to the second significant digit. By accounting for the long-range polarization effect, the S-wave scattering length was determined to be -12.3 a_0 and -10.6 a_0 for μ^+-^4He and μ^+-^3He scattering, respectively. Furthermore, the distortion of helium in μ^+-^3He scattering was examined and compared to that of $^3He\mu^+$ bound states. The distortions in μ^+-^3He scattering were found to be minimal, while the first $^3He\mu^+$ bound state exhibiting the largest distortion due to the proximity between μ^+ and ^3He.

Categories

Molecules

Presentation

Poster presentation (virtual)

R04

Characterizing single photon from an atom array

Toshiki Kobayashi, Yuya Maeda, Kentaro Shibata, Makoto Yamashita, Shuta Nakajima, Rikizo Ikuta, Takashi Yamamoto

Osaka University, Toyonaka, Japan

Abstract

Quantum networks connecting quantum processing nodes are key components for realizing complicated communication tasks such as distributed quantum computation and quantum repeaters. In recent years, the system of neutral atom arrays has demonstrated computational capabilities using numerous neutral atom qubits. Additionally, various demonstrations of photonic interfaces based on neutral atoms have been reported, making these neutral atom arrays promising candidates for quantum processing nodes.

In this paper, toward the realization of the photonic interface, we characterize photons emitted from a single site in an atom array by measuring the second-order correlation function. In our experiment, we prepare an ^{87}Rb single-atom array by using 852-nm holographic optical tweezers with the objective lens of NA = 0.7. To collect scattered photons into a single-mode fiber, cooling light and repump light are irradiated to the atoms. The collected photons are split by a fiber-based half beamsplitter and then detected by two avalanche photodiodes (APDs) to measure the second-order correlation function. As a result, we obtained $g^{(2)}(0)=0.14\pm0.14$ which clearly shows the nonclassical photon statistics of the photons. This is an important step toward the realization of the photonic link in the atom arrays.

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation (virtual)

R05

Towards the development of the strontium lattice clock design

Mikhail Gurov, Elena Gurova

FSUE VNIIFTRI, Moscow, Russian Federation

Abstract

In this research we present the results of the experiment for obtaining beatnotes between two dual systems with high finesse cavities. The way for obtaining the long-term integrations of beatnotes data are shown. The design of the atomic narrow beam thermal oven for the optical lattice clocks and fountains is presented. The features of the oven are non-vacuum replaceable heaters.

Poster

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Categories

Clocks and metrology

Presentation

Poster presentation (virtual)

R06

Staggered superfluidity of ultracold bosons at finite temperatures

Kuldeep Suthar[1,2], Kwai-Kong Ng[3]

[1]Department of Physics, Central University of Rajasthan, Ajmer, India. [2]Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan. [3]Department of Applied Physics, Tunghai University, Taichung, Taiwan

Abstract

Ultracold atoms trapped in optical lattices provide an ideal platform to simulate the low-energy behaviour of condensed matter models. This system provide an excellent control over the interatomic interaction strengths, and thus can be used to understand the interaction-induced quantum phenomena. The properties of strongly correlated materials is affected by the bond-charge interaction of extended Hubbard models. Such processes can be mimicked by density-induced particle tunneling of ultracold bosons and results into staggered quantum states. We investigate the role of thermal fluctuations on the existence of staggered superfluid and supersolid phases using side-decoupled Gutzwiller and quantum Monte Carlo approaches. We show that the staggered to normal state transition is of Kosterlitz-Thouless type and further demonstrates the parameter regime of coexistence of staggered phases in harmonically trapped lattice boson at finite temperature. Our theoretical study paves the way to observe novel staggered quantum phases in dipolar quantum gases experiments.

Poster

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Categories

Many body physics

Presentation

Poster presentation (virtual)

R07

Modelling crystalline structures in the time domain.

Arkadiusz Kuroś[1], Weronika Golletz[2], Andrzej Czarnecki[3], Krzysztof Giergiel[4], Arkadiusz Kosior[5], Krzysztof Sacha[2]

[1]Institute of Physics, Jan Kochanowski University, Kielce, Poland. [2]Instytut Fizyki Teoretycznej, Uniwersytet Jagielloński, Kraków, Poland. [3]Instytut Matematyki, Uniwersytet Jagielloński, Kraków, Poland. [4]Optical Sciences Centre, Swinburne University of Technology, Melbourne, Australia. [5]Institut für Theoretische Physik, Universität Innsbruck, Innsbruck, Austria

Abstract

Periodically driven many-body quantum systems provide a comfortable platform for modelling crystalline structures in the time dimension. This allows us to study the temporal physics of condensed matter and to explore new phenomena [1].

Here we present a simple implementation of non-separable lattices in the time domain that can be generated for a Bose-Einstein condensate bouncing in resonance on the oscillating mirrors. The proper choice of the time-periodic oscillations of the mirrors makes it possible to influence the effective behaviour of the particles. In particular, the system can behave like an N-dimensional fictitious particle moving in an N-dimensional crystalline structure [2]. As a concrete example, we show how to realize a two-dimensional Lieb lattice model with a flat band in the geometry of the Möbius strip [3].

[1] K. Sacha, Time Crystals (Springer International Publishing, 2020).

[2] W. Golletz, A. Czarnecki, K. Sacha, A. Kuroś, New J. Phys. 24, 093002, (2022).

[3] K. Giergiel, A. Kuroś, A. Kosior, K. Sacha, Phys. Rev. Lett. 127, 263003, (2021).

Categories

Quantum computing, simulation & networks

Presentation

Poster presentation (virtual)

R08

Relativistic Coupled-Cluster Calculations for Clock Transition Properties in Al^{+} and Pb^{2+}

Palki Gakkhar[1], Suraj Pandey[1], Ravi Kumar[2], Dilip Angom[3], B. K. Mani[1]

[1]Department of Physics, Indian Institute of Technology Delhi, New Delhi, India. [2]Department of Chemistry, University of Zurich, Zurich, Switzerland. [3]Department of Physics, Manipur University, Manipur, India

Abstract

Atomic systems offer a plethora of fundamental and functional properties and, therefore, of importance to several key implications. Some examples where atoms can serve as important probes include, atomic clocks, parity and time violations, and the search for variation in the fundamental constants. Atomic systems, however, form a complex many-body system for which the exact solution is nontrivial. This poses a serious challenge in the theoretical investigations of the properties. In this context, relativistic coupled-cluster (RCC) theory is one of the most reliable many-body theories for structure and properties calculations for atoms and ions.

In our group at IIT Delhi, we have developed RCC-based theories for properties calculations of closed-shell, one-valence and two-valence atomic systems. These theories are implemented as sophisticated parallel FORTRAN codes [1]. In this poster, we shall present our recent results on the clock transition properties of Al^{+} [2] and Pb2+ [3]. Using our in-house RCC code, we have computed excitation energies, E1 and M1 transition amplitudes and oscillator strengths, dipole polarizability, and the lifetime of the metastable clock state. For Al^{+}, our computed lifetime of 20.2 s for 3s3p $^3P_0$ clock state is in excellent agreement with the experimental value of 20.6 s. For Pb^{2+}, our calculations predict a high lifetime of 9.8 x 10^6 s for 6s6p $^3P_0$ clock state.

[1] B. K. Mani et. al., Comp. Phys. Comm. 213, 136 (2017).
[2] Ravi Kumar et. al., Phys. Rev. A. 103, 022801 (2021).
[3] Palki Gakkhar et. al., https://arxiv.org/abs/2403.15841

Poster

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Clocks and metrology

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