ICAP Summer School
St John's College, Oxford
8th-12th July 2024

Lecturers and Lecture Abstracts

(Each lecturer has two 1 hour 15 minute slots)

Tracy Northup – Ion trapping and Cavities

Ion traps allow us to achieve precise control over the motion and electronic states of atomic ions; cavities allow us to achieve precise control over single photons. We will examine how these two systems provide the basis for an interface between light and matter at the level of single quanta. How can we describe coherent processes in such an interface? How can we describe interactions with the environment? What do we learn from landmark experiments from the past decades, and what questions can today's state-of-the-art experiments answer? These and other questions will be addressed.

Jean Dalibard – Coherent Matter Waves

In these lectures, I will present some remarkable phenomena related to quantum gases, including their superfluid properties and the stabilization of topological structures such as solitons and vortices. I will show how the possibility of working with mixtures of quantum gases considerably enriches the range of observable phenomena, and discuss some recent experiments conducted around these systems.

Michel Brune - **Quantum simulation with optical tweezers and Rydberg atoms**

Quantum simulators based on arrays of single Rydberg atoms have become one of the leading platforms for quantum simulation and quantum information processing. It is based on the preparation of ground state atom arrays in optical tweezers, promoted to Rydberg levels providing controlled long-range interactions. The lectures will present this platform and current achievements, including many body physics of spin systems and applications to combinatorial problems. The performance limits will be discussed and I will show that the use of circular Rydberg atoms instead of low angular momentum one opens exciting perspectives for quantum simulation on long timescales

Arno Rauschenbeutel - Light-matter coupling in quantum nanophotonics

Nanophotonics and optical microcavities offer opportunities to manipulate and exploit the quantum properties of light by integrating quantum emitters into nanostructures. From a technological point of view, this is attractive because it lends itself to the realization of reliable quantum applications such as quantum light sources or quantum simulators. Surprisingly, the tight confinement of light provided by such photonic nanostructures does not only strongly increase the light-emitter interaction strength. It also leads to a longitudinal component of the light's polarization, which fundamentally changes the nature of the interaction. In particular, the interaction strength can become dependent on the propagation direction of the light - forward and backward. In this context, one also speaks of chiral coupling between light and emitters. In my talk, I will present the theoretical and experimental foundations of light-matter coupling in quantum nanophotonics and discuss some of the new functionalities and applications that have emerged from this rapidly developing field.

David Lucas - **Ion trapping and Quantum Computing**

In the first lecture, I will cover the basics of radio-frequency Paul traps (as generally used for quantum computing setups), trapped-ion qubits and quantum logic gates. In the second lecture, I will describe how trapped ions can be networked over optical fibre links by interfacing them with individual photons; this is one possible method of scaling up quantum processors to large numbers of qubits. I will give some examples of quantum networking applications using the two-node ion trap network experiment which we have built here at Oxford.

Francesca Ferlaino - Dipolar physics with ultracold atomic "magnets"

Institut für Experimentalphysik, Universität Innsbruck & IQOQI- Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

This lecture focuses on the physics of quantum-degenerate dipolar gases. In such systems, long-range and anisotropic collective interactions between particles build up, disclosing a plethora of intriguing new phenomena in many-body quantum physics. As building blocks of our systems, we will primarily focus on strongly magnetic lanthanide atoms, such as erbium and dysprosium. However, a large part of the physics discussed will equally apply to dipolar molecules. We will first review the basic properties of magnetic lanthanides relevant for quantum gas experiments. Subsequently, we will demonstrate how these properties open unprecedented routes, enabling achievements such as direct quantum degeneracy with identical fermions or the emergence of new states of matter, such as self-bound macrodroplets and supersolids. Finally, we will discuss the creation of extended Hubbard models and spin models in lattice-confined, long-range correlated particles.

Ana Maria Rey - Building with Crystals of Light and Quantum Matter: From clocks to quantum computers

Harnessing the behavior of complex systems is at the heart of quantum technologies. Precisely engineered ultracold gases are emerging as a powerful tool for this task. In my lectures I will explain how ultracold alkaline earth atoms (AEAs) trapped by light can be used to create optical lattice clocks – the most precise timekeepers ever imagined. I am going to explain why these clocks are not only fascinating, but of crucial importance since they can help us to answer cutting-edge questions about complex many-body phenomena and magnetism, to unravel big mysteries of our universe and to build the next generation of quantum technologies.

More specifically, during my lectures I will discuss why an unique appeal of AEAs fermionic atoms featuring n internal levels is their unique SU(n) symmetric collisions and how this symmetry can give rise to complex many-body phenomena and magnetism. The latter opens a path to engineer synthetic materials with no yet known counterpart in nature. I will also discuss how to use laser fields to make neutral AEAs behave as charged electrons in ultra-strong magnetic fields, and as a tool to engineer useful entangled states. I will finally explain why the proposed schemes open a window to enhance clock sensitivity beyond what is possible with uncorrelated atoms, and, set a foundation for future quantum computers.

Ron Folman - Can a Rock be a Wave? From 100 years of De-Broglie's Wave-Particle Duality, to Quantum-Gravity.

It is almost exactly 100 years since de-Broglie made public his outrageous hypothesis regarding Wave-Particle Duality (WPD). I will discuss matter-wave interferometry in the context of complementarity and WPD. I will then ask the question of whether there is a limit to the mass we can send through an interferometer, and explain what are the hindering factors. Specifically, I will use the Stern-Gerlach (SG) effect, which has become a paradigm of quantum mechanics, to illustrate the problems involved in interferometry of large masses. I will then describe how the atom chip may be useful in realizing a large-mass interferometer.

I will briefly describe how the realization of such an experiment could open the door to a new era of fundamental probes, including the realization of previously inaccessible tests of the foundations of quantum theory and the interface of quantum mechanics and gravity, including the probing of exotic theories.

Finally, as an anecdote noting also de-Broglie's less popular assertion, namely, that the standard description of QM is lacking, I will also present interferometry in the eyes of Bohmian mechanics, which is an extension of de-Broglie's ideas concerning the pilot wave.

Time permitting, I will also discuss technological applications stemming from interferometry.

https://tzin.bgu.ac.il/atomchip/

ICAP Summer School Timetable

Monday 8th July

15:30 - 18:30	Arrival and registration		
19:00 - 20:00	Welcome reception		

Tuesday 9th July

09:00 - 10:15	Lecture 1	Jean Dalibard	Coherent Matter Waves
10:15 - 11:15	Coffee break and poster session (A)		
11:15 - 12:30	Lecture 2	David Lucas	Ion trapping and Quantum Computing
12:30 - 14:00	Lunch break		
14:00 - 15:15	Lecture 3	Michel Brune	Quantum simulation with optical tweezers and Rydberg atoms
15:15 - 16:00	Coffee break		
16:00 - 17:00	Student talks session 1	Ryuji Moriya	Density-dependent coherence in a 88Sr tweezer array atomic clock
		Neomi Lewis	Spin squeezing in an array of atomic ensembles via Rydberg Dressing
		Shrestha Biswas	Ultracold field-linked tetratomic molecules
17:00 - 17:15	Short break		
17:15 - 18:30	Lecture 4	Tracy Northup	Ion trapping and Cavities
	Free evening		

Wednesday 10th July

09:00 - 10:15	Lecture 5	Michel Brune	Quantum simulation with optical tweezers and Rydberg atoms
10:15 - 11:15	Coffee break and poster session (A)		
11:15 - 12:30	Lecture 6	David Lucas	Ion trapping and Quantum Computing
12:30 - 13:30	Lunch break		
13:30 - 16:00	Optional lab tours		
16:00 - 17:15	Lecture 7	Jean Dalibard	Coherent Matter Waves
17:15 - 17:30	Short coffee break		
17:30 - 18:30	Student talks session 2	Jana El Badawi	Realization of a continuous superradiant laser with ytterbium atoms
		Sanaa Agarwal	Directional superradiance in a driven ultracold atomic gas in free-space
		Ashwathnarayanan Madhusuda	Binary supersolids with Bose-Einstein condensates
18:30 - 20:00	Dinner		
20:00 - 21:15	Lecture 8	Arno Rauschenbeutel	Light-matter coupling in quantum nanophotonics
21:15 - 22:30	Career session/discussion		

Thursday 11th July

09:00 - 10:15	Lecture 9	Ana Maria Rey	Building with Crystals of Light and Quantum Matter: From clocks to quantum computers
10:15 - 11:15	Coffee break and poster session (B)		
11:15 - 12:30	Lecture 10	Ron Folman	Can a Rock be a Wave? From 100 years of De-Broglie's Wave-Particle Duality, to Quantum-Gravity
12:30 - 14:00	Lunch break		
14:00 - 15:15	Lecture 11	Tracy Northup	Ion trapping and Cavities
15:15 - 16:00	Coffee break		
16:00 - 17:00	Student talks session 3	Poppy Joshi	Developing Bose-Einstein condensate Microscopy
		Lex Joosten	Einstein-Podolsky-Rosen Experiment with spatially separated entangled Bose Einstein Condensates
		Jean-Baptiste Gerent	Ultra-cold 87Rb in a 2D spherical trap: bubbles in the International Space Station.
17:00 - 17:15	Short break		
17:15 - 18:30	Lecture 12	Francesca Ferlaino	Dipolar physics with ultracold atomic “magnets”
19:00 - 22:00	Formal dinner		

Friday 12th July

09:00 - 10:15	Lecture 13	Ron Folman	Can a Rock be a Wave? From 100 years of De-Broglie's Wave-Particle Duality, to Quantum-Gravity
10:15 - 11:15	Coffee break and poster session (B)		
11:15 - 12:30	Lecture 14	Arno Rauschenbeutel	Light-matter coupling in quantum nanophotonics
12:30 - 14:00	Lunch break		
14:00 - 15:15	Lecture 15	Francesca Ferlaino	Dipolar physics with ultracold atomic “magnets”
15:15 - 16:00	Coffee break		
16:00 - 17:00	Student talks session 4	Gokul Vengillasery Illam	Cavity-based non-destructive detection in ultracold gases
		Eric Sierra Garzo	Universal scaling laws for correlated decay of many-body quantum systems
		Martin Steinel	Black-body radiation shifts of ion-based optical clocks
17:00 - 17:15	Short break		
17:15 - 18:30	Lecture 16	Ana Maria Rey	Building with Crystals of Light and Quantum Matter: From clocks to quantum computers
	Free evening		

Saturday 13th July

	Summer school end		

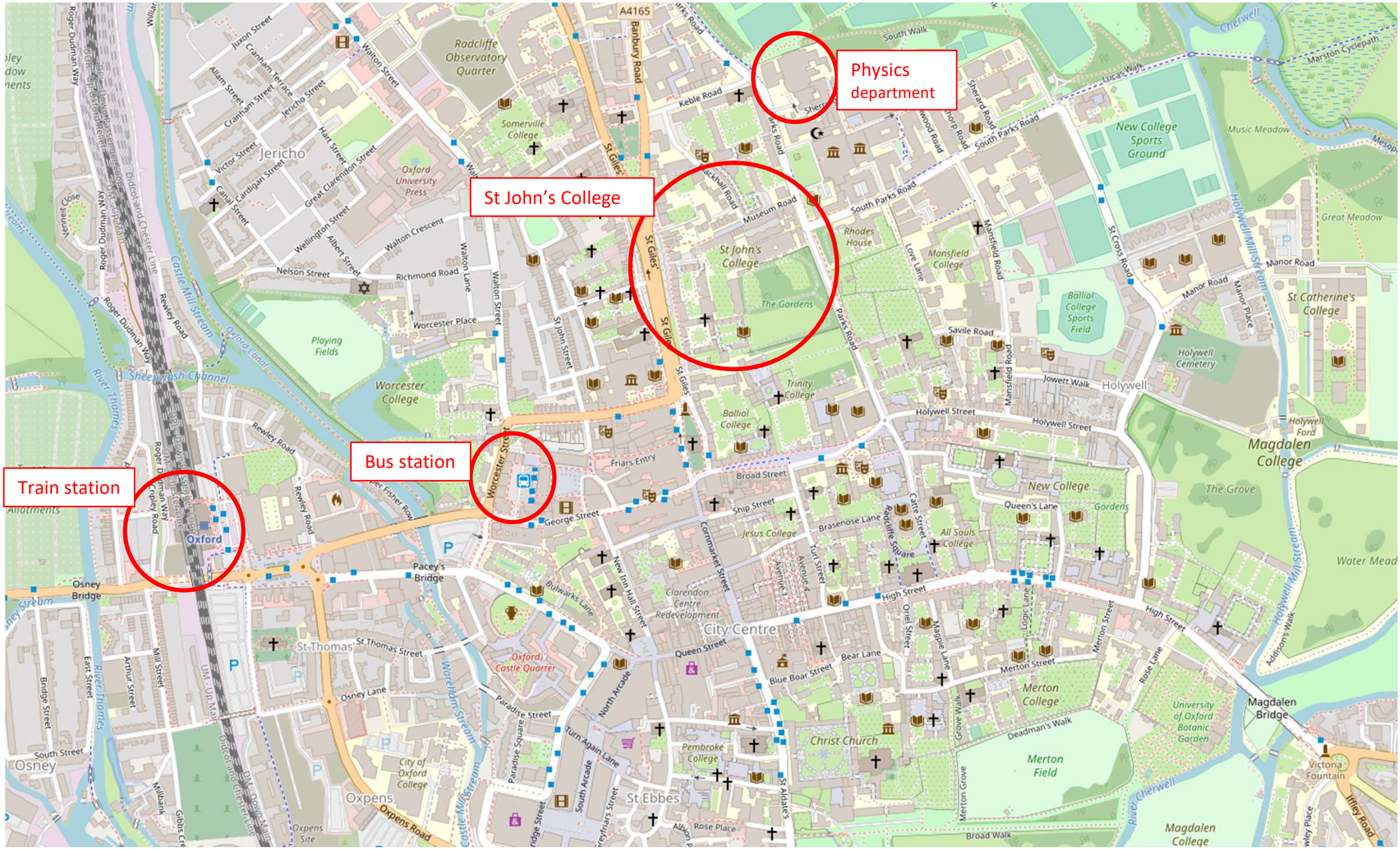
Poster Session A

Zeger Ackerman	University of Amsterdam, Netherlands	Quantum Gates with Trapped Ions Using the Optical Magnus Effect
Archie Baldock	Durham University, UK	Zeeman-Sisyphus deceleration of CaF molecules
David Baur	ETH Zürich, Switzerland	Bragg-spectroscopy of a dissipation induced instability
Shrestha Biswas	Max Planck Institute of Quantum Optics, Germany	Ultracold field-linked tetratomic molecules
Katie Challoner	University of Oxford, UK	Microcavity Fabrication and Characterisation for an Ion-Cavity Quantum Network
Thomas Clarkson	The University of Auckland, New Zealand	Modelling simultaneous strong coupling of an atom to two nanofibre cavity modes
Yingying Cui	ETH Zürich, Switzerland	Trapped-Ion Quantum Computing with Penning Traps
Nella Diepeveen	University of Amsterdam, Netherlands	Trapped ions in optical tweezers
Junlei Duan	Fudan University, China	Concurrent spin squeezing and field tracking with machine learning
Dror Einav	Weizmann institute of science, Israel	Superposition of Nuclear Spin-Isomers
Sarah Embacher	Universität Innsbruck, Austria	Towards sub-wavelength trapping potentials for ultracold Erbium using Q-plates
Ekaterina Fedotova	EPFL, France	A cavity microscope for programmable long-range interactions between fermions
Forouzan Forouharmanesh	University of Waterloo, Canada	Towards superfluid flow experiments with periodic boundary conditions
Kristina Galstian	Russian Quantum Center, Russia	Mid-circuit measurements of optical qubits in 171Yb+ ions using auxiliary Zeeman sublevels
Luca Guariento	Università di Napoli Federico II and CNR-INO, Italy	Rydberg Strontium atoms in array of optical tweezers
Johanna Hennebichler	IQOQI Innsbruck, Austria	Exploring Impurity Dynamics in Ultracold Quantum Gases with Raman Transitions
Jette Heyer	University of Hamburg, Germany	Ultracold and Ultrafast: Creating and detecting matter made of electrons, ions and Rydberg atoms
Mateja Hrast	Institute of Science and Technology, Austria	Ro-vibrational spectroscopy of chiral molecules with vortex beams
Omar Hussein	University of Waterloo, Canada	Towards a 1D Periodic Trap
Gregor Janson	Institute of Quantum Physics, Ulm University, Germany	Osborn Coordinates in Curved Spacetime - Relativistic Signatures in Atom Interferometry
Lex Joosten	Universität Basel, Switzerland	Einstein-Podolsky-Rosen Experiment with spatially separated entangled Bose Einstein Condensates
Nadav Kandel	Weizmann institute of science, Israel	Towards Experimental Realization of a Photon-Atom Square-Root of SWAP Gate
Neomi Lewis	Stanford University, USA	Floquet transverse-field Ising dynamics in a Rydberg-dressed optical tweezer array
Chen Lu	University of Cambridge, UK	Atom Interferometry (AION)
Julian Lyne	Max Planck Institute for the Science of Light, Germany	Purcell modified Doppler cooling of quantum emitters inside optical cavities
Louise McCaul	University College London, UK	RF electric field sensing with atoms in superpositions of Rydberg states with oppositely oriented electric dipole moments
Nehal Mittal	LKB, Paris, France	Probing topological phase transition and critical physics of a synthetic quantum Hall system
Sebastian Morris	University of Cambridge, UK	Evidence for elastic three-body interactions in the collapse of a BEC
Anabel Ovide Gonzalez	Universitat Politècnica de València, Spain	Scaling and assigning resources on QCCD Ion Trap architectures
AISWARYA R	Indian Institute of Technology Patna, Bihar, India	Elastic electron scattering from alkali earth metals- analysis using MCDF approach
Daniel Rodriguez	University of Colorado-Boulder, USA	A new generation 27Al+ optical clock
Eilam Rosenberg	Weizmann institute of science, Israel	Quantum Router for QRAM
Nikita Semenin	Lebedev Physical Institute of the Russian Academy of Sciences	GHZ state creation in a linear ion trap via a single amplitude-shaped radial laser beam
Henry Sewell	Imperial College London, UK	Quantum Sensors for Inertial Navigation
Eric Sierra Garzo	Columbia University, USA	Universal scaling laws for correlated decay of many-body quantum systems
Martin Steinel	Physikalisch-Technische Bundesanstalt	Black-body radiation shifts of ion-based optical clocks
Gokul Vengillasery Illam	Raman Research Institute	Cavity-based non-destructive detection in ultracold gases
Feiyang Wang	University of Cambridge, UK	Toward 2D Uniform Quantum Gases
Chun Kit Wong	University of Innsbruck, Austria	Dipole-Mode Spectrum and Hydrodynamic Crossover in a Resonantly Interacting Fermi-Fermi Mixture
Mikhail Yaushev	Lebedev Physical Institute of the Russian Academy of Sciences	Cold thulium atomic beam for continuous loading of the narrow line MOT

Poster Session B

Carlos Luis Alarcón Robledo	Imperial College London, UK	Towards a high phase-space density AlF gas.
Zsuzsánna Bálint	Babeş-Bolyai University, Cluj-Napoca, Romania	Excitation of the helium by proton and antiproton impact – corelation effects
Giacomo Bisson	ETH Zürich, Switzerland	A novel experimental setup for ultracold fermionic potassium
Shao-Wen Chang	University of California, Berkeley, USA	Towards degenerate fermi gas in an optical kagome lattice
Robbie Cruickshank	University of Strathclyde, UK	Stability of superfluids in tilted optical lattices with periodic driving
Hans Dang	Max Planck Institute for the Science of Light, Germany	Feedback Cooling the Motion of a Trapped Ion
Klaudia Dilcher	University of Warsaw, Poland	Kalman Filters applied to atomic sensors
Balázs Dura-Kovács	Max Planck Institute for Quantum Optics, Germany	Realising fast readout for dual species Rydberg arrays
Jana El Badawi	FEMTO-ST/UTINAM, France	Realization of a continuous superradiant laser with ytterbium atoms
Mai Faibish	Weizmann institute of science, Israel	Cryogenic System for Atomic-Molecular Ion Trap
Simon Fischer	University of Cambridge, UK	Joule expansion of a homogeneous Bose gas
Suyash Gaikwad	University of Basel, Switzerland	Optical memory in a rubidium microfabricated vapor cell
Fiona Hellstern	University of Stuttgart, Germany	A Dysprosium Quantum Gas Microscope
Jost Herkenhoff	Max-Planck Institute for Nuclear Physics, Germany	Sympathetic cooling of ions using electron cyclotron radiation
Thomas Hinde	University of Oxford, UK	Fabrication and characterisation of microlens arrays for scalable ion trap cooling, addressing and readout
Chenxi Huang	University of Illinois at Urbana-Champaign, USA	Strongly interacting dynamics in Rydberg synthetic dimensions
Naman Jain	Max Planck Institute of Quantum Optics, Germany	Rapid Fermionic Quantum Simulator for Random Unitary Observables
Moming Jia	Univerisity of Innsbruck, Austria	Deployable Quantum Network Node Based on Coupling Between Trapped 40Ca+ Ions and High Finesse Optical Cavity Mode
Poppy Joshi	University of Sussex, UK	Developing Bose-Einstein condensate Microscopy
Marcin Kozbiał	University of Warsaw, Poland	Spin noise spectroscopy of an alignment-based atomic magnetometer
Nils Krause	University of Otago, New Zealand	Energy Damping of a Jones-Roberts Soliton: Analytical and Numerical Results
Nila Krishnakumar	Scientific employee at PTB Braunschweig , Germany	Design and Fabrication of an 8-qubit Surface-Electrode Ion Trap Quantum Processor Chip for Swapping Demonstration
Kelvin Lim	Nanyang Technological University, China	Optical superoscillatory techniques for subwavelength trapping and manipulation of cold atoms
Sebastian Luff	Max Planck Institute for the Science of Light, Germany	State discrimination with an 174Yb+ ion
Venkat Ramana Marupaka	Atominstitut, TU Wien, Austria	Local outcoupling modes for repeated measurements in tunnel coupled atoms
Anastasiia Mashko	University of Waterloo, Canada	Rydberg Atom Array Quantum Simulator for Advancing Transformative Technologies
Chirantan Mitra	Nanyang Technological University Singapore	Creation of a skyrmion spin-texture in an ultracold strontium gas
Ryuji Moriya	Durham University, UK	Density-dependent coherence in a 88Sr tweezer array atomic clock
Omar Moutamani	University of Strathclyde, UK	Vortex Dynamics in Ultracold Quantum Mixtures
Lu Qin	University of Nottingham, UK	Enhancing shock wave generation in dissipative and nonlocal nonlinear Rydberg media
David Reinhardt	Institute of Quantum Technologies, Ulm, Germany	Ellipse fitting and error estimation of differential atom interferometry experiments on the ISS
Chiara Rogora	Università di Trento and INO-CNR, Italy	Physics of ultracold spin mixtures in low and stable magnetic field environment
Jillis Schokking	VU Amsterdam, Netherlands	Radiofrequency electron spin resonance spectroscopy in HD+
Jean Servais	Université libre de Bruxelles, Belgium	Resonant states in three-body exotic atoms
Sankalp Sharma	Nicolaus Copernicus University	Unlocking ultra-short time-scale many-body entanglement generation through atom-pair coupling to cavity photons
Felix Spriestersbach	Max-Planck-Institute of Quantum Optics, Germany	Coherent Control of Strontium in an Optical Lattice: Spectroscopy of a M2 Transition and a Fine-Structure Qubit
Jannik Ströhle	Ulm University, Germany	Dimensional Reduction in Quantum Optics
Lorenzo Versini	University of Oxford, UK	Towards Scalable Quantum Computing with Cavity Integrated Ion Trap nodes
Agata Wojciechowska	University of Warsaw, Poland	Exotic ultralong-range Rydberg molecules
Tianyi Yan	University of Nottingham, UK	Probing ergodic breaking dynamics with Rydberg atom quantum simulator

Oxford City Centre



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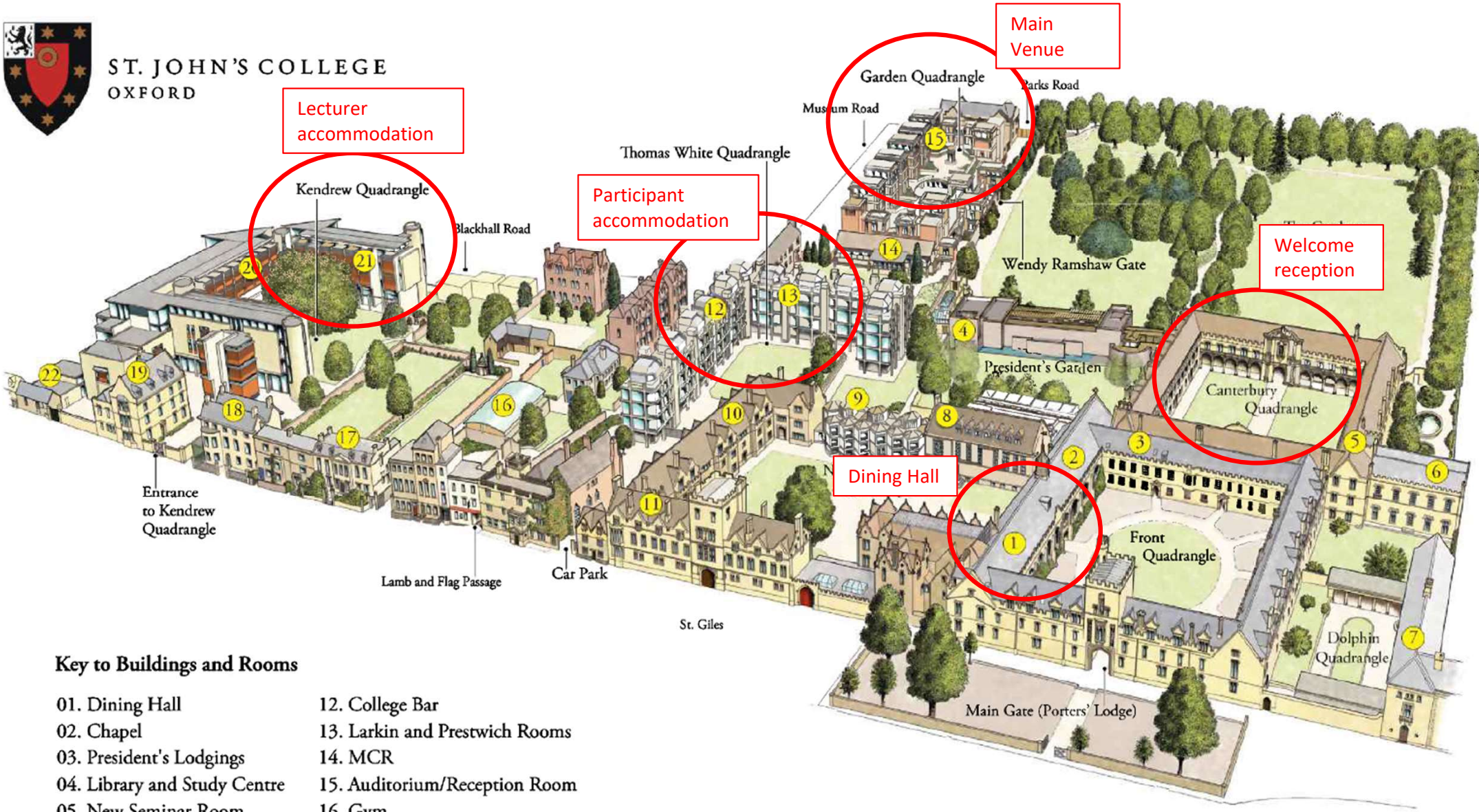

Key to Buildings and Rooms

01. Dining Hall
02. Chapel
03. President's Lodgings
04. Library and Study Centre
05. New Seminar Room
06. Holmes Building
07. Dolphin Lecture Room
08. SCR
09. Beehive
10. Bursary
11. North Lecture Room
12. College Bar
13. Larkin and Prestwich Rooms
14. MCR
15. Auditorium/Reception Room
16. Gym
17. St Giles House
18. Alumni Office and Guest Rooms
19. 21 St Giles
20. Kendrew Café/Gym/Events Room
21. Law Library
22. The Barn/Artist's Studio