Materials and Processes for Quantum Information, Computing and Science Focus Topic
Room B231-232 - Session QS-TuM

AVS Quantum Science (ALL INVITED SESSION)

Moderators: Eray Aydil, New York University, Ivan Petrov, University of Illinois at Urbana-Champaign

8:00am **QS-TuM1 Quantum Technologies from Cold Atoms to Matter-waves***, **Philippe Bouyer**,* CNRS, France **INVITED**

The remarkable success of atom coherent manipulation techniques has motivated competitive research and development in precision metrology as well as quantum simulation.

Our ability to cool down atoms to temperature near absolute zero lead to the production of new state of matter e.g. dilute atomic Bose-Einstein condensates (BEC) and degenerate Fermi gases (DFG) where the single or collective quantum behaviour of the particles takes over their classical properties. At these temperatures, atoms can be described by matter waves which behaviour can help understanding quantum properties of conduction, or with which we can create matter-wave sensors that are sensitive to rotation, acceleration or gravitation.

Quantum transport (eg the conduction of electrons in an imperfect crystal) is today widely investigated by using atoms in controlled potentials that mimic the properties of a solid or a semiconductor. While the ideal case is when no defects exist in the periodic potentials used to reproduce the solid matrix, it is also possible to introduce controlled disordered that will lead to peculiar quantum conduction properties. Semi-classical theories, such as those based on the Boltzmann equation, often fail to fully describe the transport properties and the ultra-cold atoms provide a "quantum simulator" to investigate such properties. These properties extend from Anderson localization, percolation, disorder-driven quantum phase transitions and the corresponding Bose-glass or spin-glass phases.

Matter-wave inertial sensors – accelerometers, gyrometers, gravimeters – use our exquisite control of the matter-wave resulting form cooling atoms near absolute zero. They are today all at the forefront of their respective measurement classes. Atom inertial sensors provide nowadays about the best accelerometers and gravimeters and allow, for instance, to make the most precise monitoring of gravity or to device precise tests of general relativity. The outstanding developments of laser-cooling techniques and related technologies allowed the demonstration of matter-wave interferometers in micro-gravity. Using two atomic species (for instance ^{39}K and ^{87}Rb) allows to verify that two massive bodies will undergo the same gravitational acceleration regardless of their mass or composition, allowing a test of the Weak Equivalence Principle (WEP). New concepts of matter-wave interferometry are also currently developed to study sub Hertz variations of the strain tensor of space-time and gravitation, providing a new window of observation for gravitational waves detectors.

I present here some recent advances in theses fields

8:40am **QS-TuM3 Generating Maximal Entanglement Between Spectrally Distinct Solid-state Emitters***, D. Hurst,* University of Sheffield, UK*; K. Joanesarson,* University of Sheffield, UK, Tech. University of Denmark*; J. Iles-Smith,* University of Sheffield, UK*; J. Mork,* University of Denmark*; **Pieter Kok**,* University of Sheffield, UK **INVITED**

We show how to create maximal entanglement between two spectrally distinct solid-state emitters embedded in a waveguide Mach-Zehnder interferometer. By tailoring the input to the interferometer, we optimise the concurrence of the emitter qubits states and show that a two-photon input state can generate deterministic maximal entanglement even for emitters with significantly different transition energies and line-widths. The optimal frequency is determined by two competing processes: which-path erasure and interaction strength. Smaller spectral overlap can be overcome with higher photon numbers, and quasi-monochromatic photons are optimal for entanglement generation. Our work reveals a rich underlying structure in multi-photon scattering from two non-identical emitters, and provides a new methodology for solid-state entanglement generation, where the requirement for perfectly matched emitters can be relaxed in favour of optical state optimisation.

9:20am **QS-TuM5 From Quantum Atom Optics to Living Cells with Sculpted Light***, **Halina Rubinsztein-Dunlop**, T. Neely, G. Gauthier, T. Bell, A. Pritchard, K. Goddard-Lee, A. Stilgo, I. Favre-Bulle, S. Zhang, T. Nieminen, I. Lenton,* University of Queensland, Australia **INVITED**

Spatial light modulators (SLM) or Digital Micromirror Devices (DMD) give us a great flexibility in sculpting light. What is means is that we have perfect tools that can be used for production of configurable and flexible confining potentials and utilise them to confine atoms as well as lager scale objects and conduct novel experiments outlining light –matter interaction in these systems. In general, we divide the techniques that are used to sculpt light to those based on time average methods and those utilising SLMs in either Fourier plane or direct imaging plane. A Gaussian beam can be modulated using two-axis acousto-optic modulator (AOM) to create highly configurable time-averaged traps. SLMs in Fourier plane control the phase and /or amplitude of an input Gaussian beam, with the pattern representing the spatial Fourier transform of the desired amplitude pattern. The optical system then focuses this sculpted light pattern to the plane containing the system of interests, performing a Fourier transform and recovering the desired pattern. The optical system then focuses this sculpted light pattern to the plane containing the system of interests, performing a Fourier transform and recovering the desired pattern. DMD can configure the amplitude of an input beam either in the Fourier plane or in a direct imaging configuration. Sculptured light produced using these methods promises high flexibility and an opportunity for trapping and driving systems ranging from studies of quantum thermodynamics using ultra cold atoms to trapping and manipulating nano and micron-size objects or even making measurements *in-vivo* inside a biological cell.

In this talk, I will present techniques and results that open up new avenues for the study of quantum fluids, be it by providing a concise atomtronic model for predicting superfluid transport or expanding the accessible parameters space available to fundamental studies of turbulence. The results from our studies of Onsager vortices will be also presented. The realization of negative temperature vortex distributions, long predicted by Onsager, open up the experimental study of the full phase-diagram of 2D vortex matter.

Finally I will demonstrate how carefully sculpted light can be used in microsystems including microthermodynamics and heat engines at that scale.

11:00am **QS-TuM10 Spin-helical Particles: An Enabling Platform for Quantum Matter and Quantum Technologies***, **Yong P. Chen**,* Purdue University **INVITED**

Spin is one of the most fundamental quantum properties of particles. In this talk I will describe our experimental studies of “spin-helical” particles (analogous to neutrinos with spin locked to the momentum, but for electrons and atoms) as a powerful platform to realize novel quantum matter and enable new applications in quantum technologies --- such asquantum information, quantum energy, and even quantum chemistry. In particular, we have demonstrated spin-helical electrons [1,2] on the surface of “topological insulators” (TI) and discovered a “topological spin battery” [3], opening the possibility to electrically induce and readout a nuclear and electronic spin polarization with exceptionally long lifetime --- which we present as a remarkable demonstration of the “topological protection” unique to TI. We further observe unusual behaviors in superconducting Josephson junctions and SQUIDs made out of our TIs [4,5,6], paving the way for using such spin-helical electrons to realize “topological superconductor” proposed to harbor “majorana fermions” that could enable scalable, topologically-protected quantum computing. Time permits, I may also describe an experiment on spin-helical (bosonic) atoms, realized using light-matter interaction to engineer “synthetic” spin orbit coupling and gauge fields on laser-cooled ^{87}Rb atoms in a Bose-Einstein condensate (BEC). We demonstrate a new “interferometric” approach for quantum control of chemical reactions (in our case photoassociation of two atoms into a molecule) by preparing reactants in spin superpositions [7]. It would be interesting to extend such ideas and explore such "quantum beam" experiments the context of surface chemistry and catalysis for example.

Refs: [1] J.Tian et al. Sci. Rep. 5, 14293 (2015); [2] J. Tian et al., Nature Comm. 10, 1461 (2019); [3] J.Tian et al., Science Advances 3, e1602531 (2017); [4] Luis A. Jauregui et al., APL 112, 093105 (2018); [5] M.Kayyalha et al., PRL 122, 047003 (2019); [6] M.Kayyalha et al., arXiv:1812.00499; [7] D.Blasing et al., PRL 121, 073202 (2018)

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