ABSTRACTS

Colloquium

17:00 — 18:00 Jabez J. McClelland (NIST, USA), *Ultrabright ions from ultracold atoms*

Bright sources of charged particles represent a key enabling technology for imaging and nanoscale fabrication with the best possible spatial resolution, temporal sensitivity, and coherence. Traditionally, brightness is achieved by devising ways to get as many charged particles as possible to emit from as small a source area as possible. Sources such as the liquid metal ion source or the field emission electron source are representative of this approach. We have developed a new type of source that takes a radically different approach to attaining high brightness. Utilizing the ultracold temperatures achievable with laser cooling, our source can produce ion beams that not only have very high brightness, but also provide a wide choice of ionic species and a narrow energy spread. This source allows the creation of focused ion beams (FIBs) of new species such as alkalis and alkaline earths with nanometer resolution and picoampere currents, opening new opportunities for nanoscale imaging, material modification and ion implantation. For our first realization, we have constructed a source based on photoionization of a Li magneto-optical trap and mated this source with a conventional FIB column. I will discuss applications of this focused ion beam, both as an imaging tool and as a potential enabler of nanoscale ion transport studies. I will also discuss development of a new, higher brightness cold atom source with applications in nanomachining and integrated circuit edit.

ABSTRACTS
10:30 Session 1

10:35 — 11:00 Paul Griffin (Strathclyde), *Single-shot, phase-insensitive readout of an atom interferometer*

Atom interferometers allow the measurement of forces, which often weakly couple to E-M waves, by measuring the differential phase shifts induced in the atomic wavefunction by the interaction. This atomic phase can then be readout against a lab-frame reference, typically the spatial phase of an optical standing wave. This readout is the major limitation to practical measurement, as the readout requires long temporal-stability of the optical phase, without which the resolution of the atomic signal is lost.

We have built an atom interferometer that is inherently insensitive to the phase noise of the readout system. In this talk I will describe new features developed in our Bose-Einstein condensate system, including tuneable, high-fidelity, symmetric atomic-beamsplitters through a multi-pulse, Kapitza-Dirac scheme. We introduce an atomic homodyne detection that transfers the atomic phase into a temporal atomic beatnote, and show how the entire interferometric signal can be readout in a single shot. First results from the system include a measurement of the fine-structure constant, as well as the strong sensitivity of the atomic phase to gravity.

11:00 — 11:20 Nick Parker (Newcastle), *Dipolar vortices and dark solitons in the quantum ferrofluid*

The achievement of Bose-Einstein condensation with atoms possessing significant magnetic dipole moments [1-4] affords new opportunities to explore the interplay of magnetic effects with the coherent nature of the condensate. This system realizes a quantum ferrofluid, that is, the superfluid analog of the classical ferrofluid. Here we discuss how the dipolar interactions modify quantized vortices, the fundamental nonlinear excitations of superfluids in two- and three-dimensions. As well as distorting the vortex profile, the dipolar interactions cause each vortex itself to approximate a macroscopic dipole; the vortex-vortex interaction then develops a novel anisotropic and long-range contribution [5]. This is shown to significantly modify the two-vortex dynamics and has implications for multi-vortex states such as vortex lattices and the BKT transition. We also discuss the corresponding effect for dark solitons, the 1D analogs of vortices, and prospects for soliton “crystals”.

[1] A. Griesmaier, J. Werner, S. Hensler, J. Stuhler, and T. Pfau, Phys. Rev. Lett. **94**, 160401 (2005).
[2] Q. Beaufils, R. Chicireanu, T. Zanon, B. Laburthe-Tolra, E. Marechal, L. Vernac, J. -C. Keller and O. Gorceix, Phys. Rev. A **77** , 061601 (R) (2008)
[3] M. Lu, N. Q. Burdick, S. H. Youn, and B. L. Lev, Phys. Rev. Lett. **107**, 190401 (2011).
[4] K. Aikawa, A. Frisch, M. Mark, S. Baier, A. Rietzler, R. Grimm, and F. Ferlaino, Phys. Rev. Lett. **108**, 210401 (2012).
[5] B. C. Mulkerin, R. M. W. van Bijnen, D. H. J. O'Dell, A. M. Martin, and N. G. Parker, Phys. Rev. Lett. **111**, 170402 (2013).

ABSTRACTS

11:20 — 11:40 Peter Molony (Durham), *Creation of 87RbCs molecules in the rovibrational ground state*

Ultracold and quantum degenerate mixtures of two or more atomic species open up many new research avenues, including the formation of ultracold heteronuclear ground-state molecules possessing a permanent electric dipole moment [1]. The anisotropic, long range dipole-dipole interactions between such molecules offer many potential applications, including novel schemes for quantum information processing [2] and simulation [3]. Heteronuclear ground-state molecules have been created in KRb [4] and, very recently, in RbCs [5]. Here we present our recent results including, the complete Feshbach spectroscopy of an ultracold 85Rb-Cs mixture [6] and the formation of ultracold Cs2 and 87RbCs Feshbach molecules [7,8]. Finally we show a simple design for a tuneable, narrow-linewidth, two-colour laser system [9] and demonstrate transfer of the 87RbCs Feshbach molecules into the rovibrational ground state via Stimulated Raman Adiabatic Passage (STIRAP) [10].

[1] L.D. Carr et al., New J. Phys. 11(5), 055049 (2009)
[2] D. DeMille, Phys. Rev. Lett. 88, 067901 (2002)
[3] A. Micheli et al., Nat. Phys. 2, 341 (2006)
[4] K.-K. Ni et al., Science 322, 5899 (2008)
[5] T. Takekoshi et al., Phys. Rev. Lett. 113, 205301 (2014)
[6] H-W. Cho et al.,Phys. Rev. A 87, 010703(R) (2013)
[7] M.P. Köppinger et al. New J. Phys. 16 115016 (2014)
[8] M.P. Köppinger et al. Phys. Rev. A 89, 033604 (2014)
[9] P.D. Gregory et al. New J. Phys. 17, 055006 (2015)
[10] P.K. Molony et al., Phys. Rev. Lett. 113, 255301 (2014)

12:10 Session 2

12:10 — 12:35 Jiannis Pachos (Leeds), *Knots, computation and materials*

Combining physics, mathematics and computer science, topological quantum computation is a rapidly expanding field of research focused on the exploration of quantum evolutions that are resilient to errors. In this talk I will presentation a variety of different topics starting from characterizing knot invariants, their quantum simulation with exotic particles called anyons and finally the possible realization of anyons in the laboratory.

12:35 — 12:55 Viv Kendon (Durham), *Quantum walks and their uses*

Quantum versions of random walks have found many applications in quantum computation, quantum transport, and as models of quantum processes. I will give a short overview of some of their properties and uses, including the non-reversing quantum walk that can model a dimer on a lattice [http://arxiv.org/abs/1303.1966; PRA 89, 042332 (2014)]

ABSTRACTS

12:55 — 13:15 Chris Wade (Durham), Optical bistability and terahertz sensing with a Rydberg vapour

Recently our group demonstrated intrinsic optical bistability in a room temperature Caesium vapour cell [1]. The bistability is accompanied by a nonequilibrium phase transition between states of low and high Rydberg occupancy [2]. We have found that it is possible to cross the phase transition by driving resonant terahertz frequency transitions between neighbouring Rydberg states. In this 'terahertz detector' configuration the phase transition enhances the response of the system to the terahertz radiation. I will begin the talk by introducing the optical bistability effect, and move on to discuss terahertz sensing.

[1] C. Carr et. al., Phys. Rev. Lett., 111, 113901 (2013)

[2] M. Marcuzzi et. al., Phys. Rev. Lett., 113, 210401 (2014)

13:15 — 13:25 Daniel Benedicto Orenes (Birmingham), *Pursuing quantum magnetism with cold atoms*

Since the advent of laser cooling techniques quantum gases have become a broad field of research worldwide due to interesting features, e.g. long-time coherence, that increase the potential applications of these systems in both fundamental science and technology. Dipolar interactions in atomic vapours, usually washed out by Zeeman shifts at even Earth-level magnetic fields, can be observed in ultra-cold vapour gases in certain experimental conditions, bringing new phenomena to the already rich dynamics of the system. Dipole-dipole interactions can play a significant role in the dynamics of a spinor Bose-Einstein condensate, however in case of 87Rb atoms in their ground hyperfine state an ultra-low magnetic field environment (~nT) is required. My research is focused on building of an experimental apparatus for studying the magnetic dipolar interactions in rubidium. The requirements include an all-optical formation of the Bose-Einstein condensate and an extremely good magnetic shielding of the setup. We present the current progress, with the 2D and 3D magneto-optical trap operating and the challenges in our set up .

ABSTRACTS
14:30 Session 3

14:30 — 14:55 Manuel Valiente (Heriot-Watt), *Interacting gauge theory with ultracold Bose gases*

I show how density dependent gauge potentials can be induced in dilute gases of ultracold atoms using light-matter interactions. I study the effect of the resulting interacting gauge theory and show how it gives rise to novel states in the ultracold gas at the semiclassical level. In particular, this system supports chiral solitons in one spatial dimension. The nonlinear dynamics in the presence of a current nonlinearity arising from the gauge field and an external harmonic trap are found to give rise to dynamics which violate Kohn's theorem; where the frequency of the dipole mode strongly depends on the strength of the mass current in the gas. The linearised spectrum reveals how the centre of mass and shape oscillations are coupled, whereas in the strongly nonlinear regime the dynamics is irregular.

14:55 — 15:15 James Keaveney (Durham), *Faraday filtering in atomic vapours: from Hamiltonian to application*

The interaction between atoms and light is of essential importance in many areas of physics, and a quantitative understanding of this interaction is therefore beneficial for a variety of reasons, both from the point of view of fundamental physics and for designing applications. We have developed a detailed numerical model [1] of the electric susceptibility (*ElecSus*) for alkali-metal vapours that calculates transition strengths and frequencies, and accounts for applied magnetic field, Doppler broadening and several other experimental effects.

ElecSus can be used as a tool to fit experimental data [2] or predict novel effects, and has already found use in designing an atomic optical isolator [3]. Here we explore one particular application of *ElecSus*; Faraday filtering (often called FADOF filters). A Faraday filter is a high-contrast, ultra-narrow bandpass filter that utilises the birefringent and dichroic properties of atomic media in an applied magnetic field. The filter's transmission profile is strongly dependent on the magnetic field strength and the atomic number density. ElecSus has been used to optimise the performance of such filters, and we see excellent agreement between the theoretical prediction and experimental data [4].

Finally, we explore a further application of Faraday filtering in the context of laser design. Frequency selection is achieved by placing an atomic Faraday filter inside the external cavity of a diode laser system. By carefully engineering the optimal conditions for Faraday filter performance, it is possible to realise a single-mode, single-frequency laser which operates only at the cooling/repump transition frequencies. We envisage that such a system can become a turn-key, maintenance-free laser system for laser cooling experiments.

[1] M. A. Zentile *et al.*, ElecSus: A program to calculate the electric susceptibility of an atomic ensemble, Comp. Phys. Commun. **189**, 162-174 (2015).
[2] M. A. Zentile *et al.*, The hyperfine Paschen-Back Faraday effect, J. Phys. B **47**, 075005 (2014).
[3] L. Weller *et al.*, Optical isolator using an atomic vapor in the hyperfine Paschen-Back regime, Opt. Lett. **37**, 3405 (2012).

[4] M. A. Zentile *et al.*, Atomic Faraday filter with equivalent noise bandwidth less than 1 GHz, Opt. Lett. **40**, 2000 (2015).

15:15 — 15:25 Neal Radwell (Glasgow), *Spatially dependent electromagnetically induced transparency*

Recent years have seen vast progress in the generation and detection of structured light, with potential applications in high capacity optical data storage and continuous variable quantum technologies. Here we measure the transmission of structured light through cold rubidium atoms and observe regions of electromagnetically induced transparency (EIT), using the phase profile as control parameter for the atomic opacity. With q-plates we generate a probe beam with azimuthally varying phase and polarisation structure, and its right and left circular polarisation components provide the probe and control of an EIT transition. We observe an azimuthal modulation of the absorption profile that is dictated by the phase and polarisation structure of the probe laser. Conventional EIT systems do not exhibit phase sensitivity. We show, however, that a weak transverse magnetic field closes the EIT transitions, thereby generating phase dependent dark states which in turn lead to phase dependent transparency, in agreement with our measurements.

16:00 Session 4

16:00 — 16:20 Arin Mizouri (Durham), *A moving trap Zeeman decelerator*

Our research is part of an experimental programme to build a quantum simulator using polar molecules. The aim of this programme, entitled “MicroKelvin Molecules in a Quantum Array” (MMQA), is to cool high densities of molecules to microKelvin temperatures and trap them in an optical lattice to create an ideal, tuneable and highly versatile tool for modelling strongly-interacting quantum systems and understanding the remarkable quantum phenomena they exhibit. [1]

For the direct molecule-cooling route, where molecules are cooled all the way to the ultracold regime (as opposed to first cooling atoms and associating them to form molecules), the MMQA programme has identified a promising pathway -– buffer-gas beam formation and magnetic deceleration of CaF, to reach milliKelvin temperatures, followed by laser cooling in a MOT and sympathetic cooling with laser cooled Li atoms in a microwave trap to reach microKelvin temperatures. [2]

In this talk, progress in the magnetic deceleration part of the pathway will be presented. A modified design of a moving magnetic trap Zeeman decelerator [3] will be described and the results obtained so far will be discussed.

[1] A. Micheli et al., Nat. Phys. 2, 341 (2006).

[2] S. K. Tokunaga et al., Eur. Phys. J. D 65, 141 (2011).

[3] A. Trimeche et al. Eur. Phys. J. D 65, 263 (2011).

ABSTRACTS

16:20 — 16:30 Graham Bruce (St-Andrews), ***High density sub-Doppler laser cooling of ^{40}K using grey molasses on the D_2-line***

Grey molasses is a powerful tool for laser cooling atoms with poorly-resolved hyperfine structure to below the Doppler limit at high densities. It is commonly implemented on the D_1-line after an initial magneto-optical trapping (MOT) phase on the D_2-line [1–3]. We show, using numerical solutions of the Optical Bloch Equations and experiments with ^{40}K, that efficient grey molasses can also be realised on the D_2-line using the same lasers as for the MOT.

For the optical molasses phase, the cooling laser is detuned by −22 MHz from the F = 9/2 → 11/2 transition, and the repumper laser frequency is brought close to a two-photon Raman resonance. The energies of the dressed states vary with the polarization of the light, and with the Raman detuning. When the two-photon detuning lowers the energies of the dark states below those of the bright states, the resultant grey molasses cools the atoms to 42 μK at a density of 1.4×10^{10} cm^{-3}, and provides an efficient method for direct loading of 10^7 atoms into a 200 W crossed optical dipole trap at 1070 nm.

[1] D. Rio Fernandes, F. Sievers, N. Kretzschmar, S. Wu, C. Salomon and F. Chevy, Europhys. Lett. 100, 63001 (2012)

[2] A. T. Grier, I. Ferrier-Barbut, B. S. Rem, M. Delehaye, L. Khaykovich, F. Chevy and C. Salomon, Phys. Rev. A 87, 063411
(2013)

[3] G. Salomon, L. Fouche, P. Wang, A. Aspect, P. Bouyer and T. Bourdel, Europhys. Lett. 104, 63002 (2013)