Organisers: Davide Proment, E-mail d.proment@uea.ac.uk

Each talk is 25 minutes. More information is available here

Superfluids and turbulence

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Dr Fabian Maucher (Durham University, UK)

Title:
Self-Organisation of Light in Optical Media with Competing Nonlocal Nonlinearities

Abstract (see attachment for figures):
This talk will present recent work on nonlinear light propagation in the presence of competing local and nonlocal nonlinearities [1]. Such system could be realized in a gas of thermal alkali atoms [Fig. 1(a)]. Then, the nonlocality of the nonlinearity arises from the diffusive atomic motion and the simultaneous coupling of light to near-resonant transitions involving two incoherently coupled hyperfine levels can give rise to the competion between the non-linearities. Apart from spatial soliton formation, the different length scales of the nonlocality can give rise to filamentation and subsequent self-organised hexagonal lattice formation in the beam profile upon unidirectional propagation [Fig. 1(b)], akin to the superfluid-supersolid phase transition in Bose-Einstein condensates (BECs). The particular role of the optical vorticity in the process of pattern formation will be emphasized and the order of the phase-transition discussed [2].

References
[1] F. Maucher, T. Pohl, S. Skupin, and W. Krolikowski, Phys. Rev. Lett., 116, 163902 (2016)
[2] F. Maucher, T. Pohl, S. Skupin, and W. Krolikowski, Opt. Data Process. Storage 3, 13 (2017)

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Dr Hadi Susanto (University of Essex, UK)

Title: Bifurcations in an annular binary superfluid flow past an obstacle

Abstract:
We consider the dynamics of two coupled miscible Bose-Einstein condensates in ring traps, modelled by coupled one-dimensional nonlinear Schrödinger models with periodic boundary conditions, when an obstacle is dragged through them. Above certain rotation velocities, localized solutions with a nontrivial phase profile appear. In the infinite domain, it was shown that there are two different speeds of sound provides the possibility for three

dynamical regimes: when both components are subcritical, no nucleation of coherent structures; when both components are supercritical they both form dark solitons; in the intermediate regime, we observe the nucleation of a structure in the form of a dark-antidark soliton. In periodic domain, there are many critical velocities. At each critical velocity, the steady flow solutions disappear in a saddle-center bifurcation. These interconnected branches of the bifurcation diagram lead to additions of circulation quanta to the phase of the associated solution. The complex dynamics of the identified waveforms and the instability of unstable solution branches are demonstrated.

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Prof. Simon Gardiner (Durham University, UK)

Title: Imprinting of knotted vortices on atomic superfluids with light and the creation of knotted optical longitudinal polarisation structures

Abstract (see attachment for figures):
Following seminal theoretical [1],[2] and experimental [3],[4],[5] work on constructing knotted optical vortices in laser light in the paraxial approximation, we have studied the creation of knotted ultracold matter waves in atomic Bose–Einstein condensates via two-photon Raman transitions [6], as well as the creation of knotted structures in the longitudinal polarization component of light beyond the paraxial approximation [7]. The Raman transition allows an indirect transfer of atoms from the internal state |a⟩ to the target state |b⟩ via an excited state |e⟩. This enables us to imprint 3D knotted vortex lines embedded in the probe field to the target state density (see Fig. 1).
We have illustrated our approach to structure the longitudinal polarisation component of light by demonstrating linked and knotted longitudinal vortex lines acquired upon nonparaxially propagating a tightly focused subwave-length beam (see Fig. 2). We note that the remaining degrees of freedom in the transverse polarization components can be exploited to generate customized topological vector beams.

References
[1] M.V. Berry, M.R. Dennis, Knotted and linked phase singularities in monochromatic waves, Proc. R. Soc. Lond. A 457 2251 (2001)
[2] M.V. Berry, M.R. Dennis, Knotting and unknotting of phase singularities: Helmholtz waves, paraxial waves and waves in 2 + 1 dimensions, J. Phys. A: Math. Gen. 34 8877 (2001)
[3] J. Leach, M.R. Dennis, J. Courtial, M.J. Padgett, Knotted threads of darkness, Nature 432, 165 (2004)
[4] J. Leach, M.R. Dennis, J. Courtial, M.J. Padgett Vortex knots in light, New J. Phys. 7, 55 (2005)
[5] M.R. Dennis, R.P. King, B. Jack, K. O'Holleran, M.J. Padgett, Isolated optical vortex knots, Nat. Phys. 6, 118 (2010)
[6] F. Maucher, I.G. Hughes, S.A. Gardiner, Excitation of knotted vortex lines in matter waves, New J. Phys. 18, 063016 (2016)

[7] F. Maucher, S. Skupin, S.A. Gardiner, I.G. Hughes, Creating complex optical longitudinal polarization structures, Phys. Rev. Lett. 120, 163903 (2018)

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Dr Thomas Billam (Newcastle University, UK)

Title: Classical turbulence from quantum vortex dynamics

Abstract:
We explore the possible regimes of decaying two-dimensional quantum turbulence, and elucidate the nature of spectral energy transport, by introducing a dissipative point-vortex model with phenomenological vortex-sound interactions. For weak dissipation and large system size we find a regime of hydrodynamic vortex turbulence in which energy is transported to large spatial scales, resembling the phenomenology of the inverse cascade observed in classical incompressible fluids, and connected to the theory of negative temperature "equilibrium" states originally introduced by Onsager. We also demonstrate the emergence of an effective enstrophy cascade in direct numerical simulations of the point-vortex model of decaying 2D superfluid turbulence. We will discuss ongoing work aimed at finding efficient, and experimentally realistic, methods to force turbulence in quasi-2D Bose-Einstein condensate experiments, and on non-equilibrium vortex dynamics in rapidly-rotating condensates.

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Dr Krzysztof Pawłowski (Center for Theoretical Physics of the Polish Academy of Sciences, Poland)

Title: Nonliner phenomana from the many-body perspective in the dipolar bosonic gas

Abstract:
The atoms moving on a circle and interacting via short-range repulsive forces are often described with a non-linear equation possessing dark-solitons among solutions.
The more fundamental is the many-body model, known as the Lieb-Liniger model. Over the last few years beautiful relations between the two descriptions has been found, together with the methods to extract the mean-field phenomena out of the many-body eigenstates of the Lieb-Liniger model. Here we would like to follow the same

routes but for much less understood system of N dipoles on the ring. I will show our results about dipolar solitary waves in the mean-field model and then the numerical solutions of the exact many-body description.
For N bosons with dipolar interactions the role of solitons may be taken by the so called roton state, i.e. there exists a continuous transition between the many-body soliton and the many-body roton.

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Dr Hayder Salman (University of East Anglia, UK)

Title: Detecting Solitons on Quantized Superfluid Vortices

Abstract:
Using a Gross-Pitaevskii equation for a superfluid with suitably tuned parameters to model an electron bubble in superfluid Helium-4, we study the dynamics of the negative ion moving under the influence of an applied electric field. Full 3D simulations are performed to uncover the complex spatio-temporal dynamics for the motion of a bubble trapped on a quantised vortex. Our numerical simulations reveal the dynamical mechanisms that determine the limiting velocity of these ions. Using results obtained from our simulations, we put forward a theory in order to explain the recently measured electron mobilities at very low temperatures. This provides evidence for the presence of Hasimoto soliton excitations residing on the cores of vortices in superfluid Helium-4.

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