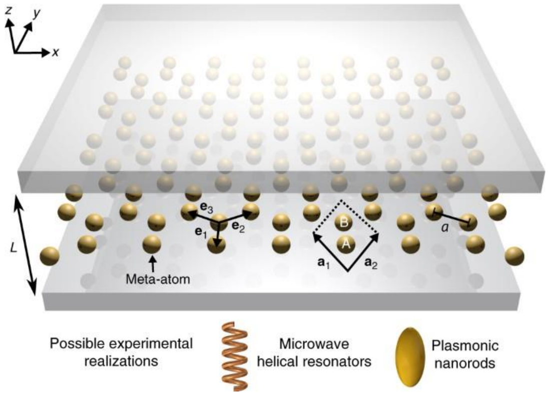
University of Exeter, School of Physics and Astronomy

PhD project in condensed matter theory

Title: ***Quantum theory of topological phase transitions for cavity polaritons in optical metasurfaces***

Supervisors: **Dr. Eros Mariani** and **Dr. Charles Downing**

Abstract – The investigation of topological states of matter has recently become one of the hottest topics of research in physics, leading to the award of the Nobel Prize in Physics to Haldane, Kosterlitz and Thouless in 2016. Topological states of matter exhibit fundamental properties that are protected by their symmetries and cannot be easily altered by small perturbations. This feature makes them the ideal candidates for hosting excitations able to carry information in a topologically protected way. While this seems ideal in view of potential applications in information technology, it can also represent a drawback as the topological phases, once imprinted in the design of a system by breaking specific symmetries, lack the tunability expected from conventional computing and IT devices.



An example of a metasurface realised in a honeycomb array of optical resonators embedded in a photonic cavity [adapted from Ref. [1])

In this project we will explore topological phases of matter in optical metasurfaces – artificial two-dimensional materials realised by designing specific symmetries in arrays of sub-wavelength optical resonators (like e.g. a planar assembly of interacting nano-scale antennas, see Figure). By means of the quantum formalism developed by Hopfield, we will study the bandstructure and fundamental topological properties of the hybrid light-matter excitations of the system (called polaritons) [1]. Due to the hybrid nature of polaritons as half-light half-matter quasiparticles, we will aim to tune their bandstructure and topological properties by modifying the photonic environment alone via an enclosing planar optical cavity [2]. This will allow us to realise topological phase transitions while preserving the lattice symmetries fixed by design at the fabrication stage of the metasurface. We will explore the physical properties of the interfaces between inequivalent topological phases of polaritons in the metasurface, as well as the effect of disorder and lattice distortions on the polaritonic topological phases. In parallel, we will explore the possibility to miniaturise the metasurface to the atomic thickness limit by means of coupled nano-patterned metallic layers. In this context we will analyse the role of metallic gates as a tool to tune the bandstructure of polaritons, launch them, guide their propagation and amplify them via selective parametric resonances.

Methodology – This project will predominantly involve analytical techniques of condensed matter theory, including quantum field theory, quantum optics and many-body quantum theory. It is recommended that interested students are fluent with the fundamental tools of those topics and techniques in order to get a quick start in this advanced project.

For further information on this project please contact
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[1] C.-R. Mann, T. J. Sturges, G. Weick, W, L. Barnes and E. Mariani, Nat. Commun. **9**, 2194 (2018).
[2] C.-R. Mann, S. A. R. Horsley and E. Mariani, Nat. Photonics **14**, 669 (2020).