Tunable Topological Dirac Light

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Confining light to the nanoscale, manipulating and transporting it controllably and efficiently over long distances would represent a breakthrough for a new generation of miniaturized ultrafast optical devices. The information would be carried by topologically protected photonic states rather than by slow charges (as in more conventional mesoscopic electronic devices), with dramatic benefits in terms of reliability and efficiency against heating, quantum dissipation, and decoherence. This conceptual revolution will be enabled by the realization of textured (meta)-surfaces with nanoscale structures that offer novel ways to manipulate light in integrated photonic chips. In this PhD project we will use advanced theoretical tools from condensed matter physics to pioneer the exploration of novel topological photonic states and their use for groundbreaking device applications. Our goal is to establish the foundations of *Tunable Topological Dirac Metamaterials* based on two-dimensional (2D) arrays of nano-antennas embedded in ultrathin photonic cavities, hosting a new form of "Dirac light" with unprecedented topological properties.

We have recently unveiled theoretically [1] that the interaction between light in a photonic cavity and the dipolar resonators in a honeycomb array gives rise to a new type of excitation – *Dirac light* – that transports the radiation in the metasurface (see figure). This new half-light/half-dipolar (polariton) excitation inherits its nature of a topological Dirac particle from the honeycomb lattice symmetry, while at the same time it acquires new fundamental properties that crucially depend on the strength of the light-matter interaction. This can be tuned by locally modifying the parameters of the cavity (e.g., its thickness), resulting in dramatic qualitative changes in the fundamental properties of Dirac light, including a tunable dispersion, a propagation speed that can be made to vanish, as well as the manipulation of its topological Berry phase accompanied by the inversion of chirality [1], or the breakdown of the bulk-edge correspondence principle [2], that has no counterpart in any real or artificial graphene systems explored so far.

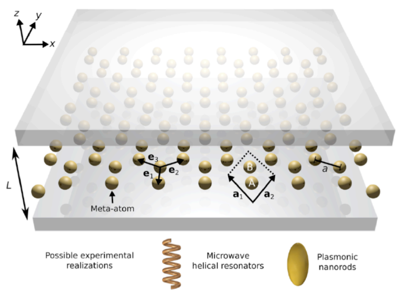

Figure: Schematics of a cavity-embedded honeycomb metasurface. The light-matter coupling can be tuned by the distance L between the two mirrors forming the cavity, while preserving the intrinsic symmetry of the system.

In this theoretical PhD project we will aim to (i) exploit the tunable dispersion of Dirac light to control its propagation, locally slowing it down and confining it, (ii) manipulate its transmission through impurities, barriers, and interfaces, (iii) optimize its mobility and lifetime, and (iv) deflect its motion via fictitious magnetic fields generated by straining the lattice (thus bestowing Dirac light with an effective charge and creating topologically protected edge states). Achieving our ambitious goals will establish a crucial milestone for realizing a new generation of tunable 2D optical devices exploiting concepts from relativistic quantum theory in table-top setups.

[1] C.-R. Mann, T.J. Sturges, G. Weick, W.L. Barnes, E. Mariani, Nat. Commun. **9**, 2194 (2018).
[2] C.A. Downing, T.J. Sturges, G. Weick, M. Stobinska, L. Martin Moreno, Phys. Rev. Lett. **123**, 217401 (2019).