4D Topological Physics with Synthetic Dimensions

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Dimensionality plays a key role in our understanding of topological phases of matter, with different topological invariants characterising systems with different numbers of spatial dimensions. In a 2D quantum Hall system, for example, the robust quantisation of the Hall response is related to the first Chern number: a 2D topological invariant of the energy bands. Generalising up to four spatial dimensions, a new type of quantum Hall effect emerges that is instead related to a 4D topological invariant called the second Chern number.

Although this 4D topological physics may at first seem abstract, recent developments in ultracold atoms and photonics have opened the door to seeing such higher-dimensional effects in the laboratory. In this talk, I will focus on how we could use so-called "synthetic dimensions" to realise 4D quantum Hall systems experimentally with cold atoms [1] or photons [2]. As I will explain, this gives us access to a surprisingly rich variety of different topological phases of matter, as the 4D quantum Hall effect is associated with several distinct symmetry classes of systems. Interestingly, this includes systems which, unlike other 2D and 4D quantum Hall models, do not rely on (artificial) gauge fields, but which can be engineered through lattice connectivity [3]. This opens the way towards harnessing synthetic dimensions for the exploration of a new class of systems that only have nontrivial band invariants in four dimensions or higher.

[1] H. M. Price, O. Zilberberg, T. Ozawa, I. Carusotto and N. Goldman, Phys. Rev. Lett. **115**, 195303 (2015).

[2] T. Ozawa, H. M. Price, N. Goldman, O. Zilberberg, and I. Carusotto, Phys. Rev. A **93**, 043827 (2016).

[3] H. M. Price, arXiv:1806.05263.