# *Creating, moving and merging Dirac points with a Fermi gas in a tunable honeycomb lattice*

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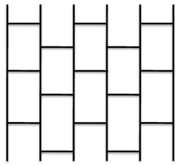
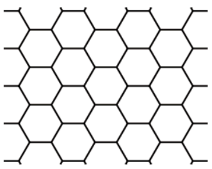
Recommended and a commentary by Tin-Lun Ho, Ohio State University

One of the major efforts in cold atom research today is to use atoms in optical lattices to simulate important lattice models in condensed matter physics. These efforts, if successful, will shed lights on many unresolved problems, and will allow one to explore novel generalizations that are difficult to achieve in conventional condensed matter systems, (such as high spin fermions, multi-species quantum Hall states, etc.) Already these efforts have yielded impressive results. One example is the realization that the entire phase diagram of an infinite homogenous system can be deduced from the non-uniform density profile of a tiny trapped gas. Another example is creation of synthetic gauge field as well as spin-orbit interaction in cold atom systems, (which I discussed in two Commentaries last year). The experiment by Esslinger's group at ETH discussed in this Commentary, which demonstrates the presence of Dirac points in a "rectangular" version of the honeycomb lattice (Fig. (1A) below), is another significant step in the current effort of quantum simulation.

(1A)

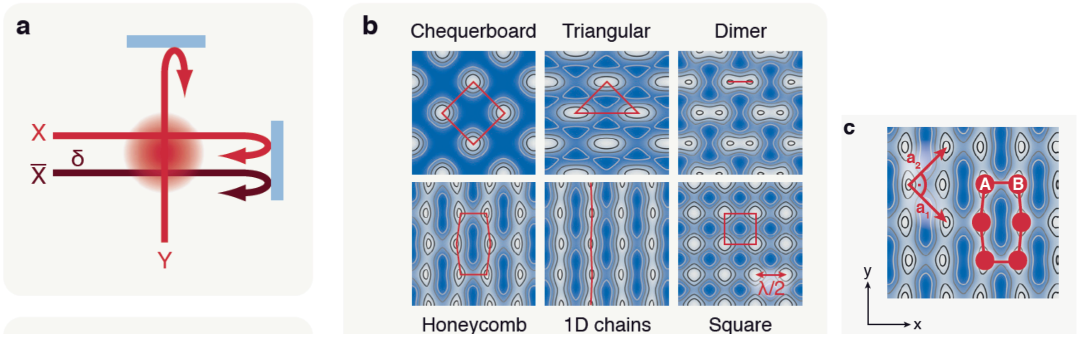


(1B)



The lattice in the ETH experiment is shown in Fig.2a. It is created by two reflected laser beams along x and one along y. By adjusting the phases of these lasers, one can change the locations of constructive and destructive interferences to create different type of lattices, (see Fig. 2b), including the honeycomb equivalence shown in Fig.2c, which is represented schematically in Fig.1.

Fig.2



To demonstrate the presence of Dirac points, the authors loaded the lattice with a cold

Fermi gas so that its momentum distribution is confined in the first Brillouin Zone. A linear magnetic field gradient is then applied along the x-axis, which acts on the neutral fermions as like an electric field on electrons. Subsequently, fermions with different momenta follow different trajectories according to the semi-classical equation of motion, and undergo a Bragg reflection when they reach a Bragg plane. If the trajectory of a fermion never comes close to a Dirac point (such as trajectory (1) in Fig.3), the fermion will kept in the first Brillouin Zone by Bragg reflections. On the other hand, it the trajectory comes close to a Dirac point (such as trajectory (2) in Fig.3), the fermion will make transition to the upper band, which is amount to going into the second Brillouin Zone in the extended Zone scheme. By imaging the fermions after they evolve under the field gradient over a period of Bragg reflection, one can determine not only the existence, but also the location of the Dirac point, as the latter is reflected by the location in the second Brillouin Zone at which fermions emerge (Fig.3a). Using the same imaging method, the ETH group has also demonstrated the capability of the changing the locations of the Dirac points by adjusting the phases of the lasers.

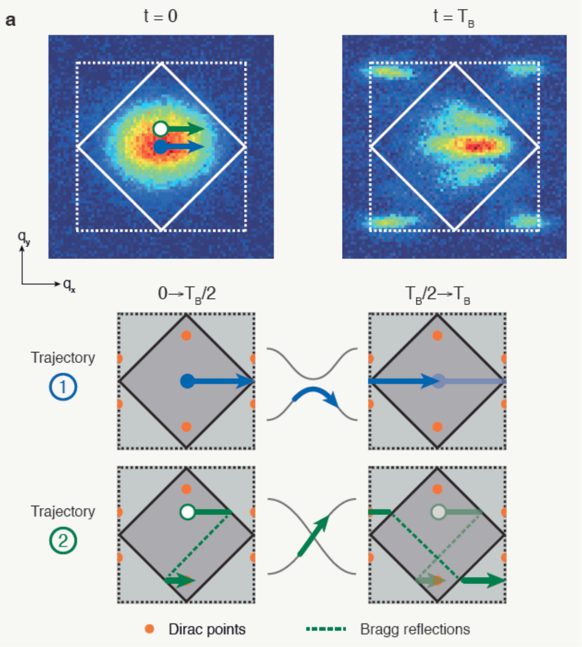


Fig.3

The realization of Dirac points in quantum lattice gases has created the opportunities to study various fundamental aspects of Dirac point physics in ways different from solid state physics. For example, one can directly measure the Berry phase around a Dirac point by interfering packets of fermions (or bosons) traveling on different sides of it. One can also introduce a sharp tunneling barrier as narrow as one or two lattice space using a sheet of light to explore the tunneling of edge states near the barrier. Even more exciting is the possibility to study interaction effects, where interaction strength can be varied significantly using Feshbach resonance. The possibilities are numerous.