- **Quantum Hall effect from the topological surface states of strained bulk HgTe**, C. Brüne, C.X. Liu, E.G. Novik, E.M. Hankiewicz, H. Buhmann, Y.L. Chen, X.L. Qi, Z.X. Shen, S.C. Zhang, and L.W. Molenkamp, Phys. Rev. Lett. **106**, 126803 (2011).

- **Gate-tuned normal and superconducting transport at the surface of a topological insulator**, B. Sacépé, J.B. Oostinga, J. Li, A. Ubaldini, N.J.G. Couto, E. Giannini, and A.F. Morpurgo, arXiv:1101.2352.

Recommended with a commentary by Carlo Beenakker, Leiden University

Massless Dirac fermions can be confined without the energy cost of zero-point motion. This unusual property of the Dirac-Weyl equation is at the origin of the half-integer quantum Hall effect in graphene. The confinement of a massless electron in a cyclotron orbit produces a bound state at zero energy, without the usual $\frac{1}{2}\hbar\omega_c$ offset. This Landau level is shared equally between the conduction and valence bands, so it only contributes half as much to the Hall conductance as the higher Landau levels — hence the quantization in half-integer units of the conductance quantum (which in graphene is $4e^2/h$, including the spin and valley degeneracies).

The surface of a three-dimensional topological insulator is, as Shoucheng Zhang likes to call it, "one-quarter graphene". There is no valley degeneracy (because the Dirac cone is at the center of the Brillouin zone, rather than at a corner) and there is no spin degeneracy (because of strong spin-orbit coupling). The conductance quantum is therefor e^2/h, one quarter the value in graphene. In a magnetic field the top and bottom surfaces contribute in parallel to the Hall conductance, so the expected quantization is in half-integer units of $2e^2/h$ — or equivalently, in odd multiples of e^2/h.

This transport signature of Dirac fermions at the surface of a topological insulator has now been reported by a Würzburg-Stanford collaboration. The Dirac cone itself was first observed spectroscopically in 2008 in a Bi compound, but transport experiments proved difficult because of parallel conduction through impurity states in the bulk band gap. The Würzburg group has a monopoly on MBE-grown HgTe, which has negligible impurity states. Although bulk HgTe has no band gap, the lattice mismatch with a CdTe substrate can open a gap in a sufficiently thin layer (70 nm). This is still thick enough that the top and bottom surfaces conduct independently (since the surface states extend only a few nm into the bulk).

The expected quantum Hall plateaus at odd multiples of e^2/h are observed in magnetic fields up to about 6 T. At higher fields plateaus at even multiples appear as well, which is convincingly explained by Brüne *et al.* in terms of a different carrier density at the top and bottom surfaces.

A magnetic field is one way to confine Dirac fermions and test for the absence of zero-point motion. An electrostatic potential cannot provide this confinement (because of the Klein tunneling effect), but a superconducting pair potential can. Absence of zero-point motion then means that the bound state is in the middle of the superconducting gap (so at zero excitation energy). Because of particle-hole symmetry, such a midgap state would be a particle that is its own antiparticle. This is the defining property of a Majorana fermion, a concept from the early days of particle physics that is now emerging in condensed matter.

Superconducting confinement in a topological insulator is demonstrated in a preprint by Sacépé *et al.* from Geneva. They used 10 nm thin Bi_2Se_3 flakes, exfoliated from single crystals, contacted by two closely spaced superconducting electrodes. The observation of a supercurrent flowing between the electrodes, in the absence of a voltage bias, demonstrates the phase coherent confinement of carriers by the pair potential. This geometry has no bound state, because there is no confinement parallel to the electrodes, but it's a first step towards the realization of Majorana fermions in topological insulators.