Developments in anyonic interferometry

- **Braiding of Abelian and non-Abelian anyons in the fractional quantum Hall effect**, S. An, P. Jiang, H. Choi, W. Kang, S.H. Simon, L.N. Pfeiffer, K.W. West, and K.W. Baldwin, arXiv:1112.3400.
- **Telegraph noise and the Fabry-Perot quantum Hall interferometer**, B. Rosenow and S.H. Simon, arXiv:1111.6475.

Recommended with a commentary by Carlo Beenakker, Leiden University

Quasiparticles in the fractional quantum Hall effect are collective excitations involving a circulation in the two-dimensional (2D) electron gas driven by the Lorentz force from a perpendicular magnetic field. The elementary excitation of unit vorticity is produced by an h/e increment of the flux through the system. If such a vortex is moved slowly (adiabatically) along the circumference of the system it picks up a phase $\alpha = 2\pi Q/e$ proportional to the enclosed charge Q. This is the Aharonov-Casher effect, the dual of the more familiar Aharonov-Bohm effect (where a charge encircles a vortex, while here a vortex encircles a charge). The fractional charge $e^* = \nu e$ and unit vorticity of a quasiparticle in a fraction-ν filled Landau level thus translates directly into a nontrivial phase $\alpha^* = 2\pi\nu$ accumulated by one quasiparticle encircling another. Such exotic particles are called *anyons.* (My favorite introduction is by Ady Stern, arXiv:0711.4697.)

While the fractional charge was measured in the 1990's through shot noise experiments, the fractional phase had remained elusive. The experiments reported this December by Woowon Kang and his group provide clear-cut evidence for an $\alpha^* = 2\pi/3$ phase at $(2 + 1/3)$-filled Landau levels. They measure the conductance oscillations as a function of gate voltage of a Fabry-Perot interferometer, consisting of a μm-size disc with two narrow openings to pass a current. As a function of time the oscillations show random phase slips close to $2\pi/3$. This telegraph noise is interpreted as the tunneling of charge $e^* = e/3$ quasiparticles into or out of the disc, driven by voltage fluctuations in the doped substrate. Detailed modeling by Bernd Rosenow and Steven Simon, including also the effect of Coulomb charging, supports this interpretation. There is not much data yet, only two phase slips are reported, but with more statistics this is likely to become a conclusive demonstration of the existence of Abelian anyons.

The anyons at $\nu = 1/3$ are called Abelian, because the order in which one is moved around the other does not matter (the multiplication of phase factors commutes). Non-Abelian anyons appear in the Moore-Read state at (2+1/2)-filled Landau level. An h/e increment of the flux now produces two quasiparticles of charge $e^* = e/4$, rather than the single $e/2$ quasiparticle one might have expected for $\nu = 1/2$. The reduction by a factor of two of both the quasiparticle charge and vorticity reduces to $\frac{1}{4} \times 2\pi\nu = \pi/4$ the phase accumulated when one quasiparticle encircles the other.

This is still an Abelian contribution. The anyons become non-Abelian because of the 2^n-fold degeneracy of the ground state of $2n$ quasiparticles. The adiabatic motion of quasiparticles around each other amounts in general to noncommuting unitary operations on the ground state manifold. In the Fabry-Perot interferometer the ground state degeneracy is predicted to manifest itself as an additional phase increment of $\pm\pi/2$, where the $\pm$ sign depends on the detailed configuration of the $2n$ quasiparticles in the disc. The difference between an even and an odd number of quasiparticles, studied in earlier experiments by Robert Willett and his group [see Physics **3**, 93 (2010) for a commentary] is not observed here, perhaps because the device is too small.

What is observed is telegraph noise with a phase slip close to $5\pi/4$, interpreted as the combined effect of a $\pi/4$ phase slip from the increment of the quasiparticle number and a π phase slip from the $\pm$ switch in the ground state degeneracy. The interpretation is not quite as convincing as for the Abelian anyons, firstly because these phase slips do not directly test for the ground state degeneracy and secondly because phase slips in a range of values between π and $5\pi/4$ are observed as well.

Midgap states (socalled Majorana fermions) bound to vortices in exotic (chiral p-wave) superconductors provide an alternative pathway to the realization of non-Abelian anyons (see arXiv:1112.1950 for an introduction). In both systems there is rapid experimental progress. These are exciting times.