A quantum spin Hall effect in monolayer graphene without time reversal symmetry

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The quantum spin Hall (QSH) effect[i] is a two dimensional electronic phase characterized by an excitation gap in the bulk but gapless, helical boundary states. Since its original discovery in HgCdTe quantum wells[ii], the QSH effect has become nearly synonymous with the time-reversal invariant two dimensional topological insulator. I will describe recent experiments in which we demonstrate a QSH effect *without* time reversal symmetry, realized by exploiting the particle-hole symmetry of the anomalous Landau level in monolayer graphene[iii]. Using large in-plane magnetic fields, we drive a transition from a spin-unpolarized insulating phase to a spin-polarized metallic phase with ~$2e^2/h$ conductance, in which we observe the nonlocal transport signatures of the QSHE. Simultaneous capacitance measurements, which probe the bulk, show that throughout the transition and into the QSH regime, the bulk gap never closes, in contravention of expectations in the more familiar, time reversal invariant case where the QSH represents a topologically distinct phase of matter. The transition itself occurs via an intermediate canted antiferromagnetic state[iv], which hosts gapped, partially helical edge states that have no analog in topological insulators.

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