Quantum SpinonHall Effect

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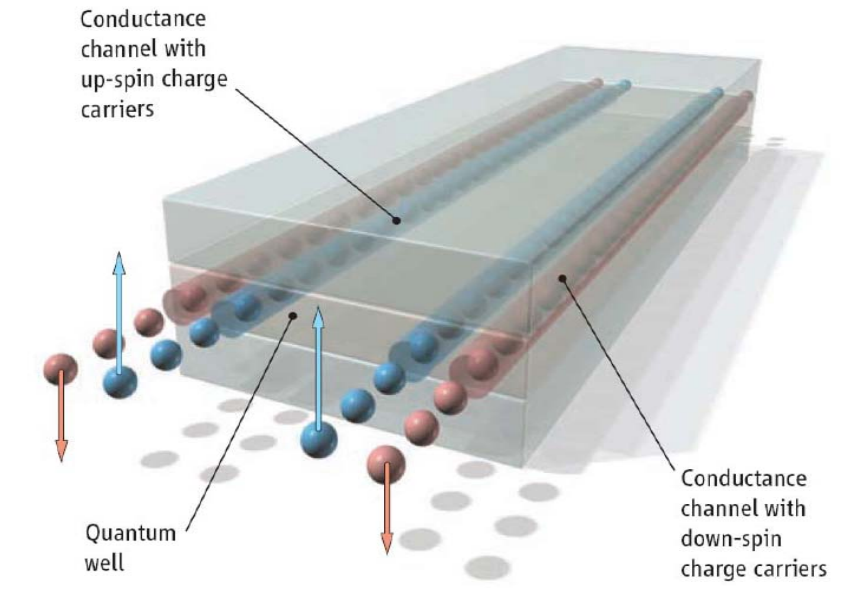
Outline

- Motivation & Model
- Method & Results
- Experimental signature
- Stability
- Future directions

Motivation & Model

Graphene with spin-orbit interactions supports the **quantum spin Hall effect.** Requires TRS and gap in bulk.[Kane &Mele, 2005]

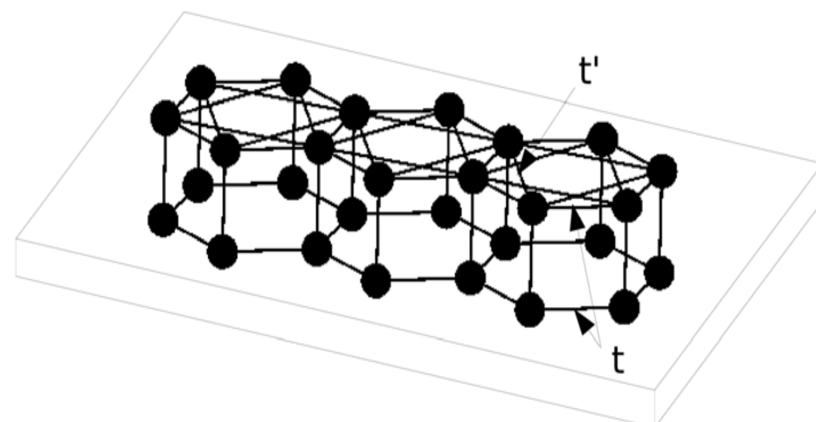


Schematic of the spin-polarized edge channels in a quantum spin Hall insulator.

Hubbard model on honeycomb lattice may support a U(1) spin liquid state with fractionalization near MI. Gapless (Dirac) spinons in bulk. [Lee & Lee, 2005]

Goal: to explore possibility of QSHE arising simultaneously with fractionalization. Need to reconcile QSH bulk gap with U(1) gapless spin liquid →bilayer.

Honeycomb latticebilayer with AA stacking and spin-orbit interaction on layer 1, at half filling.

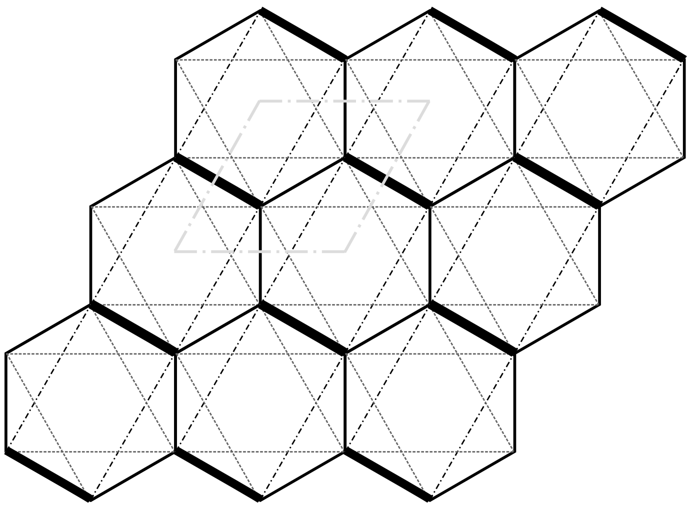


Treat *H* in MFT, using the slave-rotor representation, following Lee & Lee.

Note: U’=2U → interaction involves $n_{i1}+n_{i2}$ only. θ conjugate to n.

Mean Field Solution

For U'~2U, $\theta_{i1}=\theta_{i2}=\theta_i$. Introduce valence bond fields to decouple the quartic terms:

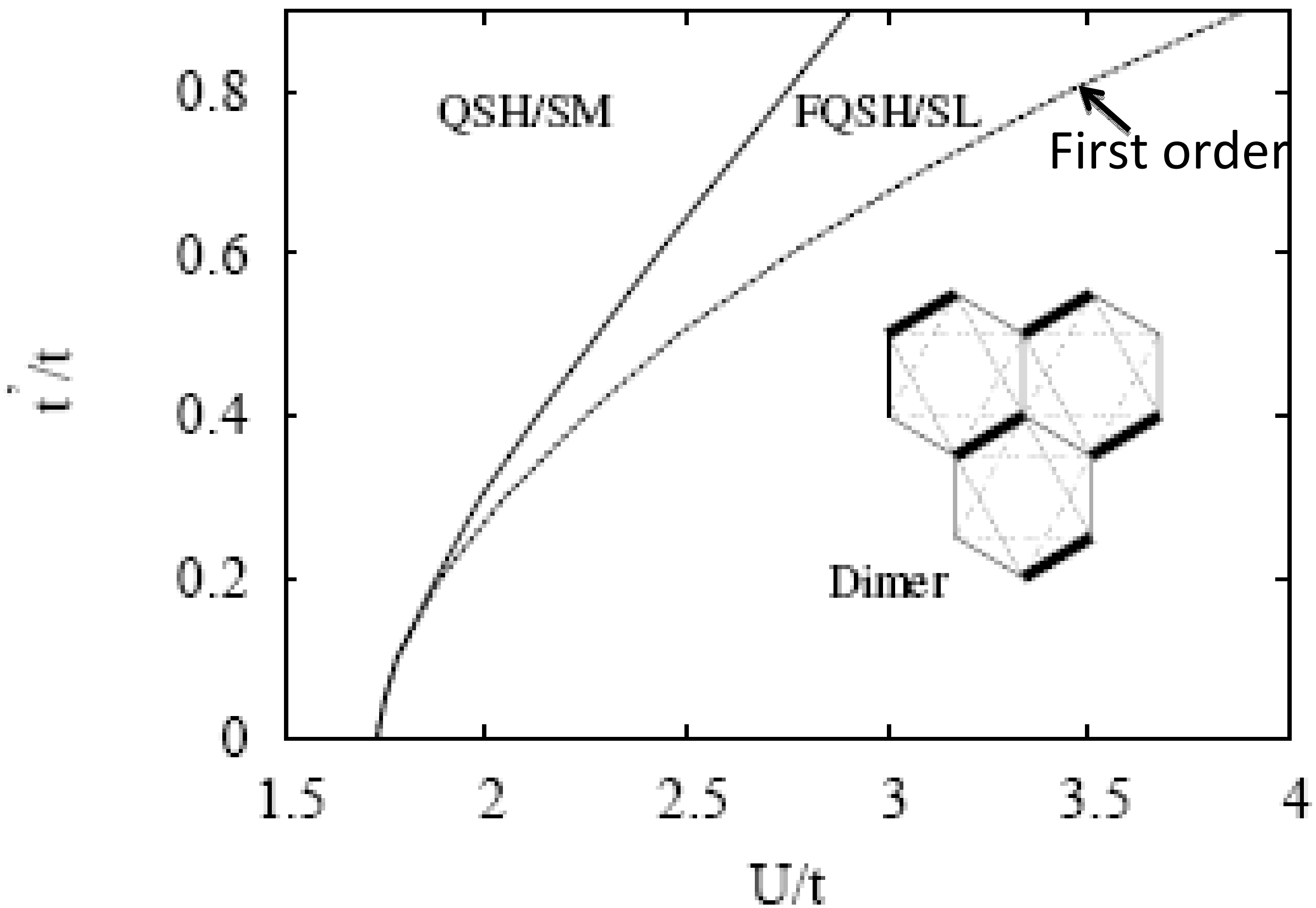


Look for MF solutions corresponding to uniform or periodic valence bond fields.

Small U: uniform solution → conventional QSHE in layer 1 and gapless Dirac fermions (semi-metal) in layer 2.

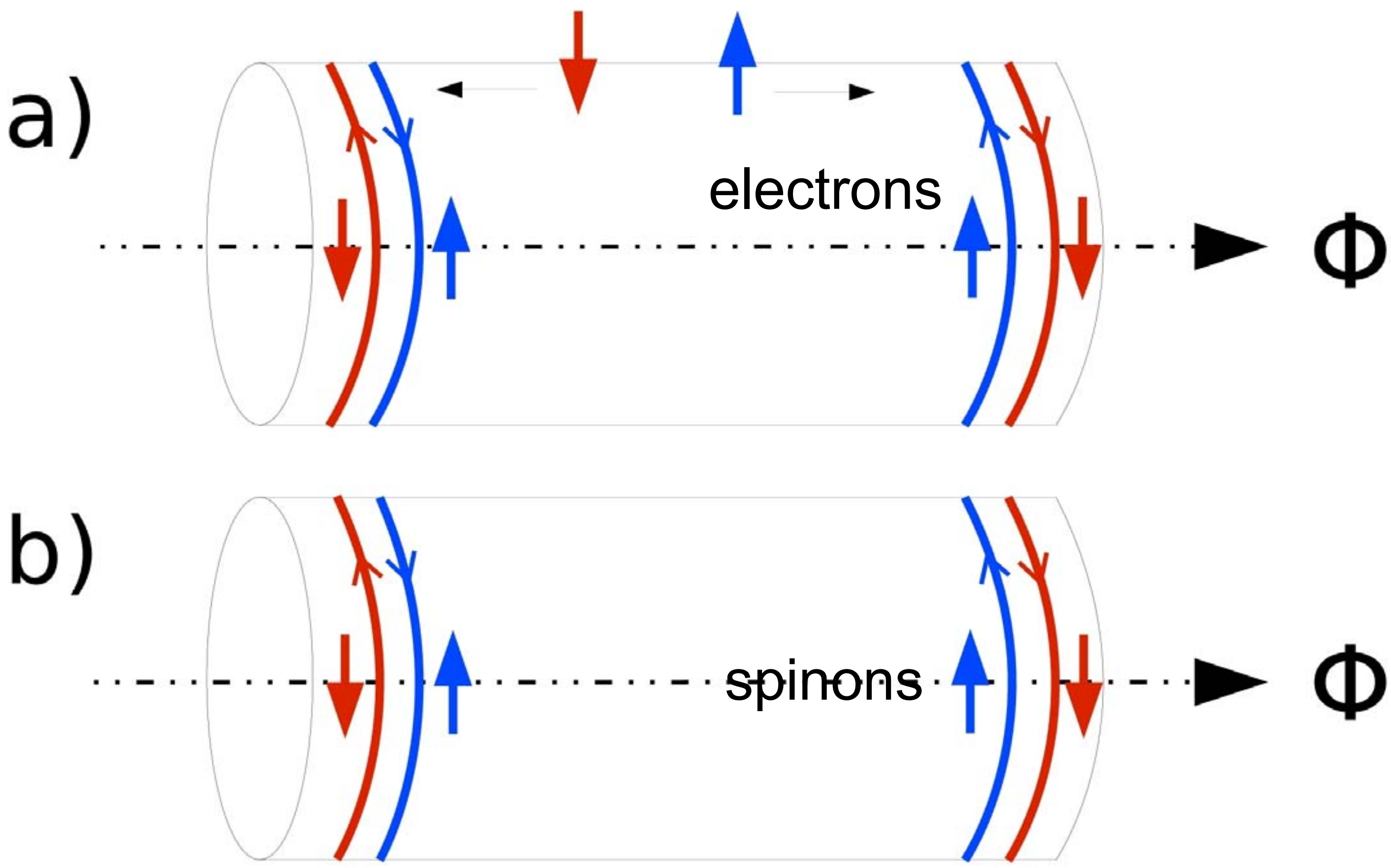
Large U: AFM and dimerized VBS state are degenerate on honeycomb lattice. For bilayer and t'=0, there is a SU(4) symmetry associated with spin and layer index → SU(4) singlets favored. Look at dimerized VBS states.

Find region near MI transition, for sufficiently large t' and U, where a FQSH state is stable in MFT. Note MF term:



FQSH/SL phase: Chargons gapped and massless U(1) gauge field.
1st layer: Spinons gapped in bulk with Kane-Mele spectrum, and gapless spinon edge modes.
2nd layer: Dirac spinons in bulk.

FQSH: edge modes are neutral spinons.



Spin 1 transport in QH case

No spin transport in FQH case

Stability of the Edge Modes

- Need to consider effect of fluctuations and perturbations.
- Compact U(1) gauge theory &instantons: Not a problem when S_z is conserved. Large N Dirac fermions suppress instantons (Hermele et al. 2004). Note key role of 2nd layer.
- U(1) gauge field couples to spinons in both layers. Quantum fluctuations of 1+1D gapless fermions open up gap for the gauge field at the edge → fluctuations of gauge field at edge are suppressed.
- Direct spin-flip interactions between layers (which would break S_z conservation in layers): Scaling argument gives d=-1+O(1/N)+O(K-1).
- Note: there is no tunneling between layers in this model.

Future Directions

- Chargons are gapped → work with spin model. Low energy states for large U satisfy $n_{i1}+n_{i2}=2$ (6 states/site). Adding higher order ring exchanges could help stabilize the phase.

- Note bilayer (or extra flavour) is crucial here for stability. Perhaps QSHE arising with gapped spin liquid (Z_2) would avoid this.

- More realistic model and/or generalization to three dimensions