Excitonic Chern insulator and heavy fermion liquid in AB-stacked $MoTe_2/WSe_2$ moire bilayers

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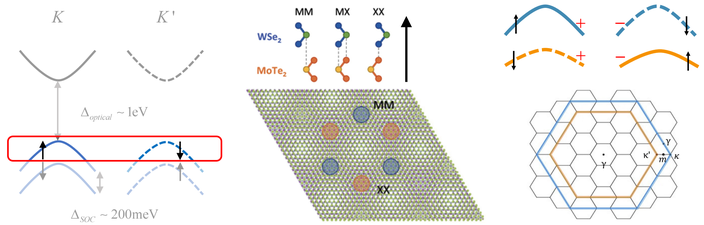
Motivation

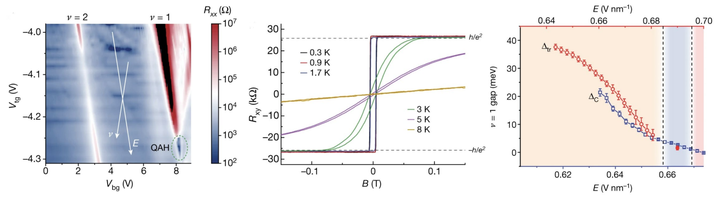
AB-stacked $MoTe_2/WSe_2$ moire bilayers



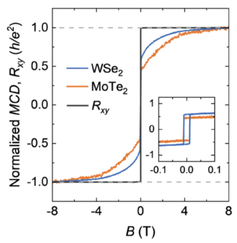
- Strong Ising-like SOC + AB stacking
  ⇒ Opposite spin-valley locking in two layers.
- Moire potential (7% lattice mismatch)
- Wannier orbitals on AB sublattices are layer-polarized.
- Strong interaction in layer B.

Lattice model: Honeycomb, (A) free electron, (B) correlated electron

Experimental evidences on valley-coherent QAH

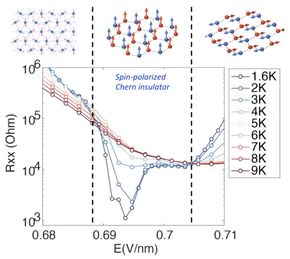


- Valley coherent QAH
- Partial spin polarization from MCD
- QAH survives 8T (spin-polarized limit)
- Finite charge gap at transition
- QAH onsets as soon as charge transfer into WSe_2



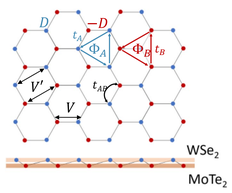
Lessons from experiments

- QAH ⇒ hybridization between AB
- Interlayer tunneling? [1]
  - ➢ Suppressed by symmetry
  - ➢ Favors valley alignment
- Interlayer Hund's* / dipole-dipole?
  - ➢ Layer mixing small, negligible
- Interlayer interaction
  - ➢ $U_{AB} n_A n_B \rightarrow U_{AB}\, \chi\, c_A^\dagger c_B \sim t_{AB} c_A^\dagger c_B$ (exciton condensation)



p+ip exciton Chern insulator

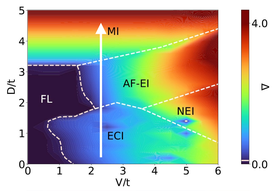
- Lattice model: Kane-Mele + U + V

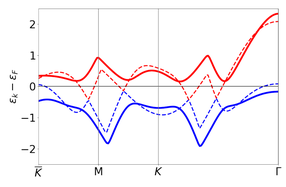


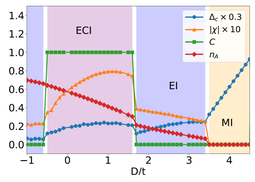
$$H = -t_{AB}\sum_{\langle ij\rangle}(c^\dagger_{i;\alpha}c_{j;\alpha} + h.c.) + D\sum_i (-1)^{\sigma_z(i)} n_i$$
$$- t_A \sum_{\langle\langle ij\rangle\rangle_A} (e^{i\phi^A_{ij}\tau_z} c^\dagger_{i;\alpha} c_{j;\alpha} + h.c.)$$
$$- t_B \sum_{\langle\langle ij\rangle\rangle_B} (e^{i\phi^B_{ij}\tau_z} c^\dagger_{i;\alpha} c_{j;\alpha} + h.c.)$$
$$+ \frac{U}{2}\sum_i n_i(n_i-1) + V\sum_{\langle ij\rangle} n_i n_j + V'\sum_{\langle\langle ij\rangle\rangle} n_i n_j$$

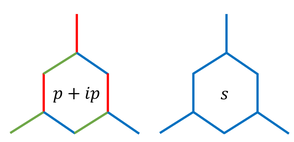
$V\chi\, c_A^\dagger c_B$

- Mean-field: Hartree-Fock + Schwinger boson



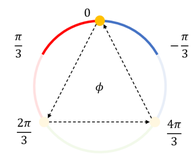


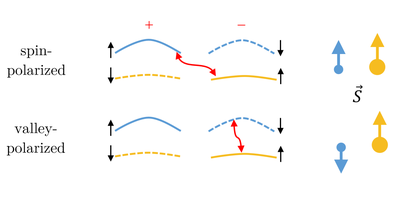


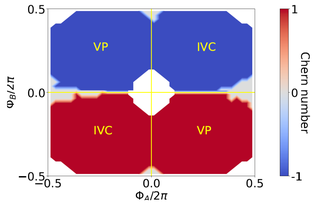


- ECI with spin polarization (valley anti-aligned on two sub lattices)
- Exciton order χ and charge gap Δ_c jumps on the phase boundary.
- Consistent with Schwinger boson mean field theory.
- At low density, trivial EI with 120° order is always favored.
- ECI at finite exciton density.

- Kinetic magnetism
  Gives a reasonable spin stiffness $J \sim x t_A > T_c$.
- $\phi_A = \phi_B = 0$, $U(2)_A \times U(2)_B$, degeneracy between valley-polarized and spin-polarized states.
- $\phi_{A/B} \rightarrow \phi_{A/B} + \frac{2\pi}{3}$ gauged away by local $U(1)_v$: $c_A \rightarrow e^{-i(\kappa\cdot r_i)\tau_z/2} c_A$
- Degeneracy lifted by perturbation in ϕ away from the high-symmetry points.



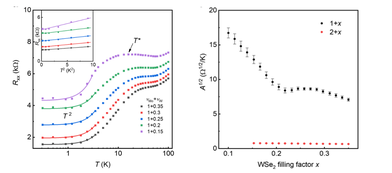


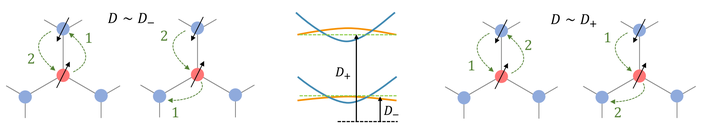


Kondo lattice and heavy fermion liquid

What is the fate at $\nu = 1 + x$?

- Gate-tunable coupling
- Resistance peak
- Enhancement of m^*





$$J_{K;1} = \frac{2t_{AB}^2}{U_B - D - 3V + 6V_B} + \frac{2t_{AB}^2}{D + U_A + V - 6V_B}$$

- $J_K \sim \frac{t_{AB}^2}{\Delta} \ll t_{AB} \ll t_{A,B}$ Kondo model not valid in HFL regime.
- Keep charge fluctuations in the Mott layer.
- Kondo physics from a t-J model?

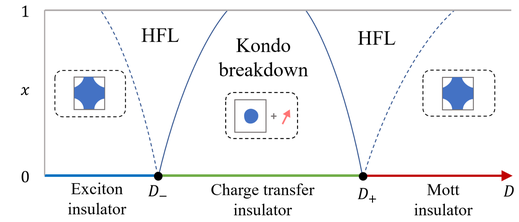
$$\tilde{J}_{K;1} = \frac{2t_{AB}^2}{D + U_A + V - 6V_B}$$
$$\tilde{J}_{K;2} = \frac{2t_{AB}^2}{D + V - 6V_B}$$

$$H = H_A + H_B + H_{AB} + H_\mu$$
$$H_B = -t_B \sum_{\langle ij\rangle} P c_B^\dagger(i) c_B(j) P + h.c. + J\sum_{\langle\langle ij\rangle\rangle} \vec{S}_B(i)\cdot\vec{S}_B(j) + (D_+ - D)\sum_i n_B(i)$$
$$H_{AB} = -t_{AB}\sum_{\langle ij\rangle} c_A^\dagger(i) c_B(j) + h.c. + \tilde{J}_{K;1}\sum_{\langle i,k\rangle}\vec{S}_A(i,i)\cdot\vec{S}_B(k) + \tilde{J}_{K;2}\sum_{i\neq j;\langle i,j;k\rangle}\vec{S}_A(i,j)\cdot\vec{S}_B(k)$$

- HFL from slave boson theory (near D_+)

$$c^\dagger_{B;\sigma}(i) = \epsilon_{\sigma\bar{\sigma}} b^\dagger(i) f_{B;\bar{\sigma}}(i) \qquad n_b + n_f = 1$$
$$H_{MF} = H_A - t_B|\langle b\rangle|^2 \sum_{\langle\langle ij\rangle\rangle_B} f_B^\dagger(i) f_B(j) + h.c.$$
$$- \sum_{\langle ij\rangle}\chi_{ij} c_A^\dagger(i) f_B(j) + h.c. + \sum_{i\in B}\Delta_b n_b(i) - g\sum_{i\in B}(b_i^\dagger + b_i)$$

- Divergent piece of J_K taken care of by t_{AB}, $\tilde{J}_K \approx 0$, $\chi_{ij} \approx t_{AB}\langle b\rangle$
- $D \gg D_+$, c_A gapped, standard slave boson theory for t-J model.
- $D \rightarrow D_+$, charge transfer to A, orbital-selective Mott ($n_A = x$, $n_B = 1$). $\langle b\rangle \rightarrow 0$, $\chi_{ij} \rightarrow 0$, flat f band (HFL)



[1] Tingxing Li, et al. Nature 600, 641–646 (2021)
[2] Trithep, Liang, PRX.12.021031
[3] Zui Tao, et al. arxiv: 2208.07452
[4] Wenjin Zhao, et al. arxiv: 2211.00263

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