Spectra of Magnetoroton and Chiral Graviton Modes of Fractional Chern Insulator

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Main results

Using DMRG(density matrix renormalization group) and TDVP(time-dependent variation principle) for dynamical properties. Our findings reveal that **(1)** the charge-neutral gap(magneto-roton gap) is much smaller than the single-particle gap both deep inside the FCI phase and near the phase boundary. **(2)** The magneto-roton gap minimum is located at the momentum of the CDW order near FCI/CDW transition, and gradually go soft when approaching phase boundary; **(3)** inside the FCI, a strong gapped chiral mode with S = −2 is present and its chirality can be tuned by flipping the time-reversal symmetry. **(4)** the chiral signal observed in the 1/3 fermionic FCI exhibits significantly reduced spectral weight compared to the bosonic case, suggesting potentially distinct behavior of CGM in fermionic FCI. ①

Measuring correlation function

The dynamical structure factor $S^\alpha(k,\omega)$ is written as:

$$S^\alpha(k,\omega)=\frac{1}{\sqrt{TN_\alpha}}\sum_j\int dt\, e^{i\omega t}\, e^{-ik(x_j-x_0)}\langle\hat{n}_{j,\alpha}(t)\,\hat{n}_{0,\alpha}\rangle$$

The correlation function to probe electronic excitation can be written as:

$$G_e^\alpha(k,\omega)=\frac{1}{\sqrt{TN_\alpha}}\sum_j\int dt\, e^{i\omega t}\, e^{-ik(x_j-x_0)}\langle\hat{b}_{j,\alpha}(t)\,\hat{b}^\dagger{}_{0,\alpha}\rangle$$

$$G_h^\alpha(k,\omega)=\frac{1}{\sqrt{TN_\alpha}}\sum_j\int dt\, e^{i\omega t}\, e^{-ik(x_j-x_0)}\langle\hat{b}^\dagger{}_{j,\alpha}(t)\,\hat{b}_{0,\alpha}\rangle$$

Where T is the evolution time for getting $|\psi(t)\rangle$, to measure chiral geometric excitation, we define $L=2$ chiral quadrupolar operators in the next nearest neighbor bond basis$\{n_i\cdot n_j\}$:

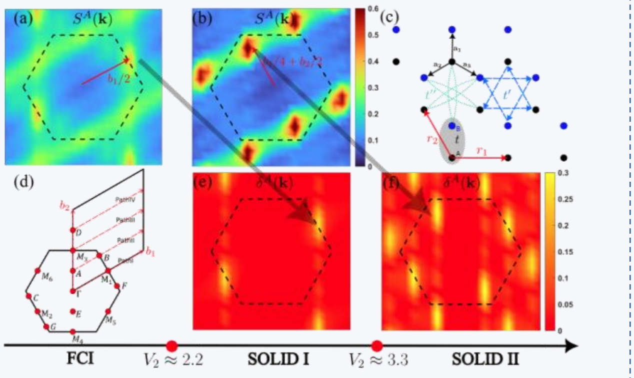
$$O_m^\pm=\sum_l e^{\pm iL_z\phi_l}\, n_{r_m}n_{r_m+\delta_l}$$

And measure its' response function.

$$G_\pm^\alpha(k,\omega)=\frac{1}{\sqrt{TN_\alpha}}\sum_j\int dt\, e^{i\omega t}\, e^{-ik(x_j-x_0)}\langle\left(\hat{O}^\pm{}_{j,\alpha}(t)\right)^\dagger\hat{O}^\pm{}_{j,\alpha}(t)\rangle$$

Hamiltonian and phase diagram

Fig.1 Equal time density correlation function $S^A(k)$ and charge correlation function $\delta_n^A(k)$ along the parameter path we choose, the system undergos a FCI-SolidI-SolidII phase transition. (a),(b) are the $S^A(k)$ of FCI phase and SolidI Real (c) and reciprocal space (d) of honeycomb lattice FCI model (e),(f) are the $\delta_n^A(k)$ of Solid I phase and Solid II phase ① ②

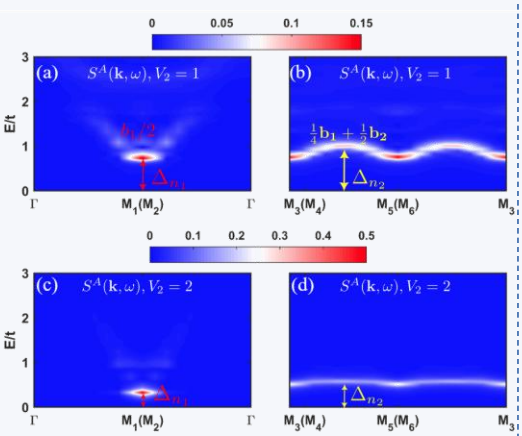


We work on the topological flat band Hamiltonian on honeycomb lattice with the lower flat band ½ filled by hardcore boson or 1/3 filled by spinless fermion.

$$H=-t\sum_{\langle i,j\rangle}(b_i^\dagger b_j e^{i\phi_{ij}}+H.c.)-t'\sum_{\langle\langle i,j\rangle\rangle}(b_i^\dagger b_j+H.c.)-t''\sum_{\langle\langle\langle i,j\rangle\rangle\rangle}(b_i^\dagger b_j+H.c.)+V_1\sum_{\langle i,j\rangle}n_in_j+V_2\sum_{\langle\langle i,j\rangle\rangle}n_in_j$$

Magneto-roton mode

Roton spectrum of FCI phase.(a),(b) are the dynamical structure factor $S(k,\omega)$ deep inside FCI phase along Path I and Path III. Two rotons relavent with the CDW phases are marked with Δ_{n_1} and Δ_{n_2} with its' gap denoted by arrow. The dashed line dipict the dispersion relation of roton that we draw manually. (c), and (d)are that of near the phase boundary $V_1=4, V_2=2$. The 1st roton gap is much smaller than the 2nd roton and 1st-roton gap in FCI phase. As the 1st roton gradually condenses, its weight increase. The point we denote inside the bracket is the identical point that is connected by a reciprocal lattice vector in momentum space

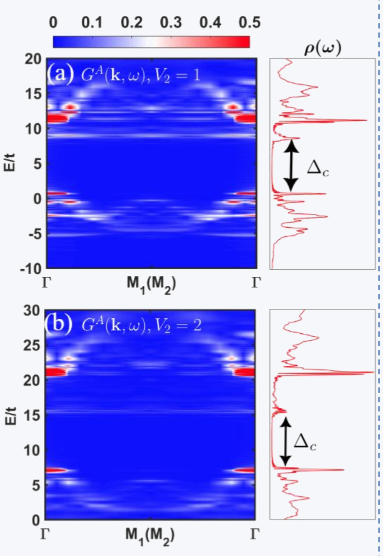


Charge excitation

(a),(b) is the Charge excitation G_e^α and G_h^α. We plot the spectrum as well as the density of state $\rho(\omega)=\int dk\, G(k,\omega)$.

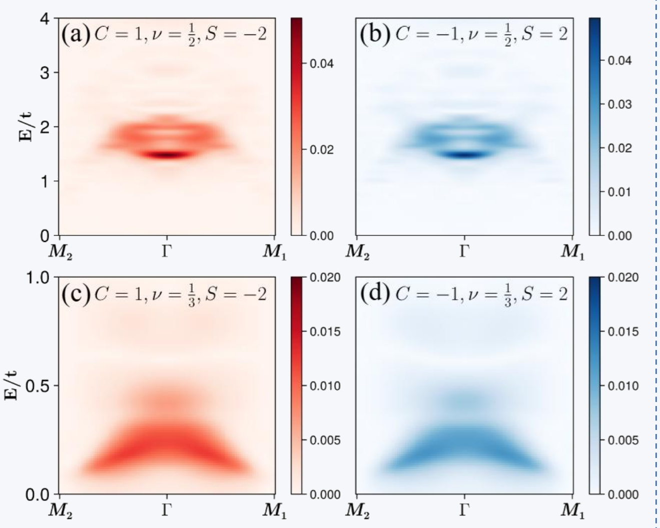
We revert the dispersion of hole according to particle hole symmetry $G^h(k,\omega)=G^c(-k,-\omega)$ and plot two branches of dispersion together.

The estimated charge gap is denoted by black arrow, which is much larger than neutral gap when approaching phase transition point and even get larger.



Chiral graviton mode

CGM measured in ½ bosonic FCI and 1/3 fermionic FCI, $g_\pm(k,\omega)=G^\pm(k,\omega)-G^\mp(k,\omega)$ measure from ±1 chern band, we observe clear graviton mode above the Γ point, with it's energy roughly double of roton gap. Such chirality could be reverted by chiral transformation.



Bibliography

①Min, Long, et al . arXiv:2501.00247
② Lu, Hongyu, et al. "Vestigial Gapless Boson Density Wave Emerging between $\nu=1/2$ Fractional Chern Insulator and Finite-Momentum Supersolid." arXiv preprint arXiv:2408.07111 (2024).