Physics of Kagome Metals

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Tanusri Saha-Dasgupta
SNBNCBS

References :

1. **Interplay of magnetism and topological superconductivity in bilayer kagome metals, PRL, 2020**
2. **Upcoming preprint**

Funding :

1. **SERB-DST**
2. **Max Planck Partner Group Grant**

Two Central areas of excitement in present quantum condensed matter

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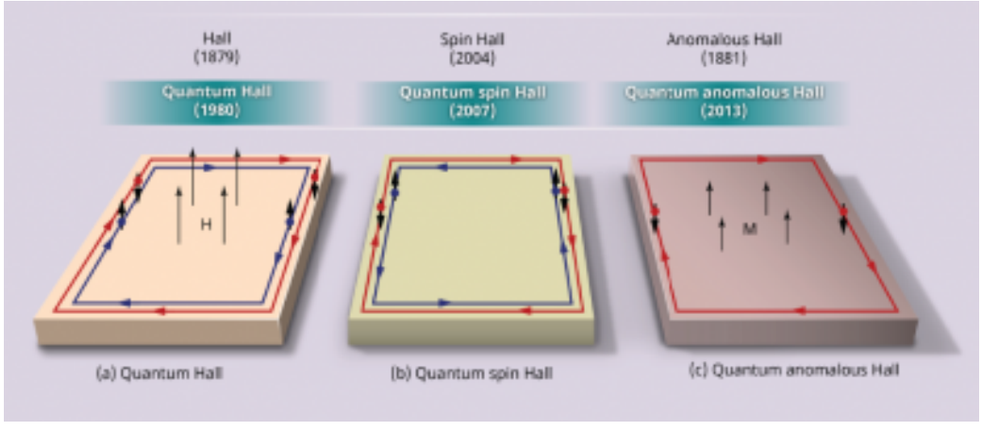
Band Topology



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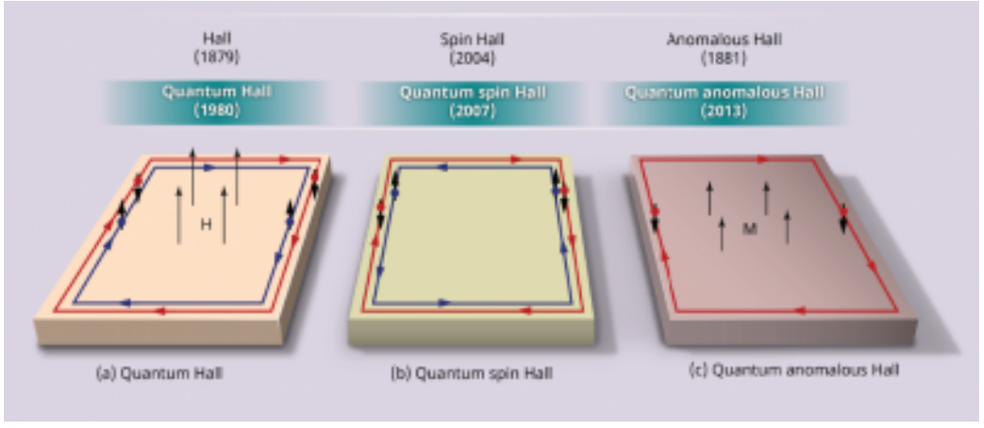
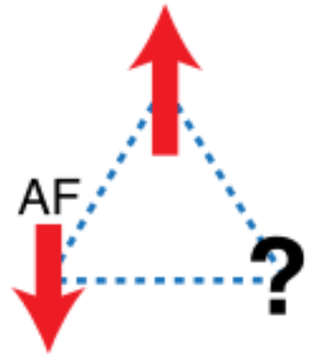


Competing Interactions



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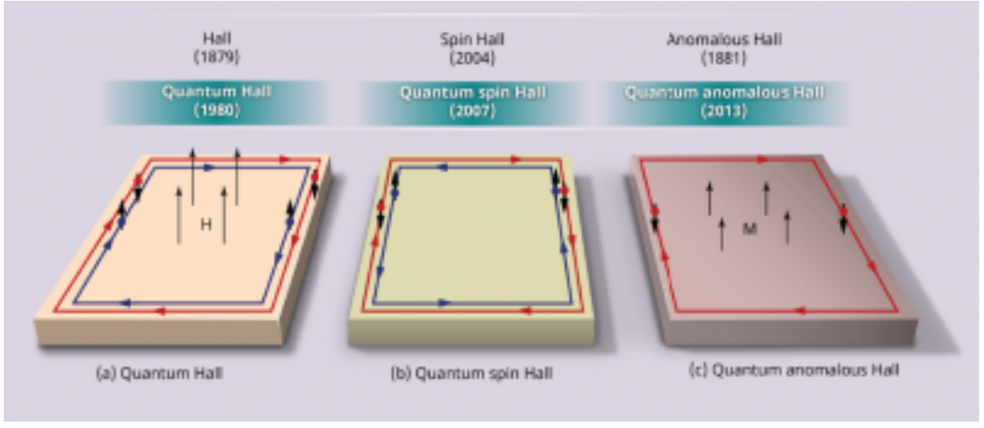

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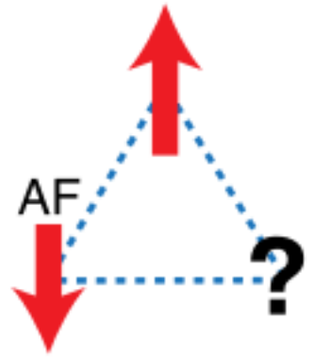

A lot of insights into the novel physics of these systems over the last four decades

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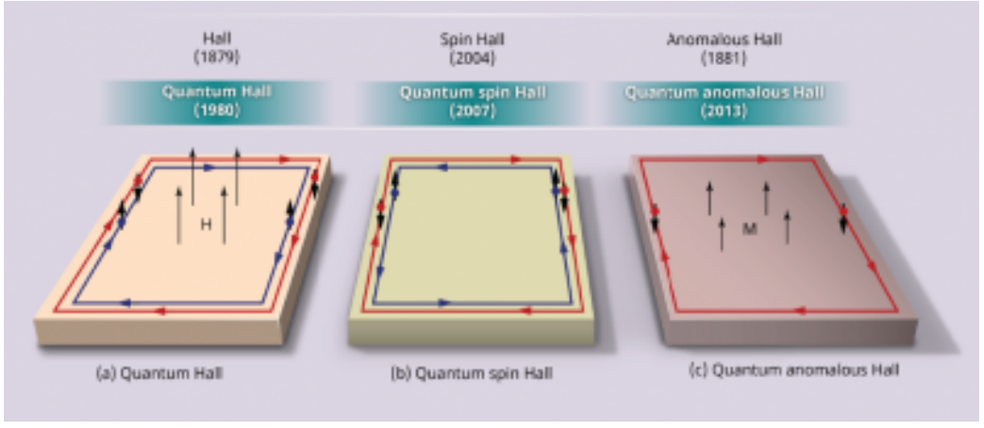

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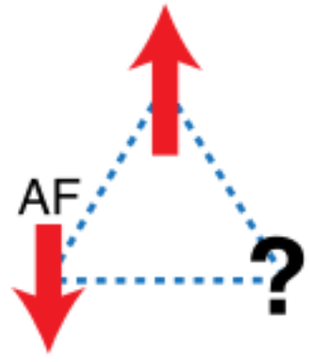

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Concretely sets up the question of the present times :

What is the fate of interactions in partially filled topological band ?

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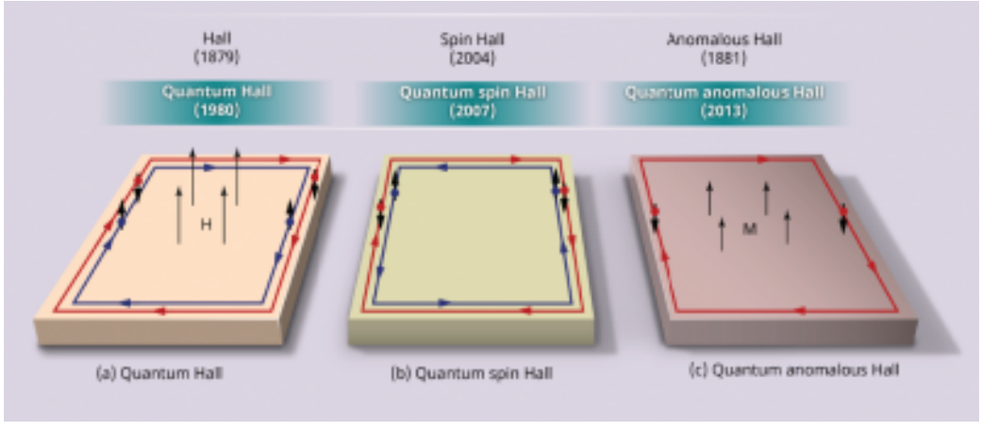

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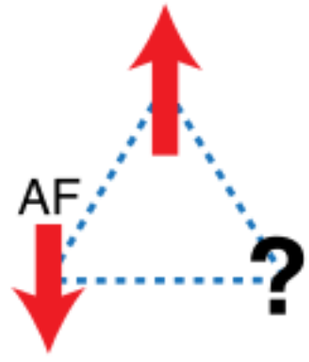

A lot of insights into the novel physics of these systems over the last four decades

Concretely sets up the question of the present times :

What is the fate of interactions in partially filled topological band ?

This generalizes the question of Fractional quantum hall effect to a much larger settings
With more MANY more material contexts

Fractional Chern Insulators, Moire systems, topological flat bands…….

A natural platform : Topological flat / almost flat bands

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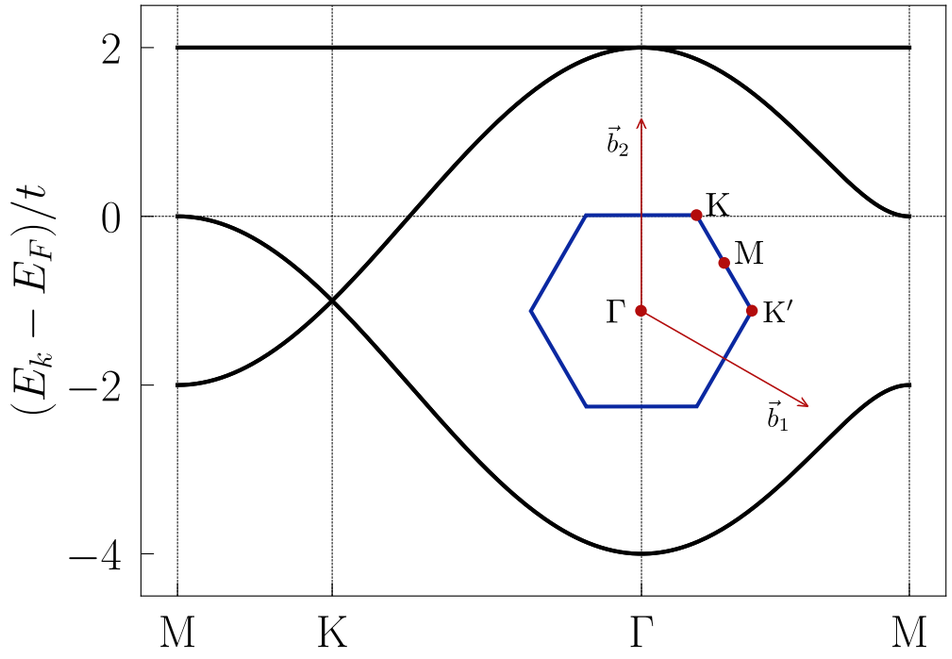

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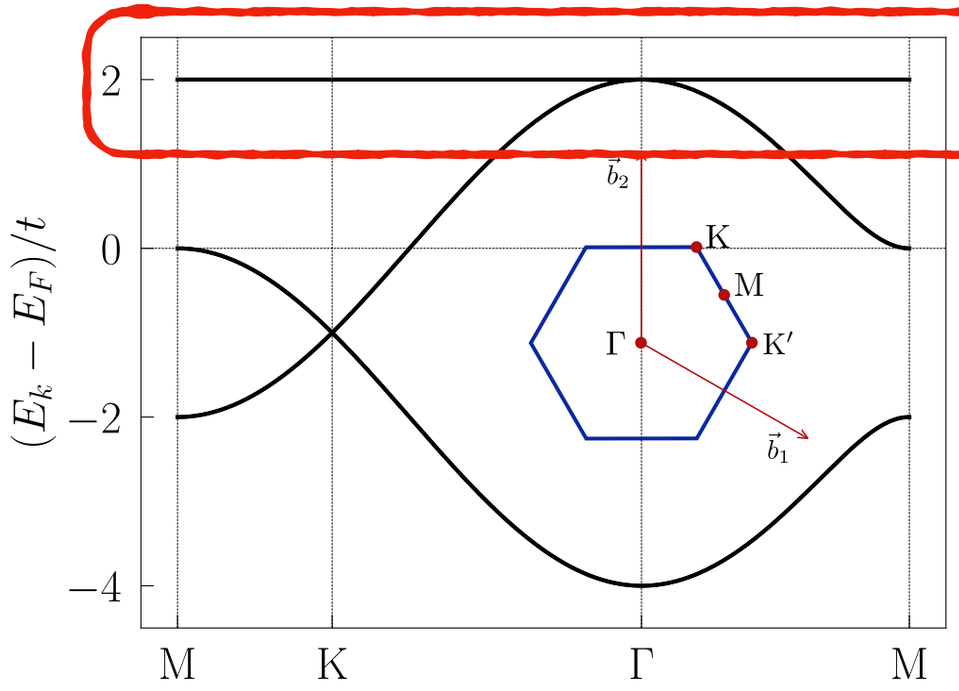

- Trivial Flat bands (isolated orbitals) can be isolated but are singular but interesting (SYK, Topological order….)
- Non-trivial flat bands cannot be isolated. They have band touchings without breaking symmetries

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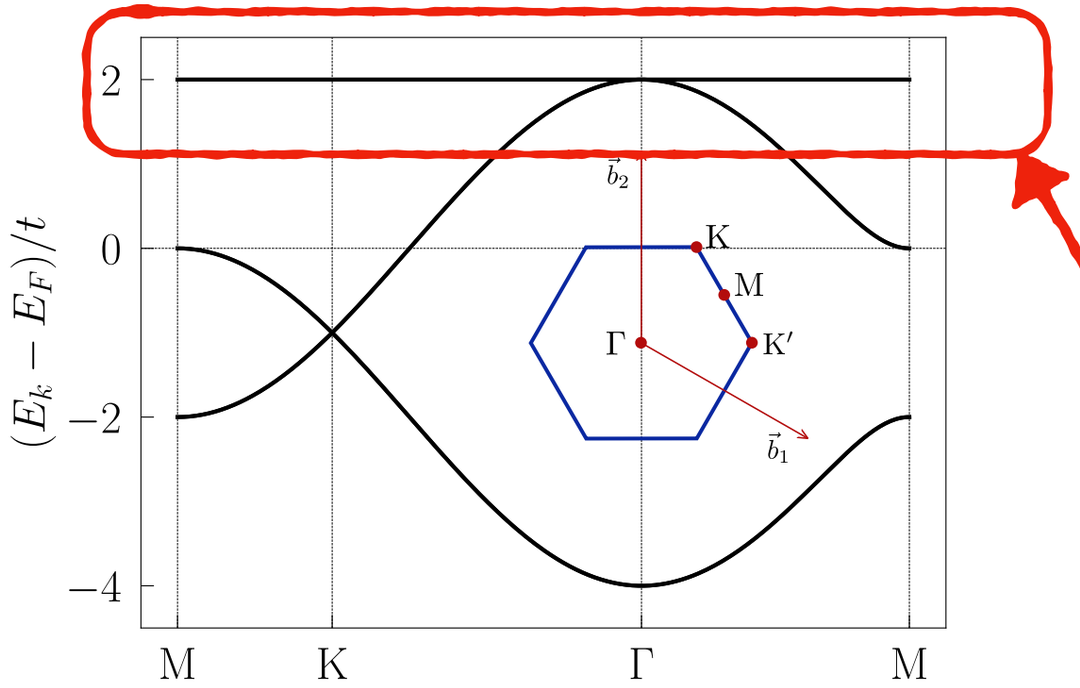

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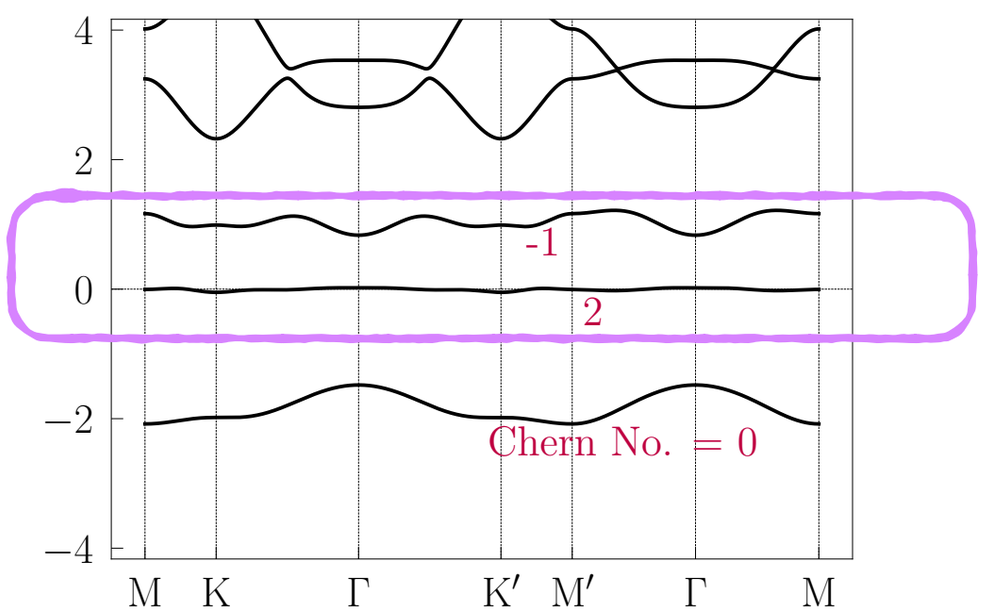

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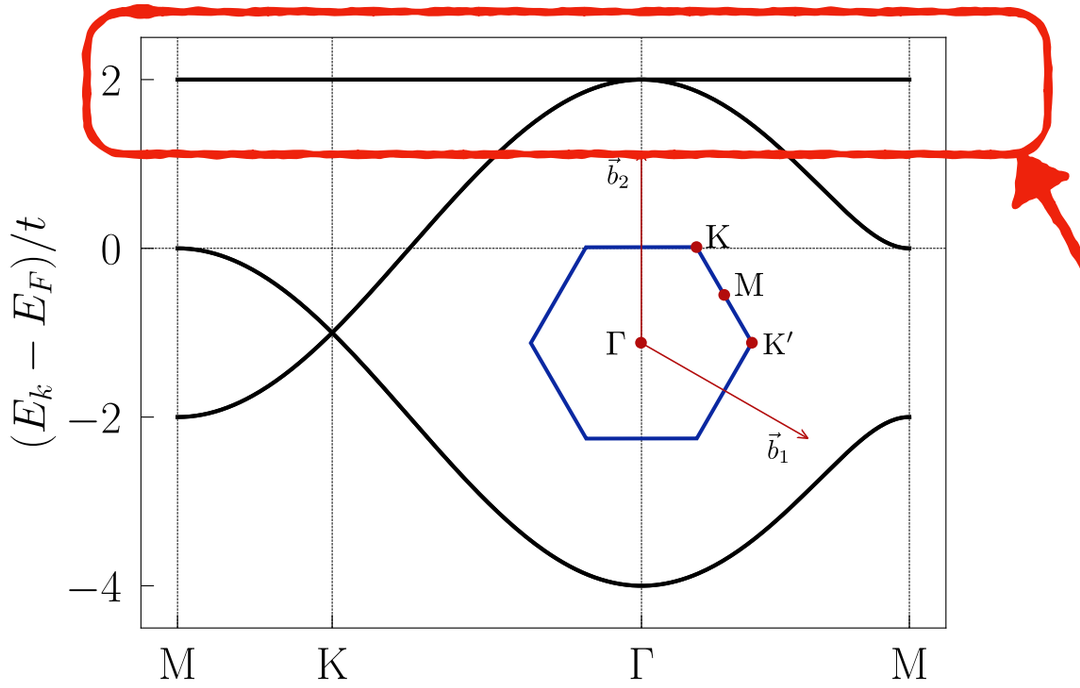

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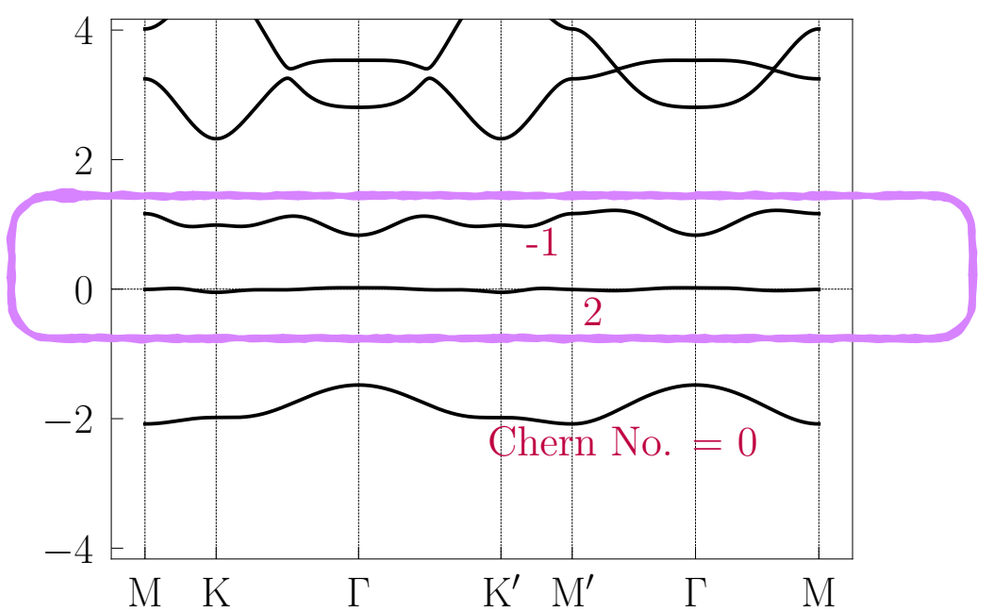


- On breaking of symmetry such as time reversal can lead to isolated (almost) flat band with topological invariants

Question for the talk :

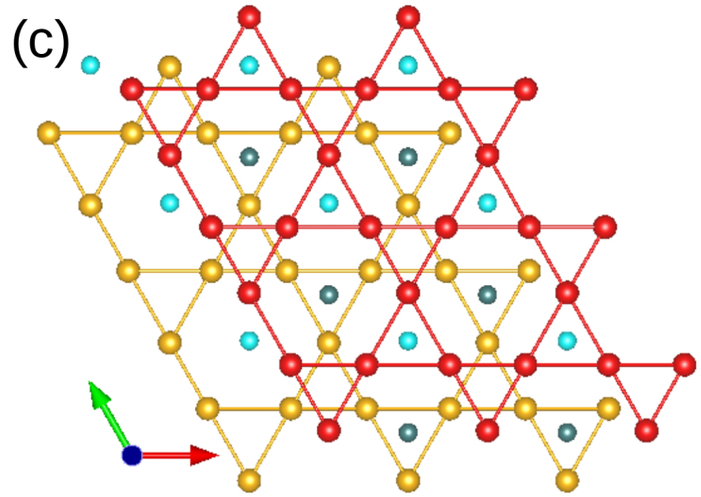
What is the effect of electron-electron interactions in a partially filled Chern band ?

A quick answer : Natural instabilities are different from that of a trivial band

The material Motivation : Many Kagome Metals

This Talk : Bilayer kagome intermetallics M_3Sn_2 M = 3d Transition metal

Our Interest : Fe_3Sn_2



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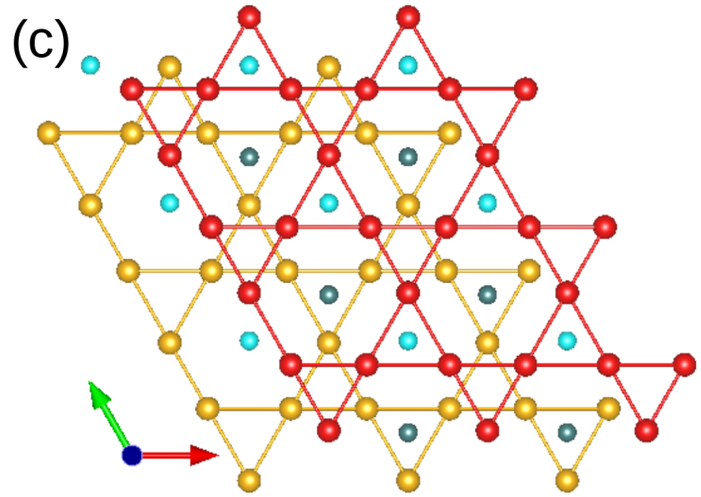
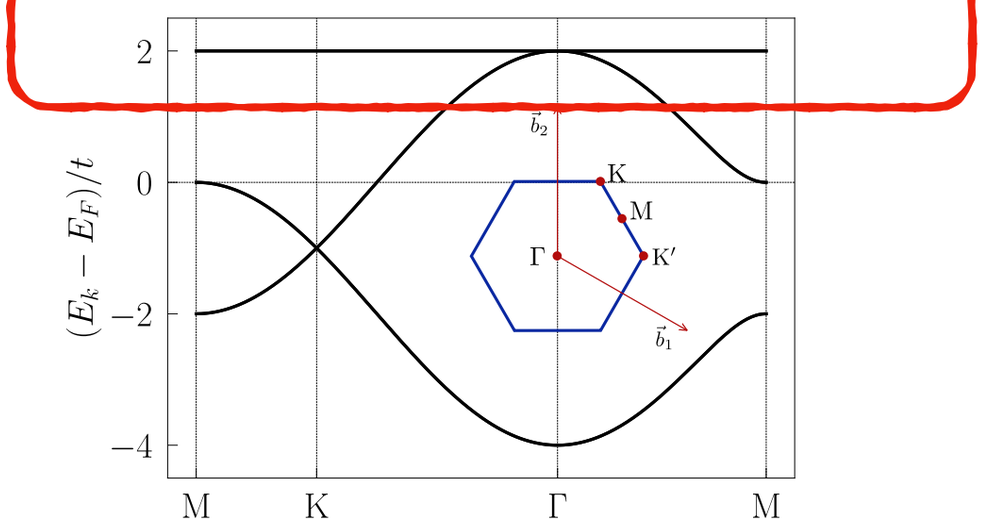
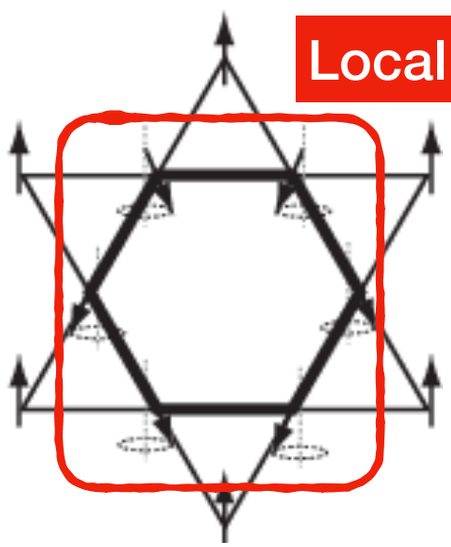


Both (antiferro)magnetic interactions as well as electron hopping can be frustrated in the Kagome geometry.

Flat band

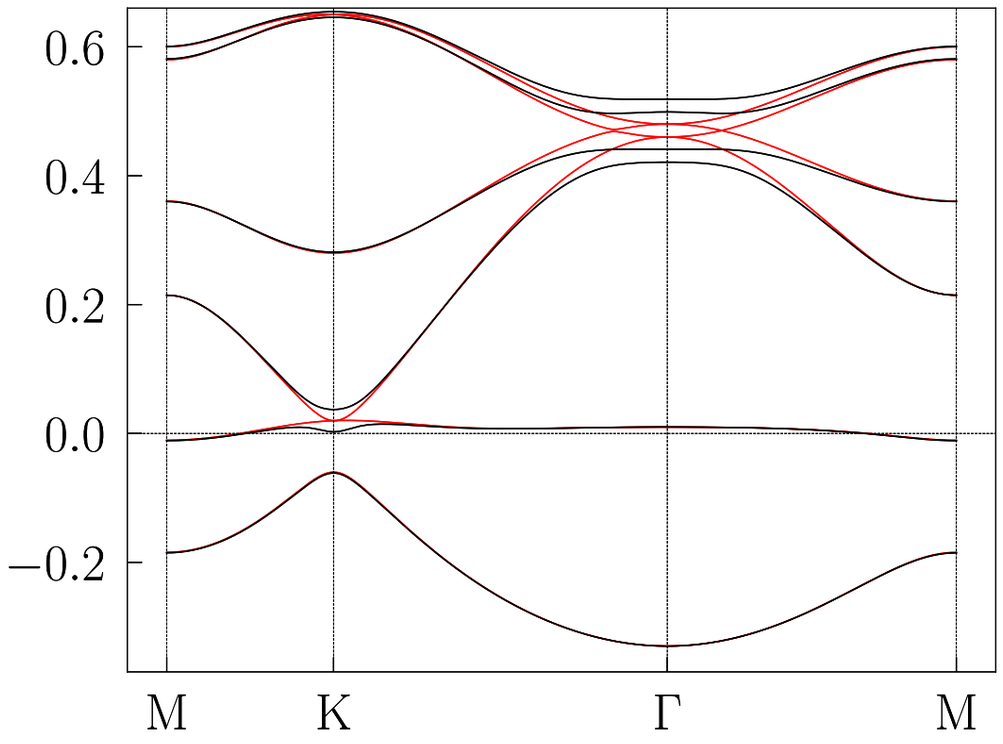


Local zero modes



Minimal model for Bilayer Kagome Band-structure

Minimal one orbital hopping model with short range hopping and interlayer hybridization



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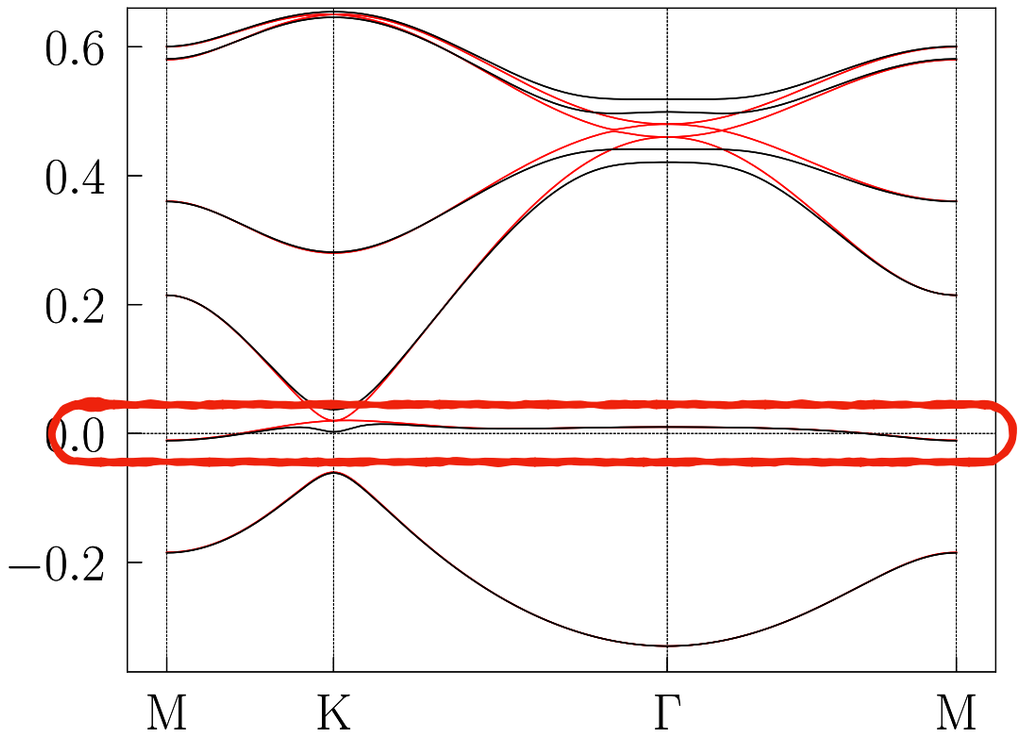

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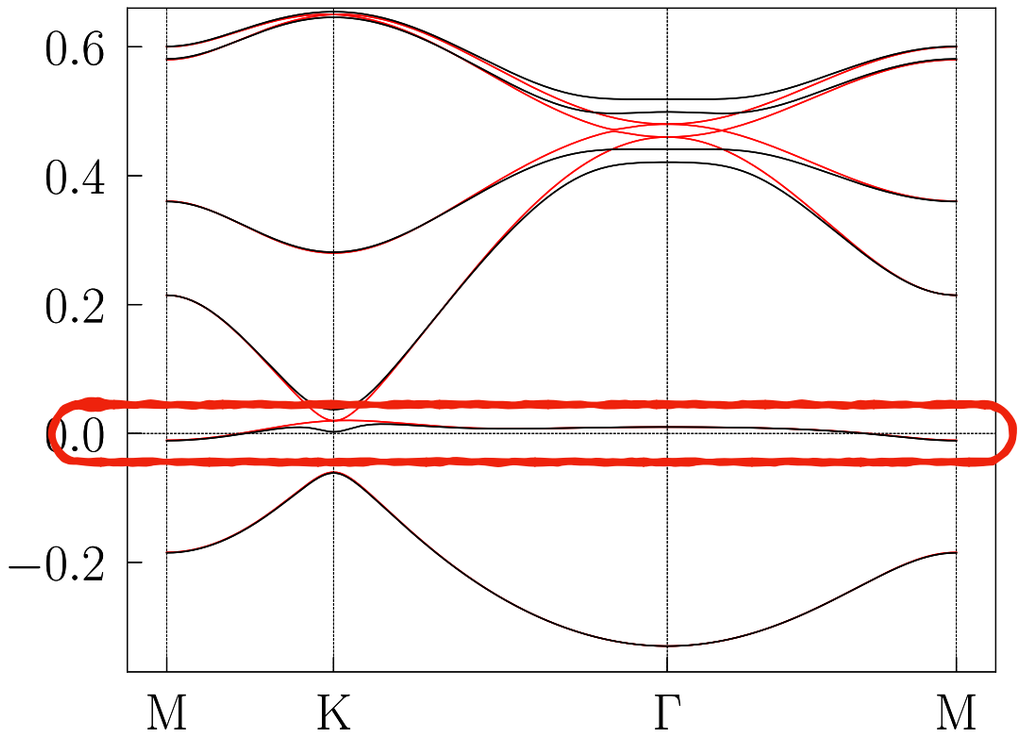

Effect of short range interactions :

$$H_{Int} = U \sum_i n_i(n_i - 1) + \sum_{ij} V_{ij} n_i n_j$$

Drives (almost) Flat-band ferromagnetism

(Seen in experiments for bulk materials)

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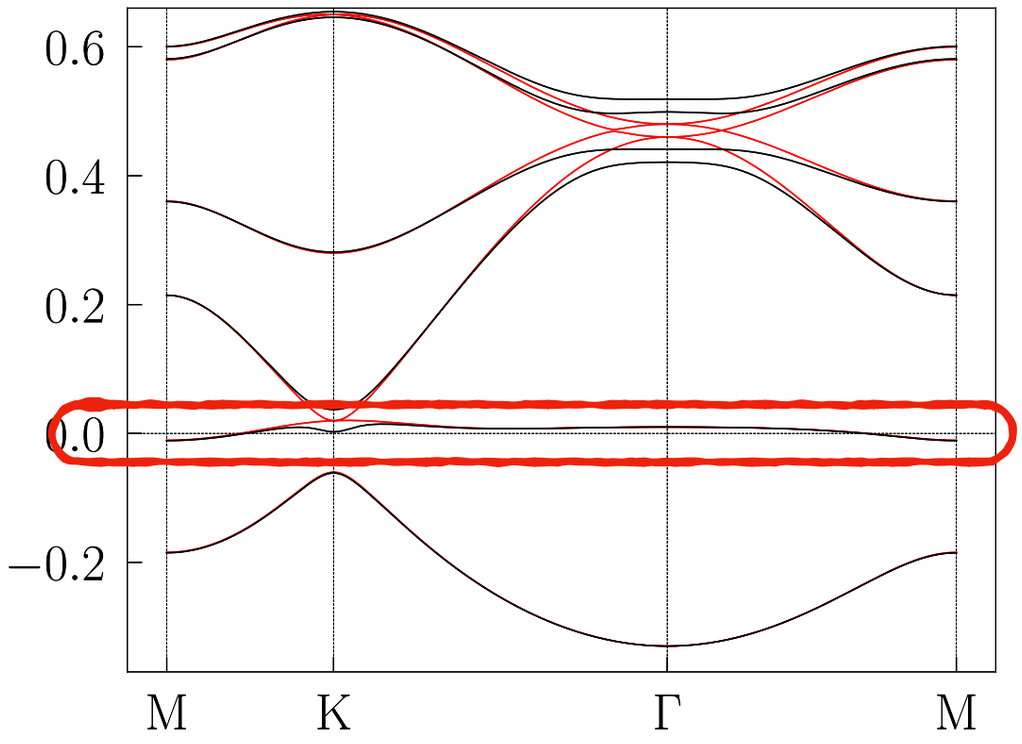

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HF spin-polarised Band structure ←

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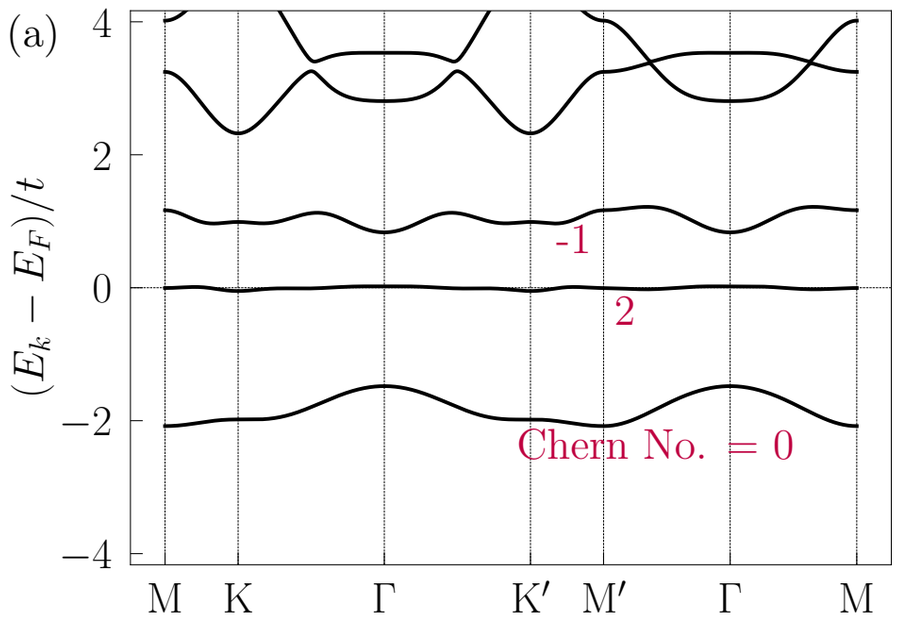
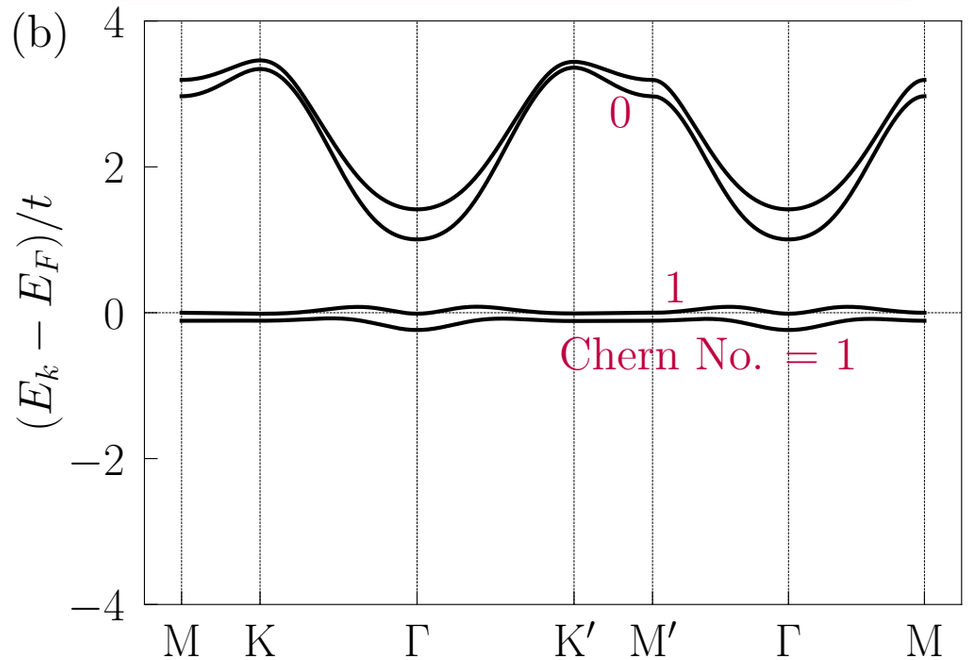
HF spin-polarised Band structure : The Chern Metal

Strong inter-layer Hybridization



Weak inter-layer Hybridization



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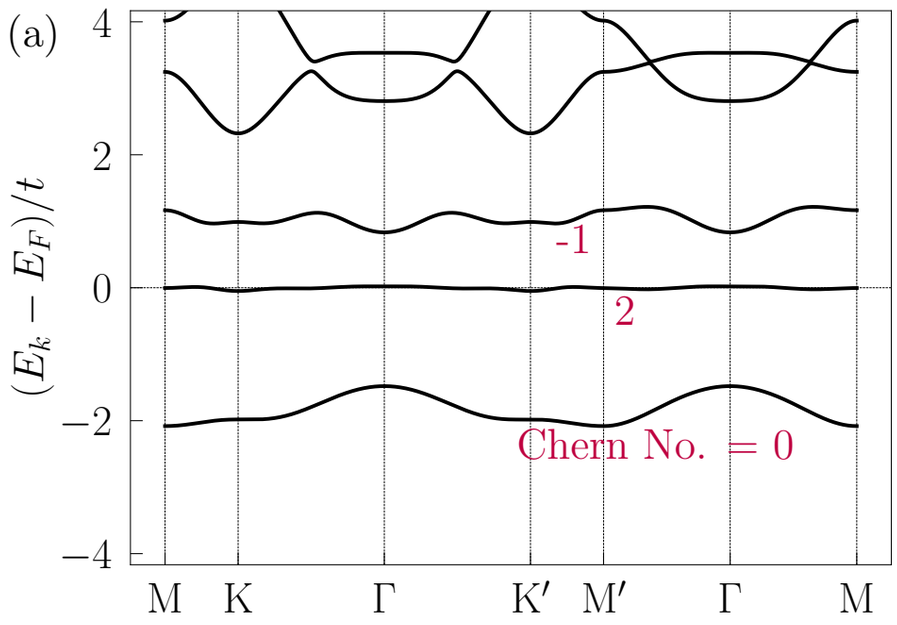

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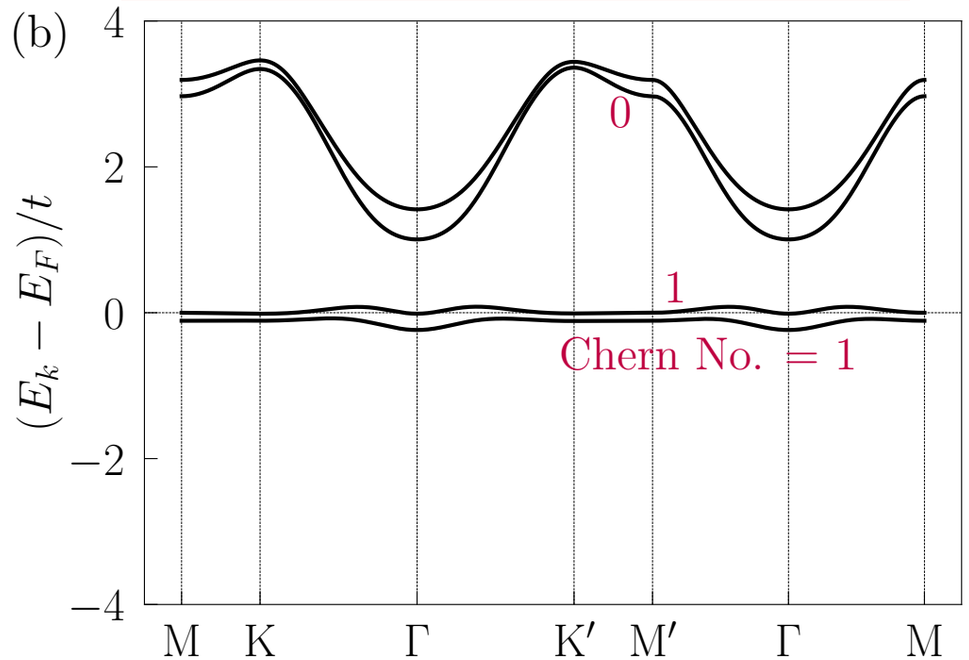
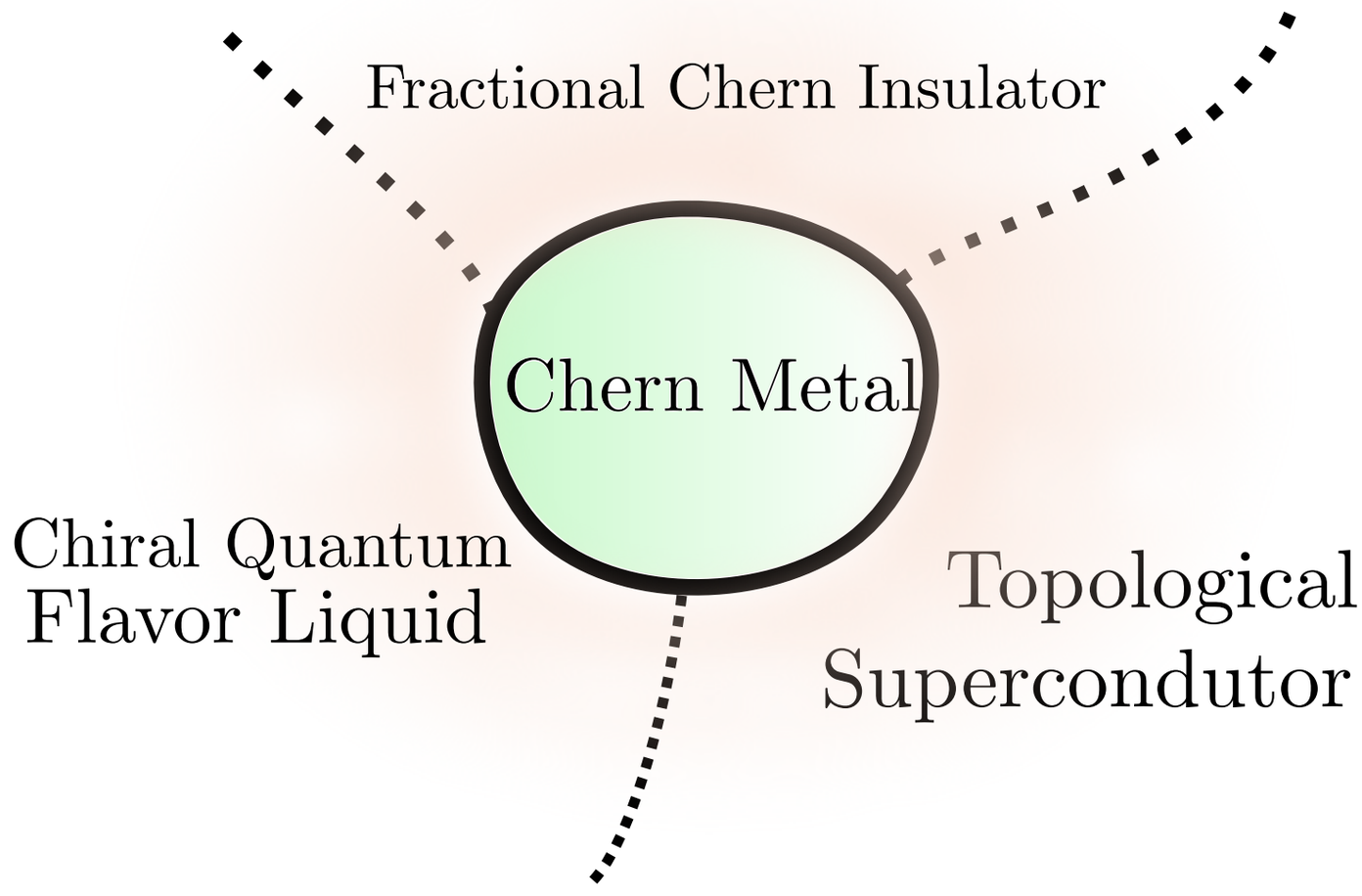


Partially filled Chen Band (Almost flat) : **Chern metal**

Question : What is the fate of the left over e-e interactions in the Chern band ?

$$H_{Int}^{eff} = \mathscr{P}\,[\quad \sum_{ij} V_{ij} n_i n_j \quad]\,\mathscr{P}$$

Chern Metal as the parent of many different Novel phases



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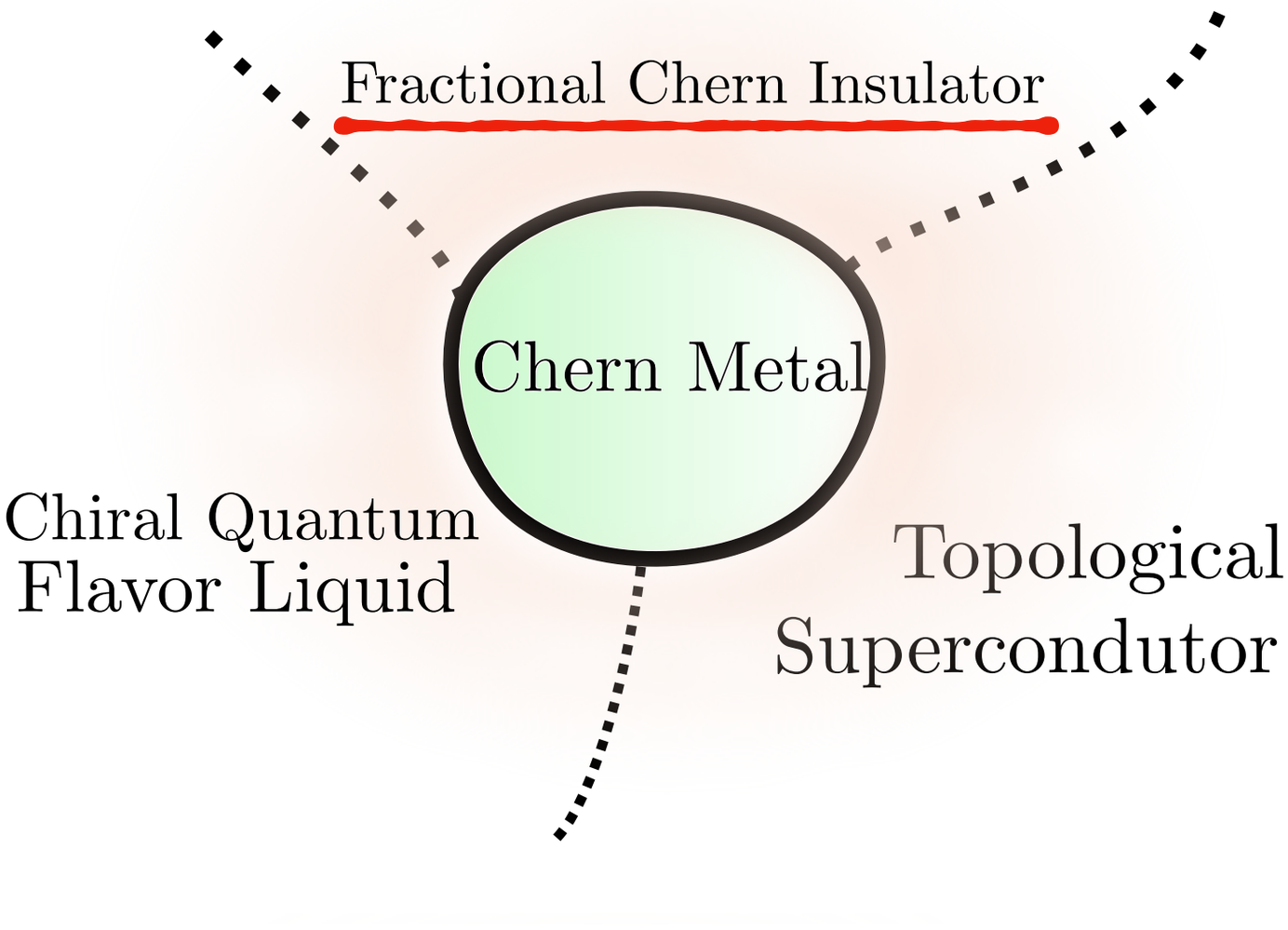
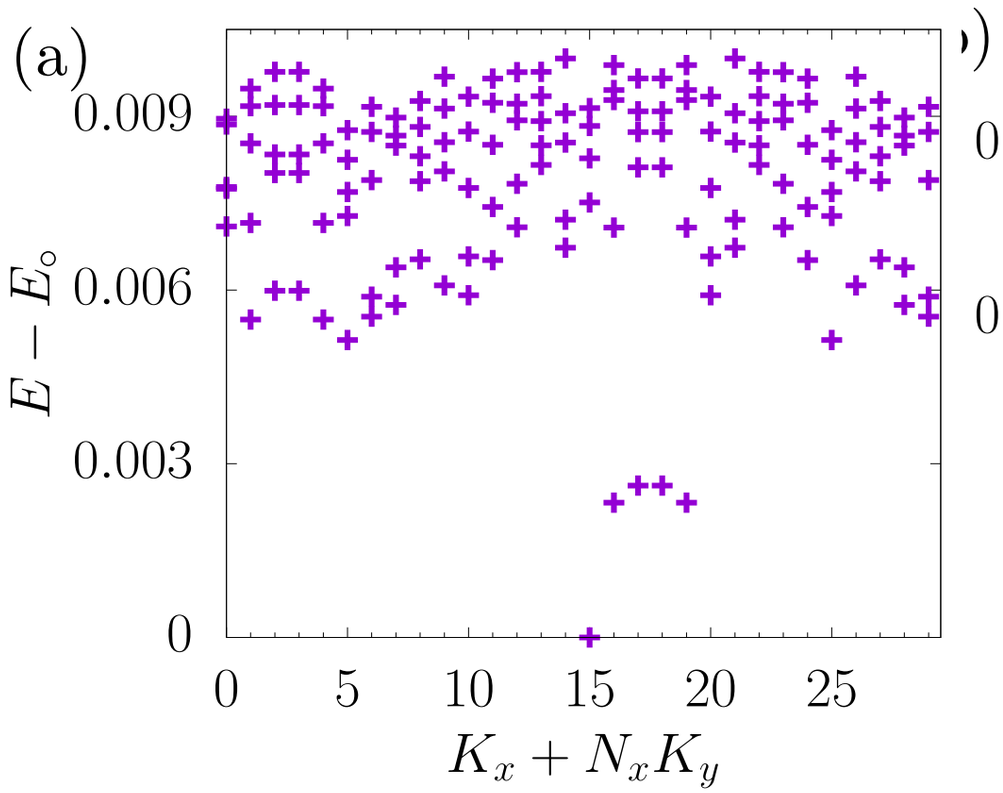


Fractional Chern Insulator

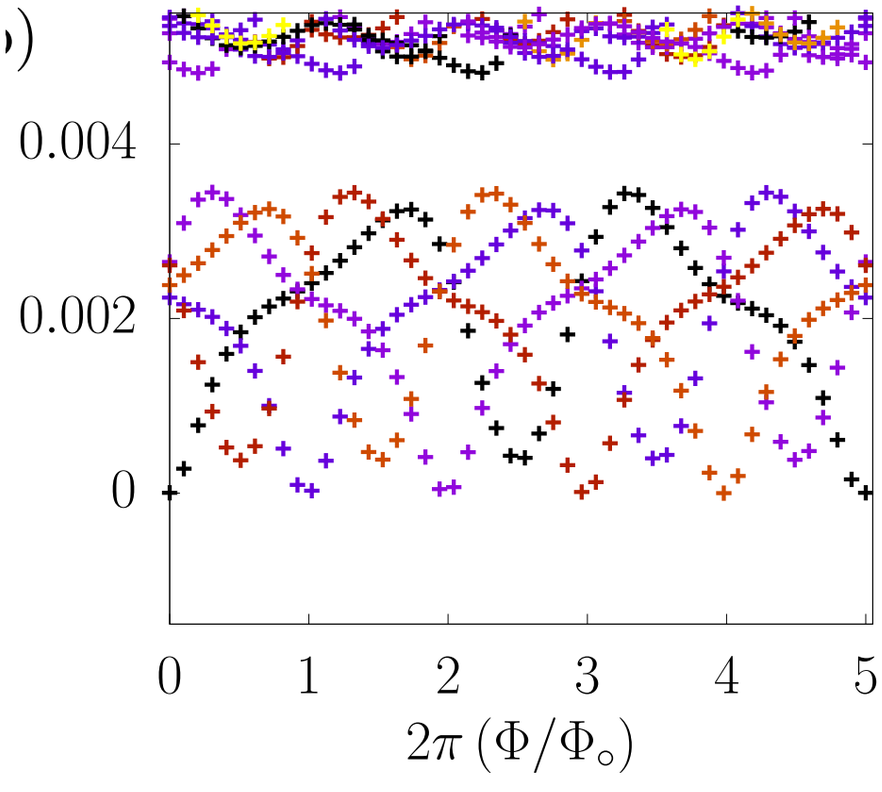
K-space ED of the projected Hamiltonian

$$H_{\rm int} = \mathcal{P} \sum_{k_1,k_2,k_3,k_4} V^{\alpha_1,\alpha_2,\alpha_3,\alpha_4}_{k_1,k_2,k_3,k_4} c^\dagger_{k_1,\alpha_1} c^\dagger_{k_2,\alpha_2} c_{k_3,\alpha_3} c_{k_4,\alpha_4} \mathcal{P} \ .$$

1/5-Laughlin state in the STRONG interlayer hybridized limit



Energy Spectrum



Flux threading

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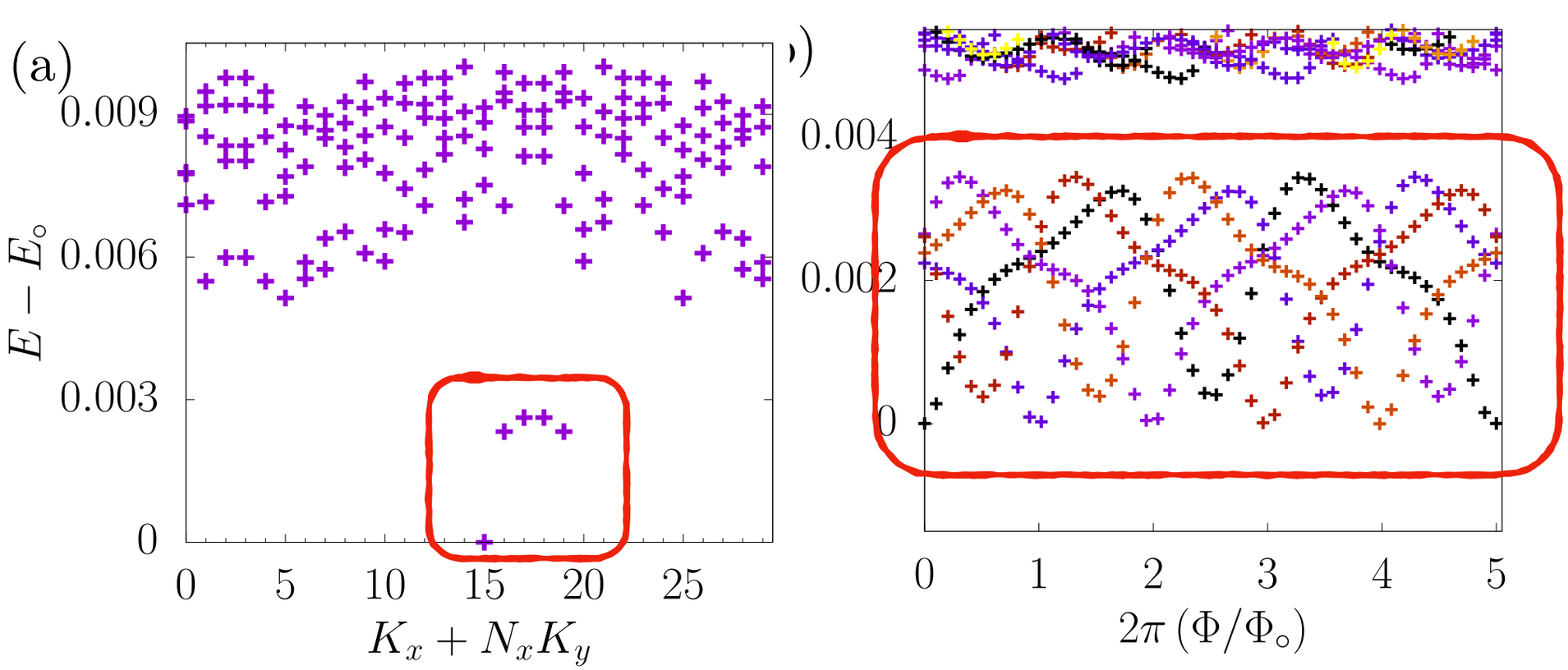

Energy Spectrum

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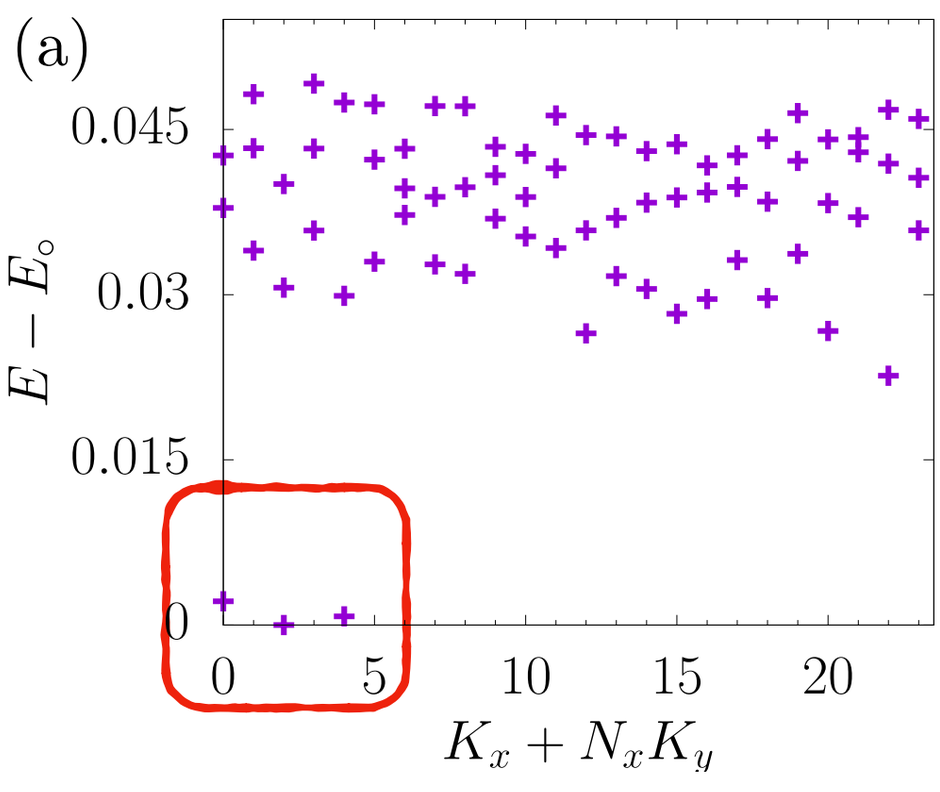
1/3-Laughlin state in the WEAK interlayer hybridized limit



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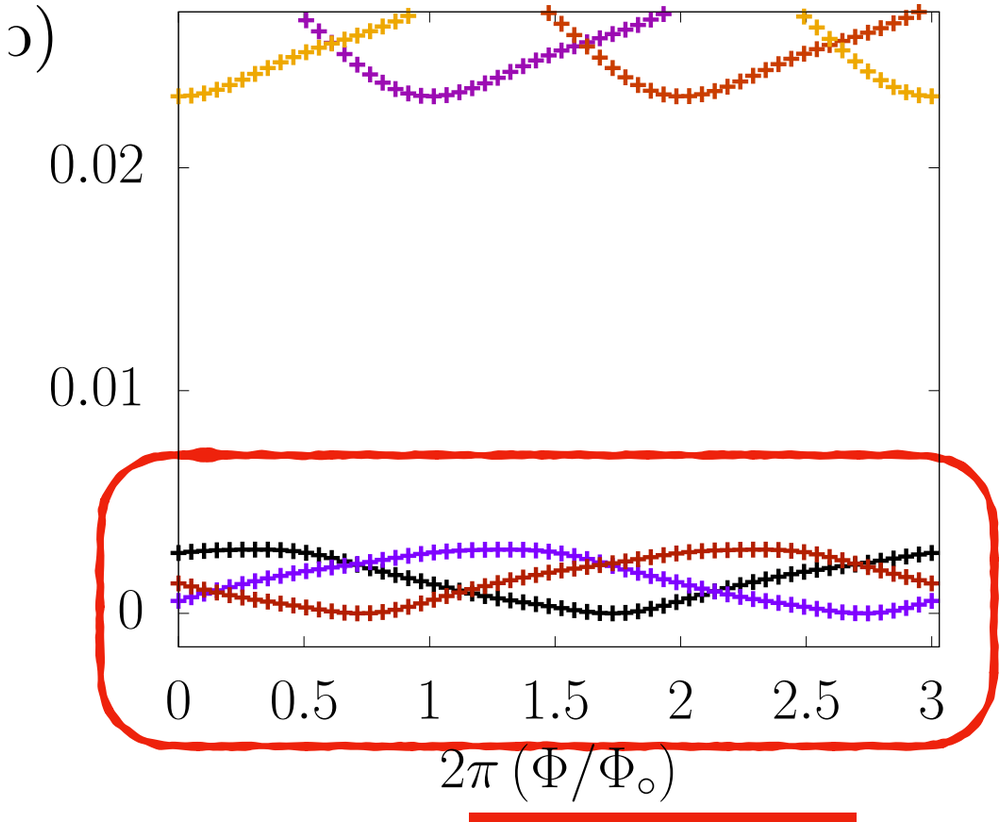
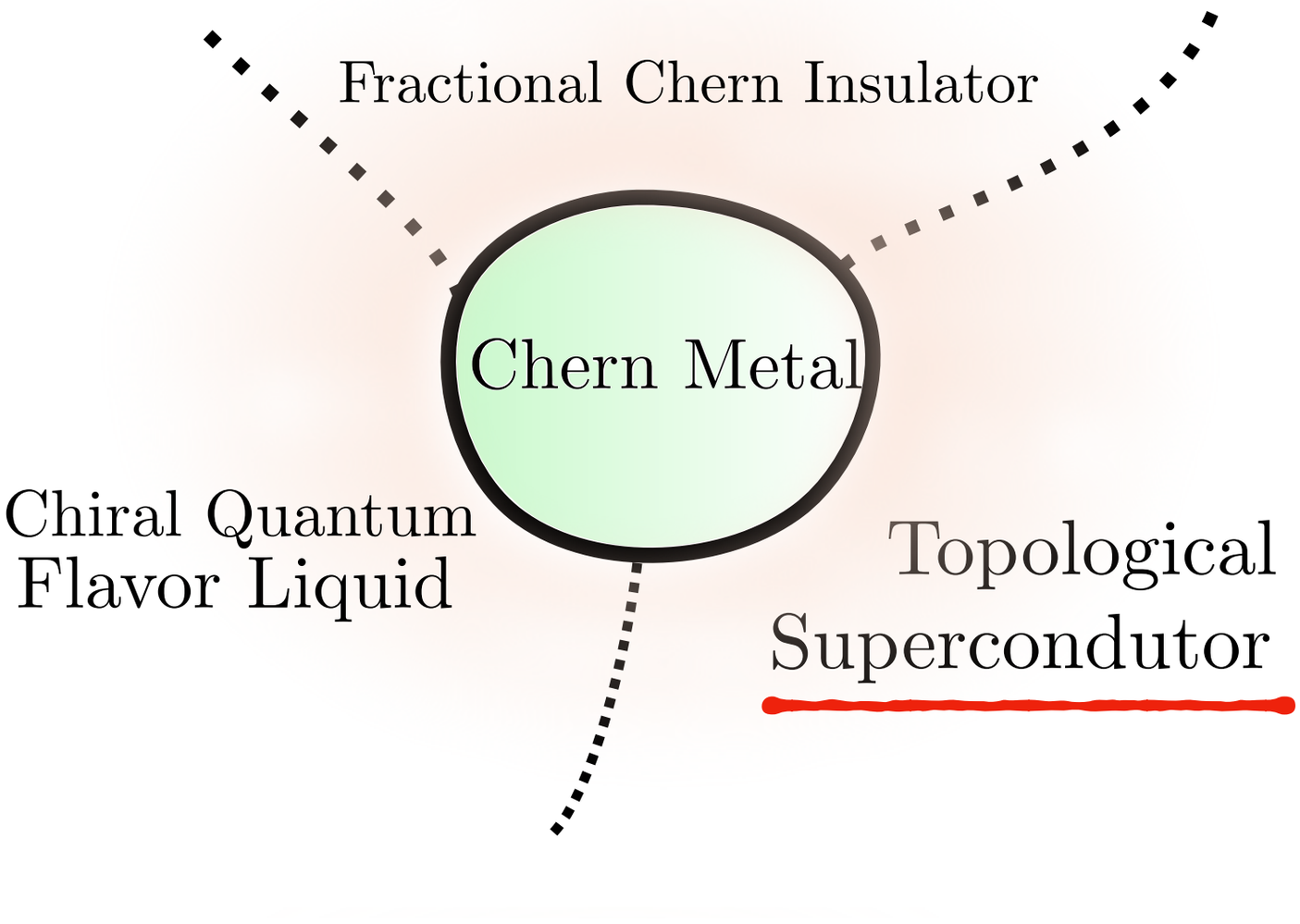


Flux threading

Chern Metal as the parent of many different Novel phases



Chern Metal as the parent of many different Novel phases

Fractional Chern Insulator

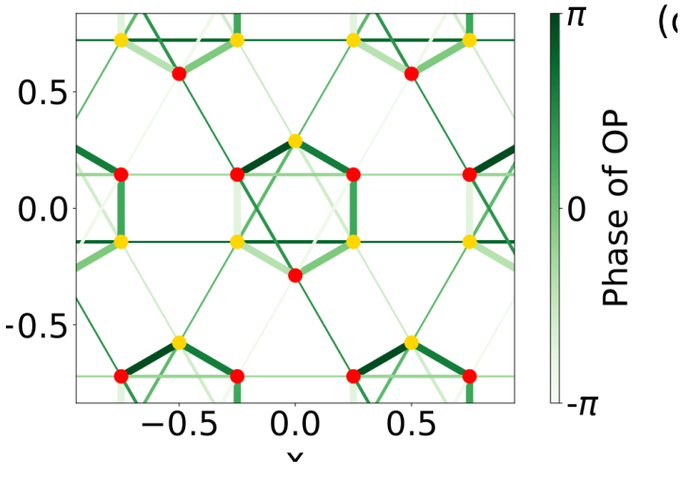
Chern Metal

Chiral Quantum
Flavor Liquid

Topological
Superconductor

BCS calculations

Chiral p-wave SC



Chern Metal as the parent of many different Novel phases

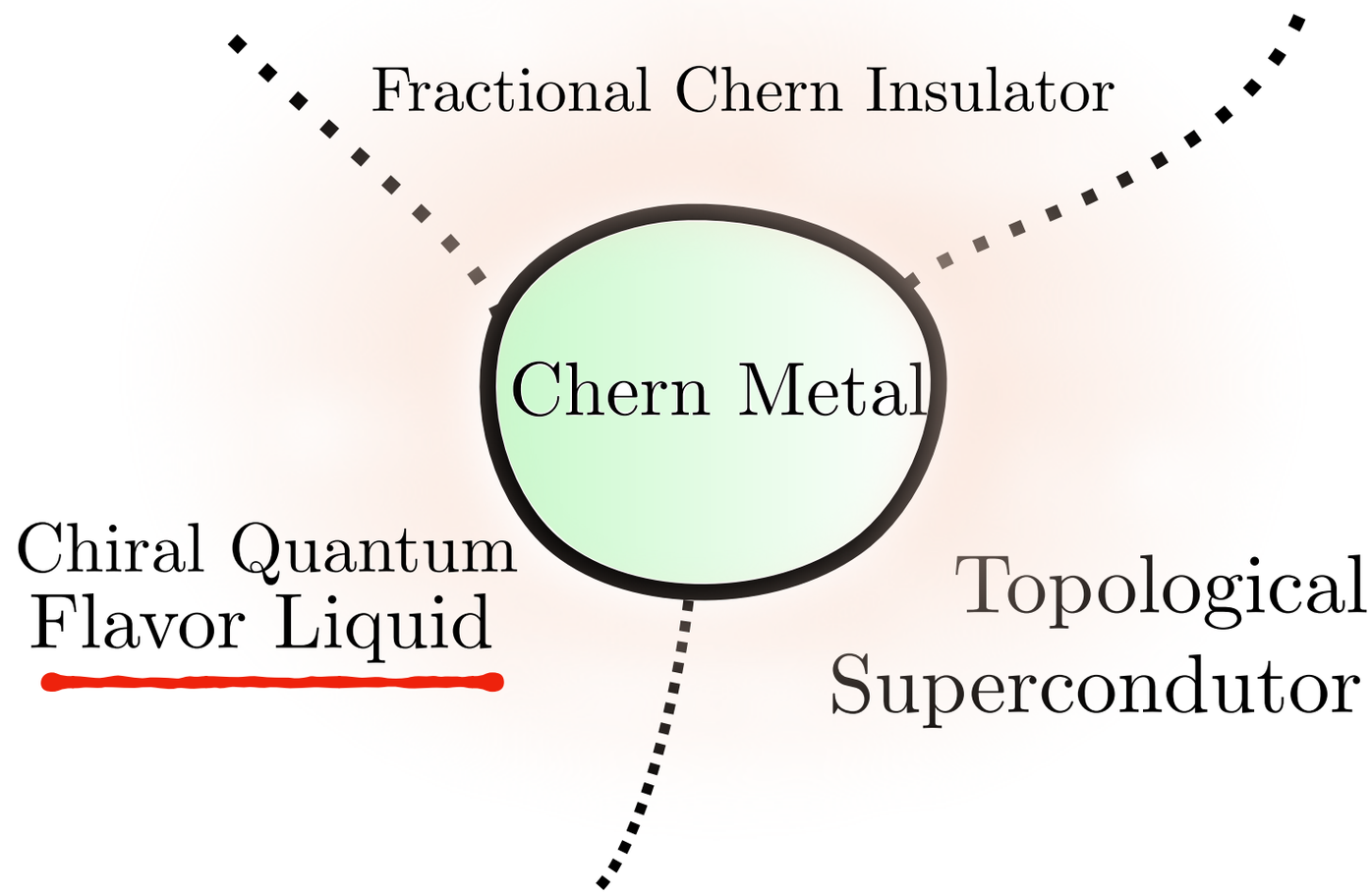
Electrons in terms of partons :

$$c_a = bf_a$$

(a is layer index ⇒ Flavour)

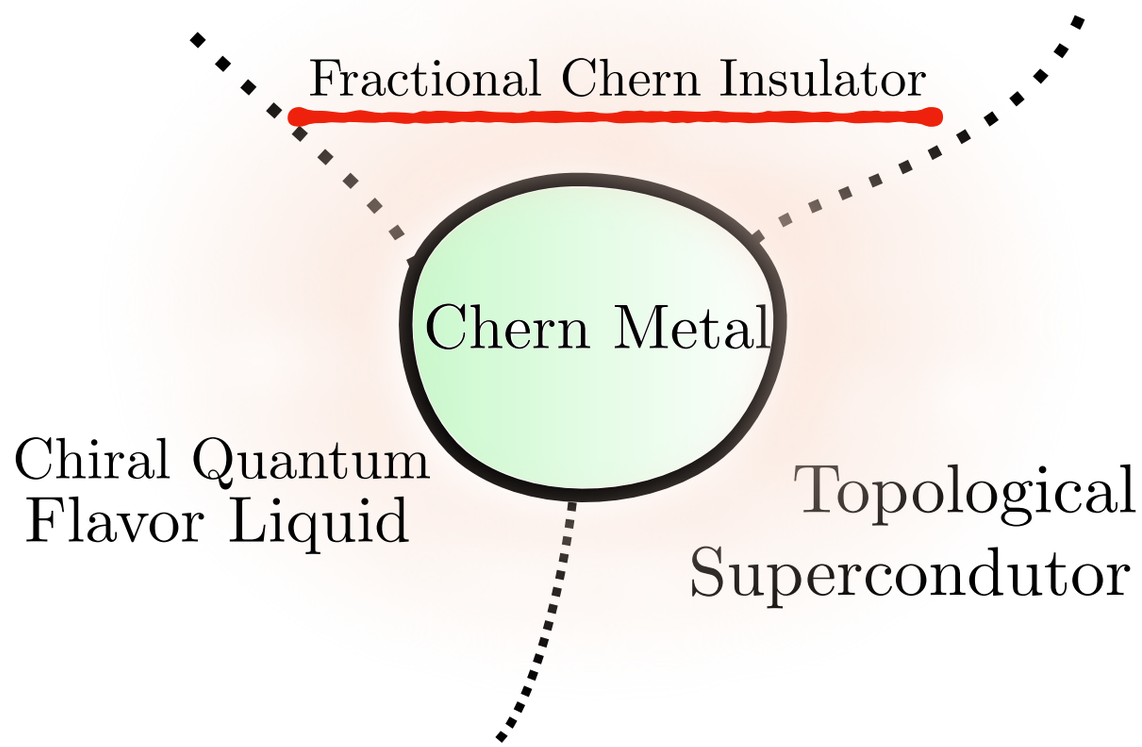
$b \rightarrow$ Bosonic chargon

$f \rightarrow$ Flavour Fermion



- Chern metal :
    - $f \rightarrow$ Chern band, $\langle b \rangle \neq 0$ (condensed, Superfluid)
- Chiral Flavour Liquid :
    - $f \rightarrow$ Chern band, $\langle b \rangle = 0$ (Trivial Mott Insulator)

Recasting of the Fractional Chern Insulator in terms of the partons



- The Fractional Chern Insulator :
    - $f \rightarrow$ Chern band, $b \rightarrow$ Bosonic Integer Hall Phase
    - The Effective filling of the Chern band is changed by the flux of the emergent U(1) gauge field.

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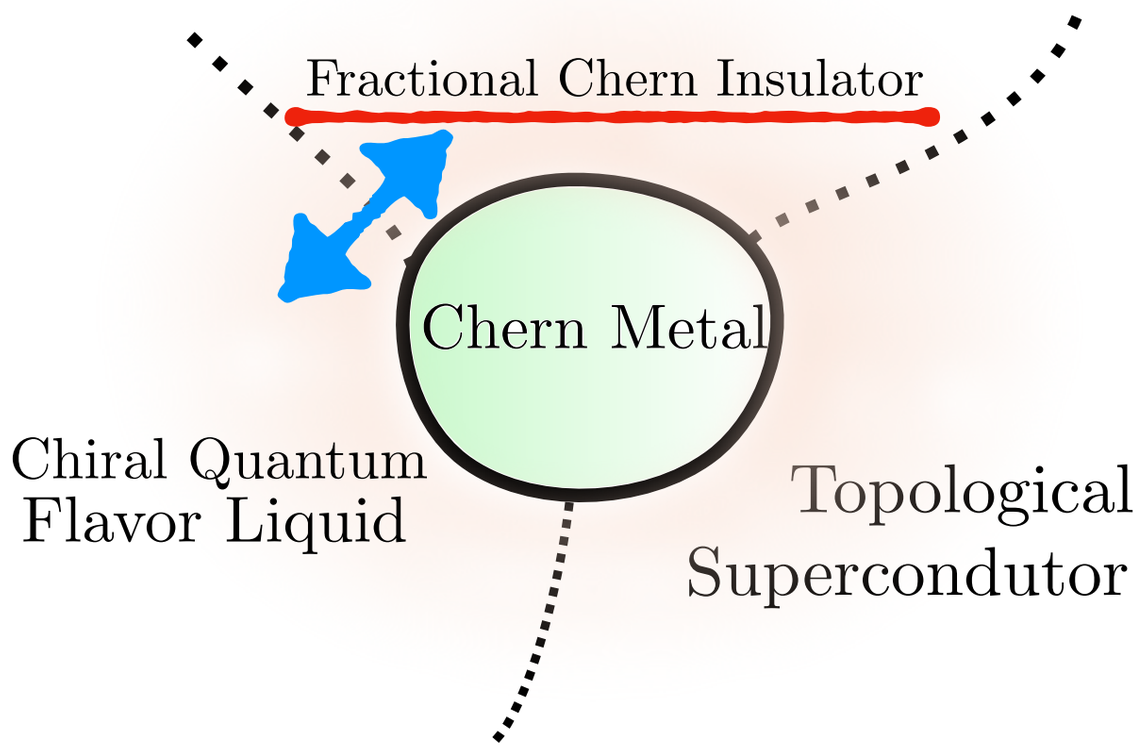

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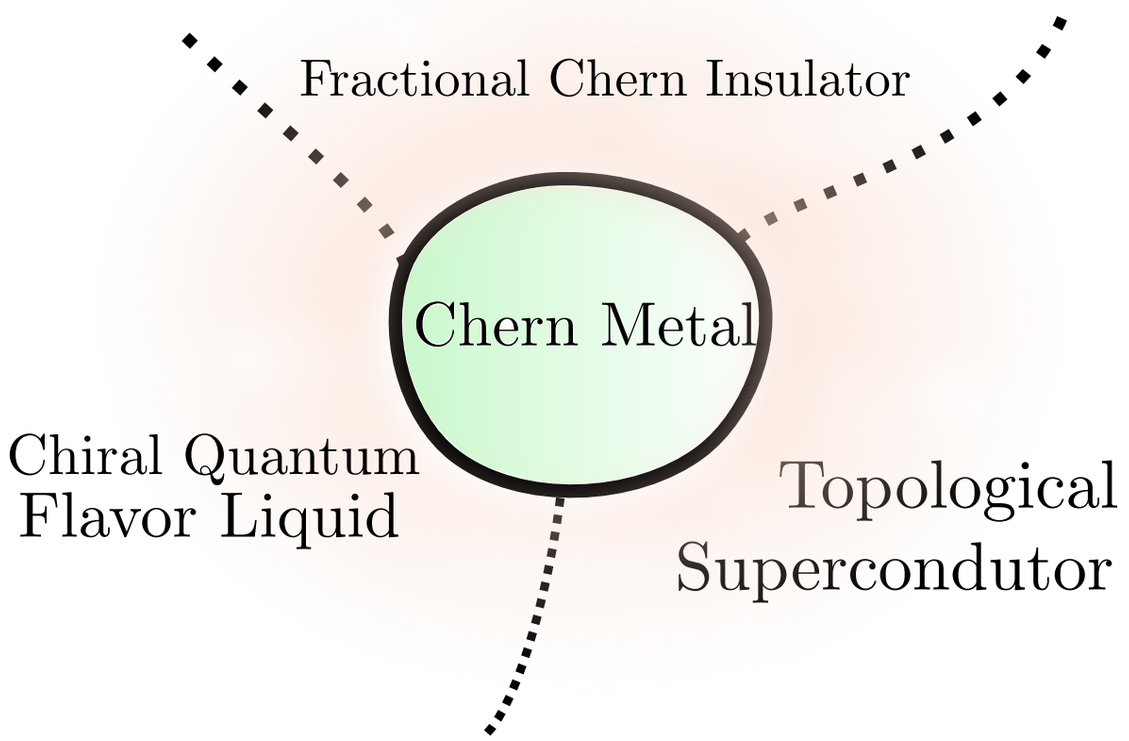
- The Transition between the FCI and the Chiral Flavour liquid is a BIQH plateau transition

Summary



- The chern metal is the parent of many novel phases
- A good place to look for such exotic phase and transitions is Kagome metals

Thank You