Superconducter vortex spectrum in type-2 WSM

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Weyl semimetal:

- Bands touch at isolated k-points in the Brillouin zone.
- Low energy excitations follow Weyl (massless chiral Dirac) equation.

Breaking either time-reversal $(\boldsymbol{\tau} : \boldsymbol{k} \rightarrow \boldsymbol{-k})$ or spatial Inversion $(\wp : \boldsymbol{r} \rightarrow -\boldsymbol{r})$

N. P. Armitage et.al., Rev. Mod. Phys. **90**, 015001 (2018)
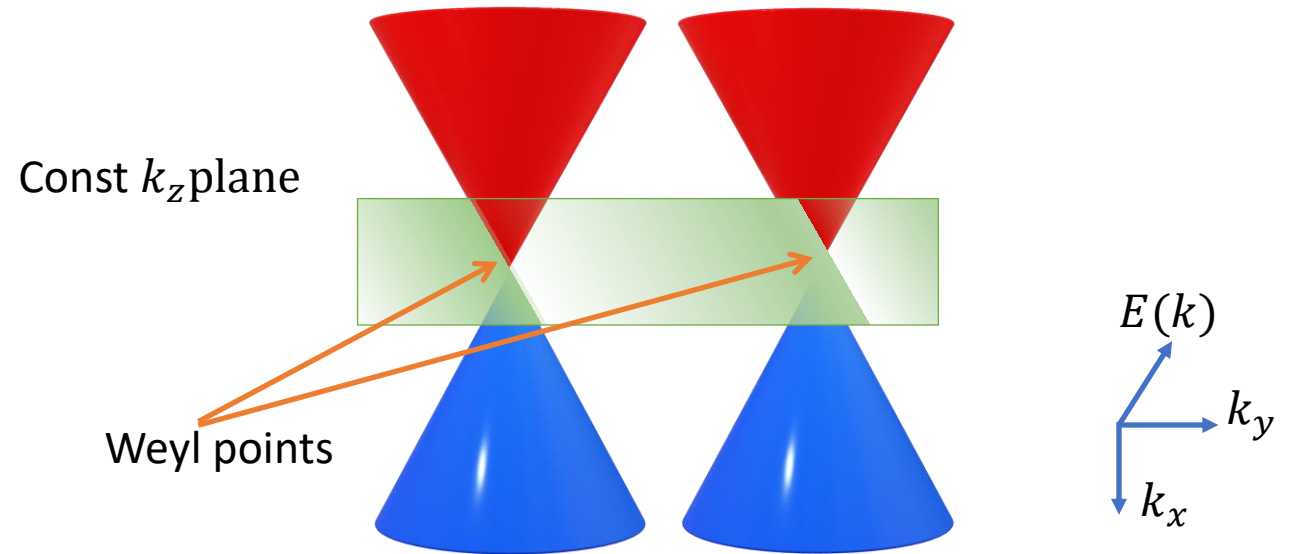
Linear Model:

$$\hat{\mathcal{H}}_{\mathrm{WP}}(\mathbf{k}) = \sum_{i=1,2,3} \gamma_i k_i \hat{\sigma}_0 + \sum_{i,j=1,2,3} k_i A_{ij} \hat{\sigma}_i$$

$$E_{\pm}(\mathbf{k}) = \sum_{i=1,2,3} \gamma_i k_i \pm \sqrt{\sum_{j=1,2,3} \left(\sum_{i=1,2,3} k_i A_{ij} \right)^2} = T(\mathbf{k}) \pm U(\mathbf{k})$$
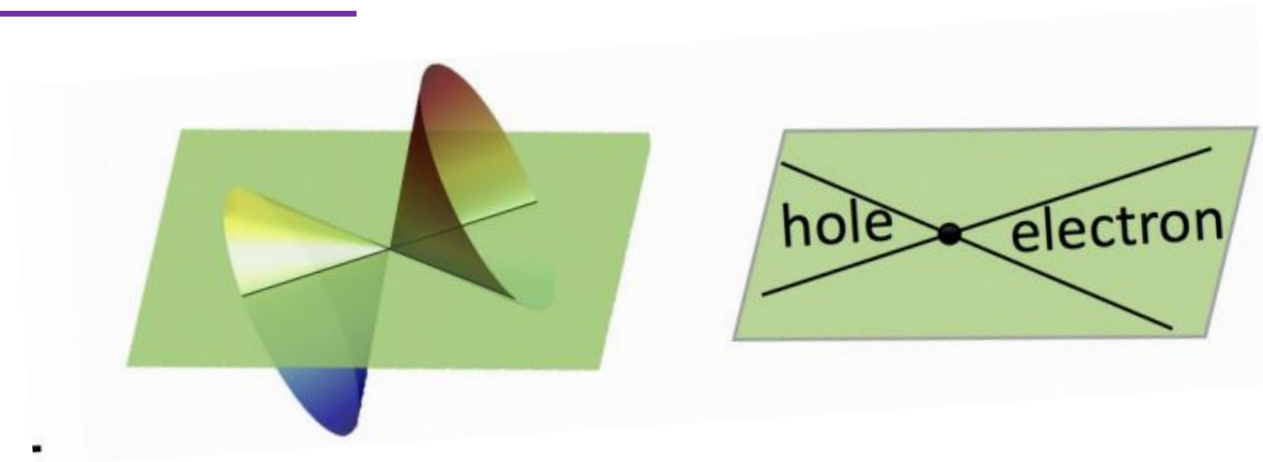
Type I WSM:

- $\gamma = 0$

- Zero density of states at the Fermi energy.

- Weyl points occur in pairs

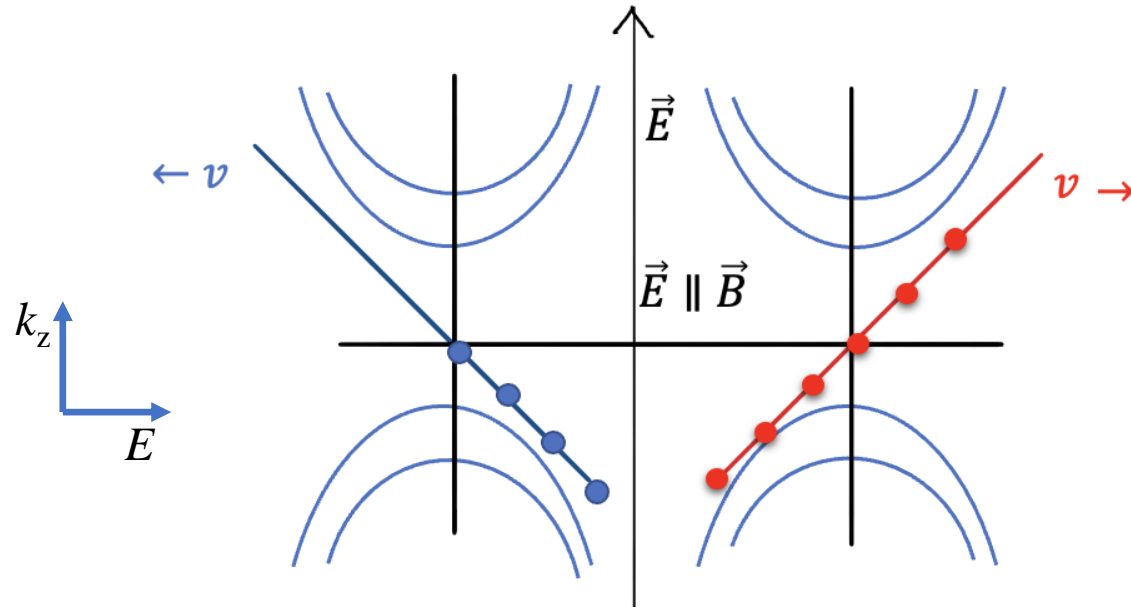Const k_z plane

Weyl points

$E(k)$

k_y

k_x

Type II WSM:

- Tilted bands
- Finite density of states at Fermi energy
- Shows chiral anomaly only when $T(\hat{k}) > U(\hat{k})$

Soluyanov, A., Gresch, D., Wang, Z. *et al.* Type-II Weyl semimetals. *Nature* **527**, 495–498 (2015)

Chiral Magnetic effect:

- External magnetic field creates Landau levels

- Chiral zeroth Landau level

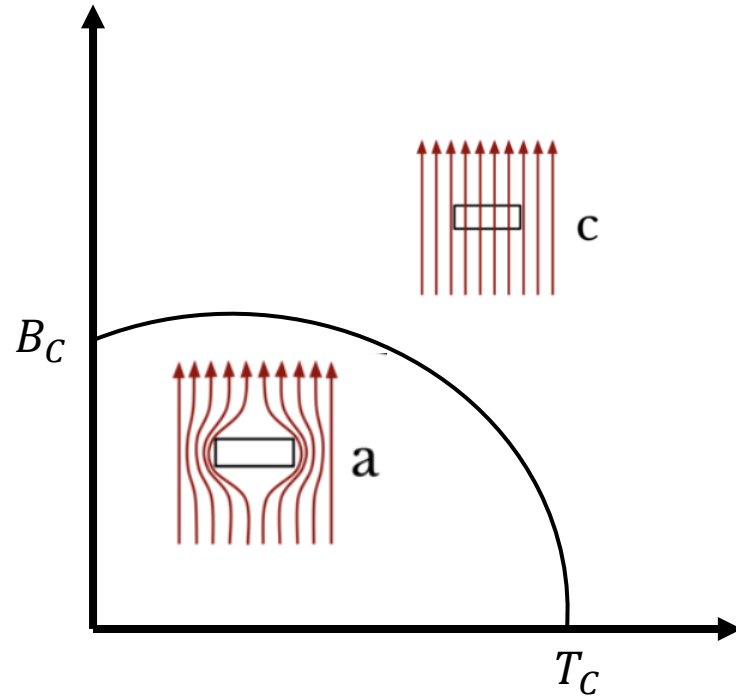- External electric field facilitates axial current via chirality imbalance
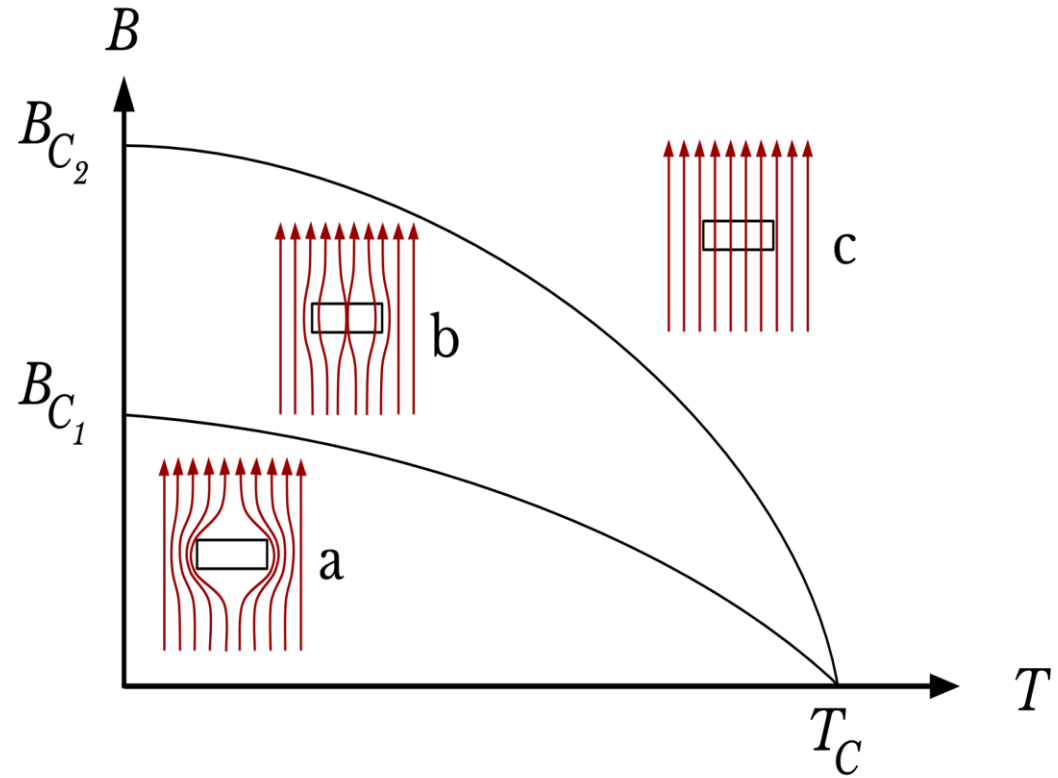
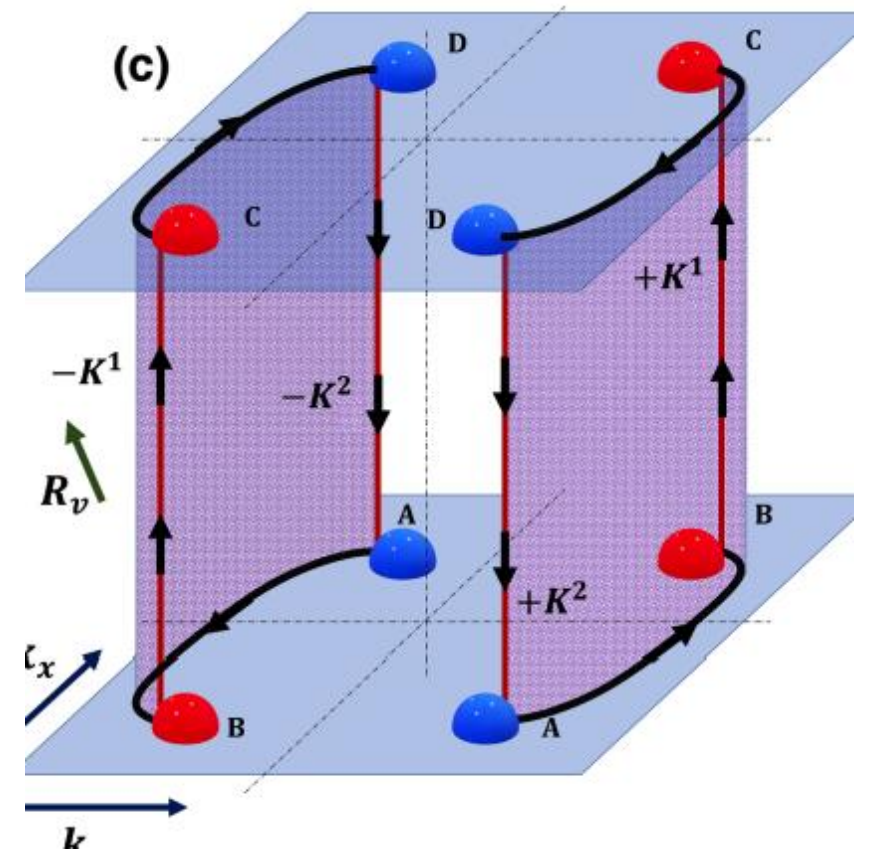| Type I	Type II
CME happens for any direction of B	CME is shown only when B is in direction where $|T(\boldsymbol{k})| > |U(\boldsymbol{k})|$

Superconductors:

Type I

Type II

Topological superconductor: Superconductor with non-zero Topological invariant

Previous works:

For type-1 WSM

- $E_n^{\pm} = \pm\varepsilon\left(n + \dfrac{1}{2} + \dfrac{\varphi}{2\pi}\right); \quad \varepsilon = \dfrac{\Delta}{\xi l_{FA}}$

R. Giwa and P. Hosur, Phys. Rev. Lett. **130,156402**(2023)

Material to realize bulk topological superconductor

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Transition metal dichalcogenides(TMDs)
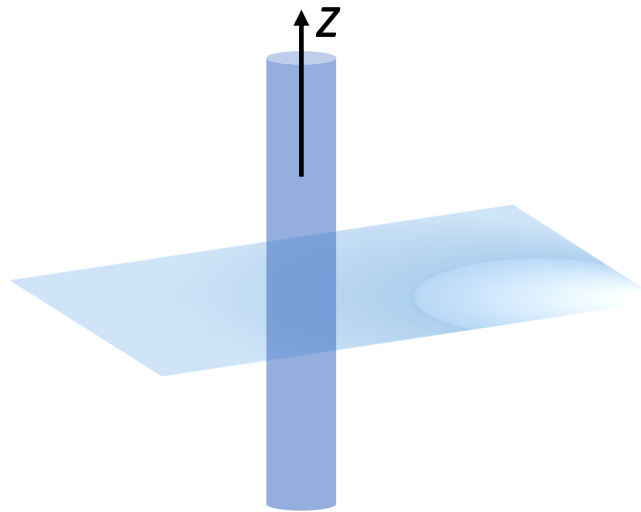
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Semi-metallic TMD: WTe_2, $MoTe_2$

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WTe_2 , $MoTe_2$: Type-2 WSM

Qi, Y., Naumov, P., Ali, M. *et al., Nat Commun* **7**, 11038 (2016)

Problems:

- Non-zero density of states at zero energy
- Broken translational invariance in the plane perpendicular to the vortex

k_x, k_y are not good quantum numbers

For a single node:

- For type-I : $H_{BdG} = \tau_z \widehat{\boldsymbol{k}}.\boldsymbol{\sigma} + (\tau_x \widehat{\boldsymbol{x}} - \tau_y \widehat{\boldsymbol{y}})\frac{\Delta}{\xi}$

$$E(n_X, n_Y) = \pm\sqrt{\frac{2\Delta}{\xi}(n_X v_X + n_Y v_Y)}$$

$\langle X, Y|GS\rangle = (0, 0, 0, 1)^T f_{00}(X, Y)$ $f_{00}(X, Y) \propto \exp[-\frac{\Delta}{2\xi}\left(\frac{X^2}{v_X} + \frac{Y^2}{v_Y}\right)]$

R. Giwa and P. Hosur; Phys. Rev. Lett. **127**, 187002, 2021

- For type-II: $H_{BdG} = \lambda kx + \tau_z \widehat{\boldsymbol{k}}.\boldsymbol{\sigma} + (\tau_x \widehat{\boldsymbol{x}} - \tau_y \widehat{\boldsymbol{y}})\frac{\Delta}{\xi}$

NEXT..

- Include surface Fermi arc contribution.
- Construct semi-classical orbits for type-2 WSM.

Thank You!

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