Surface States in Holographic Weyl Semimetals

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Iberian Strings '17

1612.00836 Martin Ammon, Markus Heinrich, A.J. & Sebastian Moeckel

Outline

1. Weyl Semimetals
2. Weyl Semimetal in Holography
   - Model
   - Surface States
3. Last thoughts

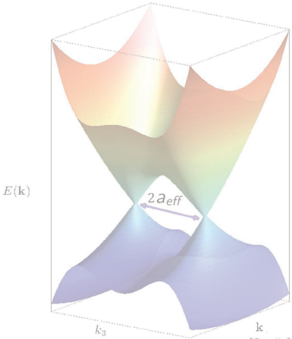
Weyl Semimetals

What is a semimetal?

A semimetal is a material with small overlap between valence and conductance bands.

What is a Weyl semimetal (WSM)?

- In WSM the overlap occurs at isolated points in the Brillouin zone ("nodes") at the Fermi level.
- These can be seen as sources of Berry curvature → topological protection.
- The effective d.o.f. are massless, relativistic fermions.
- Nodes are non-degenerate → Weyl.
- Nielsen-Ninomiya theorem ⟶ Nodes appear in pairs.



[Cortijo]

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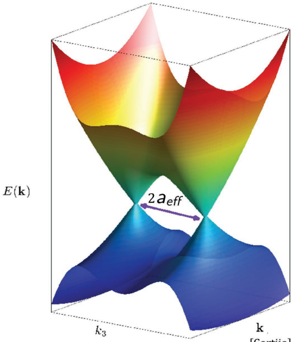


[Cortijo]

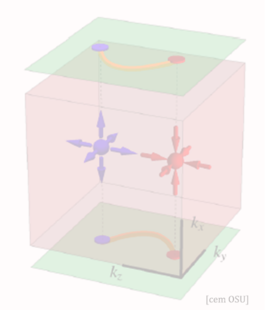
Weyl semimetals features

Anomaly induced transport

$$\mathbf{J} \sim \mu_5 \mathbf{B} + \mathbf{B}^2 \mathbf{E} + \mu \mathbf{B}_5 + \mathbf{a}_{eff} \times \mathbf{E}$$

Weyl semimetals have protected surface states

- The Fermi surface presents curves linking the Weyl nodes of opposite chirality at the surface of the material: Fermi arcs.
- Weyl nodes are topologically protected and so are the Fermi arcs.
- These modes behave as 1+1 massless fermions.



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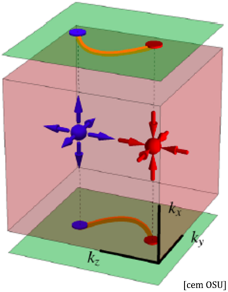

[cem OSU]

Topological Phase Transition

Field theory model

$$\mathcal{L} = \bar{\psi}(i\gamma^\mu \partial_\mu + \gamma_5 \gamma_z a + M)\psi$$

M > a

$$\mathcal{L}_{eff} = \bar{\psi}(i\gamma^\mu \partial_\mu + M_{eff})\psi$$

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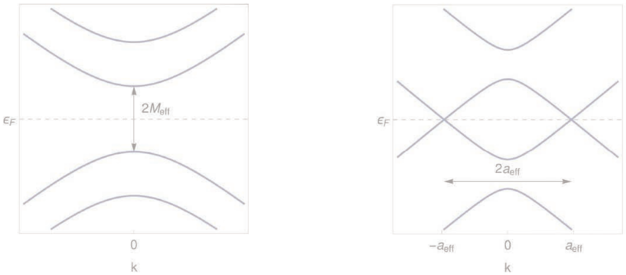

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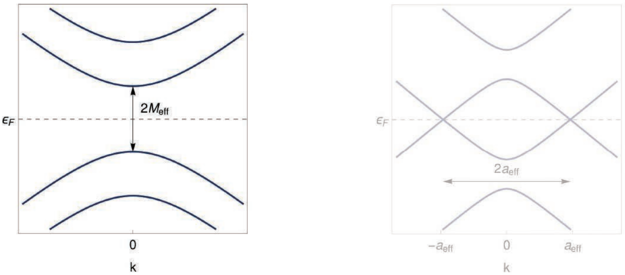

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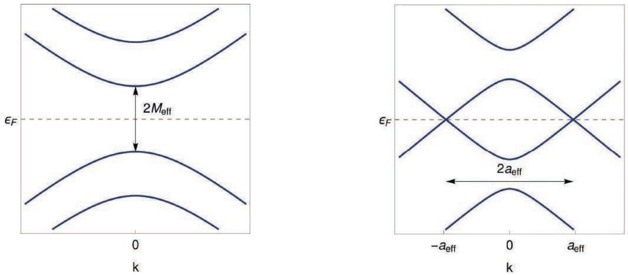

[Heinrich]

The best thing about Weyl semimetals... They exist!

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NATURE PHYSICS | LETTER

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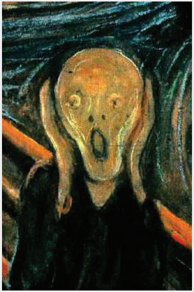

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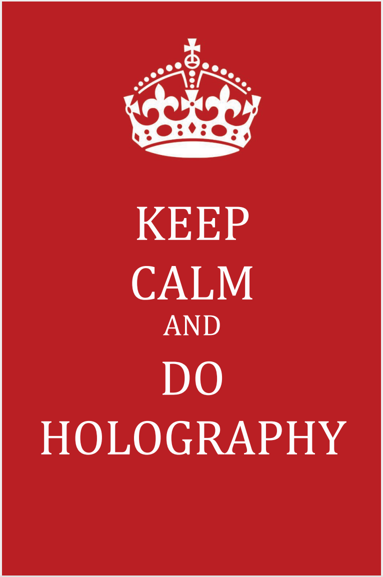

Holographic Weyl Semimetal

Bulk Lagrangian

$$\mathcal{L} = -\frac{1}{4}H^{ab}H_{ab} - \frac{1}{4}F^{ab}F_{ab} + (D_a\Phi)^*(D^a\Phi) - V(\Phi) + \frac{\alpha}{3}\epsilon^{abcde}A_a\left(F_{bc}F_{de} + 3H_{bc}H_{de}\right) ,$$

$F = dV$, $H = dA$, $D_a = \partial_a - iqA_a$ [Landsteiner, Liu '15] [Landsteiner, Liu, Sun '15]

The idea

- Axial-Vector anomaly → U(1)'s coupled via Chern-Simons
- M (i.e. explicit breaking of axial symmetry) → scalar coupled to axial + b.c.

Background Schwarzschild-AdS_5 $ds^2 = -f(\rho)dt^2 + f^{-1}(\rho)d\rho^2 + \rho^2(dx^2 + dy^2 + dz^2)$

Field Ansatz and asymptotic conditions

$$A_z(\infty) \sim a + ..., \qquad \varphi(\infty) \sim M + ...$$

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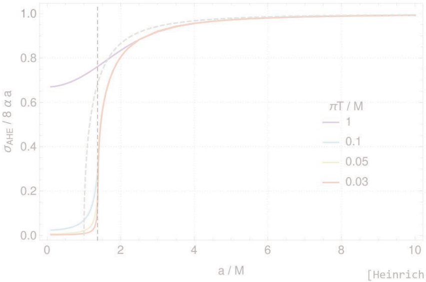
Holographic Weyl Semimetal

Two independent dimensionless parameters

$$\tilde{T} \equiv T/M \qquad \tilde{a} \equiv a/M$$

Order Parameter: Anomalous Hall Conductivity

$$\sigma_{AHC} = \lim_{\omega \to 0} \frac{1}{i\omega} \langle J_x J_y \rangle_R = 8\alpha A_z(\rho_H)$$



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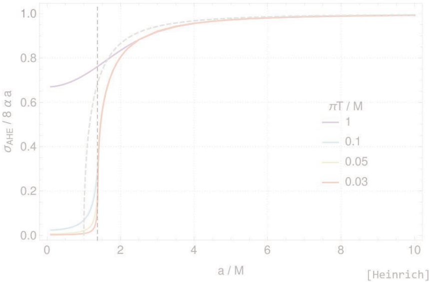

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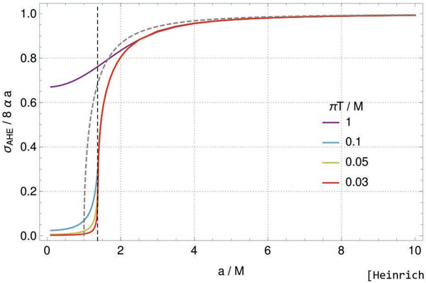


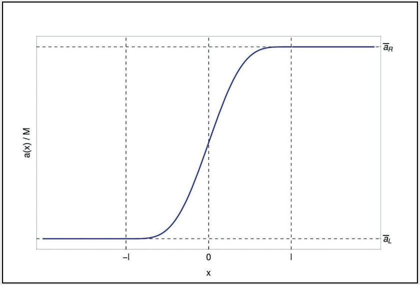
[Heinrich]

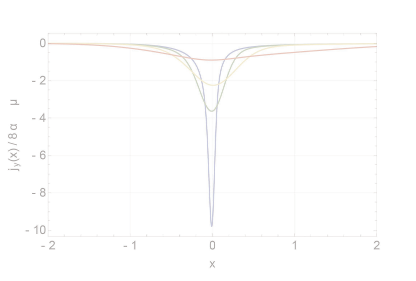
HWS Surface states

Field Ansatz

$$A_z(x,\infty) = a(x), \qquad \varphi(x,\infty) = M,$$

$$V_t(x,\infty) = \mu, \qquad V_y(x,\infty) = 0$$





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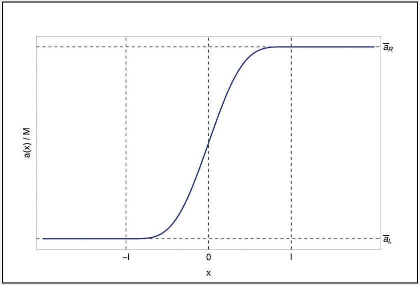
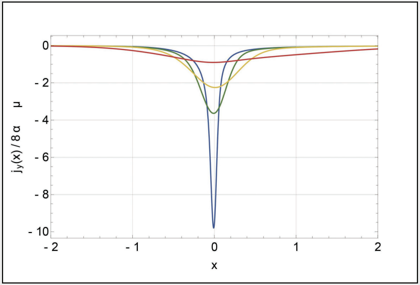
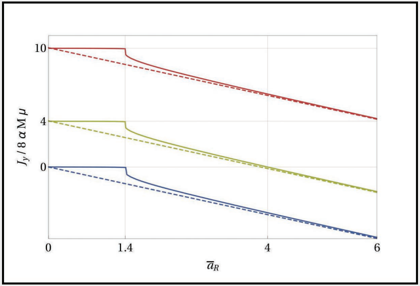




HWS: Integrated surface current



- At high temperatures (dashed) there is no trace of the phase transition.
- At low temperatures the integrated current is constant for $\bar{a}_R < \bar{a}_c$.
- It does not follow the weak coupling $a_{eff} = \sqrt{a^2 - M^2}$.

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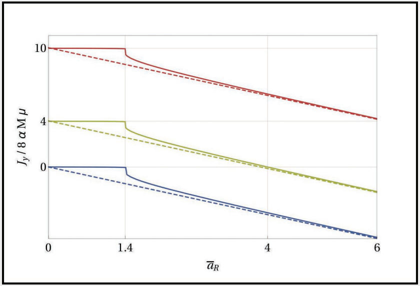

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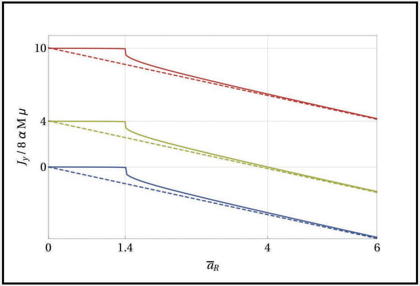

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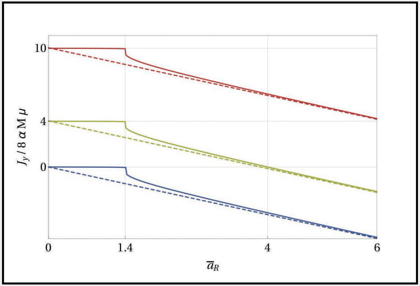

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Last thoughts

The integrated current has a linear dependence on the AHC

$$J_y = \frac{\mu}{2\pi^2}\left(a_{\mathrm{eff},L} - a_{\mathrm{eff},R}\right) = \mu\left(\sigma_{\mathrm{AHE},L} - \sigma_{\mathrm{AHE},R}\right)$$

- This supports the idea of the IR "a" (the AHC) as the effective node distance.
- Fermi Arcs can be thought of as the zeroth Landau level induced by the effective $\mathbf{B}_5 = \nabla \times \mathbf{A}_5$, [Chernodub et al. '13]
- It is not obvious since the well known CME formula $\mathbf{J} = \frac{1}{4\pi^2}\mu\mathbf{B_5}$ holds only in the homogeneous case.
- This restricts the (axial) chiral magnetic conductivity in presence of inhomogeneous (axial) magnetic fields.

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Open questions

- Is the constraint on the inhomogeneous CME model dependent?
- Directly compute the Fermi Surface?
- Can corrections to the dissipationless surface current be computed in holography?
- What about disorder? (in progress)
- What about inversion symmetry?

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