Strongly-coupled Weyl semimetals from AdS/CMT

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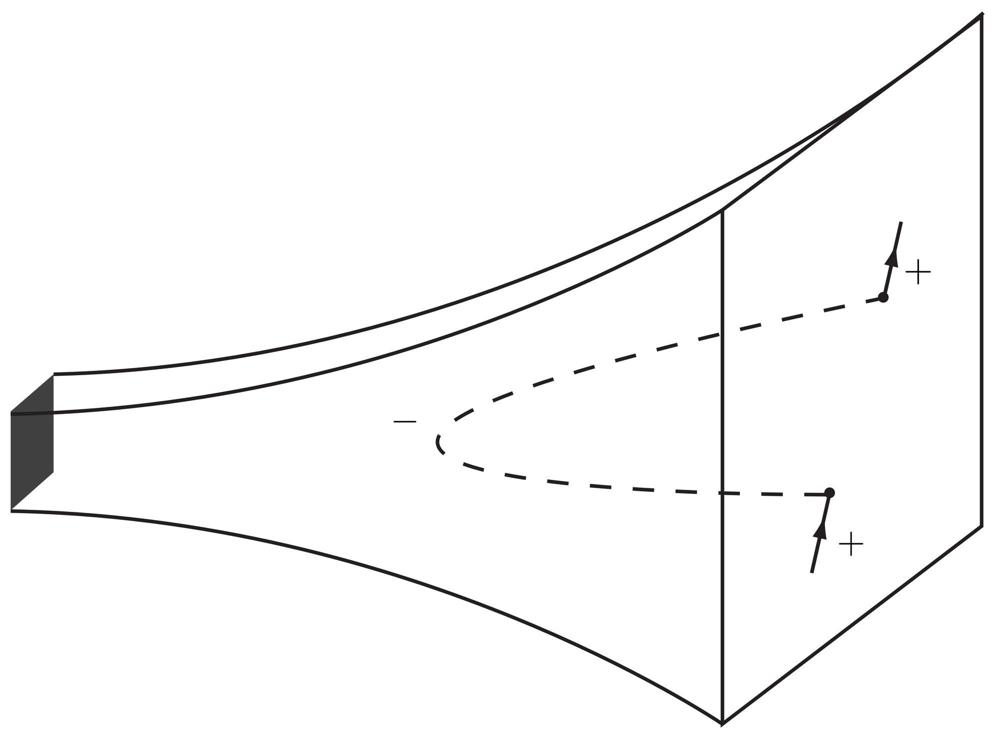
Introduction

Weyl semimetals are condensed-matter systems with fascinating and unusual properties, that result from the topological nature of the band structure. Most of the theoretical work is done on free or weakly-interacting Weyl semimetals. It is interesting to explore these properties also at strong coupling, using techniques from the AdS/CMT correspondence. Here, we present our recent theoretical work [1], in which we propose a holographic model for a class of strongly-coupled Weyl semimetals.

AdS/CMT for single-particle correlations

The model consists of a 5-dimensional gravitational Lifshitz background with Dirac fermions $\Psi = (\Psi_+, \Psi_-)$ of mass M. In our set-up, we also include a boundary term in the action that describes free, elementary, 3+1-dimensional Weyl fermions.



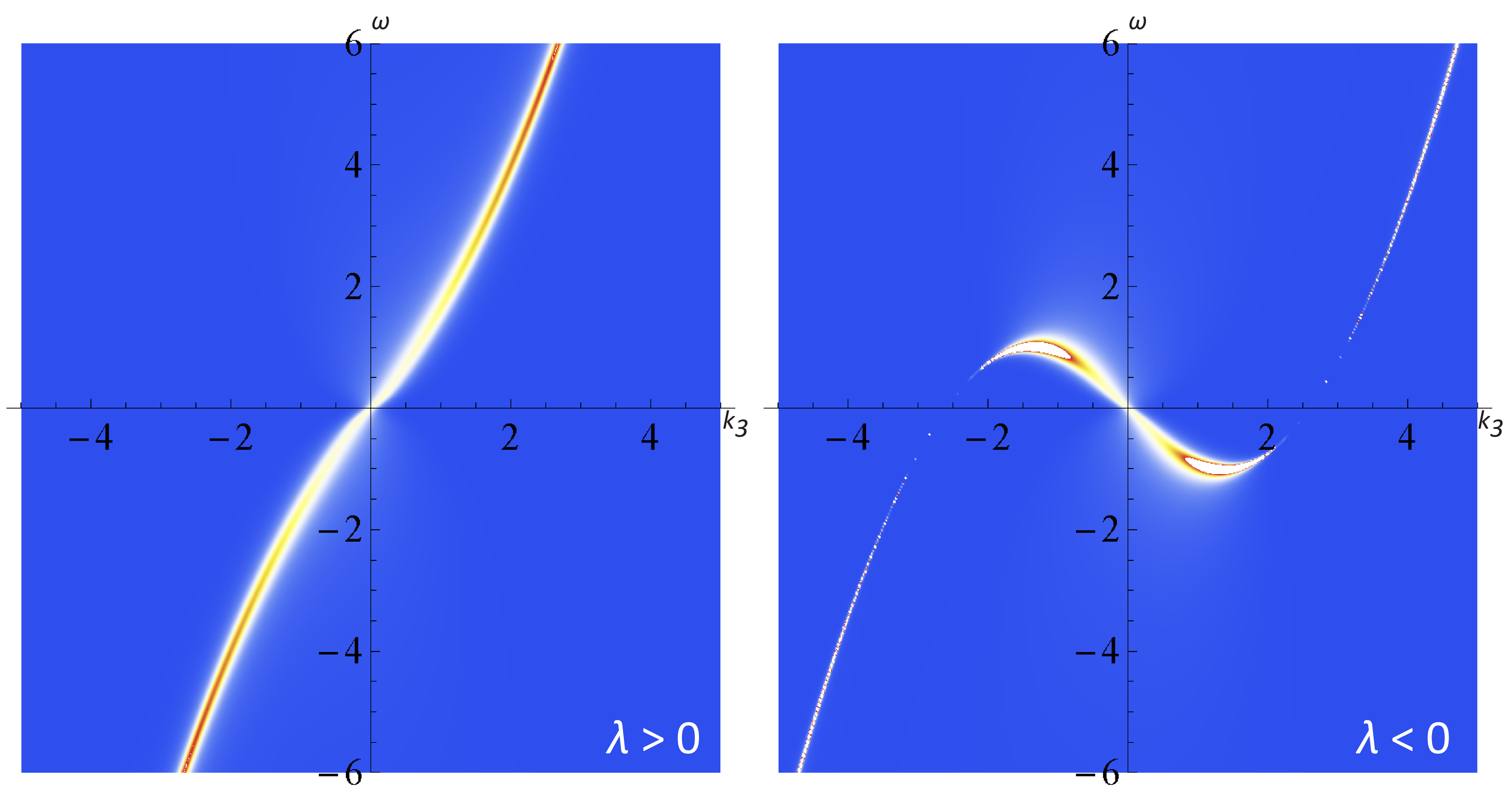
Solving the Dirac equation in the gravitational background yields $\Psi_- = \Sigma\ \Psi_+$ (see left). Together with the boundary term, we obtain an effective action for Ψ_+. The function Σ is the holographic self-energy, by construction an effective description of the interactions between the boundary fermions. Hence, the boundary system is an interacting Weyl semimetal with Lifshitz scaling. The result for the retarded single-particle Green's function is

$$G_R^+(\vec{k},\omega) = -\frac{1}{\omega - \frac{1}{\lambda}\vec{\sigma}\cdot\vec{k}|k|^{z-1} - \Sigma(\vec{k},\omega)}$$

λ denotes the strength of the spin-orbit coupling and thus depends on the microscopic properties of the material. Here, we study how the physics changes as a function of λ.

Single-particle spectra

From the holographic Green's function, we compute the spectral-weight function. This particular quantity is experimentally observable in condensed-matter systems. Below, we have plotted one of the spin components of the spectral-weight function for a dynamical scaling exponent z = 2, temperature T = 1/30 and M = 1/4, and for two values of the parameter λ. Our results show that the system has strong interactions in the infra-red, where the self-energy is dominant over the kinetic energy, while in the far ultra-violet the system becomes free.

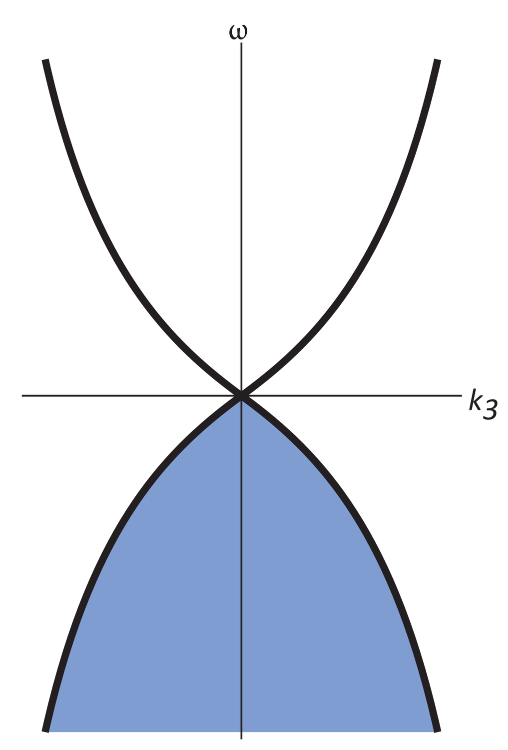


Free Weyl semimetal

A Weyl semimetal is a 3-dimensional gapless semiconductor based on chiral fermions. In the non-interacting case and for low energies, the Hamiltonian is

$$H = \pm\vec{\sigma}\cdot k$$

where the sign in front denotes the chirality.



Since one cannot write down mass terms for Weyl fermions, the gaplessness of the system is topologically protected at zero chemical potential. This gives rise to interesting topological properties [2,3], for example

- A non-zero anomalous Hall conductivity due to non-zero Berry curvature [4].
- Gapless surface states in a certain region of momentum space, the so-called ``Fermi arc''.

We will investigate these properties also at strong coupling using our holographic model.

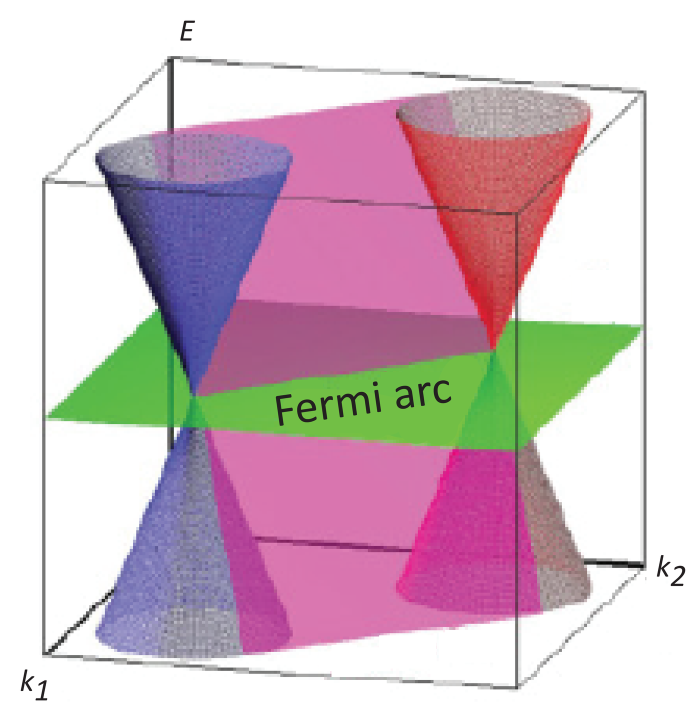
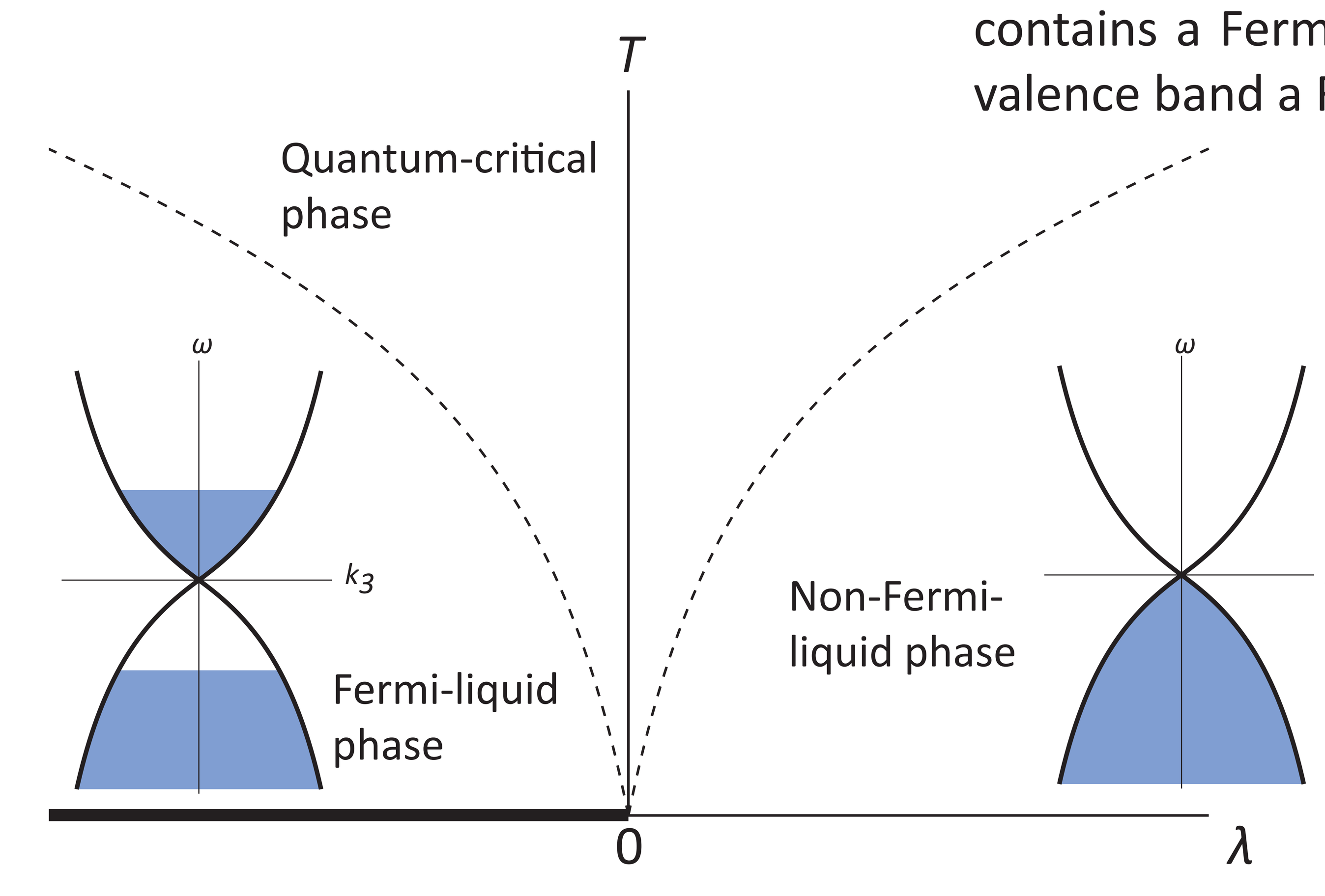


Figure on the right is taken and adapted from [2].

Quantum phase transition

The inclusion of a holographic self-energy leads to the existence of several different phases including a non-Fermi-liquid phase and a Fermi-liquid phase with two Fermi surfaces, separated by a quantum phase transition (see phase diagram below).

We also show the non-interacting band structure and how it is populated in the ground state of each phase. In particular, for $\lambda > 0$ the conduction band is empty and the valence band is completely filled, whereas for $\lambda < 0$ the conduction band contains a Fermi sea of particles and the valence band a Fermi sea of holes.



References

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