Amorphous Kramer-Weyl Semimetals

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Abstract

While nearly half of all crystals exhibit topological properties, little is known about topology in amorphous materials. In this study, we developed a model of amorphous chiral Kramer-Weyl semimetals, where widely used topological markers such as the Bott index or the local Chern marker are trivially zero due to time-reversal symmetry. We thus proposed an alternative way to characterize the survival of Weyl fermions in strongly disordered systems. Our results indicate that Nielsen-Ninomyia's doubling theorem, which states that Weyl fermions must come in pairs of opposite chiralities on a periodic lattice, also holds in the absence of long-range lattice order.

Model

This model is time-reversal symmetric and chiral, as it has no inversion symmetry and no mirror symmetries. Time-reversal symmetry forces Weyl fermions at all time-reversal invariant momenta, hence known as Kramers Weyl fermions. Upon open boundary conditions, Weyl fermions of opposite chirality are connected by chiral Fermi arcs. The above model is defined on a spin-full cubic lattice. The Bloch Hamiltonian reads:

$$\mathcal{H} = \sum_i \sin(k_i)\sigma_i + \sum_i \cos(k_i)\sigma_0 .$$

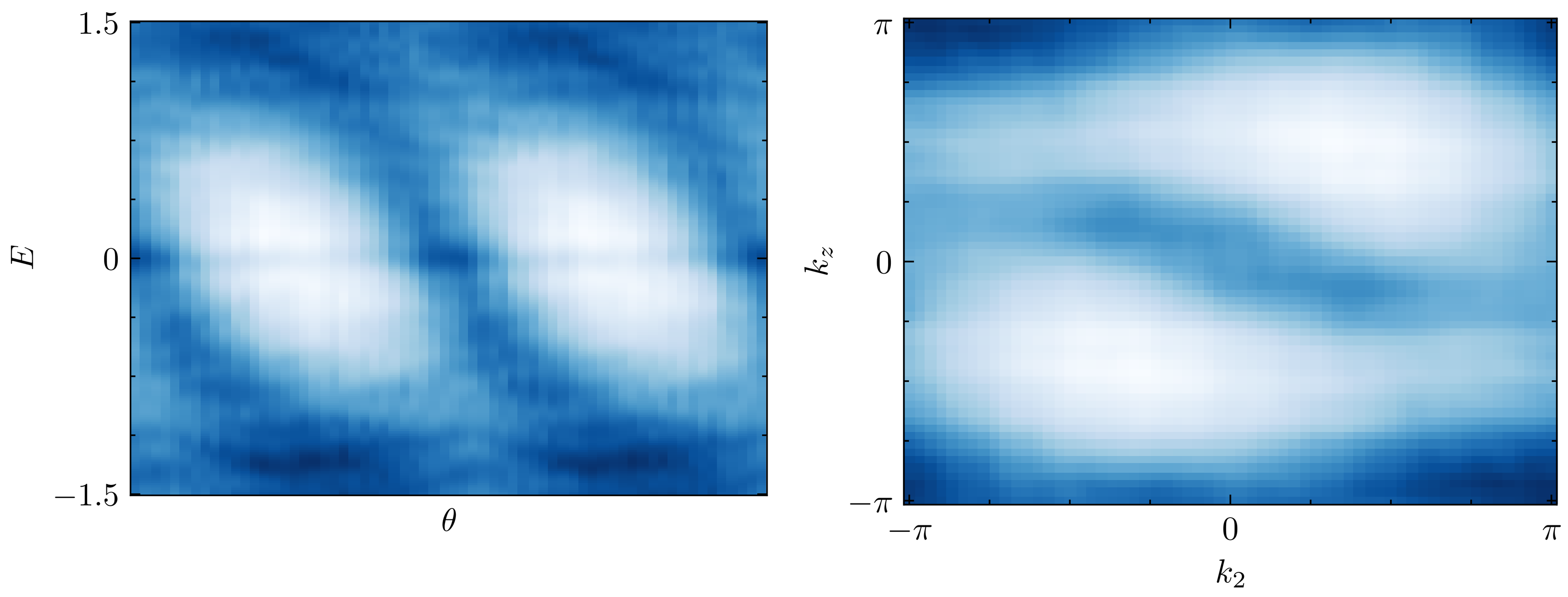
One can write a real space version of the above Hamiltonian:

$$\mathcal{H} = \sum_{i\neq j} c^\dagger_{i,\alpha} T_{\alpha\beta}(r_{ij}, \theta_{ij}, \phi_{ij}) c_{j,\beta},$$

where the hopping terms interpolate the behavior of the initial model when sites are no longer placed on a regular cubic lattice.

ARPES

One can simulate the ARPES spectrum (Angle-resolved photoemission spectroscopy) of the material by numerically computing the green function and projecting it over the plane waves.

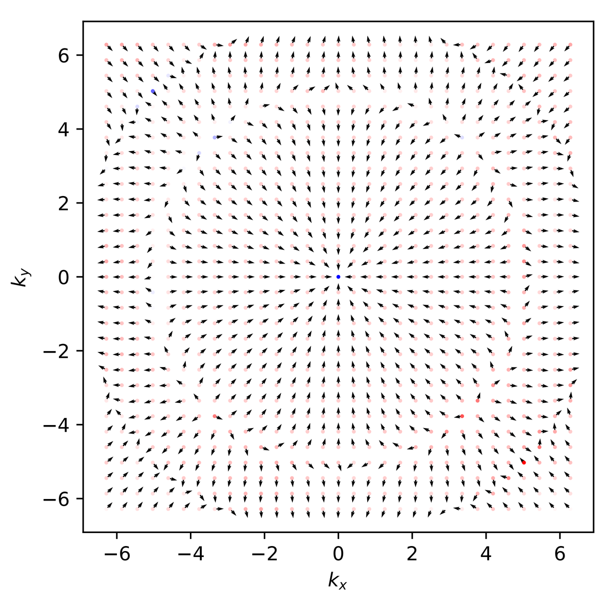


Left: Spectral function along a circular path around Gamma point.
Right: Spectral function in a 2D cut in k-space at given energy.
Both plots are for a disordered systems where sites have been displaced from their original positions using gaussian distribution.

Spin texture

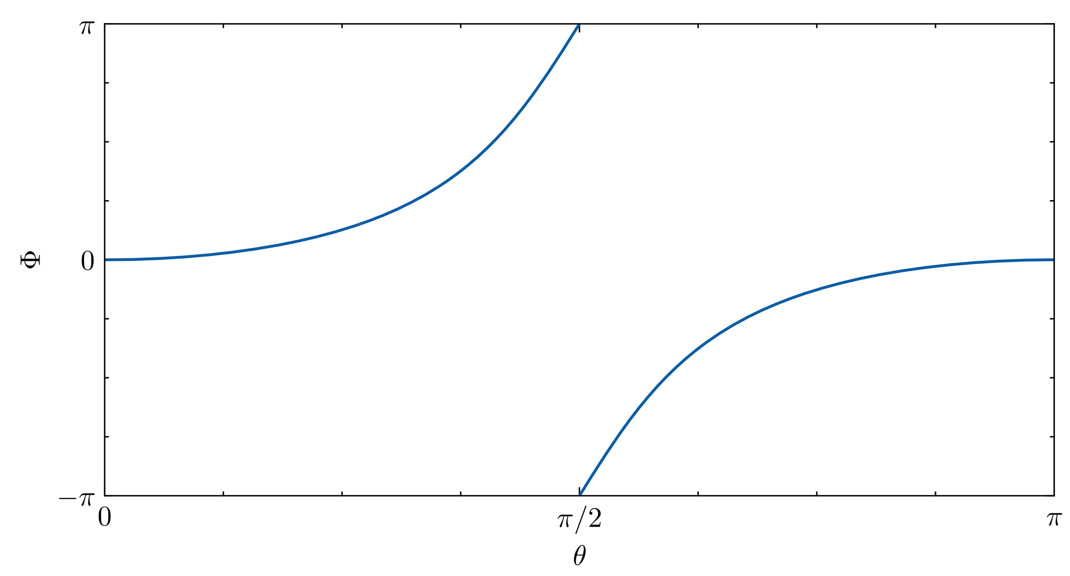
The model at hand has the peculiar properties that there is a one to one correspondence between the berry curvature and the spin texture. Hence, computing the latter would give some insight on the topology of the system. To do so, we introduce an effective k-space Hamiltonian and compute the expectation value the spin operator.

Spin texture ($\langle\sigma\rangle$) of the disordered system.
The expectation value has been calculated using the eigenstates of the effective k-space Hamiltonian.



Wilson loop

Despite not being able to compute Bott index or local Chern marker due to time-reversal symmetry, one can compute, using the effective Hamiltonian eigenvectors, the Wilson loop's winding number to get the monopole charge.



The Wilson loop is winding once, hence the system possesses a +1 charge at Gamma point.

Conclusions

We have developed a model of amorphous chiral semimetal and shown that the Weyl node at gamma point survives in presence of strong disorder. Moreover, we have performed the first computation of Wilson loop for a fully disordered system.