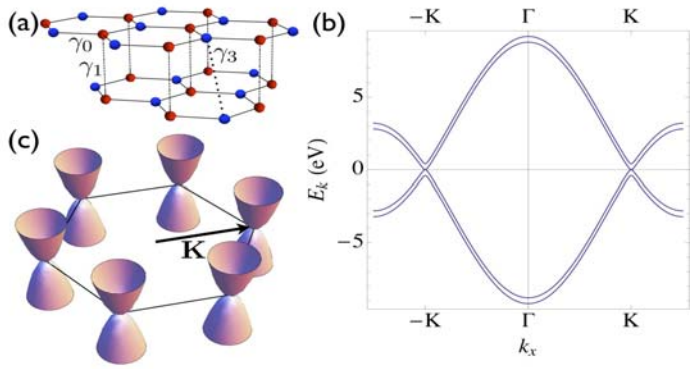
Excitonic and Superconducting Orders in Doped Honeycomb Bilayer

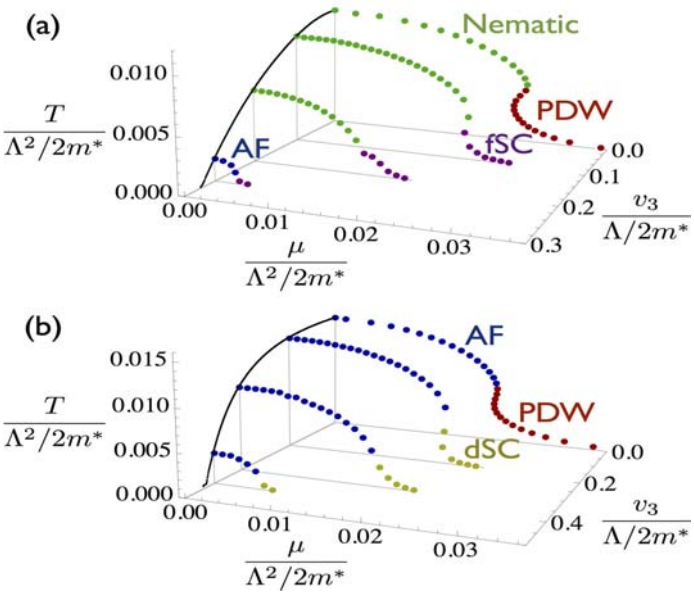
J.M. Murray, O. Vafek, V. Cvetkovic (FSU, NHMFL)

Introduction/Abstract



The appearance of unconventional superconductivity upon suppressing excitonic (i.e. non-superconducting) order by adding charge carriers to a system occurs in many solid-state systems, yet remains to be fully understood. Using a weak-coupling renormalization group (RG) procedure, we resolved this issue for the case of repulsively interacting electrons on the honeycomb bilayer, realized experimentally as bilayer graphene[1,2]. This system, shown in Figure 1, features quadratically touching energy bands at the corners of the Brillouin zone, and is known to be unstable to multiple types of excitonic ordering near half filling. In our work, we have shown within a controlled calculation how fluctuations in various channels can generate an attractive interaction between electrons from bare repulsive interactions, and that this attractive interaction leads to superconductivity upon doping the system away from half filling, leading to small Fermi surfaces.results in the anisotropy of the spectral gap on both hole and electron FS's.

Results and Conclusions



In the first of our two recent papers [1], we focus on firmly establishing the mechanism of unconventional superconductivity theoretically within an idealized model of perfectly parabolic bands at zero temperature. In our more recent work [2], we generalize the previous work to include finite temperature, as well as the distortion of the energy bands due to further-neighbor electron hopping. The appearance of unconventional superconductivity is robust to these effects, at least for parameter values relevant for describing bilayer graphene. The phase diagrams in Figure 2 show the characteristic temperatures for ordering in various channels as a function of chemical potential and v3, which characterizes the strength of trigonal warping. As established previously, the most likely ordered phases at half filling are nematic, realized for longer-ranged interactions and shown in Figure 2(a), and antiferromagnetic, realized for shorter-ranged interactions and shown in Figure 2(b). Upon doping, these give way to various types of superconducting order, with the most likely instabilities occurring in pair density wave (PDW), f-wave, and d-wave channels. The PDW features electron pairs with finite total momentum, leading to a spatial modulation of the superconducting condensate. The d-wave phase, meanwhile, is actually a chiral, time reversal symmetry breaking combination of d-wave order parameters. This “d+id” phase is an analogue of the chiral p-wave phase in superfluid helium. It is currently unclear which of the cases shown in Figure 2 more nearly describes the physics of bilayer graphene, but given rough estimates of disorder effects and the fact that signatures of excitonic order have already been observed experimentally, it seems that experimental realization of unconventional superconductivity could be possible in either case.

References

[1] Oskar Vafek, James M. Murray, and Vladimir Cvetkovic, arXiv:1309.3123 (2013) [8 pages].
[2] James M. Murray and Oskar Vafek, arXiv:1312.6831 (2013) [21 pages].