GRAPHENE AND 2DM VIRTUAL CONFERENCE & EXPO

Graphene online 2020 October 19-23

Disorder-enhanced p-wave superconductivity in graphene

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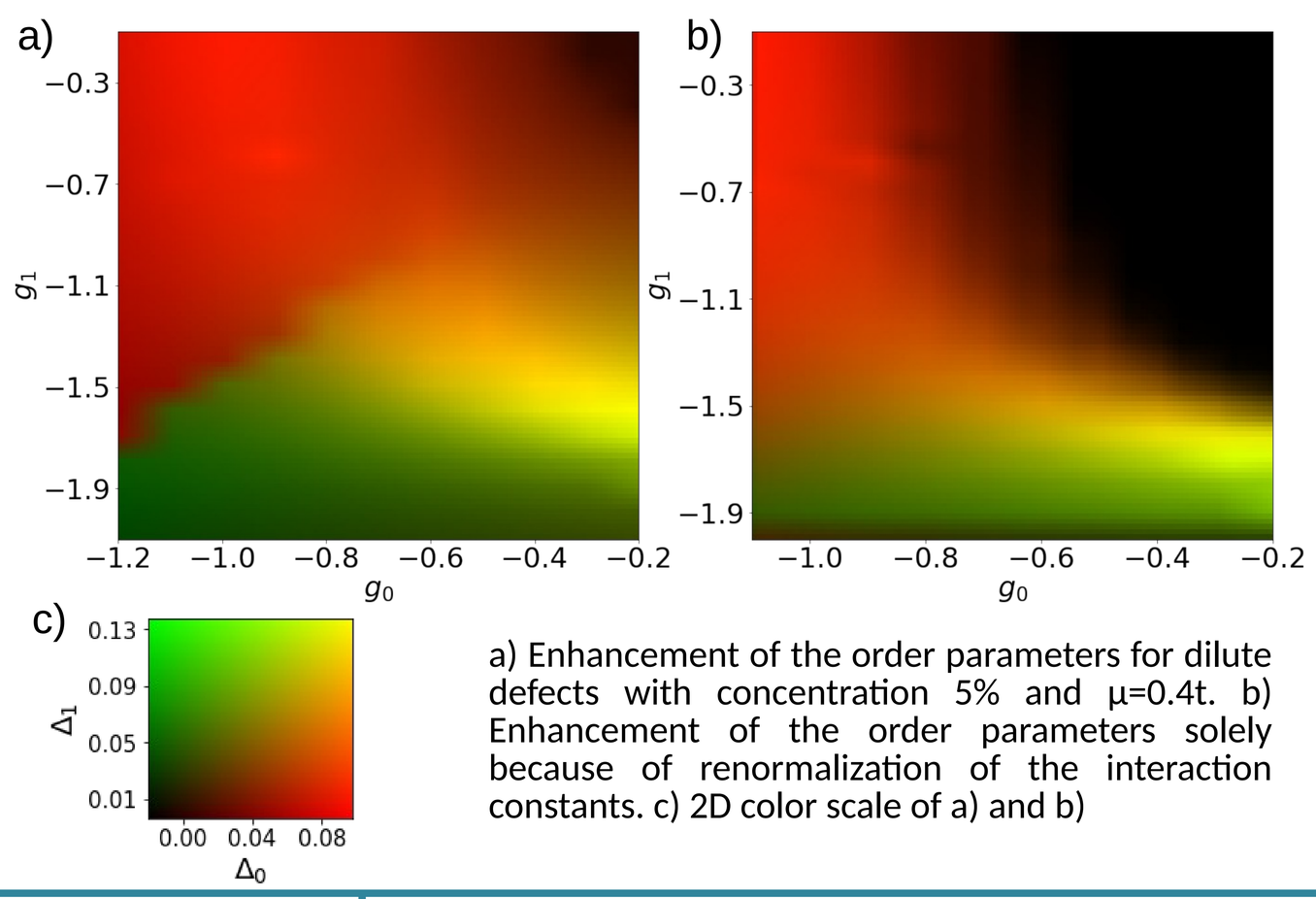
Introduction and motivation

Superconductivity is one of the most fascinating and well-studied topics in Condensed Matter Physics, and ever since their early discovery, several types of superconductors have been discovered. Despite intense search, p-wave pairing in superconductors remains contested, but it promises to be able to exhibit some exotic quantum phases. In the presence of a magnetic field, the resulting p-wave superconducting vortices in graphene have been predicted to be able to host stable Majorana zero-energy modes, with practical applications to quantum computing [1].

Disorder is usually detrimental in condensed matter systems, but it known to be able to enhance superconductivity in some situations, due to the appearance of superconducting islands around the impurities. We want to examine whether it is possible to selectively enhance p-wave superconductivity due to the presence of disorder.

Results

In [2], the authors show the phase diagram of plasmon-mediated metal-coated superconducting graphene, where p-wave may exist, in competition with s-wave. At zero chemical potential μ, this system is able to have well-separated p-wave and s-wave phases, close to a mixed-symmetry phase, but at finite μ, all phases are of mixed symmetry. To this we add dilute defects which have the effect of weakening the graphene bonds around the defect site. This has the effect of renormalizing μ and the electron-electron interaction constants g_0 (s-wave) and g_1 (p-wave), allowing us to move around the phase diagram by changing the concentration of defects. Our findings cannot be explained by this renormalization alone, because the order parameters (which changed smoothly in the clean limit) now change abruptly across a given curve in the g_0,g_1 plane when the defects are present. **We find regions where s-wave superconductivity is enhanced (red), p-wave is enhanced (green) and where both are enhanced (yellow).**

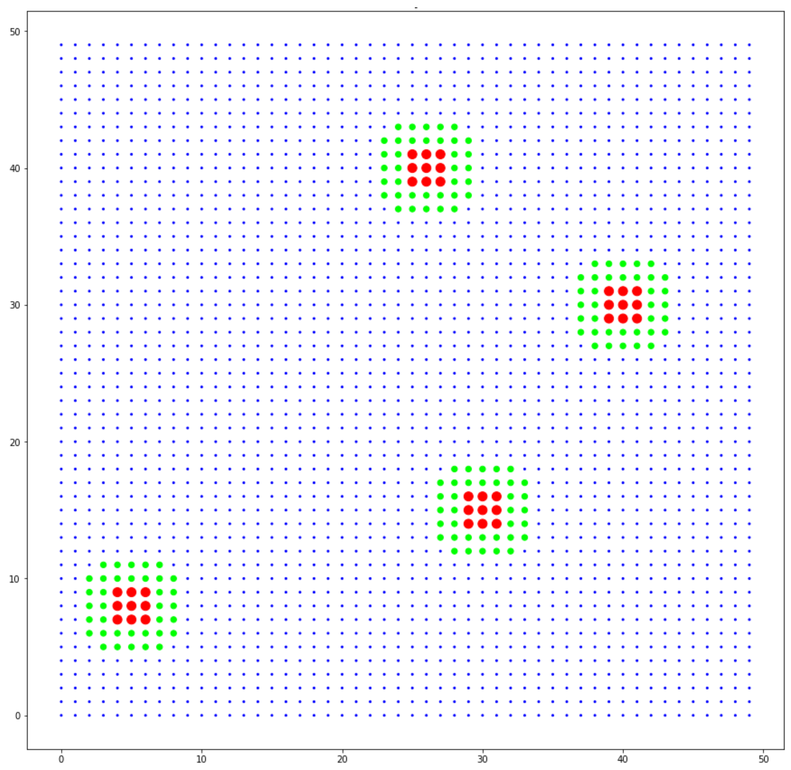


a) Enhancement of the order parameters for dilute defects with concentration 5% and μ=0.4t. b) Enhancement of the order parameters solely because of renormalization of the interaction constants. c) 2D color scale of a) and b)

Numerical method

Disordered superconductors are notoriously difficult to simulate, even in a tight-binding framework. A typical mean-field treatment of superconductivity yields a set of coupled self-consistent equations that has to be solved for each site in the lattice. This is the reason why only small systems (~10^4 atoms) are studied.

We implemented in KITE [3] a modification of the Chebyshev-Bogoliubov-de Genes method [4] in order to simulate large systems (10^7 atoms), which yields improved spectral resolution and smaller statistical fluctuations. To achieve this, we restricted the order parameters to assume a uniform value in the bulk of the superconductor but allowed them to vary in a region or radius z around each impurity. Since we expect the behaviour of the order parameter to be similar around each impurity, we may then specify an identical spatial profile f(r) for the order parameter inside every circle and find the function f(r) which satisfies the self-consistent equations within these restrictions. This function was computed using a modification of the stochastic evaluation of the trace, which is very efficient for large systems.



Example of a spatial profile function f(r). Each color represents one different value of the image of f. The impurities would be at the center of the red region.

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Graphene online 2020