Mottness-Induced Healing In Strongly Correlated Superconductors

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Introduction

Strong electronic correlations are believed to be essential for a complete understanding of many classes of unconventional superconductors, such as the cuprates, heavy fermion superconductors, organic materials and iron pnictides. Among the many puzzling features of these systems is their behavior in the presence of disorder. In the case of the cuprates, experiments have shown that these d-wave superconductors are quite robust against disorder as introduced by carrier doping. In particular, there seems to be a "quantum protection" of the d-wave nodal points. Other anomalies were found in the organics and the pnictides. Although it is controversial whether conventional theory is able to explain these features, strong electronic interactions can give rise to these impurity screening effects. Indeed, they have been captured numerically by the Gutzwiller-projected wave function[1], even though a deeper insight into the underlying mechanism is still lacking. Similar impurity screening phenomena have been found as a result of strong correlations in the metallic state of the Hubbard model.

Results and Discussion

Our analytical and numerical results demonstrate that (i) for sufficiently weak correlations we recover the results of the conventional theory, in which the variations of the different fields induced by the impurities show oscillations with a long-ranged power-law envelope; (ii) for strong interactions and in several different broken symmetry states, the amplitude of the oscillations is strongly suppressed by a common pre-factor x, the deviation from half-filling; (iii) the spatial disturbances of the SC gap are healed over a precisely defined length scale, which does not exceed a few lattice parameters around the impurities; and (iv) this "healing effect" is intrinsically tied to the proximity to the Mott insulating state, even though it survives up to around 30% doping.

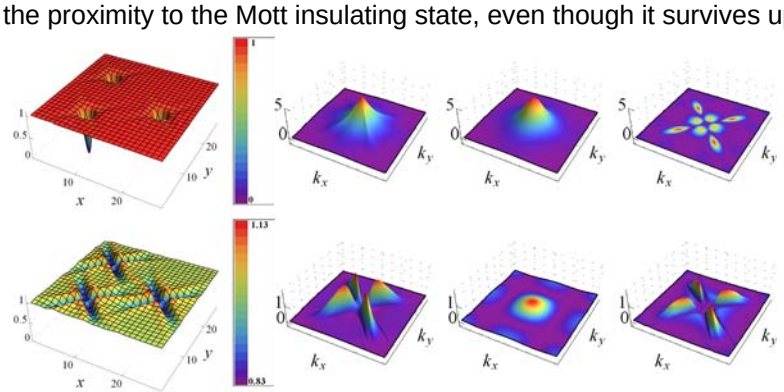

Figure 1. Spatial variations of normalized local SC gap $\frac{\Delta_i}{\Delta_0}$ (first column) and the corresponding power spectra $S(k)$, $S(k)_{loc}$ and $S(k)_{nonloc}$ (second to fourth columns), in the presence (top) and in the absence (bottom) of correlations for $x = 0.2$. The strong suppression of gap oscillations by correlations can be traced to the dominance of the local, spherically symmetric power spectrum [$S(k)_{loc}$] over the non-local anisotropic part [$S(k)_{nonloc}$].

Conclusions

We presented a detailed numerical and analytical treatment of the effects induced by dilute nonmagnetic impurities placed in correlated superconductors and metals. Our main finding is the inextricable link between the healing of gap and charge disturbances as well as the suppression of both in the proximity to the Mott insulating state. We suggest that this phenomenon is generic to any system close to Mott localization. In contrast, we do not expect it to be found in heavy fermion superconductors, in which strong correlations are restricted to strongly localized f-shell electrons.

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References

[1] Garg, A., *et al.*, Nature Phys. **4**, 762-765 (2008).