Levy de Castro et al. Reply

LEVY, G., et al.

Abstract

A Reply to the Comment by Flora Onufrieva and Pierre Pfeuty.

Reference


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Levy de Castro et al. Reply: In [1], the scanning tunneling spectra of Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10+x}$ (Bi-2223) were analyzed using the microscopic model of Bogoliubov excitations interacting with the $(\pi, \pi)$ spin resonance. Onufrieva and Pfeuty [2] stress that self-consistency induces modifications of the theoretical spectra. Self-consistency complicates the calculation, especially when this is to be integrated within a least square fit as in [1]. Therefore it is of interest to clarify whether the changes brought by self-consistency are of a qualitative or quantitative nature. After commenting two points raised in [2] we will give arguments in favor of the second alternative.

According to the authors of [2], “the origin of the large valleys... has nothing to do with VHS [van Hove singularity]”. As pointed out in [1]—and confirmed in [2]—the valley (dip) is an inverted image of the coherence peak. Without a VHS in the bare density of states (DOS) the coherence peak would be much weaker (see Ref. [24] in [1]), and the dip would consequently be much less pronounced. Therefore the very pronounced dips in cuprates are, in our opinion, fingerprints of VHS in the bare DOS. Furthermore, the VHS is the only source of electron-hole asymmetry in this model and electron-hole asymmetry is clearly visible in the self-consistent DOS in [2]. The qualitative characteristics of this asymmetry, namely, a higher coherence peak and a stronger dip at negative energy, are the same as in the non-self-consistent DOS.

Onufrieva and Pfeuty also emphasize the importance of self-consistency for the evaluation of the pairing gap. Whether their approach is valid for this evaluation is controversial, due to the absence of Migdal theorem for spin fluctuations and the use of a phenomenological spin susceptibility. Among other concerns, the role of the continuum of spin excitations must be addressed. This continuum has little effect on the tunneling spectra and could thus be neglected in [1,2], but it carries a substantial spectral weight and is therefore expected to be crucial for a proper calculation of the gap.

The most noticeable difference between the non-self-consistent DOS in [1] and the self-consistent result at strong coupling in [2] is the presence or absence of a double minimum in the dip at negative energy. As stated in [1] a double minimum is not observed experimentally and would be smeared out by taking into account the lifetime of the spin resonance. A recent analysis involving this effect indeed produced new sets of parameters leading to a better fit without double minimum [3]. We think that the mechanism by which the double minimum is suppressed is the only qualitative difference between [1] and [2]. Other differences are of a quantitative nature and/or can be attributed to a different choice of parameters. It may be useful to emphasize a few statements made in [1], which all remain valid when self-consistency is implemented. (1) The STM spectra of optimally doped Bi-2223 can be accurately reproduced by a thermally broadened DOS, without background removal. (2) The theoretical DOS matches the experimental spectra if and only if the normal-state dispersion, i.e., the VHS, is included in the model. Statements 1 and 2 contradict the widespread opinion that the STM is not sensitive to features of the bare DOS. They also underline that ad hoc procedures occasionally used to “normalize” STM spectra of cuprates might unphysically suppress or enhance genuine DOS features such as dips or electron-hole asymmetries. Although detailed fits of the spectra using the self-consistent model look difficult and have never been tried so far, the results of [2] suggest that such fits could provide an excellent description of our experimental data. (3) The signature of the VHS is present in the STM spectra, not as a peak as one could expect, but as two strong electron-hole asymmetric dips. (4) The absence of a VHS peak in the STM spectra is due to the interaction of electrons with collective modes, not to a possible insensitivity of STM tunnel junctions to features of the bare DOS. (5) The value of the collective-mode energy $\Omega_s$ cannot be deduced from the position of the second-derivative ($d^2I/dV^2$) peak, as was done in Ref. [31] of [1]. The mechanism illustrated in Fig. 2 of [1] can be readily extended to the self-consistent case, leading to the conclusion that $\Omega_s$ is given by the energy difference between peak and dip minimum, as confirmed by the calculations [2].

Microscopic models that can be used to interpret the unusual shape of STM spectra in high-$T_c$ superconductors are of great help and value. Even if not perfect, the model used in [1] has provided many insights (as well as the best fits so far), and thus indicates the direction for further improvements. Concerning the extraction of $\Omega_s$ from the experimental spectra our policy up to now has been to use the peak-to-dip energy difference [3]. The self-consistent approach of Onufrieva and Pfeuty provides theoretical support for this strategy.

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