Electrons in cuprates: A consistent ARPES view

A.A. Kordyuk\textsuperscript{a,b,*}, V.B. Zabolotnyyy\textsuperscript{a}, D.V. Evtushinsky\textsuperscript{a,b}, B. Büchner\textsuperscript{a}, S.V. Borisenko\textsuperscript{a}

\textsuperscript{a} IFW Dresden, P.O. Box 270116, D-01171 Dresden, Germany
\textsuperscript{b} Institute of Metal Physics of National Academy of Sciences of Ukraine, 03142 Kyiv, Ukraine

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Abstract

Angle resolved photoemission spectroscopy (ARPES) has been playing a crucial role in understanding physics behind high-temperature superconductivity. Our ARPES investigation of superconducting cuprates, performed over a decade and accomplished by very recent results, suggests a consistent view of electronic interactions in cuprates which provides natural explanation of both the origin of the pseudogap state and the mechanism for high-temperature superconductivity. Within this scenario, the spin-fluctuations play a decisive role in formation of the fermionic excitation spectrum in the normal state and are sufficient to explain the high transition temperatures to the superconducting state while the pseudogap phenomenon is a consequence of a Peierls-type intrinsic instability of electronic system to formation of an incommensurate density wave. In view of these results and their projection to numerous other materials, two general questions are arising: is the normal state in 2D metals ever stable and how does this intrinsic instability interplay with superconductivity?

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tronic scattering in cuprates. In particular, they provide natural explanation of different temperature dependence of the nodal and antinodal renormalizations. As illustrated in Fig. 1, the nodal ‘kink’ in fermionic dispersion is a result of the interband scattering on the spin-fluctuations from the upper, universal, weakly temperature-dependent branch of the spectrum ($Q_2$ vector), while the scattering between the antinodal regions ($Q_1$ vector) is determined by the middle of the spin-fluctuation spectrum where a large peak, known as a ‘resonance mode’ [11], appears just below $T_c$.

The determined value of the spin–fermion coupling constant, $U = 1.59$ eV, gives an estimate of $T_c$ which exceeds 150 K [10]. This demonstrates that spin-fluctuations have sufficient strength to mediate high-temperature superconductivity.

The actual $T_c$ can be reduced by a variety of effects. Two of them, the phase fluctuations of the order parameter and competition with other types of order make a link to the pseudogap phenomenon, not considered in this analysis. In Ref. [12] we have shown that the electronic density ordering is the most probable origin of the pseudogap in cuprates.

Performing careful temperature- and momentum-resolved photoemission experiments [12], we have found that the depletion of the spectral weight in slightly underdoped Bi(Tb)-2212 superconductor, usually called the “pseudogap,” exhibits an unexpected non-monotonic temperature dependence: decreases linearly approaching $T^*$ at which it reveals a sharp transition but does not vanish and starts to increase gradually again at higher temperature.

Fig. 3 illustrates the temperature evolution of the pseudogap presenting a temperature map (panel a) and momentum integrated energy distribution curves (EDCs) measured at different temperatures and compared to each other (panels b and e) as well as to the similar EDCs but measured for each temperature along the nodal direction (panels c, d, f, g). The gap is seen as a shift of the leading edge midpoint (LEM) of a gapped EDC. Since the leading edge
of the momentum integrated EDC of the non-gapped spectrum is expected to stay at zero binding energy for any temperature, as it is observed for the nodal EDCs (Fig. 2c, d, f, g), the finite shift of the LEM is a good empirical measure for a gap of unknown origin. From the temperature map presented in Fig. 2a one can easily see an unusual temperature evolution of the gap (in terms of the colorscale, the LEM corresponds to the white color): first it decreases with increasing temperature up to about 170 K, then it starts to increase again.

The temperature dependence of the LEM is summarized in Fig. 4 (left panel) where it is compared to the similar quantity measured for TaSe2 (right panel), for which it is known that the pseudogap results from the incommensurate charge density wave [13–15]. The observed one-to-one correspondence between the temperature dependences of the pseudogap for Bi-2212 and TaSe2, which is discussed in details in Ref. [12], suggests that density wave ordering also appears in cuprates and, reducing the electron density of states at the Fermi level, competes with superconductivity. While the evidence for such a competition is also reported by other groups [16,17], the exact nature of the ordering remains unclear. One may assume that the spin-fluctuations, being a dominant mediator for electronic interactions in cuprate, play also the role of the main driving force for the electronic instability resulting in the spin density wave formation. This assumption, however, requires future experimental verification.

Attributing the pseudogap phenomenon to a Peierls-type incommensurate density wave in both cuprates [12] and dichalcogenides [13–15], together with indication of similar electronic instability in other 2D metals such as pnictides [18,19], arise two old and forgotten general questions [20]: is the normal state in 2D metals ever stable and how does this intrinsic instability interplay with superconductivity?
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References