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FOR MORE INFORMATION
Sasa V. Dordevic, Department of Physics, The University of Akron
sasha@physics.uakron.edu

The Electron-Boson Spectral Function $\alpha^2F(\omega)$ of High-T_c Superconductors

S.V. Dordevic[1], C. C. Homes[1], J.J. Tu[1], T. Valla[1], M. Strongin[1], P.D. Johnson[1], G.D. Gu[1] and D.N. Basov[2]

[1]Department of Physics, Brookhaven National Laboratory; [2]Department of Physics, University of California, San Diego

We have developed and implemented a new numerical procedure for extracting electron-boson spectral functions from infrared (IR) and angle-resolved photoemission spectroscopy (ARPES) data. The new method is based on inverse theory and has numerous advantages over previously employed procedures. Using this new method we have calculated the electron-boson spectral functions of high-critical-temperature (high-Tc) cuprates, from both IR and ARPES data obtained at the NSLS. The spectral functions have a characteristic shape, dominated by a pronounced peak at low energies and a significant contribution at higher energies.

The nature of the collective boson mode responsible for superconductivity in the cuprate family of high-critical-temperature (high-T_c) superconductors is currently the center of great controversy in the field. Two opposing views have been battling for supremacy. The older scenario, dating back to the early 90s, argues for spin-fluctuations as the pairing glue for high-T_c superconductivity. More recently, phonons have been put forward as possible mediators for superconductivity in the cuprates.

The physical quantity that characterizes coupling between charge carriers and collective bosonic modes is a so-called Eliashberg electron-boson spectral function $\alpha^2F(\omega)$. It is one of the most important characteristics of a boson-exchange superconductor. This function can be obtained from tunneling, photoemission (ARPES), or infrared (IR) spectroscopy. However, the process of obtaining $\alpha^2F(\omega)$ is nontrivial because $\alpha^2F(\omega)$ is convoluted in the experimental data. For example, in the IR case the celebrated Allen result relates $\alpha^2F(\omega)$ to the experimentally accessible quasiparticle scattering rate $1/\tau(\omega)$ through an integral relation:

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$$\frac{1}{\tau(\omega)} = \frac{2\pi}{\omega}\int_0^{\omega}(\omega-\Omega)\alpha^2F(\Omega)d\Omega. \qquad (1)$$

We have recently developed a new numerical procedure for extracting $\alpha^2F(\omega)$ based on a mathematical procedure called inverse theory. The method uses a so-called singular value decomposition (SVD) of matrices and has numerous advantages over previously employed procedures. For example, the inversion can be performed not only at T= 0 K but also at higher temperatures, the effect of the superconducting energy gap can be taken into account, and the numerical error can be controlled. Using this new procedure we have re-analyzed our IR and ARPES data on several families of cuprate data, part of which were obtained on NSLS beamlines U10A and U13UB.

Figure 1 displays inversion calculations on IR data at 10 K for underdoped $YBa_2Cu_3O_{6.6}$ (YBCO) with T_c= 59 K. The right panels show scattering-rate data (green lines) and the left panels present the calculated spectral function $\alpha^2F(\omega)$ (blue lines). The right panels also show the scattering rate $1/\tau_{cal}(\omega)$ (red lines) calculated from the corresponding spectral function on the left. Different panels display inversion results with different levels of smoothing, i.e. different levels of error. The spectral function has a characteristic shape, with a pronounced peak in the far-IR followed by a strong dip and a significant contribution at higher frequencies. The peak is believed to originate from the coupling of charge carriers to the so-called (π, π)-resonance observed in neutron-scattering experiments. More recently, phonons have been advocated as an alternative explanation.

Similar numerical procedures can also be applied to ARPES. **Figure 2** displays inversion calculations of ARPES data of optimally doped $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) with T_c= 92 K obtained at beamline U13UB. The top panels display data in the normal state (above T_c), whereas the bottom panels display the data in the superconducting state. The right panels are measured quasiparticle dispersions (red dots) and the left panels are calculated $\alpha^2F(\omega)$ values. The right panels also show calculated spectral functions (green lines).

The importance of this new numerical procedure goes beyond high-T_c superconductors, IR, and ARPES. Similar numerical procedures can be applied to conventional superconductors, as well as to other experimental methods whose data can be described by an integral equation similar to Eq. 1 on the previous page.

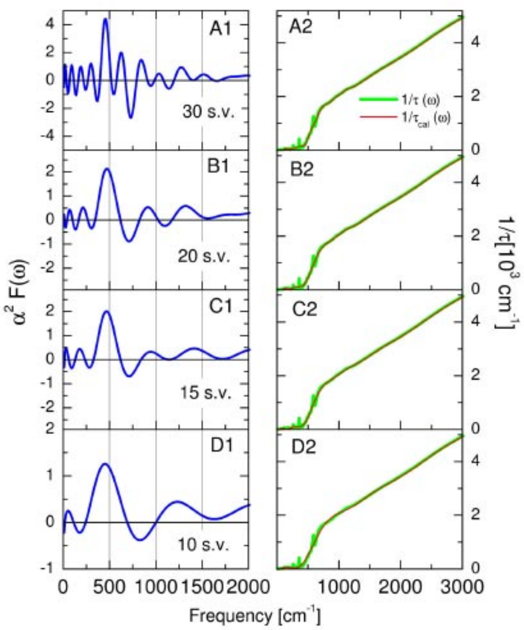

Figure 1. *Spectral function $\alpha^2F(\omega)$ for underdoped $YBa_2Cu_3O_{6.6}$ with T_c= 59 K. The left panels show $\alpha^2F(\omega)$ and the right panels show the experimental $1/\tau((\omega))$ along with $1/\tau_{cal}(\omega)$ calculated from the corresponding spectral function on the left. The level of smoothing is easily controlled by the new inversion procedure.*

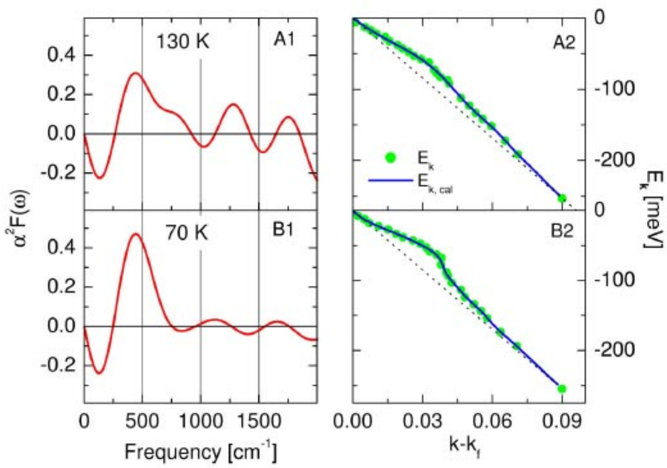

Figure 2. *The spectral function $\alpha^2F(\omega)$ of optimally doped BSCCO with T_c=92 K, extracted from ARPES data. The left panels show $\alpha^2F(\omega)$ spectra and the right panels show the ARPES quasiparticle dispersion E_k (green circles) and calculated dispersion $E_{k,cal}$ (blue lines).*