

# Electronic Structure of Colossal Magnetoresistive (CMR) Oxides

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## INTRODUCTION

Colossal Magnetoresistance (CMR) is the huge drop in resistance a material feels upon the application of a magnetic field. It is found to occur in a variety of doped manganese oxides with perovskite or layered perovskite structures[1,2], which are very similar to the structures of the high temperature superconductors. At high temperatures the materials are insulating while at temperatures below a phase transition temperature  $T_c$  they are metallic. Coincident with the metallic state the material is a ferromagnet while above  $T_c$  it is a paramagnet. The application of a magnetic field for  $T$  near  $T_c$  reduces the resistivity by a few orders of magnitude, i.e. it displays a colossal negative magnetoresistance. The origin of the CMR effect is not understood, nor are many of the other important properties such as the nature of either the metallic or insulating states.

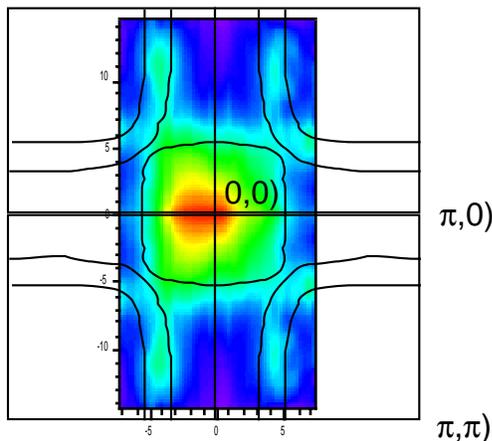
Our group has been performing angle-resolved photoemission studies of the CMR oxides to understand the electronic structure and physics of these remarkable compounds[3-5]. Using the new ultra-high resolution facilities at the ALS we have begun uncovering qualitatively new and exciting results which may shed light on the nature of these as well as other correlated electron systems.

## EXPERIMENTAL

We used the angle mode of the High Energy Resolution Spectrometer (HERS) at beamline 10.0.1 to simultaneously measure spectra over a  $\pm 8$  degree angular space with an angular resolution of better than  $\pm .01$  degrees and an energy resolution of about 15 meV. We cleaved single crystalline samples of the layered manganite  $\text{La}_{1.2}\text{Sr}_{1.8}\text{Mn}_2\text{O}_7$  which had a  $T_c$  of 126K. The data shown here were cleaved and measured at a temperature of 20K at a vacuum of  $4 \times 10^{-11}$  torr.

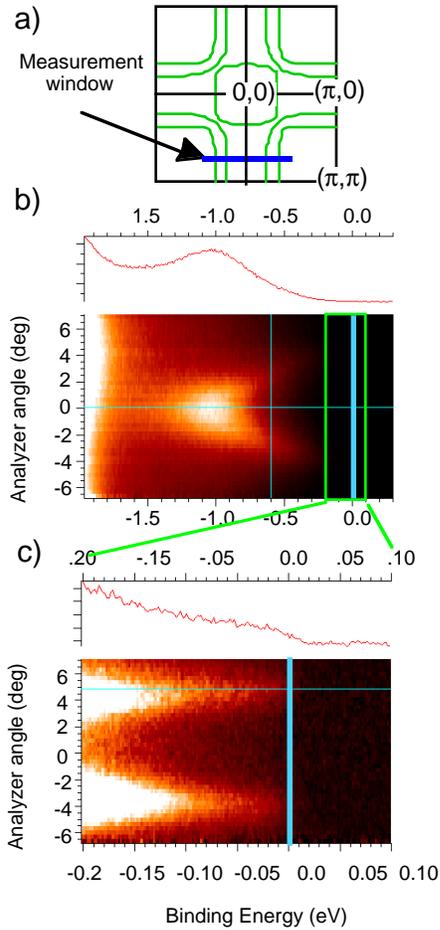
## RESULTS

**Figure 1** shows the measured ARPES spectral intensity very near  $E_F$  over a large portion of the first Brillouin zone. The high intensity regions on this plot should correspond to Fermi Surface (FS) locations. This is the most complete FS measurement to date on a CMR oxide. Superimposed over the data is the FS calculated in the spin-polarized Local Density Approximation (LSDA) by Hamada et al. [3, 6]. We see a satisfactory agreement between the data and the experiment.



**Figure 1.** ARPES spectral intensity of  $\text{La}_{1.2}\text{Sr}_{1.8}\text{Mn}_2\text{O}_7$  measured near  $E_F$  at low temperature. Dark lines are the calculated Fermi Surface.

One set of Energy Distribution Curves (EDC's) from this new data is shown in **figure 2**. **Panel a** shows the location of the cut in the Brillouin zone, while **panels b and c** show the EDC's in the first 2 eV near  $E_F$ . We see maximum intensity at 0 degrees (along the high symmetry line of the Brillouin zone) at about 1 eV binding energy (also see the upper red curve for the EDC spectrum at this angle noted by the blue horizontal line). The color scale plot shows that the max intensity portion disperses towards  $E_F$  as we move away from this angle, as seen also in our older lower resolution data[3-5]. A blowup of this new data very near  $E_F$  is shown in **panel c**. We see that the spectral weight only reaches  $E_F$  at about  $\pm 4.8$  degrees, although the weight there is exceedingly small. This is the location of the FS seen in **figure 1**. An EDC



**Figure 2.** Low temperature ( $T=20\text{K}$ ) Scienta data from  $T_c=130\text{K}$   $\text{La}_{1.2}\text{Sr}_{1.8}\text{Mn}_2\text{O}_7$ . The data was taken over a 14 degree cut as shown at top. The green lines in this figure are the Fermi surfaces obtained from a band structure calculation[6]. The middle panel shows the dispersion of the  $e_g$  band. The bottom panel shows a blowup of this data very near  $E_F$  ( $= 0$  eV).

much of the same basic physics. The deviation from the expectations of the quasiparticle concept appear to show up much more strongly in the manganites (probably because they are right on the verge of the metal-insulator transition) and so in a number of ways appear to be the most direct system with which to study these effects.

## ACKNOWLEDGEMENTS

This work made use of analysis software written by J. Denlinger.

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taken along the horizontal blue line at  $\theta=4.8$  degrees (top curve of **panel c**) shows the real Fermi cutoff. This is the first measurement of a real Fermi edge cutoff from a layered manganite, and the first ever from a manganite taken in angle-resolved mode. However, the way in which the spectra of **figure 2** approach  $E_F$  is very unusual. For a typical non-correlated metal, we would expect the feature to approach  $E_F$  with no loss in intensity. Instead, the feature loses weight drastically as  $E_F$  is approached.

Looking back at figure 2, we see that there is a dispersive portion of the spectrum which clearly crosses the Fermi level, as expected for a metal. However, closer inspection shows that there is nothing like a quasiparticle peak in the spectra. While the Fermi edge is only observed at specific k-points associated with the Fermi surface, no dispersive quasiparticle peak very near  $E_F$  is observed. Instead, the states just appear as an edge sloping up to and then cut off by the Fermi function. If such behavior is confirmed and found to be robust, it would signal a dramatic departure from the quasiparticle and Fermi Liquid concepts which should have the sharp dispersive feature near  $E_F$ . Instead it appears that the weight all the way up to  $E_F$  is "incoherent", a behavior which would appear to be consistent with the possibly complete lack of a coherent Drude peak in the optical conductivity data of this same material [7]. Since the quasiparticle concept is at the very heart of how we understand many-body interactions and correlation effects in solids, a departure from it would mean that we would have to develop a completely different paradigm for the electronic behavior of correlated electrons in a solid. A number of forward-thinking theorists have been following this path for studies of both the manganites [8,9] and high temperature superconductors [10-12].

Somewhat similar behavior has been appearing in the high  $T_c$  superconductors (especially in underdoped samples) but the departure from the quasiparticle expectation is not so severe and so it has not been universally agreed that there was a need to abandon these ideas. We believe that it is likely that the behavior of the near- $E_F$  states of the manganites and cuprates (and possibly other correlated electron systems) have many of the same deep underpinnings and are likely controlled by

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This work was partly funded by the Office of Naval Research.

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