**Fermiology of bilayer colossal magnetoresistant manganites**

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**Outline**

- Intro. to colossal magneto-resistant manganites
  - bilayer systems: La\(_{2-2x}\)Sr\(_{1+2x}\)Mn\(_3\)O\(_7\)

- Angle-resolved photoemission data:
  - history, status quo
  - Fermi surfaces
  - quasiparticles
  - coupling to boson mode(s)
  - surprises in the temperature dependence

- Summary, conclusions and outlook
Colossal (negative) magnetoresistance: CMR

- double exchange means: ferromagnetic (FM) situation favours hopping
- CMR effects of 4000%


Bilayer managanites

- reduced dimensionality
  - greater role for fluctuations
  - connection to the high Tc cuprates?
  - strong anisotropy
- (even) larger CMR effect
- cleavage surfaces suitable for surface sensitive probes:
  - ARPES
  - STM / STS

La, Sr, O rock salt blocks
double MnO₂ planes

cleavage here

pic: Matt Rosseinsky

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La$_{2-2x}$Sr$_{1+2x}$Mn$_2$O$_7$ as 'parent insulator', $x$ gives no. of additional holes

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Expectations from band structure calculations

- **DFT says: half-metallic ferromagnet**
  
  Majority band: quasi-2D Fermi surface

- **$e_g$ bandwidth: both**
  
  $3d_{x^2-y^2}$ and $3d_{z^2-r^2}$ are occupied


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ARPES of 2L manganites: history

**Colorado group:**

- **ghost Fermi surface, pseudogap**
  
  Dessau et al., PRL1998
  
  data: $x=0.4$

- **Fermi surface nesting (no QP's anywhere)**
  
  Chuang et al., Science 2001
  
  data: $x=0.4$

hv=50eV

integrated $\pm 200$meV of $E_F$
**ARPES of 2L manganites: status quo**

**general statement 2L manganites:** nodal metal (Fermi arc)
- Data: $x = 0.4$


**QP’s at antinode**
- No QP’s for $x = 0.4$
- Data: $x = 0.36, 0.38, 0.4$

Colorado Z. Sun et al. PRL (2006)

**ARPES of 2L manganites: status quo**

**Metallicity above $T_c$ (phase separation)**
- Data: $x = 0.38$, AB band

**Crystal characterisation: x=0.36**

LEED image (T= 40K, 95eV) of cleaved LSMO (x= 0.36) surface

- sharp transitions, excellent cleavage surfaces

**Hunting down the QP’s**

- low energy spectral weight all round the AB Fermi surface

S. de Jong et al. 2006

$\nu=56\text{eV}$
Energy distribution curves

- note:
  'QPs' at all $k_F$'s for LSMO

$k_F$-EDCs

Intensity (arb. units)

1 2 3 4 5 6 7

Binding energy (eV)

1.0 0.5 0.0 0.0 0.1 0.2

$\nu\nu = 56\text{eV}$

peaks not yet resolution limited......

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μ - ARPES: AB band (at the SLS)

$\nu\nu = 56\text{eV}$

at $(\pi/a,0)$

antibonding band:
sharp QP, resolution limited width

S. de Jong et al. 2006
bonding band:
\[ E_F \text{ MDC width (0.07 } \pi/a \text{) is double that of the AB band} \]

**What about the BZ diagonal?**

- AB band
- B band
- Zone diagonal

FWHM
- 0.035 \( \pi/a \)
- 0.07 \( \pi/a \)
- 0.1 \( \pi/a \)

Binding energy (eV): 56 eV, 73 eV, 56 eV

Intensity (arb. units): 0.0, 0.0, 0.0
for $x=0.36$:

- QP's visible for:
  - AB FS at $(\pi/a,0)$ and zone diagonal
  - and for BB FS at $(\pi/a,0)$

**Renormalisation effects at $(\pi/a,0)$**

- coupling to collective (bosonic) mode(s):
  - clear deviation from non-interacting dispersion between 60 and 110meV
  - also seen in MDC width ($\rightarrow$ QP inverse life-time)
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Temperature dependence at $(\pi/a,0)$

- $T_C=130\text{K}$
- $\text{BE} (\text{eV})$ vs. $\text{BE} (\text{eV})$
- $\text{BE} (\text{eV})$ vs. $\text{BE} (\text{eV})$
- $\text{BE} (\text{eV})$ vs. $\text{BE} (\text{eV})$
### T-dependence: renormalisation effects ($\pi/a,0$)

![Graph](image1.png)

**E-E_F (eV)**

- Peak position ($k_y$) MDC FWHM ($\pi/a$)
- MDC FWHM ($\pi/a$)

**T-values:**
- $T=30$
- $T=95$
- $T=145$

**Notes:**
- $h\nu=56\text{eV}$
- At ($\pi/a,0$)

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### T-dependence: MDC width at ($\pi/a,0$)

![Graph](image2.png)

**E-E_F (eV)**

- Strong T-dependence for low energies
- Change in form within FM-M phase ($30 \rightarrow 95\text{K}$)

**T-values:**
- $T=30$
- $T=95$
- $T=145$

**Notes:**
- $h\nu=56\text{eV}$
- At ($\pi/a,0$)
T-dependence: at $(\pi/a,0)$ and BZ diagonal

Image showing energy bands at $30\,K$, $95\,K$, and $145\,K$.

$T_c$ is marked as the critical temperature.

$\nu = 56\,eV$

S. de Jong et al. 2006

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T-dependence: $k_F$ EDC's at $(\pi/a,0)$ and BZ diagonal

Image showing energy distribution with $k_F$ dependence.

Giant temperature dependence, $k$-dependent.

QP peak more robust at antinodes.

Spectral weight shift even larger at nodes.

S. de Jong et al. 2006
**T-dependence: metallic phase above $T_c$?**

- Two phase model doesn't work here
  - QP peak only for $T<T_c$
  - Different high E behaviour for the two k-points

**Conclusions**

- Quasiparticles are to be found on both the AB (at zone face and diagonal) and BB Fermi surfaces for $x = 0.36$
- No such thing as a (general) nodal metal
- Strong renormalisation effects clearly identified:
  - Phonon-orbitons
  - Strongly T-dep.: magnetism (analysis underway)
- Anomalous temperature dependence:
  - huge shifts of spectral weight
  - Can't fit a 2-phase model
Glimpse of something hot off the beamline......

$\nu = 56\text{eV}$

S. de Jong et al. 2007

Glimpse 2

$\nu = 73\text{eV}$

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? possible breakdown of 100% spin polarisation ?

\[ \nu = 73 \text{eV} \]

\[ \text{Glimpse 2} \]

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The Credits

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