Complexity in Transition Metal Oxides

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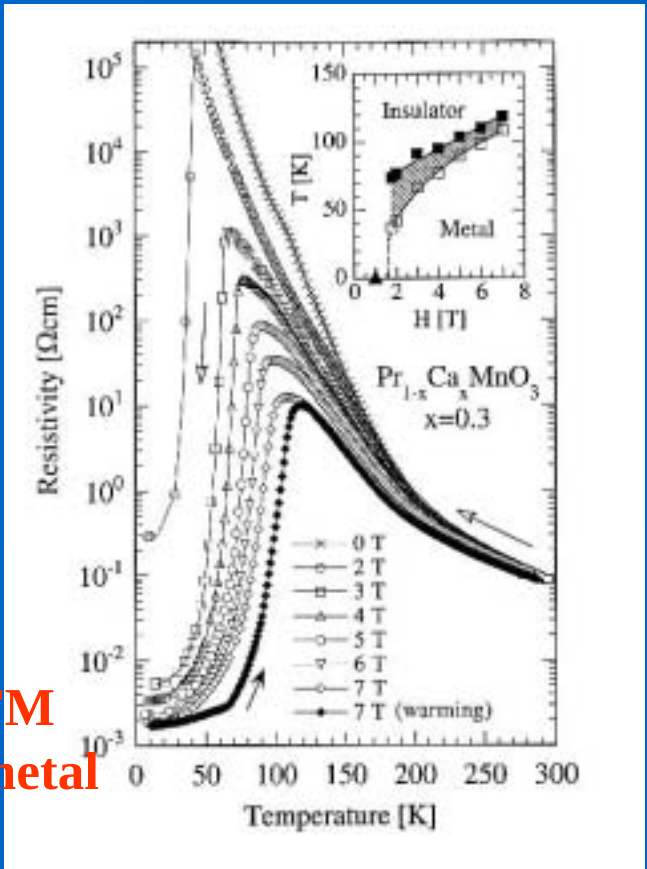
Main message: Experiments and MC simulations show signs of ``complexity'' in hard materials

- CMR manganites (review)
- Underdoped High-Tc cuprates (new)
- Ruthenates, cobaltites (Leighton). Also in diluted magnetic semiconductors?! (Schiffer)

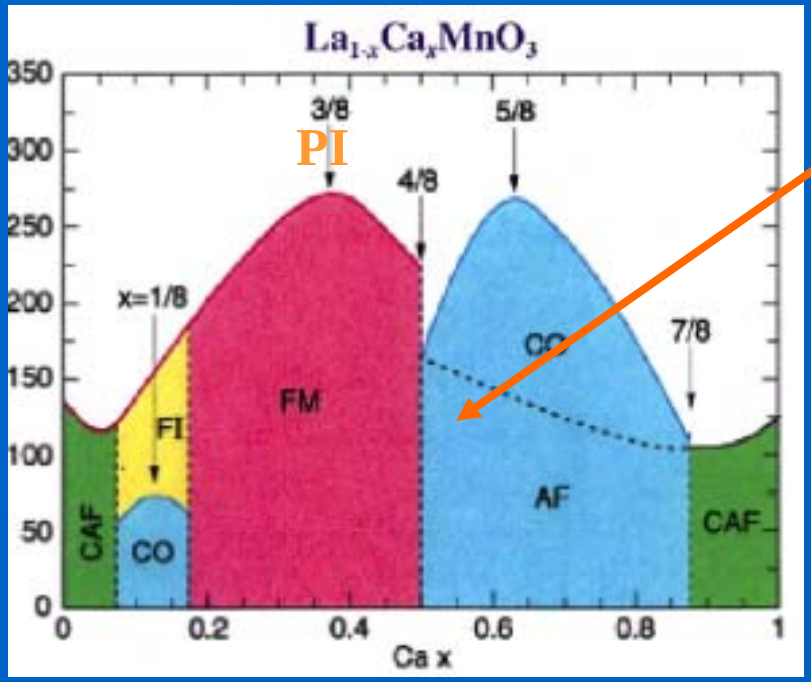
Common theme emerging:

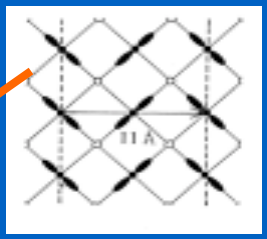
Clustered states and dramatic effects as a result of small perturbations (complexity?)

(I) CMR manganites:



FM metal

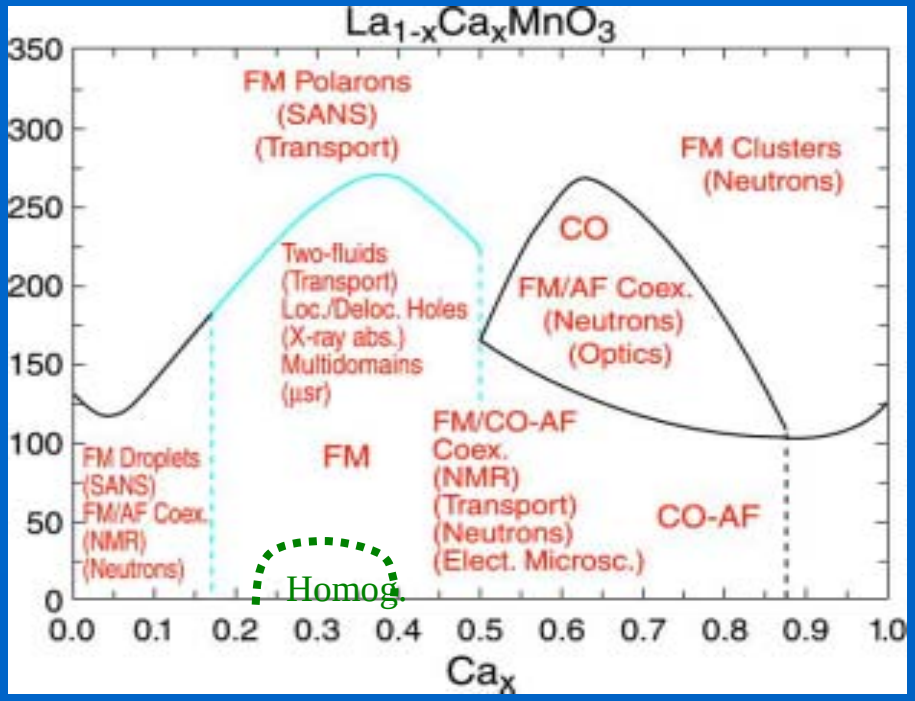




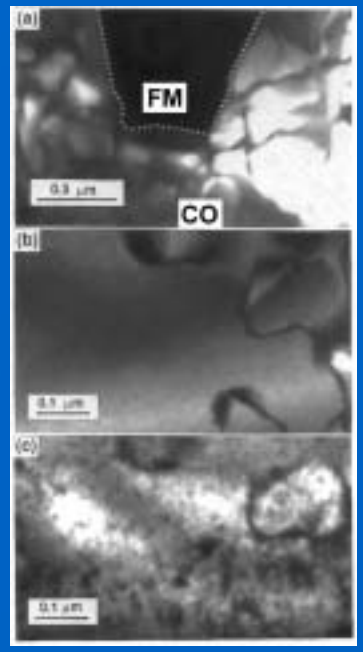
CE-type
Spin, charge, orbital order

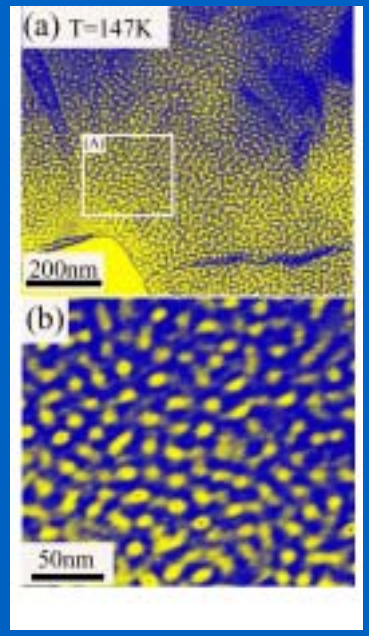
Rich phase diagram, several states competing. Common feature of many Strongly Correlated Electronic systems.

Recent Trends: Phase Coexistence in Manganites



A.Moreo et al.,
Science 283, 2034 (1999).





Uehara et al., Nature '99
LaPrCaMnO
EM

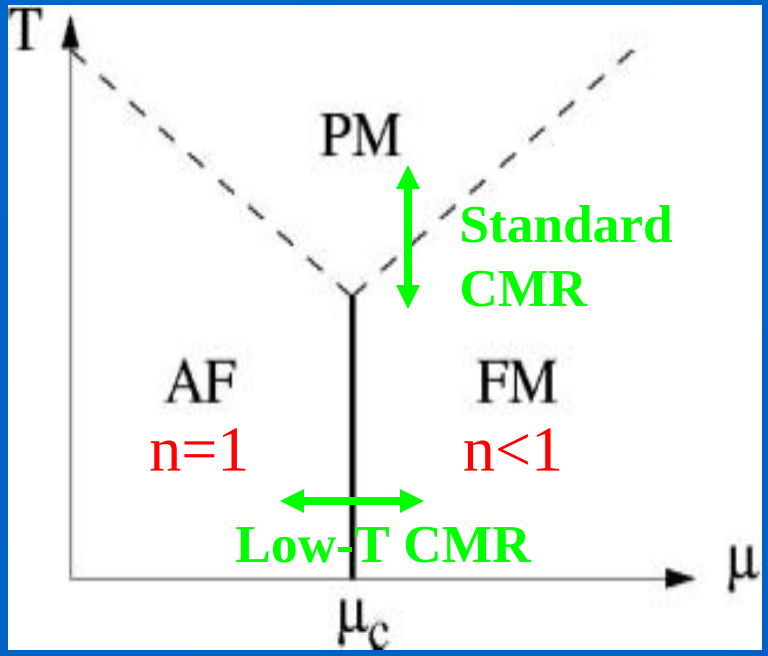
Mori et al.
Lorentz micros.
FM nanodomains
Tc=85K, T*=170K

$La_{0.25}Pr_{0.375}Ca_{0.375}MnO_3$

Summary of MC/MF Results

(without quenched disorder)

- FM, AF /CO, and Electronic Phase Separation are observed. Experimentally-observed ordered phases have been found/predicted.

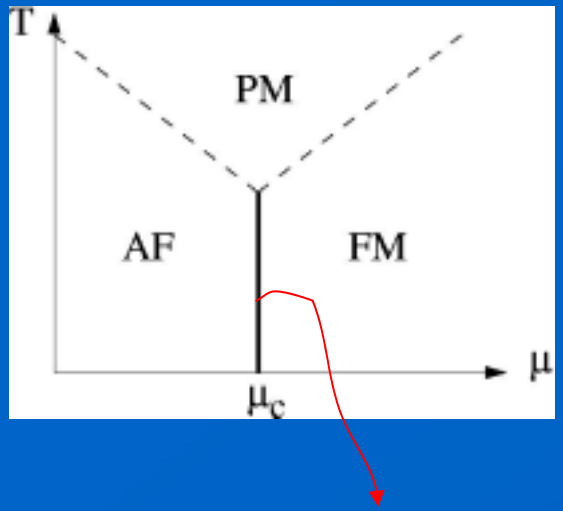


Yunoki et al. 1998.

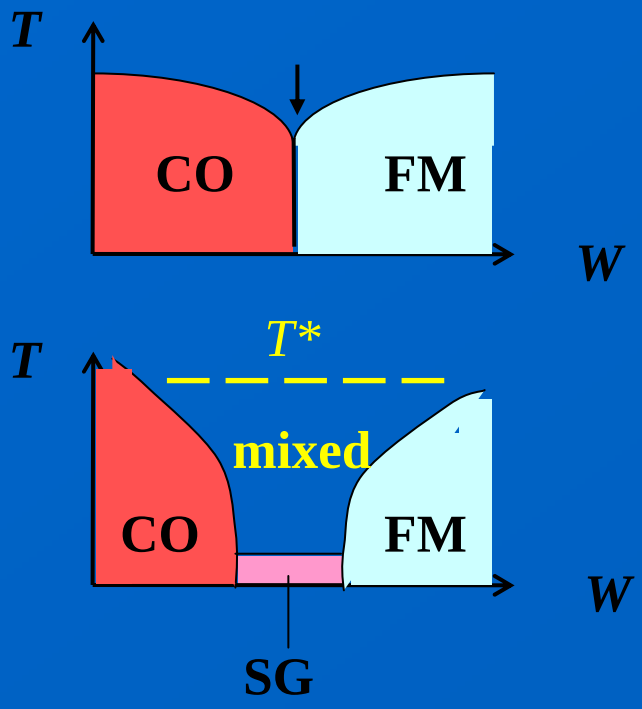
First-order transitions separate FM from AF states, at different or equal electronic densities.

Phase Competition in the Presence of Quenched Disorder

Clean limit result:



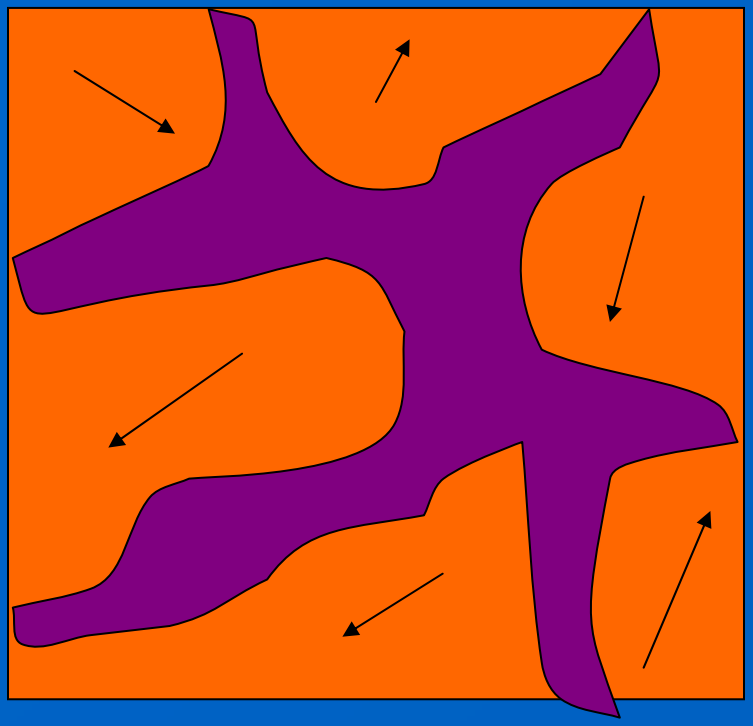
First order



Toy Model with Disorder Burgy et al., PRL87, 277202 (2001). See also Nagaosa et al. T* also discussed by Salamon.

For experiments see Akahoshi et al. PRL 2003; Argyriou et al., PRL; De Teresa

Conjectured CMR State in Manganites



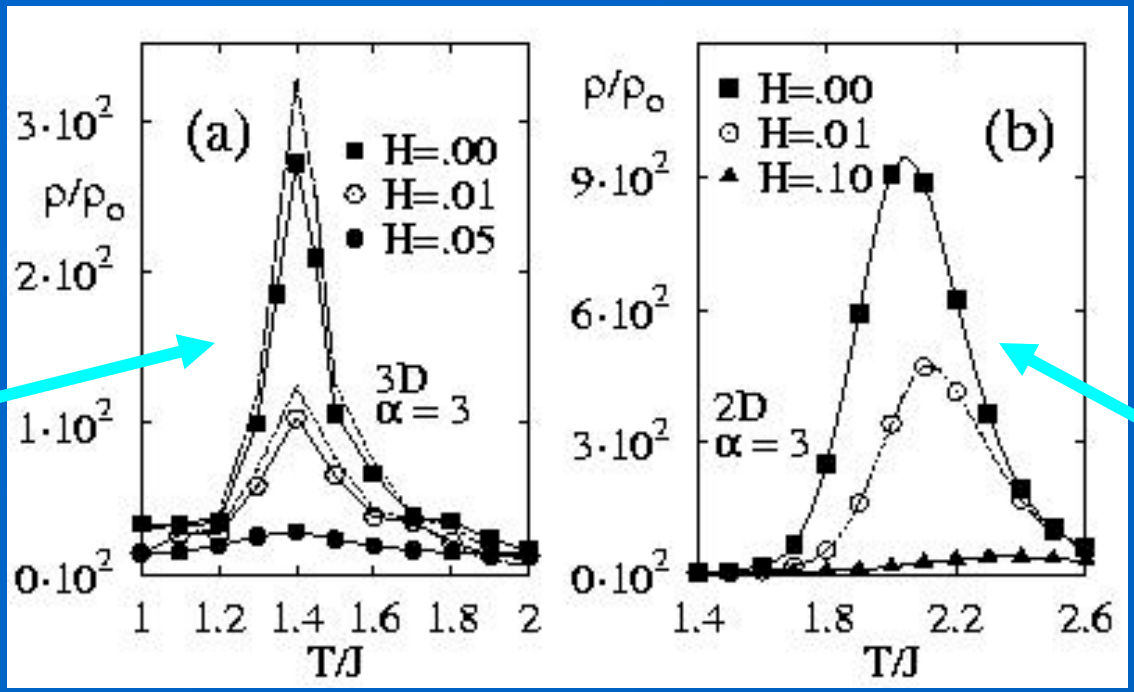
TCurie<T<T*

High susceptibility to external magnetic fields

(see also Cheong et al.)

MC for a ``Toy Model'' with correlated disorder to mimic cooperative JT effects

(J. Burgy et al., PRL92, 097202 (04); A. Bishop, T. Egami et al.)



3D

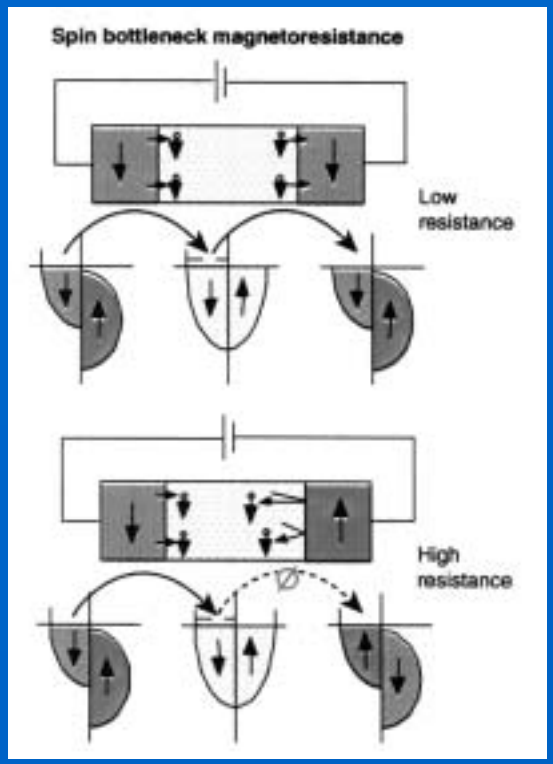
2D

3D and 2D are very similar. Is finite disorder truly needed or ``infinitesimal'' is enough?

(Chandra, Schmalian, Wolynes, Dobrosavljevic,…)

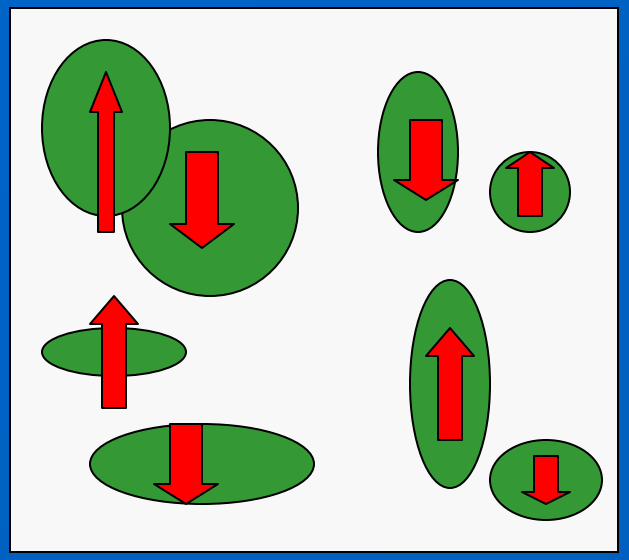
Similarities with GMR effect ?

GMR



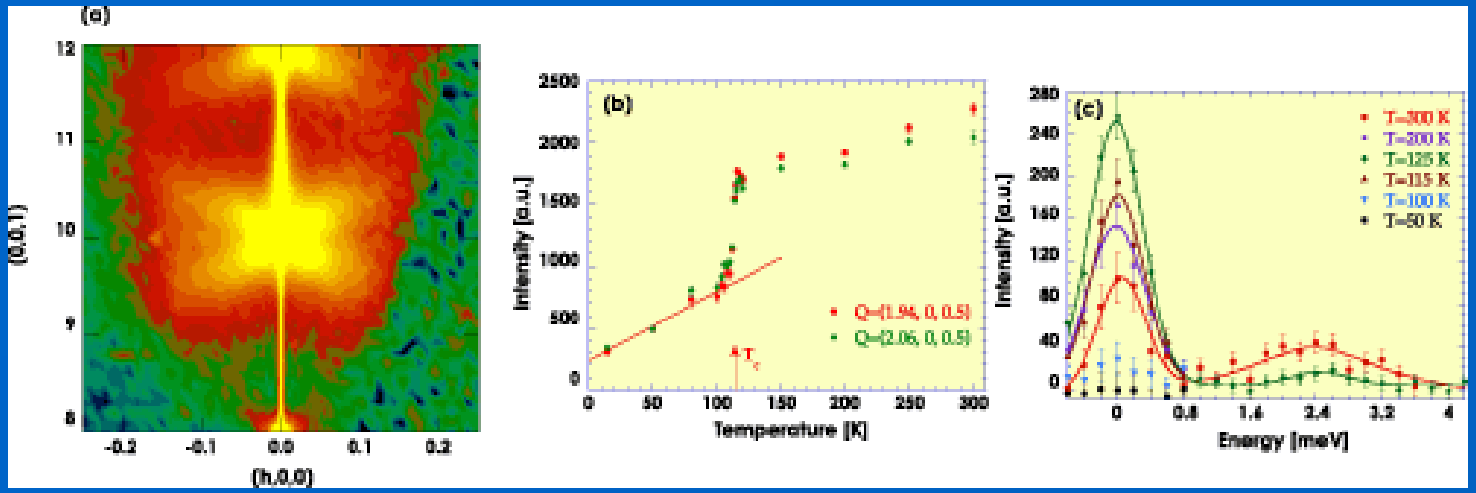
Prinz

CMR



GMR at small distances?

High energy X-rays sources are crucial to see inhomogeneities above TCurie

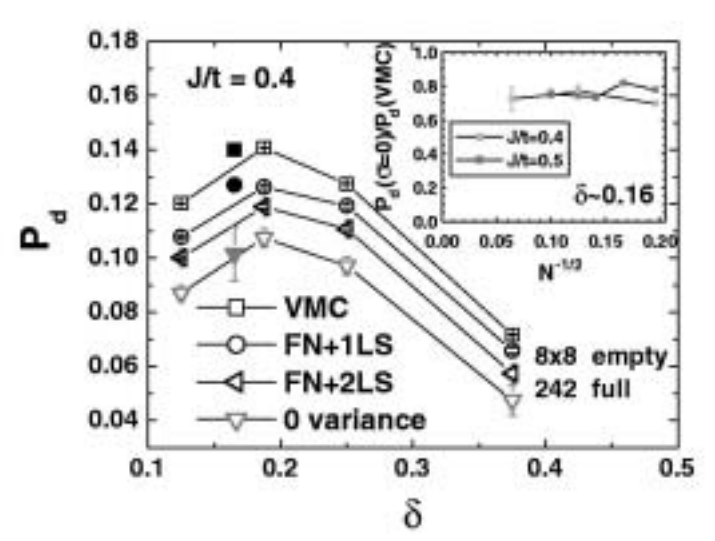


Argonne's group (plus other groups)

More work should be carried out to clarify the nature of the polaronic states above TCurie. Do they indeed cluster? Is T* a reality? We are very close to solving the CMR problem!

(II) High-temperature superconductivity

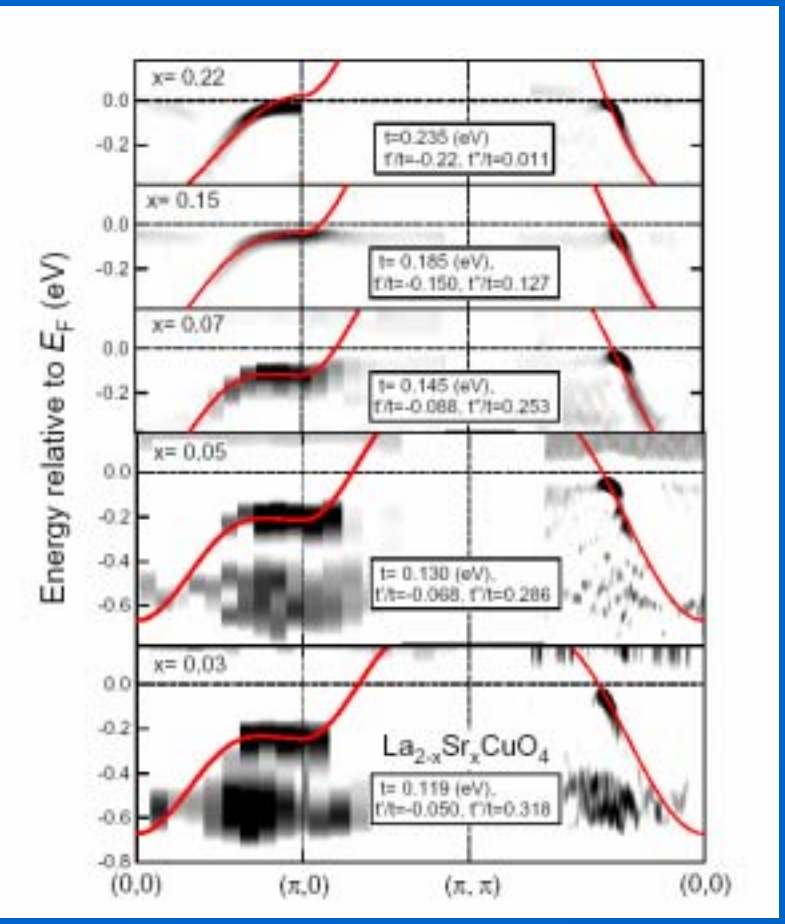
Sorella et al., PRL 88, 117002 (2002)



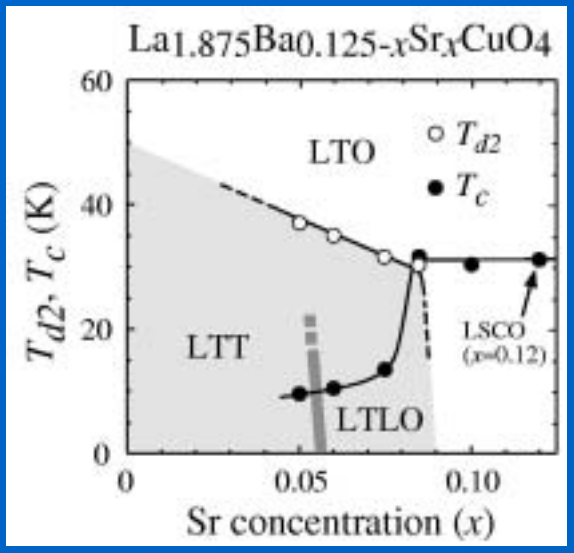
SC appears in t-J simulations due to short-range AF, as in 2-leg ladders
However, other studies show stripes.
Several phases in competition.

•Hubbard and t-J computational investigations ***are reaching the limits of what can be done.*** Fortunately, dominant tendencies have been identified.

First-order transitions in cuprates? Are stripes universal?

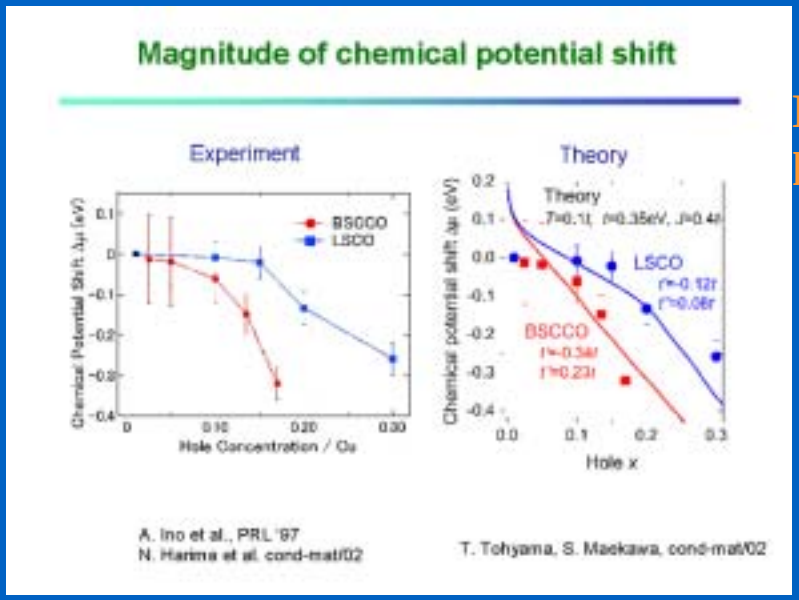


Fujimori et al.



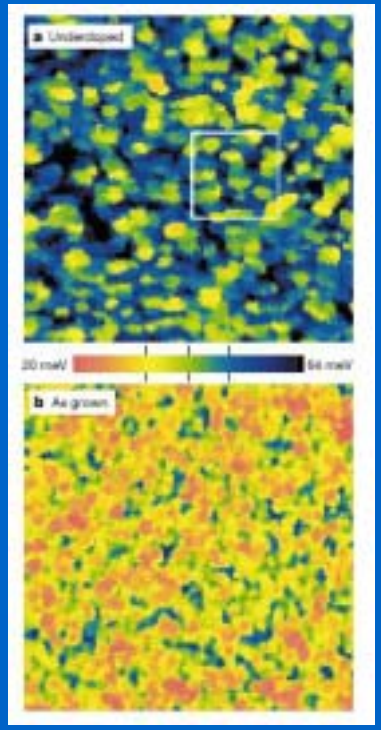
Fujita et al.
Elastic N. Scatt.

See also electron doped Cu-oxides, organic SC.

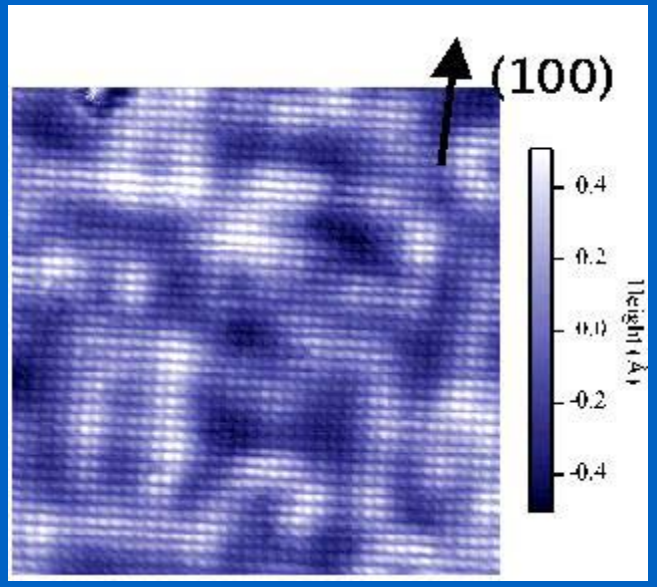


Not all HTSC have stripes?

Recent Trends: Inhomogeneities in cuprates



Ca2-x Nax Cu O2 Cl2



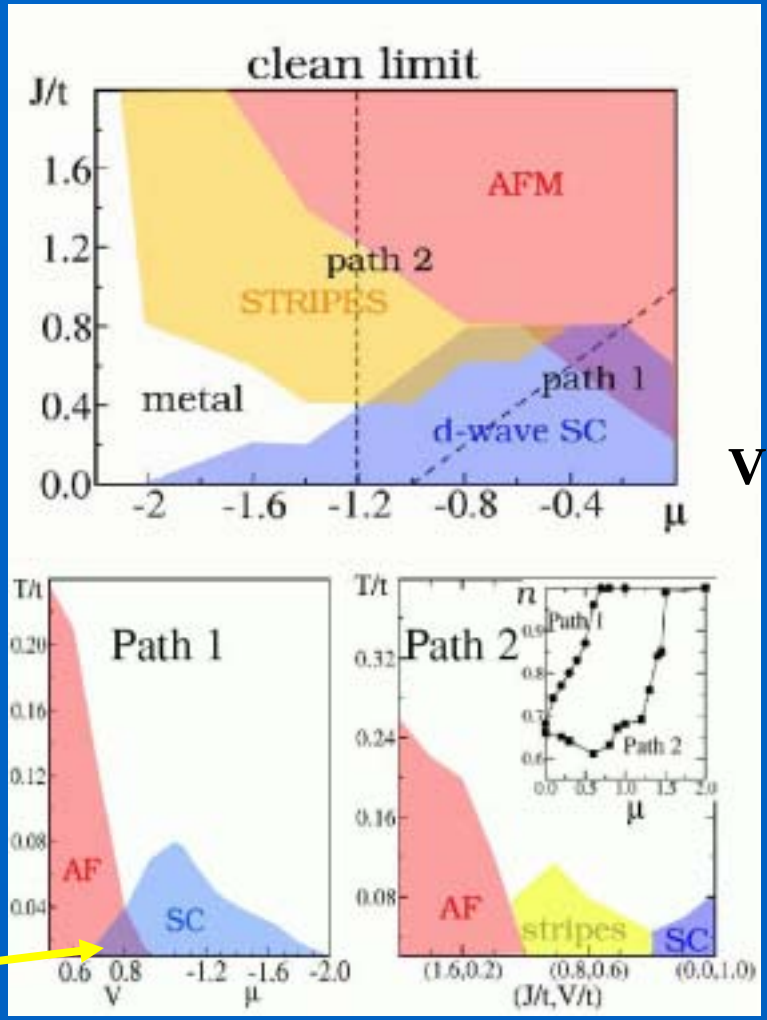
STM inhomogeneities. Nanoscale structures.
Large clusters and computational methods needed.

Switch to phenomenology for underdoped region …

Phenomenological SC vs. AF competition

Monte Carlo results for ``mean-field-like'' model of mobile electrons coupled to classical AF (Moreo et al., PRL 88, 187001 (2002)) and SC order parameters (Alvarez et al., cond-mat/0401474).

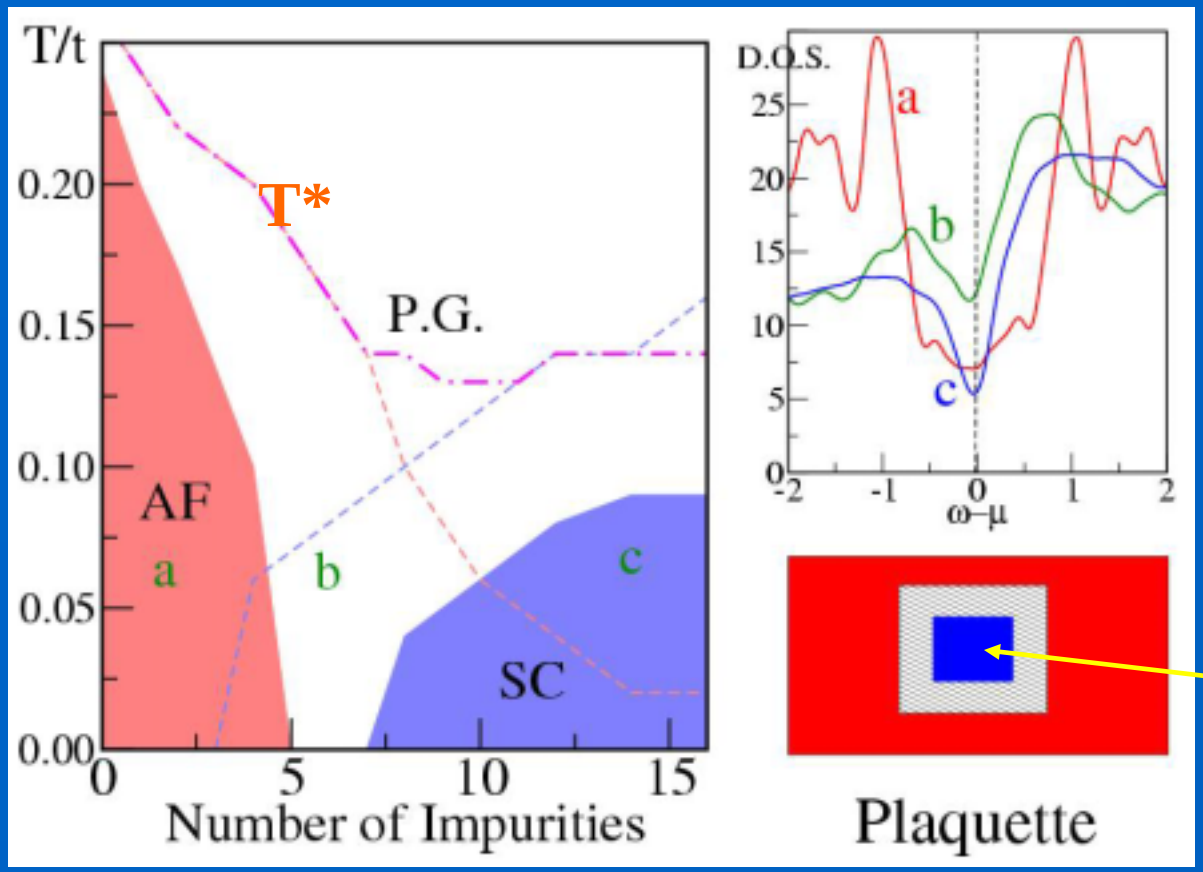
Two parameters: J and V.



V=1-J/2

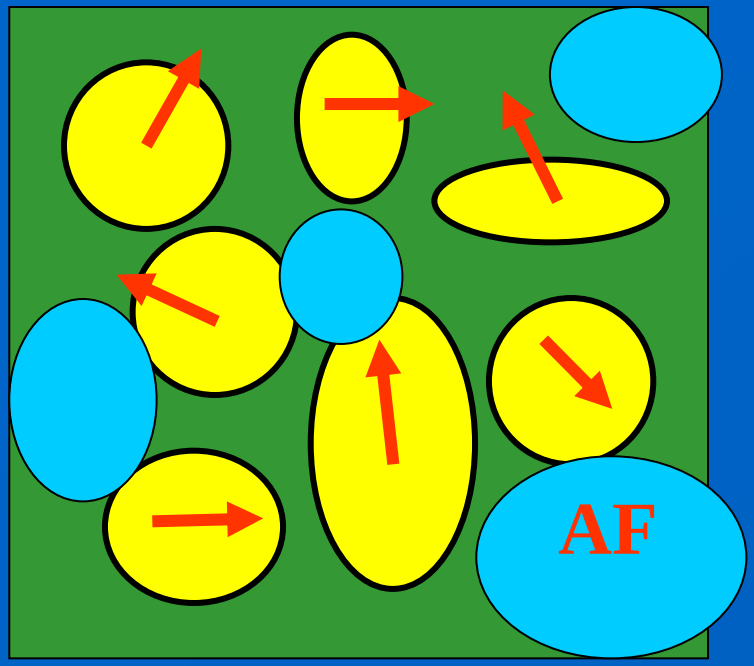
Tetracritical

Quenched disorder leads to clusters and T*, as in manganites.



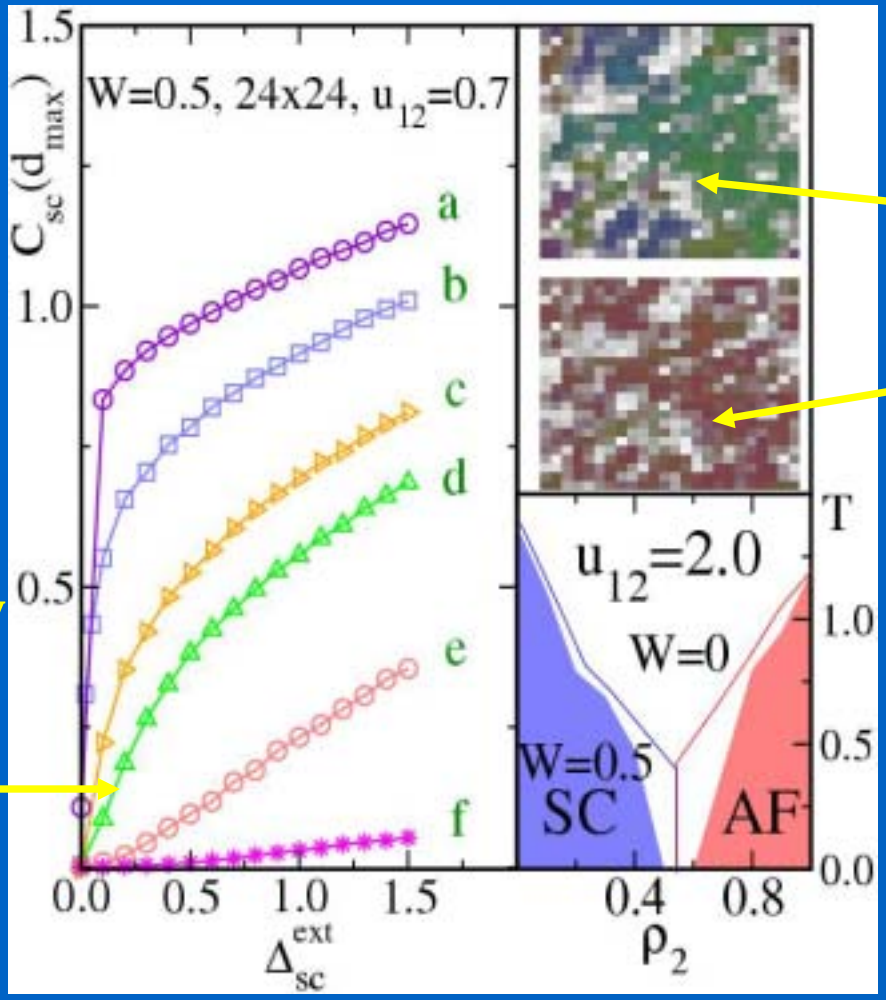
Coulombic centers, as in Sr++. Each provides 1h.

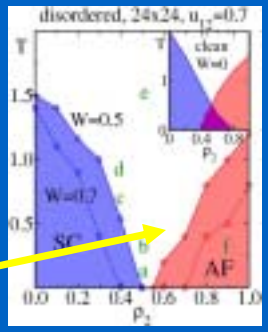
Cartoonish summary
(Alvarez et al., cond-mat/0401474)



Proposed: Random orientation of the local SC phase in glassy underdoped region

Giant proximity effect?



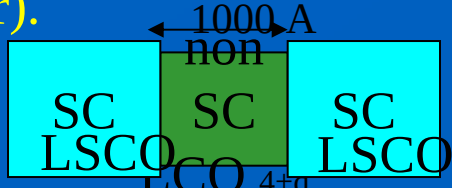


``non-SC glass''

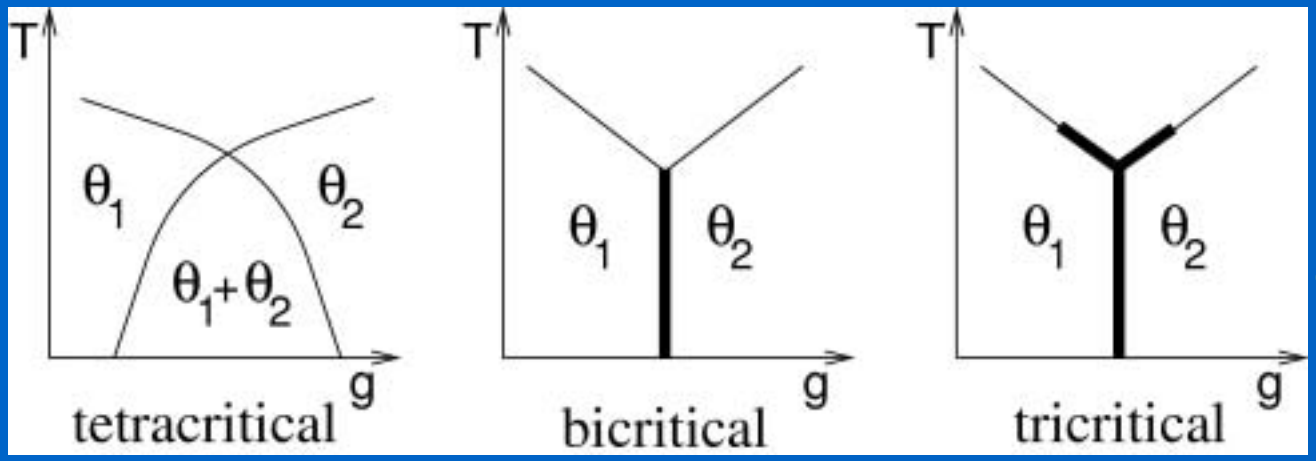
``Inhomogeneous'' superconductors

High susceptibility to ``external SC fields''

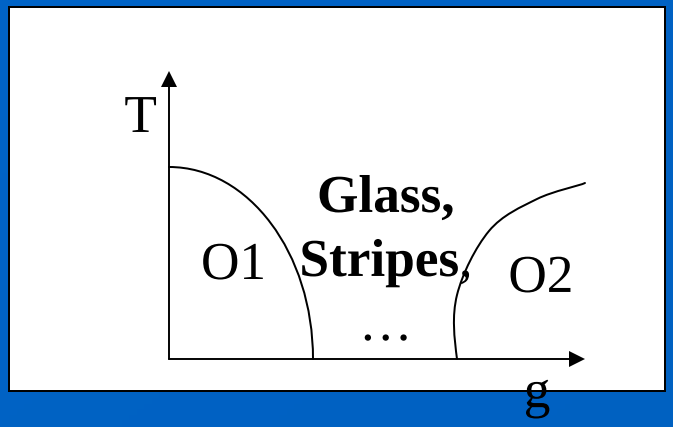
"Colossal" Effects in underdoped regime?
(``Giant proximity effect'' Decca et al. PRL, and Bozovic et al., PRL to appear).



Conclusion (I): revised menu

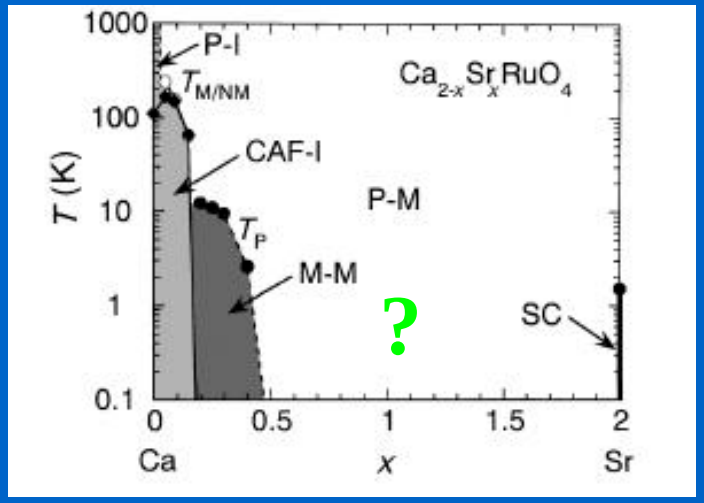


OLD LG



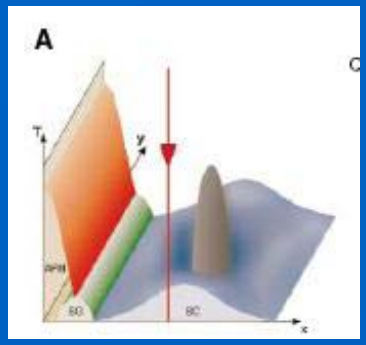
NEW

Conclusions (II): Other materials should show a similar phenomenology …



Ruthenates (Nakatsuji et al.)

In some cases even three phases may be competing, such as in cuprates with SC vs. AF vs. Stripes



Aeppli et al.

Conclusions (III): Inhomogeneities => Complexity in transition-metal oxides?

- ``Complex systems exist on the edge of chaos – they may exhibit almost regular behavior, but also can change dramatically and stochastically in time and/or space as a result of small changes in conditions.''

T. Vicsek, Nature 418, 131 (2002).

Ab-initio approaches may not work.
Computational work is important in this context.
Large scale phenomenological models will be needed.

Conclusion (IV)

- **Experiments controlling the quenched disorder strength in chemically doped TMOs will much help in the TMO context.**

Collaborators and references

G. Alvarez (ORNL); C. Sen (FSU); T. Hotta (Tokai);
M. Mayr (Max Planck); A. Moreo (UT/ORNL);
S. Yunoki (Trieste)

A. Moreo et al., Science 283, 2034 (1999); E. D. et al., Phys. Rep. 344, 1 (2001); J. Burgy et al., PRL 87, 277202 (2001); PRL 92, 097202 (2004).; E. D., *Nanoscale Phase Separation and Colossal Magnetoresistance*, Springer-Verlag, Nov. 2002; G. Alvarez, M. Mayr et al., PRL 89, 277202 (02); cond-mat/0401474.