Colossal Magnetoresistance

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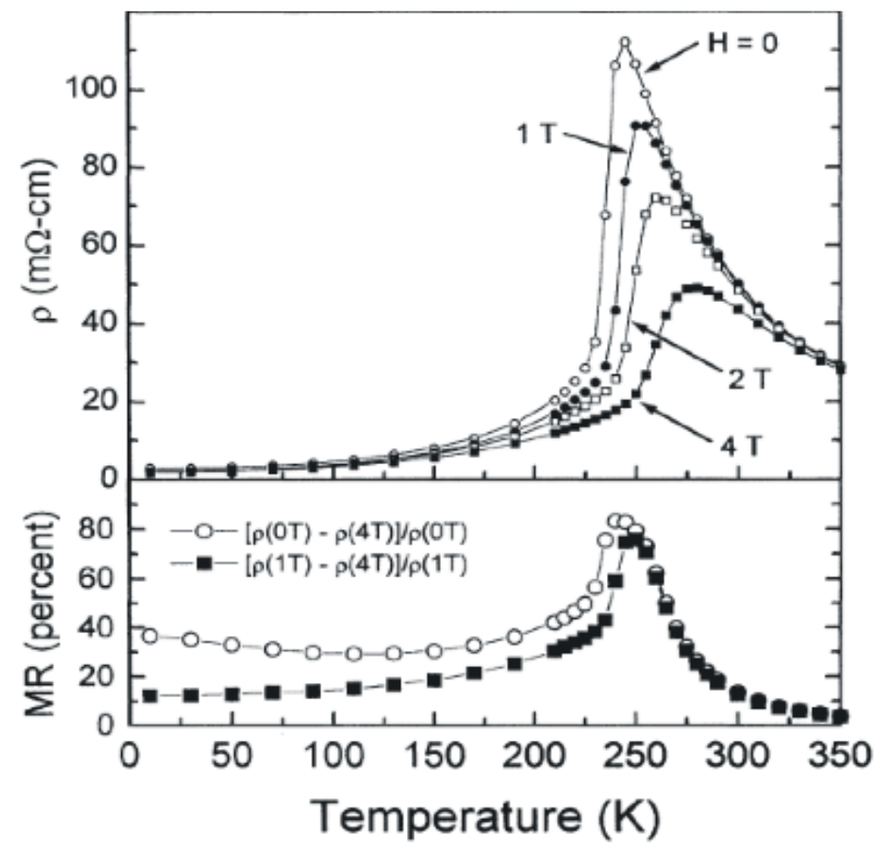
Outline

- Description of CMR
- Magnetic structure in manganites: early neutron scattering results
- Phase separation
- CMR vs. GMR

What is colossal magnetoresistance?

CMR in $La_{0.75}Ca_{0.25}MnO_3$

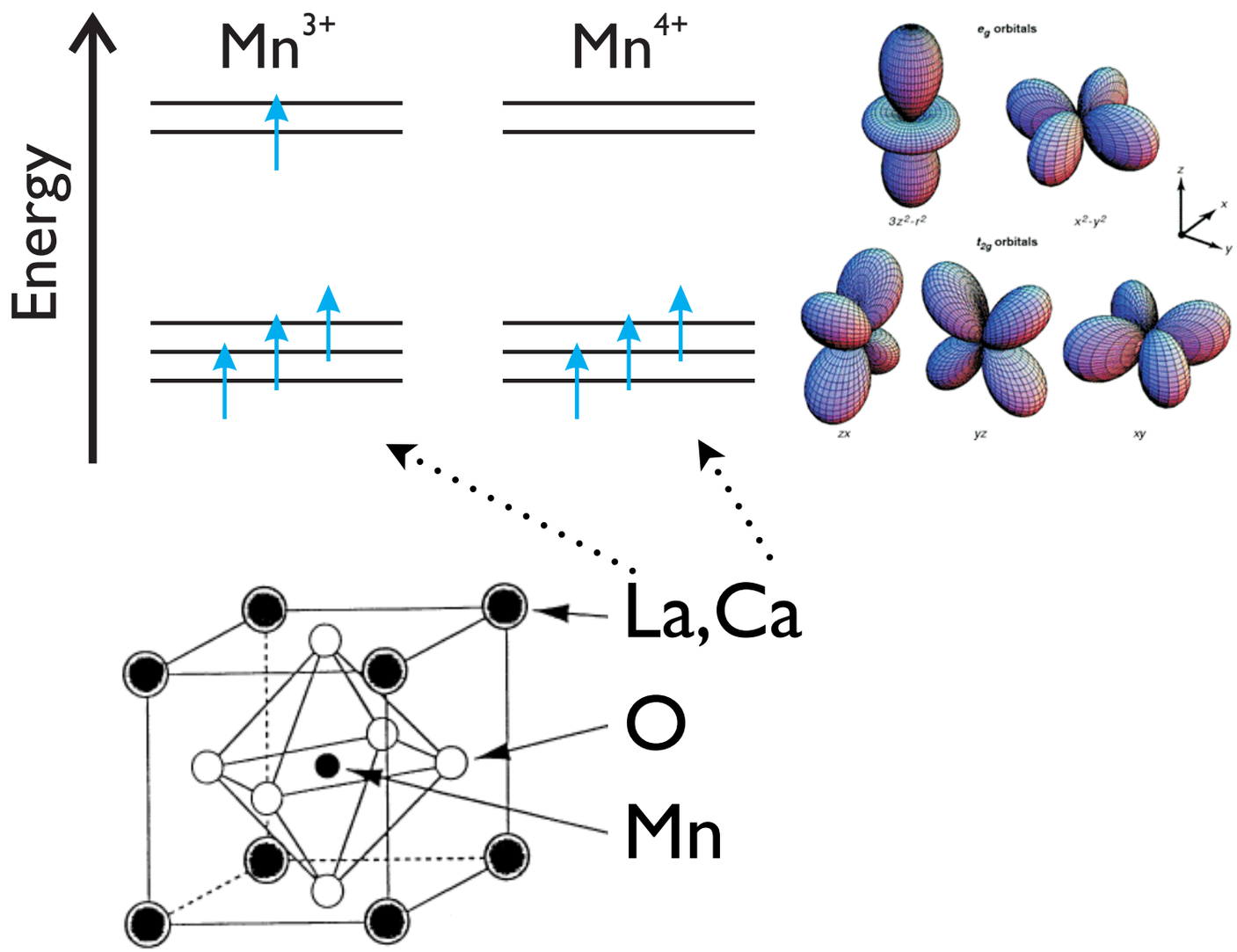


- Applying a magnetic field to a material results in a significant decrease in its resistivity
- Sample is ferromagnetic at low temperatures
- Metal-insulator transition at the curie temperature

P. Schiffer *et al.*, PRL **75**, 3336 (1995)

Manganese 3d shell

3d electron configuration



- Each Mn atom has a magnetic moment
- The e_g electron can easily hop between two atoms with the same magnetization direction
- For this interaction to dominate, we need sufficient populations of Mn^{3+} and Mn^{4+} atoms
- Is this the whole story?

Y. Tokura and N. Nagaosa, Science **288**, 462 (2000)
Dagotto, *Nanoscale Phase Separation and Colossal Magnetoresistance*. Springer, 2003

Early Experiments: Neutron Scattering

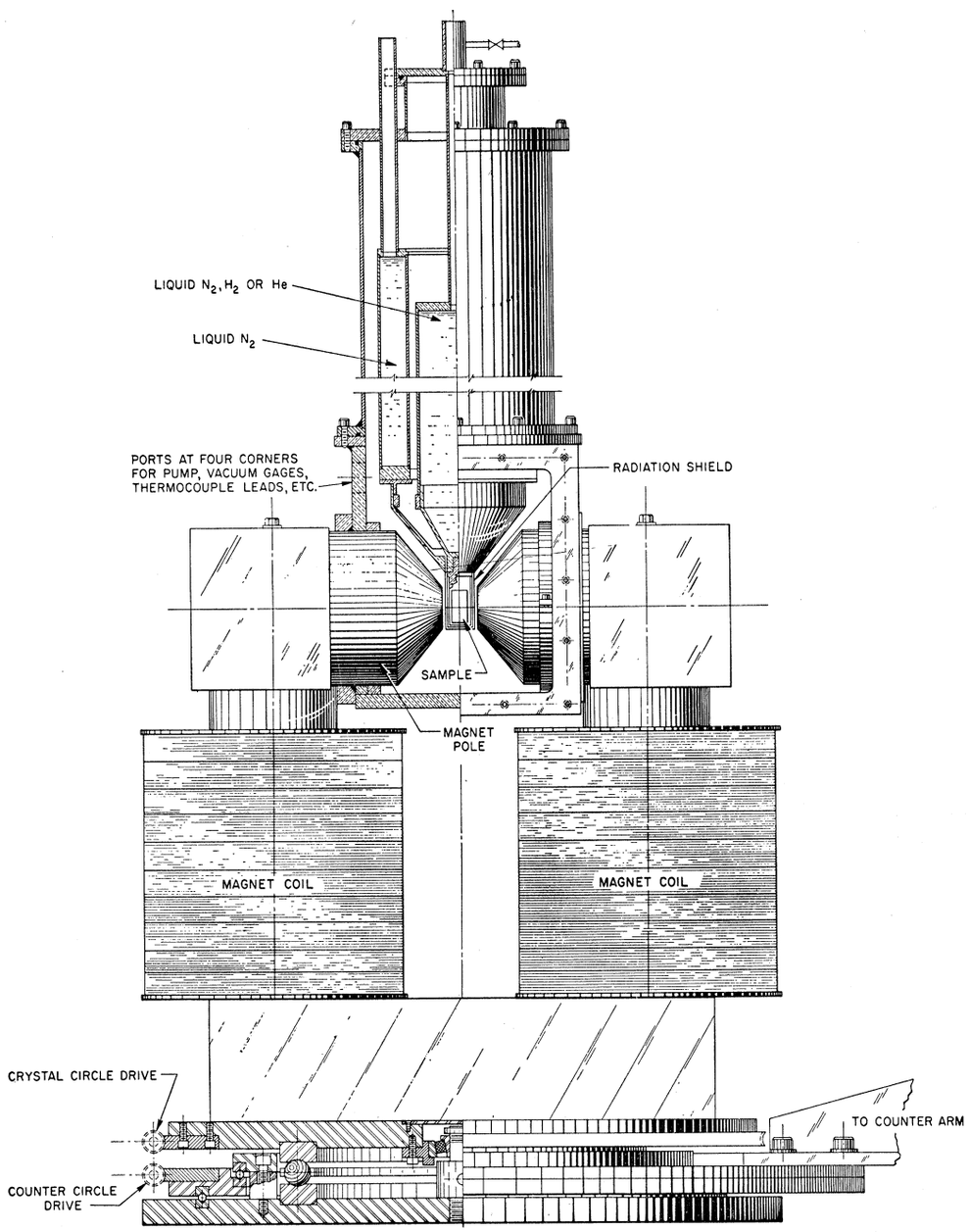
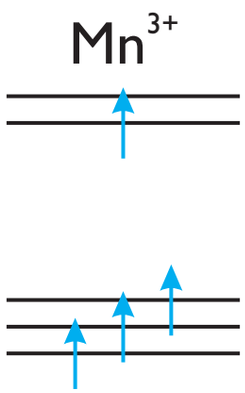


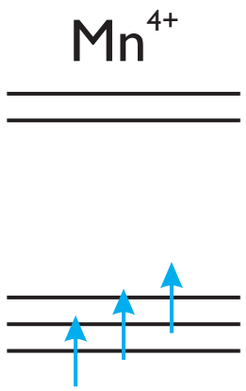
FIG. 1. Neutron spectrometer with cryostat and magnet.

"The inner cryostat and sample assembly are held in accurate alignment with the beam and the pole pieces by three nylon cords held taut by banjo type string tighteners anchored to a brass box."

E. O. Wollan and W. C. Koehler, Phys. Rev. **100**, 545 (1955)

The undoped cases: antiferromagnetic





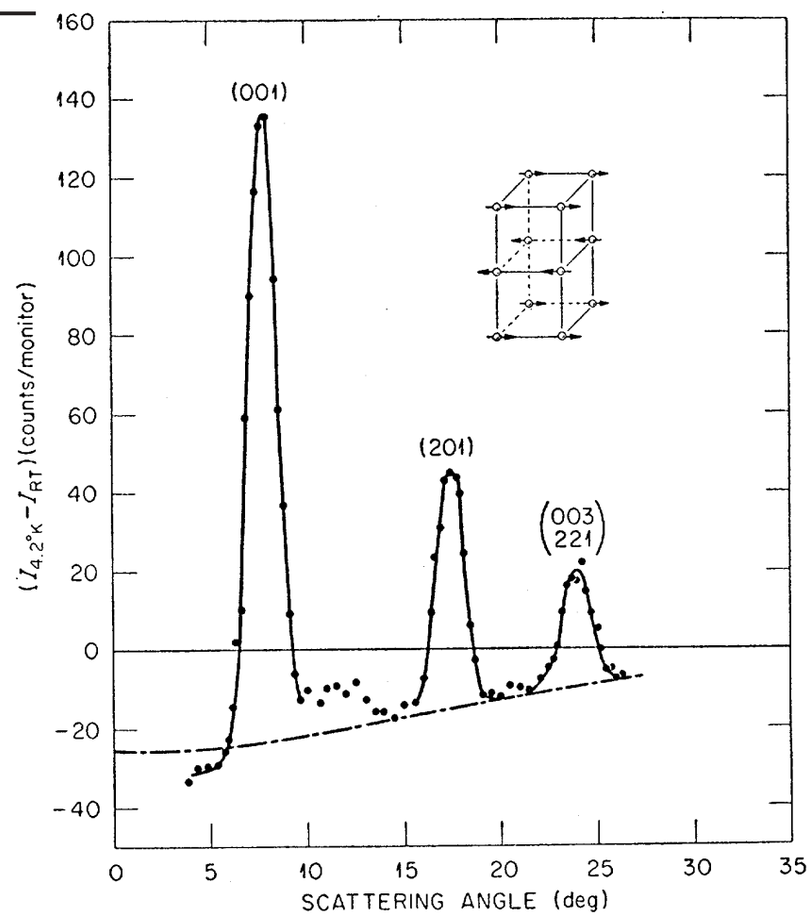


FIG. 3. Temperature difference pattern and antiferromagnetic structure (Type A) for $LaMnO_3$ No. 12.

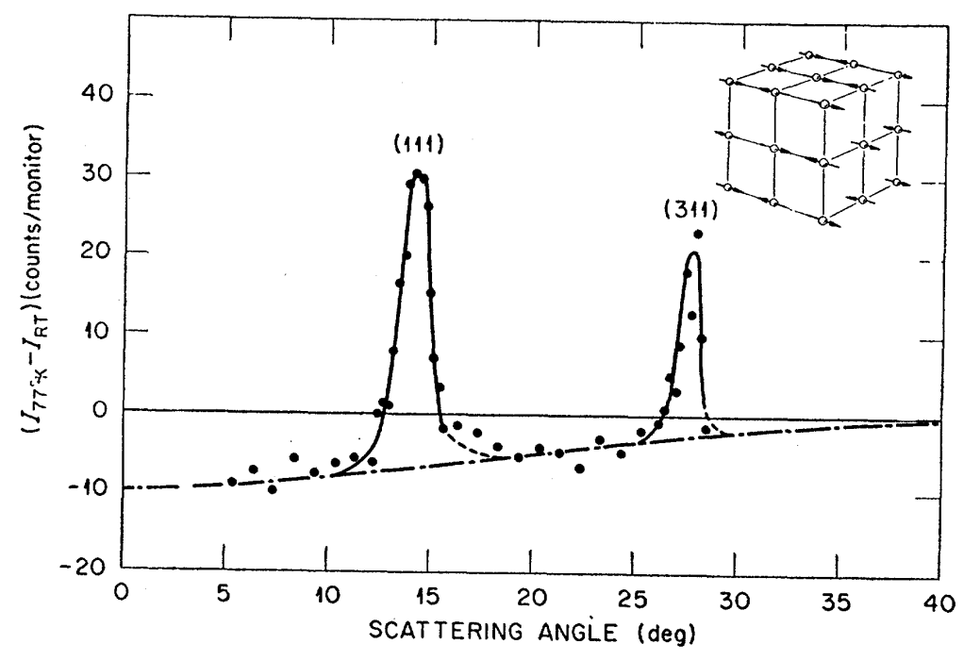


FIG. 4. Temperature difference pattern and antiferromagnetic structure (Type G) for $CaMnO_3$ No. 26.

E. O. Wollan and W. C. Koehler, Phys. Rev. **100**, 545 (1955)

Mixed valence

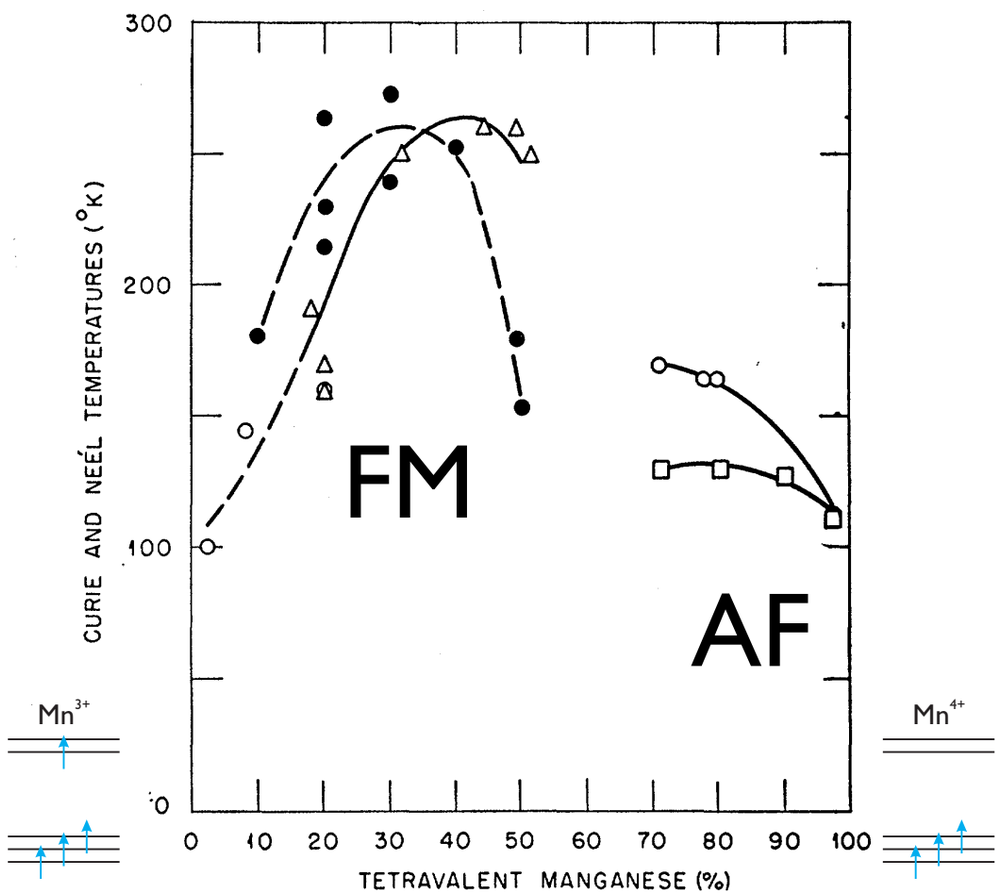
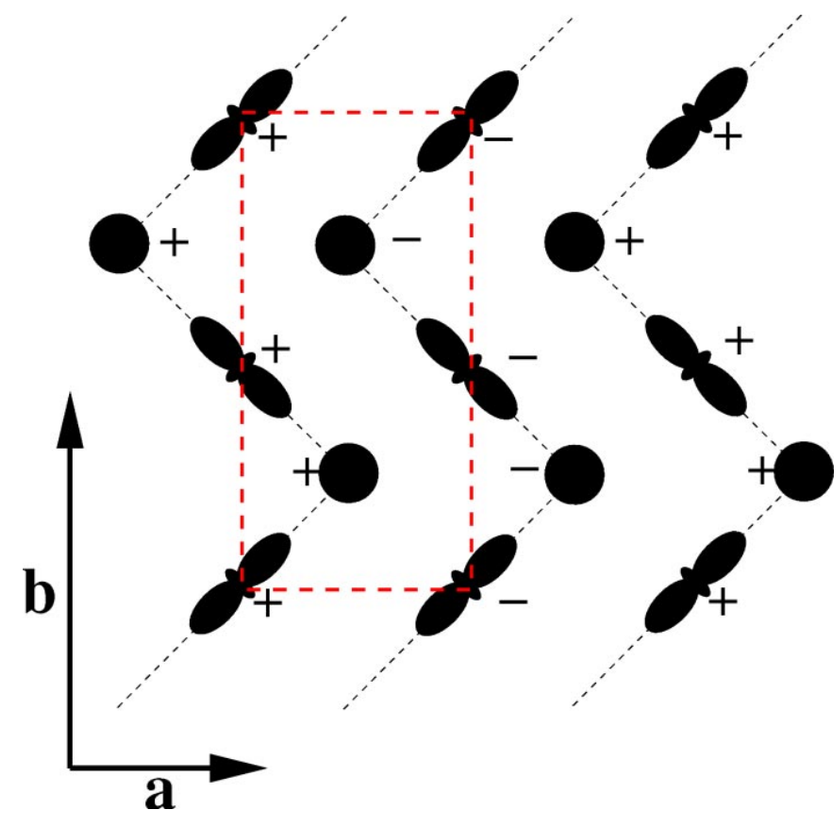


FIG. 15. Curie and Néel temperatures *vs* composition. Solid circles Jonker and Van Santen ferromagnetic saturation data, open triangles ferromagnetic neutron data, open circles and squares antiferromagnetic data, square referring to $CaMnO_3$ series.

E. O. Wollan and W. C. Koehler, Phys. Rev. **100**, 545 (1955)

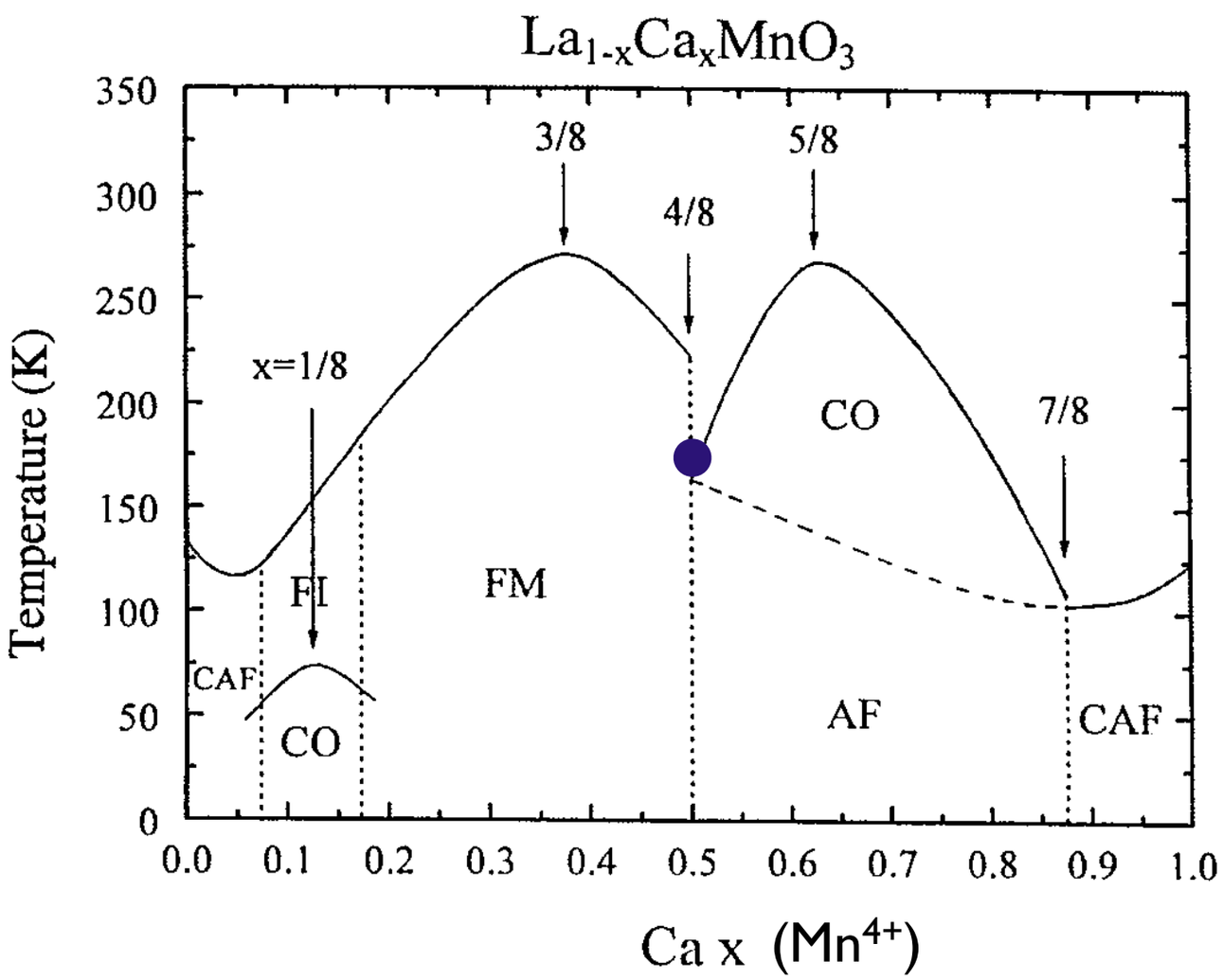
Half Mn^{3+}, Half Mn^{4+}

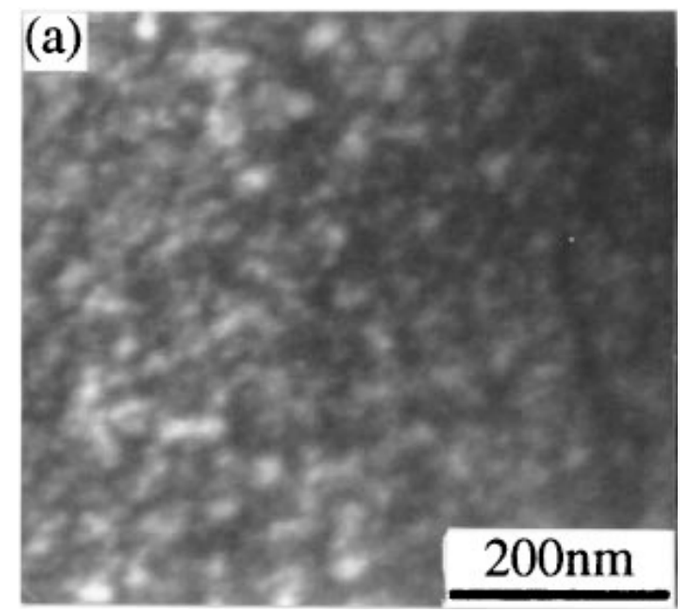


S. Grenier *et al.*, PRB **69**, 134419 (2004), following J. B. Goodenough *et al.*, Phys. Rev. **100**, 564 (1955)

The simple conductivity model doesn't explain everything

The plot thickens



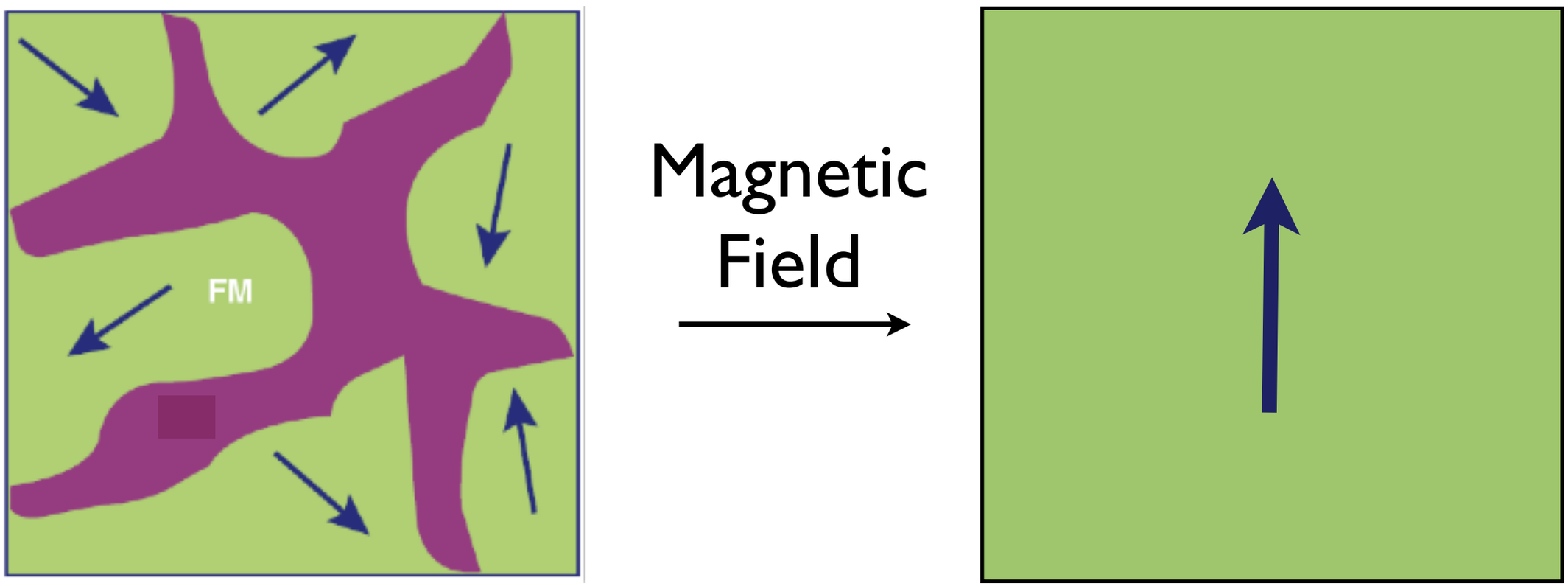


White = charge ordered

Dagotto, *Nanoscale Phase Separation and Colossal Magnetoresistance*. Springer, 2003

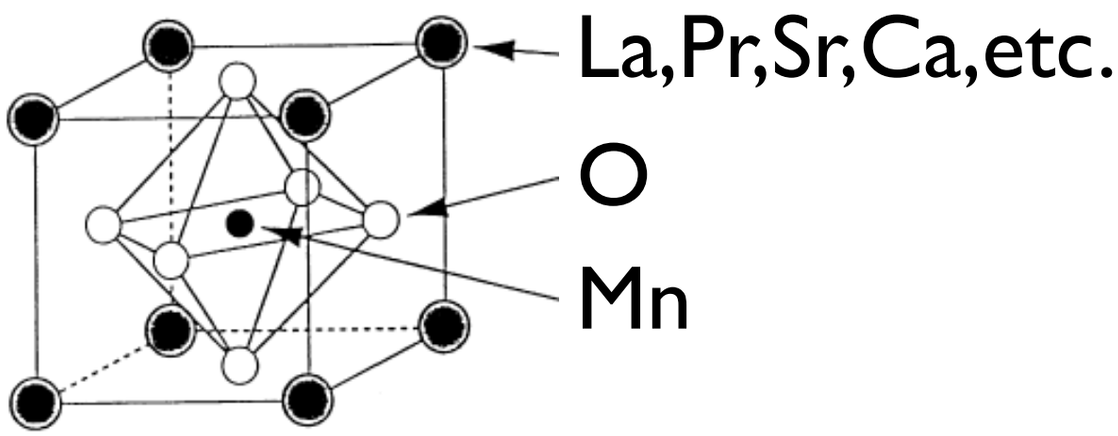
S. Mori *et al.*, PRL **81**, 3972 (1998)

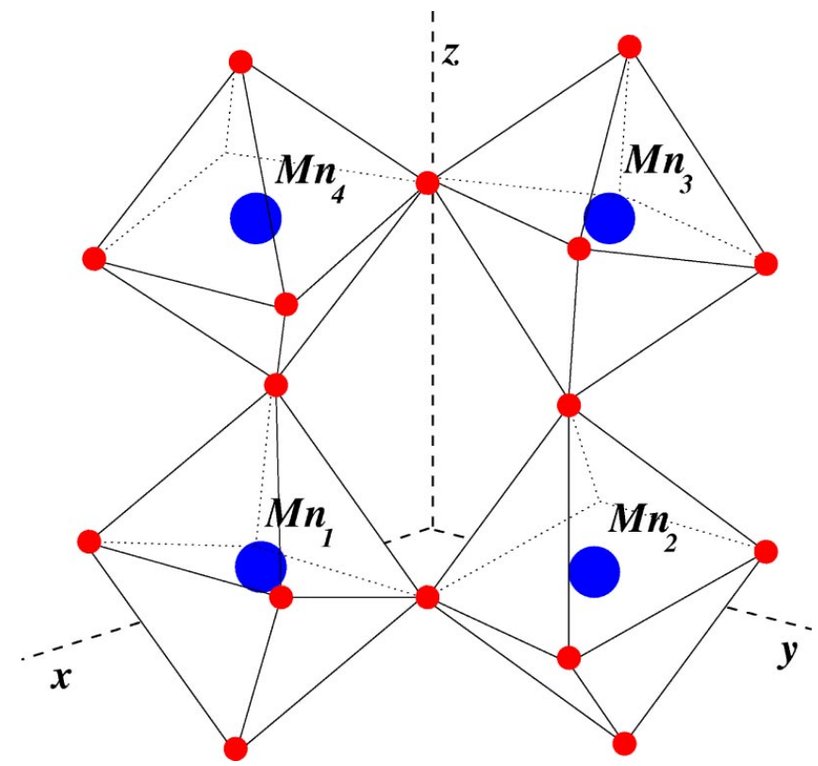
Phase Separation



Inhomogeneities in a homogeneous system!

What about the other atoms?

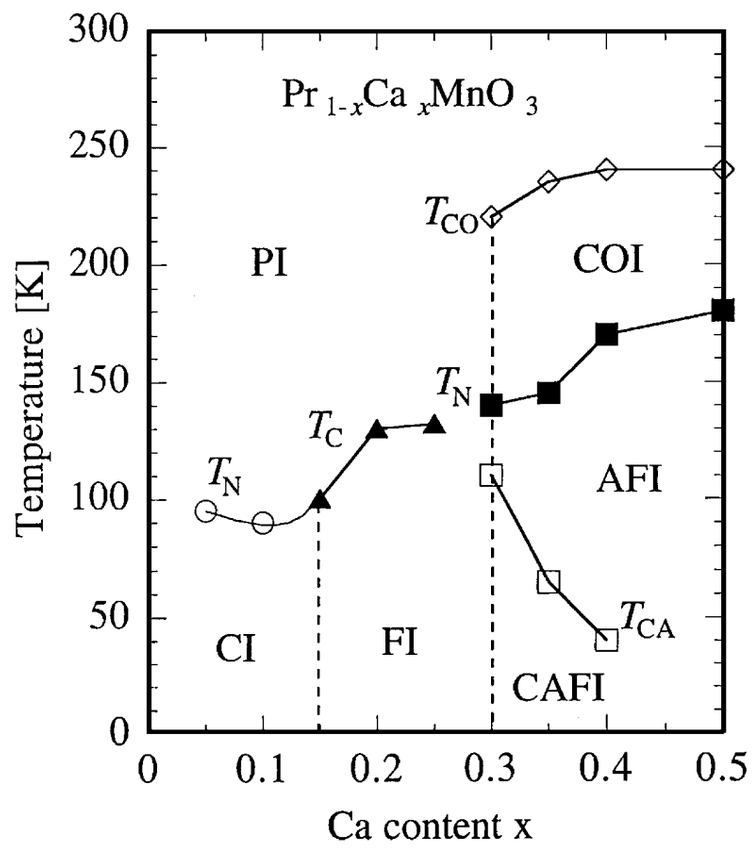


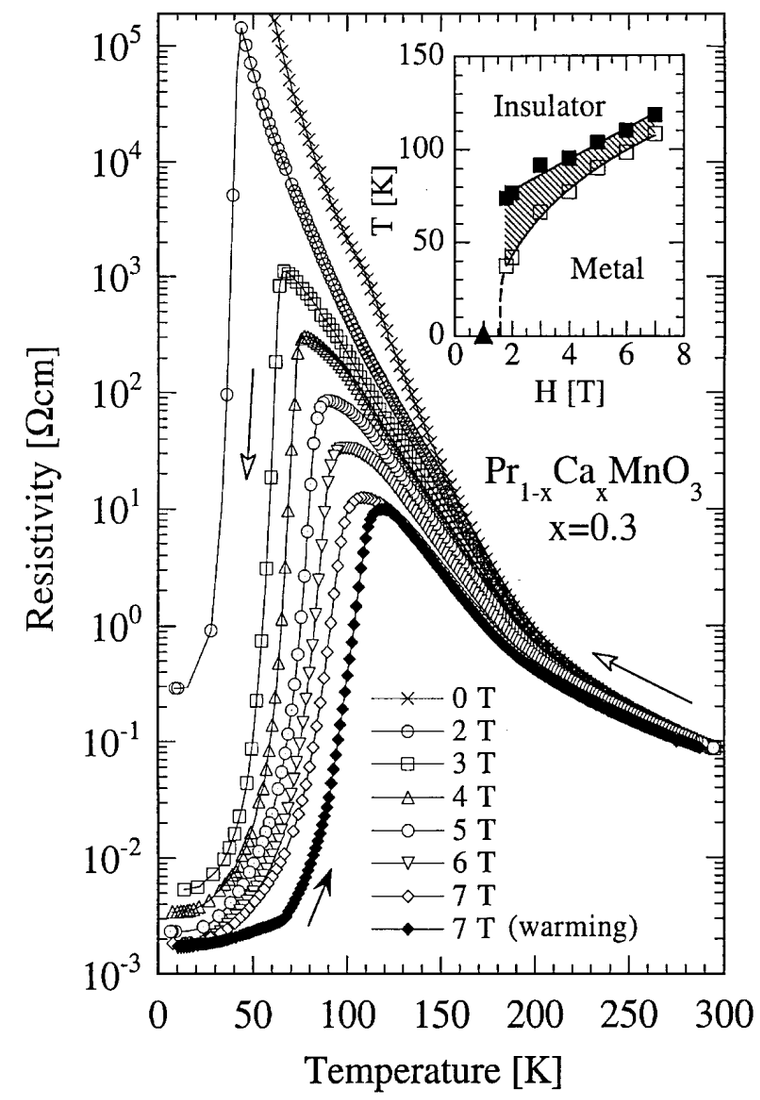


Tilted octahedra ⇒ lower conductivity and smaller ferromagnetic domains

S. Grenier *et al.*, PRB **69**, 134419 (2004)

Low-bandwidth compound: $(Pr,Ca)MnO_3$

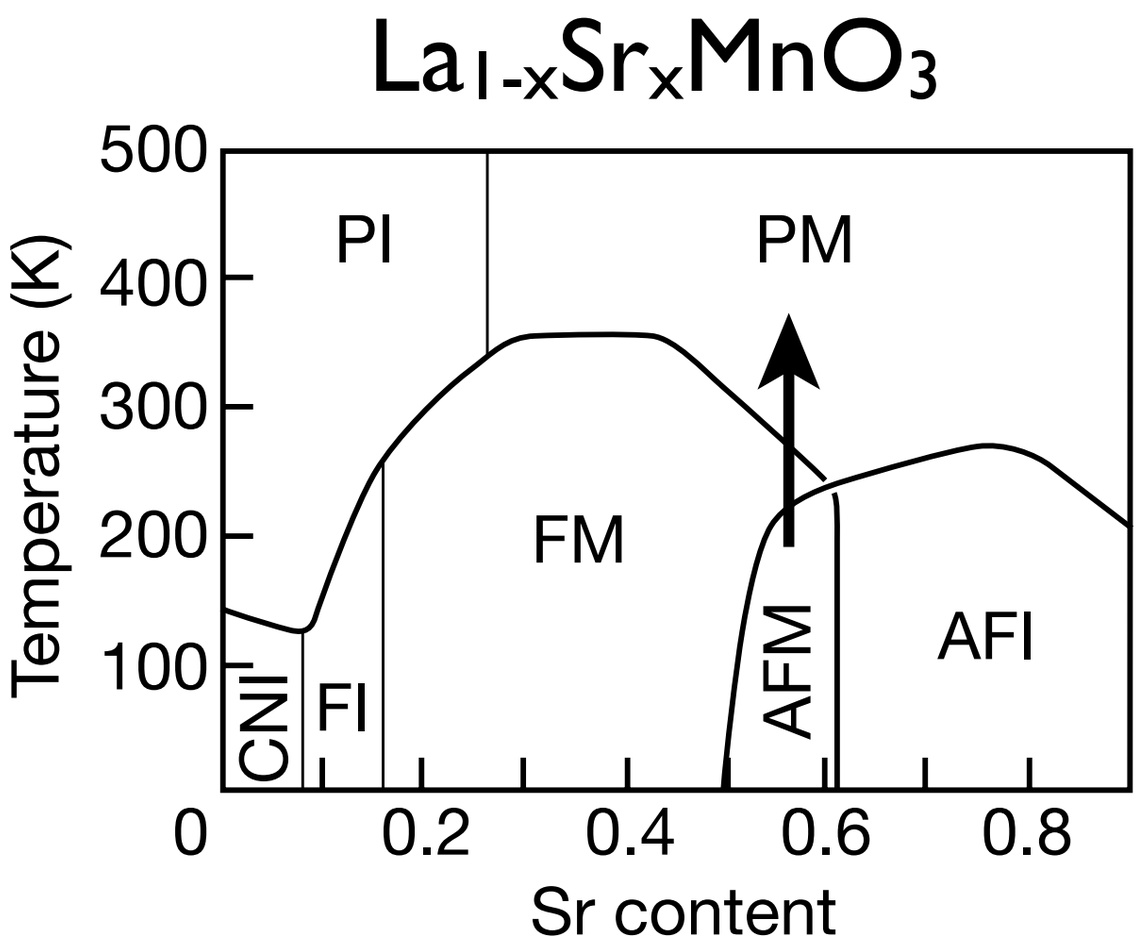


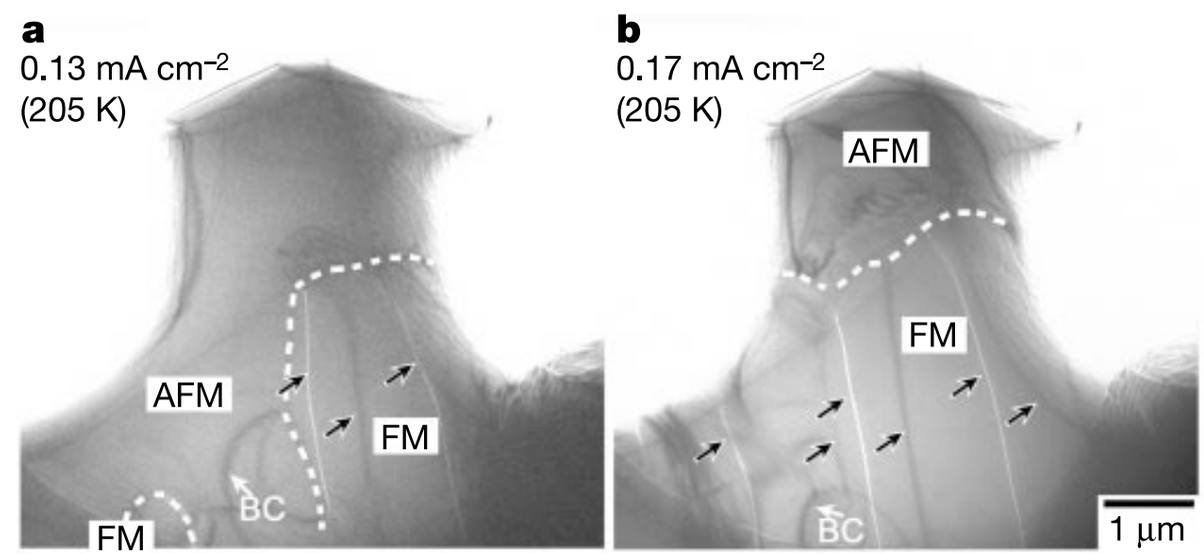


Metallic only upon application of a field

E. Dagotto, Physics Reports **344**, 1 (2001)

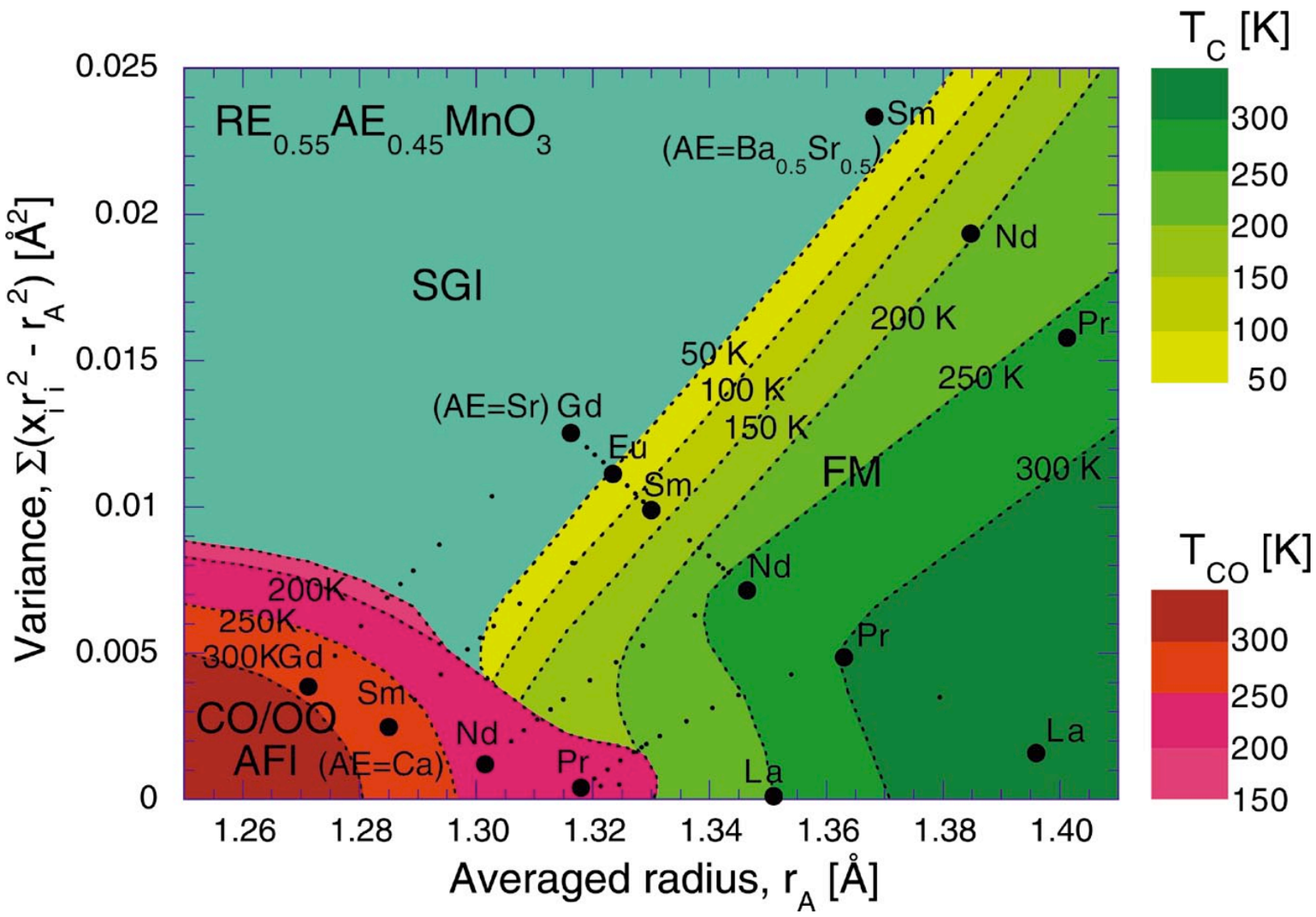
High-bandwidth compound: (La,Sr)MnO_3





Y. Murakami *et al.*, Nature **423**, 965 (2003)

The whole picture for x=0.45



Challenges for the Future

- Full explanation of phase separation
  - Growing good samples
  - Measurements that give us a clear picture of what's going on inside the materials
- Dynamics

Summary

- CMR is the result of phase separation within homogeneous systems
- A simple model of ferromagnetic metallic behavior can only take us so far
- By changing the size of the dopants, we can explore a very large phase space

So how and CMR and GMR related?

The Nobel Prize in Physics 2007

"for the discovery of Giant Magnetoresistance"

Photo: U. Montan

Albert Fert

1/2 of the prize

France

Université Paris-Sud;
Unité Mixte de Physique
CNRS/THALES
Orsay, France

Photo: U. Montan

Peter Grünberg

1/2 of the prize

Germany

Forschungszentrum Jülich
Jülich, Germany

So how and CMR and GMR related?

- CMR and GMR are **unrelated**
- GMR: magnetic multilayer systems
- CMR: single materials