

SMR.1572 - 32

**Workshop on  
Novel States and Phase Transitions in Highly Correlated Matter**

**12 - 23 July 2004**

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**Strain liquid-glass transition in manganites  
(Re-appearance of charge order)**

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These are preliminary lecture notes, intended only for distribution to participants

# Strain Liquid-Glass Transition in Manganites

## (Re-appearance of charge order)

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**Peter Sharma**

**S. B. Kim**

**T. Y. Koo**

**S. Guha**

**V. Podzorov**

**M. Gershenson**

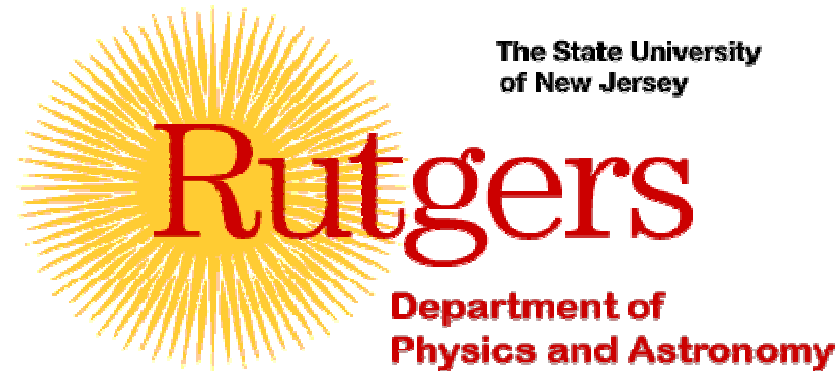
**C. H. (Sunshine) Chen**

**Yoichi Horibe**

**Shigeo Mori**

**D.D. Sarma**

**A. Fujimori**



**(National Taiwan U.)**

**(Osaka Prefecture U.)**

**(Indian Institute of Science)**

**(U. of Tokyo)**

Supported by NSF, NSF-MRSEC(U. of Maryland/Rutgers), SCMR (Seoul NU)

# Re-entrant charge order in Manganites

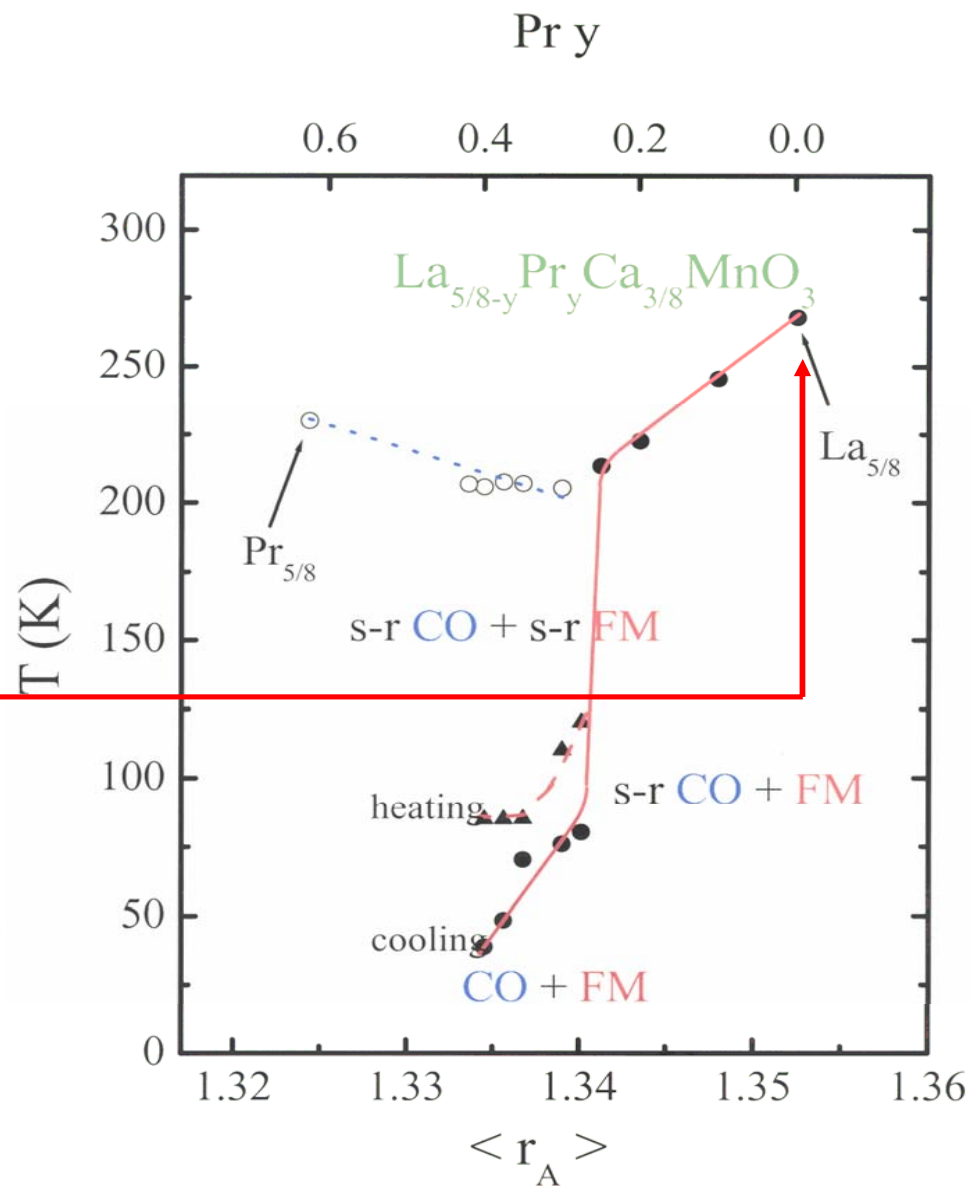
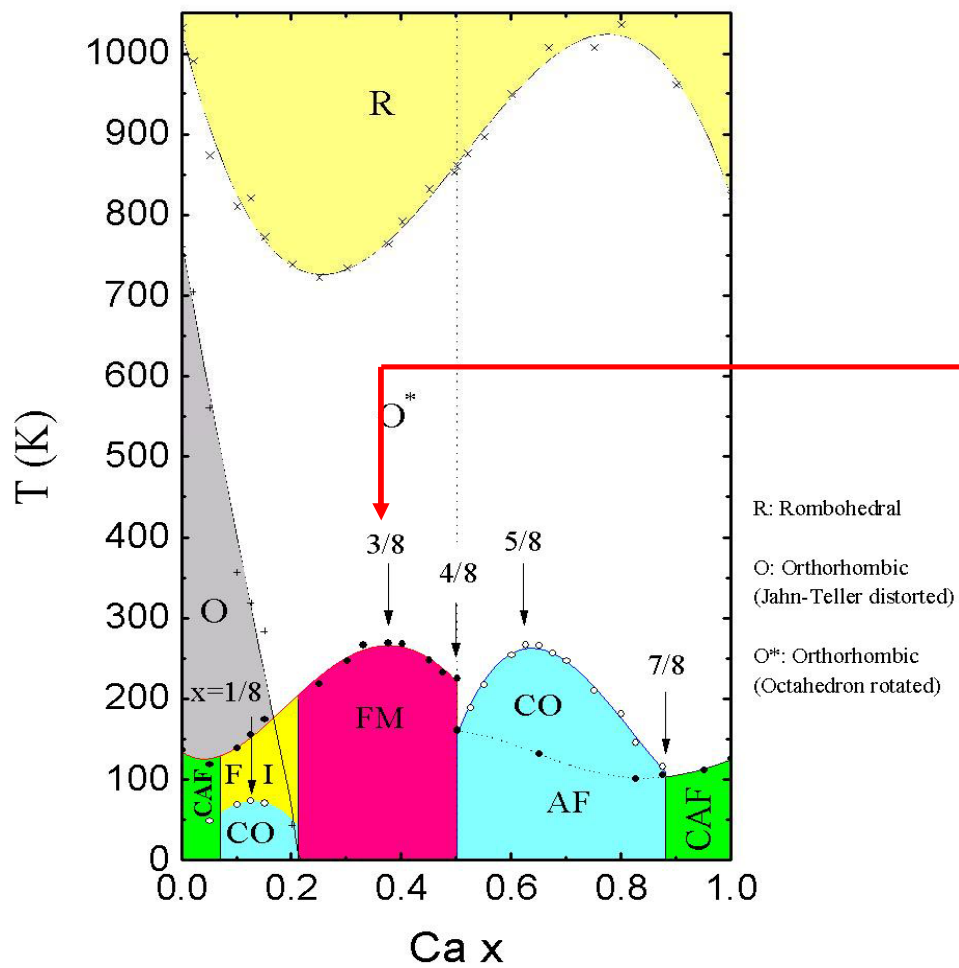
[1] E-beam-induced charge re-ordering in  $(\text{Bi,Ca})\text{MnO}_3$

[2] T-induced charge re-ordering in  $(\text{La,Pr,Ca})\text{MnO}_3$

**“Strain Liquid/Strain Glass”**

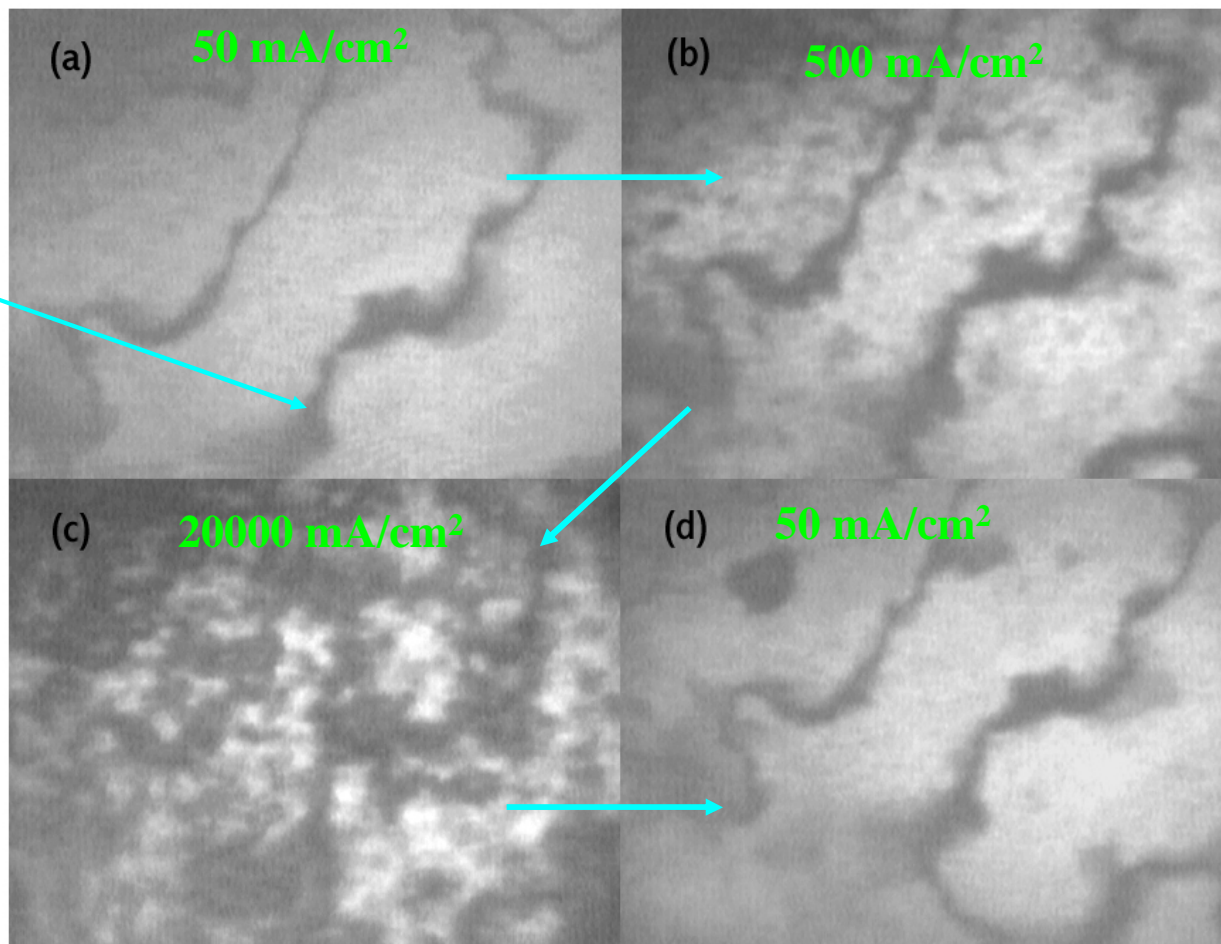
# Phase Diagram of $\text{La}_{1-x}\text{Ca}_x\text{MnO}_3$

Uehara, Kim and Cheong



# E-beam-induced melting of charge order

Strain at  
antiphase/  
discommensulation  
boundaries

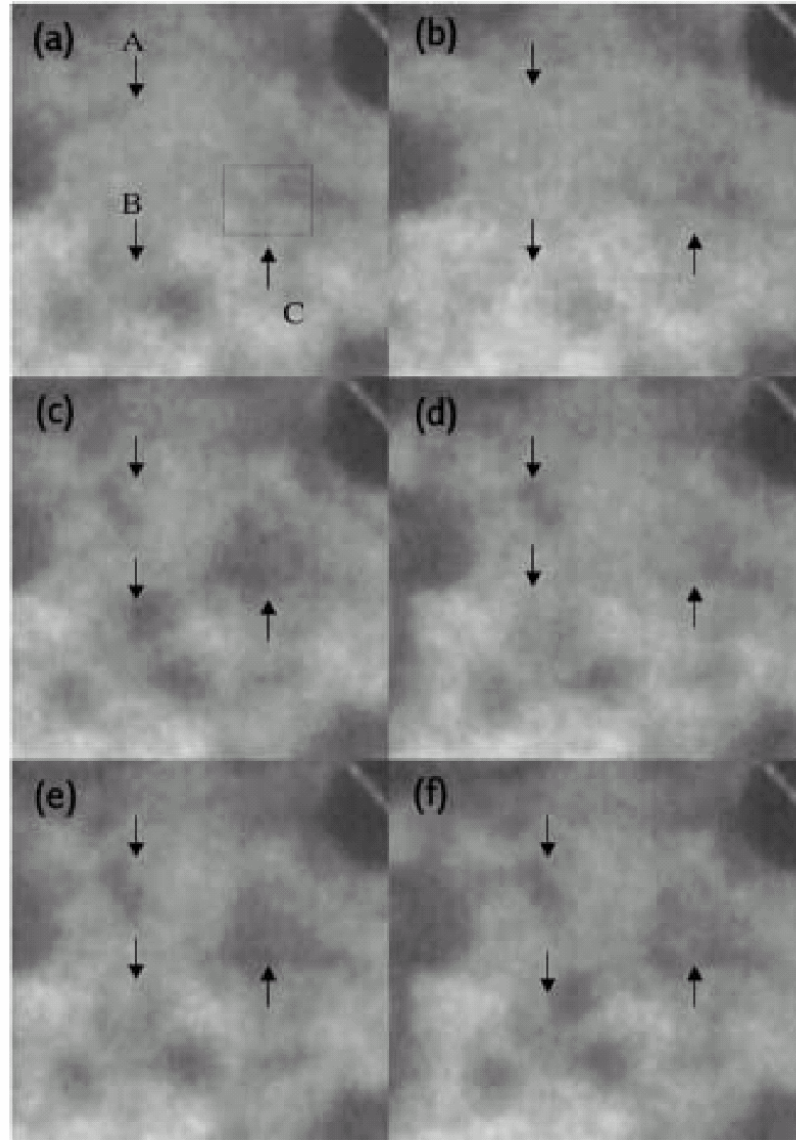


90 K 430x360 nm

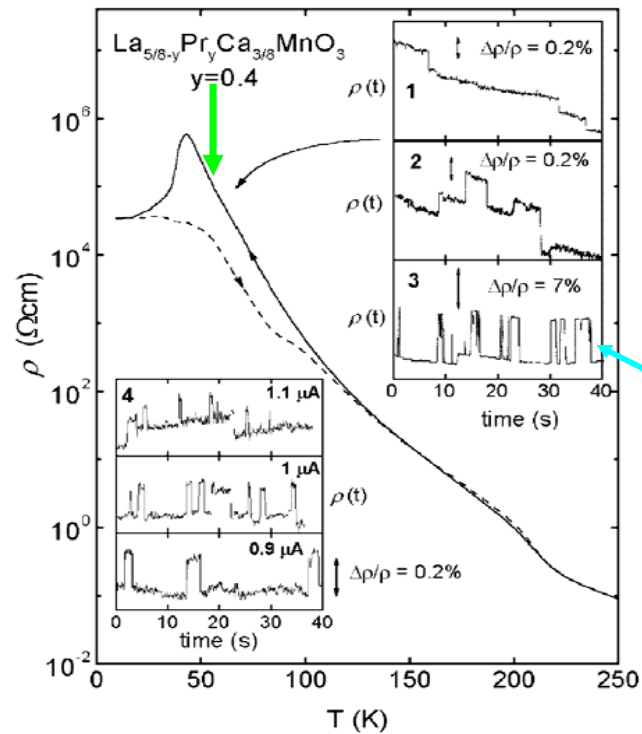
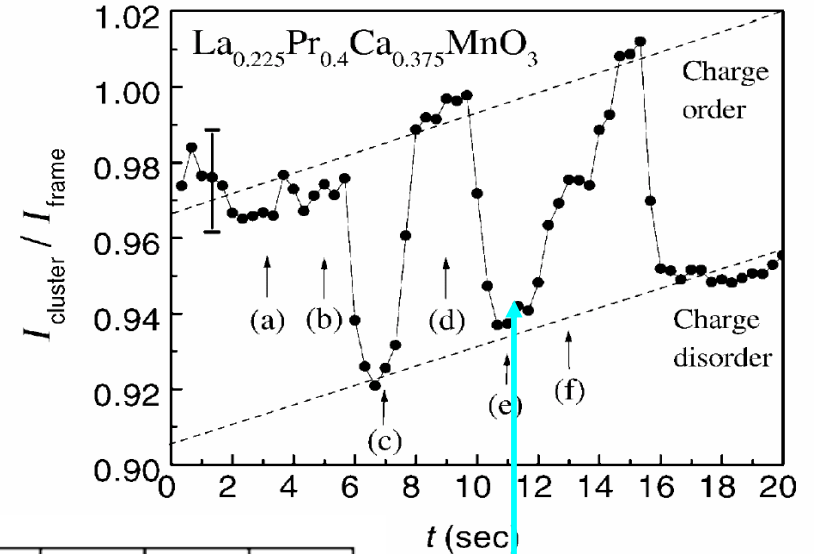
$\text{La}_{0.225}\text{Pr}_{0.4}\text{Ca}_{0.375}\text{MnO}_3$

Charge ordering is pinned !

# Charge ordering fluctuations



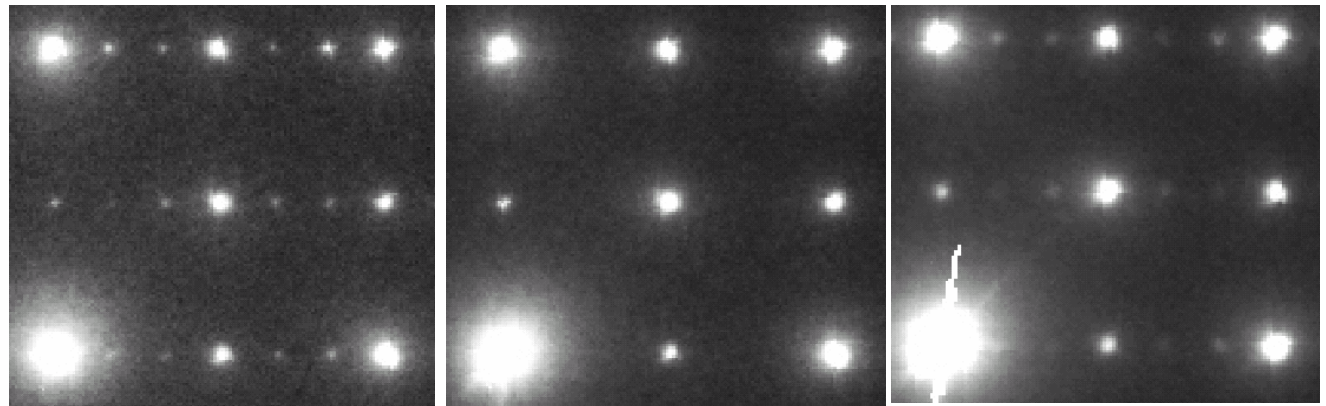
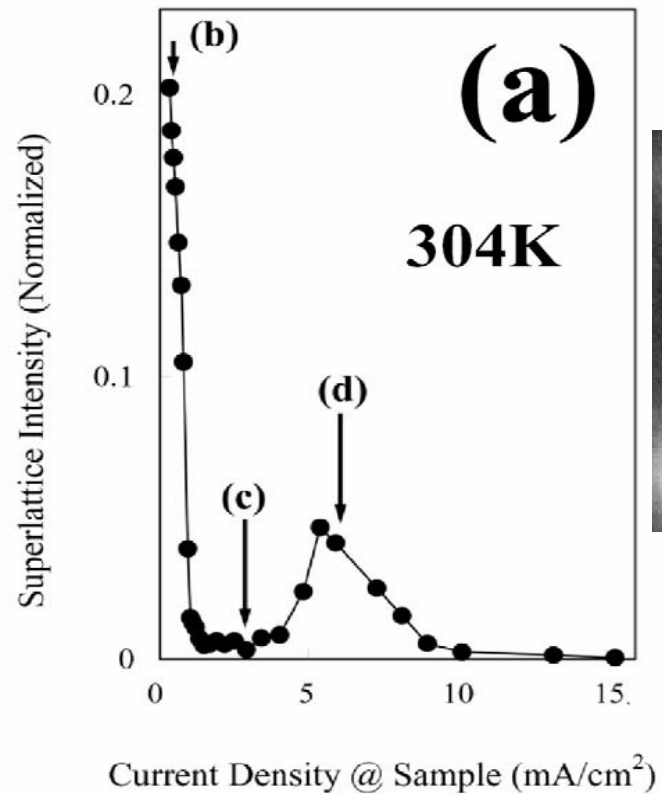
90 K  
500 mA/cm<sub>2</sub>  
100x100 nm



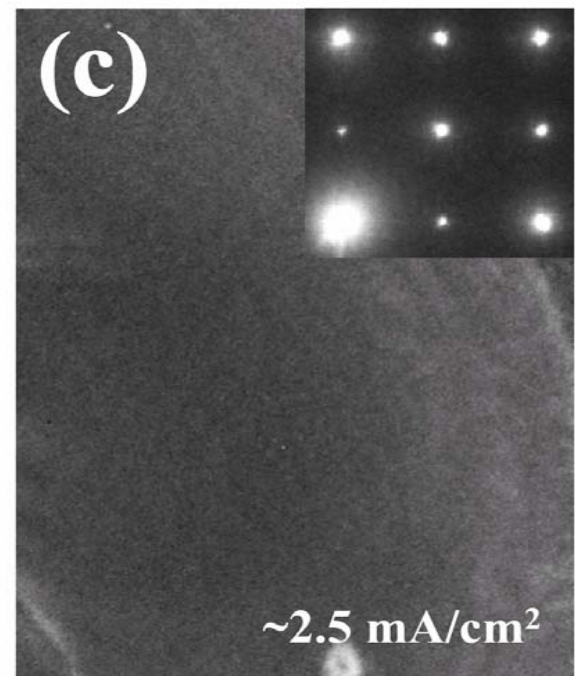
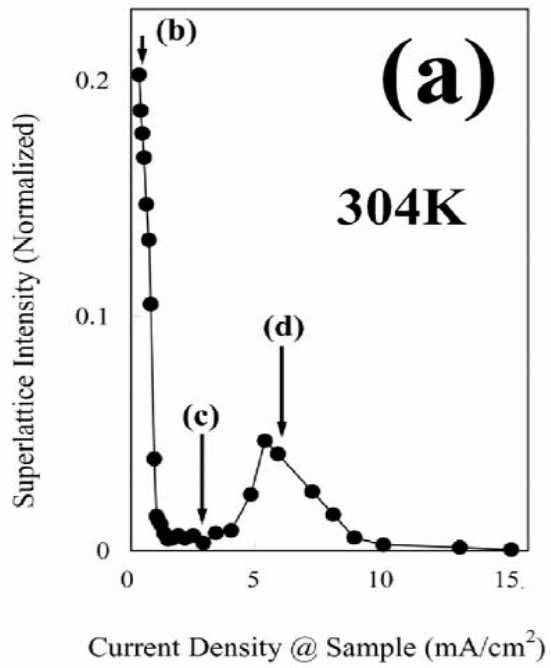
A few seconds time-scale

# Re-appearance of charge ordering in high e-beam

(Bi,Ca)MnO<sub>3</sub>

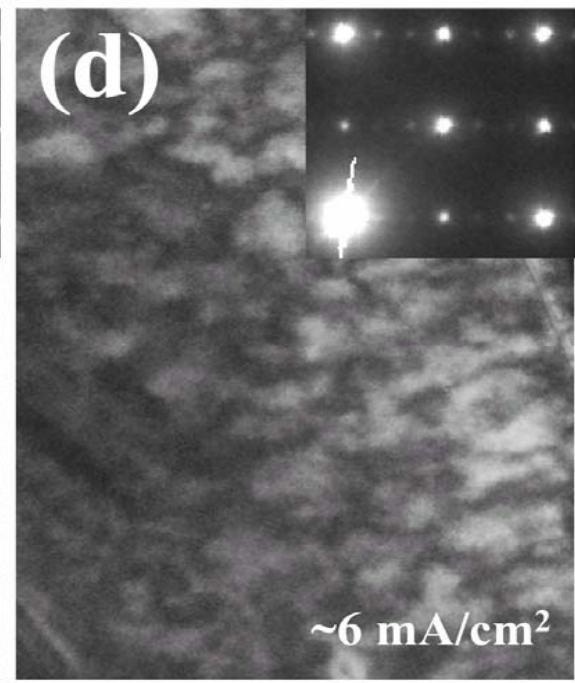
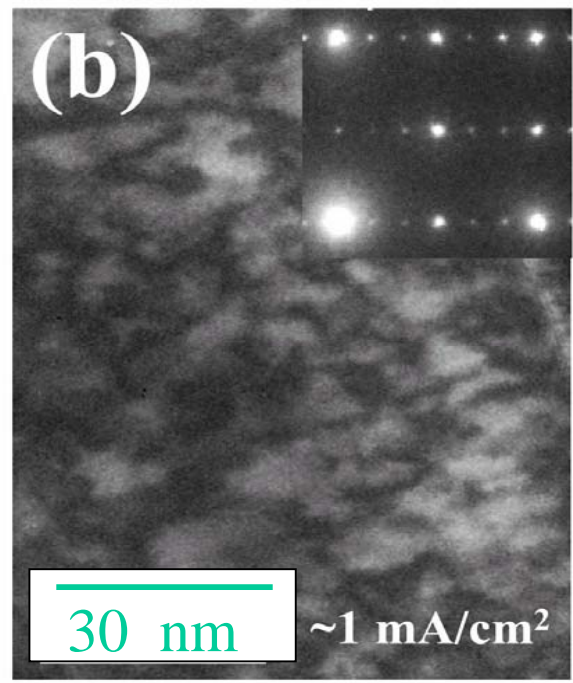




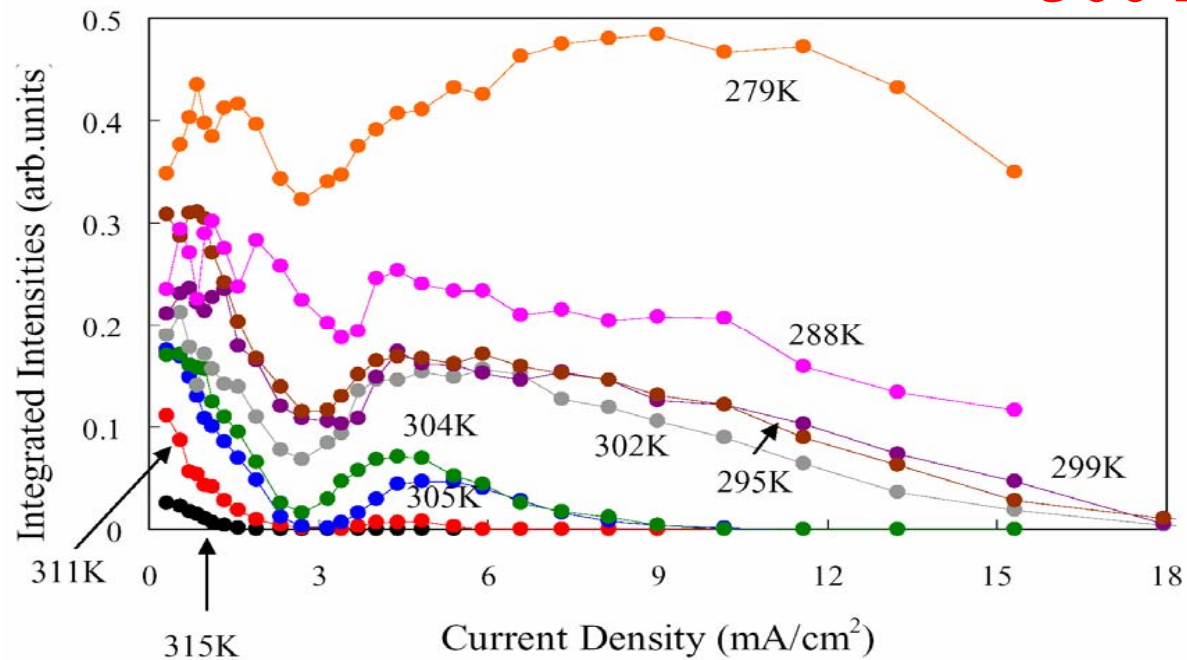
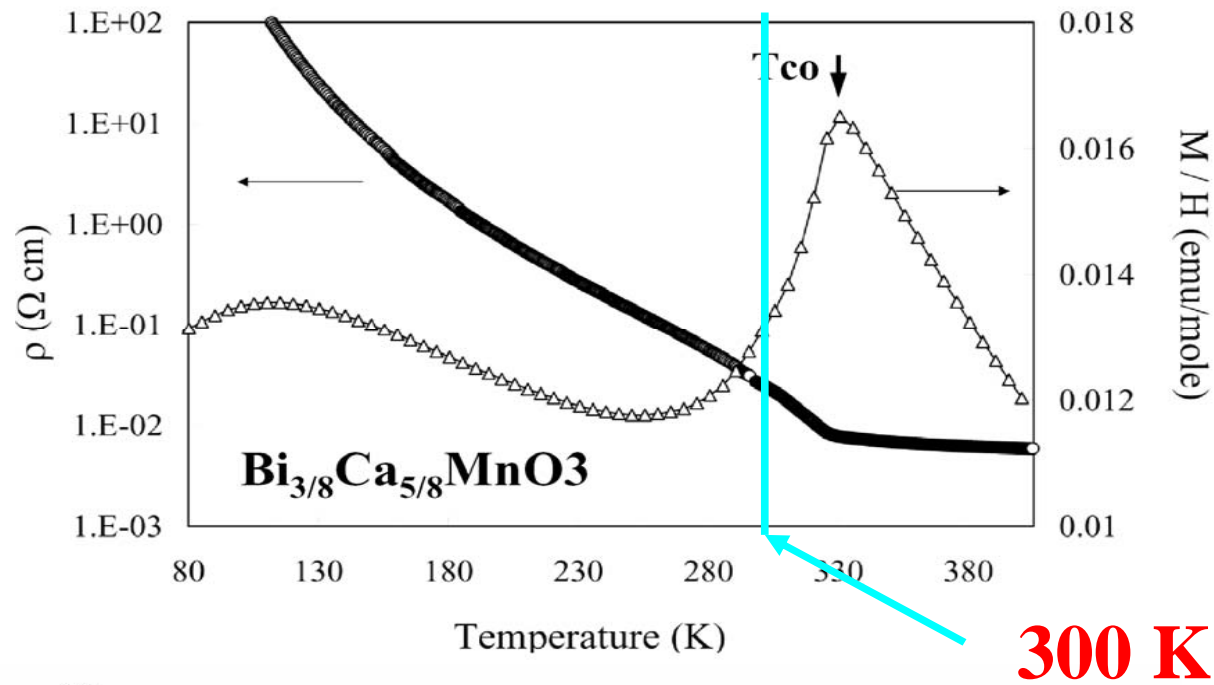


Electron diffraction pattern

Dark-field image



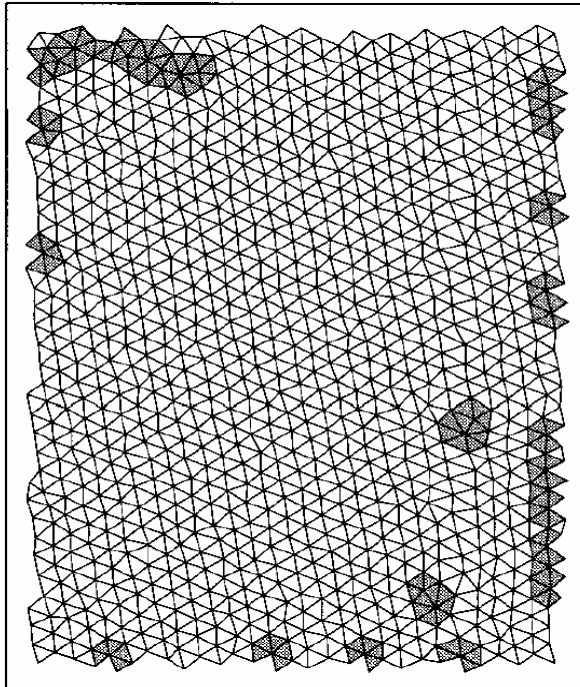




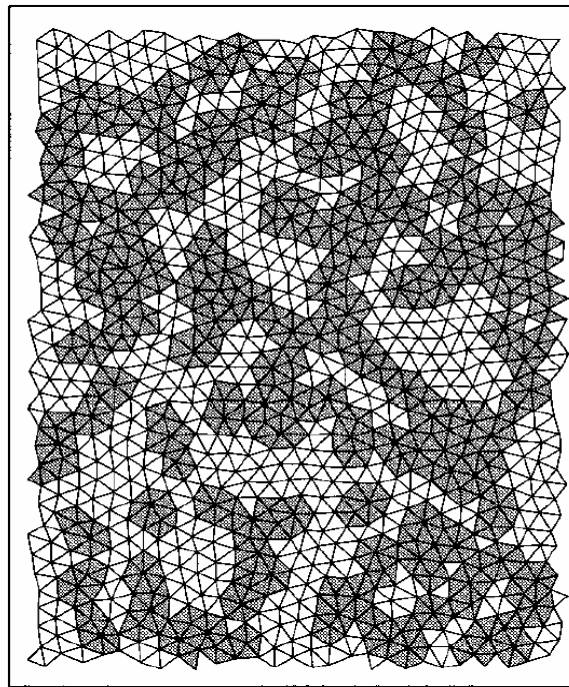
Temp. dependence of dynamic charge ordering

**Who ordered the reordering of  
charge order?**

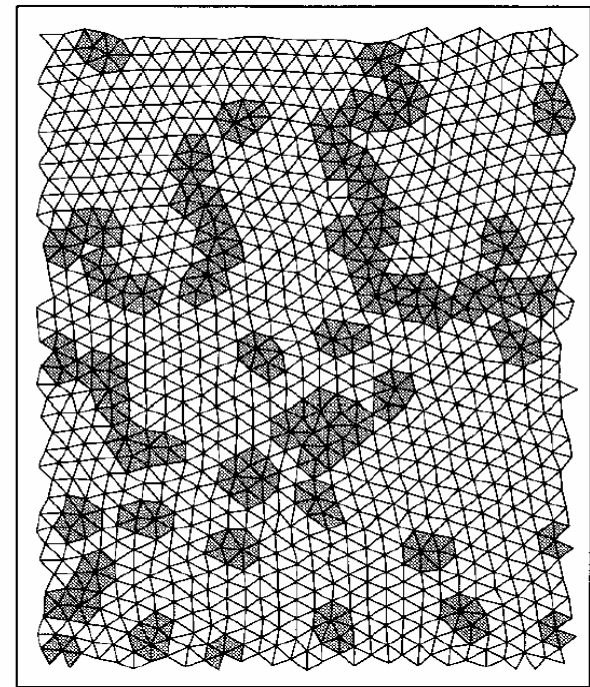
# Dynamic Reordering of Vortex lattice in 2H-NbSe<sub>2</sub>



**No drive**



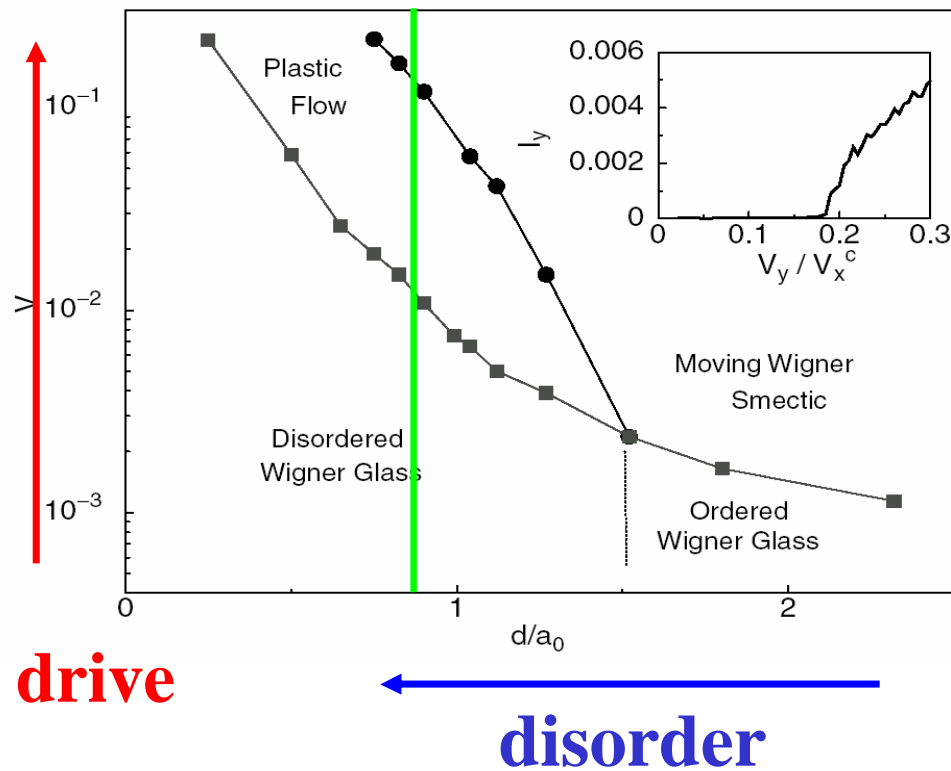
**Critical  
Depinning**



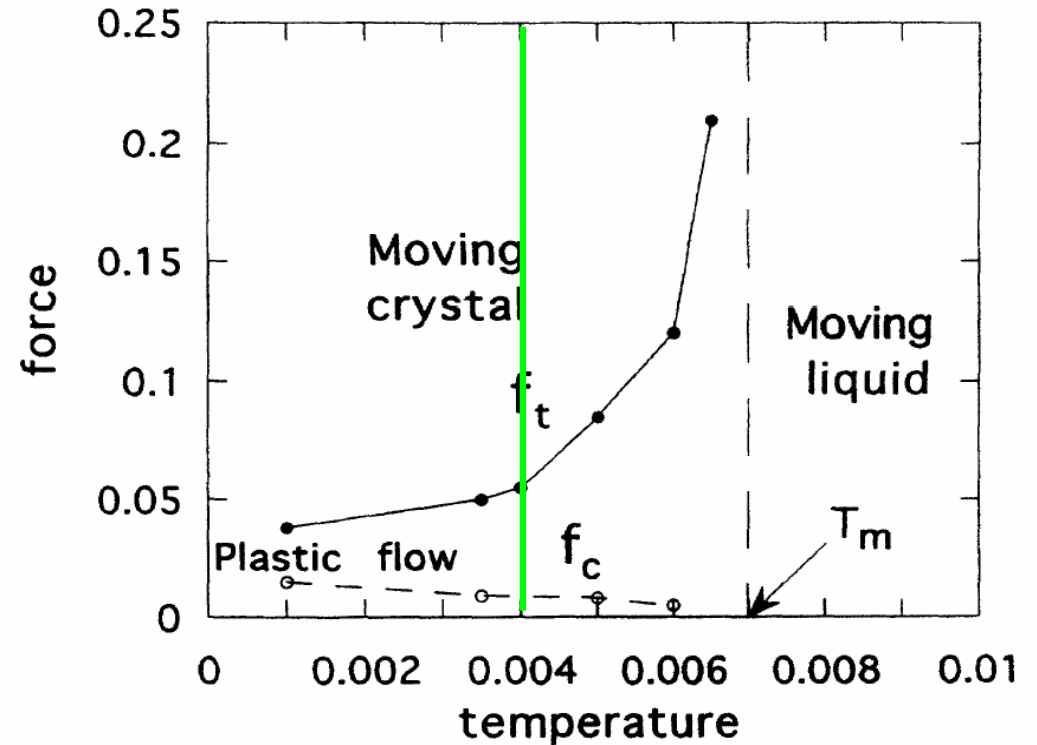
**High Drive**

**A. Duarte *et al.* PRB (1996)**

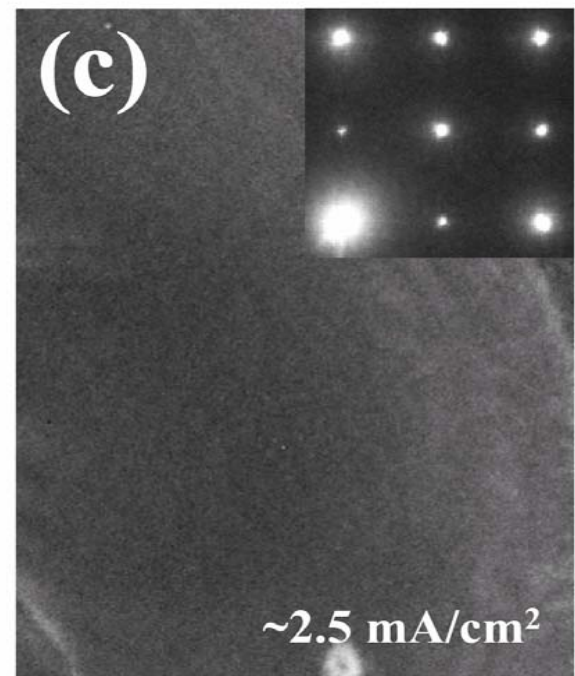
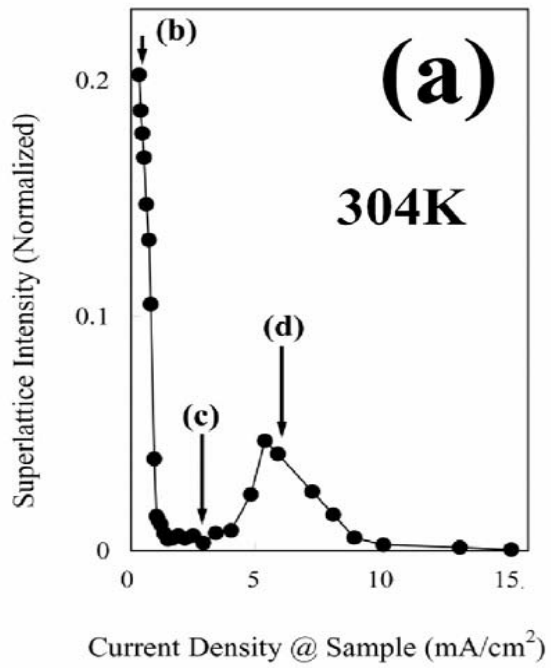
# Dynamics of disordered Wigner Crystals



C. Reichhardt *et al.* PRL (2001)

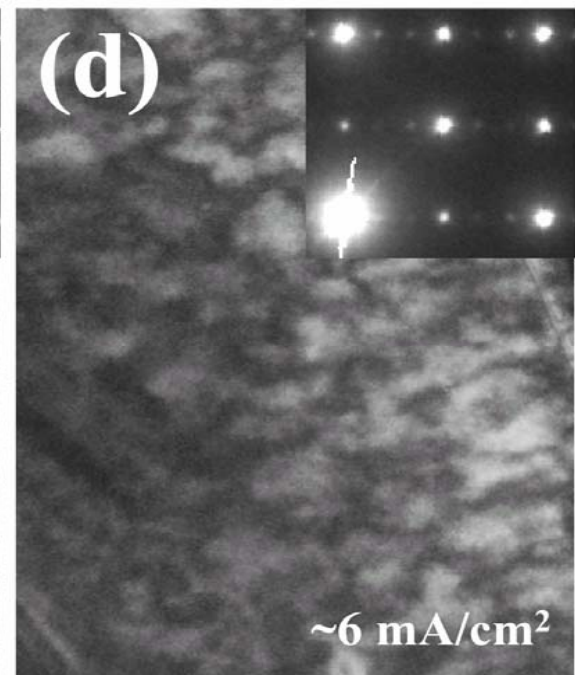
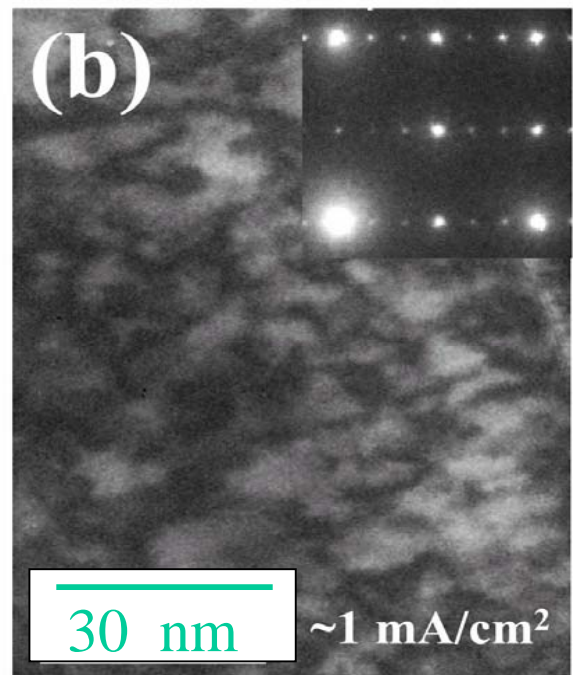


Koshelev and Vinokur, PRL (1994)



Electron diffraction pattern

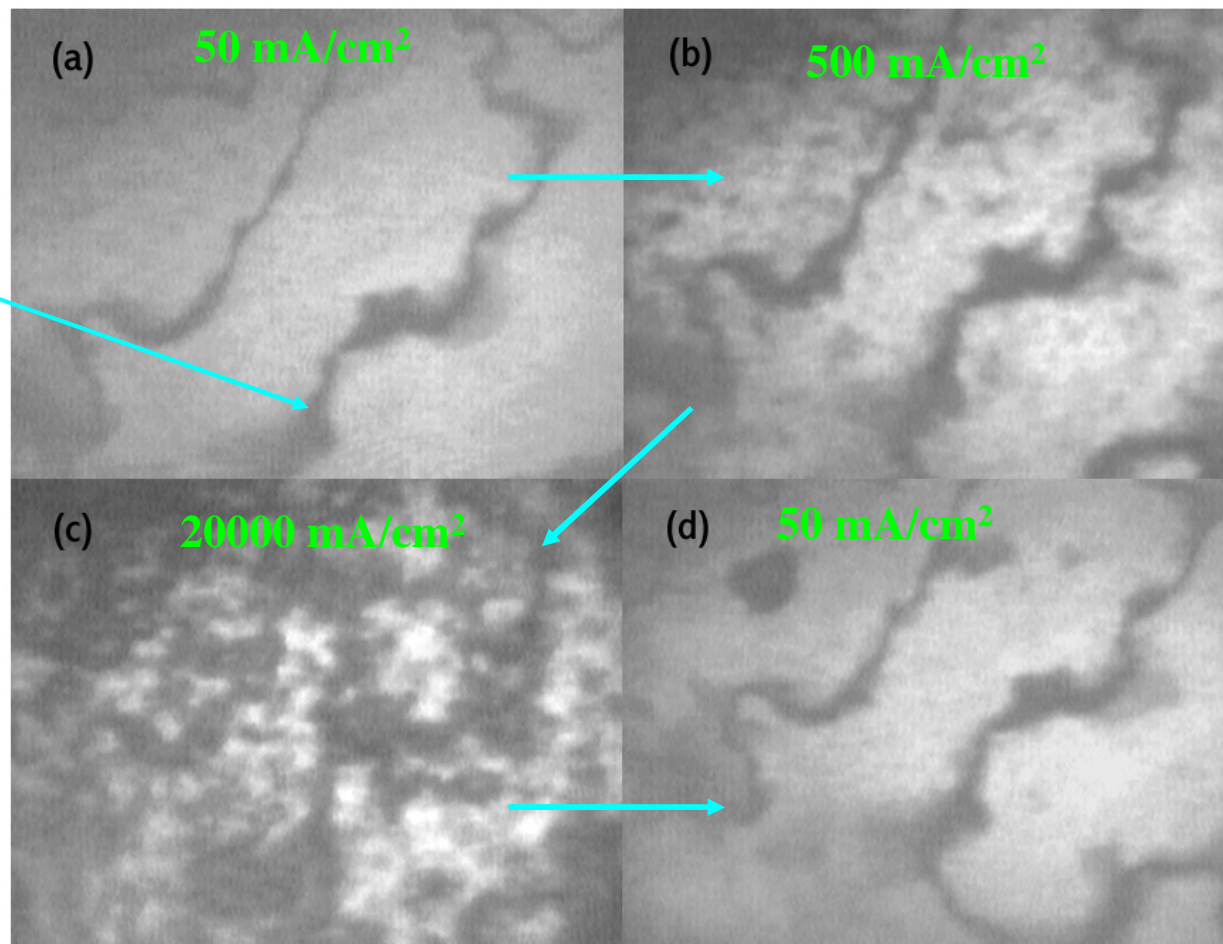
Dark-field image





## E-beam-induced melting of charge order

Strain at  
antiphase/  
discommensulation  
boundaries

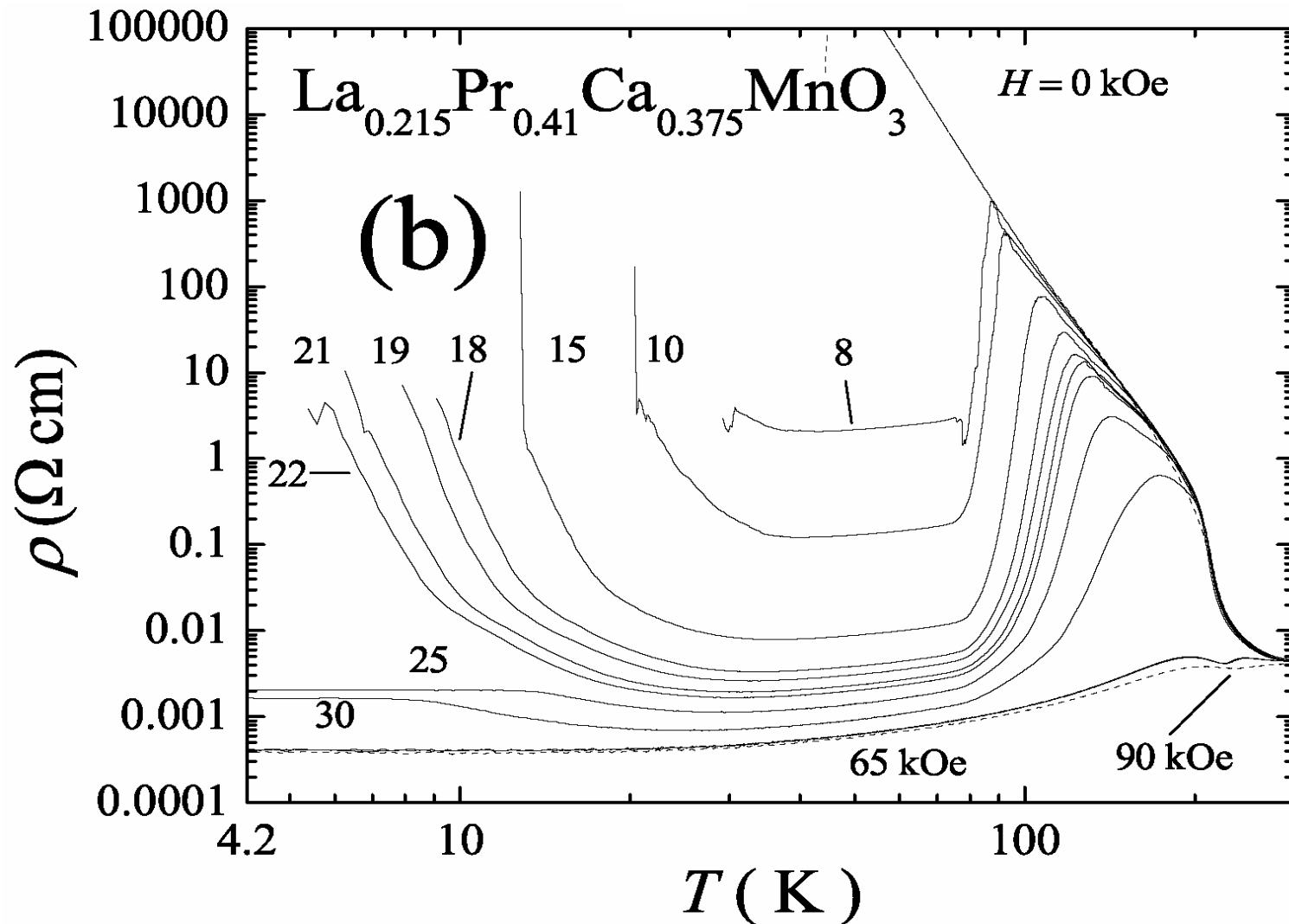


90 K 430x360 nm



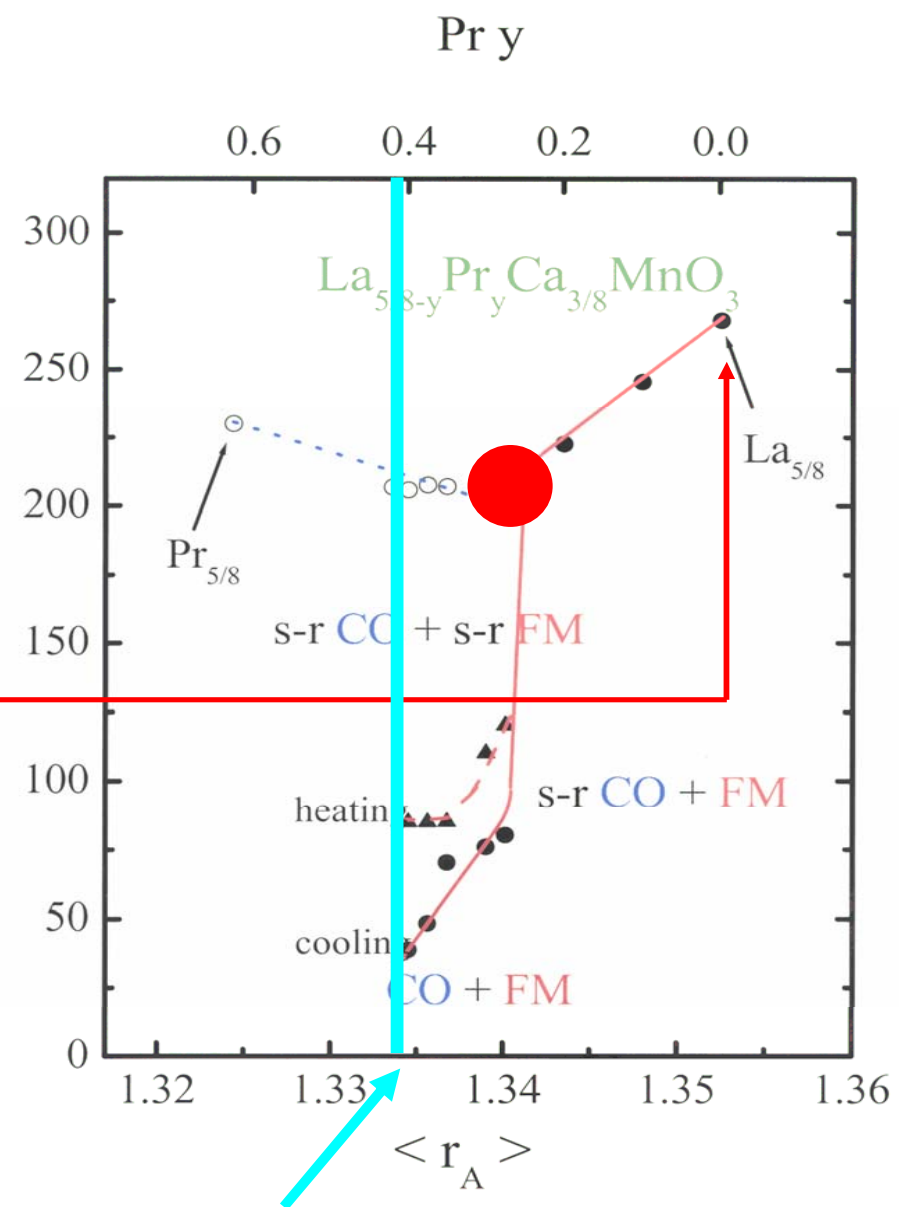
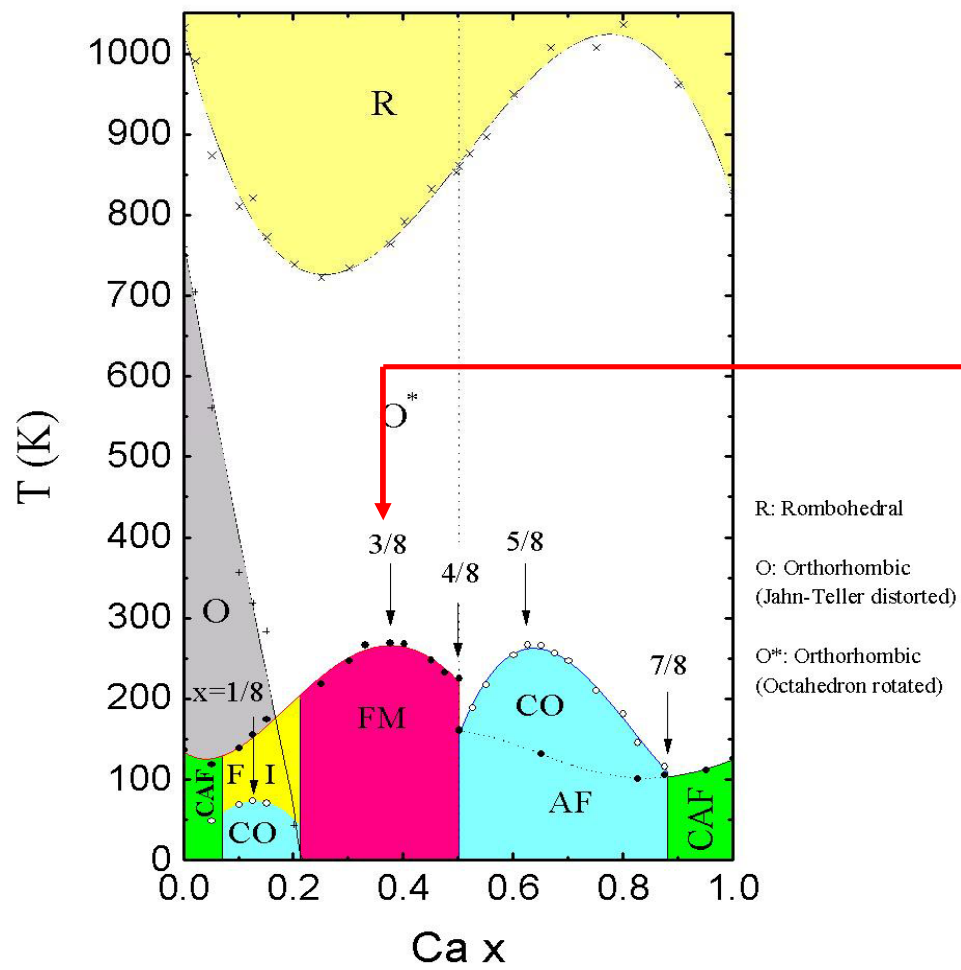


# Temp.-induced charge reordering

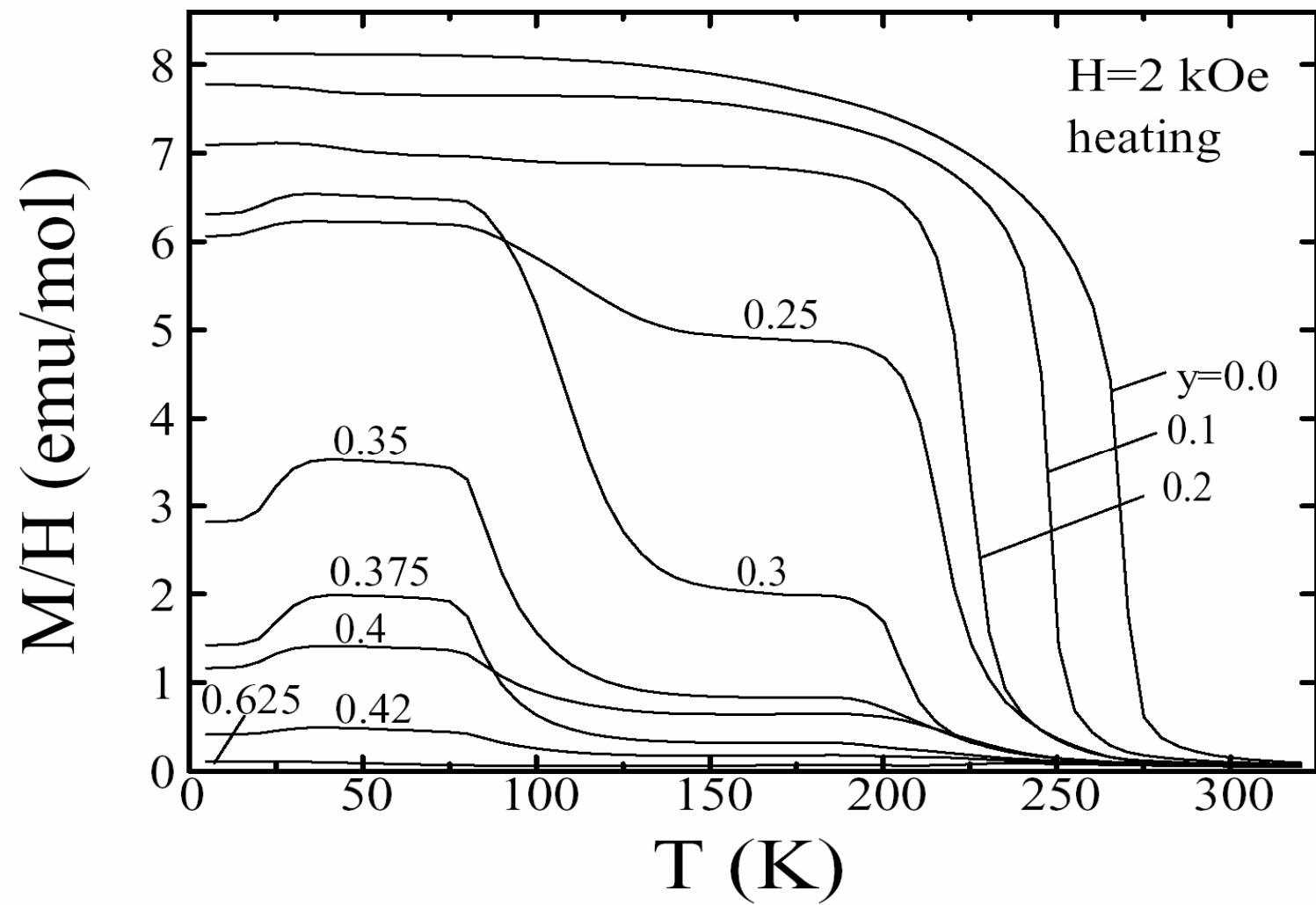


# Phase Diagram of $\text{La}_{1-x}\text{Ca}_x\text{MnO}_3$

Uehara, Kim and Cheong

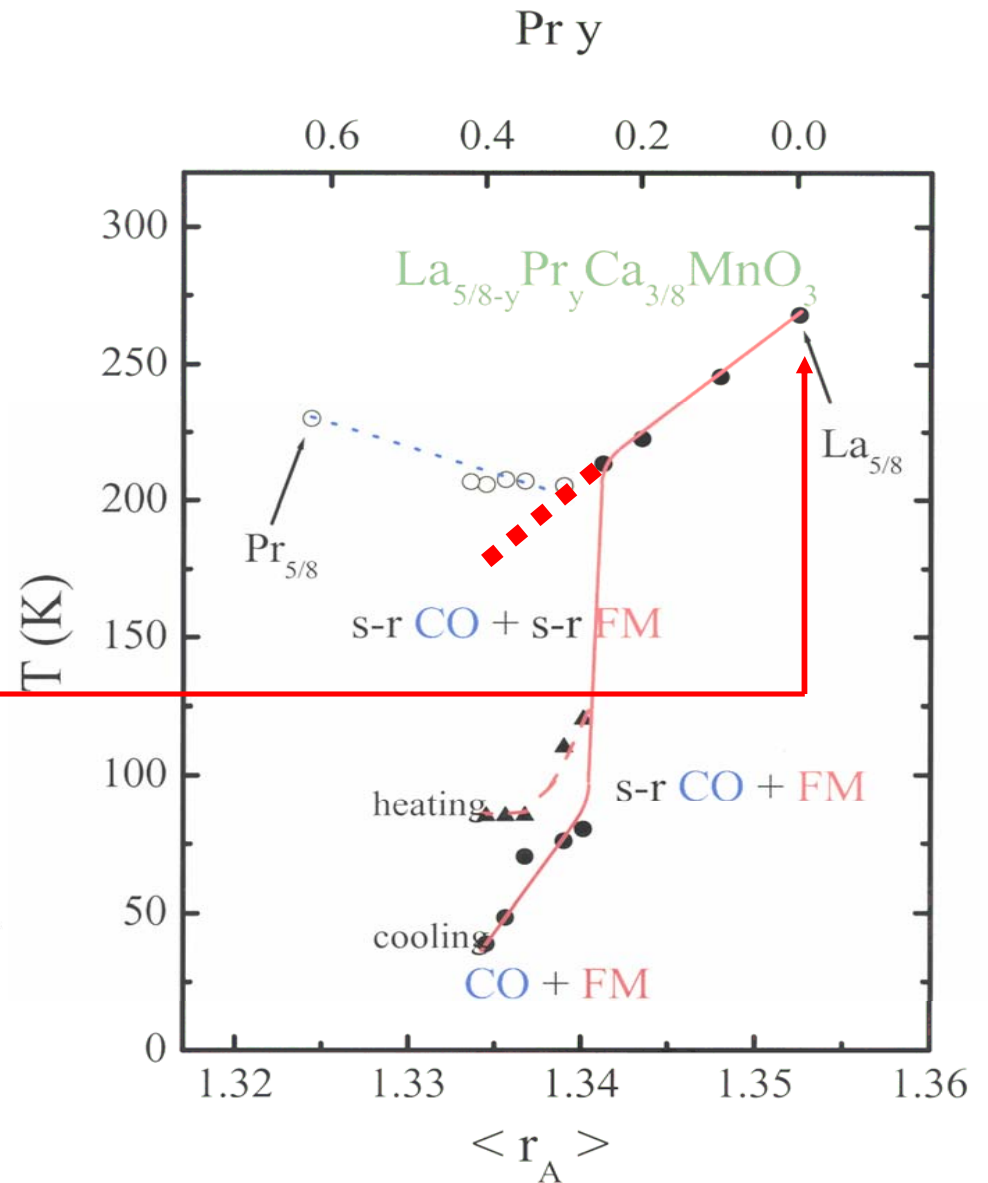
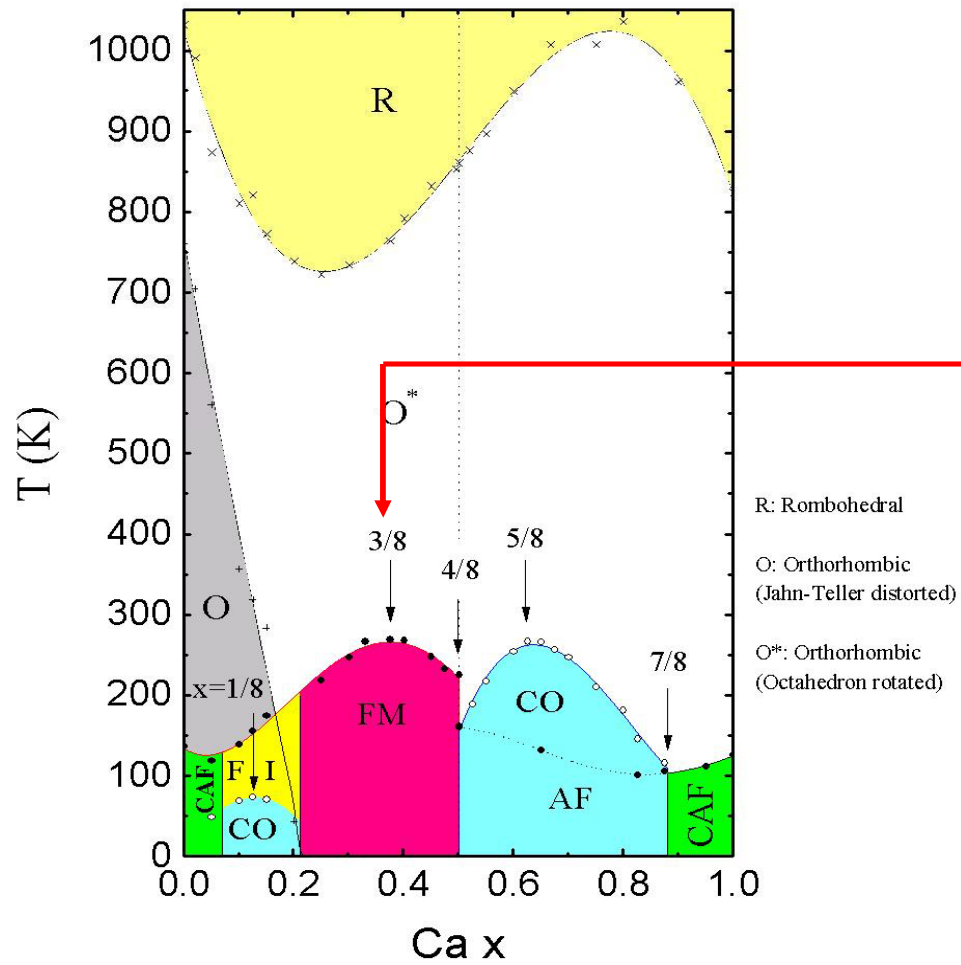


**Pr<sub>0.41</sub>**



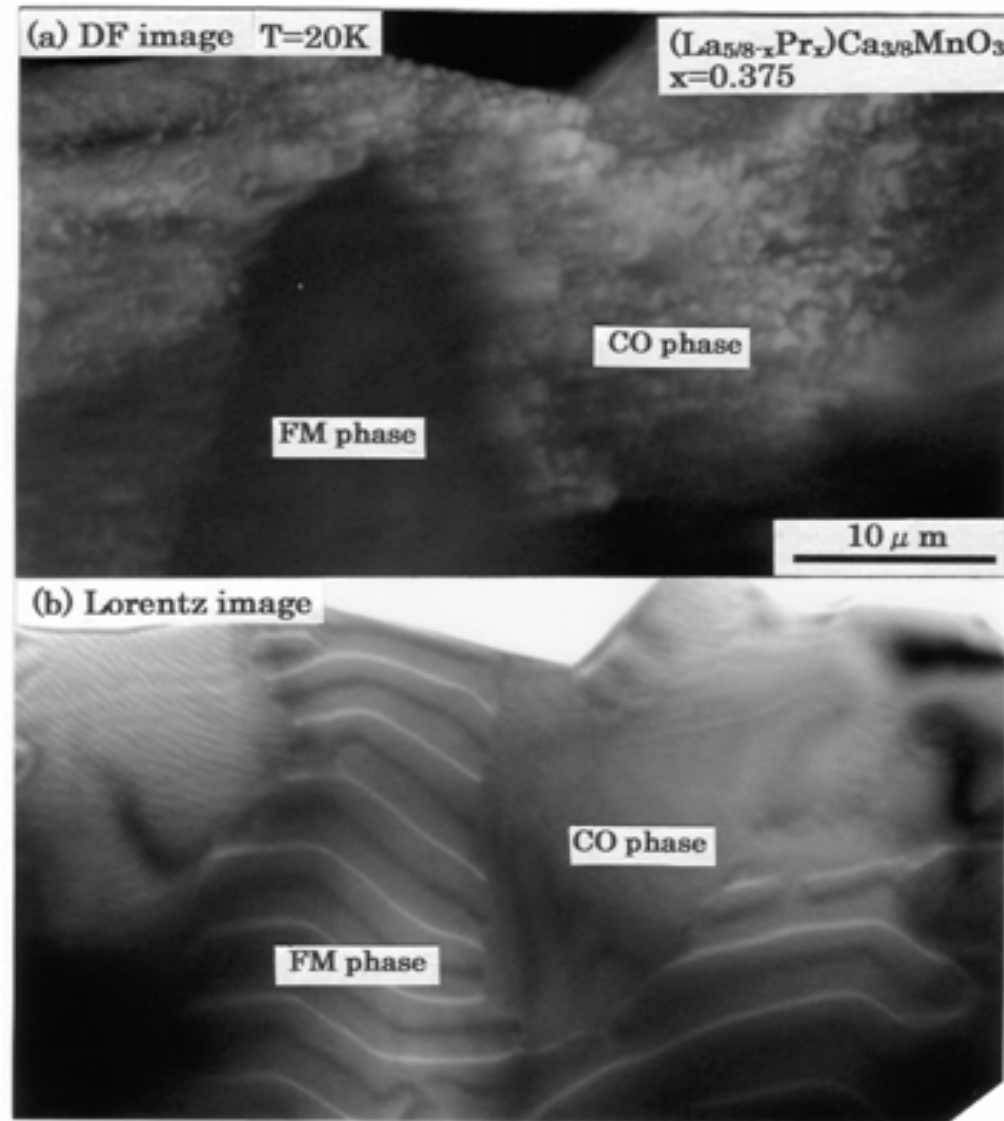
# Phase Diagram of $\text{La}_{1-x}\text{Ca}_x\text{MnO}_3$

Uehara, Kim and Cheong



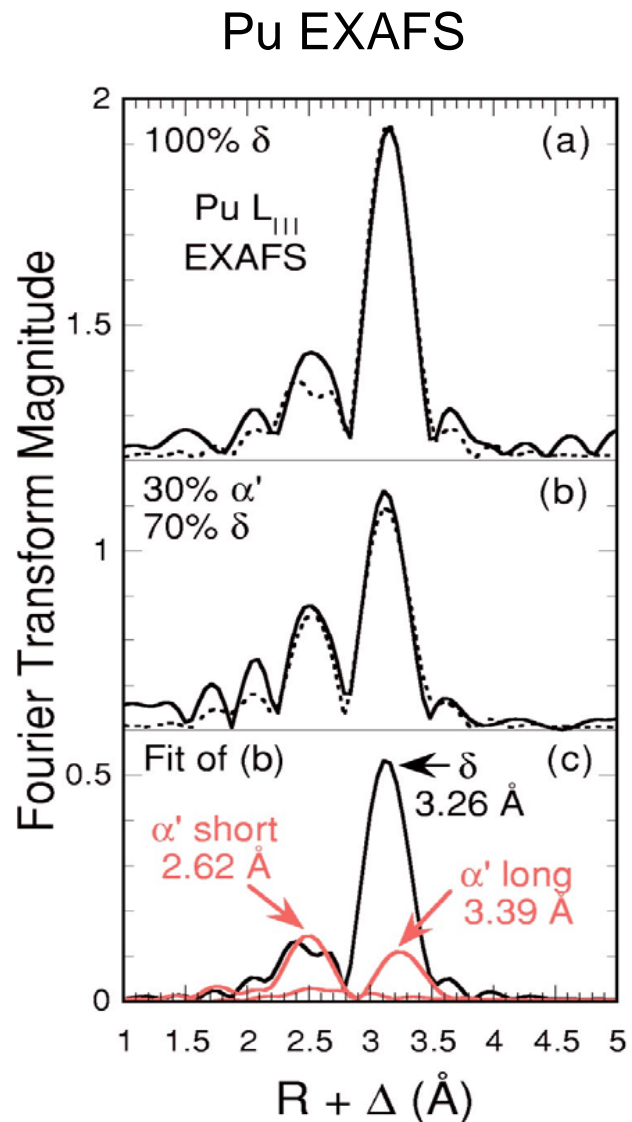


# Coexistence of FM domains and CO

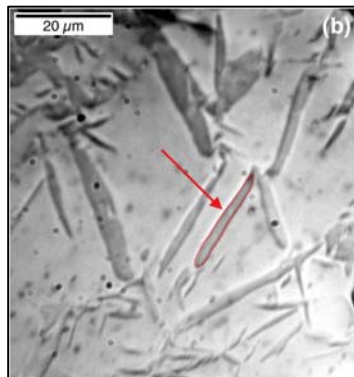




# EXAFS Temperature Dependence Yields Phase Specific Vibrational Data in Mixed Phase Material



mixed phase  
"martensite"

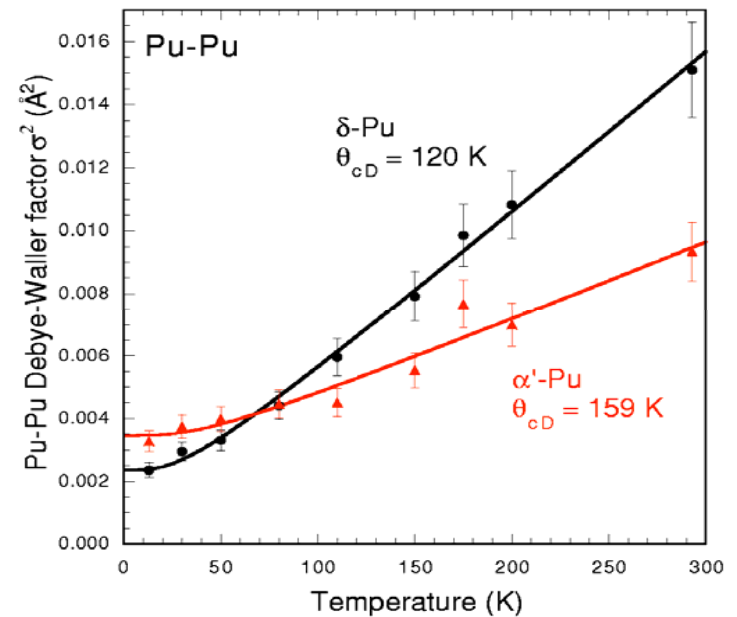


30%  $\alpha'$  70%  $\delta$   
1.9 at% Ga

Ga in  $\alpha$ -Pu Bonds are  
also separable!

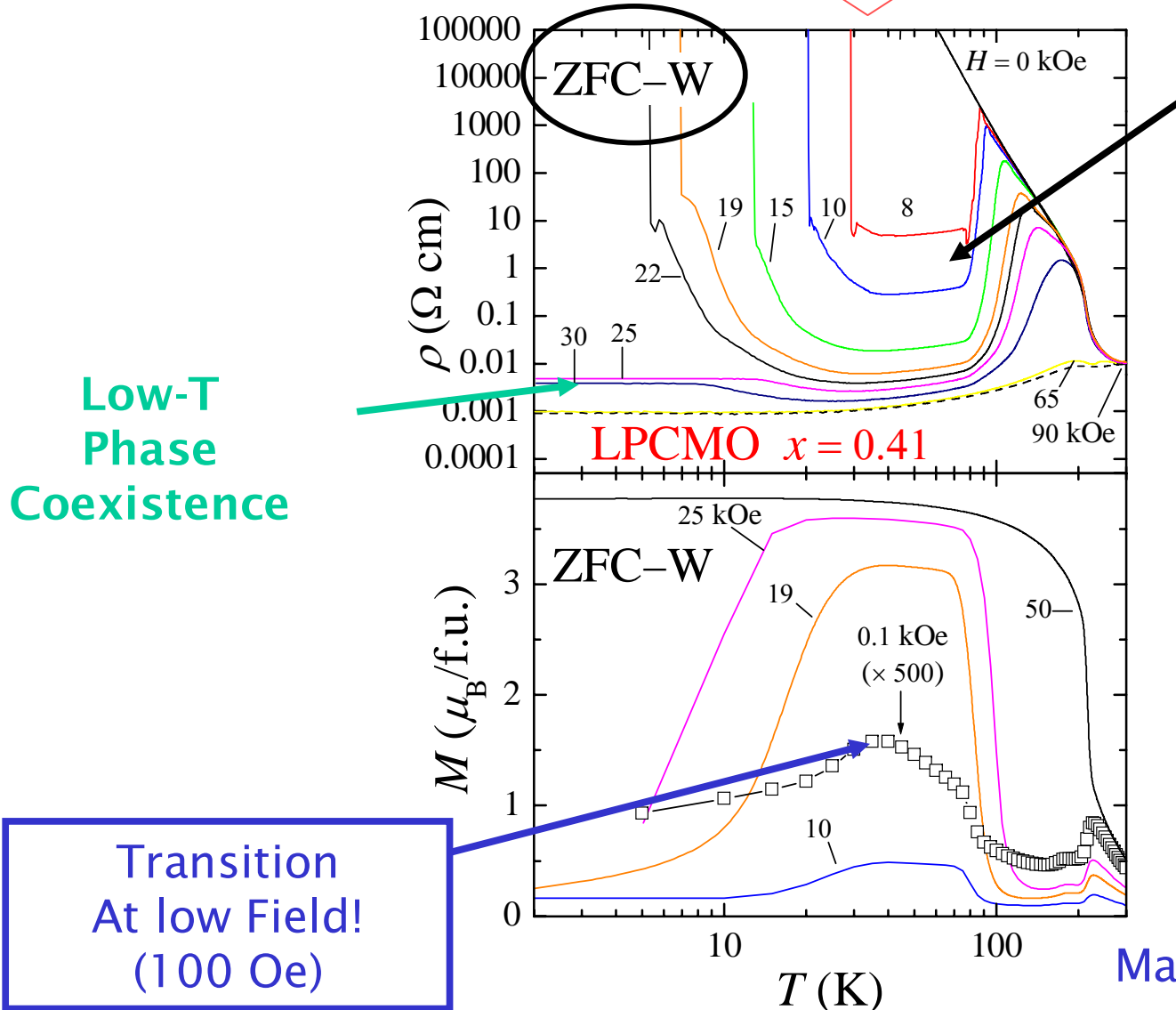
C. Booth et al.

$\alpha'$ -Pu and  $\delta$ -Pu  
Pu—Pu Displacements  
Fitted to "Debye" Model

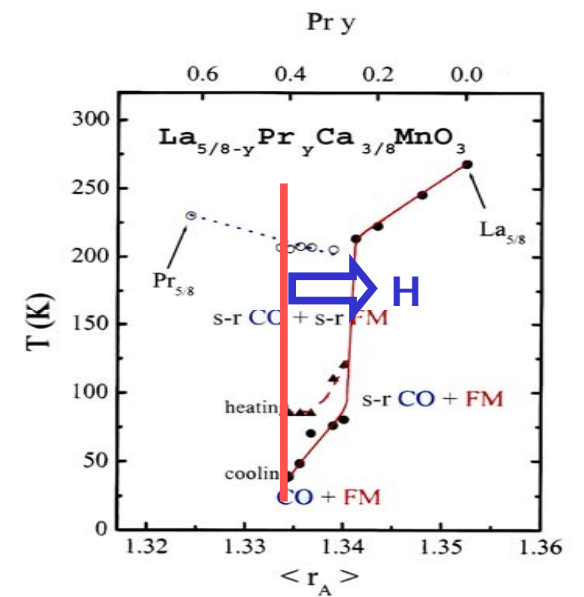


Phys. Rev. B, 2003, V67,  
224206.

# Reentrance of CO at low T?

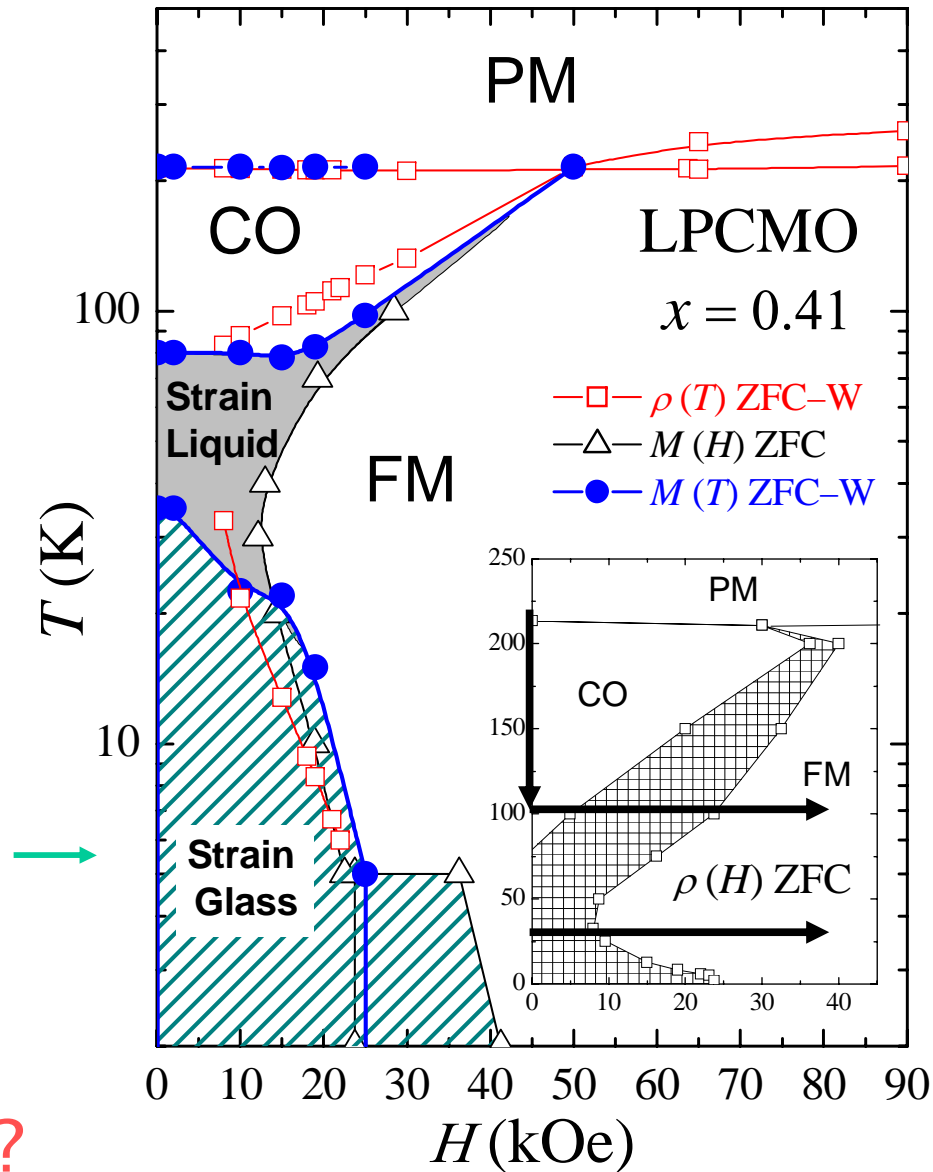


**High-T Phase Coexistence**

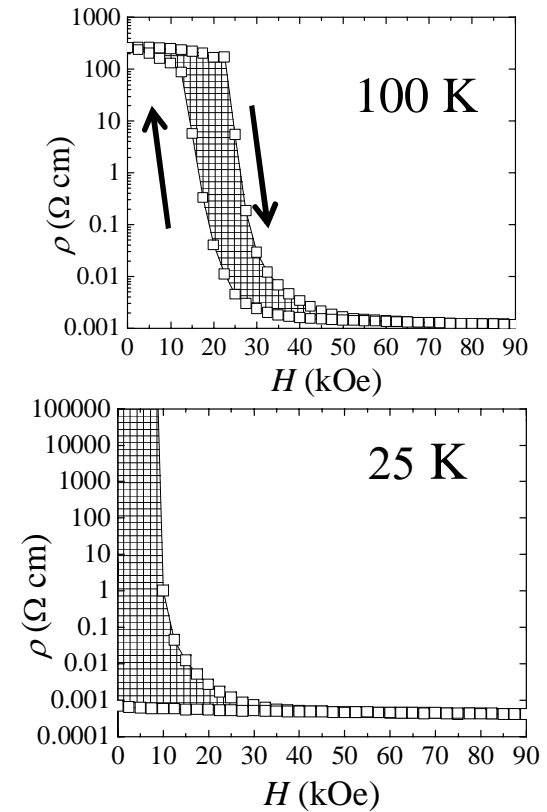


What does the **Magnetic Phase Diagram** look like?

# Magnetic Phase Diagram: A new low-T phase



$\rho(H)$ ,  $M(H)$   
obscures  
Phase Diagram



Another  
Phase  
Here!

What is it?

# Magnetic Phase Diagrams of the Manganites

CMR in PCSMO/PCMO

Bicriticality:

CO/FM competition

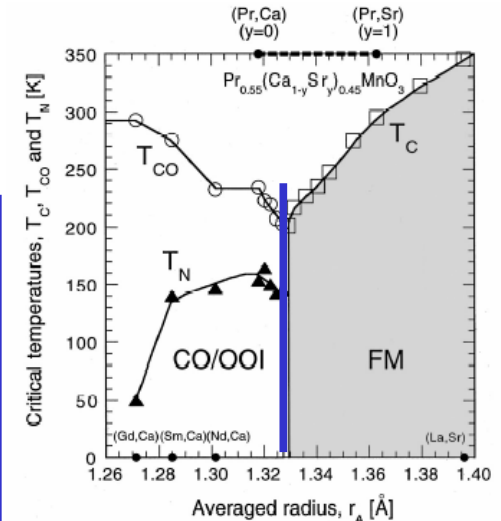
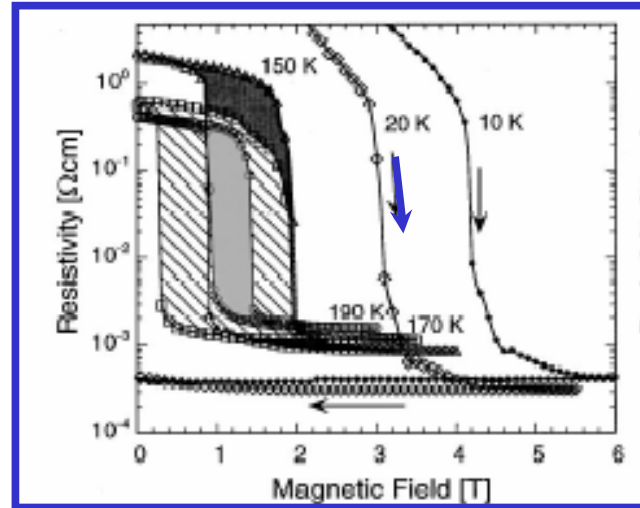
H-induced Collapse of

CO/OO states

**LPCMO**

$\mu\text{m}$ -scale PS & large CMR  
occur at low T

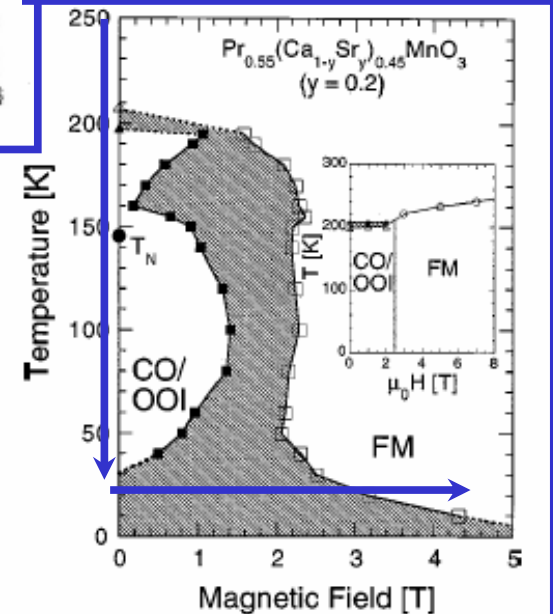
Tomioka PRB ('02)  
PCSMO



(Uehara - TEM)

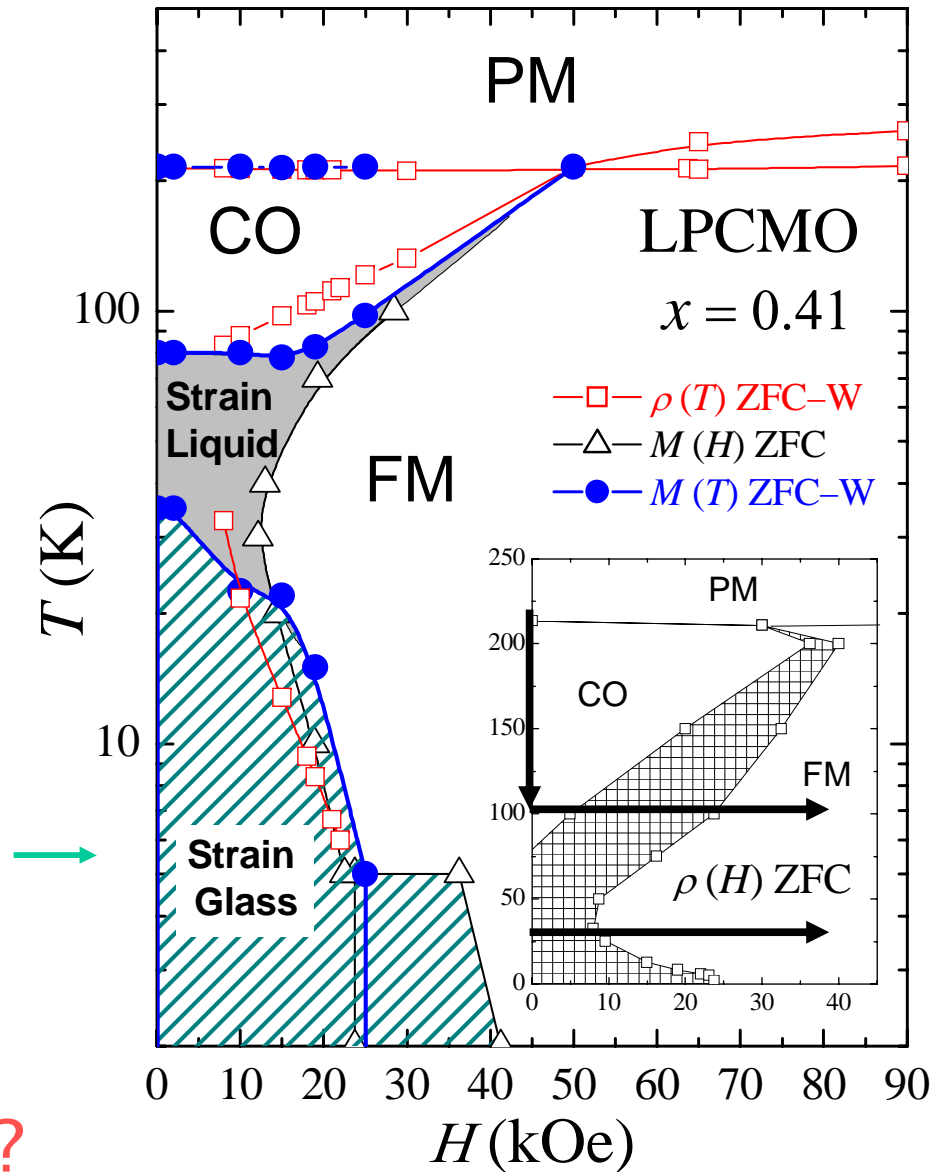
Bicriticality + Disorder

phase coexistence?

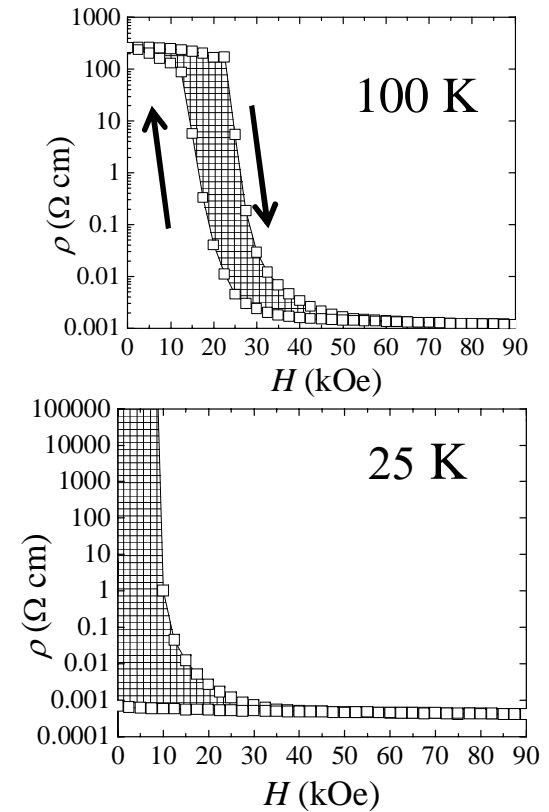


Theory : e.g. Moreo PRL ('02) vs. Motome PRL ('03)

# Magnetic Phase Diagram: A new low-T phase



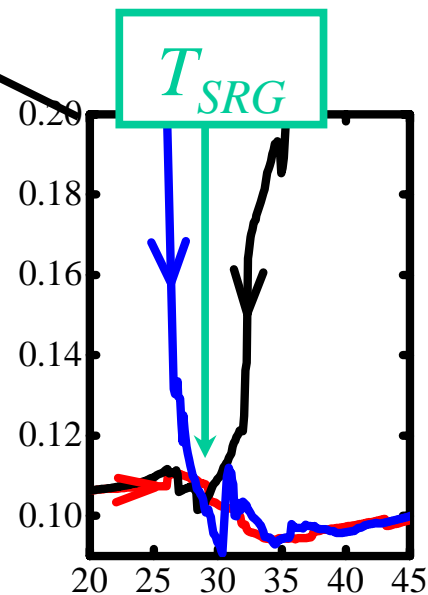
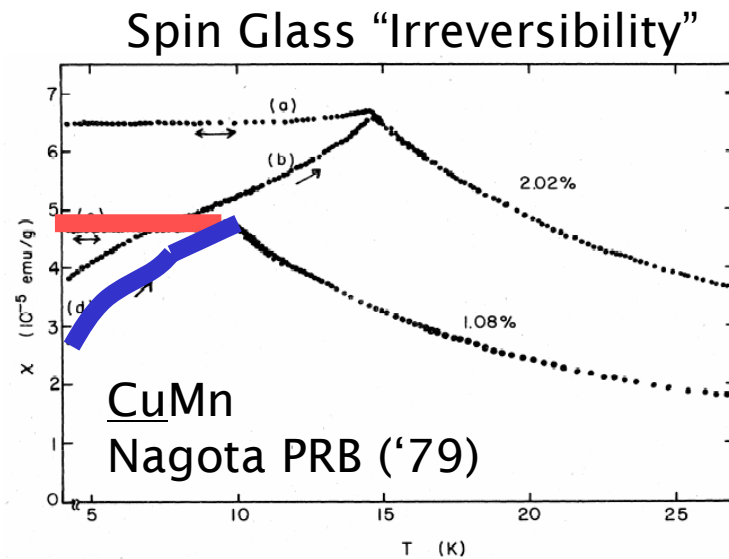
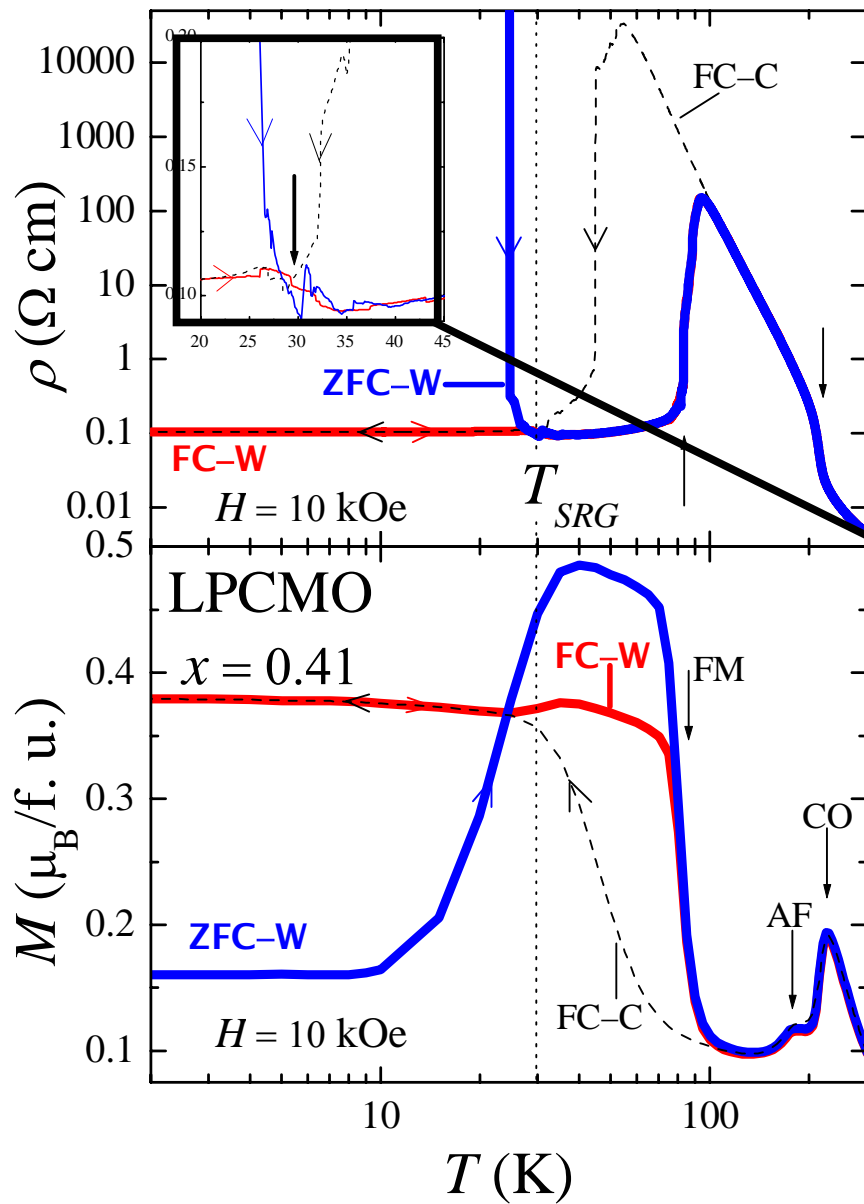
$\rho(H)$ ,  $M(H)$   
obscures  
Phase Diagram



Another  
Phase  
Here!

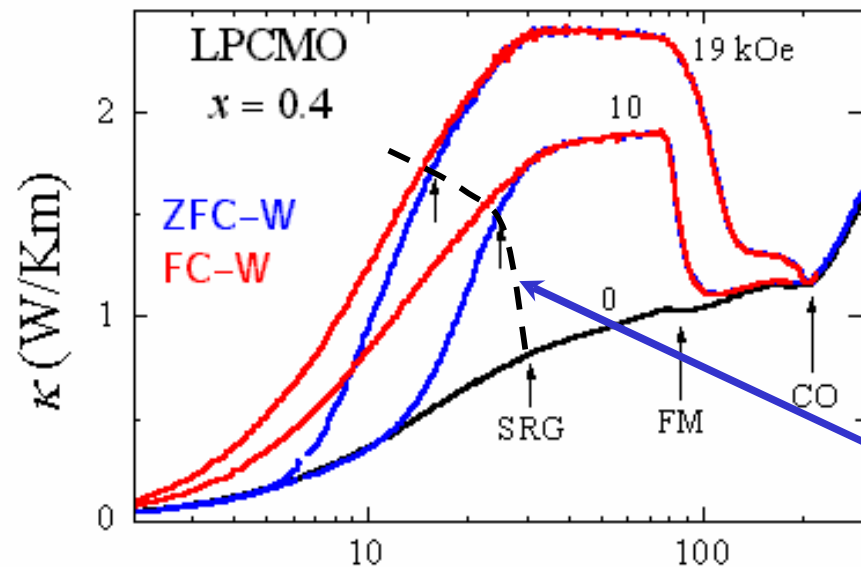
What is it?

# Spin Glass-like signatures in charge/spin sector

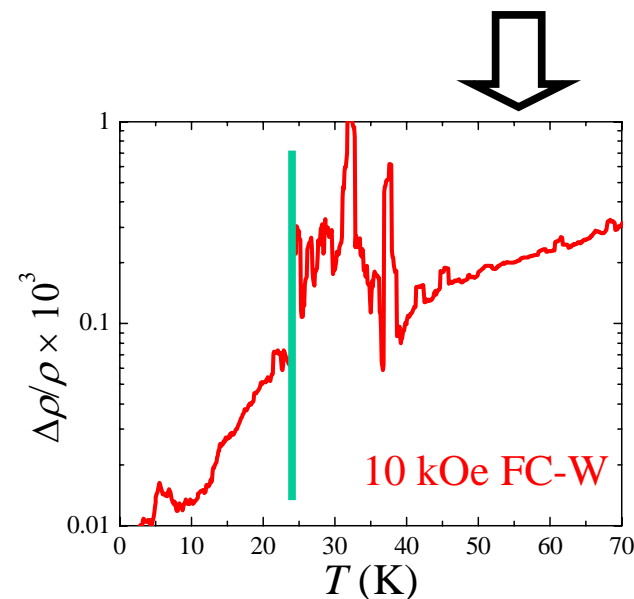
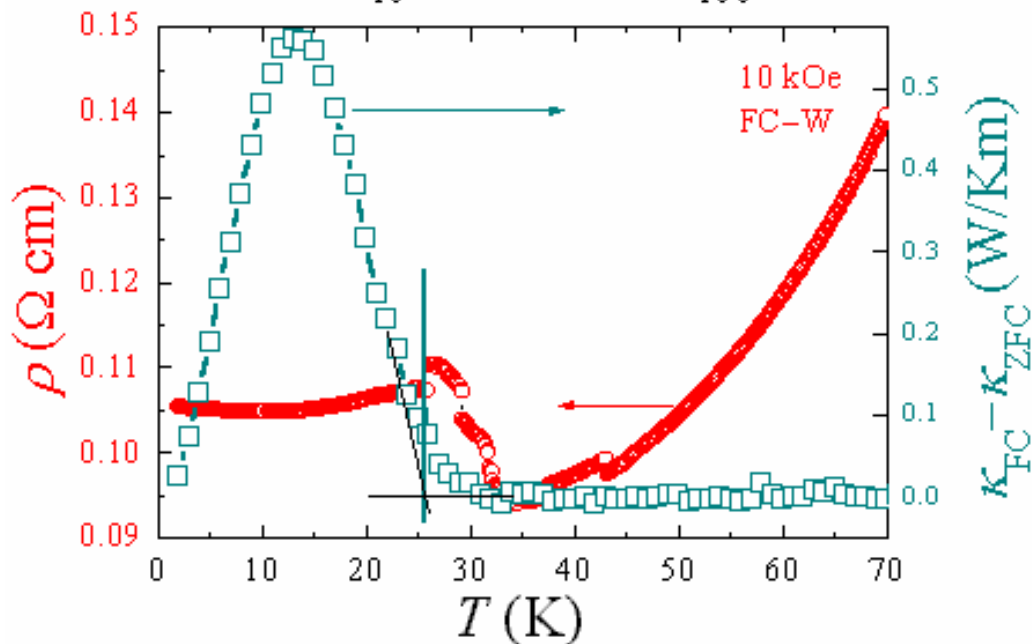




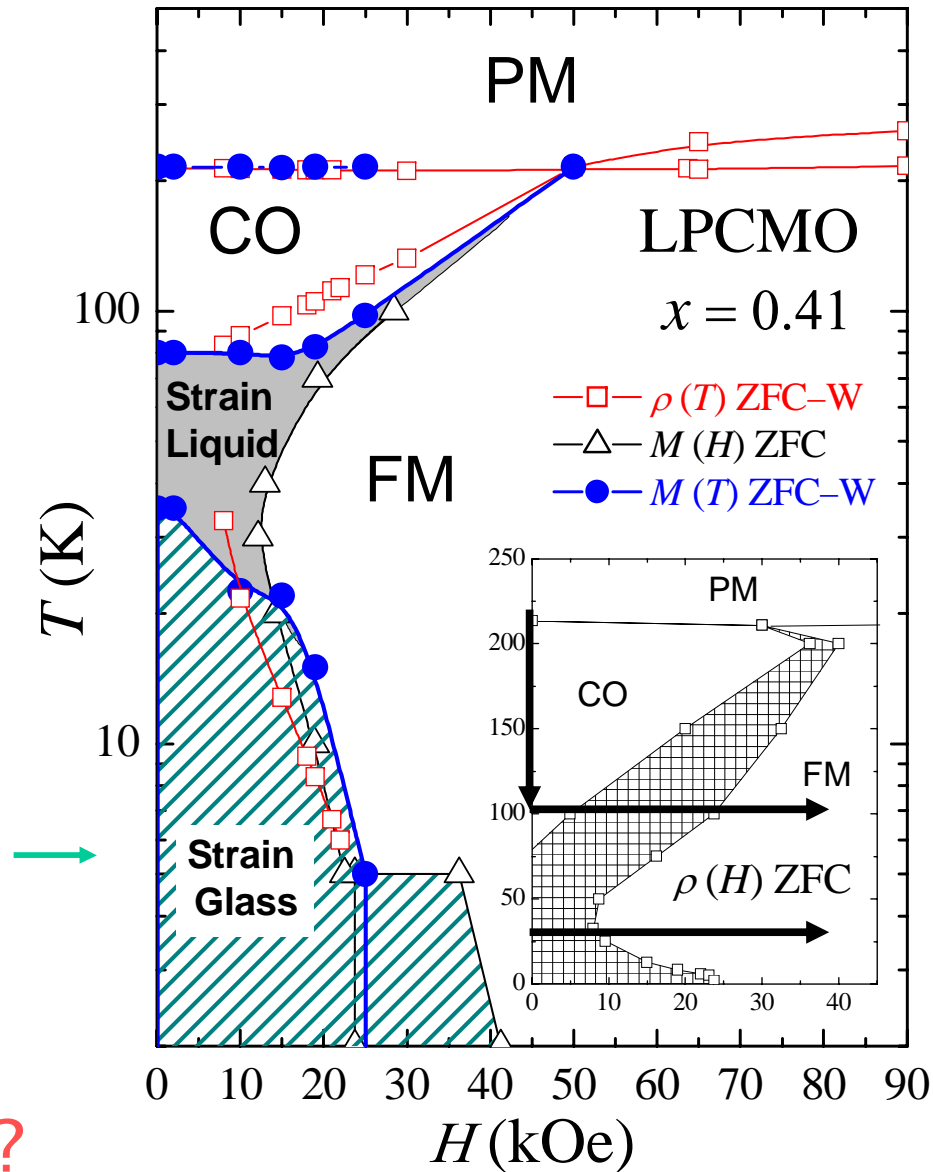
# $\kappa$ irreversibility in magnetic field



Rapid “freezing” of fluctuations within phase separated state



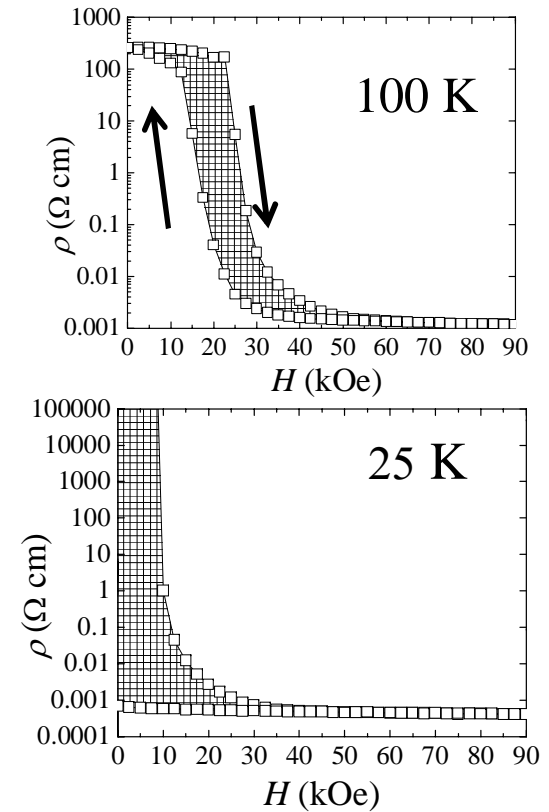
# Magnetic Phase Diagram: A new low-T phase

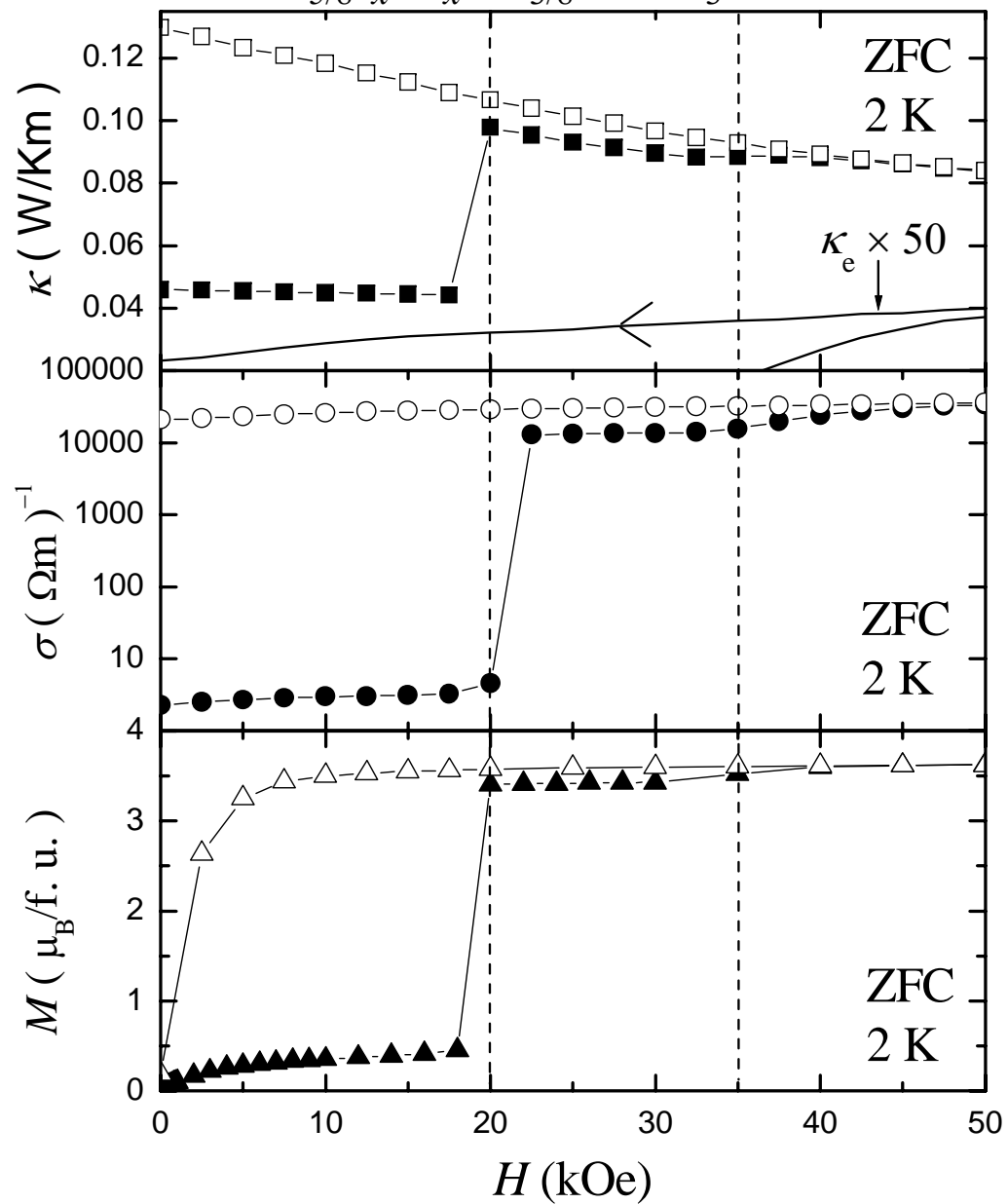


Another Phase Here!

What is it?

$\rho(H)$ ,  $M(H)$  obscures Phase Diagram





Accommodation strain

$\Rightarrow$  two phase coexistence  $\Rightarrow$  **strain glass**

**New state of mater ??**

**Bicriticality (multicriticality)**

Disorder in AFM

$\Rightarrow$  suppress  $T_N \Rightarrow$  **spin glass**