庞磁阻材料的局域化电子序在相变中的超快动态过程研究

清华大学物理系

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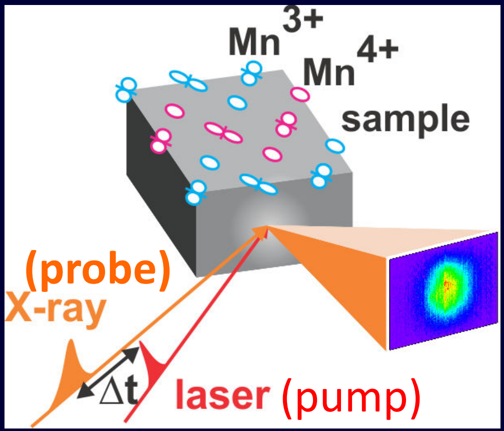
凝聚态物理-北京大学论坛 2012/12/06



Ultrafast Dynamics of Localized Electronic Ordering

- **Why localized electronic orderings?**
- **How to detect?**
- **Example: Dynamics of antiferromagnetic spin ordering in $Pr_{0.7}Ca_{0.3}MnO_3$ manganite**

(1) Melting dynamics

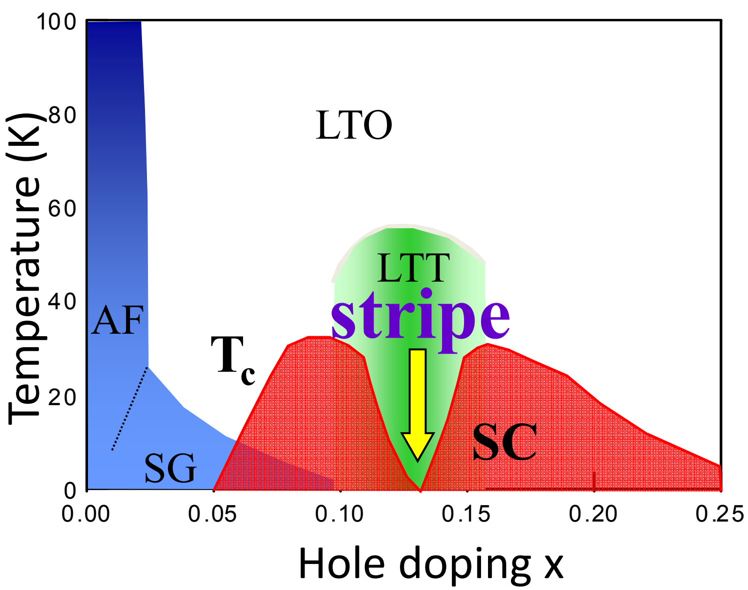
(2) Recovery dynamics

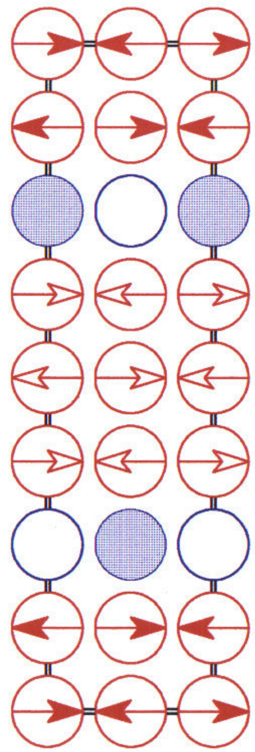
- **Conclusions and Perspectives**

Orderings in High T_c Superconductors and Multiferroic

- **High temperature superconductor**

$La_{2-x}Ba_xCuO_4$



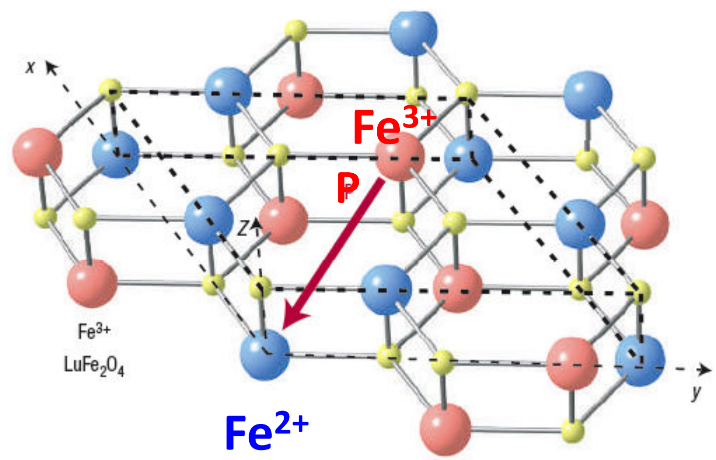


Anomalous suppression of superconductivity at 1/8 doping

J.M. Tranquada *et al.*,
Nature 375, 561 (1995)

- **Multiferroic**

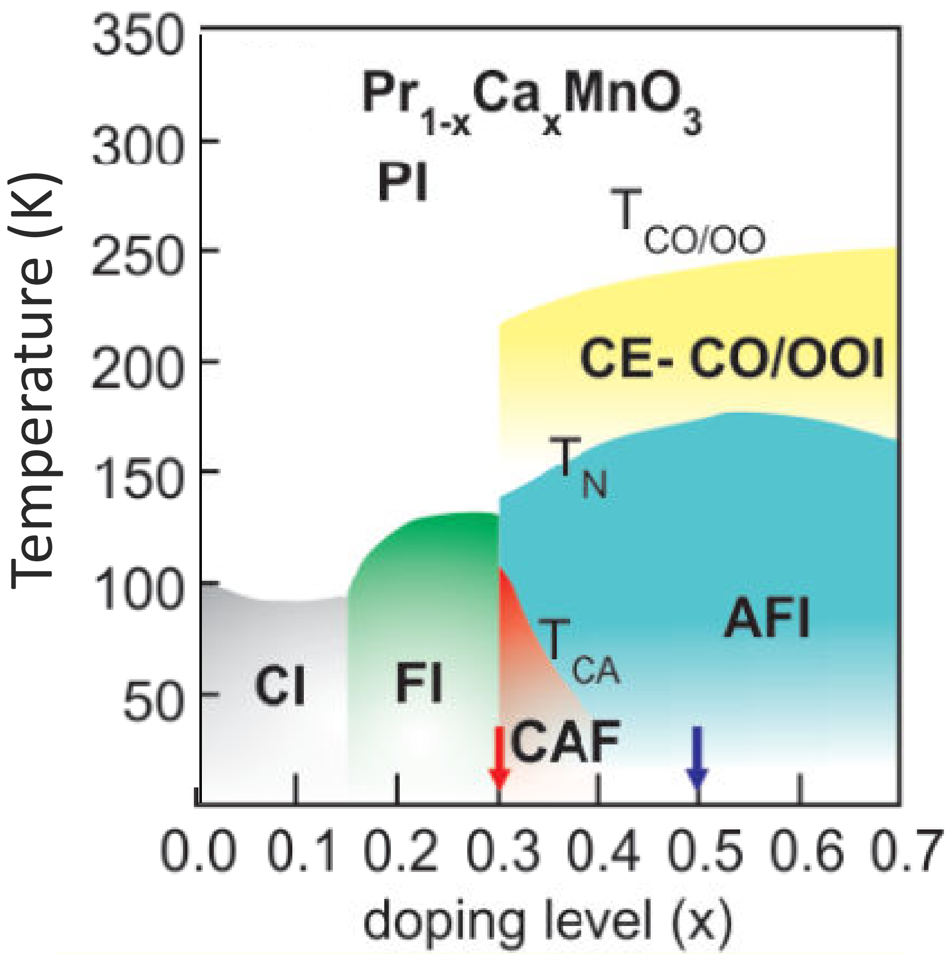
$LuFe_2O_4$ (FE, FM)

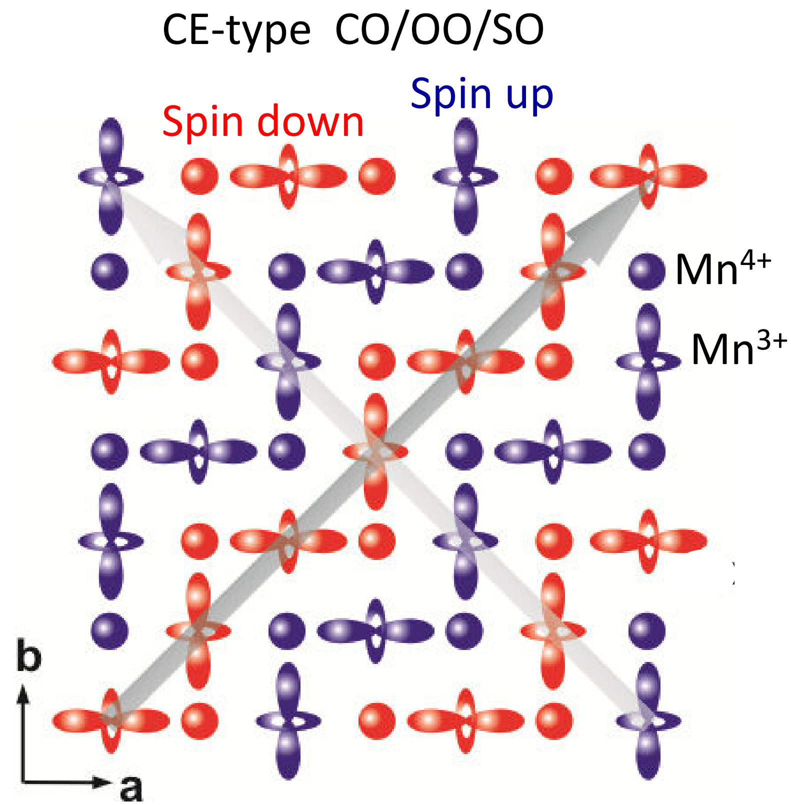


T. Kimura *et al.*, Nature 426, 55 (2003)

Charge/orbital/spin Orderings In Manganites

- Colossal magnetoresistance manganites

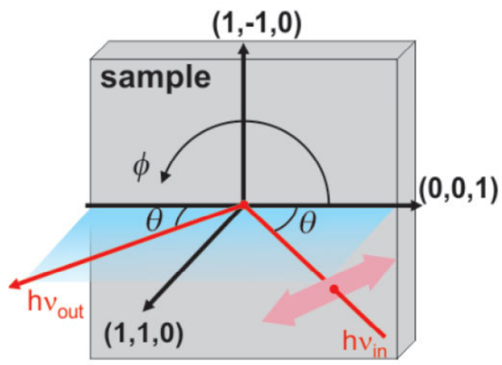




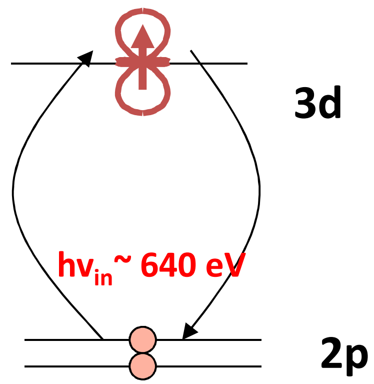
CO/OO/SO – localize electrons
FM – delocalize electrons

"Melting" of ordering: Directly relevant to insulator-metal transition

Resonant Soft X-ray Scattering (RSXS)

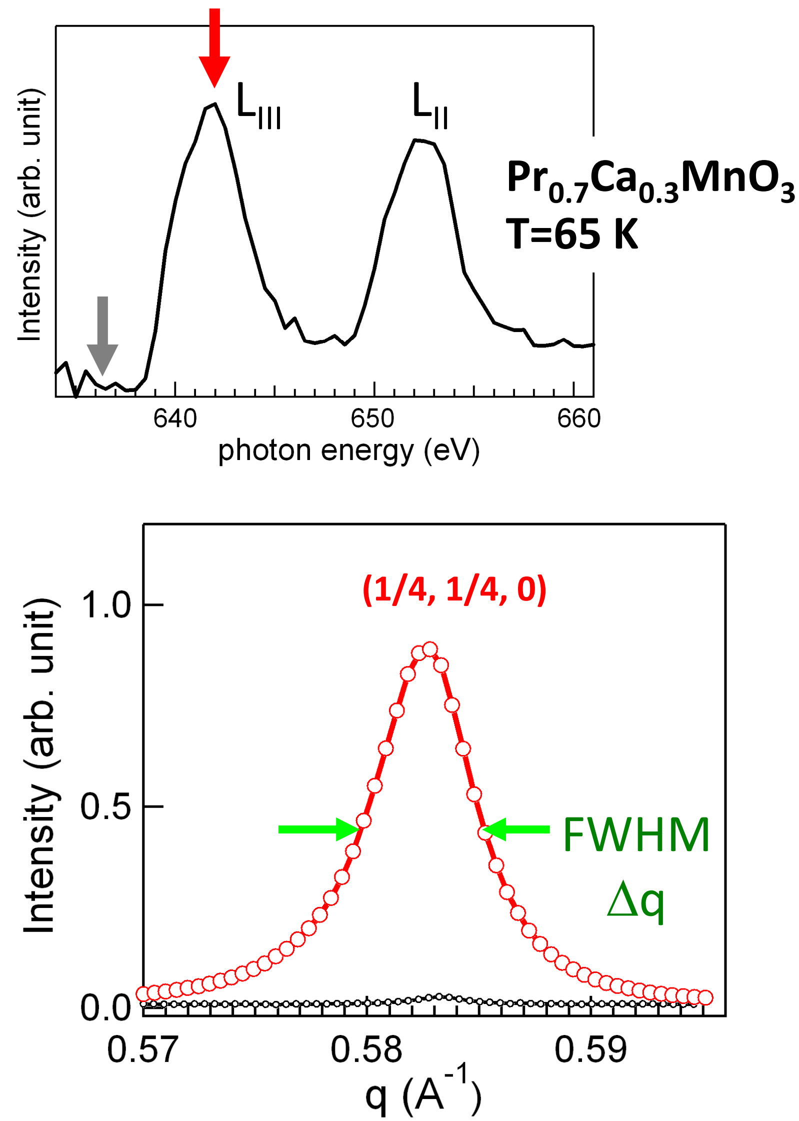


Resonance at the Mn-L edge



- Elemental and orbital specific
- Enhancement of weak **electronic** ordering signal
- Correlation length ξ ~$2\pi/\Delta q$ ~1000 A

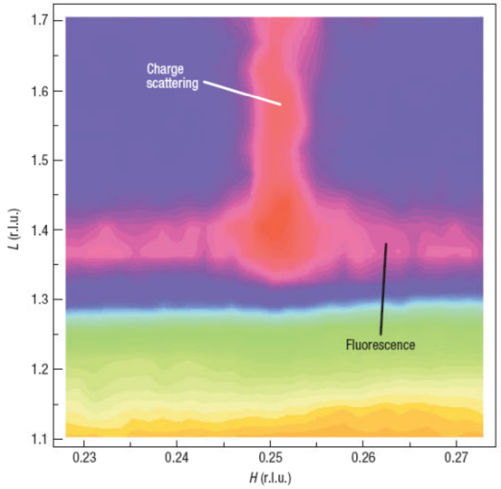
X-ray absorption at Mn-L edge



S.Y. Zhou *et al.*, Phys. Rev. Lett. **106**, 186404 (2011)

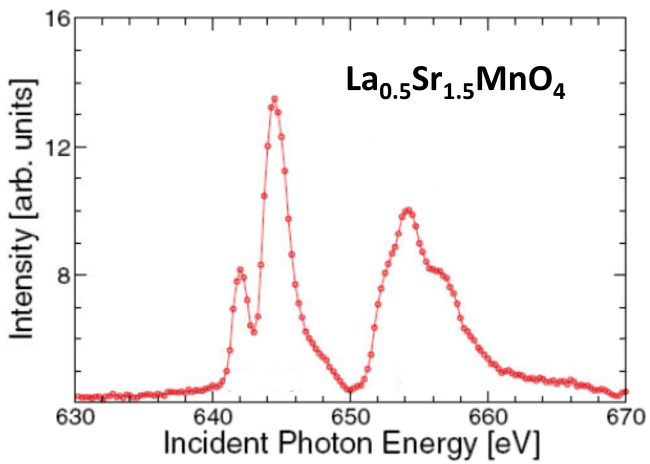
RSXS – A Direct Probe For Electronic Orderings

- O-K edge, stripe phase in $La_{2-x}Ba_xCuO_4$



P. Abbamonte *et al*., Nature Phys. **1**, 155 (2005)

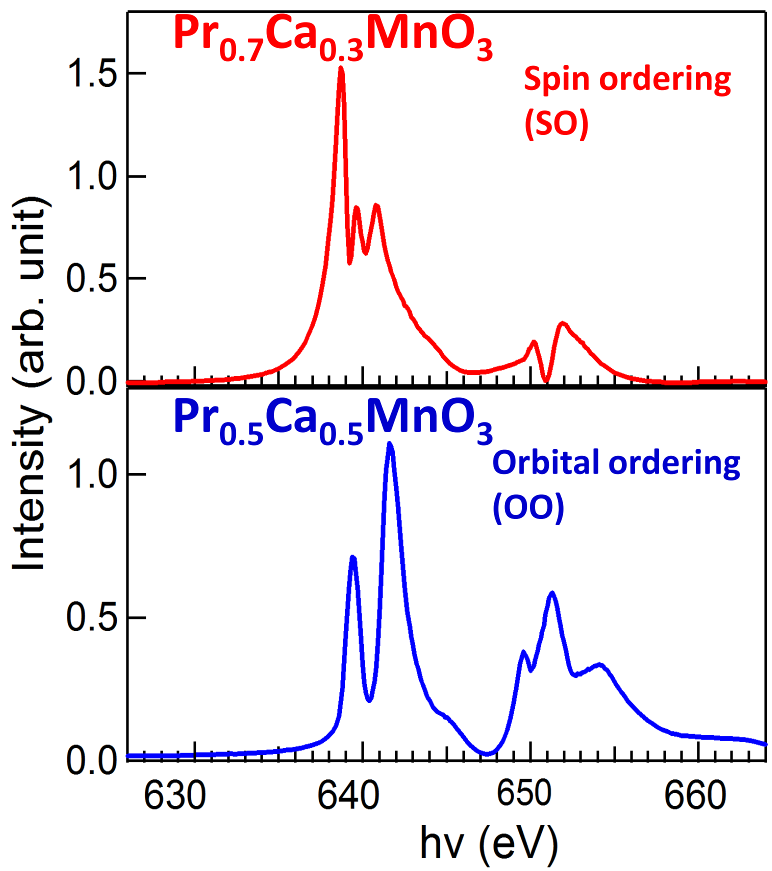
- Mn-L edge, orbital ordering in manganites



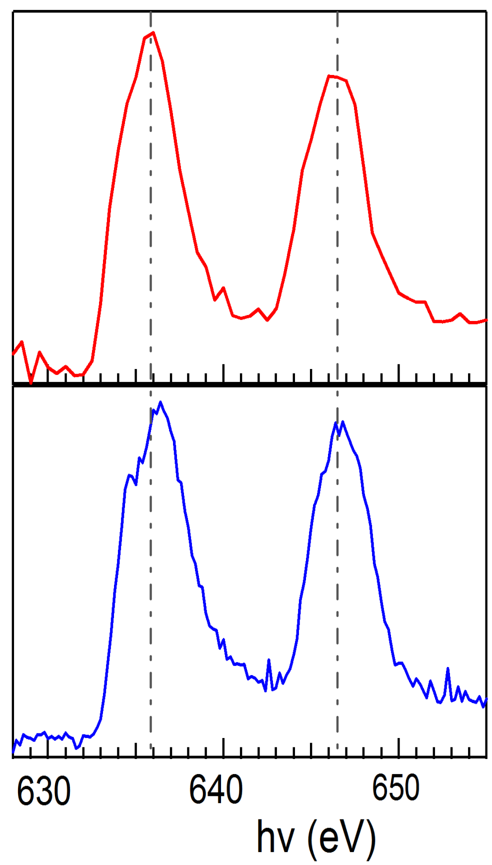
S.B. Wilkins *et al*., PRL **91**, 167205 (2003).

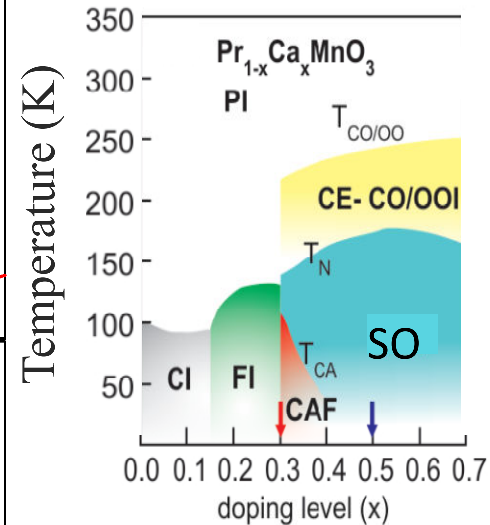
RSXS Studies On PCMO Manganites

RSXS Diffraction peak



X-ray absorption (Mn bonding)





Knowing the equilibrium state is great,

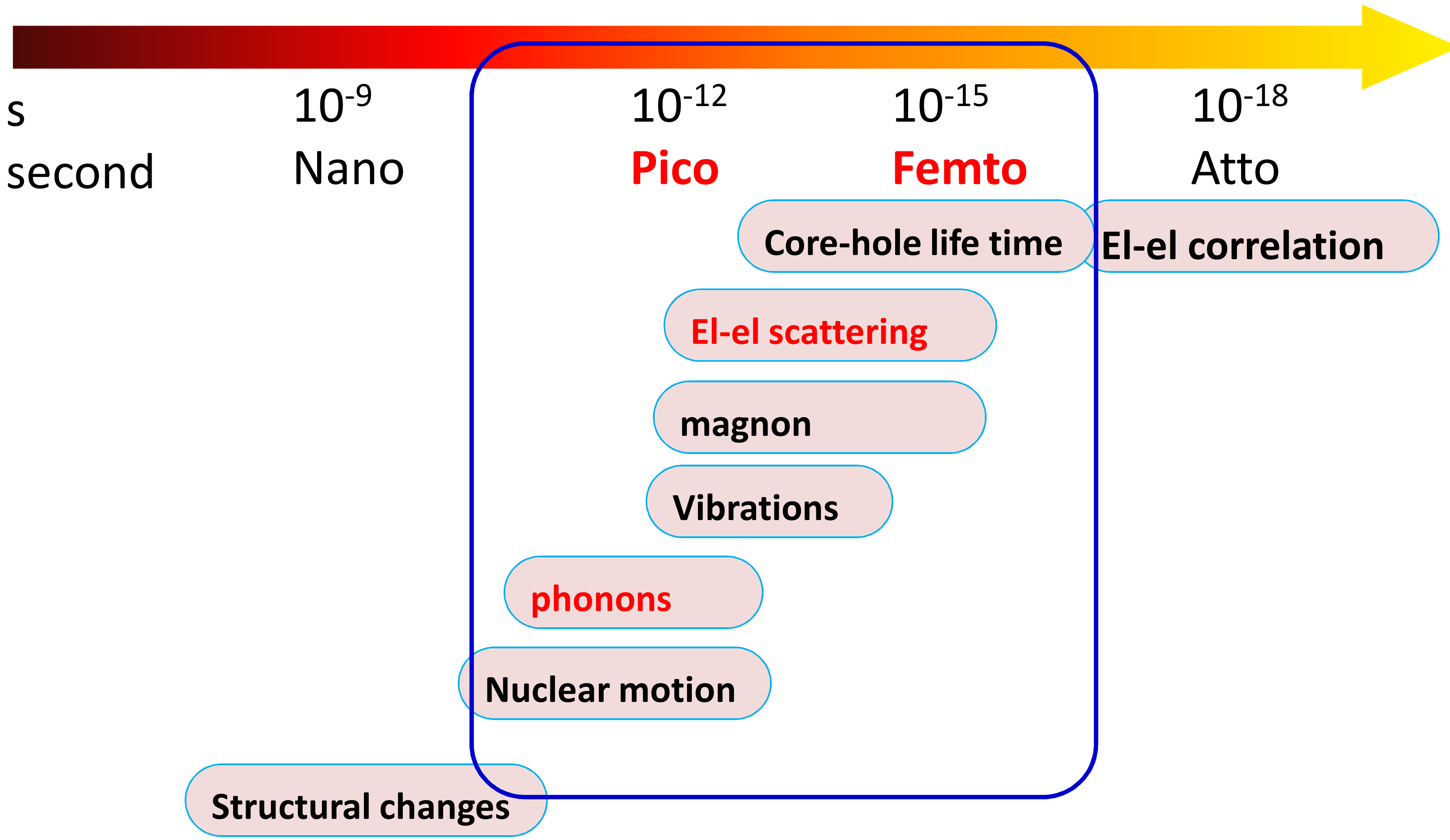
But, is it enough ? ? ?

S.Y. Zhou *et al.*, Phys. Rev. Lett. **106**, 186404 (2011)

Why do we care about ultrafast dynamics?

1 fs = 10^{-15} second

Typical time scales for elementary interactions in solids



Ultrashort light Sources That We Use

1: Synchrotron (e.g. ALS)

- **Tunable wavelength/photon energy (X-ray and EUV)**
- **high photon flux (10^{12} photons/s)**
- **pulse width 70 ps**
- **multiple experiments run simultaneously**

Ultrashort light Sources That We Use

2: Free electron laser (e.g. LCLS)

- **Coherent light source (X-Ray)**
- **Tunable wavelength/photon energy**
- **Ultrabright (10^{10} photons/pulse)**
- **Ultrashort (~ 60 fs)**

Ultrafast Dynamics of Localized Electronic Ordering

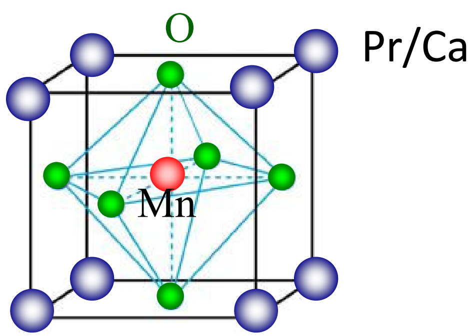
- Why Localized electronic orderings?
- How to detect?
- Example: Dynamics of antiferromagnetic spin ordering in $Pr_{0.7}Ca_{0.3}MnO_3$ manganite

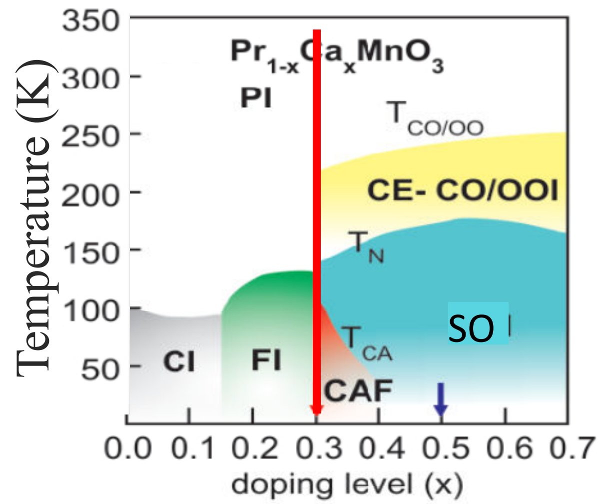
(1) Melting dynamics

(2) Recovery dynamics

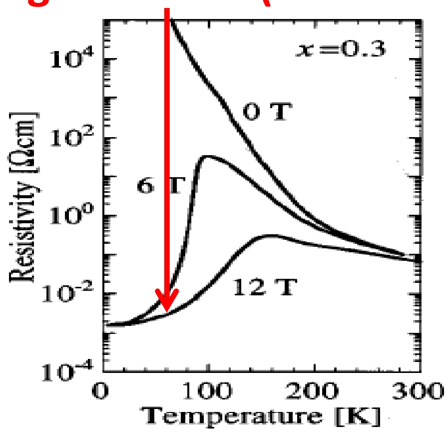
Dynamics Of CO/OO/SO And Their Roles In IMT

Time-resolved Resonant Soft X-ray Scattering (TR-RSXS)



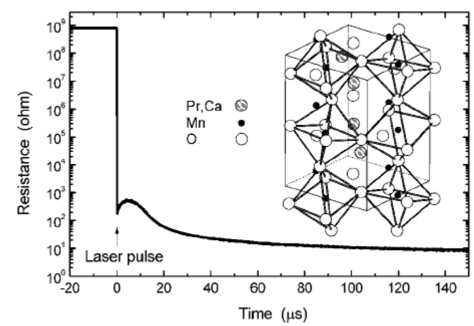


- **Magnetic field (CMR effect)**



Y. Tomioka *et al.*, PRB 1996

- **Laser (800nm, 1.5eV)**

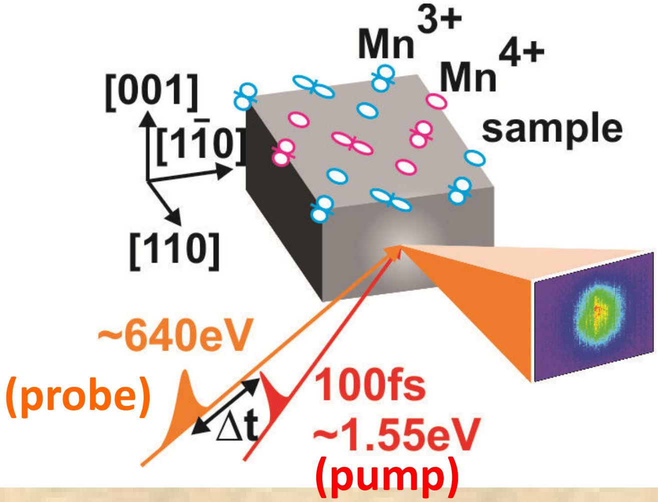


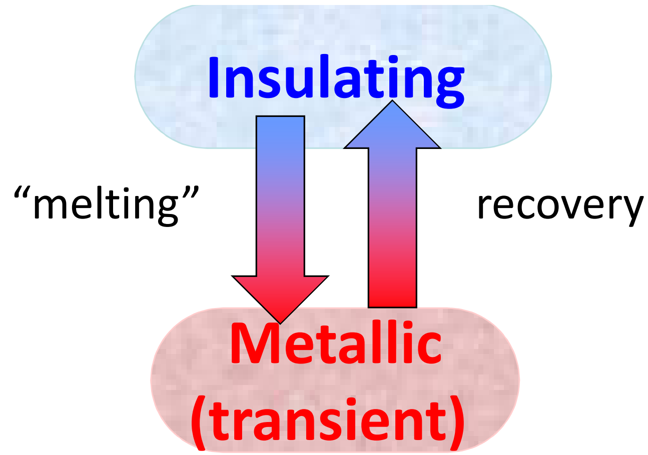
M. Fiebig *et al*, Science **280**, 1925 (1998)

Dynamics of orderings across the IMT?
What role they play in the IMT?

Dynamics Of CO/OO/SO And Their Roles In IMT

Time-resolved Resonant Soft X-ray Scattering (TR-RSXS)





1. How is the spin ordering "melted" upon laser excitation?

SXR beamline @LCLS

X-ray pulse duration: 60 fs
Dynamic range: 60 fs to 80 ps

2. How is the ordering recovered after laser excitation?

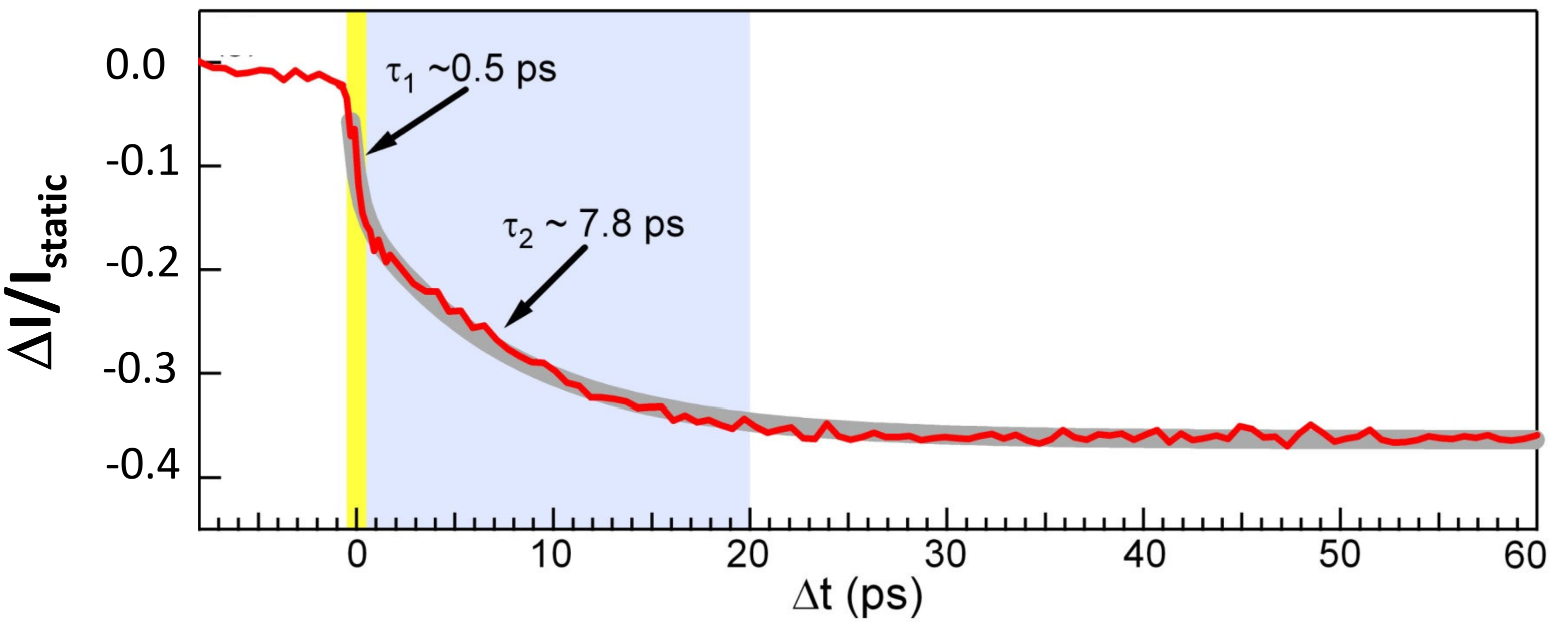
Ultrafast x-ray beamline 6.0.2 @ALS

X-ray pulse: 70 ps
Dynamic range: 70 ps to 10s

3. Role in the photo-induced insulator-metal transition?

"Melting" Dynamics From LCLS Experiment

$Pr_{0.7}Ca_{0.3}MnO_3$ T=65 K   Laser pump fluence: 1 mJ/cm^2

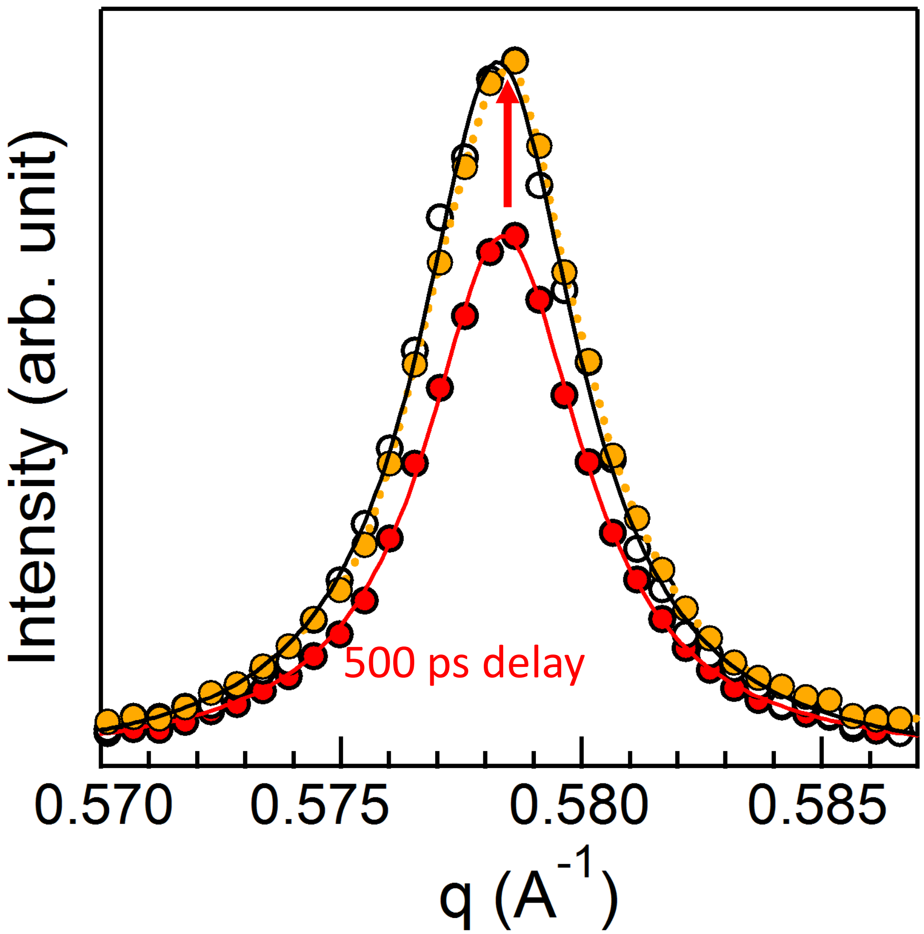


Disentangling two processes in the melting dynamics

- **< 1 ps   (electronic)**
- **~ 10 ps (lattice)**

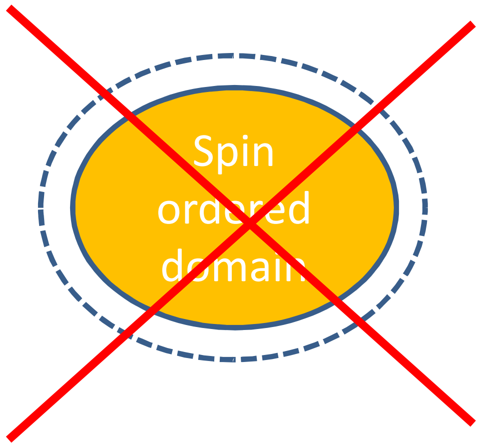
Melting of SO without change in correlation length

$Pr_{0.7}Ca_{0.3}MnO_3$ T=65 K   Pump fluence 1 mJ/cm^2



Negligible change in correlation length !

Different from thermodynamic transition



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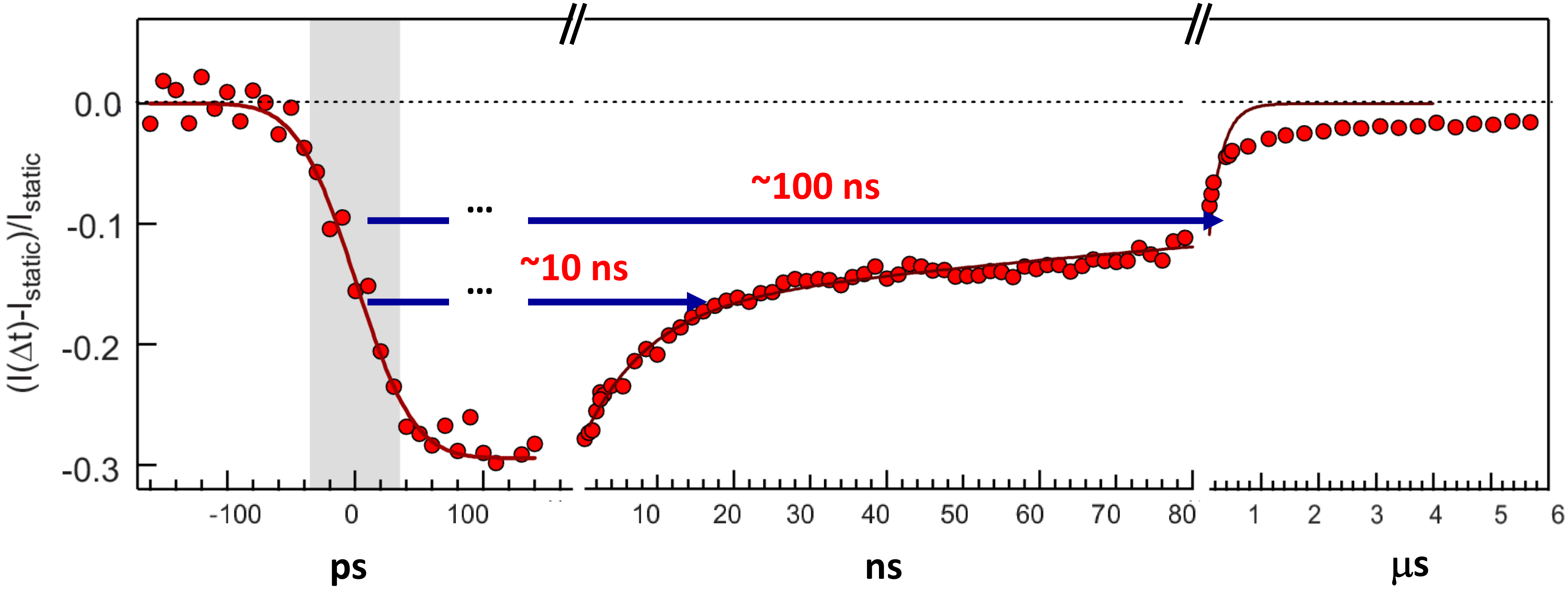
(1) Melting dynamics

(2) Recovery dynamics

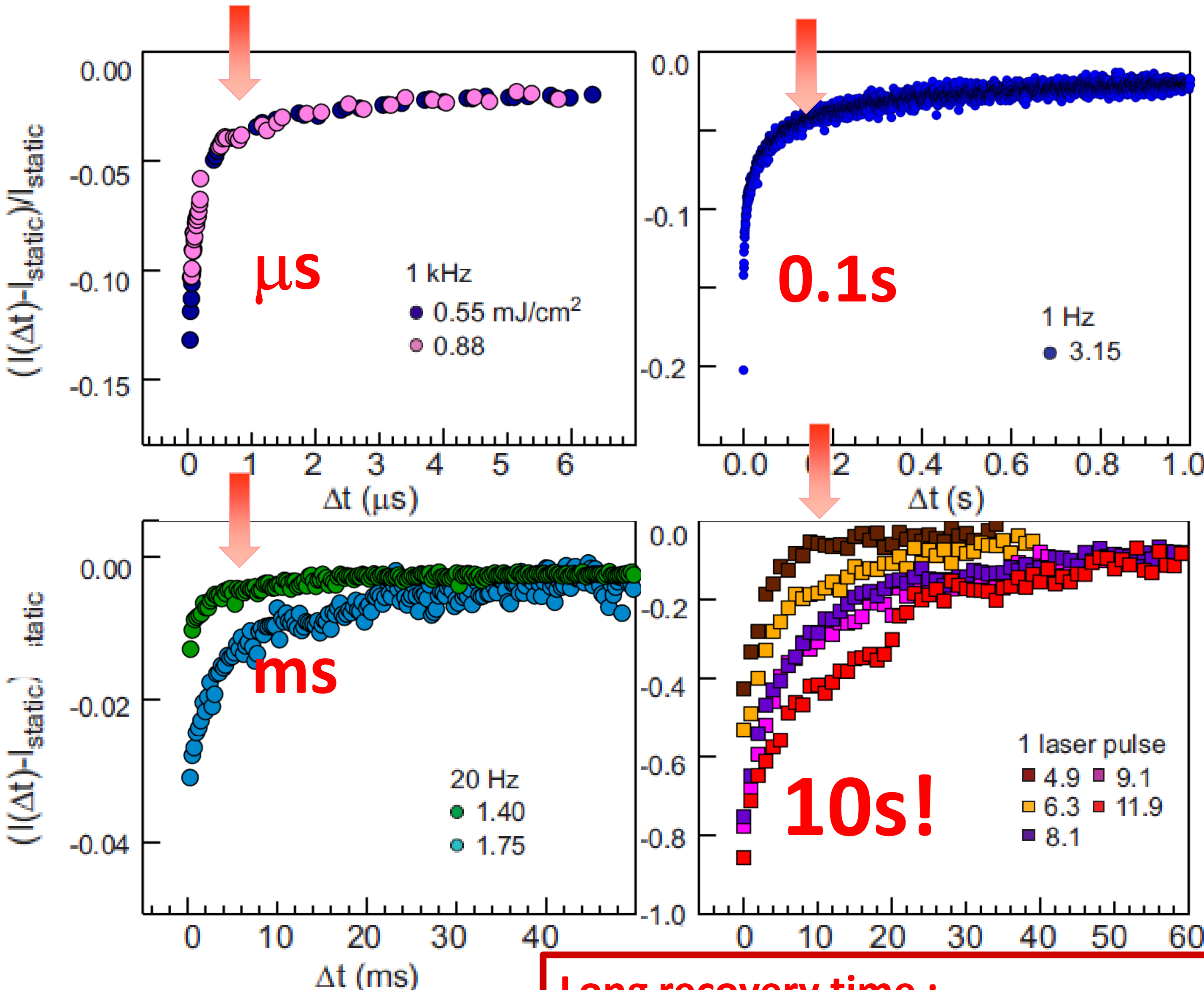
Multiple Time Scales In The Recovery Process

$Pr_{0.7}Ca_{0.3}MnO_3$ T=65 K   Pump fluence 1 mJ/cm^2



- **Multiple time scales in the recovery process**
  10 ns, 100 ns, μs …

Recovery Time Strongly Depends On Pump Fluence



Long recovery time :

Not electronic/lattice driven mechanism!

Glassy Dynamics And Stretched Exponential Function

Recovery time of spin ordering in $Pr_{0.3}Ca_{0.7}MnO_3$:

- **Multiple time scales**
- **Extremely long and increases with pump fluence (up to 10S!)**

In Glass-like (disordered, granular etc.) systems:

Structure glass, polymers, proteins *etc.*

(multiple energy time scales), a distribution of recovery time

$$y(t) = e^{-(t/\tau)^{\beta}}$$

Kohlrausch-Williams-Watts (KWW) function

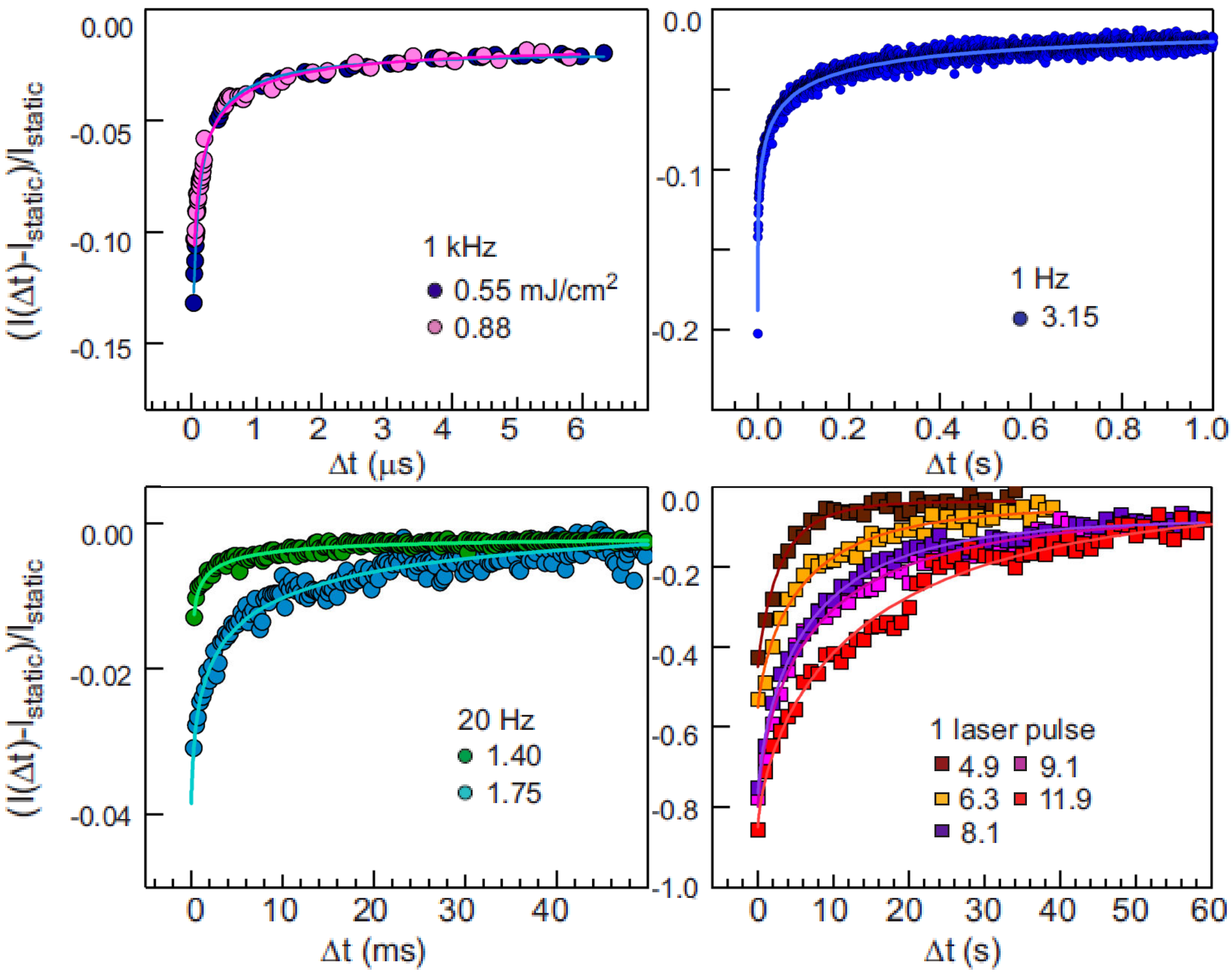
$$\beta = d/(d+2)$$

d: dimensionality of the interaction

J.C. Phillips
Rep. Prog. Phys. 59, 1133 (1996)

Stretched-Exponential Function Fit

$$y = a_0 e^{-(t/\tau)^\beta}$$ (fitting parameters: a_0, τ, β)

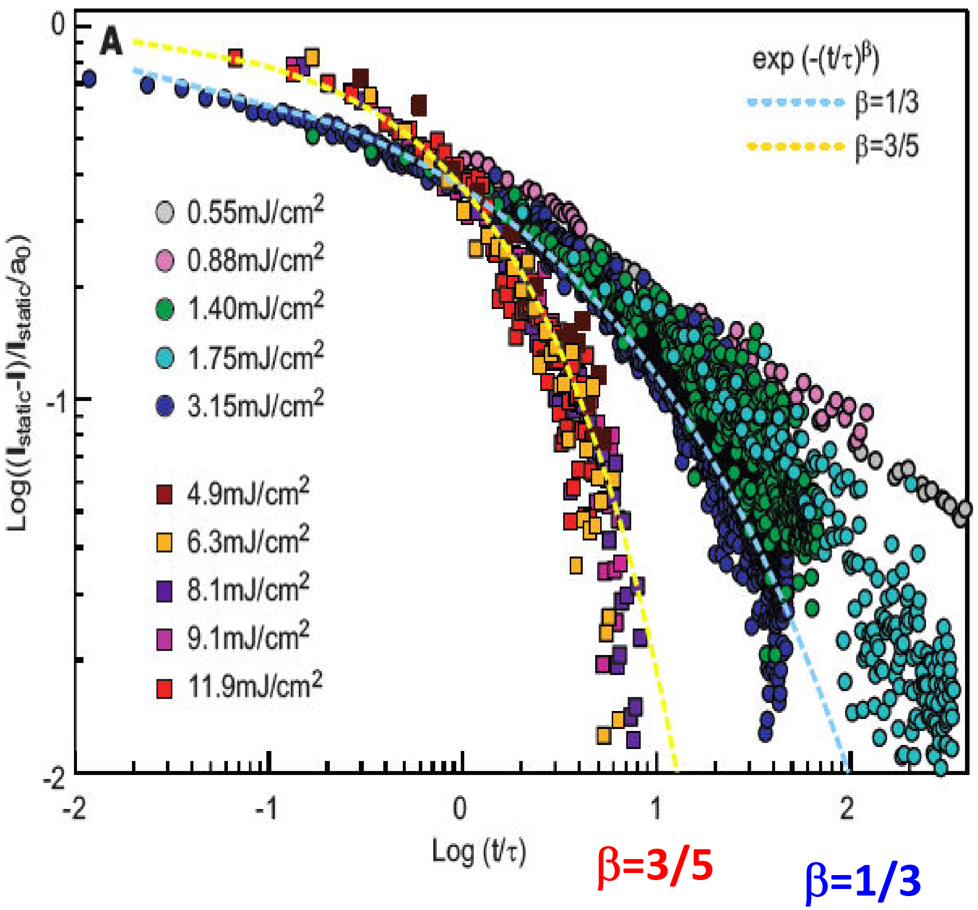


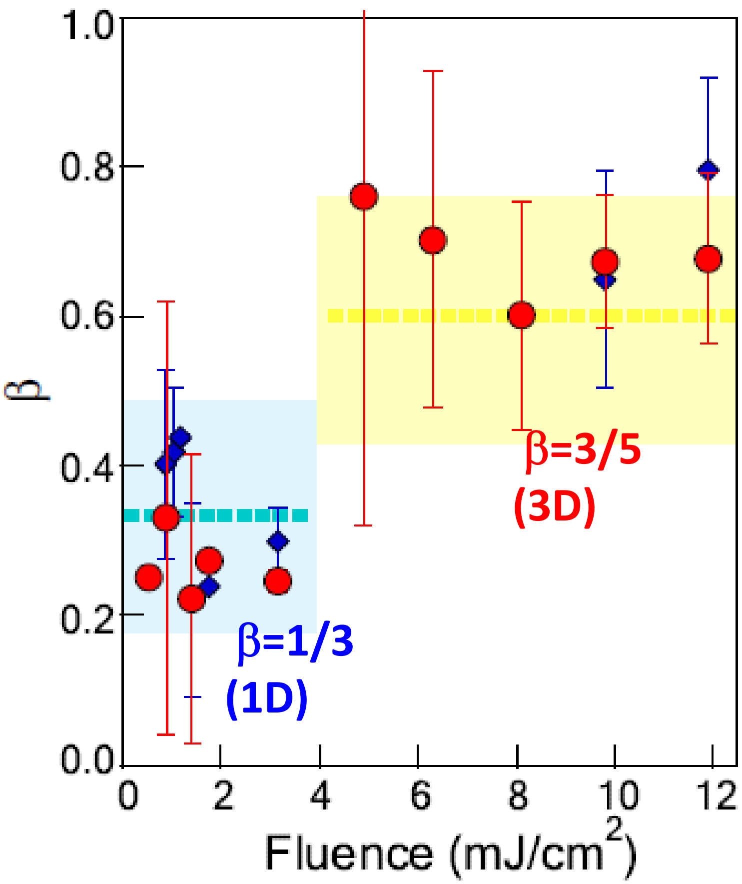
Recovery of spin ordering shares similarity to glass-like systems

Dimensional Cross-over In The Effective Interaction

$$y/a_0 = e^{(-t/t)^{\beta}}$$

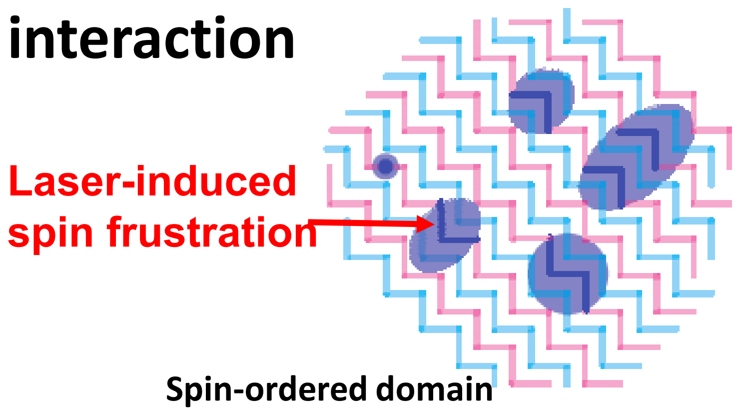
$$\beta = d/(d+2)$$

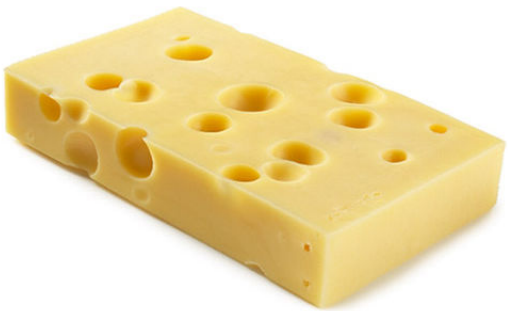




Dynamics Of Spin Ordering In $Pr_{0.7}Ca_{0.3}MnO_3$

- **"Melting" Dynamics (LCLS)**
  - ➢ negligible change in correlation length
  - ➢ two time scales
- **Recovery dynamics (ALS)**
  - ➢ Glass-like recovery dynamics
  - ➢ Dimensional crossover (1D to 3D) in the effective interaction





S.Y. Zhou *et al.,* arXiv: 1209.3452

Acknowledgement

TR-RSXS collaborators:

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ALS ultrafast x-ray (BL6)

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Joshua Turner

William Schlotter

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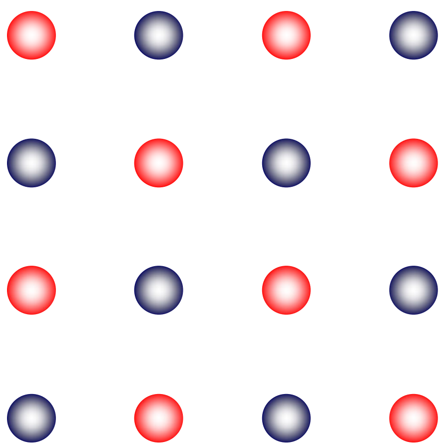
- **Perspectives on Time-resolved ARPES**

Important Variables for Quantum States in Solids

- **Real space structure/periodicity R**

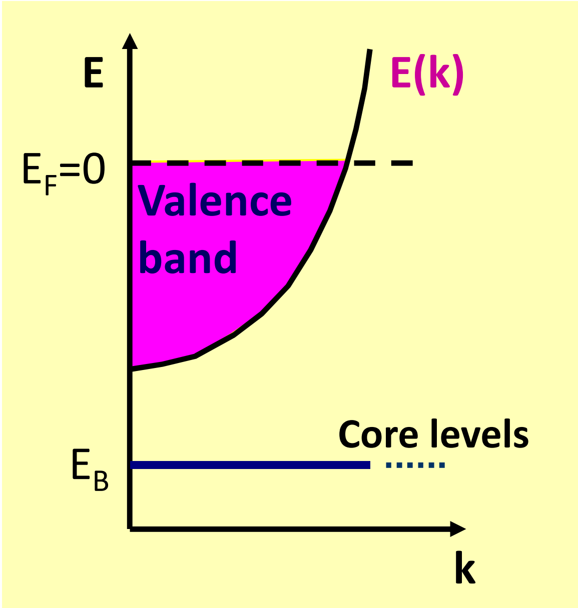
charge/orbital/spin/lattice



Resonant soft X-ray scattering (RXS)

- Localized electronic ordering

- **Energy E**
- **Momentum k**



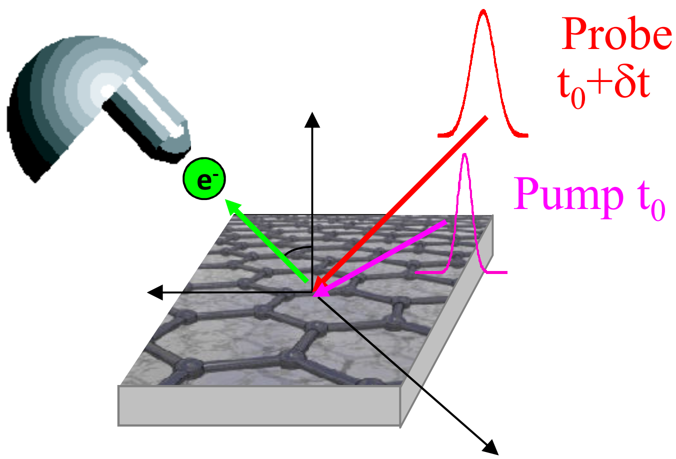
Angle-Resolved Photoemission Spectroscopy (ARPES) – delocalized electrons

S.Y. Zhou *et al.*, Nature Mater. **6**, 770 (2007)
S.Y. Zhou *et al.*, Nature Mater. **7**, 259 (2008)
S.Y. Zhou *et al.*, Nature Phys. **2**, 595 (2006)
S.Y. Zhou *et al.*, Phys. Rev. Lett. **101**, 086402 (2008)

Time- And Angle-Resolved Photoemission Spectroscopy

Time-resolved ARPES system being built at Tsinghua Univeristy

- Laser-based ARPES, ~ 50 fs pulse
- Focus on Dynamic studies (Energy, momentum, time information)



- 6 eV
- HHG (e.g. 43 eV)

- quasiparticle dynamics
- role of collective excitations

…

Lab Under Construction …

Thank you!