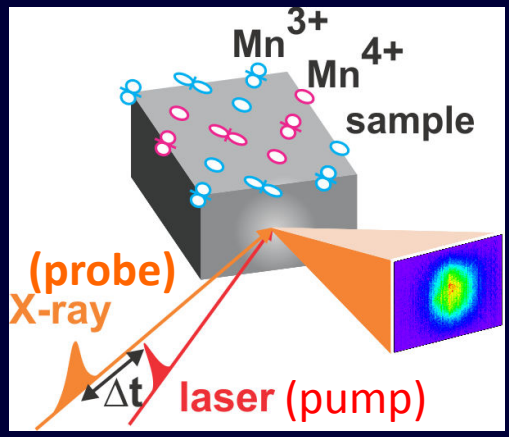
Glass-like dynamics and dimensional crossover in the antiferromagnetic spin-ordered state in a photo-excited $Pr_{0.7}Ca_{0.3}MnO_3$ manganite

清华大学物理系

周树云

Tsinghua IASTU seminar 2012/11/07



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

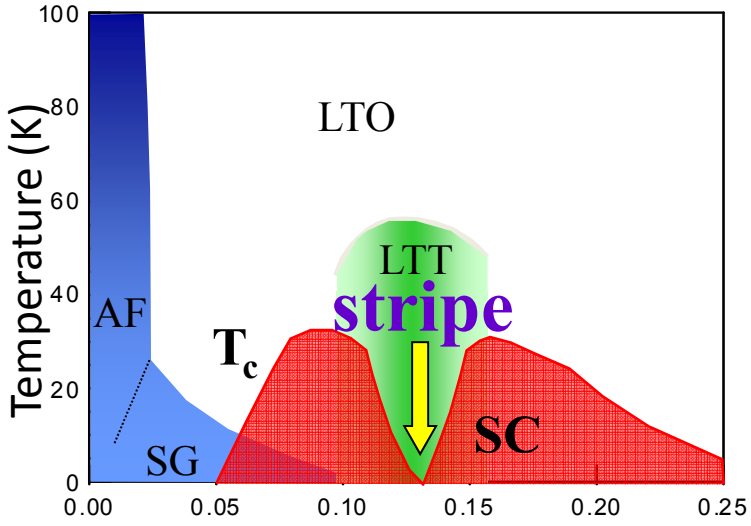
(2) Recovery dynamics

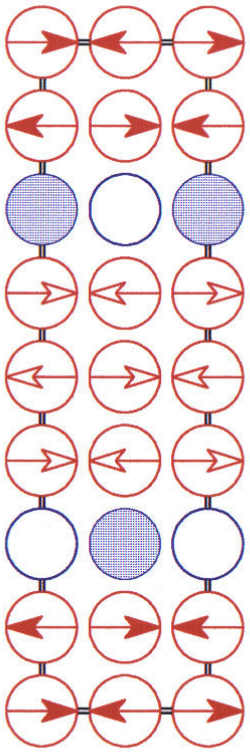
- **Conclusions and Perspectives**

Orderings in High T_c Superconductors and Multiferroic

- **High temperature superconductor**

$La_{2-x}Ba_xCuO_4$



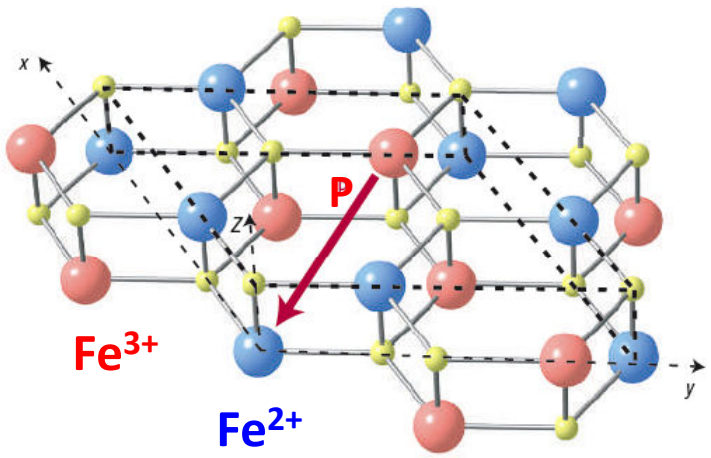


Anomalous suppression of superconductivity at 1/8 doping

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

- **Multiferroic**

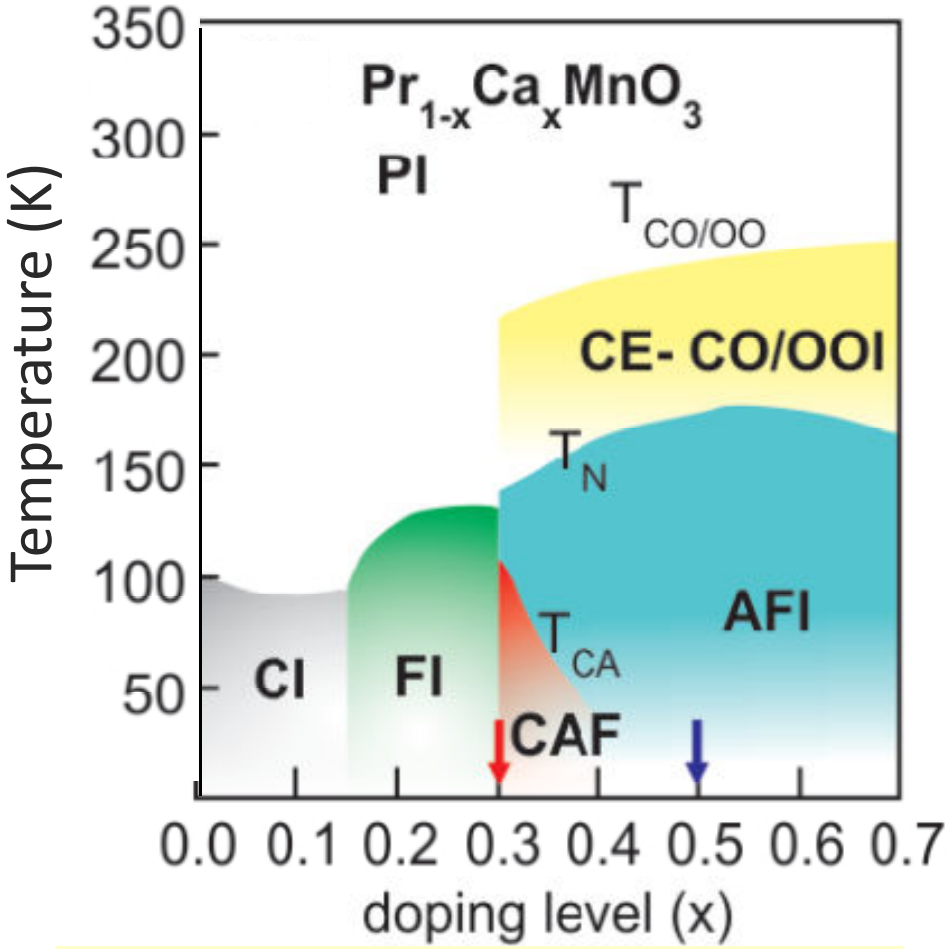
$LuFe_2O_4$ (FE, FM)

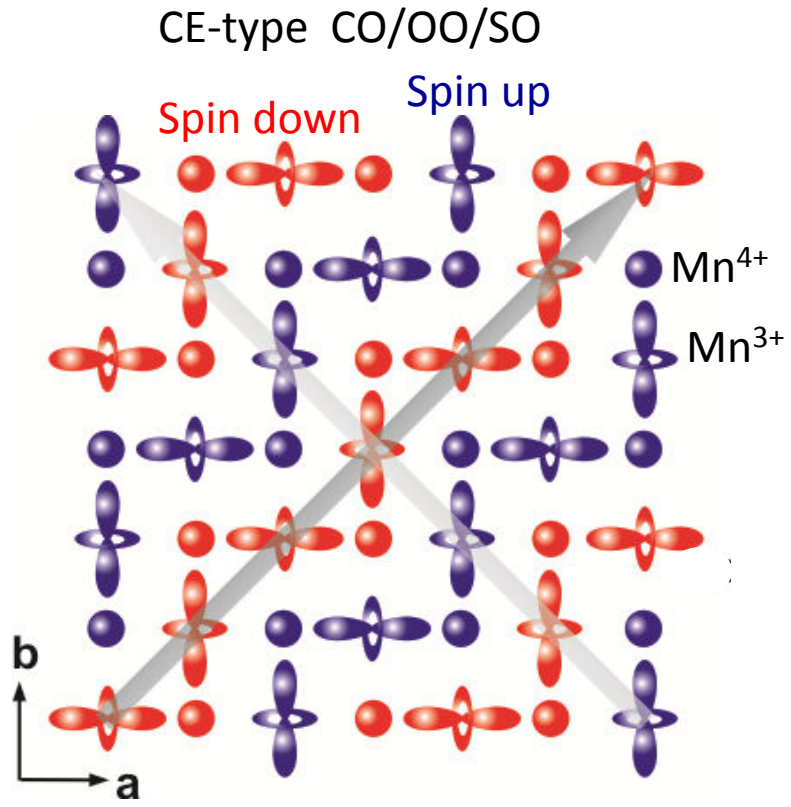


T. Kimura *et al.*, Nature 426, 55 (2003)

Charge/orbital/spin Orderings In Manganites

- **Colossal magnetoresistance manganites**

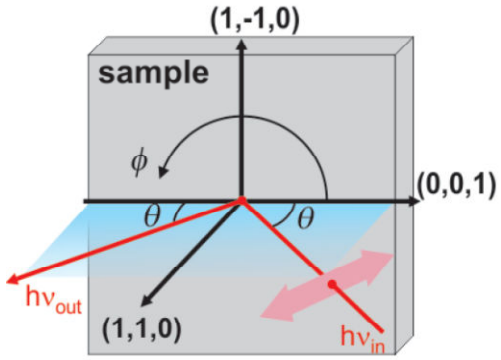




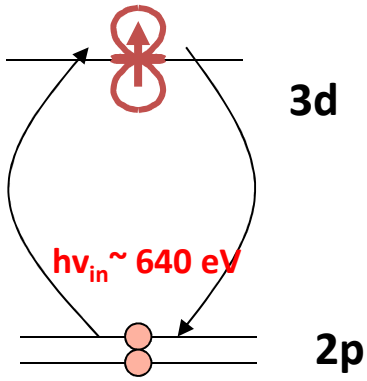
CO/OO/SO – localize electrons
FM – delocalize electrons

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

Resonant Soft X-ray Scattering (RSXS)

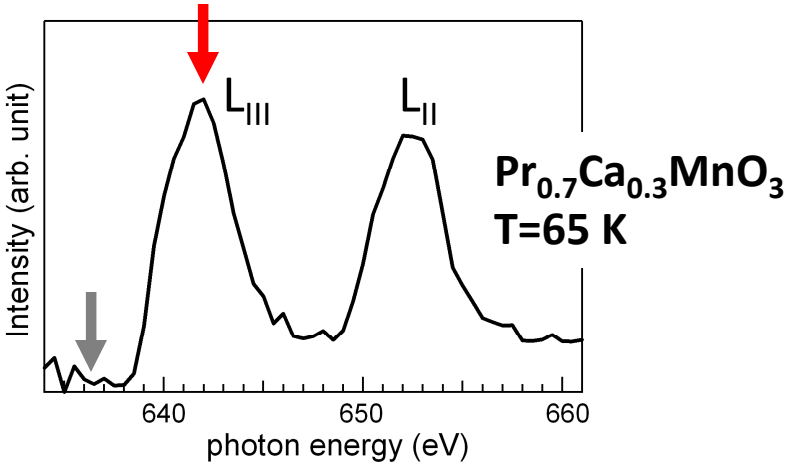


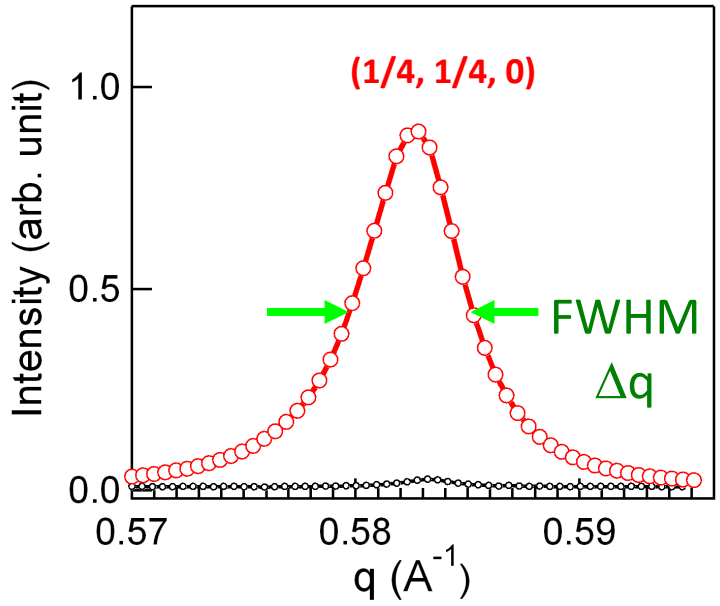
Resonance at the Mn-L edge



- 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

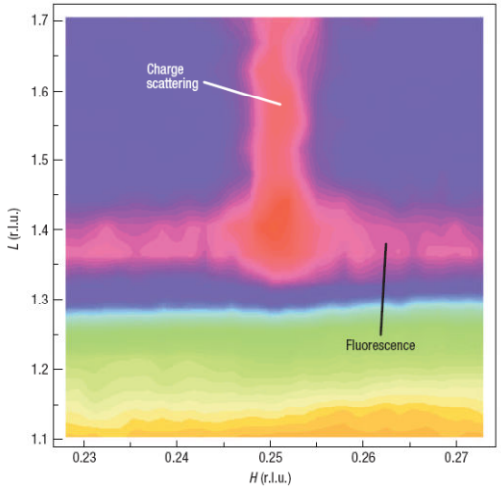




S.Y. Zhou *et al.*, Phys. Rev. Lett. **106**, 186404 (2011)

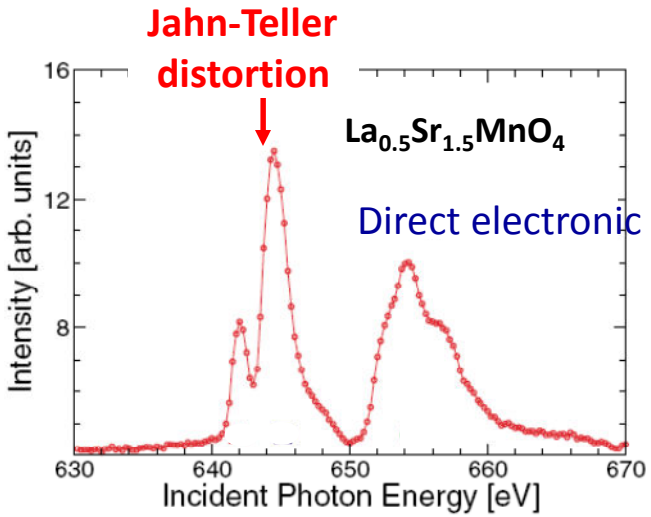
RSXS – A Direct Probe For Electronic Orderings

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



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

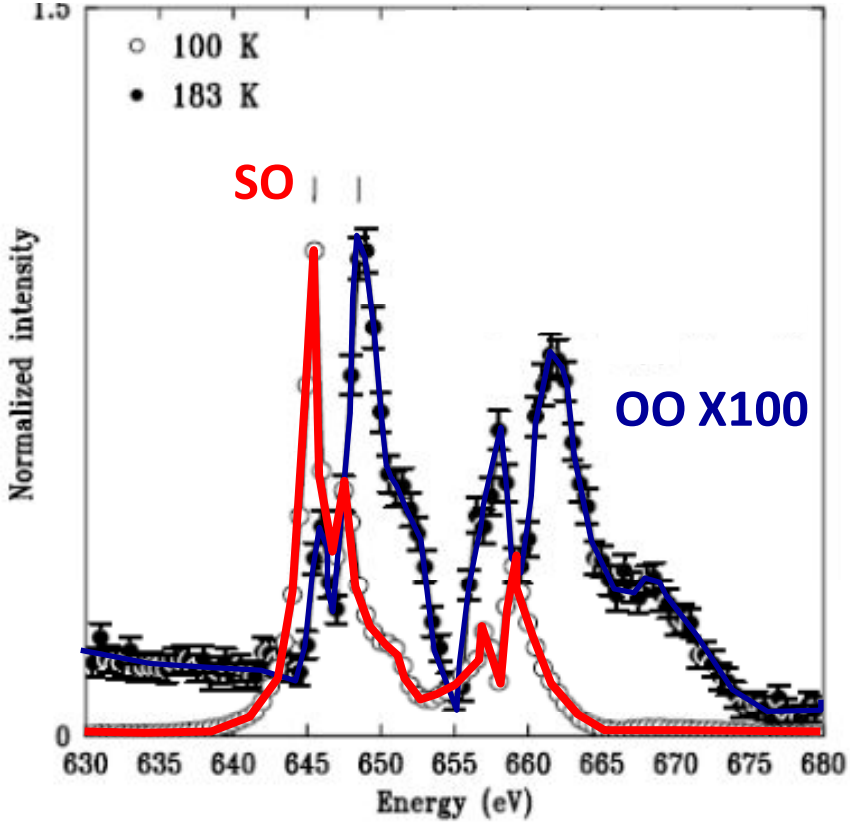
- Mn-L edge, Jahn-Teller effect and direct OO contribution



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

Resonant Soft X-ray Scattering In 40% Doped PCMO

$Pr_{0.6}Ca_{0.4}MnO_3$

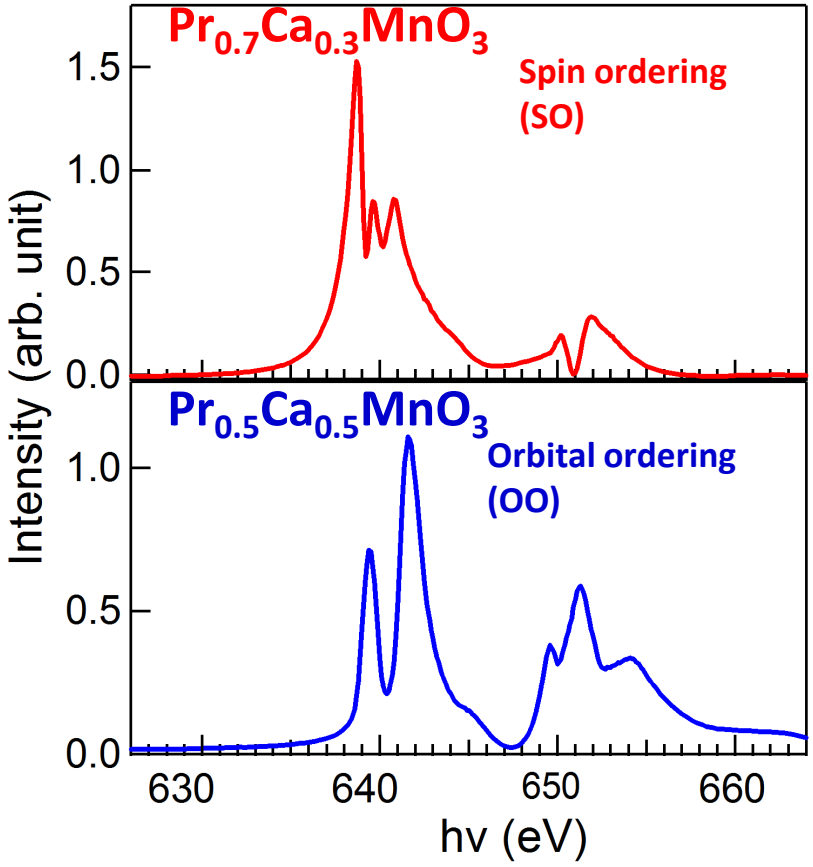


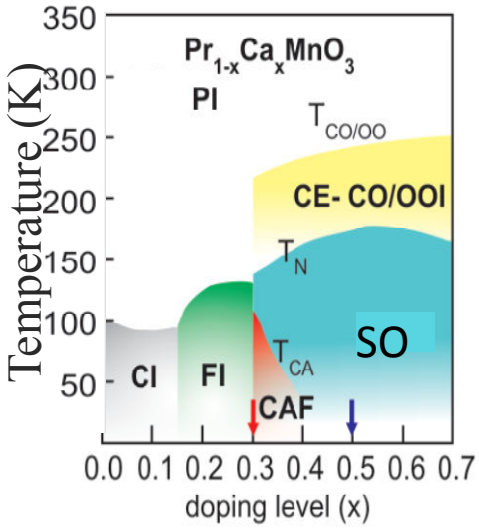
Different energy profiles for OO and SO

K.J. Thomas *et al.*, PRL **92**, 237204 (2004)

RSXS Studies On PCMO Manganites

RXS energy profiles (orderings)





Knowing the equilibrium state is great,

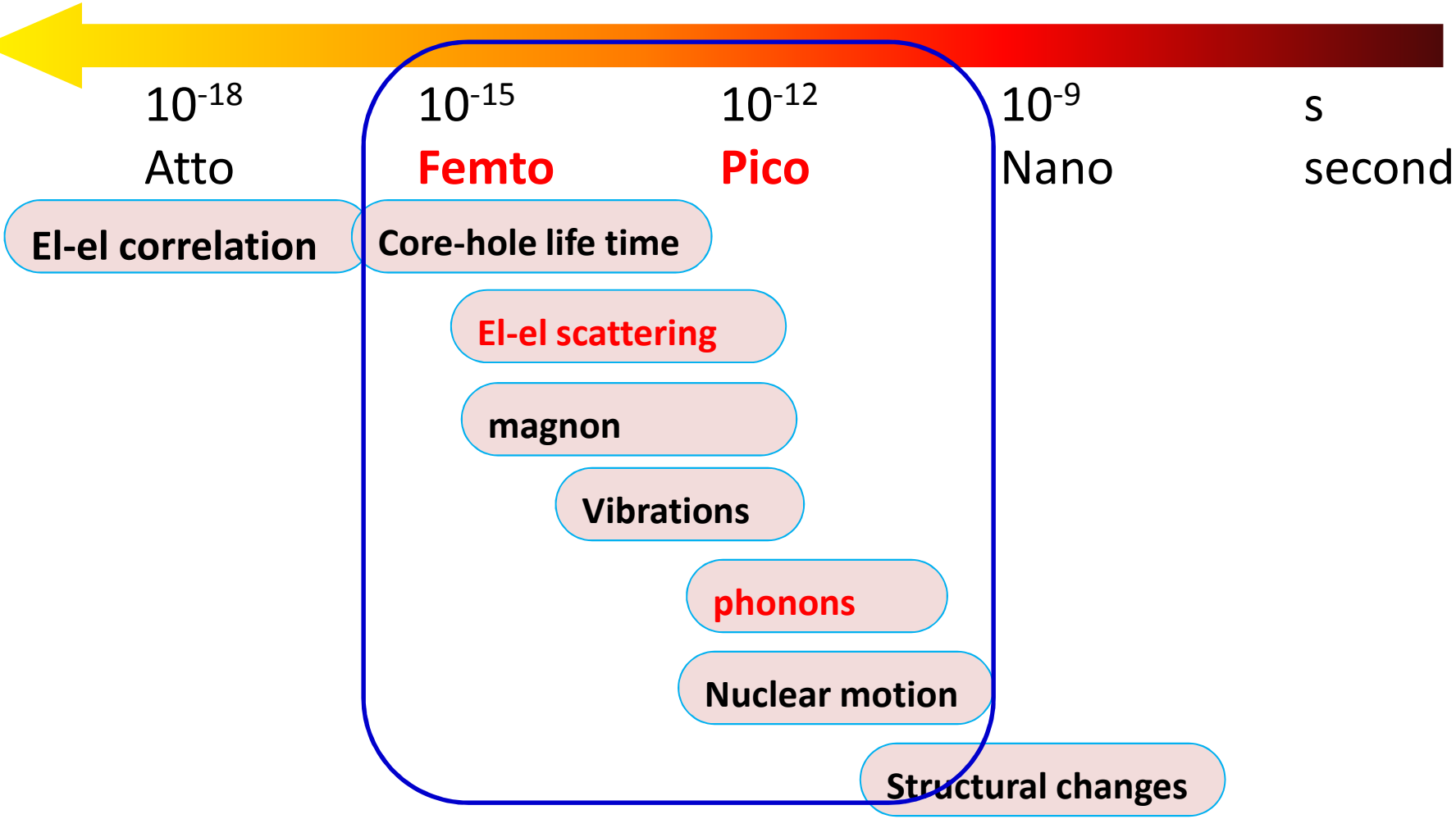
But, is it enough ? ? ?

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



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

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)
- Currently only one experiment at a time, high operating cost

Ultrafast Dynamics of Localized Electronic Ordering

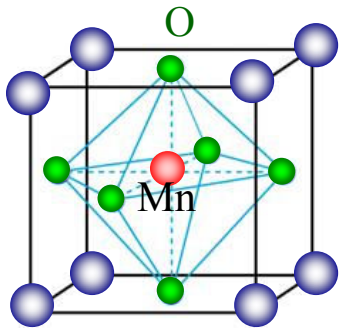
- **Why Localized electronic orderings?**
- **How to detect?**
- **Example: Dynamics of antiferromagnetic spin ordering in $Pr_{0.7}Ca_{0.3}MnO_3$ manganite**

(1) Melting dynamics

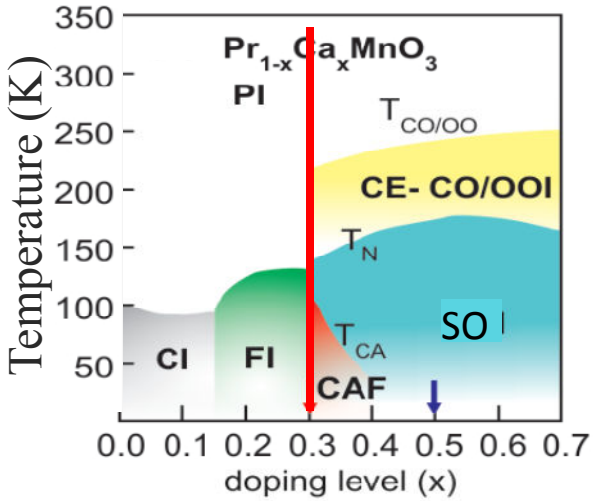
(2) Recovery dynamics

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

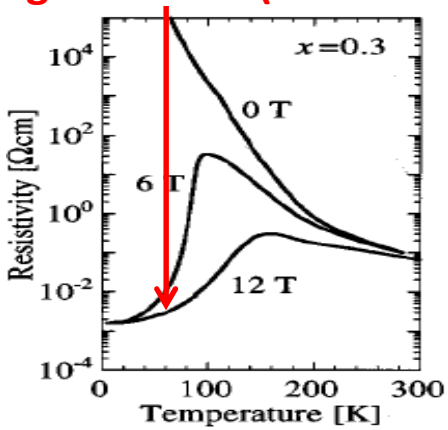
Time-resolved Resonant Soft X-ray Scattering (TR-RSXS)



Pr/Ca

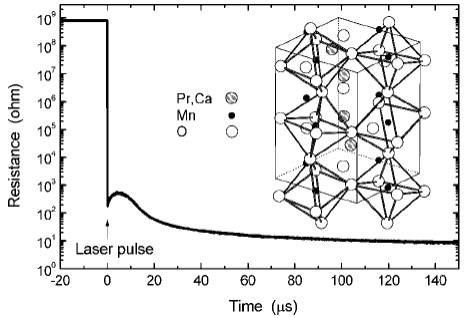


- **Magnetic field (CMR effect)**



Y. Tomioka *et al*., PRB 1996

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

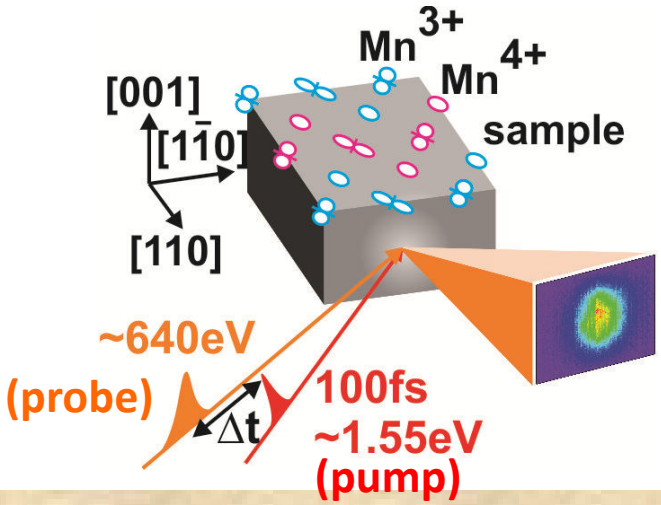


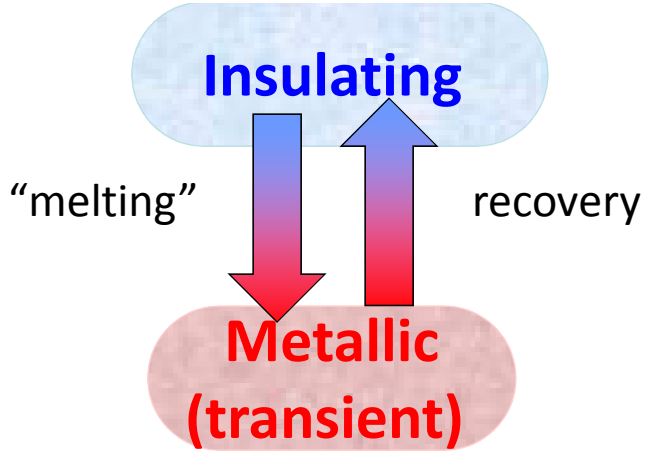
M. Fiebig *et al*, Science **280**, 1925 (1998)

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?

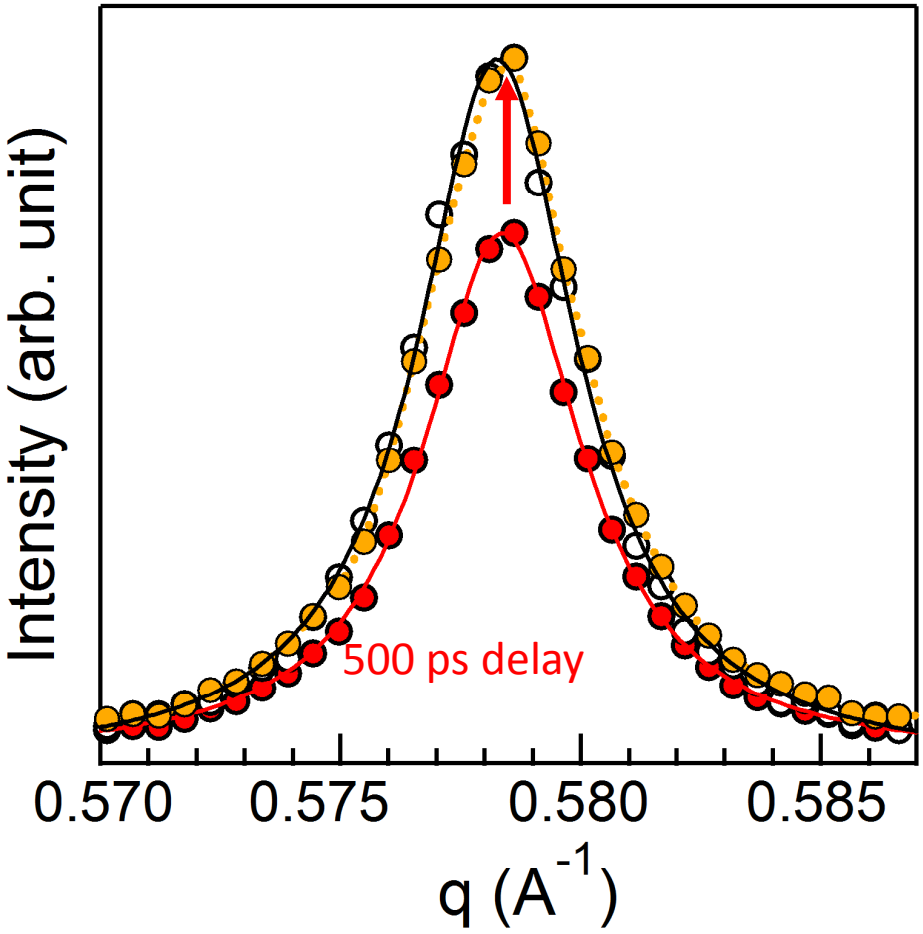
Ultrafast x-ray beamline 6.0.2 @ALS

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

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

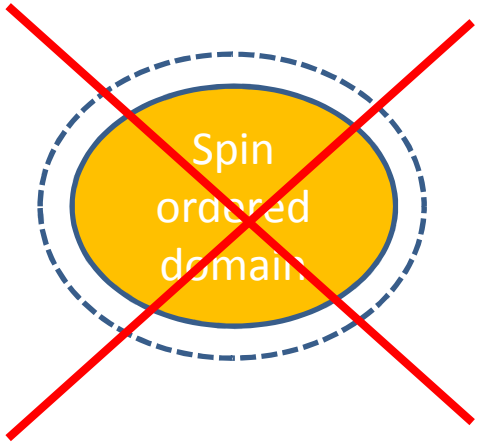
Melting of SO without change in correlation length

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



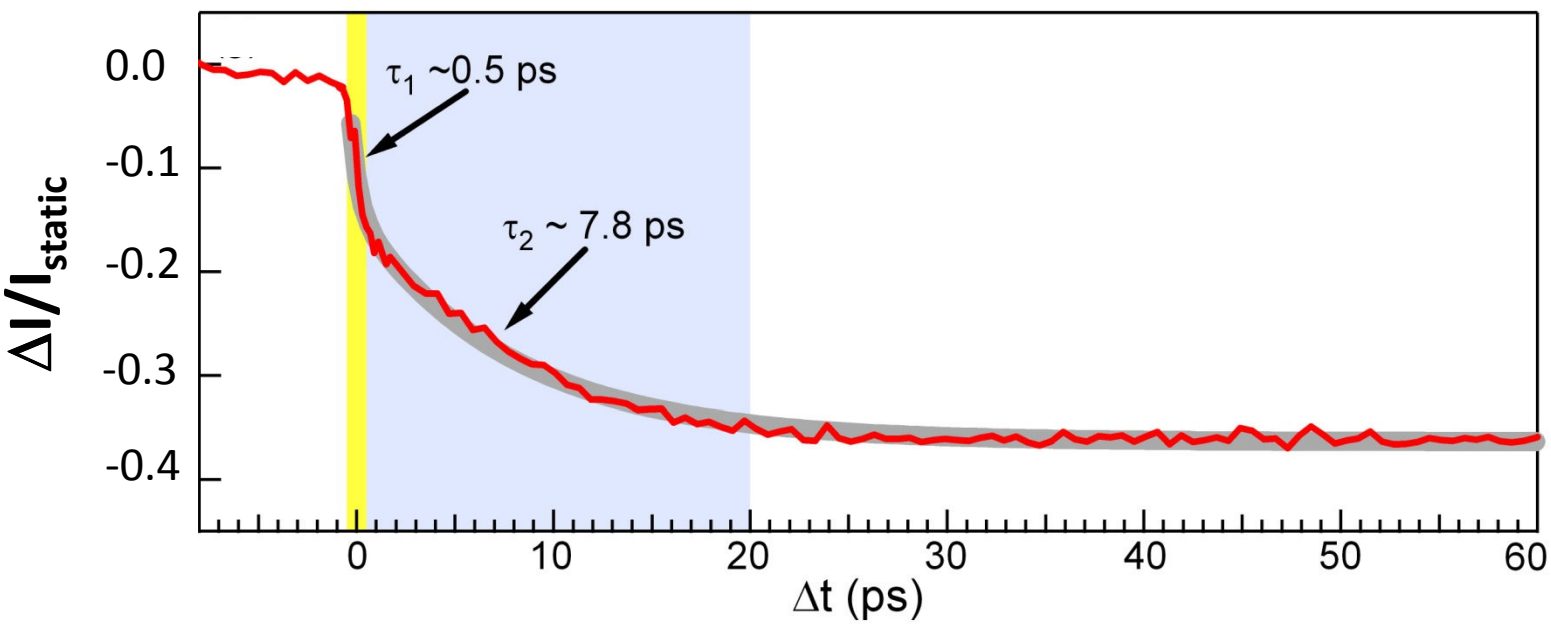
Negligible change in correlation length !

Different from thermodynamic transition



"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)**

Ultrafast Dynamics of Localized Electronic Ordering

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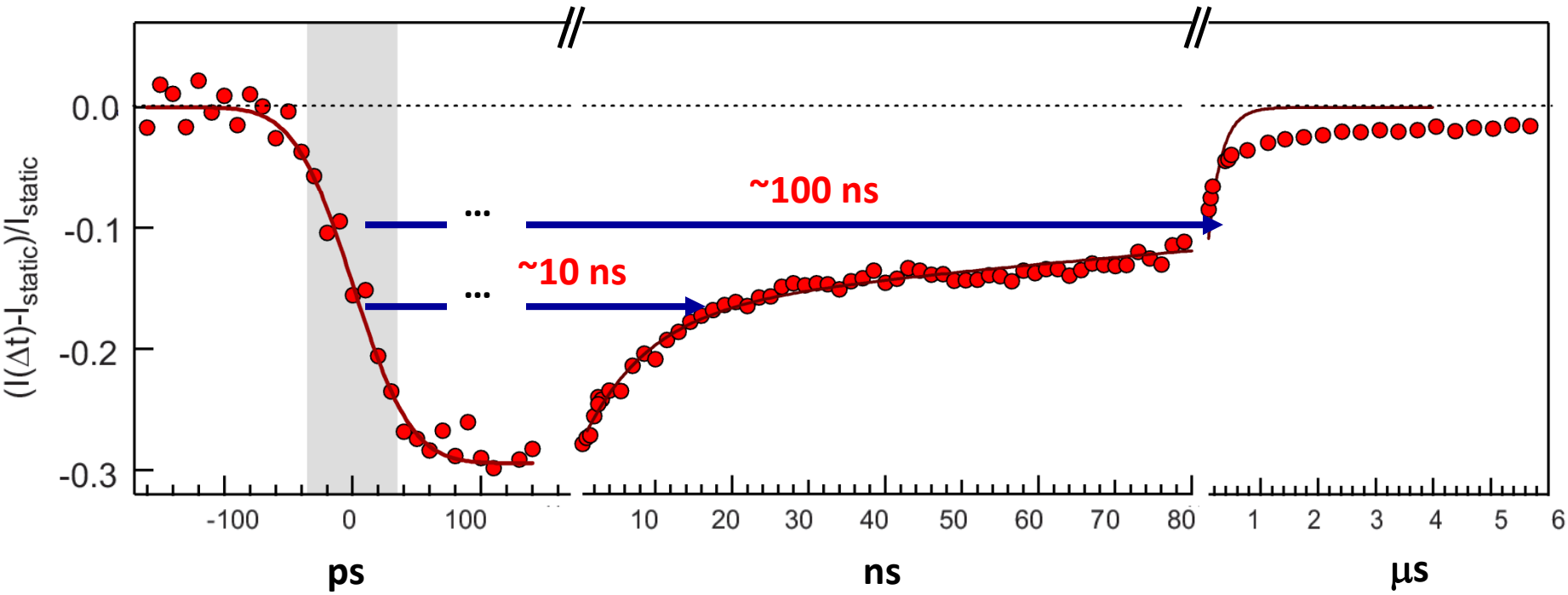
- **Example: Dynamics of antiferromagnetic spin ordering in $Pr_{0.7}Ca_{0.3}MnO_3$ manganite**

(1) Melting dynamics

(2) Recovery dynamics

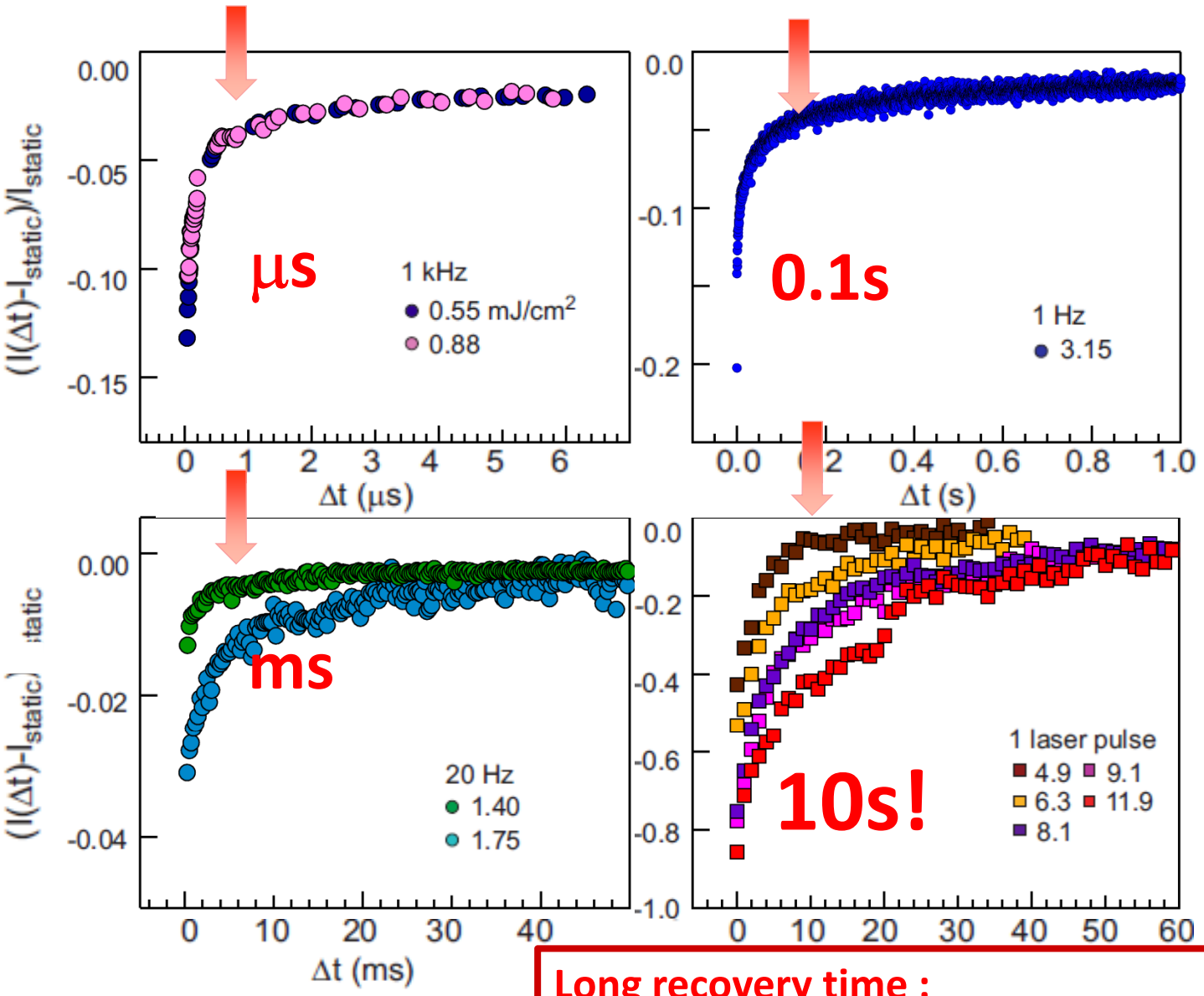
Multiple Time Scales In The Recovery Process

$Pr_{0.7}Ca_{0.3}MnO_3$ 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

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

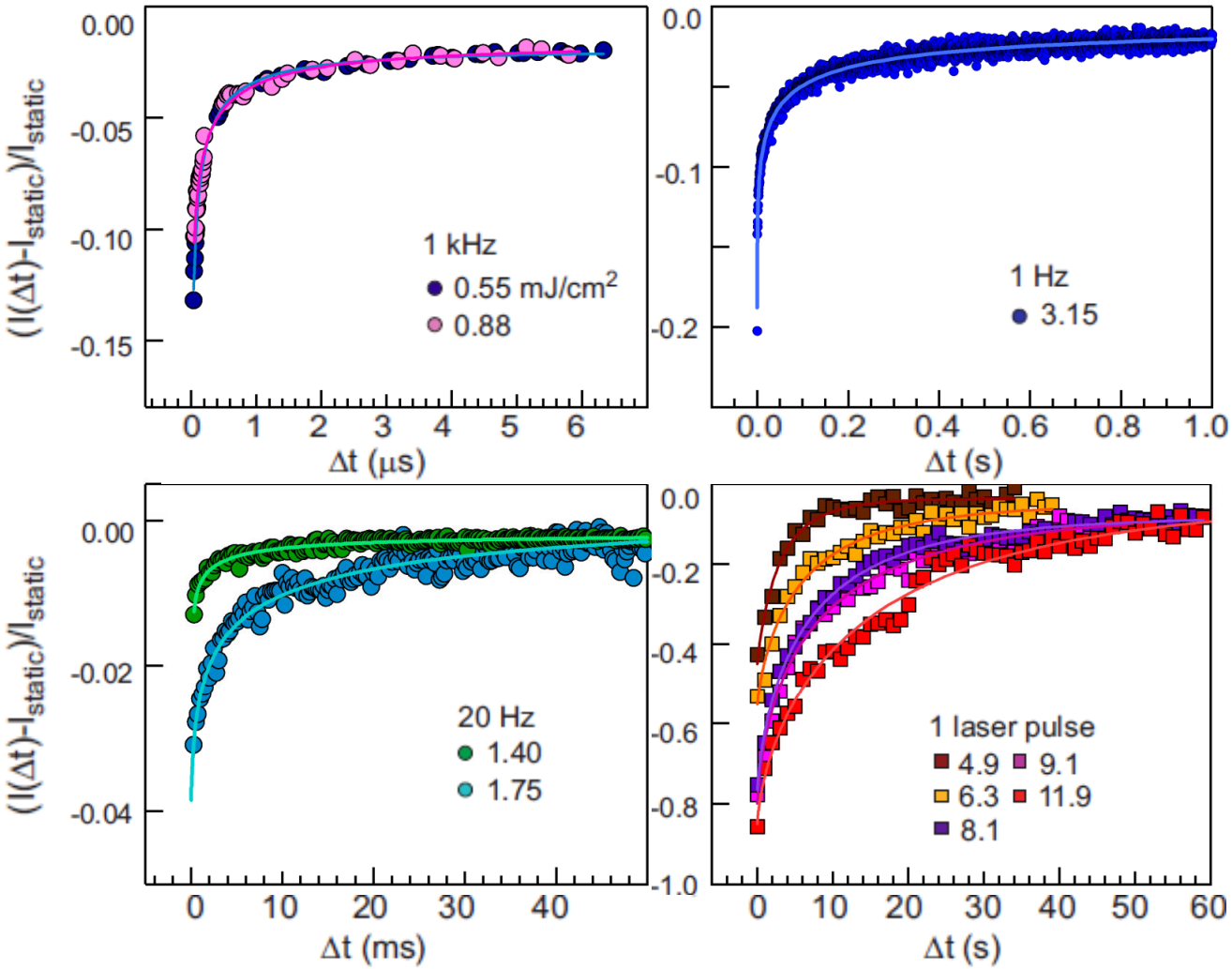
d: dimensionality of the interaction

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)

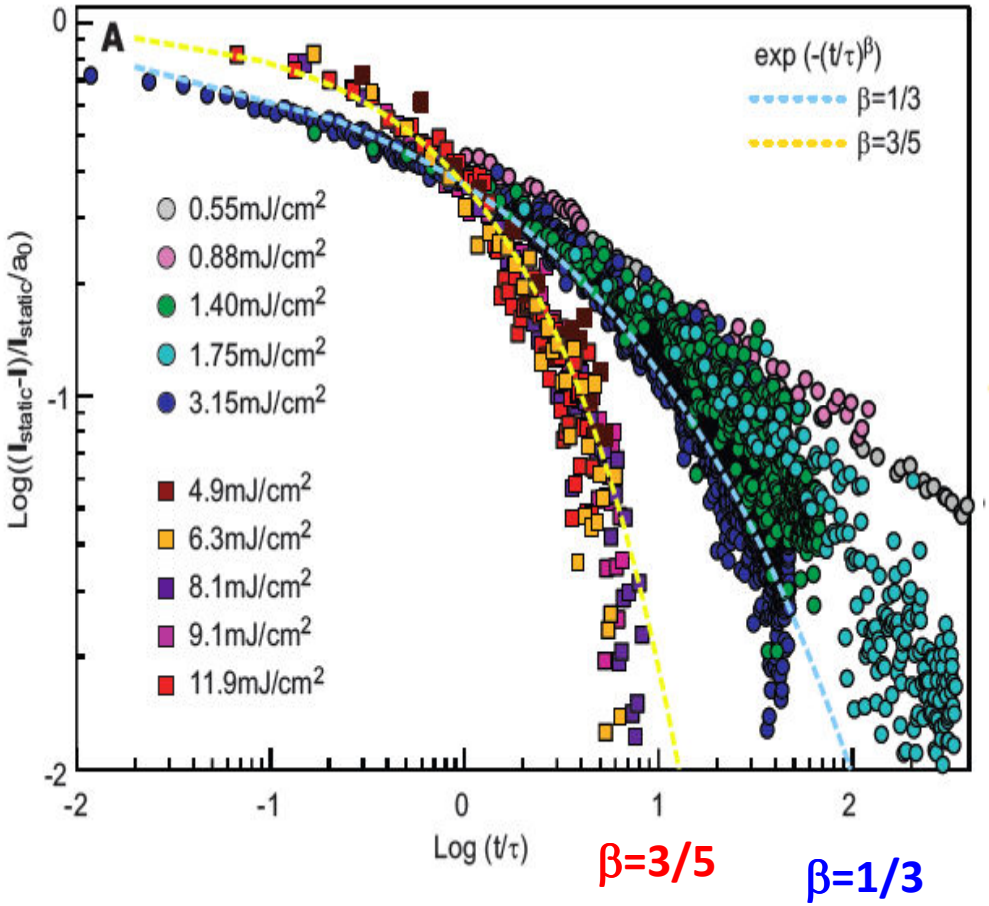


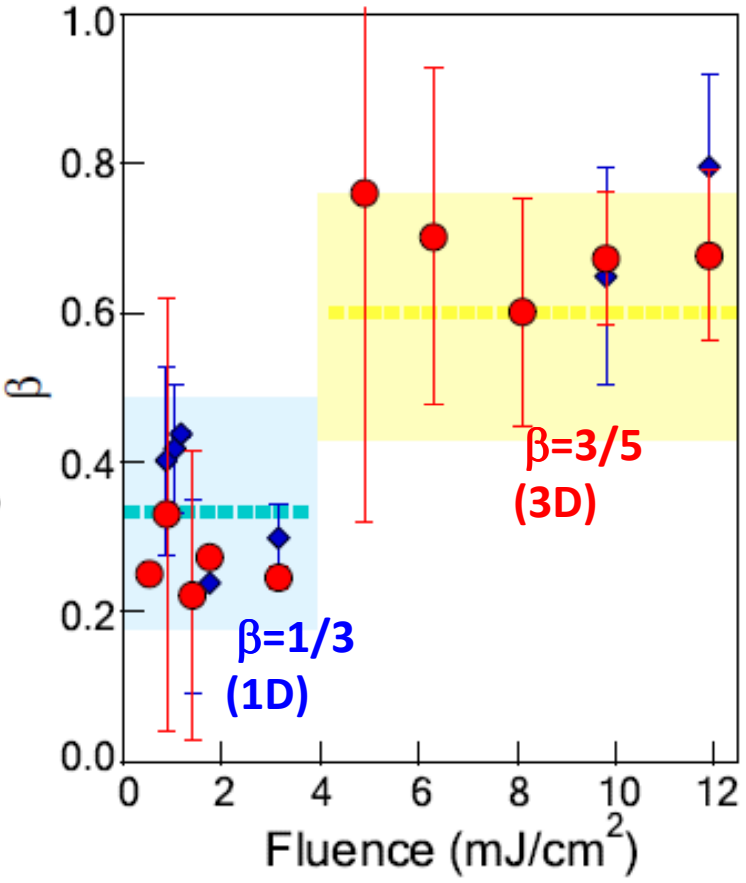
Recovery of spin ordering shares similarity to glass-like systems

Dimensional Cross-over In The Effective Interaction

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

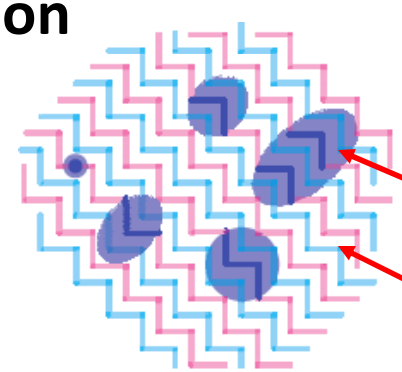
$$\beta = d/(d+2)$$





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

- **"Melting" Dynamics (LCLS)**
  - ➢ **Two time scales: < 1 ps and ~ 10 ps**
  - ➢ **Separating electronic *vs.* lattice interactions**
- **Recovery dynamics (ALS)**
  - ➢ **Glass-like recovery dynamics**
  - ➢ **Dimensional crossover (1D to 3D) in the effective interaction**



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

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TR-RSXS collaborators:

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ALS ultrafast x-ray (BL6)

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Donghui Lu

Rob Moore

Mariano Trigo

David Reis

Joshua Turner

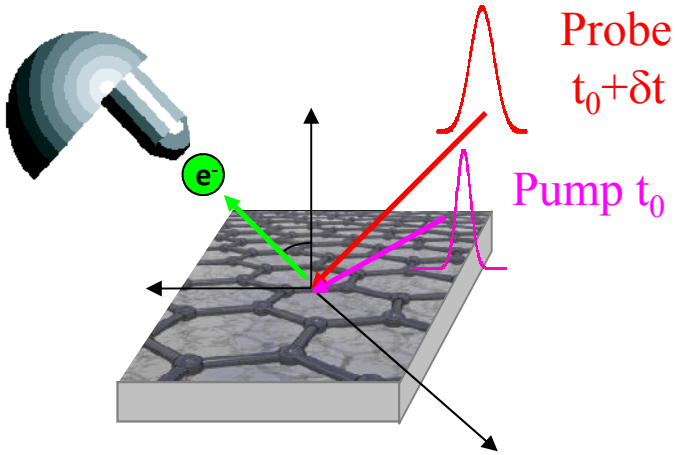
William Schlotter

Oleg Krupin

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)

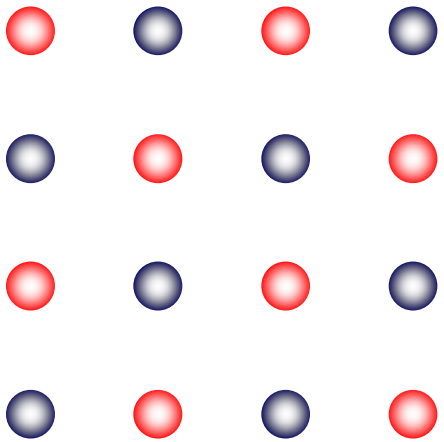
- quasiparticle dynamics
- role of collective excitations

…

Important Variables for Quantum States in Solids

- **Real space structure/periodicity R**

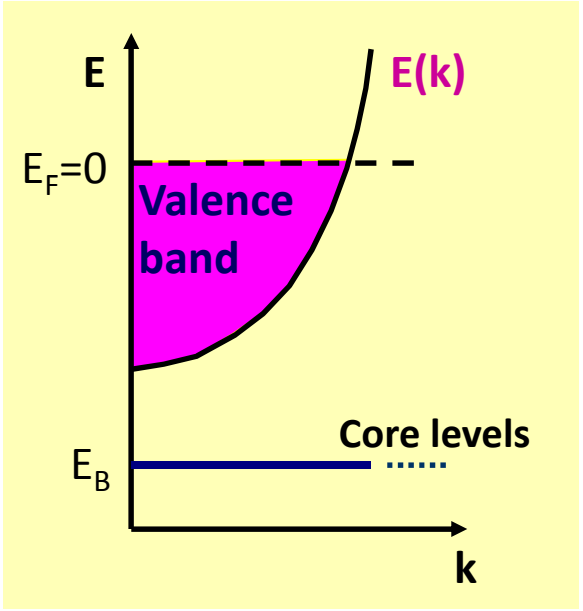
charge/orbital/spin/lattice



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)

Thank you!