Probing Magnetic Complexity with Coherent Soft X-ray Beams

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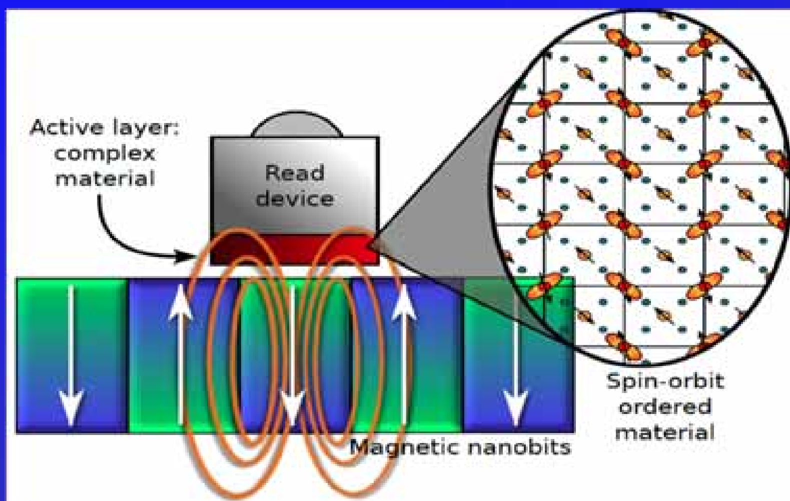
Mesoscale intermittency

Hidden rotational symmetries in magnetic domains: field driven nanoscale intermittency

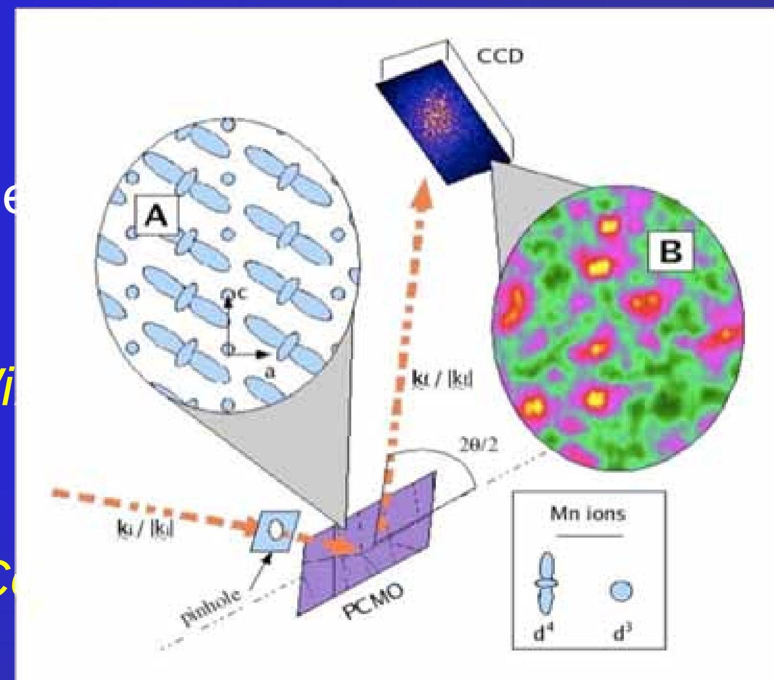
Fluctuations near the spin-reorientation transition: thermally driven nanoscale intermittency?

Observations and Speculations

Yin and Yang of Nanotechnology:
Field- vs. Thermally-Driven Dynamics



Cartoon courtesy of Sujoy Roy/ALS

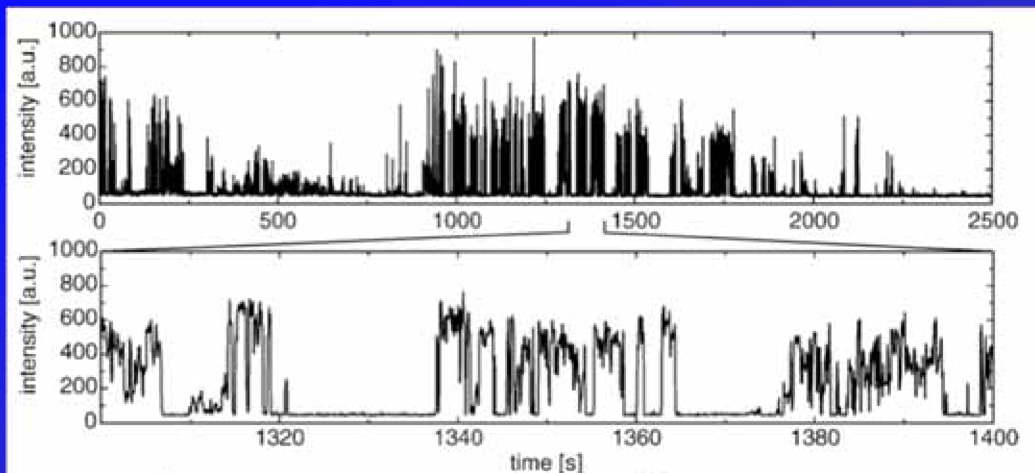


Imaging Complexity with Coherent (Soft) X-rays

Connects nanometer and micrometer length scales

- Diffractive imaging
- Speckle metrology
- Correlation spectroscopy

Luminescence Intermittency in Single Quantum Dots

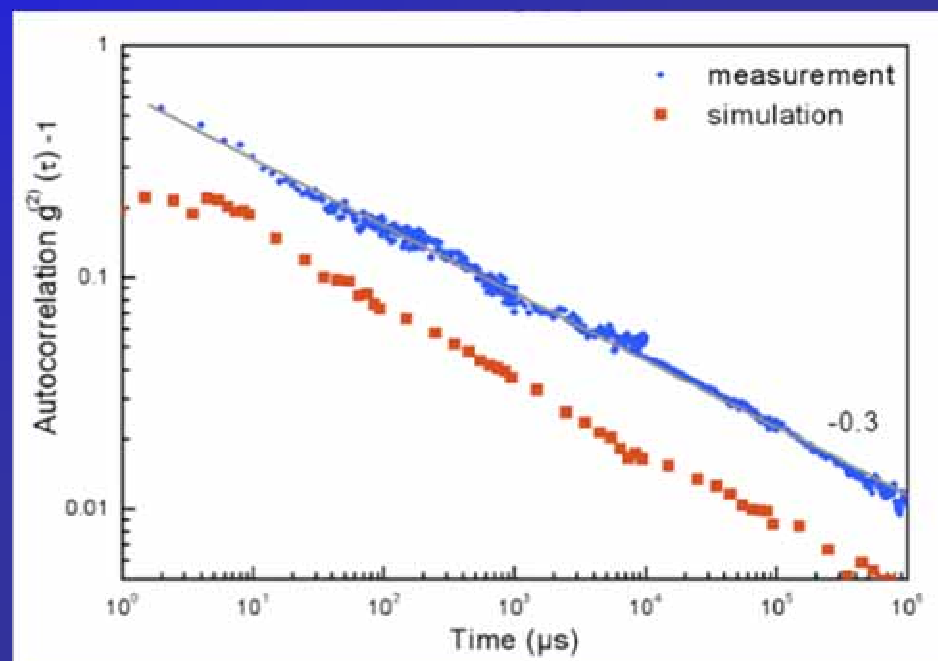


Random telegraph noise in luminescence from a single CdS nanocrystal.

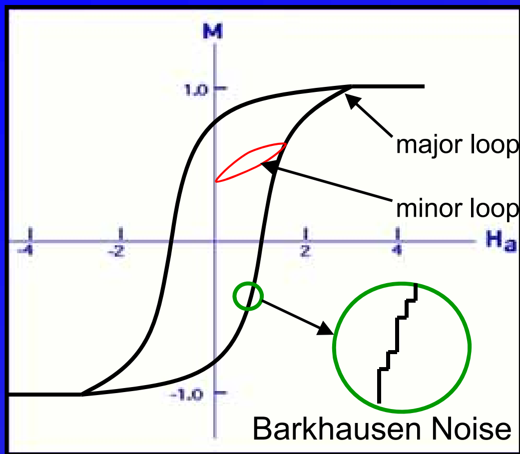
[R. Verberk, et. al. Phys Rev B 66, 233202 (2002).]

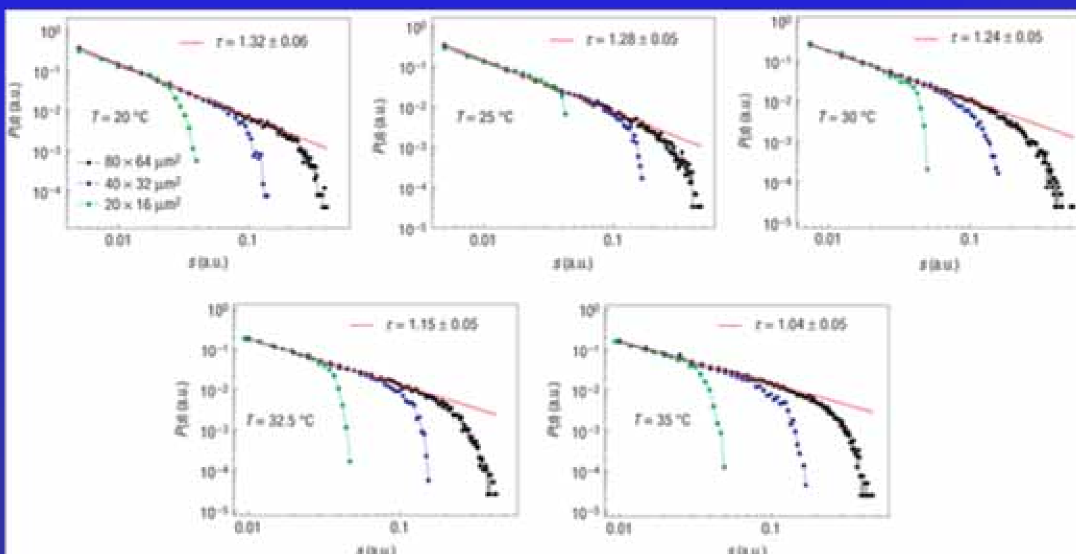
Intensity ACF shows power law behavior

[C. von Borczyskowski, et. al., Phys Rev B 71, 161302, (2005).]

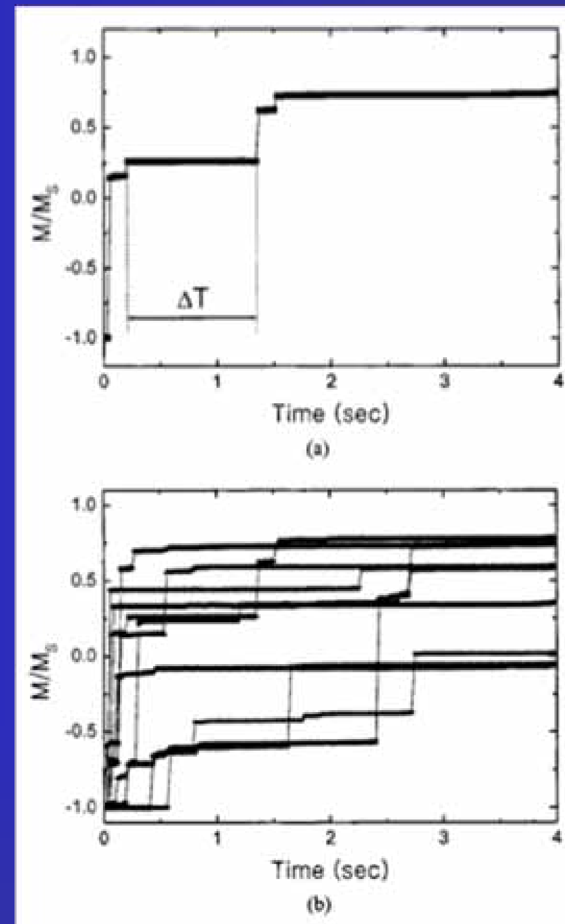


Intermittency in Magnetization Loops



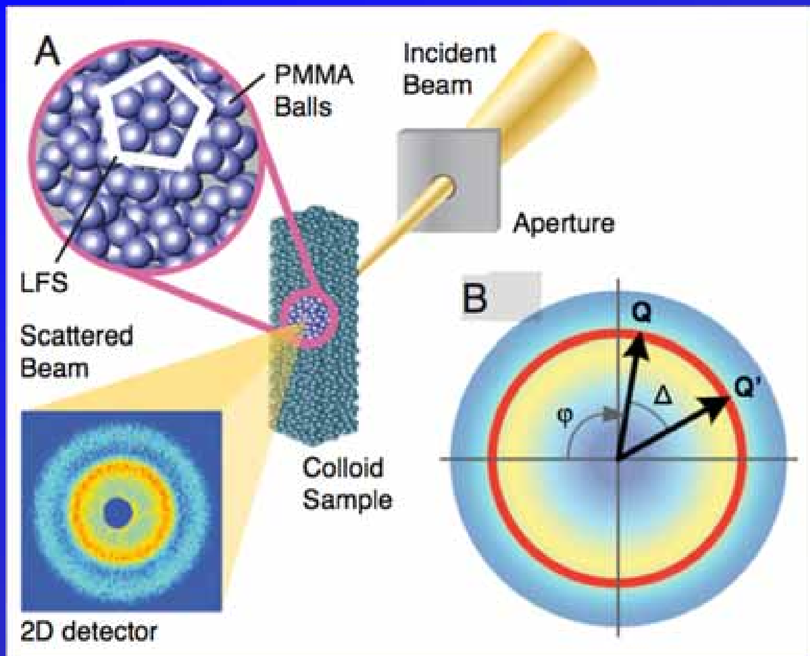


Histograms of sizes of Barkhausen events
[Ryu, Akinagas, and Shin, Nature Phys. 3, 547 (2007).]

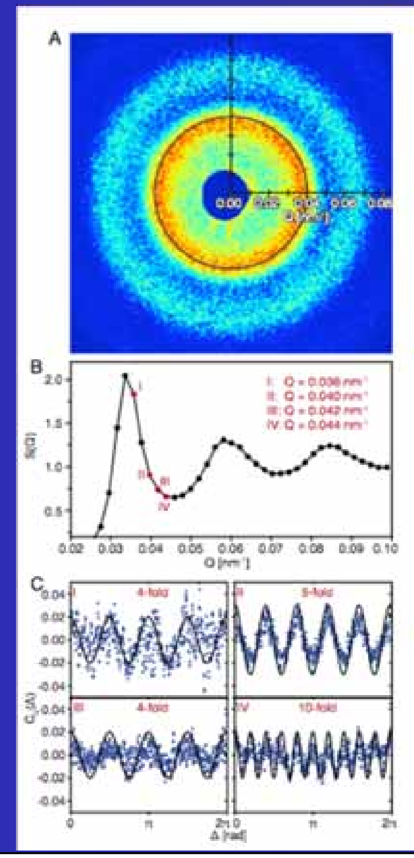


Barkhausen events in a Co thin film
[Kim and Shin, J. Appl. Phys. 95, (2004).]

Hidden Symmetries in Colloidal Glass Phase



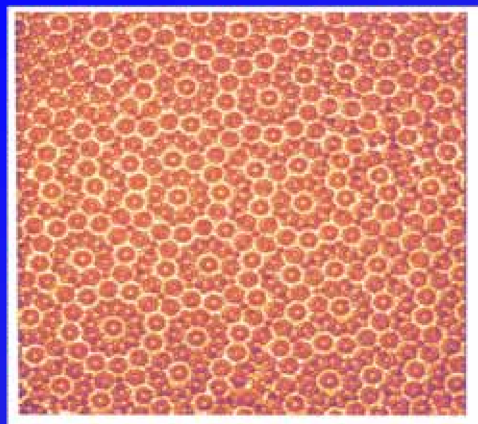
Wochner, PNAS 108, 11511 (2009).



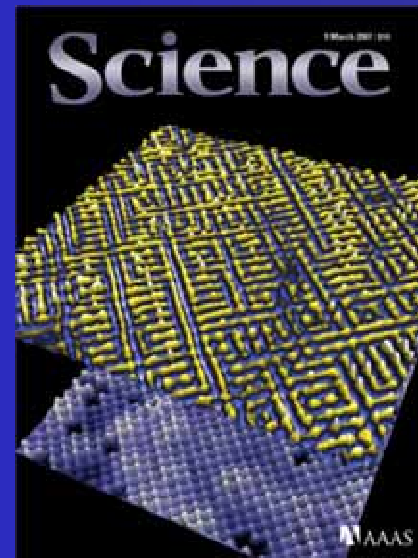
$$ACF(q,\Delta) = \frac{\sum_{annulus} I(Q,\varphi+\Delta) I(Q,\varphi)}{\sum_{annulus} [I(Q,\varphi)]^2}$$

- *3D system – no anisotropy*
- *Competing short and long-range forces*
- *Frustration leads to a non-equilibrium phase . . . . . and hidden symmetries*

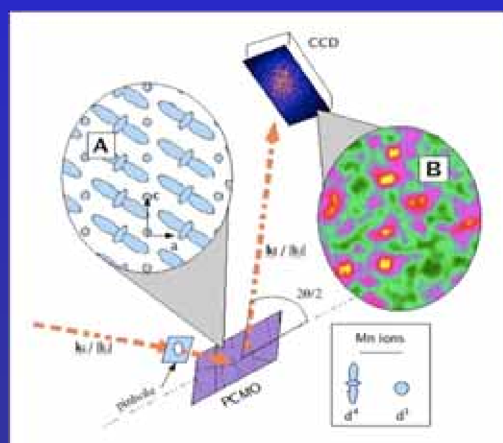
Local Symmetries and Pattern Formation



Pattern formed on silicone oil when driven vertically at two frequencies.
[Golub and Langer, RMP 71, S396 (1999).]



Electronic Patterns on Dy-Bi2212
[Kohsaka, et. al., Science 315, 1380 - Mar 2007]



Coherent, resonant scattering from PCMO
[Turner, et. Al, NJP 10, 053023 (2008)]

- XDI: imaging complex phases
- XPCS: anomalous dynamics
- Metrology: hidden symmetries

. . . if we had a lot more signal

Spin Reorientation Transition in Au:Co:Au

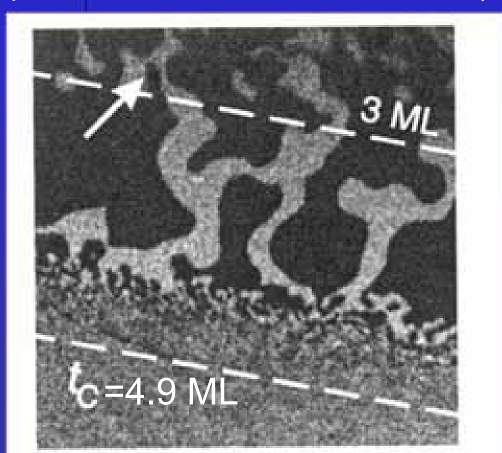
- Ultrathin Co layers -> SRT
- Competition between shape and surface anisotropy

[Pescia *et al.* *PRL 65, 2599]*

$$E = \{K_1(T) - 2\pi M_s(T)^2\}\sin^2(\theta) + K_2(T)\sin^4(\theta)$$

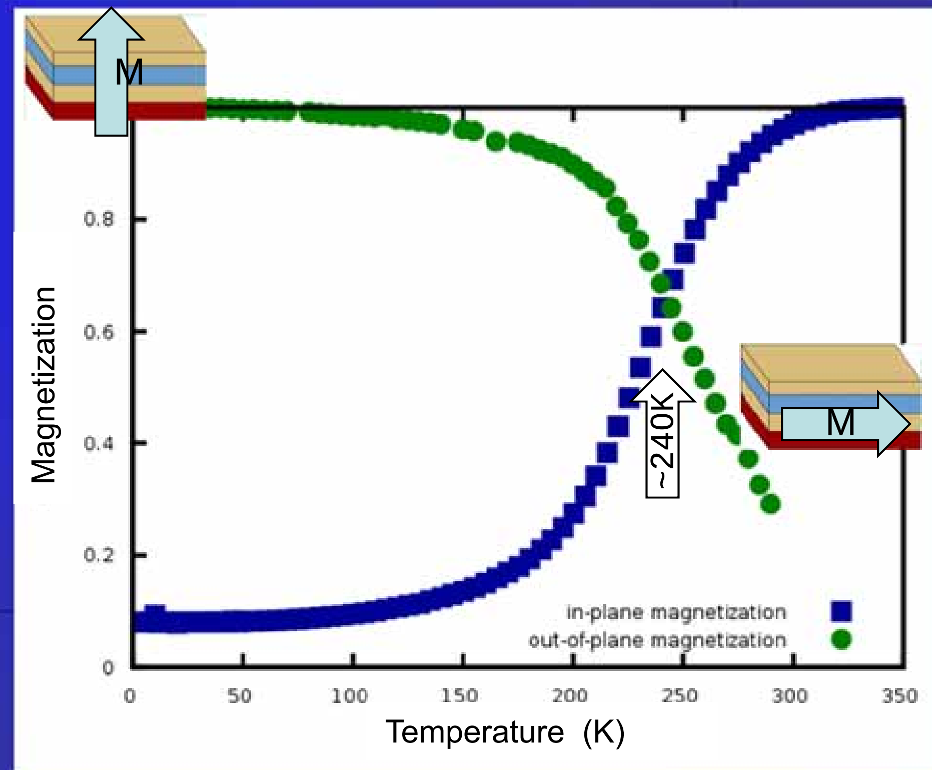
SEMPA measurements of Co/Au(111)

[Speckmann, *et. al.*, PRL **75**, 2035 (1995)]



→→ Thickness increases →→

Scale: 100 μm x 100 μm

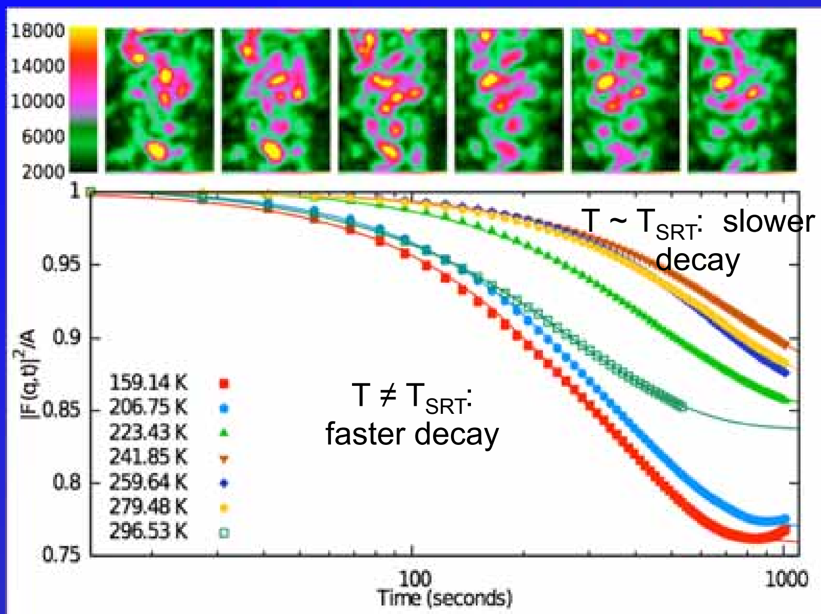


Magnetization rotates from out-of-plane to in-plane as a function of increasing temperature

[Park *et al.* *APL* ***86*** *042504]*

Complex Fluctuations near a Spin Reorientation Transition

$q = 2.58 \times 10^{-4}$ Å^{-1}



The intermediate structure factor F(q,t) measures the time the SRT system takes to decorrelate due to diffusive motion of the magnetization.

Probes complex magnetization dynamics, with a static component due to charge/surface roughness scattering.

Stretched exponential provides a decent fit. . .

$$F(q,t) \propto e^{-(t/\tau)^{\beta}}$$

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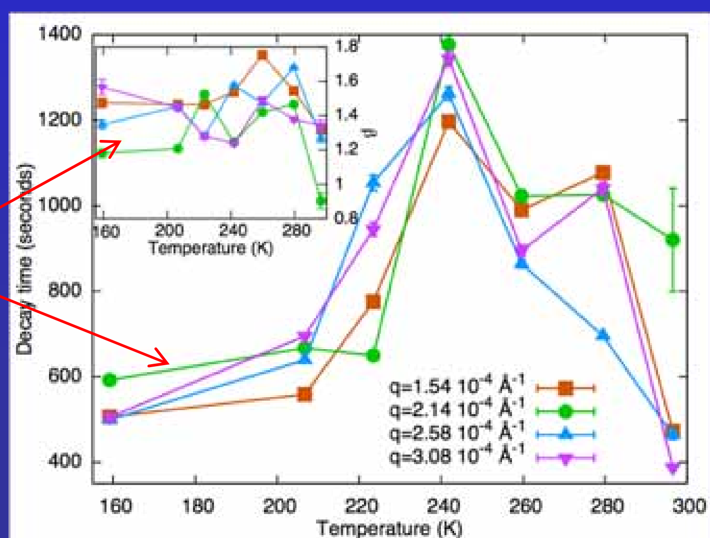
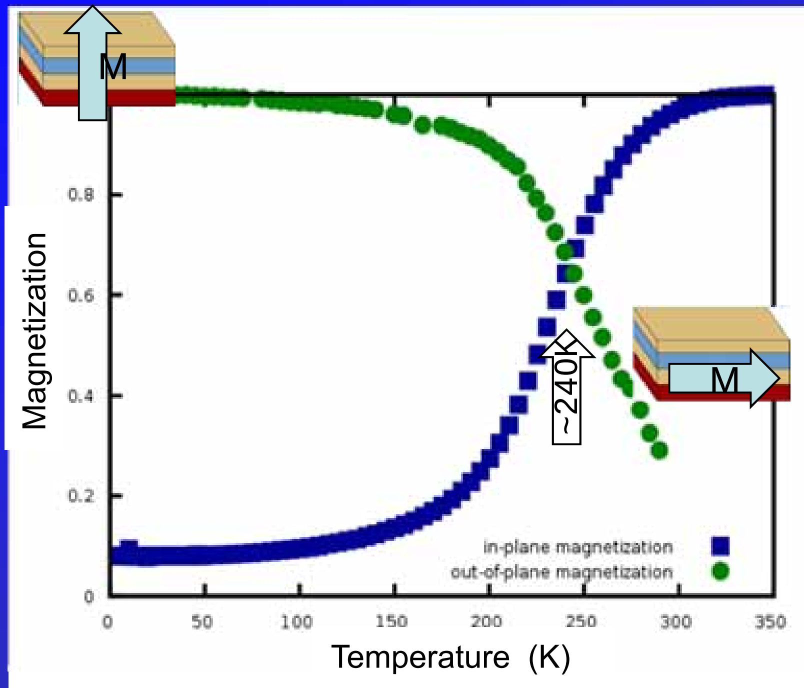


- Vestige of critical slowing down?
- $\beta > 1$: collective dynamics; too low for a jamming transition (Nature 447 **68**)
- Need larger dynamic range:, more signal, better pinhole, smaller blocker, better detector. . .

Canted Magnetization through the Spin Reorientation Transition



Why is the transition so broad?

Estimate anisotropies and $M_s(T)$ from
1)measured values at 300K for K_1 and K_2
2) scaling relations to get $K_1(T)$ and $K_2(T)$;
3) T_C tuned to predict T_{SRT}

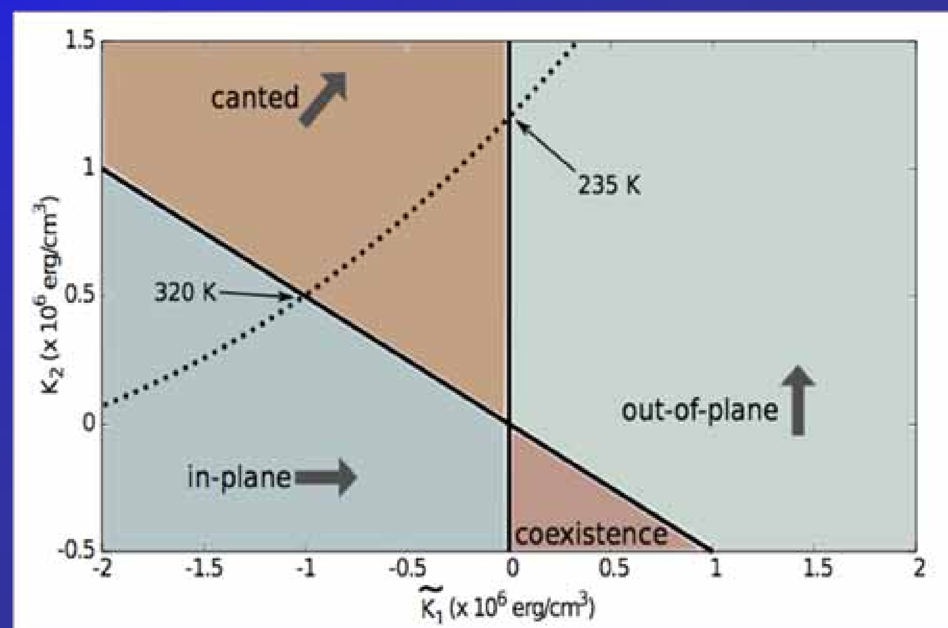
Predicts $K_2(T) > 0$ through the SRT – and does a decent job explaining the width of the transition.

Landau free energy of a uniaxial SRT system:

$$E = \{K_1(T) - 2\pi M_s(T)^2\}\sin^2(\theta) + K_2(T)\sin^4(\theta)$$

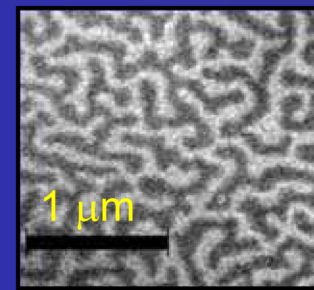
$K_2 < 0$: mixed phase of L and P domains;

$K_2 > 0$: continuous phase with canted magnetization

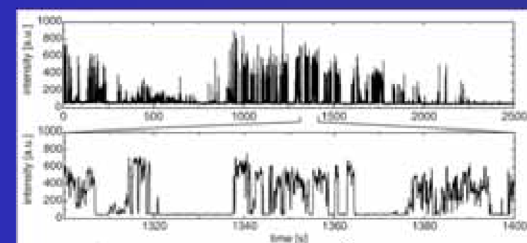


A Few Thoughts about Nanoscale Complexity

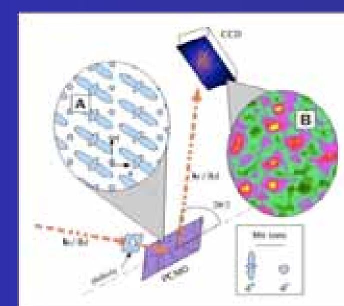
- Equilibrium/non-equilibrium issue is of prime importance in nanostructured materials.



- Externally driven nanostructured systems often exhibit unusual patterns in space an time.

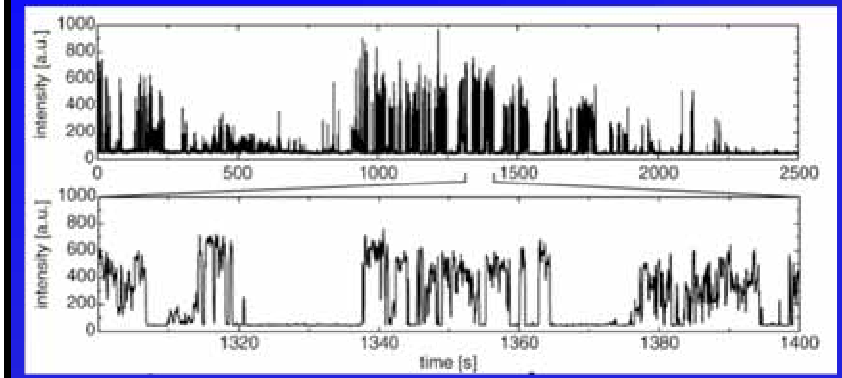


- Coherent x-ray beams provide a good way to measure these patterns in both space and time.



- *Unfortunately, with existing sources, we rarely have enough signal to probe a large enough dynamic range in either space or time.*

A Difficult Experiment: *Connecting Thermally Driven Structure and Dynamics of a Single Center*



[R. Verberk, et. al. Phys Rev B 66, 233202 (2002).]

Requirements:

High coherent flux ~10 nm focused x-ray beam

Detector with broad temporal dynamic range

A lot of patience. . .

Rare, fast events are everywhere: (bio)chemical reactions, nanostructures, cascading and switching systems, crack propagation, . . .

Thermal pathways often not measured in pump-probe measurements;

Microscopic understanding of intermittency not well understood in most cases;

Some of this will be done on FEL's with probe-probe measurements;

The stability and access to broad time and space ranges will make USR's/ERL's very helpful in understanding such systems.

Collaborators and Funding

Josh Turner	UO, LCLS
Dan Parks	UO, ALS Doctoral Fellow
Run Su	UO, ALS Doctoral Fellow
Keoki Seu	UO, ALS
Sujoy Roy	ALS
Eric Fullerton	UCSD
Charlie Falco	UAz

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