Anomalous Transport Noise in YBCO

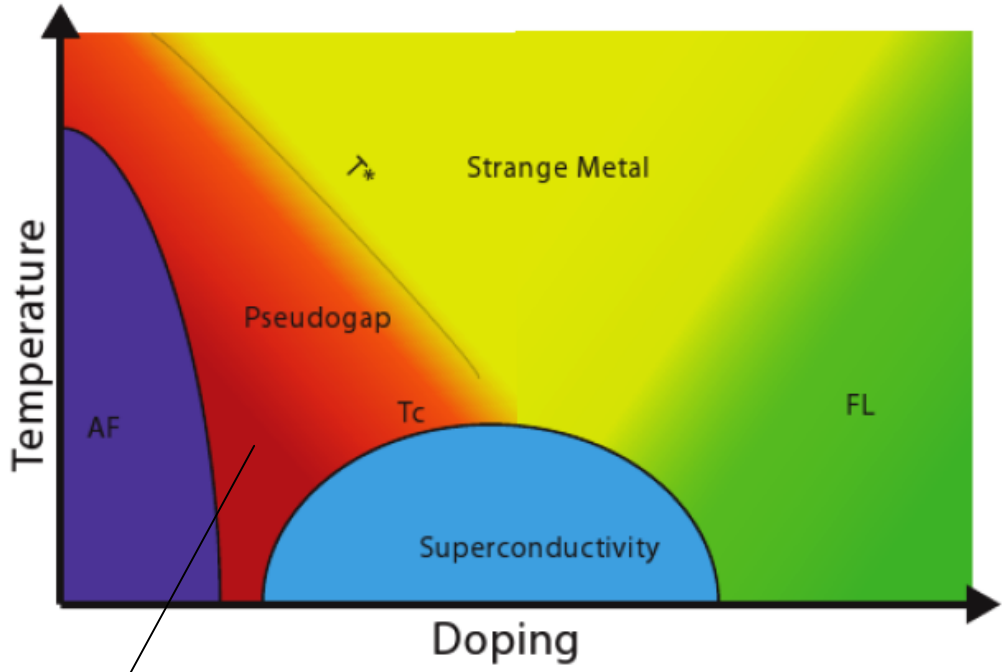
Dale Van Harlingen (started project)
David S. Caplan (kept it going despite odds, supplied most samples and slides)
Vladimir Orlyanchik (got the experiment to work, took almost all the data)
Tom Lemberger et al. (some very nice samples)
Eduardo Fradkin (theoretical guidance)

Tony Bonetti (took early data)

Hans Hilgenkamp (oriented samples)

Funded by several NSF grants

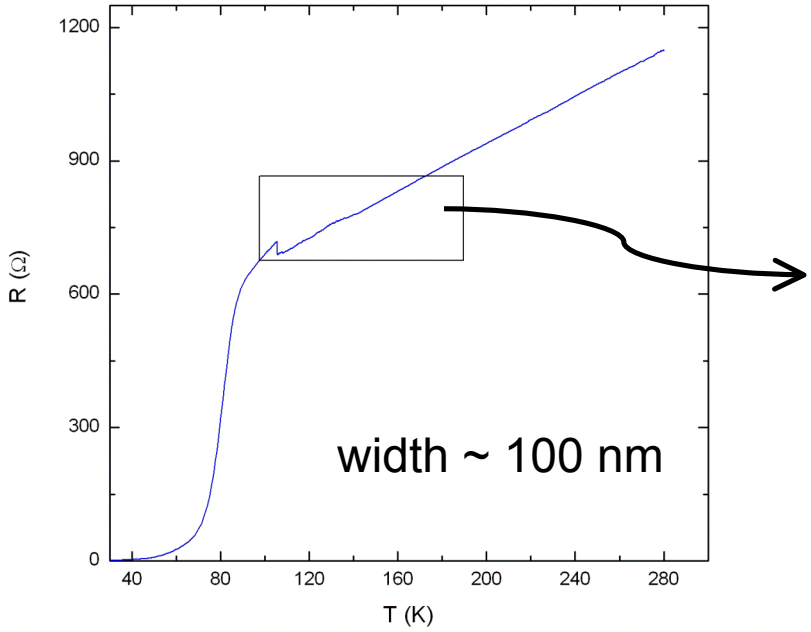
The Generic Phase Diagram



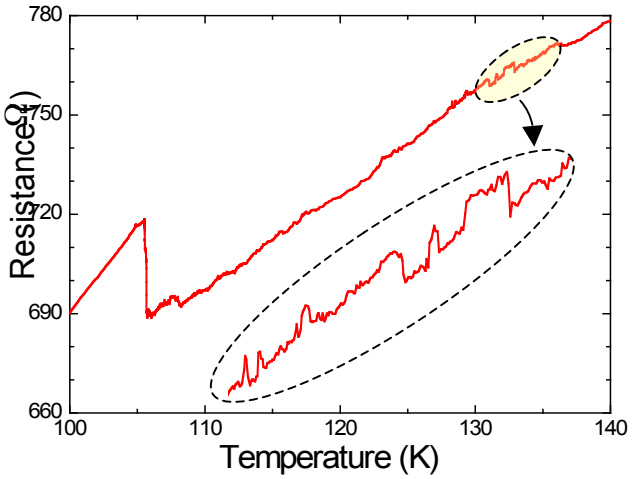
- Stripes?
- Circulating currents?
- Preformed pairs?
- Mottish bosons?

- Some AF neutron correlations
- T-dependent resistive anisotropy in untwinned YBCO
- Messy inhomogeneous STM pictures
- Rumors of anisotropic Nernst effect

Early nanowire transport data (Bonetti 2004)

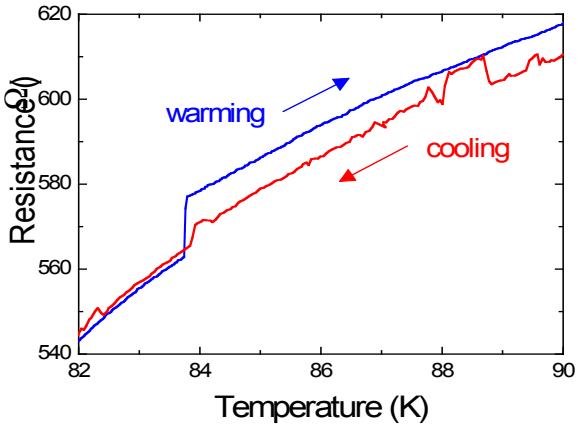


Stripe Switching?

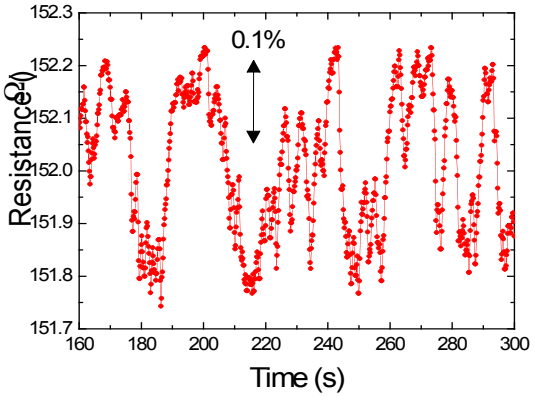


- poor characterization of onset vs. T
- No magnetic field data
- confusing data on spatial correlations
- Samples fell apart

metastable states

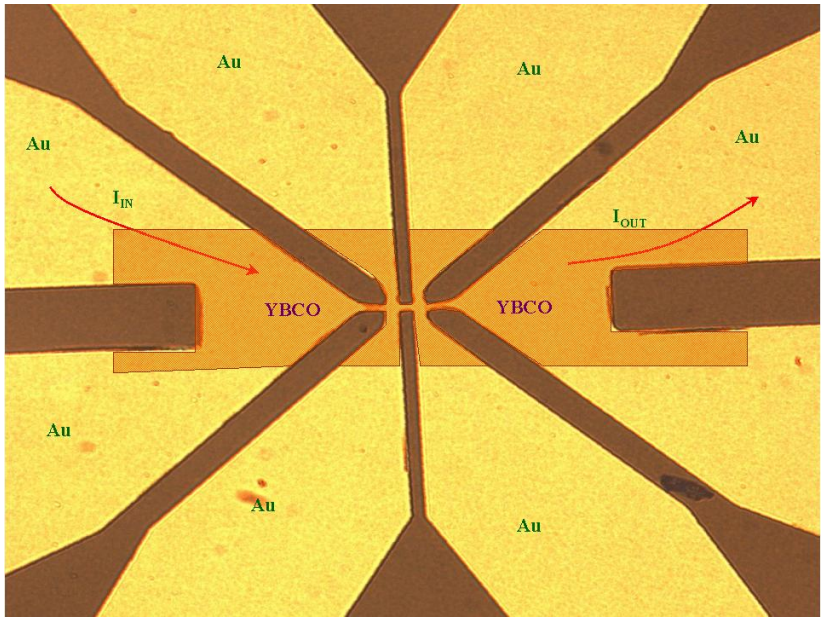


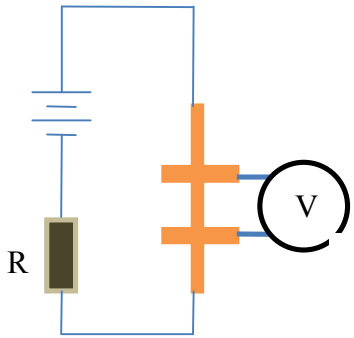
noise (once)



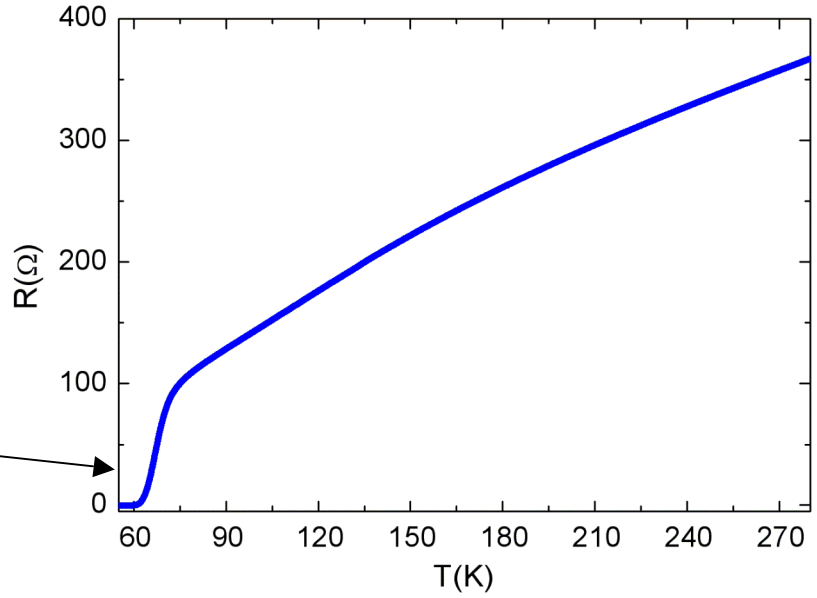
New samples

YBCO and Ca-YBCO
~300 nm thick
via Pulsed Laser Deposition
photolithographic patterns

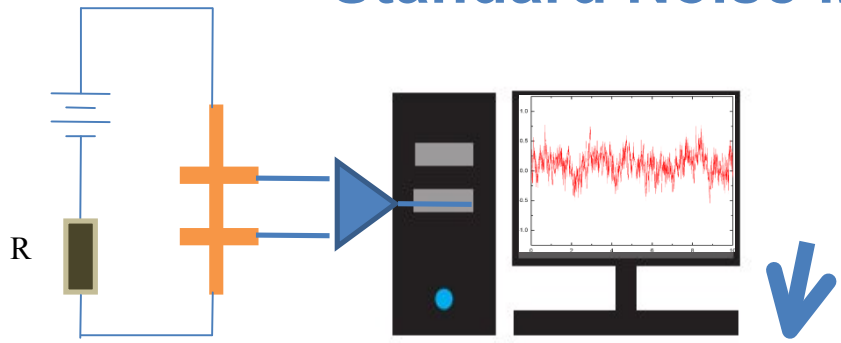


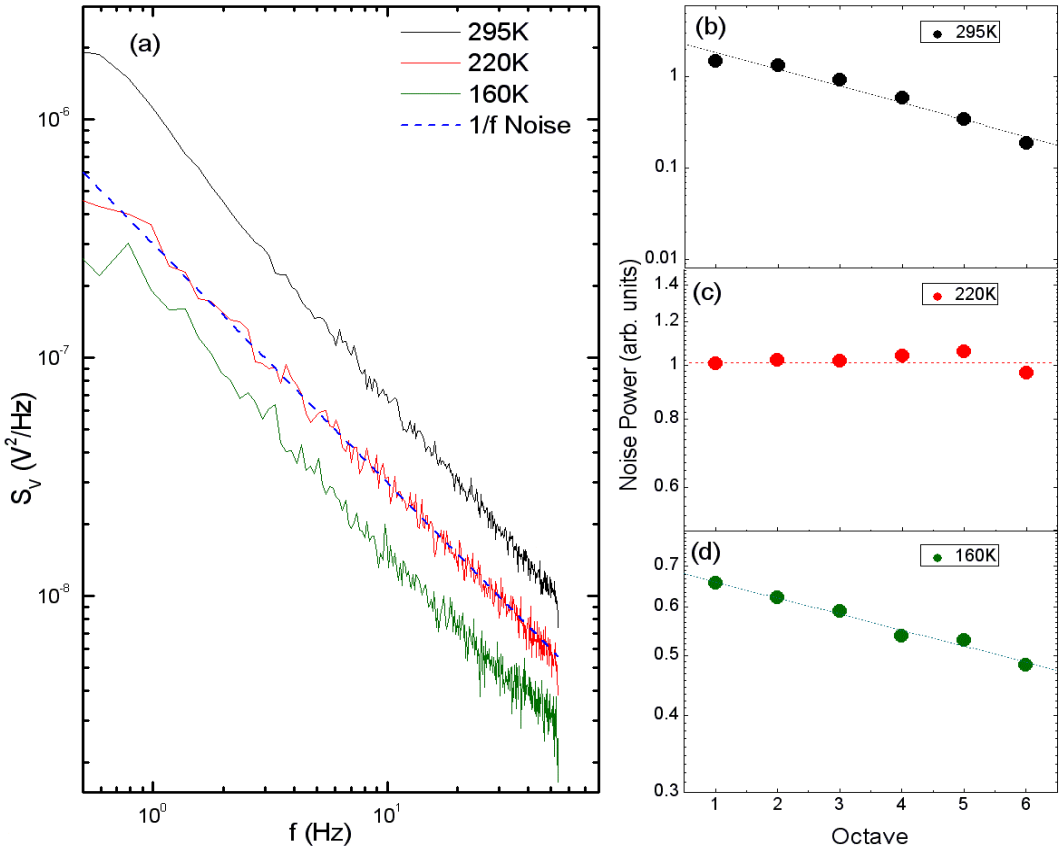


- R(T) is generally smooth
- Stable for weeks
- Sharp T_C



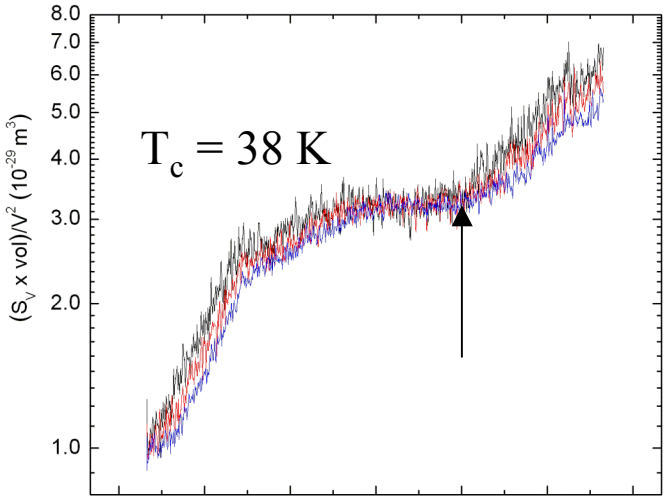
Standard Noise Measurement

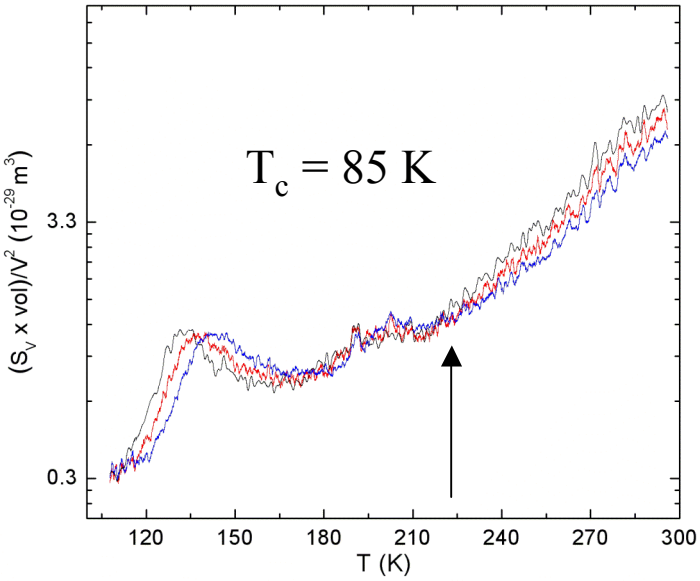


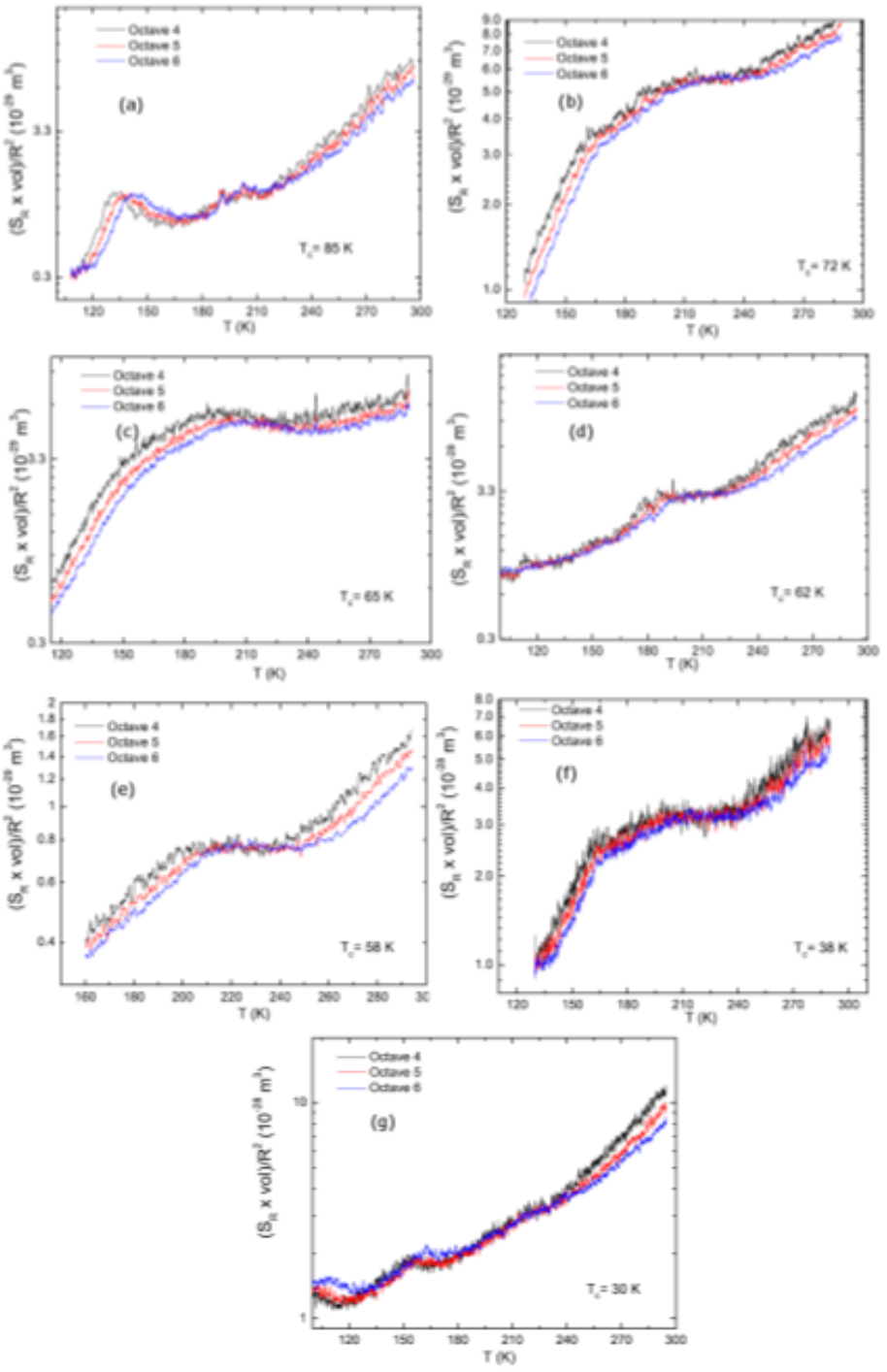


- Frequency window ~1-200 Hz
- ~Linear current response
  - little Joule heating
- Spectrum (above background) roughly of form $1/f^{\alpha}$, $0.9 < \alpha < 1.2$

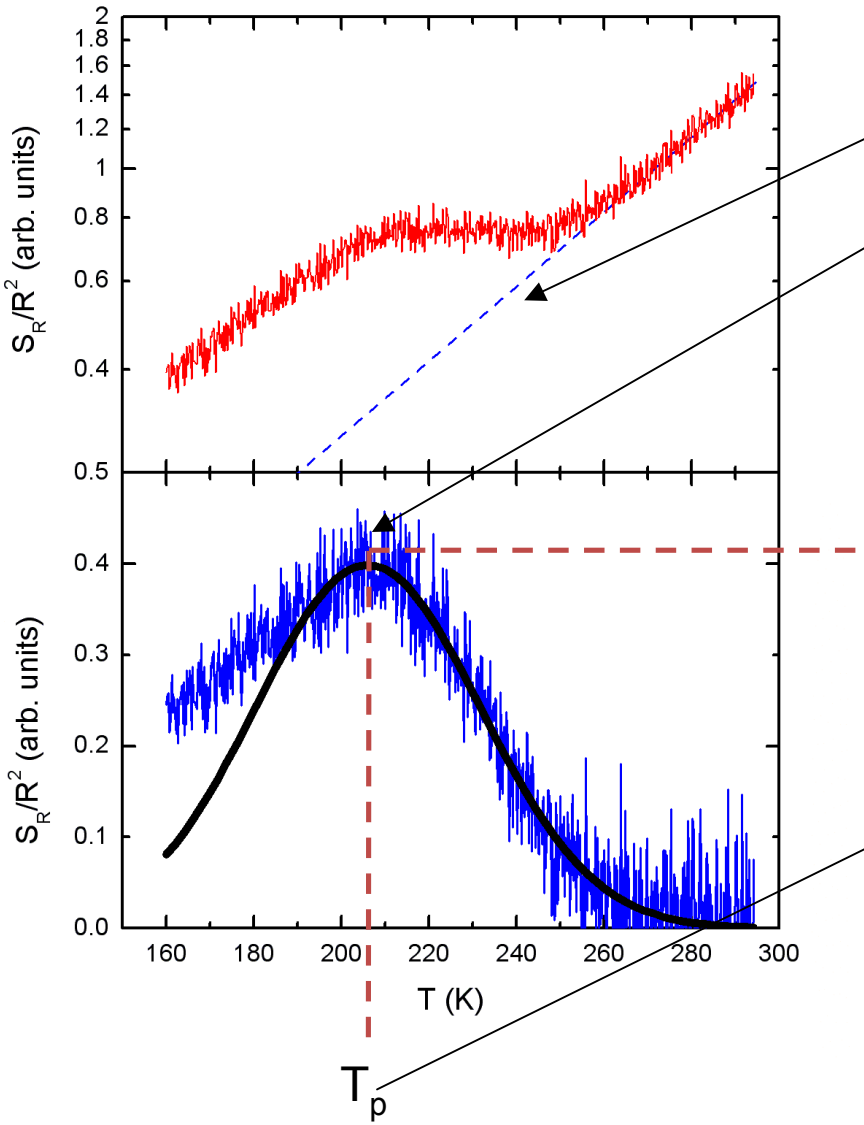
Unusual feature in the 1/f noise



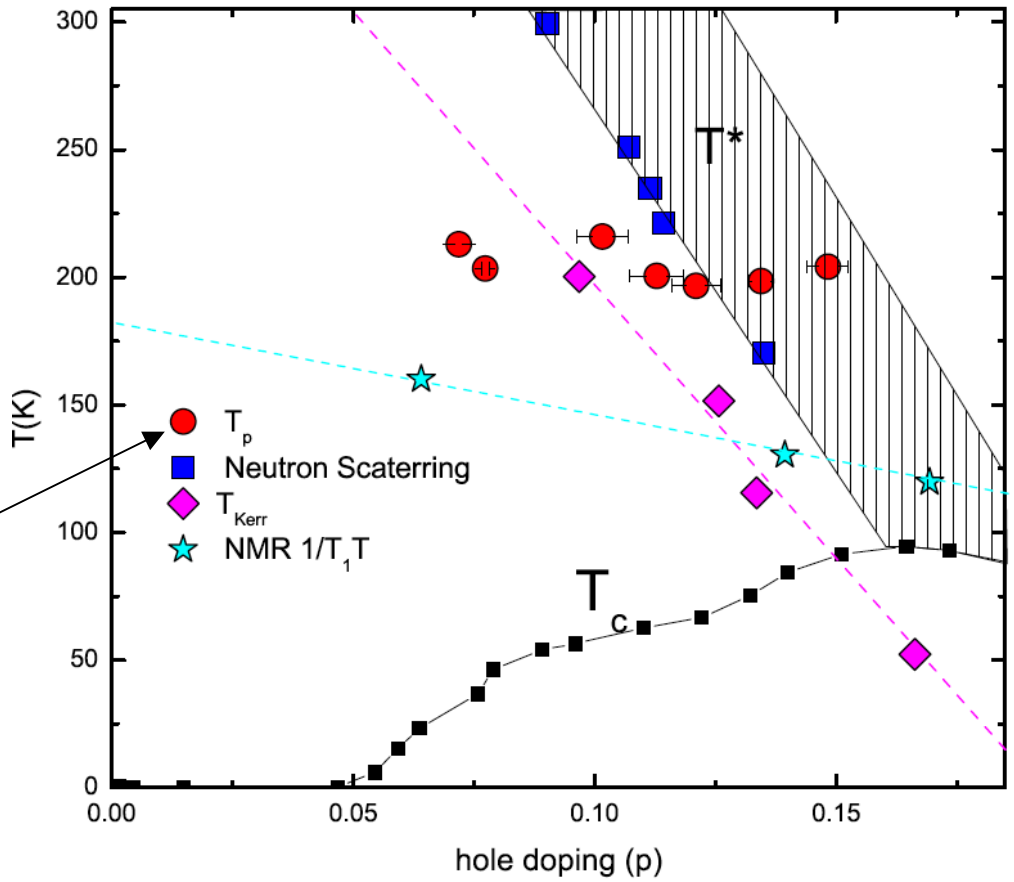




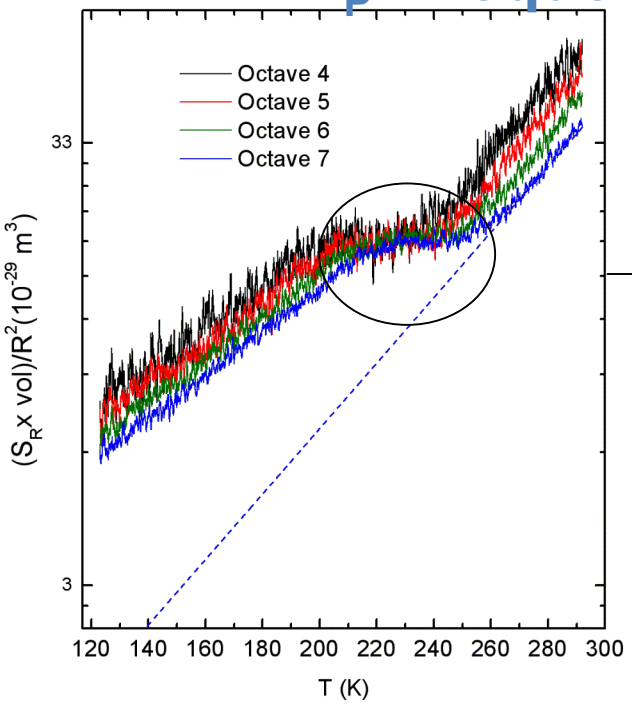
Defining a characteristic T of the feature



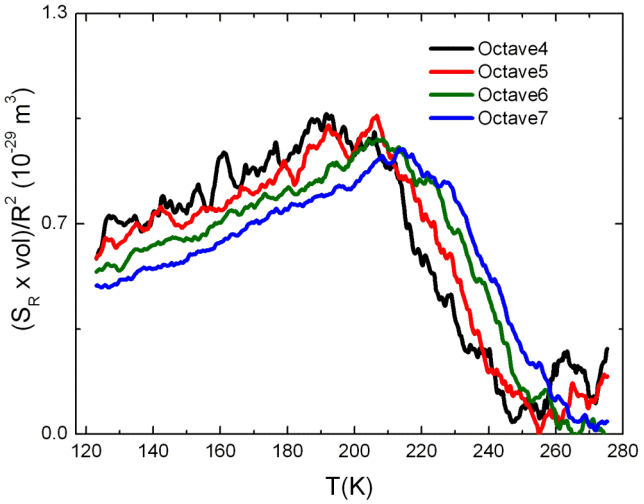
- Subtract extrapolated higher temperature noise
- Look at remainder



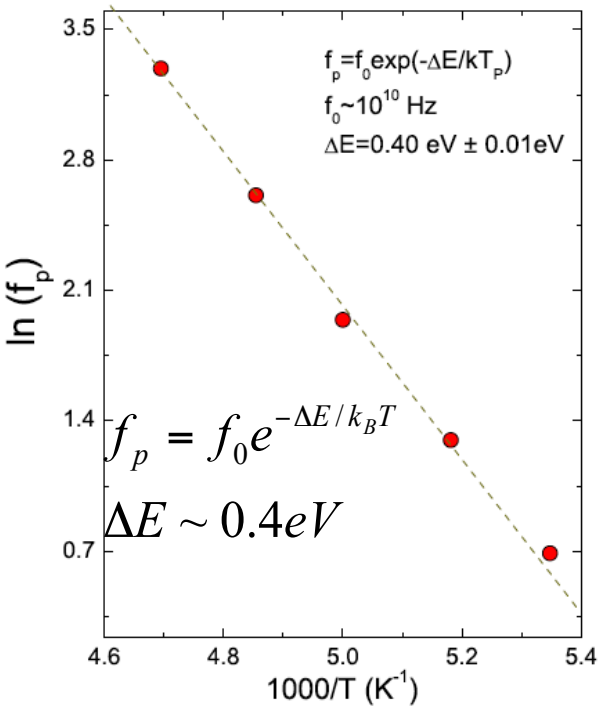
T_P Frequency Dependence



Subtract high T noise



•$T_P(f)$ fits Arrhenius dependence



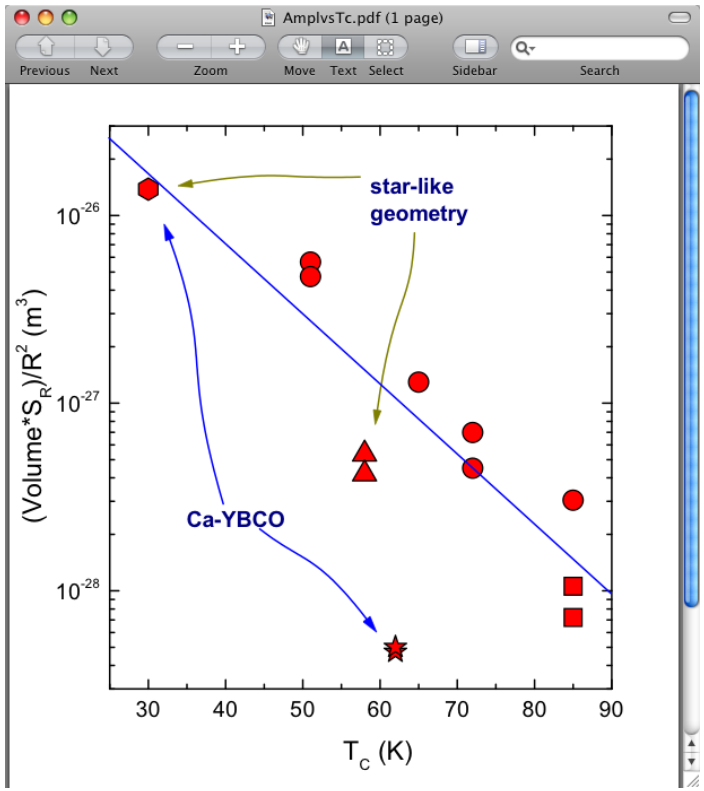
- $T_p(f)$ shows ordinary activated dependence of frequency on T
- Unlike any glass or phase transition
- Just a boring feature in a distribution?

Is the peak associated with electronic correlations?

Decreased doping → more stripe anisotropy

T_P not doping dependent, not a phase transition,
Not a sharp crossover, not related to T*

But peak amplitude is sharply doping dependent

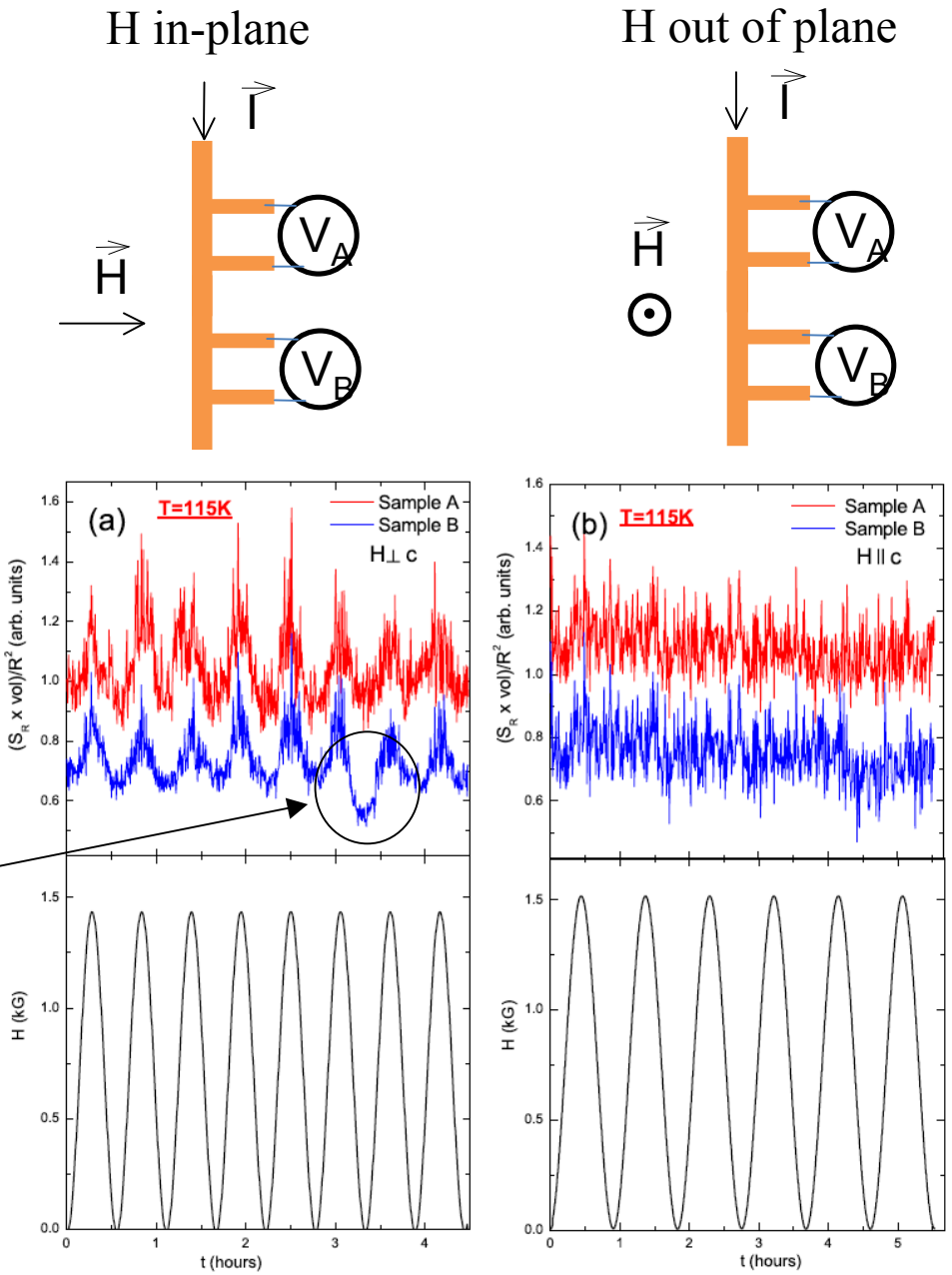


Do the low-T qualitative features look like anything special?

Low Magnetic Field Dependence

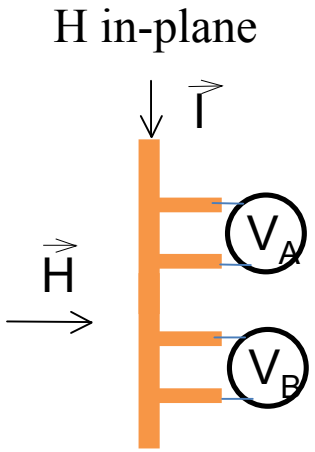
- 2 Samples separated by 15 μm
- Sweep H-field
  sinusoidally, 0 to 1.5 kG
- Noise power follows if H in-plane
  (magnetoresistance <1%)
- Not due to microphonics.
- Choice of metastable states!

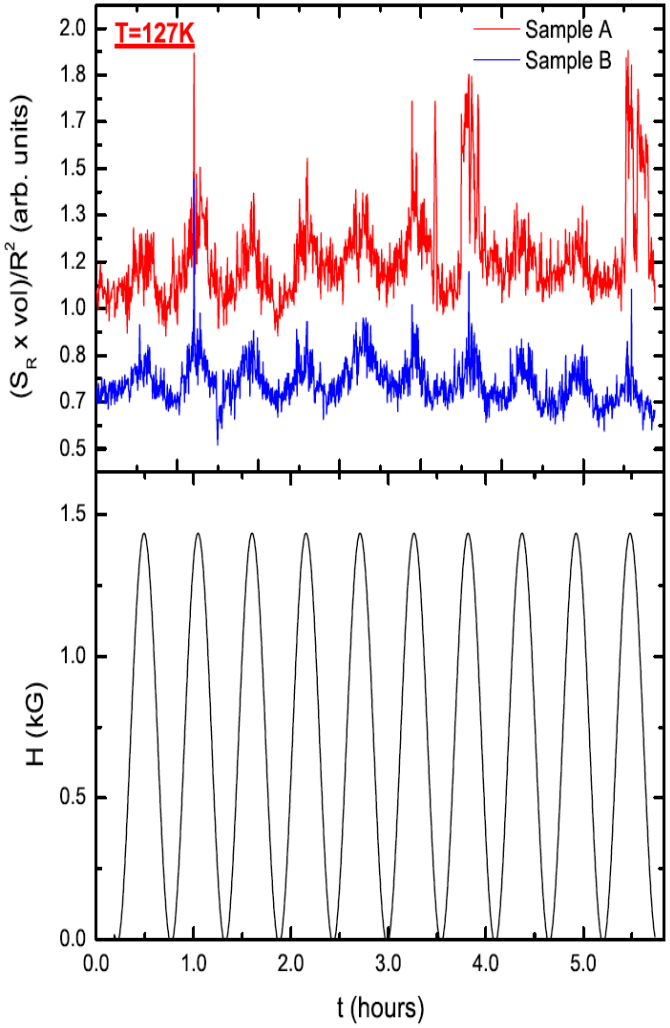
T-dependence?

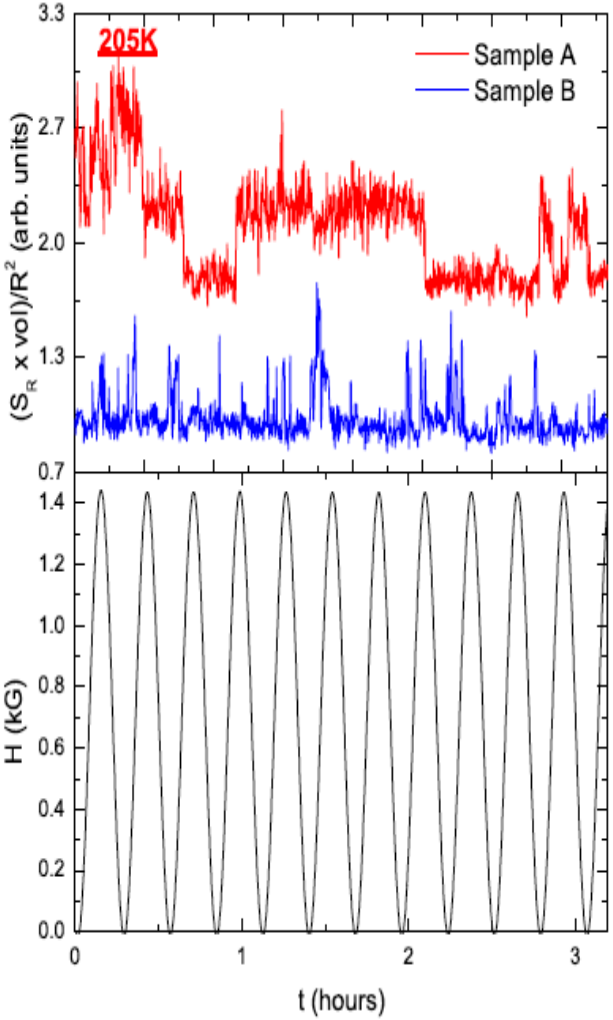


Low Magnetic Field Dependence

Becomes more irregular at higher T

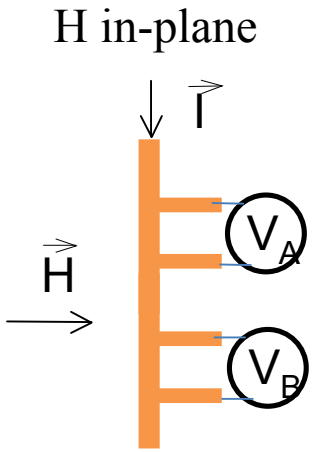


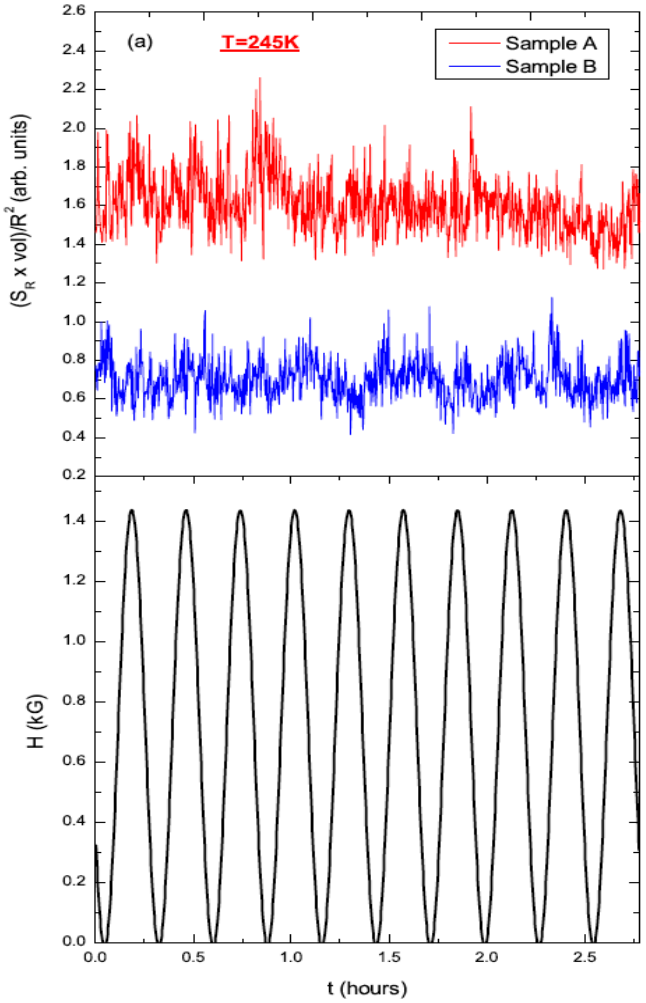


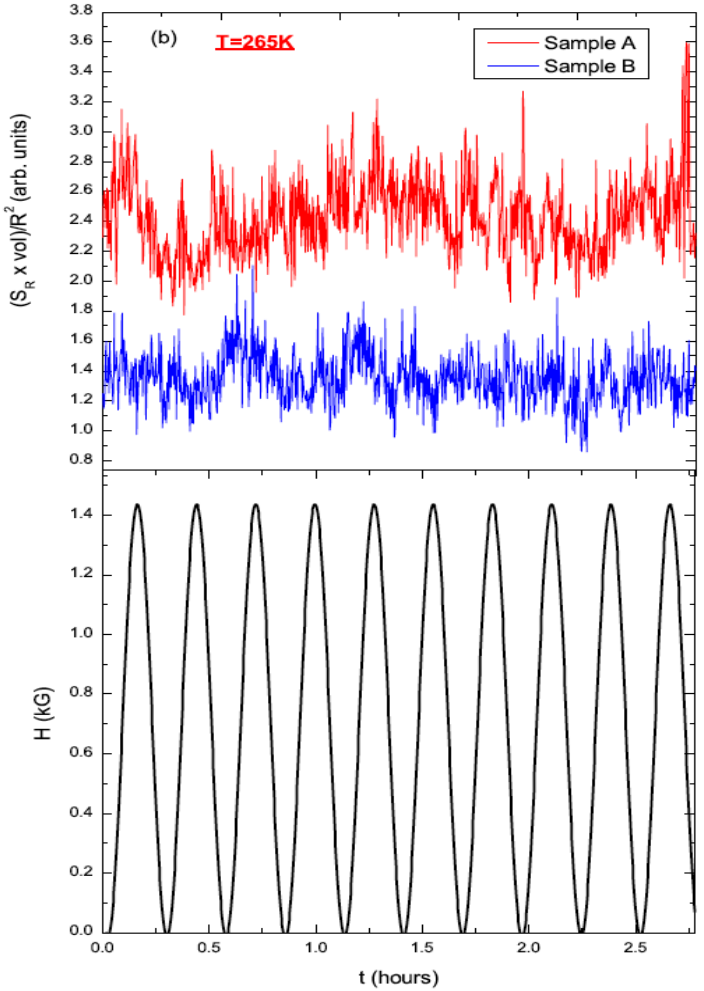


Low Magnetic Field Dependence

H dependence gone above 245 K T

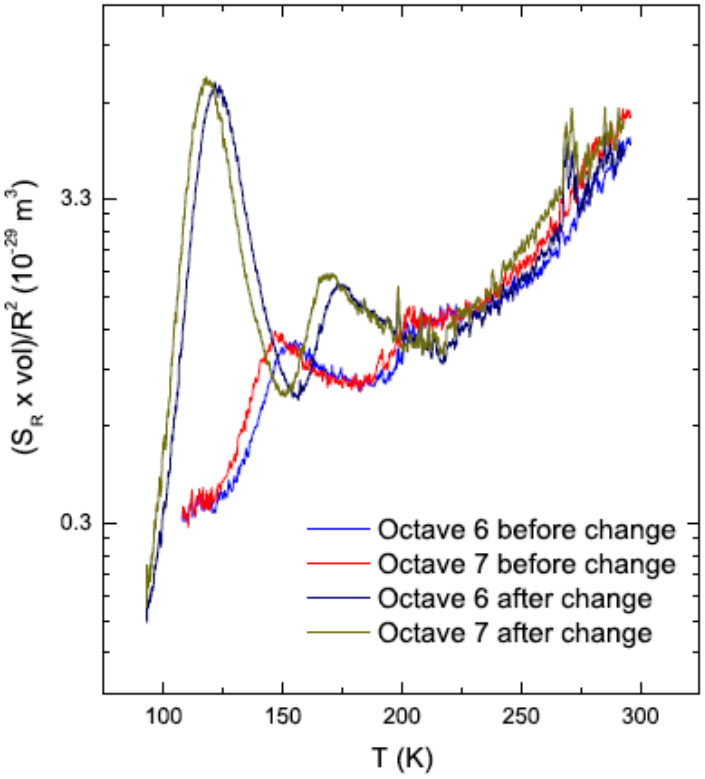


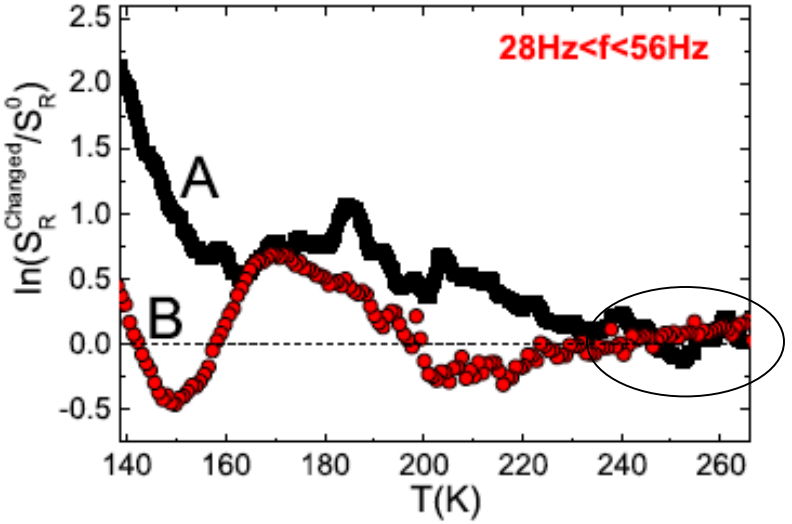




Metastable noise properties

- Samples both lost low-H dependence of noise
- Change in noise power -- only below ~ 230K
- No change in R (<< 1%)

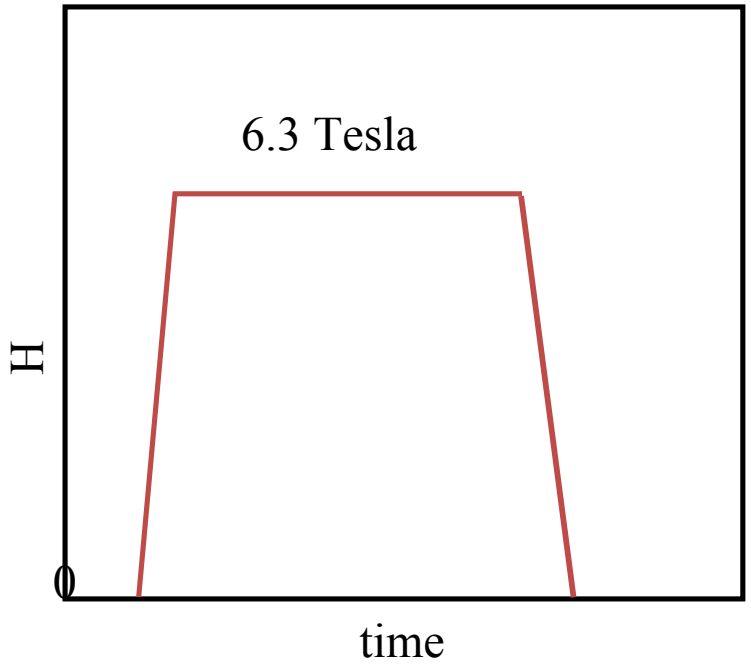


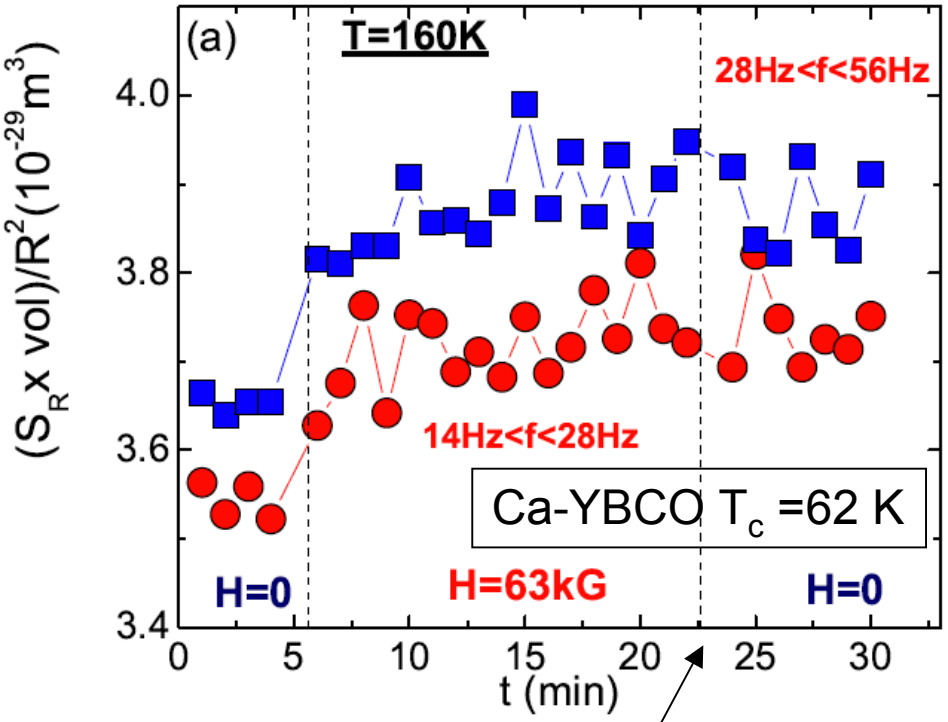


Noise below 240 K is qualitatively different

High Magnetic Field Dependence
Present in most samples, only below 240K

i. Measure noise without field
ii. Apply 6.3 Tesla out-of-plane
iii. Remove field

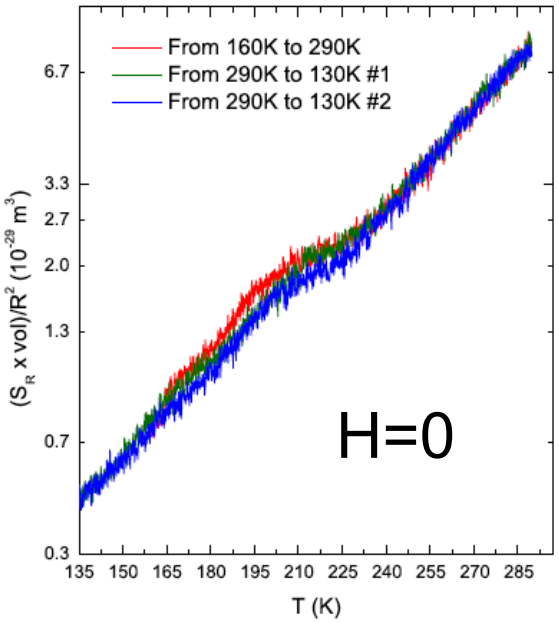




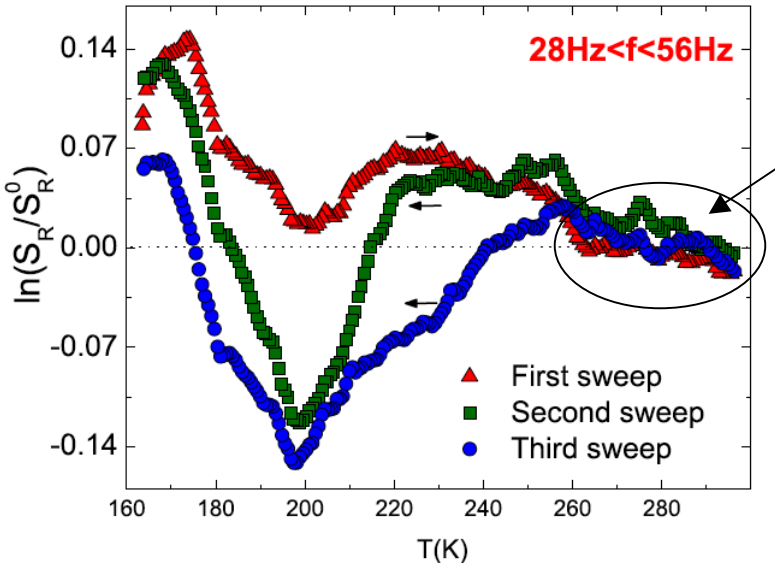
Distinct magnetic noise hysteresis
?Related to Kerr memory seen by Kapitulnik?

Relaxation of Magnetic effects

after field application



- Long time sweeps, dT/dt = 0.3 K/min
- Up to room temperature and down to 160K
- Total time > 18 hours

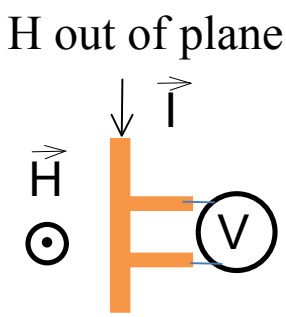


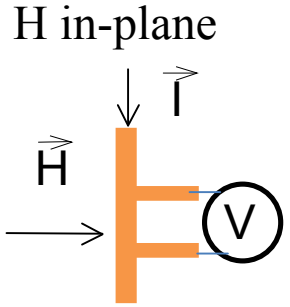
- Effects below 250K,
- Almost none above 250K

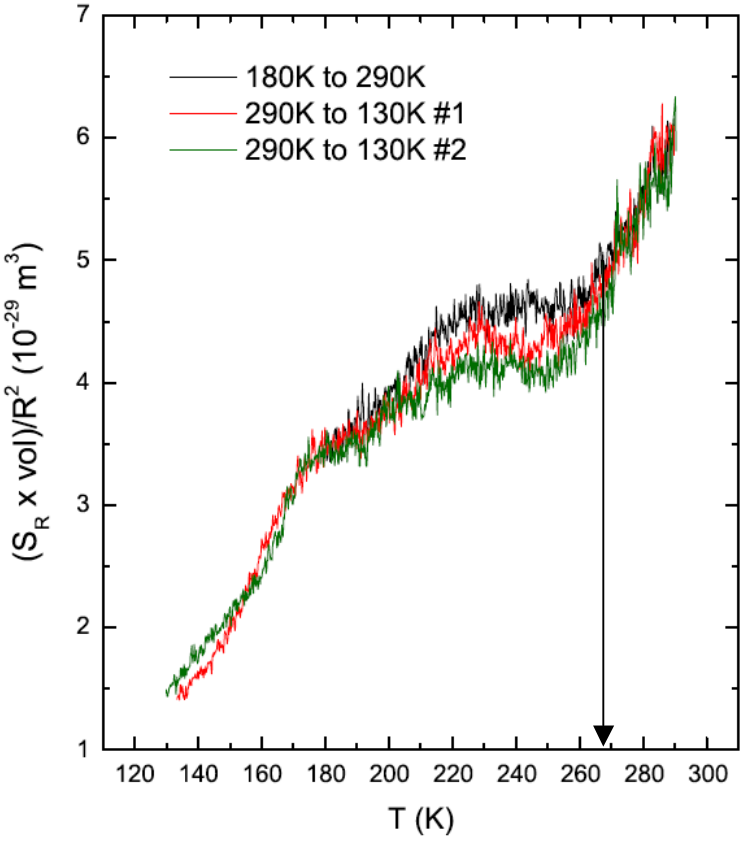
Noise below ~250 K is qualitatively different

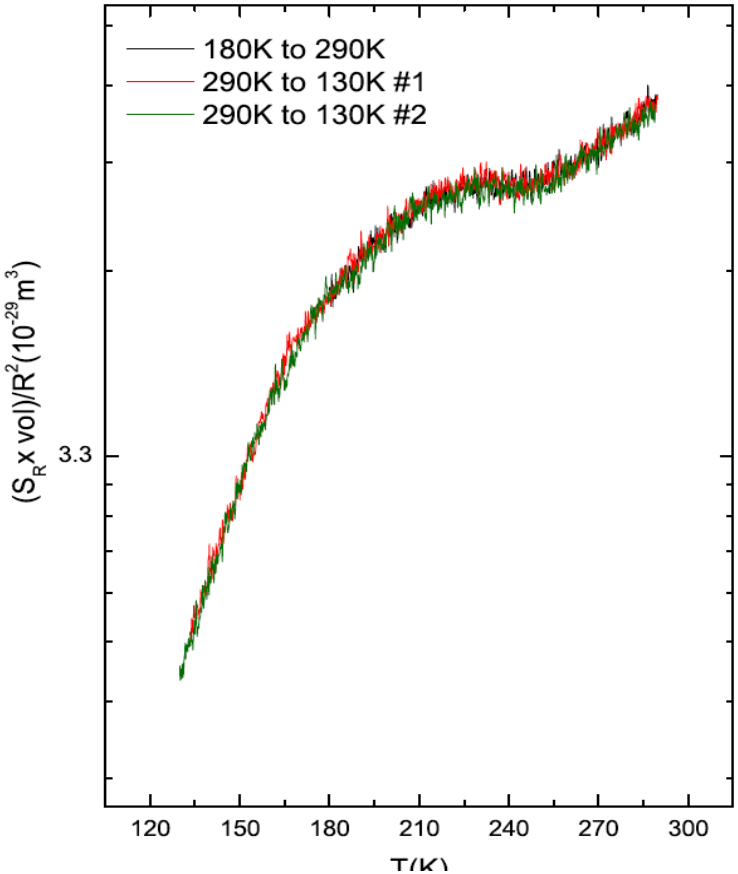
High Magnetic Field Dependence
Only out-of-plane

YBCO sample



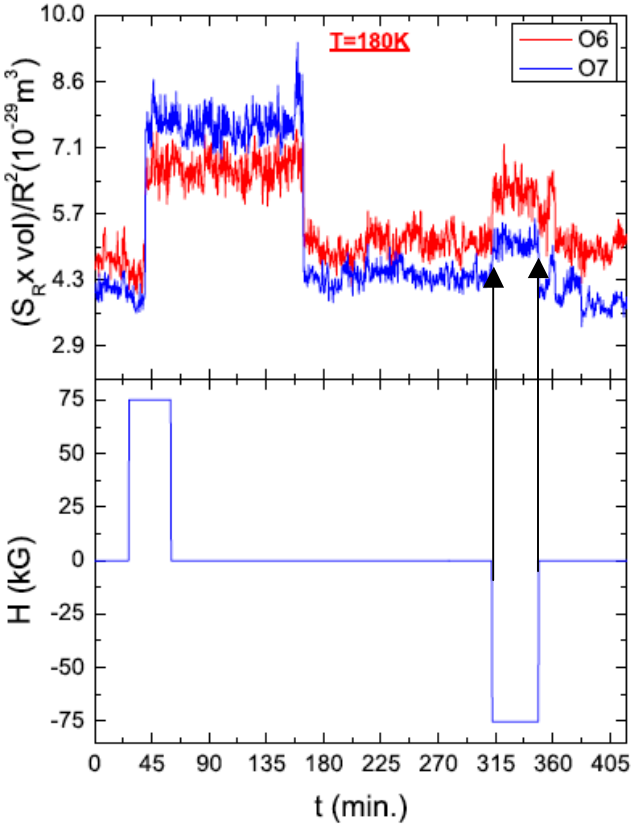




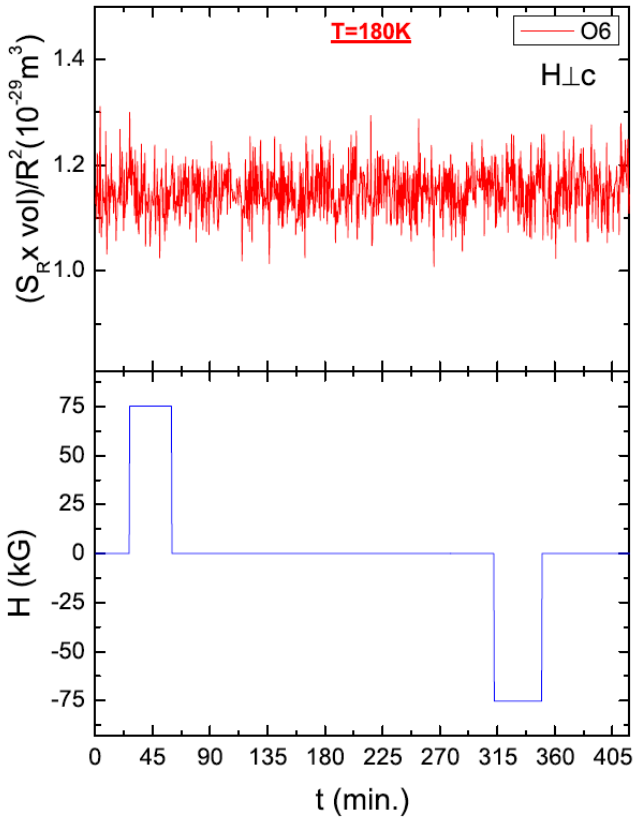


High Magnetic Field Dependence
Some memory effects

- Noise increases for both positive and negative H out-of-plane



- no effect for H in-plane



Individual Fluctuators

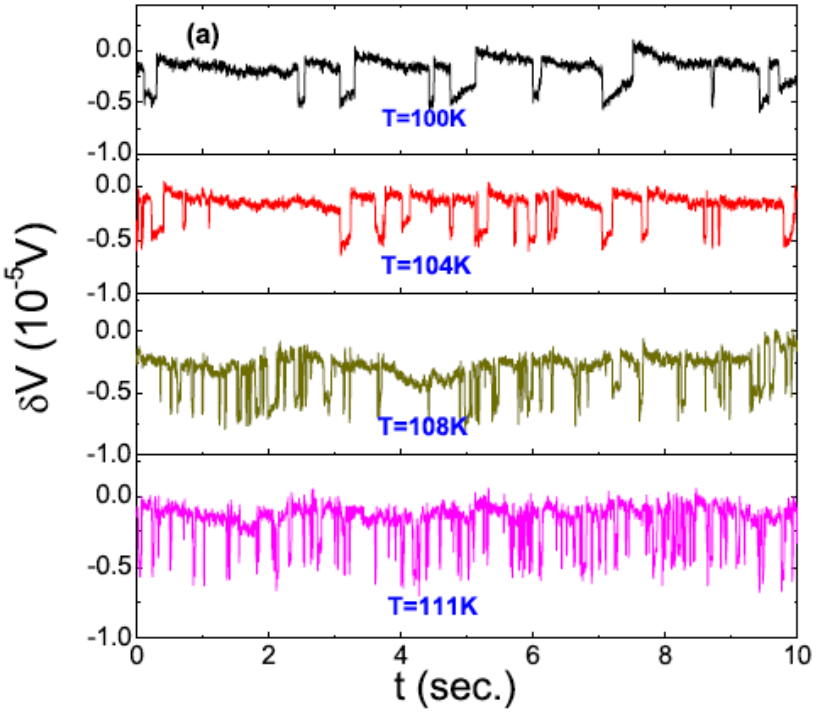
Large fluctuators ($\delta R/R > 10^{-5}$)
seen in almost every sample
only at T < ~ 180K

Point-like defect in homogeneous sample would give $\delta R/R <\sim 10^{-8}$

Implies either:
- large coherently fluctuating regions

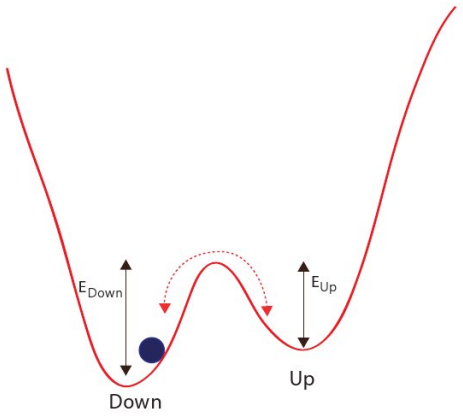
Or
- Strongly inhomogeneous conduction

Either one suggests stripes



Ordinary Arrhenius kinetics

Individual Fluctuator Thermodynamics

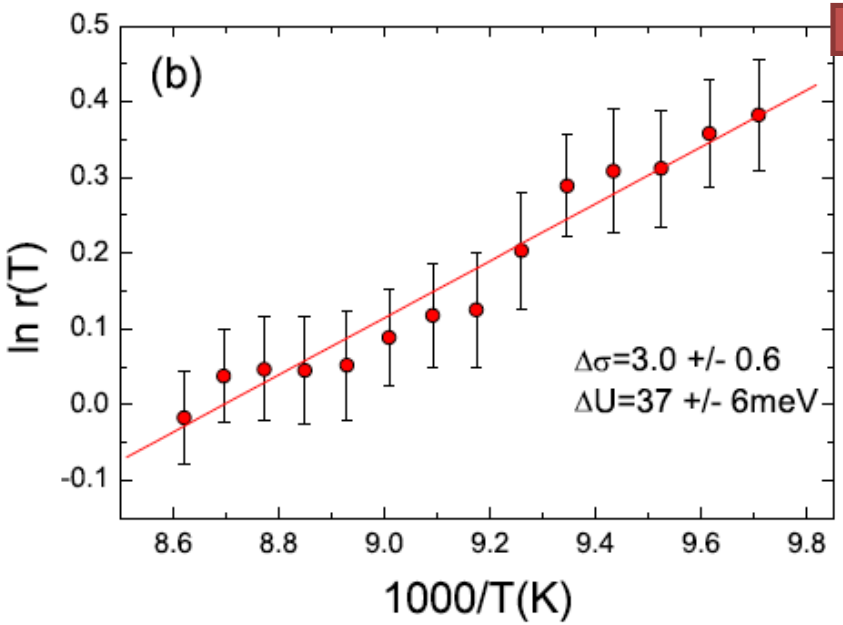


$$r \equiv \frac{\textbf{time}_{\uparrow}}{\textbf{time}_{\downarrow}} = \exp\left[\frac{\Delta F}{k_B T}\right]$$

$$\Delta F = k_B T \ln(r)$$

$$\Delta\sigma = -\frac{1}{k_B}\left(\frac{d\Delta F}{dT}\right)_H$$

$$\Delta U = \Delta F + T\Delta\sigma$$



$$0 < |\Delta\sigma| < 10$$

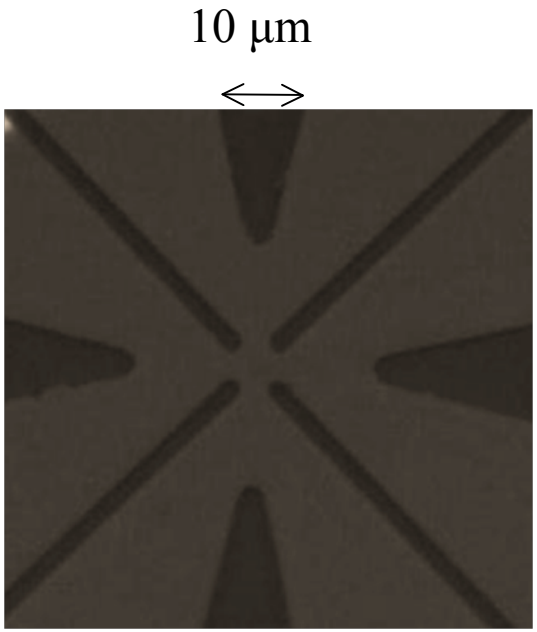
Scalar quantities (U, S) change -> Not pure rotations

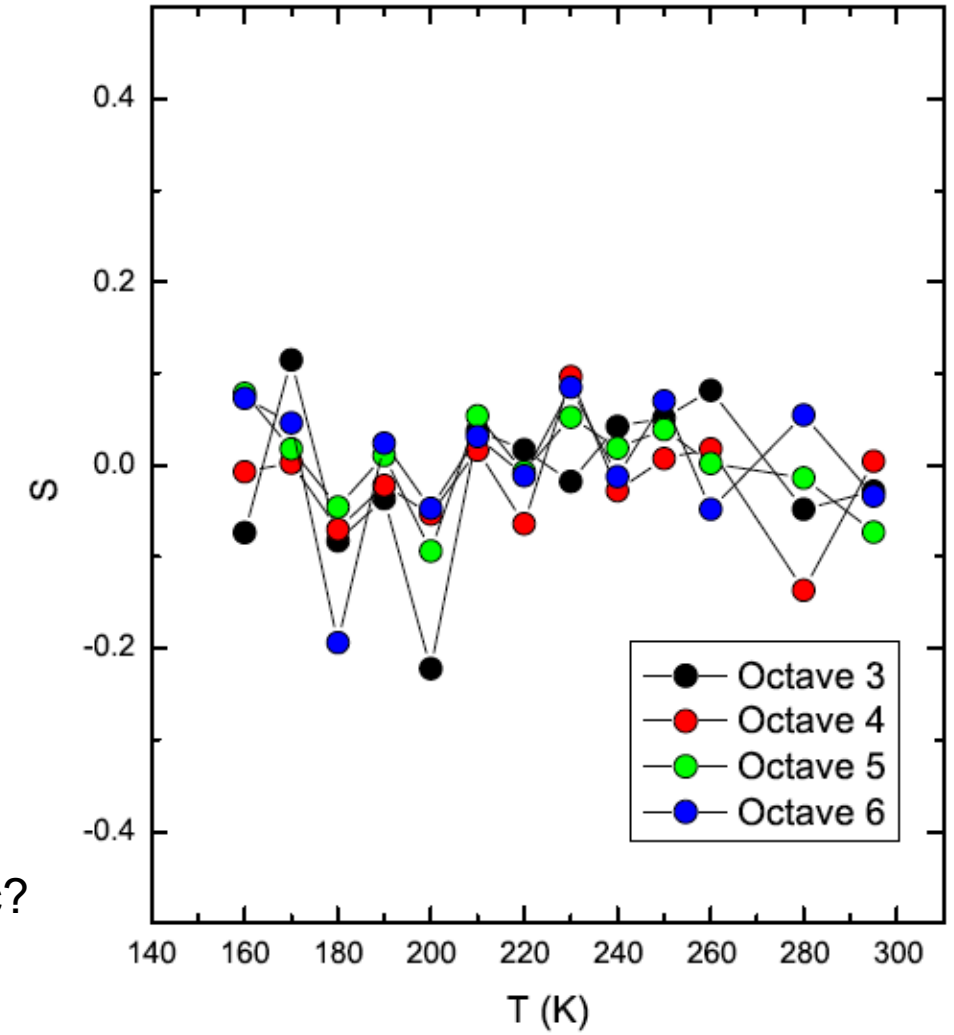
Small changes in scalars suggest *almost* rotations, not fluctuations between distinct phases

Like domain rotations in manganites in asymmetrical environment

Resistivity Fluctuation Tensor Properties

$$S \equiv \frac{\langle Det(\rho_2) \rangle}{\langle Tr(\rho_2^2) \rangle} \qquad -1 \le S \le 1$$





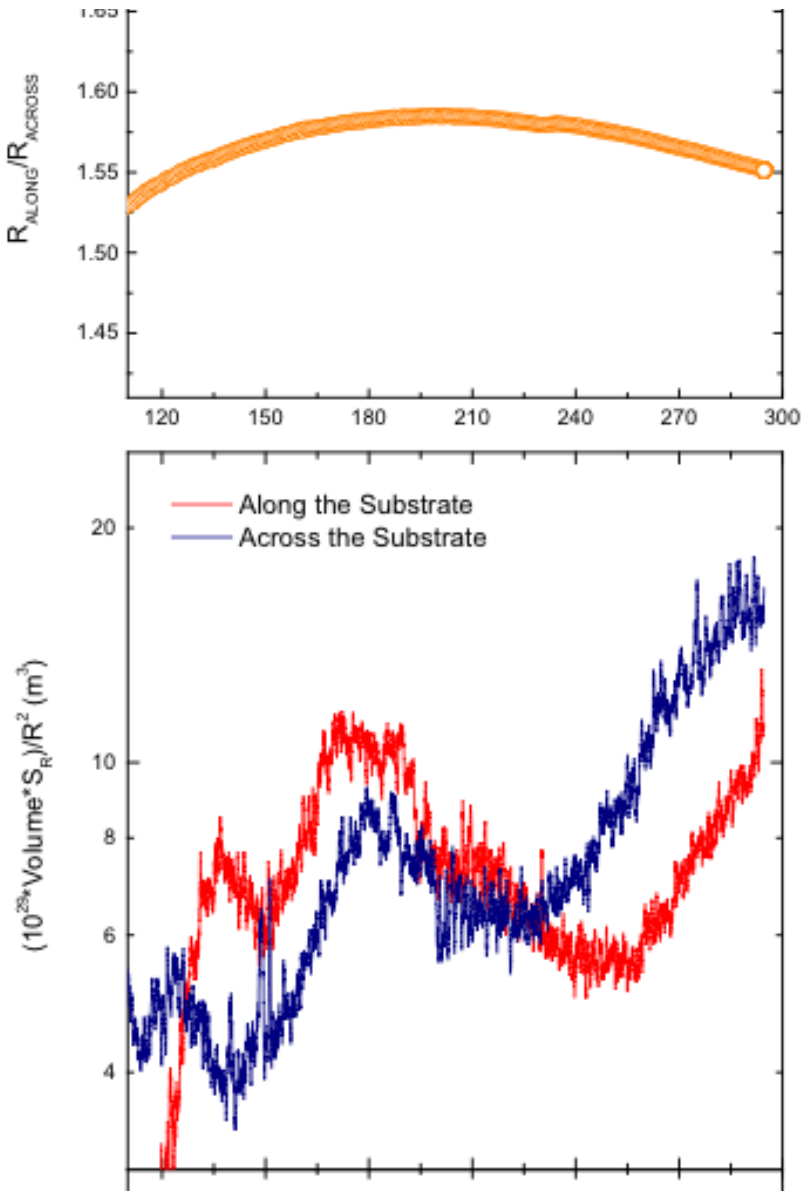
- S≈0. NOT pure rotations.
- More like mayonnaise than nematic?

Stripes are supposed to ~align with twins

Possible role of twin anisotropy?

“untwinned” sample ~85% oriented

Noise similar but not identical along two orientations



Conclusion: A dilemma

Below ~ 250 K the noise shows qualitative features expected for a disordered collective state (e.g. pinned stripes)

1. large fluctuators
2. memory and aging effects

+ a pointer toward *electronic* correlations (as opposed to structural ones)

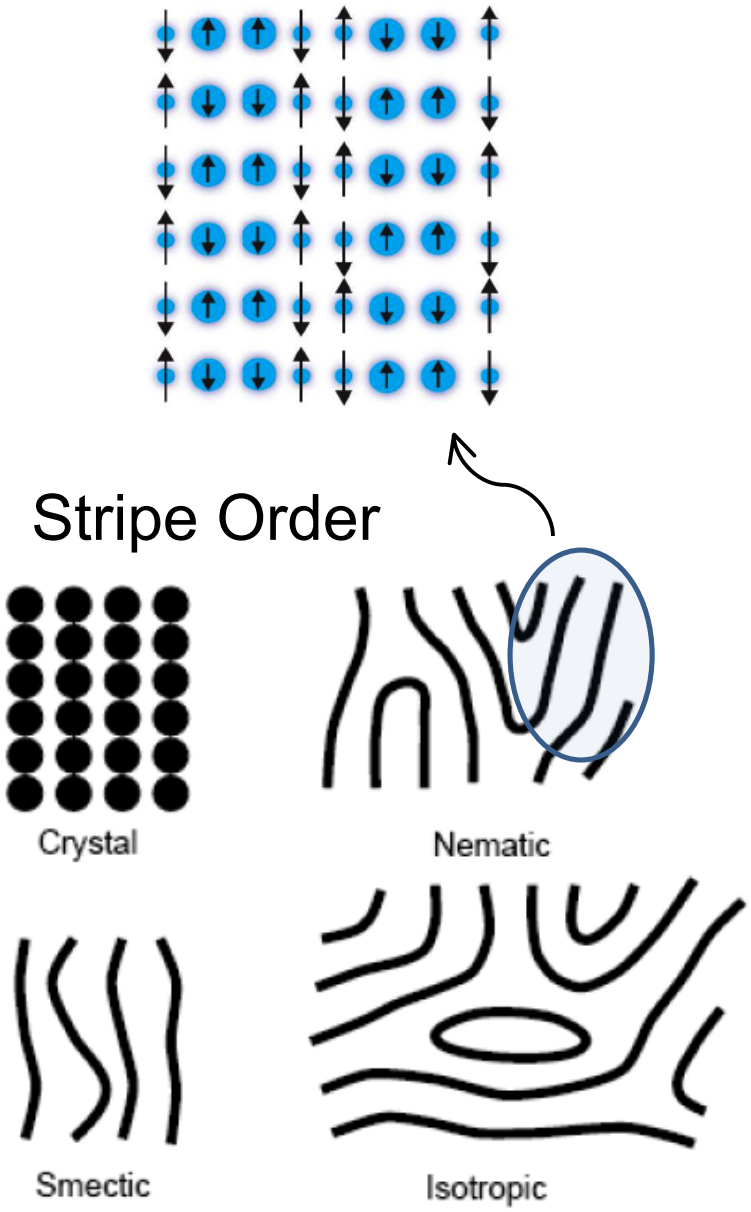
3. magnetic sensitivity (with memory)

But the onset of such regimes with noise from disordered collective states (spinglasses, pinned SDWs, relaxor ferroelectrics in all other cases looks non-Arrhenius (phase or glass transitions)

This onset at ~T_P looks like just a maximum in a distribution of fixed barrier heights?

What gives?

Possible Noise Mechanism: dynamic charge stripe domains



- If indeed due to stripe order, something must be slowing the dynamics

- We suggest pinning to defects

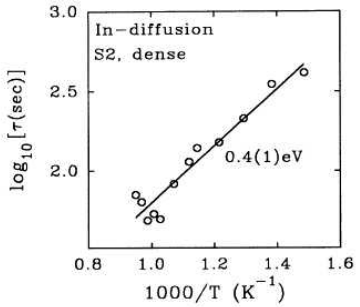
Toward a model

Usually spinglass or pinned SDW etc sets in with fully quenched chemical disorder.

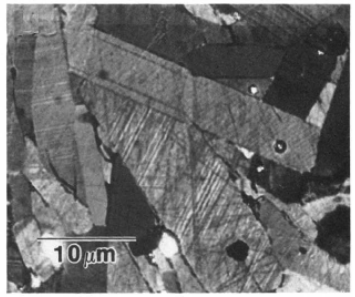
T* is pretty high.

In some places, O can move around in YBCO at low T: 0.4 eV activation energy!

David Payne, 2003



(a)



(b)

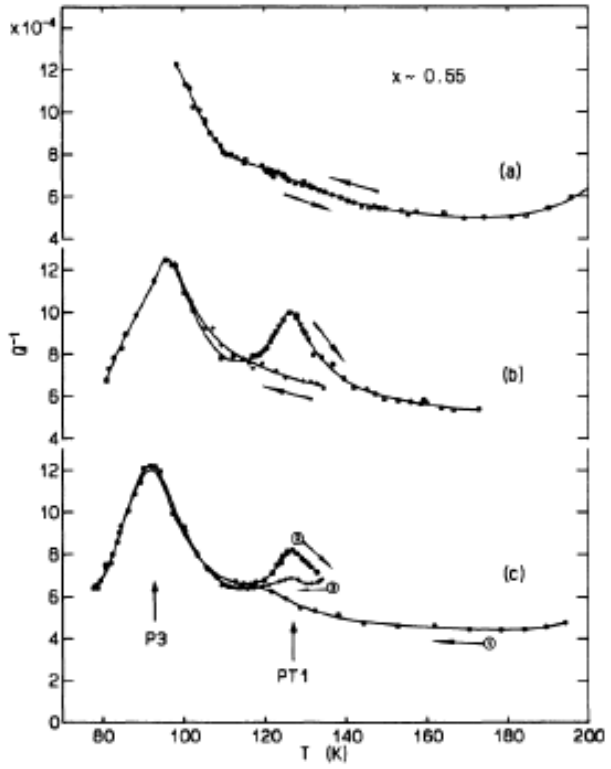
Maybe below 250 K we're seeing stripes switching around
on an essentially fixed background disorder.

Above 250 K we're seeing noise of a pattern partially averaged over some un-quenched disorder, mobile for our (f, T).

Temperature Dependent Hysteresis Of low frequency dynamics

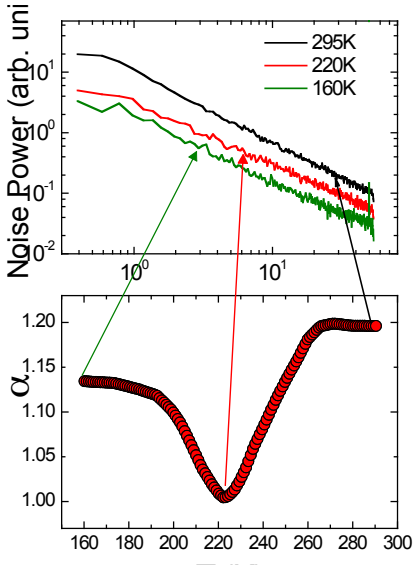
- Internal friction measurement (Cannelli 1992)

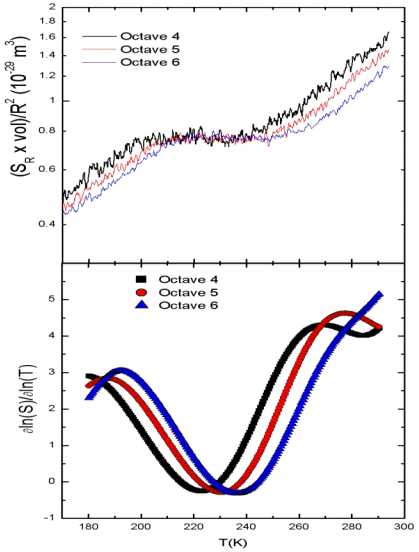
- Low-f internal friction picked up a new feature after cooling to T_C



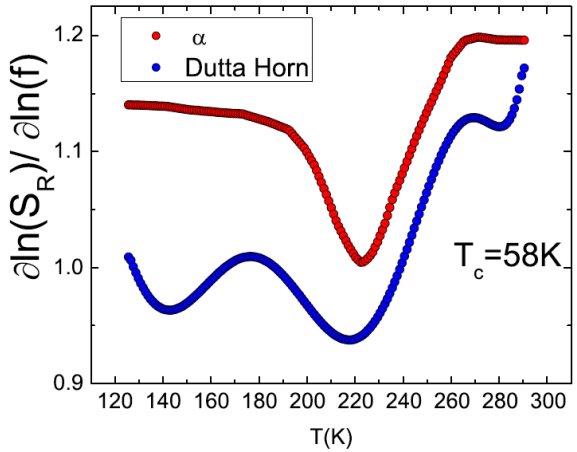
Other IF measurements pick up a variety
Of features in our (f,T) range

Dutta-Horn Model





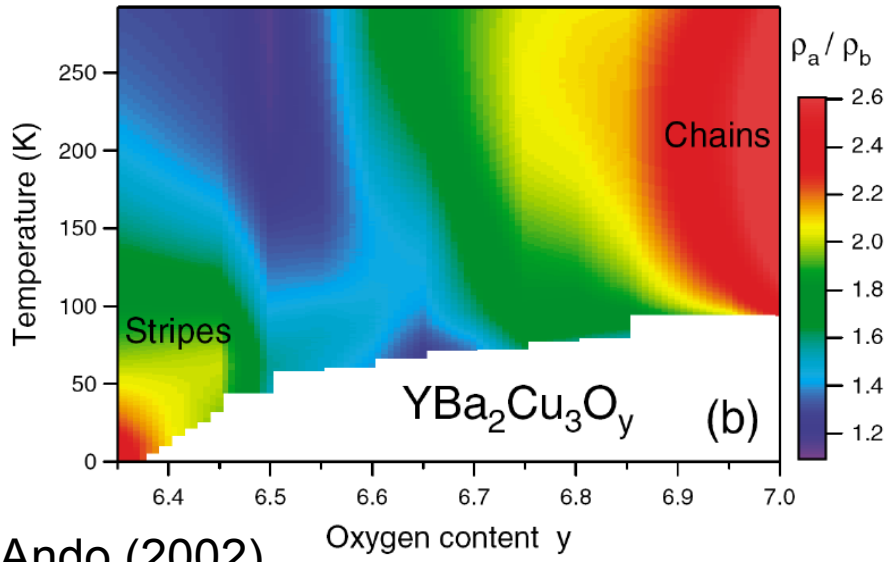
$$-\partial \ln S_R / \partial \ln \omega = 1 + \frac{1}{ln(\omega \tau_0 / 2\pi)} (\partial \ln S_R / \partial \ln T - 1)$$



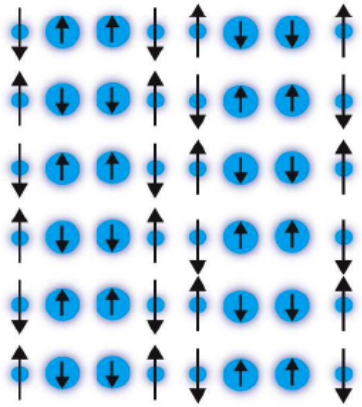
Eduardo's picture: charge stripe domains

• Charge stripes: good AF state has wrong charge density , Coulomb repulsion limits range of charge separation→ small-scale inhomogeneity

•channels with higher carrier density → anisotropic transport

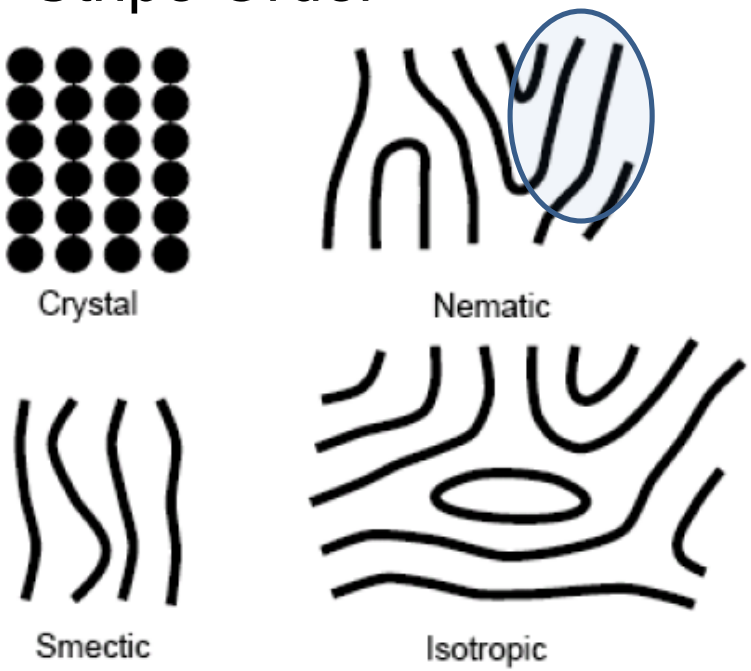


Ando (2002)



Stripe Order

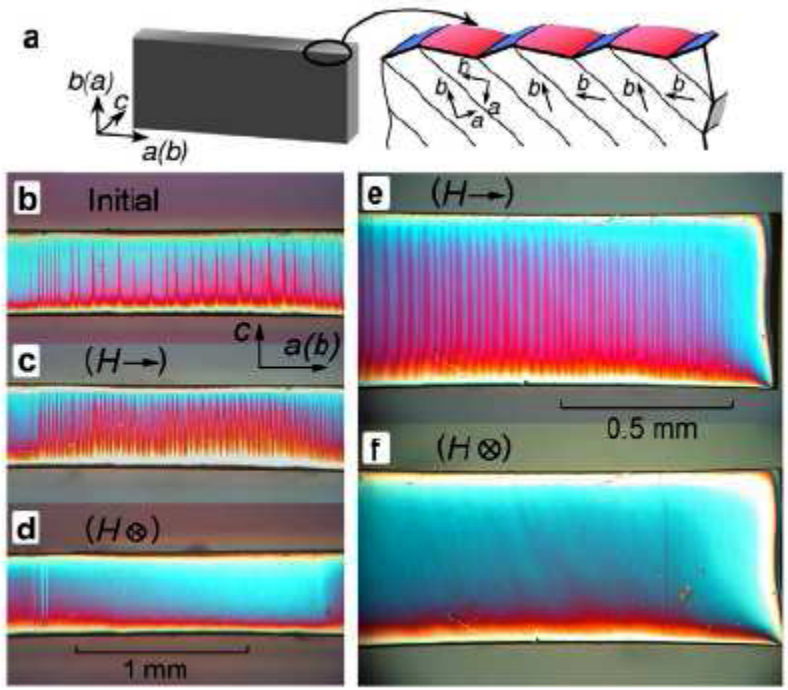
Dynamic or static?



•Like other density waves pinned by disorder, should show low-frequency switching between metastable states.

Twin Alignment

Lavrov *et al.* Nature (2001)

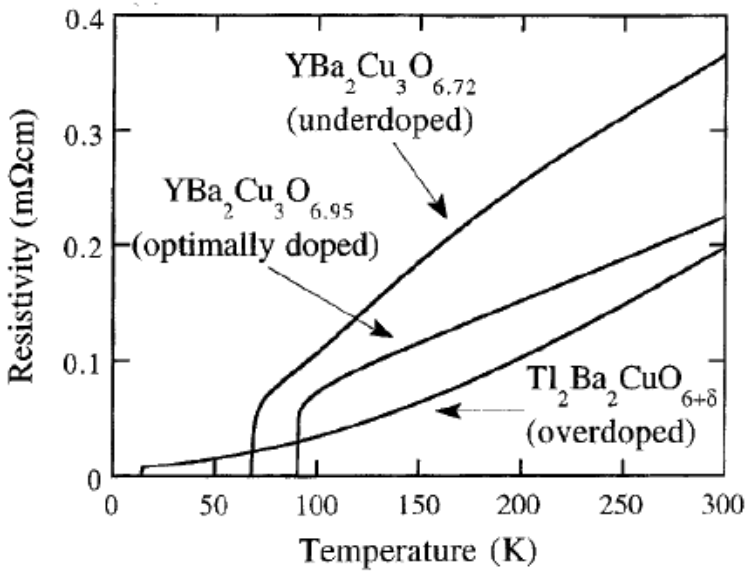


Untwinned LBCO

- LSCO shows anisotropy in magnetic susceptibility -- Lavrov *et al*. PRL (2001)
- Can align twins with high enough field
- suprisingly mobile twins, i.e. low Ea

Resistance and Doping (Ando 2002)

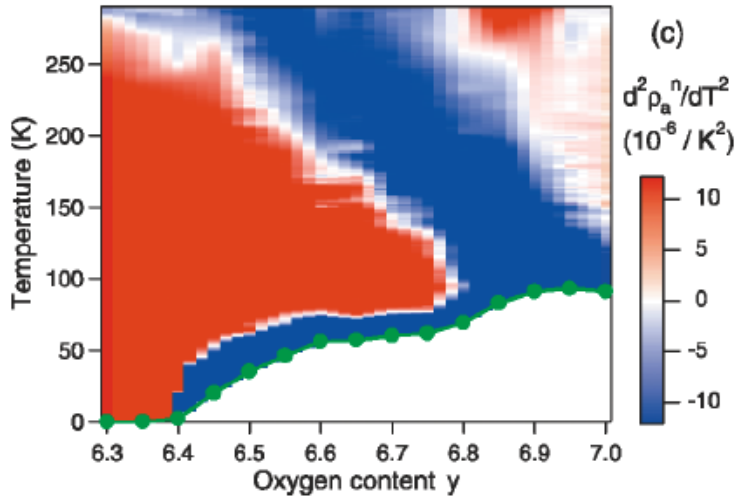
- PG shows up in $\rho_{ab}(T)$
- S-shaped curvature
- Universal to cuprates



(a)

There is underlying order associated With the PG

- STM shows inhomogeneities
- Neutron and X-ray scattering show AF and charge ordering



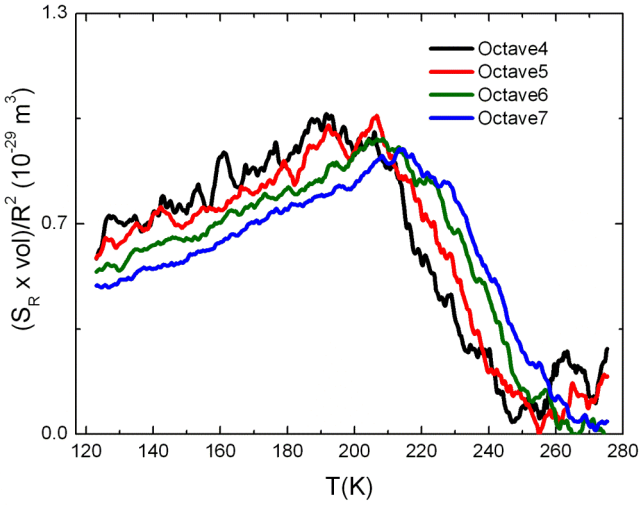
(b)

Noise Frequency Dependence

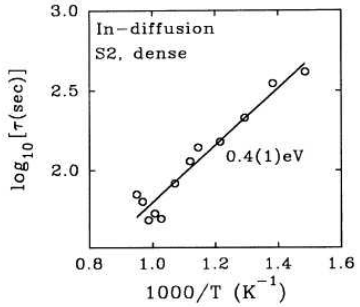
- Arrhenius dependence

$$f_p = f_0 e^{-\Delta E / k_B T}$$

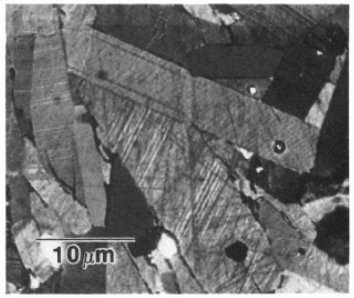
$$\Delta E \sim 0.4eV$$



Transport Diffusion Measurement

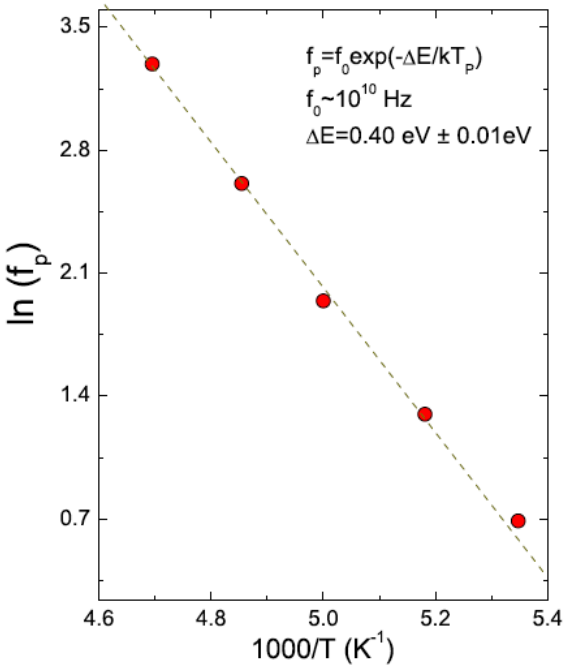


(a)



(b)

Payne (1993)



- Only in “grainy” YBCO
- E_a =0.4 eV
- Associated with extended defects (possibly twins)