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Workshop on Supersolid 2008

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Observations on supersolid phenomena using compound torsional oscillator

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Observations on Non-Classical Behaviour of Solid ^{4}He with Compound Torsional Oscillator

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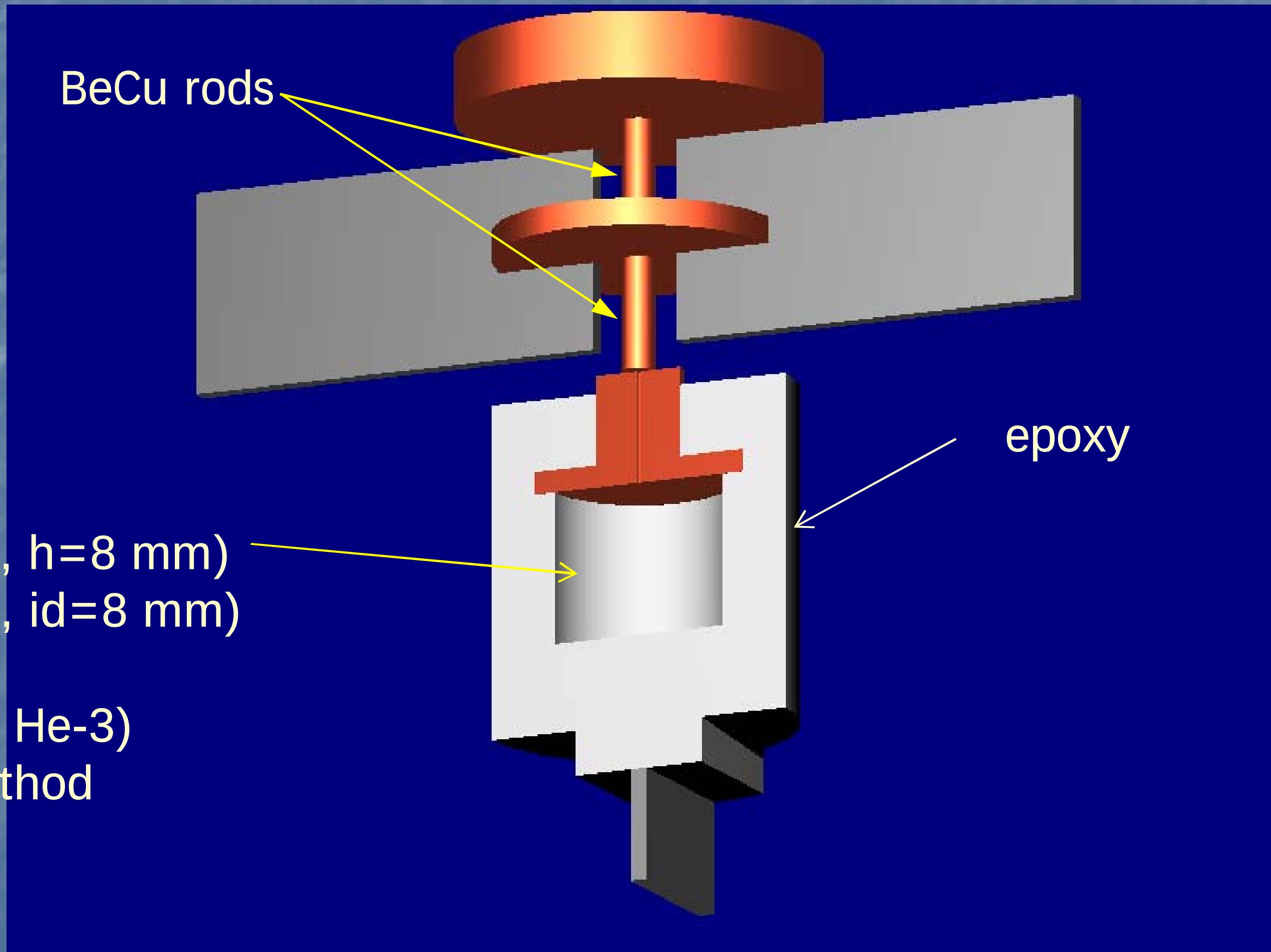
Compound Torsional Oscillator

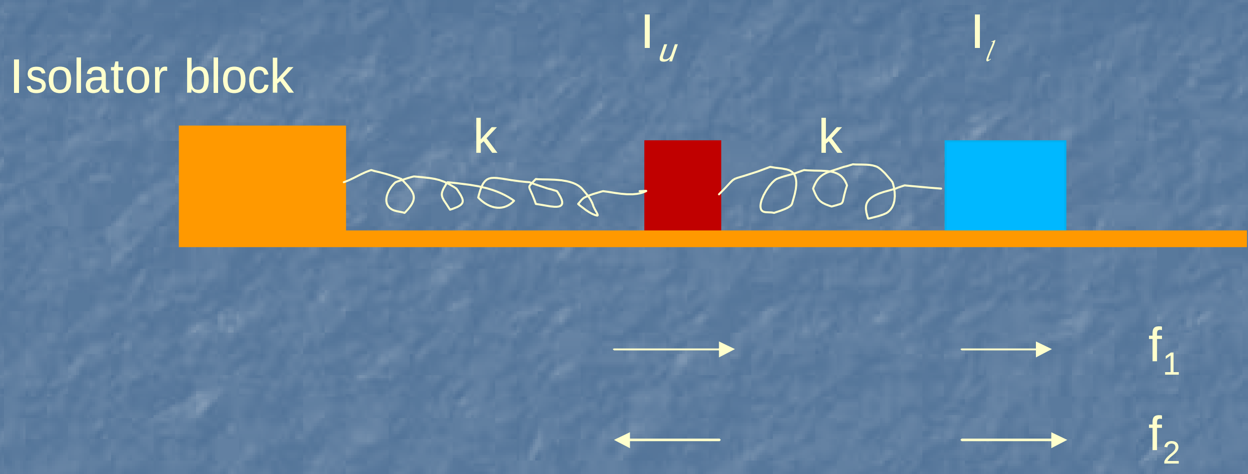


Sample chamber:
cylinder (od=10 mm, h=8 mm)
annulus (od=10 mm, id=8 mm)

He-4 (nom. 0.3 ppm He-3)
Blocked capillary method

f1(in phase motion) ~ 0.5 kHz, Q ~ 1.3M   f2(out phase) ~ 1.2 kHz, Q ~ 0.5M

Analogy to coupled oscillator



$$f_{1,2} = \frac{\sqrt{K}}{2\pi}\sqrt{\frac{I_u + 2L_l \pm \sqrt{I_u^2 + 4I_l^2}}{2I_u I_l}}$$

assuming the same torsion constant for both rods

Why Compound Torsional Oscillator?

I. probing NCRI of identical solid ^{4}He at 2 frequencies

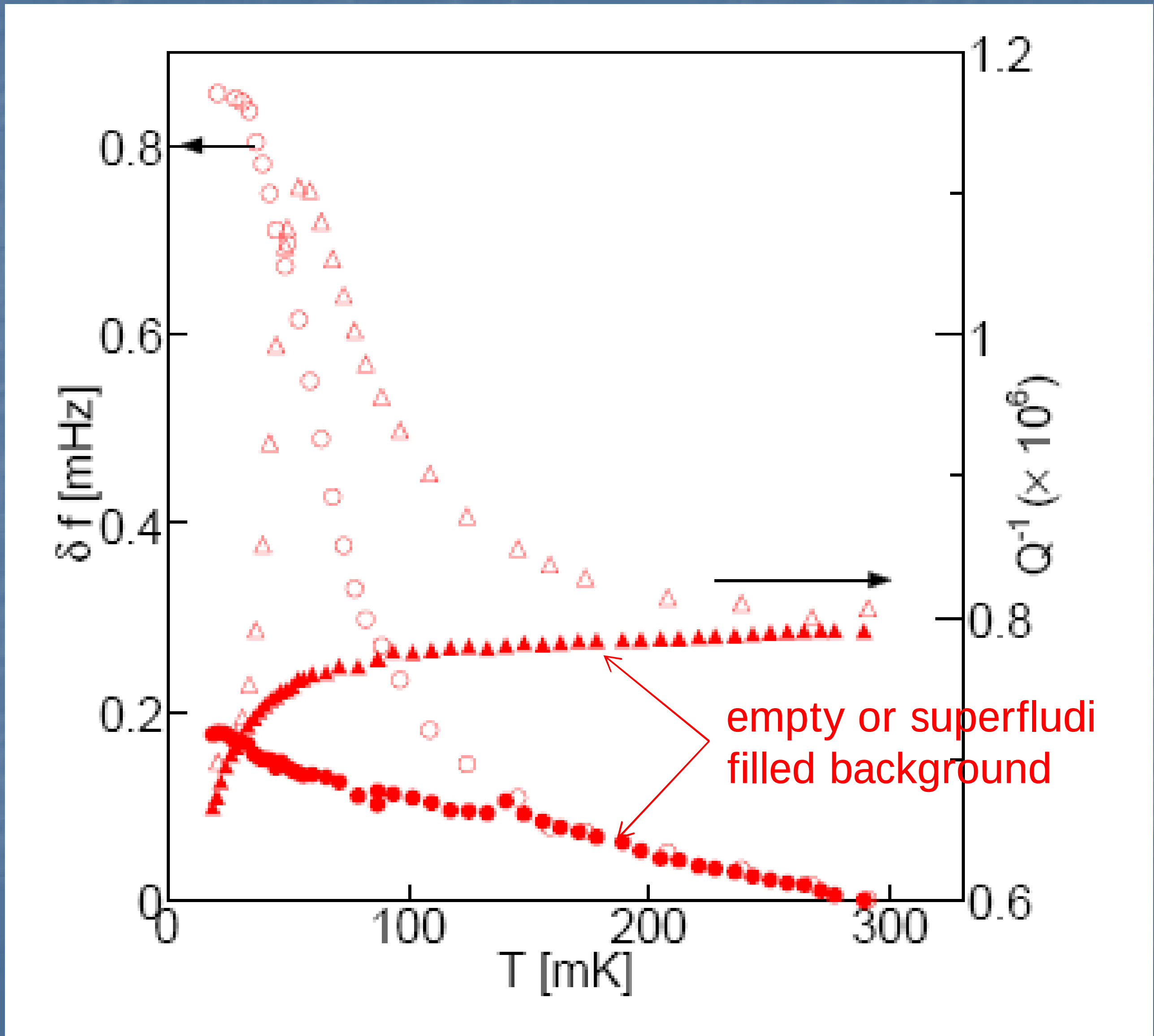
- "simple" superfluid behavior?
- critical displacement, velocity or acceleration?
- glassy solid ^{4}He (Nussinov, et al, Phys. Rev. B 76, 014530(07))
- vortex liquid (Anderson, Nature Physics 3, 160(07), Schevchenko, LTP(88))
- KT-like "film" flow along grain boundaries (Gaudio, et al(08))

II. Simultaneous drive both modes

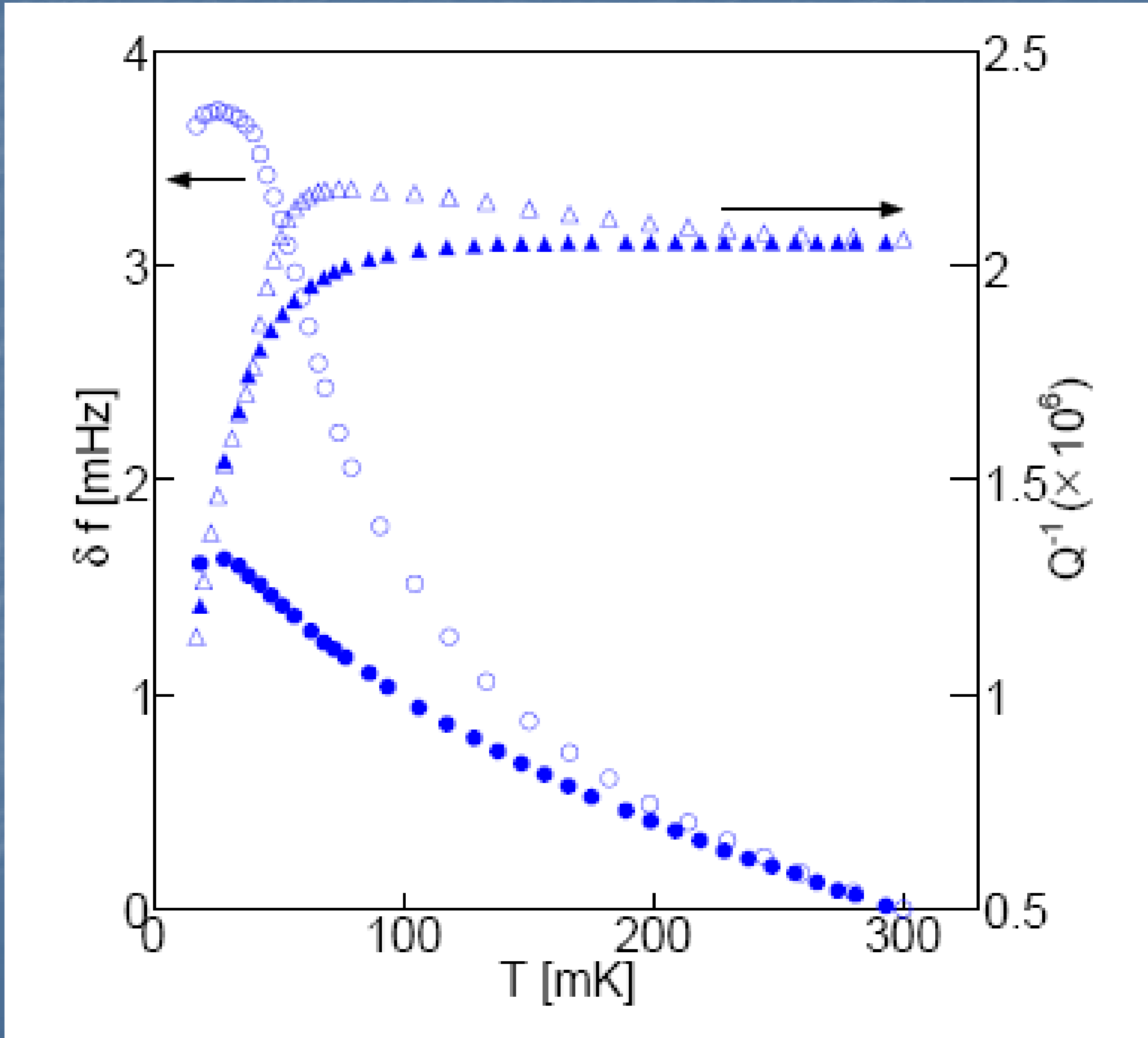
III. geometry dependence ? cylinder and annulus

Hysteresis and relaxation dynamics effects

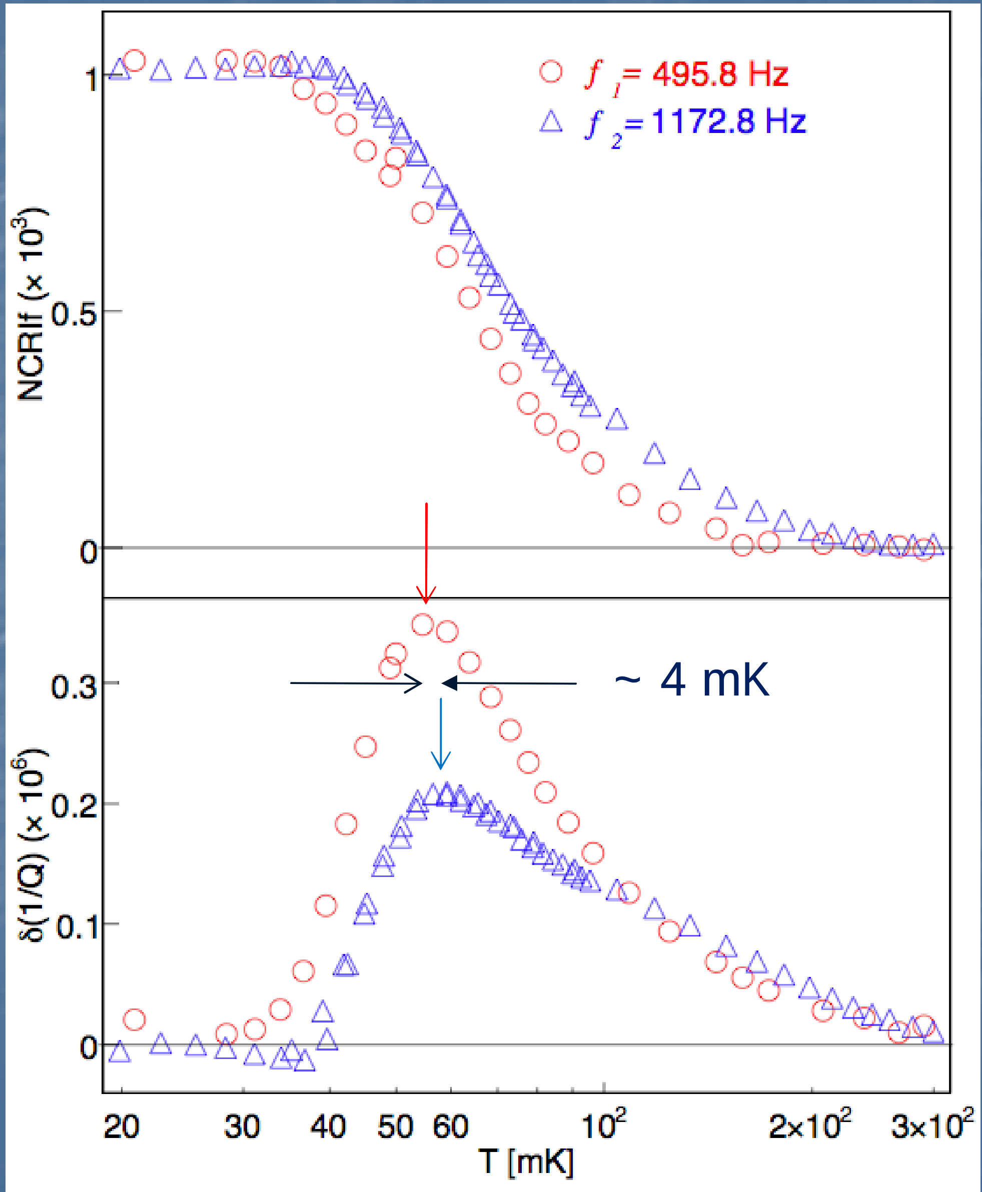
f_1 mode (496 Hz), cylinder



f_2 mode (1.2 kHz), cylinder



NCRI fraction and Dissipation



<u>Cylindrical sample</u>

(10 mm diam,8 mm high)

rim velocity < 20 μm/s

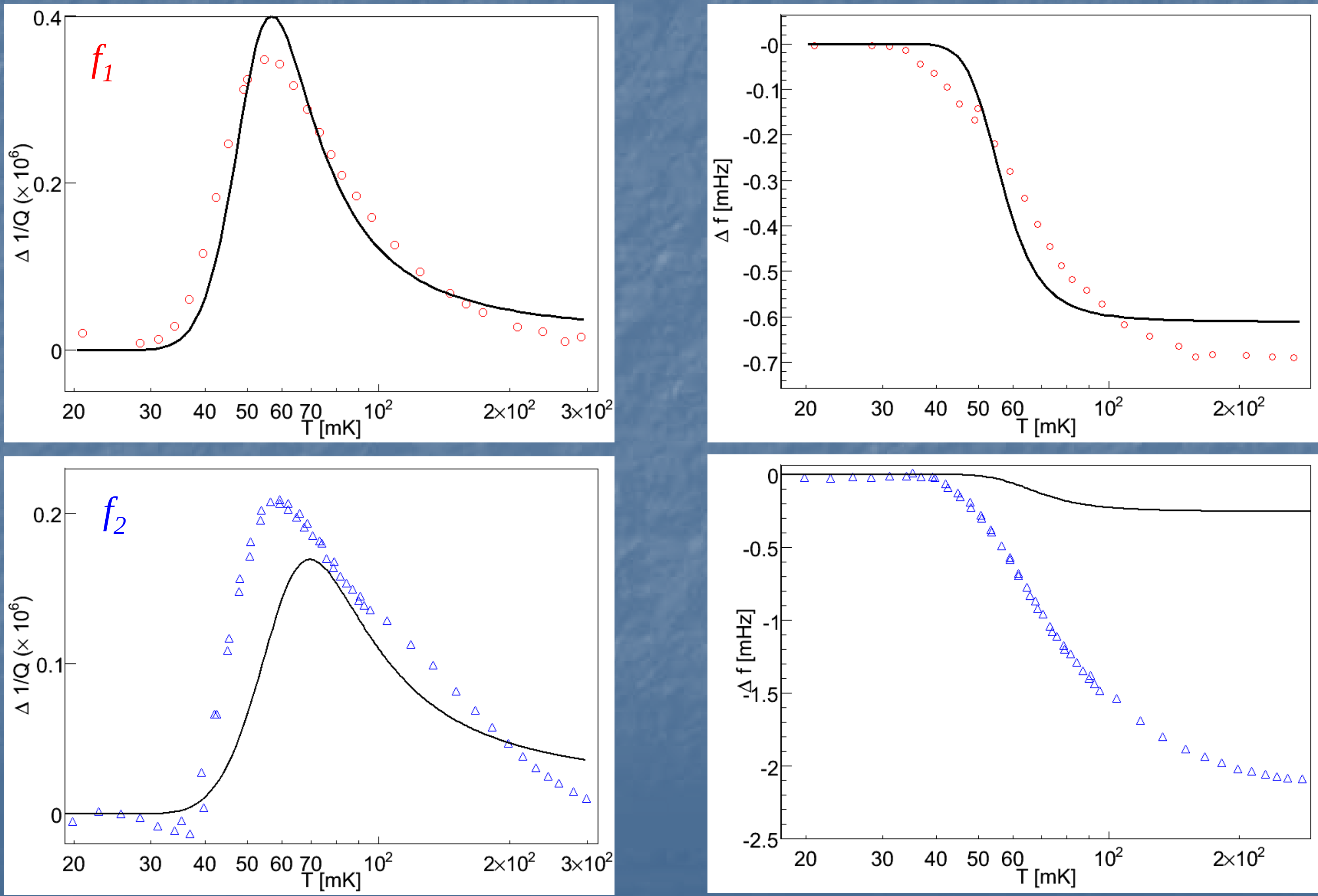
P = 37 bar

Blocked capillary growth

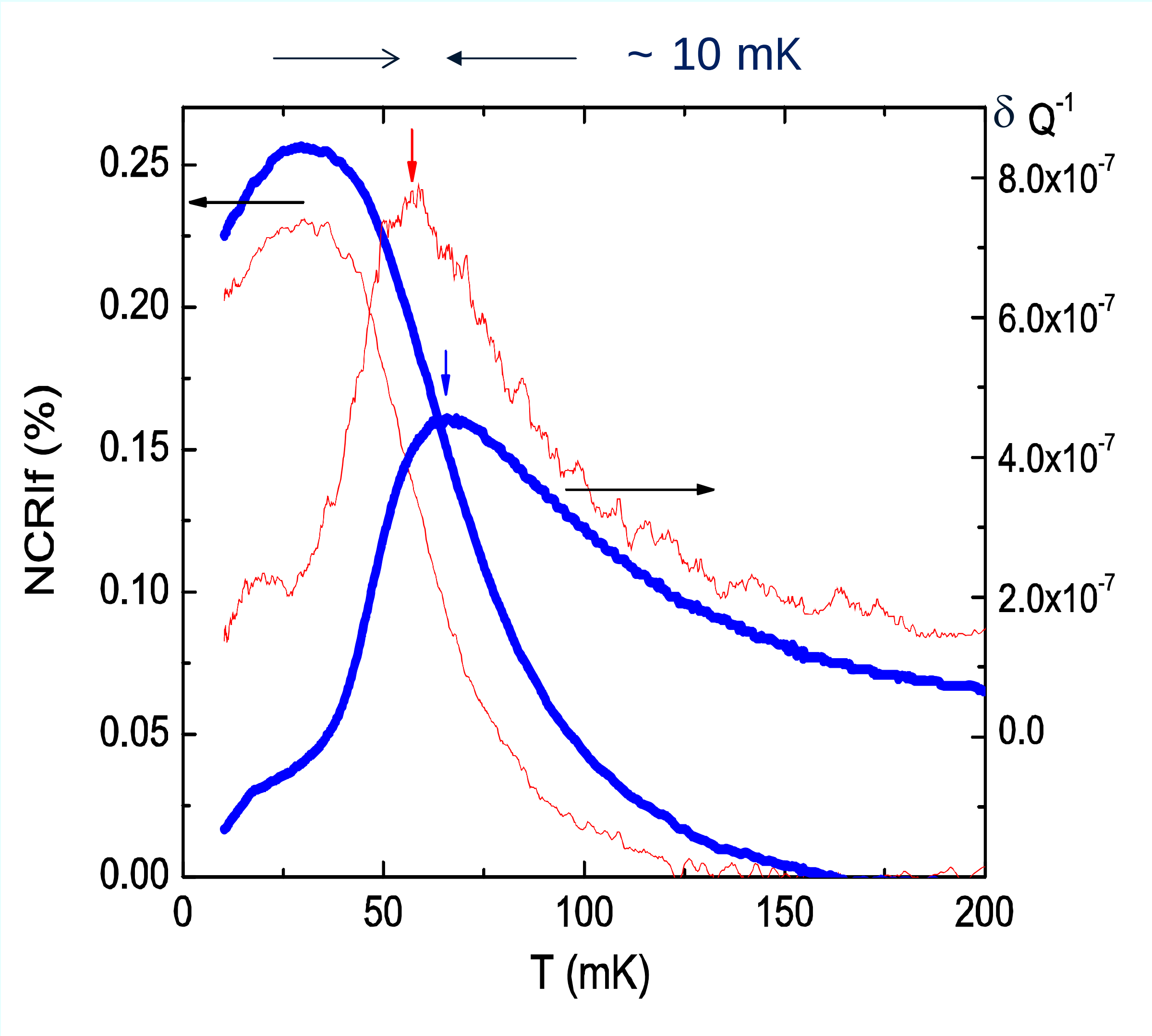
No annealing, T < 350 mK

$$\Delta Q^{-1} = \frac{As}{1+(2\pi f_0 s)^2} \qquad s = s_0 \exp(D/(T-T_0)) \qquad \Delta f = \frac{1}{f_0 - \frac{B}{f_0[1+(2\pi f_0 s)^2]}}$$

S_0 = 8.63 μs, D = 147.66 mK, T_0 = 15.92 mK, A = 2.49678x10^{-3} s^{-1} B=3.03371x10^{-1} s^{-2}



NCRI fraction and Dissipation



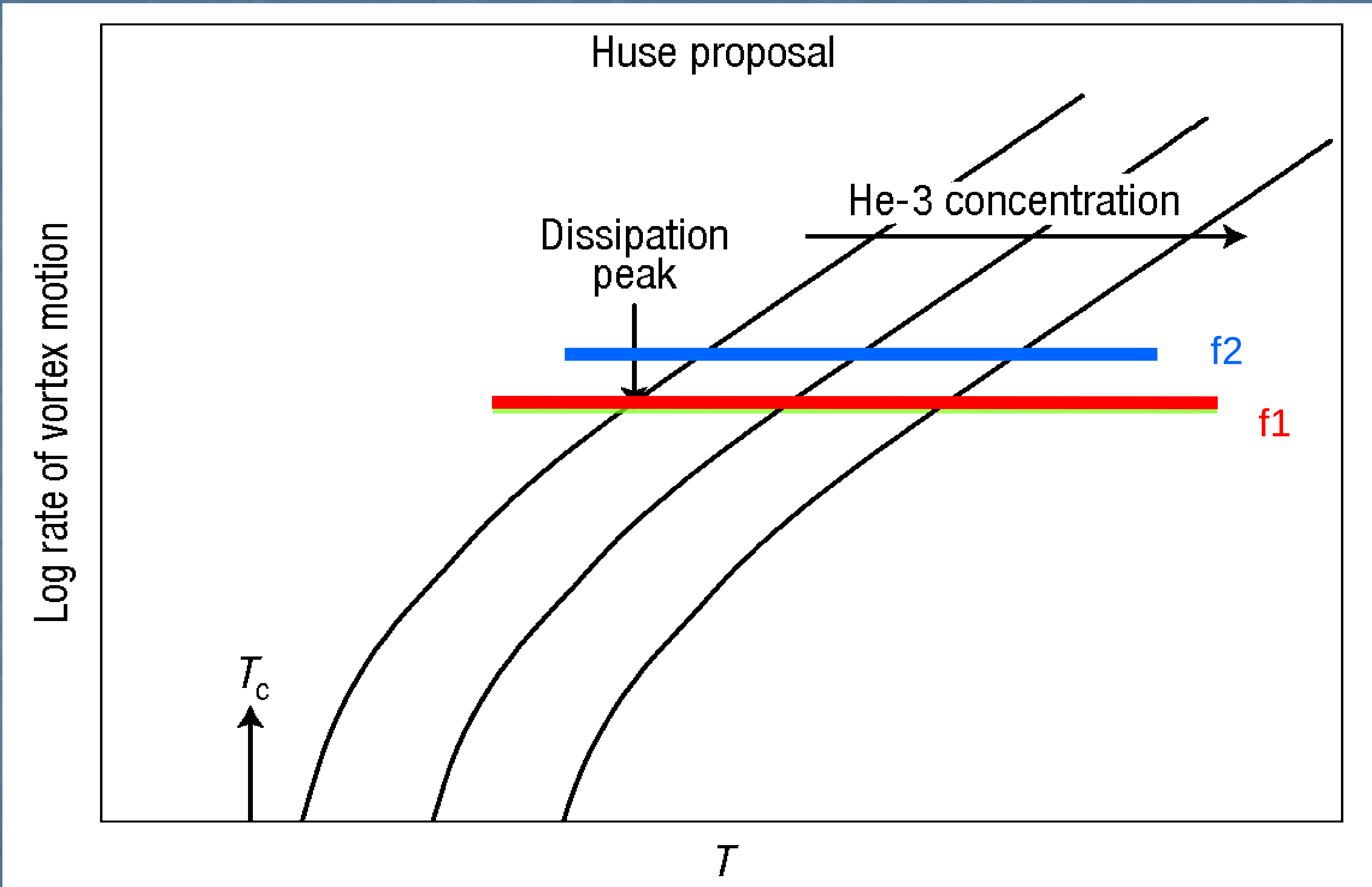
Annular sample

8 mm inner diam
10 mm outer diam
P = 42 bar
Blocked capillary growth

simultaneous low drive

vortex liquid model – dissipation response

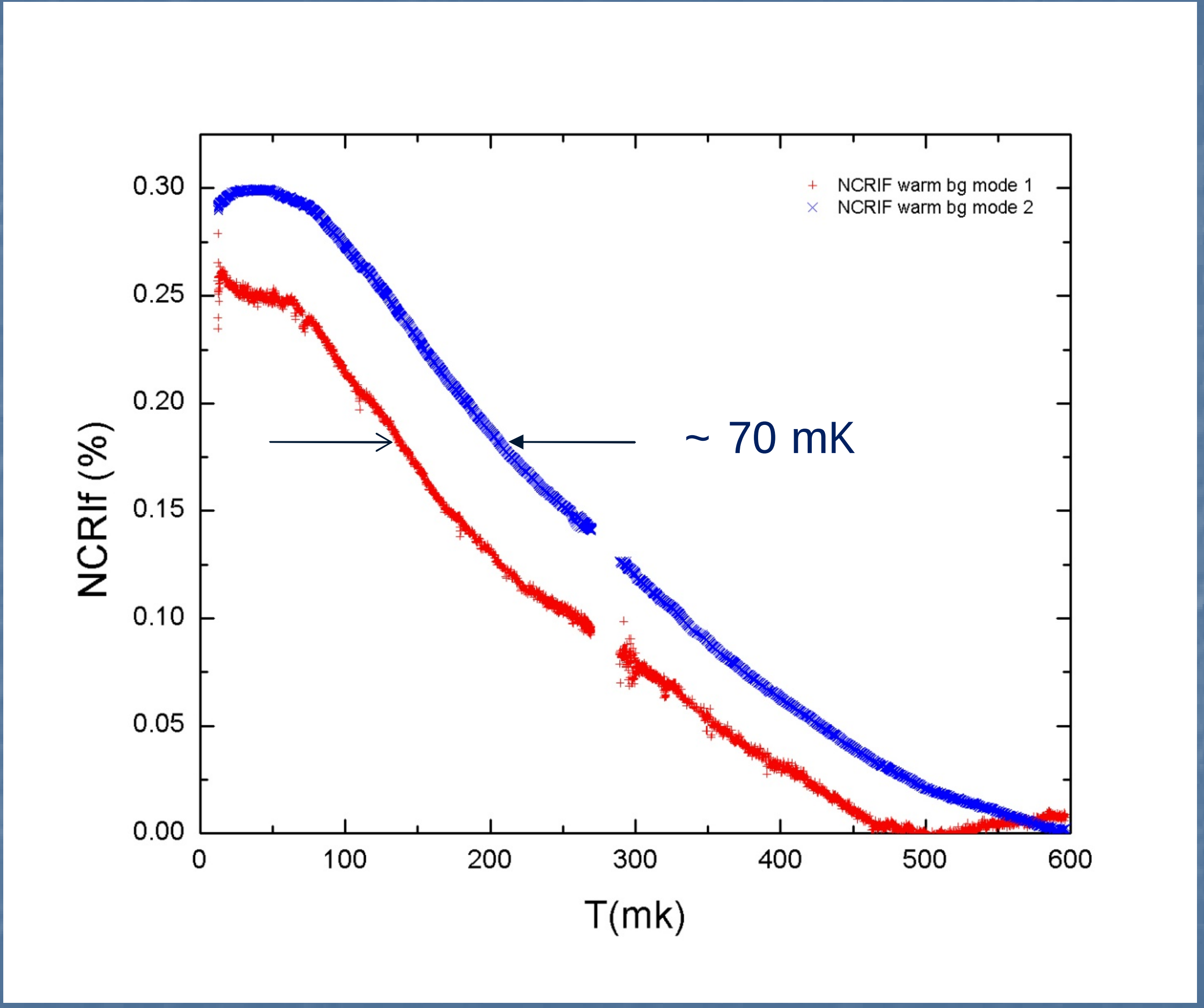
Anderson (Nature Physics 3, 160(2007))



“real” supersolid at T < Tc

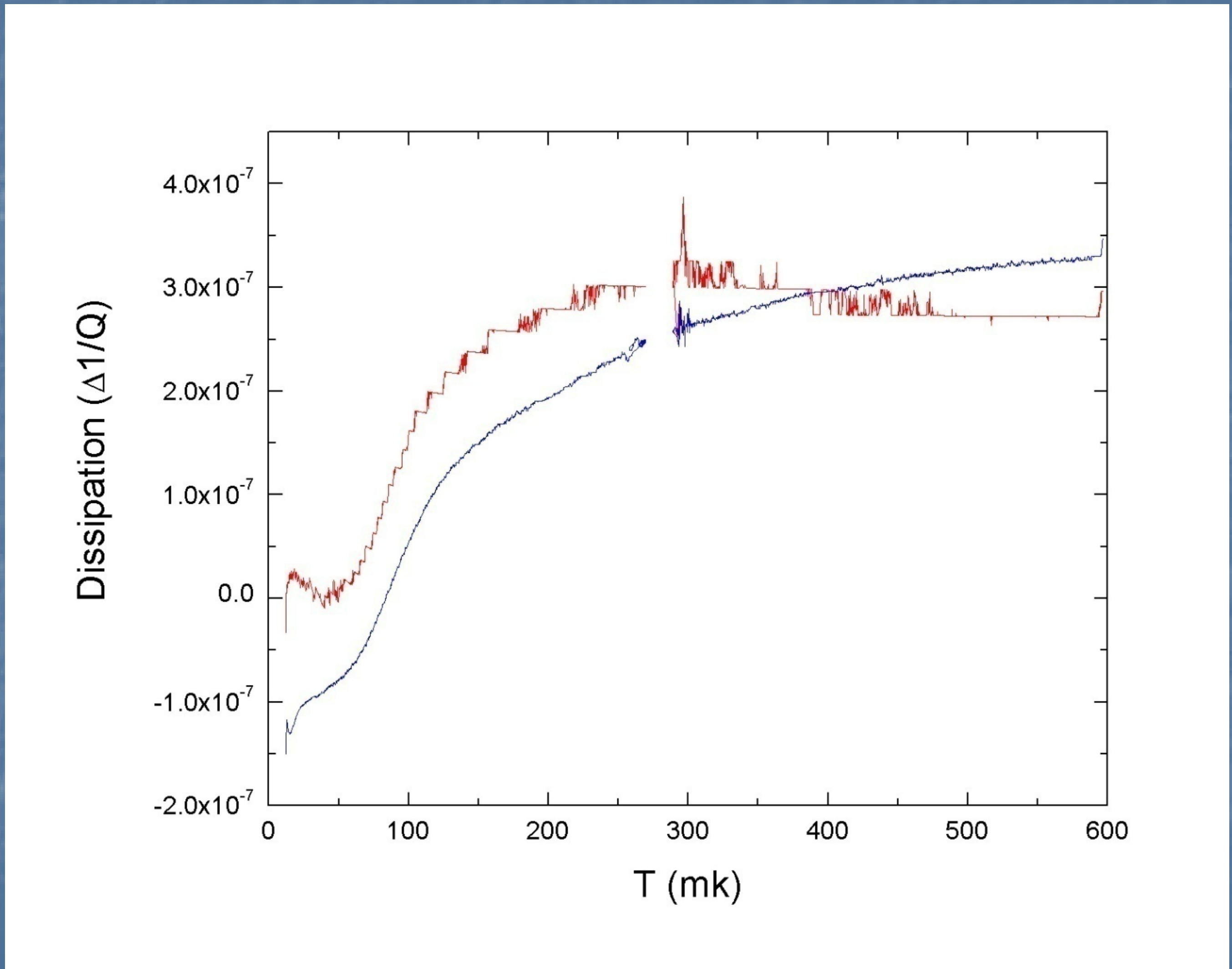
What happens with ^{3}He impurity?

"10 ppm ^{3}He" - effect on NCRIf (very preliminary)



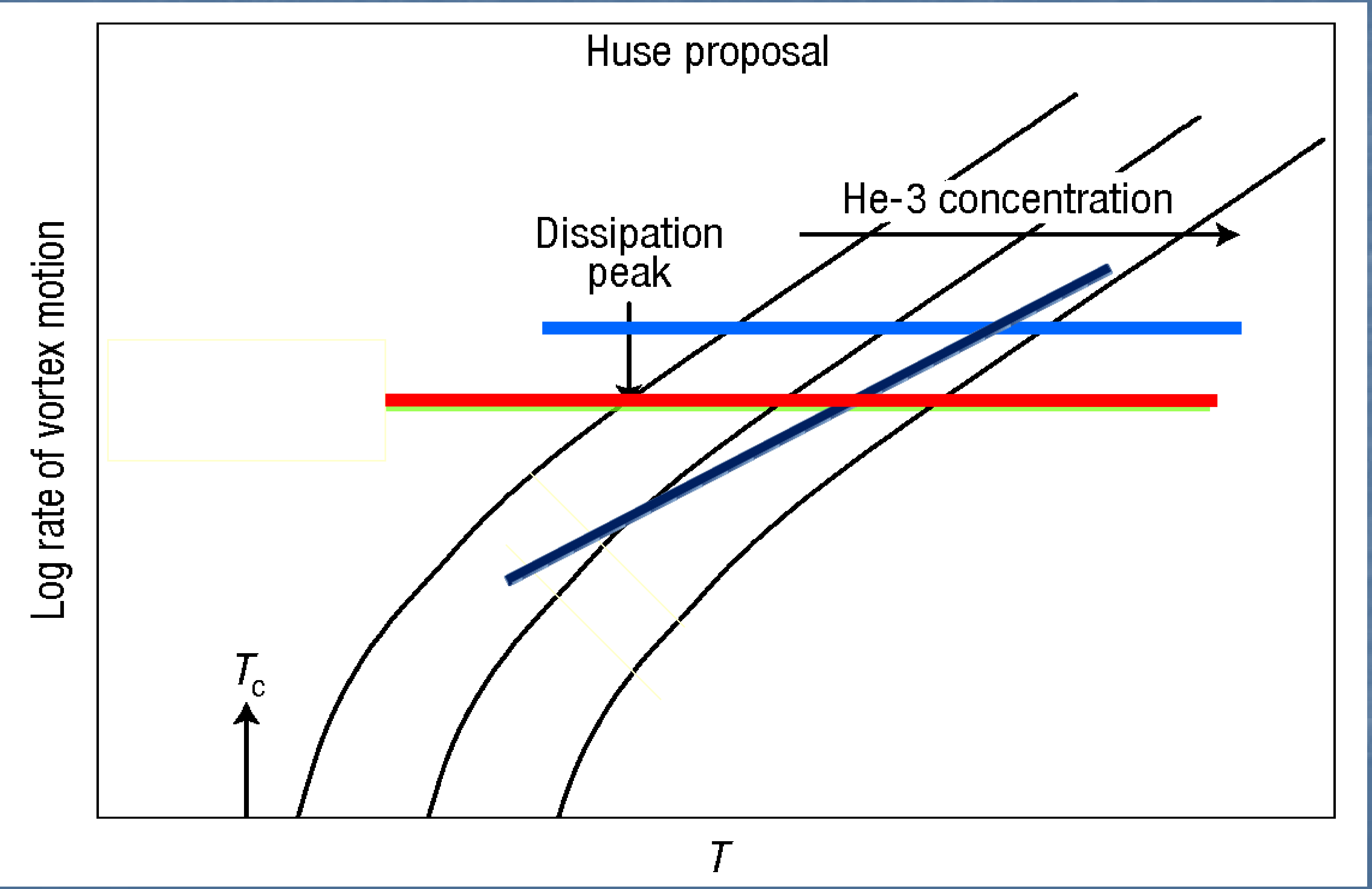
Increased onset T: confirmation of results at Penn State group
What about separation in dissipation peaks?

"10 ppm ^{3}He" - effect on dissipation (preliminary)

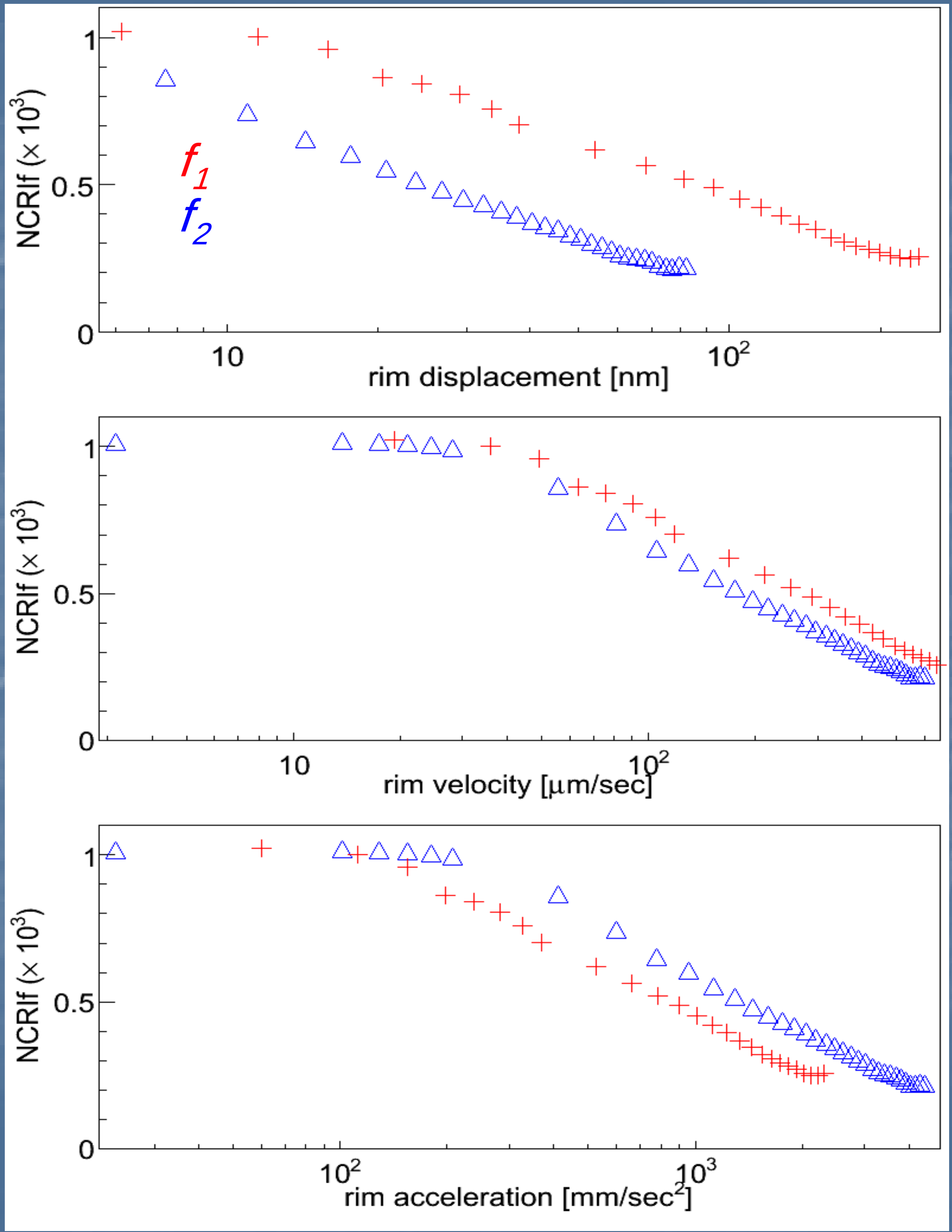


dissipation peak is weak with 10 ppm 3He ⟹ vortex liquid model?

revisit Anderson model



Velocity Dependent Suppression of NCRI fraction



Cylinder

T = 19 mK P = 37 bar

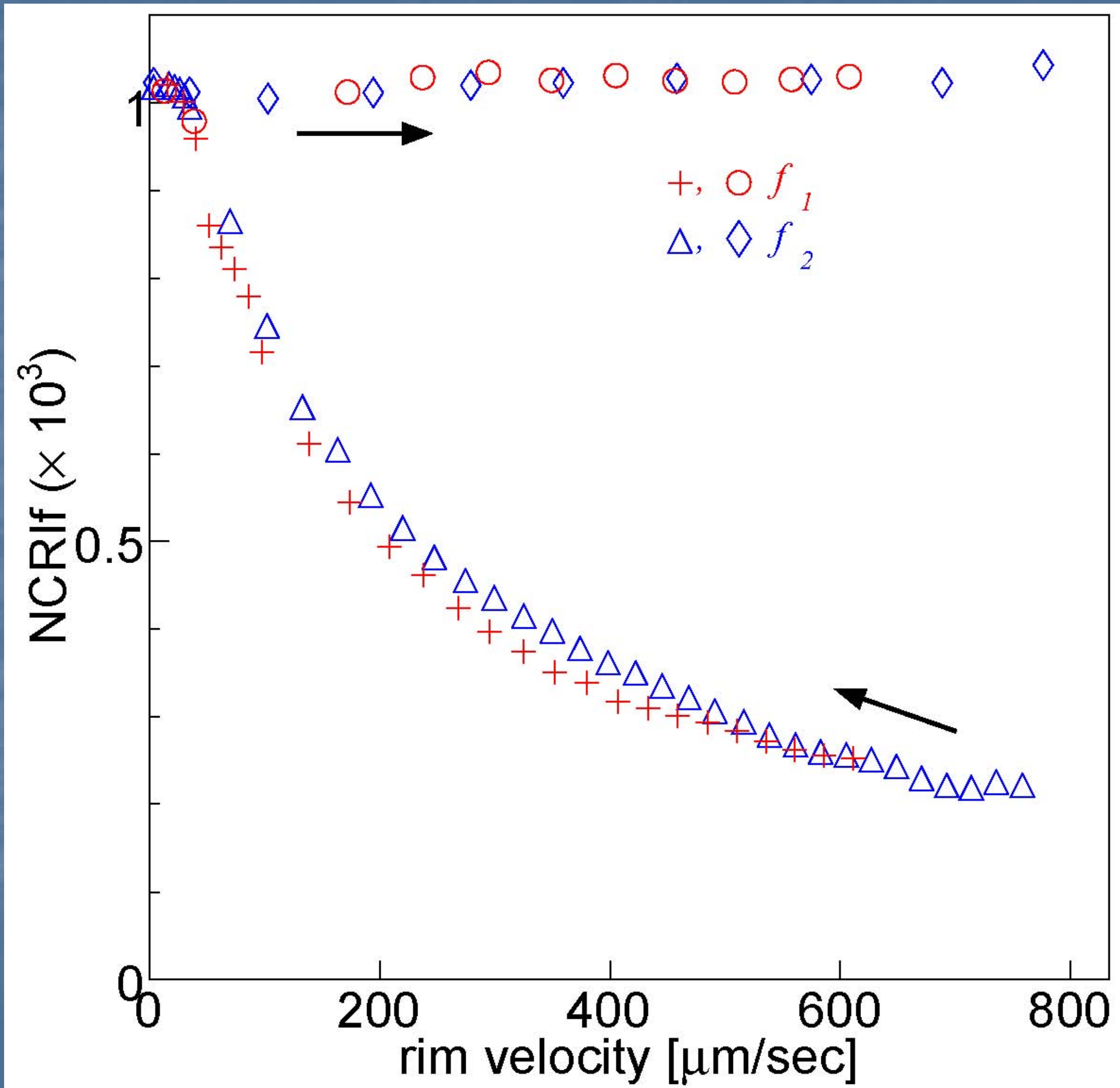
at NCRIf=0.05 %

$$\left|\frac{d_1 - d_2}{d_1}\right| = 0.7$$

$$\left|\frac{v_1 - v_2}{v_1}\right| = 0.3$$ → best match

$$\left|\frac{a_1 - a_2}{a_1}\right| = 0.6$$

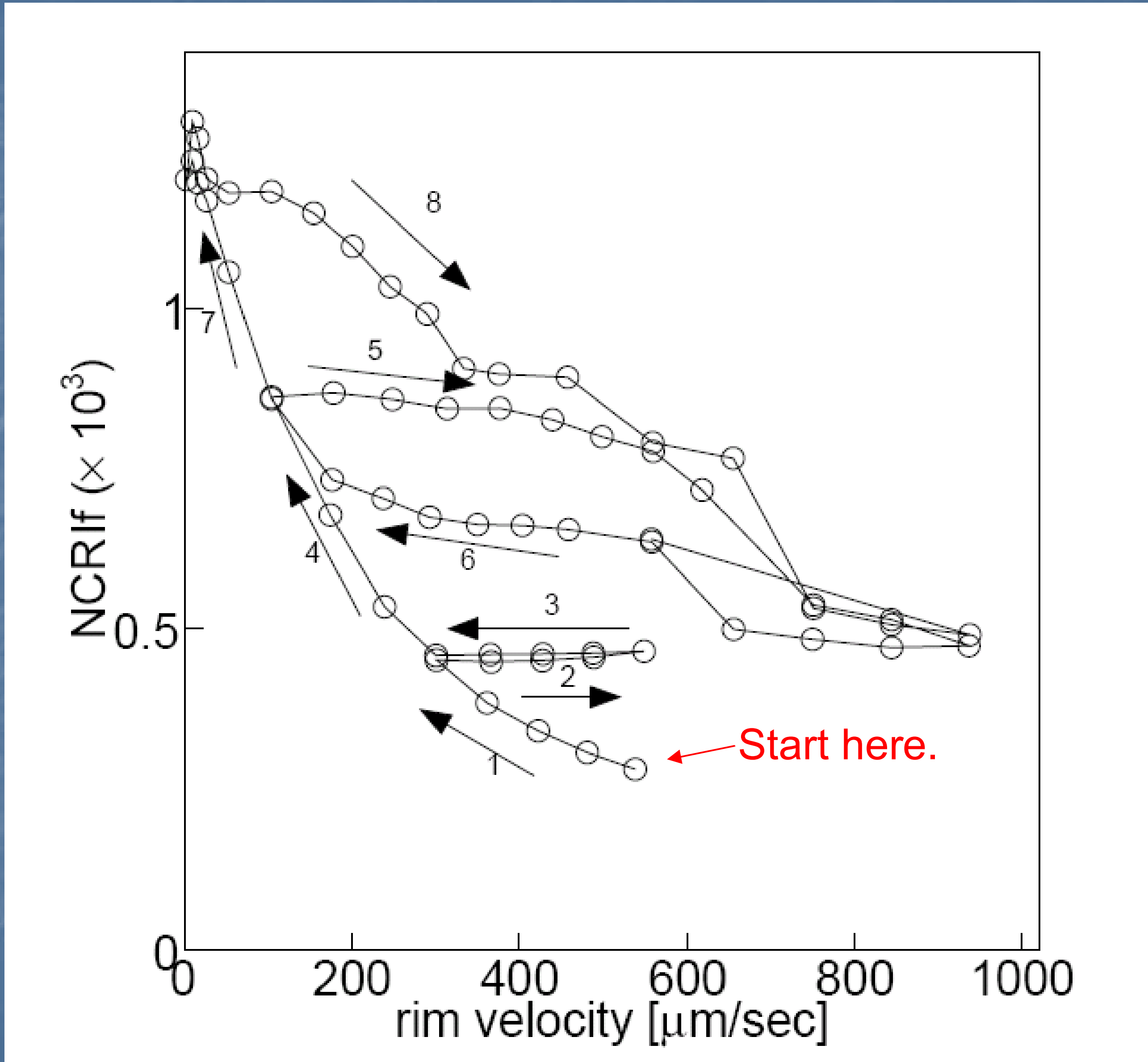
Hysteresis in velocity dependent NCRI



Cylinder
T = 19 mK P = 37 bar

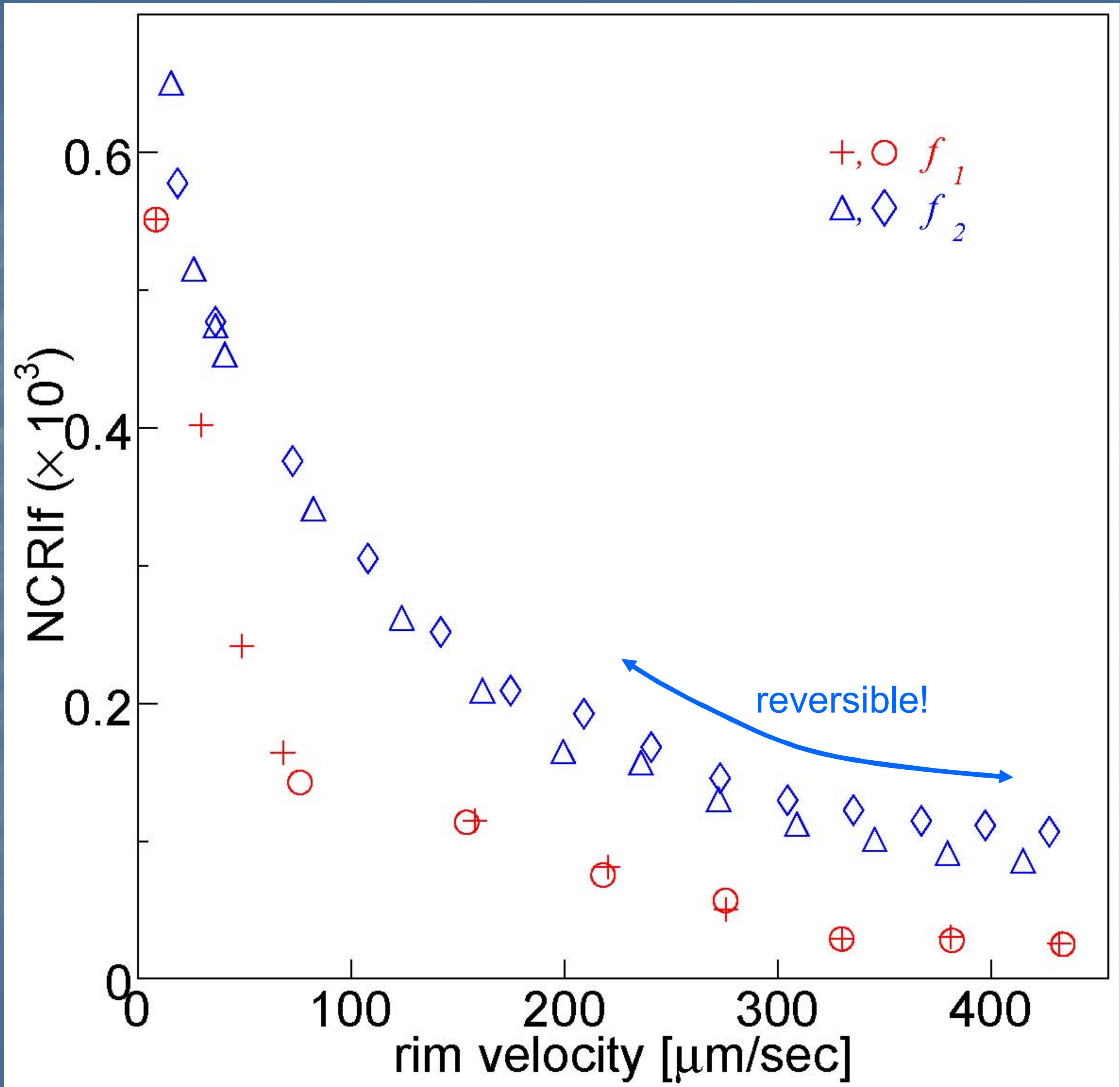
No hysteresis at 60 mK!

hysteresis at 30 mK

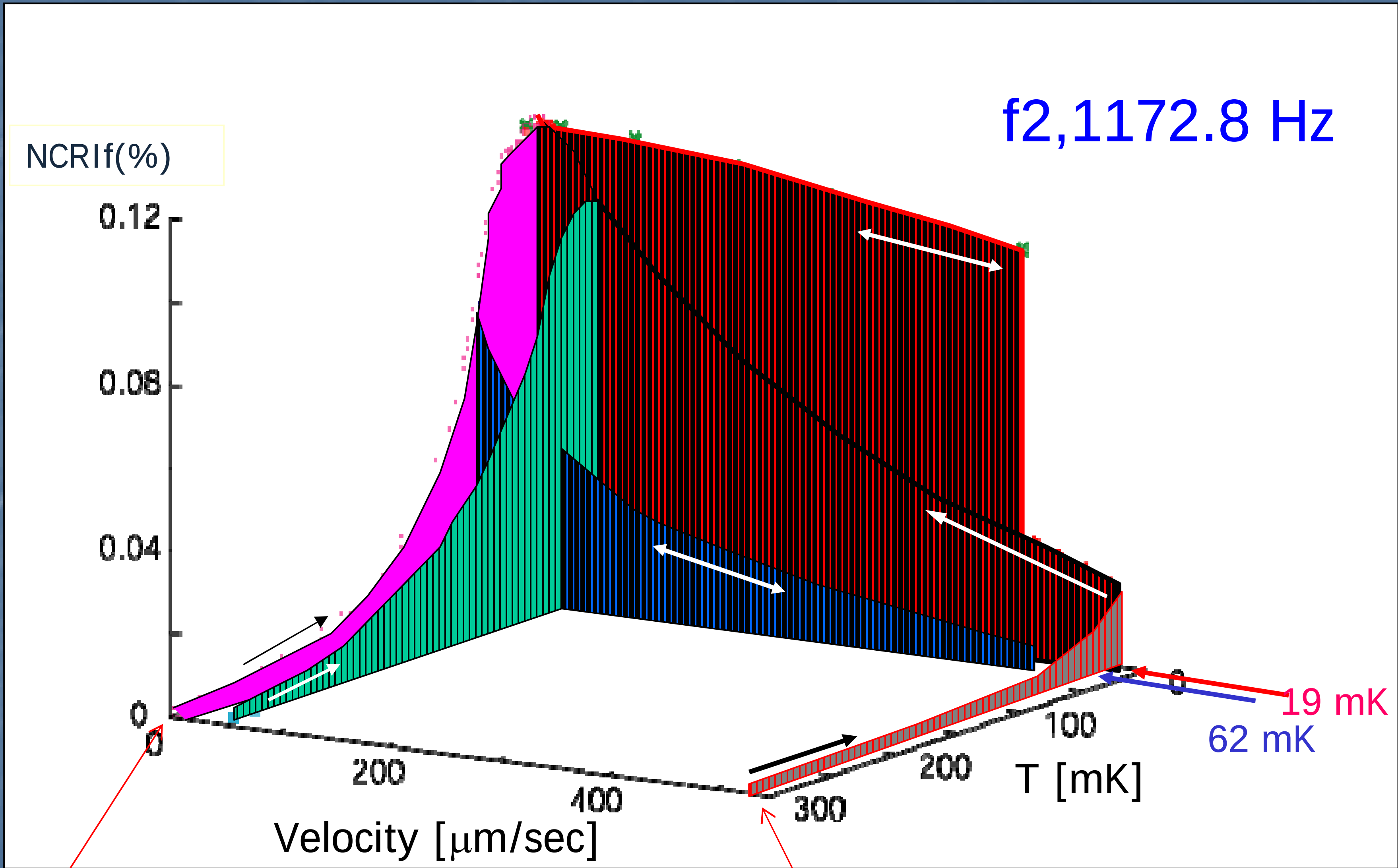


T = 63 mK

Note: no hysteresis!



Mapping of NCRIf as [ac oscillation (field) and T] are varied: cylinder sample



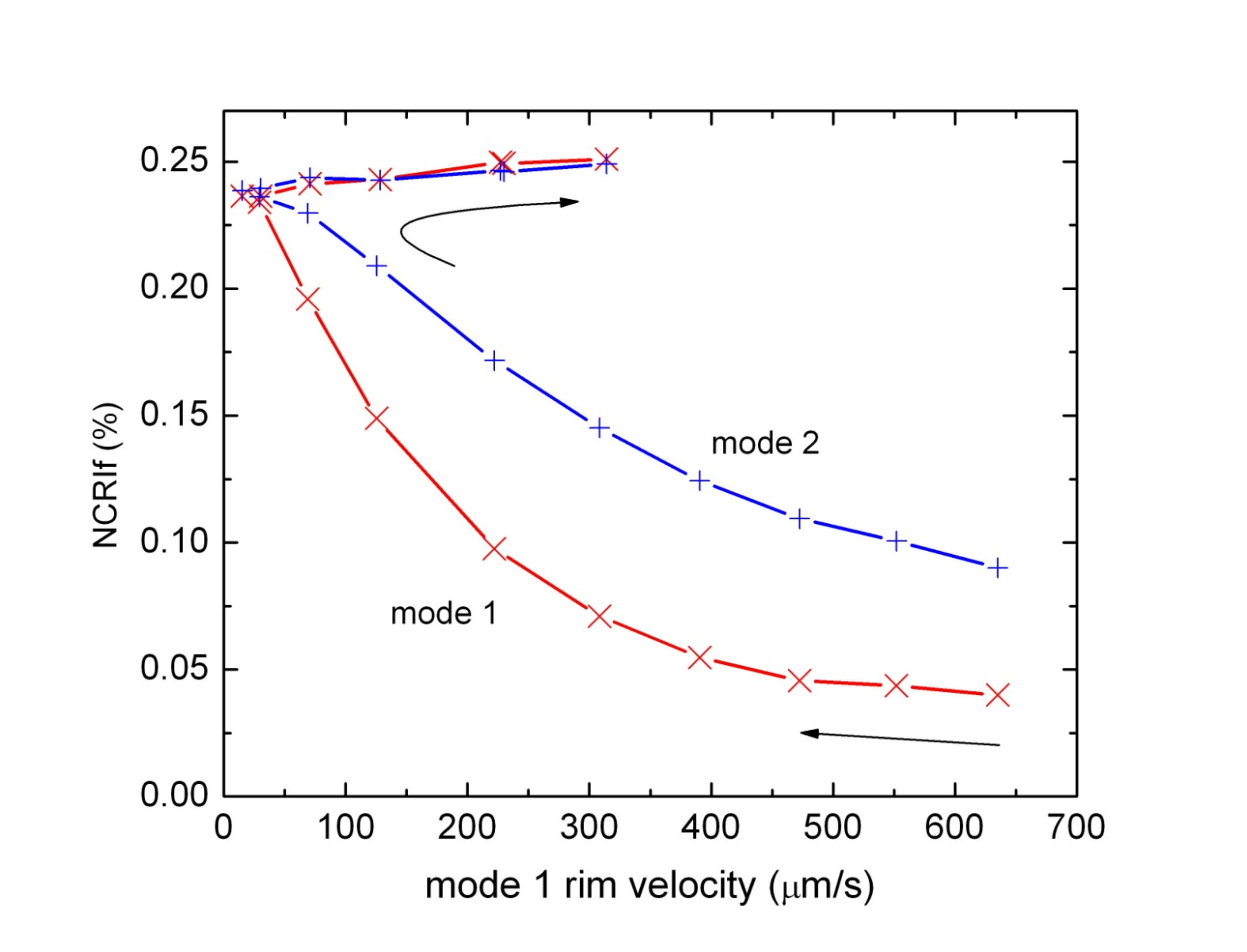
"zero-field" cooled

field-cooled

simultaneous drive:

change drive level of mode 1

with small (~15 μm/s) drive of mode 2



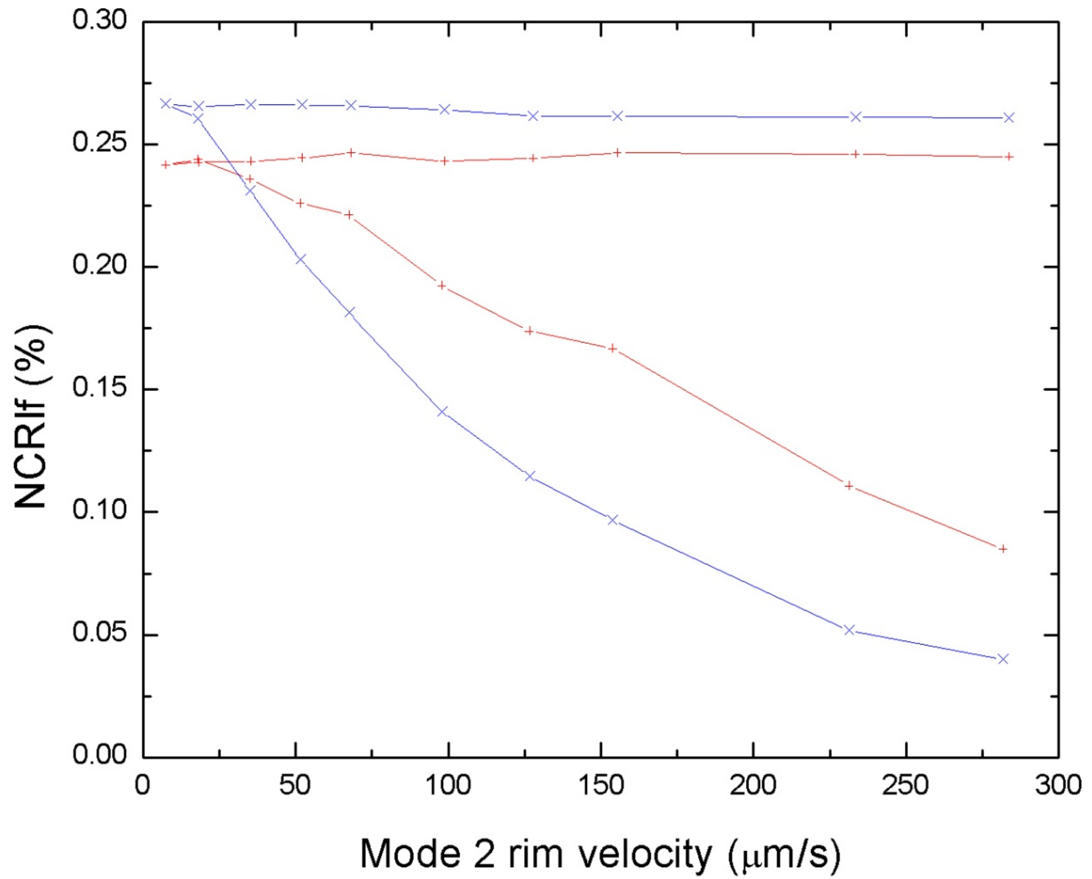
<u>annulus</u>

T = 10 mK

P = 42 bar

simultaneous drive:

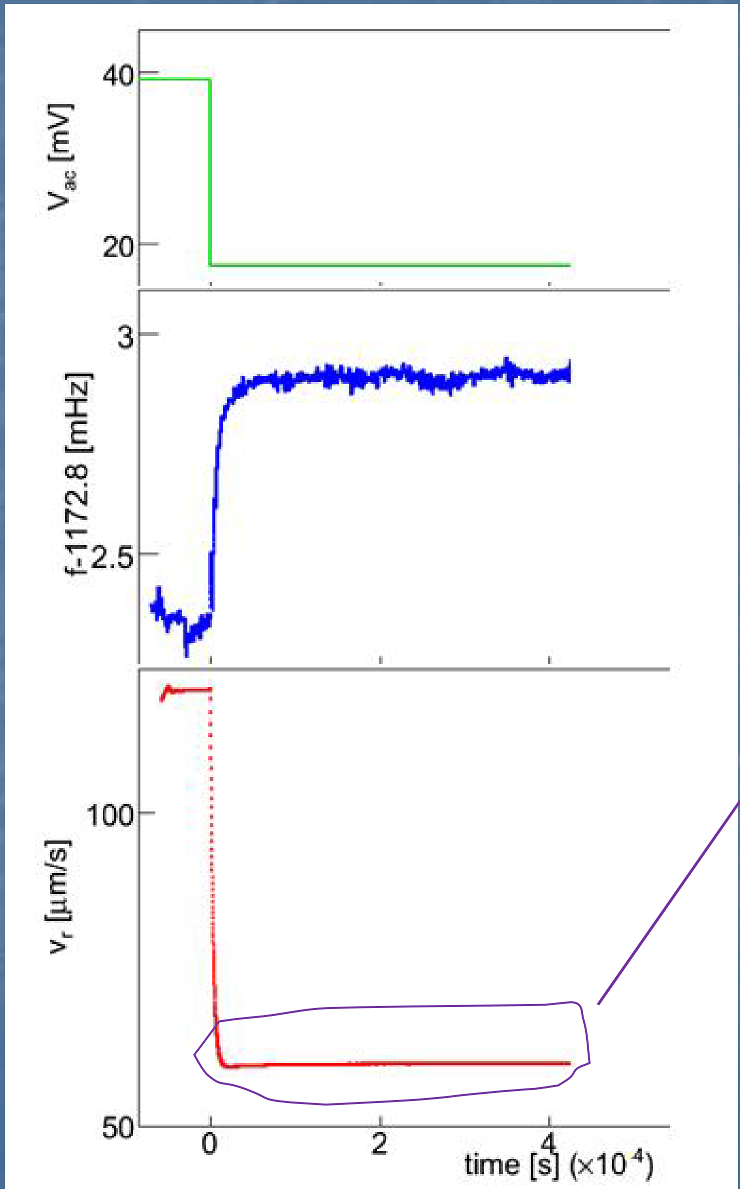
change drive level of mode 2
with small (10 μm/s) drive of mode 1

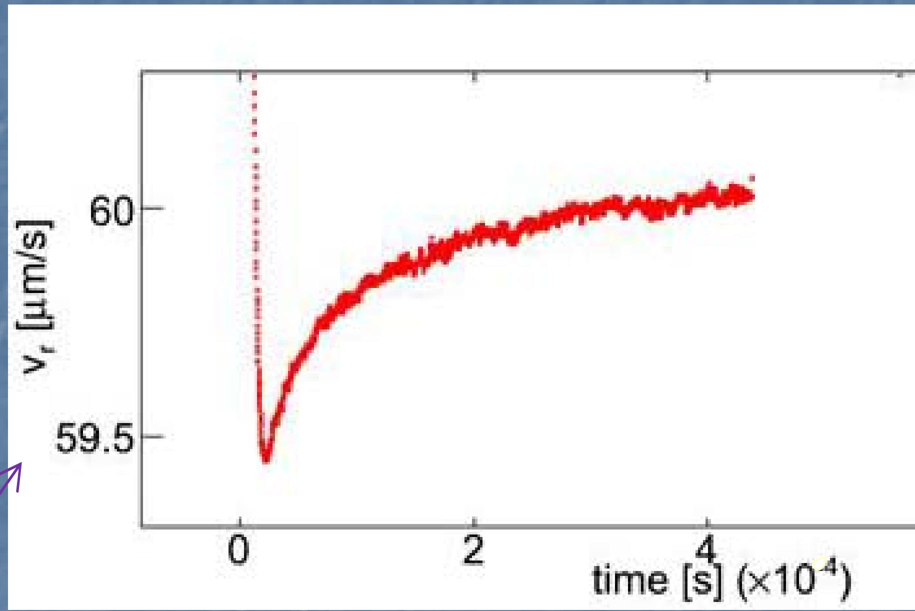


<u>annulus</u>
T = 24 mK
P = 42 bar

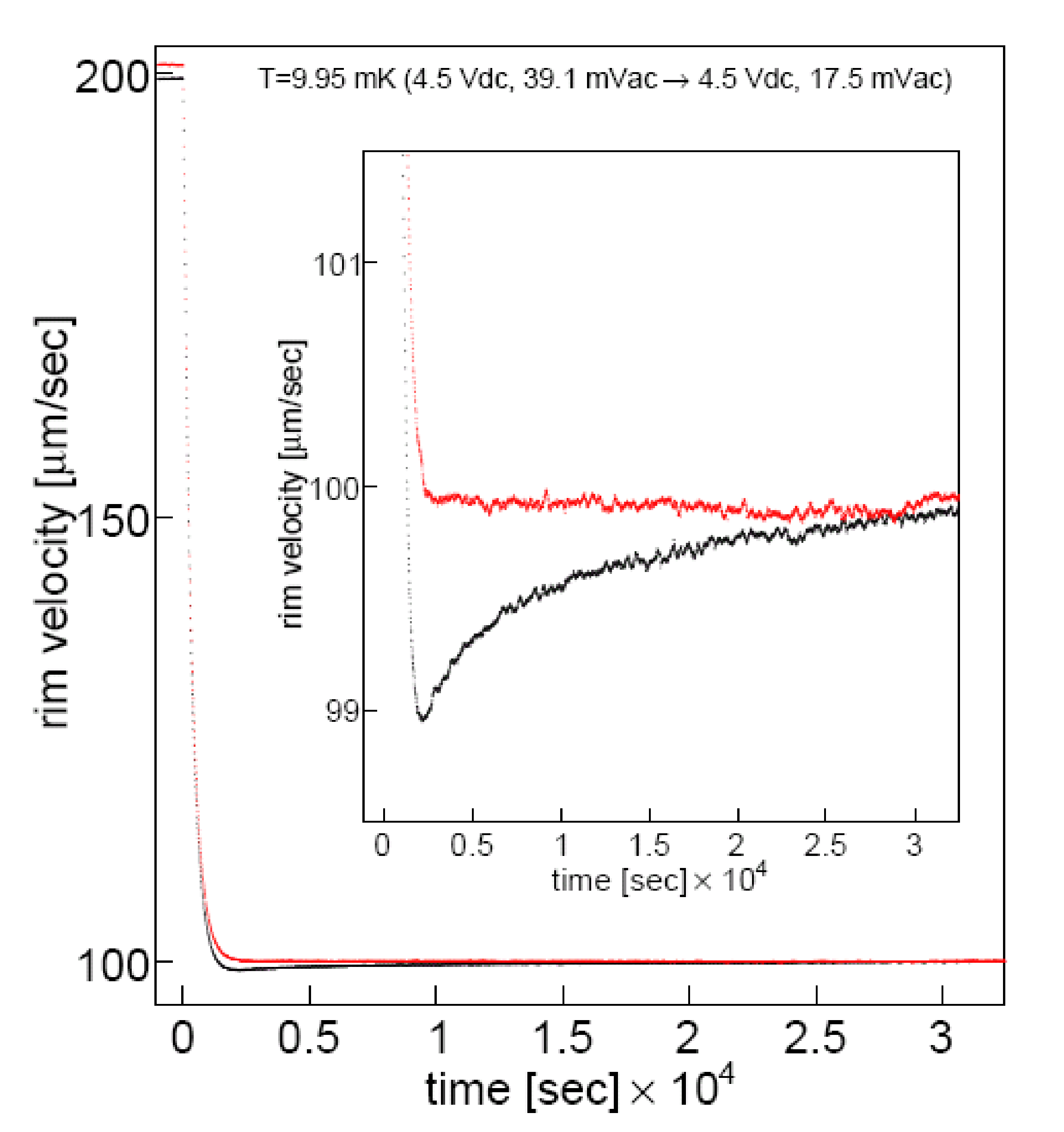
dissipation dynamics:

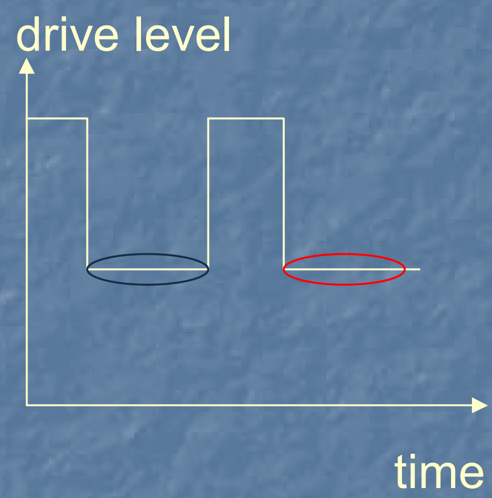
response to step change in drive level



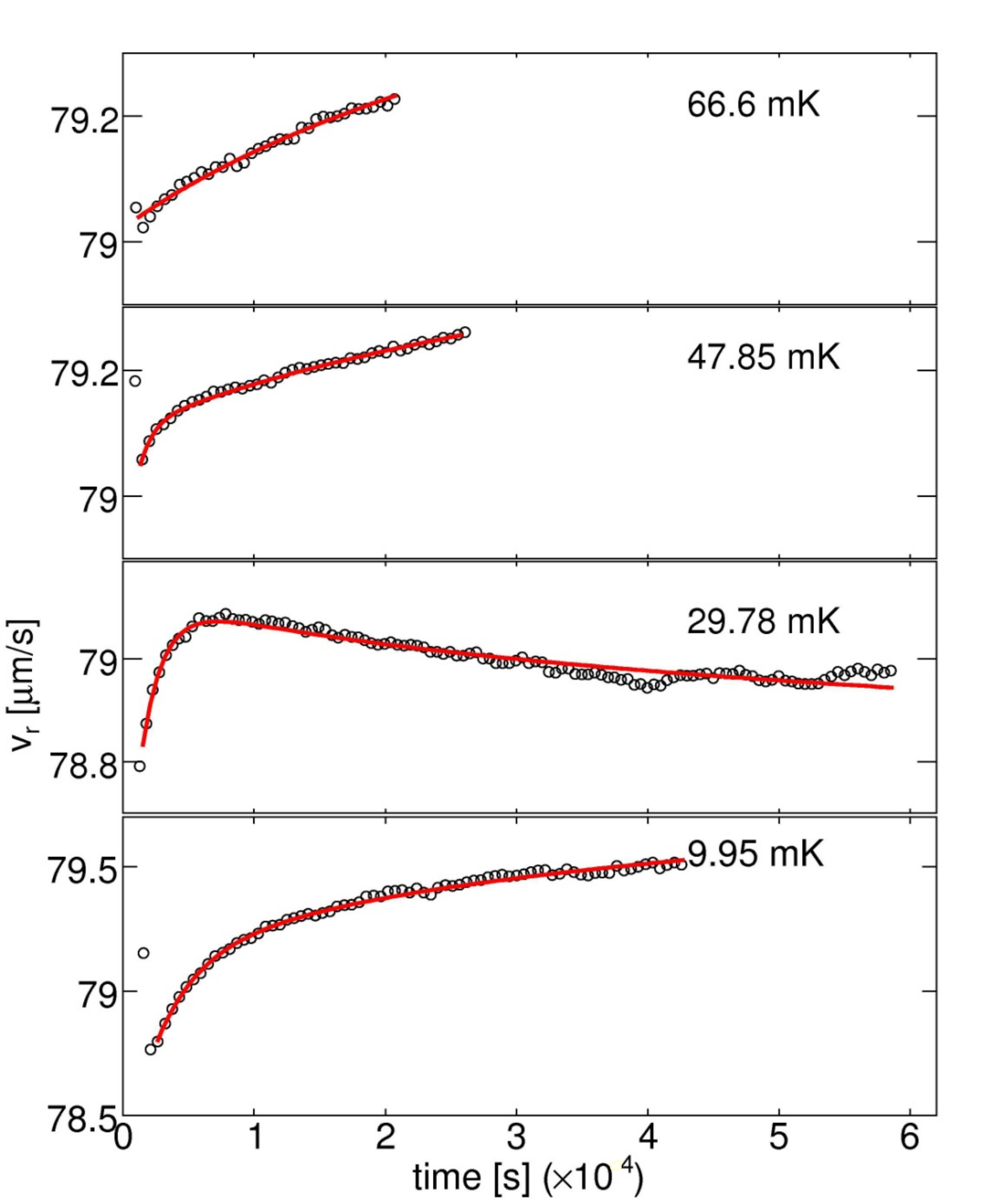


relaxation and memory (T = 10 mK)





relaxation vs. T

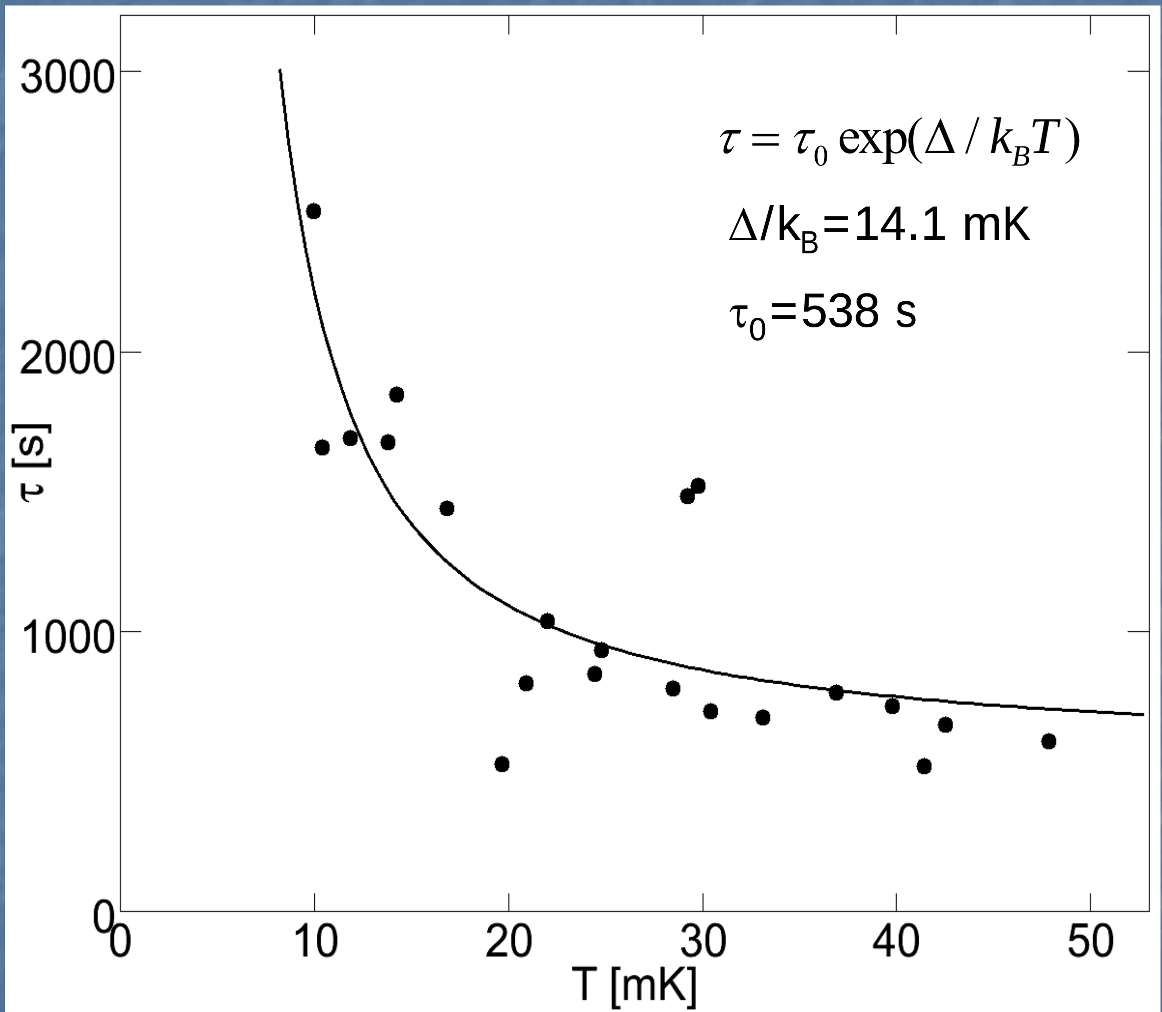


thermal relaxation

$$v_r = v_0 + B\ln(t + t_0) - C\exp(-t/\tau)$$

decay just after drive change

relaxation time τ



Mechanisms for long relaxation time ?

• different physical origin than dissipation peak in T

• recondensation of ^{3}He? Assume Dx_3 ~ 3×10^{-11} cm^2/s and $\Lambda \geq 10^5 cm^{-2}$

$$\Rightarrow \tau \approx \frac{3}{\Lambda D} \approx 1\,\mathrm{s}$$

• quantum mechanical tunneling of dislocation lines --- expected τ is too large

• same as P relaxation seen by Rittner and Reppy? -- hysteresis unexpected

• vortex liquid → solid??

Summary

compound torsional oscillator

cylindrical and annular samples

NCRIf: 0.1 ~ 0.25 %

- shifted T dependence of NCRIf and dissipation
- He-3 impurity changes T dependence, no dissip. peak
- hysteresis and reversible regimes in NCRIf and oscillator response.
- simultaneous drive
- unusual relaxation phenomena
- comparison with glassy solid ^{4}He theory on-going.
- analogy with vortex liquid model on-going.