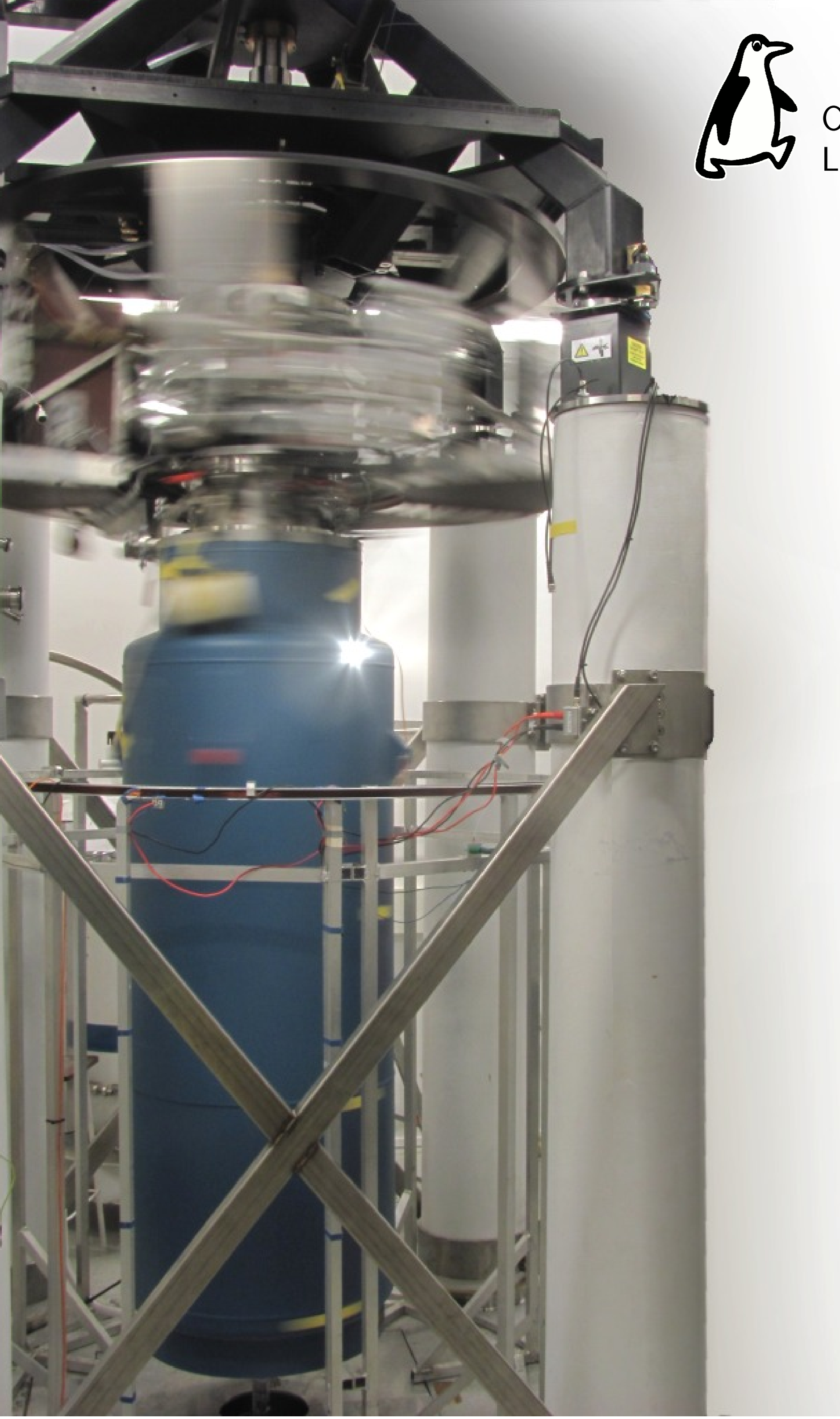

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Probing vortex cores with trapped magnon condensates in ^{3}He-B

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Sannäs, 2013

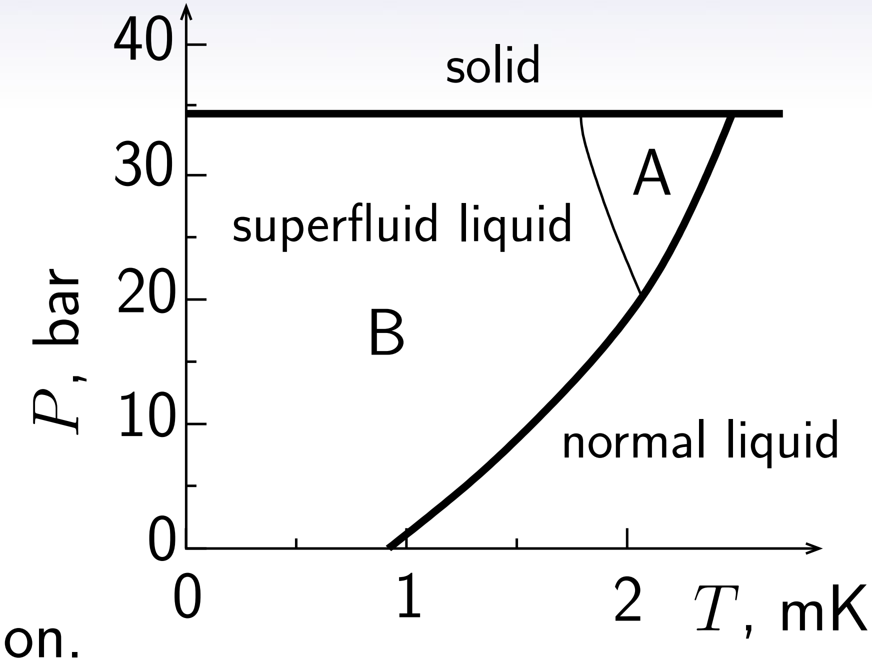
Superfluid ^{3}He-B

Cooper pairing with $L = 1$ and $S = 1$.

B-phase order parameter:

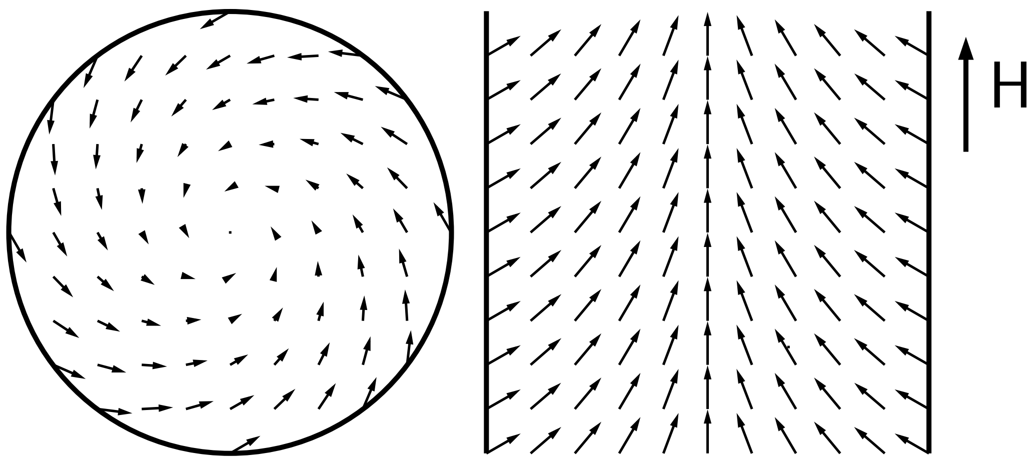
$A_{jk} = \Delta(P,T)\ e^{i\phi}\ R_{jk}(\mathbf{n},\theta)$.

R_{jk} – rotation matrix



$\theta \approx 104.5^\circ$ because of spin-orbit interaction.

Distribution of $\mathbf{n}$ (texture):



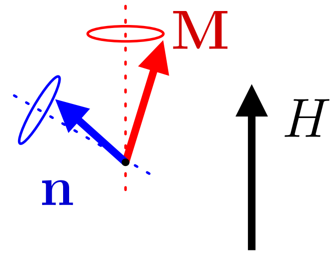
NMR in ^{3}He-B, magnons

Spin dynamics:

⋆ order parameter is involved in the motion of magnetization

⋆ texture changes precession frequency

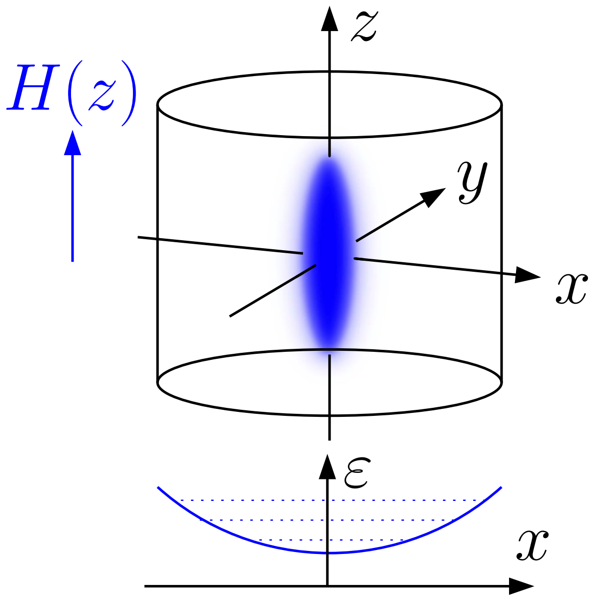
⋆ superfluid spin currents transfer magnetization

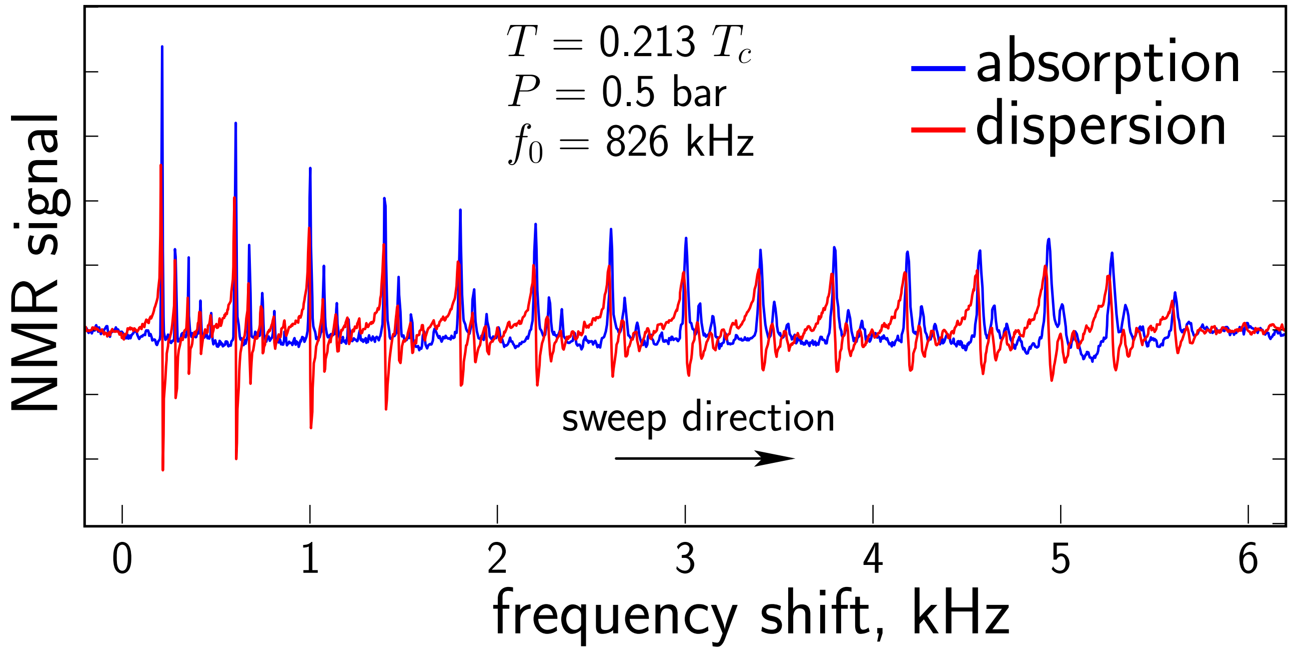


Magnons: [Volovik, JLTP 153 (2008)]

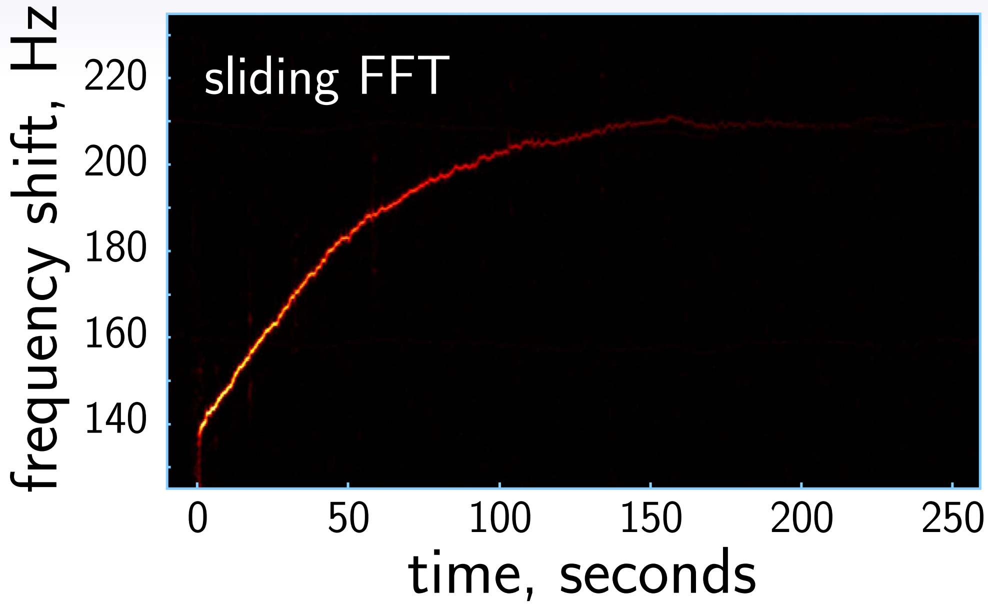
⋆ tipping angle and phase $\rightarrow$ wave function

⋆ frequency $\rightarrow$ energy

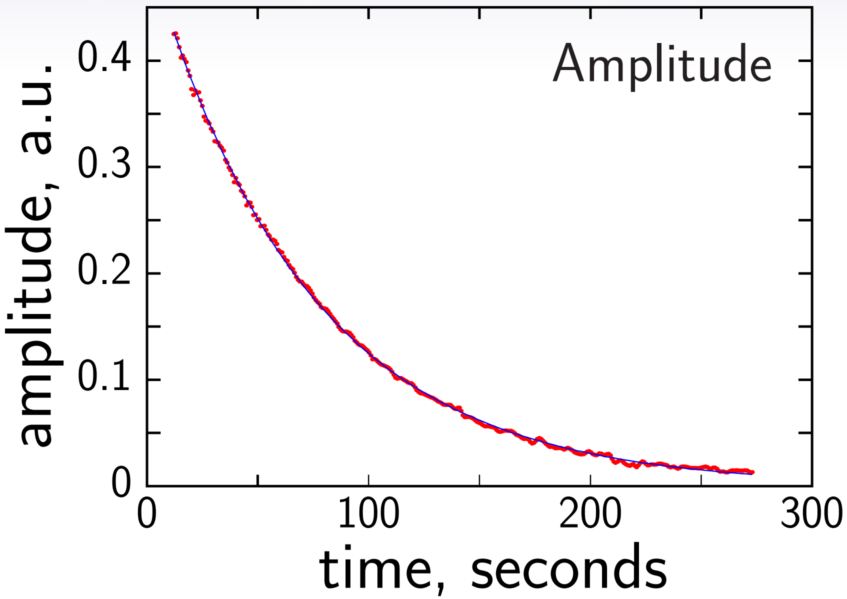




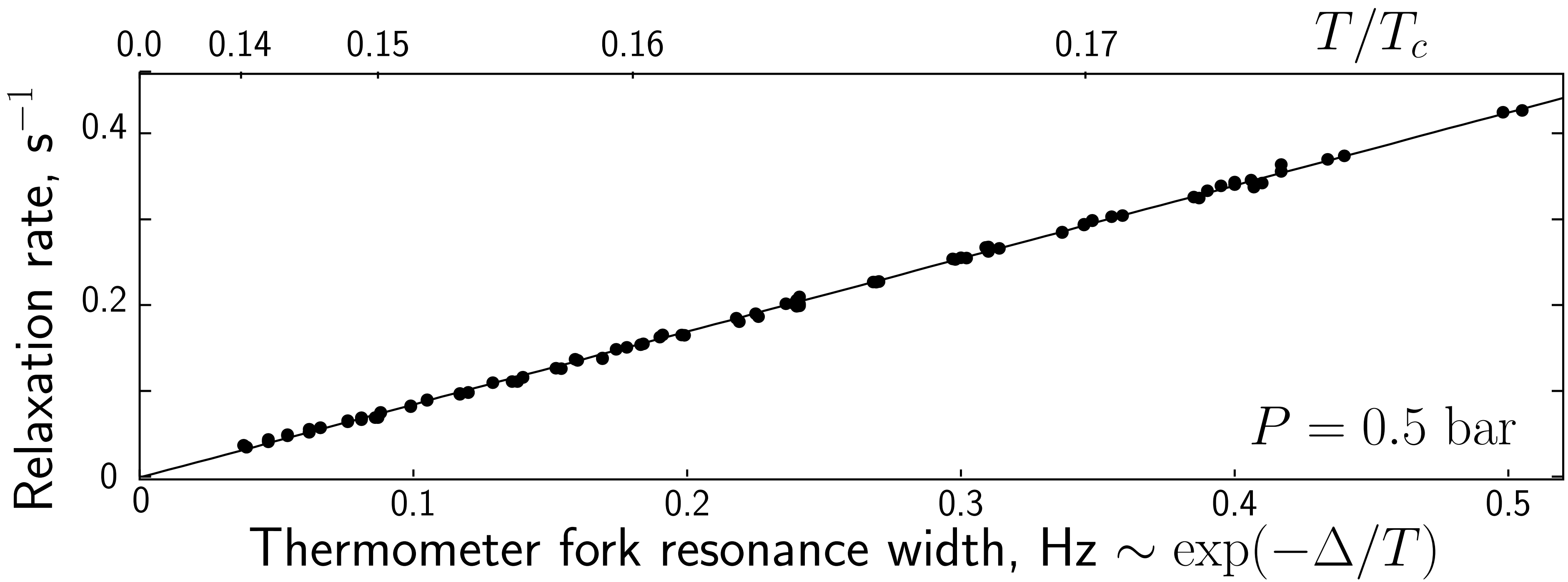
Pulsed NMR



sliding FFT
frequency shift, Hz
140
160
180
200
220
0
50
100
150
200
250
time, seconds

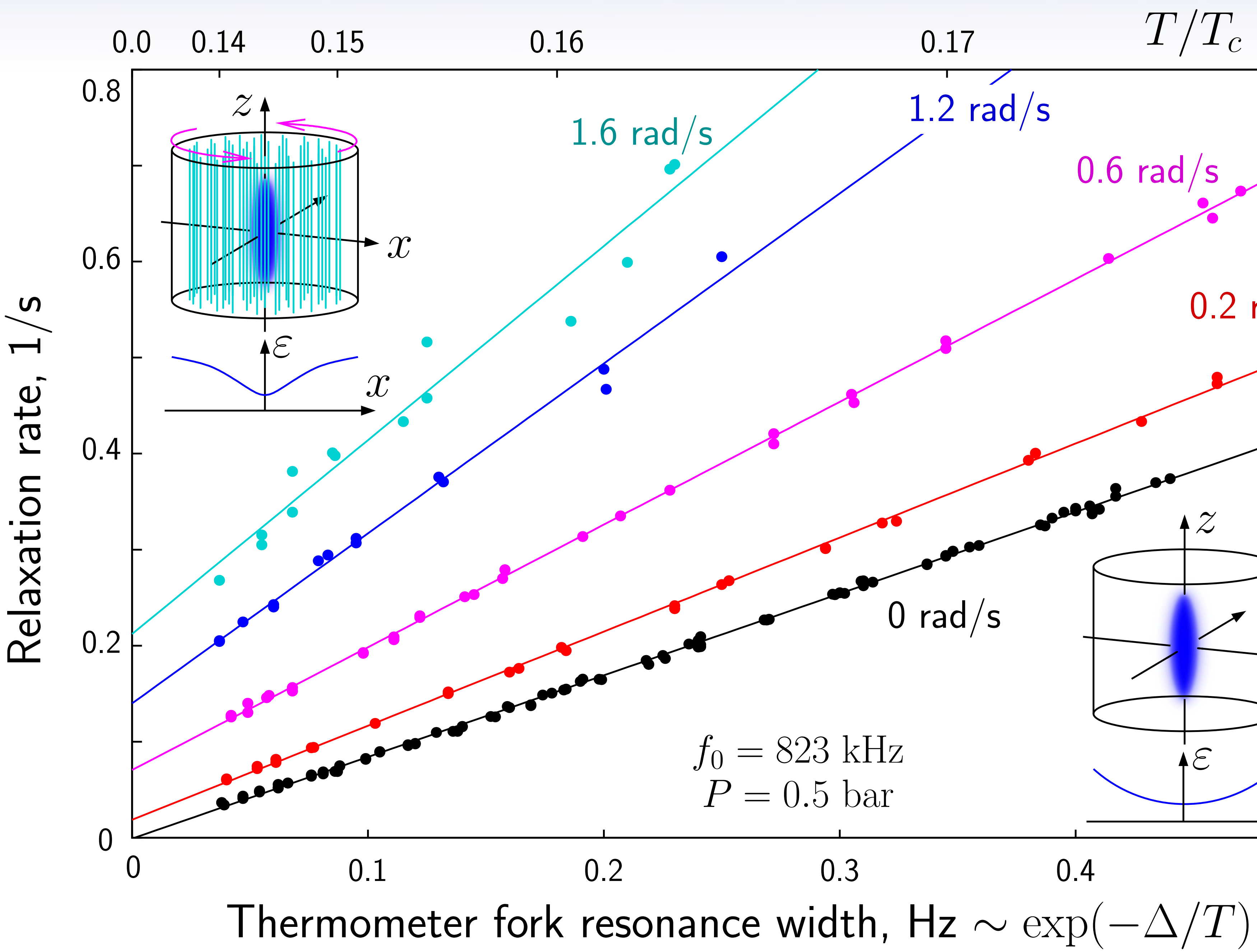


Amplitude
amplitude, a.u.
0
0.1
0.2
0.3
0.4
0
100
200
300
time, seconds



0.0
0.14
0.15
0.16
0.17
T/T_c
Relaxation rate, s^{-1}
0
0.2
0.4
$P = 0.5$ bar
0
0.1
0.2
0.3
0.4
0.5
Thermometer fork resonance width, Hz $\sim \exp(-\Delta/T)$

Relaxation vs temperature in rotation



Dissipation of energy in vortex cores

Spin-orbit energy

Magnetic anisotropy energy

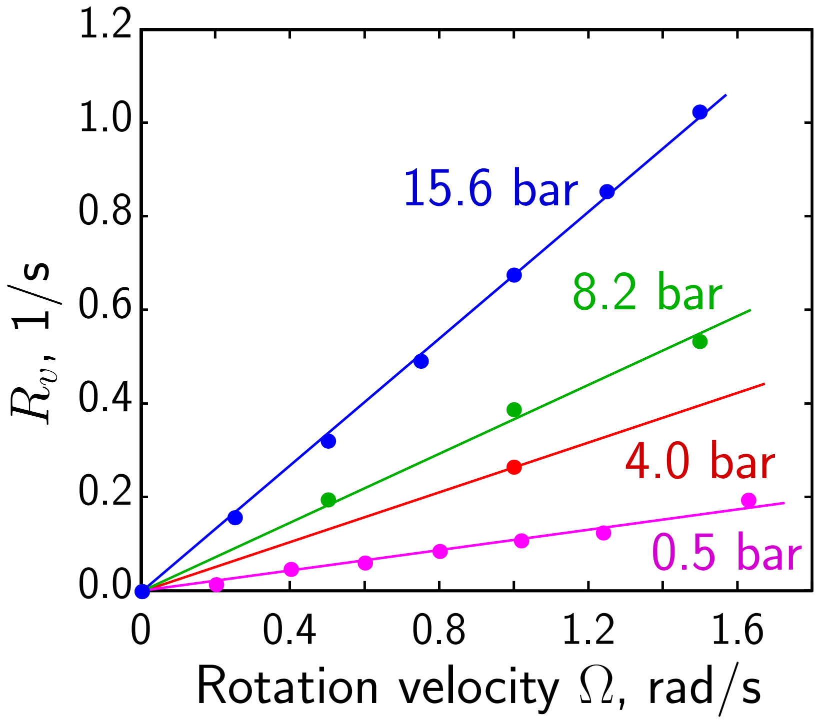
Energy of vortex core: $$F = T_D(\hat{\mathbf{b}}\cdot\hat{\mathbf{n}})^2 - T_H(\hat{\mathbf{b}}\cdot\hat{\mathbf{l}})^2$$

Friction in vortex cores

Equation of motion: $$f\,\frac{d\phi}{dt} = -\frac{\delta F}{\delta\phi}$$

Rotation velocity, number of vortices

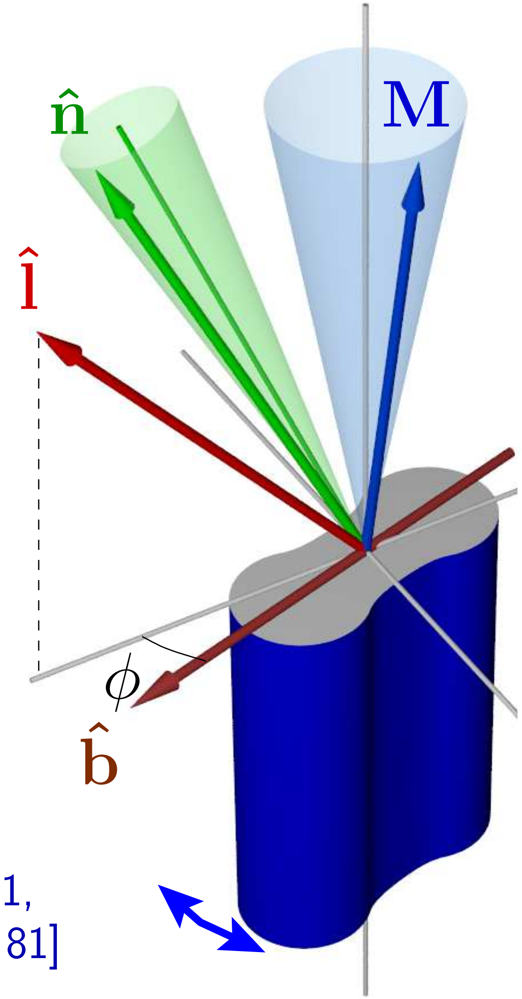
Relaxation: $$R_v \propto \Omega\ f\ \ (T_D/T_H)^2$$



[Kopnin, Volovik, 1998, PRB 57(14) 8526]

This theory also works for the interaction between HPD and vortices.

[Kondo et.al., 1991, PRL 67(1) 81]

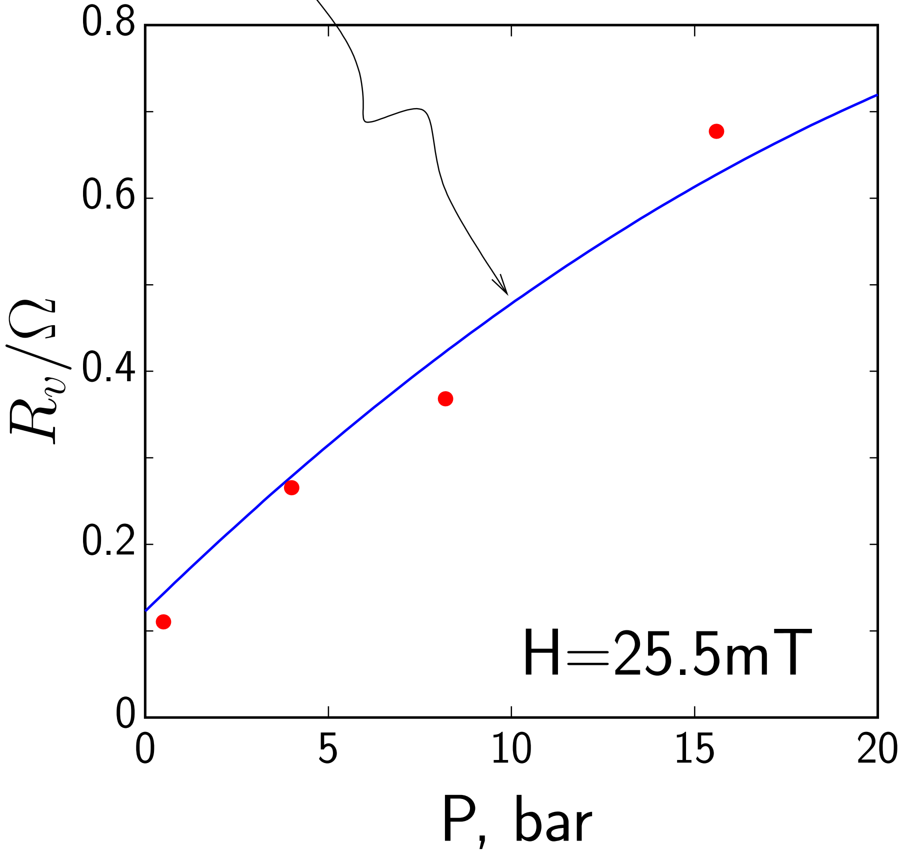


Non-axisymmetric vortex

Relaxation in vortex cores

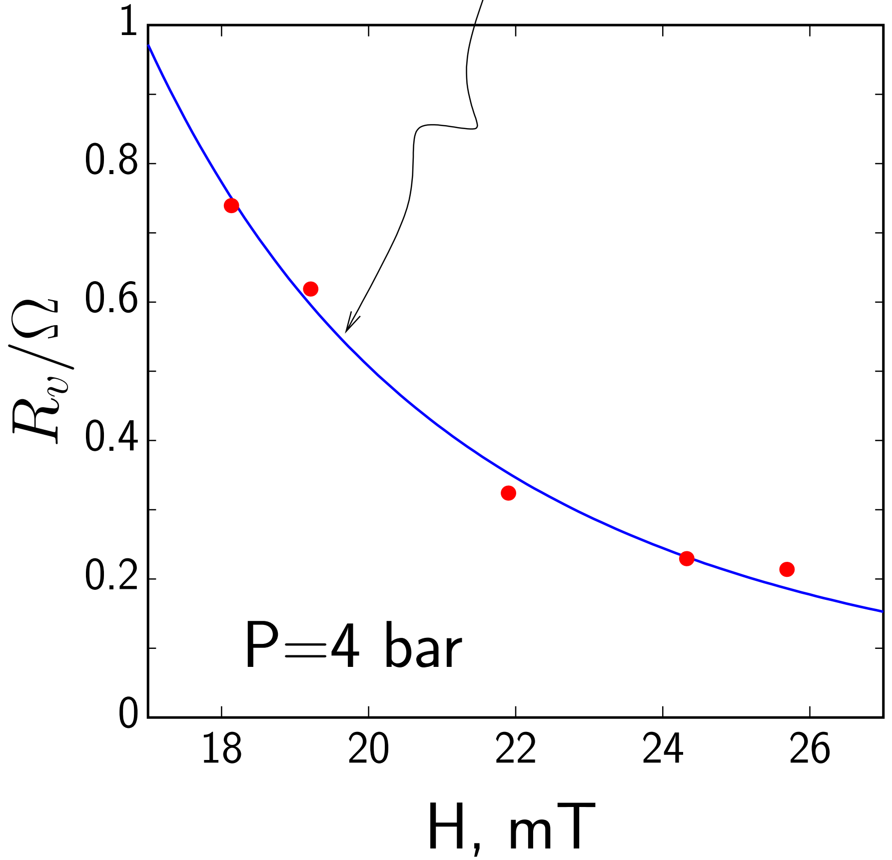
Pressure dependence:

$$R_v/\Omega \;\propto\; g_D^2\,\Delta_0^4\,\xi_0^2\,\frac{(1.5+F_0^a)^3(1+F_0^a)^2}{1+F_1^s/3}$$



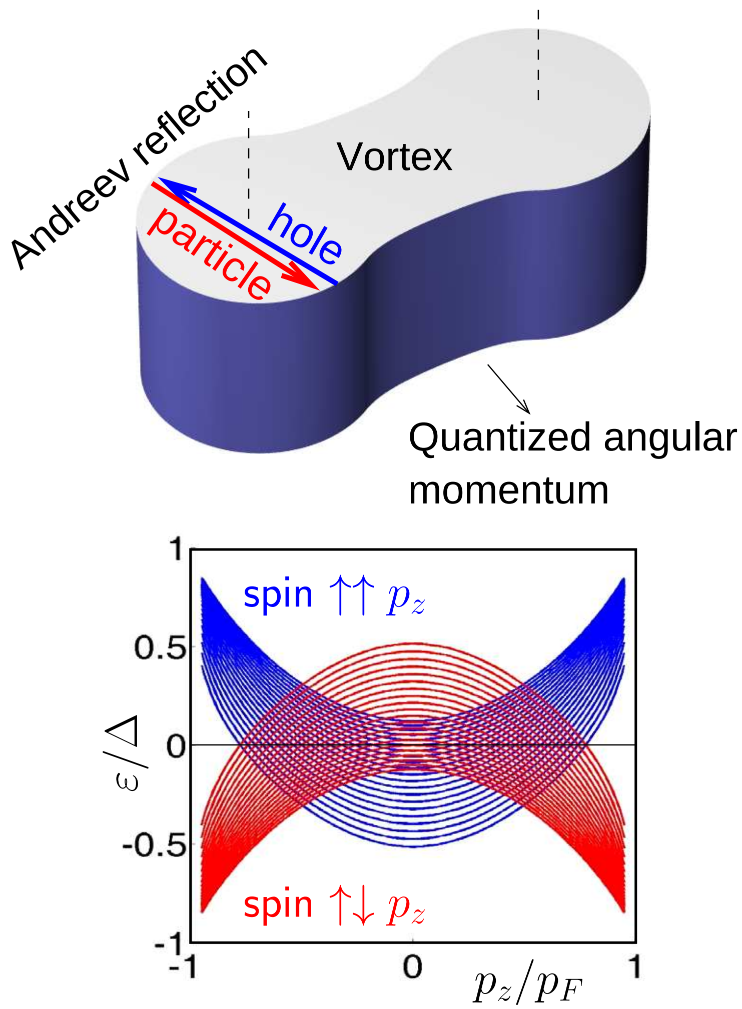
Magnetic field dependence:

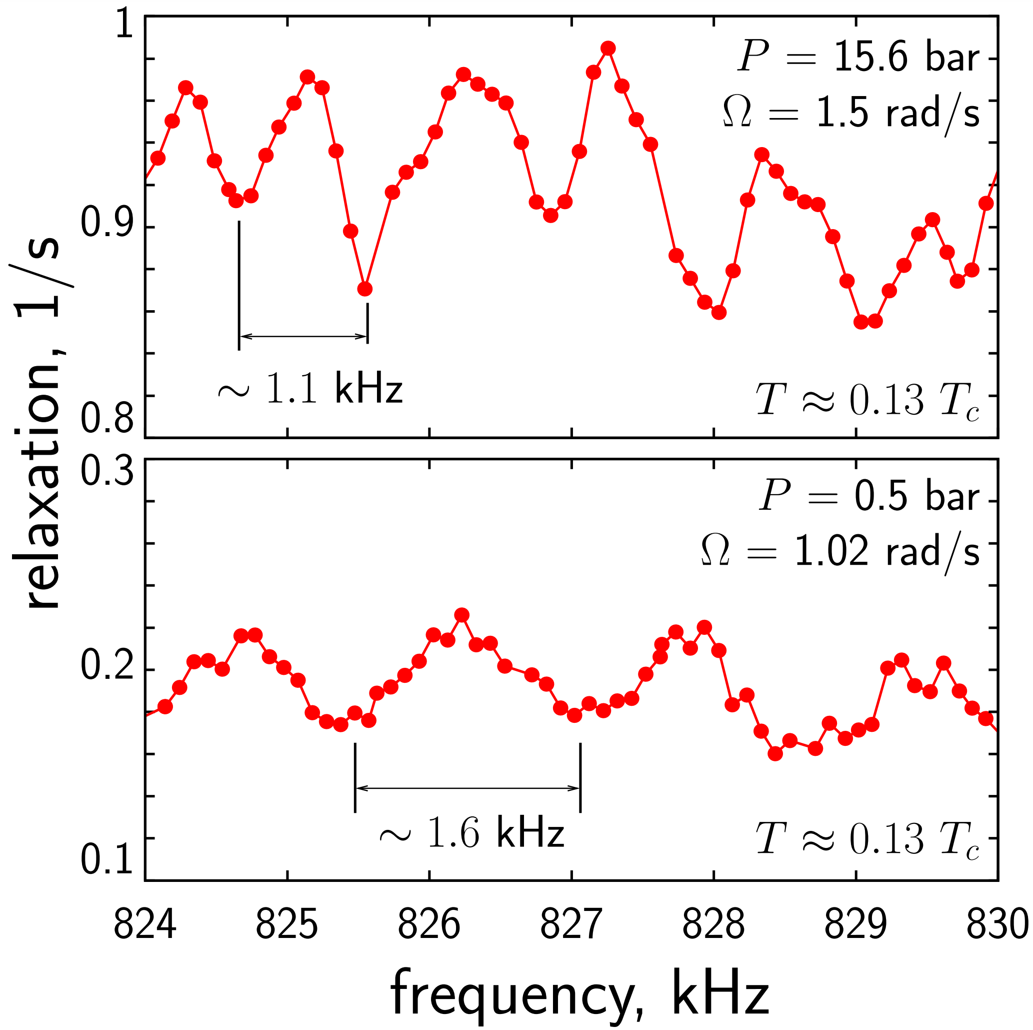
$$R_v/\Omega \;\propto\; \frac{1}{H^4}$$



Relaxation peaks in frequency dependence

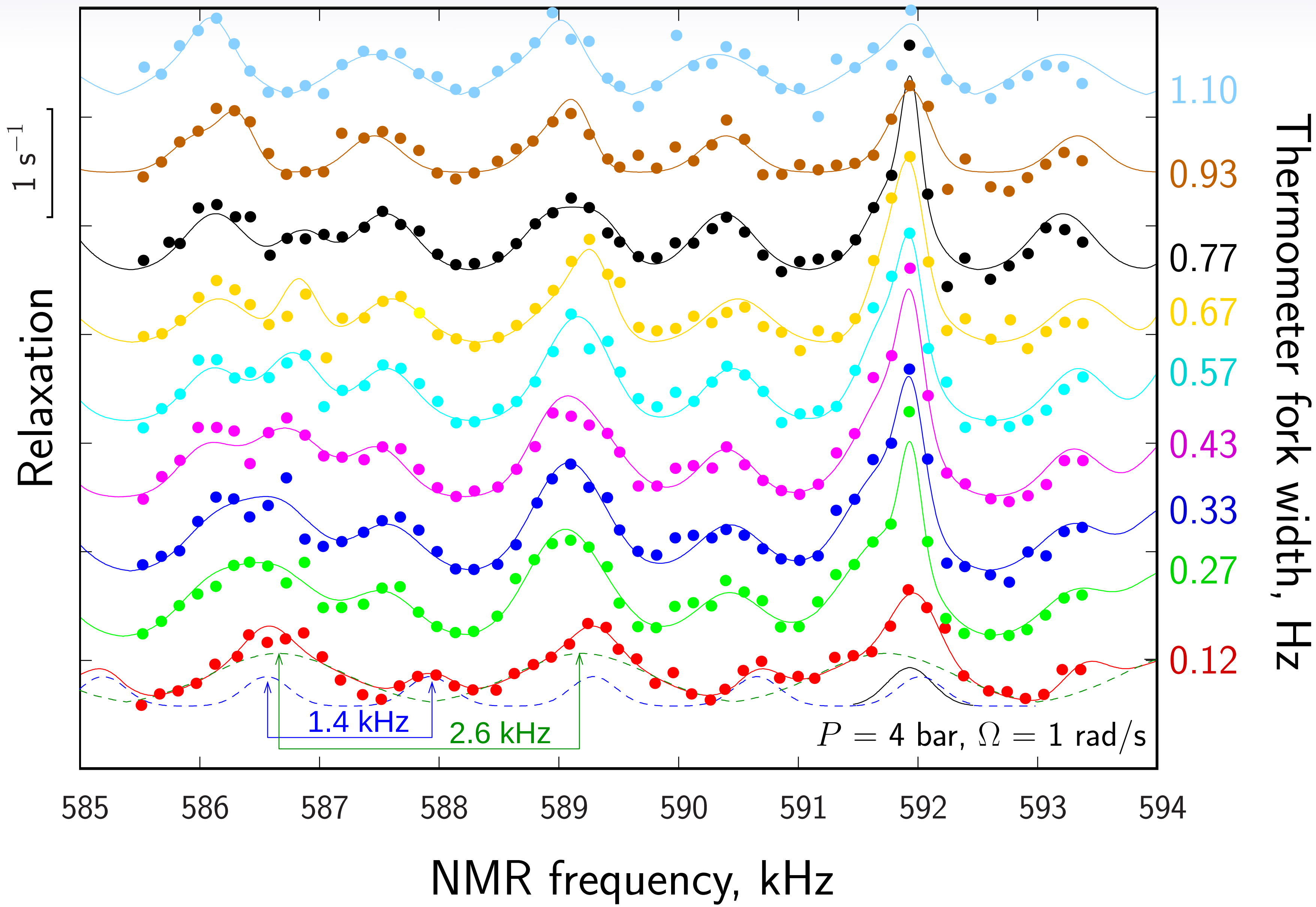
Bound states in the vortex core:



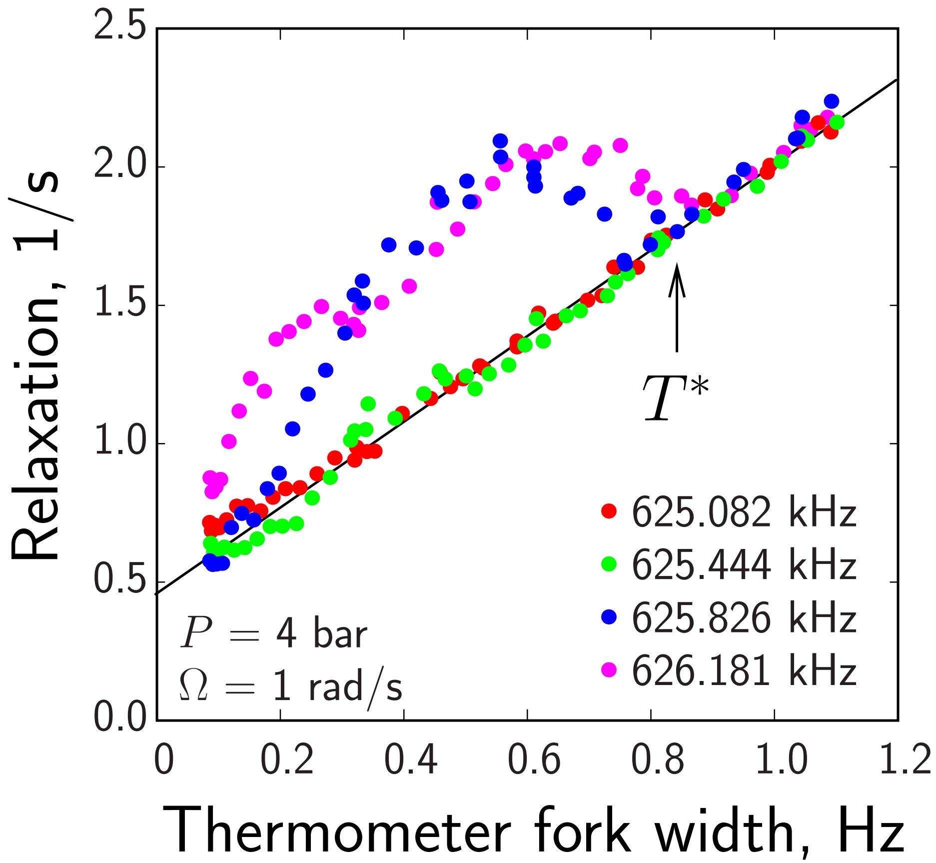


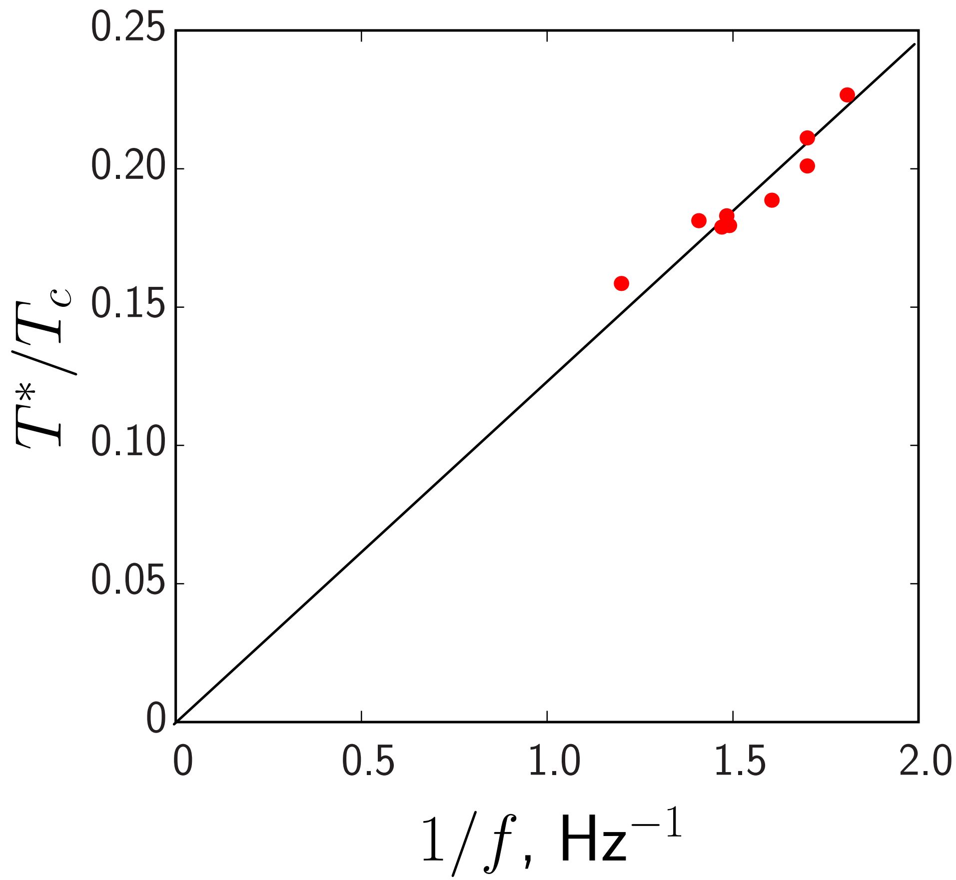
Minigap: $\omega_0 \sim \dfrac{\Delta}{a\ p_F}$, 100 kHz

Thermal behavior of relaxation peaks



Thermal behavior of relaxation peaks





Conclusions

1. Magnon BEC is a good probe for vortices in superfluid ^{3}He-B.
2. We observed dissipation of energy in vortex cores and it is in agreement with the theory and with previous measurements an higher temperatures.
2. We also observed periodic dissipation peaks at frequency dependence. This effect can be related to vortex cores, but the explanation does not exist yet.