Stability and dynamics of HPD in superfluid ^{3}He-B

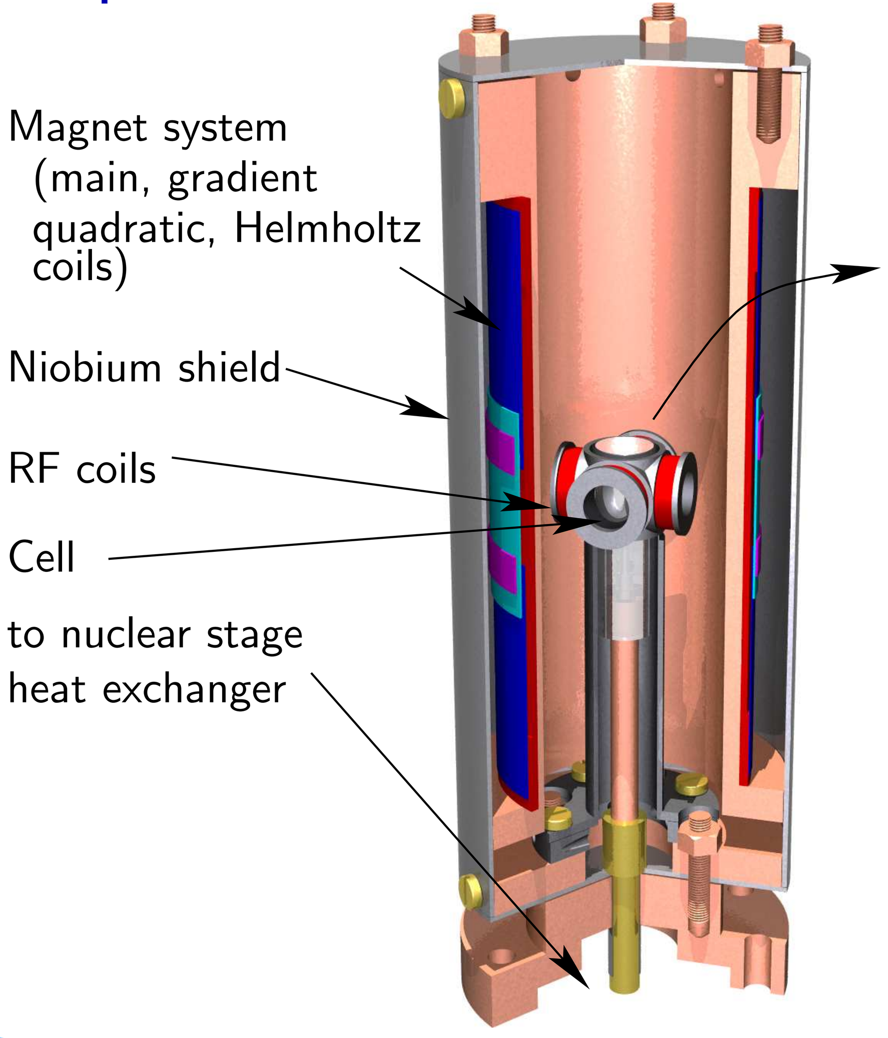
Low Temperature Laboratory

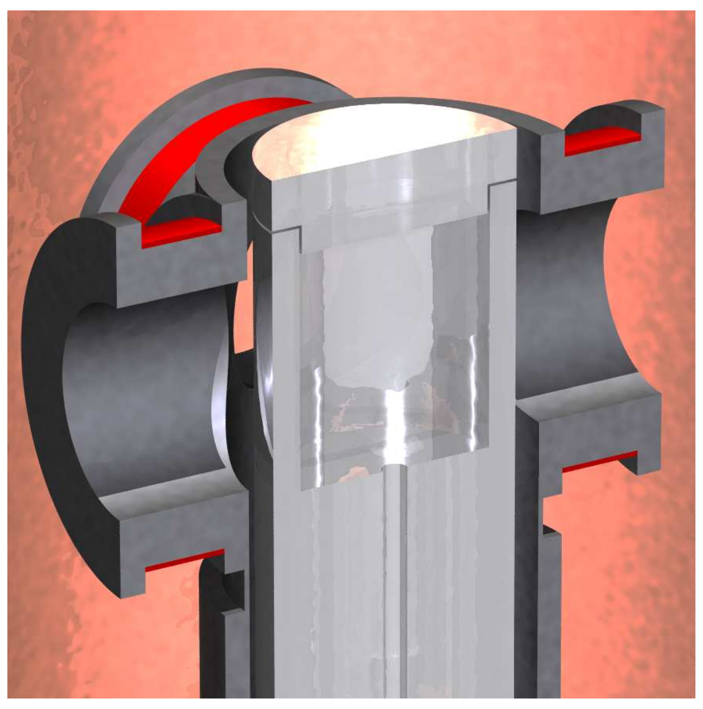
V. V. Zavjalov, A. M. Savin, P. J. Hakonen

Low Temperature Laboratory, Department of Applied Physics, Aalto University, Helsinki, Finland

Aalto University

Experimental cell

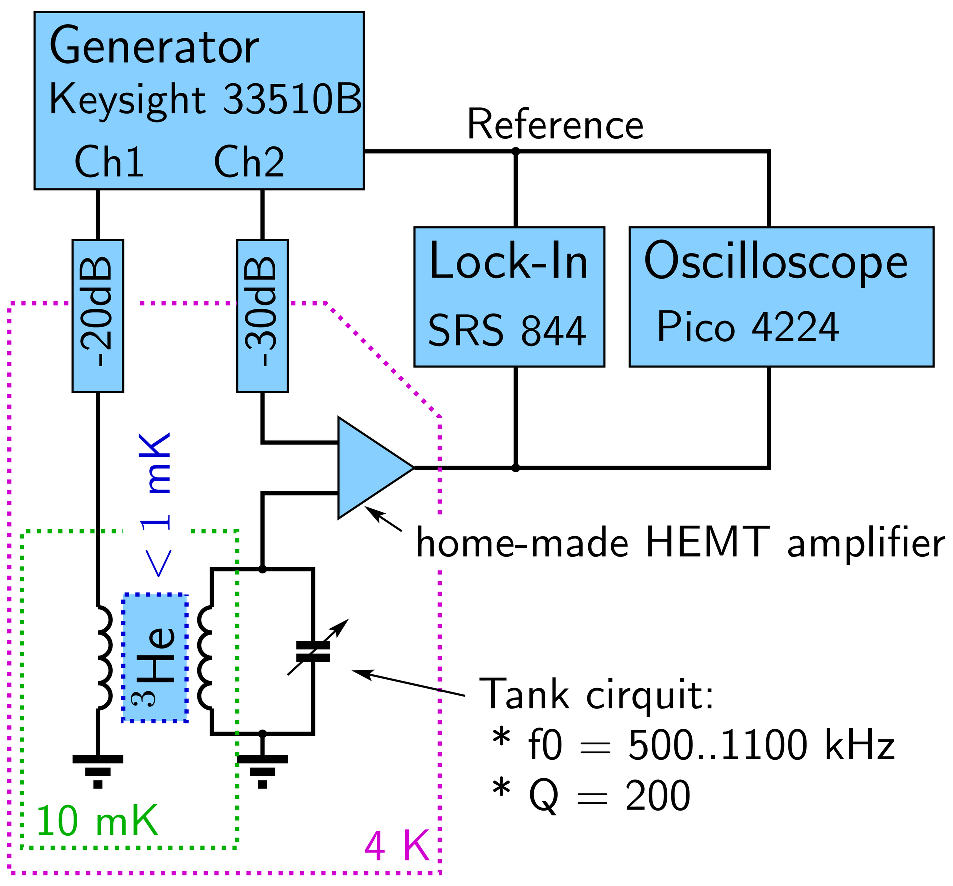




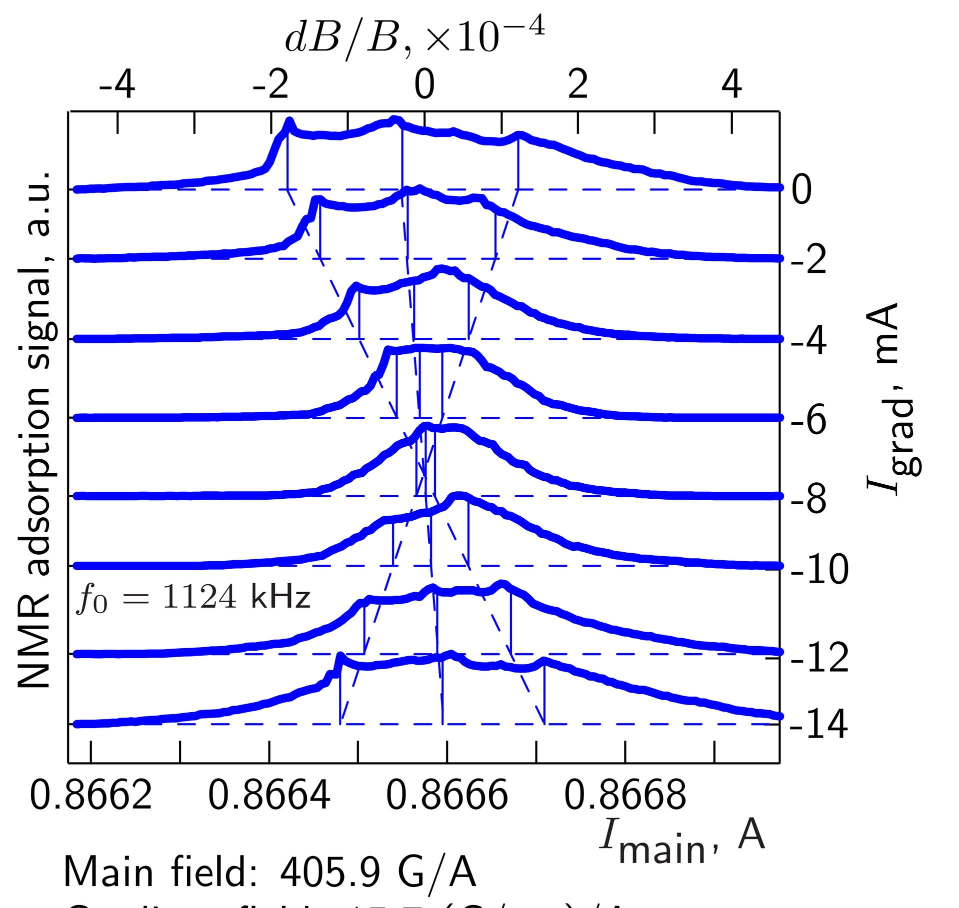
Cell (stycast 1266):
* D=7.8 mm, L=9.0 mm,
* filling line D=1 mm.

RF coils (50um copper wire):
* L = 55uH, R = 14 Ω @ 300K
* mutual L=0.15 uH, C=2.4 pF
* field: 16.6 G/A

NMR spectrometer



Field homogeneity and gradient



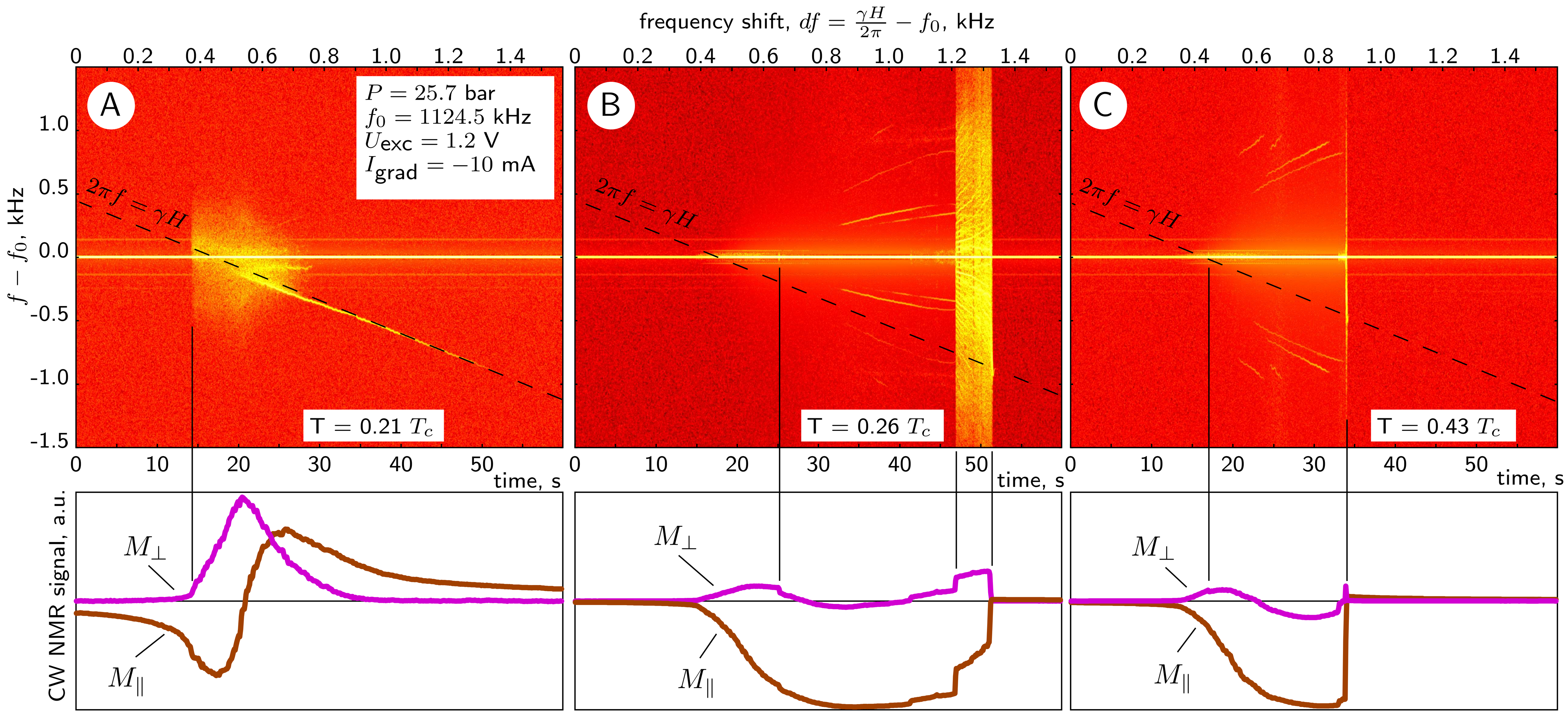
Main field: 405.9 G/A
Gradient field: 15.7 (G/cm)/A
Homogeneity: $\approx 1.5 \times 10^{-4}$

Measurements

Homogeneously precessing domain (HPD) [1,2] is created in CW NMR with frequency f_0 and RF excitation U_{exc} when field is swept down through $\gamma H = 2\pi f_0$. NMR signal is recorded by an oscilloscope.

- **A.** At low temperatures HPD can not be created because of Suhl instability [3]. A signal at Larmor frequency is observed.
- **B.** HPD is created, a few modulation modes are seen as side bands on the sliding FFT picture. At large frequency shifts there is an unstable region with almost chaotic modulation.
- **C.** At higher temperatures there is no unstable region. Different modulation modes with higher frequencies are seen.

Temperature measured by noise thermometer on the nuclear stage and is smaller then temperature of ^{3}He.



HPD theory

Spin dynamics of ^{3}He-B in magnetic field $\mathbf{H}$ is described by Leggett equations:

$$\dot{\mathbf{S}} = [\mathbf{S} \times \gamma \mathbf{H}] + \frac{4}{15}\frac{\chi_B}{\gamma^2}\Omega_B^2 \, \sin\vartheta(4\cos\vartheta + 1)\,\mathbf{n},$$

$$\dot{\mathbf{n}} = -\frac{1}{2}\,\mathbf{n} \times \Big(\frac{\gamma^2}{\chi_B}\mathbf{S} - \gamma\mathbf{H}\Big), - \frac{1}{2}\frac{\sin\vartheta}{1-\cos\vartheta}\Big[\mathbf{n}\Big(\mathbf{n}\cdot\Big(\frac{\gamma^2}{\chi_B}\mathbf{S} - \gamma\mathbf{H}\Big)\Big) - \Big(\frac{\gamma^2}{\chi_B}\mathbf{S} - \gamma\mathbf{H}\Big)\Big]$$

$$\dot{\vartheta} = \mathbf{n}\cdot\Big(\frac{\gamma^2}{\chi_B}\mathbf{S} - \gamma\mathbf{H}\Big),$$

where γ, χ_B, Ω_B are gyromagnetic ratio, susceptibility, Leggett frequency of ^{3}He-B, $\mathbf{S}$ is spin, $\mathbf{n}$ and ϑ are components of the order parameter.
In the presence of RF-field with frequency ω we can study this equation in a rotating frame where $\mathbf{H} = H_0\hat{\mathbf{z}} + H_r\hat{\mathbf{x}}$. Then in the equilibrium

$$n_x = 0, \quad n_y = \pm 1, \quad n_z = 0,$$

$$\cos\vartheta = -\frac{1}{4} - \frac{15}{16}\Big(d \pm \frac{h}{\sqrt{15}}\Big)\frac{1}{b},$$

$$\frac{\gamma^2}{\chi_B}\frac{S_x}{\omega} = \pm\sin\vartheta + h, \quad S_y = 0, \quad \frac{\gamma^2}{\chi_B}\frac{S_z}{\omega} = \cos\vartheta - d,$$

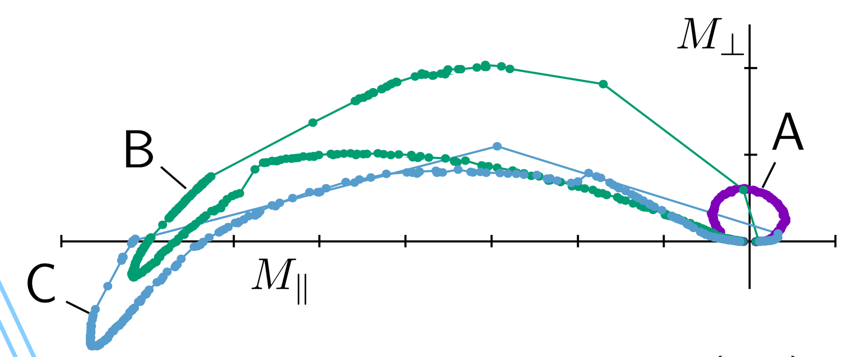
and frequencies of small oscillations near the equilibrium are [4]:

$$\Big(\frac{\omega_1}{\omega}\Big)^2 = \frac{4}{\sqrt{15}}\frac{\pm h\, b}{1 + 8/3\, b},$$

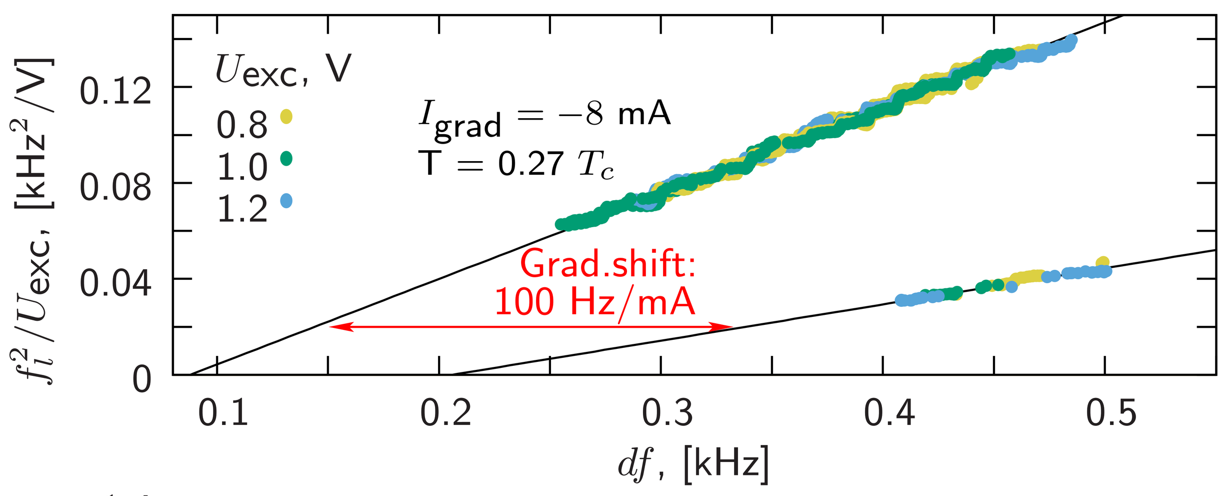
$$\Big(\frac{\omega_2}{\omega}\Big)^2 = \frac{\sqrt{15}\, d \mp h}{\sqrt{15}}\,\frac{3/8 + b}{1 + b}.$$

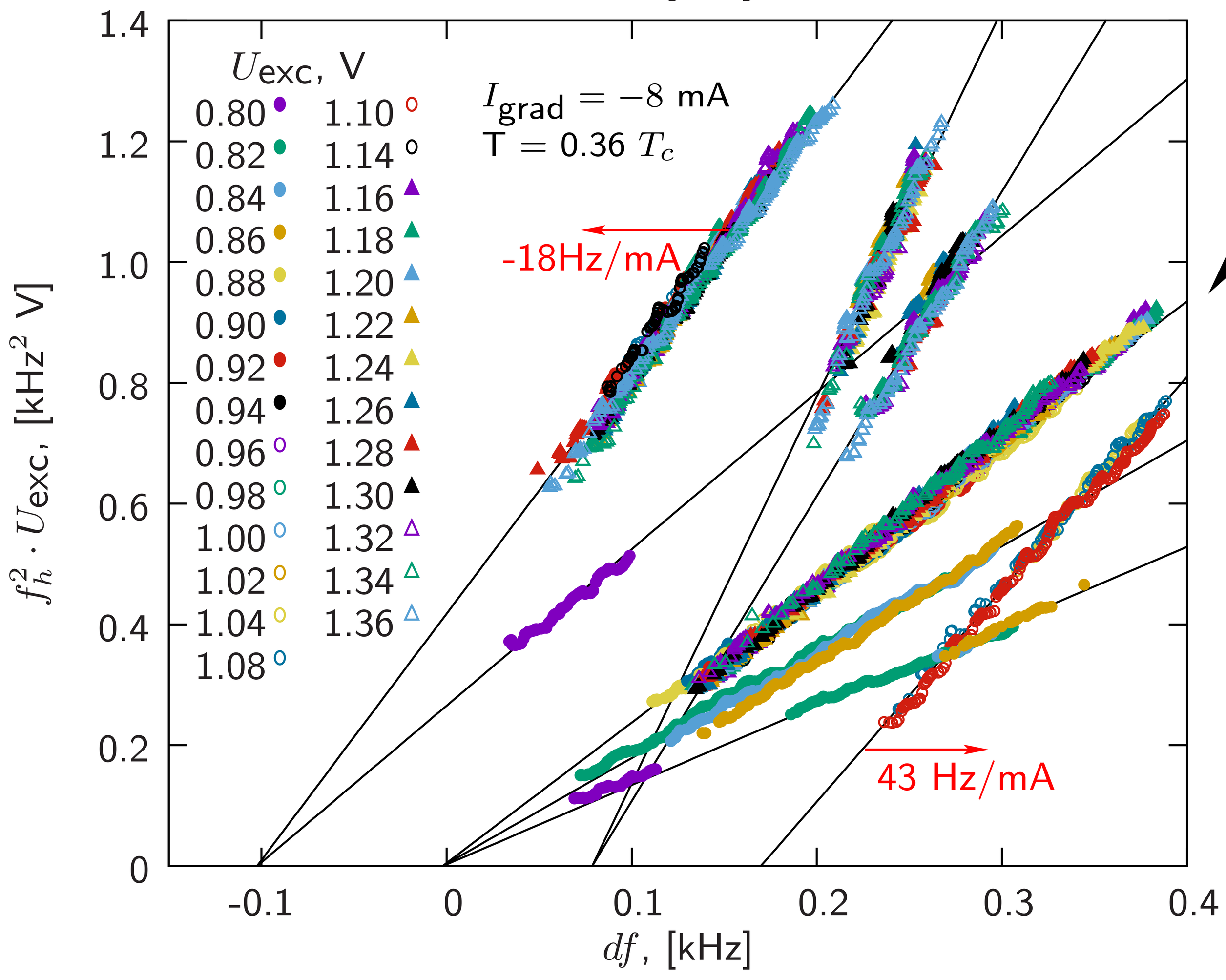
where $d = \frac{\omega - \gamma H_0}{\omega}$, $h = \frac{\gamma H_r}{\omega}$, $b = \big(\frac{\Omega_B}{\omega}\big)^2$.

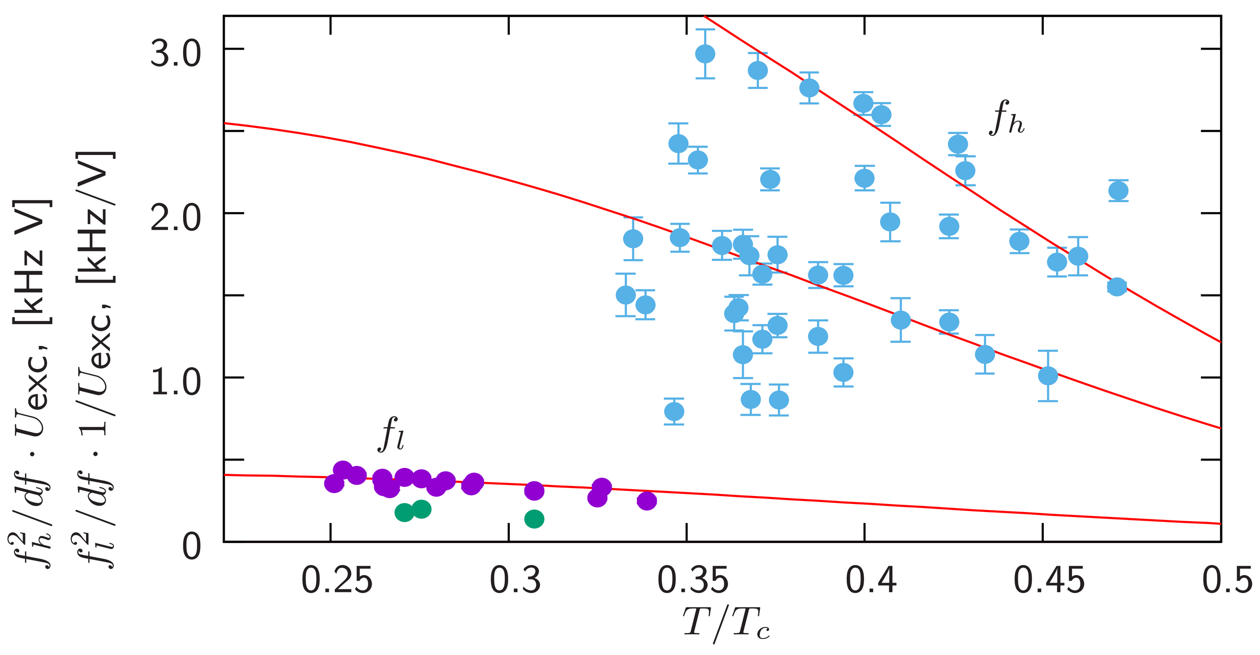
1. I. A. Fomin, JETP **61**, 1199 (1985)
2. A. S. Borovik-Romanov et.al., JETP **61**, 1207 (1985)
3. Yu. M. Bunkov et.al., Phys.B **155**& **156**, 675 (1990)
4. V. V. Dmitriev et.al., JLTP **138**, 765 (2005)



HPD with negative dispersion ($M_\parallel$) is always observed.







"Low-temperature" modes (B):

$$f_l^2 \propto d \cdot h$$

"High-temperature" modes (C):

$$f_h^2 \propto d/h$$

In the experiment

$$f_0 = 1.12 \text{ MHz},$$
$$h = 6.2 \cdot 10^{-6} \text{ (at } U_{\text{exc}} = 1 \text{ V)},$$
$$d = 0 \ldots 4 \cdot 10^{-4},$$
$$b = 4.2 \ldots 6.7 \cdot 10^{-2}.$$

Frequencies of both modes decrease with temperature (as b^2?). From gradient-caused shifts (see red arrows) we can say that modes are localized at different heights of the cell.
An additional small parameter is needed. We have

$$\frac{f_l}{f_h} \approx \frac{h}{2 \cdot 10^{-5}}$$

A possible source of this constant is a ratio of magnetic textural energy $a(\mathbf{n}\cdot\mathbf{H})^2$ and Zeeman energy $\chi_B \mathbf{H}^2$ which is $\approx 6 \cdot 10^{-6}$. We think that a non-uniform texture exists in the HPD, which stabilizes state with negative $M_\parallel$ and creates localized traps for spin-wave modes.
Additional investigation of non-uniform textures in HPD and spin-wave spectra inside them is needed.