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Light Higgs channel of magnon BEC decay in ^{3}He-B

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Superfluid ^{3}He

Fermi liquid.

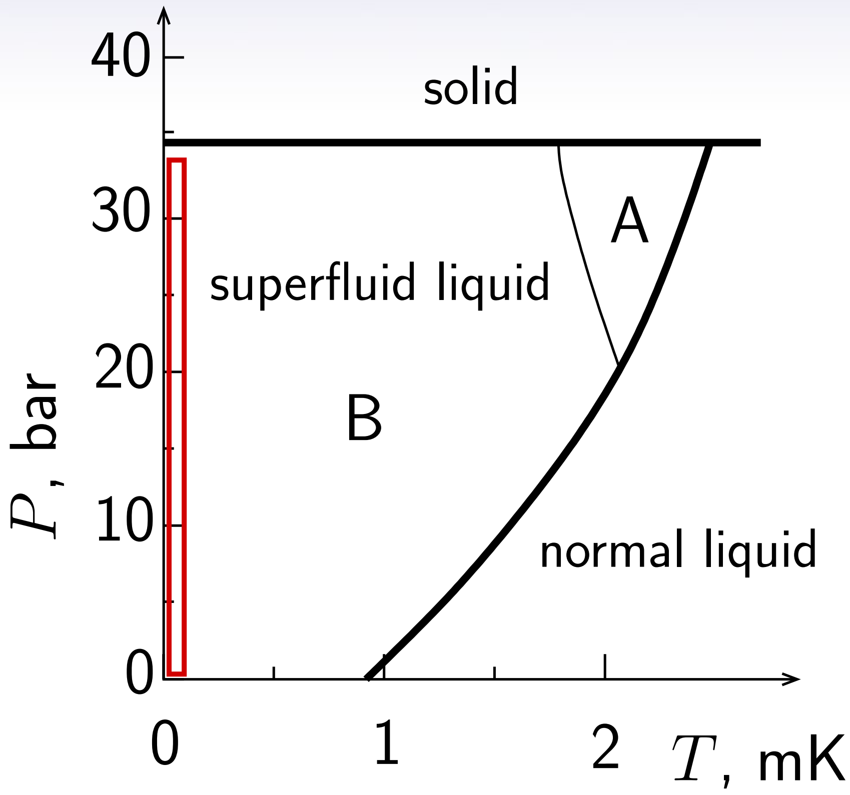
Superfluid transition at $\sim$1 mK.

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

Order parameter: 3x3 complex matrix

B phase: $A_{jk} = \Delta \, e^{i\phi} \, R_{jk}$.

(ϕ – phase, R_{jk} – rotation matrix)



Oscillations of the order parameter: 18 modes

4 phase (Nambu-Goldstone) modes

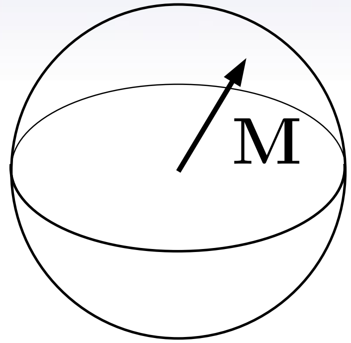
14 amplitude (Higgs) modes

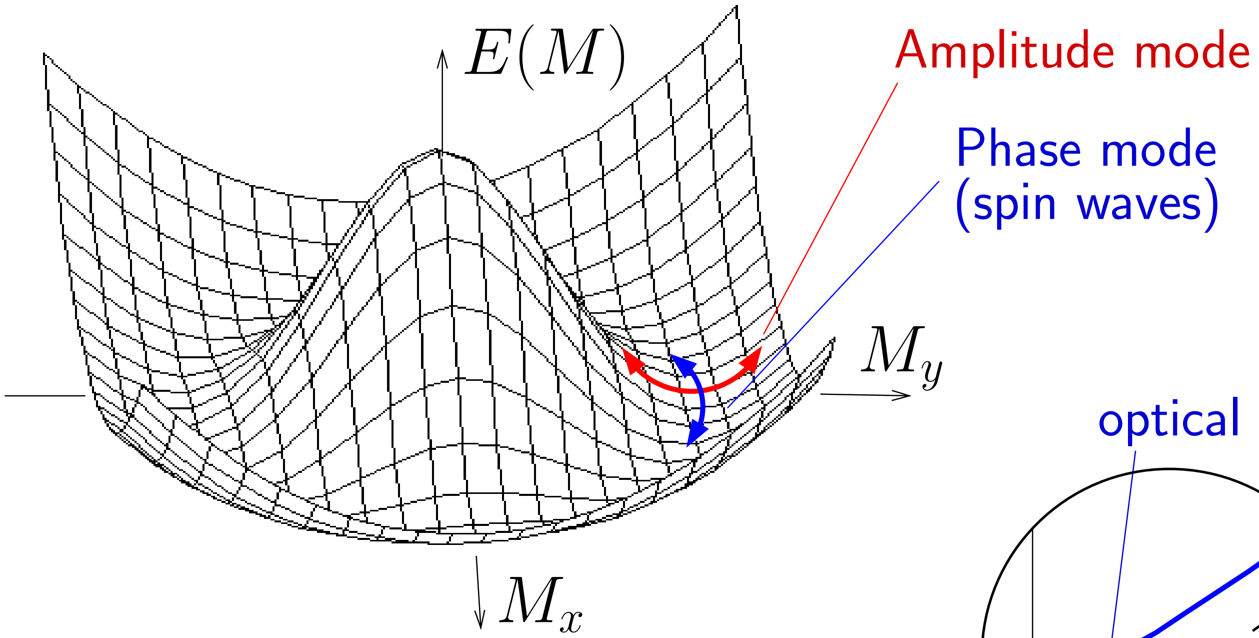
Ferromagnet

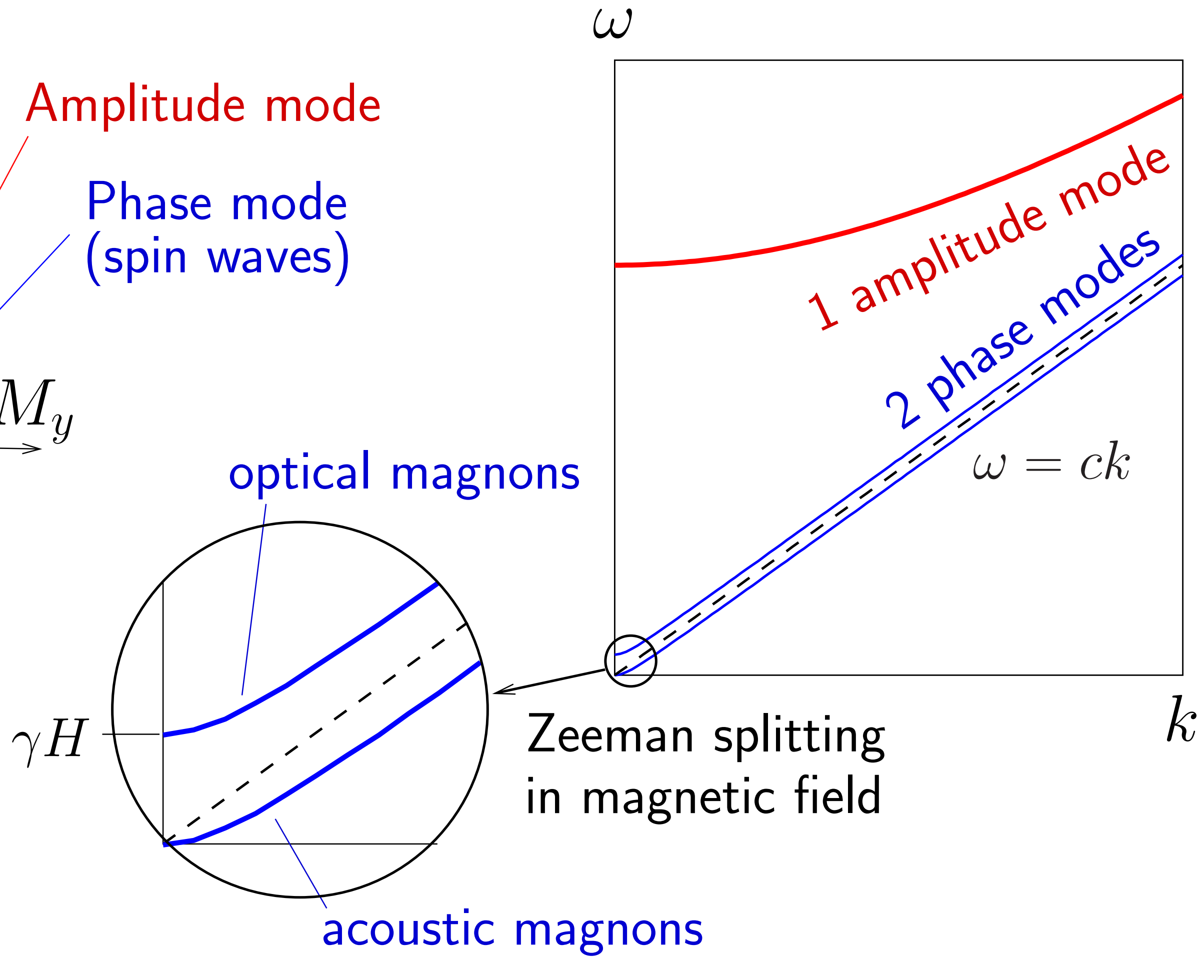
3D order parameter $\mathbf{M}$

1 amplitude (Higgs) mode

2 phase (Nambu-Goldstone) modes — spin waves



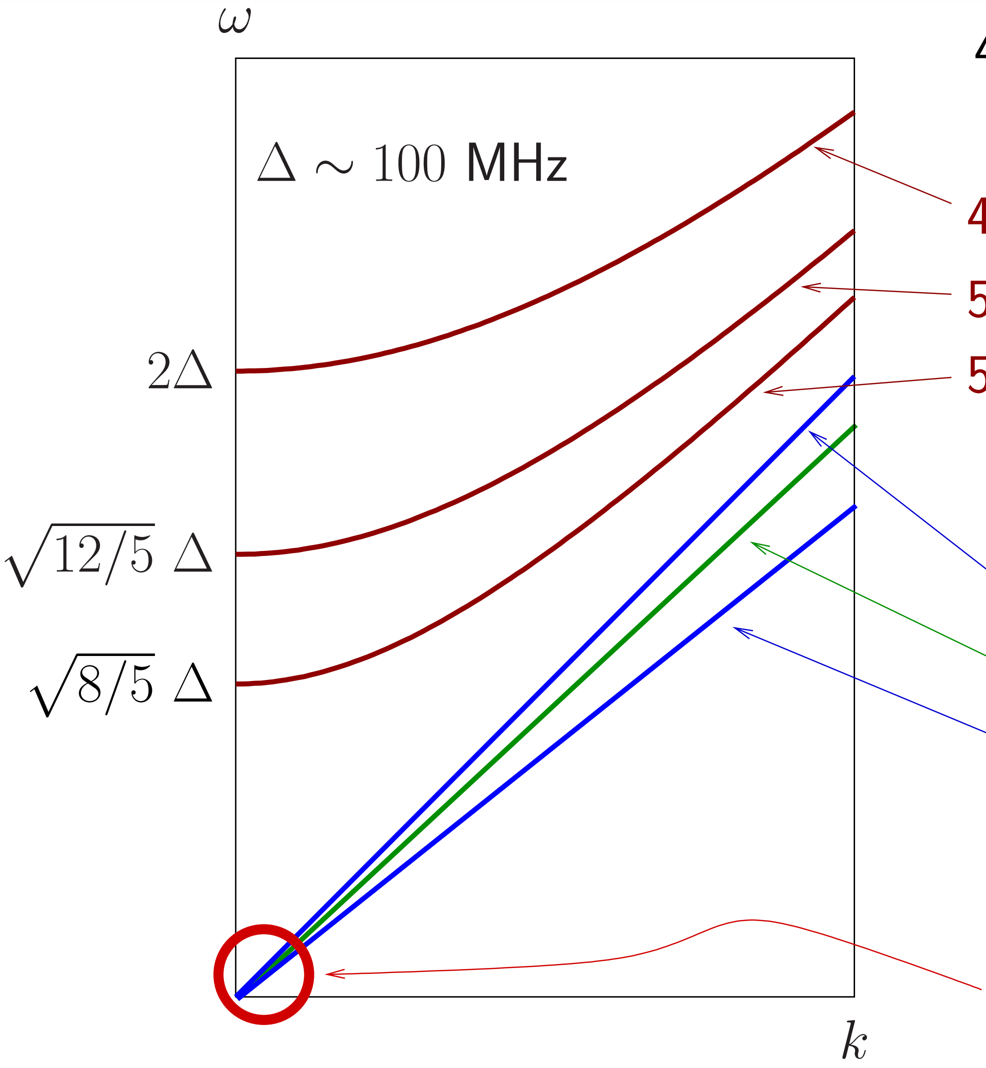




Collective modes in ^{3}He-B

3x3 complex matrix — 18 modes

4D degenerate space: $A_{jk} = \Delta \; e^{i\phi} \; R_{jk}(\hat{\mathbf{n}}, \theta)$



4 pair breaking modes

5 imaginary squashing modes

5 real squashing modes

14 heavy Higgs modes

spin wave mode (θ) ✔

sound mode (ϕ)

2 spin wave modes ($\hat{\mathbf{n}}$) ✔

4 gapless NG modes

Experiment: NMR, spin waves at ~1 MHz

Spin waves

Spin waves — motion of $R(\hat{\mathbf{n}}, \theta)$

1. magnetic field $\mathbf{H} \parallel \hat{\mathbf{n}}$

motion of $\hat{\mathbf{n}}$ $\to$ transverse spin waves, similar to ferromagnets

motion of θ $\to$ longitudinal spin waves.

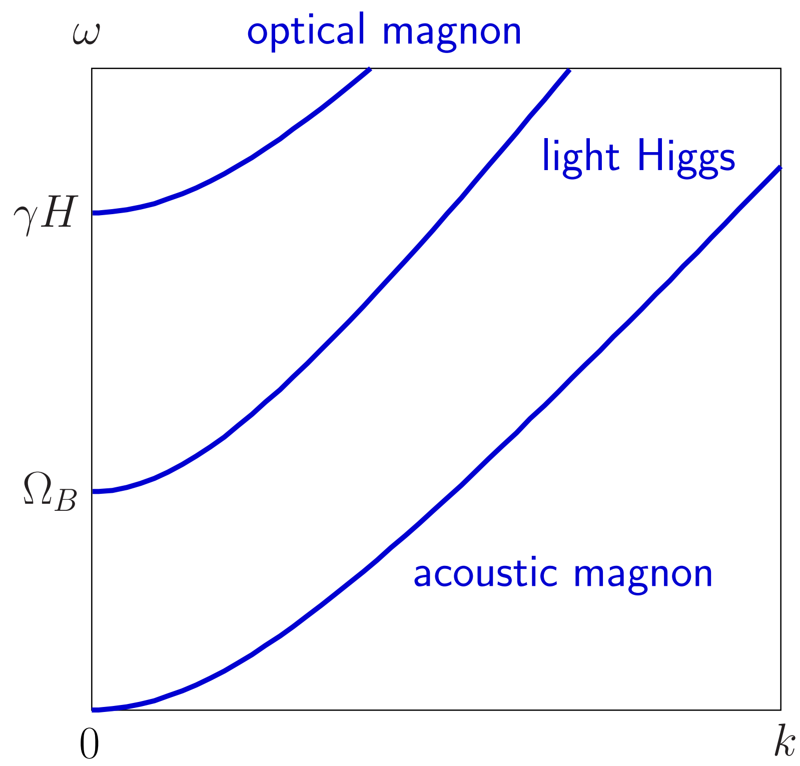
2. spin-orbit interaction:

$$F_{so} = \frac{8}{15} \frac{\chi_B}{\gamma^2} \Omega_B^2 \, (\cos\theta + 1/4)^2$$

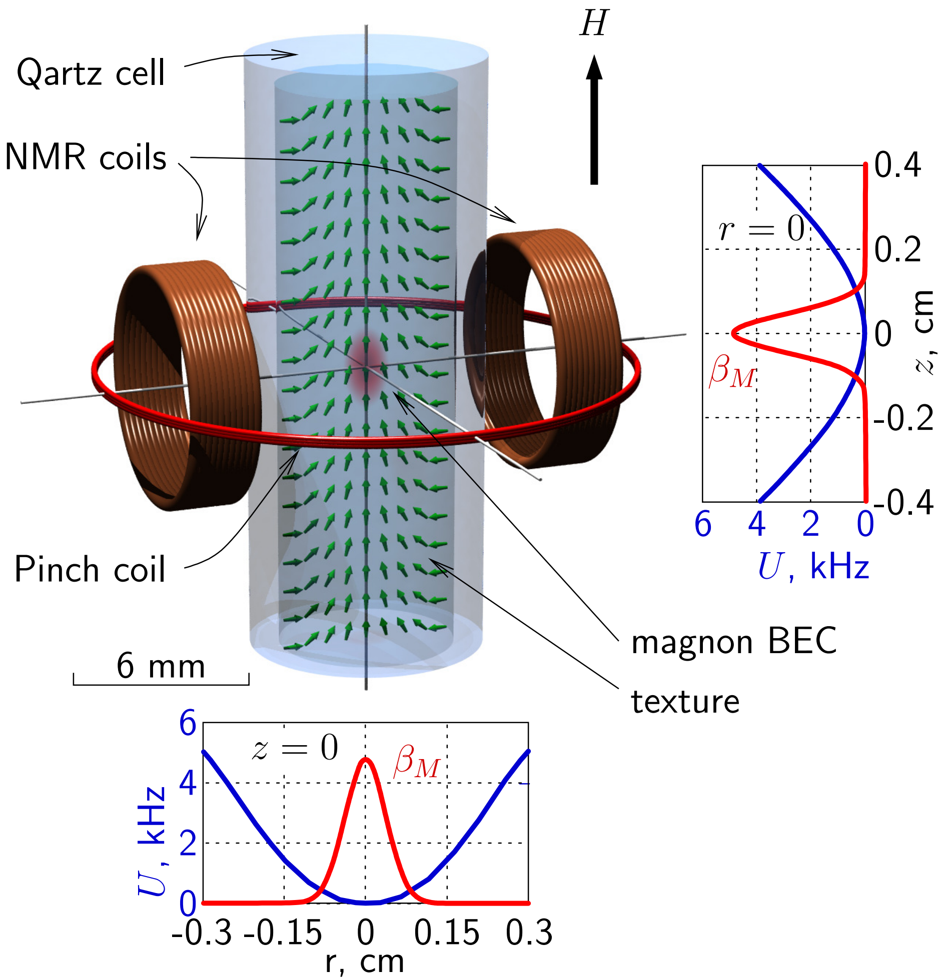
$\theta \approx 104^\circ$ $\qquad$ $\Omega_B \sim 100$ kHz

additional symmetry breaking —

light Higgs mode.



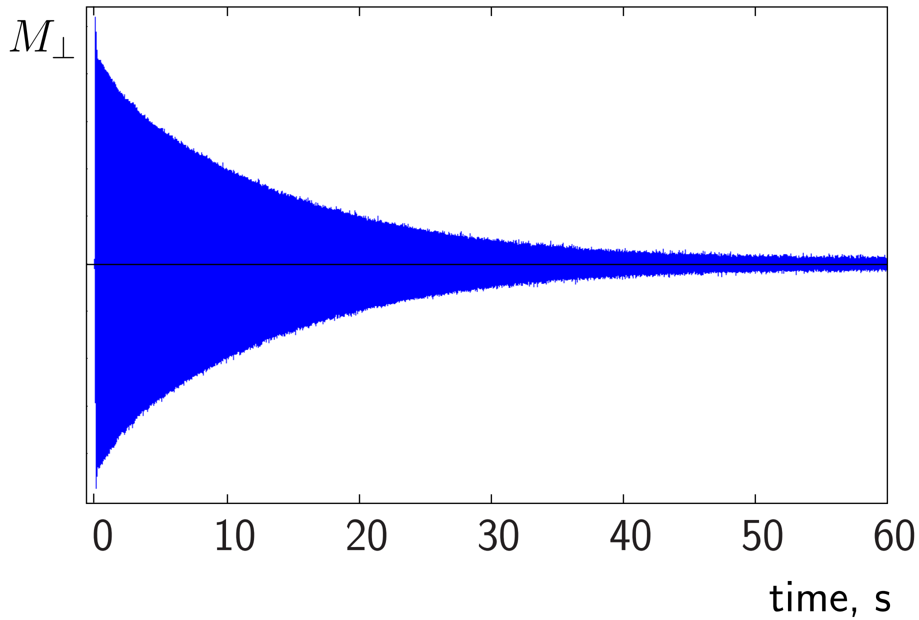
Experimental setup



Optical magnons — quasiparticles in a potential formed by texture and field.

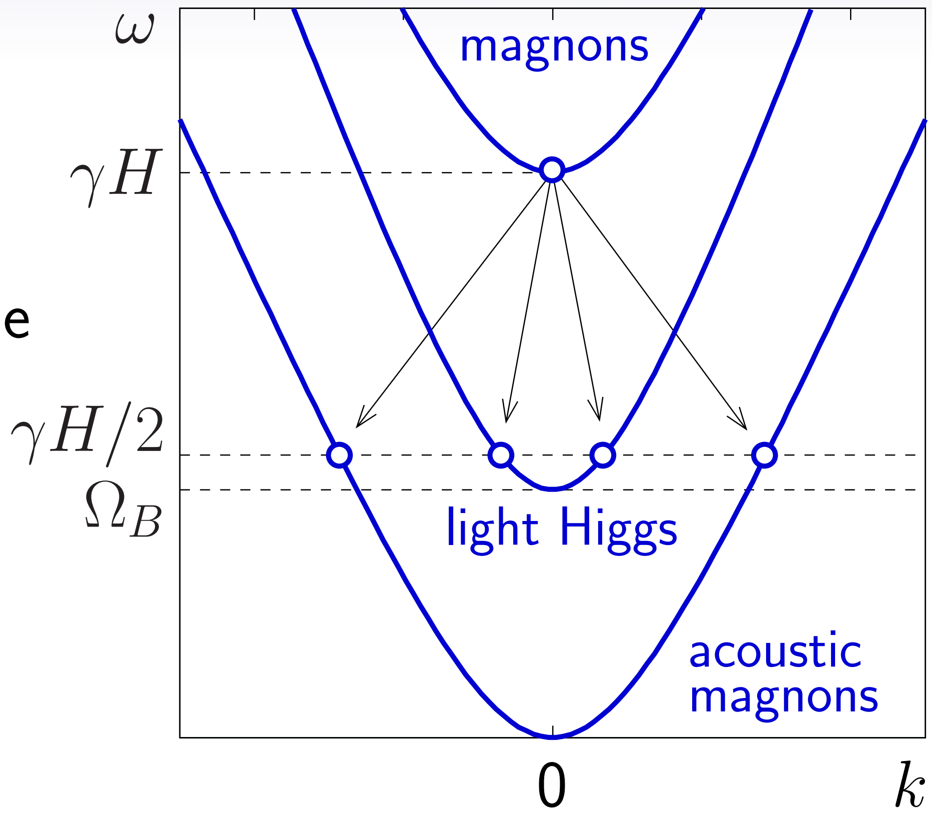
Energy minimum, $\mathbf{H} \parallel \hat{\mathbf{n}}$, BEC

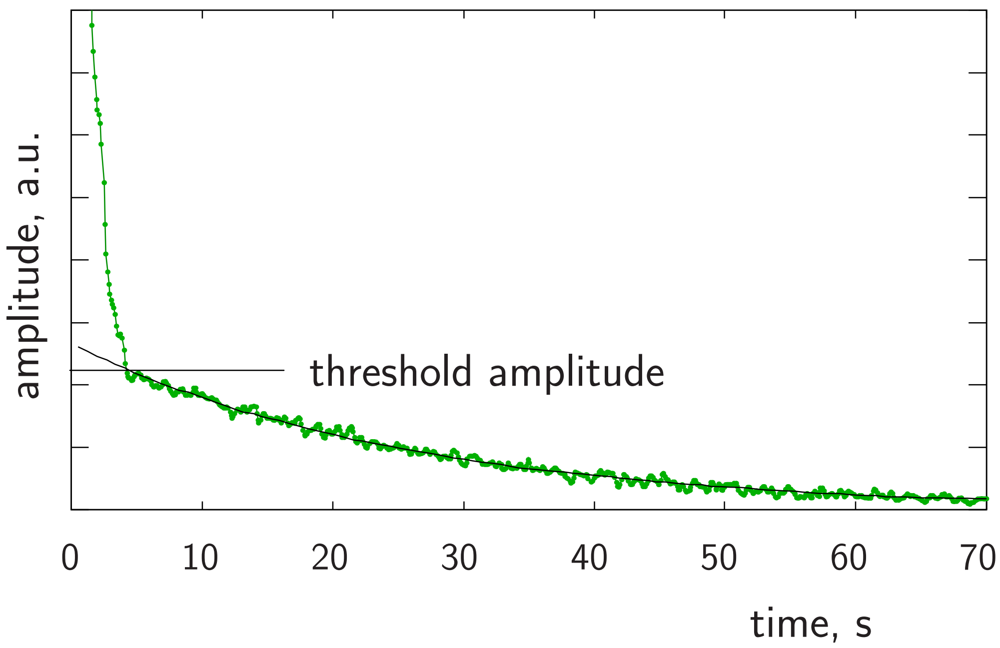
Long coherent precession:



Suhl instability

Parametric decay of optical magnons into pairs of other spin wave modes starting from some threshold amplitude



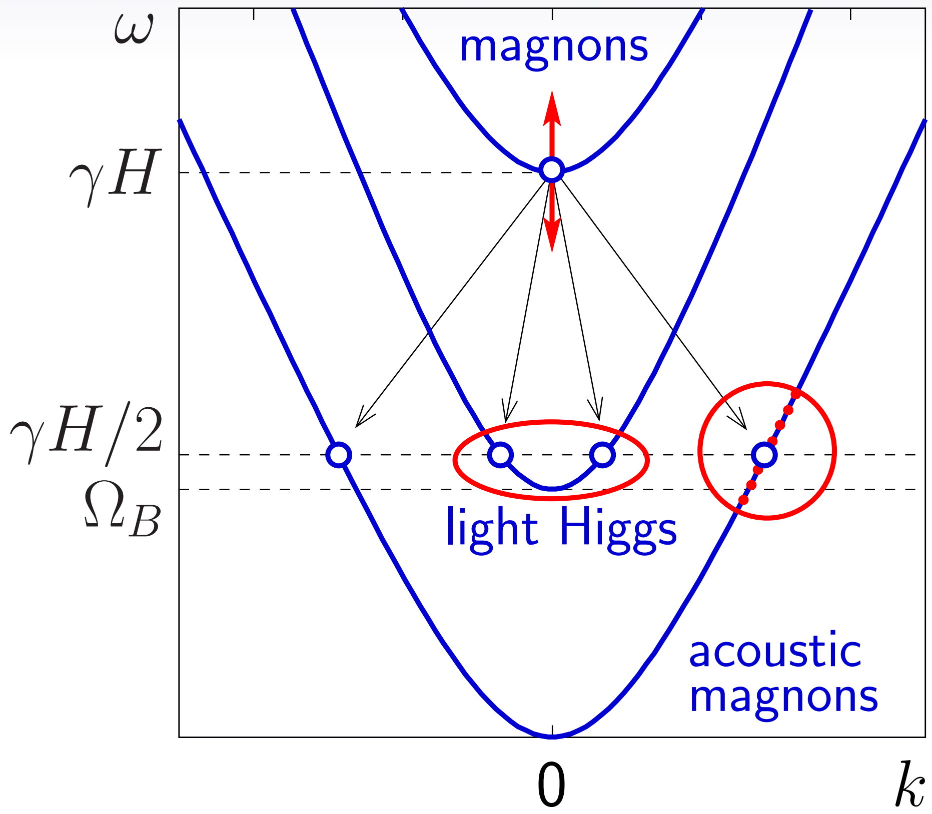


Suhl instability

Measuring the threshold vs. H:

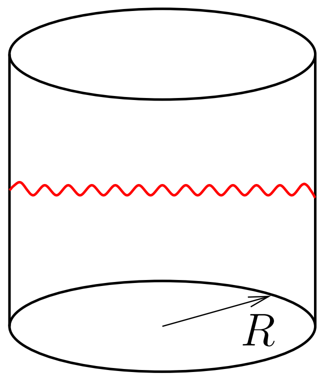
1. Light Higgs channel of decay:

   Opens at $\gamma H = 2\Omega_B$



2. Acoustic channel of decay:

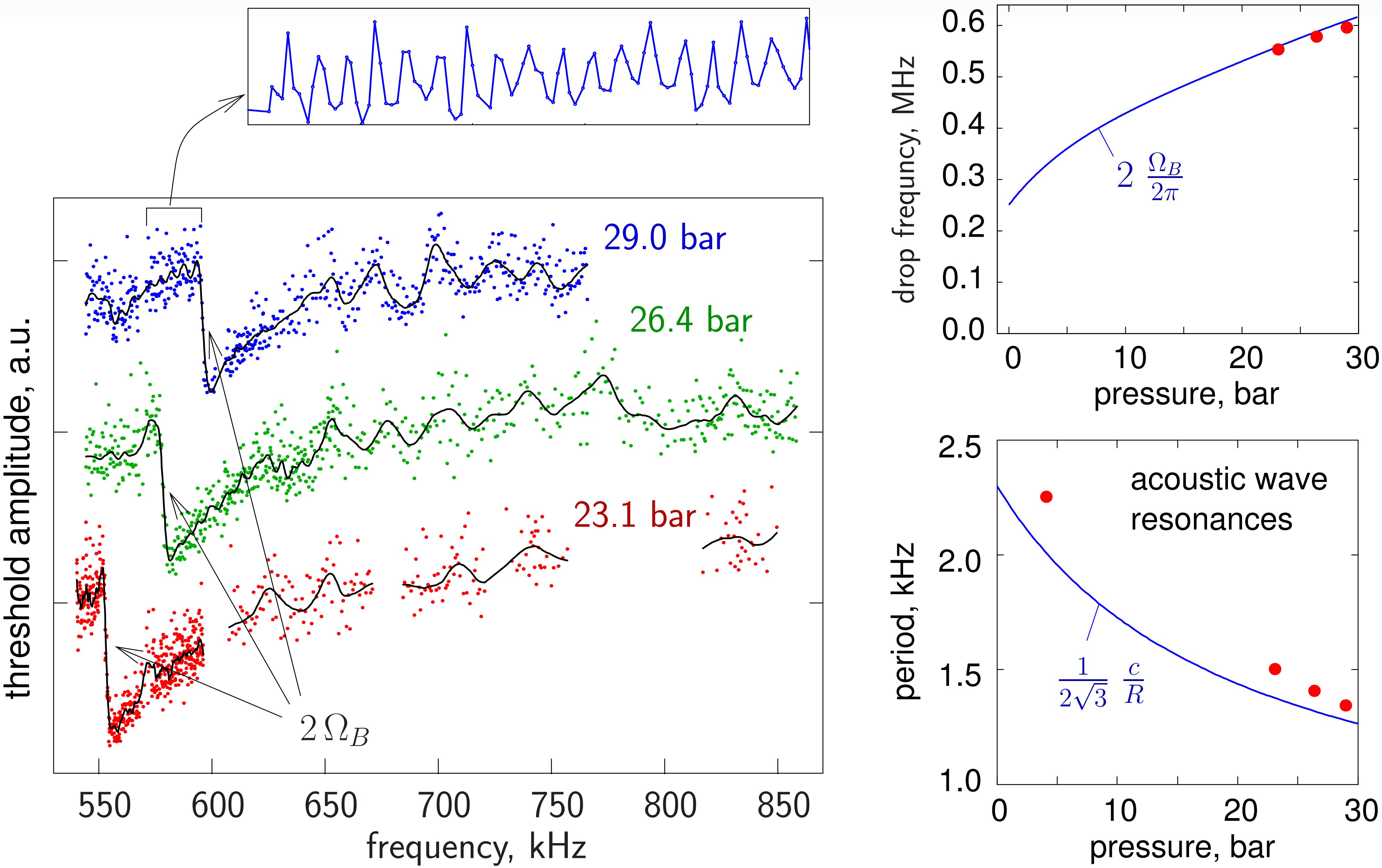
   Resonances in the cell



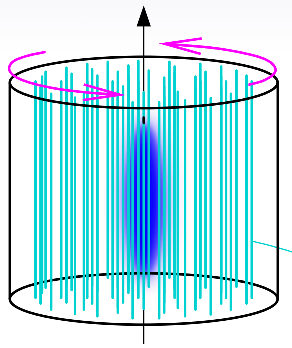
$$\int_0^{2R} k\ dr = \pi n$$

Period of resonances: $df = \frac{1}{2\sqrt{3}}\,\frac{c}{R}$

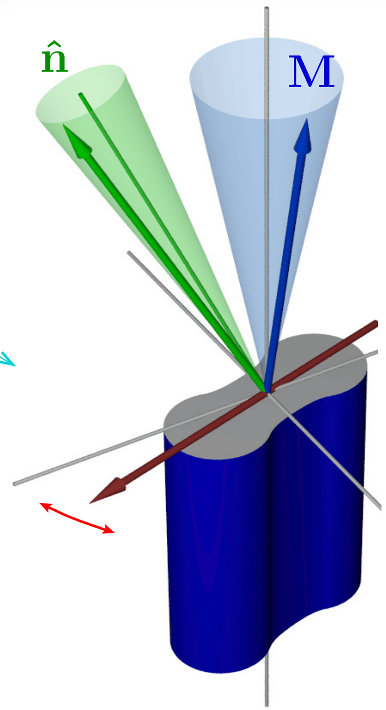
Suhl instability - experiment



Effect of vortices



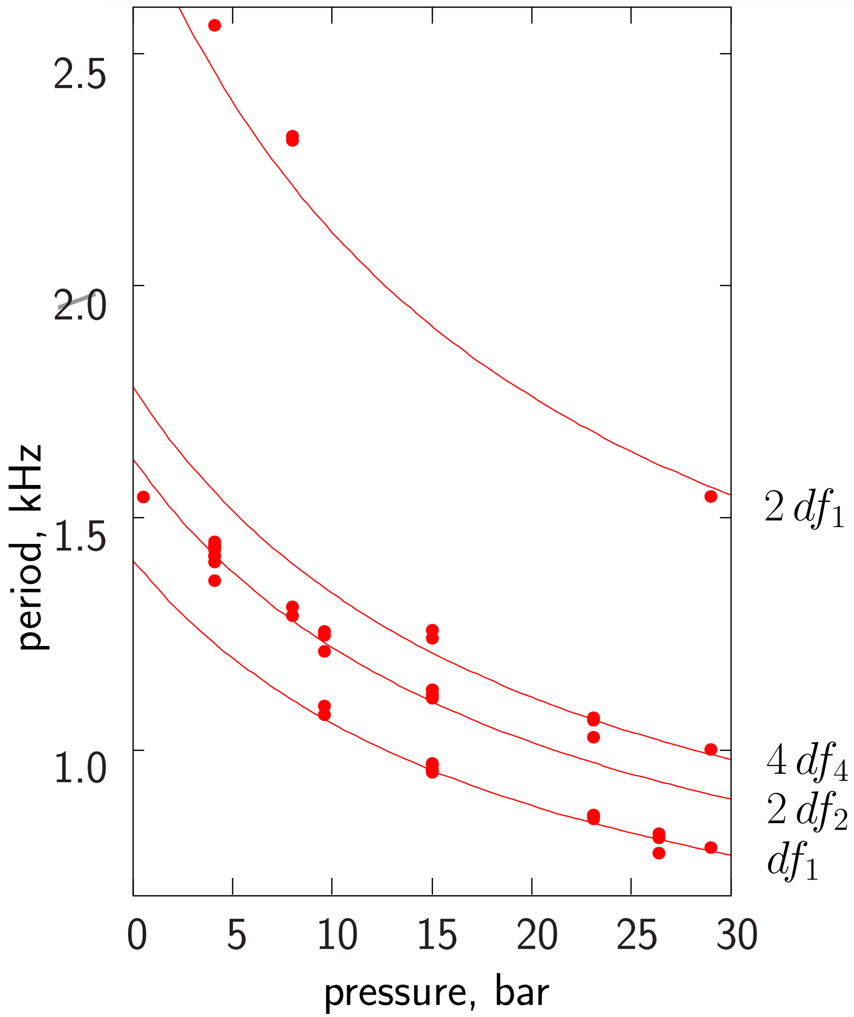
Non-axisymmetric vortex

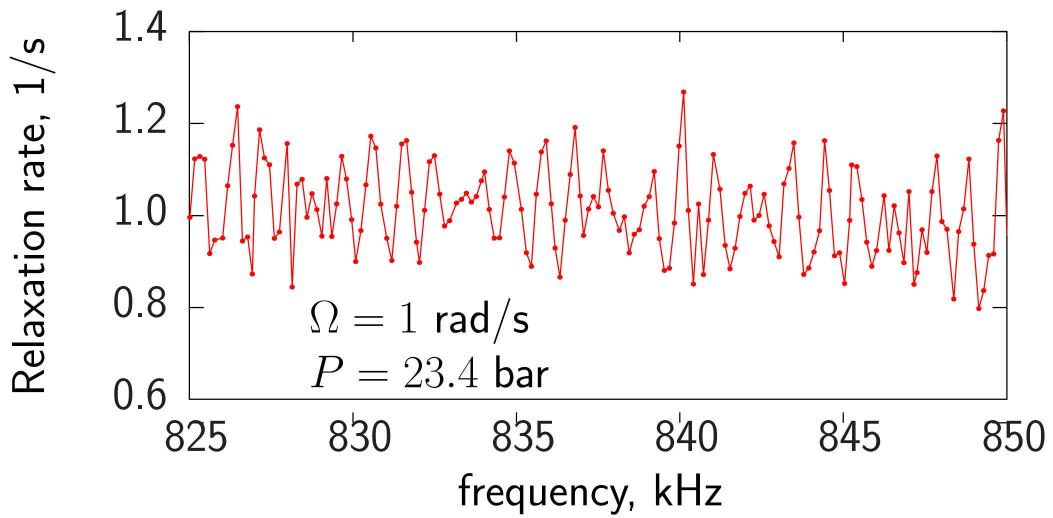


Non-harmonic oscillations

Excitation of acoustic magnons at $\omega_0,\ 2\omega_0 \ldots N\omega_0$

$$df_N = \frac{1}{4\sqrt{N(N+1)}}\,\frac{c}{R}$$





Conclusions

1. Three spin wave modes in ^{3}He-B form the analog of the little Higgs vector field. The role of the interaction, which explicitly violates the global spin-rotation symmetry, is played by tiny spin-orbit coupling. The longitudinal spin wave is an analog of the light Higgs boson. Two others are optical and acoustic magnons.
2. We observed the interplay of the all three spin wave modes in the experiment: a parametric decay of BEC of optical magnons into light Higgs bosons or into acoustic magnons. Direct excitation of acoustic magnons have been also observed in presence of vortices.
3. A possibility of excitation and detection of acoustic magnons can open a new research direction, a study of a ^{3}He sample with the short spin waves, which can be controlled by non-uniform magnetic field and the texture. The parametric excitation of light Higgs bosons gives us a good method to measure Leggett frequency.