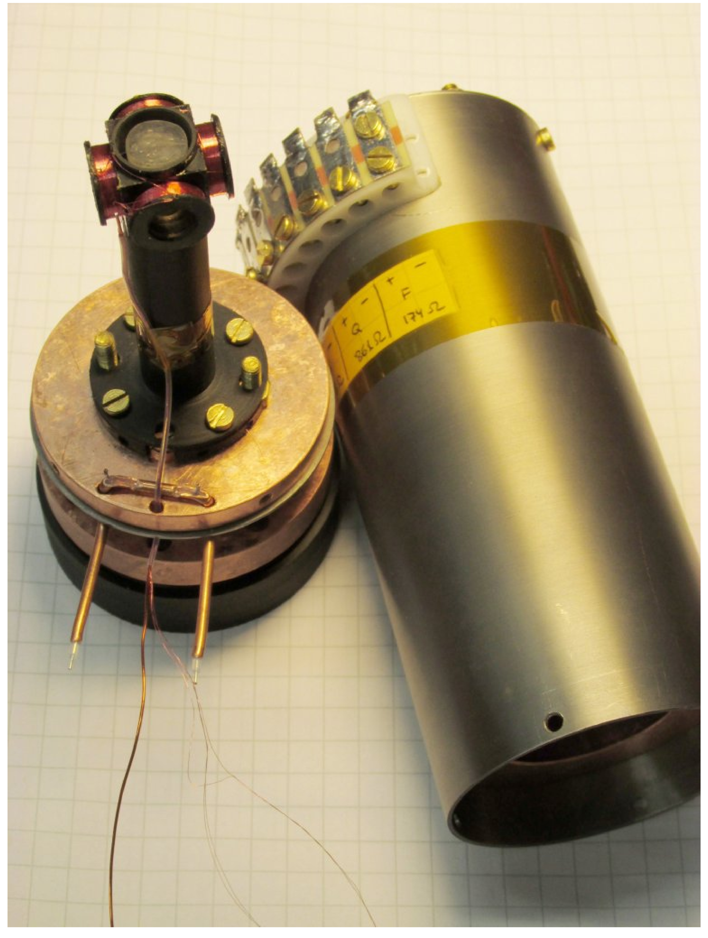
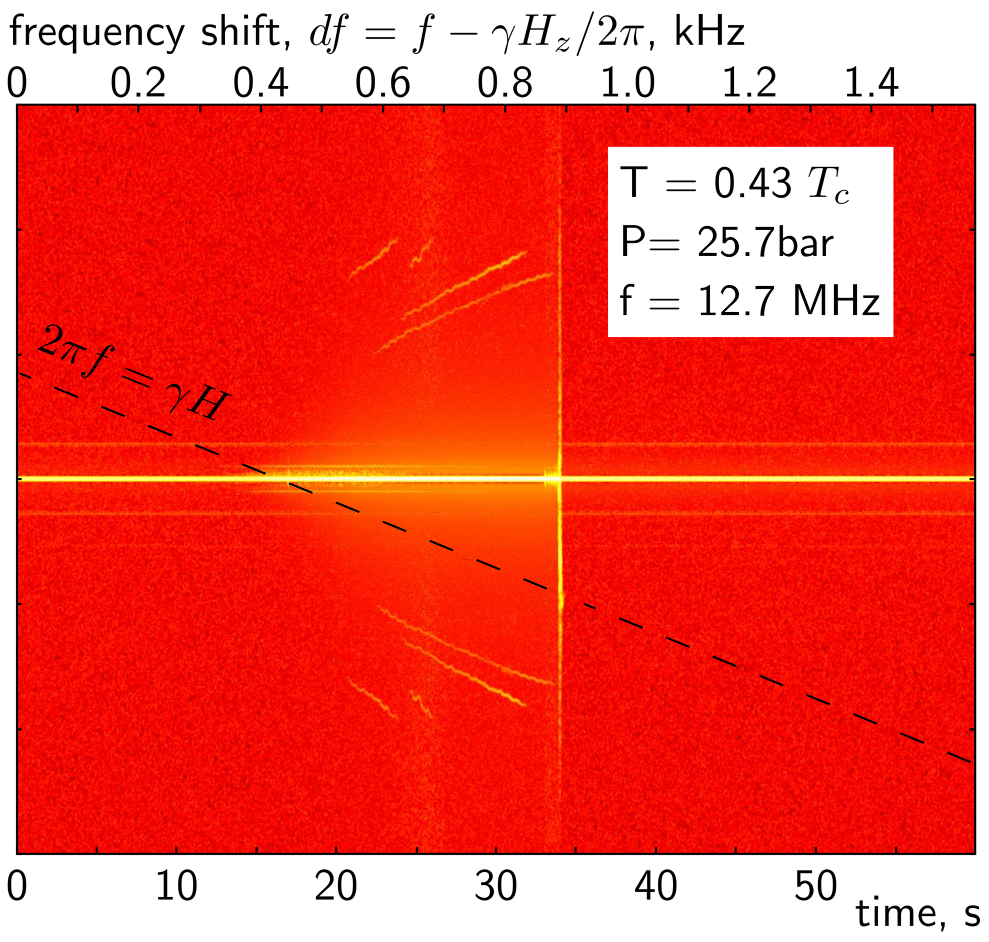
Dynamics of ϑ-solitons in the HPD state of superfluid ^{3}He-B

V. V. Zavjalov

Department of Physics, Lancaster University, Lancaster LA1 4YB, United Kingdom

Motivation: Experiment in Helsinki, 2018





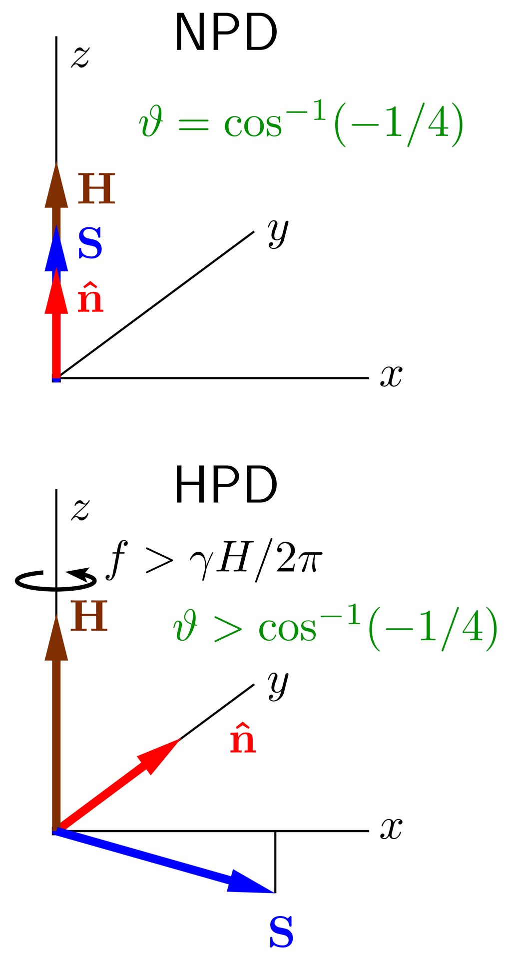
In HPD state we observed many oscillaton modes with frequency $\propto \sqrt{df}$ localized in different parts of the cell. Oscillations of solitons?

Spin dynamics, HPD and NPD states

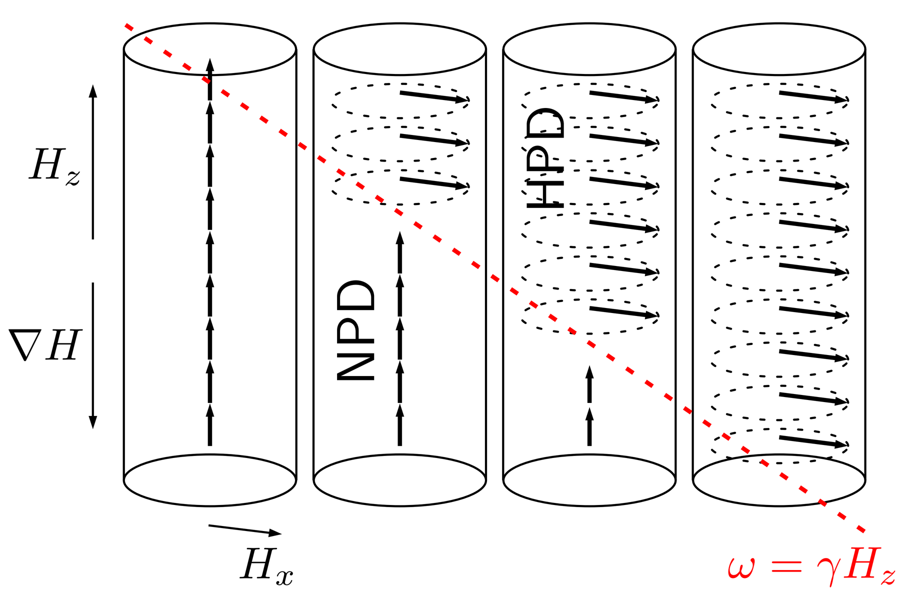
^{3}He-B: spin state is described by rotation matrix $R(\mathbf{n}, \vartheta)$

Leggett equations:

$$\begin{cases} \dot{S}_a &= [\mathbf{S} \times \gamma \mathbf{H}]_a + T_a(R) \\ \dot{R}_{aj} &= e_{abc} R_{cj} \left(\frac{\gamma^2}{\chi_B} \mathbf{S} - \gamma \mathbf{H} \right)_b \end{cases}$$

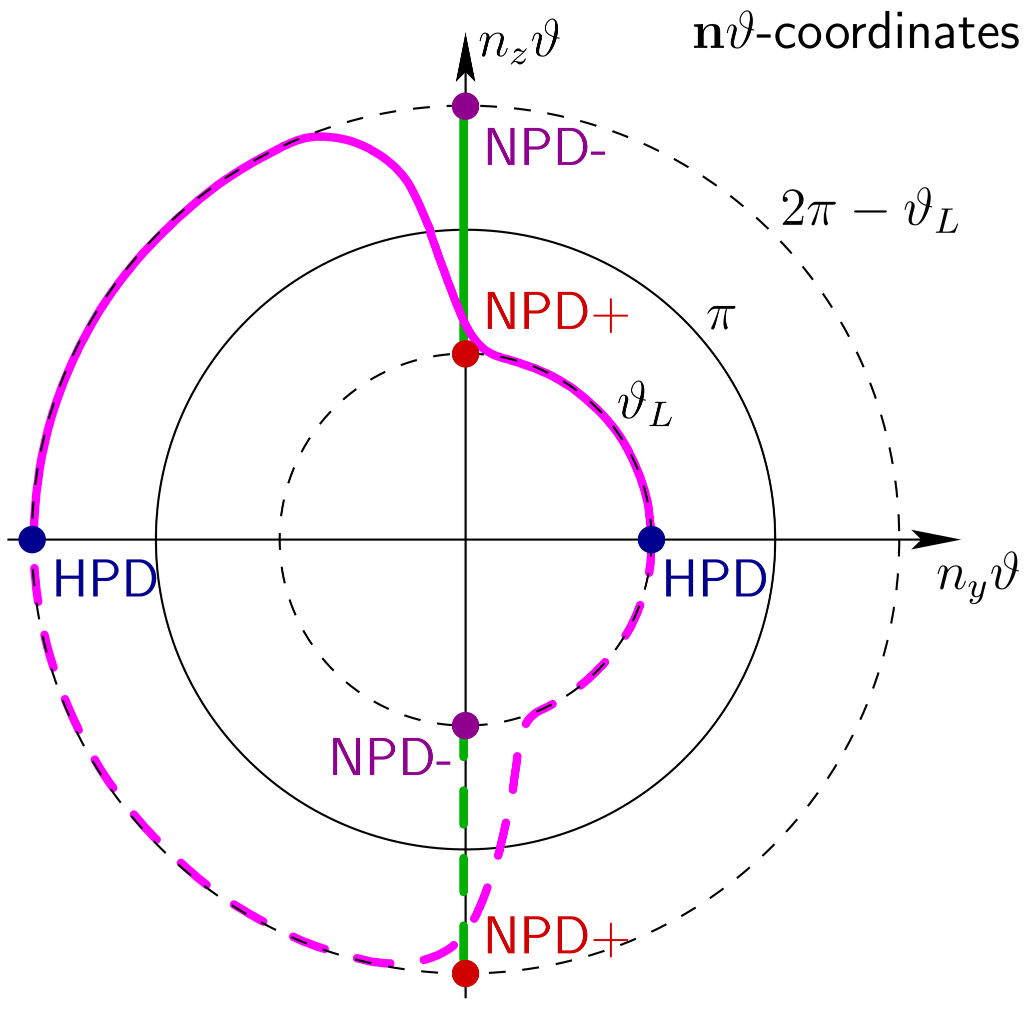


creation of HPD in CW NMR



Frequency shift: $df = f - \gamma H_z/2\pi$

ϑ-solitons



Soliton in NPD: only ϑ is changing. Exact solution:

$$\vartheta = 2\tan^{-1}\left[\sqrt{\frac{3}{5}} \tanh\left(\sqrt{\frac{65}{64}} \frac{\pm z}{\xi_D}\right)\right] + \pi.$$

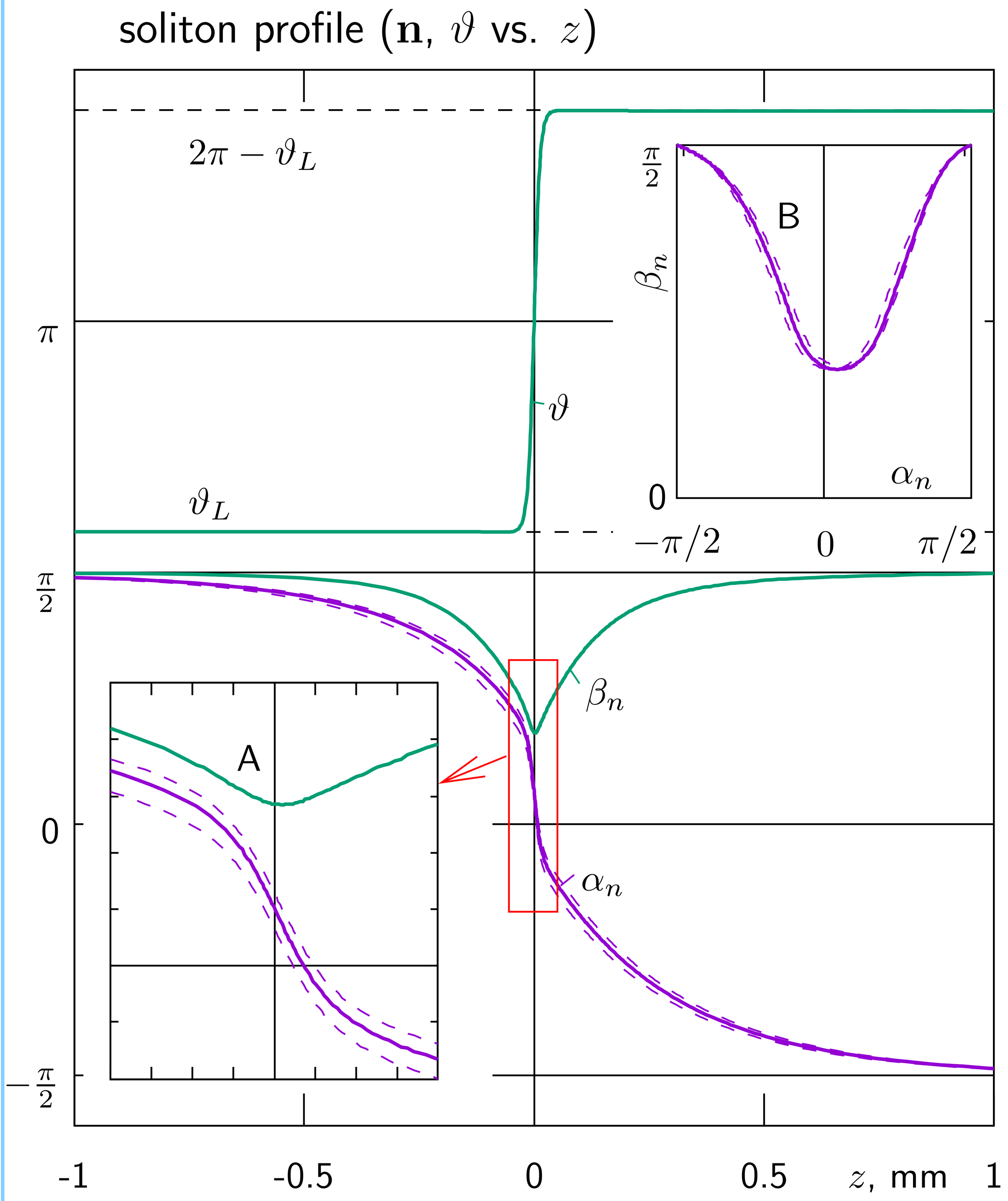
$$\xi_D^2 = \frac{65}{16}(2c_\perp^2 - c_\parallel^2)/\Omega_B^2$$

Soliton in HPD: small core where ϑ is changing and long tails where $\mathbf{n}$ is rotating.

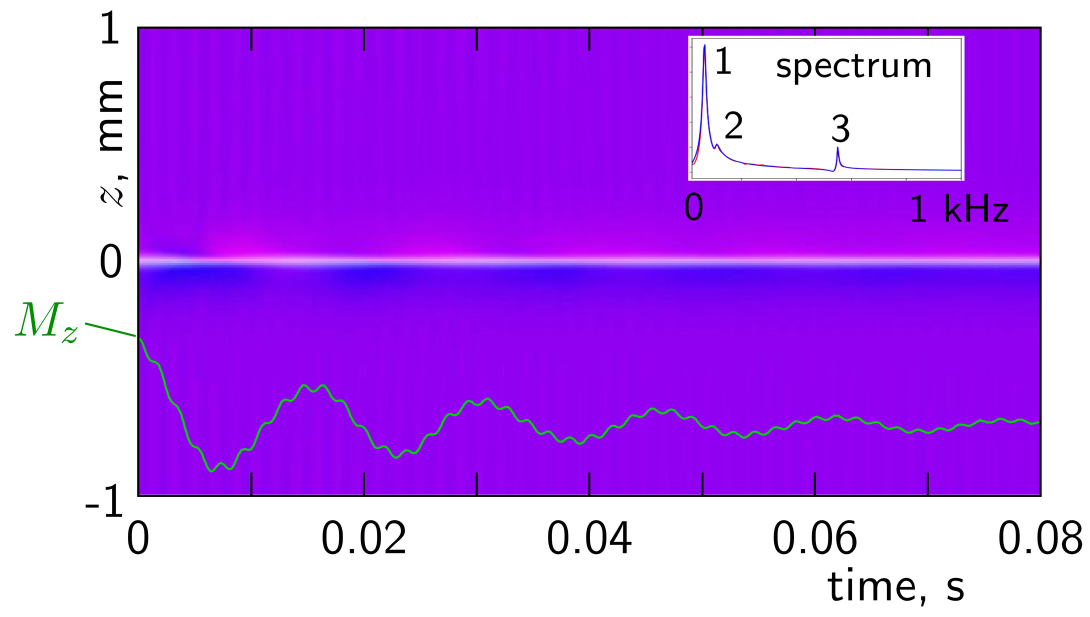
Calculation of ϑ-soliton in HPD

We solve Leggett equations numerically in 1D geometry to get soliton profile and dynamics

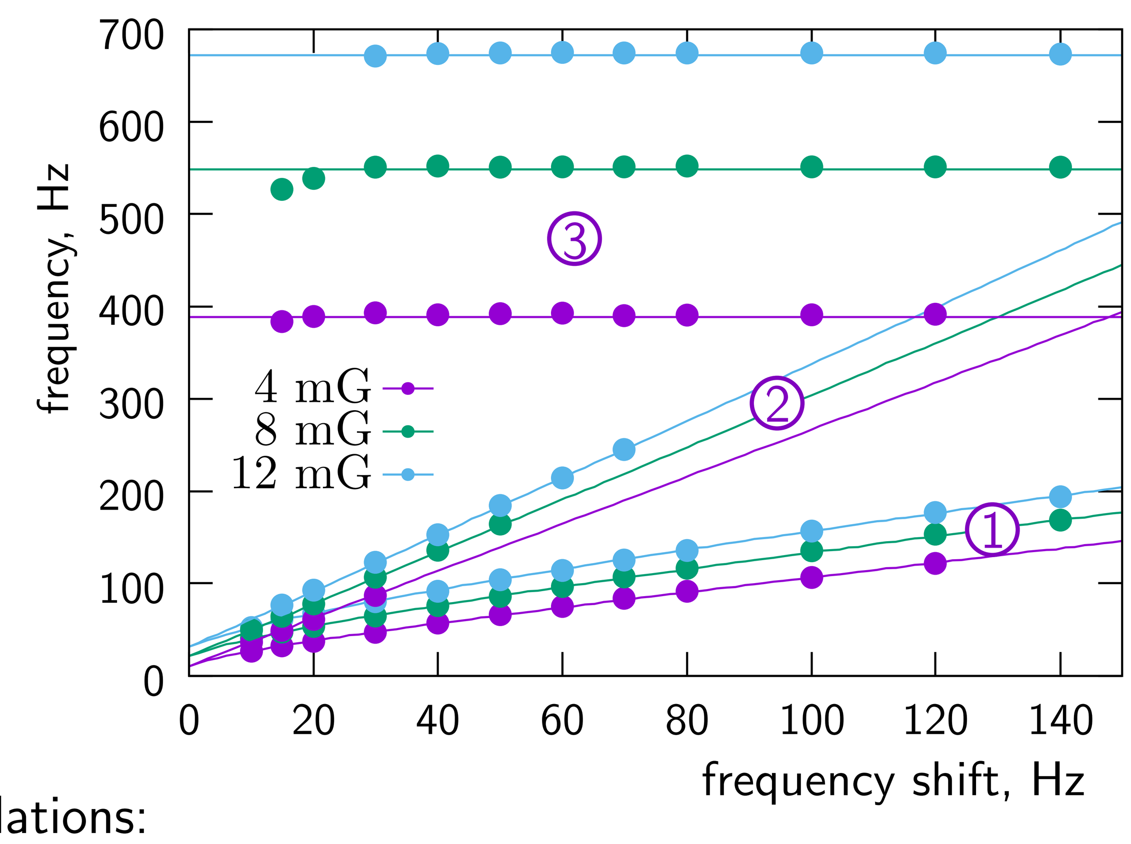
soliton profile ($\mathbf{n}$, ϑ vs. z)



soliton oscillations after step change of H_z
color: orientation of $\mathbf{n}$



Oscillation modes for three values of RF field



① 1st mode of soliton oscillations:
$f_1^2 \approx 0.75\,(\gamma H_x/2\pi)^2 + 4.0\,(\gamma H_x/2\pi)\,df$
does not depend on $c_{\parallel,\perp}$ and Ω_B (T and P)

② second mode of soliton oscillations:
weak, depends on T and P

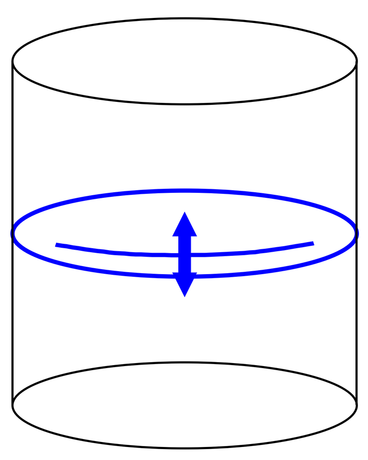
③ HPD uniform oscillations: $f_3^2 = \frac{1}{(2\pi)^2} \frac{4}{\sqrt{15}} \frac{\gamma H_x\, \gamma H_z\, \Omega_B^2}{(\gamma H_z)^2 + 8/3\,\Omega_B^2}$

Oscillation of soliton membrane

Soliton mass can be calculated from kynetic energy of a moving soliton. Mass density:

$$m = \frac{\chi_B}{\gamma^2}\left[(\vartheta')^2 + 2(1 - \cos\vartheta)\,(\mathbf{n}')^2\right]$$

Tension: total energy of membrane unit area
For ϑ-soliton in NPD:



$$M = \frac{13}{3}\frac{\chi_B}{\gamma^2 \xi_D^2} \int_{-\infty}^{+\infty} \left(\cos\vartheta(z) + 1/4\right)^2 dz,$$

$$T = \frac{16}{15}\frac{\chi_B \Omega_B^2}{\gamma^2} \int_{-\infty}^{+\infty} \left(\cos\vartheta(z) + 1/4\right)^2 dz.$$

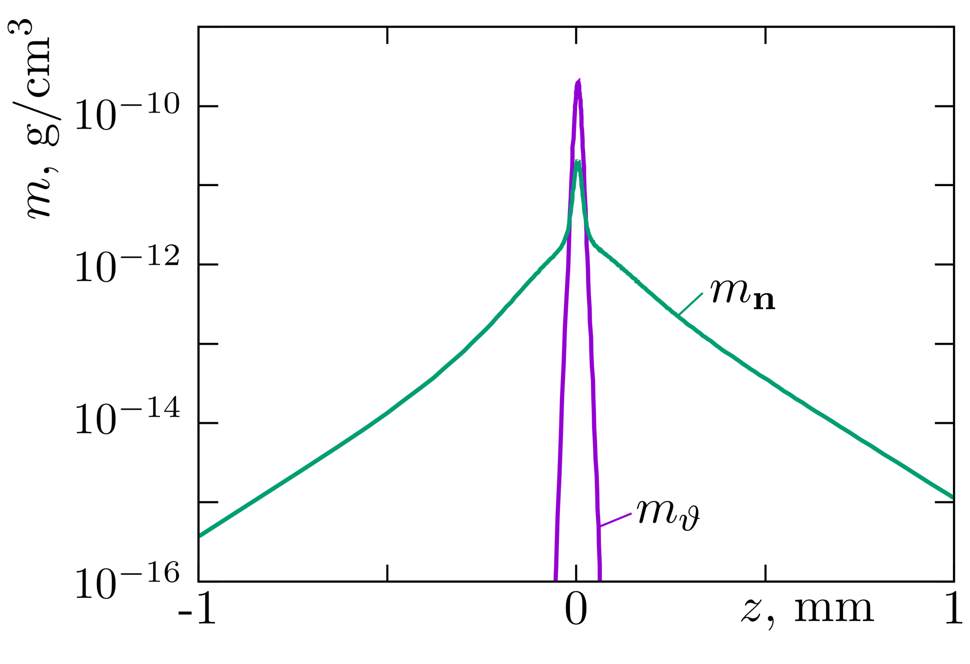
Ratio of tension and mass give square of wave velocity C along the membrane,

$$C^2 = 2c_\perp^2 - c_\parallel^2.$$

First oscillation mode: $f = 2.405\,C/r$

Mass profile and difference between HPD and NPD solitons

Mass density of a soliton in HPD



$C_{\text{HPD}}/C_{\text{NPD}}$