Optical measurement of the equation of state of metastable superfluid helium-4

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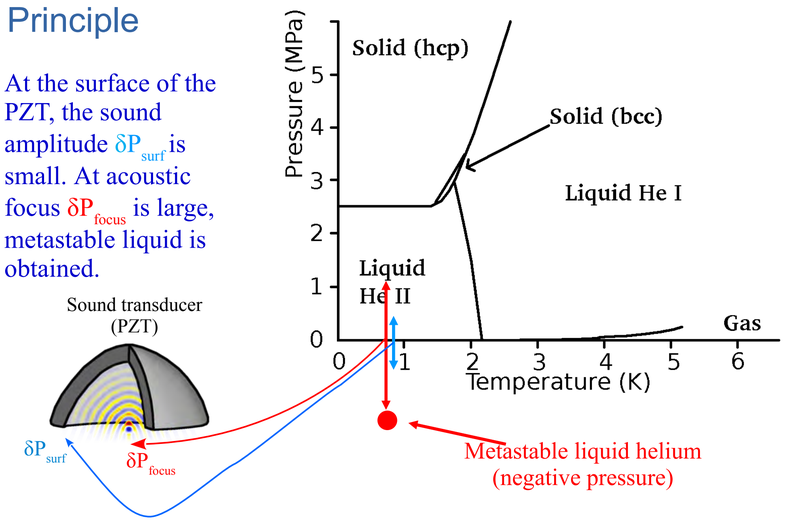
Team : polarized helium, *quantum fluids ans solids*

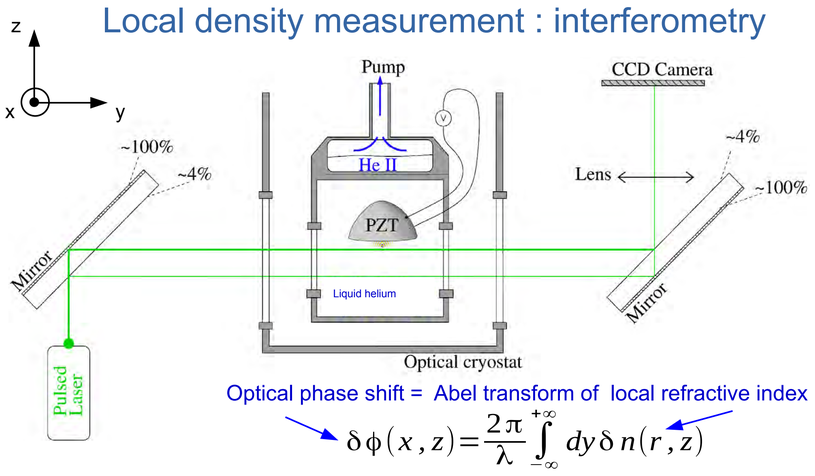
Metastable state of superfluid helium-4 : density measurement

Principle

At the surface of the PZT, the sound amplitude δP_{surf} is small. At acoustic focus δP_{focus} is large, metastable liquid is obtained.



Local density measurement : interferometry

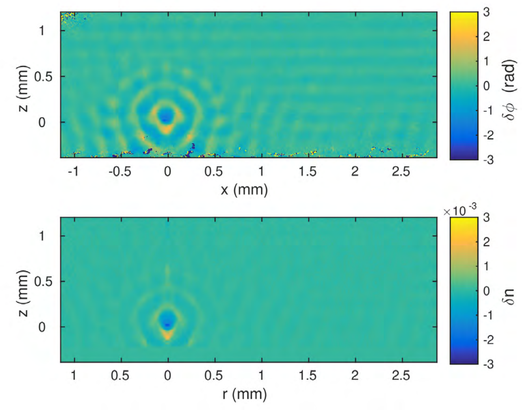


Optical phase shift = Abel transform of local refractive index

$$\delta\phi(x,z)=\frac{2\pi}{\lambda}\int_{-\infty}^{+\infty} dy\,\delta n(r,z)$$

Local refractive index = Inverse Abel transform of phase shift

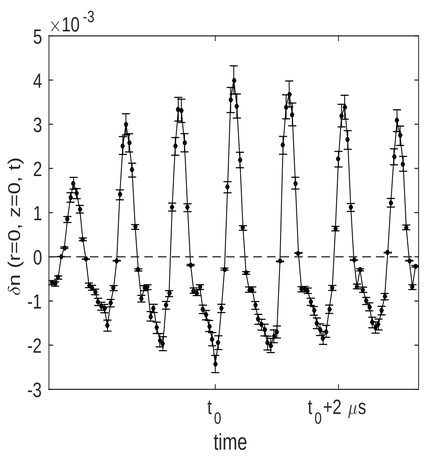
$$\delta n(r,z)=\frac{-1}{\pi}\frac{\lambda}{2\pi}\int_{r}^{+\infty} dr\,\frac{\partial(\delta\phi)}{\partial x}\frac{1}{\sqrt{r^2-x^2}}$$



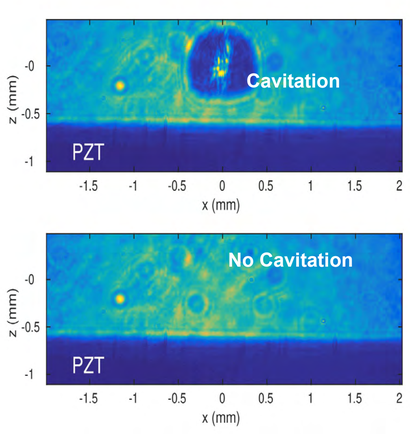
Laser pulse width = 8 ns ≪ sound period = 1 µs
→ Movies δn(r,z, t) are recorded

$$\frac{\delta n(r)}{n_0-1}=\frac{\delta\rho(r)}{\rho_0}$$ → Local density measurement

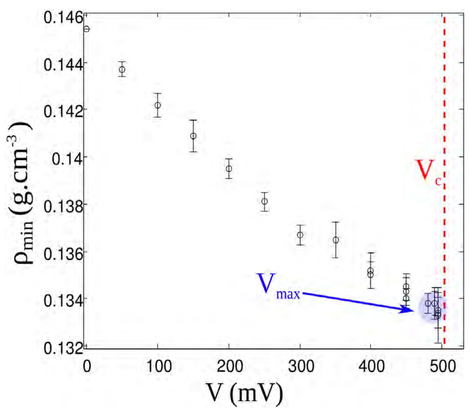
Density at acoustic focus



Cavitation



Cavitation density measurement



The space-time minimum $\rho_{min}(V)$ is founded from the refractive index movies.

An intriguing triptych

* At T ~ 1 K, we measure the cavitation density to be : ρ_{cav} = 0.1338(2) g/cm³

* Equation of state : different theorists have produced quite equivalent EoS of metastable liquid ⁴He (for instance, Dalfovo et al. PRB,**52**,1193 (1995), Maris JLTP,**98**,403 (1995))

* At T ~ 1K, Caupin et al. measure the cavitation pressure to be: -8 bar < P_{cav} < -10 bar

P_{cav} = EoS (ρ_{cav}) = -5.1 (1) bar

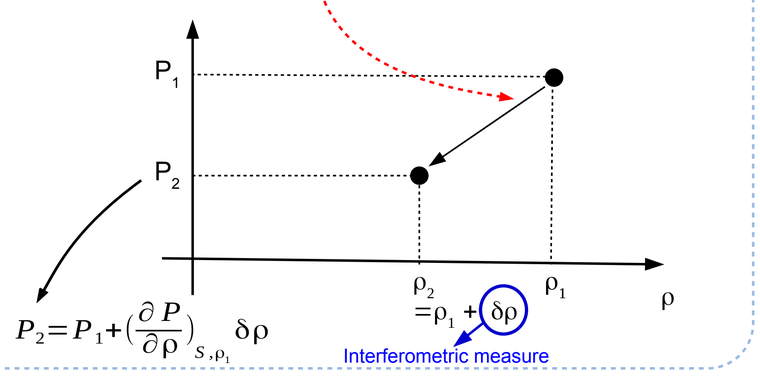
These two results are not compatible

EoS measurement of metastable liquid helium-4 : Brillouin gain spectroscopy

Difficulty metastable state = acoustic wave = 100 µm, 1 µs

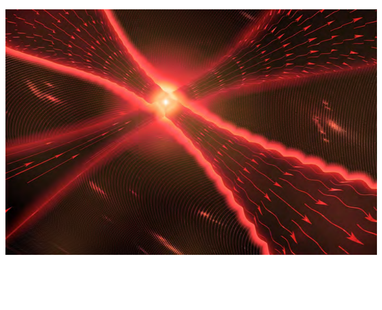
-> No direct pressure measurement

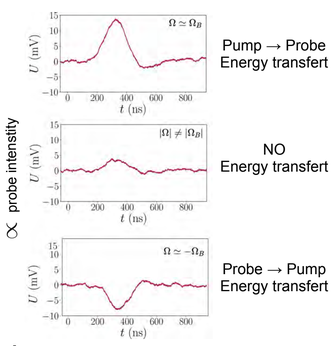
Sound velocity measurement $c_{sound}(\rho)=\sqrt{\left(\frac{\partial P}{\partial \rho}\right)_S}$ The integration of c(ρ) over ρ gives the EoS



Stimulated gain Brillouin Spectroscopy

- ►Pump (pulsed ω_1) / probe (CW ω_2) laser spectroscopy.
- ►Due to electrostriction, energy transfer between the lasers when $|\omega_1 - \omega_2| = \Omega_B$





Pump → Probe Energy transfert

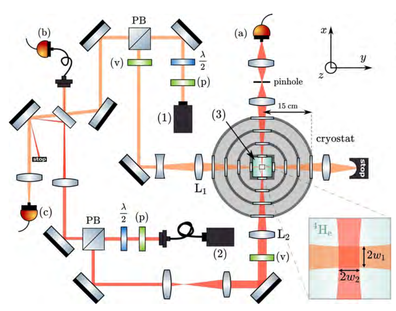
NO Energy transfert

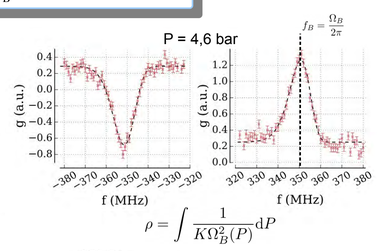
Probe → Pump Energy transfert

$$\Omega_B = 2n\frac{c_{sound}}{c_0}\omega_L \sin\frac{\theta}{2}$$ ← Angle between Pump and probe beams

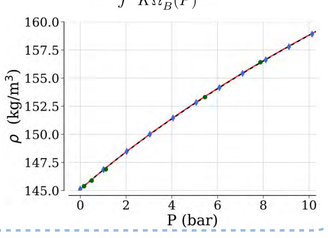
Done in Stable (P>0) Superfluid Helium-4

- ►In stable states, measurement of Ω_B as a function of P

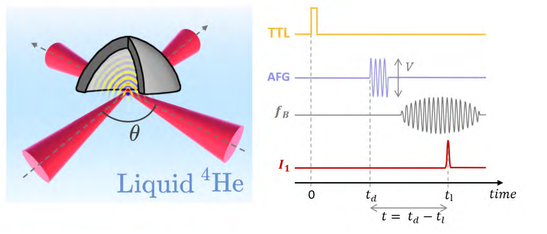


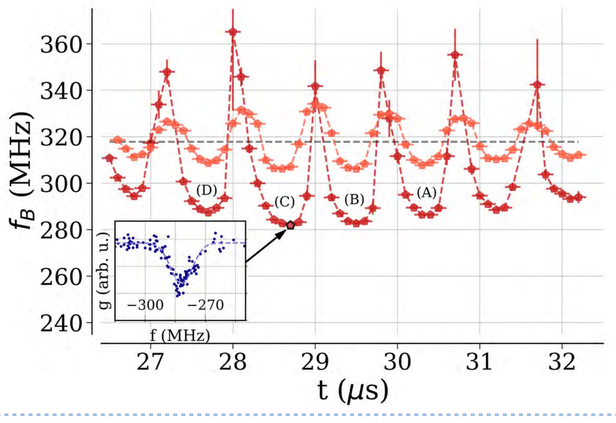


$$\rho=\int\frac{1}{K\Omega_B^2(P)}\mathrm{d}P$$

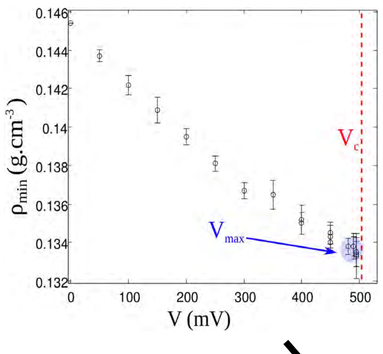


Brillouin frequencies of the metastable states





Internship : *simultaneous* density and Ω_B measurements



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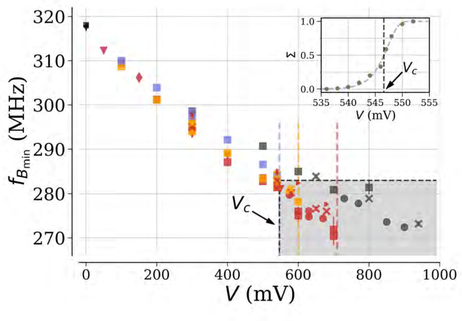

Measurement of $\Omega_B(\rho)$

Experimental EoS

$$\Omega_B^2(\rho) = A\, n^2(\rho)\, c_s^2(\rho)$$

$$n^2(\rho) = 1+\beta\,\rho$$ Clausius-Mossotti

$$P(\rho) = P_0 + \int_{\rho_0}^{\rho}\frac{\Omega_B^2(\rho')}{A[1+\beta(\rho')]}\mathrm{d}\rho'$$

Experimental EoS to compare with theory