Davis Supersolid Group
Plans in Progress

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Search for persistent mass currents in a supersolid

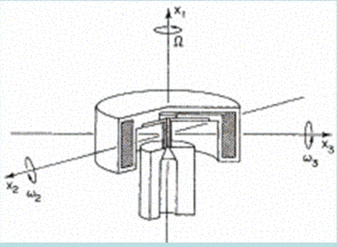
History of persistent-current annular ring experiments

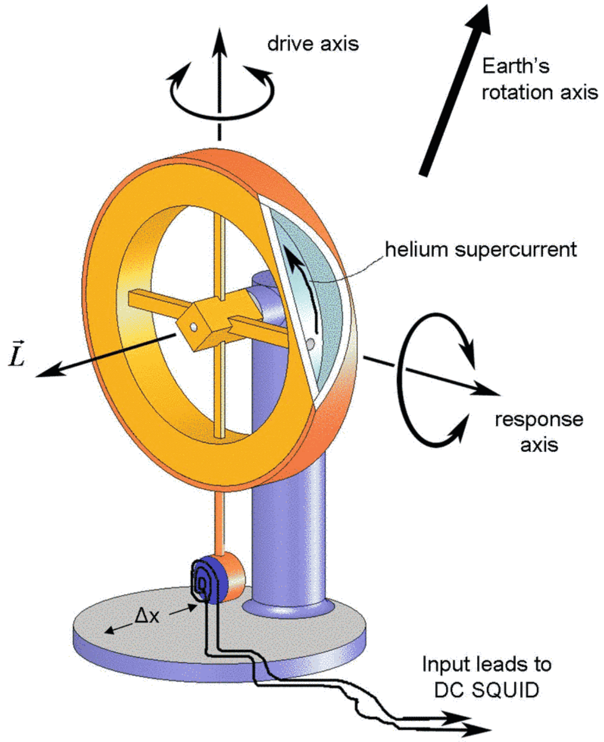
1) Kamerlingh Onnes, 1914
   - superconducting ring

2) Reppy, 1965
   - tungsten-wire ^{4}He gyroscope

3) M. Chan, Yanof, and Reppy, 1974
   - thin-film ^{4}He gyroscope

4) Gammel, Hall, and Reppy, 1984
   - ^{3}He-*B* AC-driven gyroscope (shown below)



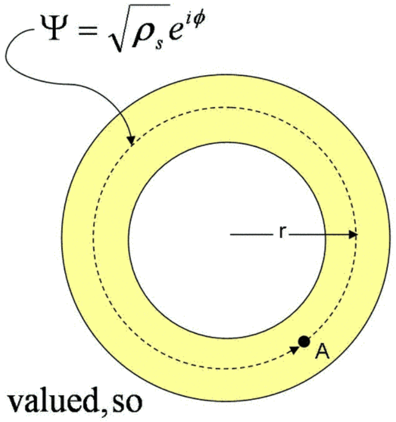


Phase and velocity relationship

$$e^{i\vec{\nabla}(\vec{k}\cdot\vec{r})} = e^{i\vec{\nabla}\phi} \Rightarrow e^{i\vec{k}\cdot\vec{r}} = e^{i\phi}$$

$$\text{thus } \vec{k} = \vec{\nabla}\phi \quad \text{but} \quad \vec{k} = \frac{m\vec{v}}{\hbar}$$

$$\text{so} \quad \vec{v} = \tfrac{\hbar}{m_4}\vec{\nabla}\phi$$



QM requires the wavefunction to be single-valued, so

$$e^{i\phi_A} = e^{i\left(\phi_A + \oint\vec{\nabla}\phi\cdot d\vec{l}\right)}$$

$$\Rightarrow \oint\vec{\nabla}\phi\cdot d\vec{l} = n2\pi, \qquad n \text{ integer}$$

(the circulation is quantized)

$$\Rightarrow \mathrm{v}_{\mathrm{slip}} = \frac{h}{m_4}\frac{n}{2\pi r}$$

thus the velocity is quantized and small dissipation events are forbidden. This allows mass currents to persist indefinitely.

Search for quantized phase slippage in a supersolid

Need:

- Large dynamic range
- ~ 1 fm/Hz$^{1/2}$ sensitivity
- Ultra-low vibration

•=> Torsion oscillator using a DC SQUID for position measurement.

Single phase-slip event signal size

$$\Delta \mathrm{v}_{osc} = \mathrm{v}_{slip}\sqrt{\frac{I_s}{I_{osc}}} = \frac{\hbar R_{He}}{m_4}\sqrt{\frac{\frac{\pi}{2}\rho_s a}{I_{osc}}} \approx 25\ \mathrm{nm}/\mathrm{s}$$

$$\Delta x_{osc} = \frac{\mathrm{v}_{slip}}{\omega_0}\sqrt{\frac{1}{2}\frac{R_{squid}}{R_{He}}\frac{I_s}{I_{osc}}} = \frac{\hbar}{m_4\omega_0}\sqrt{\frac{\pi\rho_s a R_{squid} R_{He}}{4 I_{osc}}} \approx 4\ \mathrm{pm}$$

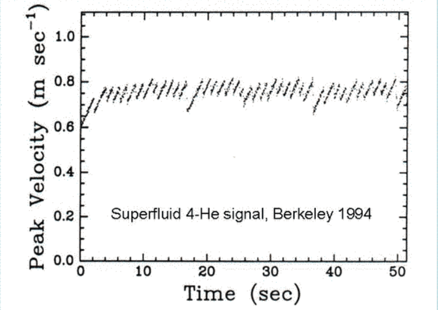
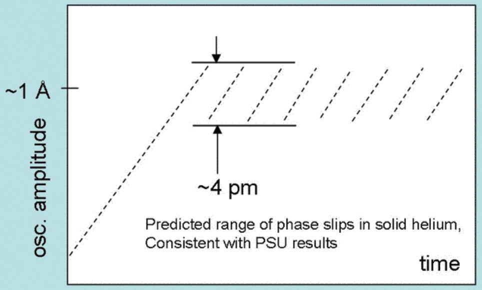


Fig. 5. Typical response of the flow oscillator showing discrete dissipation events.



Predicted range of phase slips in solid helium, Consistent with PSU results

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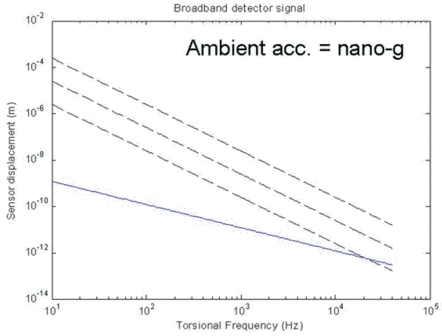
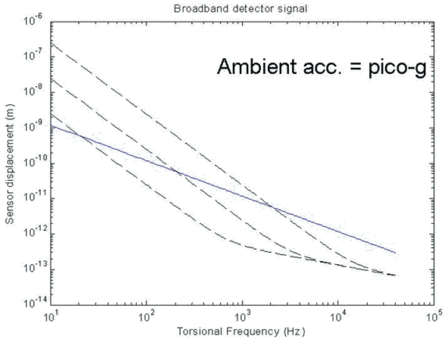
Signals (blue) and Noises (dashed)

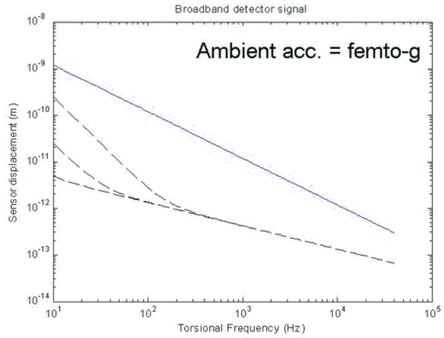
Thermal noise $\Delta\theta = \sqrt{\frac{k_B T}{\kappa}} = \sqrt{\frac{k_B T}{4\pi^2 f_0 I_0}}$

Acceleration noise $\Delta\theta = \frac{Q a_{rms}}{4\pi^2 f_0^2 R}$

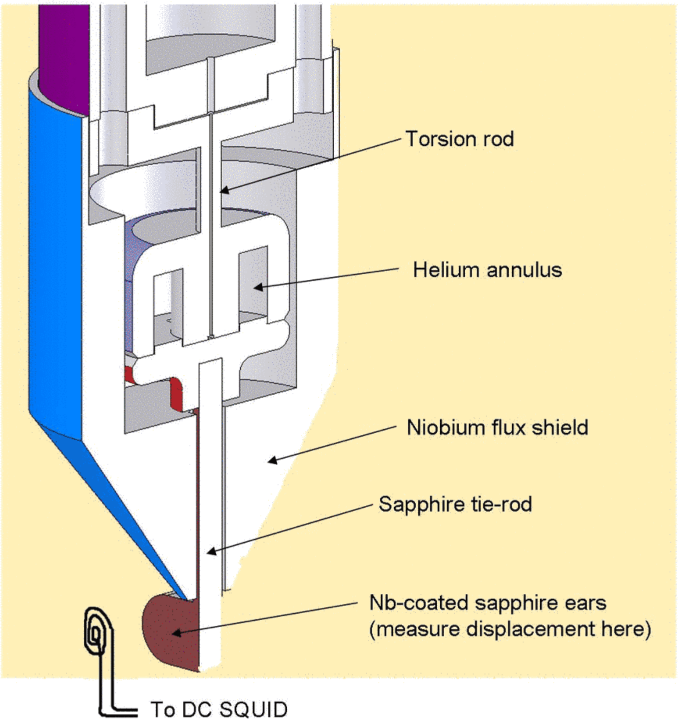
Sensitivity floor $\Delta\theta = \frac{\sigma}{R_{squid}} \sqrt{\frac{f_0}{Q}}$







DC-SQUID detected torsion oscillator



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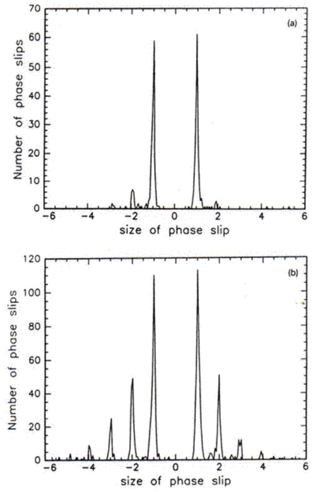

Fig. 6. (a) Typical histogram of phase slips for two directions of flow from a 0.25×0.27 micrometer aperture. The slip's size is in units of κ/L for that aperture. (b) A histogram for the same aperture as in (a), in the presence of noise. Similar histograms are observed for apertures larger than 1 micrometer under the quietest conditions achieved.