Cantilever-based measurements of short range gravity

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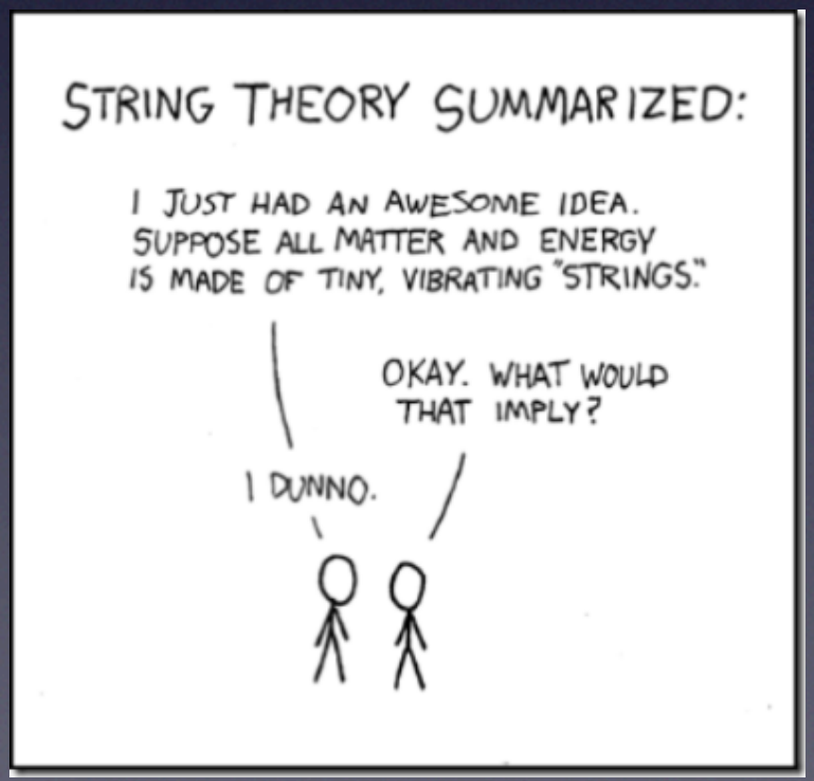
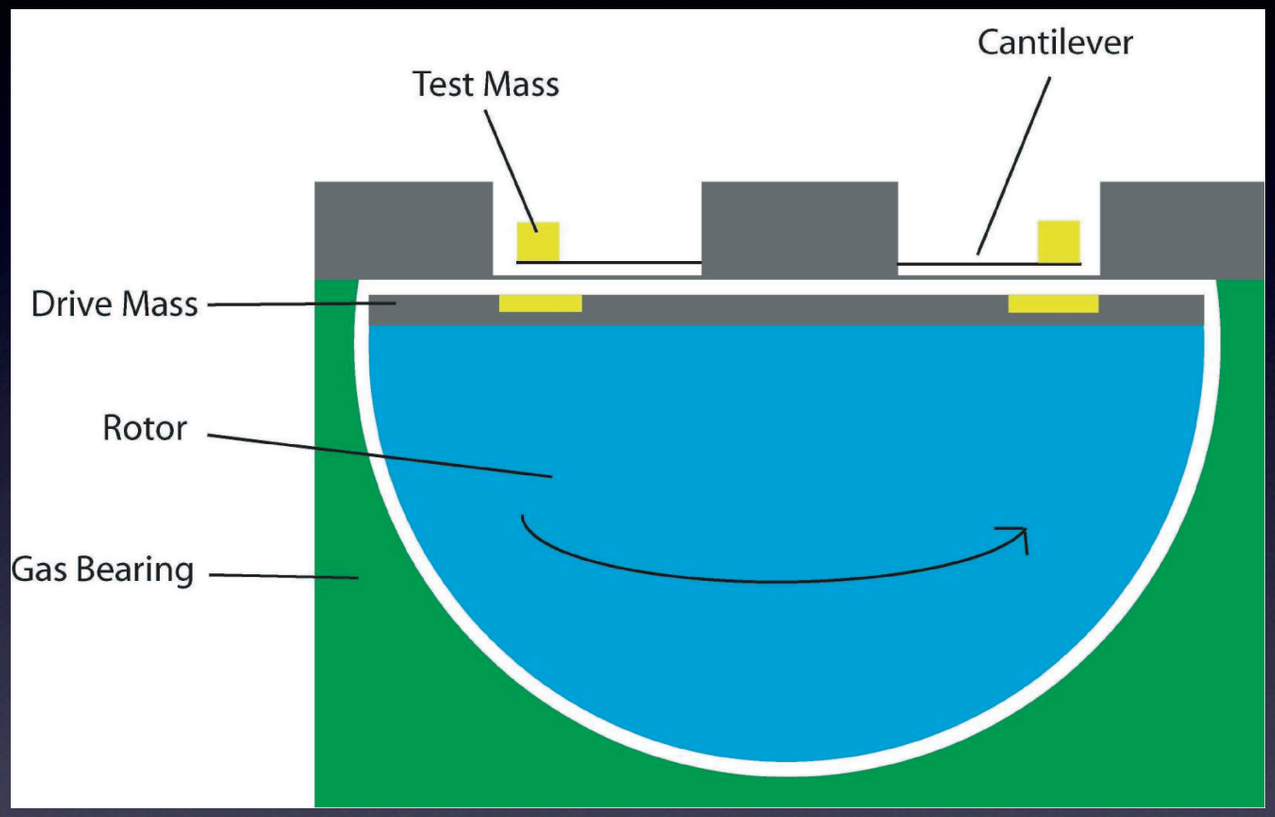
Goal: search for deviations from Newton's law at < 100 micron distance

- Only recently have tests gone below 1 mm.
- Theoretical motivations: n=2 extra dimensions with length ~100 microns

http://xxx.lanl.gov/abs/hep-ph/9803315 (Arkani-Hamed, Dimopoulos, Dvali)



Force detection using cantilevers

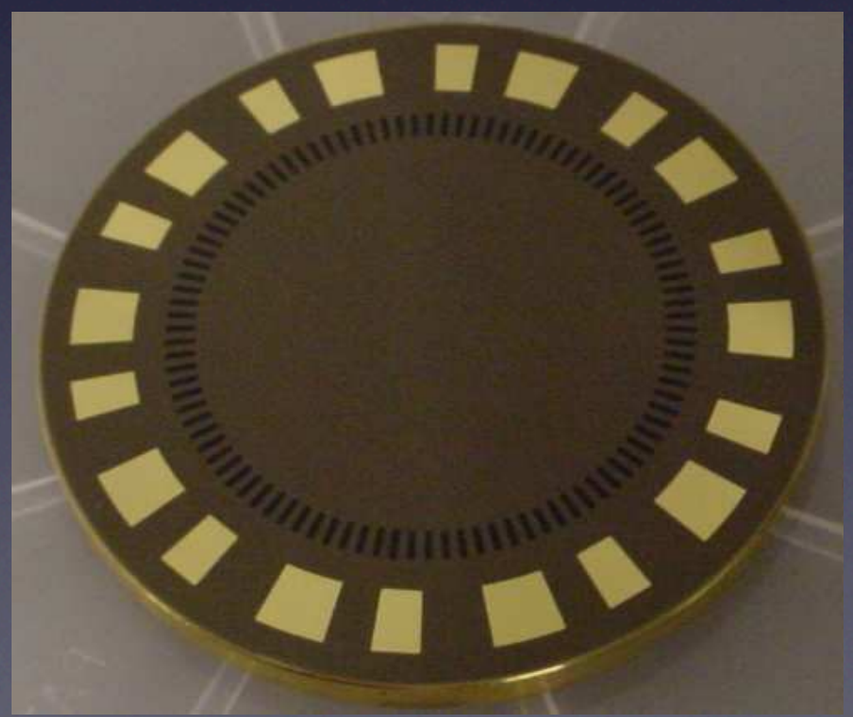


- Use an oscillating mass signal to excite a microcantiliver at resonance.
- Drive mass gives an AC mass signal
- Gas-controlled rotor spins the drive mass
- Cantilever motion measured by a Fabry-Perot interferometer

First Results: Weld et al. Phys. Rev. D77:062006, 2008

The drive mass 1

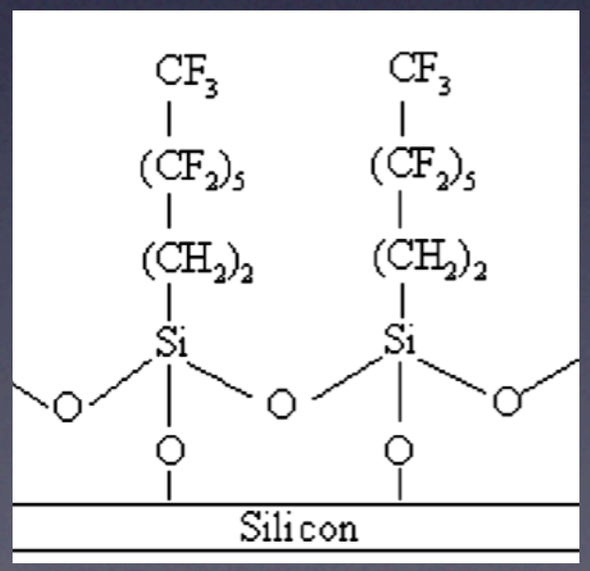
- 100 radial trenches cut into a high density material (TeCu)
- Trenches are filled with thermally matched epoxy
  - Stycast 2850 GT and FT
- Outer gold pattern is for the optical encoder - phase measurement



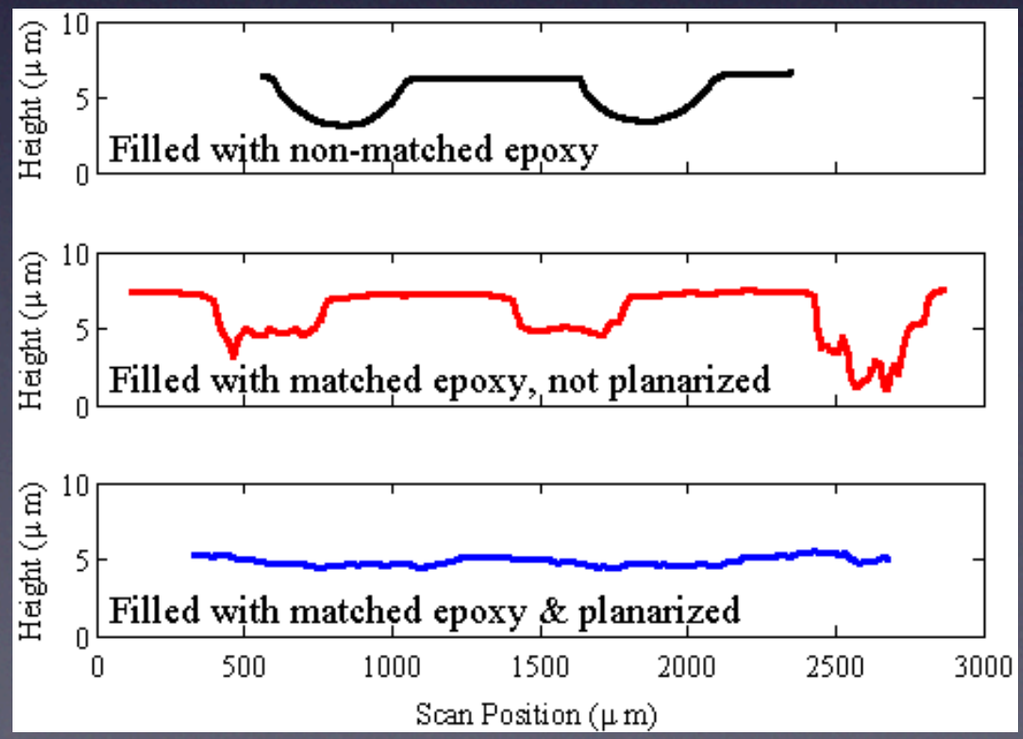
The drive mass 2 - planarization

Planarization process:

1. Trenches are filled with thermally matched epoxy
2. Polished (leaves slight corrugation)
3. Layer of Stycast 1266 using an optical flat with non-stick coating
4. Final layer of gold for encoder pattern and isoelectronic circle

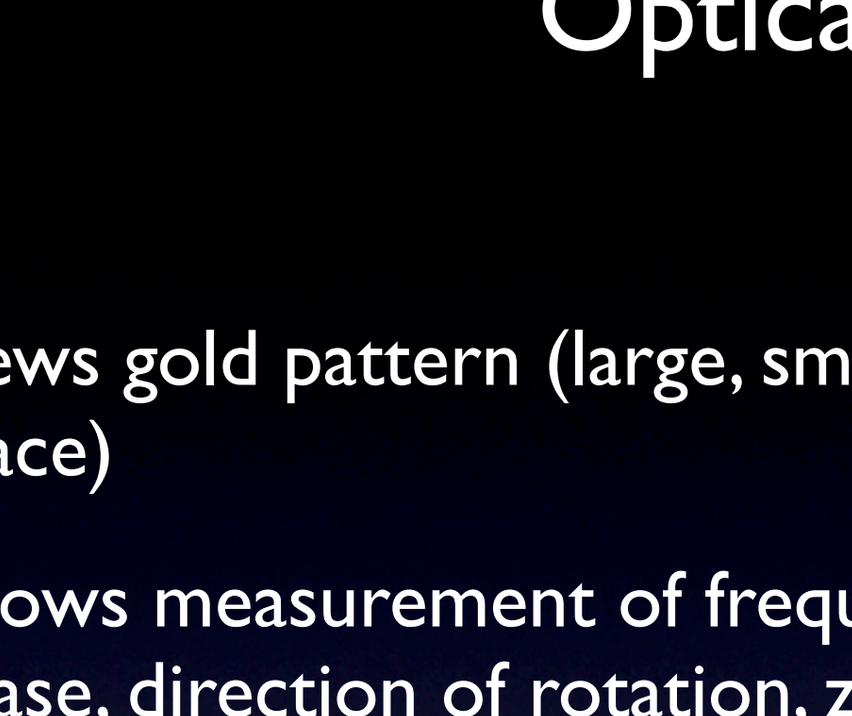


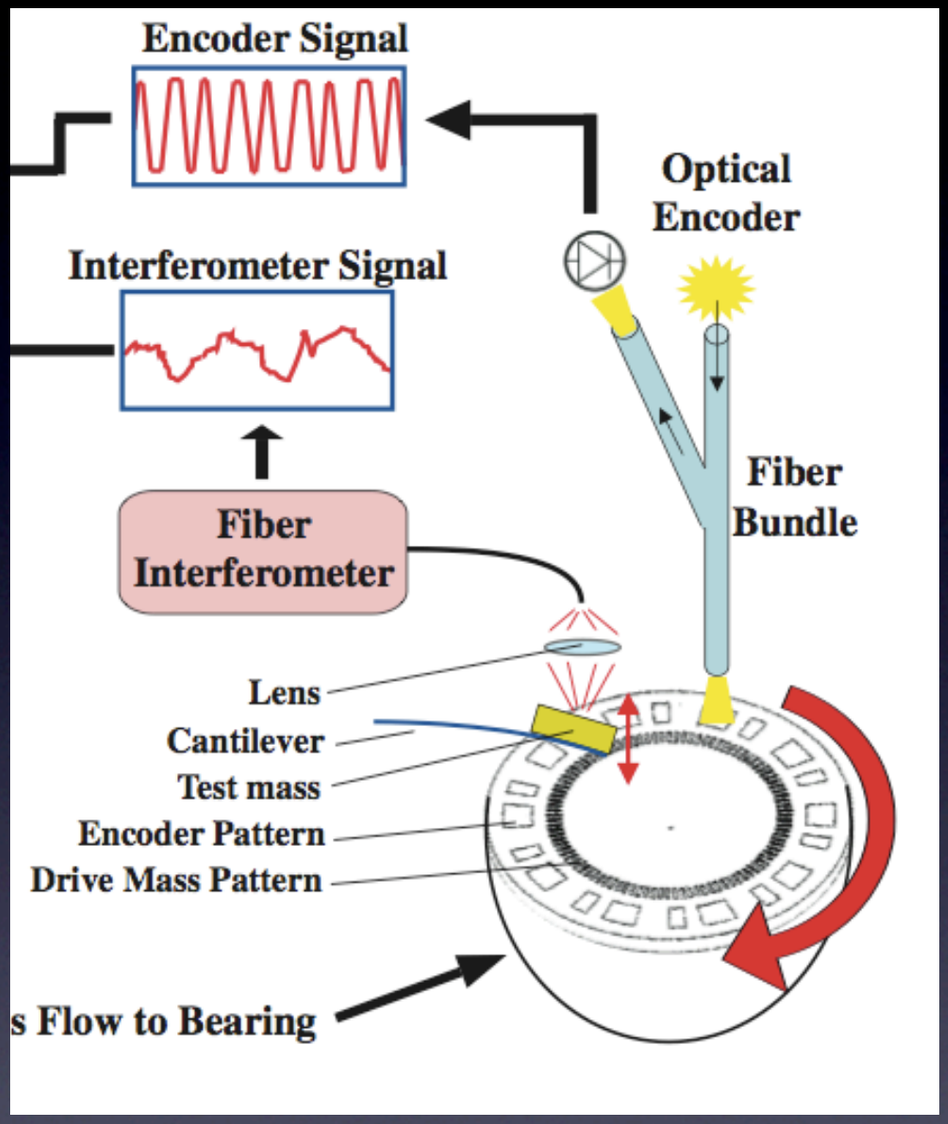
Jung et al. Langmuir 2005, 21, 1158-1161



Optical encoder

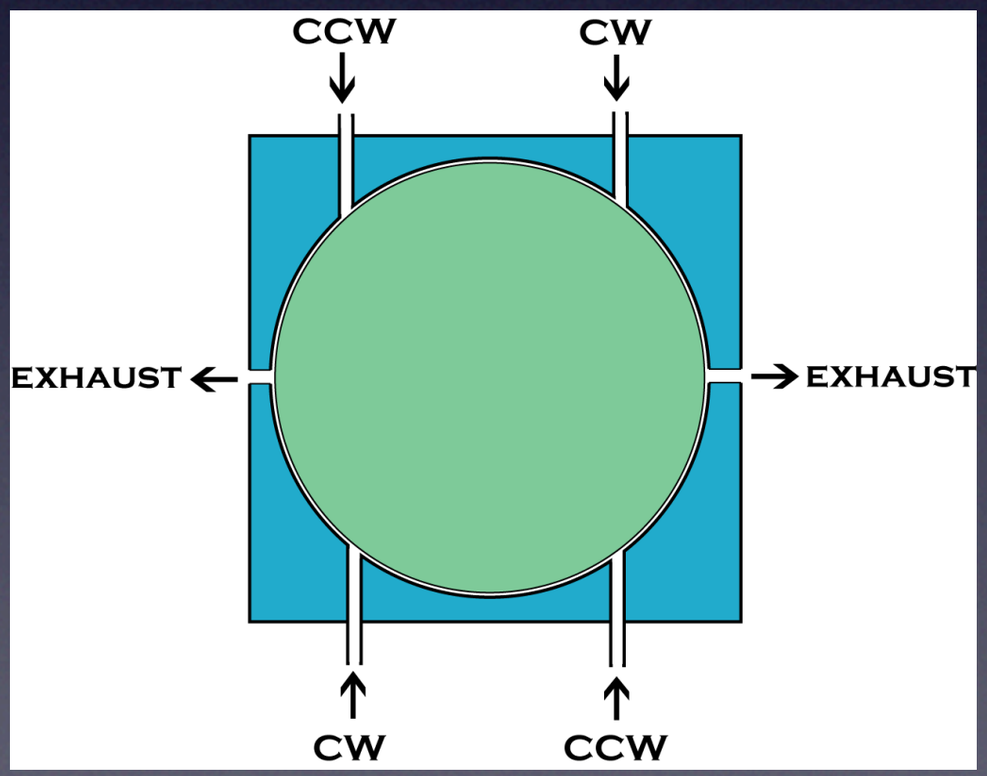
- Views gold pattern (large, small, space)
- Allows measurement of frequency, phase, direction of rotation, z

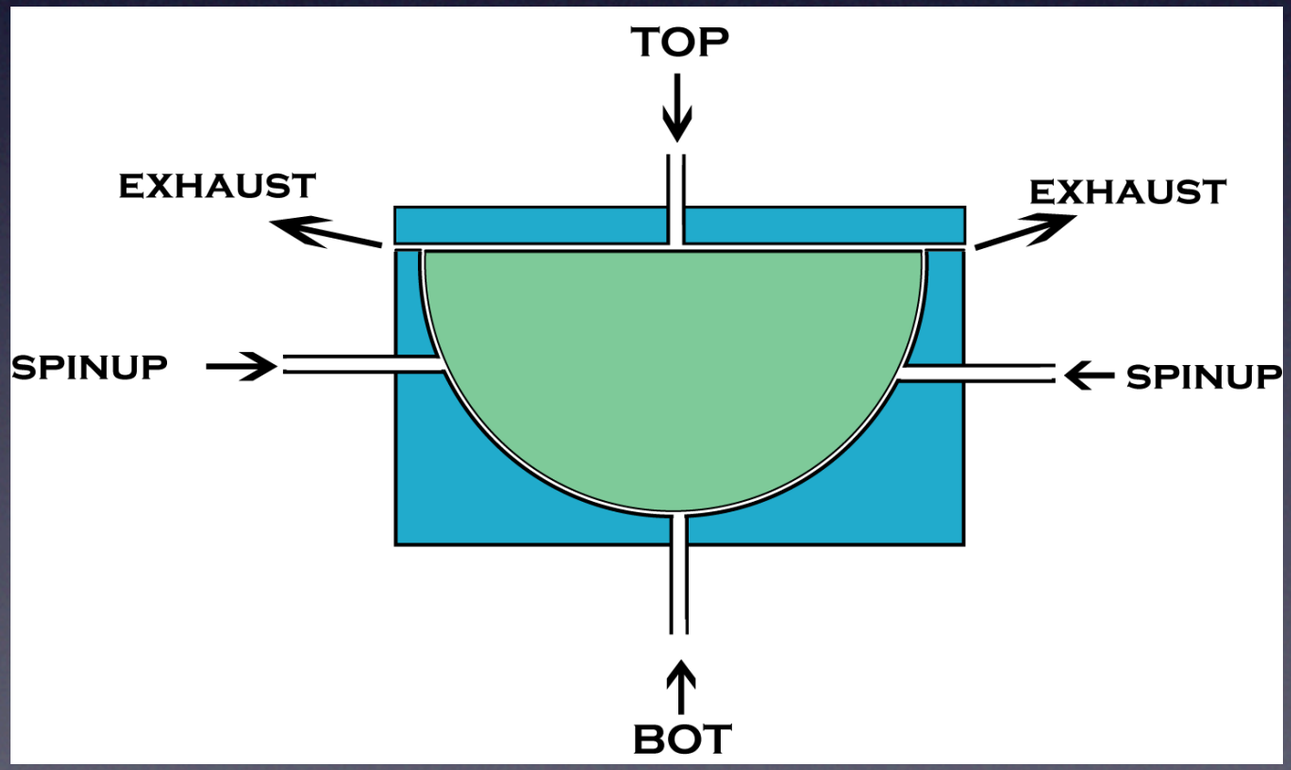




The gas bearing

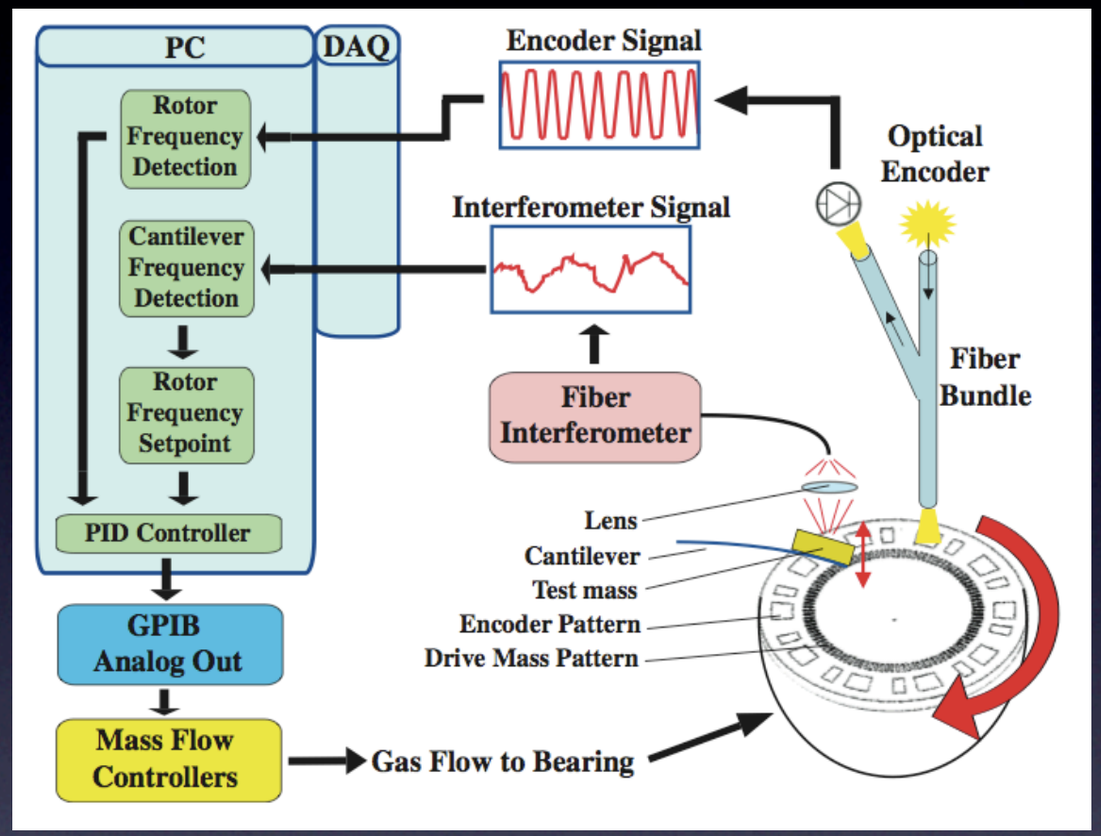
- Controlled by 4 He flows - T, B, CW, CCW
- A feedback loop controls the spinning rate
- Mass/cantilever distance can also be manipulated
- Exhaust has to go somewhere





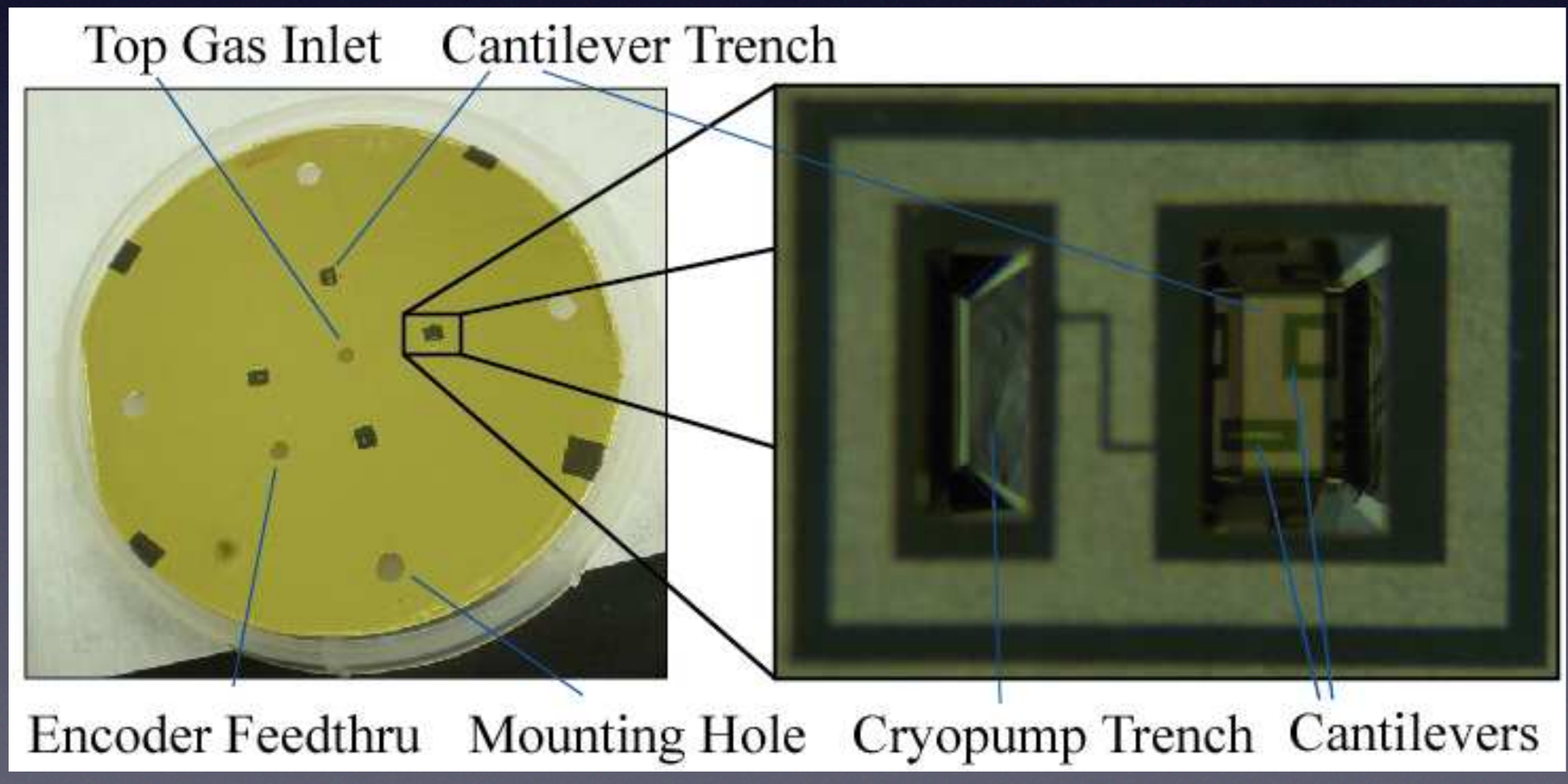
Feedback spin control

- Uses the optical encoder signal to precisely control the spin of the bearing
- A PID loop controls the CW and CCW gas flow rates



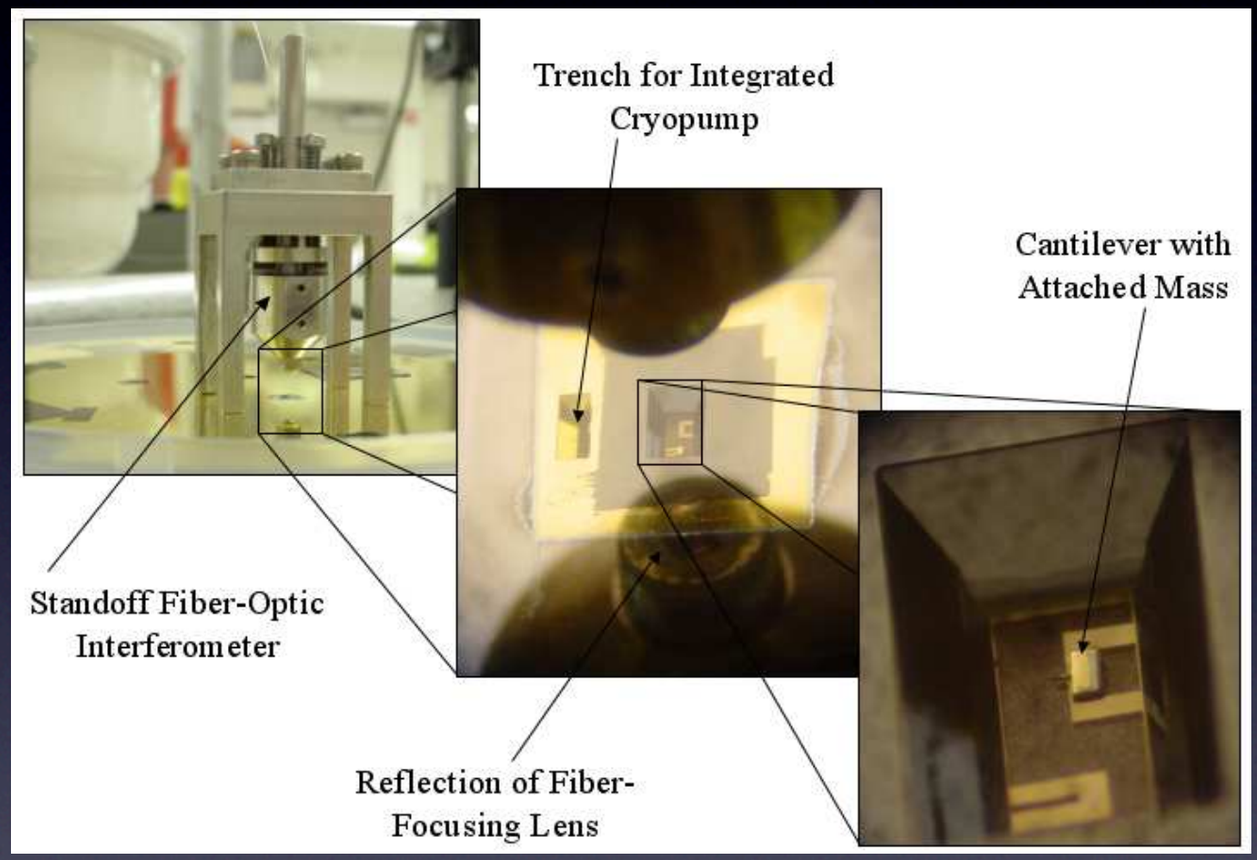
Cantilevers 1

- Etched from 4 inch silicon wafers
- Thermal noise minimized by cooling to LHe temps
- k ~ 1e-2 N/m, f ~ 350 Hz (with mass)

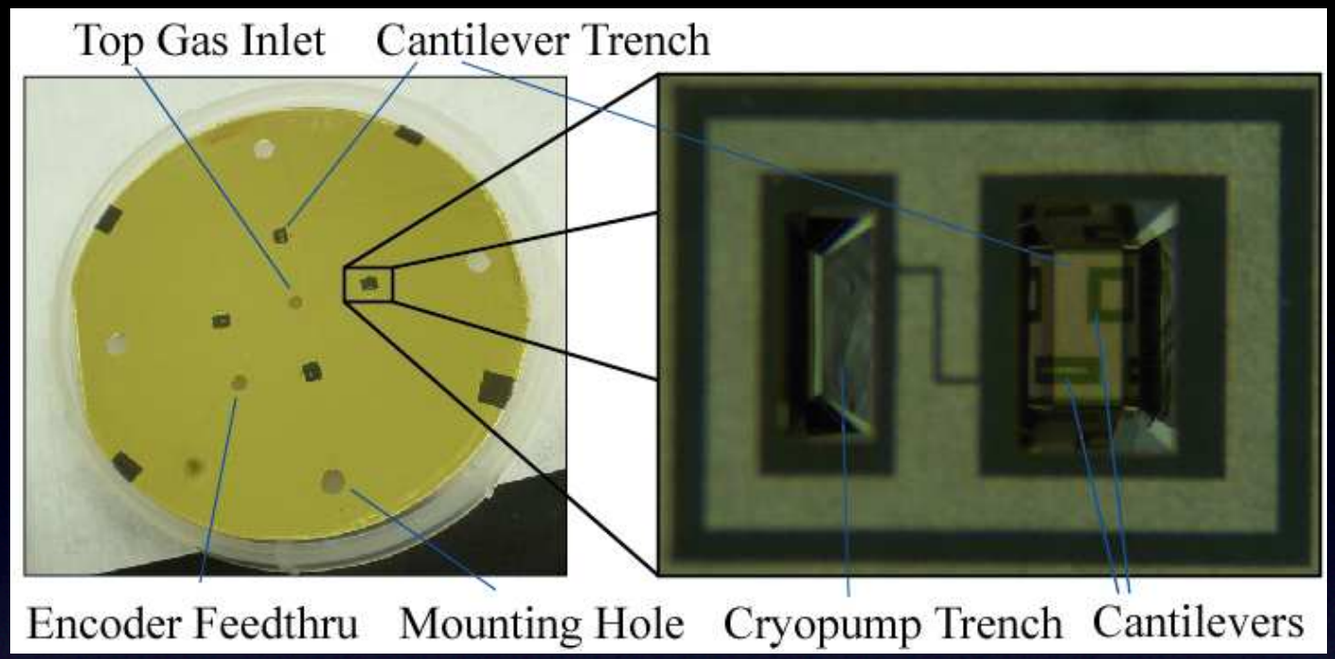


Cantilevers 2

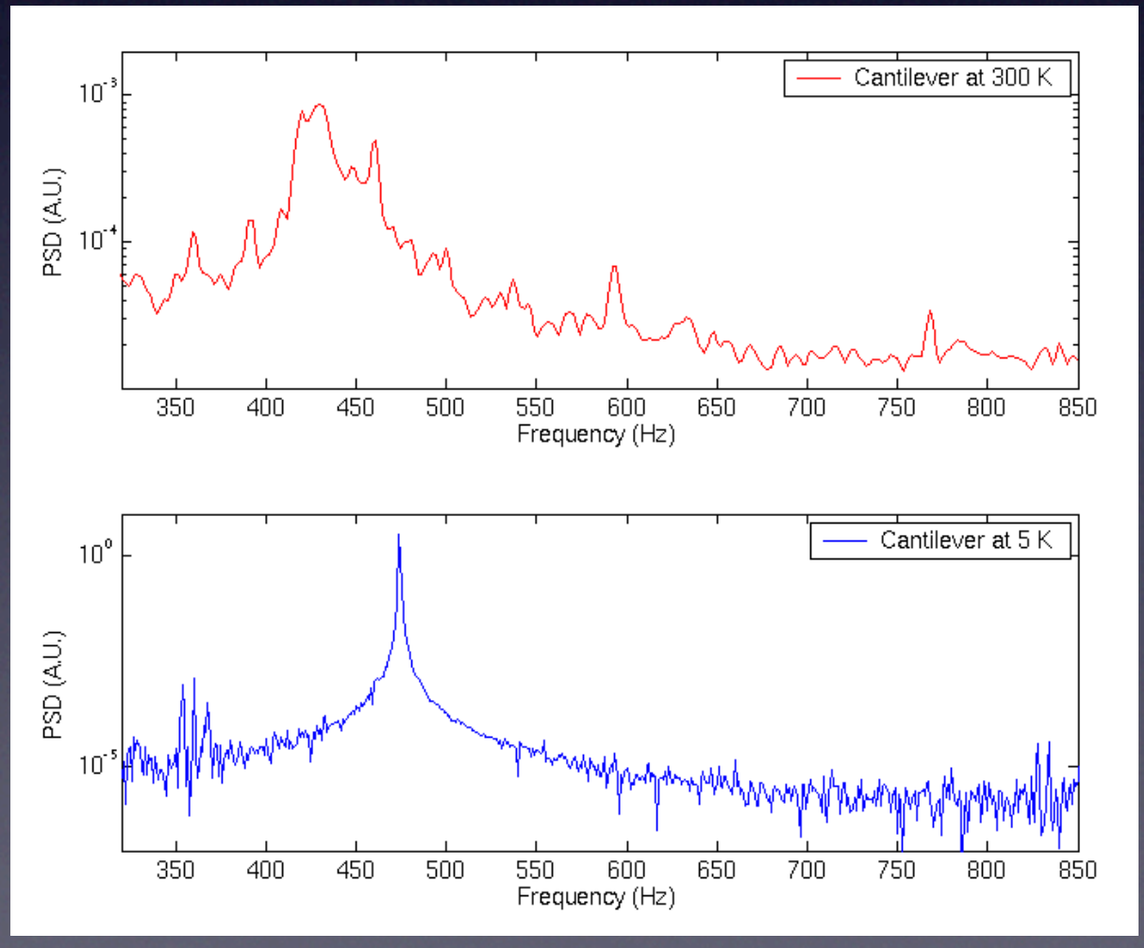
- Gold test mass
- 20 microgram
- Cantilever position is measured with a fabry-perot interferometer



Cantilever cryopump

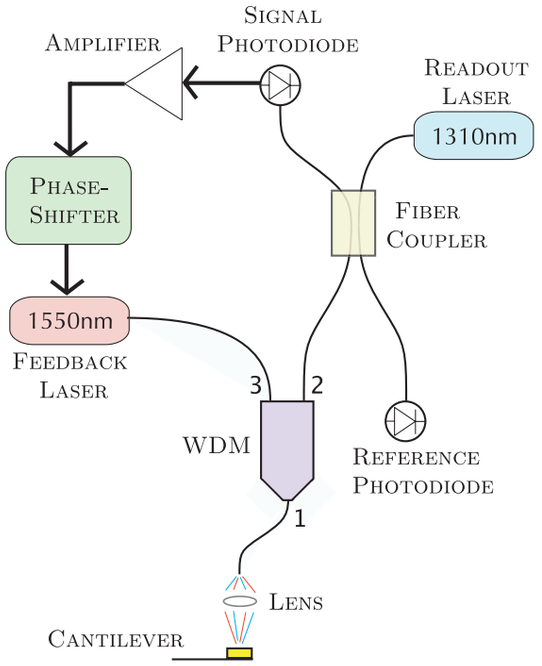


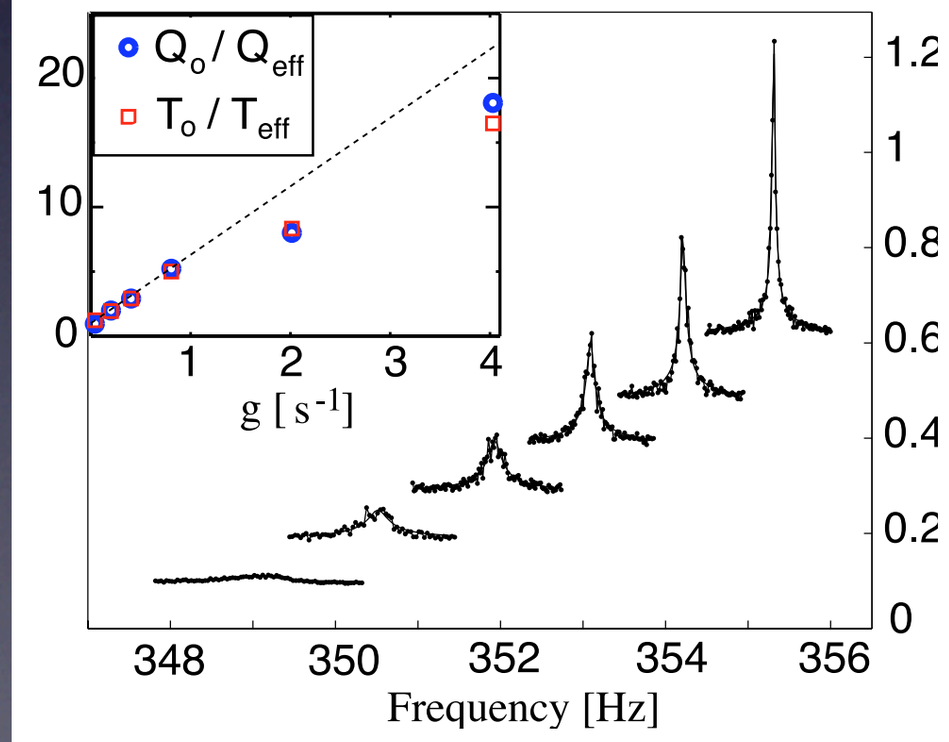
- Must be in a vacuum
- Integrated cryopump
- Works too well!
- Q = 80,000 @ 4.2 K



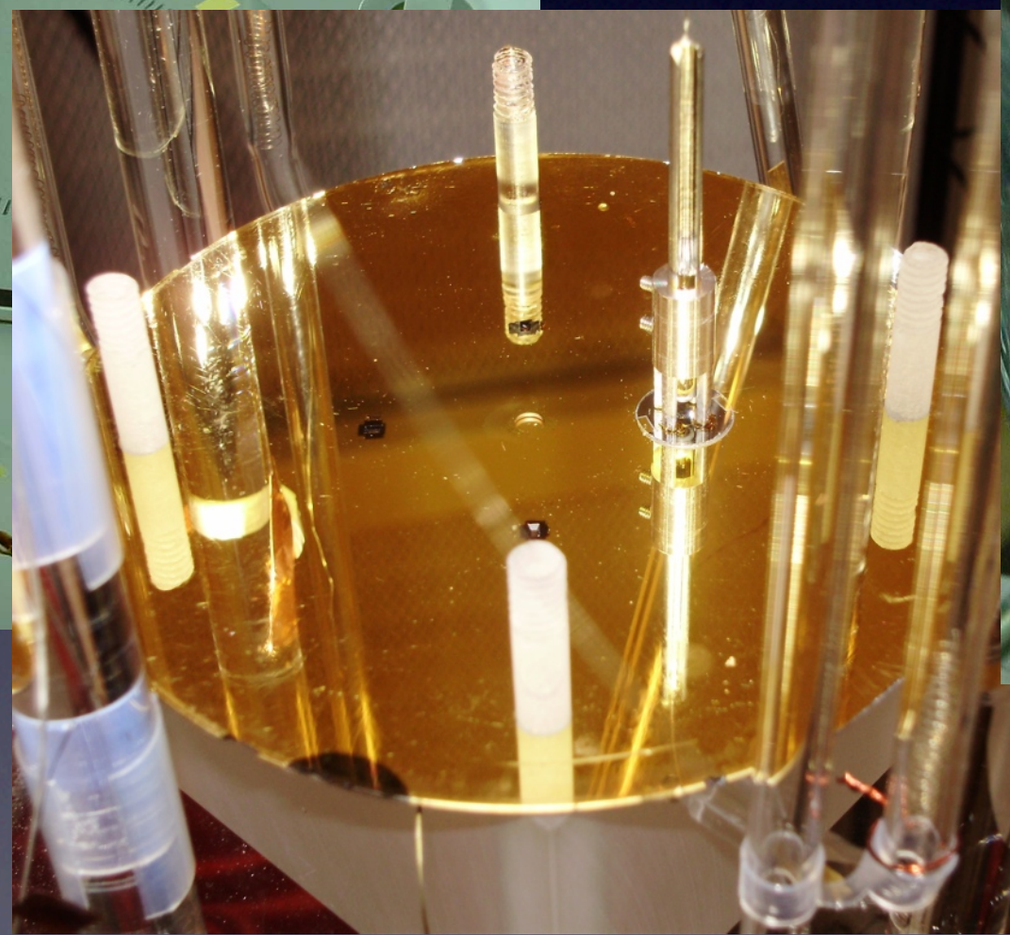
Must lower Q without effecting sensitivity.

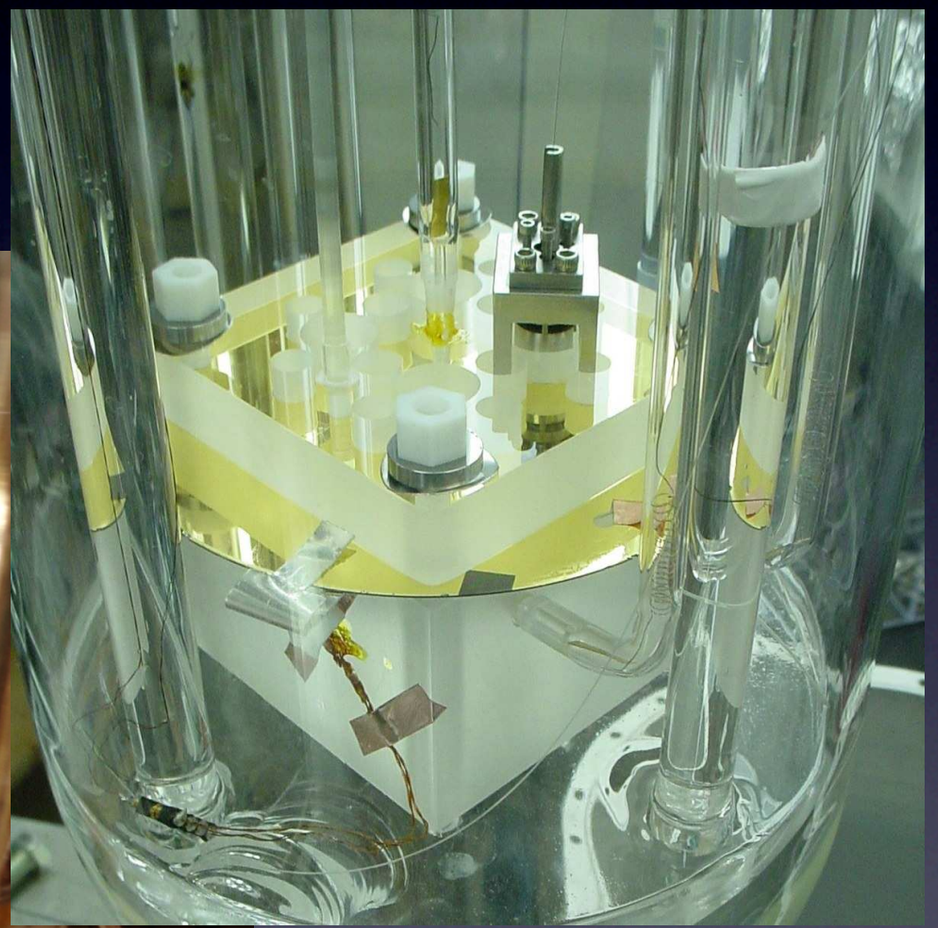
- Feedback a phase-shifted signal back to the cantilever to mimic viscous damping
- Uses exisiting optics in the experiment and radiation pressure (1550 nm laser)
- Can reduce Qeff and Teff ~ 20
- Doesn't affect force sensitivity





Assembling the experiment





Eliminating other forces

- Must minimize other forces, especially those that could act at the same frequency as the gravity signal

Casimir Force - keep distances constant

Magnetic fields - use mu-metal shielding to reduce field at sensor

Electrostatic forces - plate drive mass and cantilever wafer with thin gold layer

Also must reduce vibrational noise

Error Budget

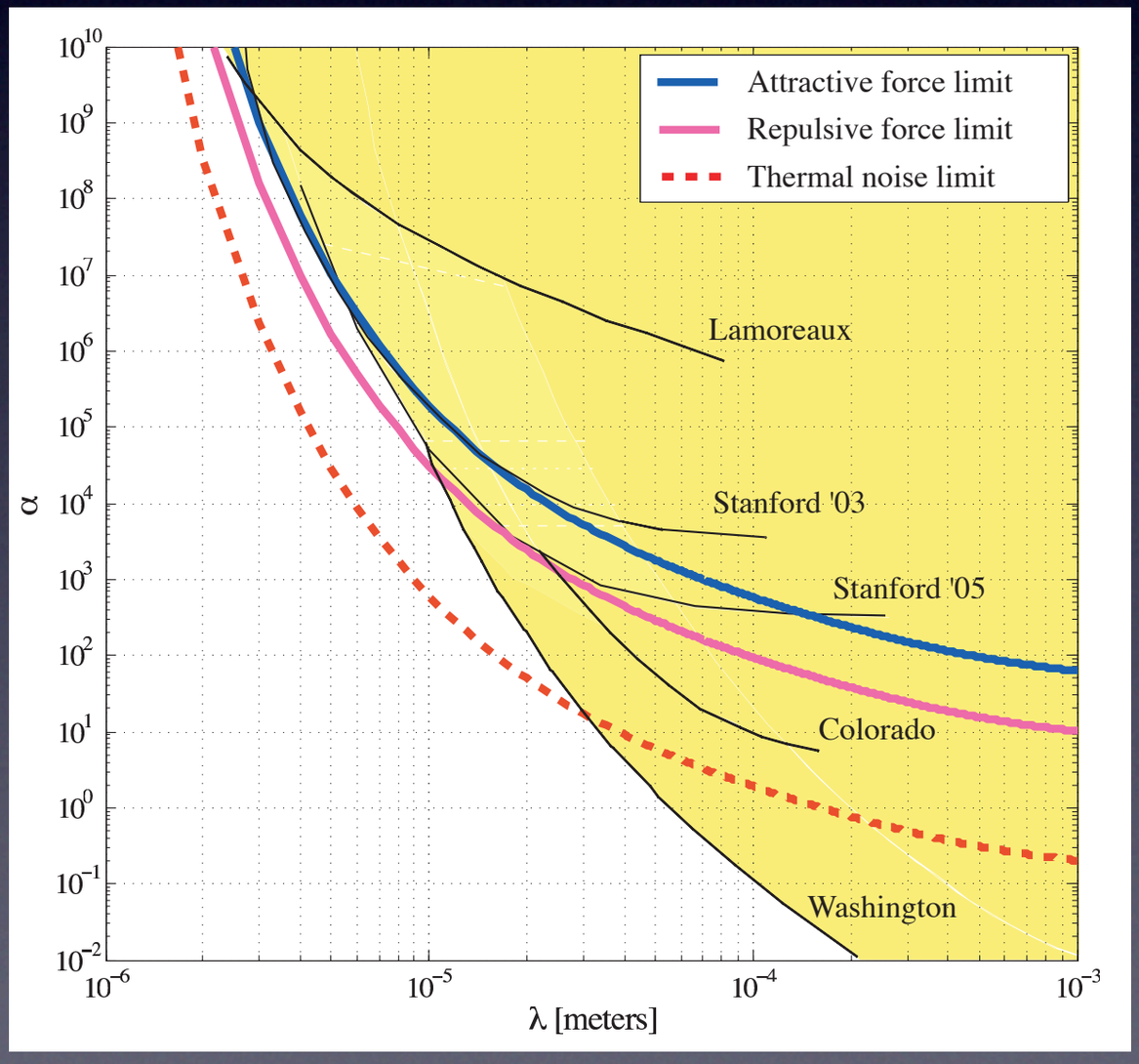
Distance	Value (μm)	Error (μm)
Thickness of planarization epoxy	0.5	0.5
Thickness of gold shield layer on drive mass	0.4	0.1
Distance between rotor and wafer	10–20	2
Thickness of gold shield layer on wafer	0.4	0.1
Thickness of silicon nitride shield	4	0.2
Distance between shield and cantilever	14	0.1
Droop of cantilever	-4	1
Thickness of cantilever	0.33	0.01
Cantilever-test mass separation	0	1
Total (for 15 μm rotor-wafer separation)	30.6	2.5

Results

- Paramaterize with Newtonian + Yukawa potential:

$$V = -\frac{G m_1 m_2}{r}\left(1 + \alpha\, e^{-r/\lambda}\right)$$

- Null results are quoted by giving alpha and lamdba exclusion limits.



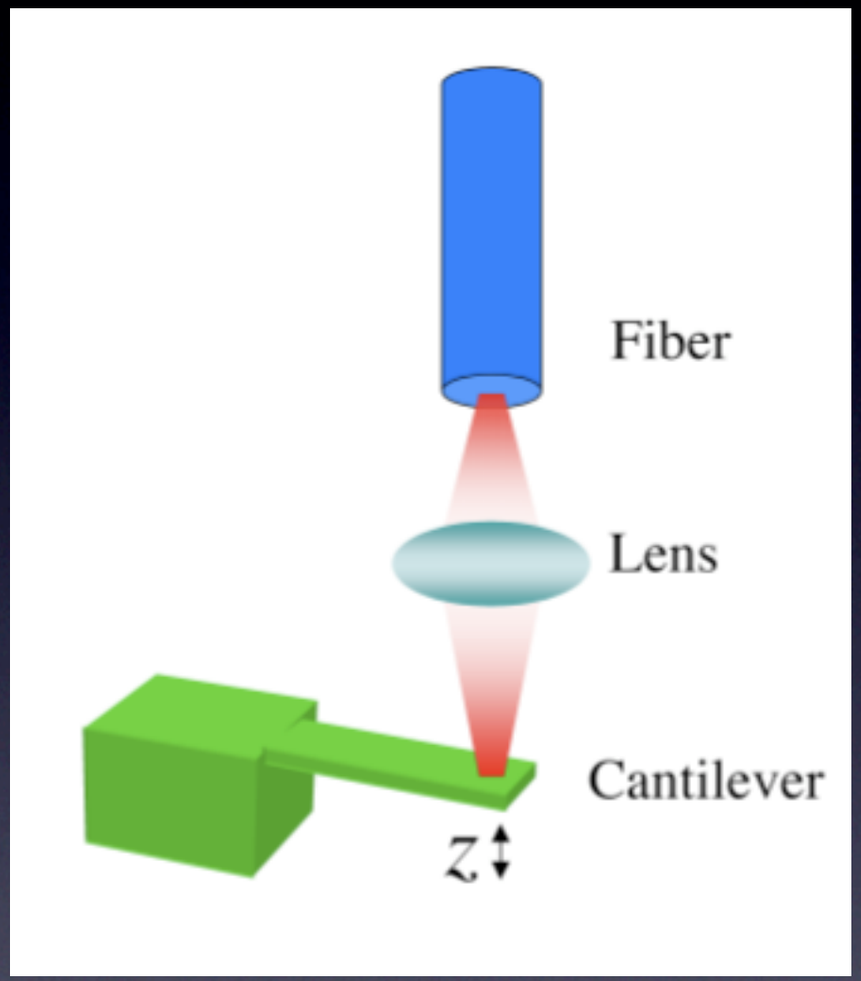
Experimental Upgrade

- A few simple improvements will greatly improve the sensitivity

1. Moved to new lab, better seismic properties
2. No liquid nitrogen boiling - new dewar
3. TeCu drive mass - can run at 4 K

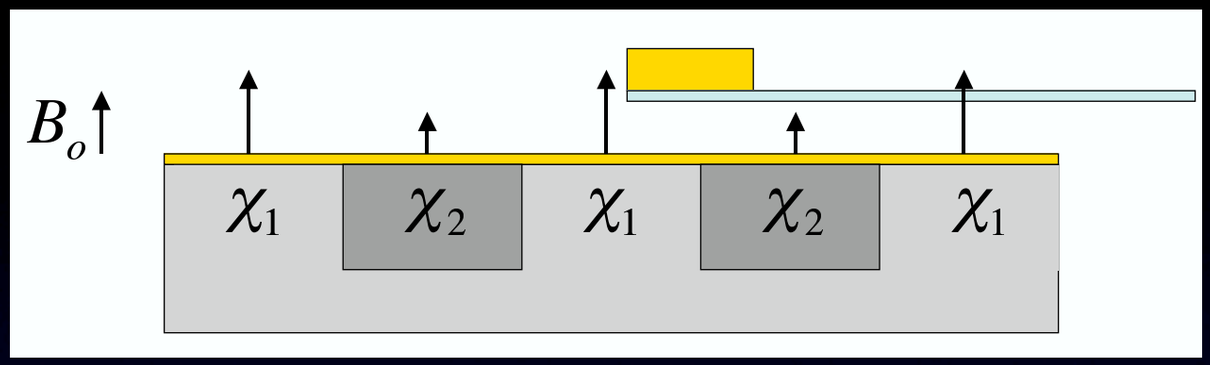
Fabry-Perot Interferometer

- 1310 nm laser
- Fiber end and cantilever makes a cavity
- $P \sim 1 - V \cos 4\pi d/\lambda$



Appl. Phys. Lett. **55**, (1989) Rugar et al.

Problem - lead inclusions in the drive mass (NA to TeCu DM)



- Macroscopic lead inclusions superconducted at T < 9 K.

- Force has same period as gravity signal
- BoE calculations suggest that the force could be large enough to be detected