Title: Resonant Detection of Short-Range Gravitational Forces

Date: Jun 17, 2014 12:00 PM

URL: http://pirsa.org/14060046

Abstract: <span>Some theories predict a short-range component to the gravitational force, typically modeled as a Yukawa modification of the gravitational potential. This force is usually detected by measuring the motion of a mechanical oscillator driven by an external mass. In this talk I will discuss such an apparatus optimized for use in the 10-100 micron distance range. The setup consists of a cantilever-style silicon nitride oscillator suspended above a rotating drive mass. Periodic density variations in the drive mass cause an oscillatory gravitational force on the cantilever, whose position is read out using optical interferometry. In order to drive the cantilever precisely on resonance, it must have a broad resonant peak; however, lower quality factors reduce force sensitivity by reducing the amplitude of oscillation for a given drive force. We solve this problem by implementing an effective damping on the oscillator by use of optical feedback. I will discuss further applications of this feedback technique, as well as improvements to the apparatus and future experiments.</span>

# Resonant Detection of Short-Range Gravitational Forces

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New Ideas in Low-Energy Tests of Fundamental Physics
Perimeter Institute
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# Acknowledgements

A. Kapitulnik
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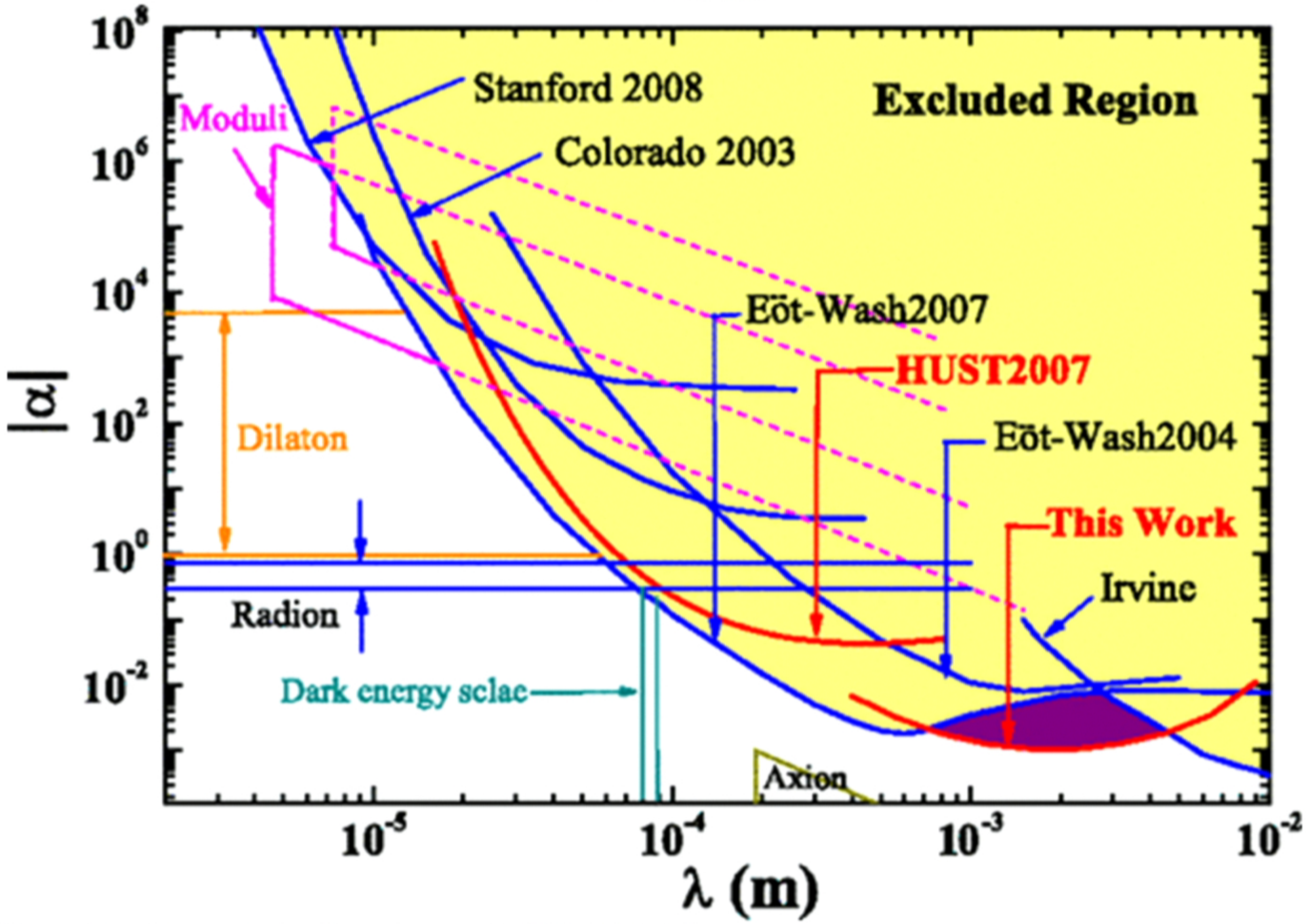
UCSB

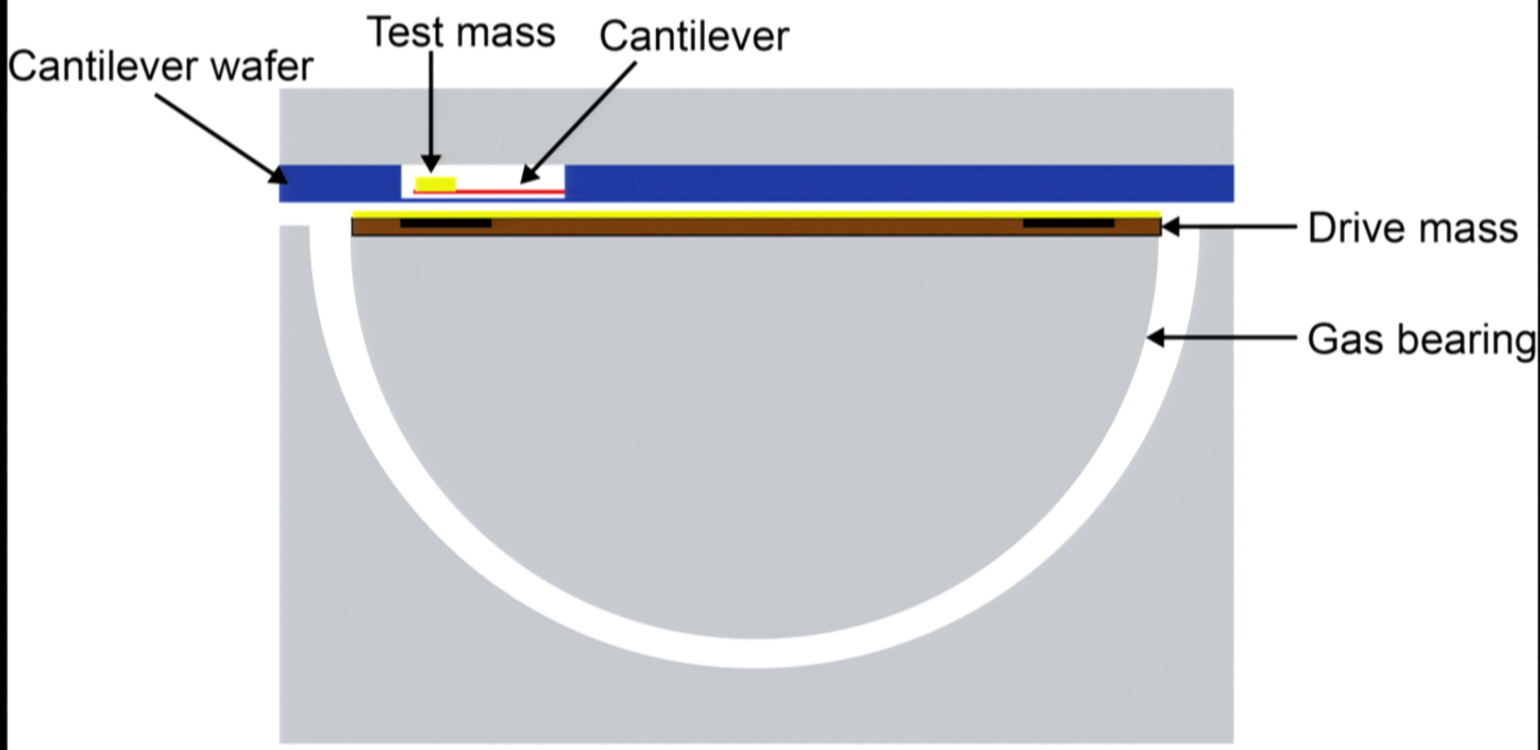
Jing Xia
UCI

# So far...




Shan-Qing Yang et al., *Phys. Rev. Lett.* **108**, 081101

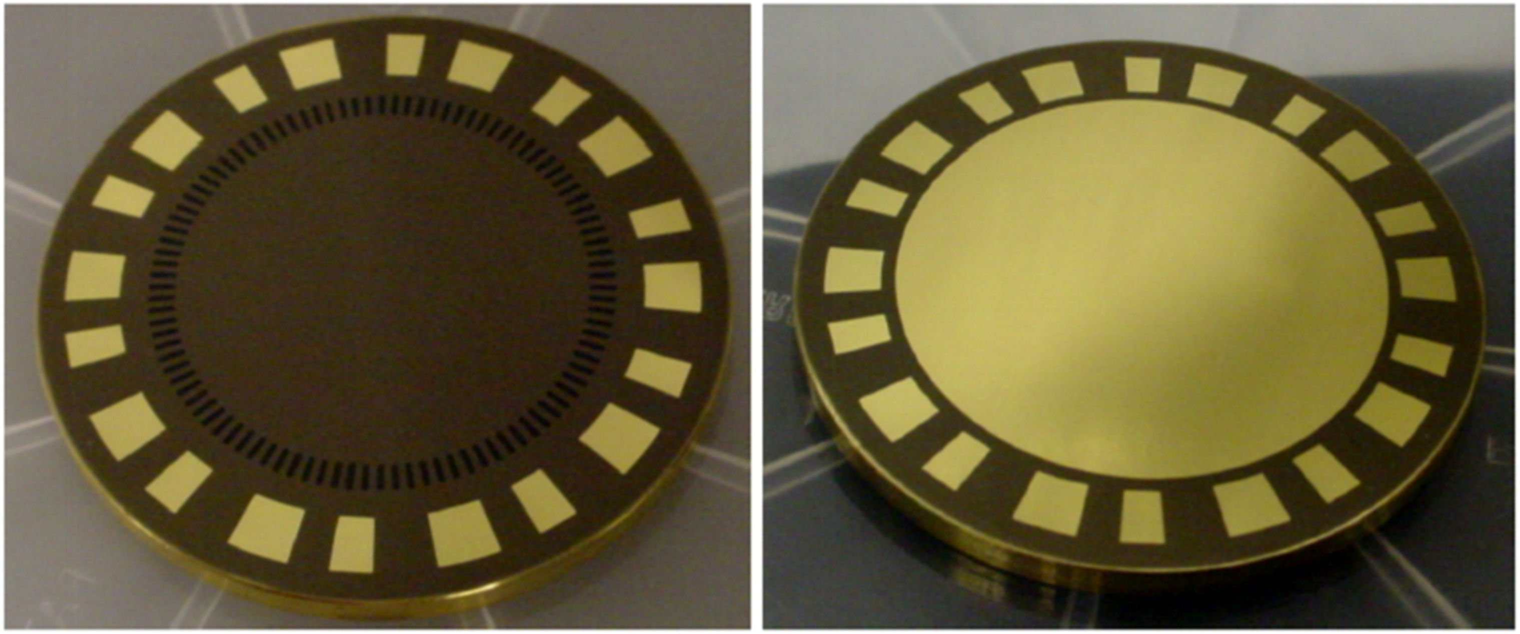
# The Basics




Spin gas bearing → alternating metal/epoxy grooves in drive mass → oscillatory force

Drive cantilever on resonance, optically detect position

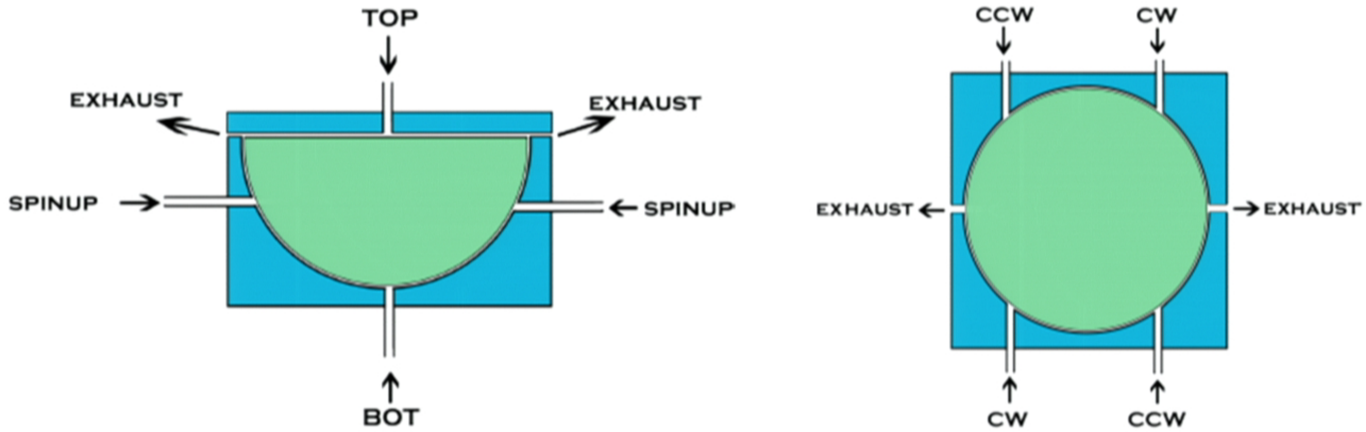
# Drive Mass

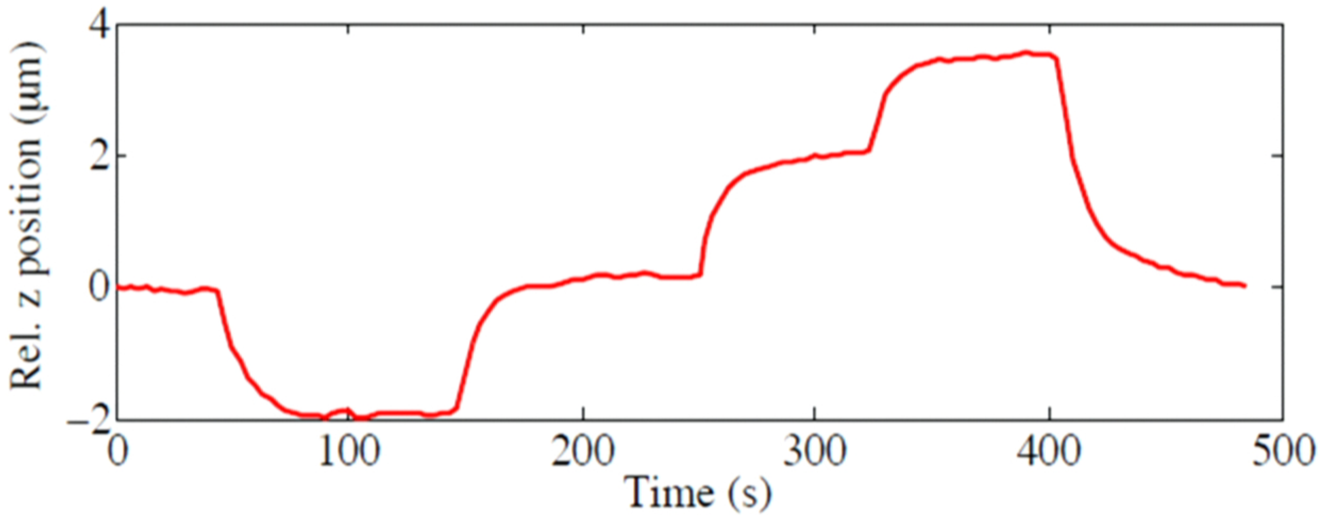


Copper or brass

Grooves filled with epoxy (lower density)

# Helium Gas Bearing



# Resonant Drive

Rotation speed control: 0.5 mHz

Mass oscillation control: 50 mHz

Intrinsic resonance linewidth ($Q$ = 80,000): ~4 mHz

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Need broader resonance!

But $F_{min} = \sqrt{\frac{4kk_BTb}{Q\ \omega_0}}$

# Feedback Cooling

$$x(t) = A\cos(\omega t + \phi)$$

$$\begin{aligned} v(t) &= -\omega A \sin(\omega t + \phi) \\ &= -\omega A \cos(\omega t + \phi - \frac{\pi}{2}) \\ &= -i\omega \times x(t) \end{aligned}$$

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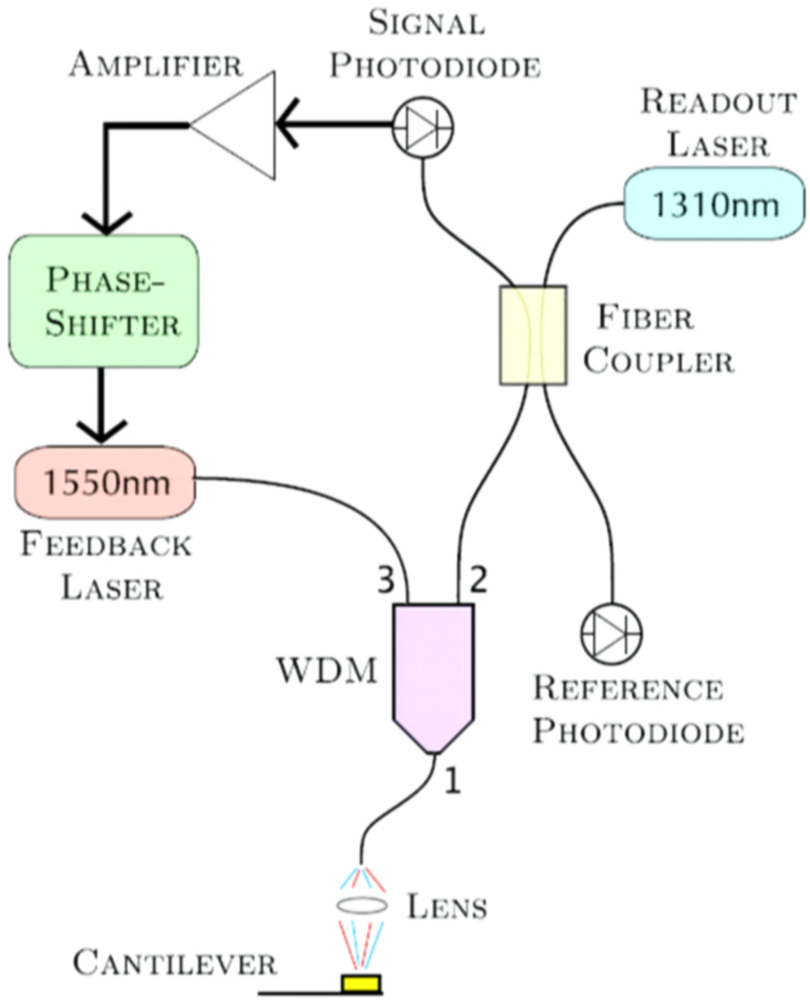
Phase shifted force → velocity dependent force → damping

Damping is "cold", eliminates fluctuations → lowers T

$$Q \rightarrow Q_0 \frac{\Gamma}{\Gamma + g}$$

$$T \rightarrow T_0 \frac{\Gamma}{\Gamma + g}$$

# Feedback Cooling



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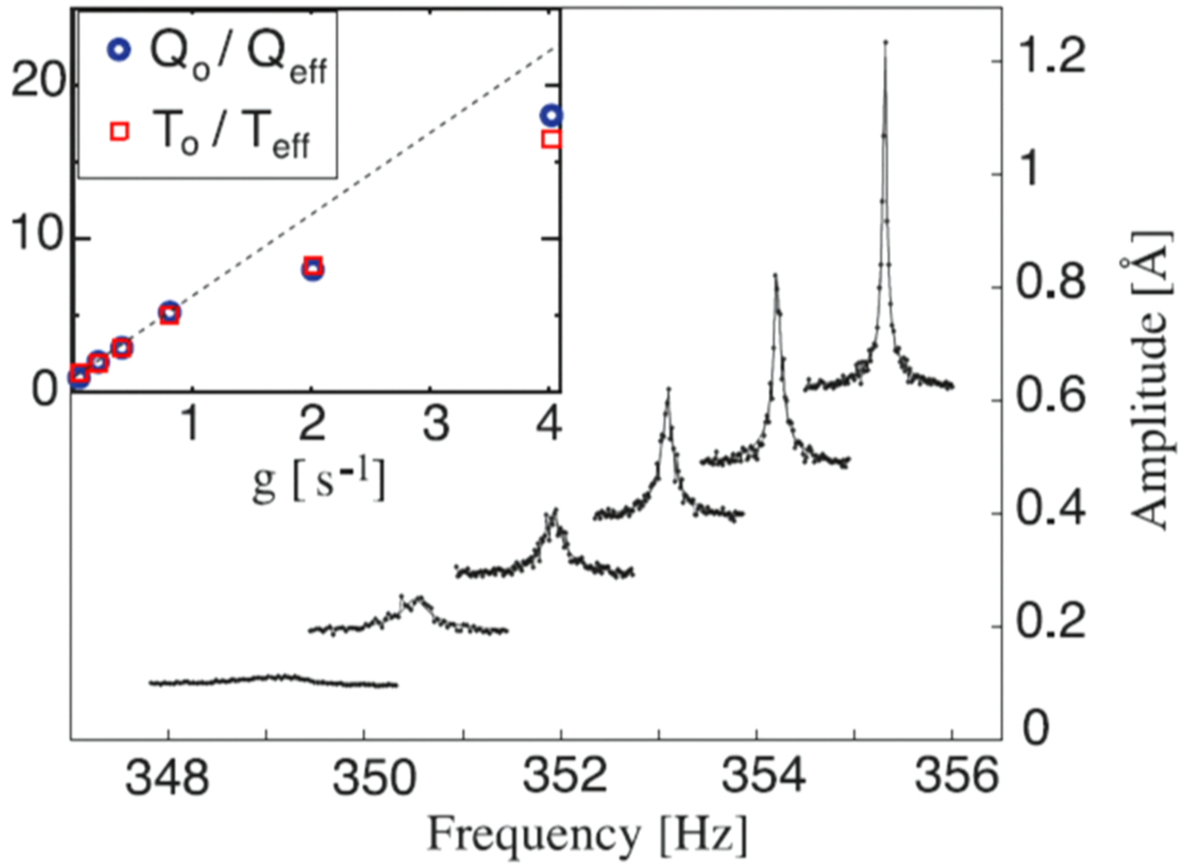

# “Recent” Improvements

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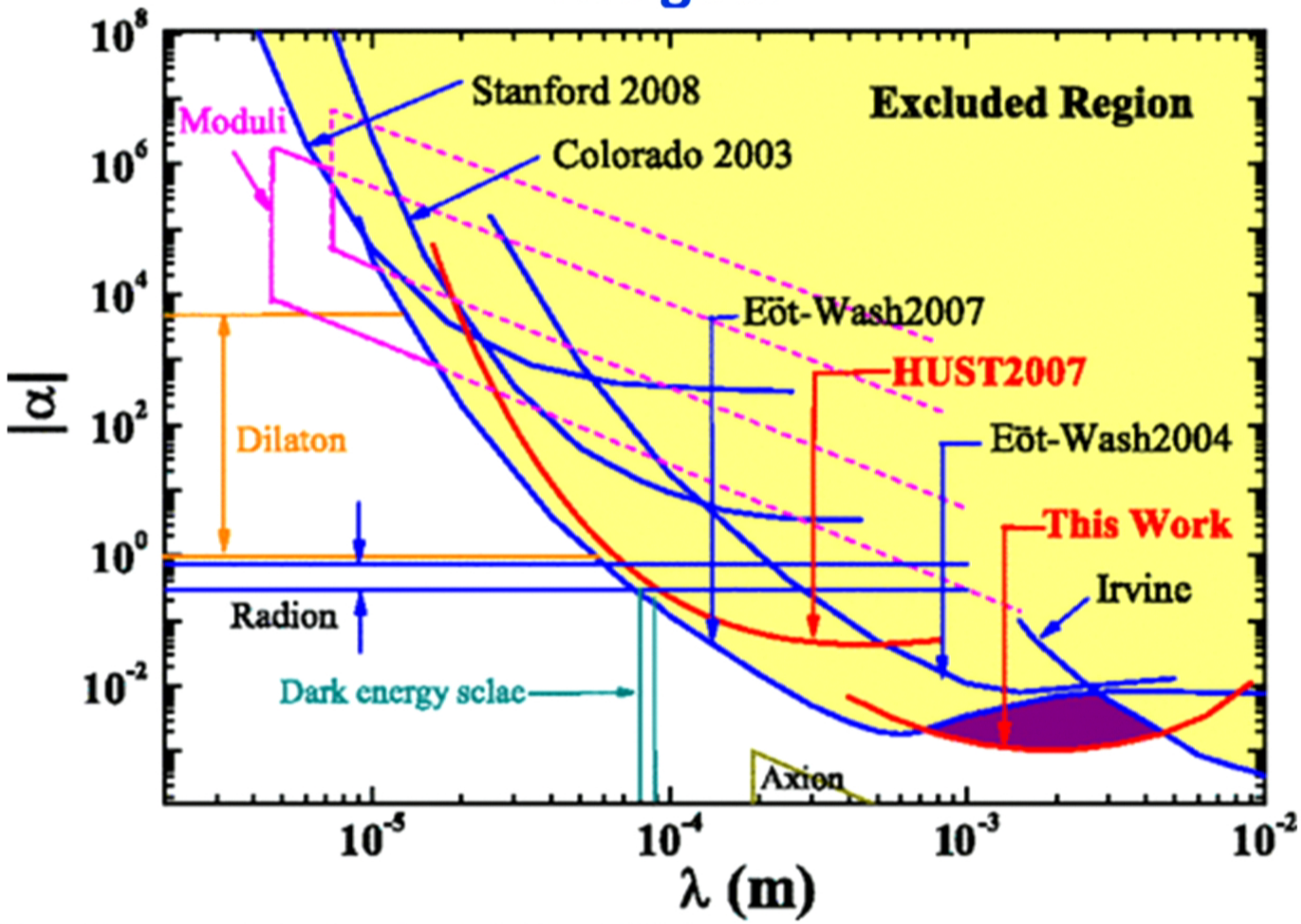
Improved drive mass → ~1.5x more force

Lower environmental vibrations + additional shielding

Computer-controlled gas flow optimization

# The goal

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# In the Future…

How strong can feedback cooling be?

- Optomechanics
- Scanning probe measurements

# Neutrinos

Neutrino-neutrino interactions (or new particle) cause $\beta$ decay with preferential direction

Peter Sturrock

# Neutrinos

Neutrino-neutrino interactions (or new particle) cause $\beta$ decay with preferential direction

Anisotropic decay → net force → detectable by cantilevers

Big, yellow, oscillatory neutrino source (period ~ 24 hours)

First calculation: ~$10^{-13}$ N force for 1 Curie (~125 $\mu$g)

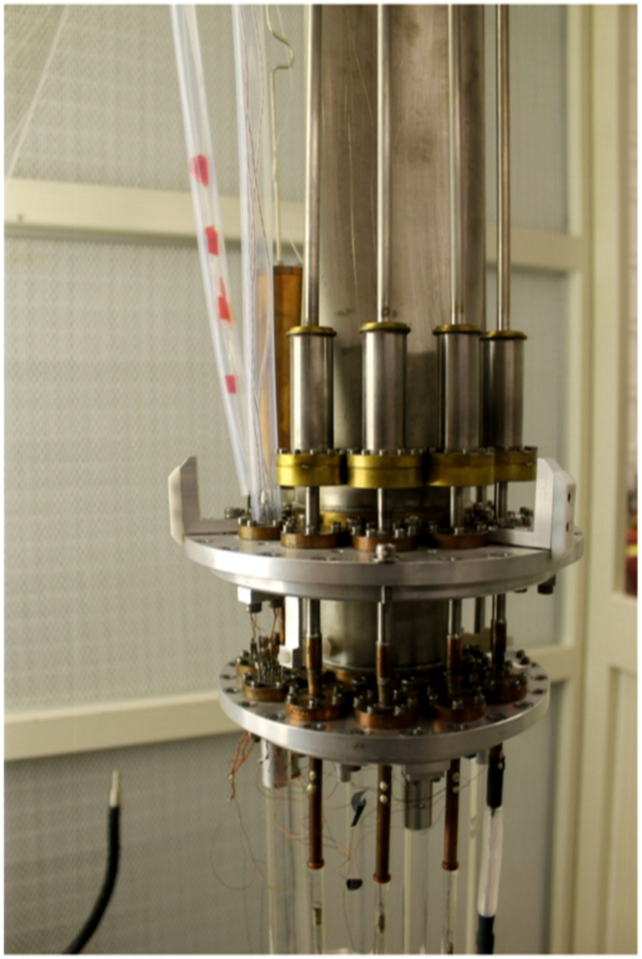
Detectable by our setup!

(Pay no attention to that 1/f noise behind the curtain → turntable?)

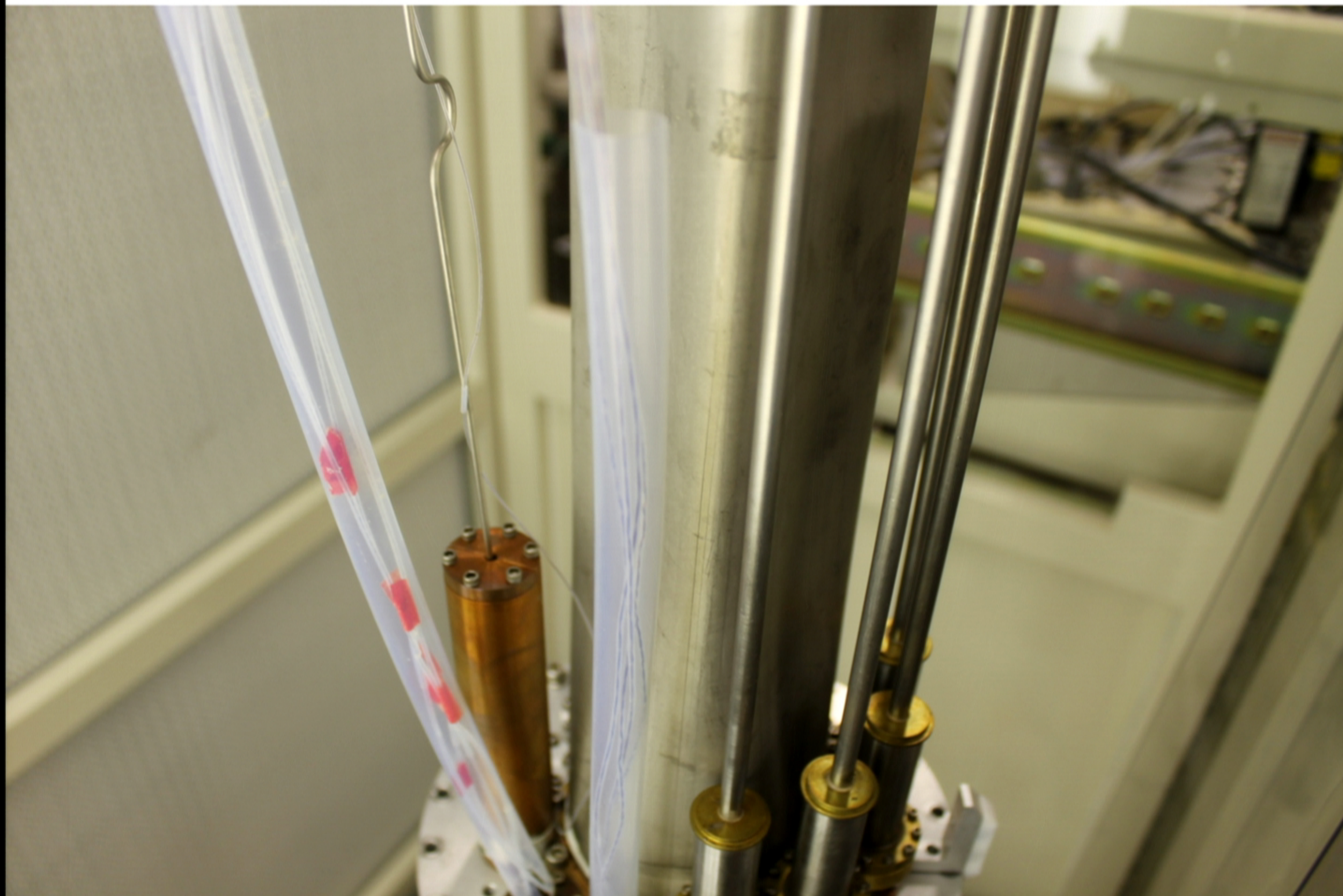
Learn about solar dynamics!

Peter Sturrock

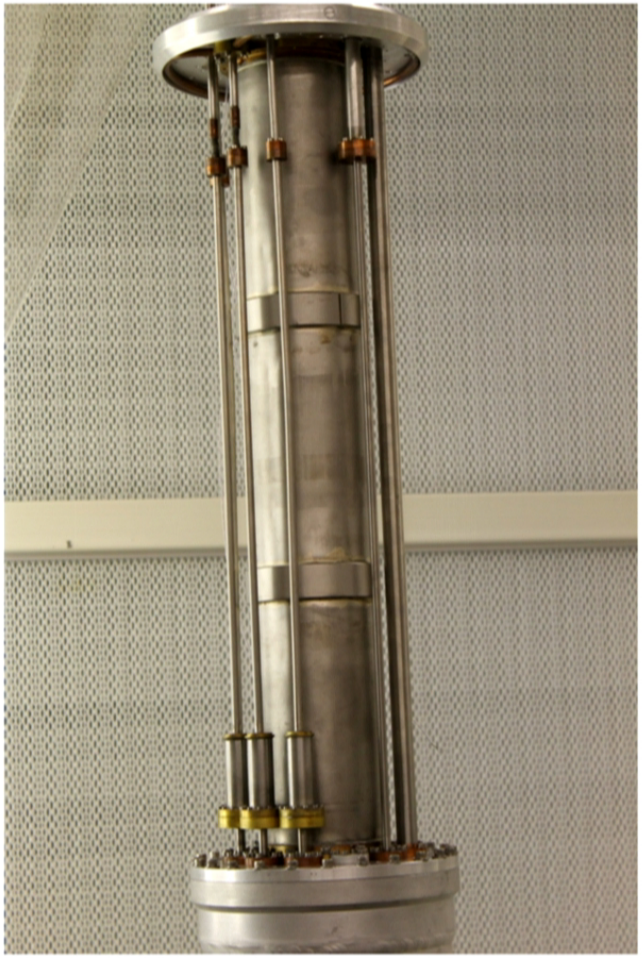
# Crunch



# Crunch



# Fix



# Possibilities

- Drive mass density contrast (~ 2x improvement possible)
- Lower temperatures → probably can't use gas bearing

  --Local cooling?

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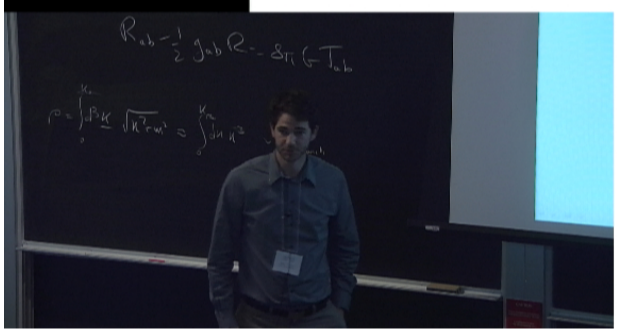
- Raise Q of cantilevers (HARD!)



# Possibilities

- Drive mass density contrast (~ 2x improvement possible)
- Lower temperatures → probably can't use gas bearing

  --Local cooling?
- Raise Q of cantilevers (HARD!)
- Increase mass overlap area (hard, but not quite as bad)
- Multiple cantilevers (CM and DM rejection)
- Parametric modulation?
- Genius ideas from the audience?