Optically Levitated Microspheres as a Probe for New Interactions

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Stanford-Yale Collaboration

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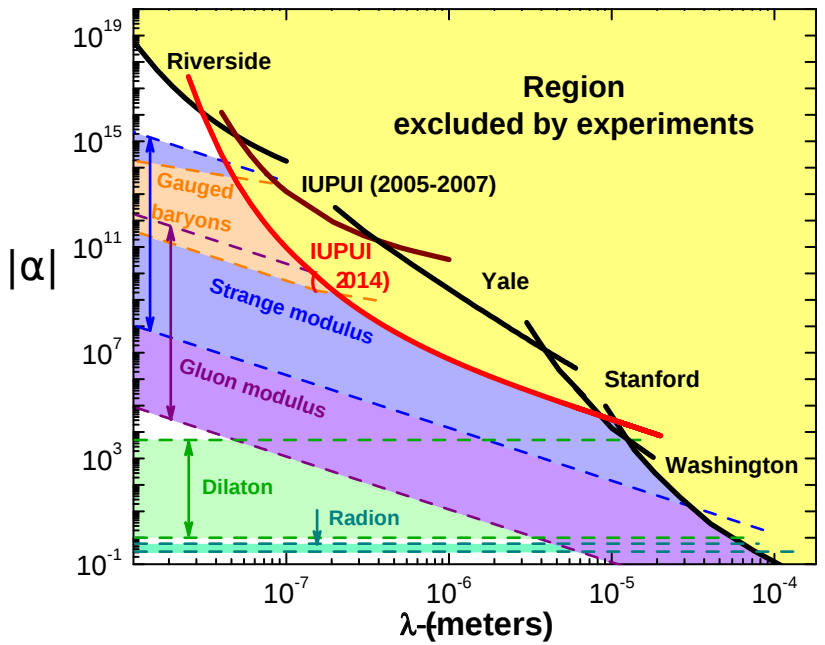
Searching for New Interactions

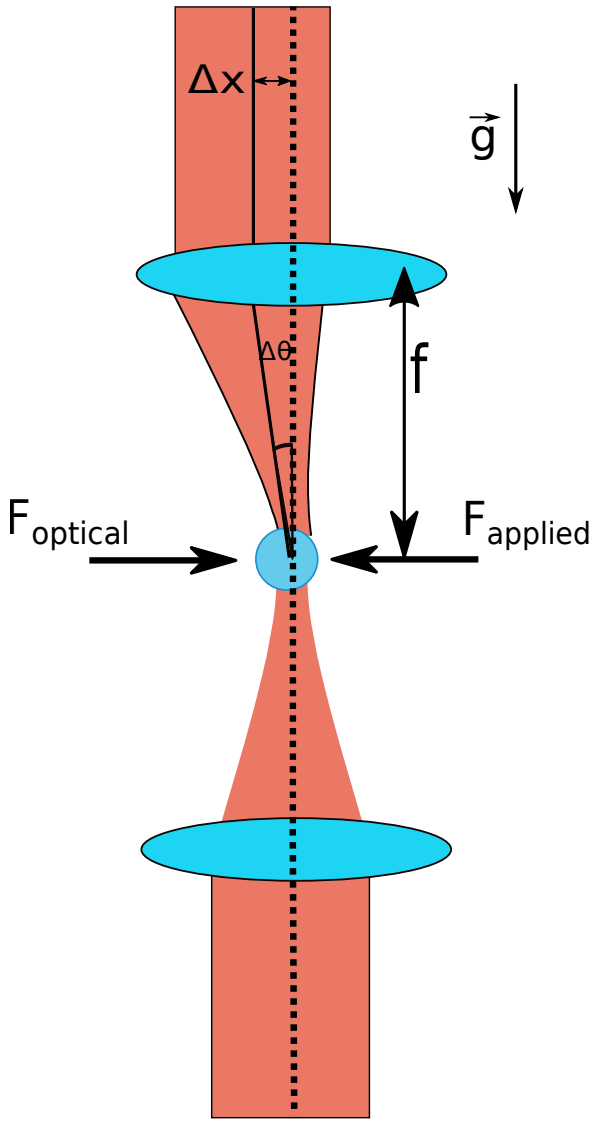
- Particle accelerators discovered many interactions by producing and detecting their quanta.
- We are searching for the exchange of classical momentum transferred by an interaction. We are interested in short range ($\sim 1\mu m$) interactions coupled to mass usually parameterized by a Yukawa potential.

$$V(r) = -\frac{Gm_1m_2}{r}\left(1 + \alpha e^{-r/\lambda}\right)$$



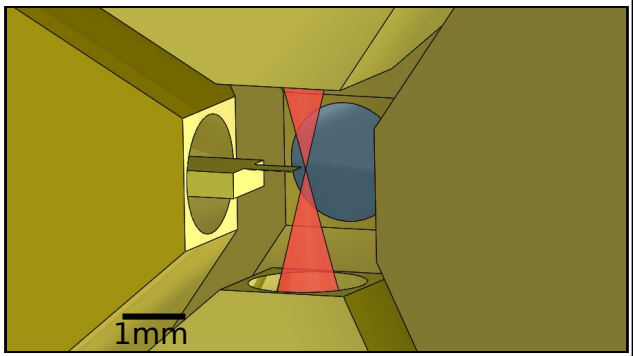
Theory regions adapted from PRD **68**, 124021 (2003)

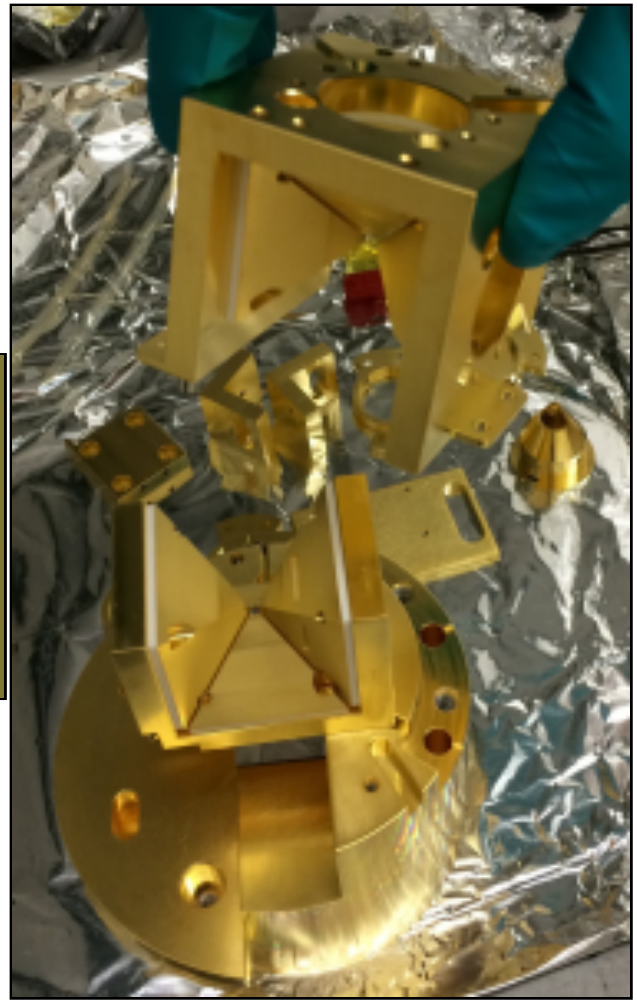
Optically Levitated Microspheres



- Difficult to measure momentum exchanges due to suspension.
- Laser radiation pressure suspension achieves excellent isolation.
- The optical force on the microsphere can be measured from the change in optical momentum flux.
- Measured force sensitivity of $\sim 5 \times 10^{-18} N/\sqrt{Hz}$ with $5\mu m$ spheres

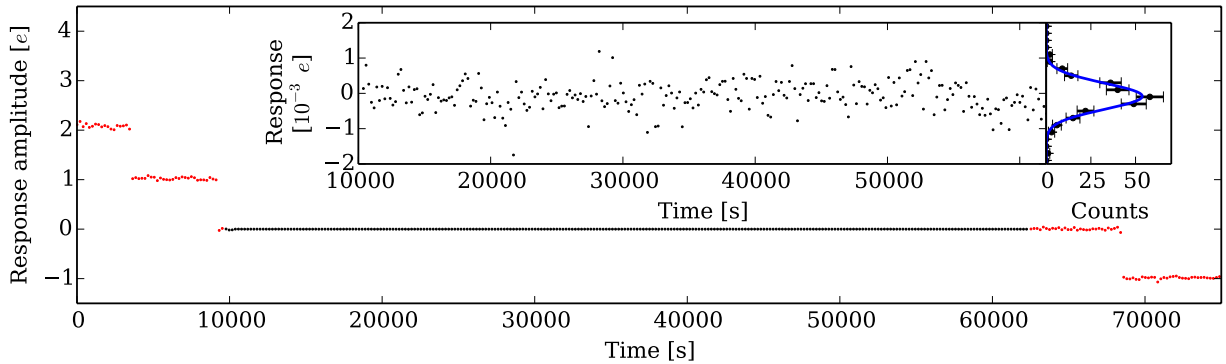
Our Trap



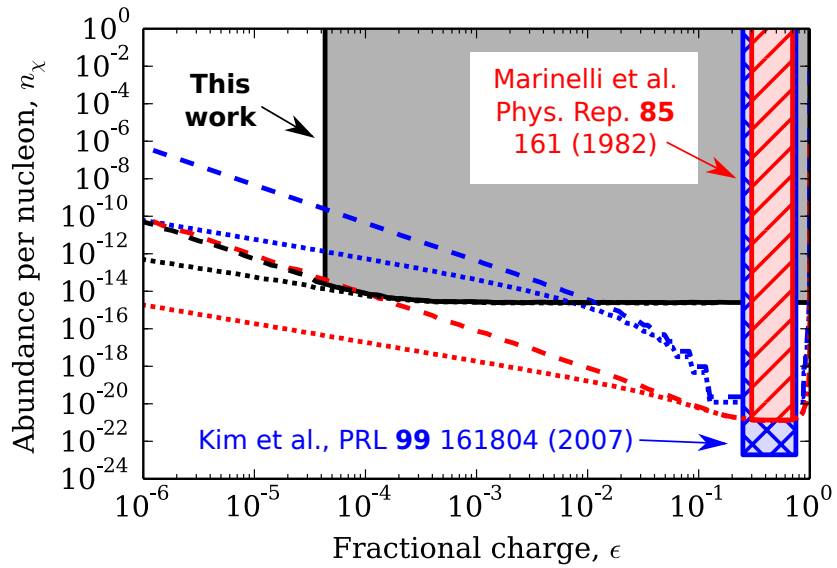


- Trap must be isolated from residual gas and stray electric fields.

Search For Millicharged Particles



- Drive microsphere with oscillating electric field while removing electrons with Xe flash lamp.
- Moore et al., PRL **113** 251801 (2014)

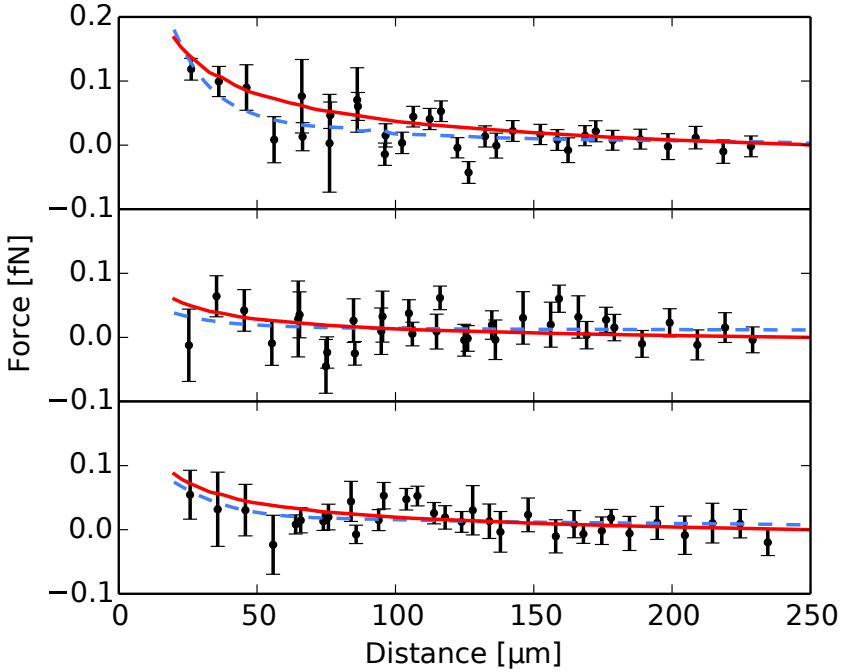


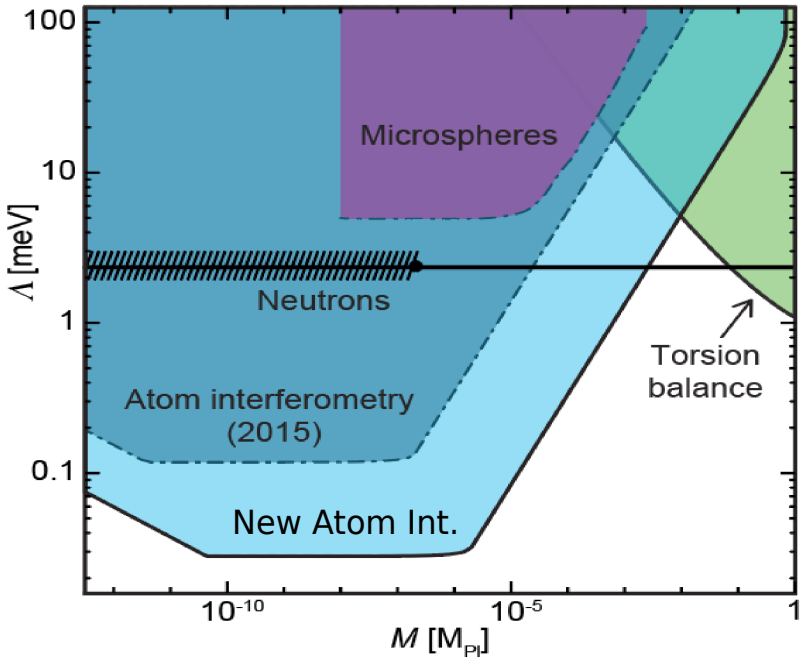
Search For 'Chameleon' Interaction

#1

#2

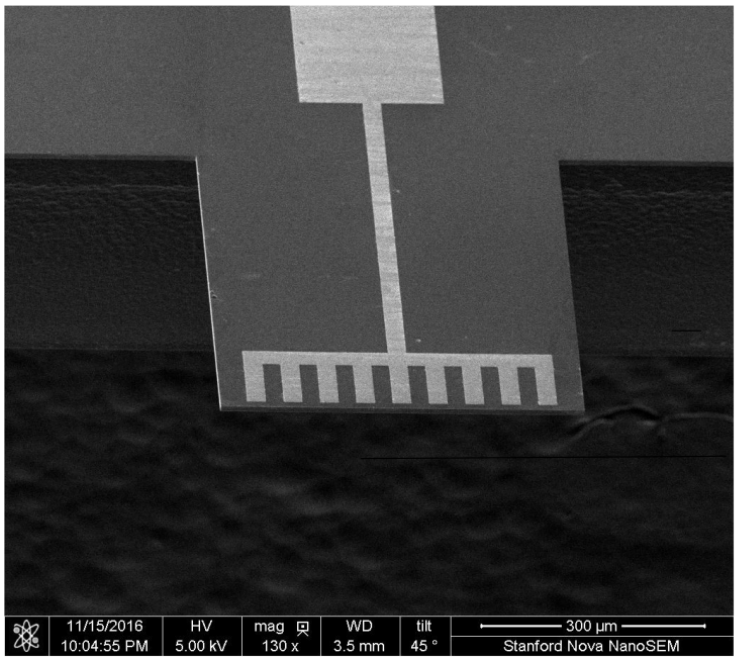
#3

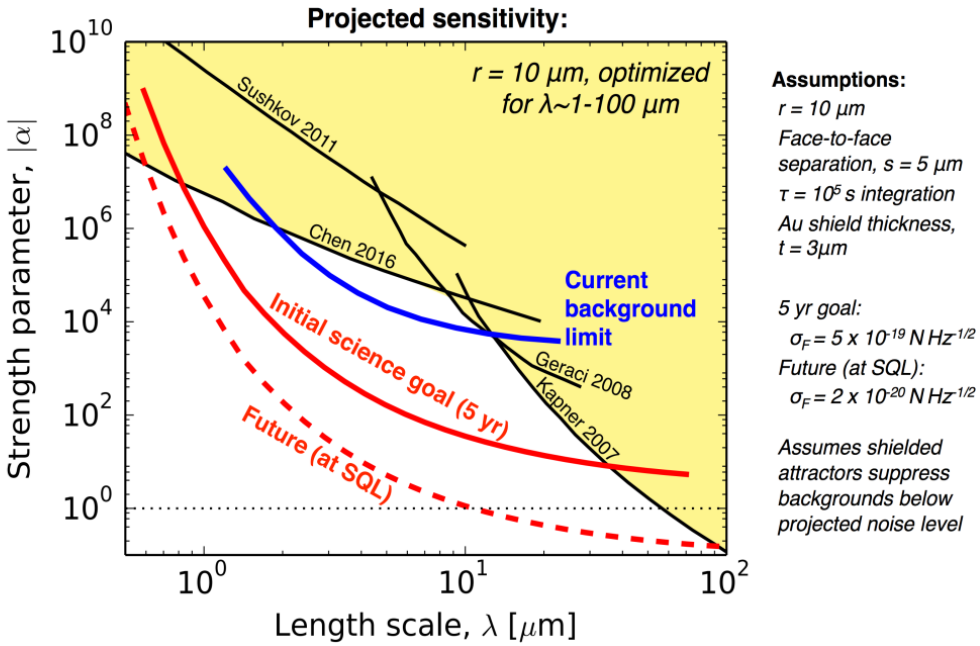




- Drive microsphere with source mass.
- Microsphere is isolated from surrounding masses reducing screening effects.
- Rider et al., PRL **117**, 101101 (2016)

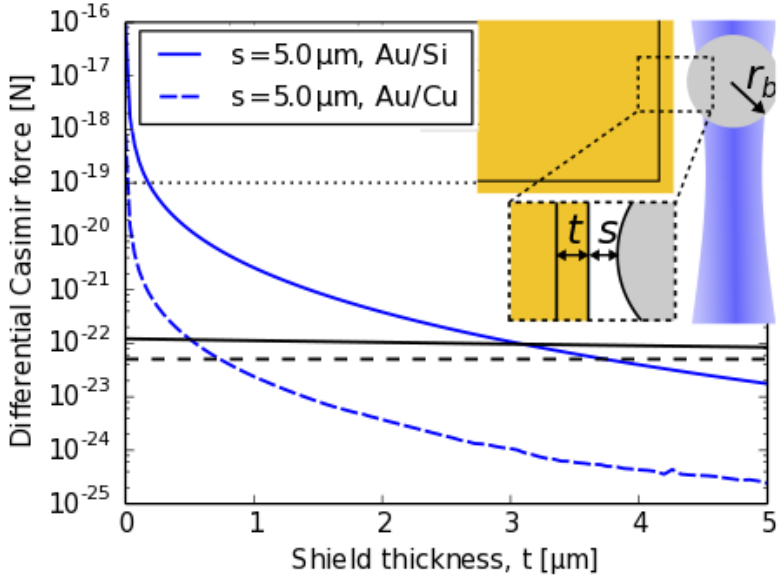
Current Work: Search for non-Newtonian Gravity





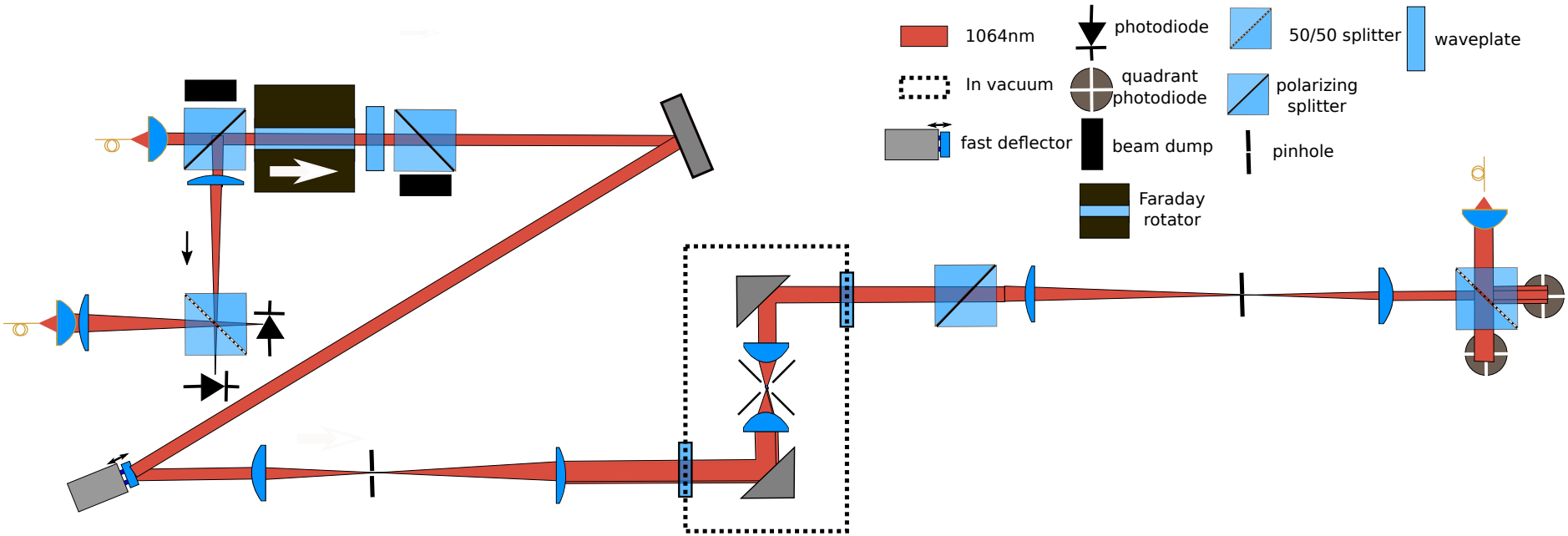
- Drive microsphere with source mass oscillating in density.
- Can probe into new parameter space.
- Fundamental backgrounds should not be significant.

Fundamental Backgrounds



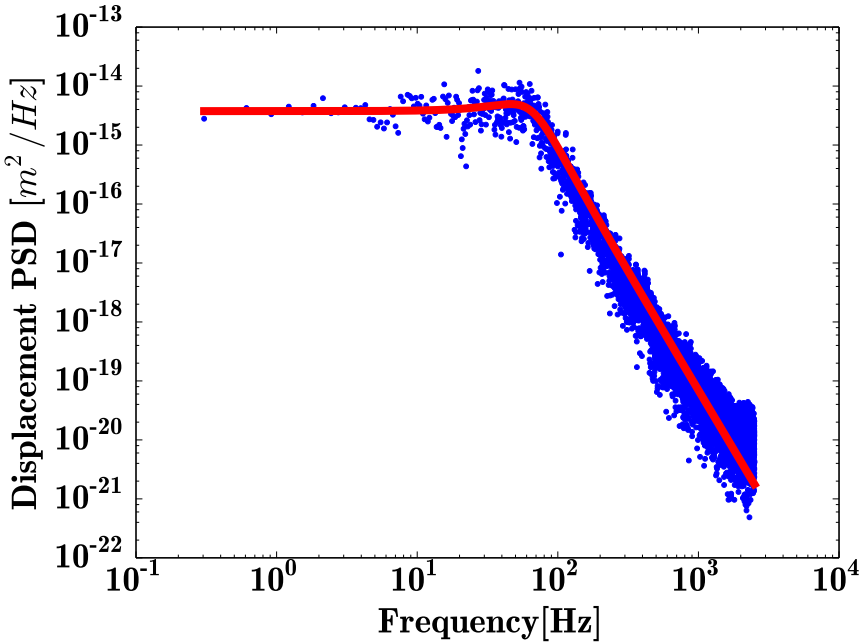
- Casimir effect leads to attractive force from the cut off of long wavelength vacuum fluctuations.
- The effect is not entirely screened by a shield of finite thickness.
- Occurs with same periodicity as density modulation.

Apparatus



- Use interference to suppress backgrounds.
- Measure axial position of sphere with interferometer.

Interferometric Measurements



- Interferometer measurement of axial position calibrated into physical units by $\lambda = 1063.9nm$.
- Can fit PSD directly to Brownian motion of harmonic oscillator $S(\omega) = \frac{2k_bT}{M\Omega^2}\frac{\Omega^2\Gamma_0}{(\Omega^2-\omega^2)^2+\omega^2\Gamma_0^2}$.
- Get T@1.5mbar $= \sim 500K$.

Conclusion

- Optically levitated microspheres are a demonstrated force sensor with excellent isolation from the environment.
- We have used optically levitated microspheres to search for millicharged particles as well as the chameleon interaction
- We expect to have a non-Newtonian gravity result soon.
- We are working on other applications of optically levitated microsheres.