Exploring Fundamental Questions in Physics with Proto-type Gravitational Wave Detectors.

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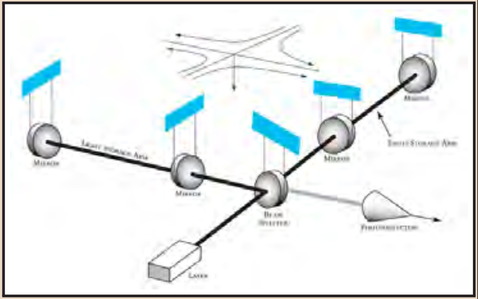
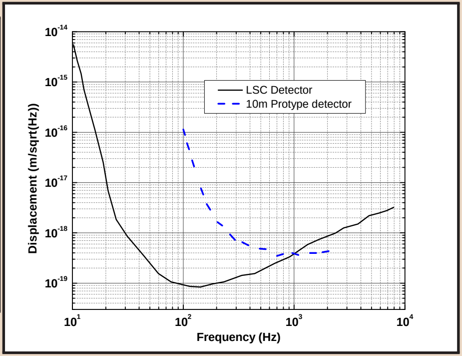
Michelson-type interferometer



Displacement Sensitivity of Gravity wave detectors



Scope

Prototype Interferometric Gravitation Wave detectors

sensitive detectors of

↓

Mirror displacement

↓

Casimir Force

↓

Short range modification to Gravity

Optical Path length changes

↓

Vacuum Polarisation

Outline

1. Short Range Gravity
   - Introduction
   - Casimir Force
   - Measure short range force with GW Interferometers
   - Summary

2. Vacuum Polarisation
   - Introduction
   - The Q & A Experiment
   - Summary

Short range gravity

Inverse square law violating forces

Predicted by String theory and other brane theoretical models that attempt unification of all the fundamental forces

- One such model is Randall-Sundrum(RS) brane-world model,

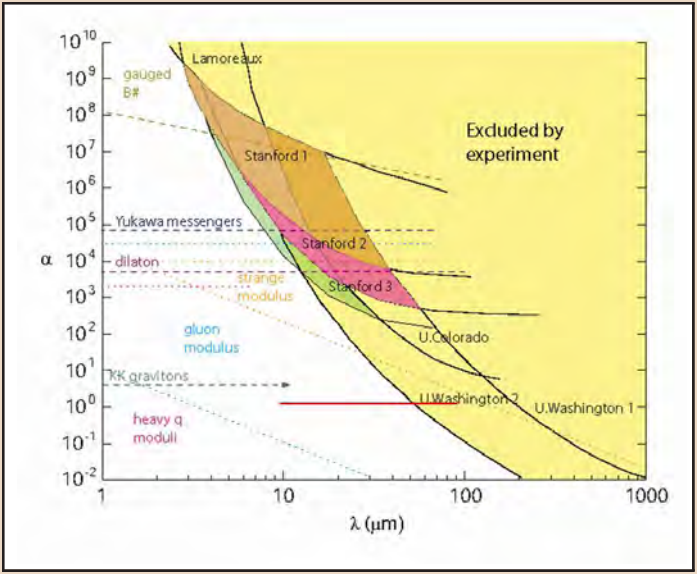
$$U_{RS}(z) \approx \frac{GM}{z}\left(1 + \frac{l_s^2}{z^2}\right)$$

- Super-symetric extensions $\rightarrow$ new forces in sub-mm regime

Paramaterization of deviations from inverse square law

$$U_{Yuk}(z) \approx \frac{GM}{z}\left(1 + \alpha e^{\frac{-z}{\lambda}}\right)$$

Constraints on the violation parameters



What is Casmir force

The Casimir Force between parallel metal plates at zero temperature

$$F_c(z) = -\frac{\pi^2 \hbar c}{240 z^4}.$$
$$= -\frac{0.013}{z_\mu^4} \quad \text{dyn. cm}^{-2}$$

where $z_\mu \equiv z$ in microns

At any finite temperature the force is given by,

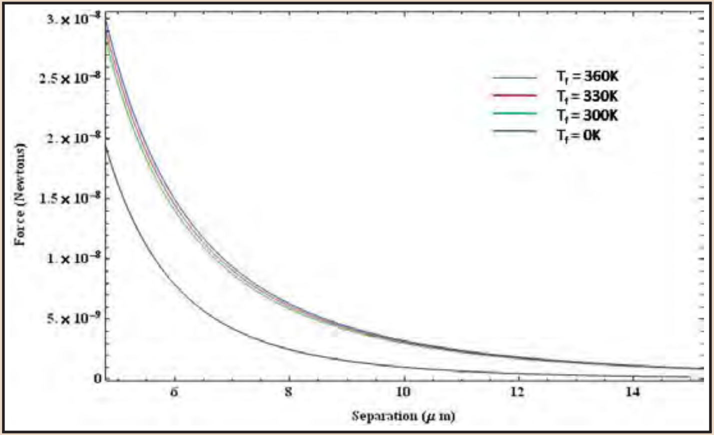
$$F_c^T(z) = -\frac{k_B T}{4\pi z^3} \sum_{n=0}^{n}{}' \int_{nx}^{\infty} \frac{dy y^2}{e^y - 1} \quad \text{where} \quad x \equiv 4\pi k_B T z/\hbar c$$

$$F_c^T(z) \simeq -\frac{\zeta(3) k_B T}{4\pi z^3} \quad \text{at high } T \ (i.e.\ x \gg 1)$$

with $\zeta(3) = 1.20206$

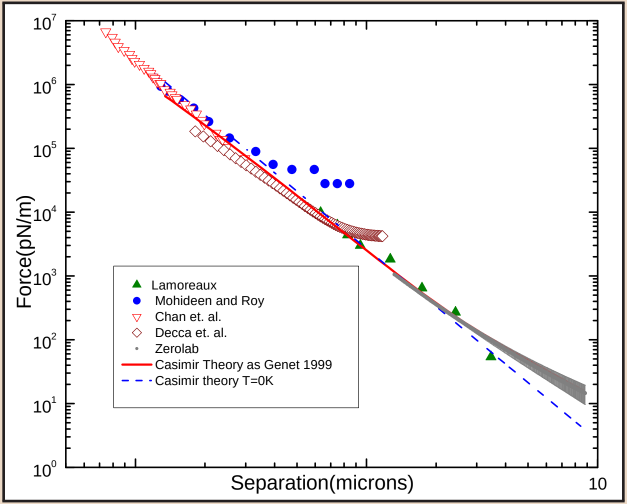
Casimir force vs Temperature

The Casimir force at various ambient temperatures for plates of about 2cm radius



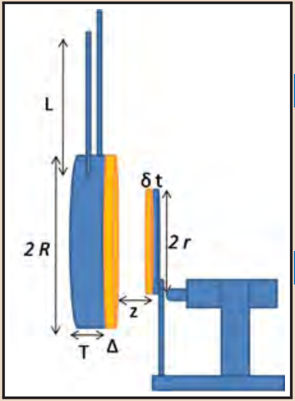
Past measurements of Casimir Force

Data from measurements of Casimir force



GWI as force transducer

Scheme to measure force



Forces acting on the suspension

Gravitational force between parallel plates

$$F_{grav}(z) \approx 2\pi^2 r^2 G \rho_1 \rho_2 T t$$

Yukawa type interaction

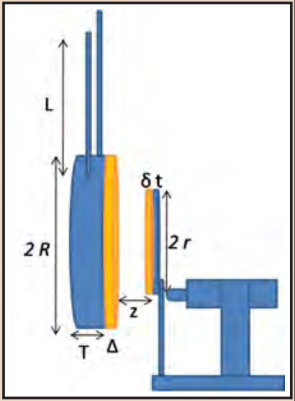
$$F_{yuk}(z) = 2\pi^2 r^2 G \alpha \lambda^2 e^{\frac{-z}{\lambda}} \left[\rho_1 \left(1 + e^{\frac{-T}{\lambda}}\right)\right] \left[\rho_1 \left(1 + e^{\frac{-t}{\lambda}}\right)\right]$$

Randall-Sundrum type force

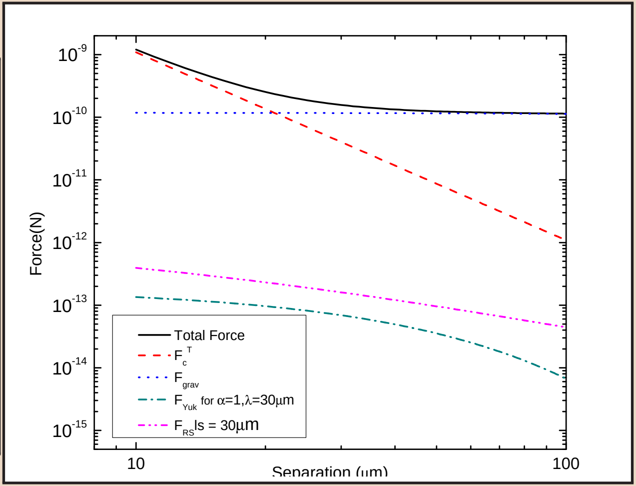
$$F_{RS}(z) = 2\pi^2 r^2 G l_s^2 . \rho_1 \ln \left[\frac{z + T + t}{z + T}\right] . \rho_2 \ln \left[\frac{z + t}{z}\right]$$

GWI as force transducer

Scheme to measure force



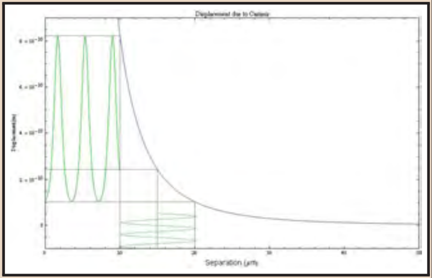
Forces acting on the suspension



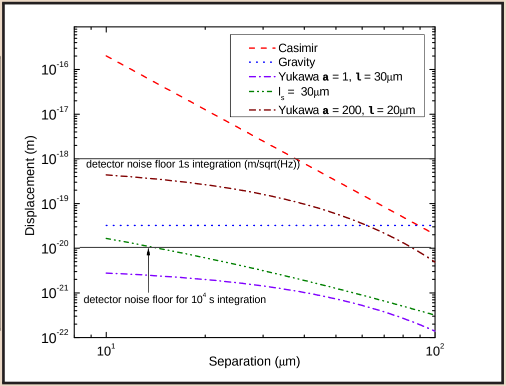
Ref: G. Rajalakshmi, C. S. Unnikrishnan, Class. Quant. Grav.,**27**, 215007 (2010), arXiv:1006.2228[gr-qc]

Expected signal

Displacement of the mirror due to the force = Force x L/m g



Expected displacement of the mirror for 2 μm modulation at 200 Hz

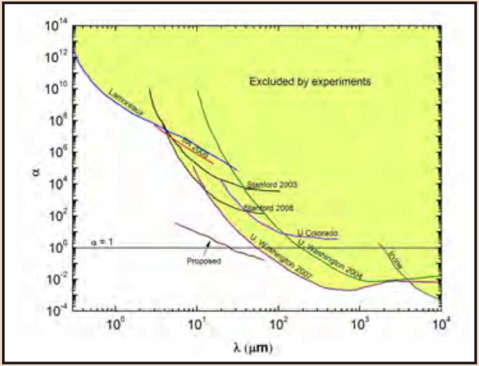


Ref: G. Rajalakshmi, C. S. Unnikrishnan, Class. Quant. Grav., **27**, 215007 (2010), arXiv:1006.2228[gr-qc]

Summary

- The Casimir force at separations of $10 - 100\mu$m can be studying with an unprecedented accuracy.
- Finite temperature effects can be detected from the force law as a function of separation and by making measurement at various temperatures between room temperature of about 25°C and 100°C.
- Improved limits can be placed on the parameters of inverse square law violating interactions in the 10μm to 100μm range from measurement of forces of order 1×10^{-11}N with a sensitivity of better than 1%.
- An experiment to directly look for deviations of inverse square law of gravity in the 10μm to 100μm can be performed.

Summary I



- The 3m prototype gravity wave detector being set up at TIFR with a sensitivity $< 10^{-17}\mathrm{m}/\sqrt{Hz}$ (in a time scale of about 3 years) can also be used for studying short range interactions

Outline

Polarization of Vacuum

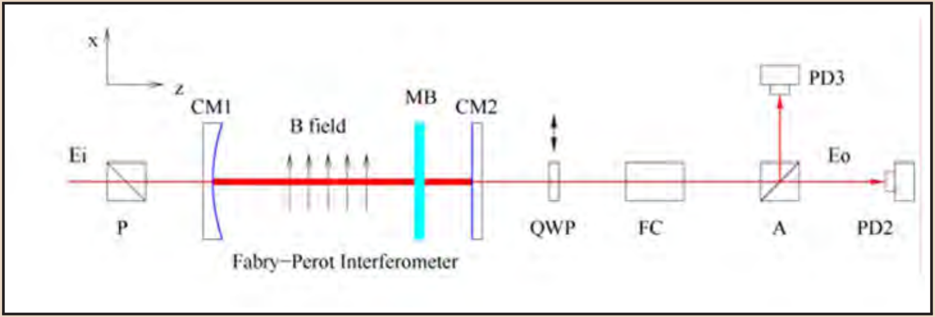
- QED predicts that photons are scattered by static electric / magnetic fields
- The virtual photon pairs of the quantum vacuum are also polarized by magnetic fields
- Light propagating thorough magnetic field in vacuum exhibits birefringence.
- In a dipolar field B the QED vacuum becomes a uniaxial birefringent medium with a difference between the refractive indexes

$$\Delta n = \mid n_{\parallel} - n_{\perp} \mid \approx \left(4.10^{-24} \text{Tesla}^{-2}\right) B_0^2 \, sin(2\theta)$$

The Q & A Experiment

- A proto-type GWI with Fabry-Perot cavity at National Tsinhua Univ,Taiwan.
- Modified to work as ellipsometer to detect vacuum birefringence
- Can also detect low mass pseudo-scaler or scaler particles that interact with photons like ‘Axions’

The Q & A Schematic



Measurement of Cotton-Mutton Effect:

Birefringence shown by medium in the presence of transverse magnetic field.

Table 3. Measured gaseous Cotton-Mouton coefficients.[58]

Gas	Normalized Cotton-Mouton birefringence[62] Δn_u at $P = 1$ atm and $B = 1$ T
N_2	$(-2.02 \pm 0.16^{\S} \pm 0.08^{\P}) \times 10^{-13}$
O_2	$(-1.79 \pm 0.34^{\S} \pm 0.08^{\P}) \times 10^{-12}$
CO_2	$(-4.22 \pm 0.27^{\S} \pm 0.16^{\P}) \times 10^{-13}$
Ar	$(4.31 \pm 0.34^{\S} \pm 0.17^{\P}) \times 10^{-15}$
Kr	$(8.28 \pm 1.26^{\S} \pm 0.32^{\P}) \times 10^{-15}$

§: Statistical uncertainty

¶: Systematic uncertainty

Ref: Mei et. al. , Modern Physics Letters A, **25**, 983 (2010), arXiv:1001.4325v2[physics.ins-det]

Summary II

- The high finesse of the Fabry-Perot cavity in the proto-type GWI has been effectively used to build a high precision ellipsometer.
- The experiment studies several fundamental issues in physics : vacuum polarisation, dark matter candidates, Cotton-Mouton effect

Conclusion

- The high sensitivity of proto-type GWI can be effectively used to measure quantities in physics that are at the edge of detectability with current experimental techniques
- The 3m proto-type being built at TIFR would have the sensitivity to required such measurments.