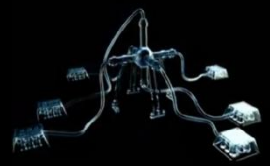


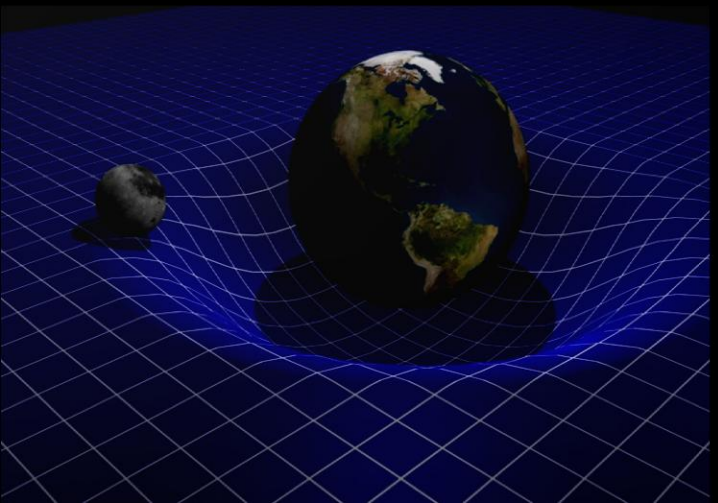
Towards Quantum Gravity Measurement by Cold Atoms

Marcilio M. Dos Santos

SUPA, RAL, Sonangol, IMechE, IOP

Quantum Gravity and Gauge Group

University of Aberdeen



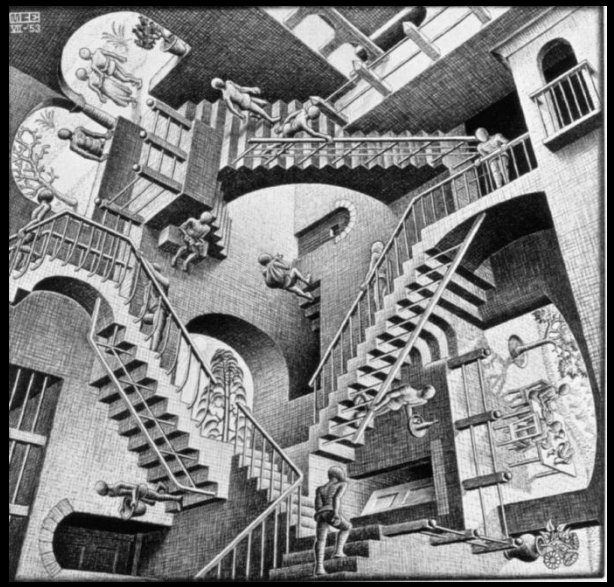
University of Nottingham

Quantum Fields, Gravity & Information

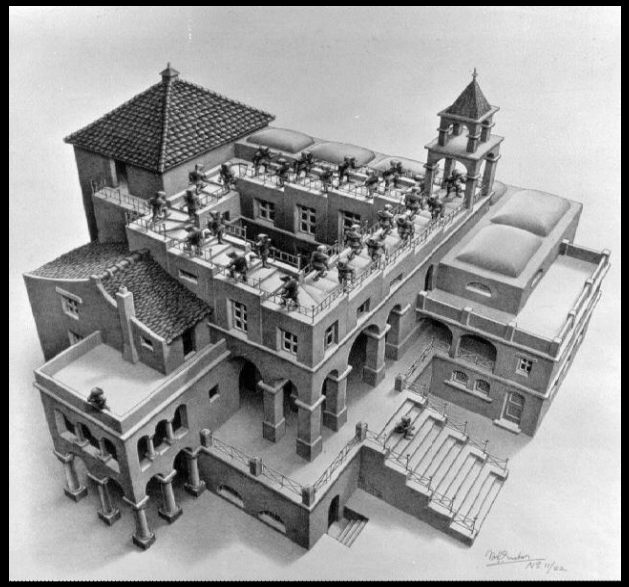
Content

1. Quantum Gravity observation difficulties
2. Probing Spacetime with cold atoms
3. Quantum mechanical and Thomas-Fermi approach
4. Mechanism of Observation (Experiment)

Quantum Gravity Observation Difficulties



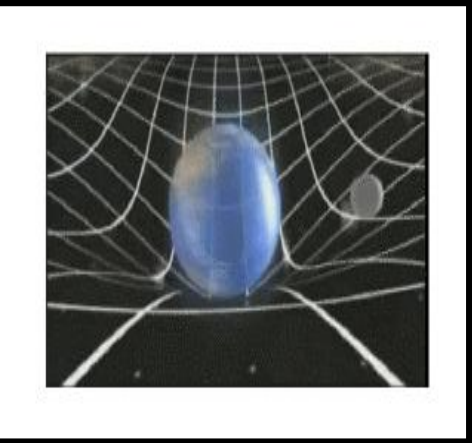
Paradoxical but Possible



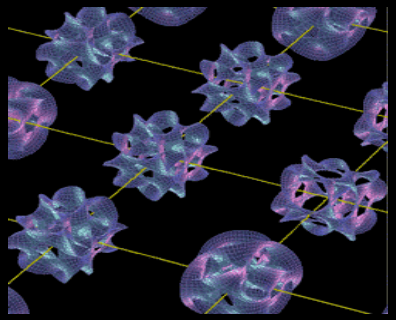
Impossibility

"Relativity" and " Ascending & Descending"
by M.C.Escher

Quantum Gravity Observation Difficulties



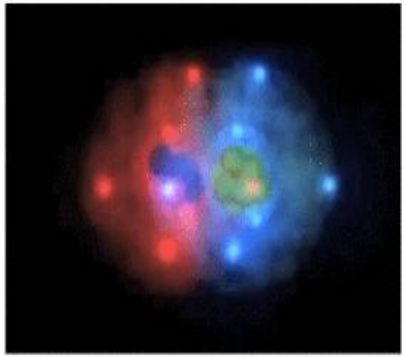
$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G T_{\mu\nu}$$



$10^{-33} cm$

$\boxed{10^{19} GeV}$

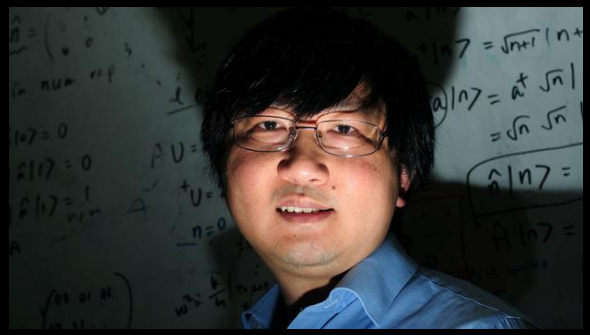
$10^{-43} s$



$$i\hbar \frac{\partial}{\partial t} \Psi(r,t) = (-\frac{\hbar^2}{2m} \nabla^2 + V(r,t)) \Psi(r,t)$$

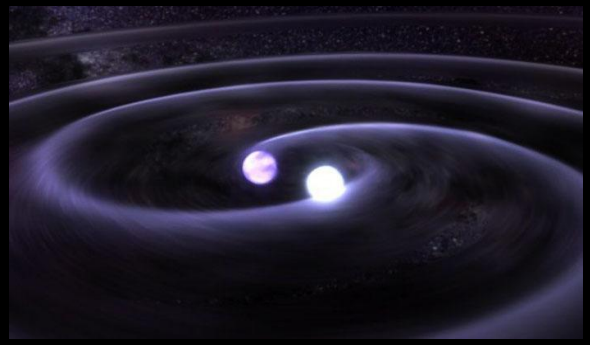
$14 \cdot 10^3 GeV$

Probing Spacetime with cold atoms



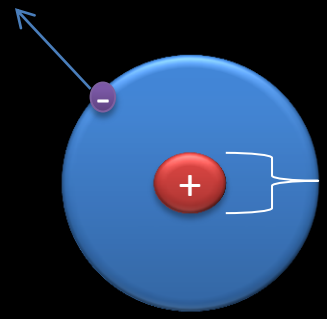
The ideal is based on a seemingly "Lamb shift of cold atoms centre of mass" induced by gravitational Perturbation.

In 2011 Charles H.-T. Wang & Collaborators proposed probing Spacetime by cold atoms



Indirect Observation of Spacetime fluctuation created by a binary star system

Cold atoms
or
BEC

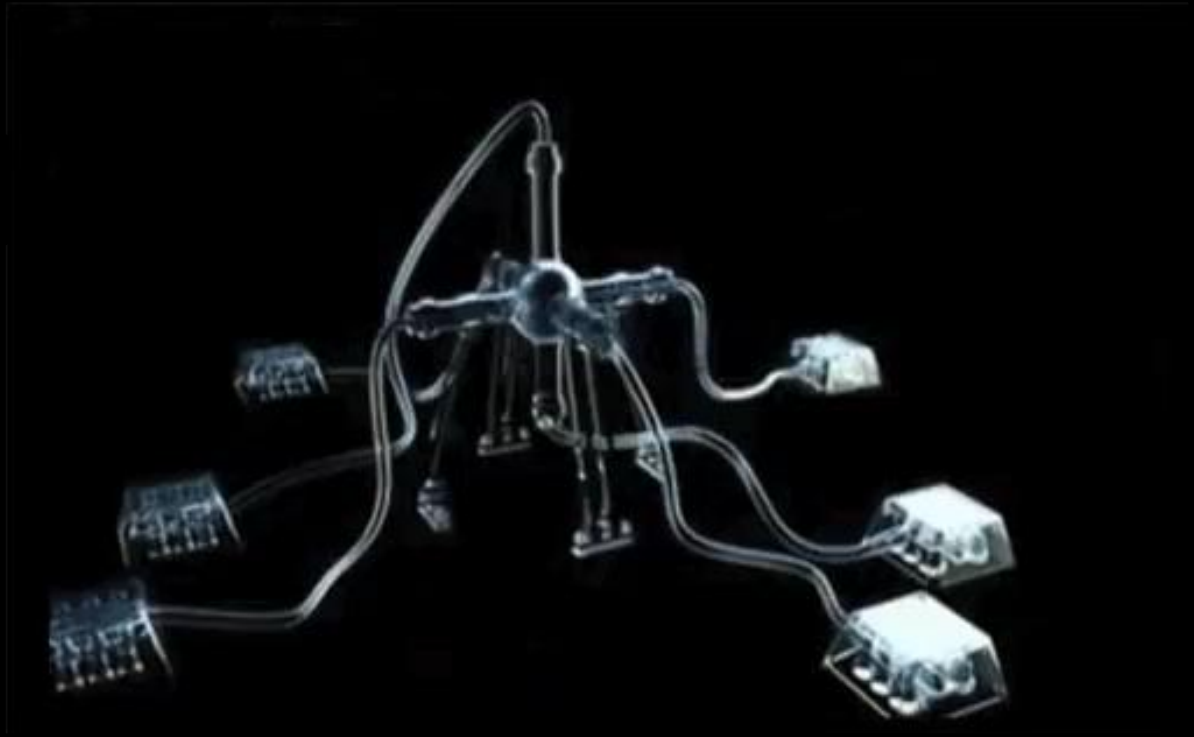


Lamb Shift of Hydrogen atom

Cold atoms

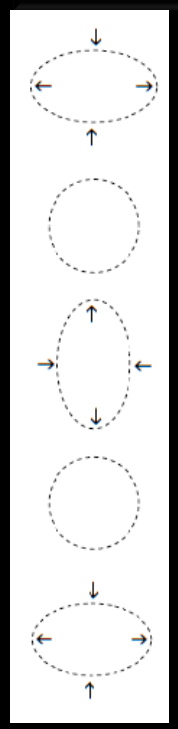
Laser with the same frequency as the atoms resonance frequency slow down atoms to temperature of microKelvin range, i.e. COLD ATOMS.

Evaporative cooling extract high kinetic energy atoms, and further lower the Temperature to nanokelvin forming BOSE EINSTEIN CONDENSATES



Animation from "Absolute zero"

Probing Spacetime with cold atoms



Quadruple oscillation sequence

From FDT, quadruple radiation of a particle and damping reach thermal equilibrium with stochastic Gravitational wave background.

$$\left\langle h_{ij} h_{ij} \right\rangle = \frac{32G}{\pi c^5} \int_0^\infty E_T(\omega) d\omega$$

Where E_T the Planck spectral density with $T \to 0$

$$E_T(\omega) = \frac{1}{2}\hbar\omega + \frac{\hbar\omega}{e^{\hbar\omega/kT} - 1}$$

BEC 2nd derivative of its 1st order standard deviation due to spacetime fluctuation

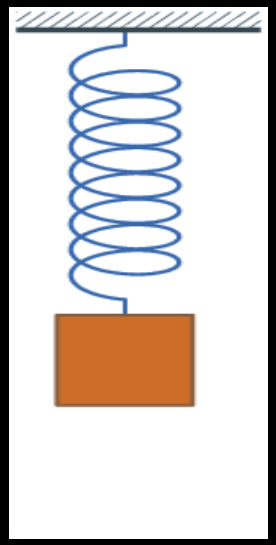
$$\frac{d^2 \left\langle x^{(1)i}(t)^2 \right\rangle}{dt^2} = \frac{32}{9\pi} v^2 t_p^2 \Omega^2$$

$$\left\langle x^{(1)i}(t)^2 \right\rangle = \left\langle \Delta r^2 \right\rangle = \frac{16}{9\pi} t_p^2 \Omega^2 \ell^2$$

$$\boxed{\left\langle \Delta V \right\rangle \approx \frac{16}{27\pi} \frac{m^3}{m_p^2} \omega^2 L^2}$$

$$\frac{\Delta E}{\hbar\omega} \approx 4 \times 10^{-23} N^2 (L/m)^2$$

Quantum Mechanical Approach



Considering a 1D harmonic oscillator perturbed by a potential *V(x,t)* , the Hamiltonian is given as

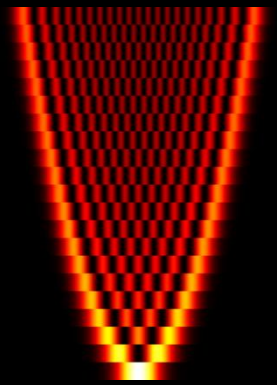
$$\hat{H} = \hat{H}_0 + V(x,t)$$

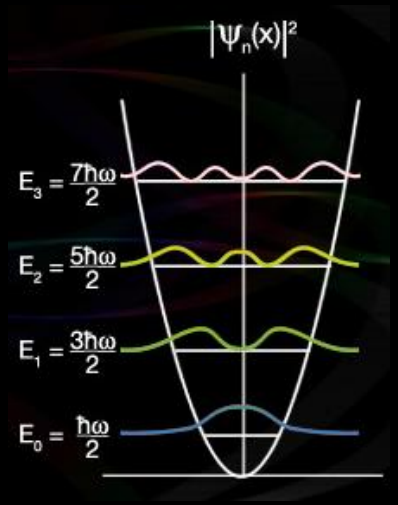
Where $V(x,t) = mA(t)x$ and $A(t) = A_0 \sin(\Omega t)$

$$V_{ni}(t) = m\langle n | A(t)x | i \rangle$$

With expected value of position of the particle as

$$\langle n | x | i \rangle = \sqrt{\frac{\hbar}{2m\omega}} \langle n | \hat{a} + \hat{a}^{\dagger} | i \rangle$$





Now the 1st order perturbation
Coefficient of probability expressed as

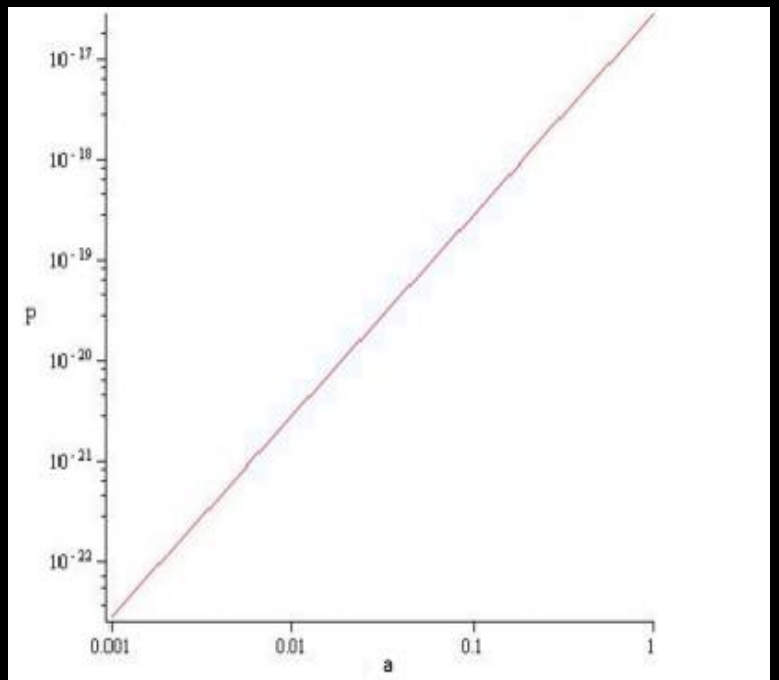
$$c_{ni}^{(1)}(t) = -\frac{im}{\hbar}\langle n|x|i\rangle \tilde{A}_t(w_{ni})$$

The mean power spectral density is

$$S_t(\omega_{ni}) = \frac{1}{t}\langle \tilde{A}_t^*(\omega_{ni})\tilde{A}_t(\omega_{ni})\rangle$$

The Transition probability is found to be

$$P_{ni} = \frac{m^2}{\hbar^2}|\langle n|x|i\rangle|^2 S(\omega_{ni})t$$



Double-logarithimic plot of power (W) as function of a (mm).

To calculate the total power absorbed by
the particle Power spectral density can be given as

$$S(\omega) = \frac{\pi A_0^2}{2}[\delta(\omega-\Omega)+\delta(\omega+\Omega)]$$

$$P = \frac{\pi m A_0^2}{4}\delta(\omega-\Omega)$$

$$\langle P\rangle = \frac{\pi m a^2 \Omega^3}{4}$$

Using a Rb87 BEC the GPE is given

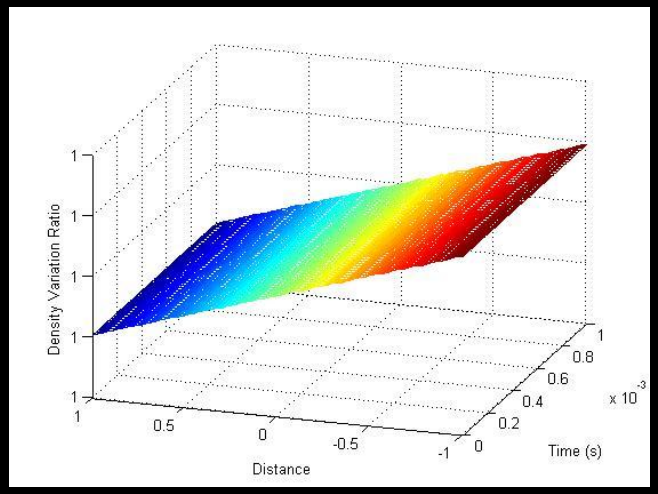
$$i\hbar\frac{\partial\psi(X,t)}{\partial t}=(-\frac{\hbar^2}{2m}\nabla^2+V(X,t)_T+\frac{4\pi\hbar^2 a_s}{m}|\psi(X,t)|^2)\psi(X,t)$$

The total trap potential includes the Mechanical induced oscillation

$$V(X,t)=mA(t)z+\sum_{x,y,z}\frac{1}{2}m_a\omega_X^2X^2$$

Thomas-Fermi approximation is used when Kinetic term in GPE is less than interaction

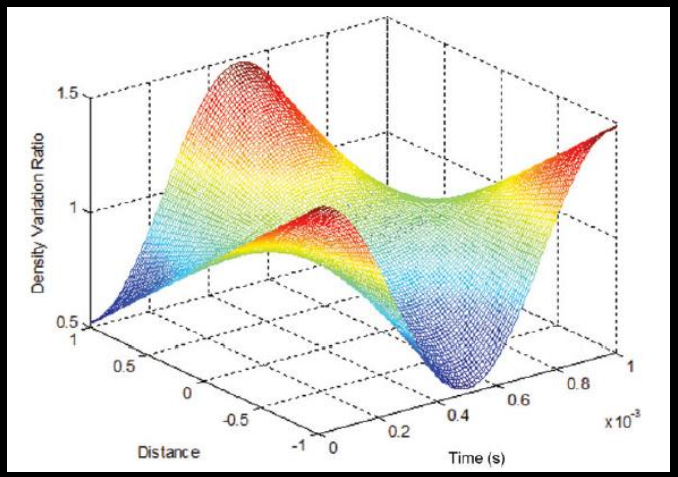
$$n_{TF}=\frac{\mu-V(x,t)}{g}\qquad n\approx\frac{\mu}{g}$$



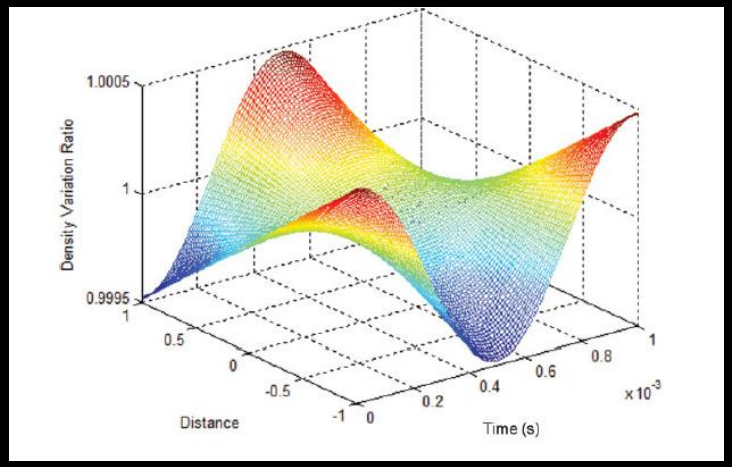
Constant ratio of 1 for small perturbation low 1Hz, 10^8, 1mm

$$\boxed{\frac{n_{TF}}{n}=1}$$

The same treatment was given to high frequency, and amplitude. There were observed perturbations on the ratio due to the mechanically induced oscillation.



Constant ratio of 1 for small perturbation low 1KHz, 10^6, 1cm



Constant ratio of 1 for small perturbation low 1KHz, 10^3, 1cm

At 2KHz, 10^6 TF approximation fails

Experimental Setup

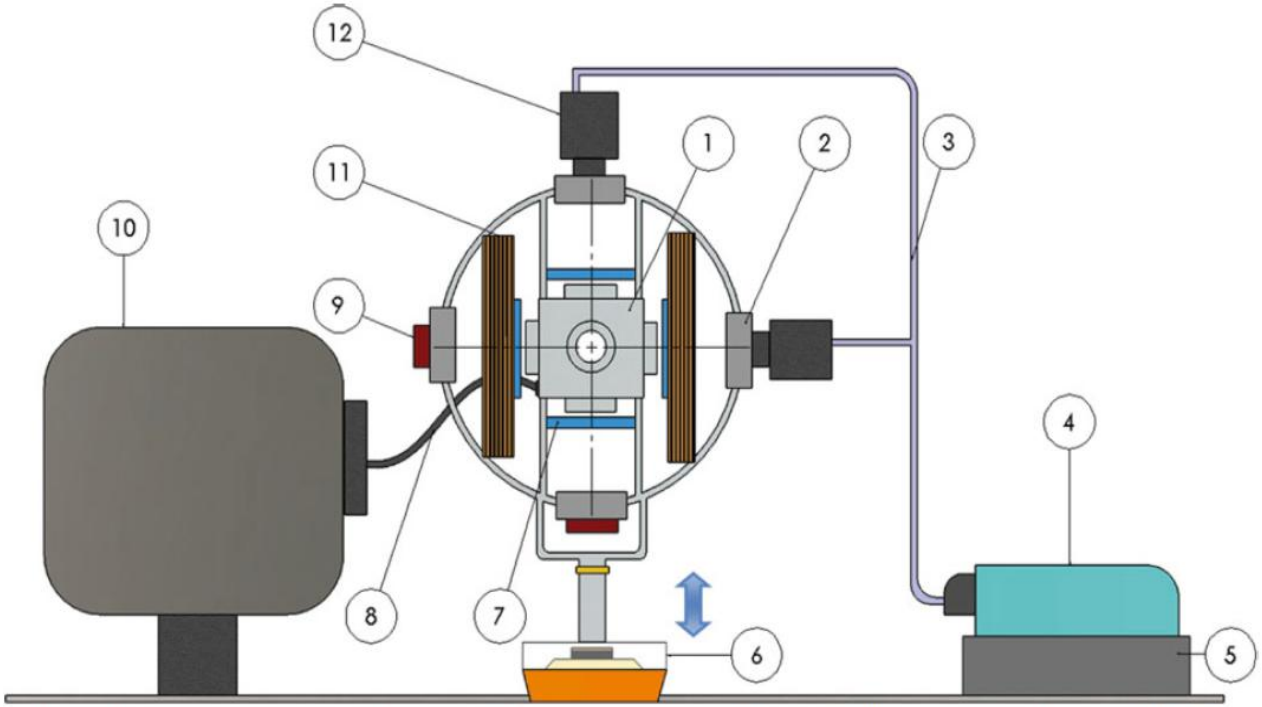
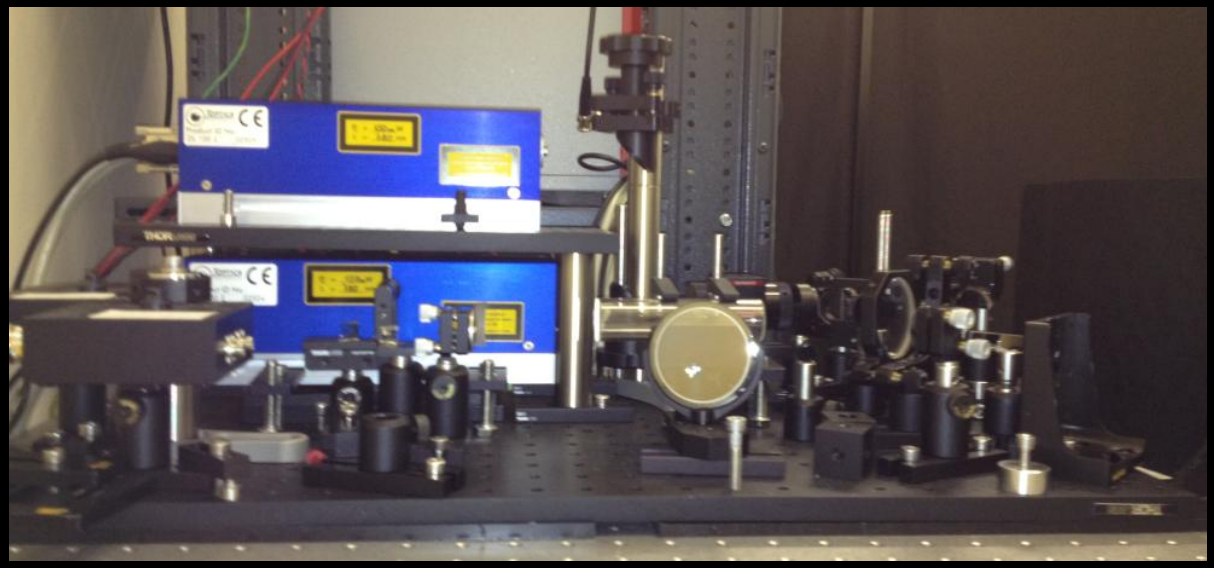
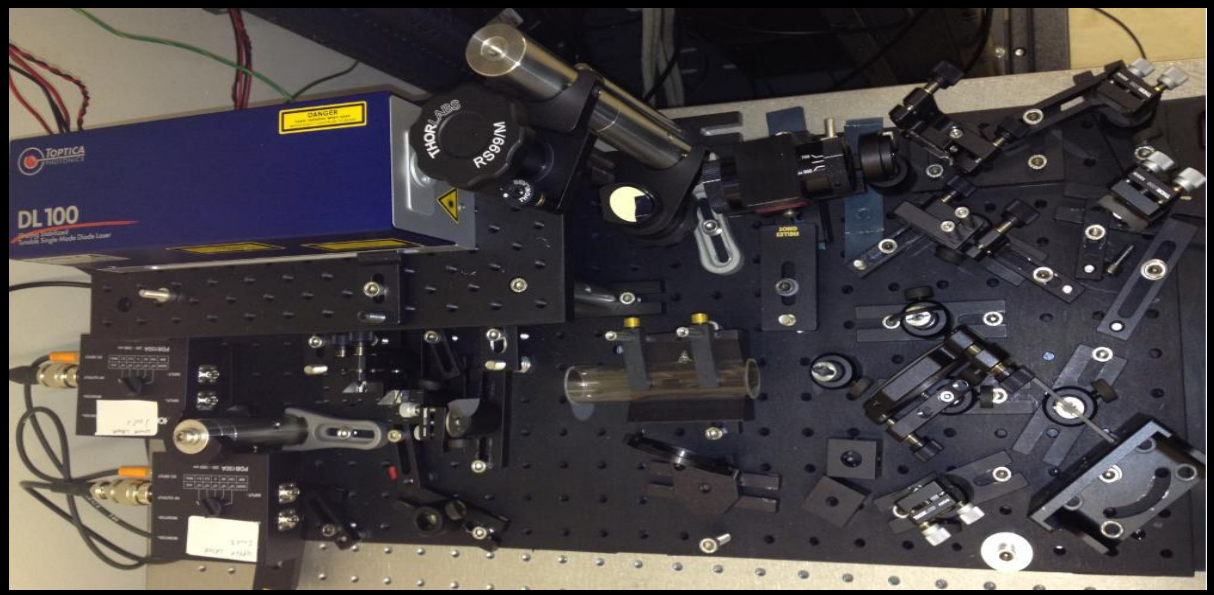


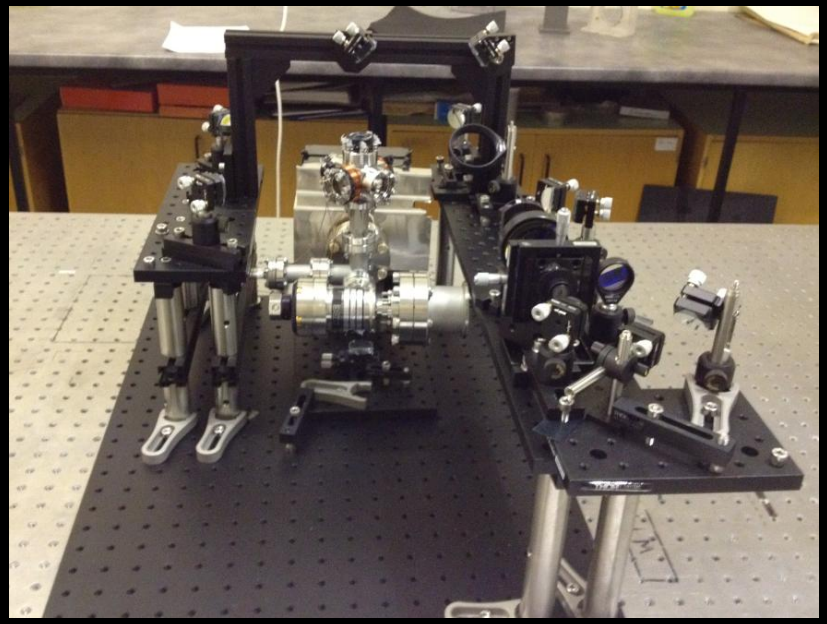
Figure 1. (Colour online) Experiment setup, 1–trap, 2–quarter wave plate, 3–fiber optics, 4–tuneable laser, 5–electro-acoustic vibrator drive, 6–electro-acoustic vabration generator, 7–TOP maginetic coils, 8–flexible vacuum pipe, 9–mirror, 10–ion pump, 11–trap magnetic coils (MOT), 12–telescope.

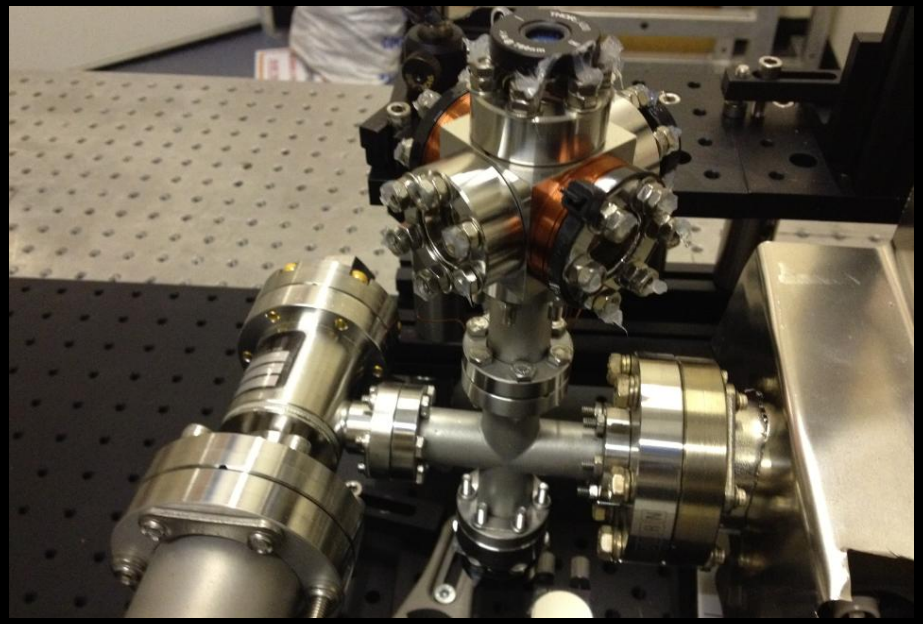
Experimental Apparatus Status





Experimental Apparatus Status





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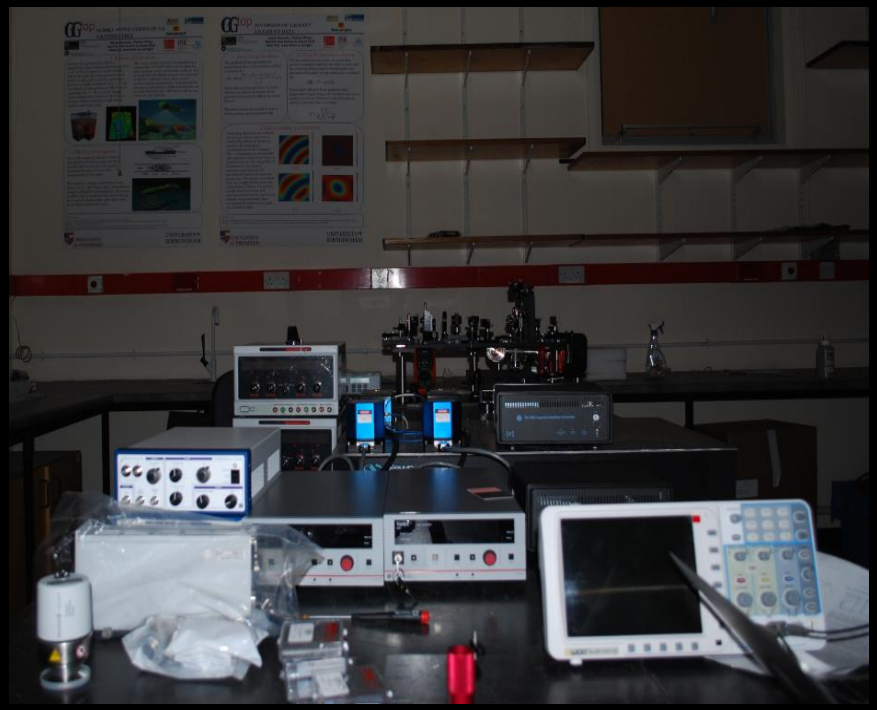

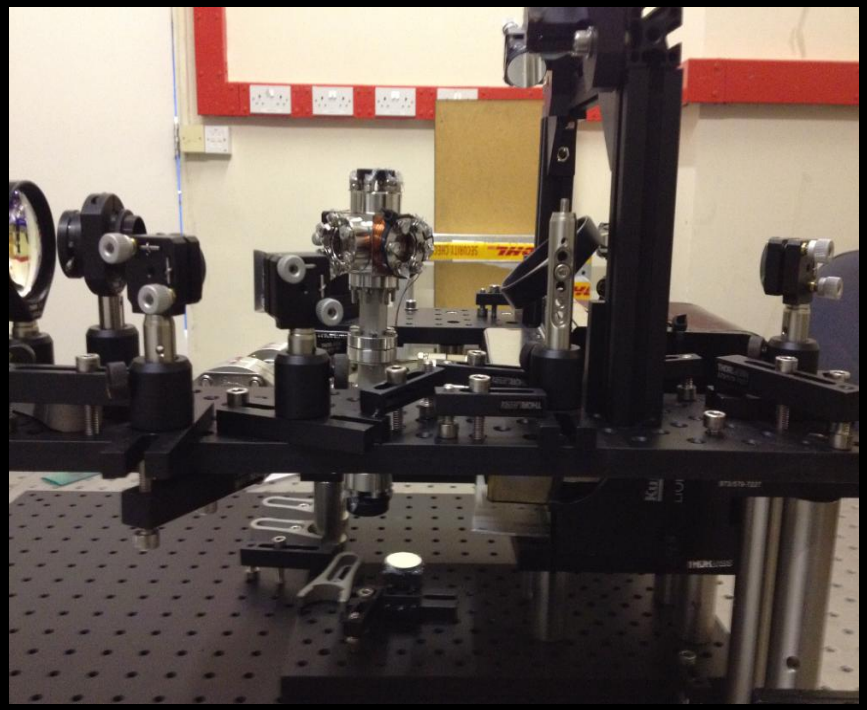

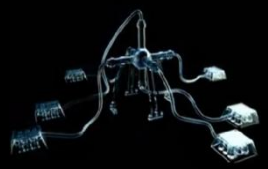

Thank You

Acknowledgements

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References:

[1] Wang, C.H.-T., Bingham, R. And Mendonca, J.T. 2012 " Probing Spacetime fluctuations using cold atoms traps". arXiv:1002.2962

[2] Dos Santos, M. M., et al.,2013"Toward Quantum Gravity Measurement by Cold Atoms" Journ. Plasma Phys. Cambridge University press. doi:10.1017/S0022377813000202