



A search for Non-Newtonian Gravity with Ultracold atoms



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Background

Various string theories predict the existence of non-Newtonian gravitational interaction due to the presence of extra dimensions. Using ultra cold atoms in a well confined potential, one can put constraints on these theories at length scales of less than $10\mu\text{m}$. This is done by carefully probing the atom-surface interaction, and then subtracting out all electromagnetic potentials (example: Casimir-Polder potential, and patch potentials) so as to detect these minute gravitational signals.

Gravity on the micron scale

Non Newtonian gravitational interaction between two masses m_1 and m_2 are represented by Yukawa-like potentials:

$$V_G(r) = -G \frac{m_1 m_2}{r} [1 + \alpha \exp(-r/\lambda)]$$

G is the Newtonian gravitational constant

α parameterize the strength of non-Newtonian gravity

λ parameterize the range of non-Newtonian gravity

For an atom of mass m close to a flat surface density ρ , the Yukawa gravitational contribution evaluates to

$$V_G(z) = -2\pi\alpha\lambda^2 G \rho m e^{-z/\lambda}$$

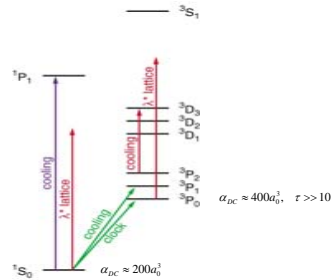
Casimir-Polder potential

The dominant electromagnetic potential near the surface is the Casimir potential, and near a perfect conductor, it can be represented as:

$$V_{CP}(r) = -\frac{C_4}{r^4}, \quad C_4 = \frac{3\hbar c \alpha_{DC}}{32\pi^2 \epsilon_0}$$

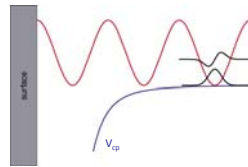
α_{DC} is the static polarizability of the atom.

Ultracold Ytterbium atoms can be used to probe these very weak potentials



- ❖ Can choose magic wavelength λ^* such that the AC stark shift of 1S_0 and 3P_0 are identical
- ❖ Narrow line laser cooling to $T \sim 10 \mu\text{K}$
- ❖ 1S_0 and 3P_0 states have different static polarizabilities, which mean they will experience different Casimir-Polder shifts.
- ❖ Ratio of Casimir-Polder shifts is given by ratio of their polarizabilities.
- ❖ 1S_0 and 3P_0 have zero magnetic moment ($J=0$), therefore only electric forces need to be considered here

Probing Atom-Surface interaction



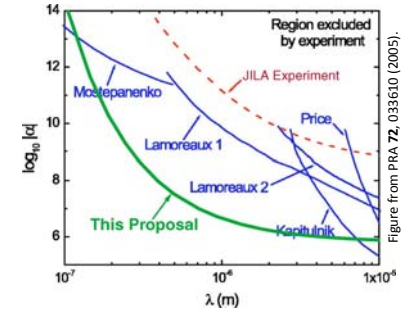
- ❖ Cool atoms to ground state of optical lattice.
- ❖ Measure frequency difference between vibration levels.
- ❖ Casimir-Polder potential perturbs frequency splitting by $\Delta\nu \sim 10 \text{ Hz}$ @ $1 \mu\text{m}$.

$$\frac{V_{CP}(^3P_0) + V_G}{V_{CP}(^1S_0) + V_G} = \frac{\alpha_{DC}(^3P_0)}{\alpha_{DC}(^1S_0)} \left[1 - \frac{\Delta\alpha_{DC}}{\alpha_{DC}} \frac{V_G}{V_{CP}} \right]$$

$$\Rightarrow V_G \approx \frac{\alpha_{DC}(^3P_0)}{\alpha_{DC}(^3P_0) - \alpha_{DC}(^1S_0)} \delta V_{CP} \quad \Delta\omega_G = -\pi\alpha G \rho e^{-z/\lambda} / \omega$$

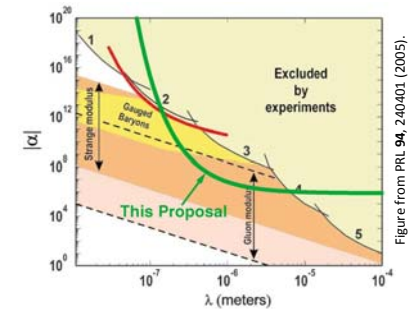
↑ Detectable gravity signal
 ↑ experimental measurement uncertainty
 ↑ Shift in trap frequency due to atom surface interaction

Expected experimental limits



- Casimir-Polder potentials cancel at the $\Delta\omega = 10^{-3}$ level.
- Casimir-Polder theory accurate at the $\Delta\omega = 10^{-1}$ level.

Theoretical predictions



References:

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