Atom Interferometry for Searching Chameleon type Dark Energy

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Introduction

The accelerating expansion of our universe has inspired to modify gravity theory with unknown scalar fields. [1] Although their self-interaction potential energies can naturally explain the *Dark Energy*, their interaction with ordinary matter predicts an additional force, which is against current gravity tests.

However, these unobserved forces could be *hided* by the *Chameleon mechanism* to evade tests with macroscopic objects.[2] Given an atom is too small to be hided by the Chameleon Mechanism, it can sense an additional acceleration due to the Chameleon Force. [3]

Experiments on searching for Chameleon

Result from our previous measurement[5] gives

$$a_{\Phi} = -77 \pm 201\ nm\ s^{-2}$$

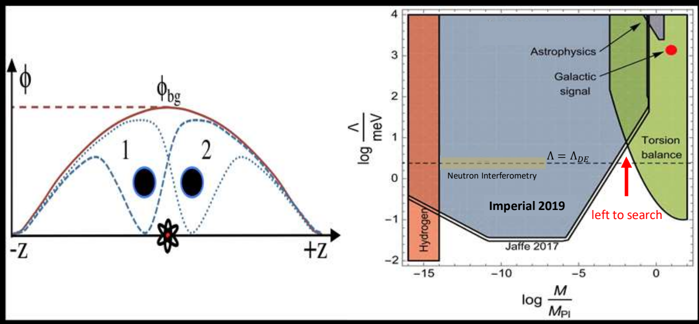

Figure 2 : Experimental setup and our result compared with other efforts to search chameleon field.

Chameleon Hided Scalar Field

Chameleon force variates its force range based on the mass density of its environment.

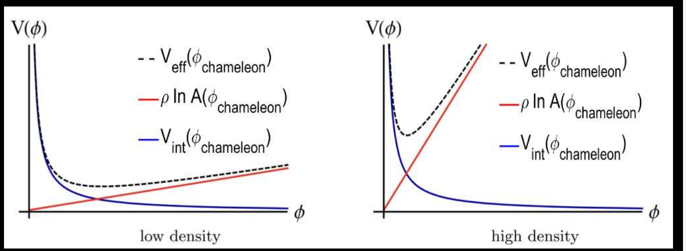

Figure 3: The principle of the Chameleon Mechanism.[4] The force range mediated by the chameleon field is related to the curvature of the minimum of the effective potential. Low density region has longer force range while the high density region has shorter force range.

The acceleration sensed by an atom due to Chameleon Field is given by

$$a_{\Phi} = -\frac{1}{M}\nabla\phi_{\Lambda,\mathrm{M}}(\vec{r})$$

which depends on 2 parameters {Λ, M}. [1]

Atom Interferometry as an accelerometer

Reversing roles of matter and light in the conventional optical interferometry, atom interferometry applies light to split and reflect atomic wavefunctions. [4]

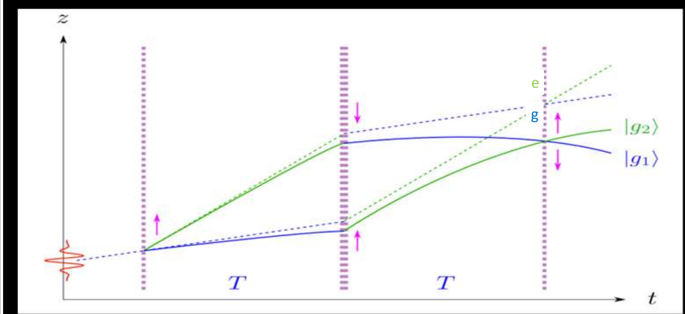

Figure 1 : Schematic diagram of $\frac{\pi}{2} - \pi - \frac{\pi}{2}$ light pulsed Atom Interferometry. [4] Solid line and dashed line give trajectories of wave packets under forced and force-free situations.

The tiny relative acceleration between a laser field and an atom can be estimated by measuring the population of atoms after 3 interferometry pulses

$$P(|e>) = \frac{1}{2}(1 + \cos\Delta\varphi)$$

$$\Delta\varphi = k a T^2$$

Improved Magneto Optical Trap (MOT)

We are trapping more atoms to upgrade our results with techniques at cost of losing number of atoms.

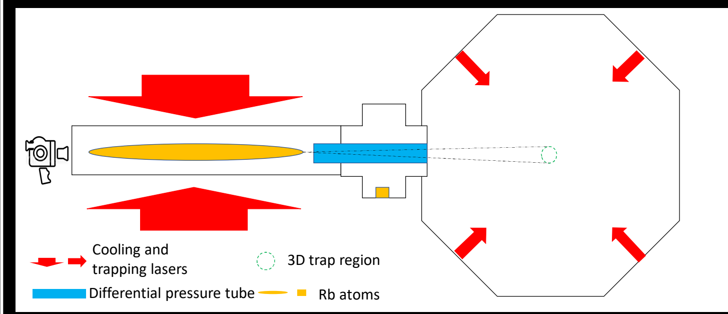

Figure 4 : Schematic diagram of experimental setup to produce 2D MOT and 3D MOT.

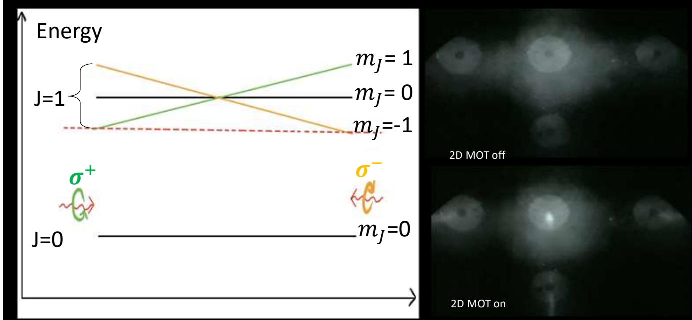

Figure 5 : Principle of Magneto Optical Trap and experimental results. The photon carrying opposite spinning direction counter-propagates in the presence of magnetic field. This lead to a trapping potential to capture atoms that will be used to perform atom interferometry.

References

[1] Justin Khoury and Amanda Weltman, Phys. Rev. D **69**, 044026 (2004)
[2] Burrage, Clare, and Jeremy Sakstein. Living Rev. Relativ 21.1 (2018): 1.
[3] Burrage, Clare, Edmund J. Copeland, and E. A. Hinds. *JCAP* 2015.03 (2015): 042.
[4] Institute of Quantum Physics, Ulm university, *https://www.uni-ulm.de/en/nawi/institute-of-quantum-physics/research/research-areas/matter-waves/atom-interferometry/* (accessed 2019)
[5] D. O. Sabulsky, I. Dutta, E. A. Hinds, B. Elder, C. Burrage, and Edmund J. Copeland, Phys. Rev. Lett. **123**, 061102 (2019)

Acknowledgement

Thanks Imperial Quantum Navigator Team, especially Dylan for tips, Xiaxi for orientation and necessary experimental skills, Shane for software demonstration, Indrinail for experimental demonstration. Also thanks Val for aids on making electronics and Aisha for discussion and experiences.

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