Experimental constraints on non-Newtonian gravity via state of the art photoassociation spectroscopy

Mateusz Borkowski[1], **Alexei A. Buchachenko**[2], **Roman Ciuryło**[1], **Paul S. Julienne**[3], **Hirotaka Yamada**[4], **Kikuchi Yuu**[4], **Kekaru Takahashi**[4], **Yosuke Takasu**[4], **Yoshiro Takahashi**[4,5]

1. Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziadzka 5, 87-100 Torun, Poland
2. Skolkovo Institute of Science and Technology, 100 Novaya Street, Skolkovo, Moscow Region, 143025, Russia
3. Joint Quantum Institute, National Institute of Standards and Technology and the University of Maryland,
100 Bureau Drive, Stop 8423, Gaithersburg, Maryland 20899-8423, USA
4. Department of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan
5. CREST, Japan Science and Technology Agency, Chiyoda-ku, Tokyo 102-0075, Japan

Deviations from the universal inverse-square law of gravitation have in recent decades been the subject of considerable experimental effort [1]. Corrections to the Newtonian law have been predicted by several extensions to the Standard Model of particle physics [2], where additional forces would appear due to the exchange of light bosons. Also, attempts at solving the hierarchy problem using extra dimensions (see e.g. [3]) also predict deviations from the $-1/R^2$ behavior at submillimeter scale. Experiments aim to constrain the magnitude of these deviations by providing limits on the magnitude α of the Yukawa-type form of the gravitational potential $V(R) = -G\frac{m_1 m_2}{R}(1+\alpha\exp(-R/\lambda))$ as a function of its range λ.

While the inverse-square gravitational interaction is well confirmed at macroscopic scales, for nanometers the current best constraints on α, are over *twenty* orders of magnitude larger than gravity itself. Such constraints are mostly provided by measurements of neutron scattering and of Casimir-Polder forces and only recently a new scheme using precise transition measurements in the H_2 molecule has been proposed. We propose a scheme based on the mass scaling behavior of photoassociation (PA) line positions. We have measured a total of 13 PA lines for three isotopes of the Yb_2 molecule. To achieve high precision, the measurements were performed using the Raman scheme in a Bose-Einstein condensate of Yb atoms (see Fig. 1, left). Systematic shifts have been eliminated by extrapolation (Fig. 1, right) leading to an unprecedented experimental accuracy of ≈ 500 Hz.

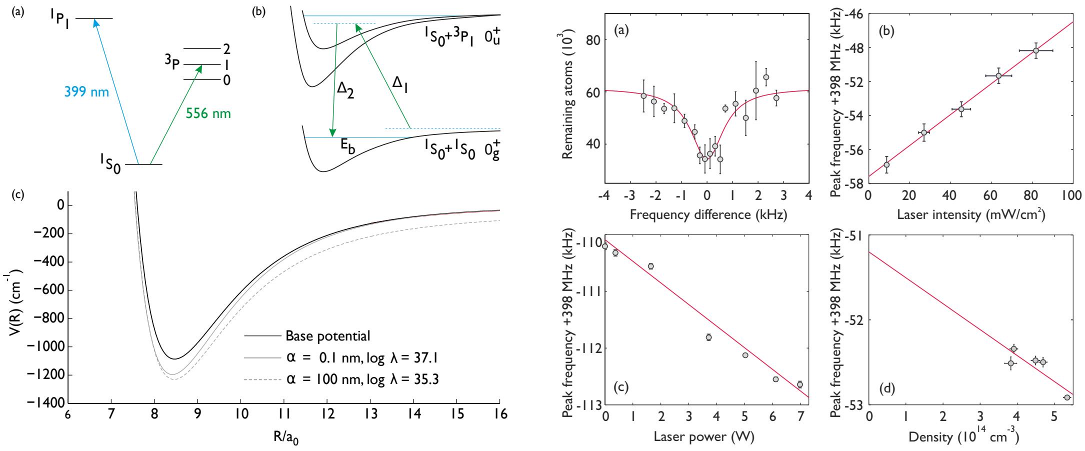

Fig. 1: Left: (a) transitions used in the experiment, (b) two-color photoassociation spectroscopy in Raman configuration, (c) impact of the Yukawa-modified gravitational potential on the atomic interaction. **Right:** High precision photoassociation spectroscopy. (a) An example Raman PA lineshape with FWHM $\approx$ 1 kHz, (b-d) extrapolation of systematic shifts caused by PA light shift, trapping laser light shift, and atomic density, respectively.

We calculate the theoretical line positions using an *ab initio*-based potential. The long range parameters and a short range 'quantum defect' of the potential are fitted to the PA data using least-squares to obtain a mass scaled model [4]. Incorporating the beyond-Born-Oppenheimer effects [5] into the model enabled us to achieve mass scaling to an accuracy of about 20 kHz. Finally, the non-Newtonian gravitational interaction is added. The value of α where the model loses its accuracy despite continued fitting is our experimental constraint on non-Newtonian gravity. Even though this is a proof of concept determination, our limits are already nearly on par with the best constraints provided by competing mature methods.

References

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