Master thesis proposal

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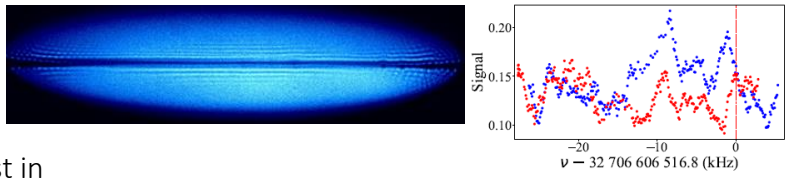
Title: Measuring fundamental constants with H_2^+: precision test within the standard model

Keywords: proton to electron mass ratio, fundamental constants, trapped ions, quantum logic, laser, frequency comb, spectroscopy, physics beyond the standard model

Scientific description:

Context: Numerous precision experiments are being carried out to probe the Standard Model of physics, with two objectives: (i) to improve knowledge of the fundamental constants in the frame of CODATA organization and (ii) to test new physics beyond the standard model.
Hydrogen molecular ions (H_2^+ or HD^+) are among the simplest molecular species. They are made of three particles, two nuclei and one electron. They are amenable to high precision energy level and transition frequency calculations with up to 12 significant digits (1 ppt) [Karr17]. Transition frequencies are particularly sensitive to the proton to electron mass ratio $\mu=m_p/m_e$, which start being improved thanks to new measurements performed on HD^+ ions [Patra20, Alighanbari23, Alighanbari25]. The relative inaccuracy on μ presently reaches about $2.\ 10^{-11}$ [Delaunay2023]. It can be further improved using H_2^+ ions.
LKB Experiment: H_2^+ ions are trapped and sympathetically cooled to mK temperatures using sympathetic cooling by laser cooled Be^+ ions. The image shows a Coulomb crystal of laser cooled Be^+ ions observed through resonance fluorescence at 313 nm. The dark line in the center is due to the presence of H_2^+ ions [Schmidt20]. First spectroscopy signals have been detected in 2025.



The intern and PhD work will consist in

- Performing H_2^+ **spectroscopy** using a 9.17 µm quantum cascade laser referenced to the Système International to give a new determination of µ using the experiment we have developed.
- Working out how quantum logic protocols can be adapted to the specific case of H_2^+ to push further the resolution and analyze time variation of fundamental constants.

CODATA: https://pml.nist.gov/cuu/Constants/
[Delaunay2023] C. Delaunay, J.-Ph. Karr et al., Phys. Rev. Lett. **130**, 121801 (2023)
[Karr17] J.-Ph. Karr, L. Hilico, V.I. Korobov, Phys. Rev. A **95**, 042514 (2017)
[Patra20] S. Patra et al. Science **369**, 1238 (2020)
[Alighanbari23] S. Alighanbari et al. Nature physics **19**, 1263 (2023)
[Alighanbari25] S. Alighanbari et al. Nature **644**, 69 (2025)
[Schmidt20] J. Schmidt, …, L. Hilico, Phys. Rev. Applied **14**, 024053 (2020).

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PhD : Mathis Panet, Diyaa Aboul Hosen
Postdoc : Maen Salman, Vincent Barbé
Collaborations
VU Amsterdam, PIIM Marseille, SYRTE Paris, LPL

Techniques/methods in use:

Applicant skills: Experimental, ultrastable lasers, ion trapping, remote control, data analysis

Industrial partnership: No

Internship supervisor(s): Laurent Hilico, Laurent.hilico@upmc.fr, 01 44 27 60 79
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Internship location: LKB, T13, 4 place Jussieu, Paris

Possibility for a Doctoral thesis: Yes, EDPIF funding, research grant funding