Atom Interferometery Driven by a Picosecond Frequency Comb

C. debavelaere[1], O. Boucher[1], C. Solaro[1] , P. Cladé[1] and S. Guellati-Khelifa[1,2]

[1] *Laboratoire Kastler Brossel, Sorbonne University, CNRS, ENS-PSL University, Collège de France,*
4 place Jussieu, 75005 Paris, France
[2] *Conservatoire National des Arts est Métiers, 292 rue Saint Martin, 75003 Paris, France*

New concepts and innovative geometries are currently being investigated to push the sensitivity of atom interferometers to the extreme and broaden their range of applications. Efforts are focused on developing a Very-Long-Baseline Atom Interferometry for testing the fundamental laws of physics, detecting low-frequency gravitational waves and hints of ultralight dark matter. They also aim to design compact and portable inertial sensors, to be deployed on earth and in space, notably for geodesy applications. All these experiments use continuous-wave (CW) lasers to manipulate matter waves.

In 2022, we realized an atom interferometer using an appropriate sequence of picosecond laser pulses [1]. Each pair of counter-propagating picosecond laser pulses diffracts the atomic wave paquet via a stimulated Raman transition between the hyperfine level of the ^{87}Rb ground state. Figure 1 shows the principle of the experimental method.

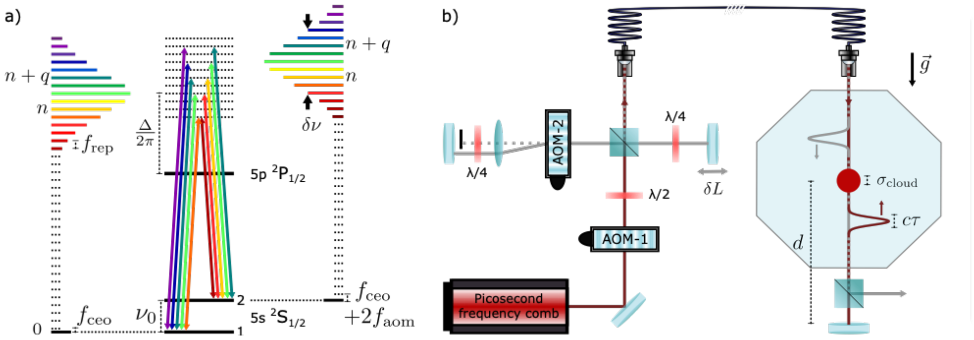

Figure 1: a) Principle of frequency-comb-driven Raman transitions between two hyperfine levels of the ground state of ^{87}Rb. b) Schematic overview of our experimental setup. The overlap position of the counter-propagating pulses is adjusted precisely by translating one of the mirrors in the delay line. The Doppler effect due to free fall is compensated by chirping the frequency of an acousto-optic modulator (AOM-2).

There are two main motivations for investigating this new approach to implement atomic beamsplitters. The first one, as for high-resolution spectroscopy [2, 3, 4], is to extend matter-wave interferometry to a wider spectral range and to more atomic species. The second reason lies in the fundamental difference between using a CW laser and a pulsed laser. In the former case, laser-atom interaction takes place at the atoms location and affects both atomic wave packets, whereas in the latter it is determined by the overlap region of the two laser pulses and targets a single atomic wave packet. This specificity is a priori a constraint that limits the interrogation time of free-falling atoms and therefore the sensitivity of the interferometer. It does, however, have the advantage of enabling original atom interferometer configurations.

I will present recent developments in this experiment and discuss some perspectives.

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Recent progress in the measurement of the rubidium recoil using atom interferometry

C. debavelaere[1], S. Gaudout[1], P. Cladé[1] and S. Guellati-Khelifa[1,2]

[1] *Laboratoire Kastler Brossel, Sorbonne University, CNRS, ENS-PSL University, Collège de France,*
4 place Jussieu, 75005 Paris, France
[2] *Conservatoire National des Arts est Métiers, 292 rue Saint Martin, 75003 Paris, France*

Light-pulse atom interferometry allows for high precision measurements of a variety of physical quantities. This method offers exciting prospects for testing the fundamental laws of physics using low-energy experiments. Notably, the measurement by atom interferometry of the recoil velocity of an atom that absorbs or emits a photon leads to the most accurate determination of the fine structure constant α. This constant is crucial for quantum electrodynamics calculations and for testing certain predictions of the Standard Model of particle physics.

Our experiment measures the recoil velocity of a rubidium atom. In 2020, we obtained a value of α with a record relative uncertainty of 8.1×10^{-11} : α^{-1}=137.035999206 (11). However, this value differs by 5.4 σ from the value deduced from the caesium recoil measurement [2] (see Figure. 1).

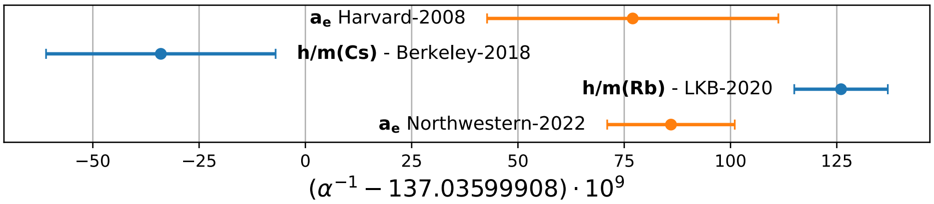

Figure 1: A comparison of the most accurate determinations of the fine-structure constant. The orange points are from a_e measurements [3, 4] and QED calculations [5] , the blue points are obtained from the measurement of Cs and Rb atomic recoil. Errors bars correspond to $\pm 1\sigma$ uncertainty.

To clarify the origin of this discrepancy, we have made several improvements to reduce and refine the control of systematic effects, in particular the effect related to laser wavefront distortions.

In this talk, I will present recent work on this experiment.

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