Experimental Demonstration of a Terahertz Frequency Reference based on CPT in a Trapped Ion Cloud

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The quantum interferences responsible for coherent population trapping (CPT) are an example of a quantum effect which is ressource for high precision measurement. Two-photon CPT has proven its relevance for spectroscopy of the GHz transition between hyperfine sublevels. We propose to use a three-photon CPT to reach spectroscopy in the THz domain, which is so far associated to rotation transitions in light molecules. The existence of a highly resolved dark line referenced to a magnetic dipole transition at 1.82~THz is observed in the laser induced fluorescence of a cloud of calcium ions, like proposed in [1]. This dark resonance results from CPT involving three optical photons at 397, 729 and 866 nm [2]. When fulfilled, the three-photon resonance condition implies a relation between the three laser frequencies and the frequency of the 1.82 THz magnetic dipole transition between the two fine-structure terms of the 3D level, which appears as the atomic reference for the dark line.

Basing a THz reference on three optical photons allows the cancellation of the first order Doppler effect by a phase matching condition involving the three laser wavevectors. We now observe a dark line with a resolved Zeeman structure, a maximum contrast of 21 % and a minimum line-width of 45~kHz in the fluorescence of a cloud made of few hundreds laser-cooled ions. The line-width is so far dominated by residual Doppler effect and fluctuations of the local magnetic field. Such a large contrast and narrow line require to maintain a phase coherence between the three lasers. This phase coherence is transferred to the 866 and 397 nm lasers from a home-made ultra-stable Ti:Sa laser emitting at 729 nm, through an offset-free optical frequency comb (OFC), phase-locked on this ultra-stable laser [3]. Very similar to 2-photon CPT, the interrogation protocole depends on numerous parameters that we have started to explore to reach sub-kHz line-width [4]. Even with a kHz line-width, the large signal to noise ratio offered by hundreds of laser-cooled ions allows the resolution to reach the 10^{-11} range by averaging data over seconds.

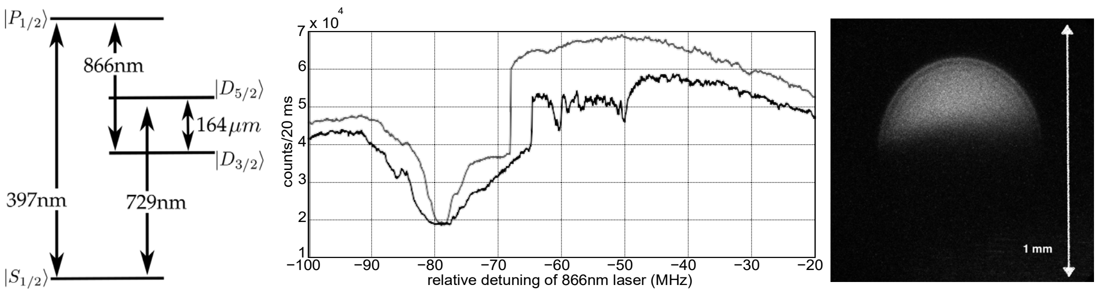

Figure 1. level scheme relevant for a three-photon CPT in Ca+, fluorescence collected from a cloud made of 630 ions, without (grey curve) and with (black curve) the 729 nm laser, picture of the cloud, showing that the sympathetic cooling is maintaining the cloud in the liquid phase, despite the radiation pressure which tends to separate the dark and bright ions.

[1] C. Champenois, G. Morigi and J. Eschner, Physical Review A 74 053404 (2006)

[2] C. Champenois *et. al, Terahertz Frequency Standard Based on Three-Photon Coherent Population Trapping*, Phys. Rev. Lett. 99, 013001 (2007).

[3] M. Collombon et. al, *Phase transfer between three visible lasers for coherent population trapping*, Optics Letters Vol. 44, No. 4 , 15 February 2019

[4] M. Collombon, et. al, *Experimental Demonstration of a Terahertz Frequency Reference based on Coherent Population Trapping*, arXiv:1903.05386 [quant-ph]