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Toward an experimental comparative study of the Doppler effect contribution between quadrupole and multipole traps

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The trapping of charged particles by radiofrequency (RF) electric fields has proven to be both a powerful and versatile tool for experimental exploration in physics and chemistry and linear ion trap happen to be candidate of choice for the design of micro-wave atomic clock for spacecraft navigation [1]. The main factor limiting the stability of such clocks is the second order Doppler effect arising from the forced micro-motion of the ions in the RF confining field. From a theoretical point of view, this effect can be reduced by the use of higher order multipole traps. This has led to the crafting of multipole traps with an increased number of RF electrodes.

It is our objective to evaluate experimentally the interest of this trade-off between mechanical complexity and reduction of micro-motion induced Doppler effect, for no direct measurement of the reduction in the Doppler effect contribution by the use of higher order multipole trap has yet been done. Our experiment, TADOTI, is equipped to trap large cold Ca+ ion clouds. Shuttling of the ions is possible between a quadrupole section and an octupole section, making for an excellent ground for the comparison of both traps'properties.

The measurement of the Doppler Effect impact is to be conducted through the use of a 3-photon dark resonance in the Ca+ ion cloud. The coherent process leading to this dark line is obtained by taking a traditional Λ-shaped configuration and coupling on a weak transition to form a N-shaped system [2]. Coherent population trapping is achieved if a proper combination of detunings between the lasers is respected. When observed in the fluorescence of an ion cloud, this 3-photon resonance has a smaller linewidth than the natural fluorescence transition or the 2-photon dark resonance and gives (theoretically) full control over the Doppler effect, given a tight control of the relative phase of each laser.

The crafting itself of multipole traps has proven challenging. Experimental realisation of cold ion clouds in our octupole have shown surprising results: instead of the tube-like structure expected from the simulations, the ions organize themselves in three distinct clouds. This is the result from a symmetry breaking in the traps' electrode arrangement that split the degeneracy of the solutions into three minima in the pseudo-potential well in which the cold ions accumulate. The potential surface is very sensitive to any form of symmetry breaking and an electrode mechanical misplacement of about 0.2% of the trap inner radius is enough to observe the splitting [3]. It is crucial to diagnose and compensate any mechanical defect of the trap before any measurement can be considered in the octupole.

[1] Good, A. (2018, February 6). NASA Tests Atomic Clock for Deep Space Navigation. Retrieved from : https://www.jpl.nasa.gov/news/news.php?feature=7053
[2] M. Collombon et. al. "Experimental Demonstration of Three-Photon Coherent Population Trapping in an Ion Cloud."Physical Review Applied 12, 034035 (2019).
[3] J. Pedregosa-Gutierrez et. al. "Symmetry breaking in linear multipole traps". Journal of Modern Optics, 65:5-6, 529-537 (2018).

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