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# Three-photon coherent population trapping for high resolution spectroscopy

A cloud of trapped ions, represented here by a four level atomic system $| S_{1/2} >, | P_{1/2} >, | D_{3/2} >$ and $| D_{5/2} >$, is probed by the collection of photons from the transition $| P_{1/2} >$ to $| S_{1/2} >$.

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**Figure :** Four level atomic system of Ca+ ions

The lambda configuration with lasers at 866nm and 397nm allows for a two-photon dark state to take place. If the $| S_{1/2} >$ state is coupled with the $| D_{5/2} >$ state (which we are going to refer to as $| S >$ and $| Q >$) a three photon dark state is to be expected 1. Indeed the transition at 729nm is weakly coupled and the sub-system is diagonalizable:

\begin{equation}
\mid S_{Q}>=N_{1}(\mid S> + \alpha\mid Q>) ~~and~~ \mid Q_{S}>=N(\mid D> - \alpha \mid S>)
\end{equation}

with a normalisation factor $N_1$, and $\alpha = \Omega_C/2\Delta C$, we achieve a new lambda-shaped system with a dark state written as:

\begin{equation}
\mid \Psi_{dark}> = N_{2} (\varepsilon \mid D> + \mid Q_{S}>)
\end{equation}

With $\varepsilon = \alpha\Omega_B/\Omega_R$ and a normalisation factor $N_2$. The condition for this state not to be coupled to the rest of the system is:

\begin{equation}
\Delta R + \Delta C - \Delta B + \alpha \Omega _{C} /2 =0
\end{equation}

To achieve a stable 3-photon coherent population trapping experimentally, one has to reduce the relative phase fluctuations of the three lasers. In order to do so, two lasers are phase-locked onto a frequency comb which is himself locked onto the 729nm laser. This 729nm ultra-stable Ti:Sa laser was built within the laboratory and has a frequency stability of better than $5 \times 10^{-14}$ for one second. For this 3-photon resonance, the phase matching condition: $\vec{K}_R + \vec{K}_C - \vec{K}_B = \vec{0}$ cancels out the first order Doppler Effect.

Recent experimental results will be presented.

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1 C. Champenois, G. Hagel, M. Houssin, M. Knoop, C. Zumsteg, and F. Vedel, "Terahertz frequency standard based on three-photon coherent population trapping", *Phys. Rev. Lett.*, vol.99, no. 1, p.013001, 2007.

## Summary

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