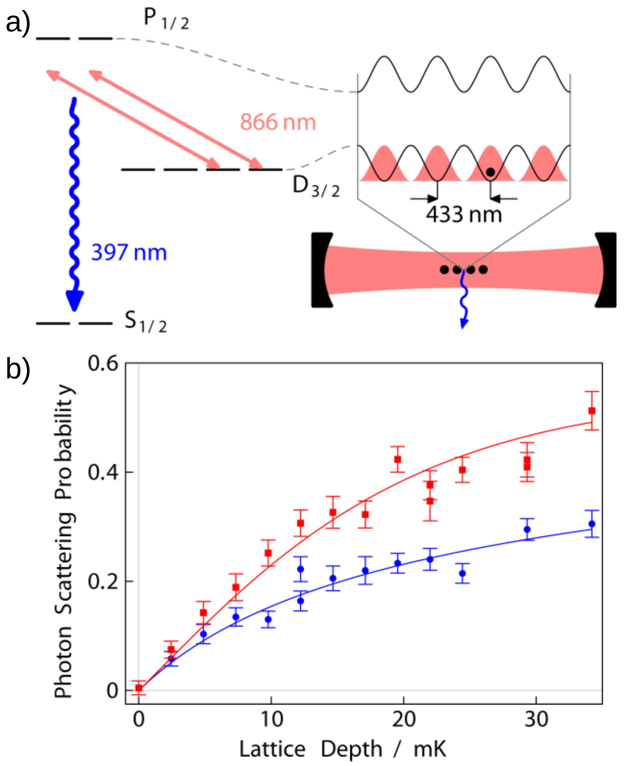
Localizing Trapped Ions in an Intracavity Optical Lattice

Rasmus B. Linnet[1], Ian D. Leroux[1], Mathieu Marciante[2],
Aurélien Dantan[1], and Michael Drewsen[1]

[1] *Department of Physics and Astronomy, Aarhus University, DK-8000 Aarhus C, Denmark*
[2] *Aix-Marseille Université, Centre de Saint Jérôme, FR-13397 Marseille, France*
rhb05@phys.au.dk

For many years, optical lattices have been used to confine ultra-cold neutral atoms in optical-wavelength-scale potentials, while ions are traditionally trapped in electrical potentials of much greater size. In a recent study we showed that it is possible to combine the two techniques to also confine ions on the wavelength-scale [1]. The prospects of such novel trapping conditions are among others quantum simulations of many-body physics [2-4] and examination of the Frenkel-Kontorova model for friction [5-6]. In the experiments, an optical lattice in the form of a standing-wave field of an optical cavity is applied to $^{40}Ca^{+}$ ions trapped in a linear Paul trap. The cavity field is tuned to be near-resonant with the $D_{3/2}$ – $P_{1/2}$ transition at 866nm in the calcium ion (fig. a). Since sub-wavelength spatial resolution are extremely challenging using regular optical imaging, we measure the localization effect of the lattice by detecting the spatially dependent fluorescence at 397nm arising from inelastic photon scattering by the lattice itself. In order to quantify the degree of localization, we compare the scattering rates obtained from blue-detuned ($\omega_{lattice}>\omega_{D3/2-P1/2}$) and red-detuned ($\omega_{lattice}<\omega_{D3/2-P1/2}$) lattices. For the same magnitude of the detuning and cavity field intensity, the lattice potentials are identical in the two cases, while the scattering rates will be significantly different. This happens because a blue-detuned lattice pins the ions at the cavity field nodes (low photon scattering rates), whereas a red-detuned lattice pins the ions at anti-nodes (high photon scattering rates). By this detection method, we have in a single-ion experiment, proven that the lattice induced localization, e.g., can increase the coupling strength of the ion to the cavity field by about 60% compared to a non-localized ion (fig. b). By localizing several ions in the optical lattice at the same time, interesting physical phenomena involving a competition between the lattice potential and inter-ion Coulomb interactions can be studied.



a) Energy levels of $^{40}Ca^{+}$. Ions in the $D_{3/2}$ state is localized by a lattice field (red arrows) and fluorescence at 397nm (blue arrow), produced in inelastic photon scattering, is detected. Position-dependent levels of localized ions on the cavity axis are shown on the right.
b) Experimental results from localization of a single ion. Full symbols: Probability to scatter a lattice photon as a function of lattice depth for red (squares) and blue (circles) lattice detunings. Solid curves: One-free-parameter model fit [1].

References:
[1] R.B.Linnet, I.D.Leroux, M.Marciante, A.Dantan, and M.Drewsen, Phys. Rev. Lett. **109**, 233005 (2012)
[2] A. Friedenauer, H. Schmitz, J. T. Glueckert, D. Porras, and T. Schaetz, Nature Phys. **4**, 757 (2008)
[3] R. Schmied, T. Roscilde, V. Murg, D. Porras, and J. I. Cirac, New J. Phys. **10**, 045017 (2008)
[4] C. Schneider, D. Porras, and T. Schaetz, Rep. Prog.Phys. **75**, 024401 (2012)
[5] I. García-Mata, O. V. Zhirov, and D. L. Shepelyansky, Eur. Phys. J. D **41**, 325 (2007)
[6] T. Pruttivarasin, M. Ramm, I. Talukdar, A. Kreuter, and H. Häffner, New J. Phys. **13**, 075012 (2011)