Observing collective effects of Strontium in an optical cavity

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The stability of the current state of the art optical atomic clocks are limited due to frequency noise of the interrogation oscillator caused by the Dick effect [1,2]. To improve future atomic clocks the frequency stability of the interrogation oscillator will need to be better than 10^{-17} at 1 s interrogation time [3-9].

Following [10-12], we investigate the possibility of exploiting collective effects to enhance the spectral purity of the local oscillator by directly interrogating cold atoms placed in a low finesse cavity. Multiple atoms strongly coupled to a single cavity mode may experience collective effects where the atomic sample acquires a collective phase with the cavity mode. This effect significantly enhances the phase response of this relatively simple system and offers a superior signal to noise ratio. Ultimately, this system may lead to a shot noise limited laser linewidth in the microhertz range [11].

Our experimental set-up consists of a standard Magneto Optical Trap (MOT) with 5×10^8 ^{88}Sr atoms placed inside a low finesse cavity (fig. 1). The cavity enhances atom-light interaction by a factor on the order of the finesse ($F = 80$) and direct spectroscopy on the weakly allowed intercombination line $^1S_0$ – $^3P_1$ ($\Gamma = 7.6$ kHz) is performed. We lock the cavity to the probe laser ensuring a standing wave in the cavity at all times. Using the so-called NICE-OHMS technique [13-15], we measure the phase response of the atoms as we scan the frequency of our probe laser.

In order to push the current limitations further we are building a novel set-up in which a continuous jet of atoms should allow us to recreate this effect and further minimize the Dick effect.

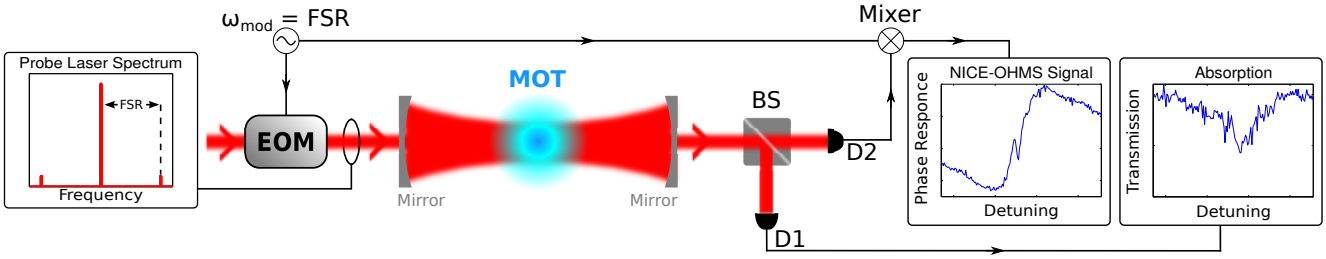

Figure 1: *A modulated laser beam interacts with cold ^{88}Sr-atoms and heterodyne detection is performed.*

References

[1] G. Santarelli *et al.* IEEE Trans. Ultrason. Ferroelectr. Freq. Control **45**, 887 (1998).
[2] P. Westergaard *et al.* IEEE Trans. Ultrason. Ferroelectr. Freq. Control **57**, 623 (2010).
[3] T. Kessler *et al.* Nature Photonics **6**, 687-692 (2012).
[4] M. J. Martin *et al.* Science **341**, 632-636 (2013).
[5] M. Bishof *et al.* Phys. Rev. Lett. **111**, 093604 (2013).
[6] B. J. Bloom *et al.* Nature **506**, 71-75 (2014).
[7] N. Hinkley *et al.* Science **341**, 1215-1218 (2013).
[8] R. Le Targat *et al.* Nat. Commun. **4**, 2109 (2013).
[9] M. Takamoto *et al.* Nature **435**, 321–324 (2005).
[10] M. J. Martin *et al.* Phys. Rev. A **84**, 063813 (2011).
[11] D. Meiser *et al.* Phys Rev. Lett. **102**, 163601 (2009).
[12] D. Meiser and M. Holland Phys. Rev. A. **81**, 033847 (2010).
[13] J. Ye, L. S. Ma, J. L. Hall JOSA B **15** 6 (1998).
[14] L. S. Ma *et al.* JOSA B **16** 2255 (1999).
[15] H. Tanji-Suzuki *et al.* Adv. In Atomic, Molecular, and Opt. Phys. **60**, 201-237 (2011).