# Sub-Kilohertz Optical Spectroscopy by Time Domain Atom Interferometry

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## Abstract

A time domain atom interferometer is used to compare the frequency of the Mg intercombination transition at 457nm with an optical oscillator with sub-kHz resolution. An estimated accurracy of $2 \cdot 10^{-15}$ is achieved with laser cooled and trapped atoms. The resolved line Q-factor is better than $10^{12}$.

## Introduction

Recently several atom interferometric measurements have reached or even surpassed "state of the art methods" in precision measurements. Ramsey-Bordé interferometers have proven to have excellent perspectives in particular for applications in high resolution spectroscopy [1]. In this kind of atom interferometry the atomic wave is coherently split, reflected and recombined by nearly resonant laser light.

The transfer of the Ramsey-Bordé scheme from the originally proposed beam experiment to a time domain interferometer increases the sensitivity and reduces systematic line shifts by several orders of magnitude.

## Principal Method

The time domain interferometer is based on a sequence of two counterpropagating pairs of laser pulses interacting with an ensemble of laser cooled and trapped atoms. The laser excitation generates an entanglement between atomic center of mass motion and internal states. The spatial separation between the different wave packets is completely reset, but due to the different phase evolutions of the partial waves during the dark periods atom interferences occur in the time domain. The two complementary interferometer exits can easily be read out by state selective detection of the number of trapped atoms.

For appropriate conditions the interference signal is only depending on the laser frequency of the beam splitting laser beams and on the dark periods T during the interference process. This behavior is the key feature for the application of this type of interferometer for high resolution optical spectroscopy with respect to optical frequency standards.

## Results

In a completely new setup the Magnesium $^1S_0$ - $^3P_1$ intercombination transition at 457nm (natural lifetime $\tau$=5.1ms) is probed on laser cooled and trapped atoms by means of time domain interferometry. The laser light for the excitation is generated by a frequency stabilized dye-laser spectrometer.

We report on experiments, where the observed interference signals show linewidths down to 491Hz (FWHM) (see Fig.1). This corresponds to a line Q-factor of $1.3 \cdot 10^{12}$ in the resolution of the intercombination transition.

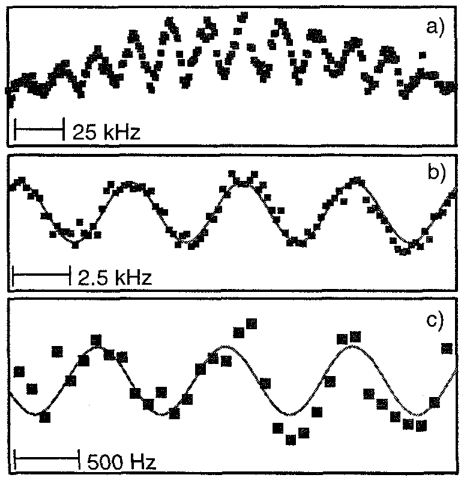


Fig. 1: Time domain interference signals detected as a function of the laser frequency. Scans for three different resolutions corresponding to different dark times T are shown: a) T=12.6μs, b) T=100μs, c) T=509μs. The integration time per data point is for a) and b) 1.1s and for c) 2.2s.

At present the obtained resolution is mainly limited by the spectrometer linewidth and is not yet limited by any fundamental effects. Due to the high estimated accuracy of better than $2 \cdot 10^{-15}$ as well as the high stability of about $2 \cdot 10^{-13}$ for one second of integration time the interferometric detection of optical transitions offers interesting perspectives for future optical frequency standards.

We will discuss further extensions of time domain atom interferometry, like multiple beam interferometry and measurements of the spatial and temporal coherence properties of the partial waves as well as applications for high precision measurements.

## References

[1] see for example in *Atom interferometry*, ed. P. Berman, Academic Press Inc. (1997).