PhD THESIS DEFENSE: Squeezed-light-enhanced magnetometry in a high density atomic vapor

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This thesis describes experiments that employ squeezed light to improve the performance of a sensitive optically-pumped magnetometer (OPM). The squeezed light source employs parametric amplification of vacuum fluctuations to produce squeezed vacuum and polarization-squeezed light tunable around the Rb D1 line. The OPM employs Bell-Bloom Optical pumping of a high density vapor (with atom number density 10^{13}) and paramagnetic Faraday rotation, also on the Rb D1 line. The setup allows convenient switching from probing with laser light to probing with polarization-squeezed light, to study the use of the latter in atomic magnetometry.

The magnetometer shows sub-pT/Hz^{1/2} sensitivity, limited by quantum noise; spin projection noise at low freqüencies (<100Hz) and photon shot noise at high frequencies Probing with polarization squeezed light suppresses the photon sho
noise by 2dB, limited by the available squeezing and optical losses in passing through th vapor. This shot-noise suppression improves the high-frequency sensitivity and increases th measurement bandwidth, with no observed loss ofsensitivity at any frequency. This resul confirms experimentally the expected evasion of measurement back-action noise in th Bell-Bloom magnetometer

The thesis also develops a physical model to explain the observed spin dynamics of th Bell-Bloom magnetometer. The model describes the combined spin and optical polarizatio dynamics using Bloch equations with stochastic drive an
detection noise terms. A perturbative approach and Fourier methods are then used to obtai analytic expressions for the magnetometer's frequency response, spin projection noise an photon shot noise. The role of measurement back-action emerges from a study of this model As polarization squeezing reduces optical noise in the detected Stokes parameter, th accompanying ellipticity anti-squeezing is shunted into the unmeasured spin component

The thesis also reports a study of squeezed-light-enhanced magnetometry at a range o atomic densities, from 2.18 10^{12} atoms/cm3 to 1.13 10^{13} atoms/cm3 . Operating wit fixed conditions of optical pumping, the signal amplitude, instrument noise spectrum an magnetic resonance width are measured as a function of atomic number density, for bot laser- and squeezed-light probing. The equivalent magnetic noise spectra are the calculated. In the photon-shot-noise-limited portion of the spectrum, the squeezed ligh probing improves the magnetometer's sensitivity and measurement bandwidth for the ful range of atomic density values. In particular, the laser-probed magnetometer shows sensitivity optimum at n ~ 6 10 ^{12} atoms/cm3, and the squeezed-light-probe magnetometer surpasses this sensitivity

The thesis concludes with a discussion of the potential of stronger optical squeezing t enhance the instrument's sensitivity in different portions of the spectrum. Using the theor model we estimate the enhancement of the equivalent magnetic noise spectrum for 2 dB 5.6 dB and perfect squeezing (zero noise in the detected polarization component) at th input to the atomic medium

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