



## Congratulations to New ICFO PhD Graduate

Dr Charikleia Troullinou graduated with a thesis 'Squeezed-light-enhanced magnetometry in a high density atomic vapor'.

September 29, 2022

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We congratulate Dr Charikleia Troullinou who defended her thesis today in ICFO's auditorium. Dr Troullinou obtained her MSc in Physics from the Boston University, in the US. She joined Atomic Quantum Optics research group at ICFO led by ICREA Prof Dr Morgan Mitchell as a PhD student. Dr Troullinou's thesis entitled 'Squeezed-light-enhanced magnetometry in a high density atomic vapor' was supervised by ICREA Prof Dr Morgan Mitchell.

### **ABSTRACT:**

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

The thesis also develops a physical model to explain the observed spin dynamics of the Bell-Bloom magnetometer. The model describes the combined spin and optical polarization dynamics using Bloch equations with stochastic drive and detection noise terms. A perturbative approach and Fourier methods are then used to obtain analytic expressions for the magnetometer's frequency response, spin projection noise and 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, the 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 of atomic densities, from  $2.18 \cdot 10^{12}$  atoms/cm<sup>3</sup> to  $1.13 \cdot 10^{13}$  atoms/cm<sup>3</sup>. Operating with fixed conditions of optical pumping, the signal amplitude, instrument noise spectrum and magnetic resonance width are measured as a function of atomic number density, for both laser- and squeezed-light probing. The equivalent magnetic noise spectra are then calculated. In the photon-shot-noise-limited portion of the spectrum, the squeezed light probing improves the magnetometer's sensitivity and measurement bandwidth for the full range of atomic density values. In particular, the laser-probed magnetometer shows sensitivity optimum at  $n \sim 6 \cdot 10^{12}$  atoms/cm<sup>3</sup>, and the squeezed-light-probe magnetometer surpasses this sensitivity.

The thesis concludes with a discussion of the potential of stronger optical squeezing to enhance the instrument's sensitivity in different portions of the spectrum. Using the theoretical 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 the input to the atomic medium.

#### Thesis Committee:

Prof Dr Robert Sewell, ICFO



Prof Dr Irina Novikova, College of Williams & Mary  
Dr George Vasilakis, FORTH IESL