PhD Thesis Defense FERRAN MARTIN CIURANA 'Coherent Sensing of Magnetic Waveforms with Spin-squeezed Atoms'

FERRAN MARTIN CIURANA

December 14, 2017

Thursday December 14th, 14:00. ICFO Auditorium

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Quantum Information With Cold Atoms And Non-classical Light

ICFO-The Institute of Photonic Sciences

Optical magnetometers use magnetically-sensitive atomic ensembles and optical read-out to detect the amplitude of magnetic fields. They have become the most sensitive instruments for measuring low-frequency magnetic fields surpassing competing technologies like superconducting quantum interface devices (SQUIDs), and find applications in a variety of fields ranging from medicine, biology and geophysics, as well as tests of fundamental physics. However, their fundamental sensitivity is bounded by quantum mechanical behavior of the atoms, which gives rise to the standard quantum limit (SQL). As many instruments are approaching this fundamental limit, it becomes necessary to explore ways to overcome the SQL. Quantum metrology studies strategies to increase the sensitivity beyond the SQL by means of quantum engineering the atomic states.

In this thesis, we investigate the quantum enhanced detection of time varying radio-frequency magnetic fields using a cold atomic ensemble of 87Rb atoms held in an optical dipole trap. We first theoretically develop a new measurement technique based on stroboscopic back-action evading measurements that takes advantage of the atomic coherenceThis measurement scheme is suitable for the detection of arbitrarily-chosen components of radio-frequency waveforms and includes radio-frequency magnetometry as a special case.

Experimentally, we demonstrate the capabilities of this technique using a linearly chirped waveform as a test case. As a first experiment, we demonstrate the selective response of the method in the coherently accumulated signal by the atoms. For this, we dispersively probe the atoms via Faraday rotation and non-destructively measure the induced magnetization.

In the last part of the thesis we demonstrate quantum enhanced magnetic field detection. In a measure-evolve-measure (MEM) sequence, a first stroboscopic quantum non-demolition (QND) measurement produces a state with reduced projection noise, followed by a period of free evolution where the atoms accumulate signal. A second QND measurement detects the change relative to thefirst measurement. We demonstrate entanglement-enhanced sensing of sinusoidal and linearly chirped waveforms, with metrologically-relevant noise reduction of $\xi_m^2 = 0.84(8)$ and $\xi_m^2 = 0.80(3)$, respectively. We achieve volume-adjusted sensitivity $\delta B\sqrt{V} = 3.96$ fT(cm3/Hz)$^{1/2}$, comparable to the best radio-frequency magnetometers.

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