Quantum sensing and optical magnetometry with hot atoms

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Quantum sensing and metrology are among the four pillars of the European roadmap on quantum technologies. Atomic quantum sensors using alkali-metal vapors, such as magnetometers, clocks, gyroscopes, GHz/THz imagers, and Rydberg-based gas detectors, can be miniaturized [1] and they have already been commercialized. Optically pumped magnetometers (OPMs), in which an atomic ensemble is optically polarized and its spin-dynamics optically detected, represent a paradigmatic quantum sensing technology, which applies to medical diagnostics, geophysics, navigation, and searches beyond the standard model. For example, OPMs are poised to replace cryogenic superconducting quantum interference devices (SQUIDs) as a more practical, flexible, and cost-effective technology for important biomedical applications like magnetoencephalography (MEG).
In this talk, after a general overview of quantum sensing and optical magnetometry [2], I will present recent results on the miniaturization of atomic sensors by using MEMS cells integrated with mass-producible 3D-printed biplanar coils [3], within the EU project macQsimal [1], and the fabrication of laser-written vapor cells (LWVCs) [4], in collaboration with the CNR/IFN. After that, I will describe state-of-the-art magnetic gradiometers [5, 6] that have reached femtotesla sensitivity up to Earth-scale fields, enabling the first detection of biomagnetism in unshielded environments [7]. Finally, I will discuss the quantum enhancement of high-density atomic sensors by using quantum resources such as squeezed light [8, 9].

[1] https://www.macqsimal.eu/
[2] D. Budker and M. Romalis “Optical Magnetometry”, Nature Physics **3**, 227–234 (2007)
[3] M. Tayler et al. “Miniature biplanar coils for alkali-metal-vapor magnetometry”, Phys. Rev. Applied **18**, 014036 (2022)
[4] V. G. Lucivero et al. “Laser-written vapor cells for chip-scale atomic sensing and spectroscopy”,
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[5] V. G. Lucivero et al. “Femtotesla nearly quantum-noise-limited pulsed gradiometer at Earth-scale fields”
Phys. Rev. Applied **18**, L021001 (2022)
[6] V. G. Lucivero et al. “Femtotesla direct magnetic gradiometer using a single multipass cell”,
Phys. Rev. Applied **15**, 014004 (2021)
[7] M. E. Limes et al. “Portable magnetometry for detection of biomagnetism in ambient environments”,
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[8] V. G. Lucivero et al. “Squeezed- light spin noise spectroscopy”, Phys. Rev. A **93**, 053802 (2016)
[9] C. Troullinou et al. “Squeezed-light enhancement and backaction evasion in a high-sensitivity optically pumped magnetometer”, Phys. Rev. Lett. **127**, 193601 (2021)

Short Biography: Dr. Lucivero graduated in 2010 in experimental quantum optics at "Sapienza" University in Rome, in the group of Prof. Fabio Sciarrino. In 2011, he joined the "Atomic Quantum Optics" group of Prof. Morgan Mitchell at ICFO-The Institute of Photonic Sciences, where he got his PhD "cum laude" in October 2016 with the thesis: "Quantum metrology with high-density atomic vapors and squeezed states of light". Between 2016 and 2019, he worked as a Postdoctoral Research Associate and Lecturer at Princeton University (Prof. Michael Romalis’ Group), where he studied fundamental effects of atomic diffusion and used a new generation of multipass cells for optically pumped magnetometers (OPMs). These research activities contributed to the first detection of magnetic fields from the human brain and heart in unshielded environments. Since October 2019, he has been a Marie-Curie COFUND fellow at the Barcelona Institute of Science and Technology (BIST), with the project "Integrated Atomic Quantum Sensing", aiming at the development of miniaturized and lab-on-chip atomic quantum devices. Since 2021, he has been Lecturer of Quantum Sensing in the Master of Quantum Science and Technology, coordinated by the University of Barcelona (UB). He has co-authored more than 20 articles in Quantum Optics, Atomic Physics, and Optical Magnetometry.