



## Master in Photonics – “PHOTONICS BCN” Master ERASMUS Mundus “EuroPhotonics”

### MASTER THESIS PROPOSAL

Starting full time from April 2025

Presentation at the end of July or beginning of September 2025

**Laboratory:** Atomic Quantum Optics group

**Institution:** ICFO – The Institute of Photonic Sciences

**City, Country:** Castelldefels (Barcelona), Spain

**Title of the master thesis:** Quantum Sensors for Magnetic Resonance Imaging

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**Keywords:** Quantum sensing, Magnetic sensing, Optical magnetometry, Spin resonance.

**Summary of the subject (maximum 1 page):**

In this project you will develop quantum sensor hardware for magnetic resonance imaging (MRI). The goal is to achieve an inexpensive, scalable form of MRI using weak magnetic fields, in contrast to the high fields (of several tesla) normally used in hospitals. Low-field MRI yields contrast that is complementary to its high-field counterpart, for instance diagnosing between healthy and diseased biological tissue[1], but at these fields detection is insensitive, and not yet satisfactorily integrated with high-throughput technologies, like microfluidics[2,3].

We recently used optical-atomic sensors, such as atomic magnetometers, as a means to detect low-field MRI in "lab-on-a-chip" platforms. This builds upon several years of having used atomic magnetometers to study nuclear spin relaxation rates in liquids and mixed-phase materials in mT fields[4], developing hardware and software for nuclear spin control[5] and exploring sensor microfabrication[6,7]. The current state-of-the-art is acquiring 2D MRI images with sub-mm space resolution, an example of which appears in Fig. 1. Our objective is to push limits of speed and sensitivity to image smaller volumes (or otherwise better resolution) in a shorter time. Possible routes to this include sensor arraying[8], or noise-reduction techniques. We are also imaging complex samples, such as those with integrated electronics or mixed materials that confound high-field MRI due to large magnetic susceptibility-induced field gradients.

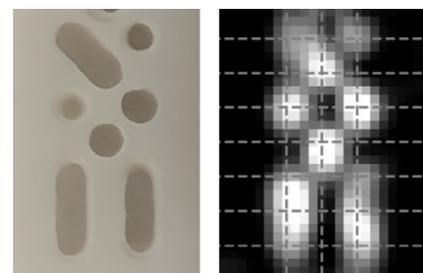


Fig. 1. (left) A photograph and (right) a  $^1\text{H}$  MRI image of a 3d-printed set of 2-mm-wide cavities, filled with water. In contrast to conventional MRI, normally done within strong magnetic fields of around 1.5 – 3 T, the ultralow-field MRI does not exceed 0.03 T. (In manuscript, ICFO)



Literature references:

- [1] <https://studenttheses.uu.nl/handle/20.500.12932/42267>
- [2] <https://doi.org/10.1016/j.jmr.2022.107280>
- [3] <https://doi.org/10.1073/pnas.0605396103>
- [4] <https://doi.org/10.1038/s41467-021-24248-9>
- [5] <https://doi.org/10.1016/j.jmr.2024.107665>
- [6] <https://doi.org/10.1103/PhysRevApplied.22.044011>
- [7] <https://doi.org/10.1063/5.0230180>
- [8] <https://arxiv.org/abs/2407.00929> (preprint)

**Objectives:**

**General**

1. To design and build precision imaging platforms using state-of-the-art quantum technologies.
2. To gain hands-on experience in quantum sensing, atomic physics, and technology development.

**Specific**

1. To integrate low-field MRI sensors, such as laser-pumped atomic-vapor sensors, into fluidic-scale "lab-on-a-chip" platforms. This includes microfabricated components to improve the performance of the atomic devices.
2. To demonstrate chip-scale MRI with sub-mm space resolution for applications like drug discovery, and clinical trials.
3. To enhance the efficiency and speed of ultralow-field MRI detection using photonics know how.

**Additional information (if needed):**

- \* Required skills: Knowledge of Python software and C++
- \* Desirable skills: Knowledge of Mathematica software.
- \* Relevant textbook knowledge: Larmor precession, Fourier transforms, Signal-to-noise calculations.