Bose-Einstein condensate sources for quantum sensors

Compact, high-repetition-rate, all-optical Bose-Einstein condensates

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Keywords	cold atoms, quantum inertial sensors, gravimetry, space instrumentation, machine-learning optimisation
Level	Master's (M2) or final-year engineering student — PhD continuation possible

Background

Cold-atom inertial sensors, including gravimeters, accelerometers, and gyroscopes, offer powerful tools for measuring gravity, with direct applications in geophysics, water-resource monitoring, inertial navigation, and space geodesy. The main challenge is no longer intrinsic sensitivity, but the transition from the laboratory to real-world operation. Future instruments must be compact, robust, and fast, while maintaining high performance in uncontrolled environments, whether deployed on vehicles, ships, or satellites.

A major part of this bottleneck lies in the atom source. Bose–Einstein condensates offer ideal properties for precision interferometry: an extremely narrow velocity distribution, long-range spatial coherence, and compatibility with large momentum transfer. Yet they are traditionally produced in bulky magnetic traps, with experimental cycles lasting tens of seconds, far too slow for field deployment. All-optical condensates, produced by evaporative cooling in a dipole trap, offer a way forward, enabling substantially higher production rates and opening the door to compact, high-repetition-rate atom interferometers.

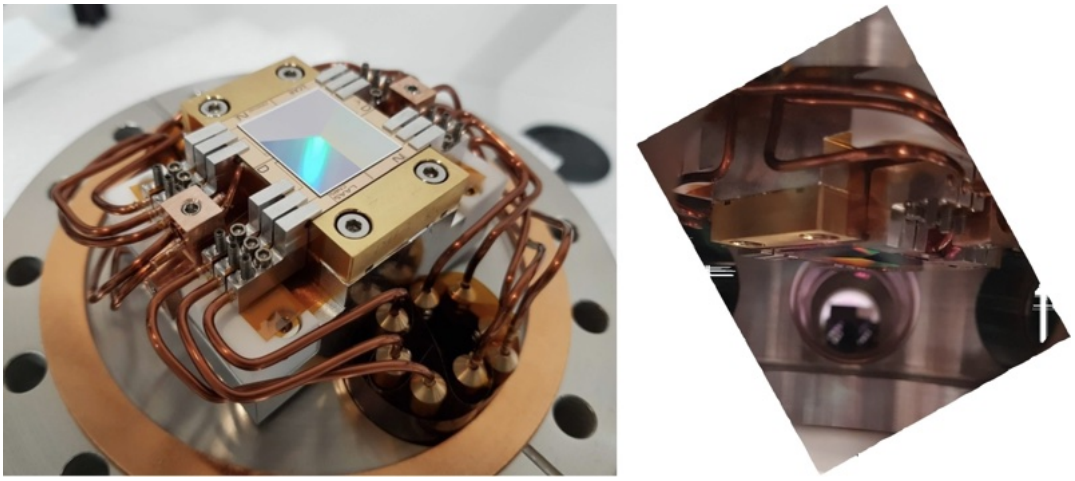


Figure 1. Core element of the compact source: the optical chip and its mount, installed on a flange of the vacuum chamber (left), with a close-up of the assembly: a cold atom ensemble is visible through the viewport (right).

Aims of the internship

The team is developing an all-optical condensate source for quantum sensors. The dual objectives are to achieve high compactness and a high repetition rate. Depending on their interests and the length of their placement, interns will specialise in one or both of the following research areas:

Compact, high-repetition-rate source The intern will implement and characterize the source, including loading the dipole trap, optimizing the optical evaporation sequence. The goal is to shorten the experimental cycle while maintaining the performance of the condensate source. The intern will also investigate and implement sub-recoil cooling techniques, including *Grey molasses* and *Raman sideband cooling*, as well as optical *painted potentials* for all-optical evaporative cooling.

Optimization with artificial-intelligence tools The cooling and evaporation sequences involve several tens of coupled parameters, making manual optimization both time-consuming and inefficient. The internship will therefore include the development of a closed-loop optimizer operating directly on the experiment, based on Gaussian-process Bayesian optimization and machine-learning methods. Beyond optimizing the source performance, this approach will provide quantitative information on the sensitivity of the experimental sequence to individual parameters, helping to the development of more robust and reproducible instruments.

Continuation as a PhD

This internship may lead to a PhD focused on the development of a quantum inertial sensor based on the atom source developed during the internship. The PhD work will involve integrating the source into an atom interferometer using optical-lattice manipulation techniques and identifying the main factors limiting its performance. A further objective will be to demonstrate new interferometer geometries based on optimal-control protocols and to assess their potential experimentally. The PhD student will also contribute to the design and evaluation of configurations adapted to space missions and field operation. The PhD will be conducted within a collaborative project involving academic partners, companies active in quantum sensing, and space agencies, including the European Space Agency (ESA) and the French space agency (CNES), a setting that prepares the candidate equally for an academic and an industrial career.

Candidate profile and application

Master's-level student (M2 or final year of an engineering school) in physics; a specialisation in optics, cold-atom physics or instrumentation will be appreciated. We are looking for someone drawn to experimental work and instrument design. Programming skills (Python) and an interest in optimisation and machine-learning methods will be an asset.

Application. Please send a CV, a transcript of records and a cover letter to `gauguet@irsamc.ups-tlse.fr` and `allard@irsamc.ups-tlse.fr`.