



Internship Opportunities 2027

Engineering students and Master's students in Optics, Photonics, Optoelectronics or Optical Communications

Contributing to the Measurement of General Relativistic Effects on Quantum States of Light

ARTEMIS Laboratory, Côte d'Azur Observatory, Nice, France

Keywords: Quantum optics; general relativity; fibre-optic interferometry; precision metrology

Internship context

Introduction: Quantum states of light and gravitational time dilation

Gravitational time dilation, also known as gravitational redshift, is a fundamental prediction of general relativity: time flows at different rates in regions subject to different gravitational potentials. Although gravitational time dilation has been tested with remarkable precision using spectroscopy and atomic clocks, gravitational phase shifts measured with massive quantum particles can generally be described within a Newtonian or semiclassical framework. Directly probing the effect of relativistic time dilation on the evolution of a quantum state of light remains an outstanding experimental challenge.

Optical interferometry provides an original route to investigating this question. A photon propagating in a coherent superposition along paths associated with different gravitational potentials can acquire a phase that depends on the proper-time difference between those paths. Measuring this phase would provide a direct experimental probe of the interplay between general relativity and quantum mechanics, enabling us to investigate how gravity affects the evolution of a quantum state of light [1–3].

This internship is part of the development at ARTEMIS of a fibre-optic interferometer designed to measure gravitational phase shifts on quantum states of light. The long-term objective is a distributed measurement between sites on the French Riviera at different altitudes, in particular Nice and the Calern Observatory. As part of this regional collaboration, the student will have opportunities to work at partner laboratories across the Côte d'Azur.

1. General framework

The experiment will use a Franson geometry made of two unbalanced fibre interferometers connected by an optical link. Each interferometer contains a short and a long path, whose length difference introduces a time delay between two components of the optical state. When the two delays are sufficiently well matched, the short–short and long–long probability amplitudes become indistinguishable and interfere. The measured phase then depends on the phase difference accumulated in the two interferometers. Placing them at different altitudes should provide access to the phase shift generated by the gravitational-potential difference.

The target signal scales with both altitude separation and interferometer imbalance. Kilometre-scale optical paths and the approximately 1,300 m elevation difference between Nice and Calern are expected to produce a gravitational phase shift on the milliradian scale. Environmental fluctuations are much larger than this signal; thermal and mechanical fibre noise, laser-frequency noise and polarisation variations must therefore be characterised and compensated to maintain stable interference over long periods.

2. Experimental principle

The two interferometers will first be built and characterised in the laboratory with coherent laser light. Polarisation-maintaining fibres will form the long paths and limit loss of interference visibility. A narrow-linewidth continuous-wave laser will provide a control field for sensing phase fluctuations. The output will be detected and demodulated to generate an error signal, which will drive acousto-optic modulators and/or piezoelectric fibre stretchers. Fast and slow actuators will compensate both rapid fluctuations and long-term drift.

Attention will be paid to matching the two optical-path imbalances, since any mismatch between their delays reduces the interference visibility, especially for sources with a short coherence length. Once validated with coherent light, the apparatus will progressively be adapted to low optical flux and then to single photons. Ultimately, events will be recorded using single-photon detectors and time-tagging electronics to reconstruct the interference fringes and estimate their phase.

Internship objectives

The internship will contribute to the construction, stabilisation and characterisation of a fibre-based Franson interferometer for a future measurement of gravitational time dilation on quantum states of light. Three work areas will be developed as the project progresses:

Construction and characterisation of the fibre interferometers

The student will help assemble the two unbalanced interferometers and characterise their components. Work will include:

- installing fibre and free-space optical components; measuring and minimising optical losses;
- controlling polarisation and measuring optical-path differences;
- matching the two interferometer delays and maximising fringe visibility.

Implementation of phase-control loops

A feedback loop will keep the interferometers at a stable operating point. The student will contribute to:

- setting up the detection chain and generating and demodulating the error signal;
- characterising the actuators and designing and optimising the control filters;
- measuring loop bandwidth and gain and assessing long-term lock stability.

Noise and phase-sensitivity characterisation

The main noise sources will be investigated experimentally and acquired time series will be used to establish the instrument noise budget. Tasks will include:

- measuring phase-noise spectral densities and thermal, acoustic and mechanical couplings;
- evaluating laser-frequency noise and analysing polarisation and visibility drifts;
- assessing stability through Allan deviation; injecting and detecting weak calibrated phase modulations;
- comparing the achieved sensitivity with the target gravitational phase shift.

Depending on progress, the student may also help transfer the apparatus from coherent-light operation to photon counting and perform its first low-flux interference characterisation.

Host laboratory

ARTEMIS Laboratory, Côte d'Azur Observatory, Boulevard de l'Observatoire, B.P. 4229, F-06304 Nice Cedex 4, France : <https://artemis.oca.eu/fr/accueil-artemis>

Duration and supervision

Six-month internship at M2 or final-year engineering-school level. Applications from highly motivated M1 students may also be considered. The internship may begin during the first half of 2027, on a date agreed with the successful candidate.

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Background and skills

A sound foundation in optics, lasers and photonics is required. Experience in experimental optics or interferometry and knowledge of Python or MATLAB would be preferred.

Methods

Fibre-optic interferometry; quantum optics; homodyne detection; single-photon detection; control electronics and feedback; spectral analysis; noise spectral densities; data processing; Allan deviation. The student will join a team with expertise in precision interferometry, quantum optics, frequency metrology and instrumentation for gravitational physics, with possible interactions with project partners at INPHYNI and the Calern Observatory.

References

- [1] M. Zych, F. Costa, I. Pikovski and Č. Brukner, 'Quantum interferometric visibility as a witness of general relativistic proper time', *Nature Communications* 2, 505 (2011).
- [2] H.-N. Wu et al., 'Single-Photon Interference over 8.4 km Urban Atmosphere: Toward Testing Quantum Effects in Curved Spacetime with Photons', *Physical Review Letters* 133, 020201 (2024).
- [3] H. Yu, D. Macri, T. Morling, **E. Polini** et al., '50-km Fiber Interferometer for Testing Gravitational Signatures in Quantum Interference', *Physical Review Letters* 136, 110803 (2026).