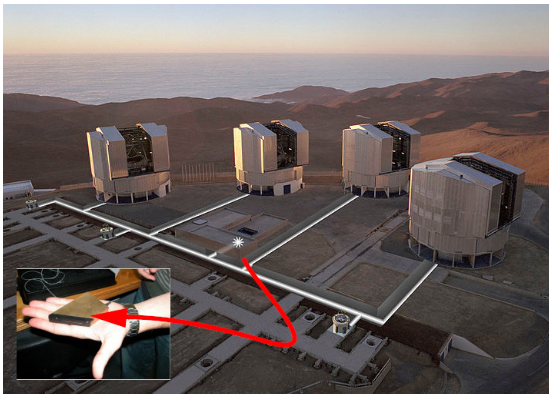
Photonics for high angular resolution astronomy



SUMMARY.
The wide availability of adaptive optics (AO) and other telescope beam stabilization techniques now make it possible to design complex instruments like **interferometric recombiners** and **spectrographs** out of ultracompact **integrated optics**. At the VLTI, several generations of instruments (PIONIER, GRAVITY and now ASGARD) are taking advantage of this technology, to great effect. At Lagrange, our group is using a laboratory setup to test and characterize devices that can, through thermo-optical effects, actively control the electric field of light of astrophysical origin without any moving parts. Next generation active spectro-interferometers are on the horizon and offer very unique opportunities for exciting astrophysical use cases like the direct detection and characterization of extrasolar planets.

OBJECTIVES

Students will be introduced to the wonderful whimsical world of photonics, a very active modern sub-field of optics concerned with the emission, transport and manipulation of light at microscopic scales. Applied as its name suggests, to astronomy, **astrophotonics**, makes it possible to design instruments that would otherwise be incredibly complex to build. With now ubiquitous access to AO and general beam stabilization techniques (or the possibility of space-borne observatories), we can take advantage of **single-mode photonics**, that is at the core of an upcoming wave of instruments. The students will gain practical exposure to two use cases that take advantage of this new modality: high-angular resolution astronomy - that we will explore through the lens of optical interferometry - and spectroscopy.

The students will see (and experience first hand) that the current R&D challenges lie (at least in the visible and near-infrared) at the interface between the telescope beams and the integrated optics - the so-called injection stage - and in the design of circuitry that can efficiently cover a wide spectral range.

The context of the recent and still ongoing commissioning of the VLTI/ASGARD instrument suite is a great opportunity to explore the potential of a prospective integrated optics high-contrast imaging recombiner called SEIDR that would implement our latest findings.

PREREQUISITES

- ☒ S1. Fourier Optics
- ☒ S1. Numerical methods
- ☒ S2. Imaging through turbulence

THEORY

by F. Martinache & N. Cvetojevic

The theoretical part of this METEOR will cover:

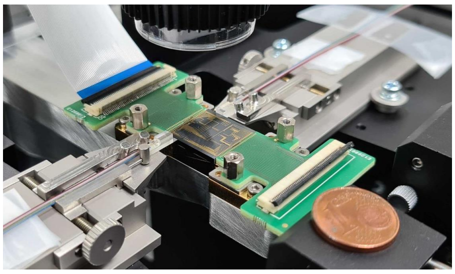
- an introduction to the field of astrophotonics, including lectures on the fundamental light guiding principles, a description of the manufacturing processes for fibers and integrated optics chips, and a review of active astronomical instruments that rely on photonics.
- an introduction to the field of optical interferometry, starting with a review of the properties of spatial and temporal coherence of light, the properties of interference fringes, the imaging capability of interferometers and high-contrast imaging use cases.
- an in-depth look at the design of several types interferometric recombiners using integrated optics: the ABCD recombiner, as well as high-contrast recombiners.

This theoretical section will conclude with a discussion of the potential future of fully photonic space borne telescope designs.

APPLICATIONS

by F. Martinache

The students choosing this METEOR will be able to take advantage of the PHOTONICS characterization test-bench hosted at the Lagrange laboratory (see Figure below) as well as the availability of early commissioning data acquired by the ASGARD/HEIMDALLR fringe tracker at the focus of the VLTI.



PHOTONICS integrated device in lab

With practical expertise gained in the characterization of the spectral behavior of (a possibly active) near-infrared 4-input beam recombiner, the students will be able to examine the fringe-tracking performance of ASGARD/HEIMDALLR at VLTI, to model and predict the high-contrast imaging potential of a new envisioned module called ASGARD/SEIDR (meaning “black-magic”).

MAIN PROGRESSION STEPS

- **Tier 1**: First half of the period : introduction and initial lab tour followed by a series of 6 lectures on photonics and interferometry (bibliography review presentation after week #2 and a written exam after the end of week #4)
- **Tier 2**: lab sessions, data-analysis and modeling toward the completion of student projects.

- **Final week**: preparation and rehearsal of the final oral presentation.

Depending on lab and staff availability, the students will have the opportunity to gain expertise in some operation aspects of the PHOTONICS test-bench. Whether working in the lab, modeling or analysing actual data, the students will requested to keep a physical and/or virtual lab book to keep track of their experiments and the progress of their understanding. The content of the lab book will be used as part of the student project evaluation.

EVALUATION

- **Theory grade [30%]**
  - Reading assignments, critical review of selected papers (30%)
  - Written exam: critical essay as well as answers to questions (70 %)
- **Practice grade [30%]**
  - Lab work / lab book practices (30%)
  - Data analysis and/or modeling work (30%)
  - Written project report (40%)
- **Defense grade [40%]**
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Taras et al (2024)
- Martinache & Ireland (2018)
- Benisty et al (2009)
- F. Martinache lectures (YT, 2005)
- F. Martinache - kernel-nulling (YT, 2020)
- PHOTONICS project webpage

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CONTACT

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