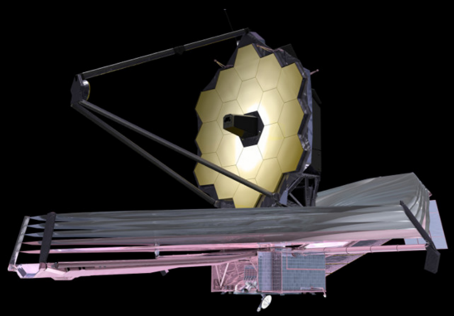
MASTER IN ASTROPHYSICS

XARA - eXtreme Angular Resolution Astronomy



SUMMARY: The angular resolution of astronomical observations is ultimately constrained or assisted by the phenomenon of diffraction, primarily driven by the size and shape of the instruments used to carry out these observations. Careful attention to details makes it possible to produce high-quality measurements that lead to insights into angular sizes smaller than this diffraction limit, a capacity sometimes refered to as super-resolution.

OBJECTIVES

- Students taking this XARA METEOR will become competent in simulating and interpreting diffraction dominated images produced by large ground based telescopes and interferometers. They will use and contribute to the development of versatile numerical tools written in python. They will gain insights into the processes that affect observations and measurements in all astrophysics and become understand most of the journal papers using data acquired by interferometers. They will also be exposed to experimental work with the KERNEL test-bench.
- Students will learn the fundamental coherence properties of starlight, use the equations of Fourier optics to describe and model diffraction, and how to exploit these equations in the context of discrete numerical simulations. They will also learn to apply the Van Cittert Zernike theorem to describe a wide variety of astrophysical sources and see how to exploit this to go from raw interferometric observables back to properties of targets.

PREREQUISITES

General Astrophysics, Fourier optics, Signal/image processing.

THEORY

by Frantz Martinache

This module will introduce you to the magical world of high-angular resolution astronomical observations: a special use case of instrumentation producing data whose general allure is dominated by diffraction effects, such as encountered when using long-baseline interferometry (in the optical or in the radio) or when attempting the high-contrast imaging of extrasolar planets with a single telescope.

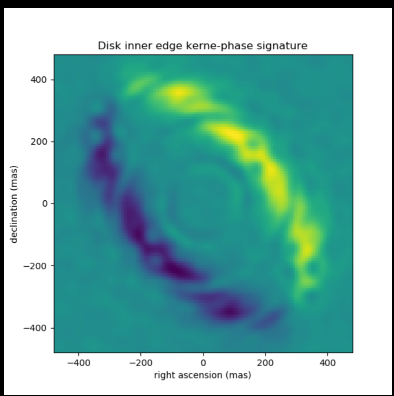
To understand such data requires to understand the fundamental coherence properties of "starlight" and how they relate to observations carried out in the optical regime either by single telescopes, using an image-object convolution relation; or by interferometers, relying on the Van Cittert - Zernike theorem. We will also put that Fourier-optics course to good use and learn to look through the three fundamental: pupil, image and Fourier plans to describe and control the diffractive contribution of our experiments.

When carried out from the ground, high-angular resolution observations are strongly affected by the presence of the atmosphere. We can either attempt to correct these effects (using adaptive optics and fringe tracking), to take them into account to understand how they affect our observations (using post-processing) and/or tune our experiments to nevertheless lead to the formation well defined and calibrated observable quantities (an idea refered to as co-conception). It is by using a combination of all options that we will be able to bring our instruments to their fullest angular resolution potential!

APPLICATIONS

by Frantz Martinache

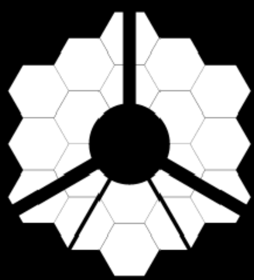
The notions introduced in the theoretical section of the course are going to be completed by a series of practice sessions, ranging from the guided use of existing interactive simulation tools to the development of custom analysis tools. The students will gain practical experience in the processing of diffraction dominated data, primarily using the technique of non-redundant aperture masking interferometry. Several applications will be covered, ranging from astrophysical use cases to optical metrology).



Interferometric (kernel-phase) signature of the inner edge of a protoplanetary disk by A. Lapel, MAUCA student (2020)

How does one go from a small collection of observable quantities to a believable description of a potentially complex medium or astrophysical target? We will look into the limits of data interpretation, the contribution of fundamental noises, become aware of the observer's subjectivity, and of the importance of the notion of hypothesis.

Students following this course will acquire a wide ranging practical skill set: they will experiment with optics, process and interpret interferometric data and learn how to build up new applications from existing numerical tools. They will gain insights into the processes that affect observations and measurements in all astrophysics. They will also benefit from the KERNEL project that proposes to apply the lessons and techniques of interferometry to process classical (i.e. non interferometric) images so as to transform any able telescope into a super-resolution machine.



Diffractive model of the aperture of the James Webb Space Telescope by J. Marquez, MAUCA student (2020)

MAIN PROGRESSION STEPS

- First half of the period : theoretical courses and numerical interactive sessions.
- Written exam & choice of a project (astrophysics or metrology applications)
- Second half of the period: project - complementary sessions.
- Last week : preparation of the final oral presentation.

EVALUATION

- Written exam based on the lecture content (40 %)
- Participation in the class (20 %)
- Oral presentation of the project (40 %)

BIBLIOGRAPHY & RESSOURCES

OCA website KERNEL news Diffraction lecture paper
Youtube lectures
XAOSIM simulation package
XARA pipeline package
XARA software documentation

CONTACT

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