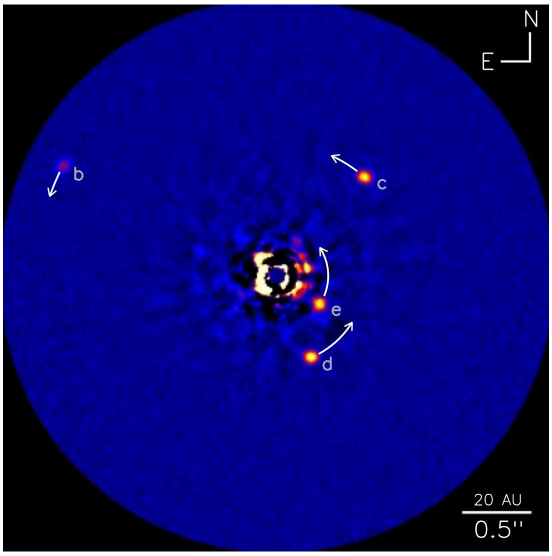
Imaging Exoplanets



SUMMARY.
Understanding the formation, evolution and diversity of extrasolar planets is one of the challenges of modern astrophysics. Numerous discoveries have revealed the complex nature of more than 5000 exoplanets, whose analysis of the chemistry of the atmospheres is crucial to determine the conditions for the appearance of life. The observation of exo-Earths is a considerable technological challenge due to the significant difference in flux between the host star and its planet, located at a short angular separation (typically 10^{10} at least of a second of arc, in the visible and near-infrared domains). Direct imaging and study, particularly of exo-Earths, exoplanets similar to Earth, requires the development of instrumental concepts where active and passive optics play an important role. This METEOR gives a broad overview of the subsystems that are part of a coronagraphic instrument for imaging exoplanetary systems.

OBJECTIVES

Planets beyond our solar system are a hot topic of modern astronomy through the development of the most up-to-date instruments since 1995, the date of the first detection (51 Pegasi-b). Known exoplanets, numbering in the thousands, have been detected using mainly indirect methods, but direct imaging enlarges the discoveries paradigm. Exoplanet direct imaging is a snapshot of the planet(s) around a central star. However, they are much fainter than their parent star and separated by small angles, so conventional imaging systems are inadequate. This METEOR provides a global introduction to the outstanding exoplanet search problem, in particular, it presents the dedicated technological and instrumental requirements for direct imaging.
A high-contrast imaging instrument for observing exoplanets must

- suppress the bright star's image and diffraction pattern,
- suppress the star's scattered light from imperfections in the telescope.

We expect students taking this METEOR to understand how exoplanets can be imaged by controlling diffraction with coronagraphy and scattered light with deformable mirrors. Students following this METEOR are expected to acquire knowledge in both theoretical and practical aspects related to exoplanet imaging, including laboratory experimentation, numerical modeling, and system dimensioning.

PREREQUISITES

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

THEORY

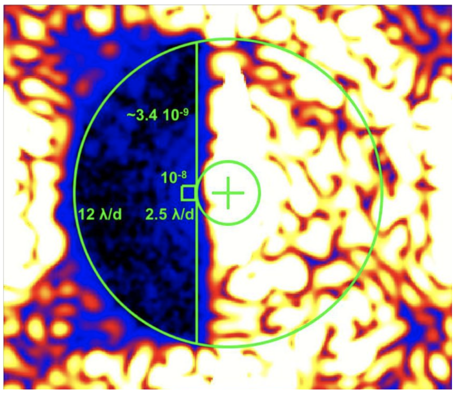
by P. Martinez

In this part of the METEOR, we discuss the theory behind stellar diffraction patterns and the impact of wavefront aberrations on the performance of high-contrast imaging instruments. In particular, we show how they induce stellar speckles in the scientific image. Using coronagraphy we show how it is possible to control unwanted radiation to some extent. We present instrumental and signal processing techniques used for on-sky minimization of the speckle pattern (sensing, controlling and suppressing speckles). The theory of wavefront control and shaping is presented and the importance of active and passive optical elements such as deformable mirrors and coronagraphs are studied.
Finally, a posteriori calibration of the speckles in order to improve the performance of coronagraphs is presented. This part includes lectures, exercises, discussions of examples, and literature research.

APPLICATIONS

by P. Martinez

The application part of this METEOR will provide specialized courses including laboratory practice with the SPEED testbed, numerical modeling, and performance evaluation. These courses will cover the area of telescope architectures, co-phasing optics and sensors, diffraction suppression systems (coronagraphy) and wavefront control (deformable mirrors). In particular, this module will benefit from numerical modeling training to simulate part of an instrument for exoplanet detection and will take advantage of privileged access to the SPEED instrumental facility (Segmented Pupil Experiment for Exoplanet Detection) at the Lagrange laboratory.



Dark hole generated on the high contrast imaging testbed (HCIT) at JPL using wavefront control

The SPEED project is an optical platform for testing systems and subsystems for high-contrast imaging (exoplanet detection) with segmented telescopes. The project is supported by various partners (Lagrange, OCA, UNS, CNES, ESO, Airbus Defense and Space, Thales Alenia Space, PACA, EU) and collaborations: LESIA (Paris), Subaru Telescope (Hawaii) and LAM (Marseille).

MAIN PROGRESSION STEPS

he METEOR program is structured in 7 modules:

- the challenges of exoplanet imaging,
- diffraction in a telescope,
- telescope and wavefront errors,
- wavefront sensing and control,
- deformable mirrors: control and suppress speckles,
- coronagraphy: control unwanted radiation,
- and basics of data post-processing & observing strategies,

with the following progression steps:

- `First half of the period` : theoretical courses, numerical practical works (exam at middle or end term, tbc).
- `Second half of the period` : Labs hands-on and practical works, student project, final report at end term.
- `Last week` : preparation of the final oral presentation and term project report.

The METEOR program is based on various pedagogic structures:

- Focus lectures that are opening lectures on a single and specific topic (e..g., ESO/SPHERE instrument, NASA/JWST, high-contrast lab. settings),
- Computer practicum that are numerical practical work (e.g., magnitude & phase, 2D Fourier transform, Zernike, PSF & MTF, diffraction in segmented telescopes, whose telescope is this?, from wavefront errors to speckles, coronagraphy, deformable mirror),
- Labs hands-on (upon availability and mini-project selection) that are practical work in lab environment (e.g., wavefront sensors, coronagraphy, deformable mirror),
- Reading assignments that are active learning based on scientific articles,
- and Mini-project (e.g., wavefront sensor to correct for non-common path aberrations, wavefront sensor to co-phase a segmented aperture, speckle temporal stability in high-contrast coronagraphic images, speckle symmetry with high-contrast coronagraphs, coronagraphy, high-dynamic-range using a deformable mirror: dark-hole generation).

EVALUATION

- `Theory grade [30%]`
  - reading assignments (written/oral questions, presentation may be asked);
  - homework assignments (oral presentation may be asked);
  - a final exam (conceptual essay and/or questions and quantitative problems).
- `Practice grade [30%]`
  - hands-on experience with the hardware and software components will be made possible;
  - computer practicum that are numerical practical work;
  - project: initiative, progress, analysis, final report.
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Exoplanets explained
- Exoplanets.eu
- SPEED project website

CONTACT

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