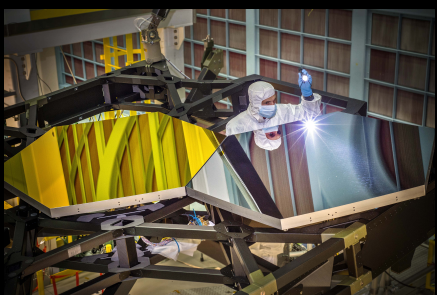
Co-phasing Segmented Optics

JWST during integration phase
Credits NASA

SUMMARY
Increasing the telescope diameter from a few meter class telescopes towards tens of meters and beyond imposes segmentation in order to keep the telescope mechanically and optically feasible and minimize failure risks. Large-segmented telescope projects from the ground or in space incorporate a number of components or subsystems that are technically challenging and have barely ever been operated on a routine basis at an astronomical telescope. Deploying segmented optics on large-scale structures turns active and adaptive optics into co-phasing optics for aligning multiple optical paths in real-time operation.Co-phasing optics that correct for the misalignment of individual segments of the primary segmented mirror is a key optical process to reach exquisite image quality and stability: to bring the segmented telescope's maximum performance close to the ideal single mirror case.

OBJECTIVES

Students following this METEOR are expected to acquire knowledge in both theoretical and practical co-phasing optics and telescope optics with segmented telescopes, including laboratory experimentation, numerical modelling, and system dimensioning. They will focus on international projects and benefit from intensive training by research.



JWST during integration phase, mirror inspection. Credits NASA

Co-phasing is the process of controlling the individual segments in a segmented mirror so that the segments form a surface nearly as good as if the segmented mirror was made in a single unit (monolithic mirror). Co-phasing implies active control of three degrees of freedom of each individual segment mirror with high precision: translation along the optical axis (piston) and rotation about two axes perpendicular to the optical axis (tip-tilt). Segments suffer from gravitation force, wind blowing, and thermal and pressure changes. If the precise alignment of each segment is not achieved, the resolution of the telescope degrades and could be the same as if the telescope had a diameter equal to the size of a single segment. Co-phasing optics strives to achieve a segment's alignment so that the telescope gets a resolution commensurable with that of a monolithic telescope of the same diameter of the segmented surface. Depending on the astrophysical objective, co-phasing must reach a precision better than $\lambda/30$ rms to a precision better than $\lambda/10$ rms (exoplanet imaging).

PREREQUISITES

This course contains literature surveys and planning projects to introduce the concepts and techniques of telescope and co-phasing optics. Because the topics explored are optics and telescope design, it covers geometrical and Fourier optics backgrounds. Knowledge in these areas is expected as well as interest in numerical modelling and practices. A natural interest in astronomical optics and instrumentation is a must.

THEORY

by P. Martinez

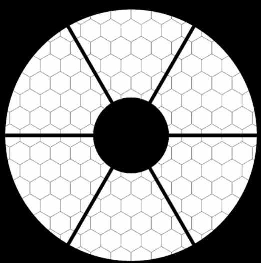
The theoretical part of this METEOR will provide insights into (1) telescope optics: understanding the relationship between the telescope optical structure and image diffraction characteristics, (2) a global introduction to segmented telescope projects, architectures, and impact on the image quality, (3) segmented telescopes needs and requirements, (4) the state-of-the-art of co-phasing systems, including fundamental limitations and systems technological maturity, (5) specialized courses for co-phasing loop control, systems dimensioning and numerical modelling, (5) laboratory illustrations with the SPEED testbed. Specific care for the dichotomy occurring between space and ground-based observatories will be discussed. In particular, a specific study of the NASA/JWST co-phasing process will be proposed in a dedicated chapter.

Because of the unique circumstances of the stable space environment, co-phasing architecture on JWST is different from large active telescopes on the ground, where the dominant factor requiring rapid correction for active and adaptive telescopes on Earth is gravity-induced deformations. Space disturbances change much more slowly than the durations of typical changes on the ground.

APPLICATIONS

by P. Martinez

The application part of this METEOR will provide specialized courses including laboratory practice with the SPEED testbed, numerical modelling with generic and peculiar co-phasing systems, and performance evaluation. These courses will cover the area of telescope architectures, co-phasing optics and sensors.



The SPEED testbed offers a telescope simulator with a primary mirror made of 163 segments

In particular, this module will benefit from numerical modelling training to simulate part or a whole system and will take advantage of privileged access to the SPEED instrumental facility (Segmented Pupil Experiment for Exoplanet Detection) at the Lagrange laboratory. The SPEED project is an optical platform for testing systems and subsystems for high-contrast imaging (exoplanet imaging) 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

The METEOR program is structured in 7 chapters: (1) introduction, (2) generality in optics, (3) basics of telescope optics, (4) segmented telescope optics, (5) active optics, (6) active control implementation, (7) phasing the James Webb space telescope, with the following progression steps:

- First half of the period : theoretical courses (exam at middle or end term, tbc).
- Second half of the period : student projects, 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:

- (1) Focus lectures that are opening lectures on a single and specific topic (e.g., the SPEED testbed co-phasing sensors, the ESO-ELT, the JWST),
- (2) Computer practicum that are numerical practical work (e.g., magnitude & phase, 2D Fourier transform, Zernike, PSF & MTF, diffraction in segmented telescopes, piston errors, interaction and control matrix),
- (3) Labs hands-on that are practical work in lab environment (e.g., co-phasing sensors and correction, diffraction in segmented telescopes),
- (4) Reading assignments that are active learning based on scientific articles,
- and (5) Mini-project, consisting of the analysis of a research article or answering an open question, students are asked to understand and reproduce the results of the article or the scientific properties raised by the question. Students can tackle the problem using either theoretical knowledge, numerical modeling or lab experiment.

EVALUATION

Active learning is expected and evaluations will be proposed in the form of:

- reading assignments (written/oral questions may be asked);
- homework assignments (oral presentation may be asked);
- part way through the METEOR a numerical project will be proposed and will be coached and facilitated;
- upon availability of the SPEED testbed lab experiments for hands-on experience with the hardware and software components that make up a cophasing optics system will be made possible;
- a final exam (conceptual essay and/or questions and quantitative problems).

The final note of the METEOR will be composed for 40% defense evaluation at the end of the METEOR, 30% evaluation (final exam + homework/reading assignments evaluations), and for 30% evaluation with the class project.

BIBLIOGRAPHY & RESSOURCES

- NASA JWST Facebook page
- European-ELT project
- SPEED project website

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