

JWST Wavefront Sensing and Control

The precise optical alignment of the [telescope optics](#) for JWST is achieved and maintained using wavefront sensing imagery from the science instruments, particularly NIRCam.

Introduction

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Periodic wavefront sensing and control (WS&C) will keep the primary mirror segments aligned and in phase, so that their wavefronts match properly and the segments act like one large [telescope](#), rather than 18 individual telescopes.

A telescope commissioning process after launch will proceed through several stages of iterative sensing and alignment correction over several months to establish the initial best on-orbit alignments. Routine monitoring observations and occasional corrections during science operations will subsequently maintain the mirror alignment. Wavefront sensing results will be made available in the archive for use by observers for any data calibration or analysis purposes.

Active optics system overview

Because of the unique circumstances of the stable space environment, the wavefront sensing system architecture on JWST is different from large active telescopes on the ground. Most significantly, JWST is free from atmospheric disturbances and gravity-induced deformations, which are the dominant factors requiring rapid correction for active and adaptive telescopes on Earth. Instead, JWST only needs corrections for wavefront aberrations that change much more slowly than the durations of typical science observations. In particular, the need for wavefront corrections during science operations will be mostly due to temperature changes that cause slight thermal expansion and contraction of portions of the observatory, typically on timescales of several days. This allows the use of the science instrument imaging detectors for periodic measurements, rather than requiring dedicated wavefront sensor detectors or continuously active segment edge sensors.

All instruments will be used for a portion of wavefront sensing during observatory commissioning, but NIRCam is the primary wavefront sensor for JWST and contains several components in its pupil wheels that are used to measure wavefront information. Because of its importance to overall observatory operations, NIRCam is comprised of two fully redundant modules. Weak lenses in the NIRCam filter wheels defocus the images to provide wavefront information. Analysis and determination of the wavefront error is performed on the ground using downlinked image data, and the necessary mirror commands are then uplinked to JWST to correct the alignments.

Each primary mirror segment has actuators on its back that provide six degrees of freedom, as well as control over the radius of curvature. The secondary mirror is also controlled in its six degrees of freedom. Thus, there are a total of 132 degrees of freedom in the telescope that need alignment, plus the focus mechanisms in each of the science instruments apart from MIRI. Other alignments, such as the tertiary and fine steering mirror, have been established during observatory assembly on the ground and are sufficiently rigid to not need correction after launch.

During commissioning

After launch and deployment, the primary mirror segments, secondary, and science instruments will be misaligned relative to each other by up to several millimeters. An iterative process using several types of wavefront sensing and control will bring these mirrors into alignment within tens of nanometers. The large dynamic range (millimeters to nanometers) means that several distinct stages and types of sensing are necessary. This commissioning process is necessarily iterative, due to finite sensing precision and also to mechanism uncertainties inherent to the coarse stage actuator design. As a result, Optical Telescope Element (OTE) commissioning will be iterative at both small scales (a given step may need to be performed several times to converge) and at much larger scales (mechanism uncertainties will likely require looping back to repeat entire sections of the commissioning plan).

The deployment of the secondary mirror, the three-mirror folded side sections of the primary mirror, and initial deployments of segments from their launch restraints will take place starting around 16 days after launch. The wavefront sensing and correction process will begin once the telescope and instruments have cooled sufficiently toward their operating temperatures, expected around 40 days after launch. This process will intersperse individual wavefront sensing and control tasks, initial activation and checkouts of the science instruments, and observatory-level calibration tasks that involve many subsystems across the whole observatory, such as the guider and attitude control system. The main stages of the process are (1) segment location and identification, (2) segment level wavefront control, (3) segment co-phasing, and (4) multi-instrument sensing and control. This process, expected to take several months, comprises a large portion of the six month-long commissioning phase. Because NIRC*am* is the main wavefront sensing sensor, high quality images will first be achieved on NIRC*am* prior to any of the other instruments, about halfway through telescope commissioning. The multi-instrument sensing process then adjusts secondary mirror alignment to optimize image quality over the full instrument suite.

Shortly after the telescope is fully aligned, a stability characterization assessment will characterize the observatory's response to changes in spacecraft attitude with respect to the sun. This will begin quantifying stability in flight, and will better inform subsequent wavefront maintenance.

For more information on OTE commissioning, see [Acton et al. \(2012\)](#) and [Perrin et al. \(2016\)](#).

During science operations

During routine science operations, the wavefront will be monitored periodically, and alignment corrections made as needed. Nominally, the wavefront will be measured every two days using NIRCcam weak lenses. Corrections are expected to be relatively infrequent, no more often than every two weeks and perhaps only a handful of times per year. The sensing and control processes together will take about 1%–2% of observatory time, which is accounted for as part of the observatory calibration overhead.

The cadence for sensing and control measurements may be adjusted in later cycles based on achieved performances in flight. This will happen as part of developing the calibration plan for each cycle, alongside the planning of the instrument calibration programs. The two-day sensing cadence has a loose tolerance; the goal will be to schedule wavefront sensing observations so as to accommodate any time-critical observations, to not disrupt part way through any long mosaic or time series observations, etc.

Note that the intent of corrections is to maintain the telescope alignment, not to intentionally change it. That is, the effect of corrections should be to bring the OTE back to the nominal aligned state that it had at the end of the commissioning period, and ensures it continually remains near that state. There is no plan for "campaign" style observation plans in which the OTE would be temporarily optimized for one instrument over another. Nor is there any need for observers to request scheduling their observations with any particular timing constraints relative to wavefront sensing. However, to mitigate any possible impacts of thermal changes to the point spread function during certain [high-contrast imaging](#) observations, cycle 1 users are directed to [force back-to-back observations of science targets and PSF reference star observations](#). Pending assessment of on-orbit performance, this restriction may be relaxed in future cycles.

The wavefront sensing image data from NIRCcam and the derived wavefront maps will be available from the MAST archive interface, similar to other calibration program data.

References

[Acton et al. 2012, SPIE 8442, 84422H](#)

Wavefront sensing and controls for the James Webb Space Telescope

[Perrin et al. 2016, SPIE 9904, 99040F](#)

Preparing for JWST wavefront sensing and control operations

[JWST technical documents](#)