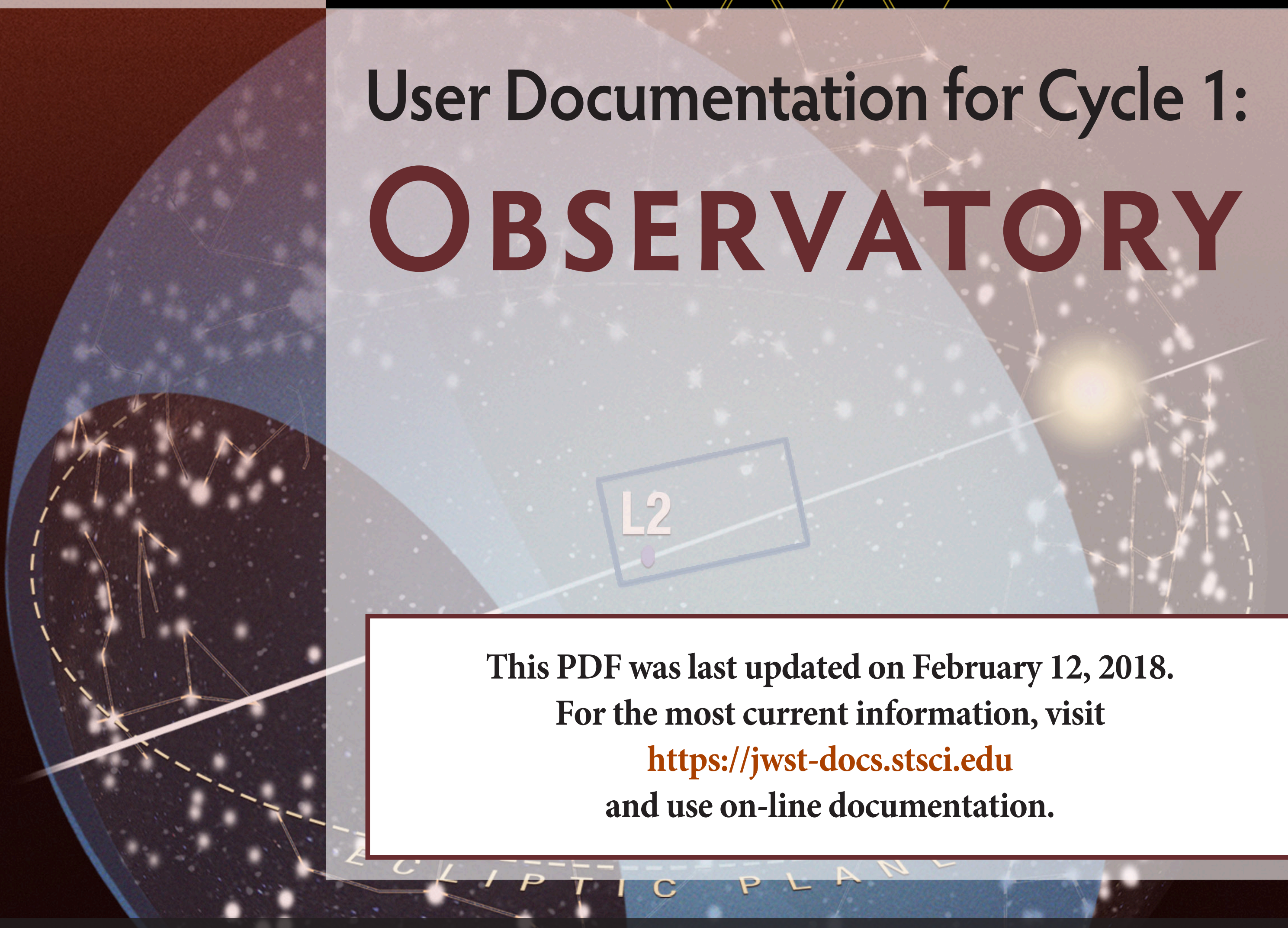
JWST

User Documentation for Cycle 1:

Observatory



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The NASA James Webb Space Telescope, developed in partnership with ESA and CSA, is operated by AURA's Space Telescope Science Institute.

JWST Observatory

The JWST Observatory includes the spacecraft bus and sun shield, Optical Telescope Element (OTE), and Integrated Science Instrument Module (ISIM).

JWST Observatory Overview

The JWST Observatory is comprised of the spacecraft bus, the sunshield, the Optical Telescope Element (OTE), and the Integrated Science Instrument Module (ISIM).

Introduction

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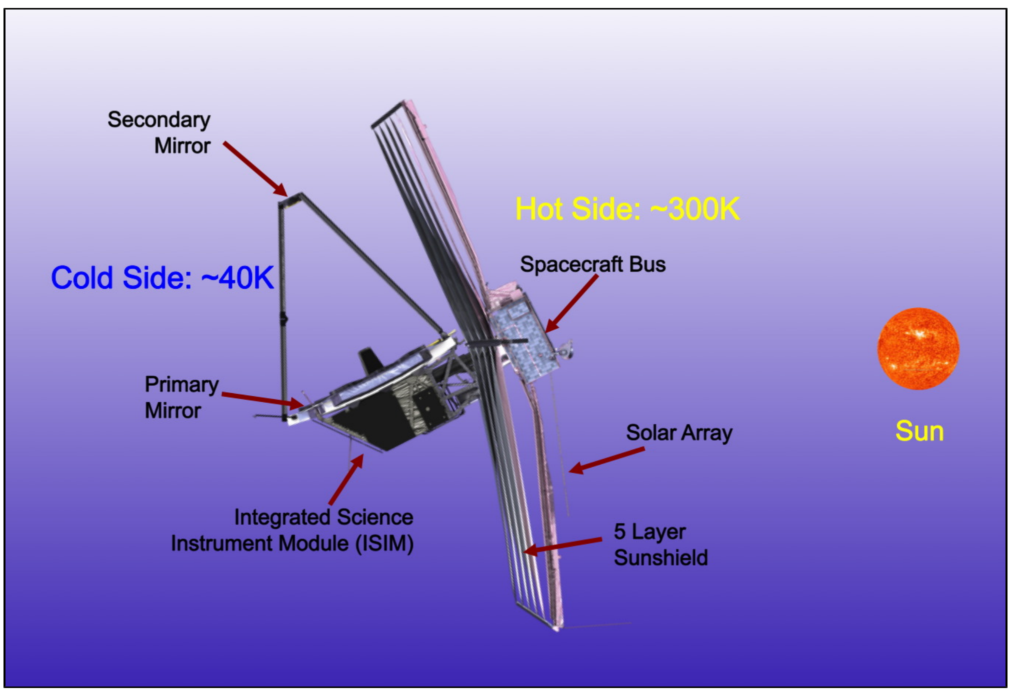
The JWST Observatory is comprised of the spacecraft bus, the sun shield, the Optical Telescope Element (OTE), and the Integrated Science Instrument Module (ISIM), as shown in Figure 1. JWST will orbit the Sun-Earth second Lagrange point.

JWST has 2 distinct thermal regions: the sun-facing 300 K hot side and the 40 K cold side. The spacecraft bus is located on the hot side. The OTE and ISIM are located on the cold side. The hot and cold sides are separated by a sun shield that intercepts over 200,000 W of radiant energy from the Sun and transmits only about 1 W to the OTE and ISIM. By radiating the Sun's energy to space, the sun shield allows the OTE and ISIM to passively cool to cryogenic temperatures, without the use of expendable cryogens.

Figure 1. JWST Observatory



Overview of JWST, showing the 300 K spacecraft bus, which is separated by the sun shield from the 40 K Optical Telescope Element (OTE) and the Integrated Science Instrument Module (ISIM).

The spacecraft bus

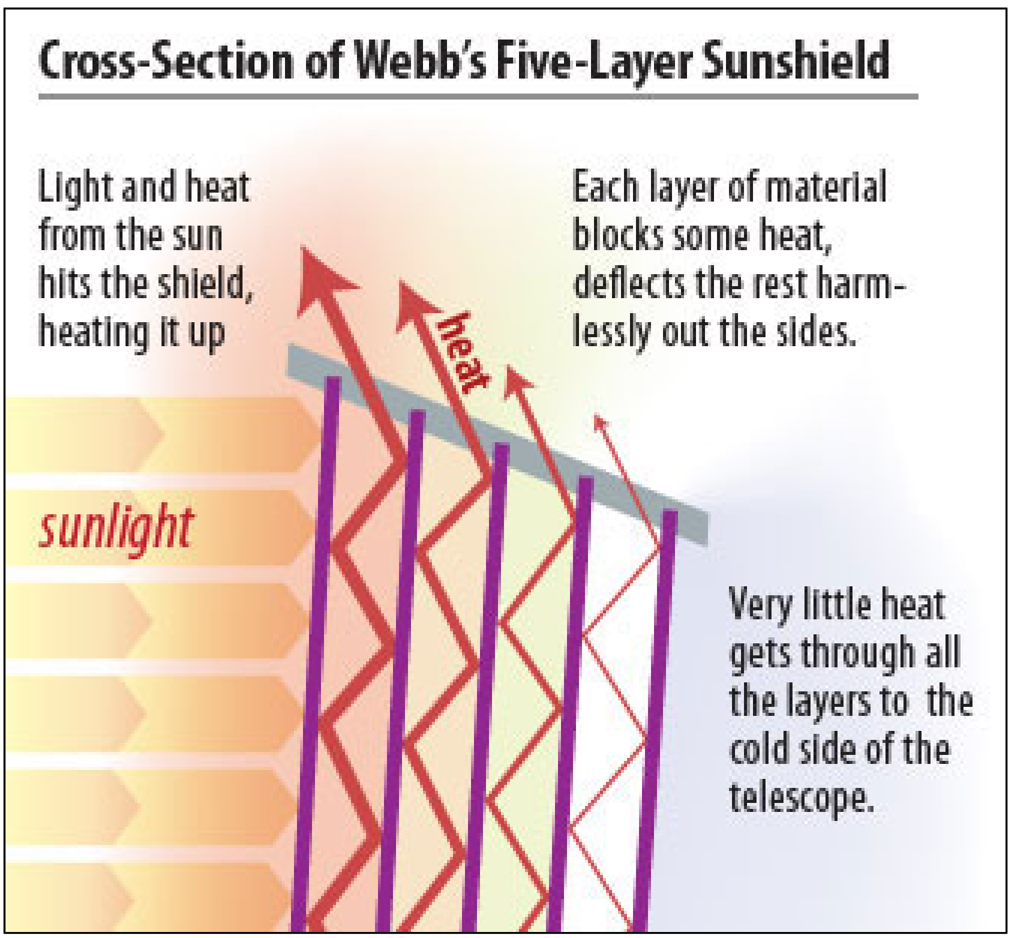
The JWST spacecraft bus provides electrical power, communications, attitude control, thermal control, health and safety functions, command and data handling, and communications services, as well as propulsion for orbit insertion, orbit maintenance, and momentum unloading. The spacecraft bus is located on the sun-facing side of the observatory and operates in a temperature of about 300 K.

The sun shield

In order for JWST to detect the infrared light from faint objects, the telescope and science instruments must be cooled to ~40 K. This cooling is done passively, by a 5-layer, tennis court-sized sun shield, whose purpose is to isolate the telescope and science instruments from the energy of the Sun, Earth, Moon, and the JWST spacecraft bus.

The sun shield is a diamond-shaped system of 5 layers of an aluminum-coated polyimide film called kapton. The dimensions of each layer are approximately 21 m long and 14 m wide. Each successive layer of the sun shield is cooler than the one below. The heat radiates out from between the layers, as shown in Figure 2.

Figure 2. JWST sun shield



The JWST sun shield redirects the Sun's energy away from the telescope and science instruments, allowing them to cool passively.

Where JWST can point

JWST must maintain an attitude such that the telescope and science instruments are protected by the sun shield from the sun. This basic constraint, combined with the geometry of the sun shield, sets the field of regard, which is the region of the sky where JWST can safely conduct science observations at a given time. The field of regard and when targets are visible will be described in JWST Target Viewing Constraints.

JWST Observatory Coordinate System and Field of Regard

The JWST Observatory, as a whole, has a reference coordinate system used by operations to define the pointing of the telescope within the field of regard (FOR), including defining the continuous viewing zone (CVZ) available to the observatory.

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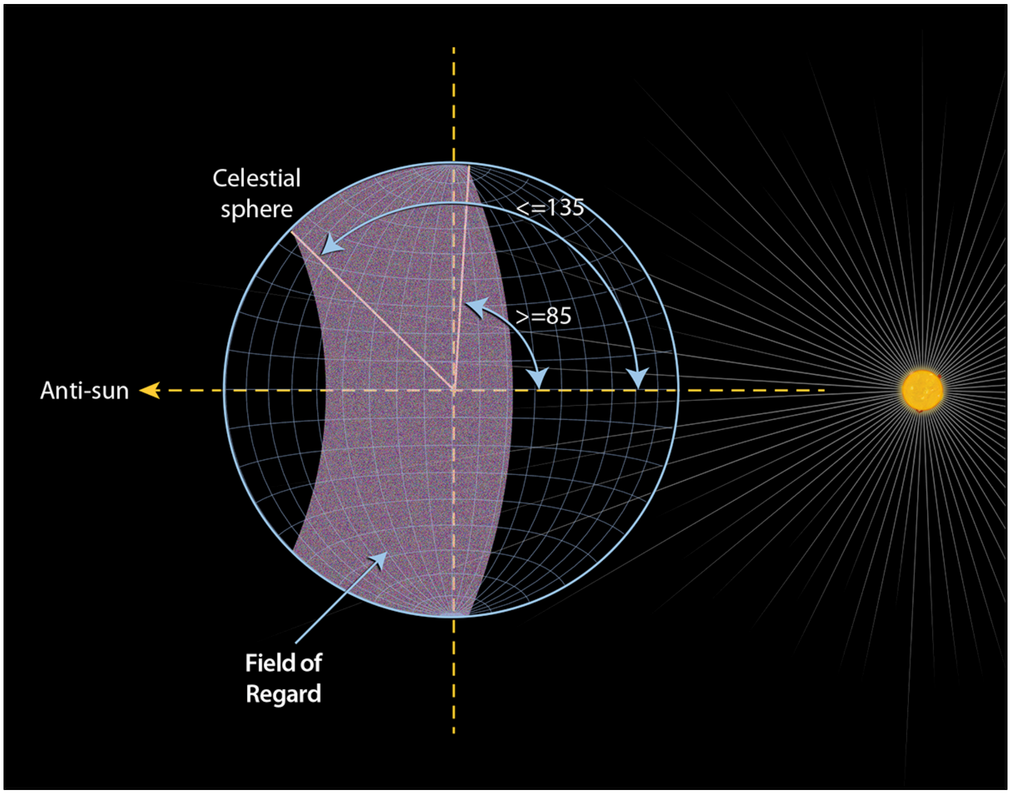
The JWST Observatory V1, V2, V3 coordinate system is primarily used in operations, but there are a number of instances where users may want to understand the orientation of the focal plane or one of the science instruments in the context of the observatory's pointing. Also, there are a number of places, for example in various APT diagnostic plots, where the V axes are used to provide an instrument-independent reference frame.

This article provides information to link the V axes definitions to other JWST software and systems. Furthermore, the JWST field of regard (FOR) defines the instantaneous region of the sky that is available for safe JWST pointing of the telescope boresight, so users should understand the JWST V1 axis in particular (the telescope boresight) in the context of the FOR–this is also described in the article.

JWST Field of Regard (FOR)

The JWST FOR is defined by the allowed range of boresight pointing angles for the observatory relative to the sun line, which must remain in the range 85° to 135° at all times to keep the telescope behind the sun shield. Thus, the FOR is a large torus on the sky that moves roughly 1° per day in ecliptic longitude, following the telescope in its path around the sun. Figure 1 shows a schematic of the FOR.

Figure 1. The JWST field of regard

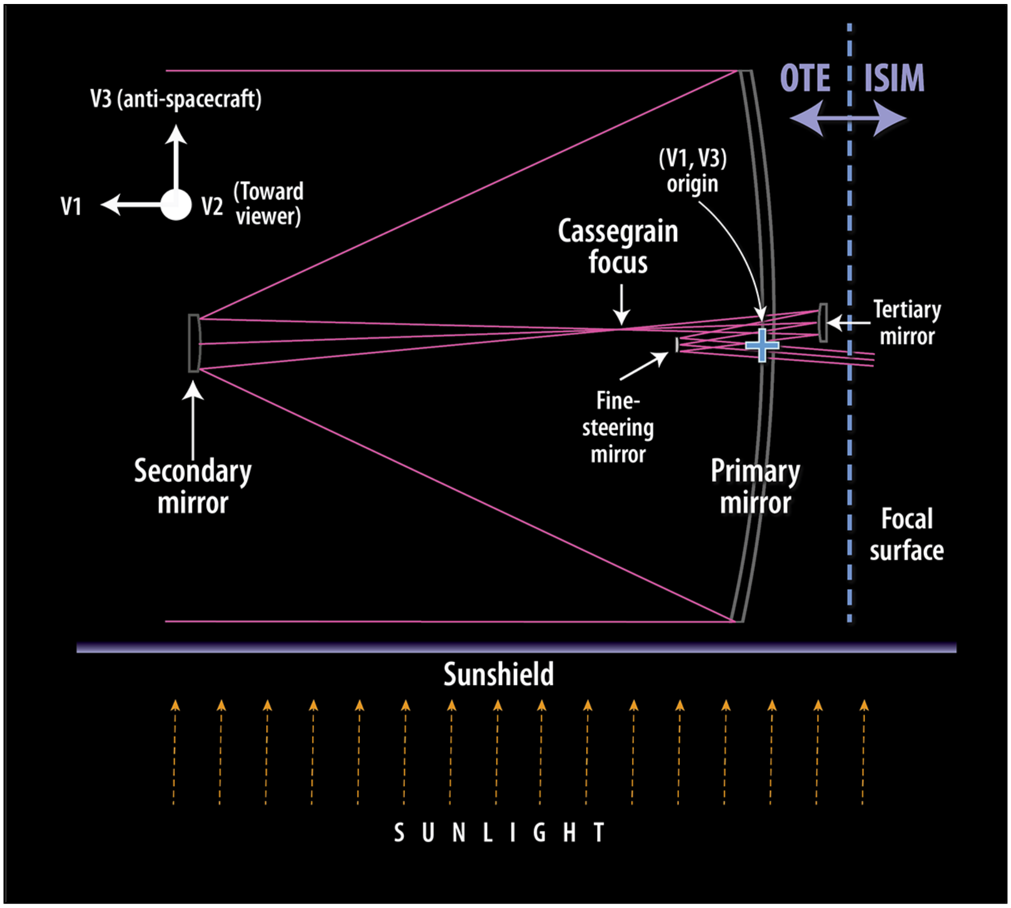


The JWST field of regard extends from a solar elongation of 85° to 135° and changes over time as the observatory orbits the sun. (Source: JWST Mission Operations Concept Document, Figure 4.10.)

The JWST Observatory coordinate system

The observatory V axes are defined with respect to the telescope, as shown in Figure 2. +V1 is the boresight of the telescope, +V3 points away from the sunshield, and +V2 is orthogonal to both of these, forming the "thumb" of a right-handed coordinate system. In the context of Figure 2, the V2 axis is pointing toward the reader (out of the screen).

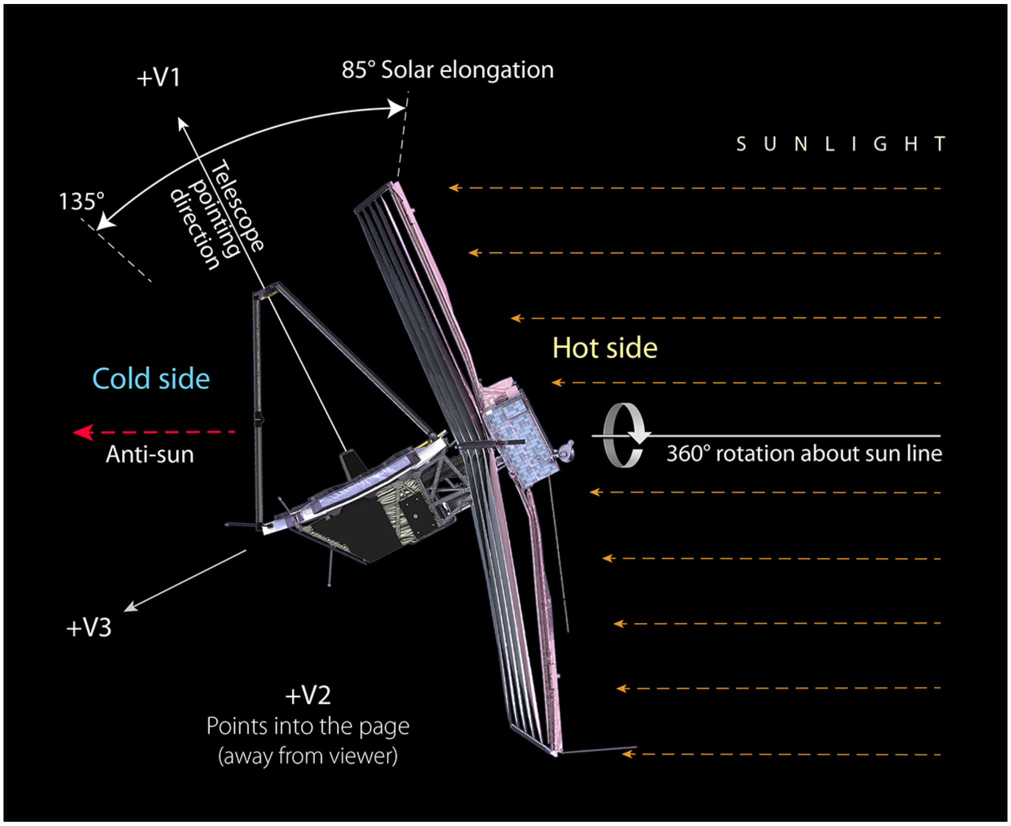
Figure 2. Schematic of the JWST V1, V2, V3 coordinate system



This schematic shows the JWST Observatory coordinate definitions. The sun shines from below in this figure, and the V2 axis points out of the screen toward the reader.

In Figure 3, the JWST coordinate system is shown in the context of the FOR. If the observatory is pointed at 90° solar elongation, the +V3 axis points toward the anti-sun, but as the boresight points elsewhere in the FOR, V3 moves away from the anti-sun direction. In the view shown in Figure 3, the +V2 axis is pointing into the screen.

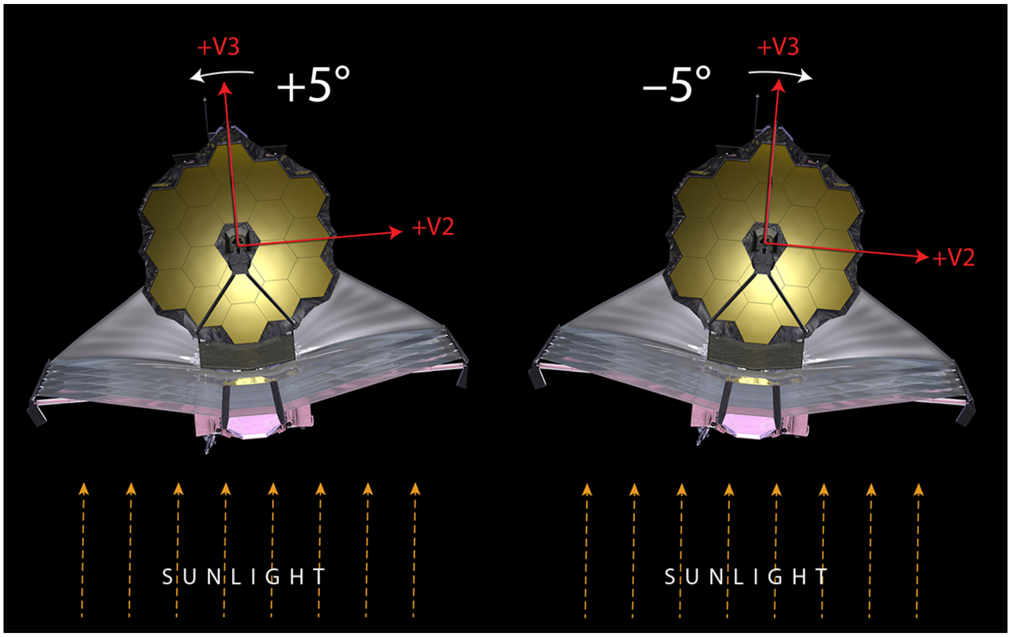
Figure 3. The JWST Observatory coordinates in the context of the field of regard.



This figure shows the JWST Observatory coordinates where V2 points into the screen. Note that the observatory can rotate around the sun line and stay within the field of regard.

Figure 4 shows another view to highlight the restrictions on instantaneous roll about the foresight (+V1 axis). The amount the observatory can roll about the V1 axis is very limited due to the requirement to keep the telescope completely behind the sun shield at all times. The ±5° value shown in the figure is only approximate as the amount of off-axis roll allowed is actually a function of the V1 solar elongation (ranging from approximately ±3° to ±7° as V1 moves from 85° to 135° solar elongation). The limitation on roll comes into play for the so-called "roll dithers" used in many coronagraphic programs. (See the JWST Dithering Overview article for more information.)

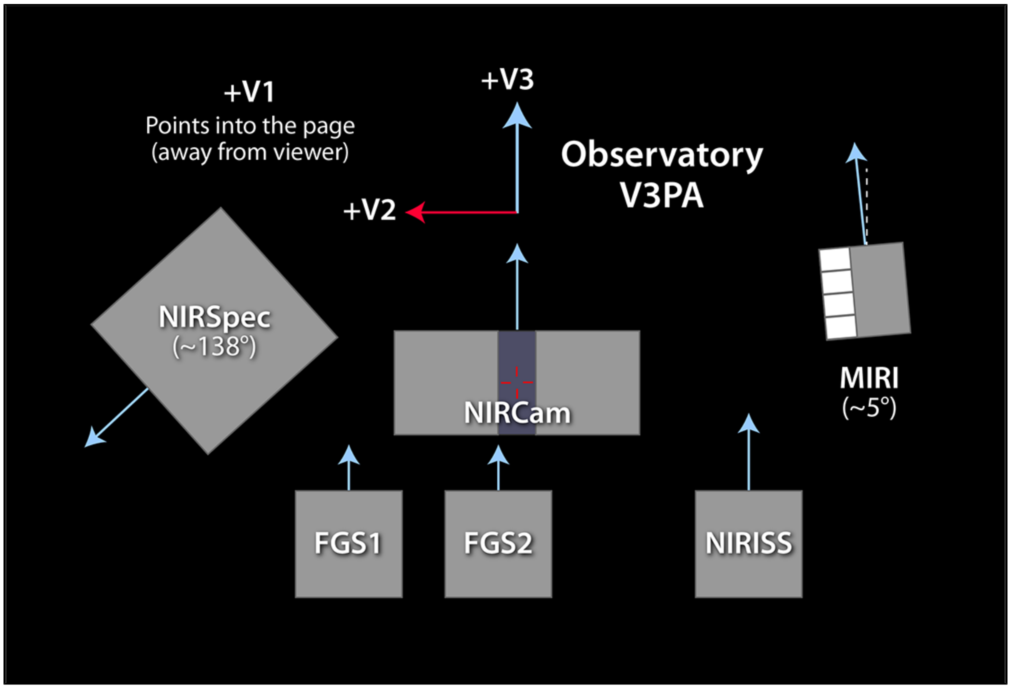
Figure 4. The JWST Observatory coordinates in the context of the roll angle.



This figure shows the JWST Observatory coordinates in context of the roll angle. V1 points toward the reader (out of the screen). Note that the sunlight comes from the bottom of this figure, and the ±5° shown is only approximate.

Figure 5 shows the connection between the V axes and the JWST focal plane. The V3 axis is the primary observatory reference axis used in APT and in operations to connect the individual instrument reference axes (blue arrows) in the planning and scheduling system to the celestial sphere. This is especially important for any observations where the positioning of the instrument fields of view on the sky is important. See the JWST Position Angles, Ranges, and Offsets article for more information.

Figure 5. The JWST Observatory coordinates in the context of the focal plane.

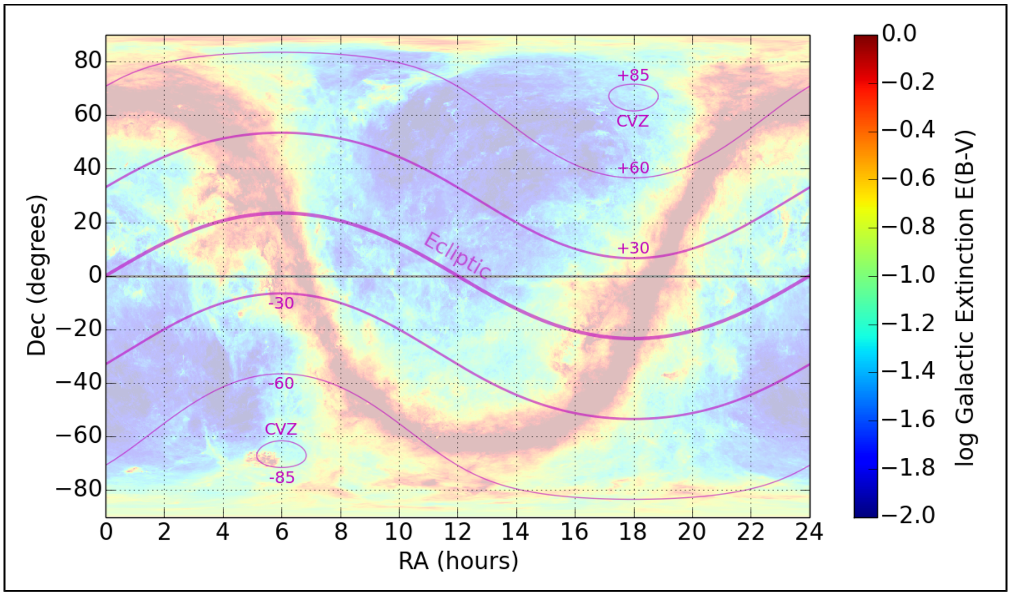


This figure shows the JWST Observatory coordinates in the context of the focal plane. The +V1 (boresight) points into the screen. The blue arrows indicate the reference axes of the individual instruments.

Continuous viewing zone (CVZ)

Because JWST operates in an ecliptic coordinate framework, there are two small continuous viewing zones (CVZs) centered at each of the ecliptic poles (see Figure 6). The 85° solar exclusion zone then determines the radius of the allowed CVZs to be essentially 5°, although any observation approaching the 85° limit will have additional limitations.

Figure 6. An all-sky map showing the location of the CVZs relative to galactic extinction.



Magenta lines show the ecliptic plane (b = 0°) and latitudes b = ±30°, ±60°, and ±85° vs. equatorial coordinates (RA and Dec). The b = ±85° ovals enclose the JWST CVZs, the areas within 5° of the ecliptic poles (b = ±90°). The background color map shows Galactic extinction measured by Schlegel, Finkbeiner, and Davis (1998). Note the higher extinction and SMC visible within the southern CVZ.

In standard J2000 equatorial coordinates, the CVZs are centered at the following coordinates:

N-CVZ: $18^h00^m00.00000^s$ +66°33'38.5520" (or 270.00000000° +66.56070889°)

S-CVZ: $6^h00^m00.00000^s$ −66°33'38.5520" (or 90.00000000° −66.56070889°)

The S-CVZ encompasses a portion of the Large Magellanic Cloud.

References

Schlegel, D. J., Finkbeiner, D. P., Davis, M. 1998, ApJ, 500, 525
Maps of Dust Infrared Emission for Use in Estimation of Reddening and Cosmic Microwave Background Radiation Foregrounds

JWST technical documents

JWST Field of View

Each JWST instrument observes an area on the sky bounded by the coordinates given here in the telescope's (V2, V3) coordinate system.

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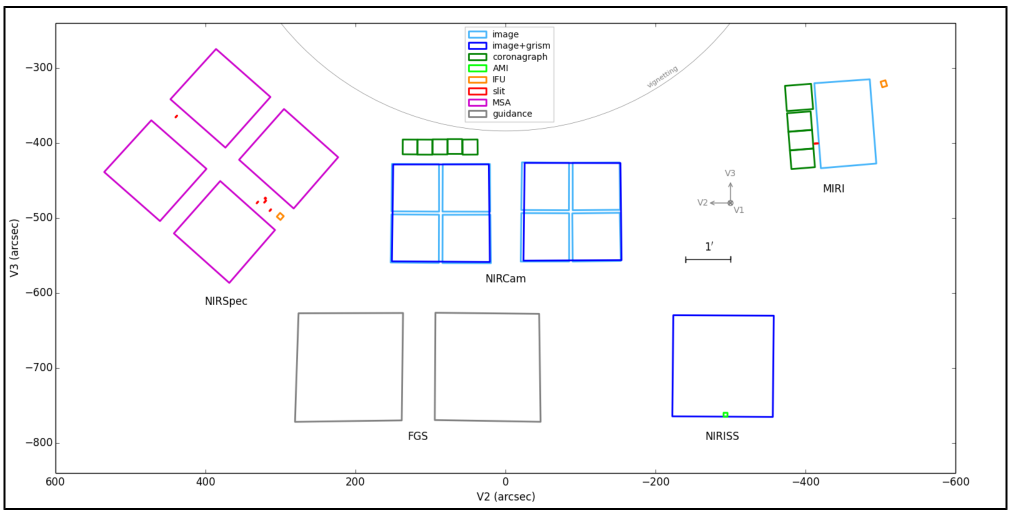
The JWST instruments view portions of the JWST focal plane, as shown in the figure below. In the accompanying table below, we provide the vertices of each region in the observatory's coordinate system (V2, V3). This is a small excerpt of data from the JWST Science Instrument Aperture File (SIAF). SIAF is a reference file used in operations that contains the official information on all apertures (e.g., NIRCam Apertures) and internal instrument coordinates.

Figure 1. The JWST field of view



Each JWST instrument observes an area on the sky as shown here in (V2, V3) coordinates. Colors indicate observing modes: imaging, coronagraphy, grism spectroscopy, slit spectroscopy, NIRISS AMI, NIRSpec MSA, NIRSpec IFU, MIRI MRS (IFUs), and guidance with FGS. For a version of this figure illustrating the types of data collected by each instrument, see the JWST Focal Plane Layout.

The SIAF excerpt table below provides the following information for various apertures defined for each instrument:

- (V2_Ref, V3_Ref): reference position in (V2, V3) coordinates (arcsec); some of these entries are used to define telescope pointings
- V3_IdlYAngle: rotation (degrees counterclockwise) of the aperture's Ideal Coordinate System Y axis relative to V3
- (V2_1, V2_2, V2_3, V2_4), (V3_1, V3_2, V3_3, V3_4): vertices in (V2, V3) coordinates (arcsec) of the quadrilateral defined by each aperture

For a few of the instruments, larger bounding box apertures are excluded from the plot above but included in the table below (marked with *).

The coordinates given below are approximate and subject to frequent minor revisions. More significant revisions are expected after launch based on flight data.

Table 1. Approximate coordinates (V2, V3) of select instrument apertures

Scroll right and down to view the full table.

Instrument	Aperture	V2_Ref	V3_Ref	V3_IdlYAngle	V2_1	V2_2	V2_3	V2_4	V3_1	V3_2	V3_3	V3_4
NIRCam	NRCALL_FULL	-0.32*	-492.59	-0.03	153.16	-153.74	-152.07	151.38	-559.27	-557.14	-426.00	-427.95
NIRCam	NRCAS_FULL	81.35*	-498.23	-0.10	153.16	19.49	20.80	151.38	-559.27	-560.22	-428.00	-427.95
NIRCam	NRCA1_FULL	120.67	-527.39	-0.57	153.16	88.90	88.69	152.08	-559.27	-559.88	-495.59	-495.15
NIRCam	NRCA2_FULL	120.11	-459.68	-0.21	151.95	88.56	88.68	151.38	-491.11	-491.49	-428.17	-427.95
NIRCam	NRCA3_FULL	51.93	-527.80	0.19	84.05	19.49	20.15	83.83	-560.03	-560.22	-495.59	-495.73
NIRCam	NRCA4_FULL	52.28	-459.81	0.06	84.00	20.39	20.80	83.71	-491.46	-491.59	-428.00	-428.20
NIRCam	NRCA5_FULL	86.10	-493.23	-0.09	151.45	20.88	22.23	149.72	-557.79	-558.60	-428.46	-428.63
NIRCam	NRCBS_FULL	-82.29*	-496.21	-0.06	-20.32	-153.74	-152.07	-21.93	-558.08	-557.14	-426.00	-425.81
NIRCam	NRCB1_FULL	-120.97	-457.75	0.38	-89.59	-152.82	-152.07	-89.52	-489.58	-489.07	-426.00	-426.35
NIRCam	NRCB2_FULL	-121.14	-525.46	0.83	-89.55	-153.74	-152.37	-89.05	-558.09	-557.14	-493.08	-493.86
NIRCam	NRCB3_FULL	-51.12	-457.78	-0.49	-21.05	-84.57	-84.75	-21.93	-489.32	-489.59	-426.40	-425.81
NIRCam	NRCB4_FULL	-51.82	-525.73	-0.34	-20.32	-84.82	-84.77	-21.16	-558.08	-557.99	-493.71	-493.47
NIRCam	NRCB5_FULL	-89.39	-491.44	-0.01	-23.98	-154.75	-153.25	-25.54	-556.87	-556.16	-426.75	-426.52
NIRCam	NRCA2_MASK210R	127.23	-405.24	-0.24	137.11	117.44	117.39	137.00	-415.05	-415.17	-395.46	-395.36
NIRCam	NRCA5_MASK335R	107.53	-405.52	-0.19	117.56	97.59	97.55	117.47	-415.45	-415.55	-395.51	-395.43
NIRCam	NRCA5_MASK430R	87.25	-405.19	-0.01	97.27	77.29	77.32	97.24	-415.17	-415.19	-395.13	-395.13
NIRCam	NRCA4_MASKSWB	67.61	-404.67	-0.08	77.46	57.75	57.76	77.40	-414.53	-414.57	-394.82	-394.81
NIRCam	NRCA5_MASKLWB	47.20	-405.44	0.35	57.20	37.13	37.29	57.30	-415.52	-415.40	-395.28	-395.43
NIRISS	NIS_CEN	-290.10	-697.50	-0.57	-222.43	-356.38	-357.71	-223.78	-764.48	-765.25	-630.26	-629.60
NIRISS	NIS_AMI1	-293.74	-762.31	-0.57	-290.73	-295.96	-296.02	-290.79	-764.96	-764.99	-759.72	-759.69
NIRSpec	NRS_FULL_IFU	300.15	-498.12	138.89	295.63	300.55	304.96	300.05	-497.56	-493.15	-498.24	-502.65
NIRSpec	NRS_S200A1_SLIT	332.14	-479.22	138.76	329.66	329.82	331.90	331.75	-478.13	-477.99	-480.38	-480.51
NIRSpec	NRS_S400A1_SLIT	321.87	-477.94	138.78	319.10	319.48	321.91	321.52	-476.84	-476.49	-479.27	-479.61
NIRSpec	NRS_S200A2_SLIT	314.98	-489.45	138.83	312.42	312.65	314.73	314.50	-488.46	-488.26	-490.64	-490.85
NIRSpec	NRS_S1600A1_SLIT	321.13	-473.68	138.77	319.11	320.26	321.30	320.15	-473.72	-472.69	-473.88	-474.91
NIRSpec	NRS_S200B1_SLIT	440.48	-364.52	138.16	437.76	437.92	440.10	439.95	-363.55	-363.41	-365.83	-365.97

NIRSpec	NRS_FULL_MSA*	378.77	-428.16	138.49	223.34	385.55	534.72	368.50	-418.79	-275.00	-439.02	-586.32
NIRSpec	NRS_FULL_MSA1	466.48	-436.16	138.24	398.68	472.27	535.09	460.68	-434.47	-369.74	-438.70	-504.11
NIRSpec	NRS_FULL_MSA2	381.89	-340.89	138.30	313.41	385.93	446.75	373.49	-338.63	-274.66	-341.68	-406.16
NIRSpec	NRS_FULL_MSA3	375.82	-516.37	138.74	307.26	380.36	442.15	368.26	-515.99	-450.72	-520.54	-586.53
NIRSpec	NRS_FULL_MSA4	291.77	-420.64	138.69	223.11	295.32	355.24	282.44	-418.99	-354.67	-422.35	-487.32
MIRI	MIRIM_FULL*	-453.36	-374.07	0.08	-381.41	-494.97	-486.22	-372.61	-436.72	-427.34	-315.00	-323.34
MIRI	MIRIM_ILLUM	-453.36	-374.07	0.08	-420.52	-494.42	-485.67	-411.71	-433.61	-427.39	-315.04	-320.33
MIRI	MIRIM_MASK1065	-393.10	-421.18	0.08	-381.24	-412.55	-410.66	-379.20	-434.74	-432.26	-407.47	-409.96
MIRI	MIRIM_MASK1140	-391.12	-396.53	0.08	-379.18	-410.64	-408.74	-377.22	-409.73	-407.25	-382.44	-384.91
MIRI	MIRIM_MASK1550	-380.25	-372.03	0.08	-377.24	-408.75	-406.82	-375.33	-385.13	-382.66	-357.86	-360.30
MIRI	MIRIM_MASKLYOT	-380.09	-337.61	0.08	-375.11	-410.13	-407.44	-372.64	-357.42	-354.72	-321.09	-323.79
MIRI	MIRIM_SLIT	-414.33	-400.69	4.36	-411.99	-416.72	-416.68	-411.95	-401.14	-400.76	-400.24	-400.62
MIRI	MIRIFU_FULL_SHCNTR_1CH	-504.48	-321.06	17.40	-502.41	-508.81	-506.55	-500.15	-325.74	-323.78	-316.38	-318.34
FGS	FGS1_FULL	207.19	-697.50	-0.02	280.66	138.36	136.62	275.96	-771.81	-769.86	-626.68	-627.03
FGS	FGS2_FULL	24.43	-697.50	0.00	94.31	-46.78	-44.86	93.43	-769.39	-771.74	-627.78	-626.34

JWST Orbit

JWST will orbit around the Sun-Earth L2 Lagrange point, located about 1.5 million km from Earth.

Introduction

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JWST will be placed in an orbit about the Sun-Earth L2 Lagrange point located about 1.5 million km from Earth, which is 4 times the distance between the Earth and the Moon.

It is incorrect to say that JWST "will be at L2." Rather, JWST will orbit around L2.

The distance of JWST from the L2 point varies between 250,000 to 832,000 km, as shown in Figure 1. The period of the orbit is about 6 months. The maximum excursion above or below the ecliptic plane is 520,000 km. The maximum distance from the Earth is 1.8 million km, and the maximum Earth-Sun angle is <33°.

L2 is a saddle point in the gravitational potential of the Solar System. Because saddle points are not stable, JWST will need to regularly fire onboard thrusters to maintain its orbit around L2. These station-keeping maneuvers will be performed every 21 days.

To maintain solar power, the orbit is designed such that JWST is never in the shadow of the Earth or the Moon during the mission.

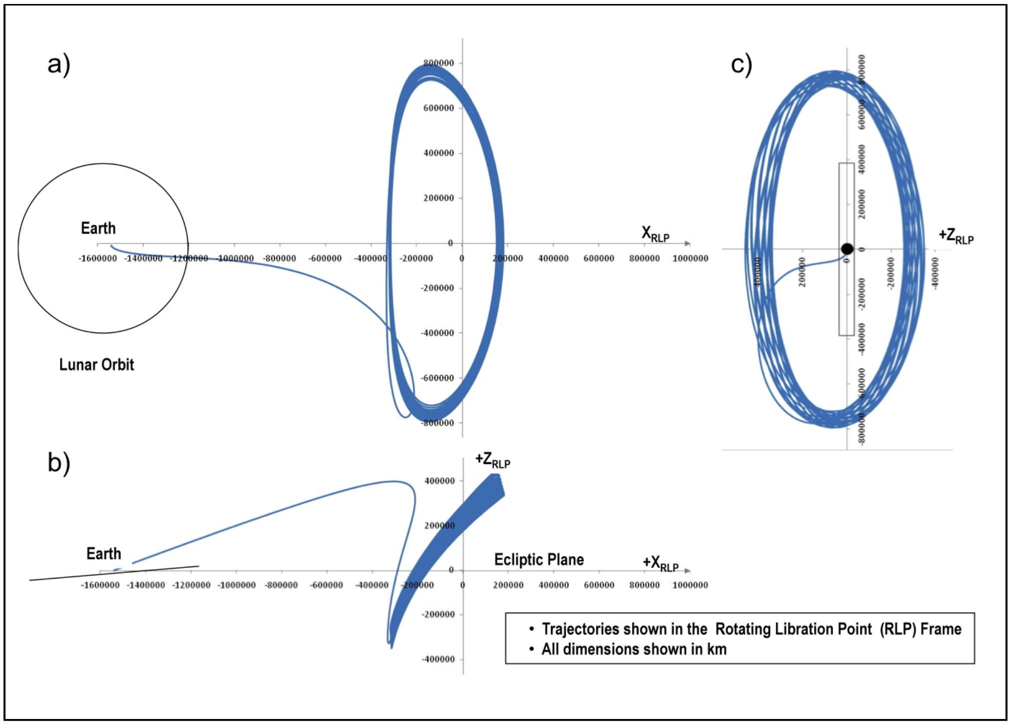
Rationale for the orbit dimensions

A larger orbit makes it easier to get the spacecraft to L2, as well as maintain its orbit. However, larger orbits can also permit stray light from the Earth or Moon to get past the sun shield and strike the primary or secondary mirrors. In addition, a larger orbit reduces communication contact opportunities.

Because JWST is solar powered, it cannot pass through the Earth's shadow during the mission. Orbits are selected that avoid shadow crossings, by selecting the launch time for a given launch day.

The L2 orbit shape is not constrained, so torus orbits, halo orbits, or Lissajous orbits are acceptable and are determined primarily by the launch's time of day and day of year. This freedom in the L2 orbit design allows for multiple launch opportunities for most months and minimizes the velocity needed to get to orbit. A trajectory can be fashioned so that JWST ‘falls into orbit’ about L2 rather than having to forcibly inject itself into a set orbit using its propulsion subsystem; this saves propellant and makes for simpler orbit maintenance.

Figure 1. JWST trajectory and orbit



A representative example of a valid JWST trajectory and orbit. Panel a is the view of the orbit projected onto the ecliptic plane; panel b is the view in the ecliptic plane, and panel c is the view along the Earth-Sun line.

Orbit maintenance

The L2 orbit has an orbit period of 6 months. While orbits about the L2 point are inherently unstable, the orbit size is large and the orbital velocity is low (~1 km/s), so the orbit "decays" slowly. However, JWST's large sun shield, roughly the size of a tennis court, is subject to significant solar radiation pressure which results in both a force and a torque. The direction of solar force varies as the observatory's attitude changes from observation to observation. The solar torque is balanced by reaction wheels, but periodically, the accumulated momentum is dumped by firing thrusters. Because JWST operations are event-driven, the observatory attitude profile and momentum dumping cannot be accurately predicted months in advance. These 2 perturbations increase the acceleration of JWST from its orbit about L2, and necessitates more frequent orbit maintenance (station keeping) maneuvers than other Lagrange orbit missions (which are typically 3–4 times per year). Accurate orbit determination will require daily tracking measurements over a period of 19 days, so station keeping will be performed every 21 days.

Orbit perturbations along the Sun-L2 axis have the greatest impact on-orbit stability. Thrusters are mounted on the spacecraft bus on the side of the sun shield facing the Sun; those used for orbit correction are oriented as far away from the sun shield as possible, and the sun shield can support a larger sun-pitch angle[1] for orbit correction than is allowed for science operations. This architecture allows thruster firing at angles up to 90° from the Sun consistent with Sun avoidance restrictions, which is sufficient to provide orbit correction in all cases.

The orbit will be biased to compensate for mean outward forces associated with gravitation of the planets and radiation pressure on the sun shield.

[1] The angle between the pointing direction and the satellite-Sun line. The "pointing direction" is the "boresight" of the telescope, also called the V1 axis of the observatory.

JWST Spacecraft Bus

The JWST spacecraft bus provides electrical power, attitude control, thermal control, command and data handling, communication, and propulsion.

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The JWST spacecraft bus provides the telescope with electrical power, attitude control, thermal control, command and data handling, communications services, and propulsion.

The solar array provides 2,000 W of electrical power for the life of the mission.

The attitude control subsystem (ACS) provides attitude determination and control for all mission phases and modes of the observatory. The ACS interfaces with the Fine Guidance Sensor (FGS), located in the Integrated Science Instrument Module (ISIM), and with the telescope's fine steering mirror (FSM) for fine pointing control during observations.

The propulsion subsystem provides the means to correct the JWST orbit, control the observatory attitude in certain modes, and unload reaction wheel momentum. Thrusters are used for orbit maintenance, momentum unloads, and some attitude control functions. The observatory carries enough propellant for at least 10 years of science operations.

The spacecraft Command & Data Handling (C&DH) subsystem supports command processing for the spacecraft bus, command routing to the ISIM and Optical Telescope Element (OTE), as well as telemetry recording and routing to the communications subsystem.

The spacecraft's solid state recorder (SSR) provides at least 58.8 Gbytes[1] of storage for science data. The ISIM Command and Data Handling (ICDH) computer creates science data files as the detectors are read out, and transfers these files to the SSR where they are staged until they can be transmitted to the ground.

[1] This article uses the S.I. definition of gigabyte: 1 Gbyte = 10^9 bytes.

JWST Attitude Control Subsystem

Pointing control and slewing of JWST is performed by the attitude control subsystem (ACS). Fine guiding additionally involves the Fine Guidance Sensor (FGS).

Introduction

Parent pages: JWST Observatory → JWST Spacecraft Bus
See also: JWST Pointing Performance, JWST Slew Times and Overheads

Pointing and slewing of JWST is done by the spacecraft flight software, which processes data from attitude sensors, instructions from the ISIM and the JWST ground system, and issues commands to actuators. The attitude control subsystem (ACS) is responsible for maintaining attitude and pointing, slew maneuvers, momentum unloading, Delta-V (orbit correction) maneuver control, high gain antenna pointing, observatory safe modes, and ensuring that the observatory remains within Sun avoidance constraints.

This page provides a functional summary how JWST controls pointing and slewing to conduct science operations. Related pages describe the predicted pointing stability and slew accuracy, as well as the predicted slew times and overheads.

Functional overview

The ACS uses sun sensors, star trackers, and gyroscopes to sense the observatory orientation and movement, as well as reaction wheels and/or thrusters to apply force or torque to the observatory for pointing control or maneuvers. The reaction wheels provide the control torques needed to maintain attitude and pointing as well as to slew. The spacecraft's star trackers provide stellar inertial attitude reference for 3-axis coarse pointing control. The ACS points the telescope boresight to within 8″ (1-σ, per axis) of the commanded position prior to guide star acquisition, without any position reference or input from the Fine Guidance Sensor (FGS).

Control of the roll orientation about the telescope's optical axis is provided by input from the spacecraft's 2 star trackers. The star trackers each have a ~16° diameter FOV, projected on to a 512 × 512 pixel CCD detector. They are oriented over 45° from the telescope boresight and each other. The star trackers compare the observed positions of bright stars ($V < 6$) to an internal star catalog. This allows the use of a single star for fine guidance within the FGS field of view (FOV) while still maintaining roll control.

The duration of slews is a function of the length of the motion. The rate of motion is determined in part by the need to keep settling times within certain limits as well as the desire to reach the new pointing as soon as possible. For slews between 25" and 3°, the slew rate is slower than for shorter or longer slews, to avoid exciting slosh modes of the propellant in the tanks. Once excited, propellant slosh can take a long time to damp (more than 20 minutes in some cases).

Fine guiding

Fine guidance is a closed loop system, in which a guide star in the FGS FOV is used to stabilize the observatory during science exposures. The FGS makes measurements of the guide star position in the plane of the sky and sends these to the ACS every 64 ms. Using the FGS data, the ACS determines the telescope pointing error to be removed, using a combination of the fine steering mirror (FSM) and the spacecraft's reaction wheels.

Each science visit uses a single guide star. Pointing changes within the FGS FOV (dithers, target acquisition motions, etc.) are specified to the spacecraft in terms of the change in the guide star location (Delta X, Delta Y) in the FGS FOV, and the change in the position angle (Delta PA) about the guide star's position.

For stationary targets, the ACS controls the FSM and reaction wheels so that the guide star remains at a fixed location in the FGS detector.

In order to change the telescope pointing orientation by more than one FGS pixel (about 0.06"), the ACS must exit the "Fine Guide" mode, execute the pointing change, and then reestablish fine guidance. Very small offsets <0.06" can be executed by the FSM, while the ACS remains in closed-loop fine guidance control.

Guiding for moving targets

For moving targets (in our Solar System), the process is similar, except that the FGS measures the guide star position in "Track" mode, which is less accurate compared to "Fine Guide" mode for a given guide star brightness. For moving targets, the ground system computes a trajectory for the guide star that keeps the solar system target stationary in the science instrument. The ACS then updates the control position of the guide star every 64 ms, and the FGS in "Track" mode adjusts the position of the guide star track box to follow the guide star.

Managing momentum

The planning and scheduling system provides predictive management of the expected momentum, but actual timelines may differ. Hence, the ACS participates in real-time management of the momentum on the observatory by monitoring the momentum as a function of time and taking autonomous action as needed to keep the observatory safe.

JWST Communications Subsystem

The JWST communication subsystem provides two-way communications with the observatory via the NASA Deep Space Network.

Introduction

Parent pages: JWST Observatory → JWST Spacecraft Bus

JWST's communications subsystem is the part of the spacecraft bus that provides two-way communications to and from the observatory during certain ground testing activities and throughout the operational phase. S-band frequencies are used for command uplink, low-rate telemetry downlink, and ranging. Ka-band frequencies are used for high-rate downlink of science data and telemetry. All communications are routed through NASA's Deep Space Network, with 3 ground stations located in Canberra (Australia), Madrid (Spain), and Goldstone (USA). There are limits on the onboard data volume and data accumulation rates.

Onboard antennas

JWST has a 0.6 m Ka-band high-gain antenna (HGA) as well as a 0.2 m S-band medium-gain antenna (MGA). Both are mounted on a common articulated platform, generally referred to as the HGA platform. The HGA platform can be articulated to point at the Earth for any orientation of the observatory. The broad beam pattern of the MGA ensures that 40 kbps real-time S-band telemetry is available with any visible ground station. S- and Ka-band links can be operated simultaneously and support all communications for commissioning and normal operations.

The Ka-band downlink data rate has 3 selectable speeds: 0.875, 1.75, and 3.5 Mbytes/s. The highest speed is the default. The lower rates can be selected when needed to account for bad weather at the ground station.

High-gain antenna

Routine two-way communications, including downlink of science data from the solid-state recorder, can occur during science observations and during slews. As seen from Sun-Earth L2, the Ka-band downlink has a beam width about the same angular size as the Earth. As such, the HGA pointing must be periodically adjusted to keep Earth centered. The HGA repointing maneuvers are expected to result in a small but measurable pointing disturbance, so they are planned not to occur during science integrations. The HGA must be moved every 10,000 s, which sets a limit on the maximum nominal duration of a science integration. There is an exception to this for certain observing modes requiring long uninterrupted integrations but where small gaps in the science data stream from a pointing disturbance is acceptable.

Some observatory engineering activities can only take place during a real-time communications contact and require the suspension of science observations.

This article uses the S.I. definitions of gigabyte and megabyte: 1 Gbyte = 10^9 bytes, and 1 Mbyte = 10^6 bytes.

JWST Propulsion

JWST's propulsion system provides maneuvering capability for orbital insertion, station keeping, and spacecraft momentum management.

Parent pages: JWST Observatory → JWST Spacecraft Bus

The JWST propulsion subsystem is the part of the spacecraft bus that provides the means to correct JWST's orbit at the second Lagrange point (L2), to control attitude in certain ACS modes, and to unload stored momentum from the reaction wheels (when necessary). JWST nominally carries enough propellant for a 10.5-year mission, pending actual on-orbit performance.

Orbit correction maneuvers, also referred to as Delta-V maneuvers, are used to augment the launch vehicle injection velocity and to maintain a transfer trajectory into orbit about L2, and then to maintain the JWST orbit around L2 (station-keeping maneuvers) for the life of the mission. There are two types of thrusters for these functions. They are mounted on the spacecraft bus to avoid introducing contamination or heat sources near the OTE/ISIM side of the observatory. The Secondary Combustion Augmented Thrusters (SCAT) are used for orbit correction (Delta-V and station-keeping), and mono-propellant rocket engines (MRE-1) are used for attitude control and momentum unloading of the reaction wheels.

The SCATs are bi-propellant thrusters, using hydrazine (N_2H_4) and dinitrogen tetroxide (N_2O_4) as fuel and oxidizer, respectively. They operate in "blowdown mode" with one tank for each type of propellant and using gaseous helium as a pressurizing agent. There are two pairs of SCAT thrusters (paired for redundancy). One pair is located near the center of the bottom of the spacecraft bus where JWST attaches to the launch vehicle. These are used for the first Delta-V maneuvers to reach L2 with the correct velocity for the operational orbit. These maneuvers are executed before the sun shield is deployed.

The other pair of SCAT thrusters is mounted on a boom on the side of the spacecraft opposite the solar array, oriented such that their thrust direction passes through the deployed observatory's center of mass. These are used for the orbit insertion Delta-V maneuver and station-keeping maneuvers. This pair of SCAT thrusters are used after the observatory is fully is deployed.

The MRE-1 thrusters use hydrazine as a propellant. There are eight MRE-1s located on the spacecraft and are oriented so that torque can be applied in roll, pitch, or yaw control axes. For momentum unloads, these thrusters are fired so that the applied torque provides the desired change in the angular momentum of the reaction wheels.

JWST Pointing Performance

JWST's in-orbit predicted performance for slewing accuracy and pointing stability are based on structural, thermal, and optical models. Actual values will be obtained during commissioning activities.

Introduction

Parent page: JWST Observatory
See also: JWST Slew Times and Overheads

The spacecraft's attitude control system (ACS) controls the pointing and slewing of JWST. This page summarizes the predicted pointing performance, based on structural, thermal, and optical models of the JWST Observatory. Actual performance will be characterized after launch during the commissioning period.

Definitions and units

Pointing accuracy is expressed as the 1-σ uncertainty per axis, meaning the 2 orthogonal axes in the plane of the sky. However, the 1-σ radial uncertainty, which is larger than the per-axis uncertainty by a factor of 1.52, is often more relevant to users. In either case, the units are arcseconds or milliarcseconds (mas).

Absolute pointing accuracy

The absolute fine pointing accuracy, without a science target acquisition, is expected to be 0.45" to 0.30" (1-σ radial error), depending on the distance between the guide star and the science instrument aperture. This uncertainty is dominated by guide star catalog position errors and pointing errors due to roll control. Target acquisitions, which are needed for spectrographic fixed slits, IFUs, and coronagraphic observations, further refine the pointing to the level of accuracy for offset slews, as shown in Table 1.

Pointing stability

For fixed targets, the pointing stability is evaluated as the root-mean-square (RMS) error in the guide star position in any 15 s interval, compared to the mean position over a 10,000 s observation. The predicted stability varies slightly from instrument to instrument, from 6.0 mas (NIRCam and NIRISS) to 6.7 mas (MIRI), 1-σ error per axis. The pointing stability includes several forms of "image motion" that determine the overall optical image quality and the telescope point spread function.

For Solar System (i.e., moving) targets, the line-of-sight pointing stability is evaluated as the RMS mean over a 1,000 s observation, for a linear rate of motion of 3.0 mas/s. This is estimated to be 6.2 to 6.7 mas, 1-σ per axis, depending on the instrument. This is much better than the required stability (16.7 mas, 1-σ per axis). At the maximum permitted rate of motion, 30 mas/s, models indicate that the pointing stability will be very similar to the slower 3.0 mas/s case.

Offset slew accuracy

Instrument field of view offsets, after guide star reacquisition, are predicted to be very accurate, generally less than 5 mas, 1-σ, per axis. This type of offset is used for dithers and target acquisitions.

Table 1. Offset angle uncertainties

Offset angle (arcseconds)	Uncertainty (mas, 1-σ, per axis)	Uncertainty (mas, 1-σ, radial)
0.0–0.5	4.0	6.1
0.5–2.0	4.2	6.4
2.0–20	4.6	7.0
20–45	5.3	8.1

References

Coe, D. 2009, arXiv:0906.4123v1 [astro-ph.IM]
Fisher Matrices and Confidence Ellipses: A Quick-Start Guide and Software

JWST technical documents

JWST Telescope

The Optical Telescope Element (OTE) of JWST consists of the primary, secondary, tertiary, and fine steering mirrors. The wavefront of the OTE is monitored and actively controlled.

Introduction

Parent page: JWST Observatory
See also: Wavefront Sensing and Control

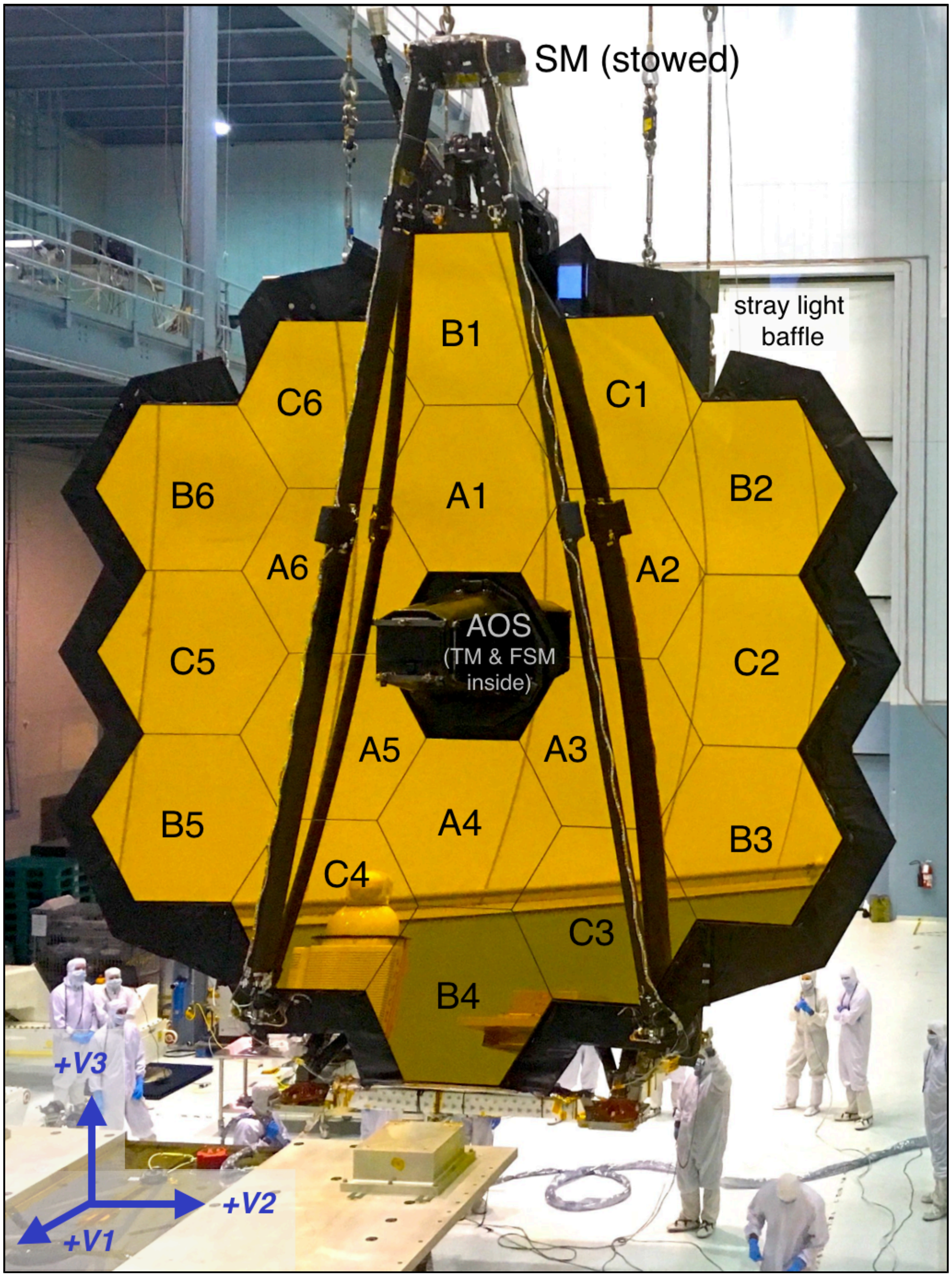
The mirror system that collects and focuses light for JWST is referred to as the optical telescope element (OTE). It has a 3-mirror anastigmat design, consisting of primary, secondary, and tertiary mirrors. A fourth flat mirror, called the fine steering mirror (FSM), is used for pointing stabilization and very small offset maneuvers. The effective focal ratio of the OTE is f/20, and the effective focal length is 131.4 m.

The mirrors are made of beryllium, which is both lightweight and very stable to temperature variations over the range of 30–80 K. The mirrors are coated with gold to provide high reflectivity from 0.6 to just beyond 28 μm.

Optical design and components

Details on the optical design, manufacturing, and testing of the JWST OTE can be found in Lightsey et al. (2012) and Lightsey et al. (2014).

Figure 1. JWST Optical Telescope Element (OTE) with components labeled



The main components of the JWST OTE are labeled above. Unseen on the back side are the mechanisms and electronics for active control of the optics, plus the primary mirror backplane support structure providing a rigid framework. This photo shows the OTE in the large cleanroom at NASA Goddard in October 2016, being positioned prior to the start of the center of curvature tests. The telescope V1,V2,V3 coordinate system is indicated; +V1 is the telescope boresight.

Primary mirror

The primary mirror is comprised of 18 hexagonal segments, each ~1.4 m in diameter, which, when properly phased together, act as a single mirror ~6.5 m in diameter. The individual segments have, on average, better than 25 nm rms surface figure error. The primary mirror serves as the aperture stop for most JWST observing modes, with the exceptions of coronagraphy and aperture masking interferometry (AMI). The unobscured collecting area of the primary mirror is 25.4 m^2. (The total polished area is slightly greater, 26.3 m^2, but the secondary mirror support struts obscure a small portion.) An opaque border around the outer edge of the primary helps minimize stray light.

Each primary mirror segment has actuators on the back that allow control of the 6 spatial degrees of freedom with a precision better than 10 nm. A seventh actuator on each segment controls its radius of curvature, allowing correction for slight manufacturing variations to ensure all 18 segments' focal lengths are very closely matched. Two segments needed larger radius of curvature corrections than the rest, and as a result, have somewhat higher surface residuals. These segments were positioned in the primary in locations blocked by the Lyot stops and aperture mask, specifically positions A1 and C3, thus minimizing the wavefront error for the coronagraphy and aperture masking modes which are most sensitive to such residuals.

Secondary mirror

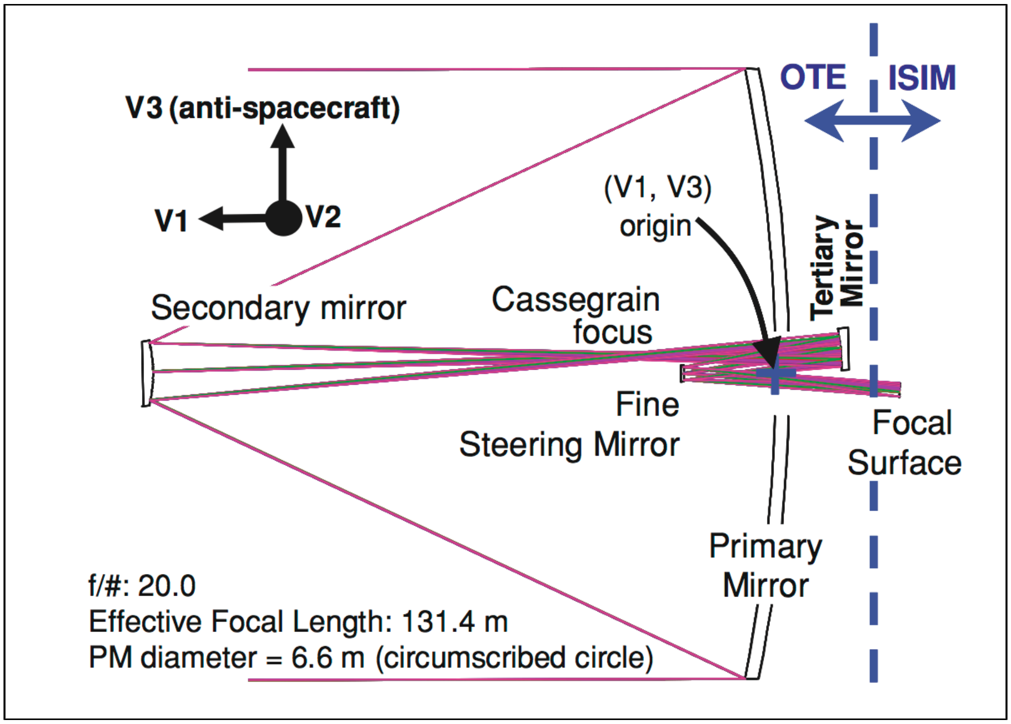
The secondary mirror is a convex circular mirror 0.74 m in diameter. A set of 6 actuators allows control of the mirror's position and orientation, similar to the control of the primary segments. The primary and secondary first bring light to an initial Cassegrain focus just before the entrance aperture of the aft optics system, where a fixed baffle also helps to block stray light.

Aft optics

The aft optics system contains a fixed tertiary mirror and movable FSM. The tertiary mirror is a concave aspheric mirror with an elongated shape roughly 0.73 × 0.52 m in size. It re-images the primary aperture onto the FSM, while canceling out aberrations to provide excellent image quality over the full field of view. Like the primary and secondary mirrors, the tertiary mirror surface figure is better than 25 nm rms. Because the tertiary is at an intermediate focal plane, in-between a focal plane and pupil plane, images taken at different field positions will see different pieces of that surface figure. This will be one of the factors contributing to field dependence of point spread functions. See LIghtsey et al. (2014) for more details.

The FSM is a high quality flat mirror used to stabilize the image during science observations. During observations, it will be continuously adjusted in X- and Y-axis tilts based on measurements made by the attitude control system as part of the fine guidance control loop. The OTE exit pupil is the image of the primary that reflects off the fine steering mirror towards the ISIM focal plane and instruments. A mask around the outer edge of the fine steering mirror helps further minimize stray light.

Figure 2. Schematic of the OTE from the side



The tertiary and fine steering mirrors are located within the aft optics system as shown here. Light exiting the OTE converges to the ISIM focal surface, where several pickoff mirrors redirect portions of the field to the science instruments. (From Gardner et al. 2006)

Deployments and wavefront control

The telescope will be phased during on-orbit commissioning; the wavefront will be periodically monitored during science operations and corrected as needed to maintain alignments.

The primary mirror segments are mounted on a graphite-composite backplane structure that is designed to be very stable. Two "wings", each supporting 3 mirror segments (B2, C2, B3 and B5, C5, B6 in Figure 1 above), are folded at launch, and will deploy once on orbit and then latch firmly into their permanent positions. The secondary is supported by a deployable tripod support structure which also latches into position following deployment. These large deployments happen within the first few weeks after launch while the observatory is en route to L2.

Bringing the mirrors from their initial deployed positions into fine alignment requires a long series of small iterative adjustments that makes use of several different variations of wavefront sensing and control. This process will begin about 40 days after launch and is expected to take about 3 months to complete.

Several OTE electronics boxes support the use of actuator mechanisms and related sensors for position, and to handle telemetry. An actuator drive unit in the spacecraft interfaces with these electronic boxes. Notably, the actuator drive unit can either run the FSM control loop, or send adjustments to the primary and secondary actuators, but not both tasks at once. Thus, during science observations when the fine steering loop is active, the other mirrors will always be static and fixed in position. The OTE electronics system is fully redundant for robust fault tolerance in flight.

Predicted performance

The OTE is required to be diffraction limited for wavelengths $\lambda \geq 2$ µm, and should deliver excellent performance over its full wavelength range down to 0.6 µm. Detailed optical alignment budgets and Monte Carlo simulations are used to model the deployment and alignment process to produce predictions for performance along with statistical confidence intervals. With 95th percentile confidence, the full observatory wavefront error level (telescope plus instrument plus dynamics) should achieve better than 100 nm rms WFE for NIRCam after completion of the WFSC process. The mean predicted performance is even better, <75 nm rms with 50th percentile confidence for NIRCam. NIRISS and FGS will see similar performance; NIRSpec and MIRI have optical budgets designed to tolerate slightly higher levels of wavefront error and this is reflected in the predicted performance. See Lightsey et al. (2014) for more details.

References

Gardner, J. P. et al. 2006, Space Sci.Rev., 123, 485
The James Webb Space Telescope

Lightsey, P. A. et al. 2012, Optical Engineering, 51, 011003
James Webb Space Telescope: Large deployable cryogenic telescope in space

Lightsey, P. A. et al. 2014, SPIE 9143, 914304-1
Status of the Optical Performance for the James Webb Space Telescope

JWST technical documents

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

Parent page: JWST Observatory

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 2 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 6 degrees of freedom, as well as control over the radius of curvature. The secondary mirror is also controlled in its 6 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 6 month-long commissioning phase. Because NIRCam is the main wavefront sensing sensor, high quality images will first be achieved on NIRCam 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 2 days using NIRCam weak lenses. Corrections are expected to be relatively infrequent, no more often than every 2 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 2-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 NIRCam 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

JWST Momentum Management

The JWST Observatory's momentum is managed both predictively and in real time by the attitude control system to keep the observatory under control at all times.

Introduction

Parent page: JWST Observatory

During science observations, solar photon pressure causes angular momentum to build up within the reaction wheels. This angular momentum must be dumped periodically by firing thrusters.

How momentum builds up

During science observations, the observatory will be pointed at a target, in an orientation at which the sun shield center of pressure is not aligned with the observatory center of mass. As solar photons hit the large sun shield, they place a torque on the observatory as a whole. The attitude control subystem (ACS) counteracts this torque by appropriately changing the spin rate on the reaction wheels, with the consequence that angular momentum accumulates in the reaction wheels. Momentum accumulation depends on the solar pitch angle, the roll orientation of the telescope, and the visit duration at a particular pointing position. The angular momentum (spin rate) of the reaction wheels must be managed to be kept within operational limits.

Managing momentum

The planning and scheduling system predicts the momentum profile for a given section of schedule delivered to the observatory, based on an assumed starting momentum and schedule of observatory pointings. Momentum changes can be managed at some level by the way a sequence of observations is planned; this is done by observing at an orientation that builds momentum in a particular reaction wheel, followed by an observation at an orientation that removes momentum from that wheel.

However, managing momentum is only one of a number of planning constraints. At some point, one or more wheels will need to be adjusted to stay within operational bounds. The planning and scheduling system inserts planned momentum unloads into the schedule as needed, based on the modeling of expected momentum buildup, currently expected to be 1–2 times per week. Each unload activity takes a few hours, in which the observatory slews to a particular orientation to minimize the impact on the orbit and then fires thrusters as needed to allow the spin rate of the reaction wheels to be adjusted. The observatory then rejoins the preplanned observing timeline.

Because loss of pointing control from saturating one or more reaction wheels could endanger the entire observatory, an important safeguard is built into the ACS. Since JWST operations are event-driven, the actual sequence of activities can differ from what was planned. For example, if a guide star acquisition fails on one observation, that observation is dropped and the observatory moves on to the next planned observation. This will obviously make the real momentum profile different from what was planned.

The onboard operating system checks the current momentum state before starting each visit. If the momentum state is judged not to be sufficient to safely complete that visit, it will autonomously request a momentum unload be performed before the visit begins. Also, while margins are built into the planned timeline, if for any reason one of the reaction wheels approaches its saturation limit, the ACS will autonomously terminate the science activities, unload momentum at the current pointing, and put the observatory into a "safe mode." Recovery from safe mode would not occur until the next ground contact when real-time communications can be established. The operating system checks prior to each visit should prevent this safety net from ever being needed, but the safety net is there as a stop gap against a dangerous situation for the observatory.

JWST Integrated Science Instrument Module

The Integrated Science Instrument Module (ISIM) is the part of JWST that contains the science instruments, the Fine Guidance Sensor, and the data-handling computer.

Parent page: JWST Observatory

The Integrated Science Instrument Module (ISIM) is the observatory element that contains the 4 science instruments as well as the Fine Guidance Sensor (FGS). It also houses electronics that (1) control the instrument detectors and mechanisms, (2) maintain the thermal environment, and (3) provide command and data processing for the science instruments and the FGS. See Figures 1 and 2.

Figure 1. The JWST Integrated Science Instrument Module (ISIM)

The JWST ISIM is shown in final preparation for thermal vacuum testing at NASA/GSFC, spring 2016.

Figure 2. The completed ISIM

The ISIM, complete with thermal blankets, on its way to the thermal vacuum chamber at NASA/GSFC, spring 2016.

The ISIM Command and Data Handling (ICDH) subsystem provides the commanding, telemetry routing, and processing functions for all of the science instruments, including the Fine Guidance Sensor. The ICDH manages the event-driven science operations of the observatory and coordinates ISIM and spacecraft activities. It performs readout mode processing of the science data, that is, formatting of the science data for each exposure before transfer to the spacecraft's solid state recorder. Software resident on the ICDH analyzes portions of the data for target acquisition purposes.

JWST Solid State Recorder

JWST can store at least 58.8 Gbytes of science data. Science data downlinks occur in two 4-hr contacts per day where each contact can transmit at least 28.6 Gbytes of recorded science data.

Introduction

Parent page: JWST Observatory

The solid state recorder (SSR) onboard JWST can hold at least 58.8 Gbytes of recorded science data.

JWST downlinks science data in two 4-hr contacts per day; each contact can transmit at least 28.6 Gbytes of recorded science data to the ground.

Limits on data rates and data volume

APT calculates the expected data rate for observations and warns users if planned observations may exceed the data volume limits. When constructing the weekly observation plan, the JWST planning system verifies that the data rates within each visit are acceptable, and that the data volume to be accumulated between contacts will not exceed the downlink capacity or the SSR capacity.

Sending science data to Earth

During normal science operations, JWST will downlink data in4-hour contacts, nominally occurring twice per day, approximately 12 hours apart. In one contact, JWST can transmit at least 28.6 Gbytes of recorded science data. If a contact is missed, science observations can continue without filling the recorder, and the ground can catch up on the next contact.

Data rate limits within ISIM

The rate at which science data can be written to the SSR is regulated by the ISIM Command and Data Handling subsystem (ICDH). The maximum ICDH sustained data rate is about 48 Mbits per second, including data packetization overheads. This corresponds to about six 2048 × 2048 full frame image files every 10.5 s. The actual data rate depends on the number of detectors simultaneously in use, their exposure parameters, and the precise timing of when their exposure readouts arrive in the ICDH for processing. The number of detectors in use at any one time could be as large as 14. For example, observations with both NIRCam modules (10 detectors), along with parallel NIRSpec observations (2 detectors), and the FGS for guiding would be sending data from 13 detectors to the ICDH. The relative timing of the arrival of data packets is unpredictable, and this uncertainty is factored into the 48 Mbps limit.

To prevent the loss or corruption of packets, the APT templates set the number of detectors in use and the rate at which data is generated. For example, in the NIRCam rapid readout mode, only one NIRCam module (five 2K × 2K detectors) can be used with NGROUPS = 1. To use both modules (ten 2K × 2K detectors) in rapid readout mode requires NGROUPS = 2. Combinations using multiple instruments must stay within the 48 Mbps limit.

> This article uses the S.I. definitions of gigabyte and megabyte: 1 Gbyte = 10^9 bytes, and 1 Mbyte = 10^6 bytes.

JWST Target Viewing Constraints

JWST has time-variable viewing constraints, imposed by a combination of observatory safety concerns and target position in Ecliptic coordinates.

Introduction

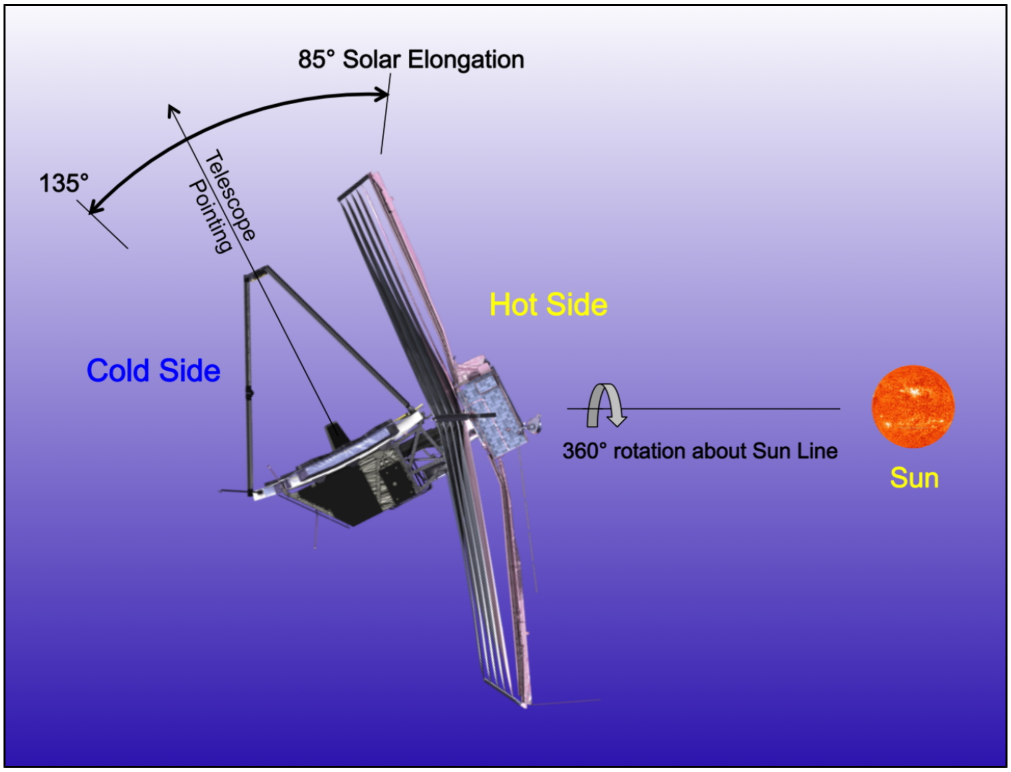
Parent page: JWST Observatory

At all times during the operational phase of the mission, the JWST telescope and science instruments must remain shielded from the sun. To not do so would endanger the entire functionality of the observatory. The geometry of the JWST sun shield limits where JWST can point at a given time and for how long. It also impacts the observatory's ability to observe the celestial sphere at certain position angles, especially for target positions at low ecliptic latitudes.

Field of regard

The JWST field of regard (FOR) is the region of the sky where scientific observations can be conducted safely at a given time. The FOR is determined by the shape of the sun shield, as shown in Figure 1. Pointing constraints imposed by the attitude control system allow the telescope to point towards targets between solar elongation of 85° and 135°, thus creating a large annulus on the sky where JWST can safely point. Over time, this annulus sweeps over the entire celestial sphere. As a result of the FOR, JWST can observe about 39% of the full sky on any given day and can access 100% of the sky over 6 months. The shape of the sun shield is also responsible for the narrow range of permitted roll orientations around the telescope boresight (the optical or V1 axis). This instantaneous roll flexibility is about ±5° but varies with time and look direction. For more on allowed position angles as a function of time and target positions, refer to JWST Position Angles, Ranges, and Offsets.

Figure 1. The JWST field of regard



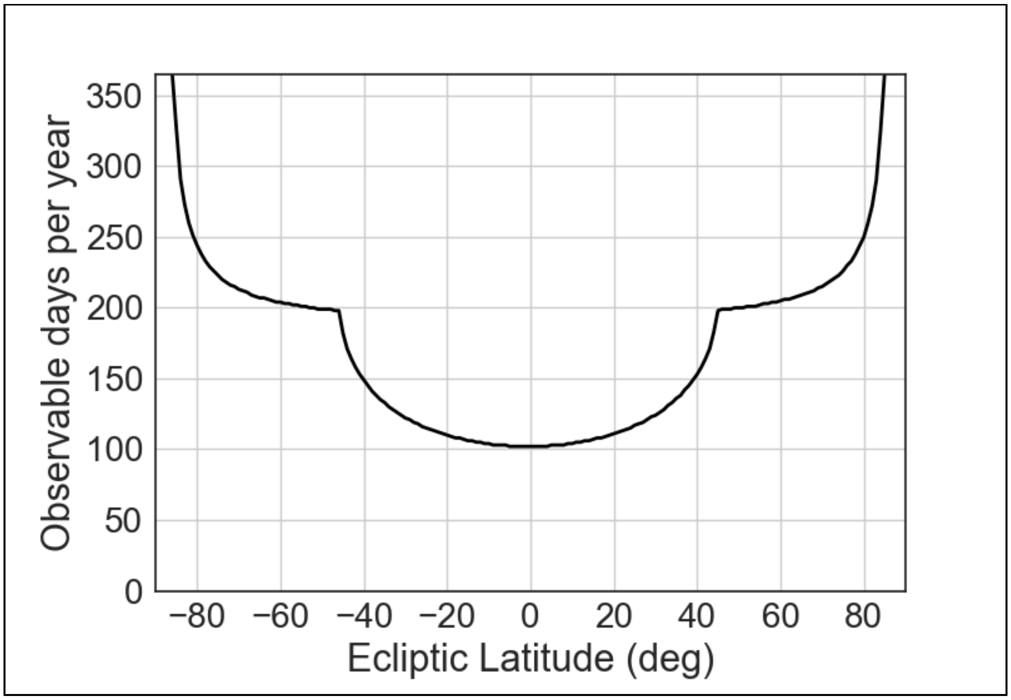
JWST can point at solar elongations between 85° and 135°, as shown in the figure above. It can also observe at any location in the 360 ° circle perpendicular to the sun line, which defines a large annulus where JWST can observe at a given time. This defines the field of regard (FOR).

Target observability

Observability with JWST is very dependent on a given target's ecliptic latitude Below 45° ecliptic latitude, JWST can observe targets in two visibility windows per year centered about 6 months apart, with each window lasting at least 50 days. Above 45° and below 85° ecliptic latitude, the visibility windows transition to one much longer visibility period. As Figure 2 shows, ecliptic latitude determines the number of days per year that targets are observable by JWST. Also, the allowed field of view position angles on the sky available for a given target are affected by the target's ecliptic latitude. These windows and allowed position angles can be calculated for a particular target using one of the JWST target visibility tools.

JWST has a relatively small continuous viewing zone (CVZ), located within 5° of the ecliptic poles. The CVZ is important for some science programs that involve monitoring throughout the year and will be useful for calibration observations. Although the instantaneous roll flexibility is still about ±5°, the JWST field of view rotates through the entire available 360° throughout the year.

Figure 2.Target observability as a function of ecliptic latitude



The number of days per year that targets are observable by JWST, as a function of ecliptic latitude. The graph shows the total number of days, but below 45° ecliptic latitude, this total visibility comes in the form of two smaller time periods separated by approximately six months. Above 45°, one longer viewing period is available for targets, lengthening until the continuous viewing zone is reached at approximately 85° ecliptic latitude. Available position angles are also limited by ecliptic latitude.

Fine Guidance Sensor, FGS

JWST's Fine Guidance Sensor (FGS) provides data for science attitude determination, fine pointing, and attitude stabilization using guide stars in the JWST focal plane. Absolute pointing and image motion performance is predicted on the JWST Pointing Performance page.

Introduction

Parent page: JWST Observatory

JWST's Fine Guidance Sensor (FGS) is a near-infrared (NIR) camera residing in the Integrated Science Instrument Module (ISIM). It has a passband from ~0.6 to 5.0 μm and operates at a temperature of ~37 K, similar to near-infrared science instruments. The FGS has two channels, each with 2.3′ × 2.3′ field of view (FOV).

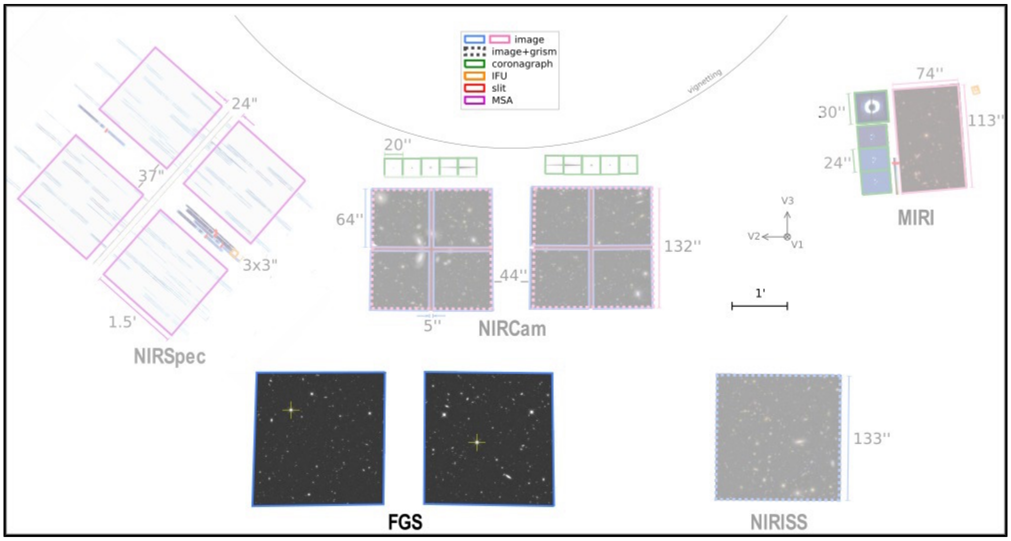
The FGS functions are:

- to identify and acquire a guide star, measure its position in one of the two guider channels, and provide this data to the JWST attitude control subsystem (ACS) for attitude determination.
- to provide fine pointing data to the ACS for attitude stabilization. The FGS can provide this data for both fixed target pointings and for moving target observations.

Guide star position data is used by the ACS for absolute (right ascension and declination) pointing knowledge and pointing control in the plane of the sky (pitch and yaw). ACS uses the data from off-axis star trackers to control the spacecraft’s roll orientation.

In addition to its critical role in executing observations, the FGS also serves as an integral part in the commissioning of the JWST Observatory, and in observation planning. FGS pointing data are archived for every science observation and may be valuable for post-observation data analysis.

Figure 1. FGS fields of view, highlighted, in the JWST focal plane



Observational capabilities

The FGS has an unfiltered passband from ~0.6 to 5.0 µm. Each focal plane array is a 2048 × 2048 HgCdTe sensor chip assembly that has a 2.3’ × 2.3’ FOV after correcting for internal field distortions. The central 2040 × 2040 pixels are light sensitive; the 4 outermost rows and columns are reference pixels for bias measurements. However, the usable FOV for guide star identification and guiding is 2.15' × 2.15' in order to provide sufficient light-sensitive pixels for flat field corrections for potential guide stars near the edge of the FOV.

The FGS has neither a shutter nor a filter wheel; therefore, its detectors are always exposed to the sky.

The JWST proposal planning system currently uses the Guide Star Catalog (GSC) version 2.4.1, which was updated in the fall of 2017. The Guide Star Selection System has been updated to use this new catalog, with improvements to astrometry, photometry, and number and distribution of stars that are available. The JWST Guide Stars article for more information.

FGS optical design

The optical assembly of the FGS is shown in Figure 2. Light from the telescope is focused onto the pick off mirror (POM), collimated by the three-mirror assembly (TMA), and focused by an adjustable fold mirror (fine focus mechanism) onto the two focal plane arrays. The fine focus mechanism allows tuning of FGS focus.

Figure 2. Layout of the FGS optical components on the optical bench

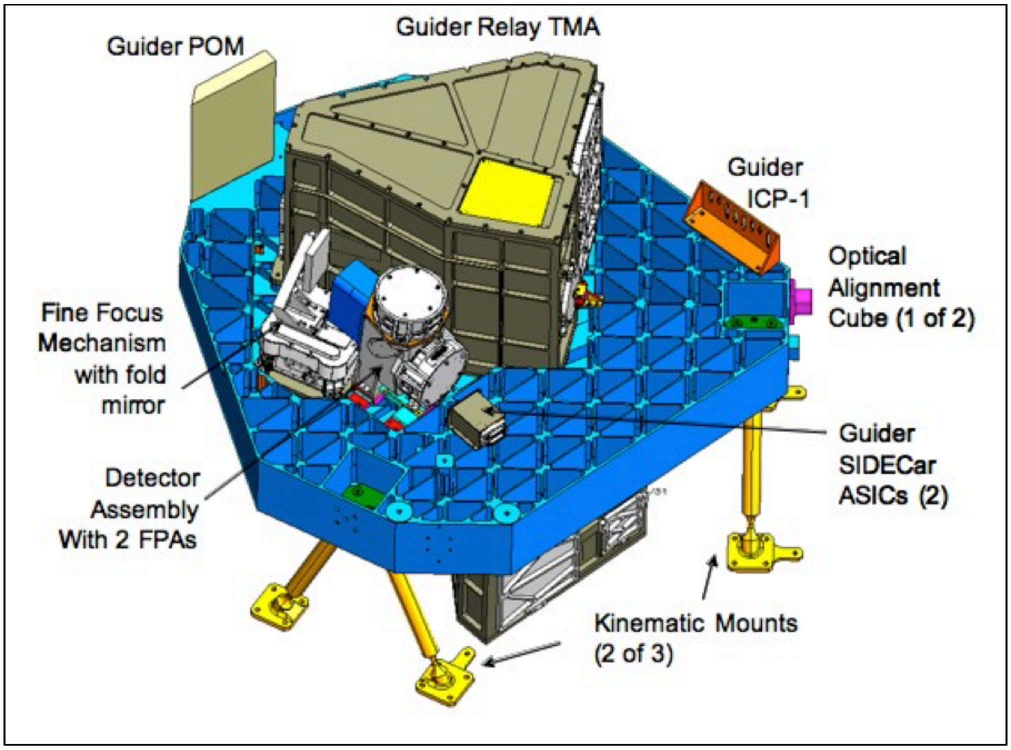


Figure courtesy of Honeywell.

FGS operations

The flight software functions and corresponding operational modes of the FGS associated with the identification, acquisition, and tracking of a guide star are briefly described below.

Identification

At the conclusion of a spacecraft slew, the telescope is pointing at the sky such that the selected guide star is near the center of one of the FGS detectors and the science target is in the desired science instrument, though not yet at the precise attitude for the scientific observation. To assure that the correct guide star is acquired, the FGS obtains an image of the sky and compares the observed positions of stars (and any other luminous objects) to a catalog of objects using a pattern-matching algorithm. To minimize smearing, the "Identification" images are obtained in a sequence of 36 subarrays of 2048 × 64 pixels with an effective integration time of 0.320 s each.

Acquisition

The approximate location of a guide star on the FGS detector is measured using the flight software

"Identification" function, or is determined at the end of a small angle maneuver that offsets the guide star from a previously known location in the FGS FOV. This is followed by executing the "Acquisition" function. . A 128 × 128 pixel (8.6” × 8.6”) subarray is centered at the expected position of the guide star. Images of the guide star within this subarray are obtained and autonomously analyzed by the FGS to locate the star. A second set of measurements using a 32 × 32 pixel (2.2" × 2.2") subarray, centered on the guide star position, is obtained. The FGS reports the position and intensity of the guide star to the ACS; this information is used by the ACS to update its knowledge of the spacecraft’s current attitude, and to bring the pointing of the telescope to within 0.45" (1-σ radial) of its commanded position.

Track

Following the successful completion of the "Acquisition" function, and ACS’s corrective maneuver of the observatory pointing, the FGS executes the "Track" function. The FGS places a 32 × 32 pixel (2.2" × 2.2") subarray on the expected location of the guide star. High cadence subarray images are obtained from which the guide star’s position centroid is determined and reported to ACS every 64 ms. The ACS then enters its “Fine Guidance Mode” to control the observatory pointing in a closed loop using the FGS position centroids. Once the guide star is within ~0.06" of its desired location, the FGS can transition to "Fine Guide" mode.

In "Track" mode the FGS will adjust the position of the 32 x 32 pixel subarray to remain centered on the guide star if the guide star moves. Thus, "Track" mode is used for moving target observations.

Fine Guide

When the FGS transitions from "Track" to "Fine Guide," a fixed 8 × 8 pixel (0.5" × 0.5") subarray is centered on the guide star position. The guide star centroid is computed from each subarray image and sent to the ACS every 64 ms. In "Fine Guide" mode, the subarray is fixed and cannot be changed without transitioning through "STANDBY"[1], which exits fine guide control, and starting again with "Track" mode.

Once in fine guide control, the absolute pointing accuracy of JWST with respect to the celestial coordinate system will be determined by the astrometric accuracy of the Guide Star Catalog and the calibration of the JWST focal plane model.

[1] In "STANDBY," the operations scripts subsystems (OSS) software is running, and the guider is waiting, ready to transition to "Operate" to execute a commandable function such as "Identification." The FGS flight software (FSW) controls the physical and electrical conditions to which the guider's performance is sensitive. In "STANDBY," the FGS FSW will be capable of sending and receiving commands, data, and software updates.

Acknowledgements

The Canadian Space Agency (CSA) has contributed the FGS to the JWST Observatory. Honeywell (formerly

COM DEV Space Systems) of Ottawa, Canada, is CSA’s prime contractor for the FGS.