JWST Position Angles, Ranges, and Offsets

Users should be familiar with JWST position angles, coordinate systems, and related nomenclature to understand the telescope’s pointing constraints. There are “special requirements” available for specifying their pointing needs.

Introduction

Observations that need specific orientations for a particular instrument's field of view on the sky can run into complications due to constraints on where JWST can point relative to the sun.

Reference angle definitions

> *See also: JWST Observatory Coordinate System and Field of Regard, JWST Field of View, JWST Instrument Ideal Coordinate Systems*

The observatory coordinate system (V1, V2, V3) is used in operations (Figure 1). The V3 axis is the relevant vector for science planning. "V3PA", which is interchangeable the "PA of the Observatory," is the position angle (PA) of this reference axis eastward relative to north when projected onto the sky.

Official reference positions and angles relative to V3PA for all defined apertures (or FOVs) are maintained in the Science Instrument Aperture File (SIAF). The SIAF is a controlled document referenced by all relevant software in the JWST operations area. It contains detailed definitions of every instrument, defined aperture, subarray, detector, and even information about transformations and distortion corrections.

A desired orientation or range of orientations for an instrument field of view (FOV) can be specified in the Astronomer Proposal Tool's (APT) Special Requirements. For a selected instrument (or mode, or a subarray), this orientation is expressed as the *aperture position angle* (APA), that is, the position angle for the "science y-axis" of the instrument FOV or detector being referenced (measured north to east).

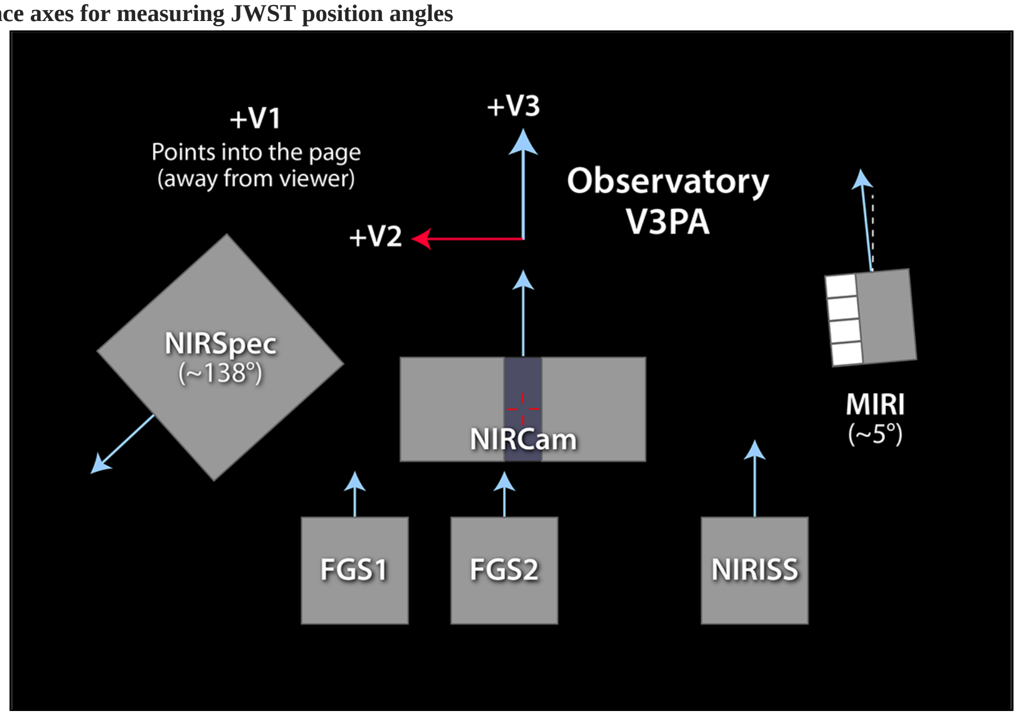
Some instruments are closely aligned to the V3 axis. Therefore, in most cases, planning tools for those instrument modes will report little difference between V3PA and APA values. Table1 provides this information for each science instrument. Users should be aware of what V3PA means because some tools, such as APT, refer to V3PA in portions of the software (like diagnostic plots). However, to first order, observers will deal with the APA, which is the angle specific to the instrument FOV they're using for a given proposed observation. The JWST target visibility tools provide information about both V3PA and APA (and the offsets between them, if any) for the various instruments.

Table 1. V3 offset angle for science instruments

Instrument	Offset Angle from V3
NIRCam	0.0°
MIRI	4.45°
NIRISS	0.57°
NIRSpec	138.5°

Figure 1 shows these reference axes in the context of the JWST focal plane. Note that the two Fine Guidance Sensors are also closely aligned with NIRCam and with V3.

Figure 1. Reference axes for measuring JWST position angles



The direction of the observatory V3 reference axis is shown by the top blue arrow. The smaller blue arrows indicate the reference directions for each instrument. NIRISS, NIRCam, and the FGSs are closely aligned with V3. MIRI is rotated a few degrees counterclockwise, and NIRSpec's reference axis is at a significantly different angle, some ~138° counterclockwise.

APT special requirements controlling position angle

See also: Aperture Position Angle Special Requirements, APT Visit Planner, Target Visibility Tools

In APT, after selecting an instrument, mode, aperture, etc., there are special requirements to specify the desired orientation of a JWST aperture or field of view on the sky, either at an absolute PA or within a range of PAs. Furthermore, the capability exists to specify that a given observation be placed at the same angle or at some offset angle (or within some range of offset angle) from another observation, which may be with the same or another instrument.

These position angle special requirements are specified as follows:

Aperture PA [value1] to [value2] Degrees [followed by information on aperture] [1]

- a minimum and maximum value are requested by the GUI in APT. (They can be the same, but this imposes strict scheduling constraints.)
- An example GUI display would look like ***Aperture PA 135 to 145 Degrees (NIRSpec All Quads|SC=3.5-13.5)***

APERTURE PA OFFSET [obs#] FROM [obs#] BY [XX] Degrees TO [YY] Degrees

- a minimum and maximum value are requested by the GUI in APT. (They can be the same, but this imposes strict scheduling constraints.)
- An example GUI display: ***Aperture PA offset 1 FROM 2 BY 10 Degrees TO 15 Degrees***

[obs#] SAME APERTURE PA AS [obs#]

- An example GUI display: ***2 SAME APERTURE PA AS 1***

> Since APA is dependent on the particular instrument FOV being referenced, users should take care to note whether the two observations being linked with ***SAME APERTURE PA AS*** are using the same or different instruments! Given the restrictions on allowed PAs versus time from the observatory level constraints, a user could easily be specifying an unschedulable observation, especially for targets at lower ecliptic latitudes.

The APT Visit Planner contains diagnostic plots to assess the allowed angles versus time and will flag unschedulable requests at the times they are specified. However, users with PA constraints or those who desire offsets may find it advantageous to use one of the target visibility tools prior to entering observations into APT to understand the overall schedulability and PA flexibility for a given target. Indeed, some preplanning may save significant time and possibly wasted effort downstream in APT in the event that certain desired angles or offsets are not available due to observatory level constraints.

[1] ***Bold italics*** font style is used to indicate parameters, parameter values, and/or special requirements that are set in the APT GUI.

The effect of a target's ecliptic latitude

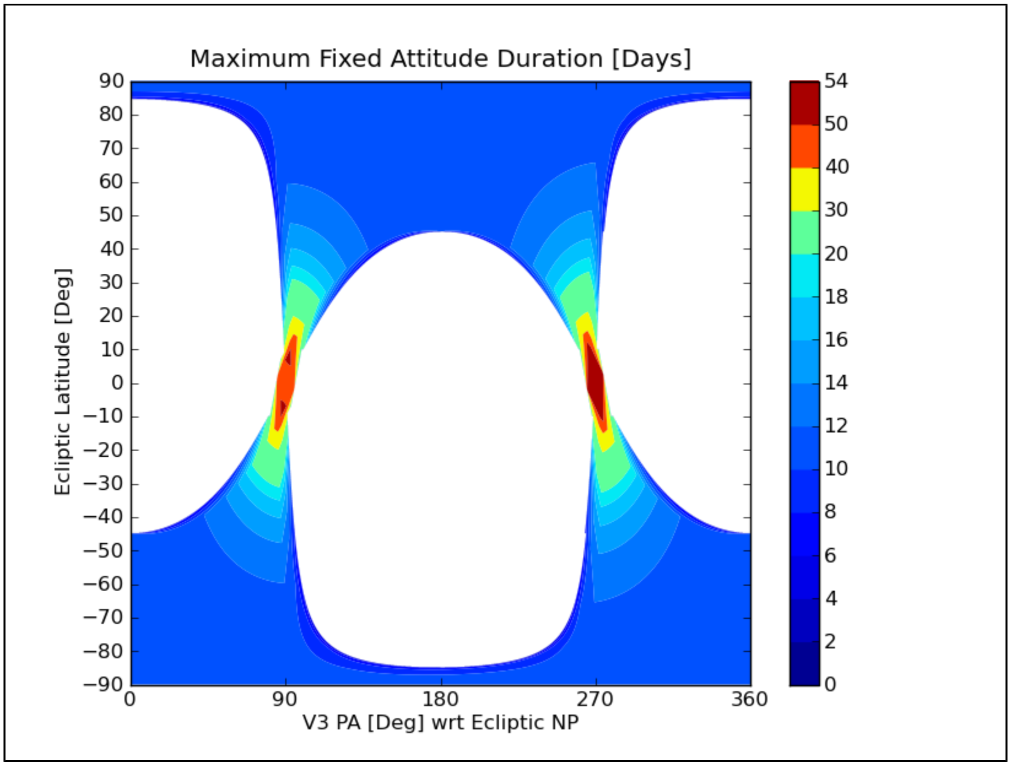
See also: JWST Target Viewing Constraints, JWST Orbit

Astronomical targets near the ecliptic plane are observable by JWST over restricted time periods; even when they're available, the *ranges* of position angles for the JWST field of view on the sky will be nearly fixed (although still allowing the nominal roll flexibility of roughly ±5°).

Targets near the ecliptic poles can be observed at nearly any time, and at any PA on the sky at some times during the calendar year. But again, at any given time, a high ecliptic latitude target will have a nominal PA with only about ±5° flexibility. This limits the length of time a target in this region can be observed at the same PA (for instance, a large mosaic observation).

At and below roughly 45° in ecliptic latitude, the available observing windows and PAs on the sky become more severely restricted, but the length of time one can remain at a given valid PA *increases*. Figure 2 demonstrates these restrictions graphically.

Figure 2. Ecliptic latitude plotted against V3 PA with respect to the ecliptic north pole



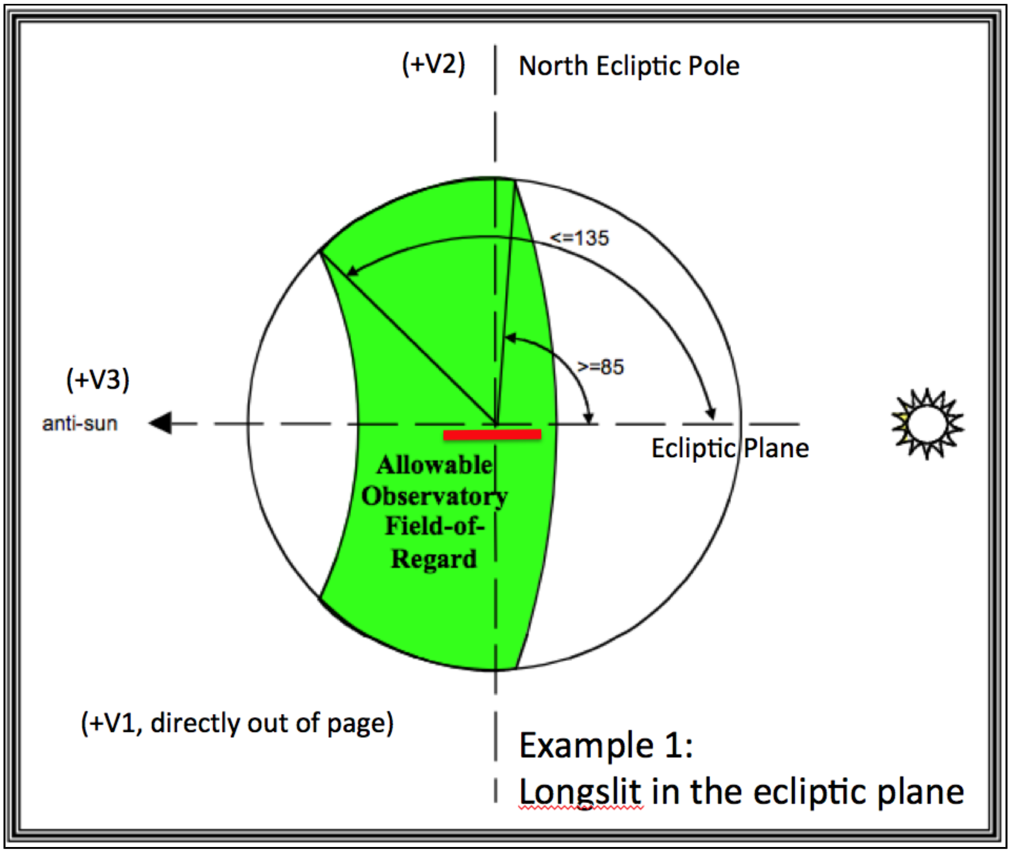
The ecliptic latitude is plotted against the V3 PA with respect to the ecliptic north pole (which by going from 0° to 360° essentially covers one year). The colorized region represents the available portion of the sky in these coordinates. This plot shows several things: the horizontal width of the colorized region as a function of latitude indicates the allowed roll range, and this is restricted at low latitudes. Additionally, the color bar indicates the maximum length of time JWST can stay pointed at a fixed attitude. Except for edge effects, no region has <10 days of visibility at given position angle. (Figure courtesy of Wayne Kinzel.)

Why do these restrictions occur?

Two extreme cases are illustrated below.

First, consider a target located in the ecliptic plane (see Figure 3). Such a target will be visible to JWST instruments for two ~50 day periods approximately six months apart, as the target cuts through the projected annular JWST field of regard (FOR) on the sky. Then, consider an imaginary long slit along the [V3] axis, as shown by the red bar in Figure 3; it is essentially oriented along the ecliptic plane at all times while the target is visible to the observatory. The PA of the JWST FOV on the sky will only have an instantaneous roll flexibility of about ±5° during this time. A large range of PAs will *never be available to JWST* for targets at low ecliptic latitudes. This limitation only improves slowly with increasing (absolute) ecliptic latitude until values of about 40°–45° are reached (see Figure 2).

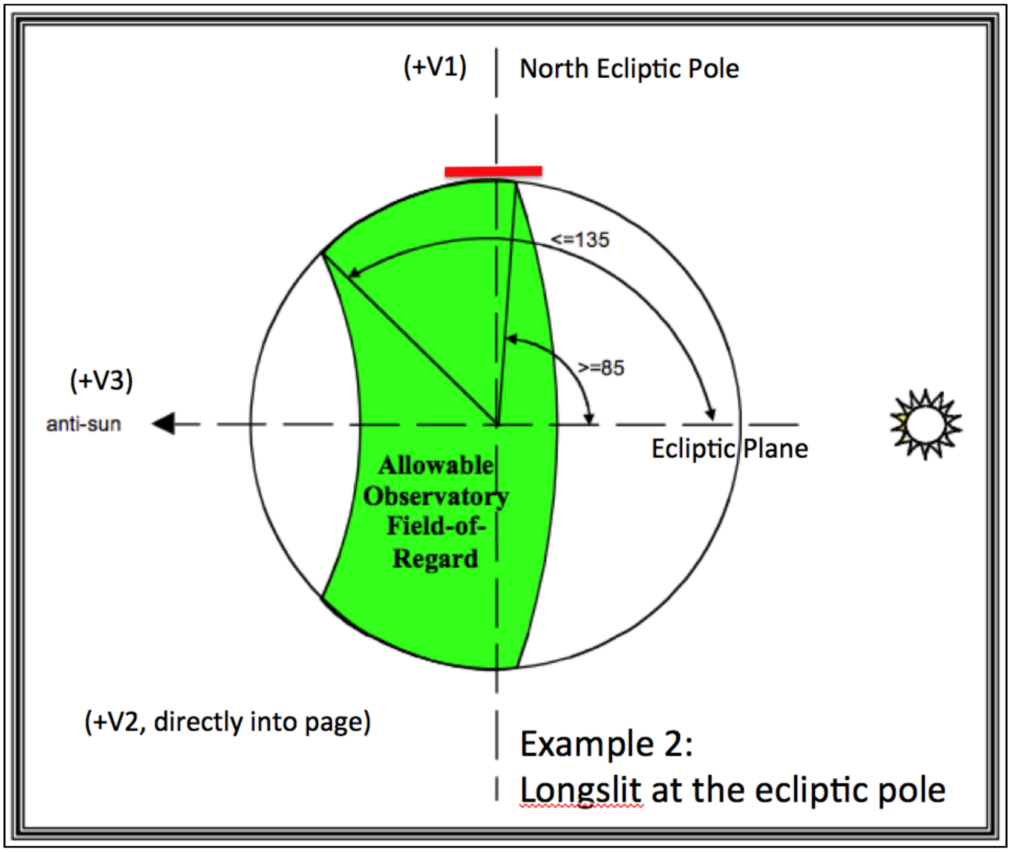
Figure 3. Imaginary long slit (red bar) shown oriented in ecliptic plane



An imaginary long slit (red bar) is shown oriented in the ecliptic plane. The observatory V1 axis is directed out of the page. As the V3 axis sweeps along the ecliptic plane, the orientation of the long slit remains essentially fixed. Referring back to Figure 2, two long windows of visibility exist during the year, but almost no roll flexibility.

Second, consider the other extreme, with JWST pointing near an ecliptic pole. An imaginary long slit is oriented, again, parallel to the observatory [V3] axis as shown in Figure 4. Imagine staying pointed in this orientation for a full year as the observatory orbits the sun. The long slit changes orientation on the sky at ~1°/day. In 90 days, the slit will be perpendicular to its starting position angle on the sky, and in 180 days the slit will be rotated 180° from its starting position angle. Hence, for targets near the ecliptic poles, although the instantaneous PA flexibility is still roughly ±5°, all PAs on the sky are available twice per year (modulo 180°). Interestingly, however, referring again to Figure 2, the *length of time* any particular PA is available is only about 10 days per instance. Such restrictions may come into play when considering large mosaics or other observations that require the same orientation on the sky.

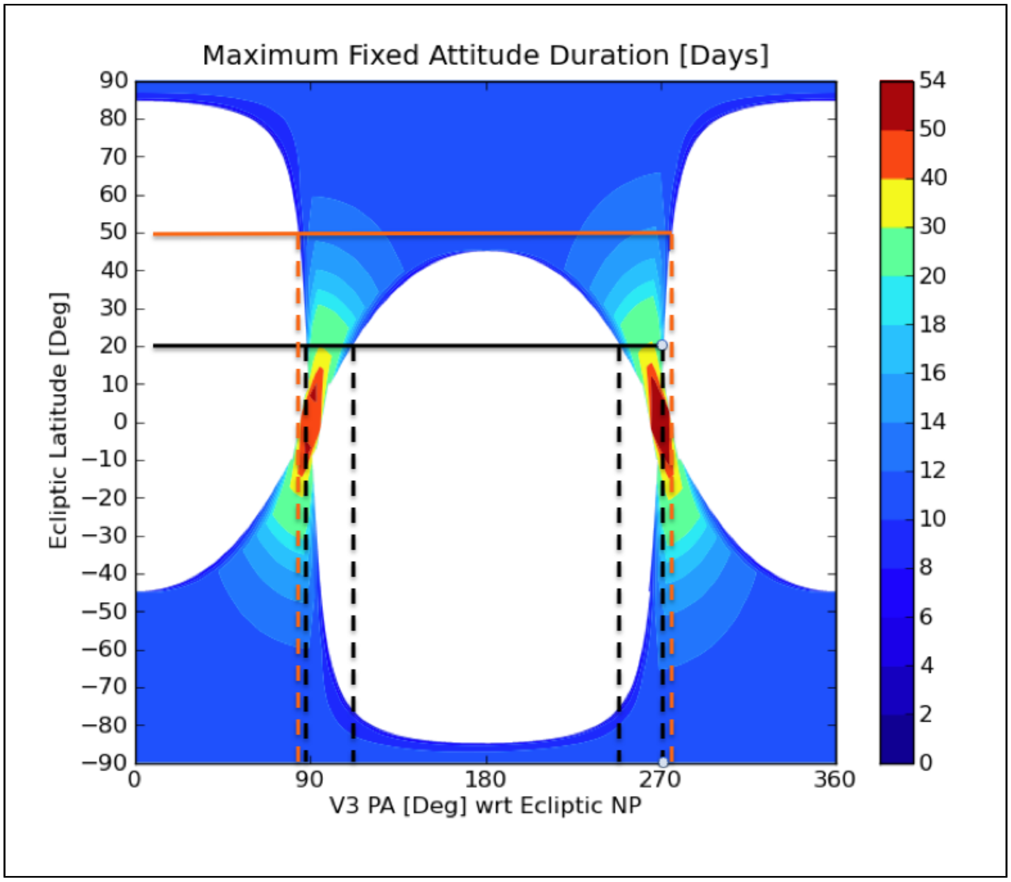
Figure 4. Imaginary long slit (red bar) pointed towards north ecliptic pole and oriented parallel to V3 axis



An imaginary long slit (red bar) is shown pointed toward the north ecliptic pole and oriented parallel to the V3 axis. As the V3 axis sweeps along the ecliptic plane, the orientation of the long slit rotates on the sky by ~1°/day, making all PAs available at some point during the visibility period.

At intermediate ecliptic latitudes, it's possible to calculate available PAs on the sky as a function of time, as was shown in Figure 2. Figure 5 shows how the range of available PAs on the sky varies with ecliptic latitude for two assumed targets: the black lines are for a target at 20° ecliptic latitude, and the orange lines are for a target at 50° ecliptic latitude. A target at 20° has two small (~25°) ranges of V3PA available. Furthermore, the two ranges are nearly modulo 180° from each other, so the total available V3PA range is restricted. At 50°, one large (more than 180°) range of V3PA is available, meaning that any PA on the sky (modulo 180°) is available at some time during the year. As mentioned earlier, a target at the ecliptic pole has the most PA flexibility (but also has limited time at a given PA).

Figure 5. Example of restricted V3PA ranges shown for targets at high and low ecliptic latitudes



A different take on Figure 2 showing the two restricted V3PA ranges for a target at 20° ecliptic latitude (black lines) and the single, much larger range of V3PA available for a target at 50° ecliptic latitude. Thus, if a user requires a specific PA on the sky for a given target, targets at low ecliptic latitudes will have much less schedulability, and in the worst case, may not be observable at the desired PA.

Examples

The schedulability of requested observations can be very limited when specifying PAs and offsets, especially if fixed angles or small ranges of allowed angles are involved. Hence, *these special requirements should only be used when truly necessary for the science*. However, there are a number of expected situations that will require this capability.

Coronagraphy

See also: JWST Coronagraphic Observation Planning, JWST Coronagraphic Visibility Tool Help

One of the most significant applications of constrained PAs and angle offset specifications will be coronagraphic observations with MIRI and NIRCam. For example, PA changes between separate coronagraphic integrations will help to identify real structure in and around a target from substructure within the point spread function (PSF). Because of concerns about changes in the PSF with time (due to thermal changes or drifts in the mirror alignments), many users will want to roll dither on coronagraphic targets at the time of their observations. Practically speaking, this will usually mean two back-to-back observations made at ±5° from nominal observatory roll at the time of the observations (for example, a first integration at −5° from nominal roll followed by one at +5°—note that no observation is taken at nominal roll).

Certain cases may also need follow up at some more substantial angular offset (e.g., 30° offset) relative to the first observations, which will need to be scheduled at a significantly later time. (Note also the potential impacts of targets at low ecliptic latitudes, for which this may be impossible due to the observatory roll restrictions.) Coronagraphic observers will want to assess their potential targets carefully, and when possible, select targets above 45° ecliptic latitude if they require large offsets in PA between observations. To help assess these situations quickly and easily, a coronagraphic target visibility tool is available to users.

Near and mid-IR imaging and mosaics

Some programs will want to obtain near- and mid-IR imaging, using NIRCam and MIRI, of a similar region on the celestial sphere. The use cases vary from a single field to larger mosaicked fields to covering an entire region such as the HUDF, or an extended source such as a nearby galaxy or H II region. Because the field sizes (and orientations at some level) are different between the cameras, some users will not only want to orient one of the cameras in a certain way to cover a desired region, but may also want to align (or roughly align) the two camera fields of view as projected onto the sky in order to maximize the overlap.

To visualize this, imagine that a single NIRCam field is obtained on an extended object, and a user wants to cover the same region with MIRI. A MIRI mosaic will be required because the MIRI field of view is smaller. If the MIRI observation is scheduled with the field rotated by 45° from the NIRCam observations, the corners of the MIRI fields in the mosaic will hang outside of the NIRCam region, and it will likely require more MIRI pointings to cover the region of interest. A user would likely want specify a PA constraint on the MIRI observation to align (at least approximately) the MIRI field of view with that of the NIRCam observation. (Note, however, there may be a allowable options offset by 90° or 180° that would increase schedulability, at least for targets above absolute ecliptic latitude, |~45°|.)

Complications

There are subtleties that can arise in the JWST planning system due to the offset between the origin of the observatory coordinate system and the coordinate system based on a given instrument aperture. Considerable effort has been expended to insulate the science user from this underlying complexity, but it may still be of use to understand that it exists.

As mentioned above, the JWST planning and scheduling system itself will operate on a system of axes (V1, V2, V3) defined with respect to the observatory. Hence, while science users may specify a PA of a particular instrument/aperture on the sky for a given observation, or a relative orientation rotated around the target location, the observatory is actually referenced to (and rotated about) the V1 axis (the boresight), which *is not coincident with the target*. For most cases, the difference in angles is slight and inconsequential. However, in a worst case scenario, close to the celestial poles, a target and the V1 axis position could be at significantly different angles with respect to the pole, which is a complication that the planning system handles internally.

Another subtlety involves the ±5° guideline on the nominal roll flexibility. The ±5° is not a hard number, but rather varies from ±3° (at 85° sun angle) to ±7° (at 135° sun angle). Thus, with careful planning, operations may be able to squeeze out an extra degree or two of roll flexibility, but it will come at the cost of making a given observation more restricted in terms of when it can be scheduled. There may be special applications, for instance, in certain coronagraphy programs, where this extra angular offset will benefit the science. Fixing observations toward the large end of this range will be very restrictive to scheduling and should only be done when scientifically justified.