# Wavefront Sensing and Controls for the James Webb Space Telescope

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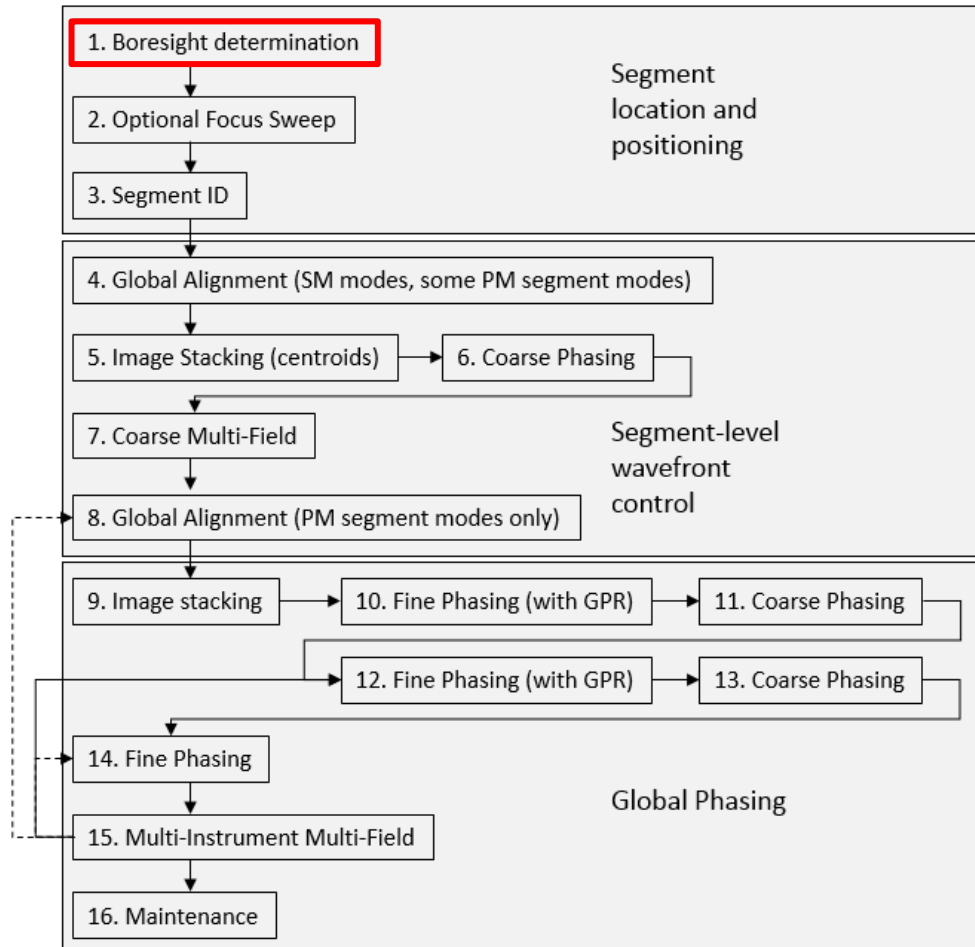# Introduction

- **James Webb Space Telescope (JWST) is unique in that it is**

  - Large (6.5 meters)

  - Space-based

  - Segmented

  - Deployable

  - Cryogenic

  - High authority

- **The telescope must be aligned in space**

  - Rely on existing science instruments (no wavefront sensor)

  - Special optical elements are placed in 8 of NIRCam's 48 filter wheel positions for WFSC

  - Images are taken and downloaded for analysis on the ground (no on-board image processing)

- **The primary mirror consists of 18 segments**

  - Hexapod allows for adjustment is 6 DOF

  - A 7th ROC actuator allows the ROC to be changed

- **The secondary mirror is also on a hexapod**

# The WFSC Process

1. Boresight determination
↓
2. Optional Focus Sweep
↓
3. Segment ID

**Segment location and positioning**

4. Global Alignment (SM modes, some PM segment modes)
↓
5. Image Stacking (centroids) → 6. Coarse Phasing
↓
7. Coarse Multi-Field
↓
8. Global Alignment (PM segment modes only)

**Segment-level wavefront control**

9. Image stacking → 10. Fine Phasing (with GPR) → 11. Coarse Phasing
12. Fine Phasing (with GPR) → 13. Coarse Phasing
↓
14. Fine Phasing
↓
15. Multi-Instrument Multi-Field
↓
16. Maintenance

**Global Phasing**

**We will touch on each of these processes briefly**

# Image Mosaic and Boresight determination



- **Telescope is slewed to a bright isolated star.**
- **~200 NIRCam images are combined to make a large image mosaic.**

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2. Optional Focus Sweep
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Global Phasing

- **SM is scanned in piston to step through image focus**
- **Phase Retrieval calculates focus error**
- **SM is placed at best focus, while guarantee that at least one spot is focused enough to allow guiding**



Seg. 1, Seg. 5, Seg. 6

SM despace (microns): -400, -200, 0, 200, 400
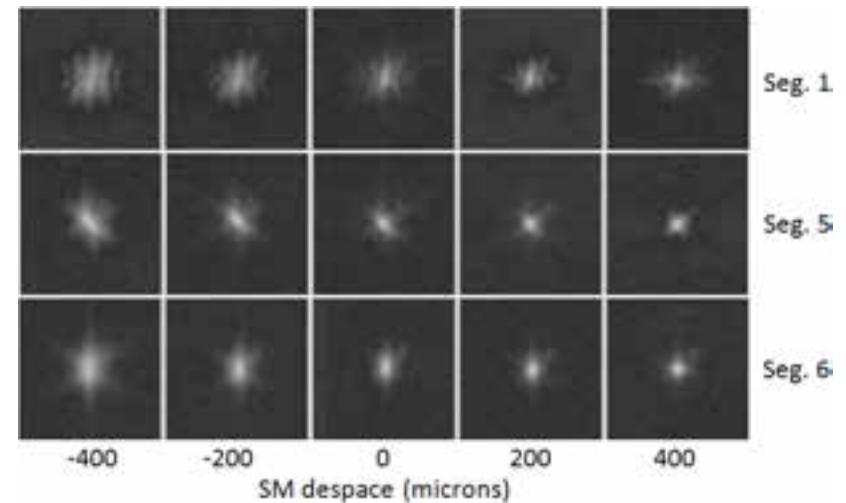
# Segment ID





- **A series of telescope pointings are planned to cover the entire mosaic**
- **At each pointing, each segment is tilted slightly so its spot will move**
- **Images are taken before and after tilting. If the image moves, we know which segment it is associated with.**
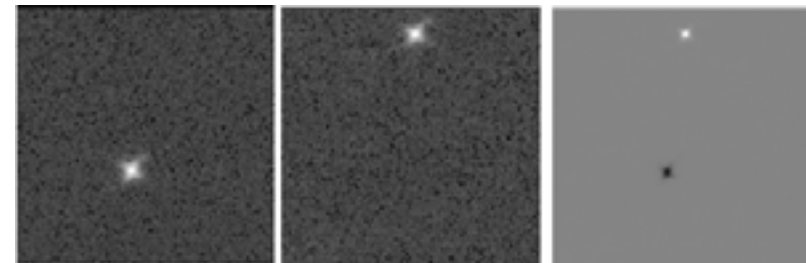


**Before tilting**          **After**          **Difference**

- **Spots are moved into a hexagonal array**
- **SM is moved in piston to create defocused images**
- **PMSA tilts are also applied to maintain array**
- **Phase Retrieval yields wavefront over each segment**
- **Global Alignment is performed twice First application controls**
    - **SM position**
    - **PMSA piston**
    - **PMSA clocking**
- **Second use of Global Alignment controls**
    - **PMSA clocking**
    - **PMSA translation**
    - **PMSA ROC**
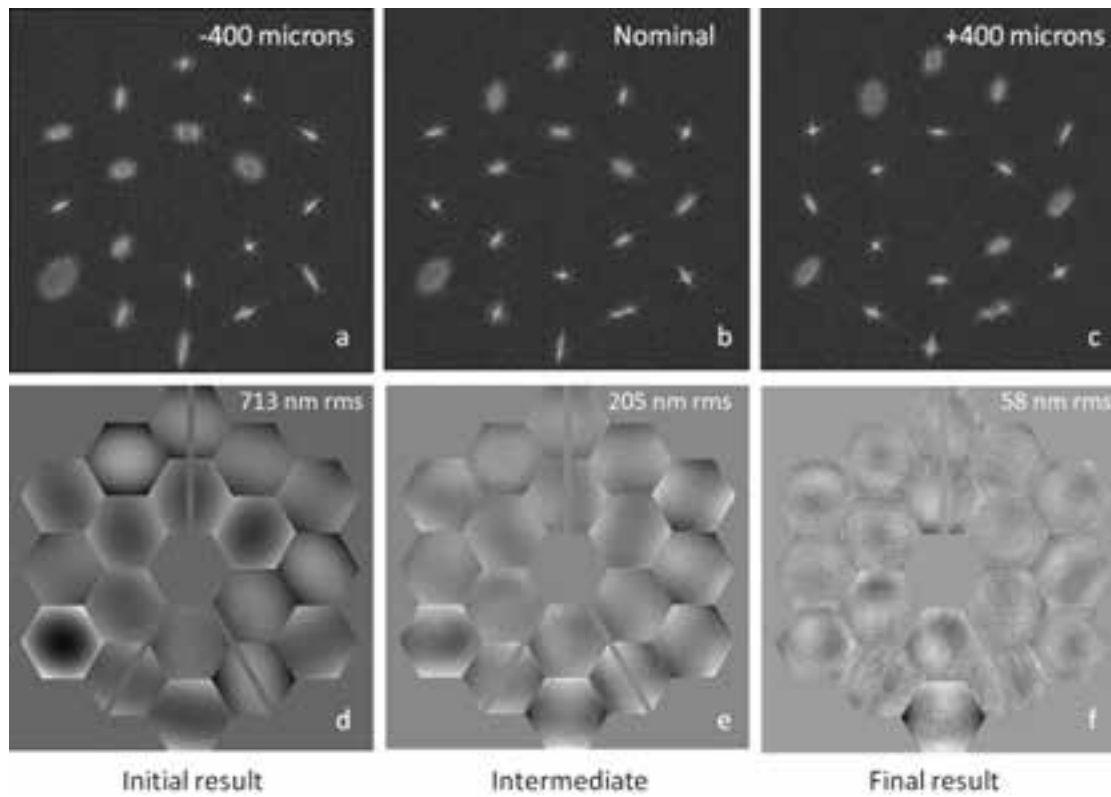
Image array

Resultant wavefront

# Image Stacking
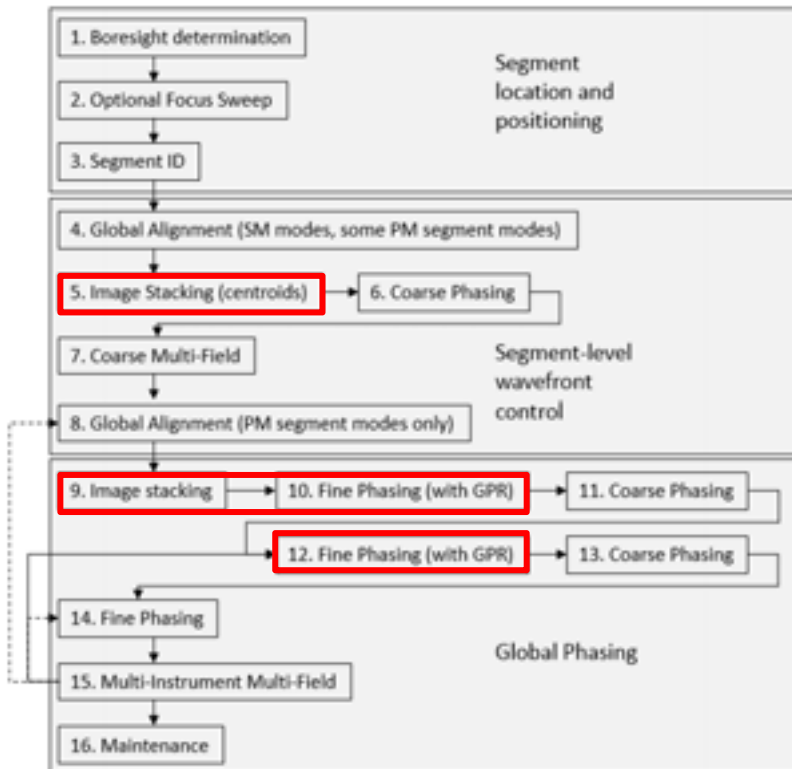


- **Image stacking is needed in preparation for coarse phasing (performed 3 times).**
- **The first stacking is based on centroids**
- **Subsequent stacking uses a Geometrical Phase Retrieval algorithm (GPR).**
- **In each case, moves must be made while conserving the fine range of the actuators.**
- **Guiding must be active during the stacking process**
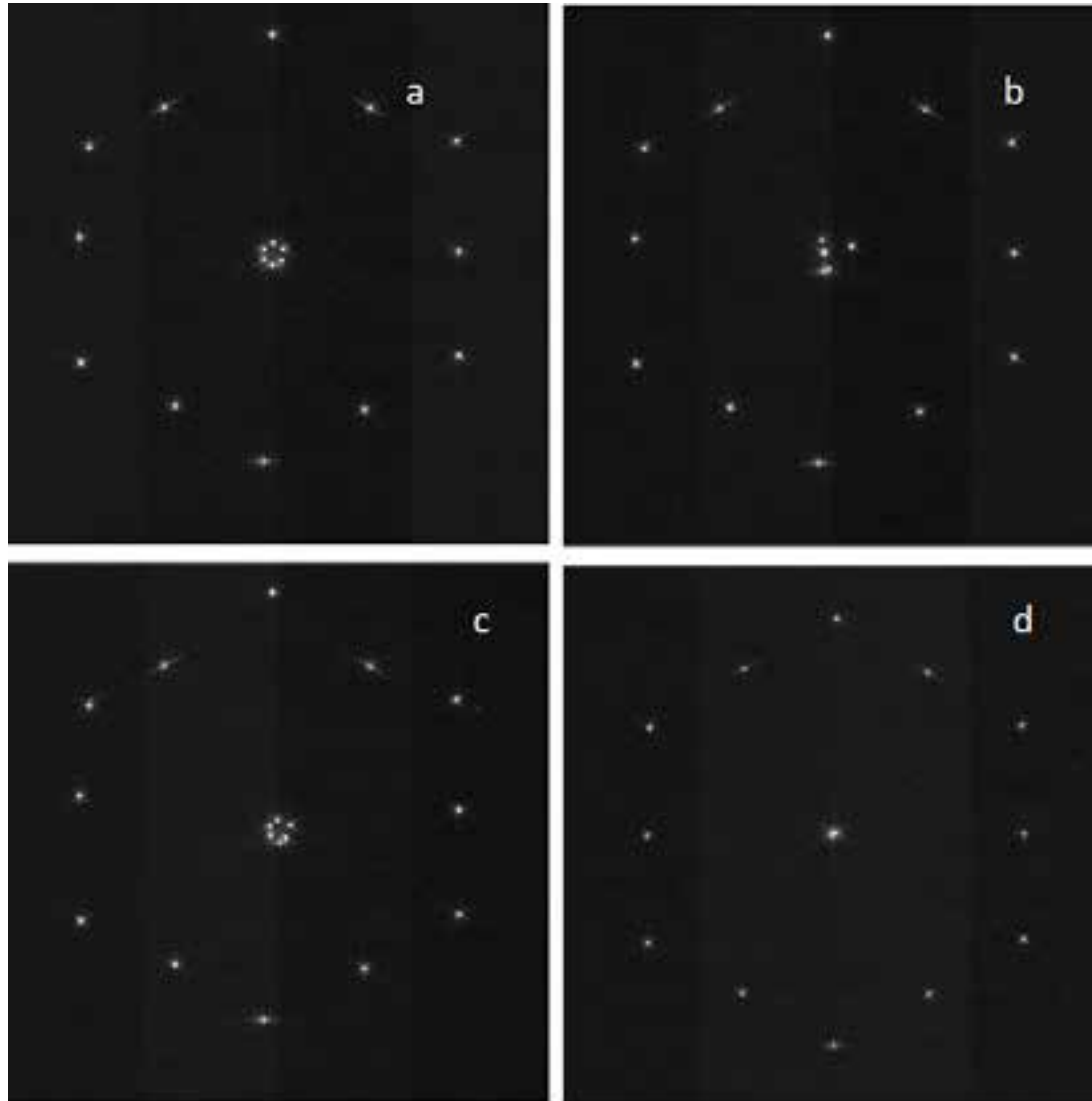
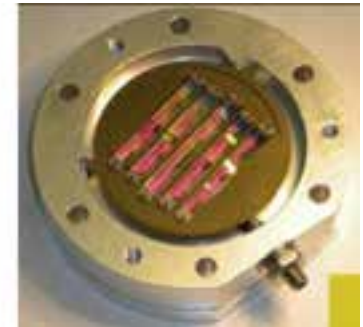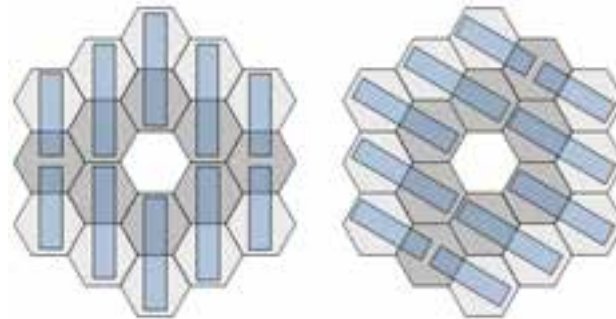**Stacking based on centroids.**

- **Guiding is performed on a spot near the perimeter.**
- **(a) Six spots are moved near the center. Their positions are measured.**
- **(b) Spots are commanded to center and fine mechanisms are recentered. They are measured and moved back to the small array.**
- **(c) Their positions are measured.**
- **(d) The spots are stacked.**

**This is repeated for the remaining segments in groups of 6. Guiding is transferred to the stacked segments during the last group.**
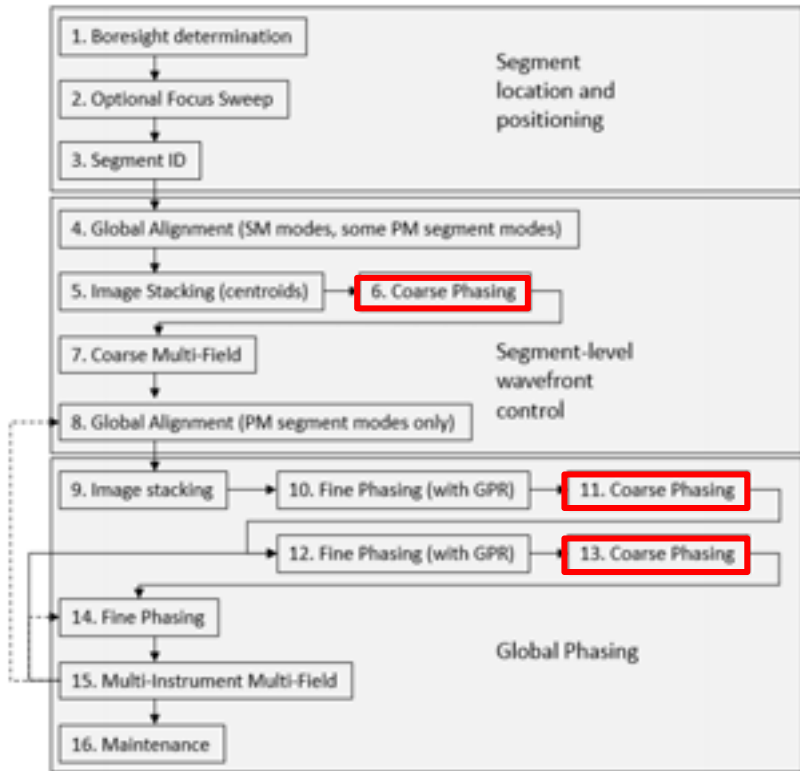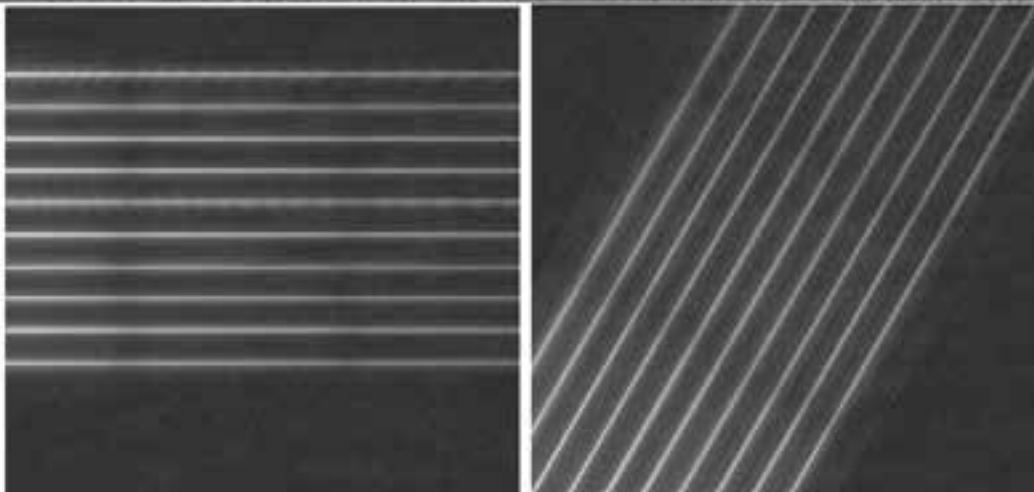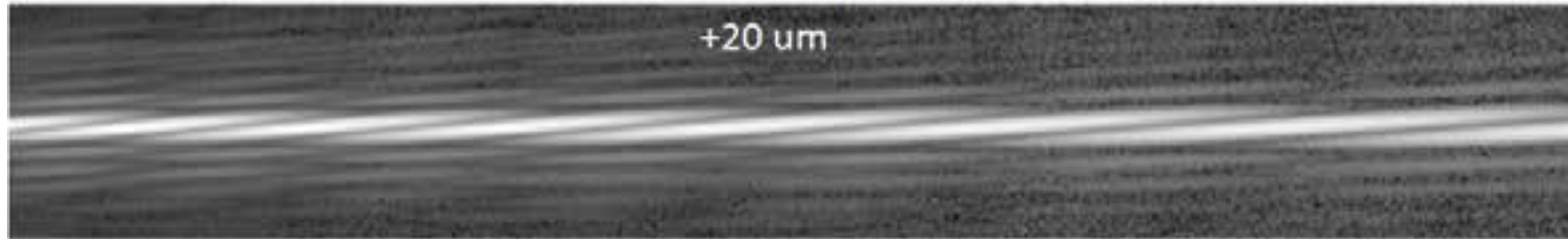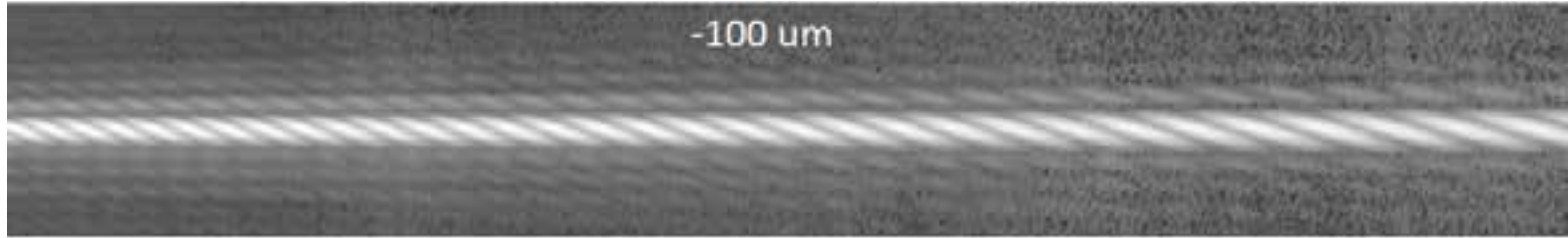
- **Coarse Phasing is performed 3 times.**
- **Goal is to reduce PMSA piston errors from >200 microns to ~0.3 microns**
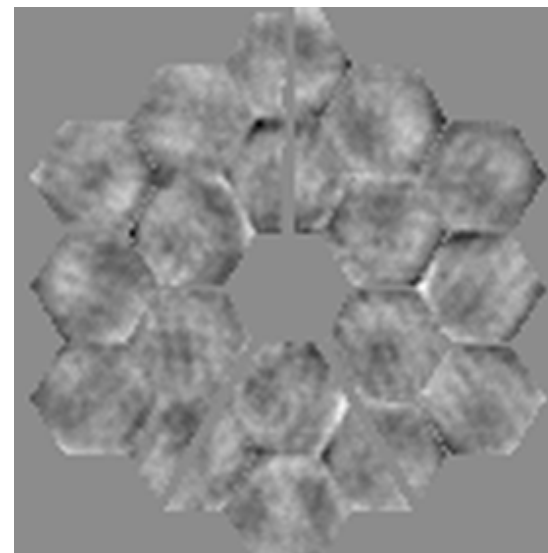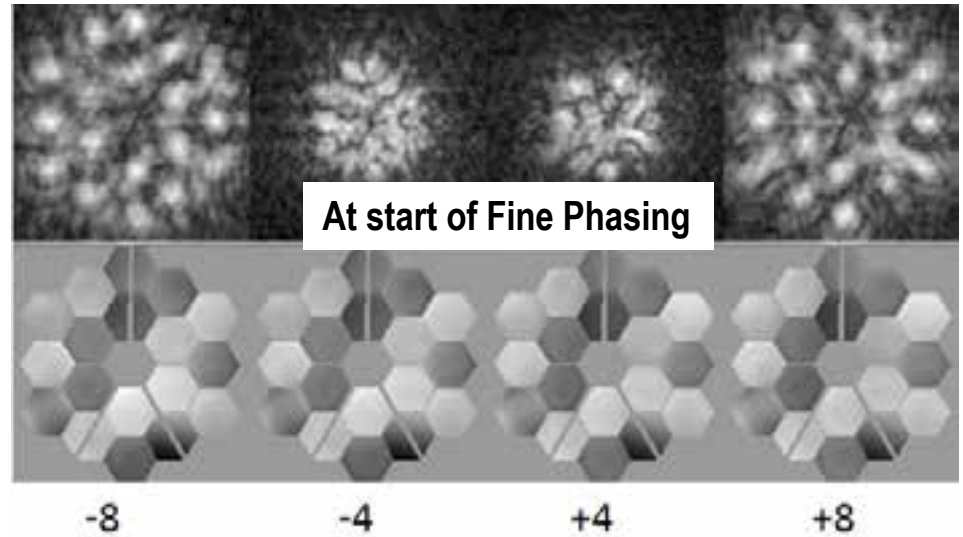- **Uses Dispersed Fringe Sensing (DFS) technology**

The flowchart on the left shows:

1. Boresight determination
2. Optional Focus Sweep
3. Segment ID

(Segment location and positioning)

4. Global Alignment (SM modes, some PM segment modes)
5. Image Stacking (centroids) → **6. Coarse Phasing**
7. Coarse Multi-Field
8. Global Alignment (PM segment modes only)

(Segment-level wavefront control)

9. Image stacking → 10. Fine Phasing (with GPR) → **11. Coarse Phasing**
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14. Fine Phasing
15. Multi-Instrument Multi-Field

(Global Phasing)

16. Maintenance

**Sample spectra**



-100 um

+20 um

**Full-frame NIRCam Images**

# Fine Phasing



At start of Fine Phasing

-8    -4    +4    +8



At end of Fine Phasing, 50 nm rms

- **Weak lenses are placed in the filter elements of NIRCam to created defocused images**
- **A Phase Retrieval algorithm is applied to calculate the wavefront**
- **Corrections are applied to completely phase the telescope, at a single field point**

- **Uses the SM to create slightly defocused images a ~ 30 field points on multiple science instruments.**
- **Phase retrieval algorithm calculates wavefront from these images. This is challenging because…**
    - **The images are generally broad-band**
    - **The image are often undersampled**
    - **On NIRSpec, the micro-shutter array and an internal stop are in the beam path**
    - **Minimal defocus is used, due to the need to guide during exposures**
- **Monochromatic, fully-sampled weak lens images (as used in Fine Phasing) generate the fine details in the wavefront.**
- **The other Phase Retrieval algorithms use this as a starting point.**
- **A pseudo-linear model is used to generate an optimal solution.**