Commissioning The James Webb Space Telescope Observatory

Paper 11443-23

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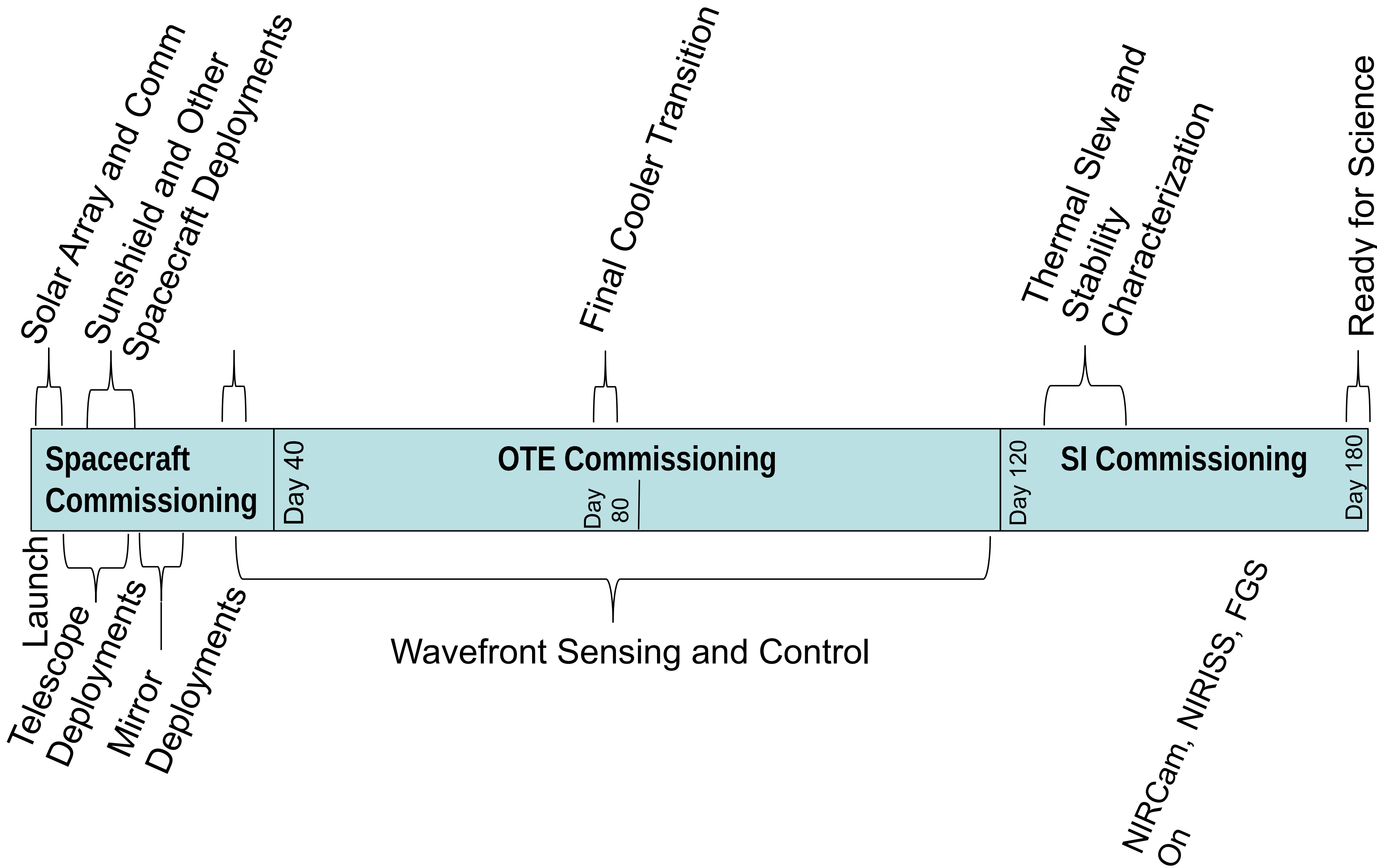
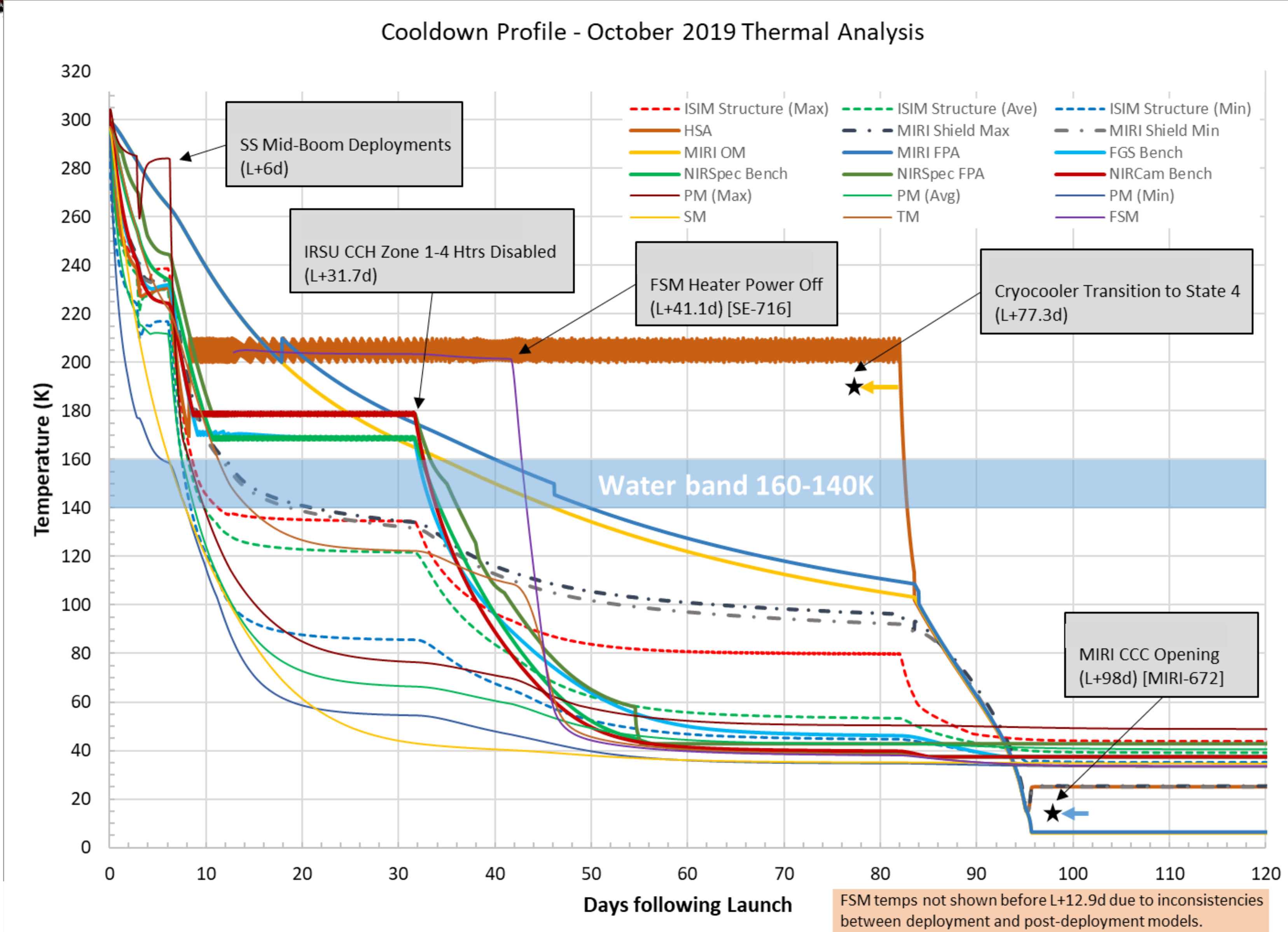
Overall Commissioning Timeline



Nominal Cooldown Profile

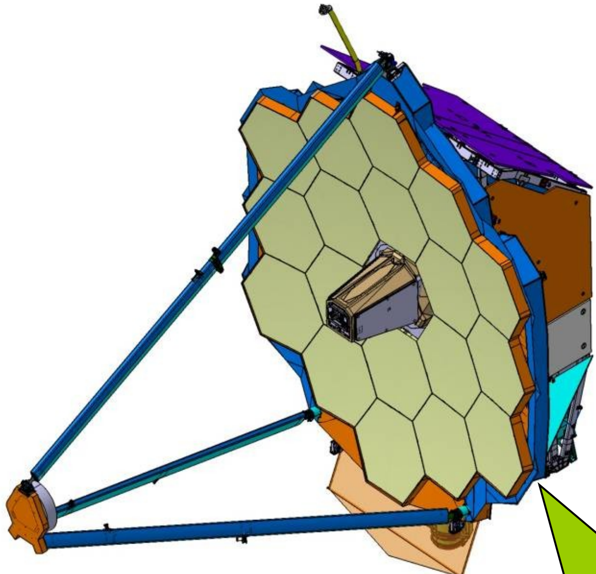


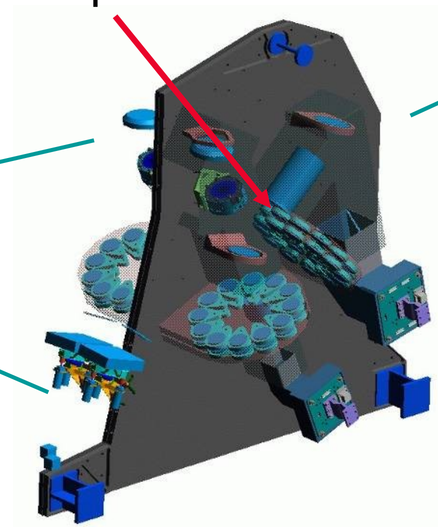
Water-Ice Measurement Philosophy

- **A key consideration as the observatory cools down is to make sure that outgassing water does not form ice on optical surfaces**
  - Key is to carefully control surfaces <140-160K while water is outgassing
- **Secondary Mirror - A lot of work has been done to assure that outgassing from heaters near motors can get ice on the Secondary Mirror**
    - Both by design – control of venting
    - And by early heater outgassing while secondary mirror is warm
- **Fine Steering Mirror – Fine Steering Mirror has a heater that will stay on until we are confident it is safe to begin cooling from a moisture perspective**
  - Have developed observing programs to take series of NIRCam and NIRSpec spectroscopic measurements when each reaches operational temp
    - Each observation analyzed for the equivalent width (EW) of the 3.1 μm water-ice feature

OTE Alignment Via Image Based WFS&C

NIRCam Pupil and Filter Wheels





In NIRCam pupil and filter wheels:

- DHS Filter (F.W.)
- 0 deg and 60 deg DHS (P.W.)
- +8 wave weak lens (P.W.)
- -8 wave weak lens (P.W.)
- +4 wave weak lens (F.W.)

PMSA: 7 DOF Adjustments
SMA: 6 DOF Adjustments

Uplink NIRCam commands and OTE mirror commands

Downlink Eng. Data and NIRCam Images

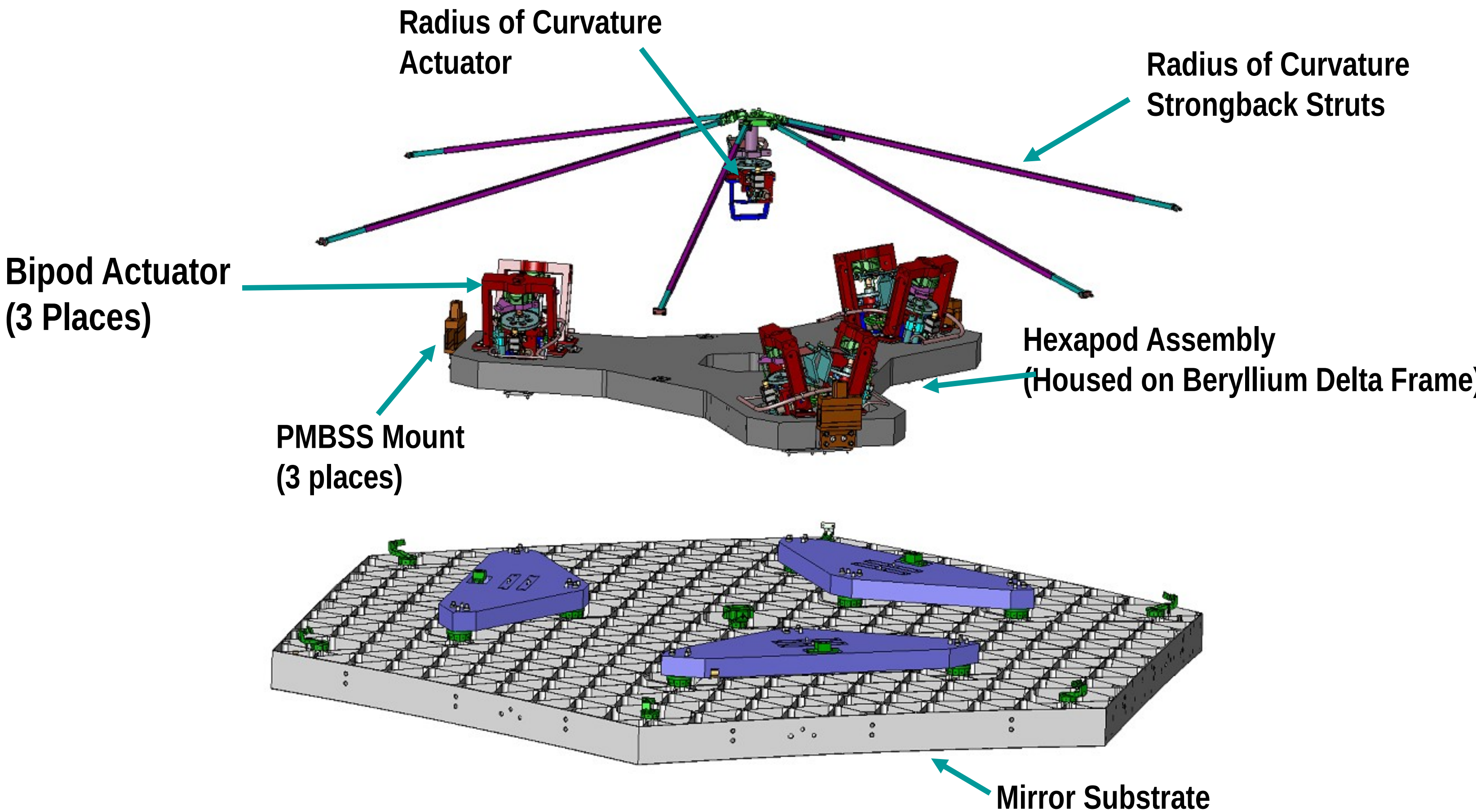
Ground Segment (S&OC)

WFS&C Software Subsystem (incl. Executive)

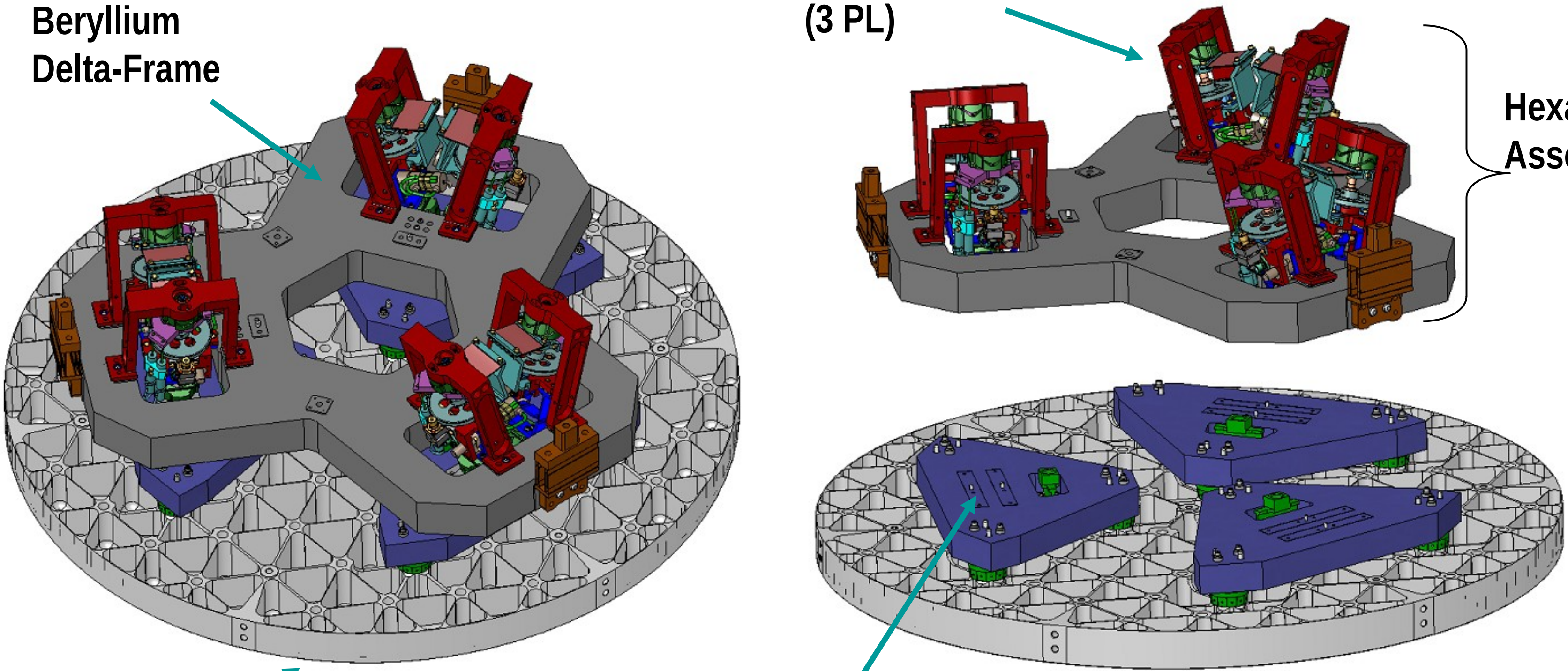
Mirror Control Software ← WFS&C Analysis Software

Green boxes indicate the components of the WFS&C subsystem

Primary Mirror Segment Assembly (PMSA) Design Description



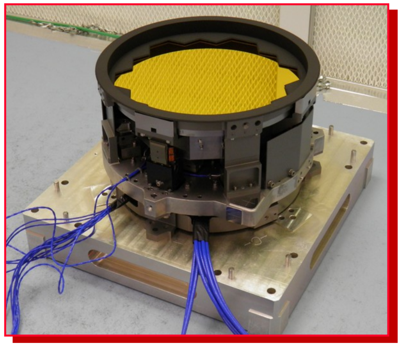
Secondary Mirror Assembly Design Description

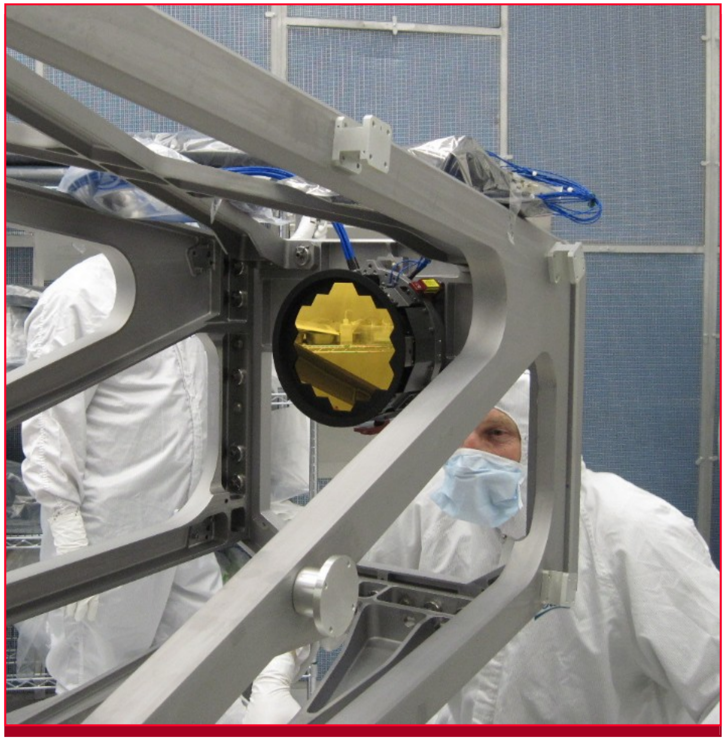


- Actuators have coarse and fine mode of operation
- Thermistors, LVDT's on both sides of actuators, resolvers on A side only
- Hexapod actuators are snubbed for launch
- Hexapod deploys off snubber 12.5mm to nominal locations

Fine Steering Mirror Design Description

- **Fine Steering Mirror (FSM)**
  - Flat optic mounted to fixed base via a tip-tilt flexure
  - Differential Impedance Transducer Position Sensors used as feedback to control voice coil actuators
    - Provides line of sight steering in two orthogonal axes
  - Decontamination Heater to maintain temperature above ISIM during cooldown

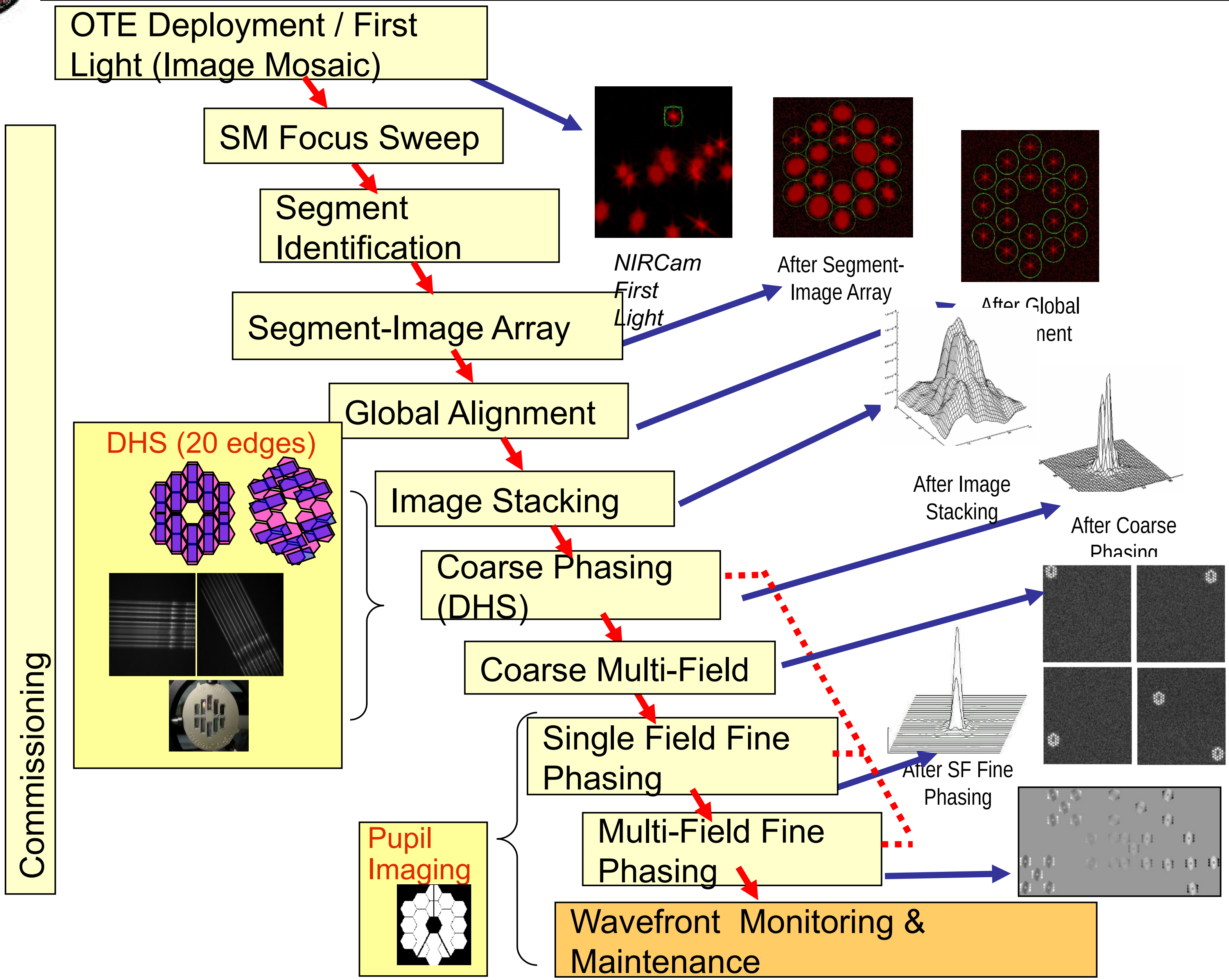




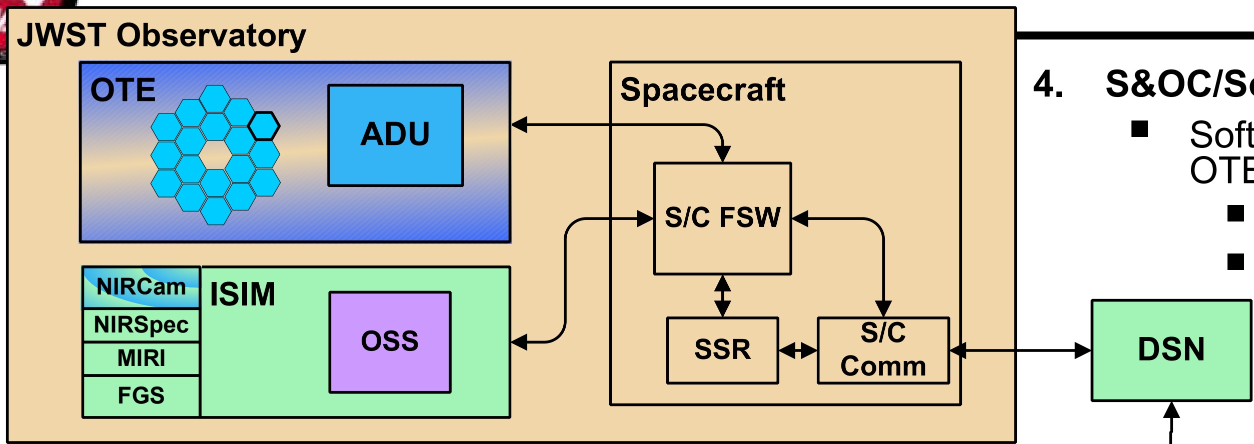
Wavefront Sensing and Control Goal

- **Wavefront Sensing and Control is the sensing, control and algorithms that <u>align</u> the OTE mirrors
(PM Segments, SM) together, and align the OTE relative to the science instruments in ISIM**
- **The goal is to take a post deployed telescope with wing and secondary mirror misalignments and align it to meet image quality requirements**
  - The image quality for JWST is specified by the Strehl Ratio which can be equated to a total WFE that has allocations that are the driver for WFSC
    - MR-110: Strehl Ratio of 0.8 at 2 μm wavelength (NIRCam)
      - Equivalent to 150 nm rms WFE
    - MR-116: Strehl Ratio of 0.8 at 5.6 μm wavelength (MIRI)
      - Equivalent to 420 nm rms WFE
    - MR-228: Error Budget flow down to **OTE allocates 131 nm rms WFE** over the fields of view of NIRCam, NIRSpec, and MIRI
- **The WFSC alignment affects the Strehl Ratio through the Wave Front Error (WFE)**
  - The allocation to WFE is divided into:
    - The very small design residual for a perfectly aligned and fabricated optics
    - ***Errors in the alignment of the optical elements relative to each other***
      - ***Including alignment of Science Instruments to OTE***
    - Errors in the fabrication of the WFE of optical elements
  - Alignments also affect **Radiometric Sensitivity** through potential vignetting and stray light
    - A key driver here is that the image of the primary can move around at the Fine Steering Mask and we need to assure that we do not vignette the mask as we align the telescope

High Level WFSC Commissioning Process

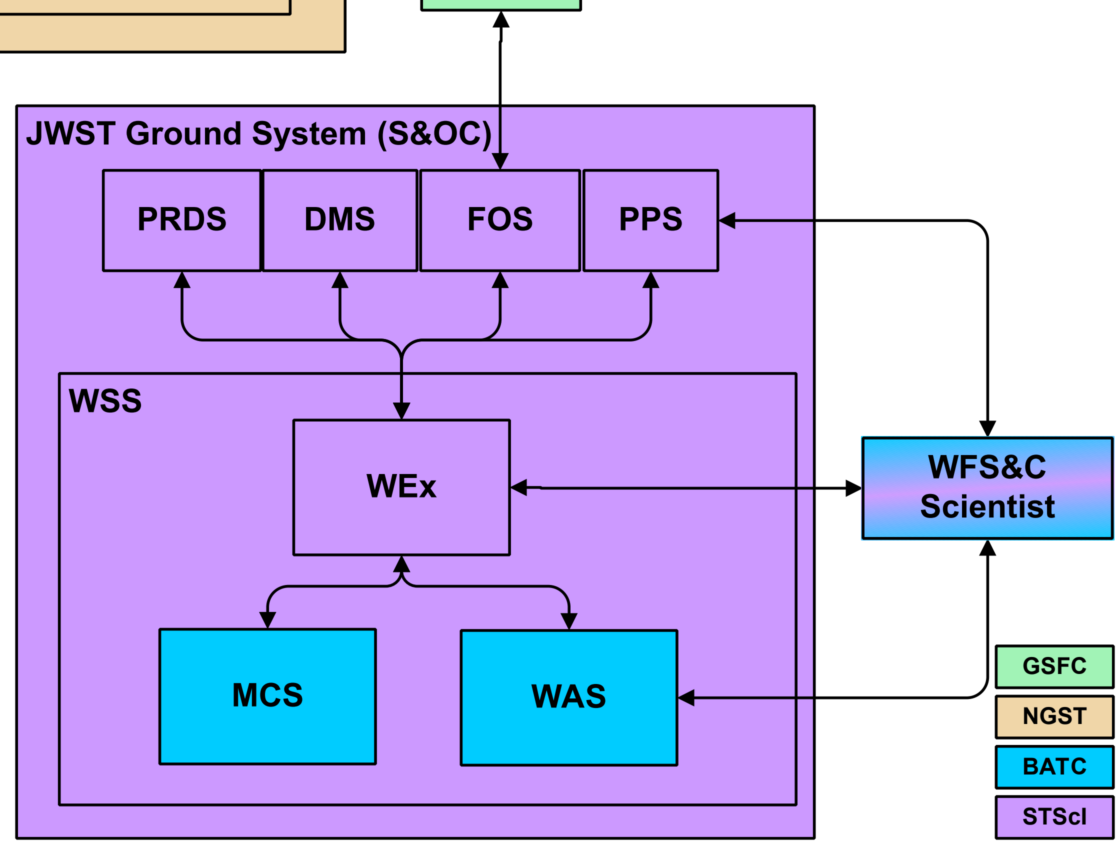


WFS&C Operational Architecture

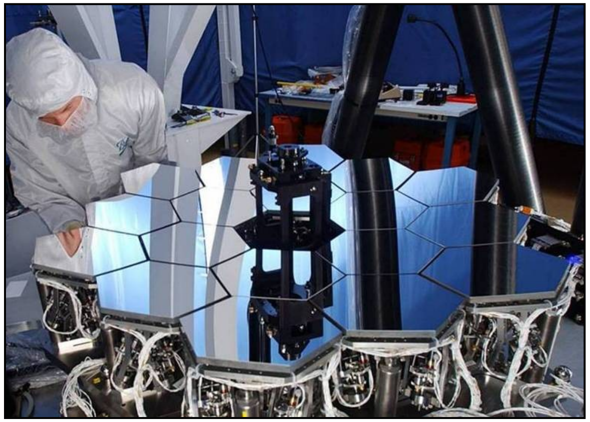


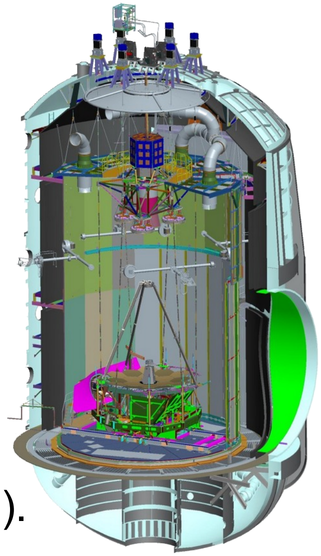
4. **S&OC/Software**
   - Software to align & maintain the OTE
     - WFS&C Executive
     - WFS&C Analysis Software
     - Mirror Control Software

1. **OTE Mirror Actuation**
   - PMSA/SMA adjustment
   - Hexapod actuators
   - Mirror position telemetry
   - WFE Alignment
2. **ISIM Imagery**
   - NIRCam Optics/Functionality for WFS
     - Bandpass filters
     - DHS for coarse phasing PM
     - 3 weak lenses for focus diversity
     - DFS (backup for DHS)
   - Imagery as needed from other SI's
     - Internal focus mechanisms
     - MIRI pupil Imaging
3. **LOS Stability for WFS&C**
   - LOS stability using only ACS
   - FGS use during WFS&C Commissioning
   - FGS use during nominal operations



How WFSC Was Validated and Tested

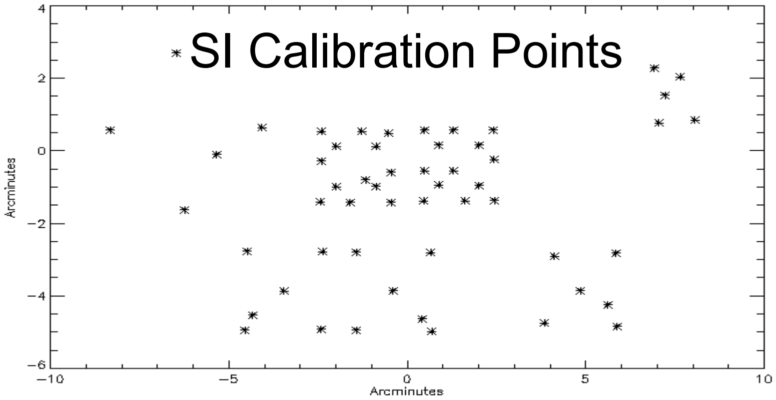


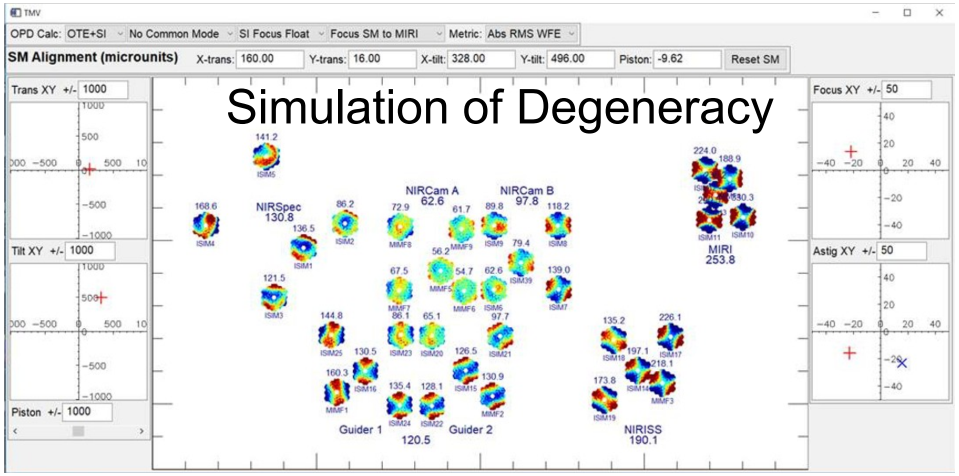


- WFSC Testbed Telescope is a 1/6th scale, fully functional model of the JWST telescope with performance traceable to JWST (TMA, 18 7-dof segments, etc.).
- TBT primary use was in validation of Flight Algorithms and software
  - We were able to validate algorithms to the limits of the environment, close to flight requirements
  - Allowed us to build confidence in the Integrated Telescope Model (ITM) that was then used to verify the flight software and algorithms
  - TBT has been realigned and is near ready for use in training and contingency work
- JSC cryotesting allowed us to test key algorithms end to end with operations using the full telescope and science instruments
  - Coarse phasing, fine phasing demo
  - Global alignment demo
  - Used OSS scripts, end to end

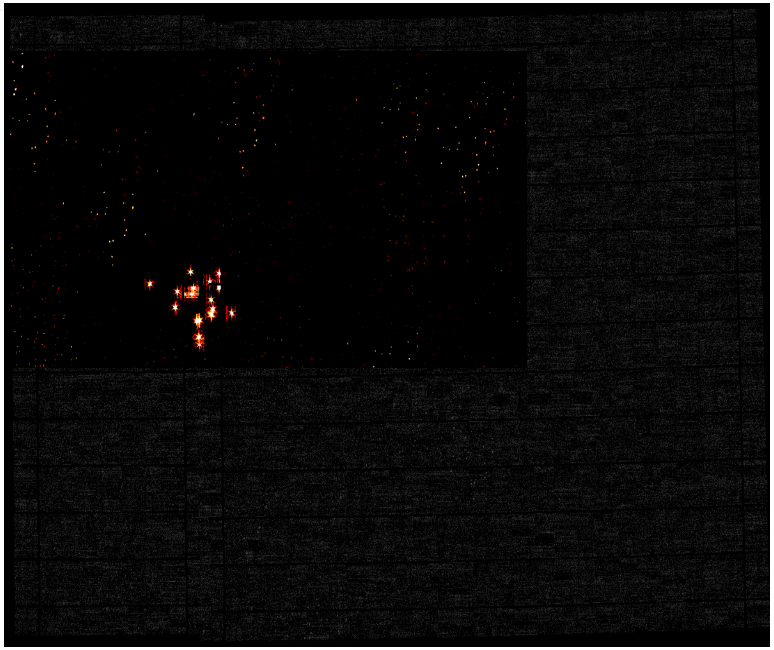
Multi-Instrument Multi-Field Alignment

- **Early in the program, we recognized that certain Primary Mirror alignments could look like a misaligned secondary mirror at a single field point creating an ambiguity (degeneracy)**
  - Key is that the primary mirror shape does not vary with field (it is at a pupil) but a misaligned secondary creates field dependent aberrations
- **To address this, we recognized that using field points in each SI over the field would allow us to break this degeneracy**
- **We developed the MIMF algorithm to address this degeneracy and carefully calibrated SIs at key field points used in this algorithm**
- **Realigning the secondary can be time consuming (several days to a week) so we carefully evaluate if it is needed each iteration working closely with the Science Community**

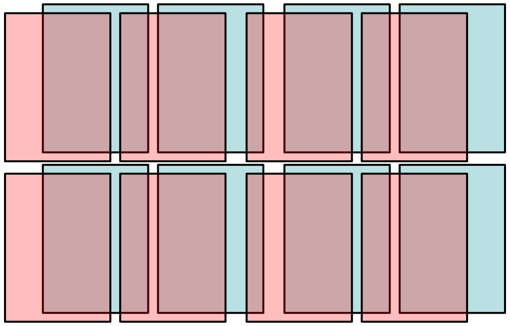




Initial Boresight Offset



MIRaGe mosaic from Team Practice 4



Scan pattern overlaps left-right; leaves small gaps between NIRCam SCA's, but gaps are smaller than expected size of initial defocused segment PSFs

Baseline plan to establish initial boresight:

- Slew to a bright isolated star
- Execute a large mosaic observation
- Add additional observations as needed until 18 spots are seen
- Plan for nominal 40x40 arcmin swath that happens incrementally (can end early)
- Geometric centroid of spots yields boresight location

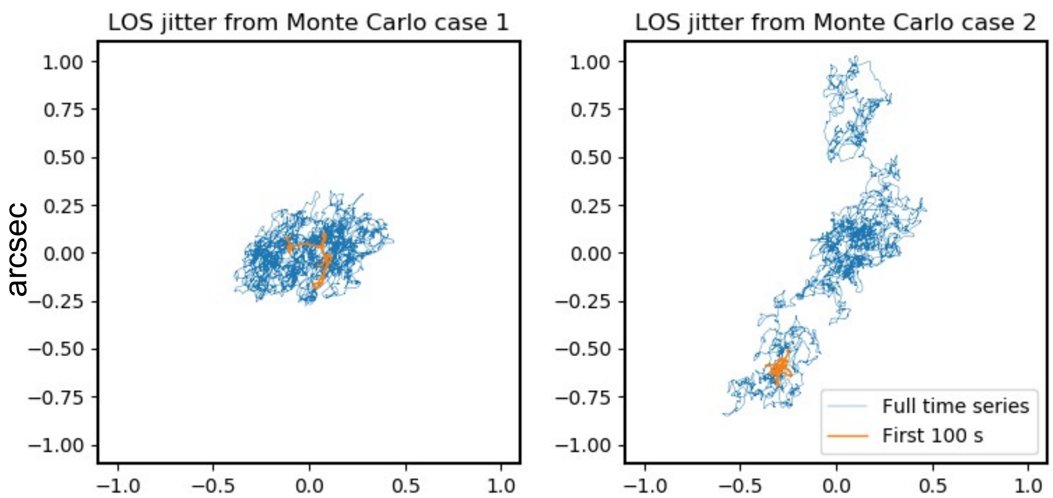
Contingency Approach if initial boresight error exceeds requirements:

- We have several options ranging from increasing the field size to using a bright globular cluster to pattern recognition.

Guiding During WFSC

- **One of the key risks we have carefully managed for Wavefront Sensing and Control is Guiding. Requires integrated functionality of FGS, FSM, and ACS.**
- **Unusual PSFs (single segments, aberrated, defocused) make guiding more challenging, and require use of special setups developed for this purpose.**
- **Guiding is first used in flight during initial Line of Sight checkout, immediately before OTE Global Alignment. This is guiding off one segment which has a larger Point Spread Function.**
- **The WFSC and Guiding teams have worked closely together for many years to assure guiding can be implemented smoothly**
  - OTE WFSC has provided Point Spread Functions that simulate guiding at the various stages of WFSC, including realistic variations
  - On top of our simulations, during JSC cryotesting we closed the guiding loop using a highly aberrated half pass source
- **In addition to all of these efforts, the team has looked at the case where guiding is not initially working and has shown that we can get all the way to Fine Phasing**

Contingency: Closed Loop Guiding Not Working



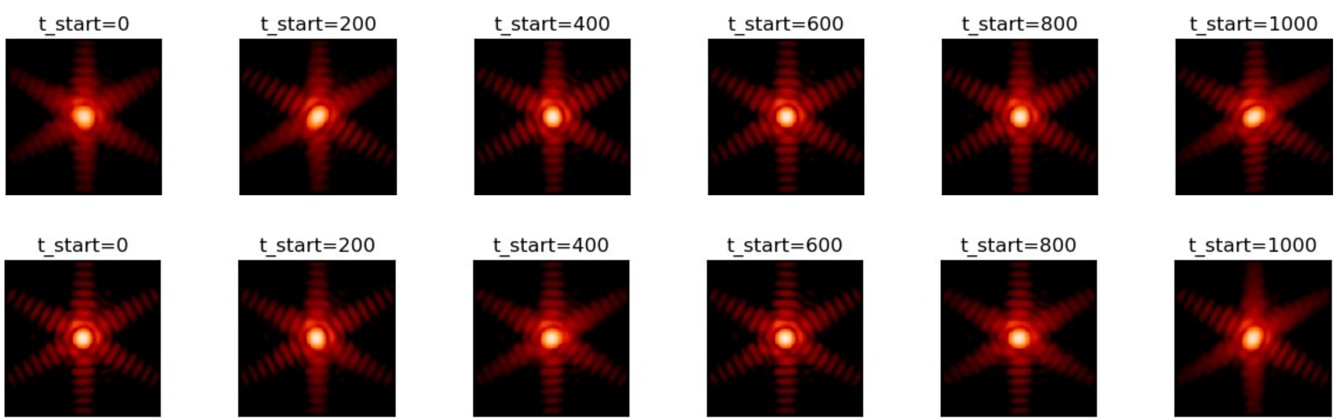
Monte-Carlo simulations over 2-hour period.

Recent sims of observatory pointing in ACS coarse mode (i.e. without closed loop guiding) predict jitter+drift < 0.25 arcsec for exposure times < 100 s.

Based on this expectation of coarse pointing, we could execute commissioning activities without guiding until Fine Phasing 1

Case 1

Case 2



Thermal Stability Activity Plan

- After the telescope is aligned over the full field, it will continue to cool to its operational temperatures.

- The optical next step will be to assess the thermal stability of the observatory:

Thermally stabilize at hot attitude
- Assess instrument electronics cyclic wavefront or other short timescale drifts and establish warm stable baseline performance for pointing stability and WFE stability.

Slew to cold attitude
- Assess frill/primary mirror, telescope wavefront drifts and pointing stability over 14 days.

Slew back to hot attitude
- Verify consistency with prior hot to cold pointing stability

- All thermal stability measurements take ~4.6 days over a 20 day time period

Science Instrument Commissioning

- **Science Instrument (SI) commissioning brings the science modes to readiness for use in scientific observations**

- **This process involves obtaining suitable preliminary calibrations and executing operational demonstrations to ensure that we know how to take science-quality data**
  - This will involve assessments of the contributors to sensitivity (throughput, image quality, backgrounds, detector noise) as well as the astrometric calibrations necessary to put targets in slits or centered on coronagraphic spots, etc.
  - Operational demonstrations will include target acquisition, dithers, mosaics

- **The SI's are commissioned mode by mode, not SI by SI**
  - For example, no reason to hold up on "point and shoot" imaging observations because of an issue with the coronagraphic target acquisition algorithm

- **SI commissioning will flow seamlessly into Cycle 1 observing**
  - The commissioning observations will have exercised the same planning tools and data pipelines that will be used by all observers

Conclusion

- **Preparations for JWST commissioning are going well**
- **Once power and communications are established, the first phase of commissioning includes the large deployments of the sunshield, tower, and wings**
- **The second phase is the mirror deployments and telescope alignment.**
  - Begins with mirror deployments
  - Wavefront Sensing and Control through an aligned telescope
- **Final phase is Science Instrument Calibration**
- **Optical commissioning uses WaveFront Sensing and Control (WFSC) algorithms that have been extensively tested and optimized**
- **The Guider and NIRCAM instruments will be used to support WFSC**
- **Once in space, it will be several months before we have confidence the telescope meets all optical requirements but we will build confidence as we go through WFSC**