

Optical Testing of the James Webb Space Telescope

David L. Aronstein, Ph.D. 2002
NASA Goddard Space Flight Center

University of Rochester
Institute of Optics
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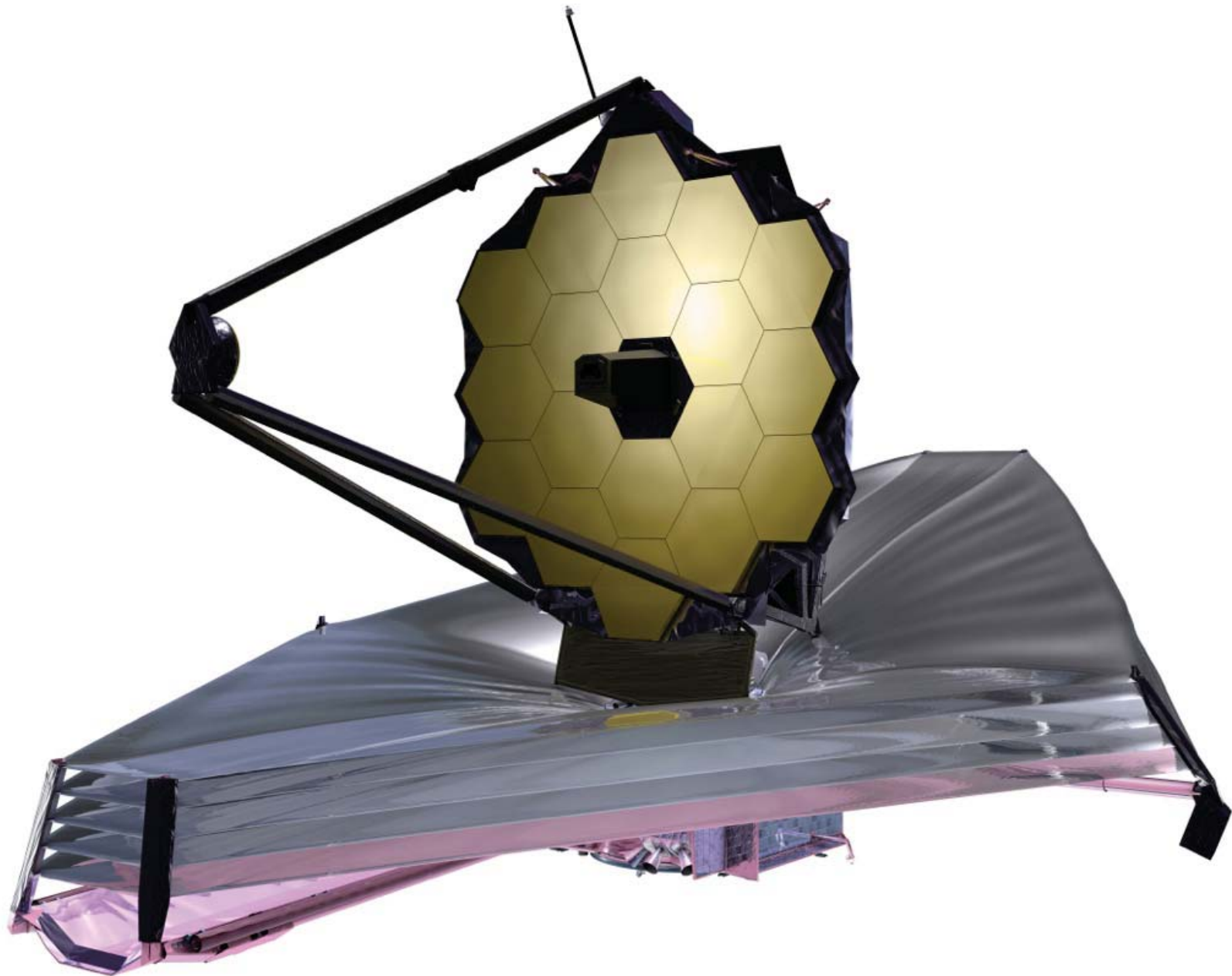


Description:

The James Webb Space Telescope (JWST) will be a large infrared telescope with a 6.5-meter primary mirror, working to a 2018 launch date. Ground testing for the JWST will occur in two test campaigns, at NASA's Goddard Space Flight Center and Johnson Space Center. The talk describes the JWST and its optical ground testing, highlighting the roles of many of the University of Rochester Institute of Optics' alumni as well as current faculty & students.

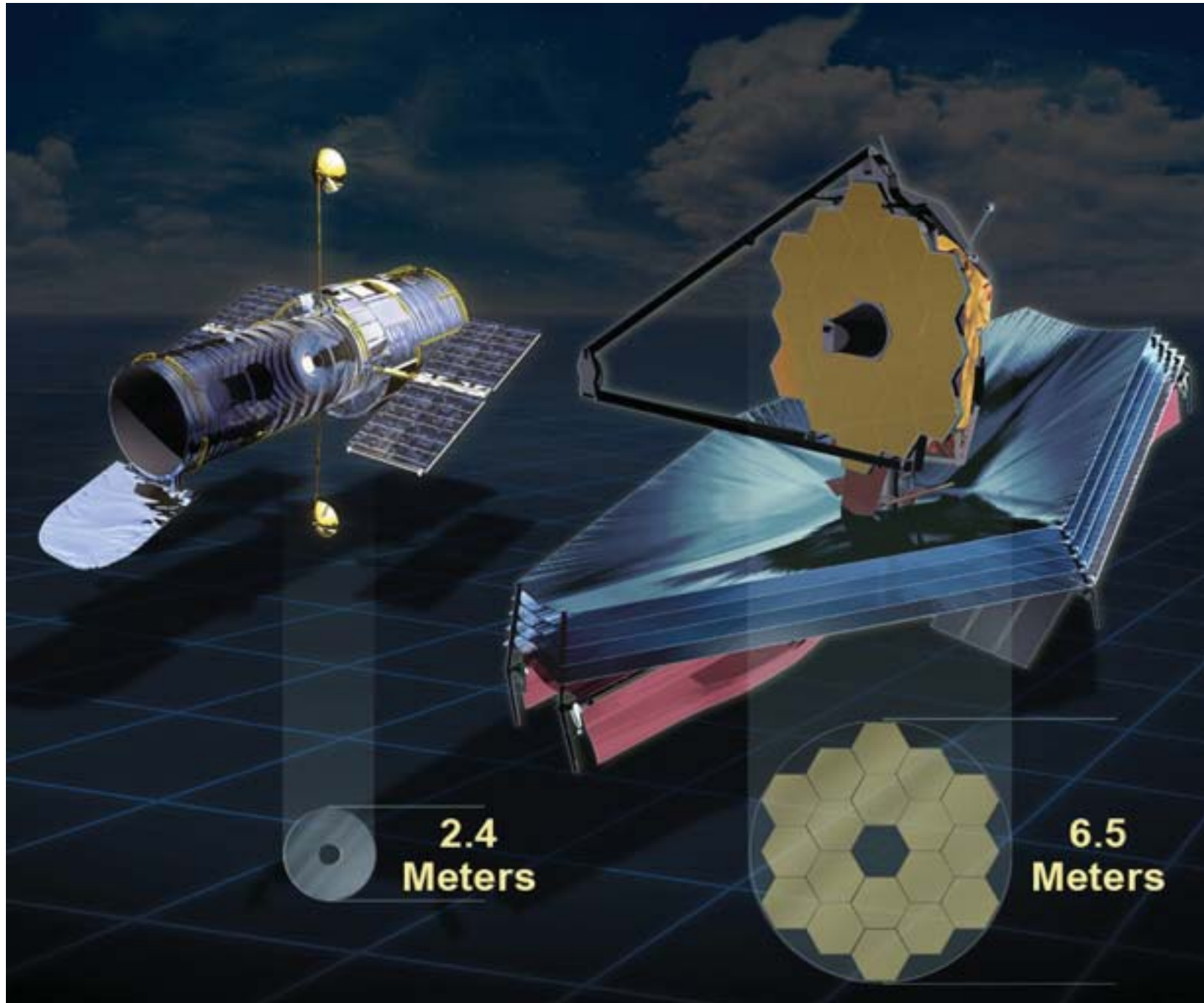


The James Webb Space Telescope



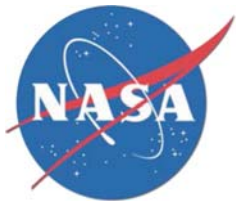


Size Comparison with the Hubble Space Telescope

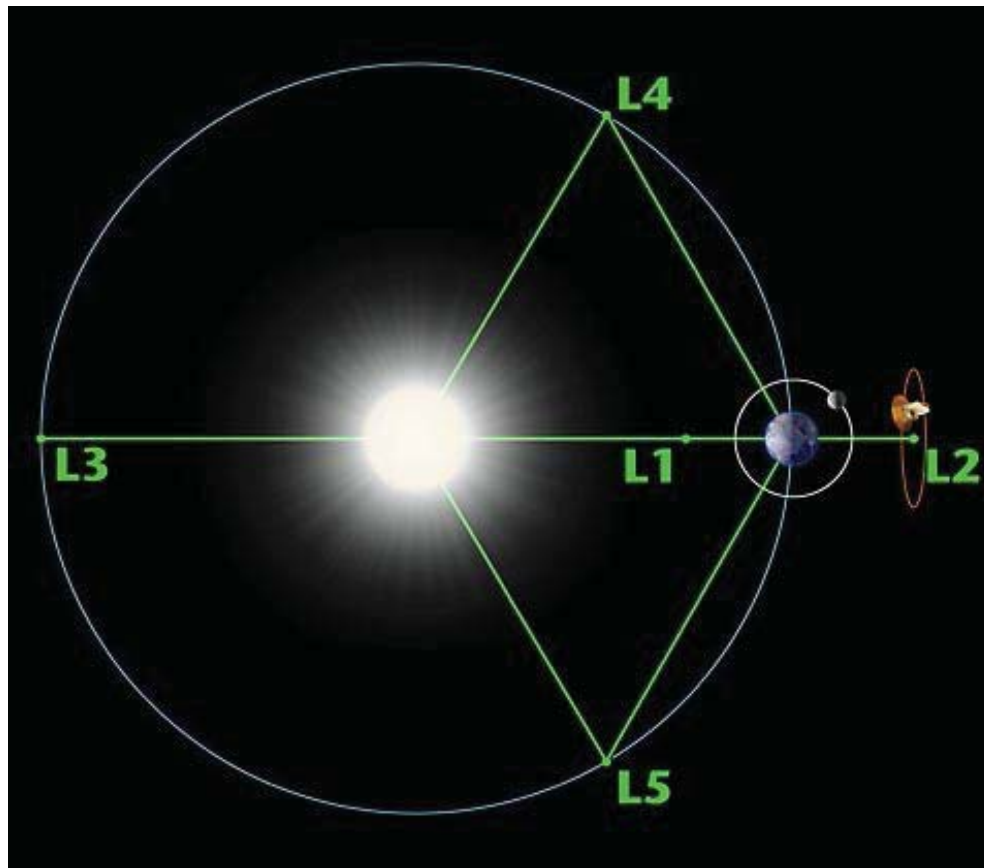




L2 Orbit



- The JWST will orbit about the 2nd Lagrange point between the Sun & Earth, about 4X further away than the moon (~1.5 million km from Earth)

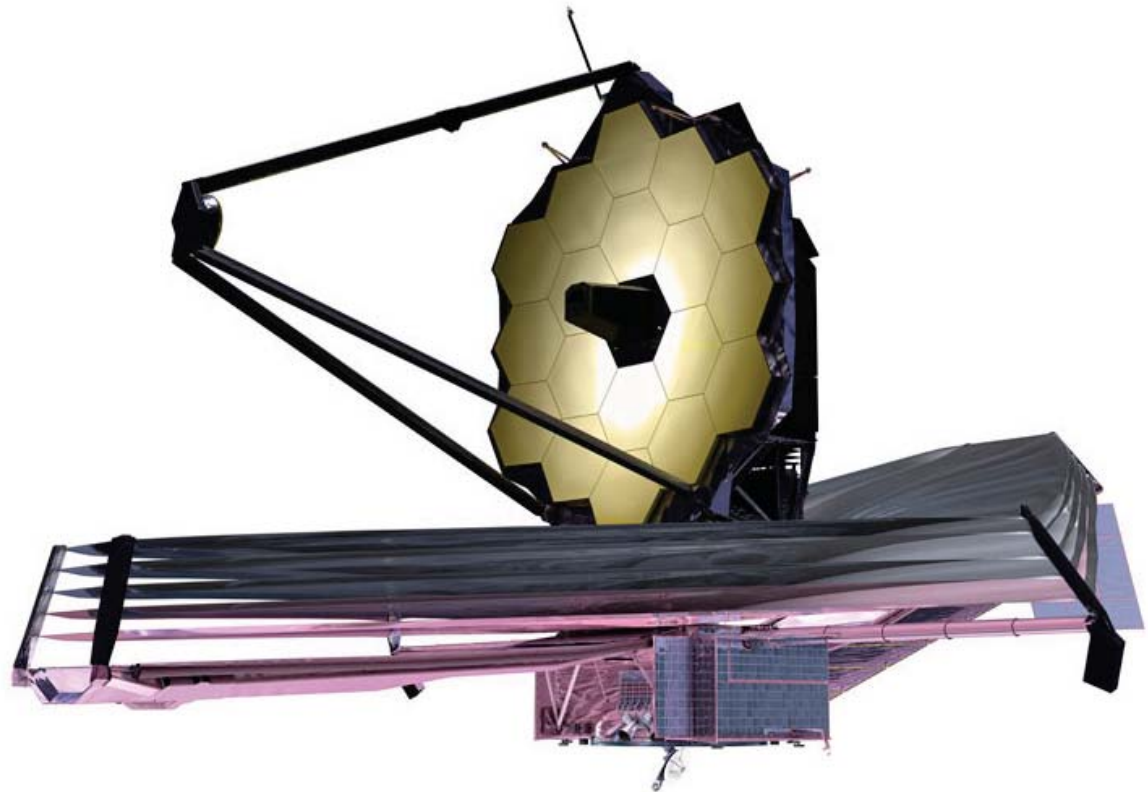




Anatomy of the Observatory



- **The James Webb Space Telescope observatory consists of:**
 - Optical Telescope Element (OTE)
 - Near Infrared Camera (NIRCam)
 - Mid Infrared Camera (MIRI)
 - Near Infrared Spectrograph (NIRSpec)
 - Near Infrared Imager and Slitless Spectrograph (NIRISS)
 - Fine Guidance Sensor (FGS)
 - Spacecraft Element (SE)
 - Spacecraft Bus
 - Sunshield





Deployment of JWST On Orbit





Image-Based Wavefront Sensing: From Hubble to the JWST

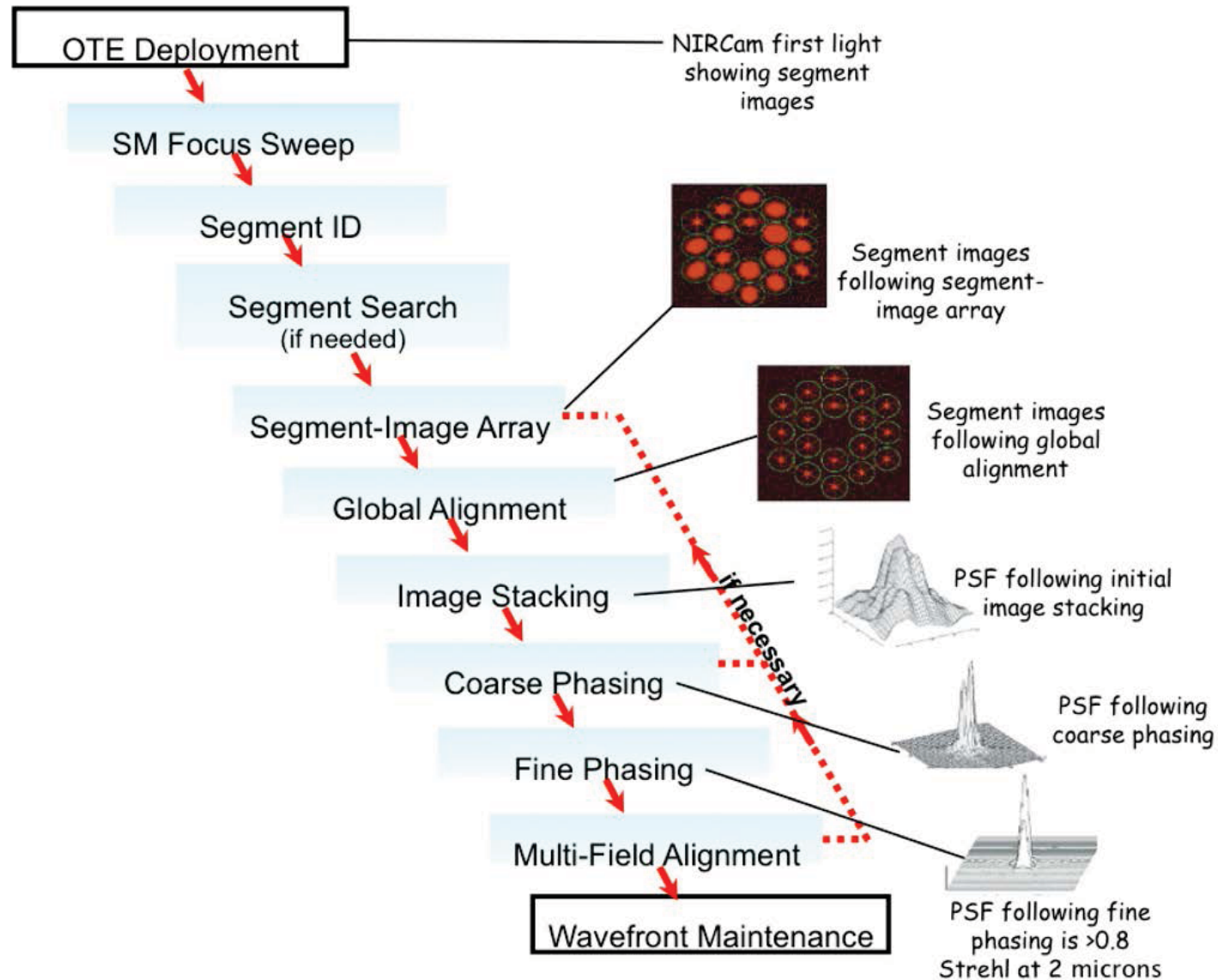


- **When the Hubble Space Telescope was launched in 1990, its initial images were highly aberrated.**

- **Two investigative directions lead to the design & successful installation of the Corrective Optics Space Telescope Axial Replacement (COSTAR) corrective optics in 1993.**
 - Prof. Duncan Moore chaired the Hubble Independent Optical Review Panel
 - The multi-team Hubble Aberration Recovery Project (HARP) included Prof. James Fienup, Joseph Marron PhD '85, and Rick Lyon MS '87.

- **The success of some of the HARP teams' use of image-based wavefront sensing (phase retrieval) to successfully determine the HST spherical aberration became a key enabling technology for JWST:**
 - Commissioning the observatory on orbit
 - Evaluating the science instruments' wavefront error during ground testing

- Aligning the OTE's mirror segments, secondary mirror, and tertiary mirror on orbit is done using a multi-step, image-based commissioning procedure:

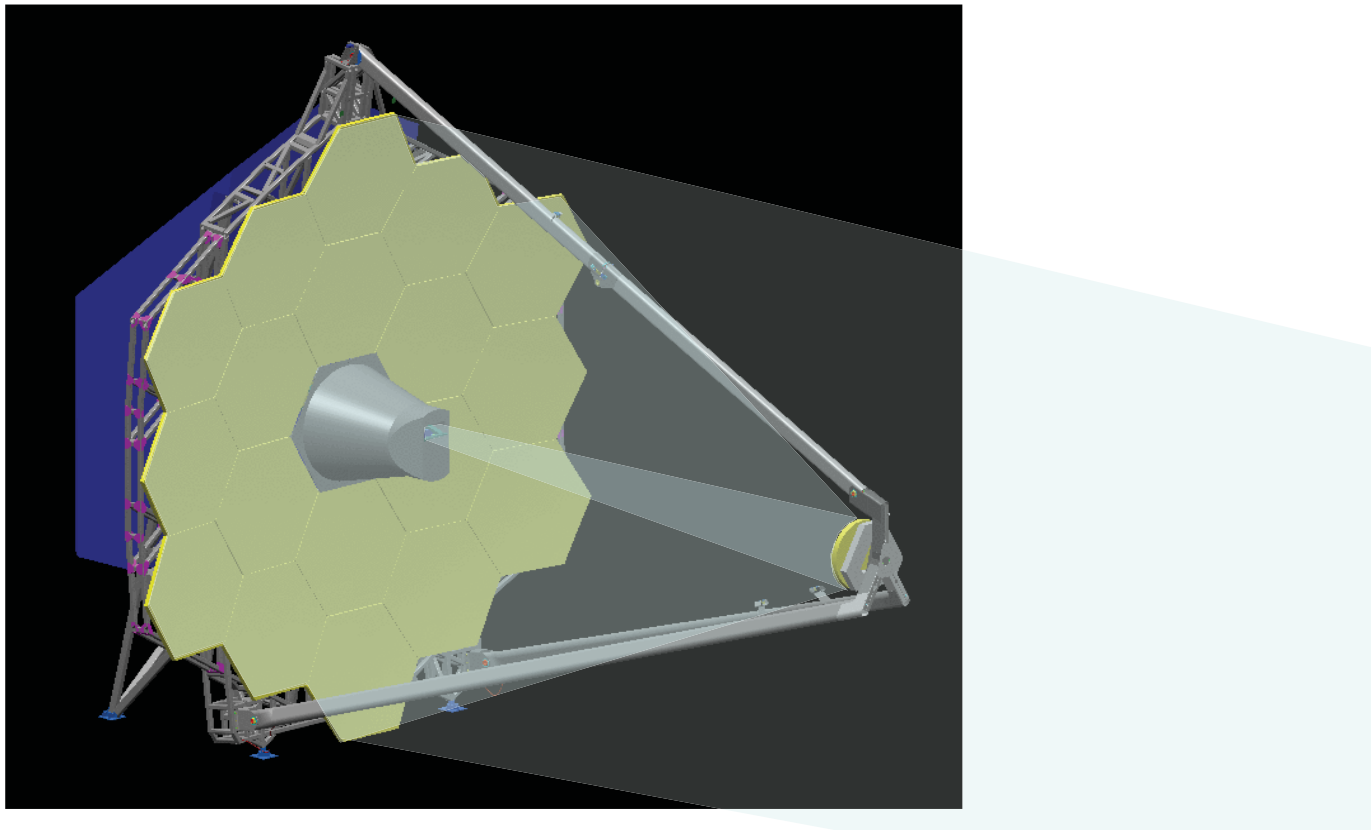




Optical Telescope Element



- The Optical Telescope Element is a three-mirror anastigmat, with a primary, secondary, and tertiary mirror.
- The primary mirror is comprised of 18 Beryllium segments.
- Each mirror segment can be moved in position, orientation, and ROC
- The telescope is designed to have diffraction-limited performance above $2\mu\text{m}$; it operates at a temperature of $\sim 40\text{K}$.



Near Infrared Camera (NIRCam)



Near Infrared Spectrometer (NIRSpec)



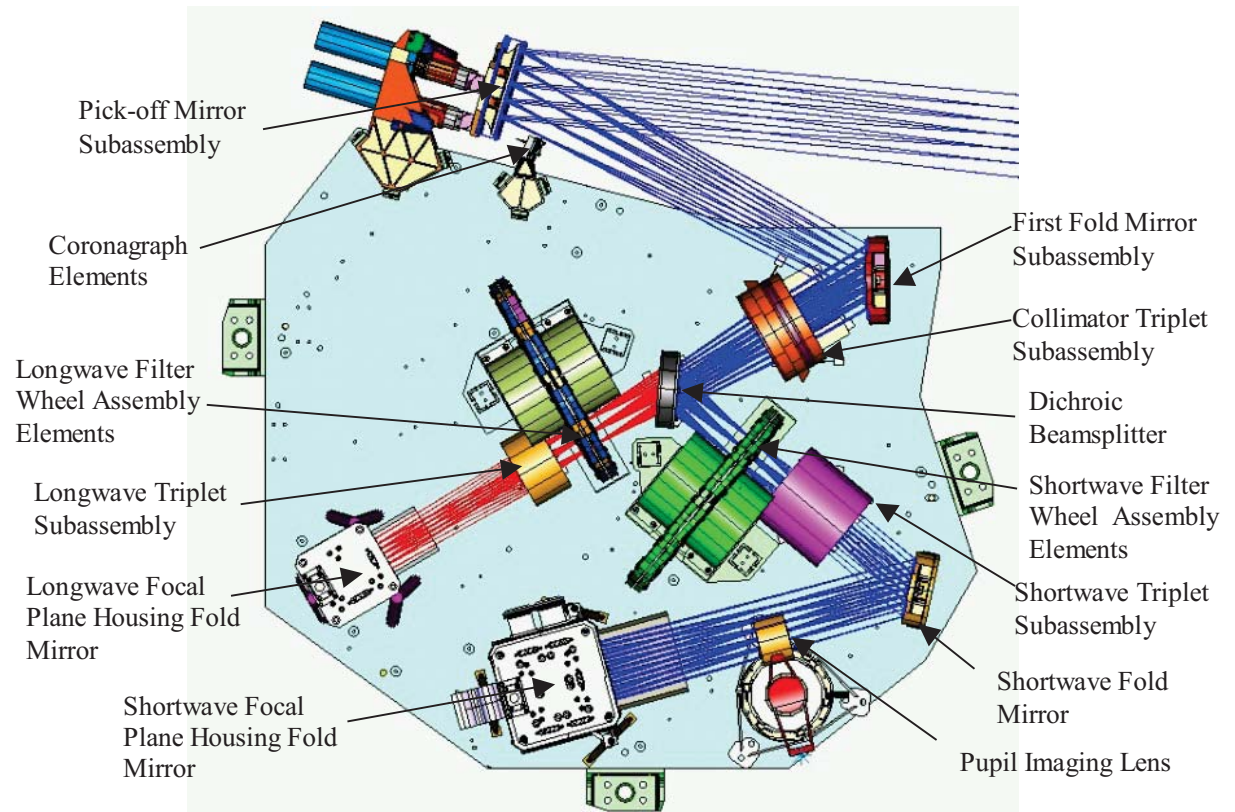
Fine Guidance Sensor (FGS)



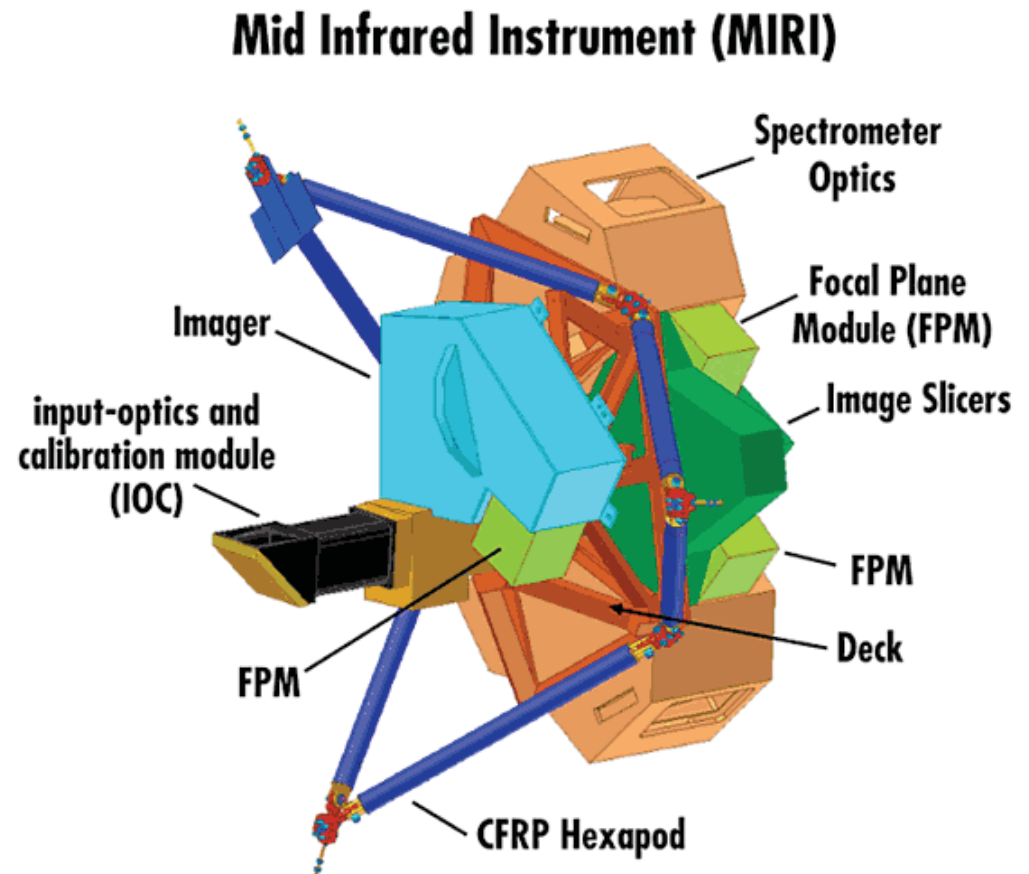
Mid Infrared Instrument (MIRI)



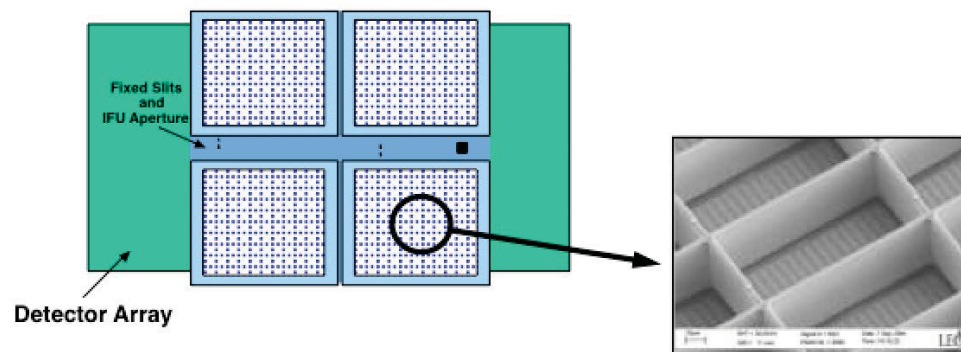
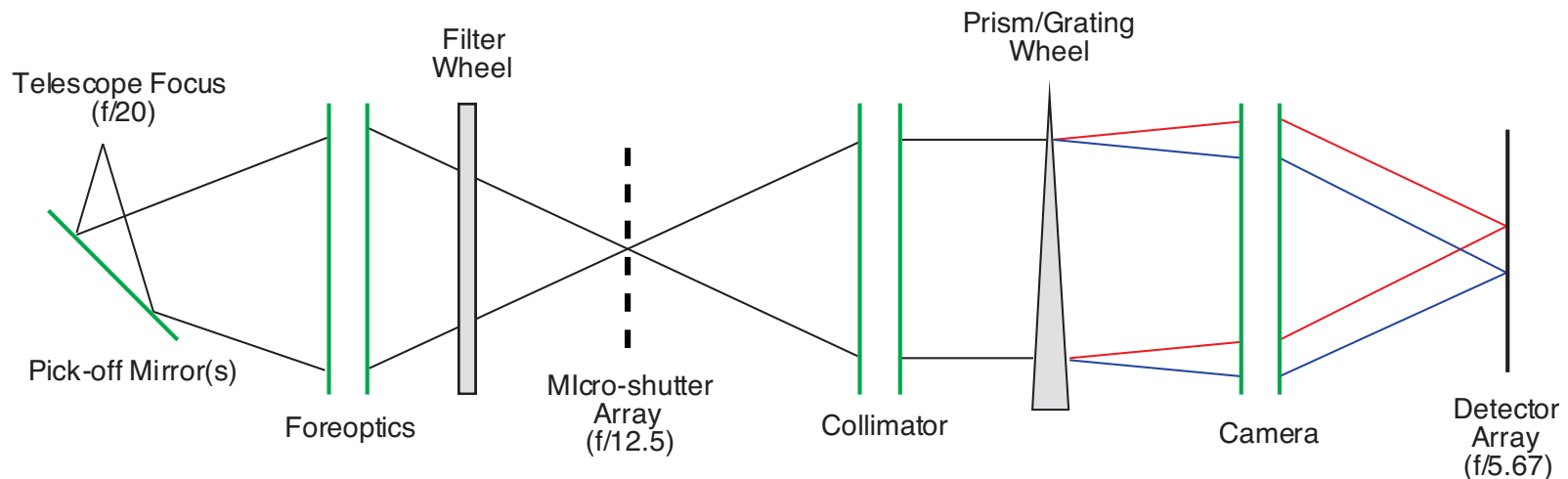
- NIRCam is the primary imager for the JWST
- Developed by University of Arizona & Lockheed Martin ATC
- Operates at 0.6 – 5.0 μm , separated into shortwave & longwave channels
- Used for imaging and coronagraphy*
- HgCdTe detector, 2048 x 2048 pixel arrays (10 in all)
- Supports wavefront sensing for commissioning and maintenance
- Refractive optics



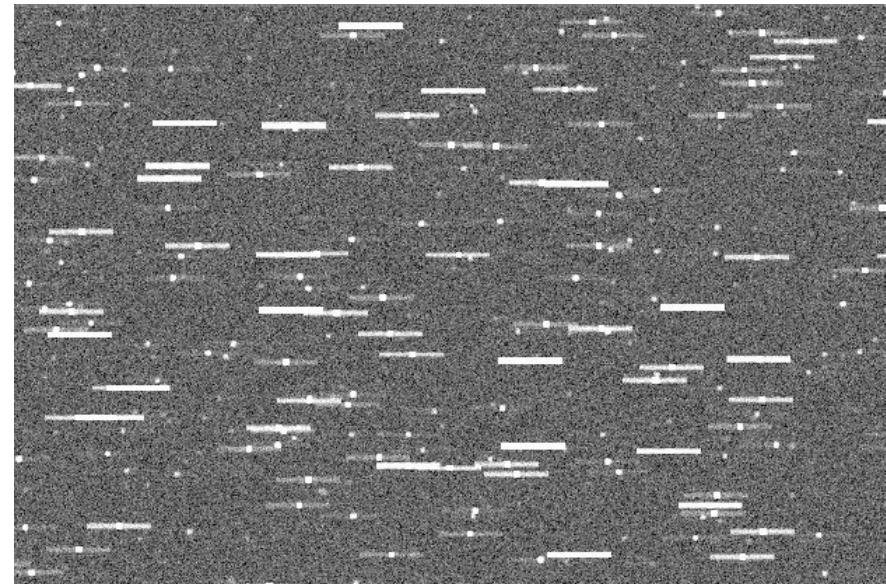
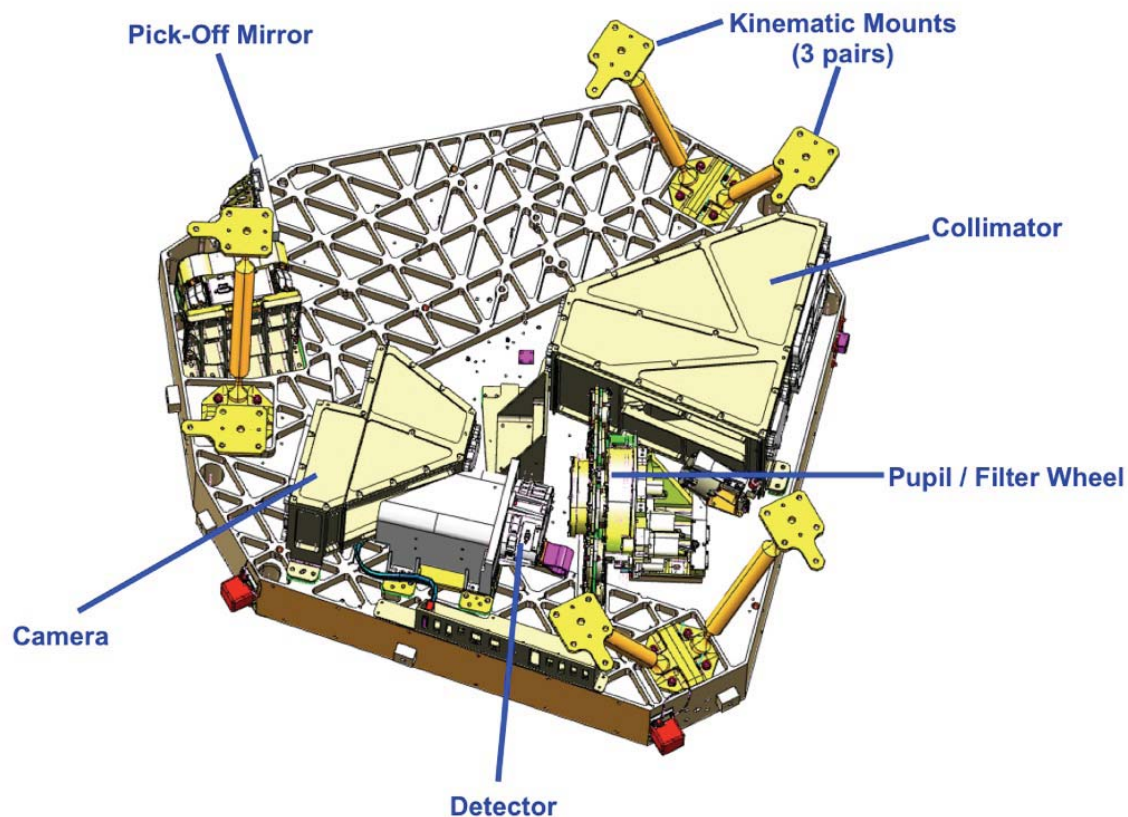
- Developed by a European Consortium and JPL
- Operates at 5 - 29 μm
- Used for mid-IR imaging (1.9 x 1.4 arcmin FOV), coronagraphy, and spectroscopy (R100 long slit, R2000 over 3.5 x 3.5 and 7 x 7 arc sec FOV integral field units)
- Si:As detector, 1024 x 1024 pixel array
- Uses external 7 K cryo-cooler



- Developed by the European Space Technology Center (ESTEC) with Astrium GmbH and Goddard Space Flight Center
- Operates at 0.6 – 5.0 μm
- Spectrographs can be obtained through programmable microshutters (for spatially resolved spectra), fixed long slits, or an image slicer (IFU)



- Developed by the Canadian Space Agency and COM DEV
- Operates at 0.8 – 4.8 μm
- The Fine Guidance Sensor is used for telescope pointing. There are two separate FGS modules for redundancy.
- The Near Infrared Imager and Slitless Spectrograph complements NIRCam's imagery and NIRSpec's spectrographs. Slitless spectrographs give spectra in one direction as well as imagery.





JWST Integration Steps & Test Campaigns



- All the optics for the JWST (the OTE mirrors, the ISIM science instruments) have been built and tested as components

- Optical testing for the JWST consists of two test campaigns:
 - **ISIM Level Testing:**
The Science Instruments are placed in the **Integrated Science Instrument Module (ISIM)** & tested as a unit, using the **OTE Simulator (OSIM)** as a light source. This testing takes place at NASA's Goddard Space Flight Center in Greenbelt, MD. There will be 3 cryo-vacuum tests of the instruments (2013, 2014, 2015)

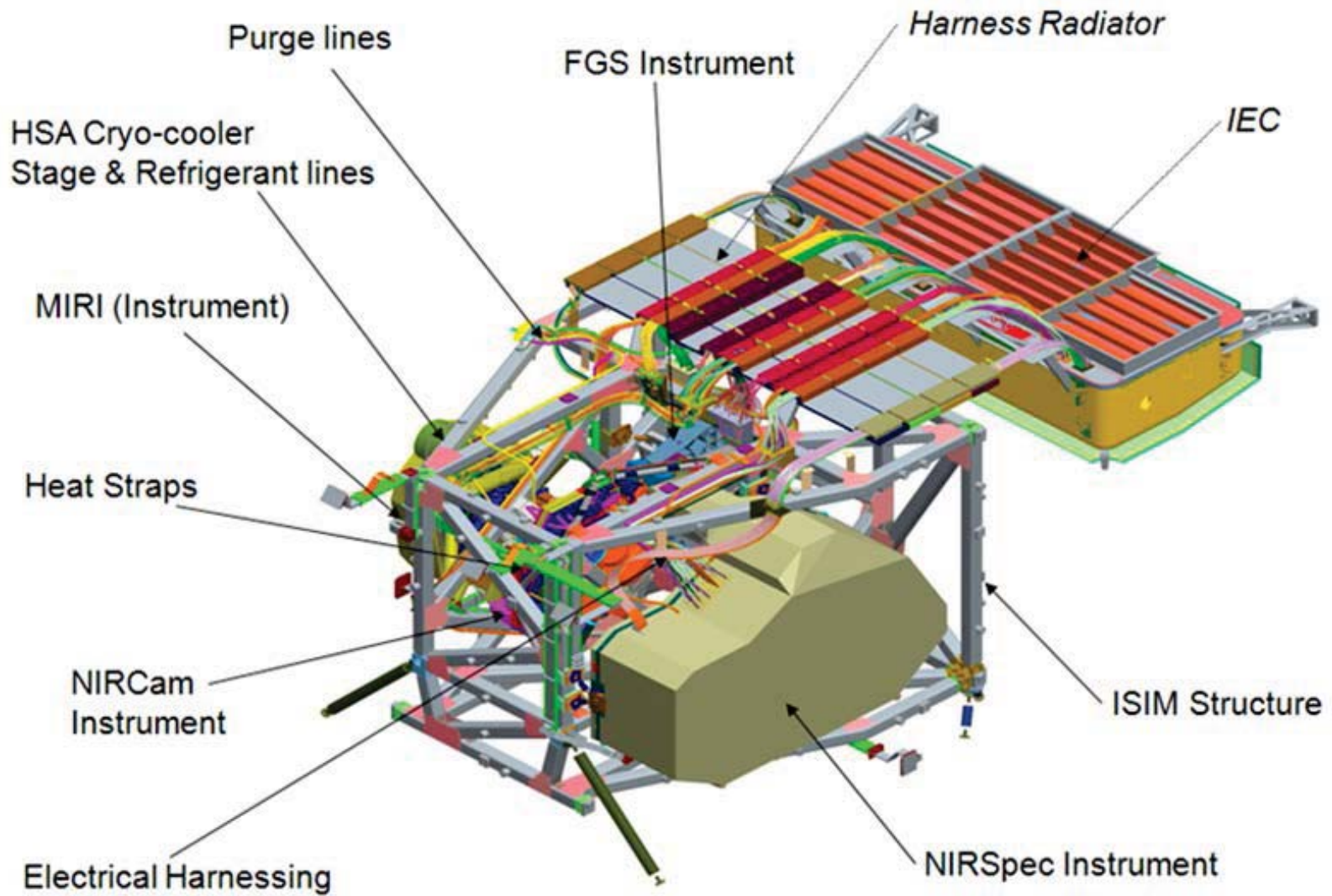
 - **OTIS Level Testing:**
The ISIM and OTE are tested together (**OTE + ISIM = OTIS**), using sources in the middle of the structure as a light source (the Aft Optical System Source Plate Assembly, **ASPA**). These tests will take place at NASA's Johnson Space Center in Houston, TX. There will be a single cryo-vacuum test of OTIS (2017)



ISIM-Level Testing



Integration into the ISIM Structure

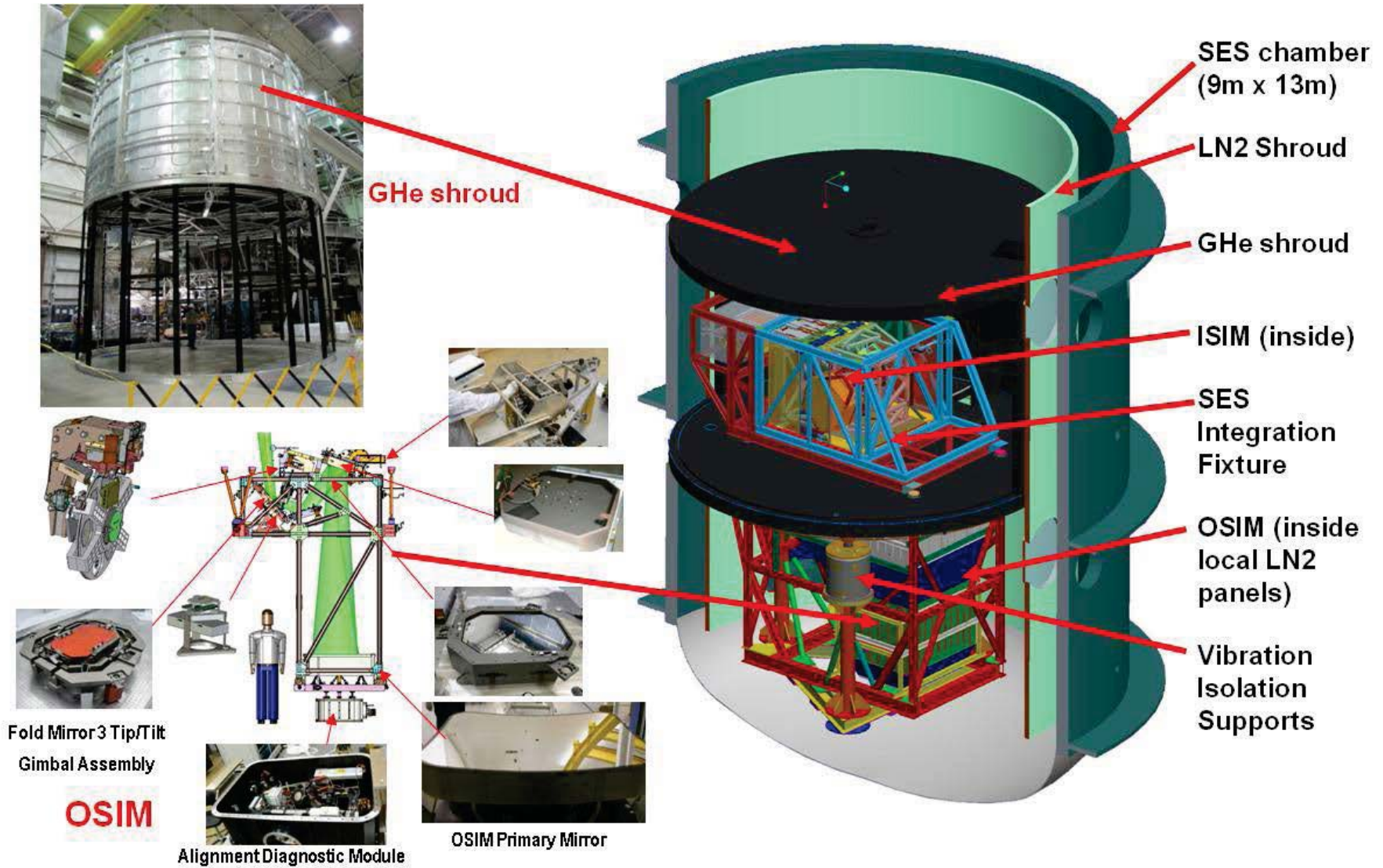




GSFC's Space Environment Simulator Chamber

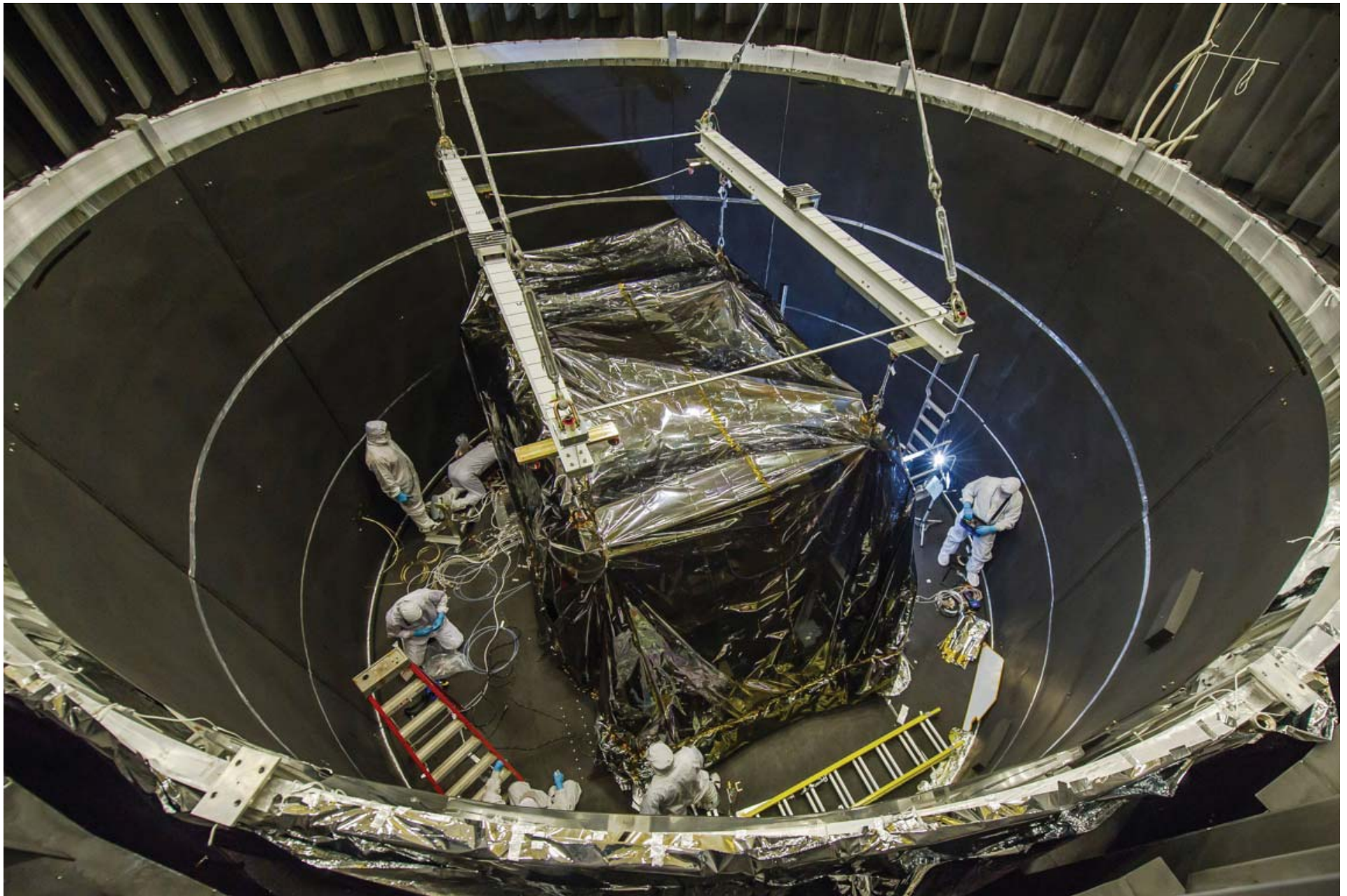


ISIM-Level Testing with OSIM





ISIM Lowered Into the Space Environment Simulator

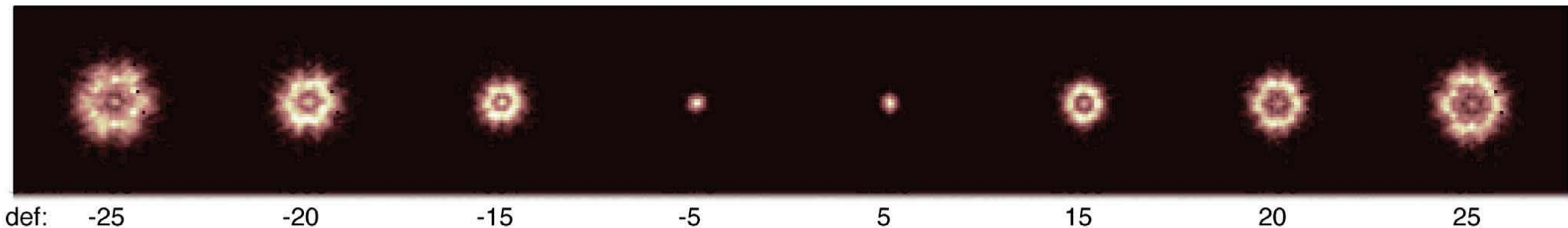




ISIM-Level Tests



- **Optical tests at ISIM level are designed to test the focus, wavefront error, boresight & pupil shear for the science instruments.**
- **Focus and wavefront error are established using focal sweeps, taking a set of images with the focus intentionally adjusted between frames. Near-focus data is used to establish best focus and far-defocused images are used to establish wavefront error using phase retrieval.**

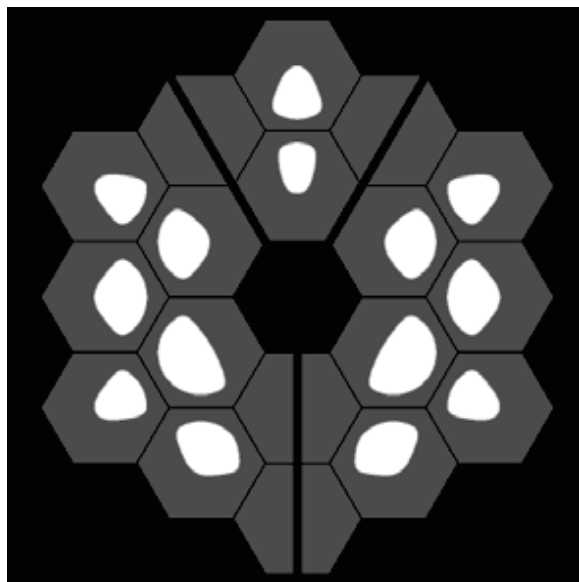




A Rochester Shout-Out: NIRSpec Coronagraph Wavefront Error



- **NIRCam has LEDs mounted inside it that can be used to align and test the coronagraphic channel. When used with a circular aperture & a prism in NIRCam, this can be used as a way to monitor the NIRCam optical performance, separate from the external illumination and testing environment.**
- **The prisms in the NIRCam longwave channel were installed incorrectly and this test can't proceed as envisioned.**
- **Dr. Fienup's group (Alden Jurling & Dustin Moore) is applying their work in Transverse Translation Diversity to develop the method for being able to do this optical monitoring of NIRCam's longwave channel**





OTIS-Level Testing

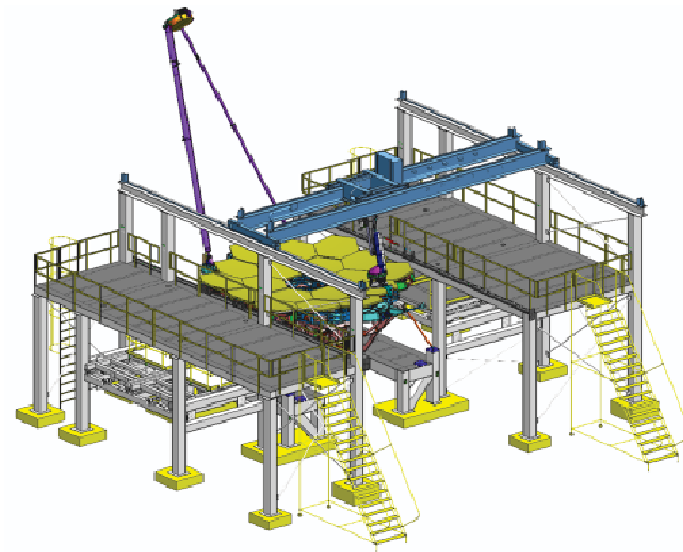


OTE Mirror Segments Under Test





Optical Alignment Stand for OTE Mirror Segments



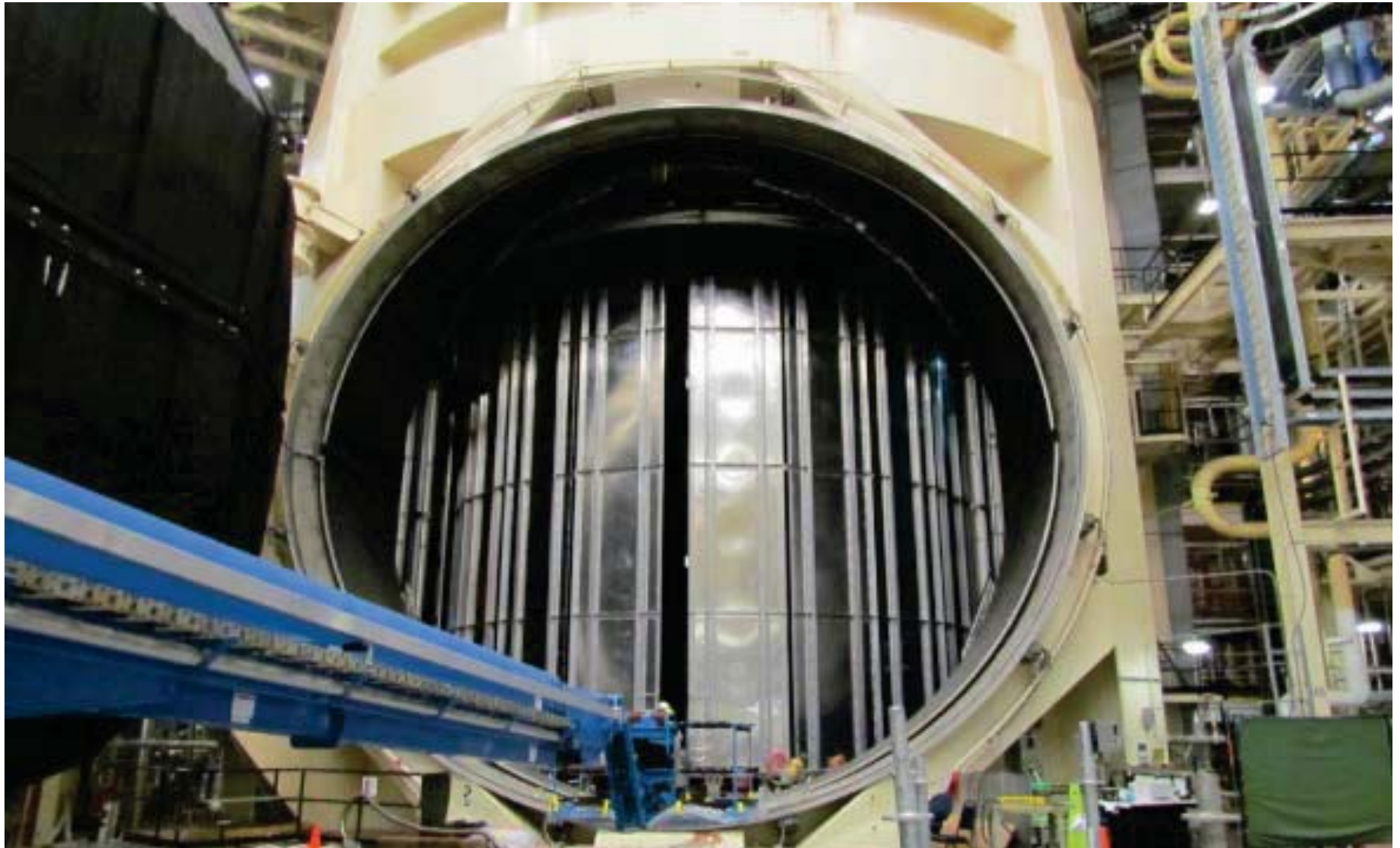


Johnson Space Center Chamber A



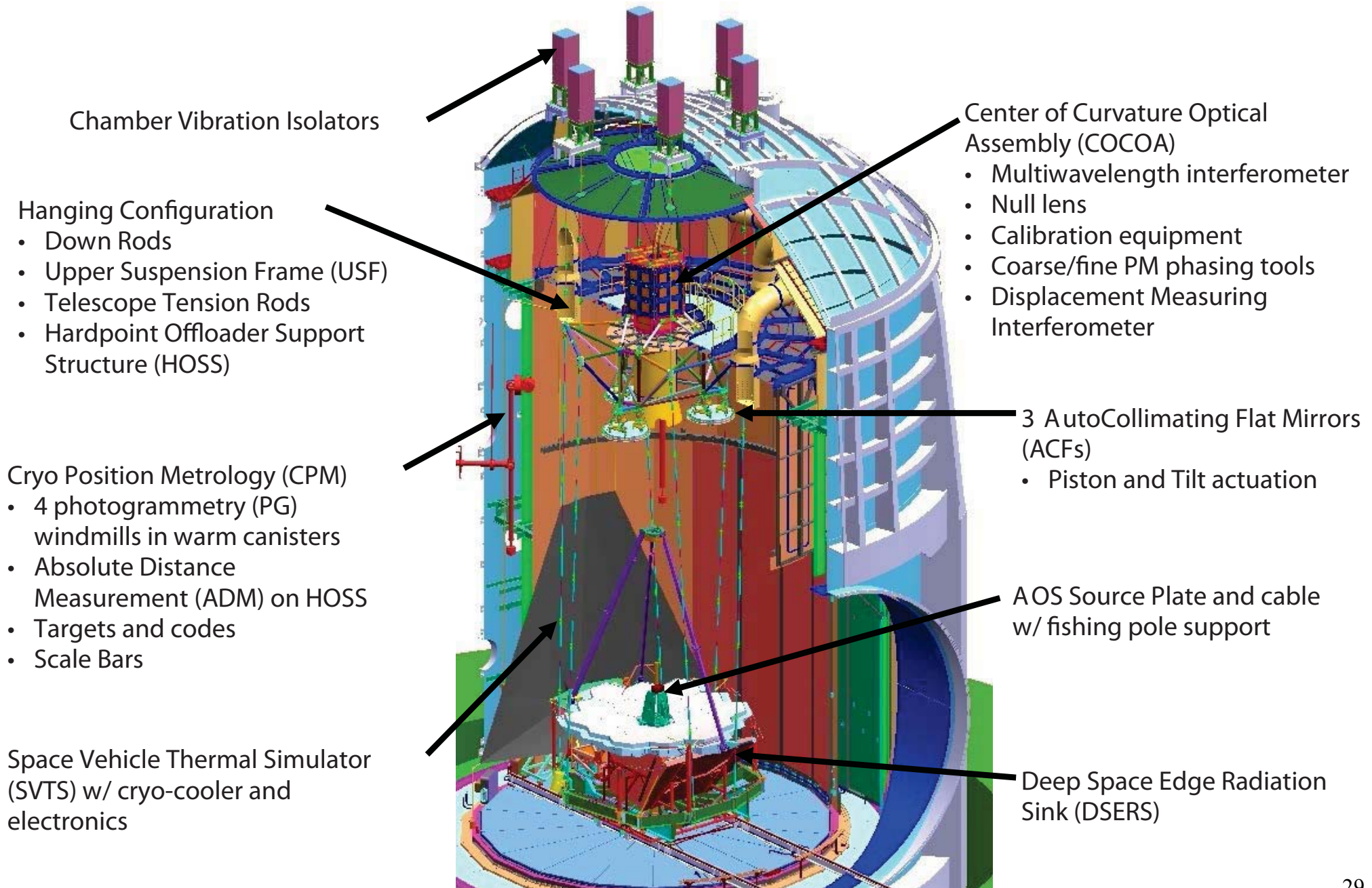


JSC Chamber A Under Renovation





OTIS-Level Testing





OTIS-Level Tests



- **Radius of curvature tests using the Center of Curvature Optical Assembly (COCOA)**

- **Tests using the Aft Optical System (AOS) Source Plate Assembly (ASPA):**
 - **“Pass And A Half” Test** for measuring OTE + ISIM instruments
Use Auto-Collimating Flats (ACFs) for returning light through the system
 - **Half Pass Test** for measuring OTE Tertiary Mirror, Fine Steering Mirror, and the ISIM instruments