James Webb Space Telescope (JWST) – 1:

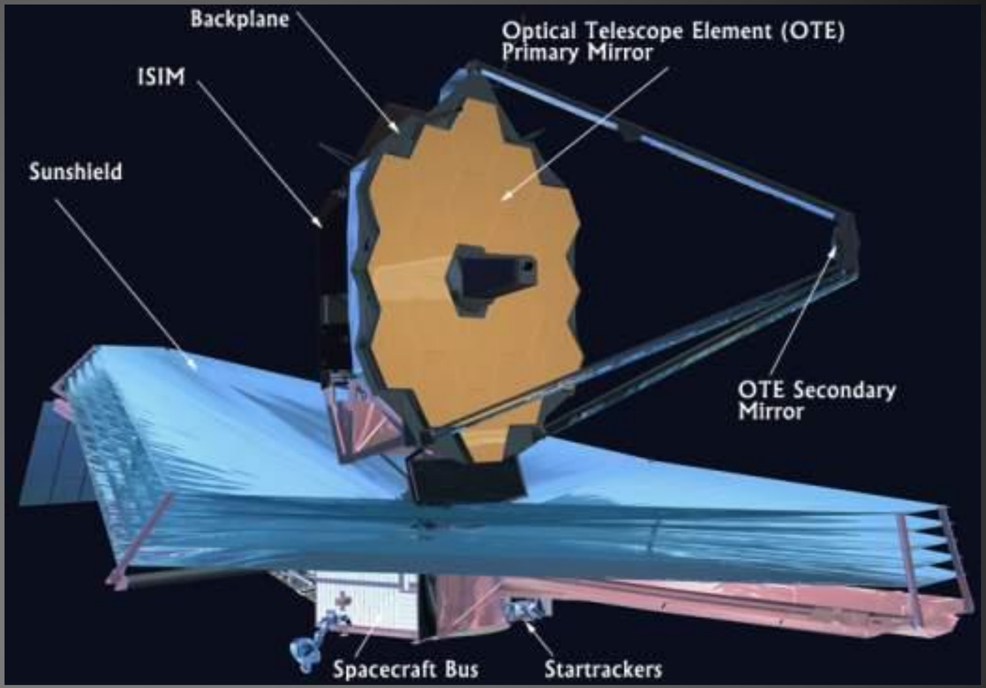
Project Status and Moving Targets

IAC Winter School – Tenerife – November 2016

J. Stansberry (STScI)

2016-10-10

James Webb Space Telescope (JWST)



Organization

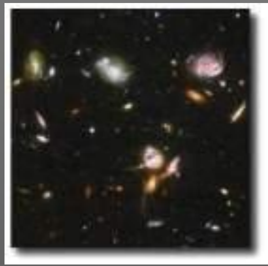
- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Aerospace Systems
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) – CSA
- Operations: Space Telescope Science Institute

Description

- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

www.JWST.nasa.gov

JWST Science Themes



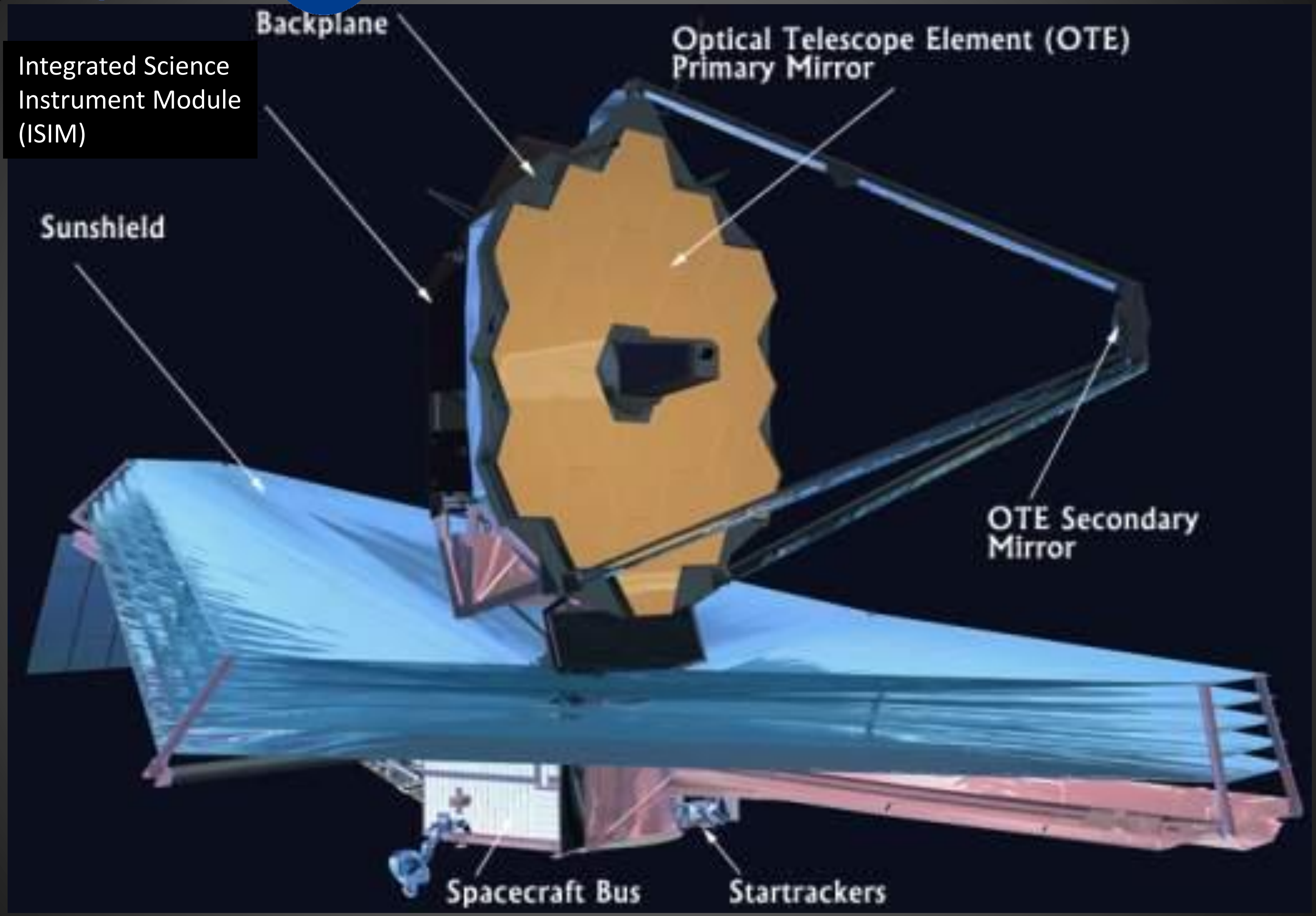
End of the dark ages: First light and reionization

The assembly of galaxies

Birth of stars and proto-planetary systems

Planetary systems and the origin of life

James Webb Space Telescope (JWST)



JWST Vital Stats

- General Astrophysical Observatory
  - Mission Lifetime: 5 years required, 10 years goal
- Primary mirror
  - 6.5 meters in 18 segments
  - Diffraction limited image beyond 2 microns wavelength
- Sunshield
  - 5 layers, 21.2 meters by 14.2 meters
  - Thermal (cooling) and scattered light control
- Perational Orbit
  - 1.5 million km (0.01 AU) from Earth, L2 point
- Operating temperature
  - Below 50 Kelvin, 5K for mid-IR instrument
- Four Science Instruments
  - Imaging, Spectroscopy, Coronagraphy
  - 0.6–28.5 microns wavelength

Yearly Themes

2013: Instrument Integration: The Science instruments will be finished and begin their testing as an integrated science payload

2014: Manufacturing the Spacecraft: Construction will commence on the spacecraft that will carry the science instruments and the telescope

2015: Assembling the Mirror: The mirror segments, secondary mirror and aft optics will all be assembled into the telescope

2016: Observatory Assembly: The three main components of the observatory will be completed (instruments, telescope, spacecraft)

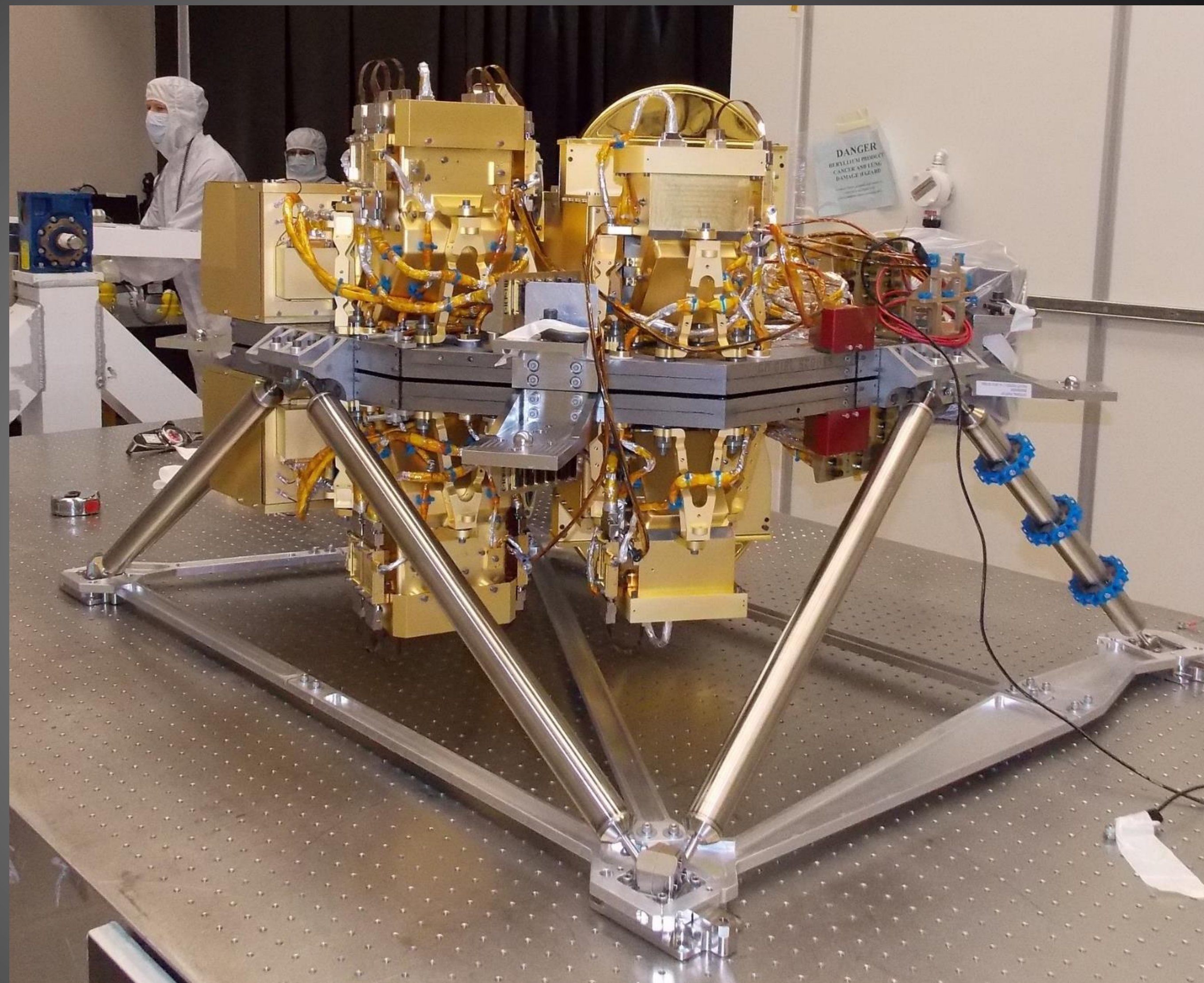
2017: Observatory Testing: The three main components of the observatory will be tested and readied for assembly (instruments, telescope, spacecraft) into a single unit

2018: Kourou Countdown: All parts of the observatory will be brought together, tested and readied for launch in Kourou, French Guiana

JWST Instrumentation - NIRCam

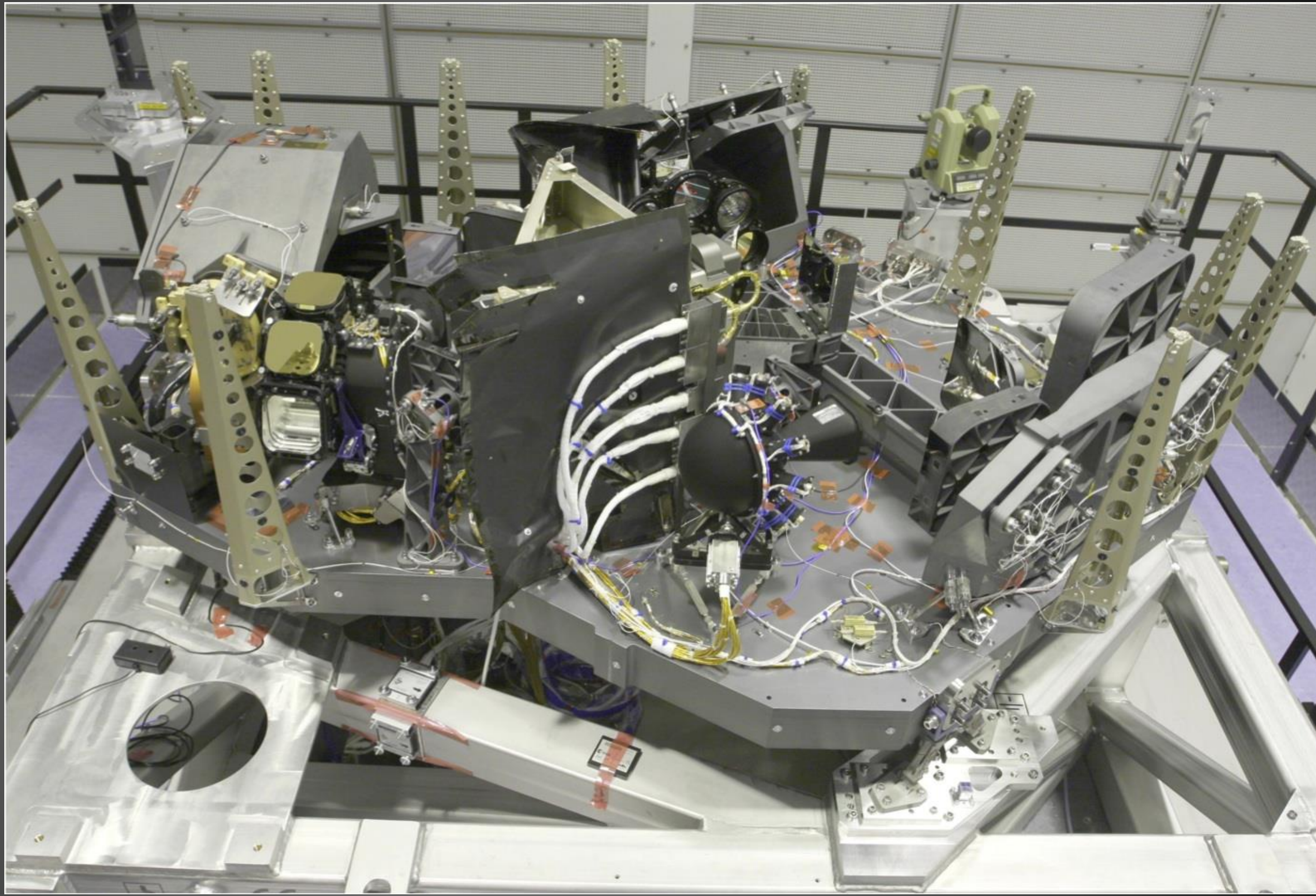
- 1 – 5 um imager
- Slitless spectroscopy (exoplanets, cosmology)

- Wavefront sensing
- 2 identical, fully redundant modules



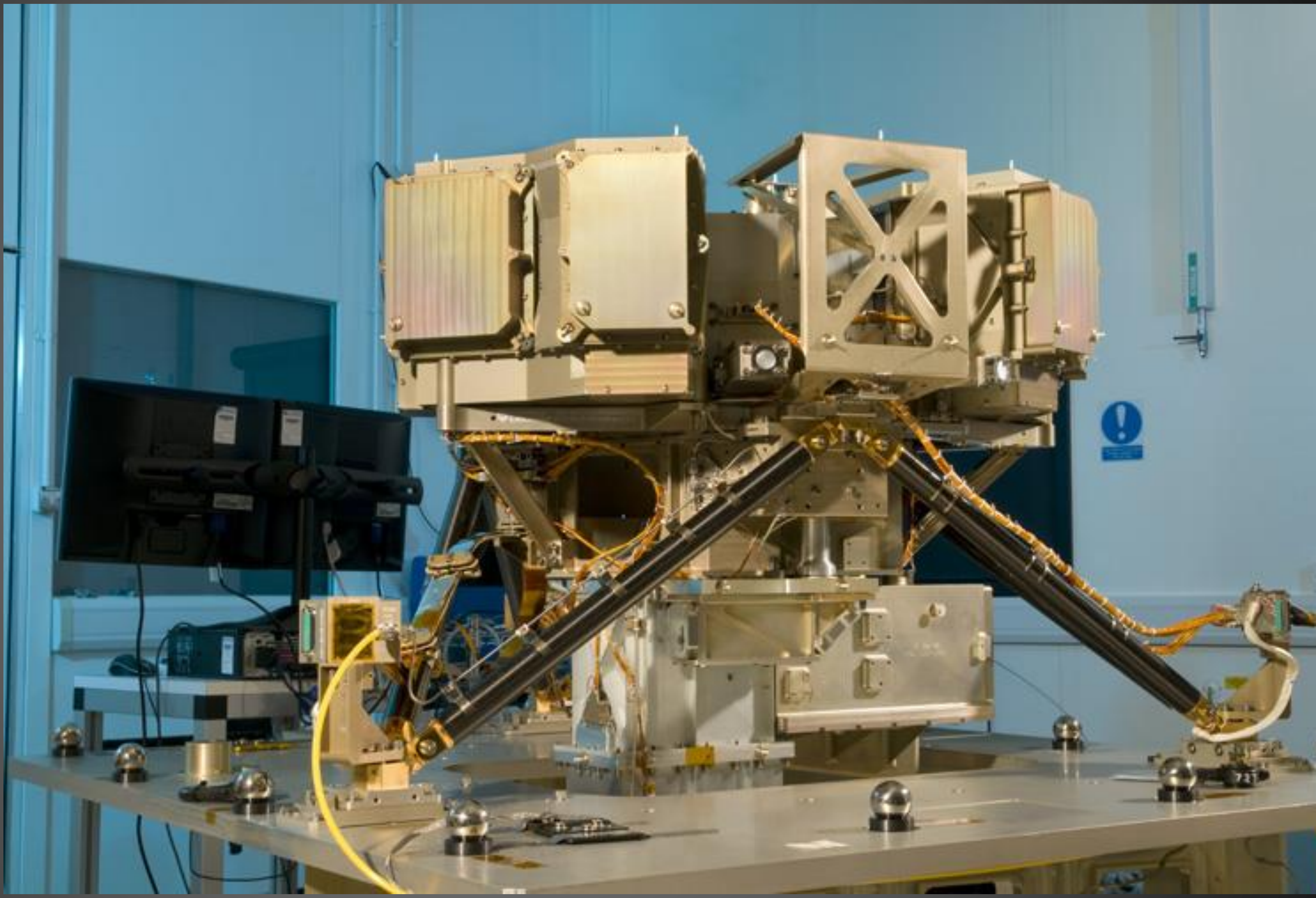
JWST Instrumentation - NIRSpec

- 1 – 5 um spectrometer
- Multi-object
- Imaging (IFU)
- 3 resolving powers



JWST Instrumentation - MIRI

- 5 – 28 um imager and spectrometer
- Imaging spectroscopy (IFU)
- R ~ 2000



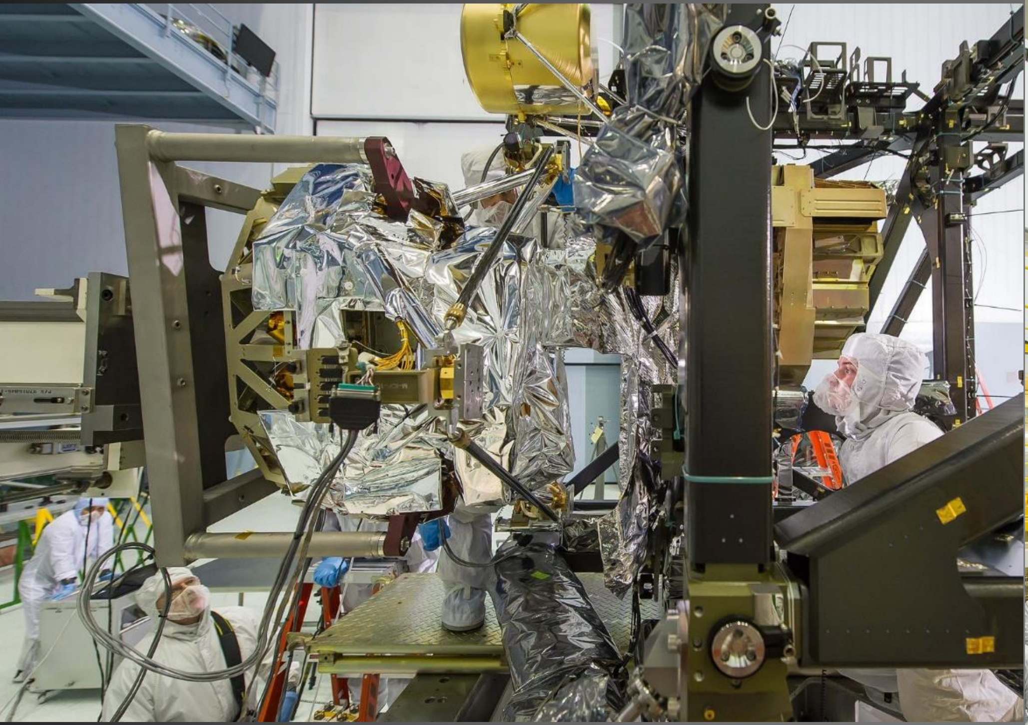
JWST Instrumentation – FGS / NIRISS

FGS:
- Fine Guidance Sensor
- Pointing correction @ 16Hz
- Key for moving targets

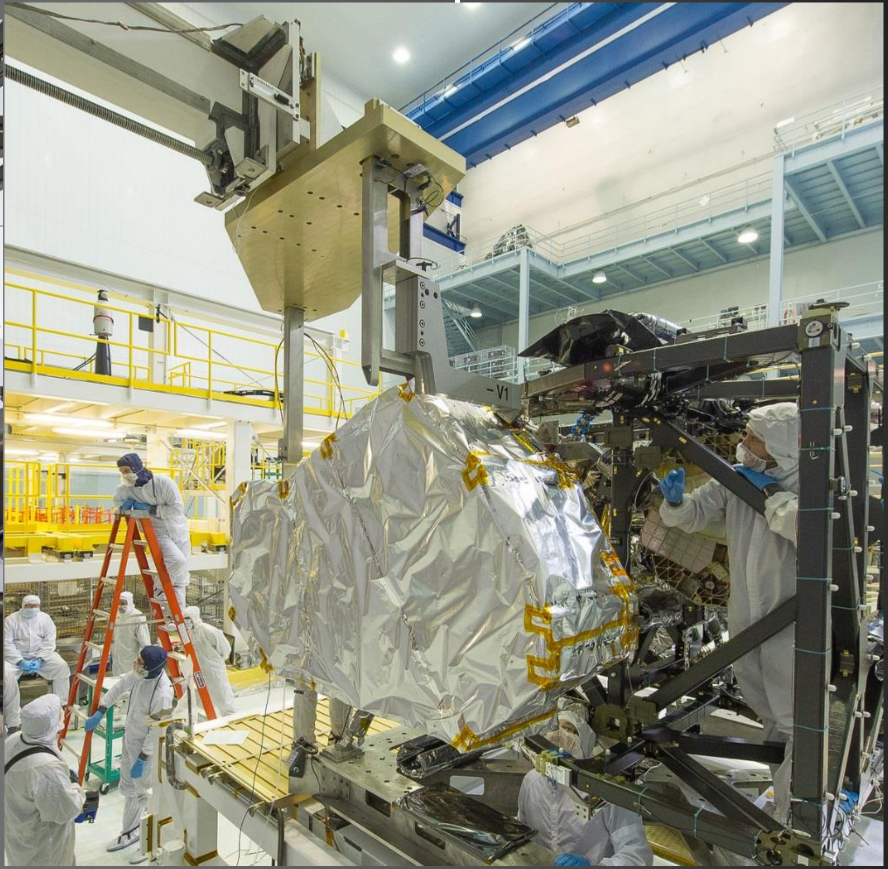
NIRISS:
- 2.5 – 5 um imager
- Slitless spectroscopy (exoplanets)
- Aperture masking interferometry

Integrated Science Instrument Module Assembly

MIRI



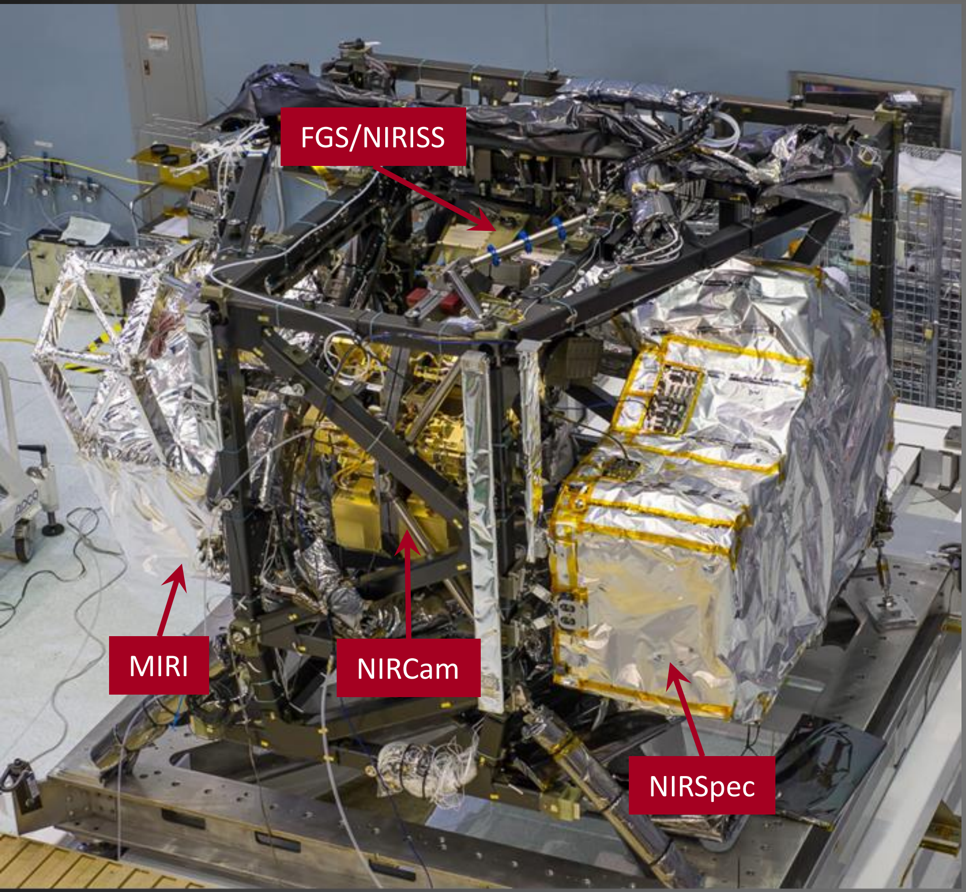
NIRSpec

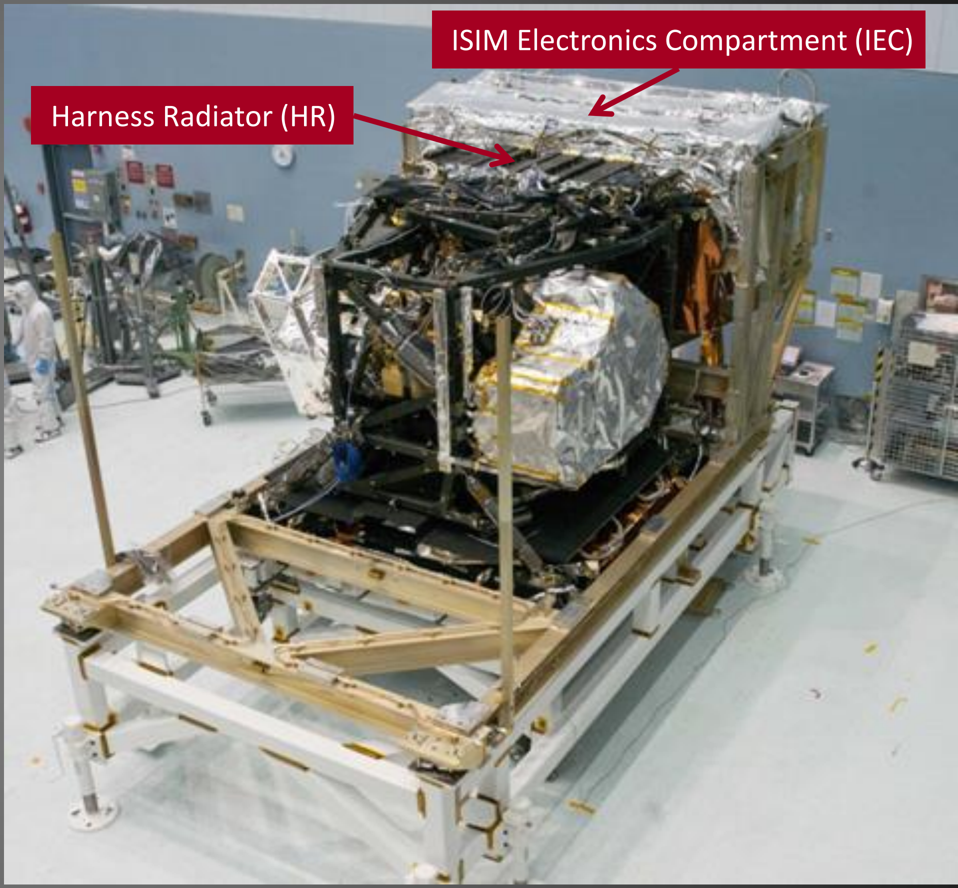


ISIM Fully Integrated for Cryo-vac and Flight

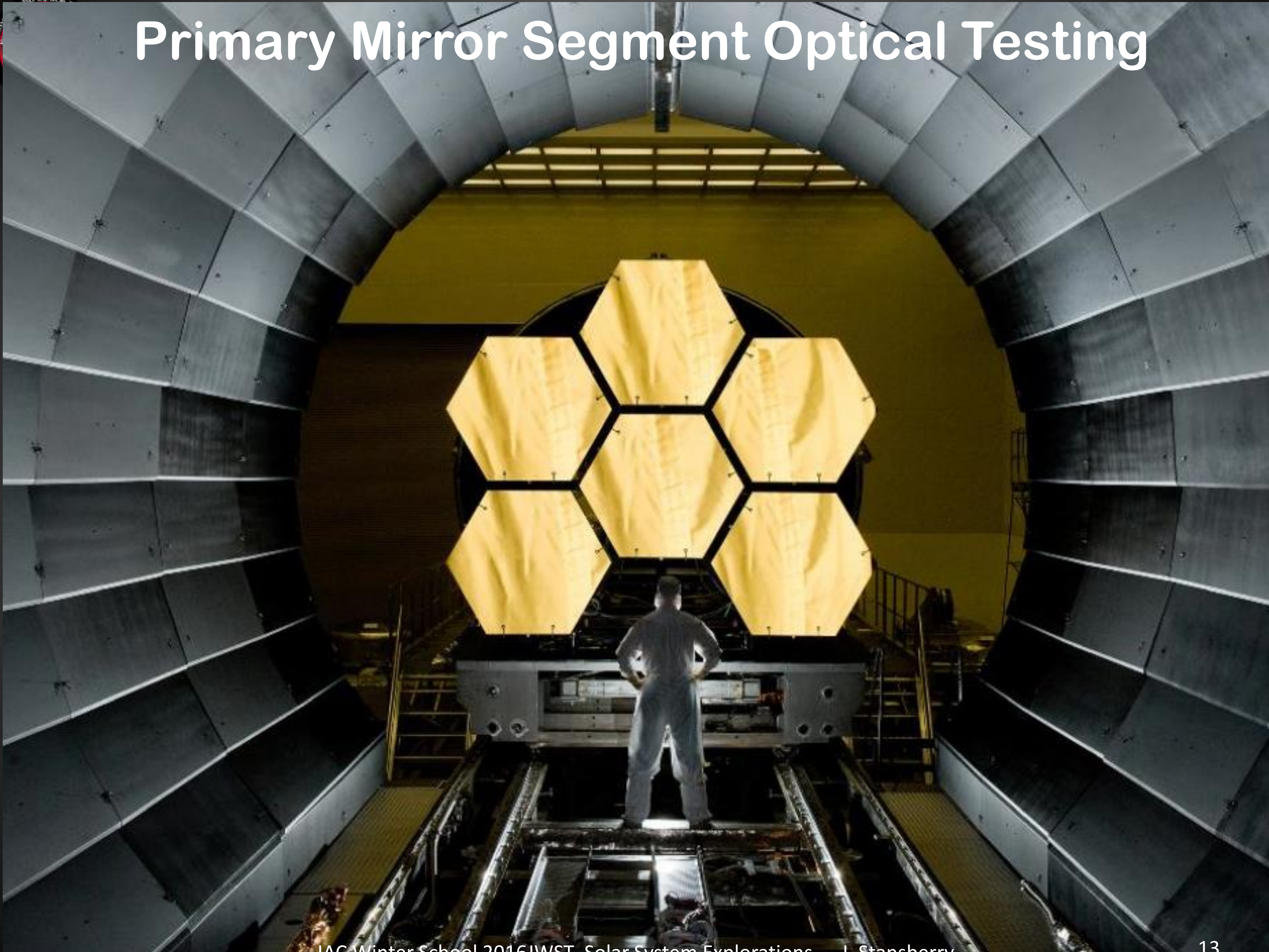
NIRCam

ISIM Fully Integrated for Cryo-vac and Flight



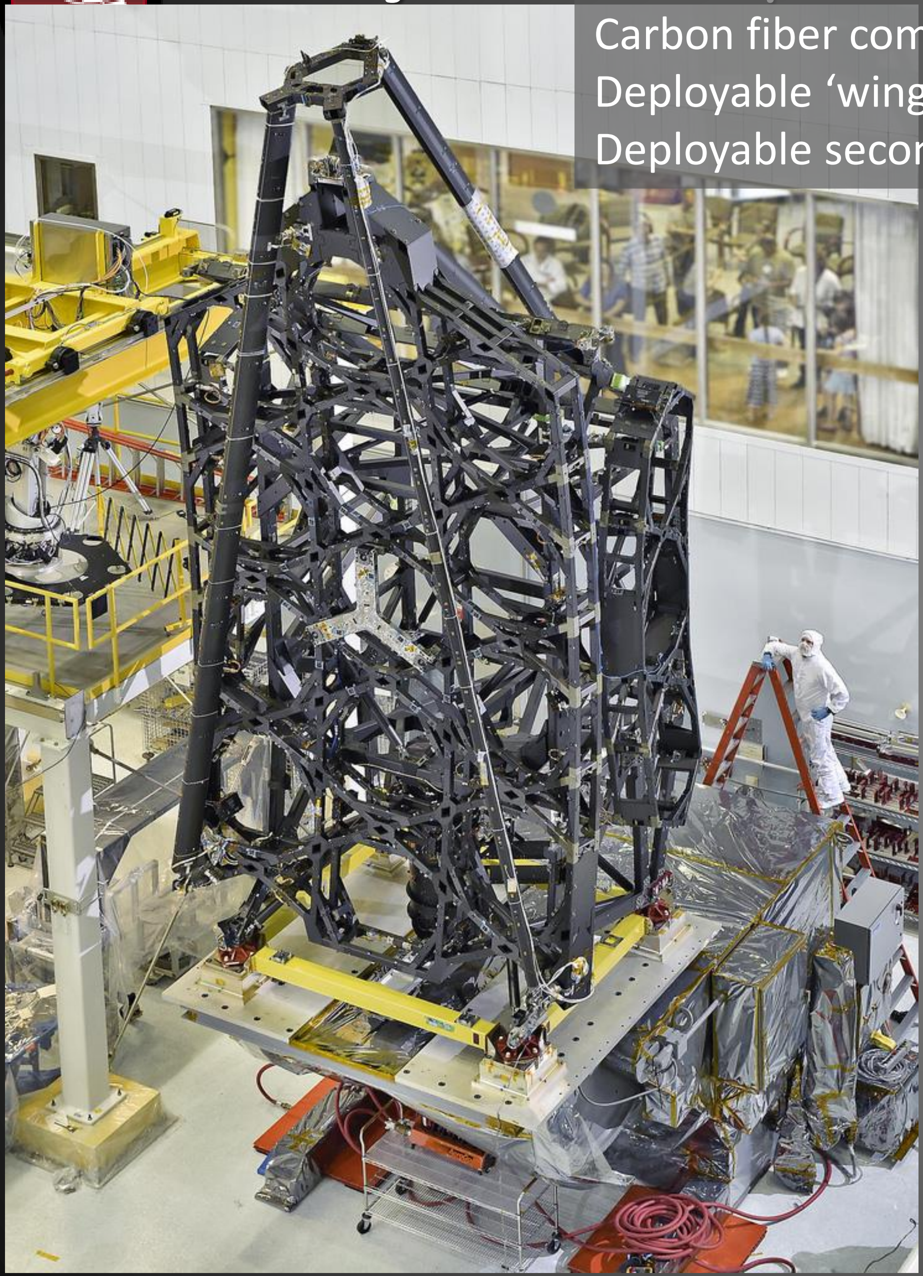


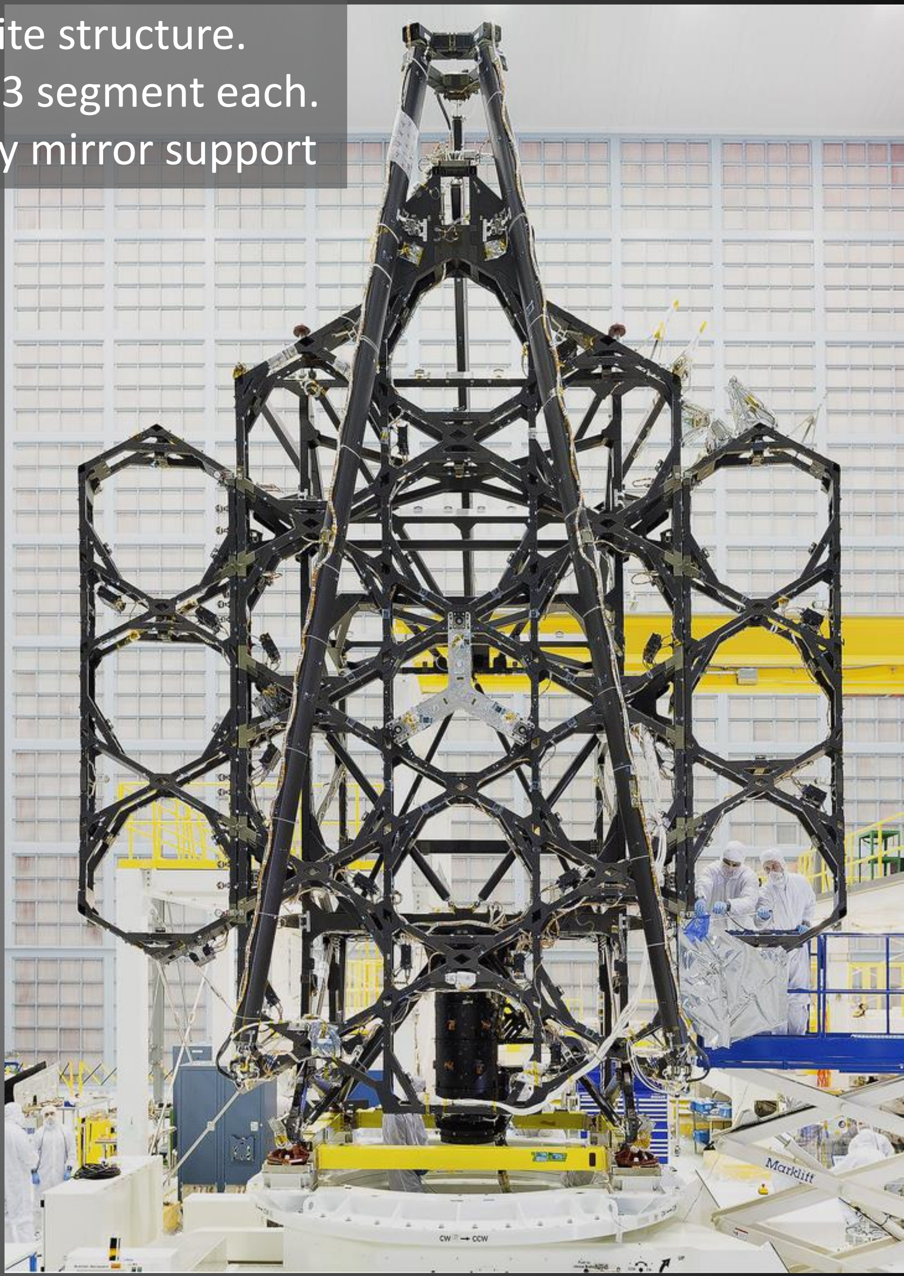
Primary Mirror Segment Optical Testing



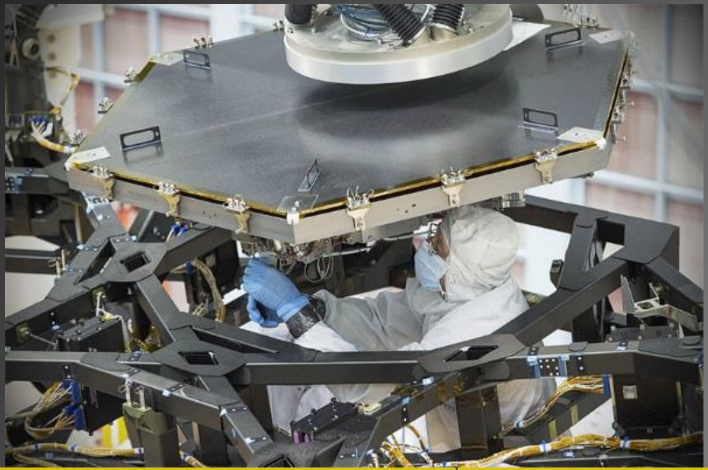
Primary Mirror Backplane

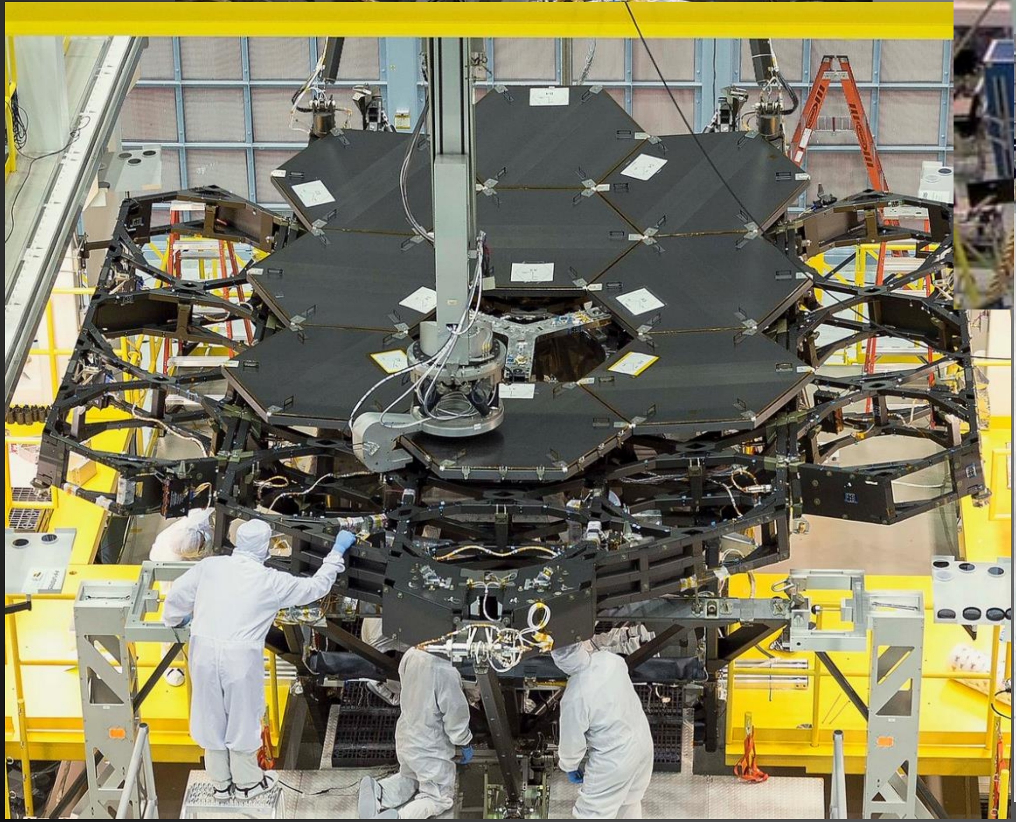
Carbon fiber composite structure.
Deployable ‘wings’ – 3 segment each.
Deployable secondary mirror support

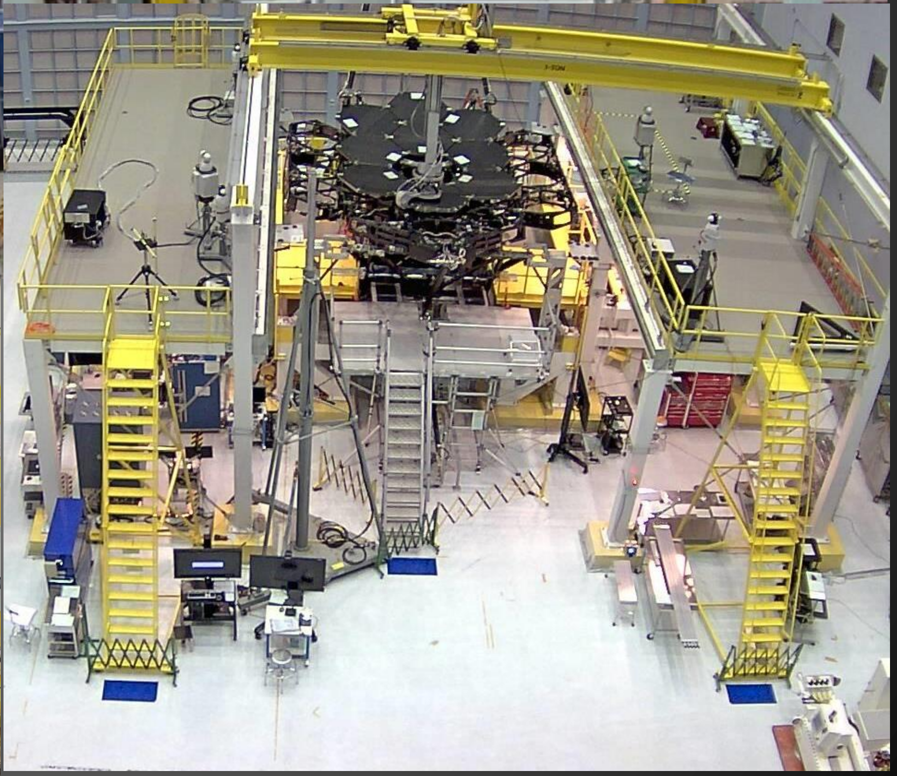




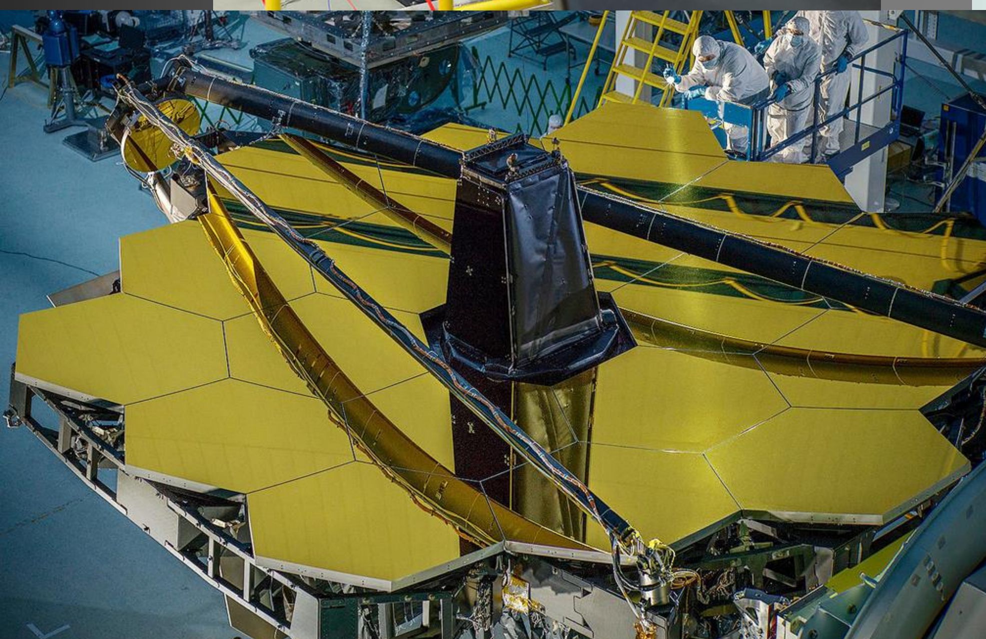
Primary Mirror Assembly



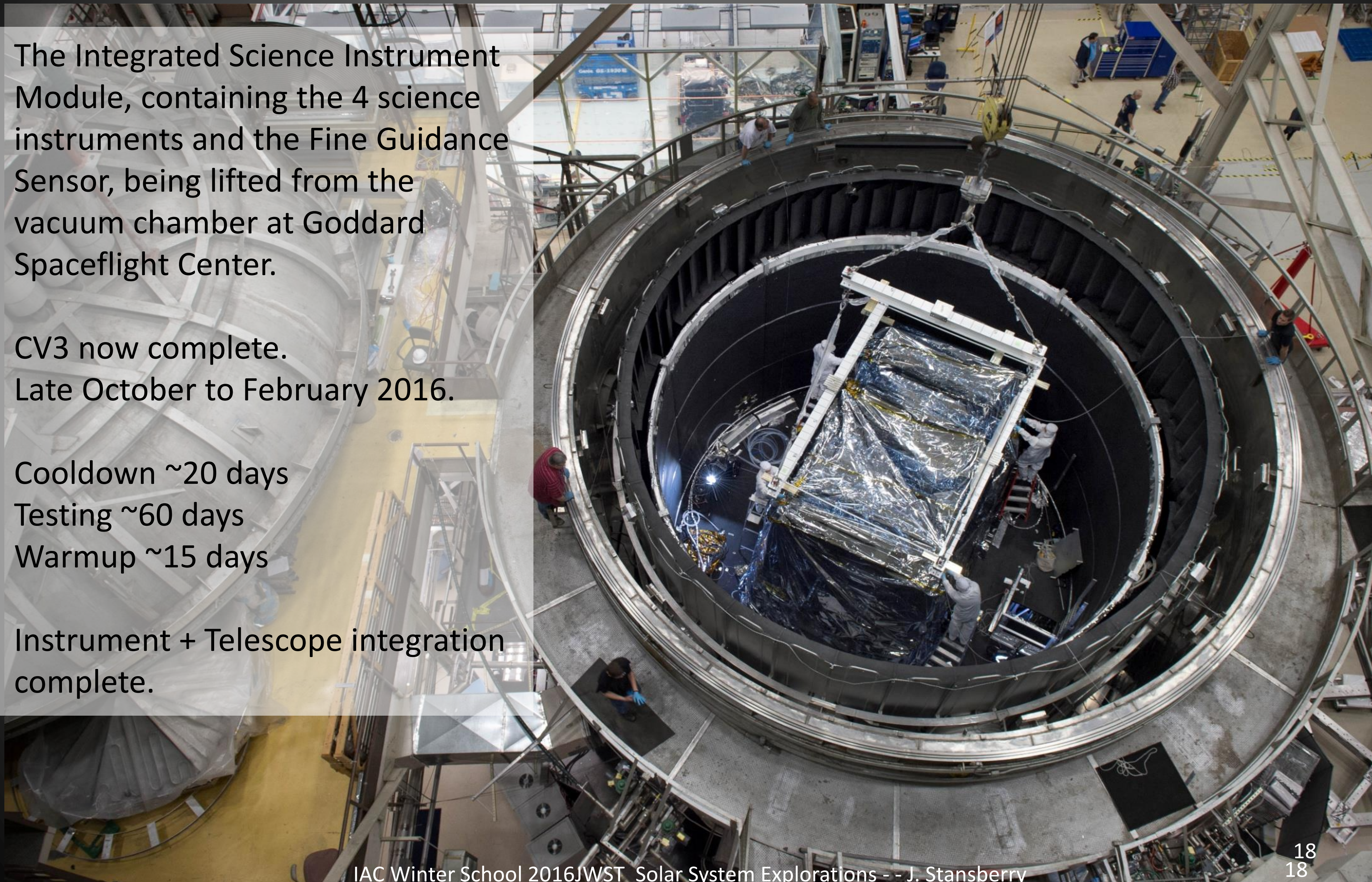




Primary Mirror Assembly



ISIM Cryo-vac 3 test complete March 2016



The Integrated Science Instrument Module, containing the 4 science instruments and the Fine Guidance Sensor, being lifted from the vacuum chamber at Goddard Spaceflight Center.

CV3 now complete.
Late October to February 2016.

Cooldown ~20 days
Testing ~60 days
Warmup ~15 days

Instrument + Telescope integration complete.

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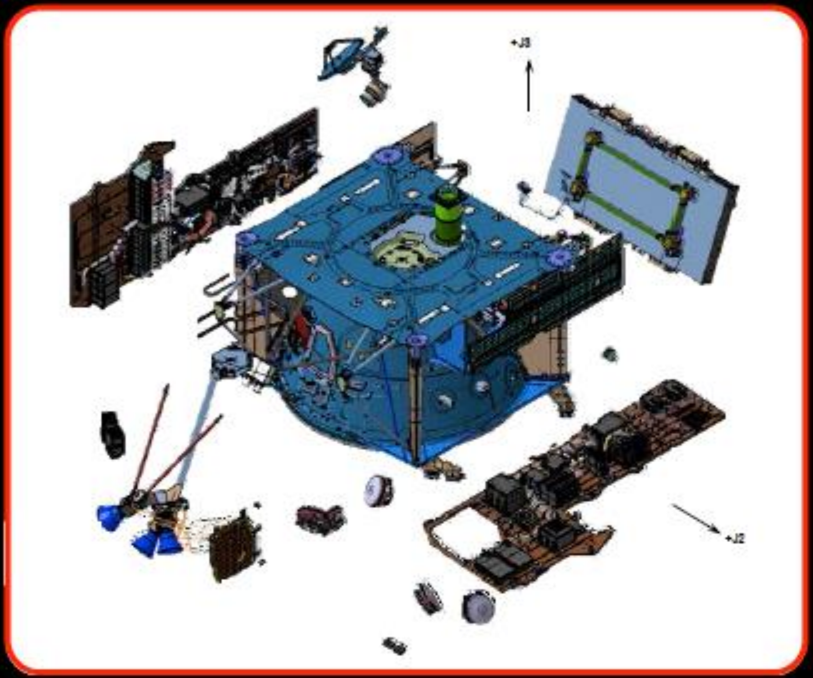
ISIM Installation

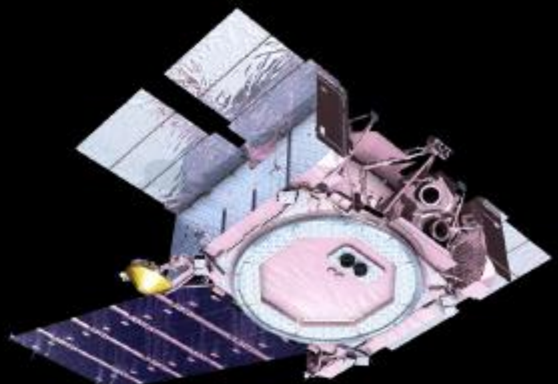
http://jwst.nasa.gov/webcam.html

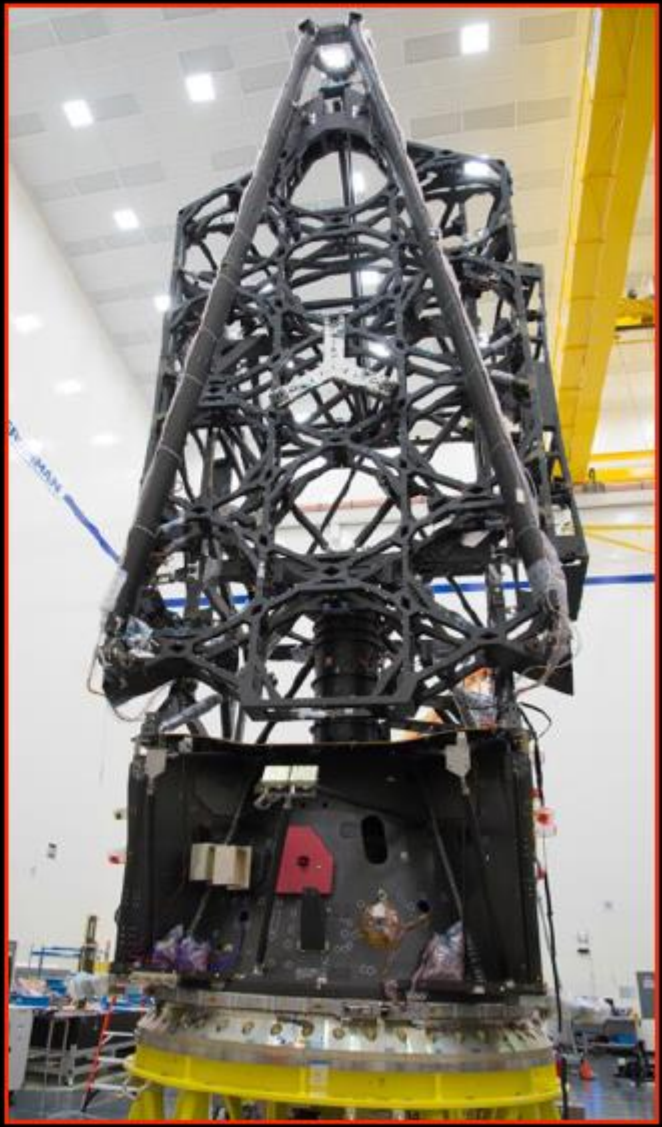
JWST Optical Telescope Element Complete

Sunshield Full Deployment Test

Spacecraft Bus - Complete







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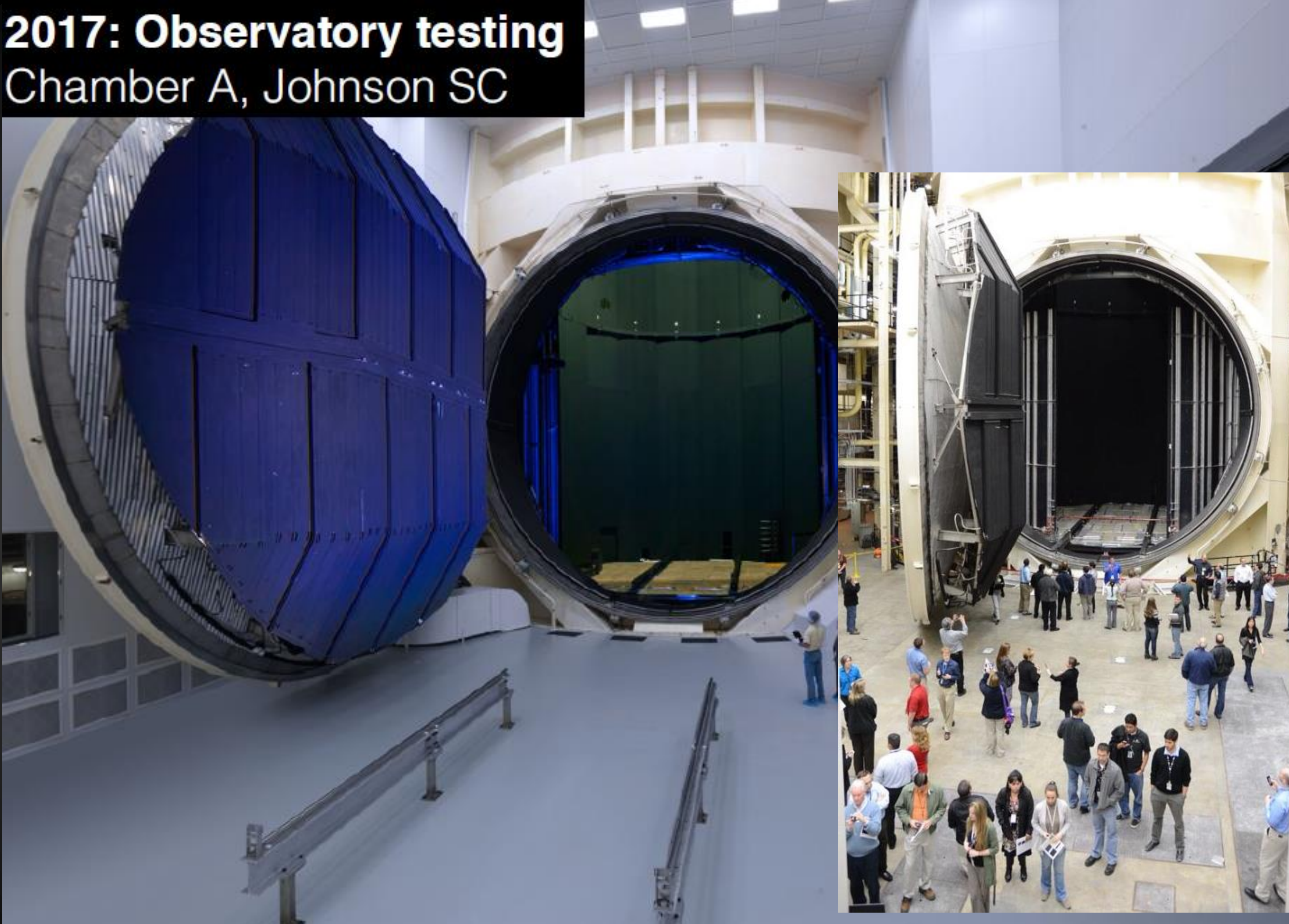
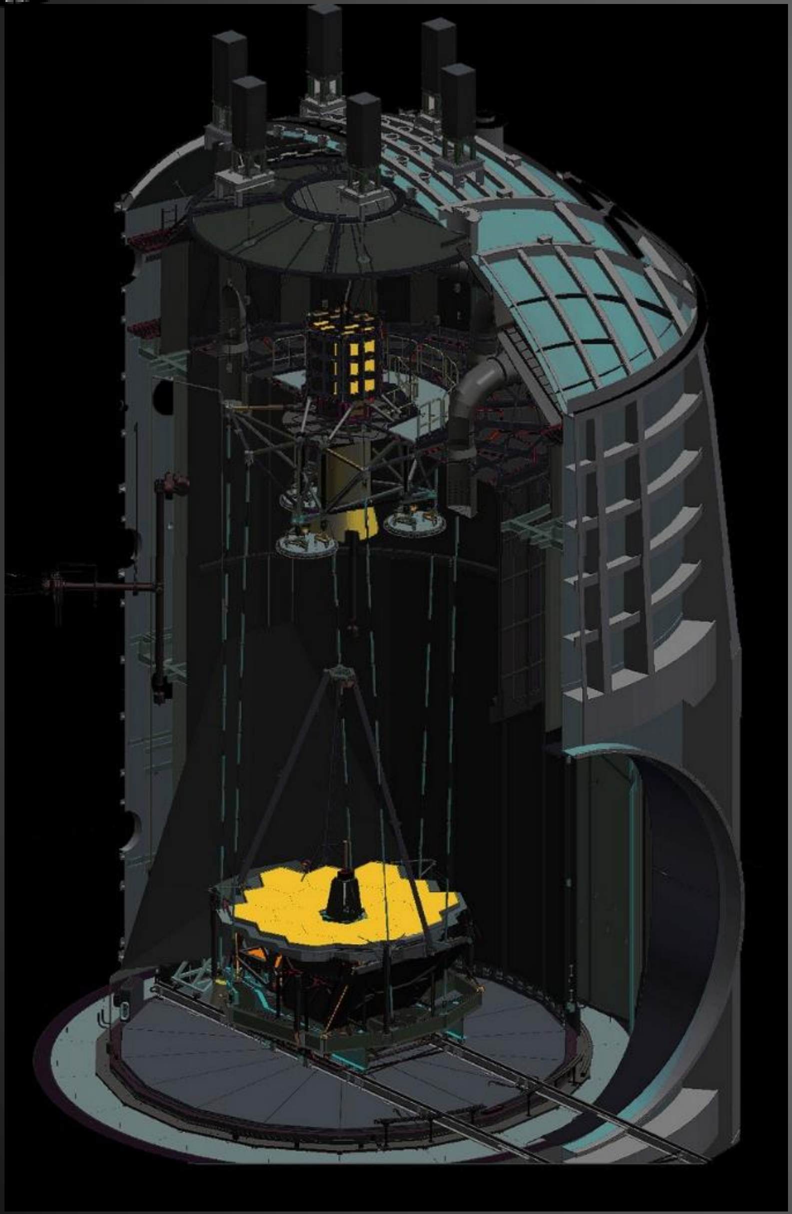
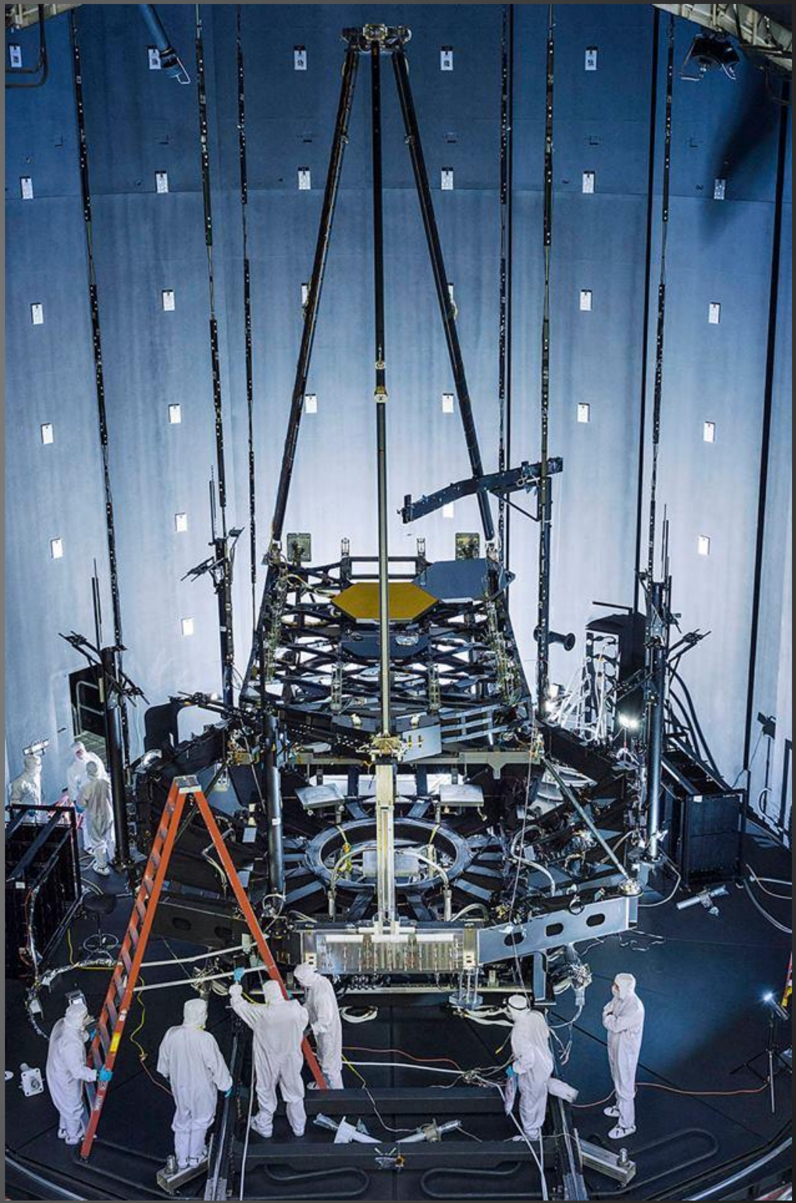
2017: Observatory testing
Chamber A, Johnson SC



OTE Optical Test at NASA Johnson - 2017





2018: Observatory integration and launch

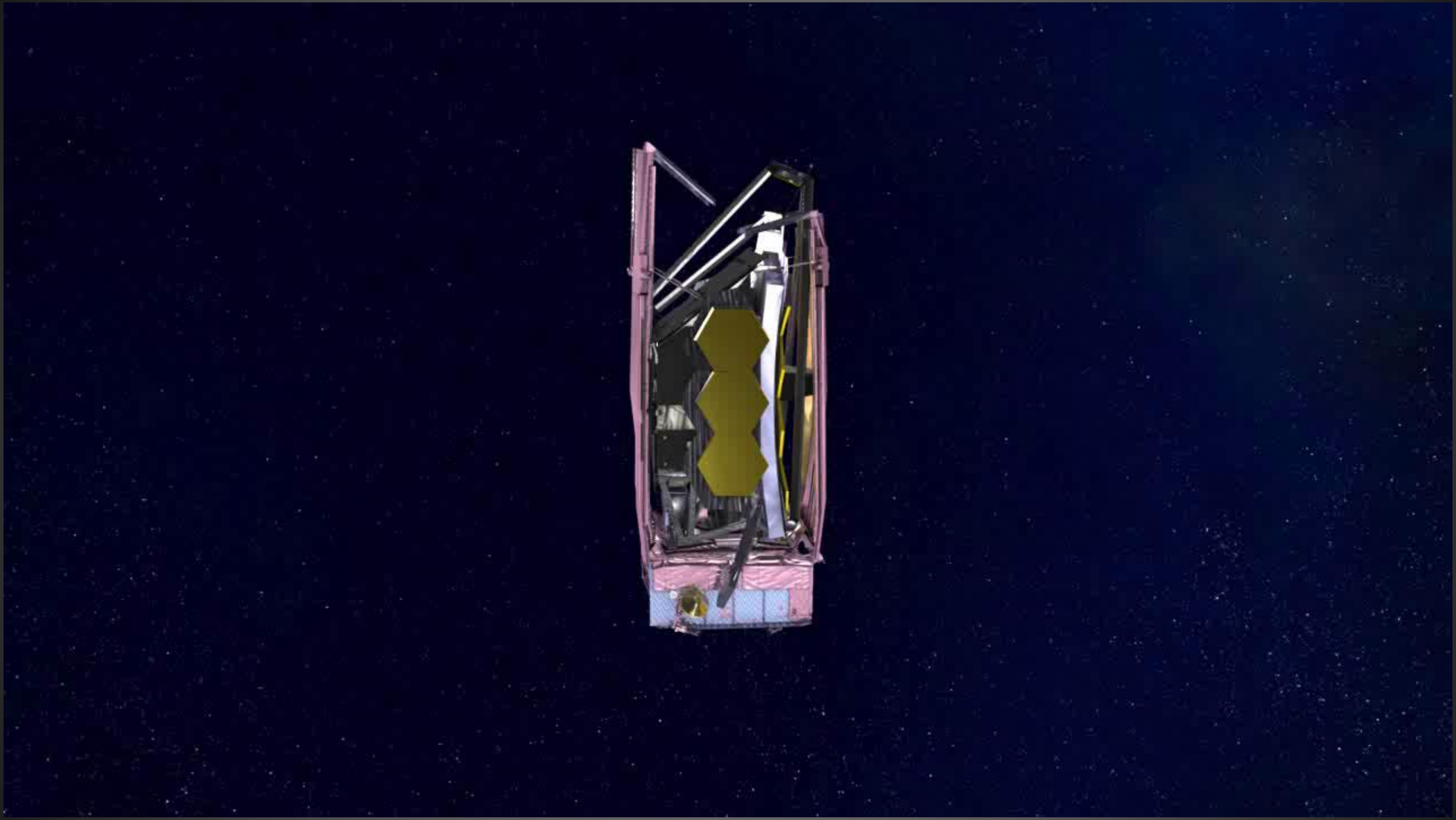
sunshield + spacecraft + observatory

Animations

- Telescope handling at Goddard
  - https://www.youtube.com/watch?v=QZYs7x7GWH8&index=4&list=PLcy1hEnsejK1JKdJlg4HSZMvOkRgN9cd8
    - https://www.youtube.com/watch?v=QZYs7x7GWH8&index=4&list=PLcy1hEnsejK1JKdJlg4HSZMvOkRgN9cd8

- Post-launch deployments
  - https://www.youtube.com/watch?v=bTxLAGchWnA&list=PL691BF261E32A4420&index=1
    - https://www.youtube.com/watch?v=bTxLAGchWnA&list=PL691BF261E32A4420&index=1

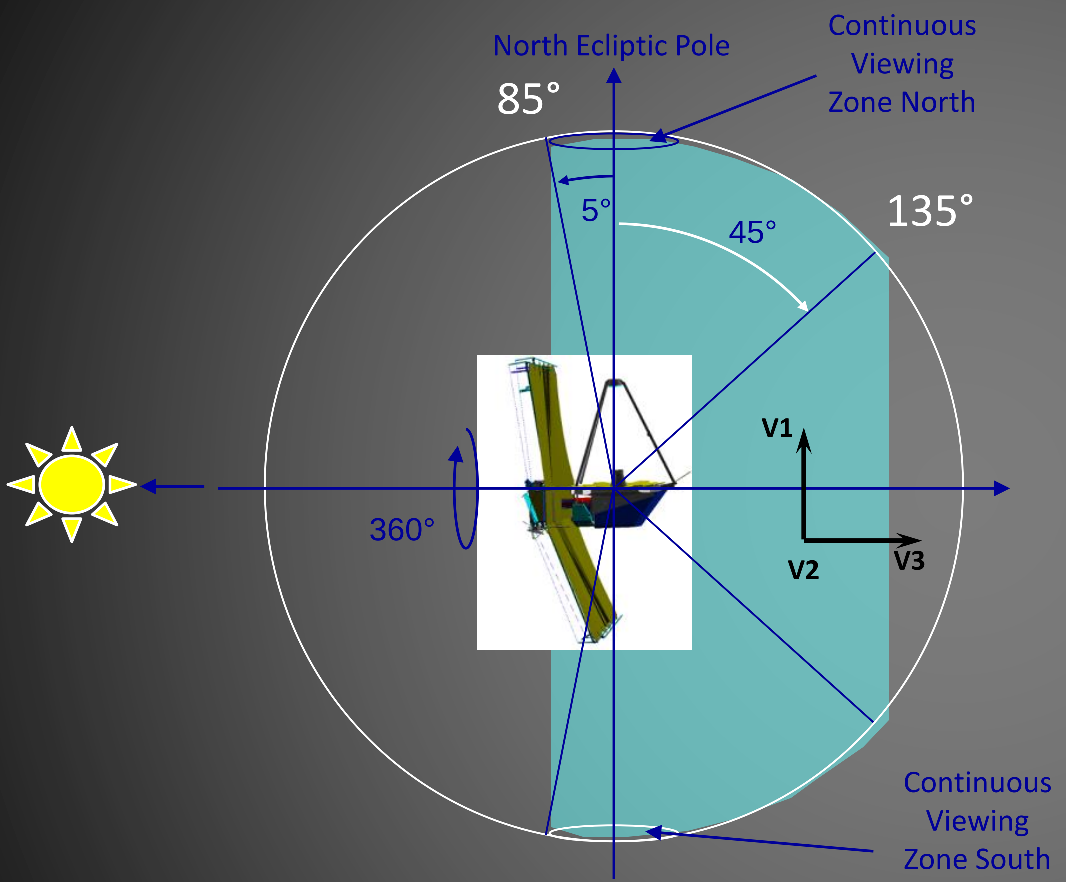
Deployments – backup video



JWST Solar System Observing

- JWST will fully support Solar System observations
  - Costs approved through NASA Planetary Sciences Division (2008)
  - Planets, satellites & rings (Mars outward)
  - Asteroids, KBOs, and comets
- Non-sidereal tracking implemented
  - Rates up to 30 mas/sec (108 "/hr) for Cycle 1 (maybe higher for Cycle 2)
    - Covers everything except fastest NEOs, comets
  - Ephemeris represented as 5^{th} O polynomial, 0.4 mas accuracy
  - Jitter ~7 mas over 1000 sec

JWST Field of Regard

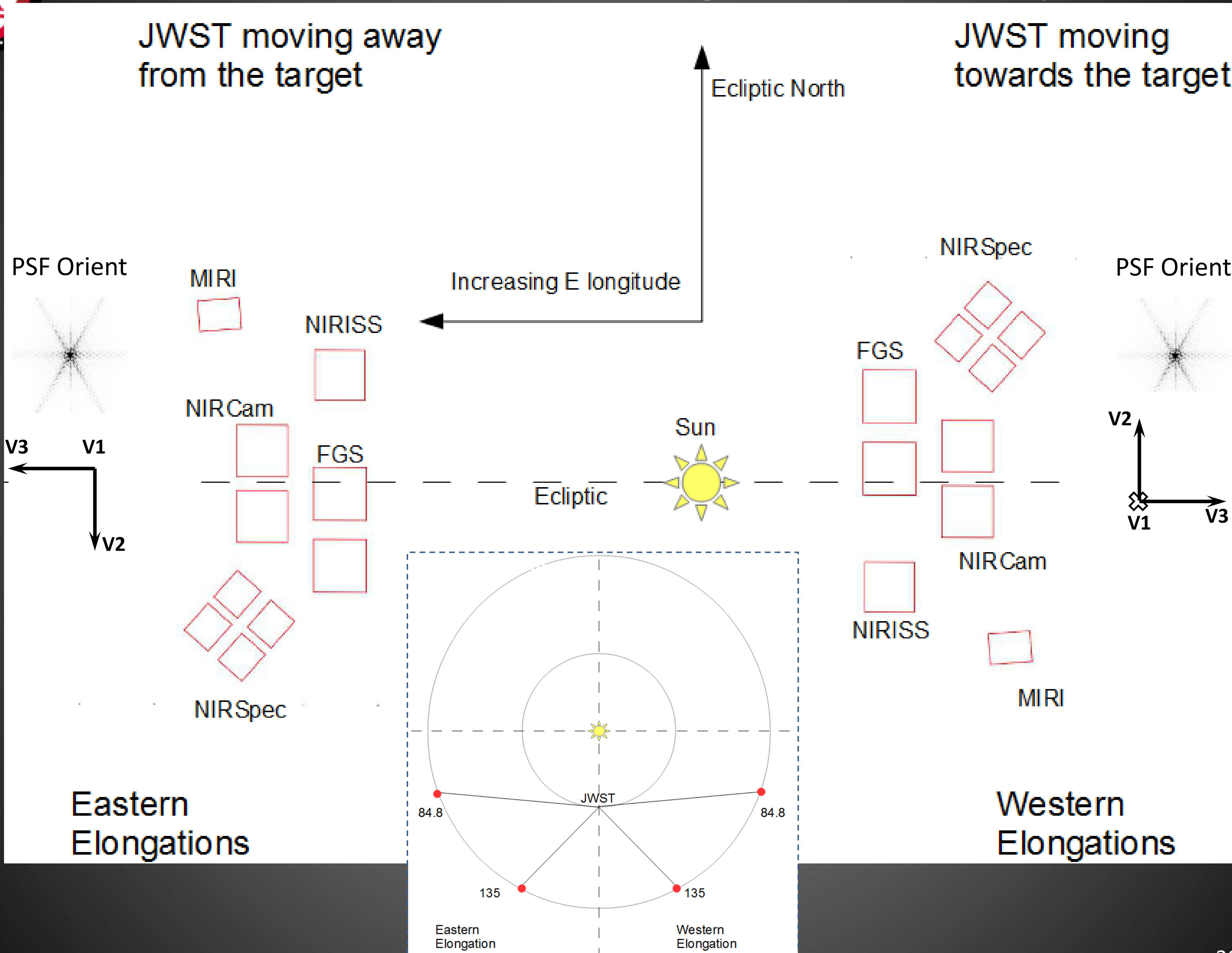


- Observatory thermal design defines the allowed Solar orientations
  - Solar elongation 85° to 135° (like Spitzer, Herschel)
  - Roll ±5° about line of sight

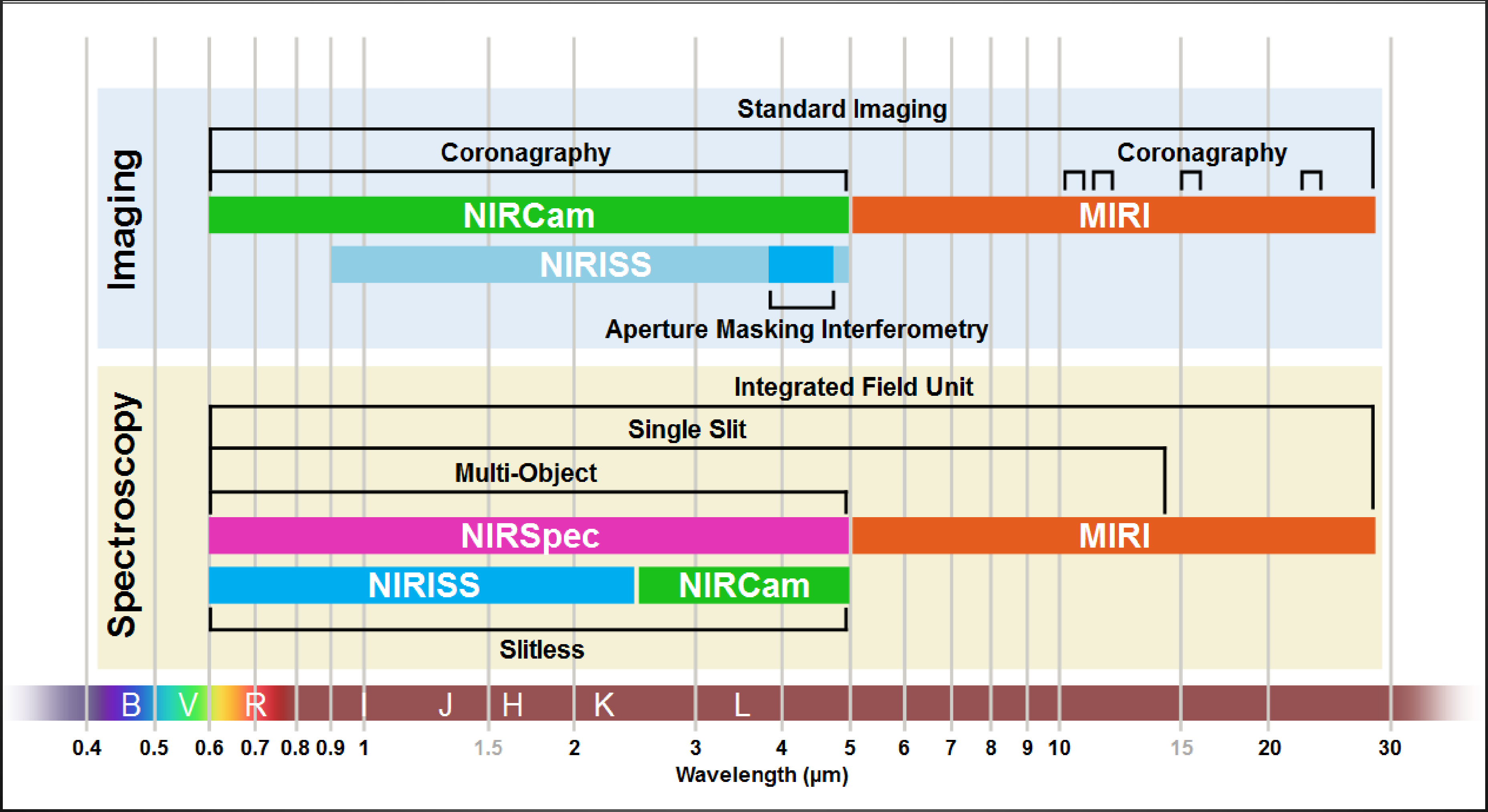
- JWST can observe the whole sky every year while remaining continuously in the shadow of its sunshield.
  - Instantaneous Field of Regard is an annulus covering 35% of the sky
  - The whole sky is covered twice each year with small continuous viewing zones at the Ecliptic poles

Solar System Targets: Observations occur near quadrature, not at opposition

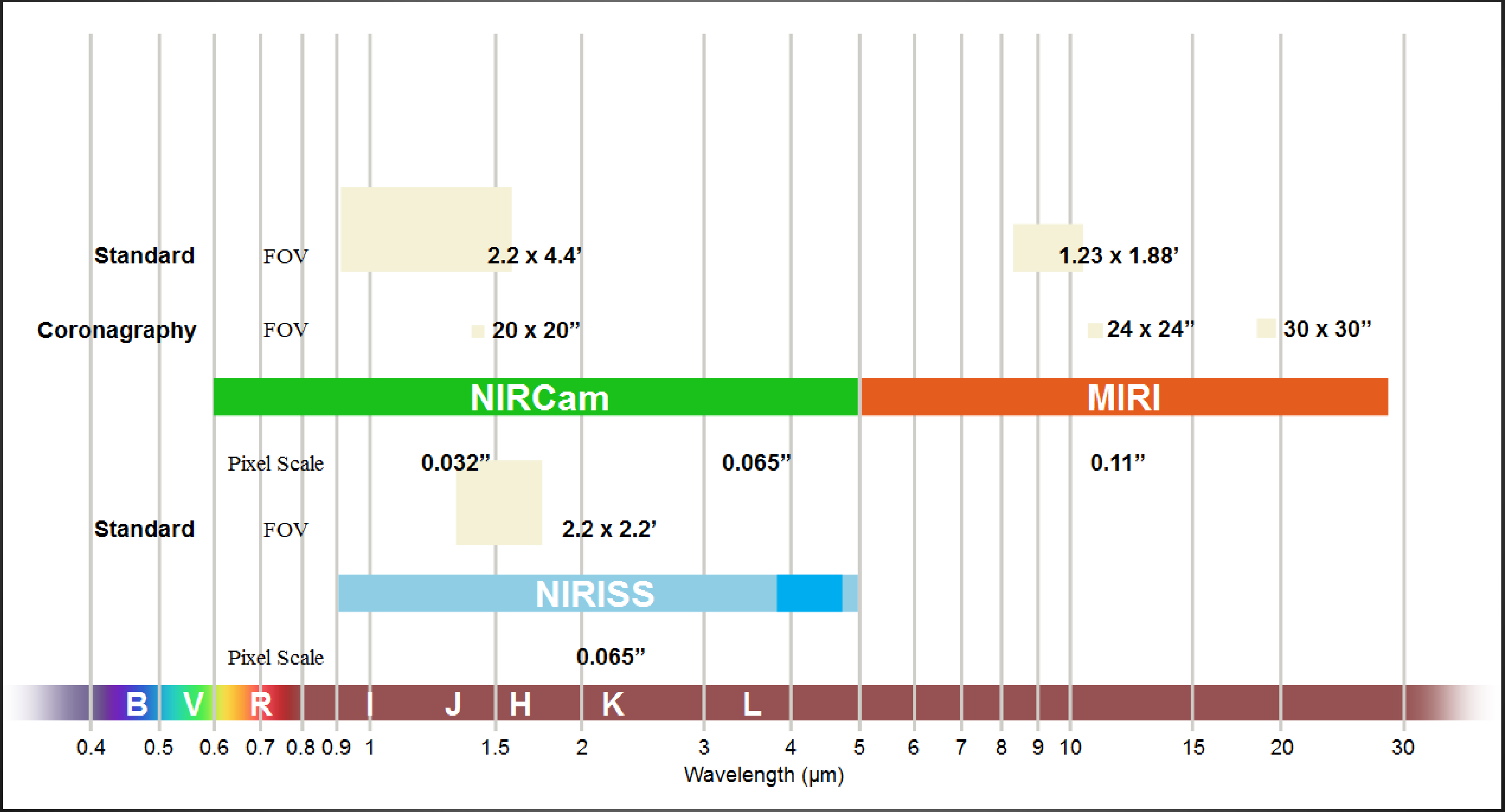
JWST Instrument FOVs for Targets in the Ecliptic Plane



JWST Instrumentation



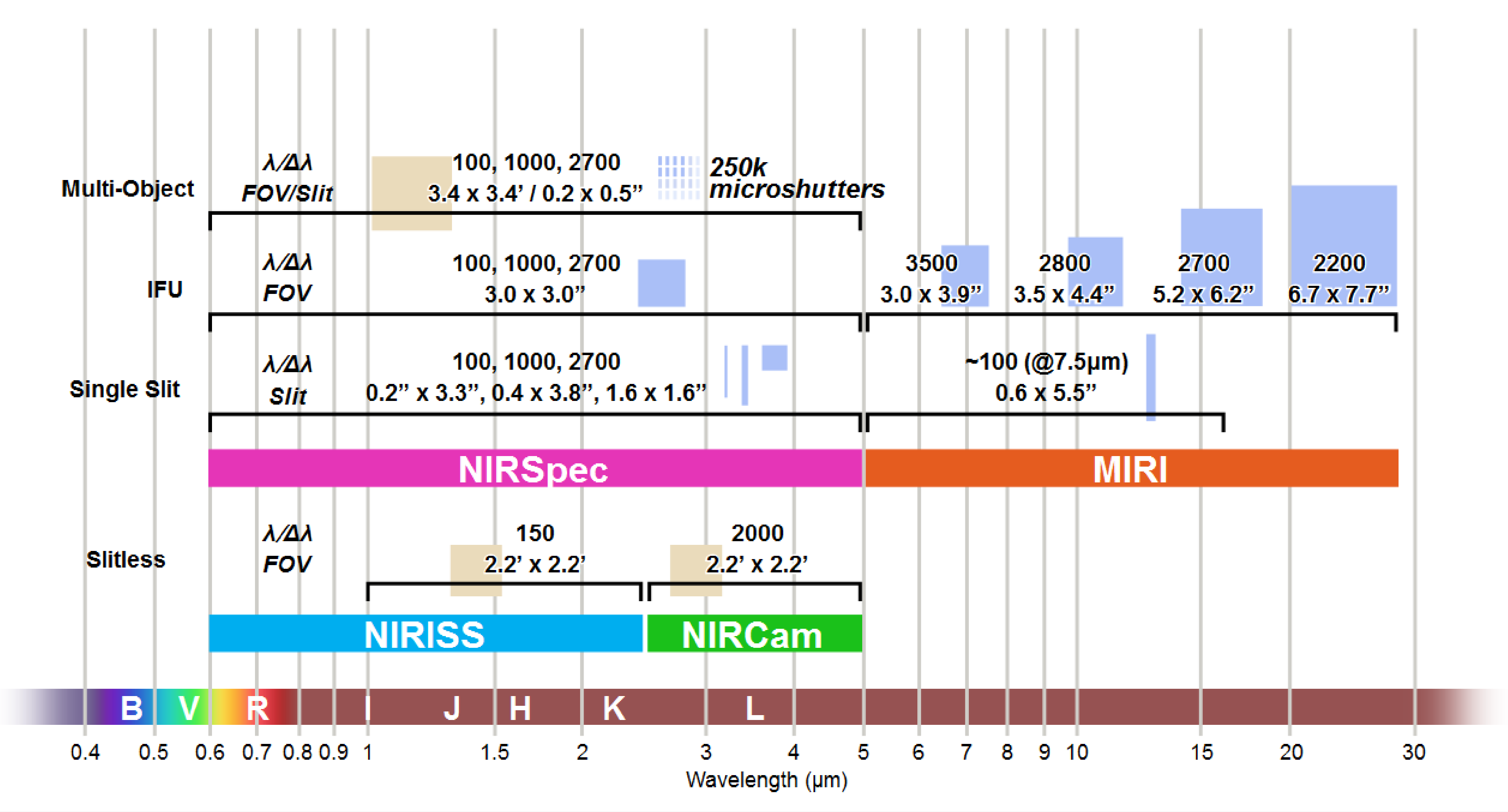
Imaging Modes



JWST Imaging Modes

Mode	Instrument	Wavelength (microns)	Pixel Scale (arcsec)	Full-Array* Field of View
Imaging	NIRCam*	0.6 – 2.3	0.032	2.2 x 2.2′
	NIRCam*	2.4 – 5.0	0.065	2.2 x 2.2′
	NIRISS	0.9 – 5.0	0.065	2.2 x 2.2′
	MIRI*	5.0 – 28	0.11	1.23 x 1.88′
Aperture Mask Interferometry	NIRISS	3.8 – 4.8	0.065	------
Coronography	NIRCam	0.6 – 2.3	0.032	20 x 20″
	NIRCam	2.4 – 5.0	0.065	20 x 20″
	MIRI	10.65	0.11	24 x 24″
	MIRI	11.4	0.11	24 x 24″
	MIRI	15.5	0.11	24 x 24″
	MIRI	23	0.11	30 x 30″

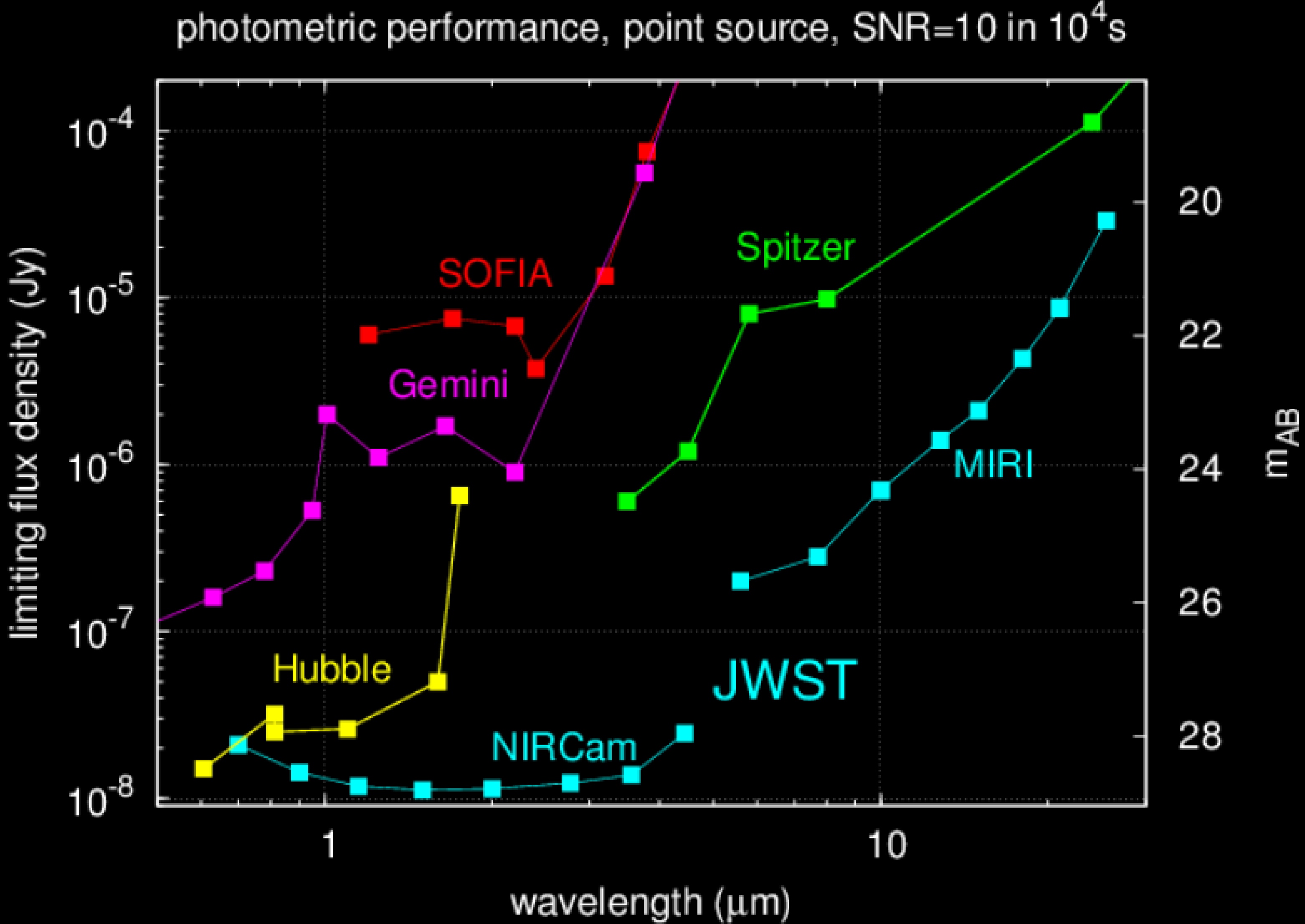
Spectroscopic Modes



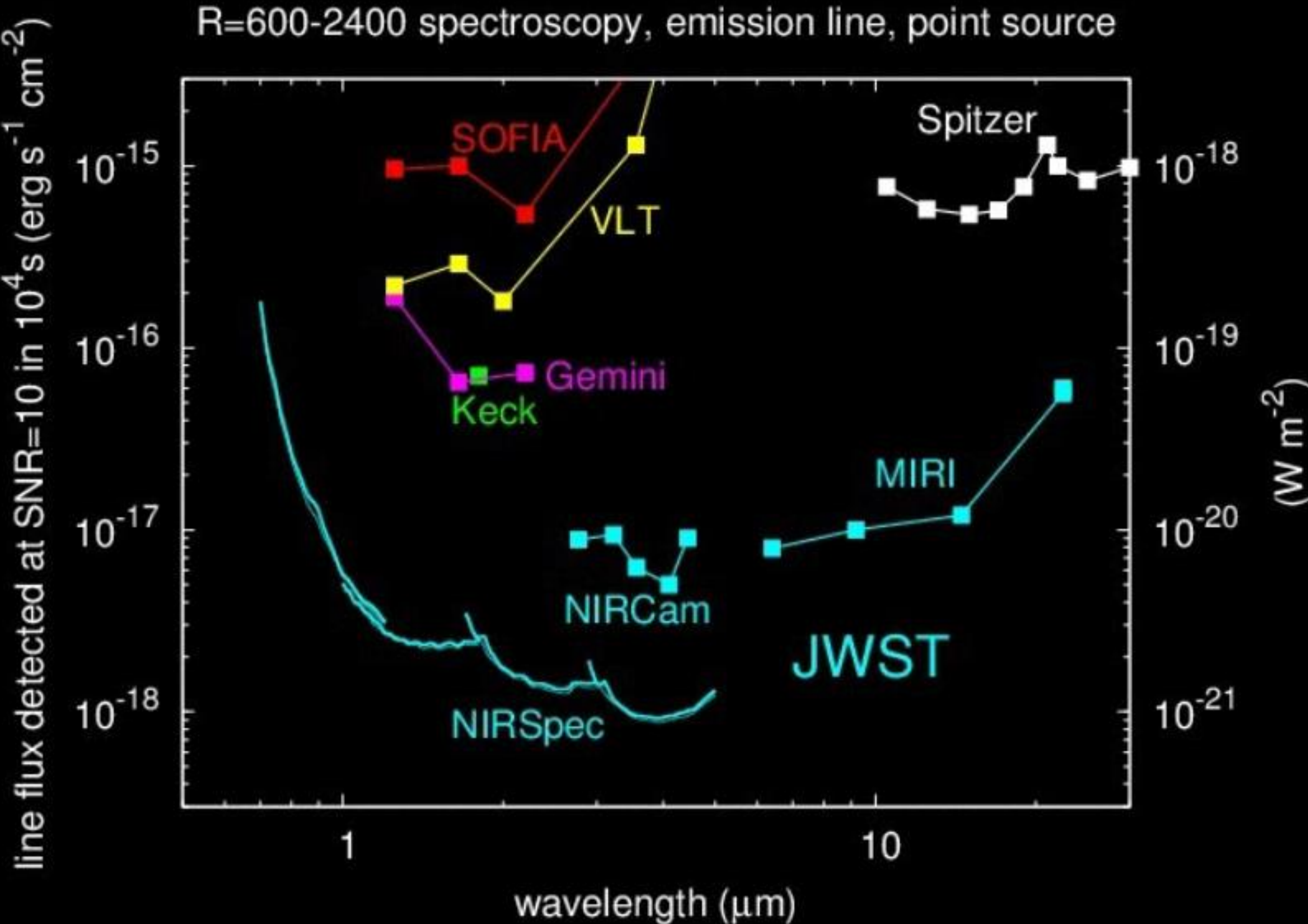
JWST Spectroscopy Modes

Mode	Instrument	Wavelength (microns)	Resolving Power ($\lambda/\Delta\lambda$)	Field of View
Slitless Spectroscopy	NIRISS	1.0 – 2.5	150	2.2′ x 2.2′
	NIRISS	0.6 – 2.5	700	single object
	NIRCam	2.4 – 5.0	2000	2.2′ x 2.2′
Multi-Object Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.4′ x 3.4′ with 250k 0.2 x 0.5″ microshutters
Single Slit Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	slit widths 0.4″ x 3.8″ 0.2″ x 3.3″ 1.6″ x 1.6″
	MIRI	5.0 – ~14.0	~100 at 7.5 microns	0.6″ x 5.5″ slit
Integral Field Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.0″ x 3.0″
	MIRI	5.0 – 7.7	3500	3.0″ x 3.9″
	MIRI	7.7 – 11.9	2800	3.5″ x 4.4″
	MIRI	11.9 – 18.3	2700	5.2″ x 6.2″
	MIRI	18.3 – 28.8	2200	6.7″ x 7.7″

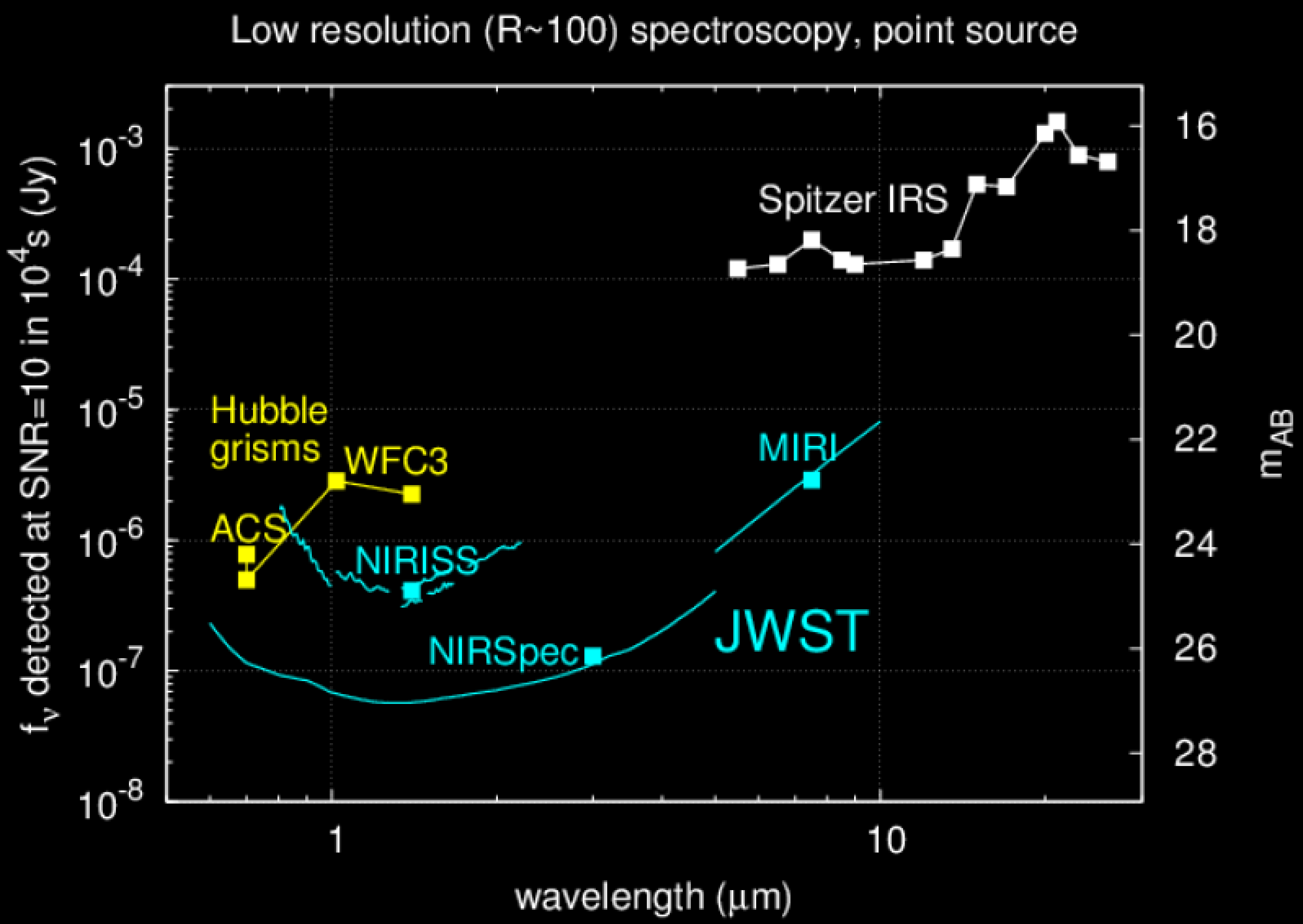
Sensitivity

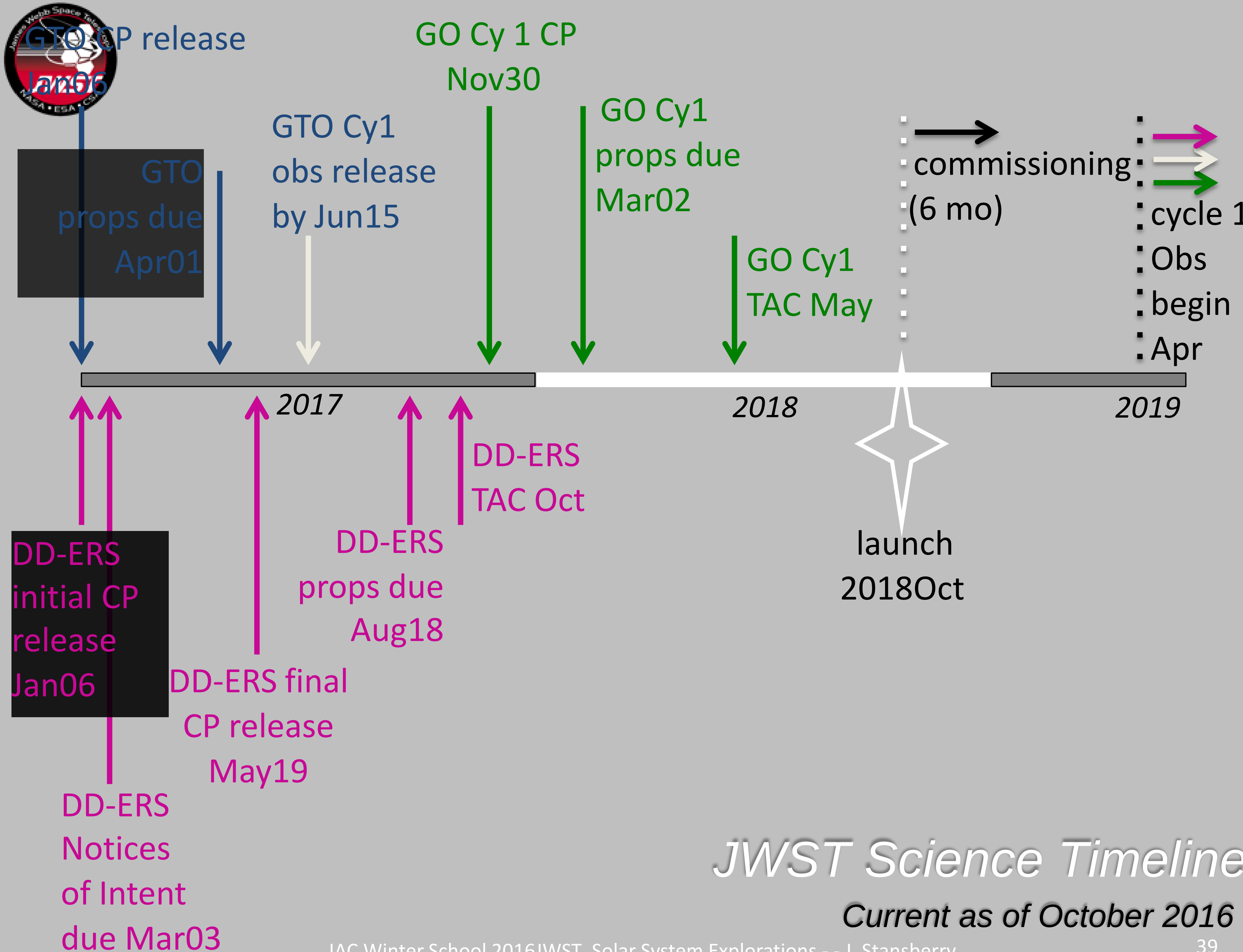


Sensitivity



Sensitivity





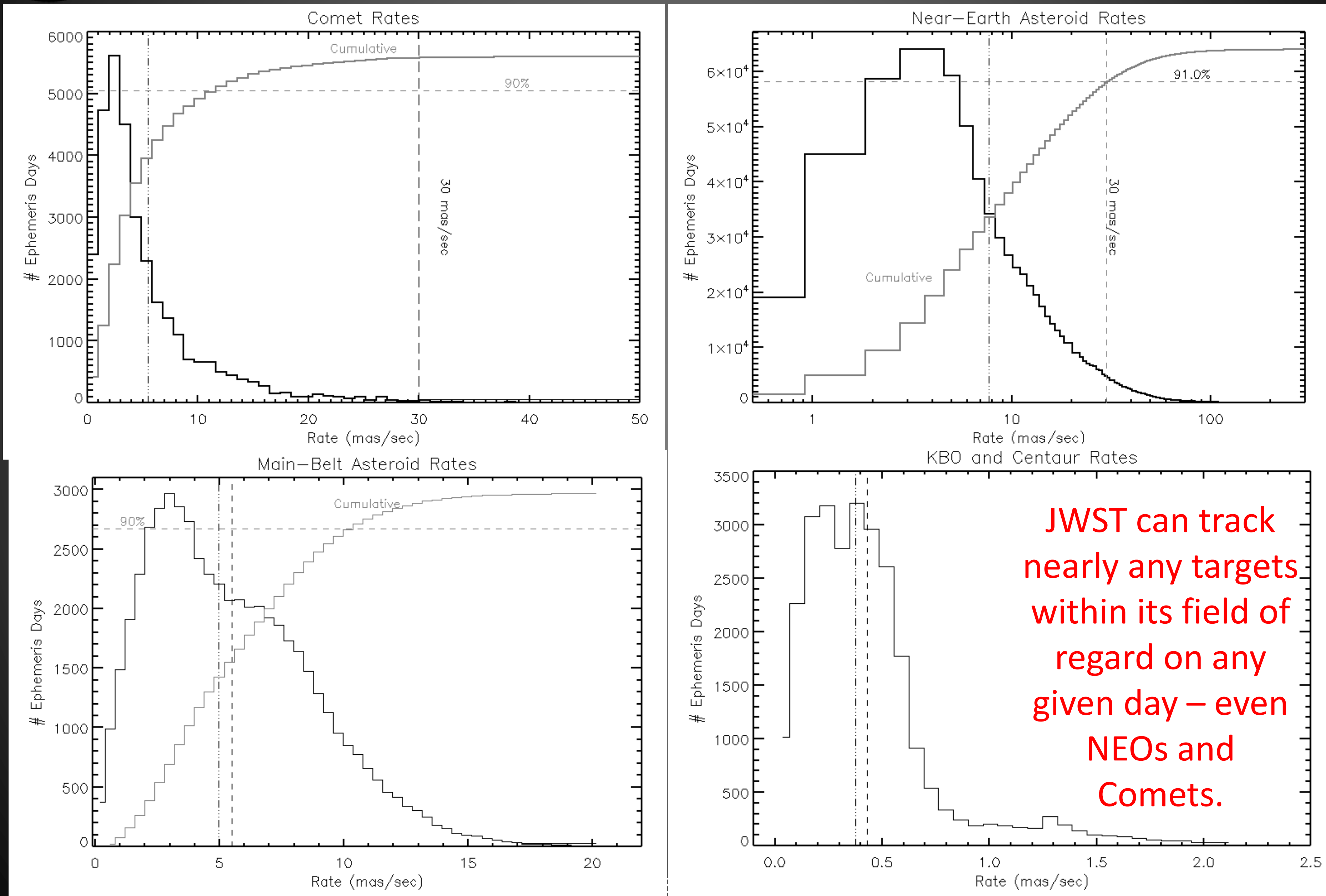
JWST Science Timeline

Current as of October 2016

Moving Targets – Observatory, Flight Software

- Non-sidereal tracking – **Implemented**.
  - Rates up to 30 mas/s (108''/hr) supported (max rate of Mars)
    - Modeling shows excellent pointing stability (< 7mas NEA), ~same as fixed targets
  - The moving-target is fixed in detector frame while exposing
    - Dithers, mosaics supported (slightly higher overheads)
  - ~1 mag brighter guide stars required for moving targets
  - Long (~1hr+ tracks) possible while guiding continuously
  - Longer observations possible using multiple guide stars

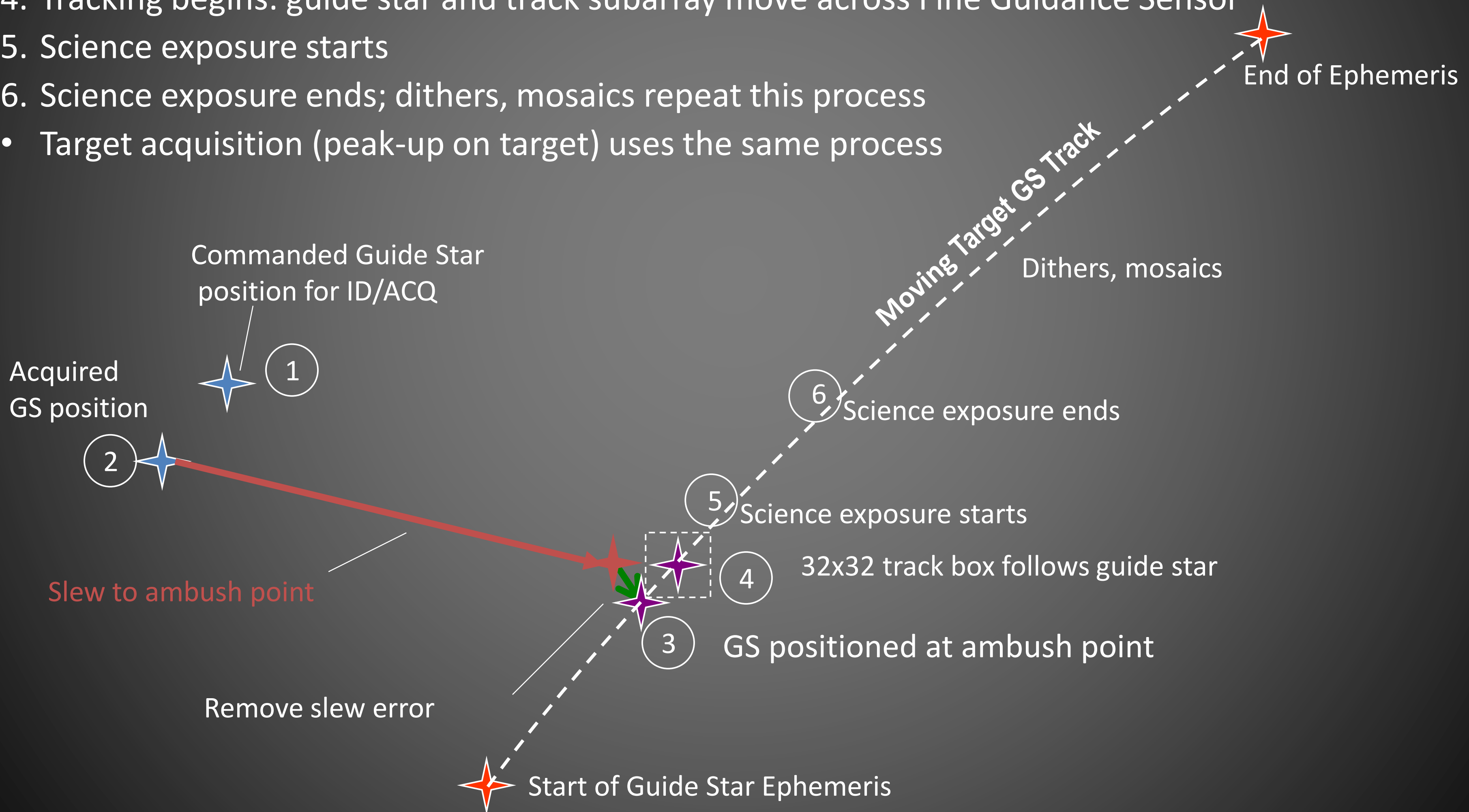
How Fast are Moving Targets Moving?



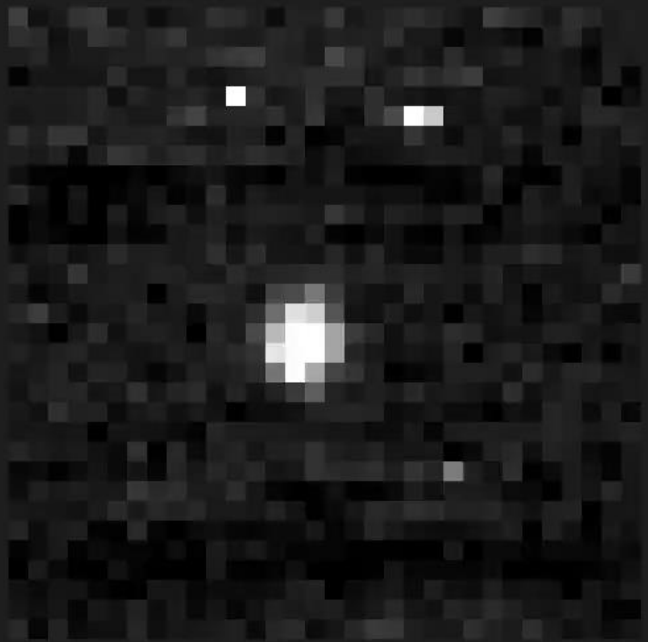
Schematic for Moving Target Observation

1. Usable guide star selected from candidate list, identified in field normally
2. Slew from acquisition point to target 'ambush point' computed and executed
3. Guide star position refined, system waits for tracking start time
4. Tracking begins: guide star and track subarray move across Fine Guidance Sensor
5. Science exposure starts
6. Science exposure ends; dithers, mosaics repeat this process

- Target acquisition (peak-up on target) uses the same process



Fine Guidance Sensor Moving Target T



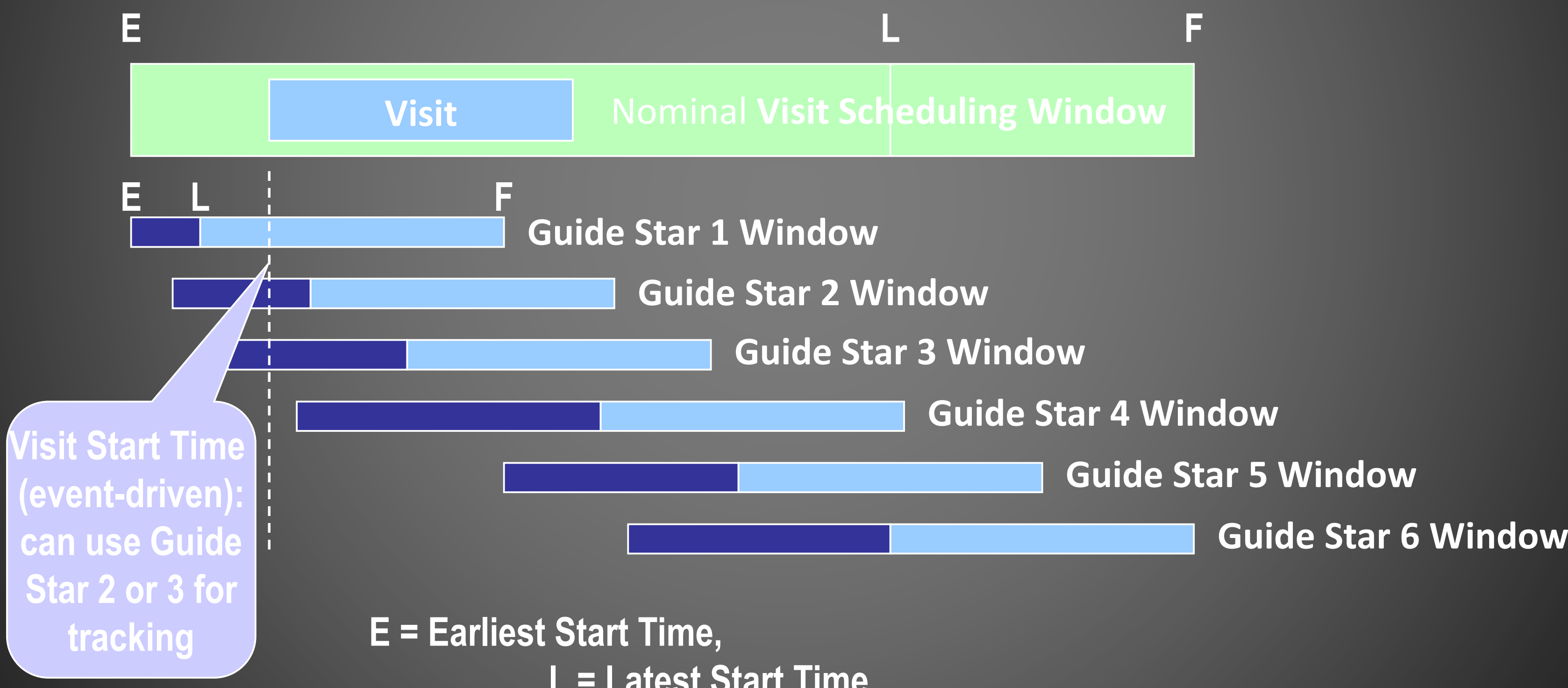
- FGS configuration
  - FGS → TRACK
  - 32x32 track box (subarray)
  - Saved image data
  - Note hot pixels
- OSIM point source
  - Moderate illumination
  - 'steps' mimic GS motion on FGS detector
- FGS FSW
  - Centroids at 16 Hz
  - FSW moves track box to follow guide star
  - NOT quite the same as MT tracking...
    - For MT tracking Box moves in manner prescribed by the ephemeris

Moving Targets – Observatory, Flight Software

- Event-driven scheduling / operations
  - Each target has many possible guide stars, useable during different windows
  - At time of observation, 1^{st} usable guide star selected, acquired normally
  - 5^{th} O Chebyshev representation of guide-star track
    - **Primarily** enables guide-stars to be used at any time during target visibility window
    - **Secondarily** allows tracking targets with ephemeris accelerations
  - Time-constrained observations are supported

Guide Stars for Moving Target Observations

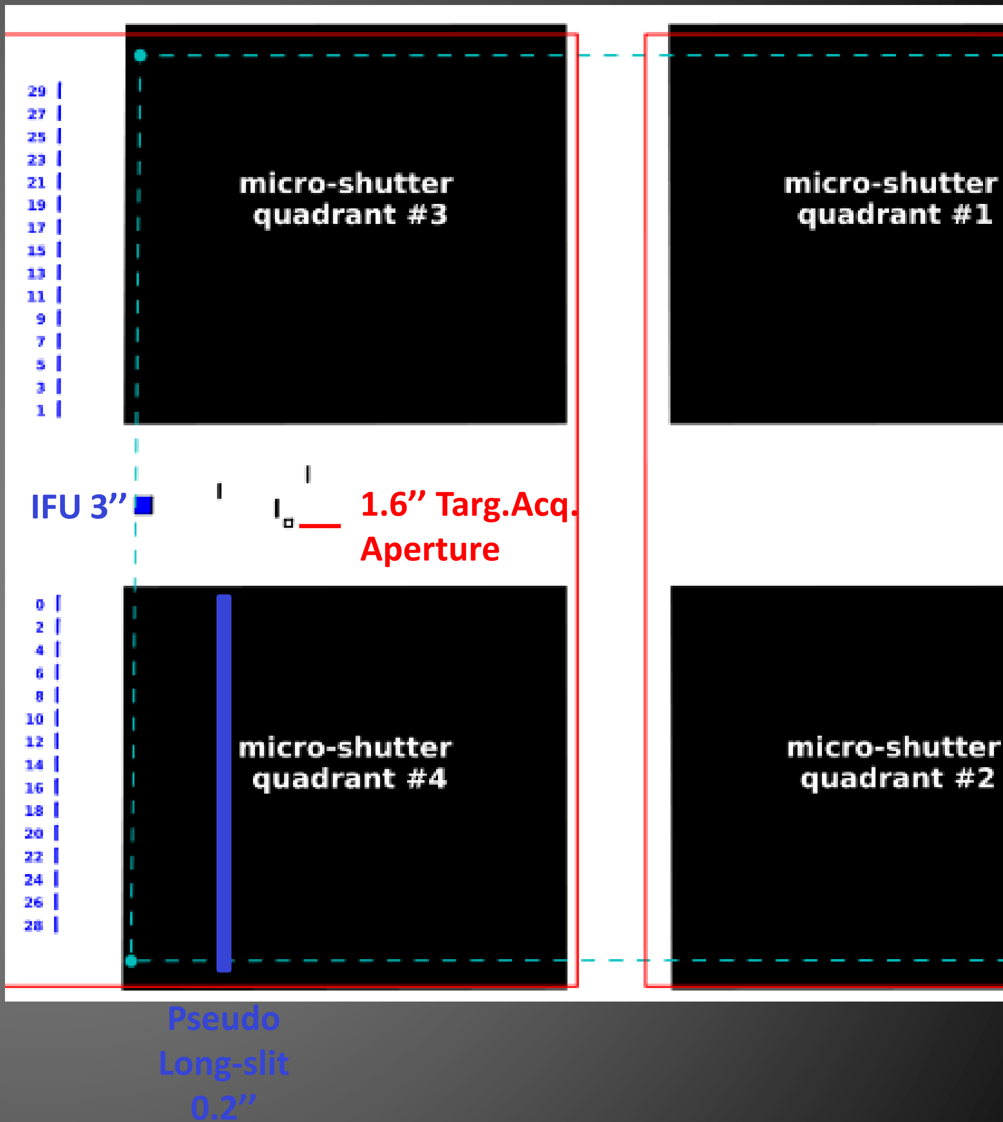
- Event-driven operations provide flexibility in use of Guide Stars for moving targets
  - Multiple sets of guide stars defined to cover complete visit scheduling window
  - Typically 3 guide stars for any time within visit scheduling window
  - Up to 200 guide star candidates per moving target observation
- Observations with different instruments require separate guide stars (and visits)



E = Earliest Start Time,
L = Latest Start Time,
F = Latest End Time (Finish)

Target Acquisition: NIRSpec

- NIRSpec TA for moving targets is not easy
  - 1.6'' square aperture
    - Ephemeris of target must be accurate!
  - Centroid calculated on-board
  - Target can be accurately (<10mas) positioned in the IFU, any of the fixed slits, or in a pseudo long-slit in the microshutter array



PASP Special Issue
(Jan 4, 2016)

Innovative Solar System Science with the James Webb Space Telescope

Stefanie Milam, Special Editor

http://iopscience.iop.org/1538-3873/128/959

11 topical papers

http://iopscience.iop.org/1538-3873/128/960

1 high-level paper (Norwood et al.)

10 JWST Solar System Focus Groups

(and 11 papers! http://iopscience.iop.org/1538-3873/128/959

- **Asteroids** (Andy Rivkin, JHU/APL)
- **Comets** (Chick Woodward, U. Minnesota)
- **Giant Planets** (Jim Norwood, NMSU)
- **Mars** (Geronimo Villanueva, GSFC)
- **NEOs** (Cristina Thomas, GSFC)
- **Occultations** (Pablo Santos-Sanz, IAA-CSIC, Spain)
- **Rings** (Matt Tiscareno, Cornell)
- **Satellites** (Laszlo Kestay, USGS)
- **Titan** (Conor Nixon, GSFC)
- **TNOs** (Alex Parker, SwRI)
- JWST Solar System Capabilities (Milam, GSFC)