The James Webb Space Telescope

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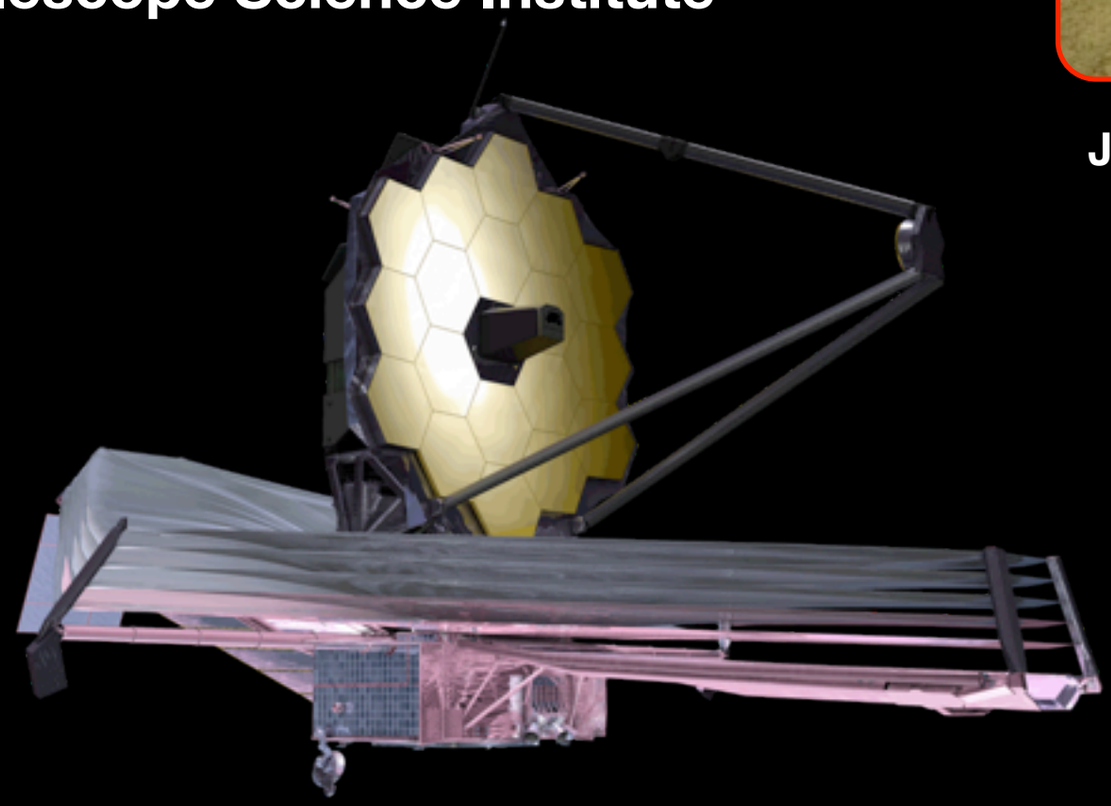
JWST Observatory Project Scientist
Goddard Space Flight Center

James Webb Space Telescope: 101

Organization

- **Mission Lead:** Goddard Space Flight Center
- Project Scientist: Dr John Mather (Nobel Laureate)
- **International collaboration:** ESA & CSA
- Prime Contractor: Northrop Grumman Space Technology
- **Operations:** Space Telescope Science Institute

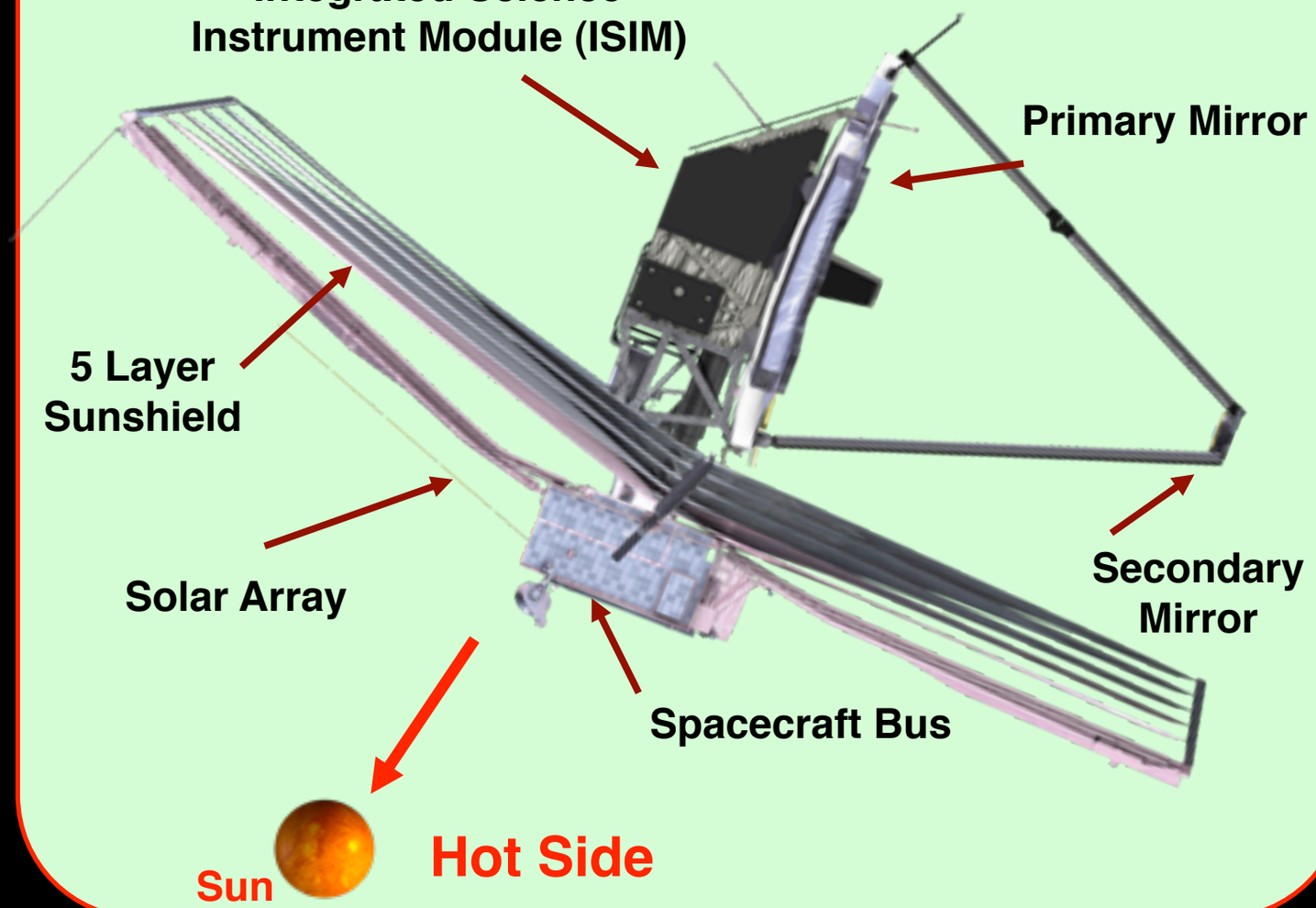
JWST Full scale model



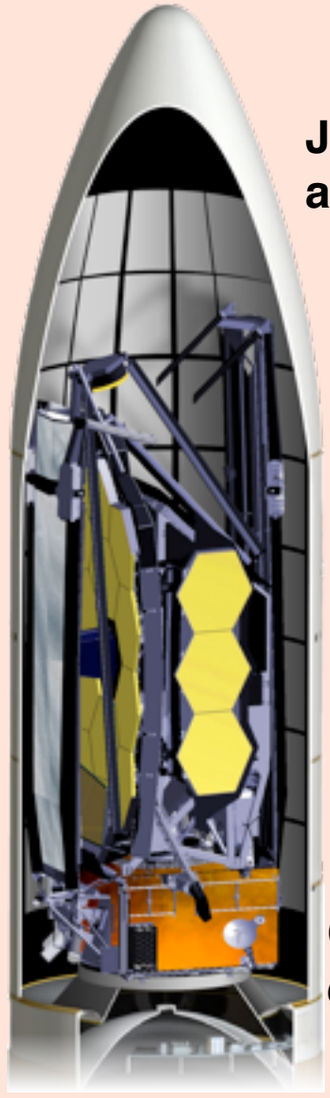
- **Instruments:**
- Near Infrared Camera (NIRCam) – Univ. Arizona
- Near Infrared Spectrograph (NIRSpec) – ESA
- Mid-Infrared Instrument (MIRI) – JPL/ESA
- Fine Guidance Sensor (FGS) – CSA

How JWST Works

Cold Side: ~40K

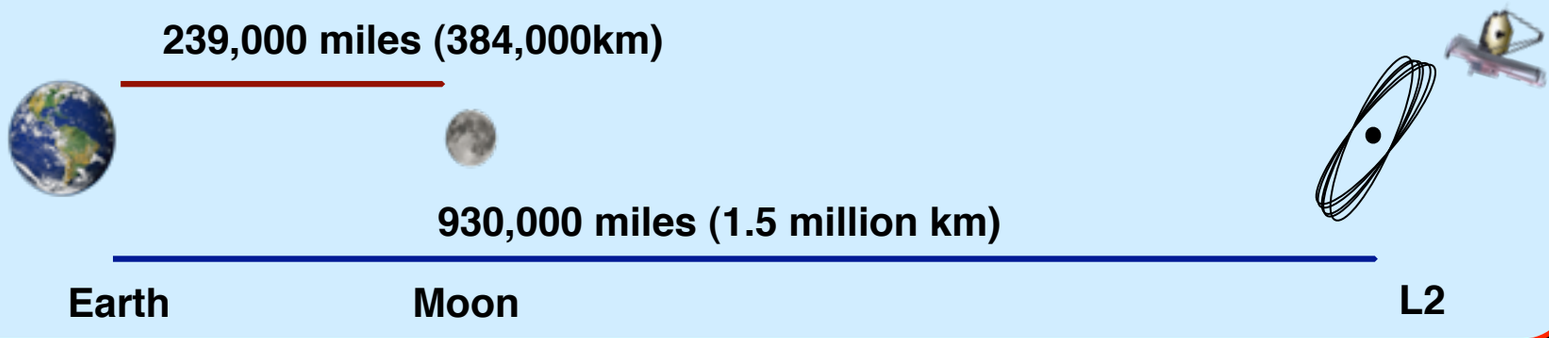


JWST is folded and stowed for launch

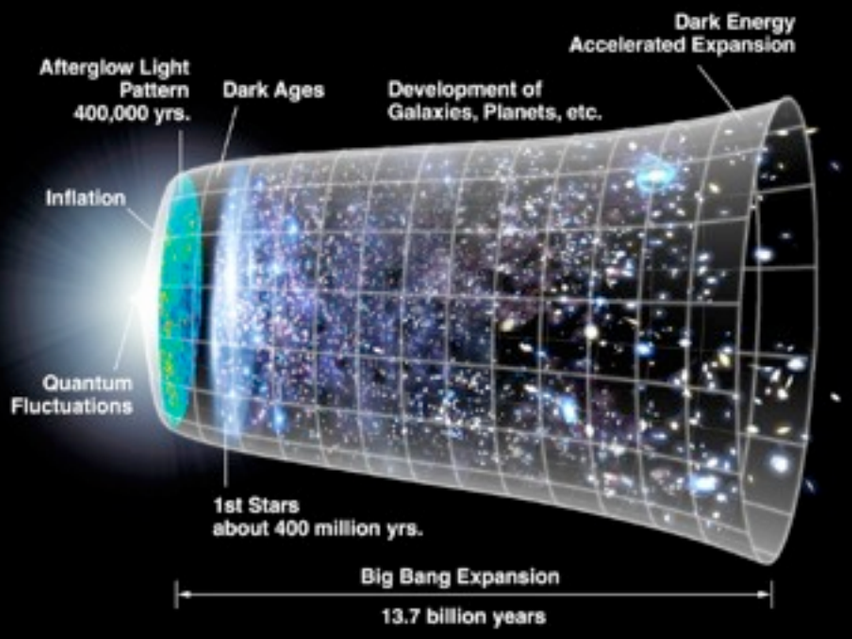


Observatory is deployed after launch

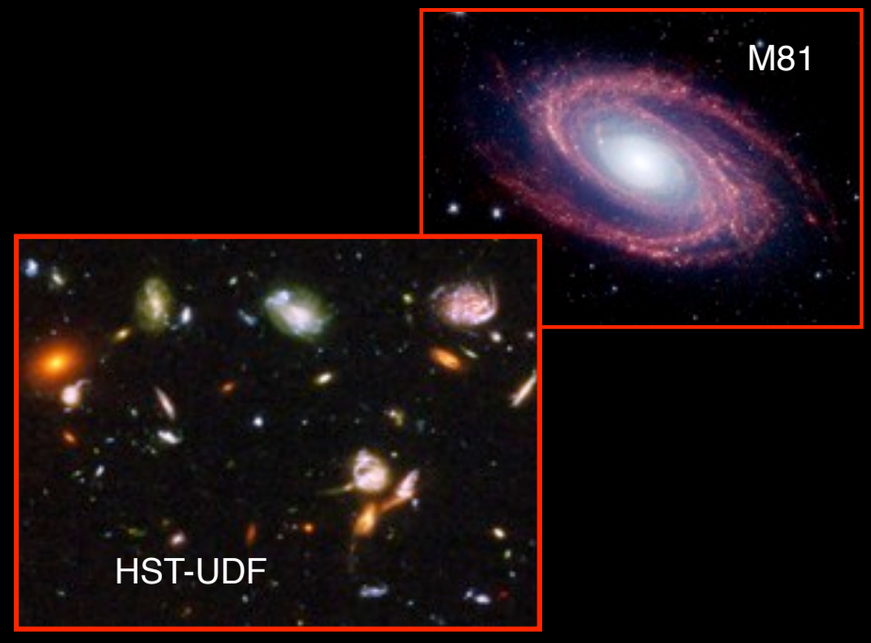
JWST Orbits the 2nd Lagrange Point (L2)



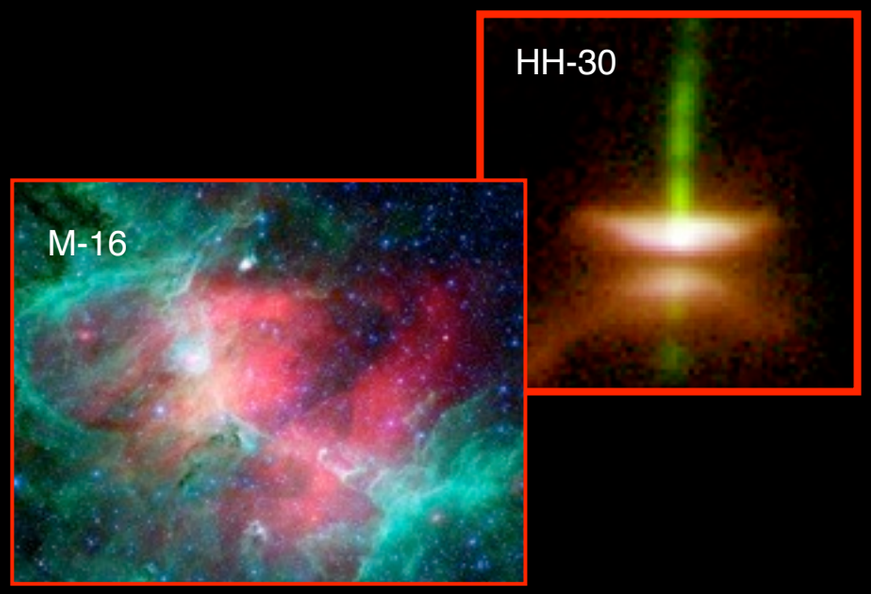
JWST Science Themes



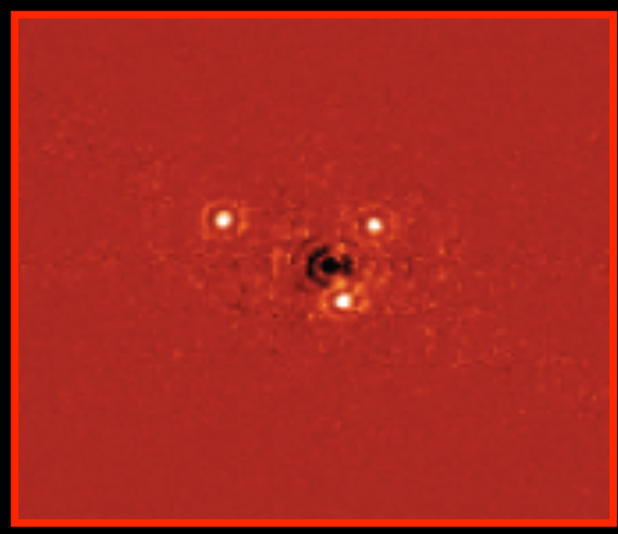
First Light and Re-Ionization



Assembly of Galaxies



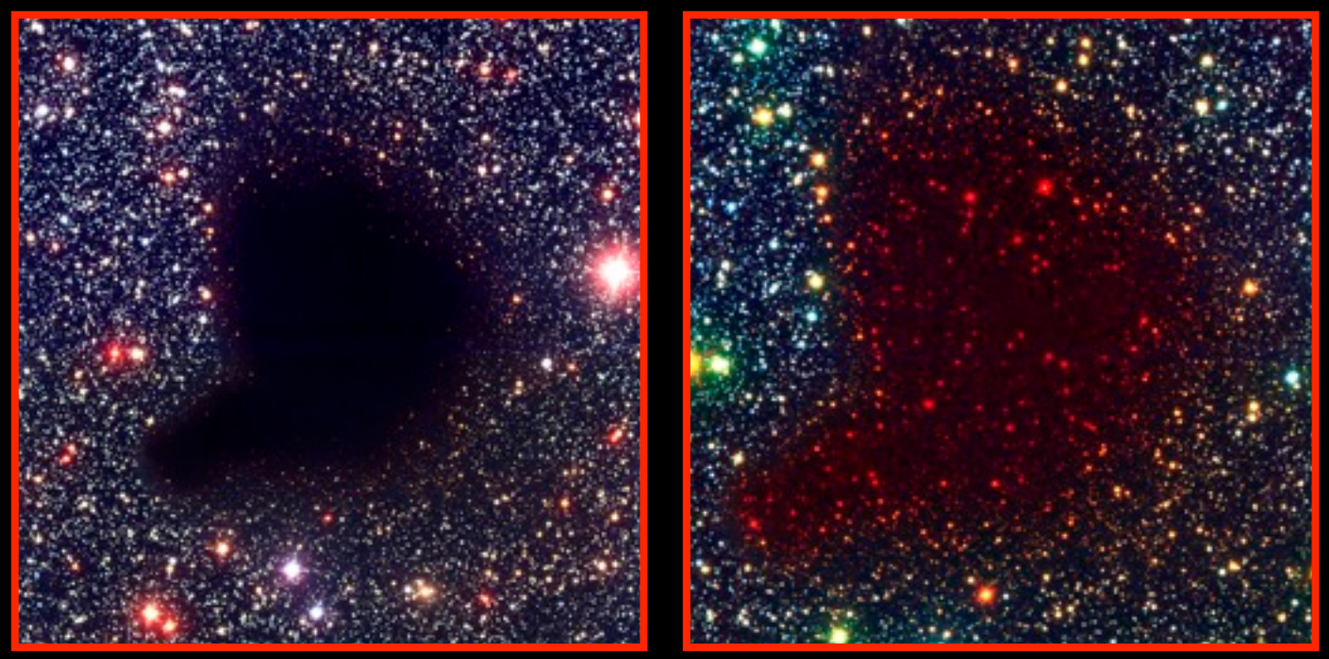
Birth of stars and proto-planetary systems



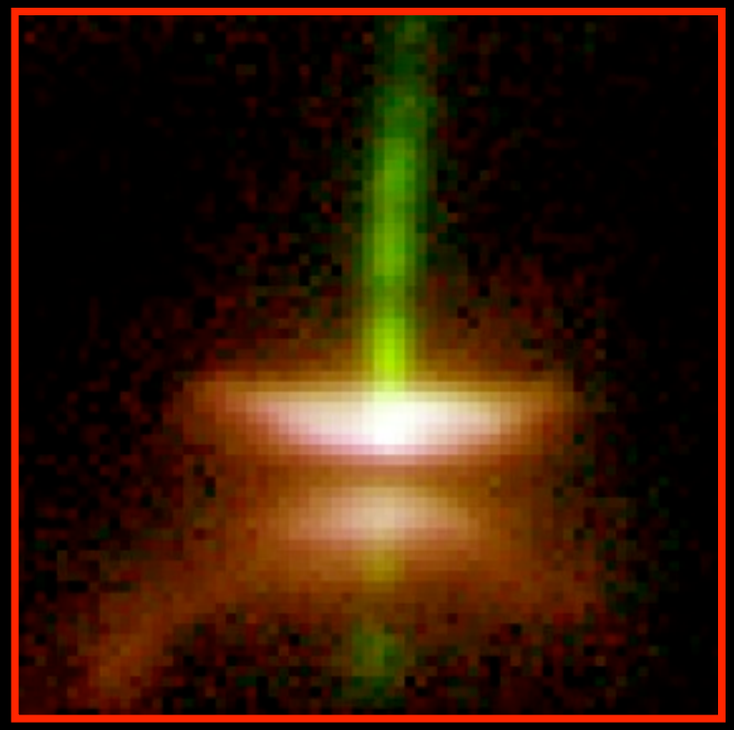
Planetary systems and the origin of life

Birth of stars and Proto-Planetary Systems

- ➡ How do protostellar clouds collapse?
- ➡ What is the early evolution of protostars?
- ➡ How do massive stars form and affect their environment?
- ➡ What is the initial mass function at sub-stellar masses?
- ➡ How do protoplanetary systems form?
- ➡ What are the life cycles of gas and dust?



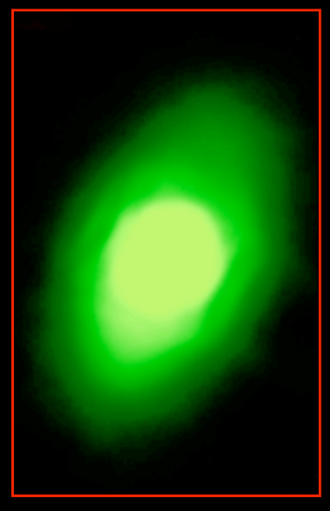
Barnard 68



Evolution of Protostars

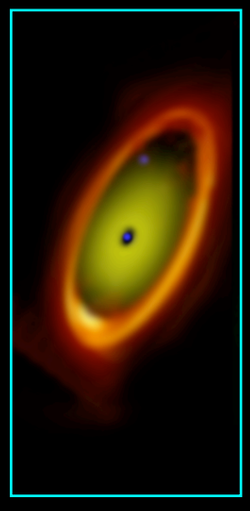
Planetary Systems & Origins of Life (PSOL)

- **Planetary Systems and the Origins of Life: To determine the physical and chemical properties of planetary systems including our own, and to investigate the potential for the origins of life in those systems**
  - **How Do Planets and Brown Dwarfs Form?**
  - **How Common are Giant Planets and what is their orbital distribution?**
  - **How Do Giant Planets Affect the Formation of Terrestrial Planets?**
  - **What Comparisons, Direct or Indirect, can be made between our Solar System and Circumstellar Disks (Forming Solar Systems) and Remnant Disks?**



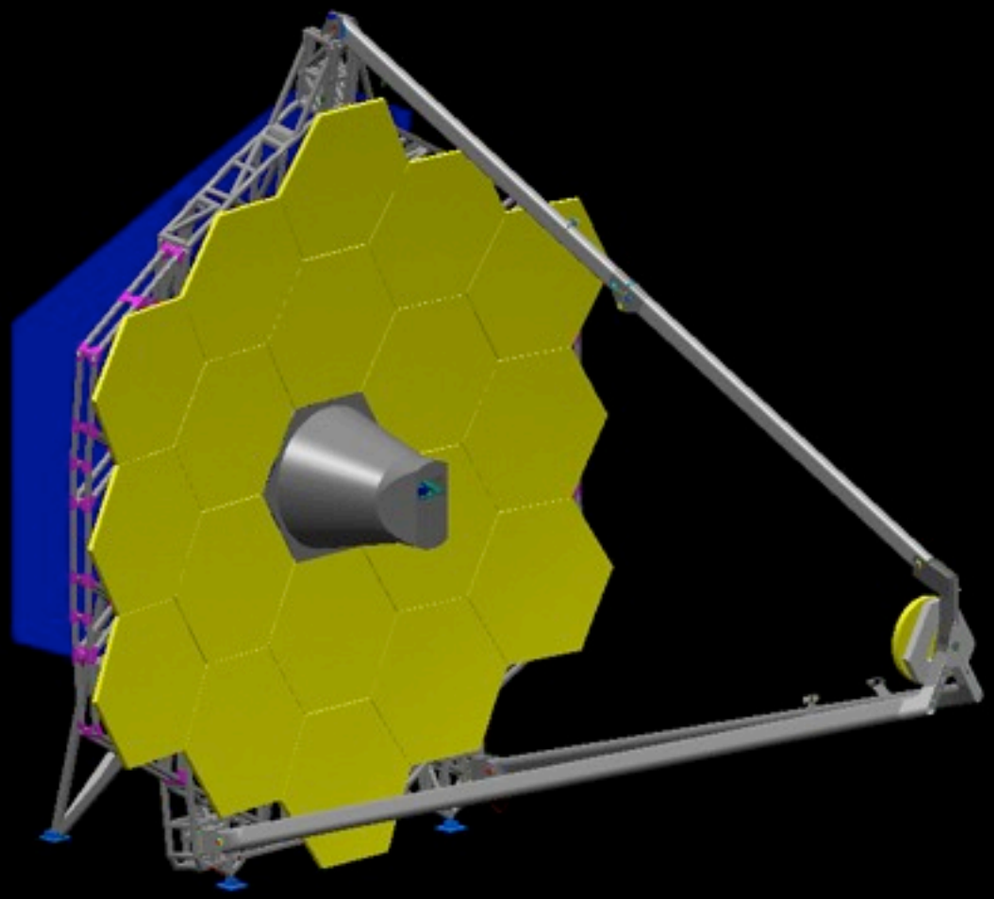
Spitzer (24 μm)

ACS (Visible)



JWST (20 μm)

JWST's Optical Design



- **Active Optical System**
  - ➡ 18 primary mirror segments
  - ➡ 6 degrees of freedom + ROC
  - ➡ 40 K temperature
  - ➡ Beryllium mirrors
  - ➡ 3 mirror prescriptions

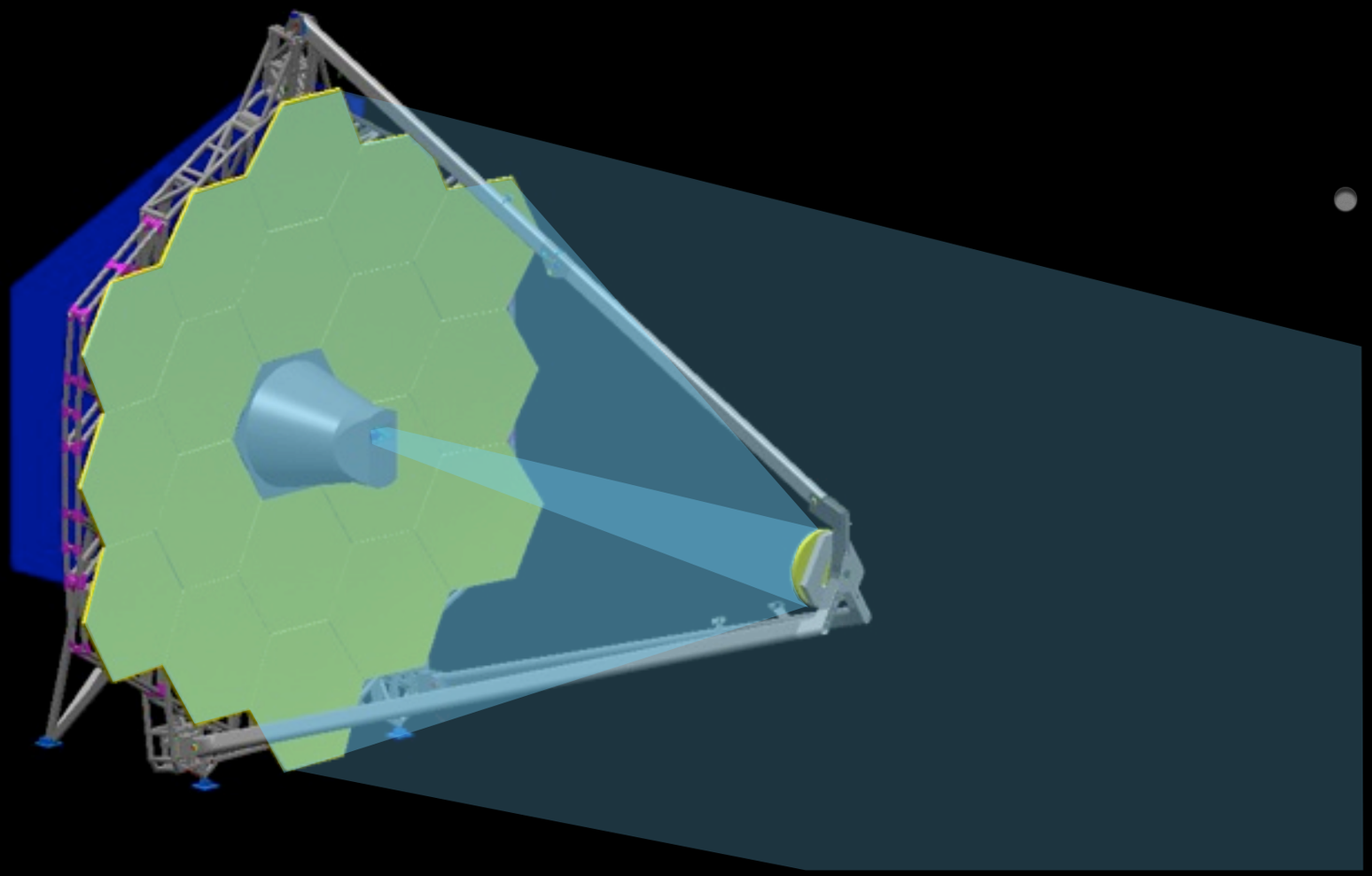
➡ 3 mirror anastigmat

➡ *Elliptical* f/1.2 Primary Mirror (PM)

➡ *Hyperbolic* Secondary Mirror (SM) creates f/9 intermediate image (6 DOF)

➡ *Elliptical* Tertiary Mirror (TM) images pupil at *Flat* Fine Steering Mirror (FSM)

JWST's Optical Design



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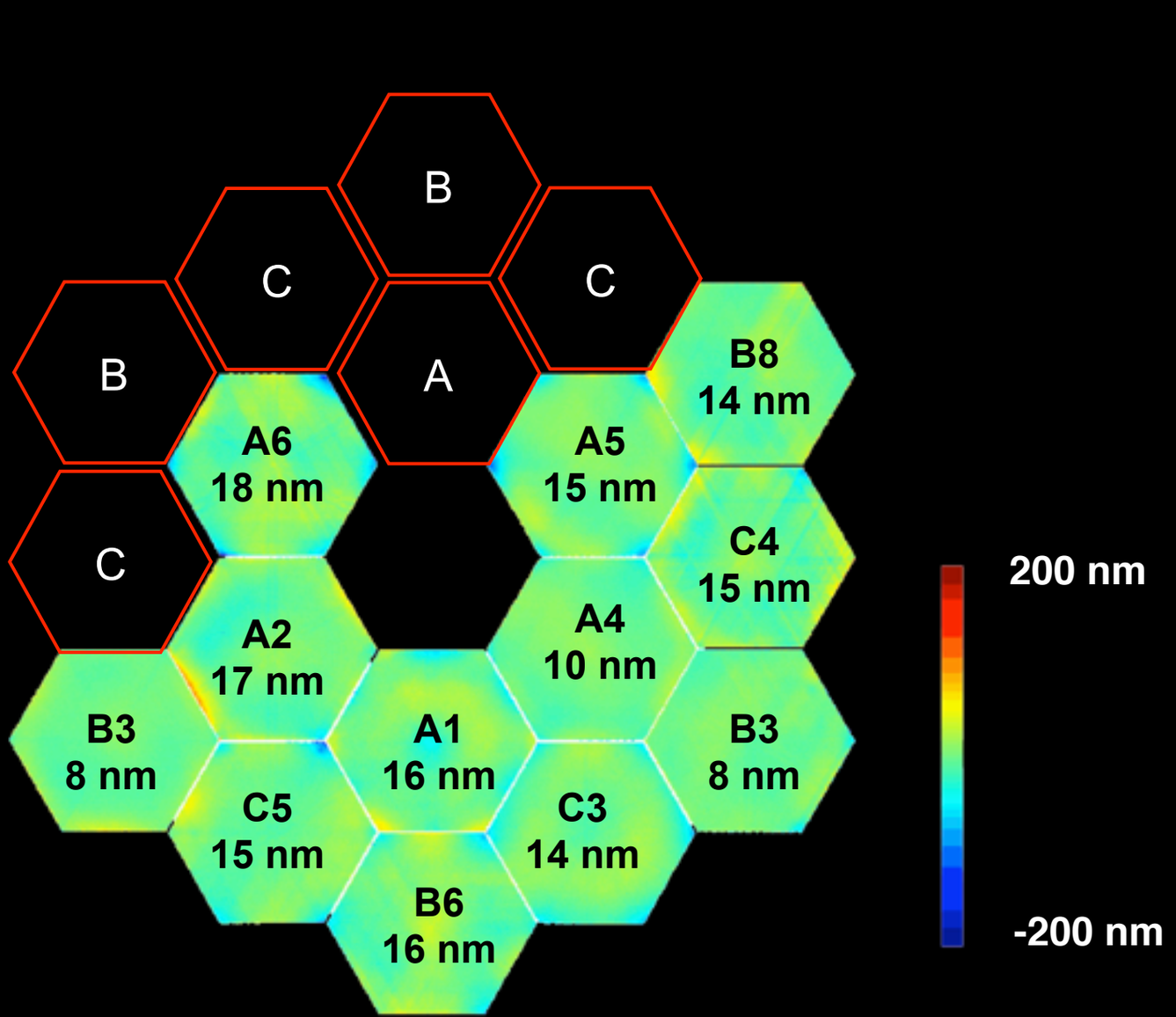
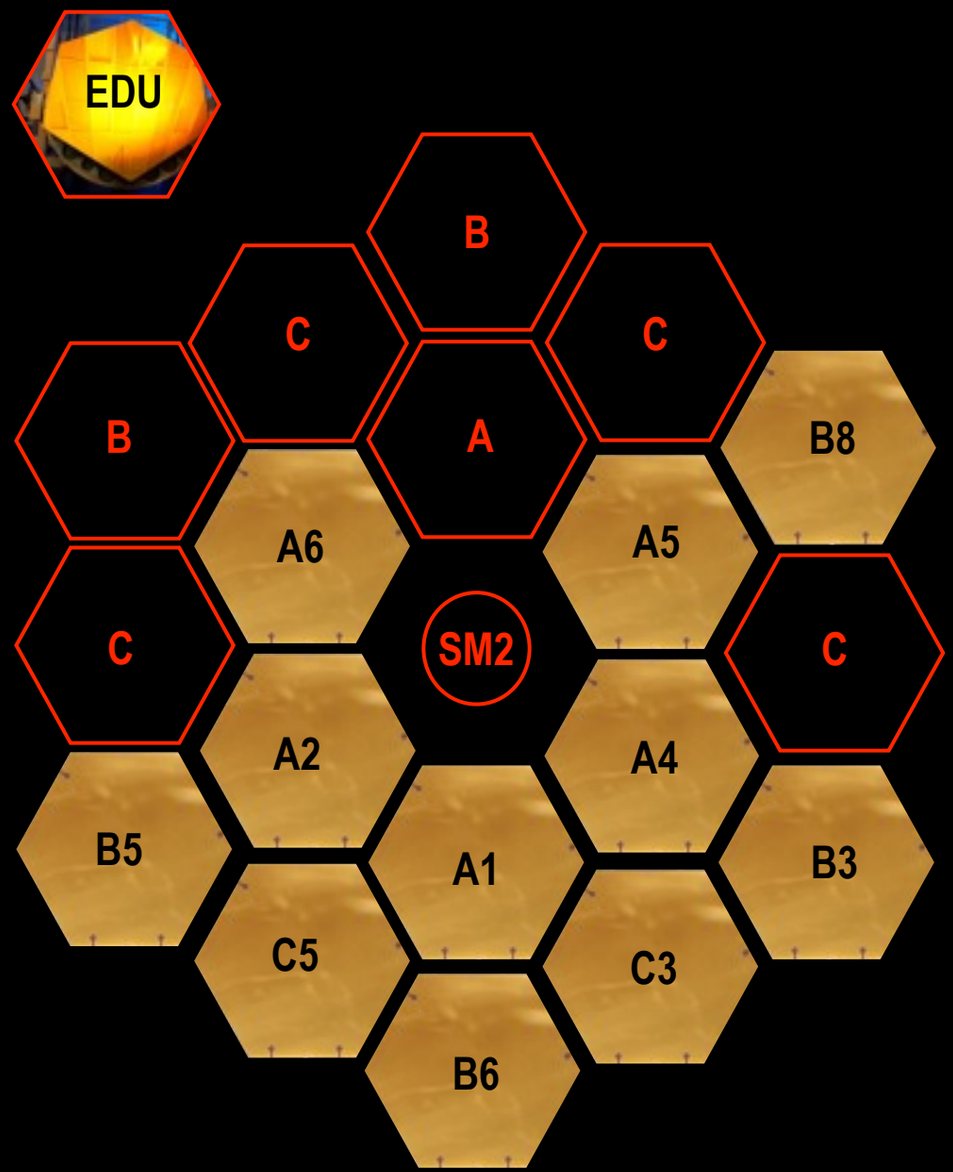
Flight Mirrors Meet Specification

- Flight mirrors delivered by Tinsley at completion of polishing

➡ Flight composite wavefront error 14 nm (requirement 17 nm)



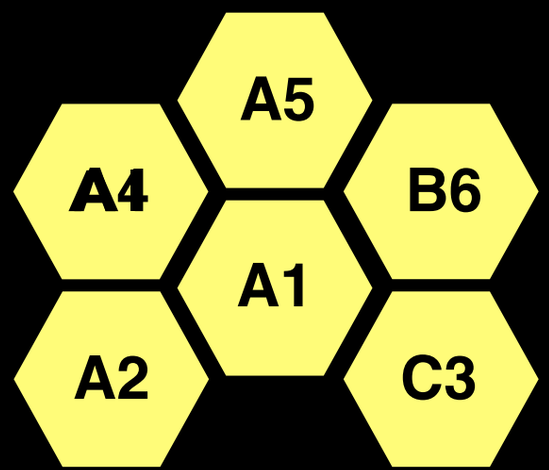
Completed polishing



Gold Coated

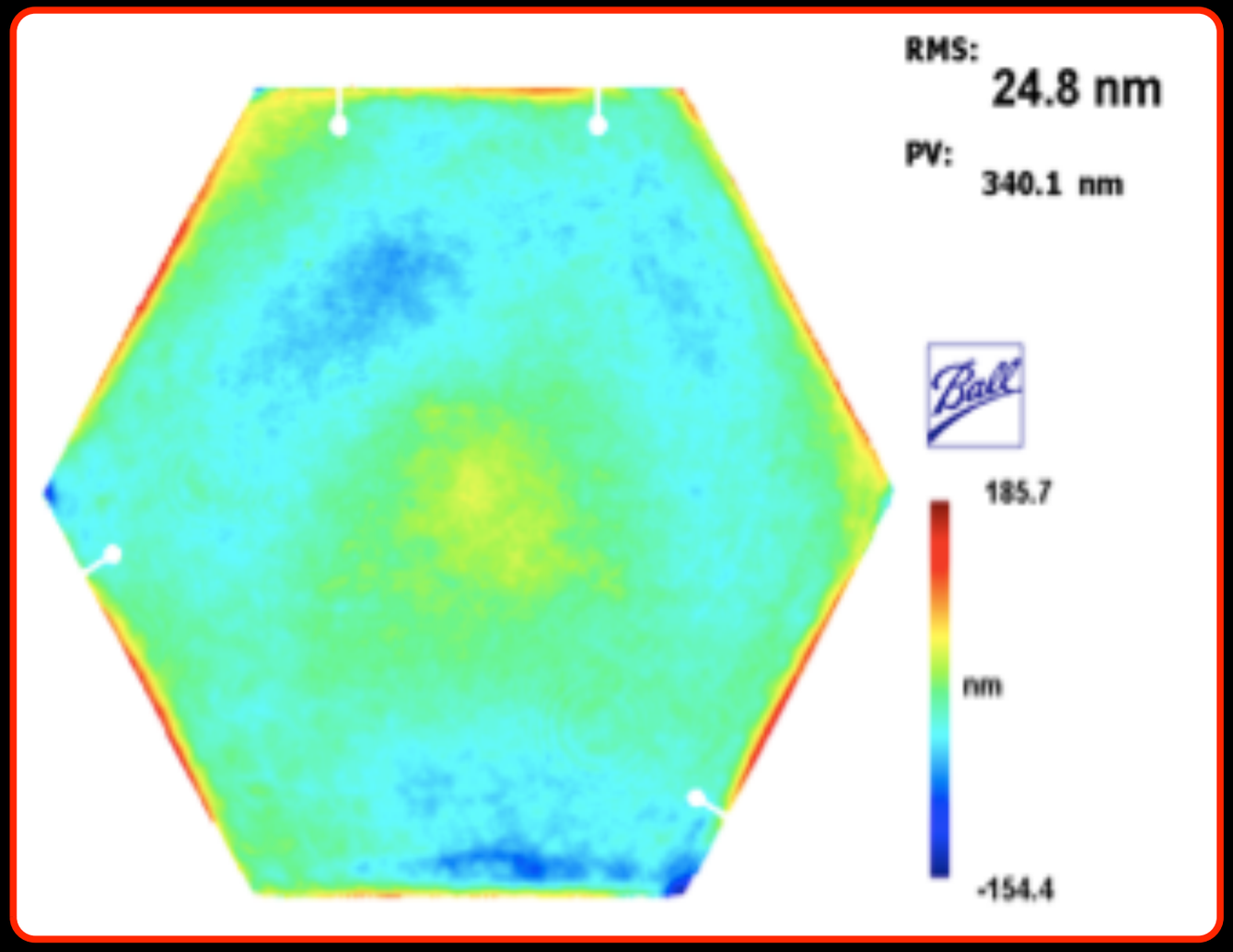
Mirror Acceptance Tests Underway

Flight Mirror A4 in acceptance vibe



First six flight mirrors in final optical cryo-test

Flight Mirror Status

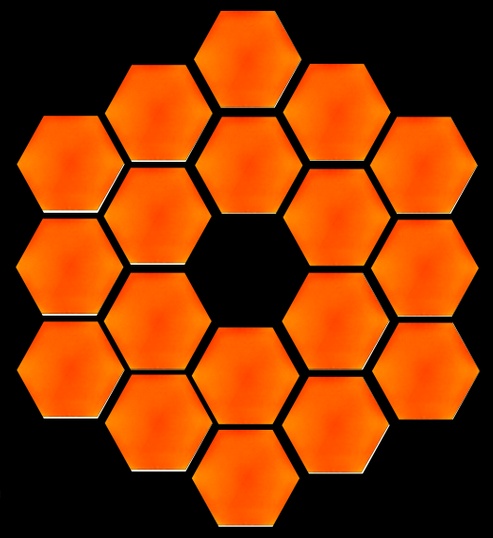


EDU Mirror Assembly Complete:
- **Final cryogenic optical test meets 25.8 nm requirement (Flight Spare)**

- **6 flight mirrors in final polishing cycle**
- **Flight Secondary in final polishing cycle**
- ***Flight mirror fabrication program will be completed this summer***

Predicted Image Quality

- Preliminary simulations of the full OTE using the XRCF A4 data as a template for all PMSA
  - Add in all optical error budget terms (Rev. V) to simulate WFSC residual & all terms
  - Jitter added as tip/tilt to PSF



- Simulated PSF through NIRCam filters
  - F444W, F200W, F115W, & F070W
  - NIRCam pixels are 0.032” (SW) and 0.065” (LW)

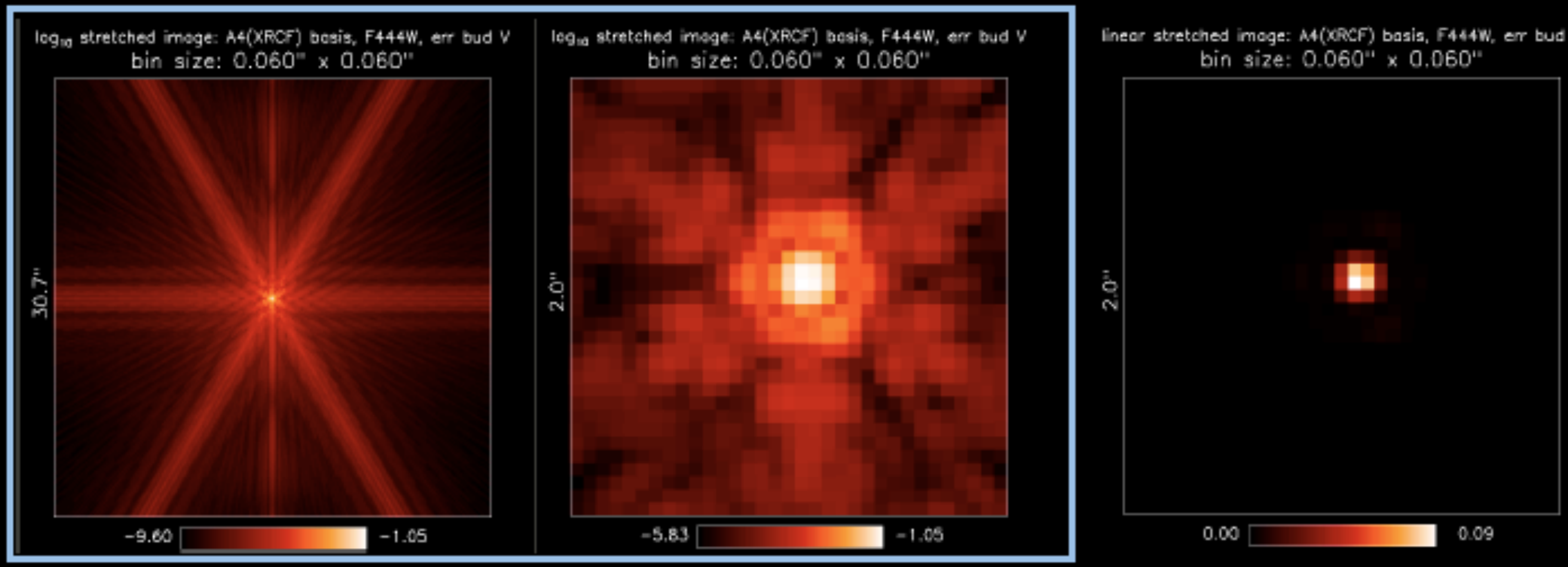
Predicted Image Quality: 2 μm & 4 μm

images binned to 0.060” pixels (NIRCam=0.065”)

$\log_{10}$ stretch

linear stretch

F444W

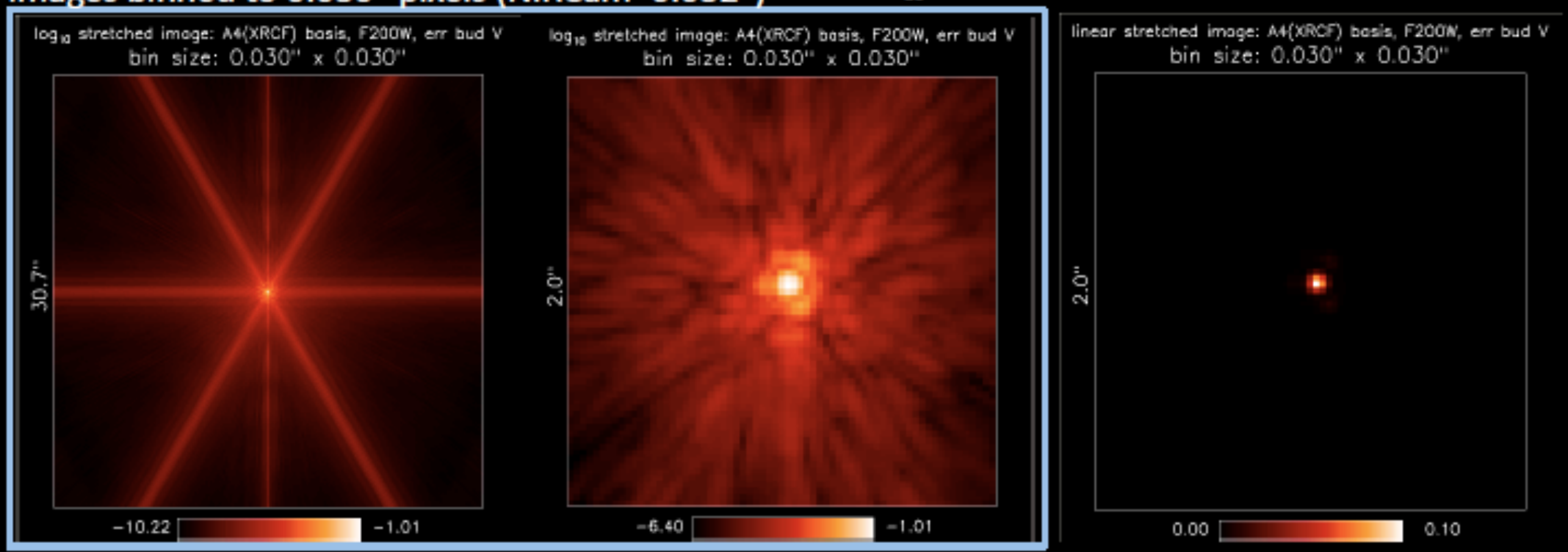


images binned to 0.030” pixels (NIRCam=0.032”)

$\log_{10}$ stretch

linear stretch

F200W



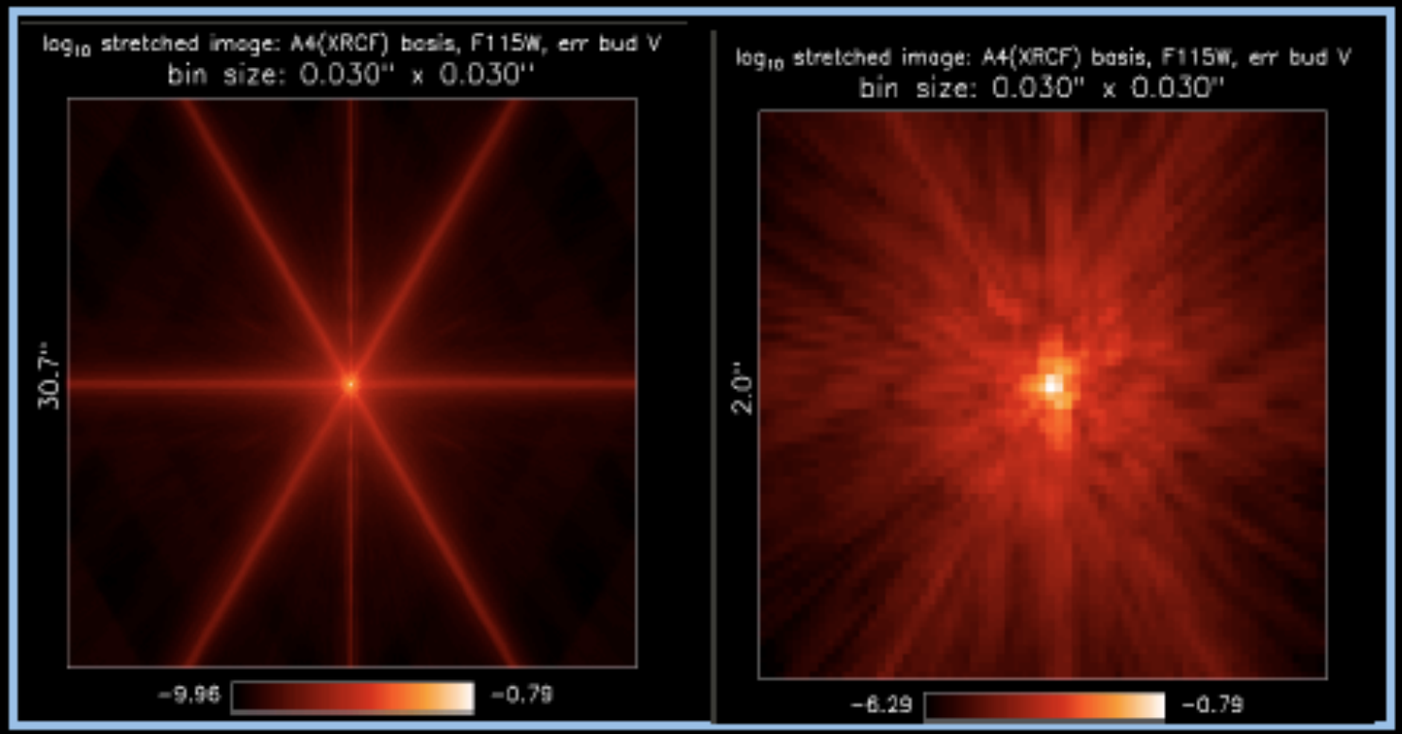
Predicted Image Quality: 0.7 μm & 1 μm

images binned to 0.030” pixels (NIRCam=0.032”)

$\log_{10}$ stretch

linear stretch

F115W

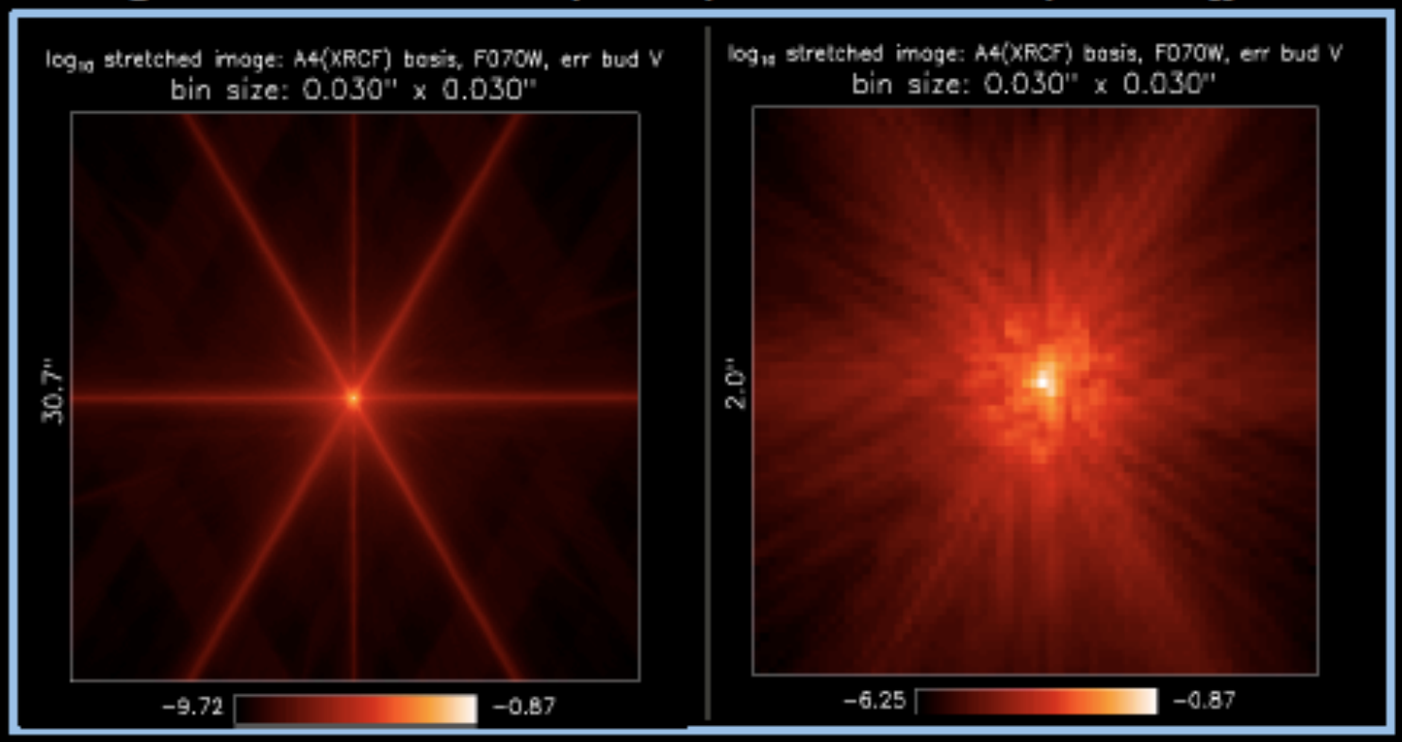


images binned to 0.030” pixels (NIRCam=0.032”)

$\log_{10}$ stretch

linear stretch

F070W



Phasing the Telescope

Commissioning

OTE Deployment / First Light (Image Mosaic

SM Focus Sweep

Segment Identification

Segment Search

Segment-Image Array

Global Alignment

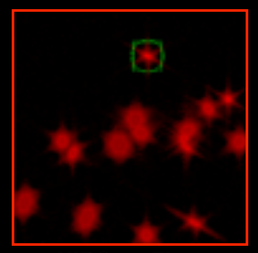
Image Stacking

Coarse Phasing (DHS)

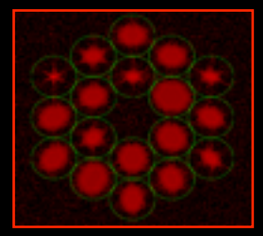
Single Field Fine Phasing

Multi-Field Fine Phasing

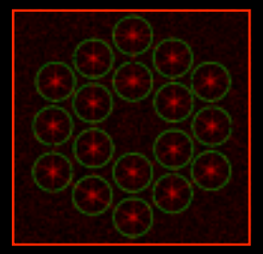
Wavefront Monitoring & Maintenance



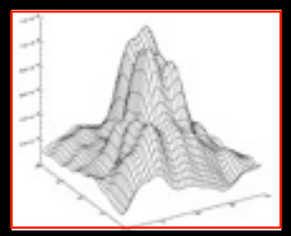
NIRCam First Light



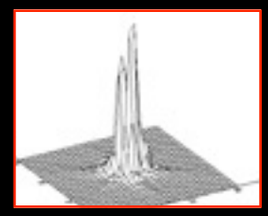
After Segment-Image Array



After Global Alignment

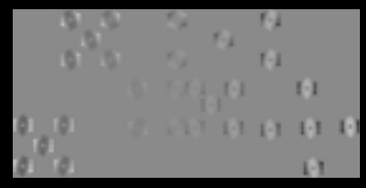


After Image Stacking

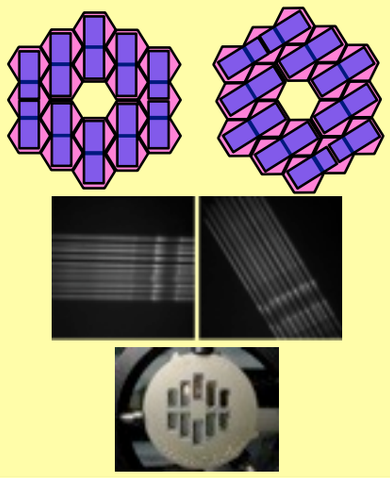


After Coarse Phasing

After SF Fine Phasing



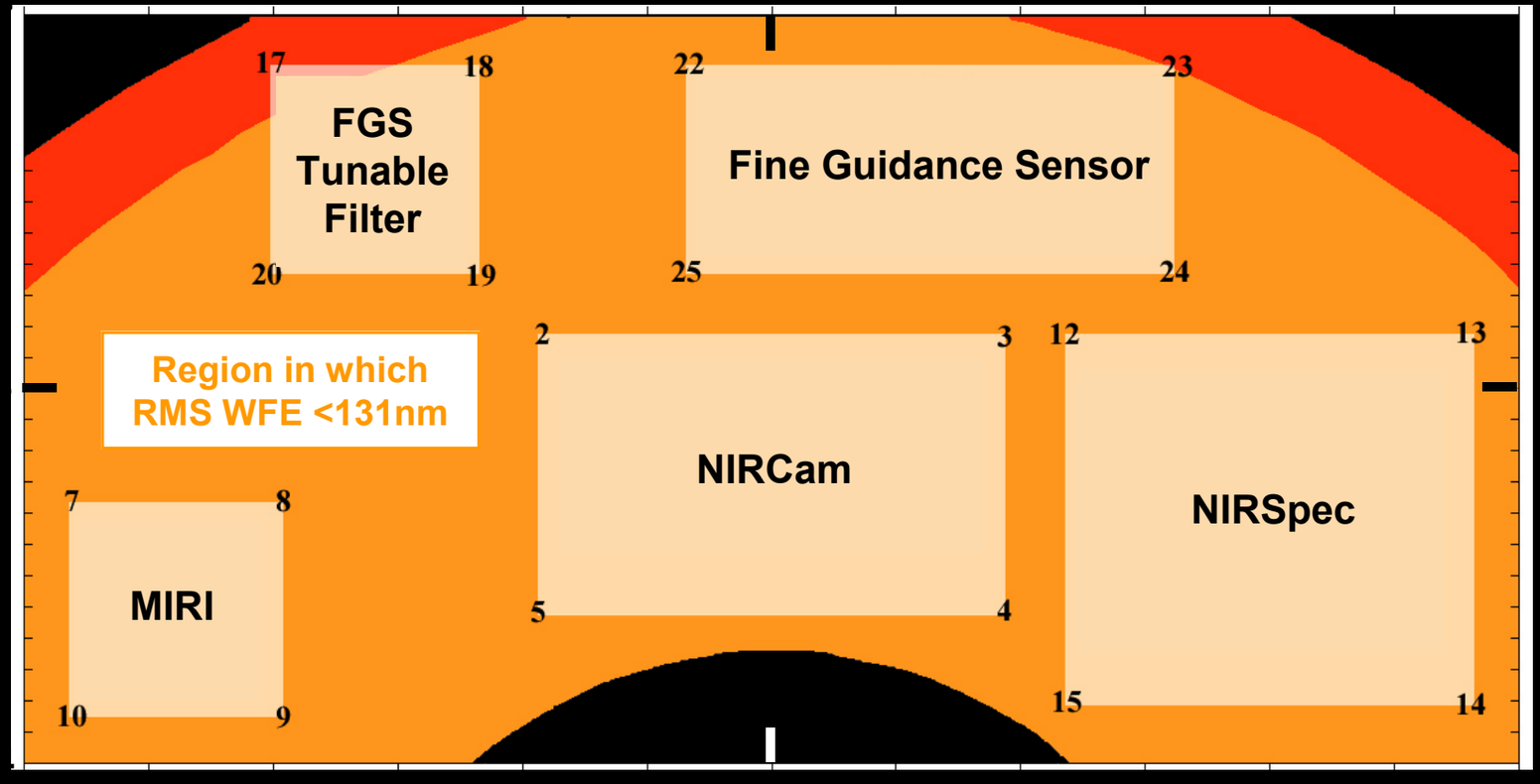
DHS (20 edges)



Pupil Imaging

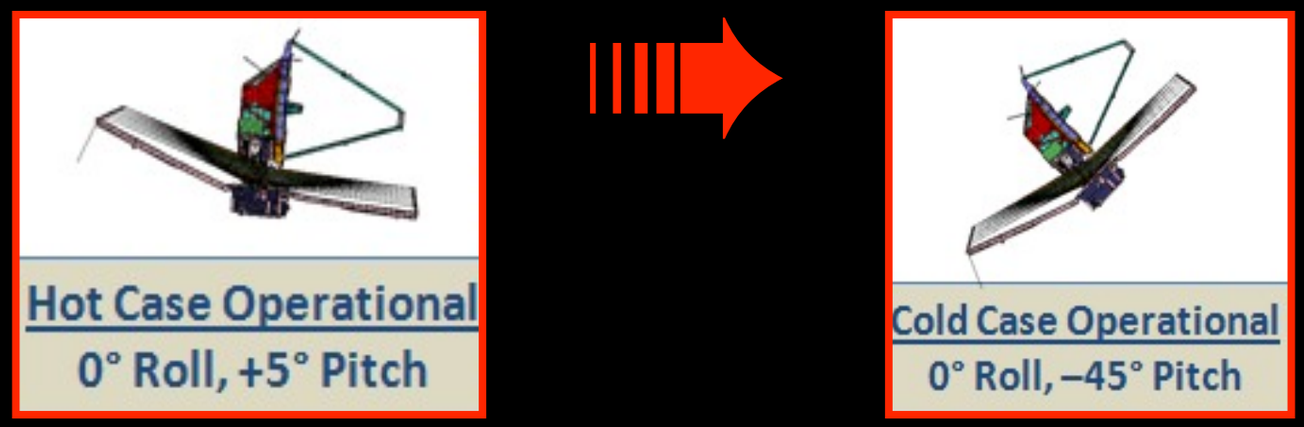
OTE Performance

- 2 μm diffraction limited imaging ➠ 150 nm WFE at NIRCam focal plane
  - ➡ Error budget allocations include OTE, ISIM, Pointing, OTE-Stability and reserves.
  - ➡ Coronagraph performance improves with WFE (e.g. Green 2005)
- Possible to optimize WFE for specific SI or field point e..g. NIRCam
  - ➡ Achieved via weighting of multi-field wavefront sensing measurements



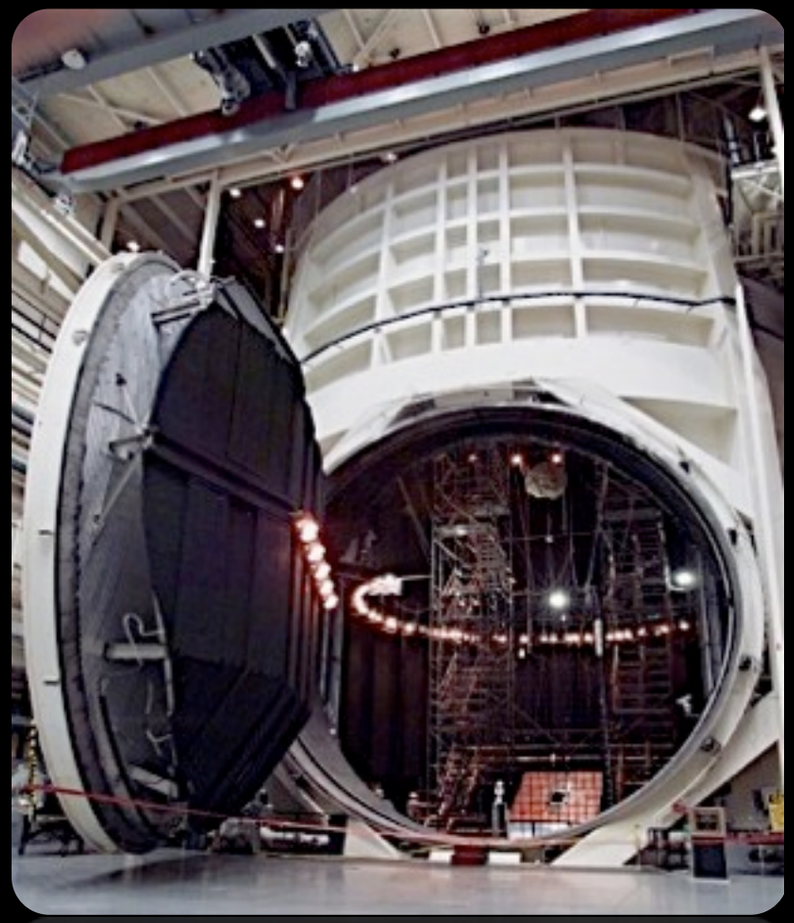
Observatory Stability

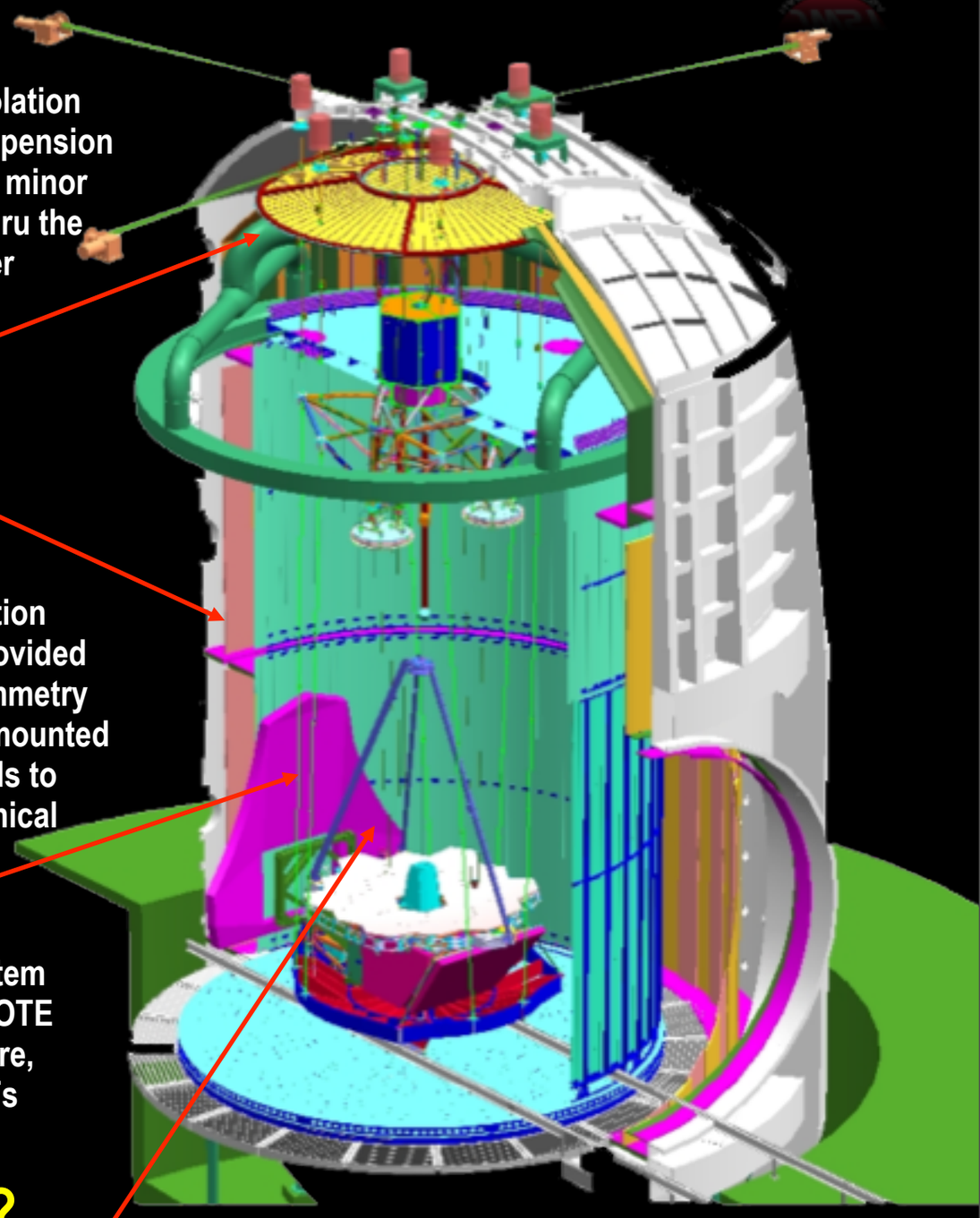
- Engineering philosopy for JWST requirements
  - ➡ Temperature distributions provided for analysis are based on a worst-case slew maneuver with the maximum expected temperature change (ΔT) over a 14-day interval between WFS&C operations



  - ➡ Worst case slew allocates ≤60 nm WFE variations over 14 d
  - ➡ Analysis of typical “Design Reference Mission” shows that WFE drift due to thermal effects likely to be lower
    - ➡ important for high contrast imaging

Verification: End-to-End Test @ JSC

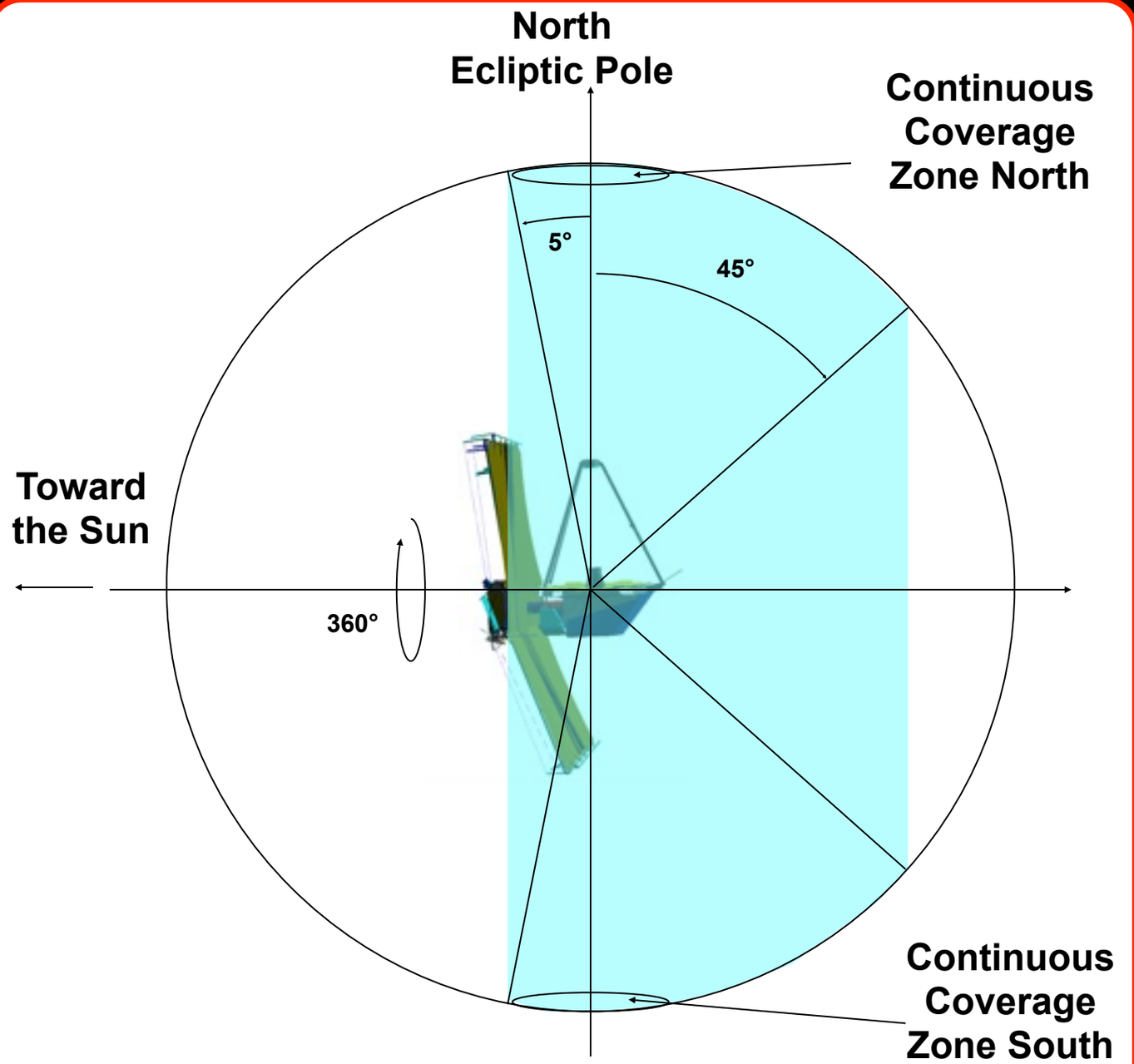




- Goals of Test
  - ➡ Optical workmanship
  - ➡ Thermal balance: do we get to operating temp?
  - ➡ Optical alignment: cryogenic observatory
    - ➡ e.g. Pupil alignments for coronagraphs

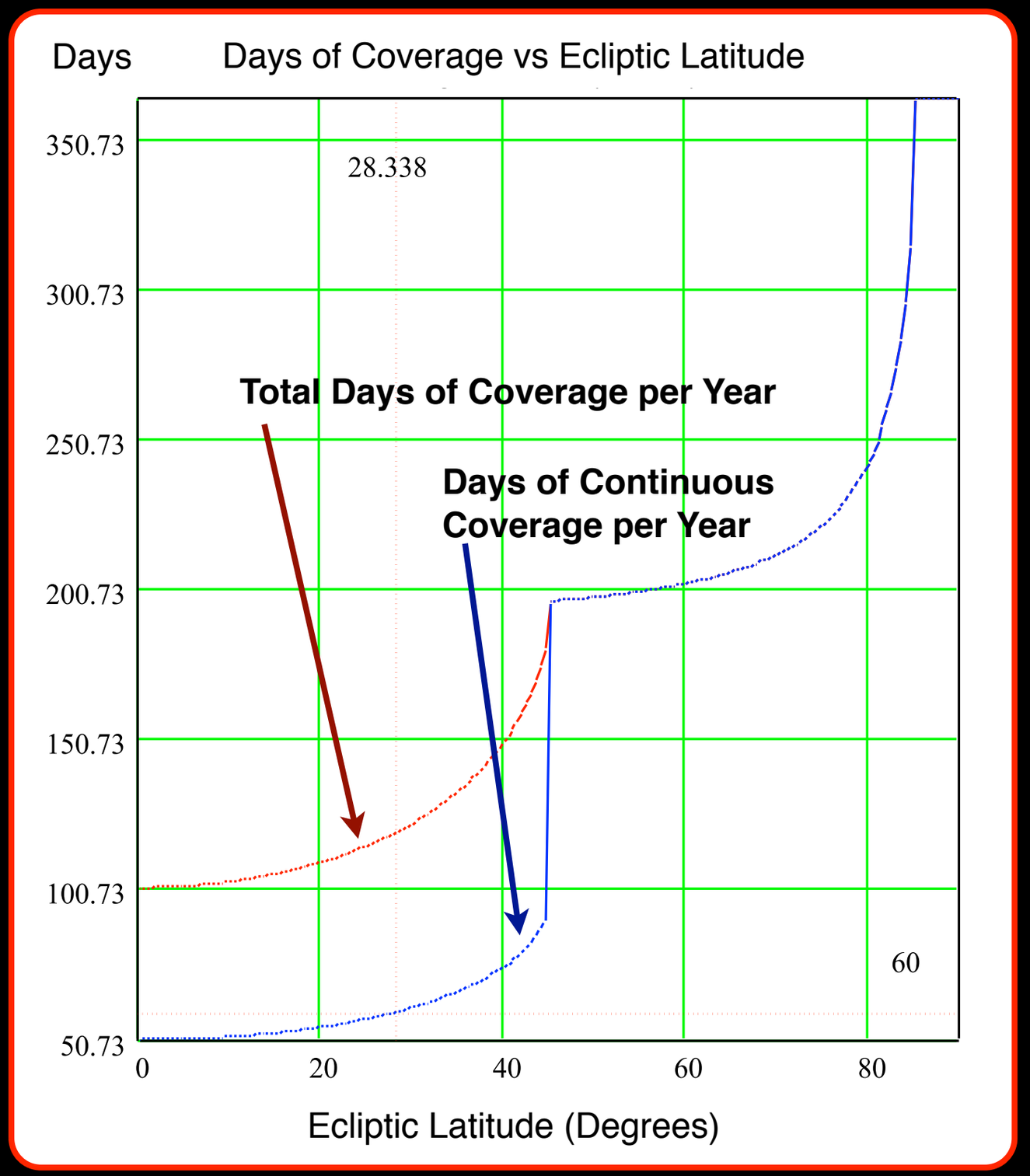
Field of Regard

- The sunshield is currently sized to provide at least 39% sky coverage
- Field of Regard is an annulus with rotational symmetry about the L2-Sun axis, 50° wide
- The observatory will have full sky coverage over a sidereal year
- The observatory will have a ±5° roll capability about the telescope's boresight
  - ➡ Impacts observational approach to coronagraphic observations



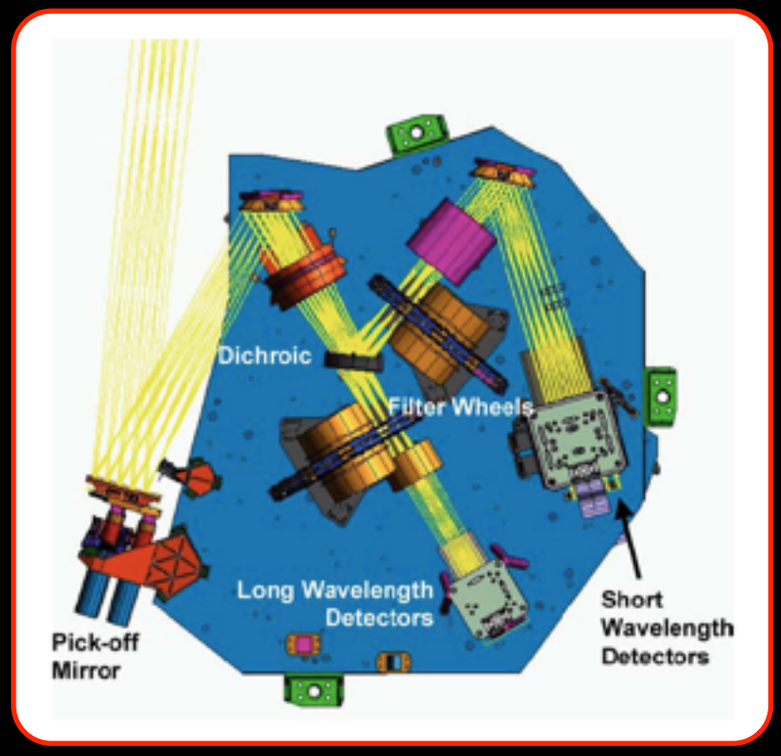
Field of Regard

- There are continuous viewing zones 5° about the North and South Ecliptic Poles
- The Coverage chart to the right shows annual coverage improves with proximity to the ecliptic poles
- Transit programs requiring multiple visits e.g. superearth spectroscopy, will need bright targets in these regions of the sky



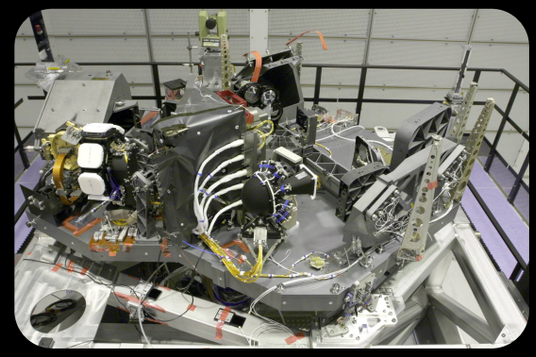
Near-Infrared Camera (NIRCam)

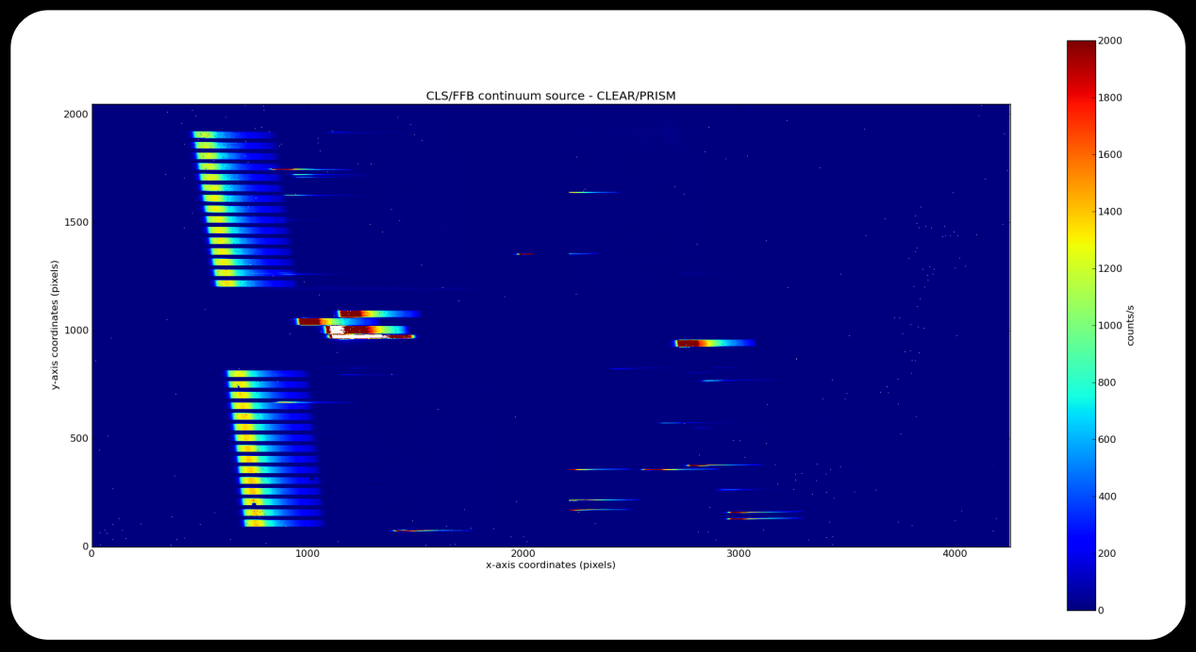
- Developed by the University of Arizona with Lockheed Martin ATC
  - Operating wavelength: 0.6 – 5.0 μm
  - Spectral resolution: 4, 10, 100
  - Field of view: 2.2 x 4.4 arc minutes
  - Angular resolution (1 pixel): 32 mas < 2.3 μm, 65 mas > 2.4 μm
  - Detector type: HgCdTe, 2048 x 2048 pixels, 10 detectors, T_{op}= 40K (passive)
  - Refractive optics, Beryllium structure



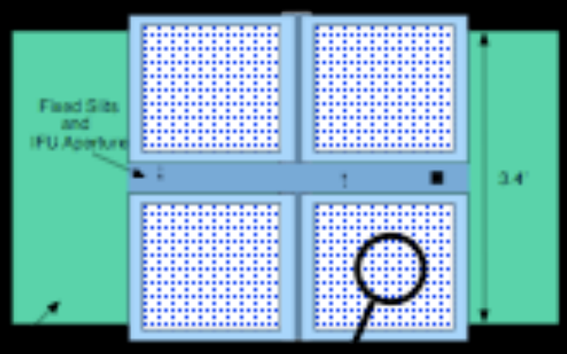
Near-Infrared Spectrograph (NIRSpec)

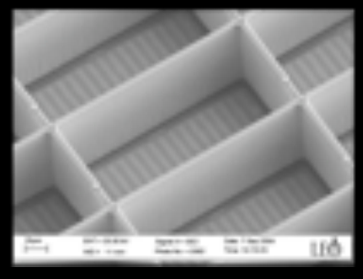
- Developed by the European Space Agency with Astrium GmbH and GSFC
  - Operating wavelength: 0.6 – 5.0 μm
  - Spectral resolution: 100, 1000, 3000
  - Field of view: 3.4 x 3.4 arc minutes
  - Aperture control: programmable μ-shutters, 250,000 pixels
  - Angular resolution: shutter open area 203 x 463 mas, pitch 267 x 528 mas
  - Detector type: HgCdTe, 2048 x 2048 pixel, 2 detectors, T_{op} = 37K (passive)
  - Reflective optics, SiC structure and optics



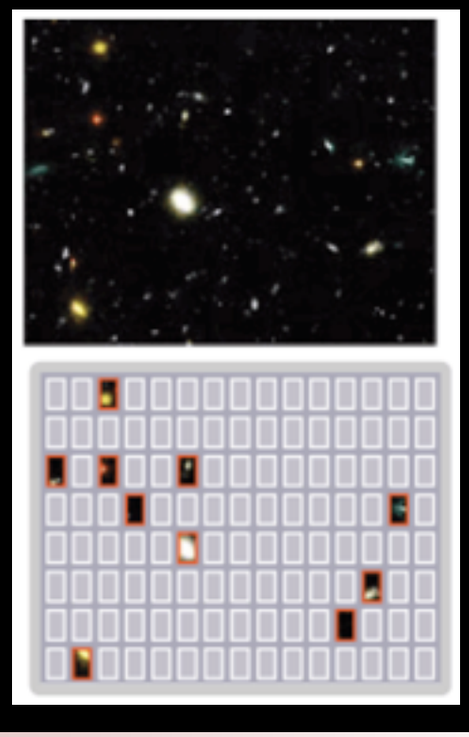


Microshutters



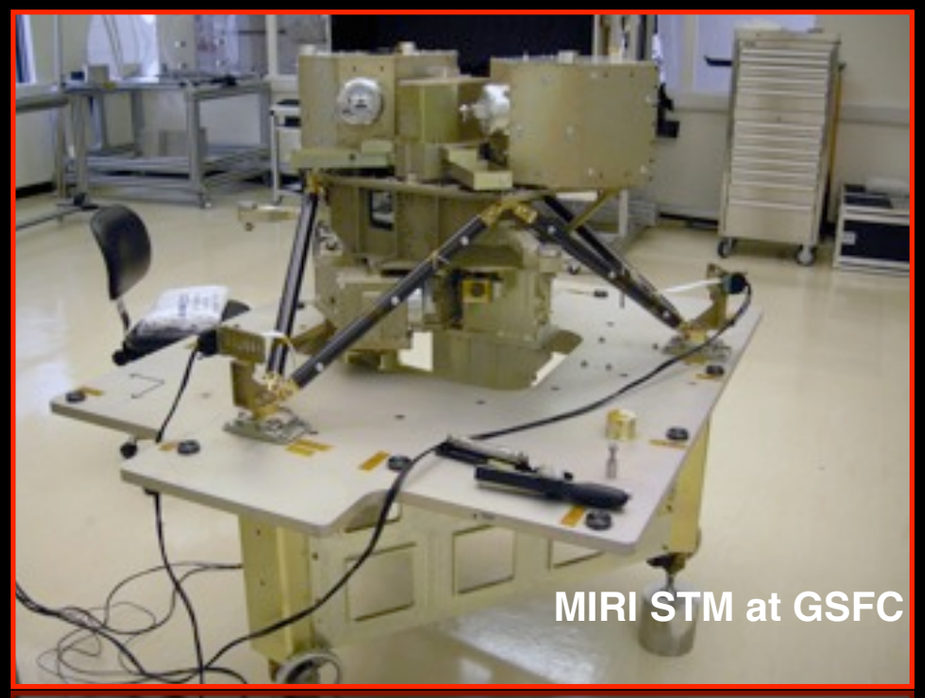


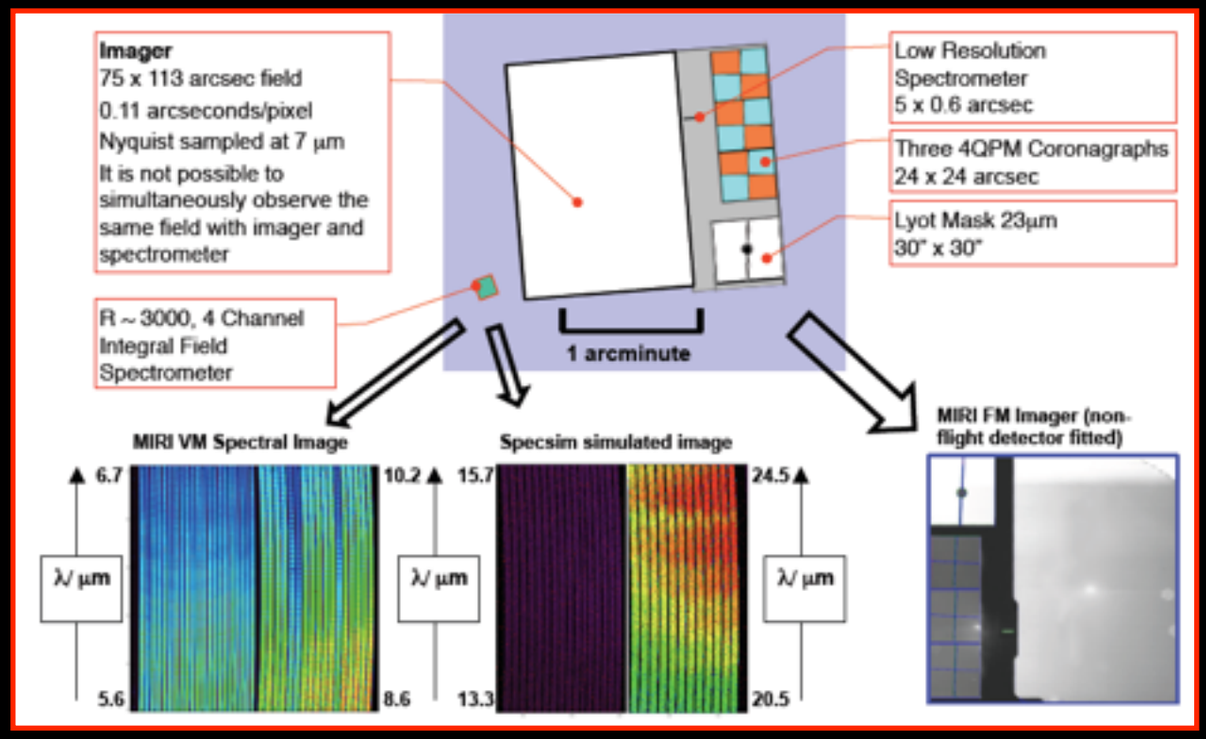
Multiple Objects
≤ 100 objects



Mid-Infrared Imager (MIRI)

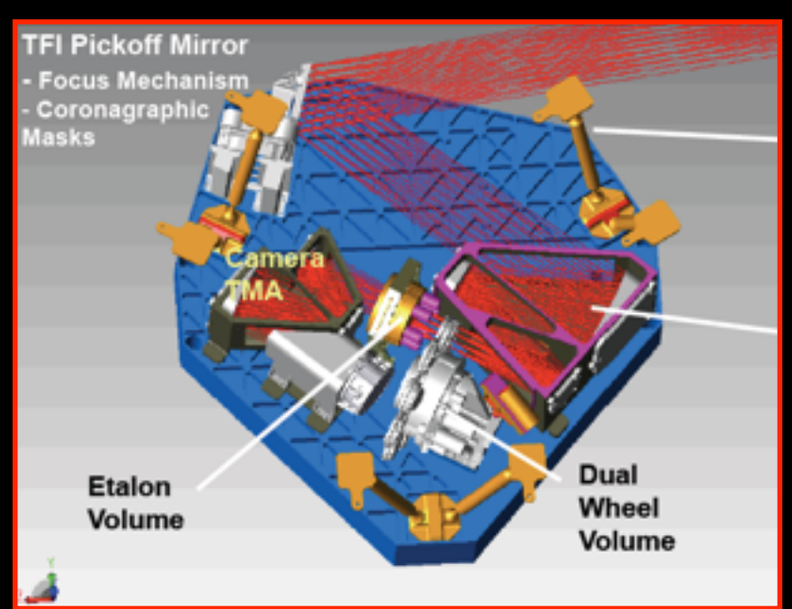
- Developed by the MIRI European Consortium and JPL
  - Operating wavelength: 5 – 29 μm
  - Spectral resolution: 5, 100, 2000
  - Field of view: 1.9 x 1.4 arc minutes broad-band imagery
  - R=100 spectroscopy 5 x 0.2 arc sec slit
  - R=2000 spectroscopy 3.5 x 3.5 and 7 x 7 arc sec integral field units
  - Detector type: Si:As, 1024 x 1024 pixel, 3 detectors, T_{op} = 7 K (cryo-cooler)
  - Reflective optics, Aluminum structure and optics

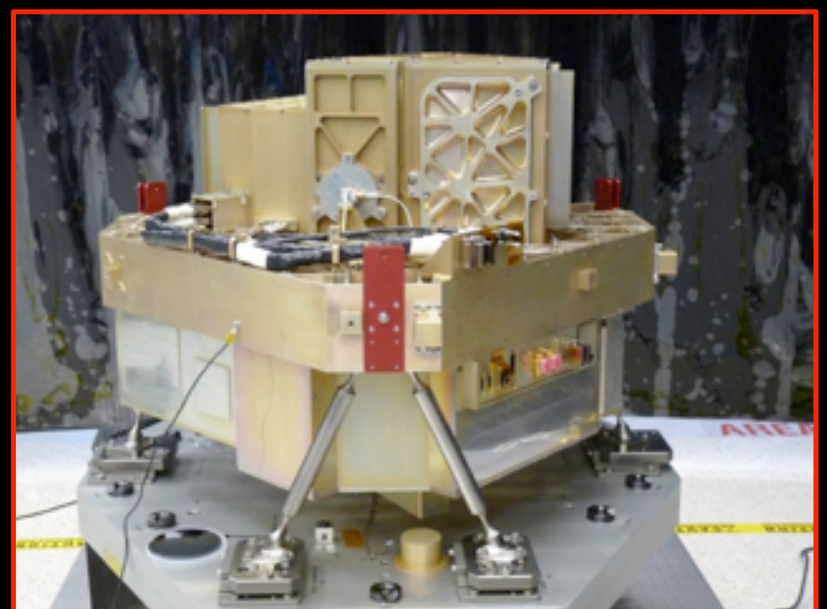

MIRI STM at GSFC



Fine Guidance Sensor/Tunable Filter Imager

- Developed by the Canadian Space Agency with ComDev
- Operating wavelength: 0.8 – 4.8 μm
- Spectral resolution: Broad-band guider and R=100 science imagery
- Field of view: 2.3 x 2.3 arc minutes
- R=100 imagery with Fabry-Perot tunable filter and coronagraph
- Angular resolution (1 pixel): 68 mas
- Detector type: HgCdTe, 2048 x 2048 pixel, 3 detectors, T_{op} = 40 K (passive)
- Reflective optics, Aluminum structure and optics

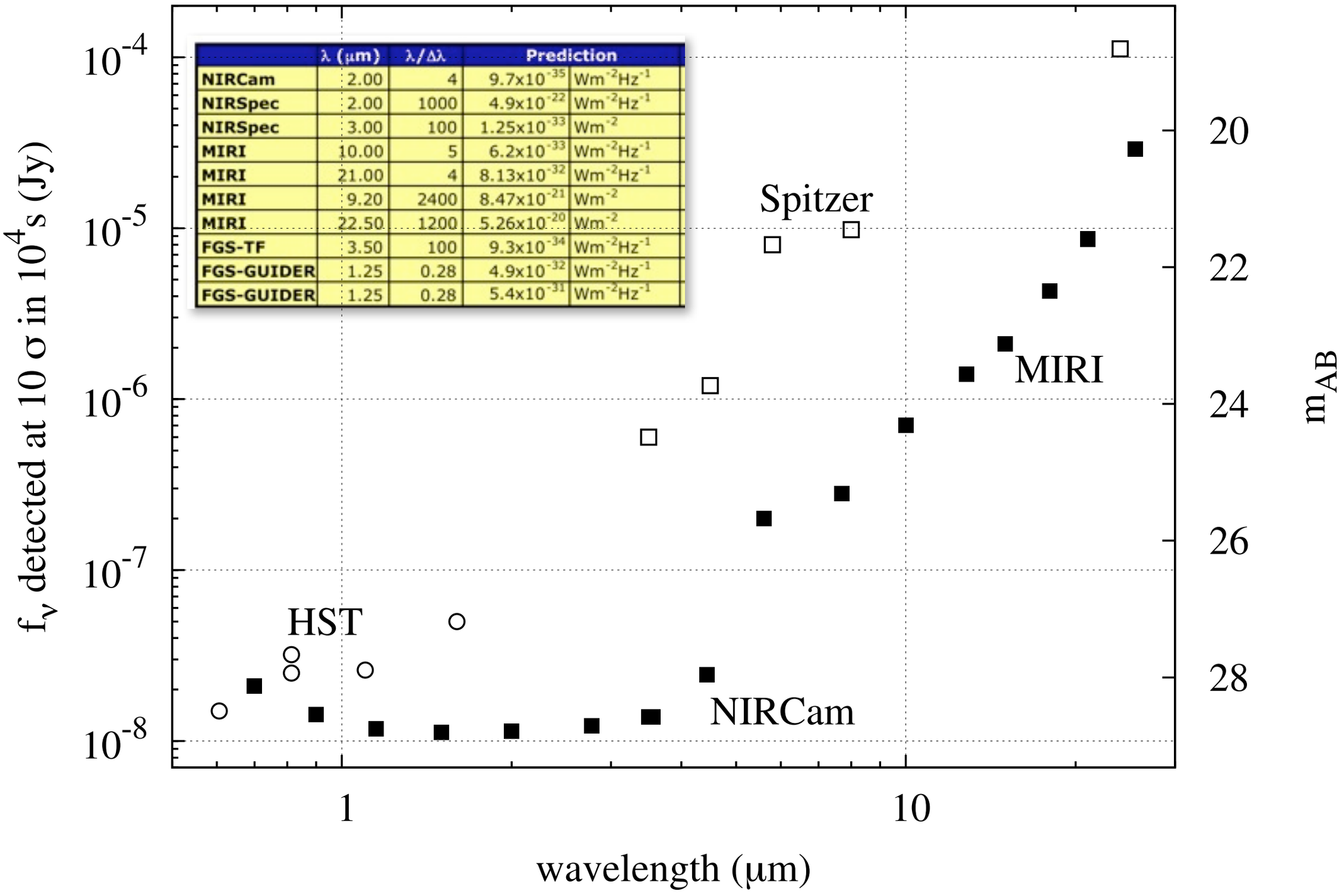




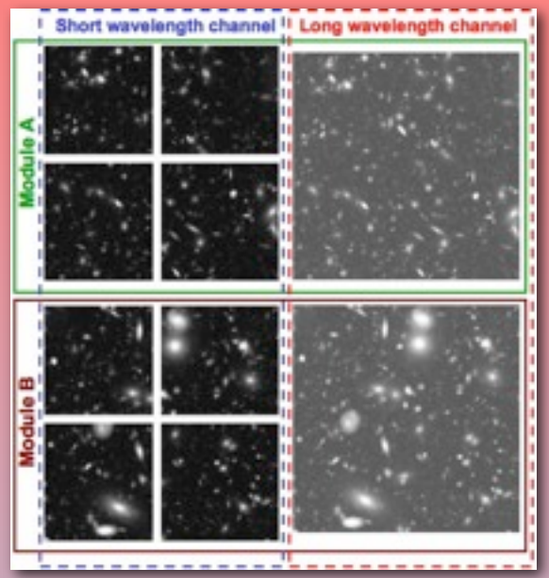
Observatory Sensitivity

Photometric performance, point source

	λ (μm)	λ/Δλ	Prediction	
NIRCam	2.00	4	9.7×10^{-35}	$Wm^{-2}Hz^{-1}$
NIRSpec	2.00	1000	4.9×10^{-22}	$Wm^{-2}Hz^{-1}$
NIRSpec	3.00	100	1.25×10^{-33}	Wm^{-2}
MIRI	10.00	5	6.2×10^{-33}	$Wm^{-2}Hz^{-1}$
MIRI	21.00	4	8.13×10^{-32}	$Wm^{-2}Hz^{-1}$
MIRI	9.20	2400	8.47×10^{-21}	Wm^{-2}
MIRI	22.50	1200	5.26×10^{-20}	Wm^{-2}
FGS-TF	3.50	100	9.3×10^{-34}	$Wm^{-2}Hz^{-1}$
FGS-GUIDER	1.25	0.28	4.9×10^{-32}	$Wm^{-2}Hz^{-1}$
FGS-GUIDER	1.25	0.28	5.4×10^{-31}	$Wm^{-2}Hz^{-1}$

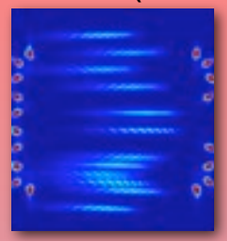


JWST Science Instruments



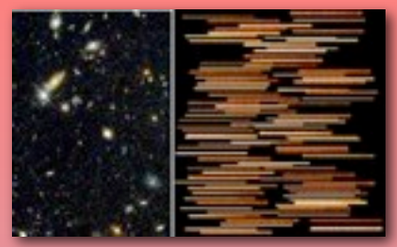
Deep, wide field broadband-imaging

Wavefront Sensing & Control (WFSC)

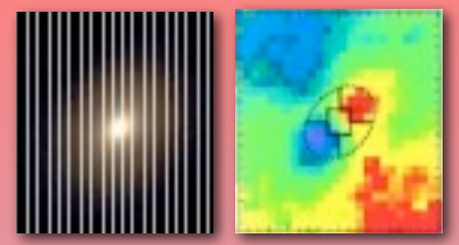


Coronagraphic Imaging

Multi-Object, IR spectroscopy

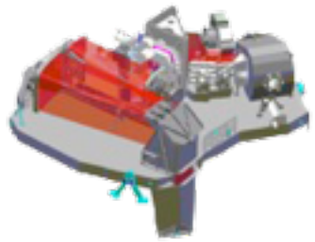


IFU spectroscopy



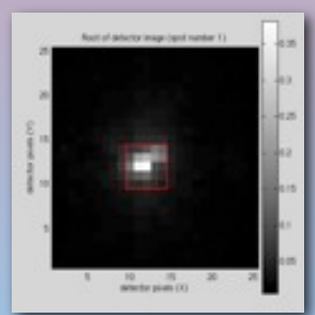
NIRCam

NIRSpec

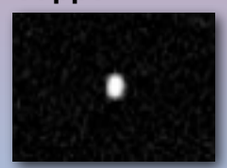


Long Slit spectroscopy

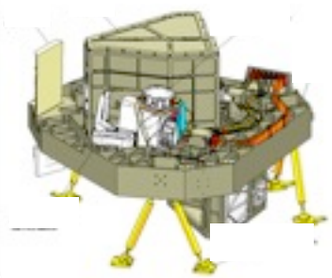
Fine Guidance Sensor



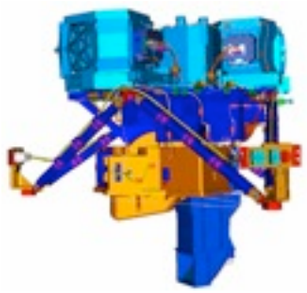
Moving Target Support



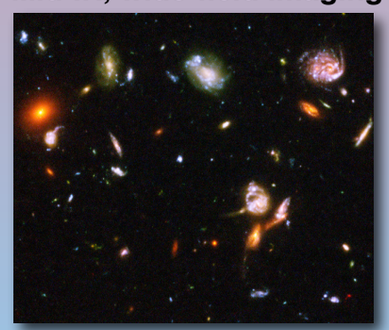
FGS/TF



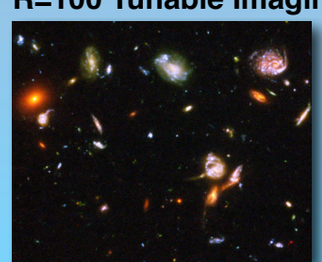
MIRI



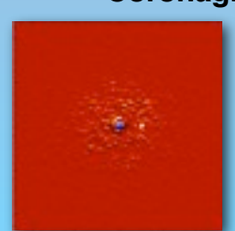
Mid-IR, wide-field Imaging

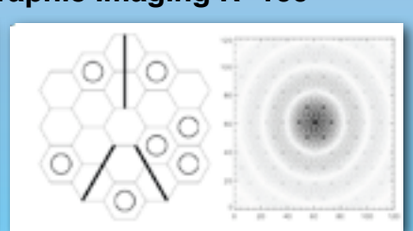


R=100 Tunable Imaging



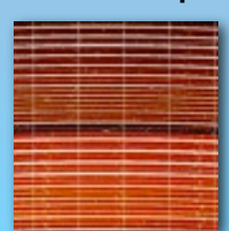
Coronagraphic Imaging R~100

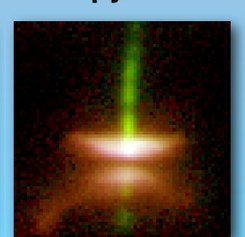




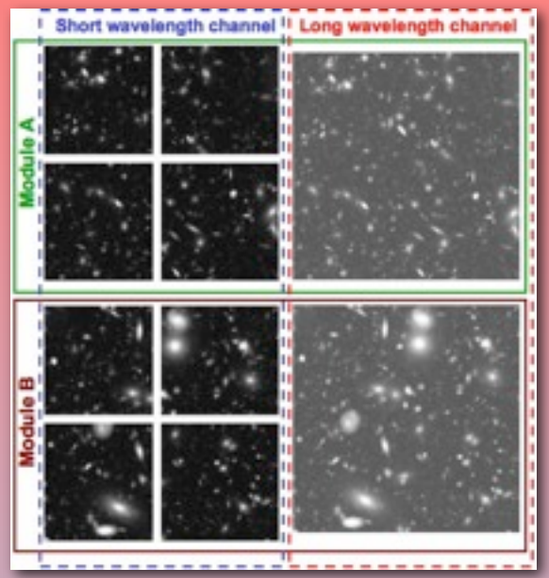
Mid-IR Coronagraphic Imaging

IFU spectroscopy



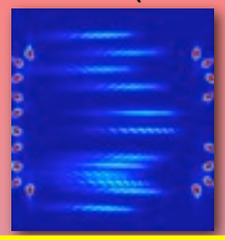


JWST Science Instruments

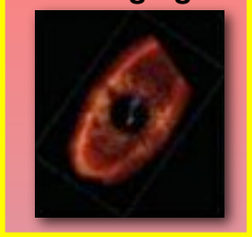


Deep, wide field broadband-imaging

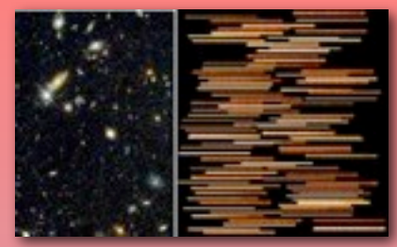
Wavefront Sensing & Control (WFSC)



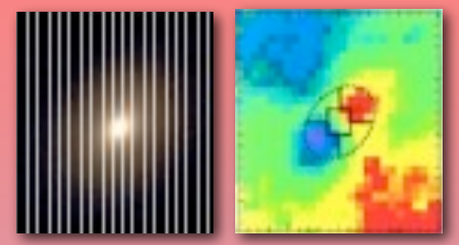
Coronagraphic Imaging



Multi-Object, IR spectroscopy

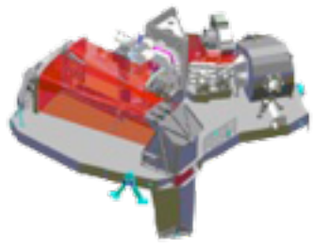


IFU spectroscopy



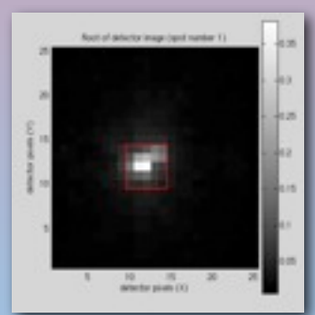
NIRCam

NIRSpec

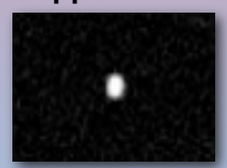


Long Slit spectroscopy

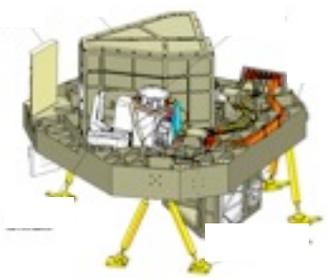
Fine Guidance Sensor



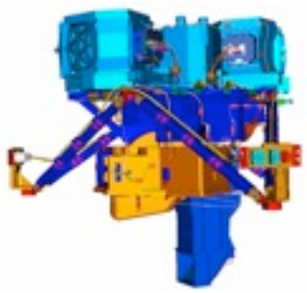
Moving Target Support



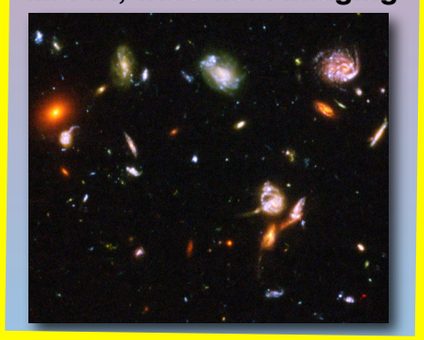
FGS/TF



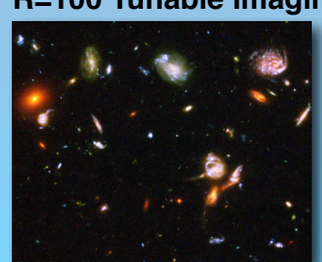
MIRI



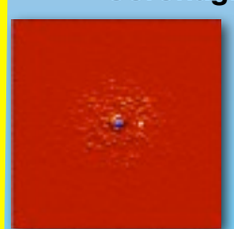
Mid-IR, wide-field Imaging

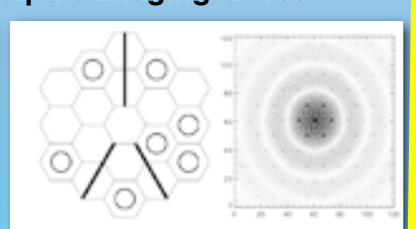


R=100 Tunable Imaging



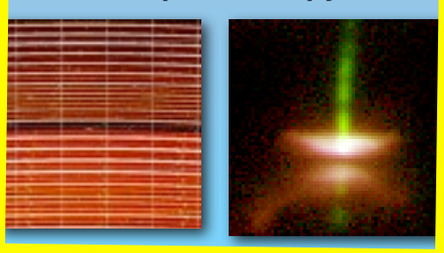
Coronagraphic Imaging R~100





Mid-IR Coronagraphic Imaging

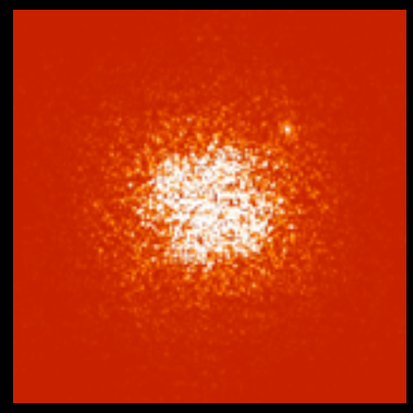
IFU spectroscopy

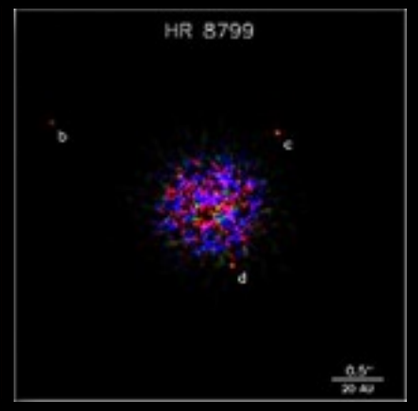


High Contrast Imaging: Coronagraphs

- **NIRCam**
  - **Band-limited mask occulters**

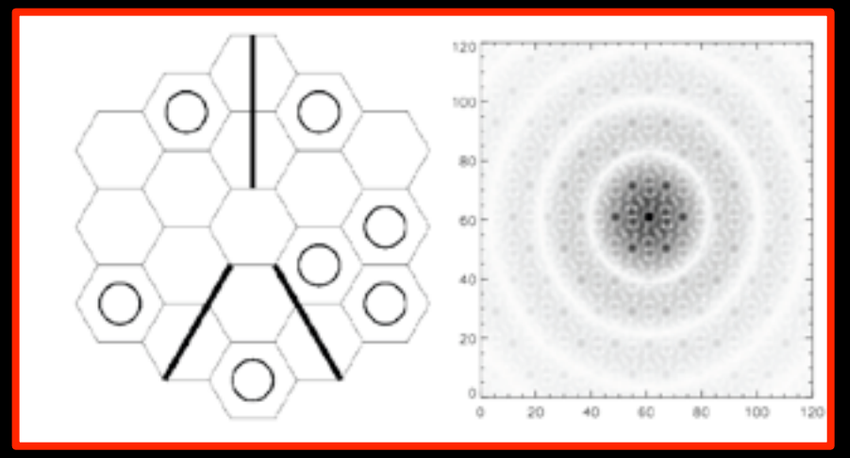
- **Tunable Filter Imager (TFI) Coronagraph**
  - **Coronagraph: Differential Speckle Imaging**
  - **Contrast gain of ~10x versus NIRCam**



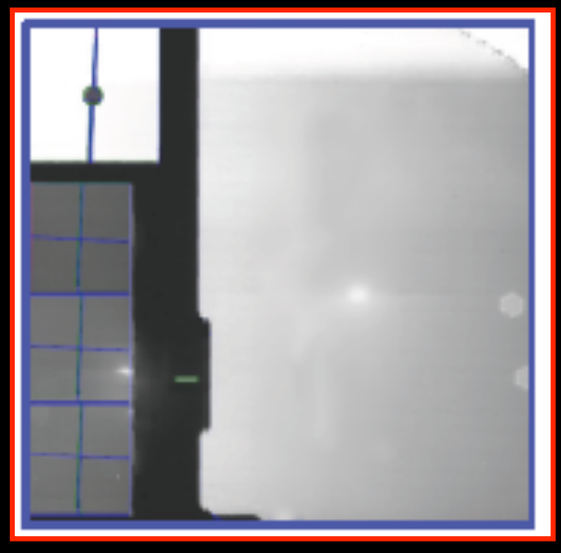


(Marois et al. 2008)

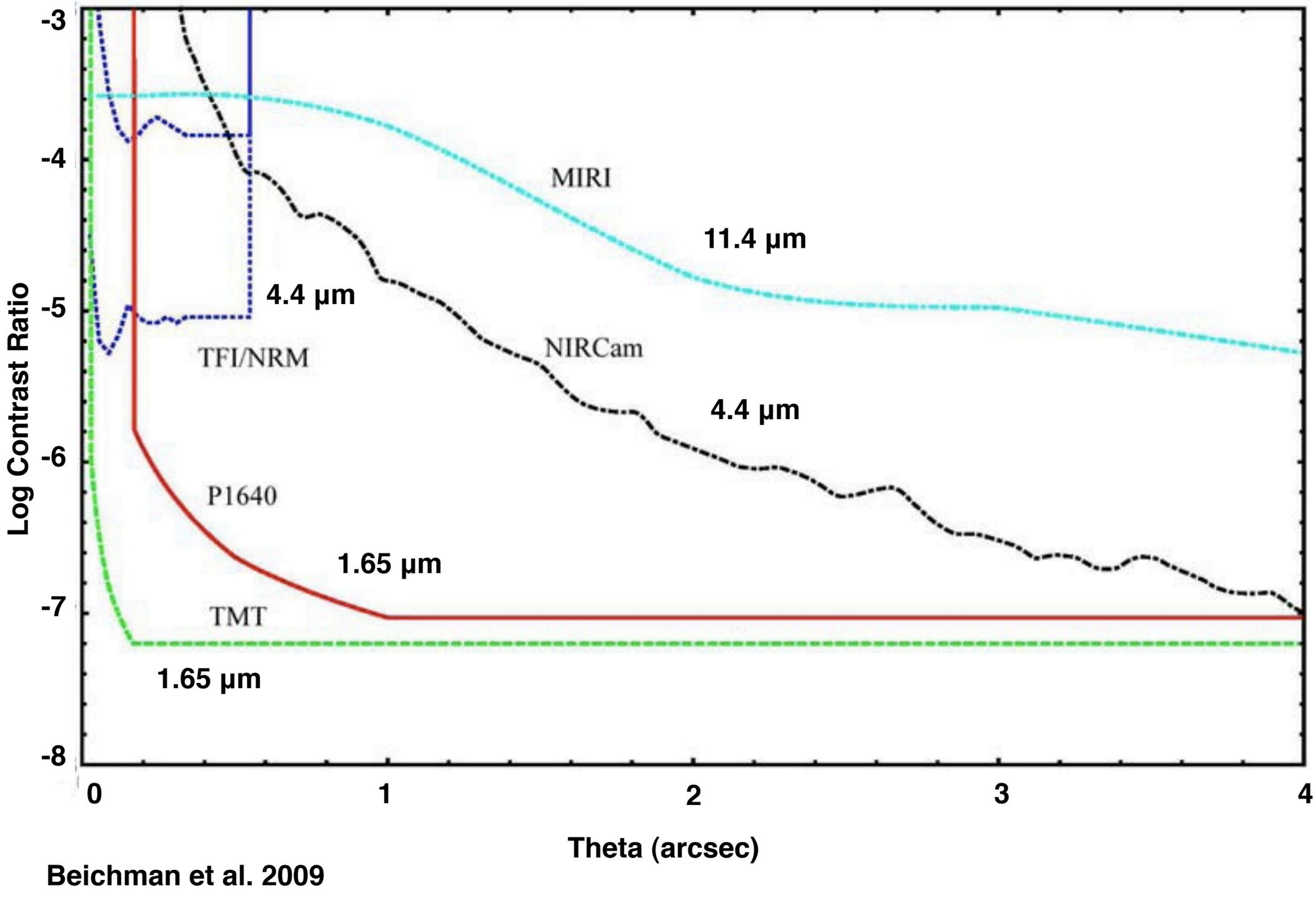
- **TFI Non-redundant Mask**
  - **Wavelength range: 1.5-2.5, 3.1-5.0 μm**
  - **Closure Phase Imaging**
  - **Trades inner working angle of 0.5 λ/D against contrast**



- **MIRI**
  - **3 Quadrant Phase**
  - **1 Lyot**

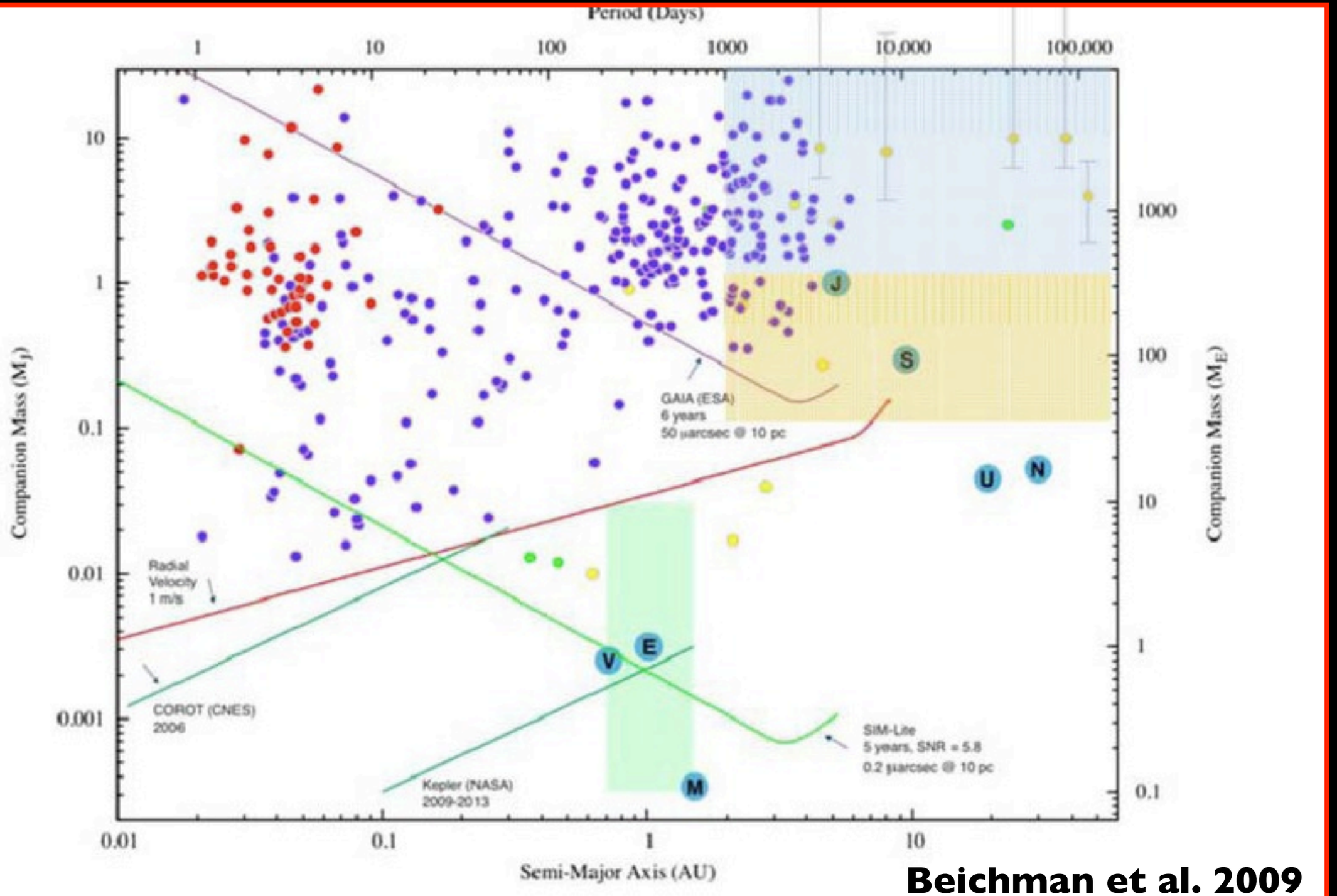


JWST Coronagraph Performance



Beichman et al. 2009

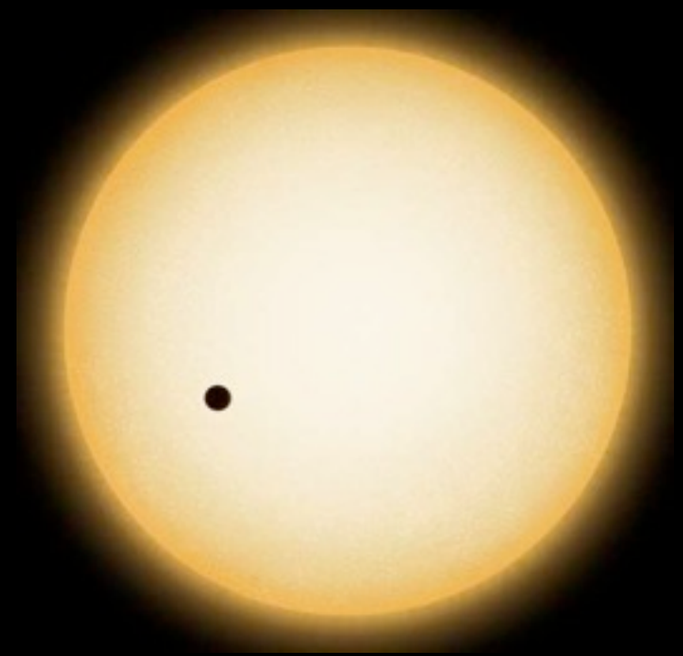
Coronagraph Discovery Space



Beichman et al. 2009

JWST is Optimum for Transit Science

- **Low background** : L2 orbit & cryogenic telescope
- **Apertures:** Slitless and/or large slit spectroscopy
- **Long dwell times:** L2 orbit
- **Image quality:**
  - Stable PSF
  - Pointing: Detailed error budget
- **Detectors**
  - Well characterized pixel response function
  - Sub-arrays
  - “NIR direct to digital” readout (ASIC)
- **Ground-testing: 3 instrument characterization phases**



JWST Transit Science Instrument Modes

	Instrument Mode	λ (μm)	R (λ/δλ)	FOV	Application
Imaging	NIRCam	0.6 - 2.3 2.4 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	**High precision light curves of primary and secondary eclipses**
	NIRCam (Defocused)	0.6 - 2.3	4, 10, 100	Defocused images radius = 0.74" radius = 1.42" radius = 2.11"	**High precision light curves of primary and secondary eclipses for** - bright targets that need to be defocused to avoid rapid saturation - reduction of flat field and pointing errors
	MIRI	5 - 28	4 - 6	1.9' x 1.4'	**High precision light curves of secondary eclipses**
	TFI	1.6 - 2.6 3.2 - 4.9	100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	**High precision light curves of primary and secondary eclipses** - bright targets that need to be defocused to avoid rapid saturation
Spectroscopy	NIRCam	2.4 - 5.0	1700	2 x (2.2' x 2.2')	**Transmission and emission spectroscopy of transiting planets**
	NIRSpec	1.0 - 5.0	100, 1000, 2700	1.6" x 1.6"	**Transmission and emission spectroscopy of transiting planets**
	MIRI-LRS	5 -11	100	Slitless	**Emission spectroscopy of transiting planets** **- Low spectroscopy**
	MIRI-MRS	5.9 - 7.7 7.4 - 11.8 11.4 - 18.2 17.5 - 28.8	3000 3000 3000 3000	3.7" x 3.7" 4.7" x 4.5" 6.2" x 6.1" 7.1" x 7.1"	**Emission spectroscopy of transiting planets** **- suitable for specific spectral features e.g. CO_2 @ 15 μm**

JWST Transit Science Instrument Modes

	Instrument Mode	λ (μm)	R (λ/δλ)	FOV	Application
Imaging	NIRCam	0.6 - 2.3 2.4 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	**High precision light curves of primary and secondary eclipses**
	NIRCam (Defocused)	0.6 - 2.3	4, 10, 100	Defocused images radius = 0.74" radius = 1.42" radius = 2.11"	**High precision light curves of primary and secondary eclipses for** - bright targets that need to be defocused to avoid rapid saturation - reduction of flat field and pointing errors
	MIRI	5 - 28	4 - 6	1.9' x 1.4'	**High precision light curves of secondary eclipses**
	TFI	1.6 - 2.6 3.2 - 4.9	100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	**High precision light curves of primary and secondary eclipses** - bright targets that need to be defocused to avoid rapid saturation
Spectroscopy	NIRCam	2.4 - 5.0	1700	2 x (2.2' x 2.2')	**Transmission and emission spectroscopy of transiting planets**
	NIRSpec	1.0 - 5.0	100, 1000, 2700	1.6" x 1.6"	**Transmission and emission spectroscopy of transiting planets**
	MIRI-LRS	5 -11	100	Slitless	**Emission spectroscopy of transiting planets** **- Low spectroscopy**
	MIRI-MRS	5.9 - 7.7 7.4 - 11.8 11.4 - 18.2 17.5 - 28.8	3000 3000 3000 3000	3.7" x 3.7" 4.7" x 4.5" 6.2" x 6.1" 7.1" x 7.1"	**Emission spectroscopy of transiting planets** **- suitable for specific spectral features e.g. CO_2 @ 15 μm**

- **NIRCam Defocused imaging for transit photometry: 4λ, 8λ, 12λ waves**

JWST Transit Science Instrument Modes

	Instrument Mode	λ (μm)	R (λ/δλ)	FOV	Application
Imaging	NIRCam	0.6 - 2.3 2.4 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	**High precision light curves of primary and secondary eclipses**
	NIRCam (Defocused)	0.6 - 2.3	4, 10, 100	Defocused images radius = 0.74" radius = 1.42" radius = 2.11"	**High precision light curves of primary and secondary eclipses for** - bright targets that need to be defocused to avoid rapid saturation - reduction of flat field and pointing errors
	MIRI	5 - 28	4 - 6	1.9' x 1.4'	**High precision light curves of secondary eclipses**
	TFI	1.6 - 2.6 3.2 - 4.9	100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	**High precision light curves of primary and secondary eclipses** - bright targets that need to be defocused to avoid rapid saturation
Spectroscopy	NIRCam	2.4 - 5.0	1700	2 x (2.2' x 2.2')	**Transmission and emission spectroscopy of transiting planets**
	NIRSpec	1.0 - 5.0	100, 1000, 2700	1.6" x 1.6"	**Transmission and emission spectroscopy of transiting planets**
	MIRI-LRS	5 -11	100	Slitless	**Emission spectroscopy of transiting planets** **- Low spectroscopy**
	MIRI-MRS	5.9 - 7.7 7.4 - 11.8 11.4 - 18.2 17.5 - 28.8	3000 3000 3000 3000	3.7" x 3.7" 4.7" x 4.5" 6.2" x 6.1" 7.1" x 7.1"	**Emission spectroscopy of transiting planets** **- suitable for specific spectral features e.g. CO_2 @ 15 μm**

- **NIRCam Defocused imaging for transit photometry: 4λ, 8λ, 12λ waves**

NIRCam/MIRI Capabilities

- **NIRCAM High precision two-channel photometry**

  → **Primary transits (short-λ) & Secondary transits (long-λ)**

- **NIRCAM Long-λ spectroscopy (2.4 - 5.0 μm)**

  Primary and secondary transits of hot Jupiters (R≤1000)

  Secondary transits of hot earths R~50

- **MIRI slitless spectroscopic mode (Low Resolution Spectrograph)**

  Detection of R~100 hot-Jupiter emission spectra in a single transit

  Detection of small (1-2 REarth) planets transiting G, K & M stars

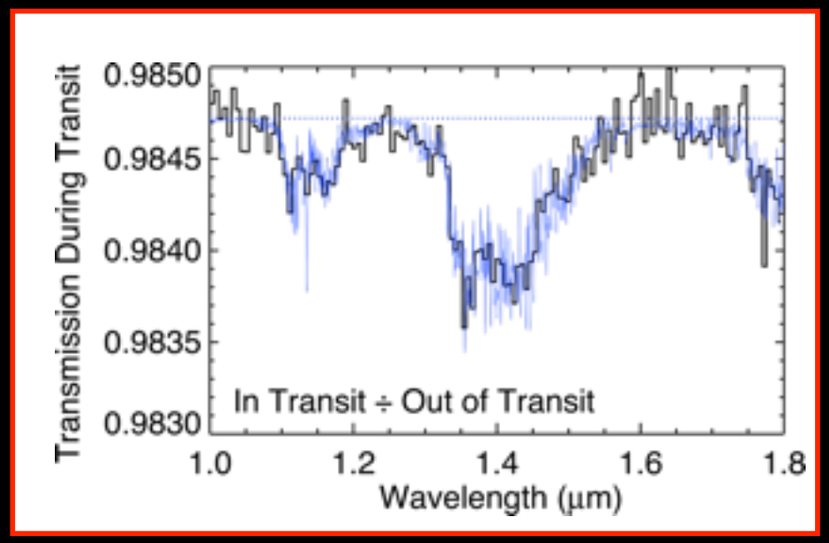
- **MIRI Medium Resolution Spectrograph**

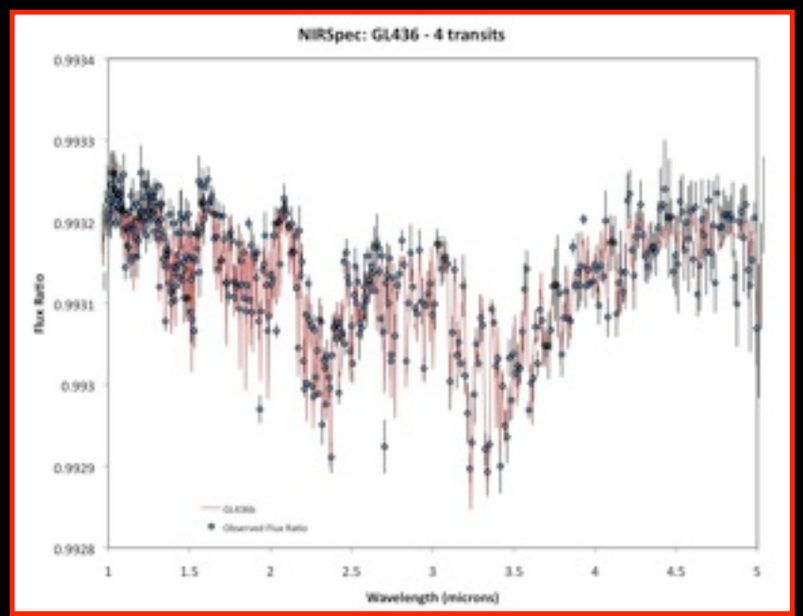
  Detection of specific spectral features e.g. CO_2 feature at 15 μm

NIRSpec Science

- Recently added 1.6'x1.6" slit for transits
- Short-λ and Long-λ spectroscopy
  - Primary and secondary transits
  - Hot Jupiters: NIRSpec can obtain spectra at a range of spectral resolutions. For the bright host stars it can conduct high precision transit spectroscopy (GKM stars) to characterize spectral features
  - Hot-Neptunes: NIRSpec can obtain transit spectra at a range of spectral resolutions. For the bright host stars it can conduct high precision transit spectroscopy (GKM stars) to characterize spectral features
  - Superearths: NIRSpec can obtain emission spectra of superearths, and detect spectral features in transmission for some atmospheric compositions (M star hosts)

NIRSpec Transit Spectrum for HD 209458 at K=12





Simulations of GJ436B by Clampin and Lindler

JWST Transit Science Summary

Observation	Targets	R	Science
Transit light Curves	Gas giants Intermediate planets Superearths	5 5 5	- Exoplanet properties e.g. Mass, radius -> Physical structure - Confirmation of Terrestrial planet transits - Transit timing: detection of unseen planets
Phase light curves	Gas giants Intermediate planets	5 5	- Day to night emission mapping: dynamical models of Exoplanet atmospheres
Transmission Spectroscopy	Gas giants Gas giants Intermediate planets Superearths planets	3000 100-500 100-500 ≤100	Spectral line diagnostics - atmospheric composition e.g. C, CO_2, CH_4 - follow-up of survey detections: TESS & Kepler
Emission Spectroscopy	Gas giants Gas giants Intermediate planets Superearths planets	3000 100-500 100-500 ≤100	- Spectral line diagnostic - Planet temperature measurements - follow-up of survey detections: TESS & Kepler

- **Characterization of superearth atmosopheres**
  - e.g. Kaltenegger & Traub, 2009, Palle et al. 2009, Deming et al. 2009
  - Spectral characterization of habitable superearths with late type parent stars will require ≥ 100 transits (spectroscopy or filter-imaging)

Post-ICRP: Steps to a Launch Date

Bottoms-up Cost Estimate + Independent Cost Estimate

→ **80% Confidence Level Preliminary Baseline**

NASA, ESA, CSA, OSTP, OMB, and Congress discussion

Formal NASA Center, Directorate, Agency Reviews

Baseline Program & Launch Readiness Date (LRD)

Post-ICRP: Steps to a Launch Date

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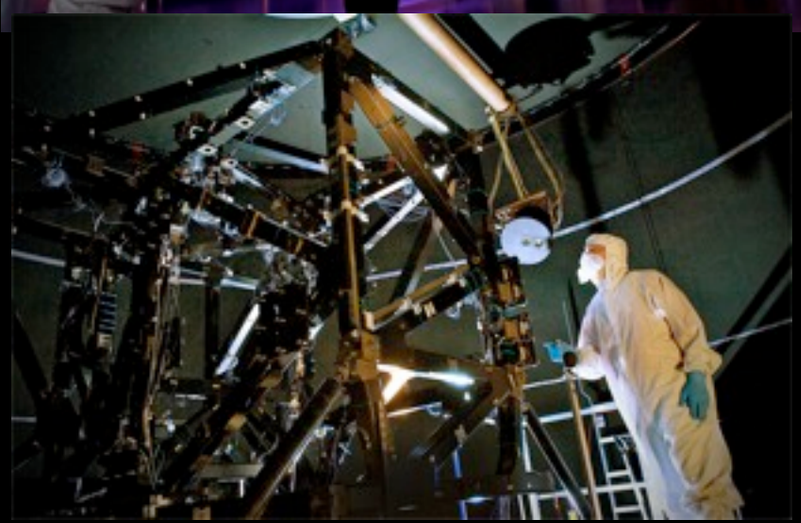


NASA, ESA, CSA, OSTP, OMB, and Congress discussion

Formal NASA Center, Directorate, Agency Reviews

Baseline Program & Launch Readiness Date (LRD)

Summary

- JWST is making excellent technical progress

- JWST will be the dominant astronomical facility for a decade, and will undertake a broad range of investigations by the astronomical community

- JWST remains the brilliant advance recommended by the 2000 Decadal Survey
- JWST science forms the underpins the 2010 Decadal Surveys
- JWST has the capability to address new observing opportunities such as exoplanet characterization.....

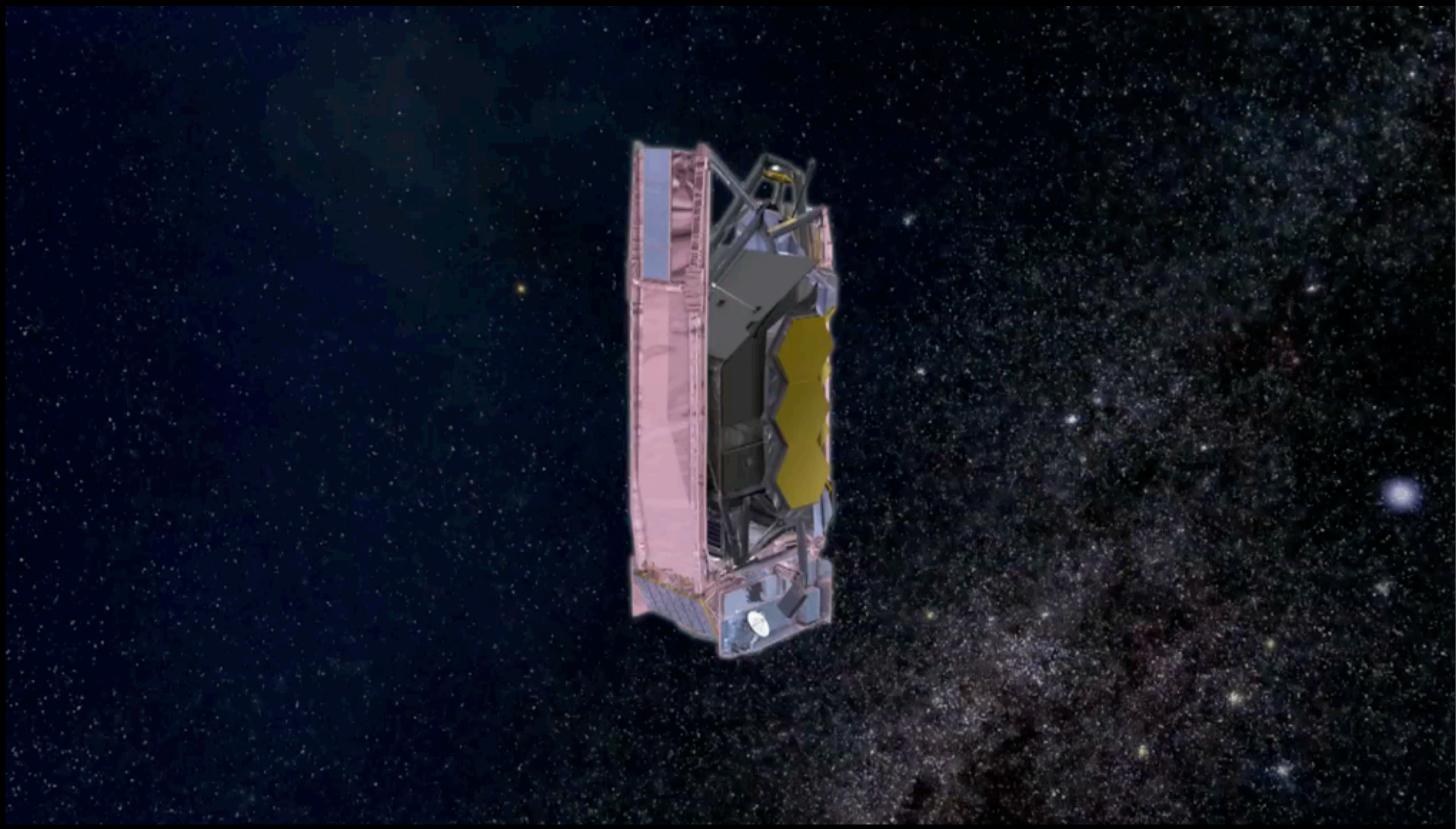
Collaborators

- JWST Science Working Group
  - JWST Science Instrument Teams:
    inc. Tom Greene, John Krist, Chas Beichman
  - JWST Transit Working Group
- Eliza Miller-Ricci (MIT), Sara Seager (MIT) and Dimitar Sasselov (CfA)
- Drake Deming (GSFC)
- Don Lindler (SigmaSpace)
- Chuck Bowers and Kong Ha (GSFC)
- Web Site: http://jwst.gsfc.nasa.gov/

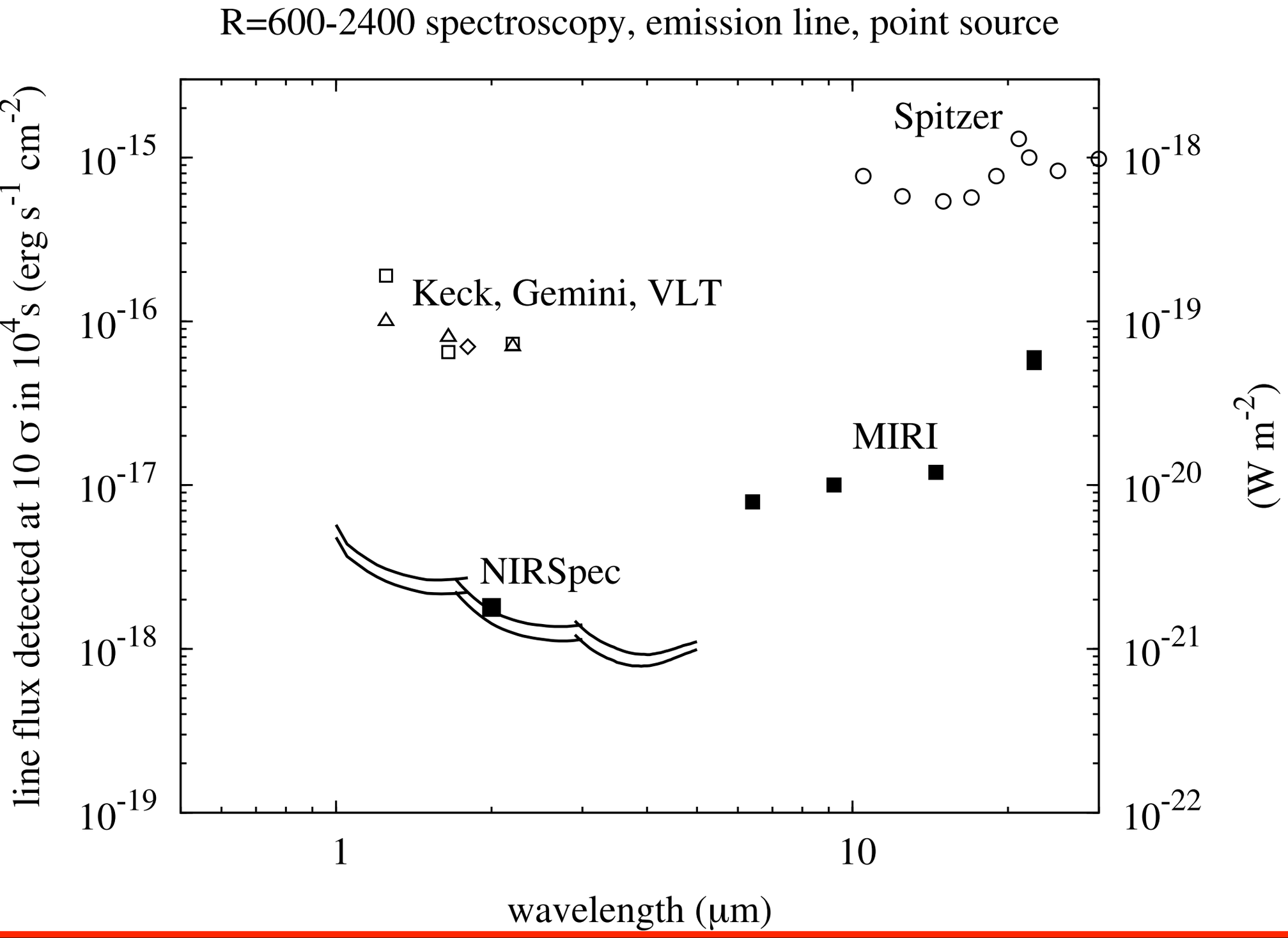
JWST Program Status

- ICRP review: Casani/Illingworth Committee
  - ➡ Technical Endorsement of Mission
  - ➡ HQ/Project is in the process of responding to recommendations in the ICRP report including:
    - ➡ New JWST Office at NASA/HQ led by Rick Howard ✔
    - ➡ Restructuring of program reporting at HQ ✔
    - ➡ Restructuring of program management team at GSFC ✔
    - ➡ Development of new budget/schedule underway at NASA HQ/GSFC ➠ Launch Date

JWST Deployment



Observatory Sensitivity



2010 Programmatic Events

TAT: Test Assessment Team
ICRP: Independent Comprehensive Review Panel

Mission Critical Design Review (CDR)
Apr 12, 2010 – Apr 16, 2010

Mikulski letter to NASA
Jun 29, 2010

United States Senate
WASHINGTON, DC 20510-2003

June 29, 2010

Lt. General Charles Bolden (Ret.)
Administrator
National Aeronautics and Space Administration
300 E Street, SW
Washington, DC

Dear Mr. Administrator:

The James Webb Space Telescope (JWST) will be the most scientifically powerful telescope NASA has ever built – 100 times more powerful than the Hubble which has already rewritten our textbooks. Congress has provided all of the funding requested for the JWST. Yet ongoing cost overruns and inadequate phasing of reserves have required an additional $95 million in fiscal year (FY) 2009 and another $20 million in FY 2010.

I am deeply troubled by the escalating costs for the JWST. The report the agency provided in response to my Subcommittee on Commerce, Justice, Science and Related Agencies Appropriations provided little comfort that the problems are behind us. Simply put, NASA must manage the cost and schedule of its large scale programs to the highest standard.

I request that you immediately initiate an independent and comprehensive review of JWST, led by experts from outside of NASA. I recommend this review be overseen by your immediate office and that you appoint individuals with the depth and range of experience to assess how to complete development of JWST within budget and on schedule. The members of the panel should be familiar with NASA management processes for large projects, as well as the Centers.

Programmatic CDR
May 11, 2010 – May 12, 2010

Initial TAT discussion
Jun 4, 2010

TAT Study
Jul 9, 2010 – Aug 20, 2010

TAT Final Report
Aug 27, 2010

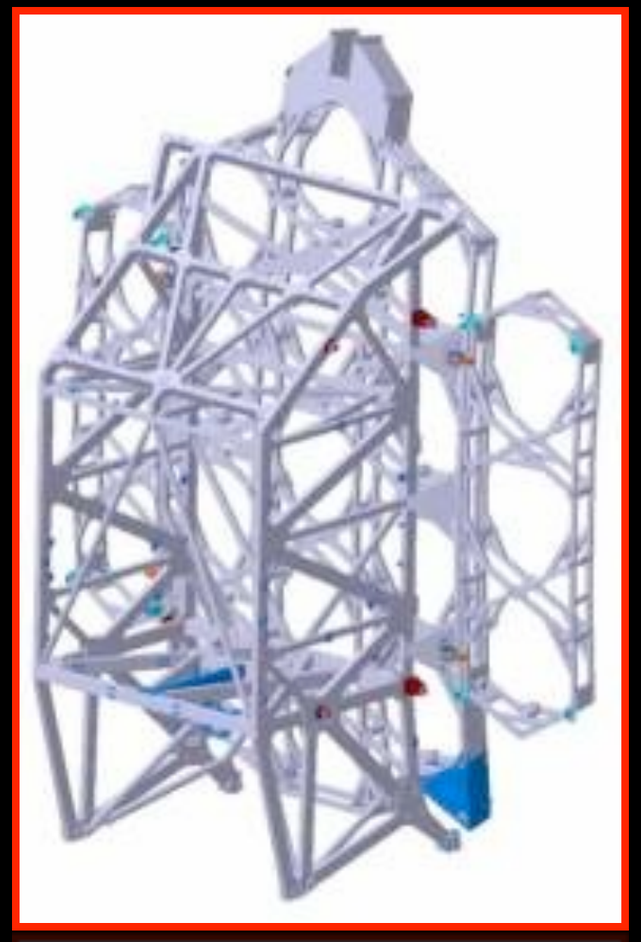
ICRP Study
Aug 23, 2010 – Oct 22, 2010

ICRP Final Report
Oct 29, 2010

Initial Agency Response
Nov 10, 2010
(media telecon)

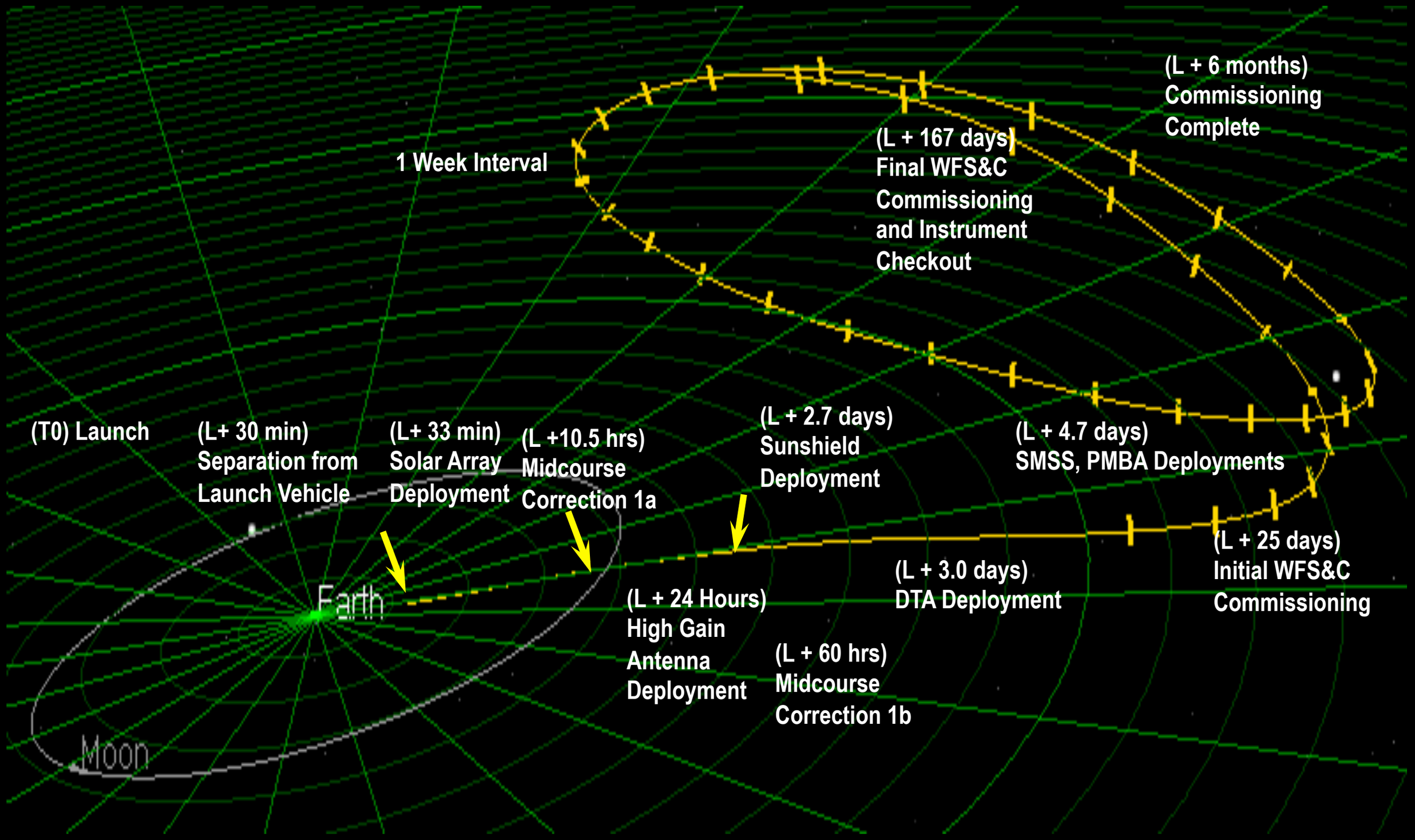
May 1, 2010 | Jul 1, 2010 | Sep 1, 2010 | Nov 1, 2010 | JWST 2010

Pathfinder/Backplane Bonding

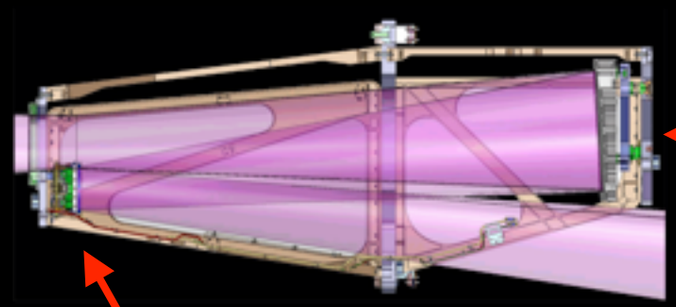


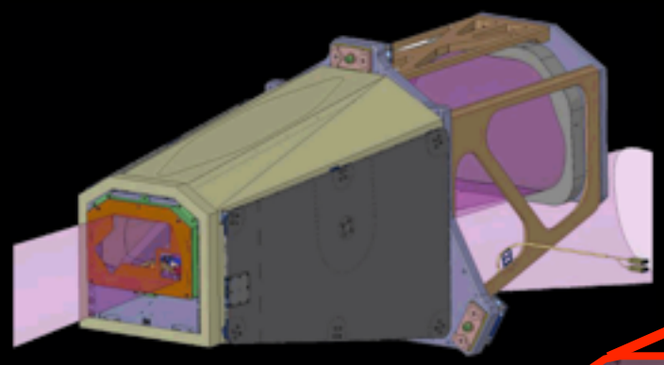
Pathfinder is complete and will be used to prepare for end-to-end optical test at JSC

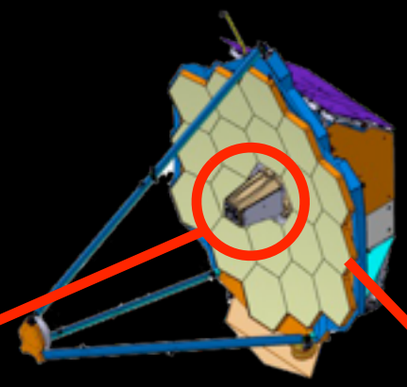
Launch to Science



Aft-Telescope Optical System



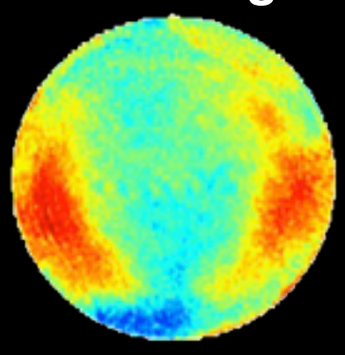




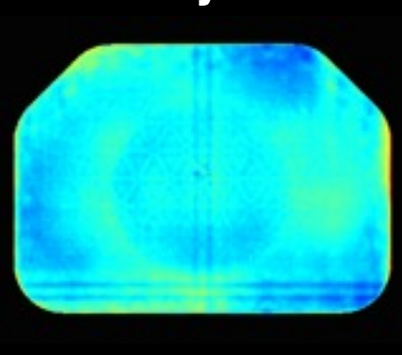
Aft optics and Aft optics bench complete

Fine Steering Mirror

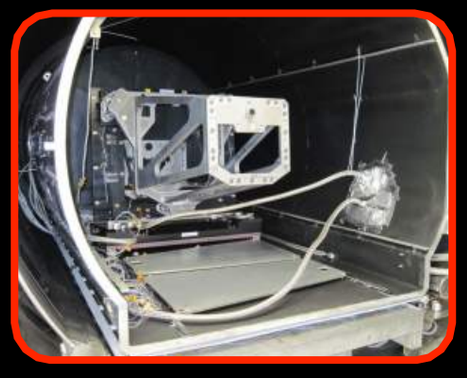
Tertiary Mirror



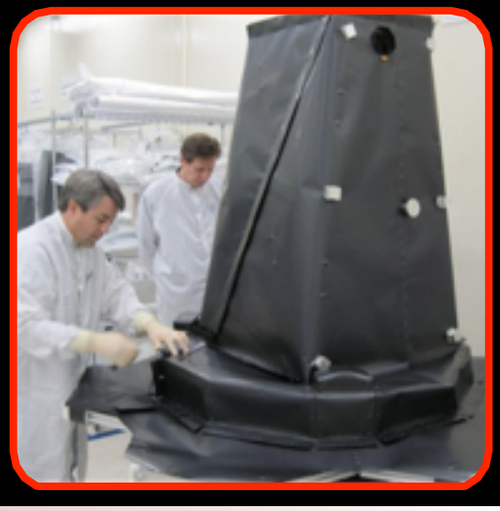
3.8 nm RMS SFE



4.3 nm RMS SFE

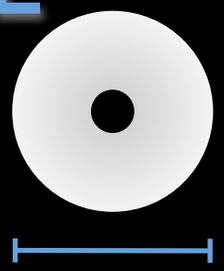


AOS bench in cryo-test



JWST and its Precursors

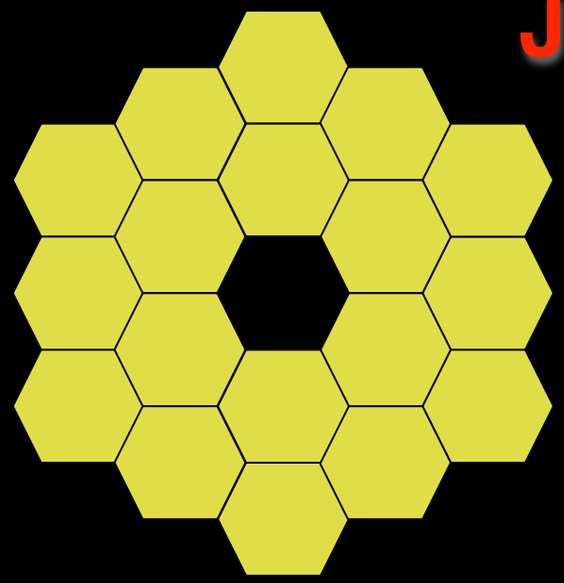
HUBBLE



2.4-meter
T ~ 270 K

123” x 136”
$\lambda/D_{1.6\mu m}$~ 0.14”

JWST



6.5-meter
T ~ 40 K

132” x 164”
$\lambda/D_{2\mu m}$~ 0.06”

114” x 84”
$\lambda/D_{20\mu m}$~ 0.64”

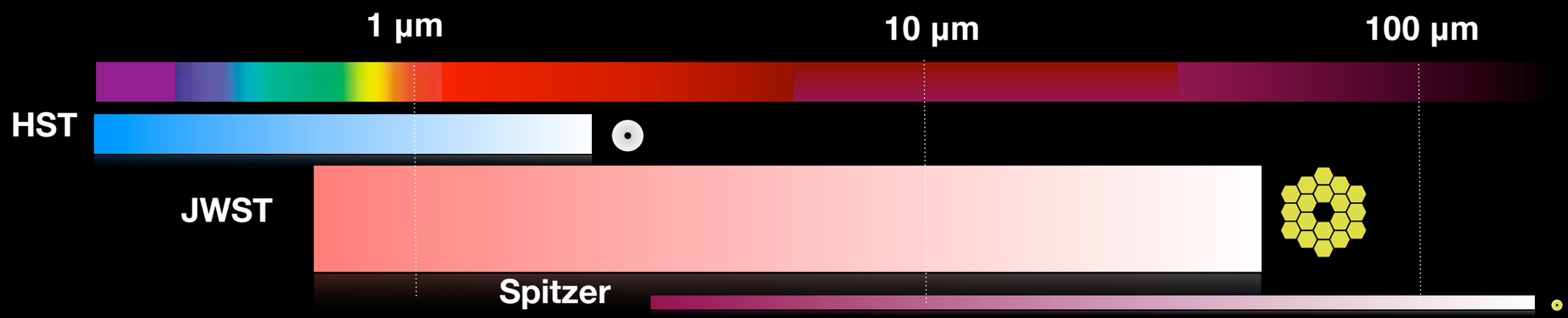
SPITZER

0.8-meter
T ~ 5.5 K

312” x 312”
$\lambda/D_{5.6\mu m}$~ 2.22”

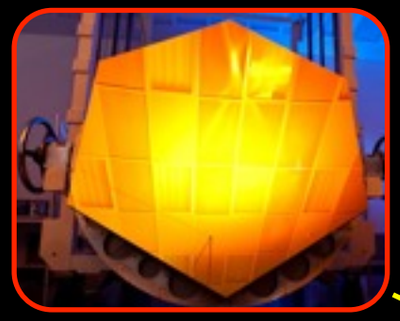
324” x 324”
$\lambda/D_{24\mu m}$~ 6.2”

Wavelength Coverage



JWST Is Under Construction

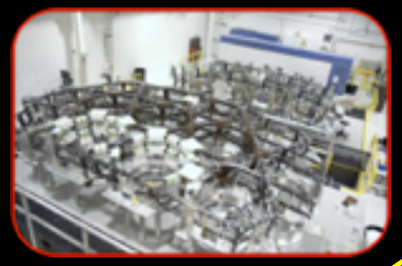
Primary Mirror Segment

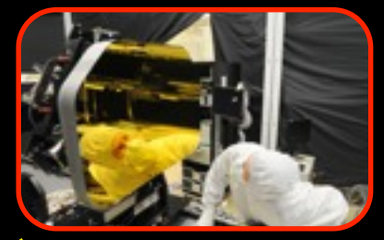


Mirror Electronics

Aft Optics System

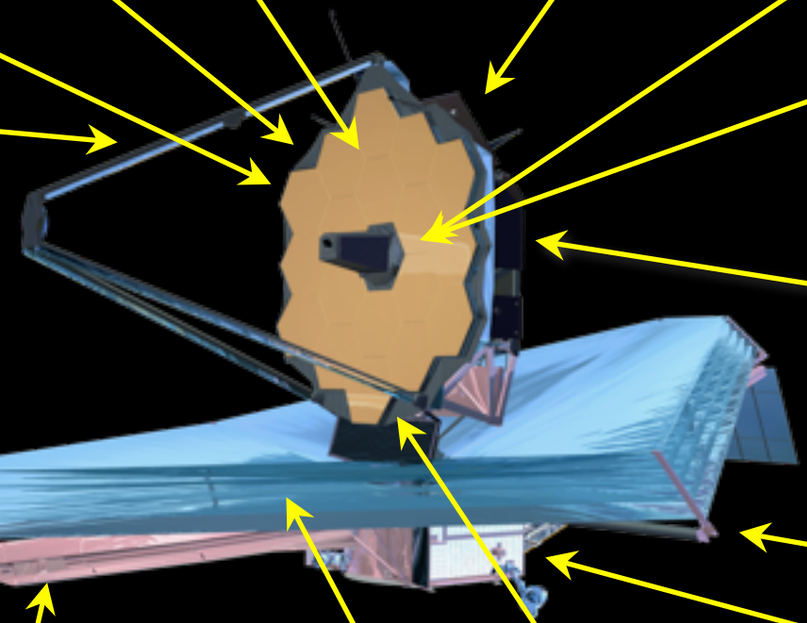
PM Flight Backplane

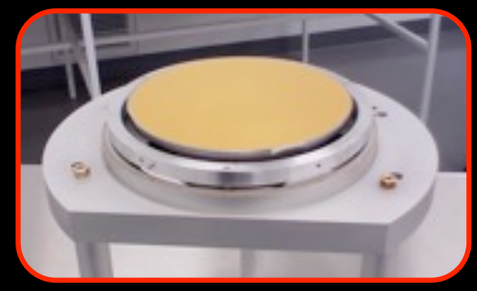




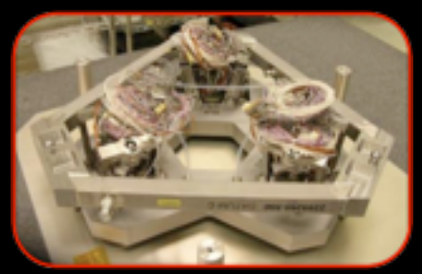
Tertiary Mirror

SMSS Pathfinder Strut





Fine Steering Mirror



SM Hexapod

ISIM Flight Bench

SM Segment

Membrane Mgmt

Pathfinder Membrane

DTA tube

IC&DH unit ETU

Mid-boom Test