

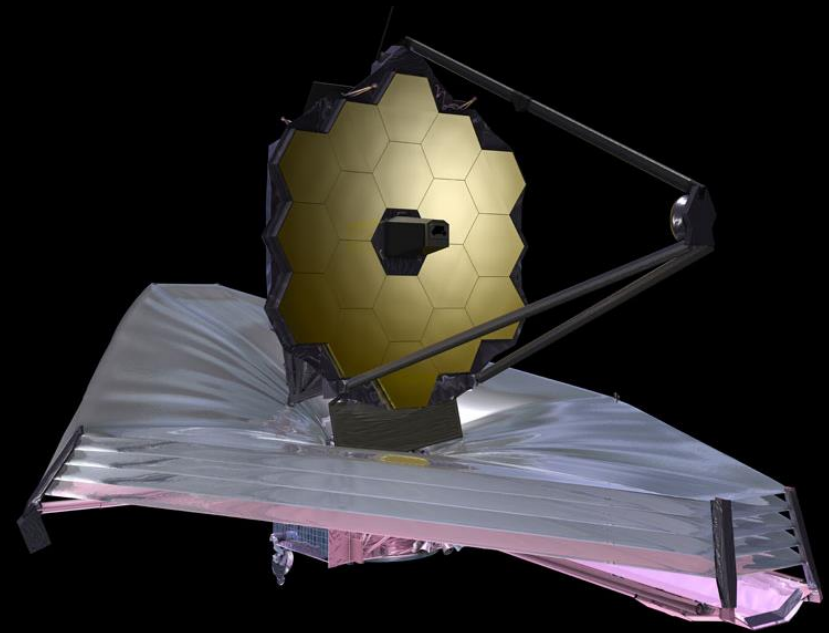


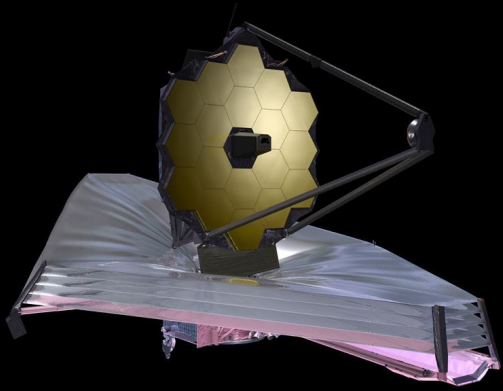
Commissioning the James Webb Space Telescope

Joseph M. Howard, NASA

Electronic Imaging 2023

January 17, 2023





Thank you!

***To the EI organizers for the invitation to speak,
To my family for supporting me through 20 years of
many trips for JWST, and for
all of **you** for coming to listen !***

James Webb Space Telescope (JWST) specifications

Entrance Pupil Diameter: 6.5 m, 18 segments

Field of View: 20x10 arcmin

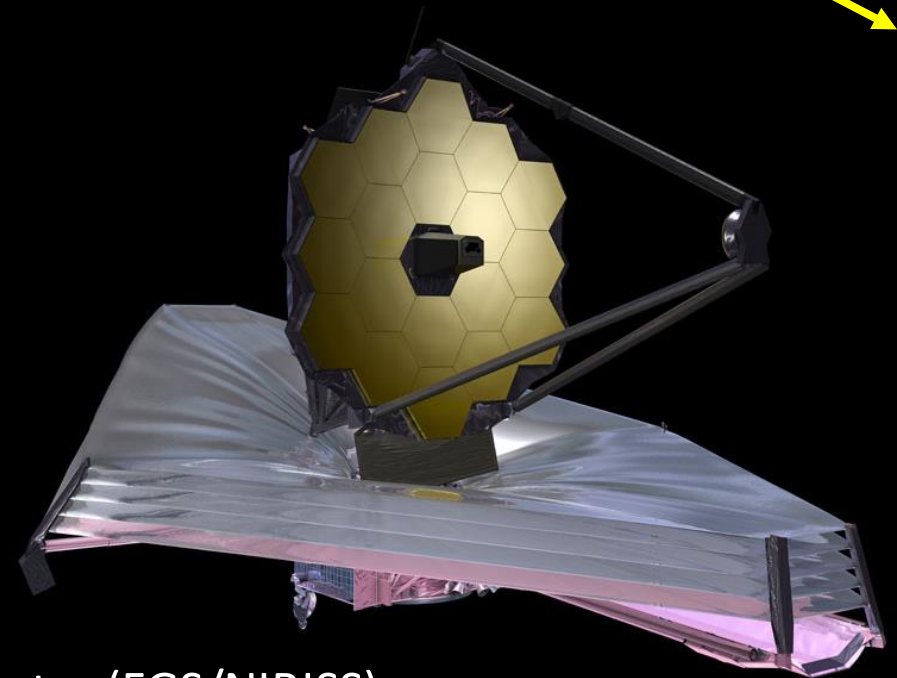
F/#: 20

Wavelength: 0.6 – 28 μm

Design Form: 3-mirror Anastigmat (TMA)

Four primary instruments/cameras:

1. Near Infra-Red Camera (NIRCam)
2. Mid IR Camera (MIRI)
3. Fine guidance sensor and imaging slitless spectrometer (FGS/NIRISS)
4. Near Infra-Red Spectrometer (NIRSpec)

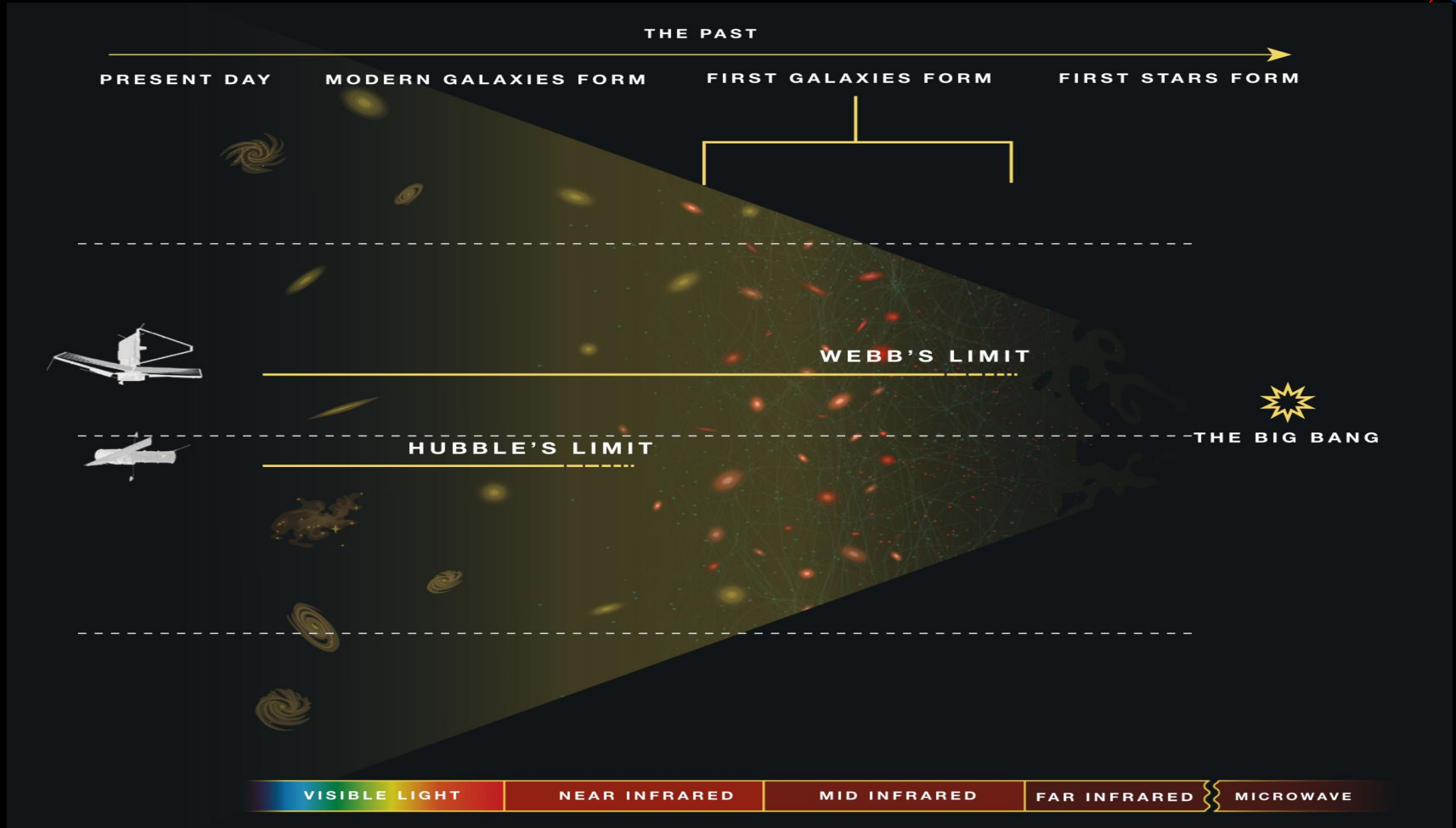


*An International
Collaboration*



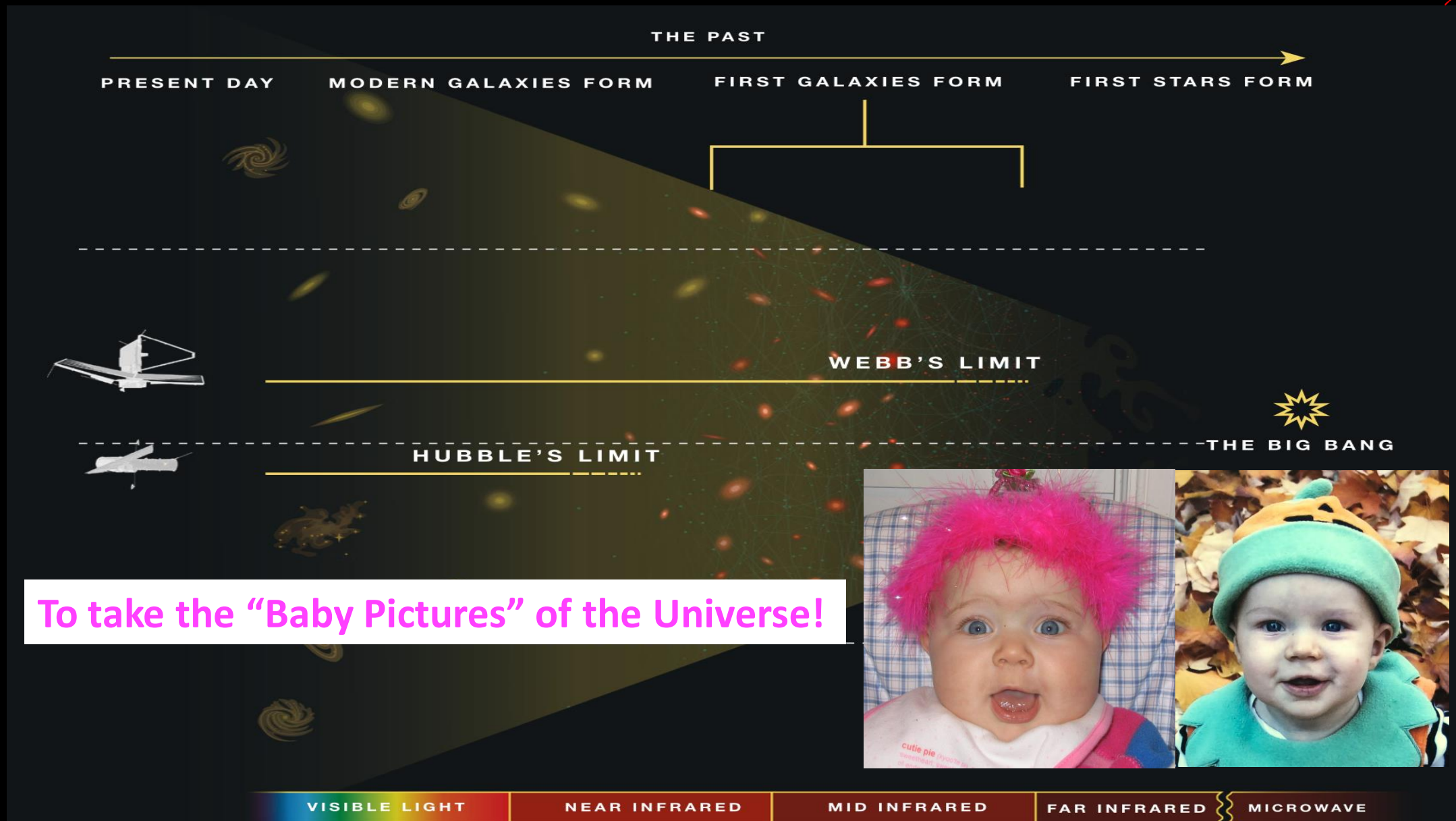


JWST Science is in the infrared (IR), to look into the past...





JWST Science is in the infrared (IR), to look into the past...



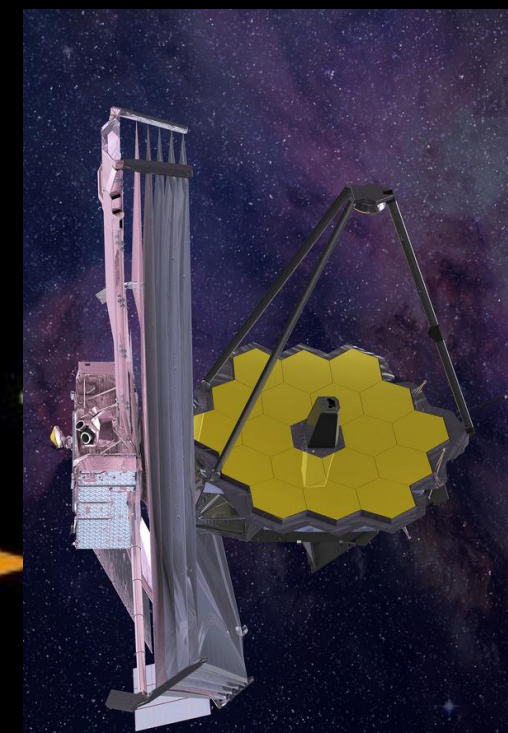
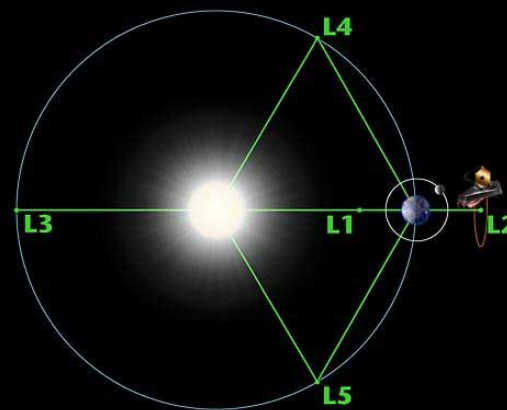
To take the “Baby Pictures” of the Universe!



JWST must be very cold to see infrared: 30K

Recipe on how to get **cold**:

1. Get far away from Earth (Sun-Earth L2 point)
2. Hide in the shade



JWST temperatures range hundreds of degrees!

Primary Mirror Segments:
30's to 50's K

Instruments:
Near-IR 35-42K
Mid-IR: 6K (cryocooler)

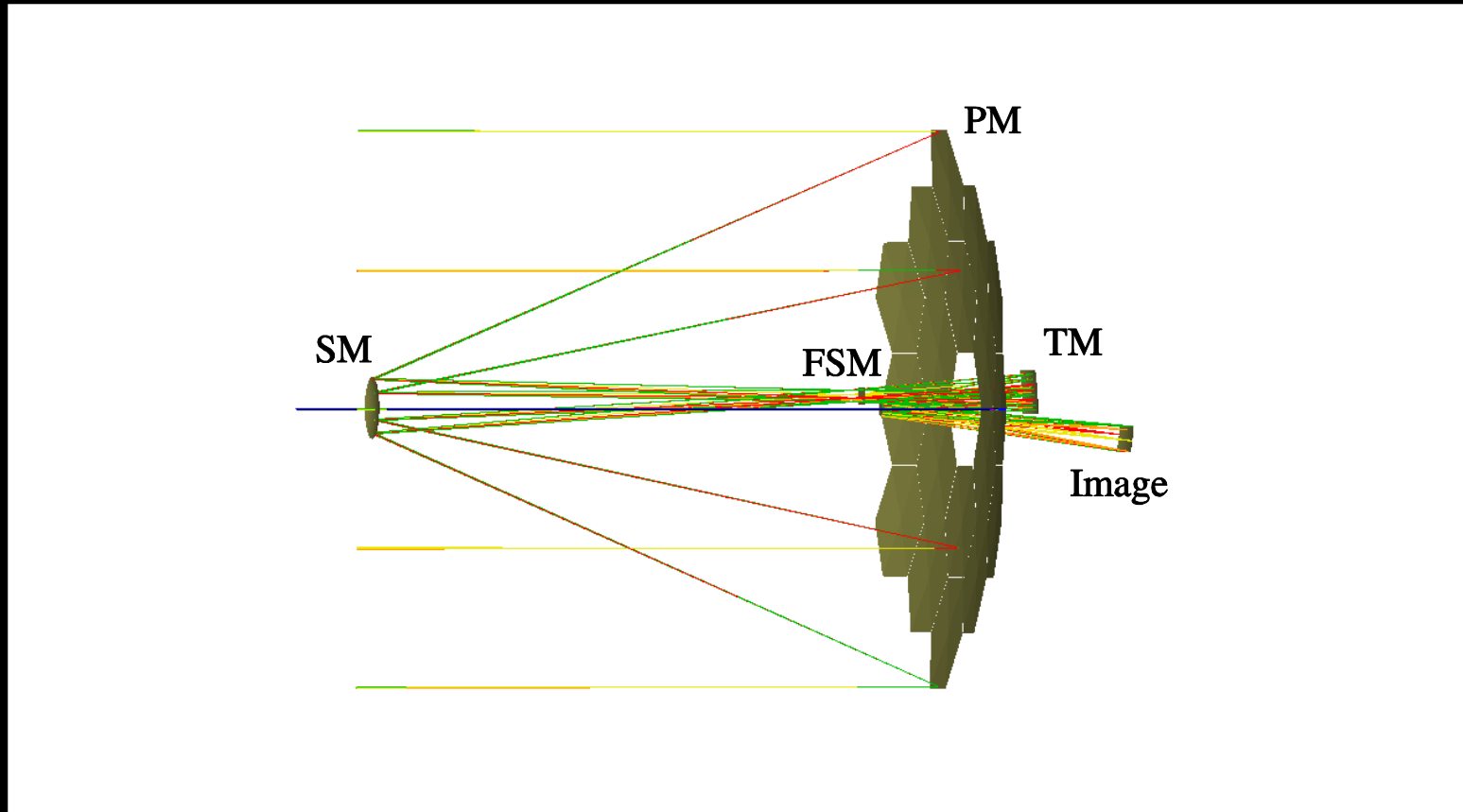
Instrument
electronics: 278K

Sunshield Layer 5: 70-85K

0 degrees Kelvin "absolute zero"
= -459.7 degrees Fahrenheit
= -273.15 degrees Celsius

Spacecraft: >300K

JWST is a 3-mirror telescope design, “TMA”



- 3 mirrors corrects 3 aberrations: **Spherical, Coma and Astigmatism**
- A 4th mirror is a FLAT fold mirror for tip/tilt pointing control
- Field of view performance is limited by higher-order blur terms

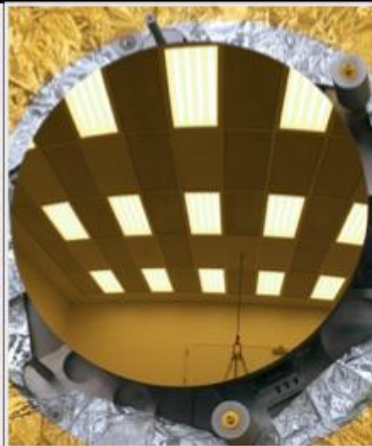
JWST mirrors



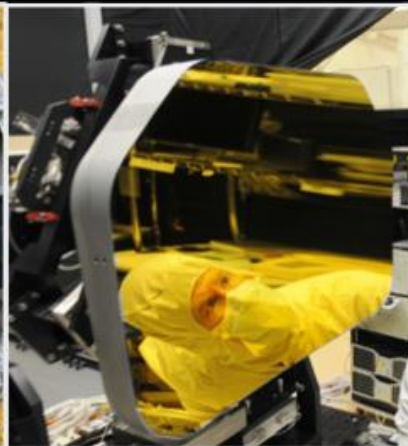
Primary Mirror Segment



Secondary Mirror



Tertiary Mirror

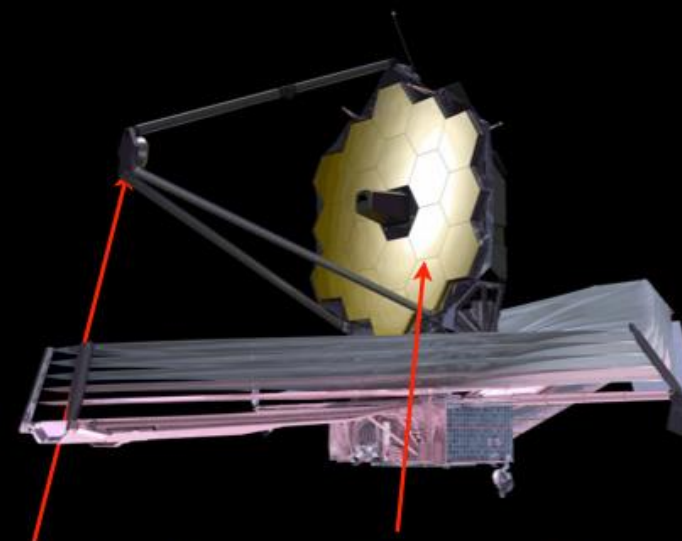
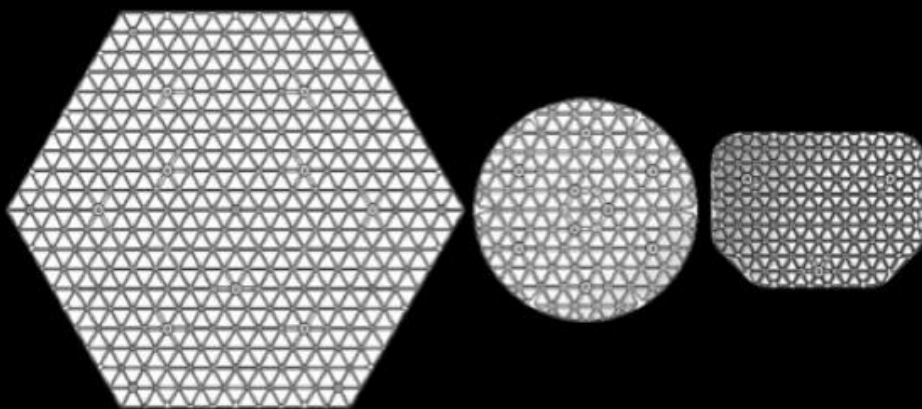


Fine Steering Mirror



Rear side view of mirrors showing relative size

1.3 m



Secondary Mirror

18 segment Primary Mirror

2017: JWST construction at NASA Goddard



John Mather, Nobel Laureate, takes a Billion Dollar "Selfie"



2021: Final Deployment Testing in Los Angeles



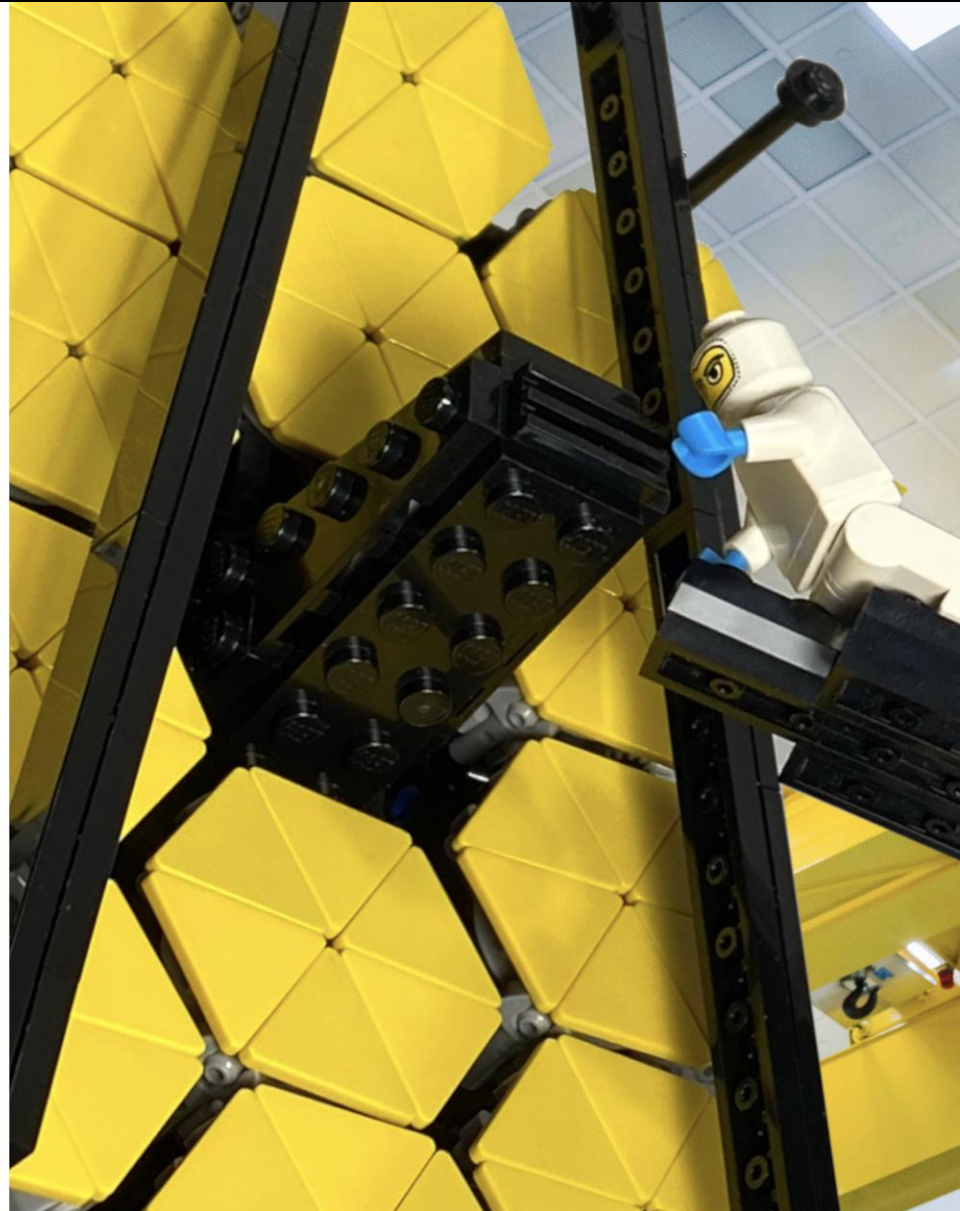
JWST “lens cover”: Remove before flight !!



Done!!! (by Larkin Carey, Ball Aerospace)



This act immortalized in the world of Legos...



December 25, 2021, ESA launch from French Guiana





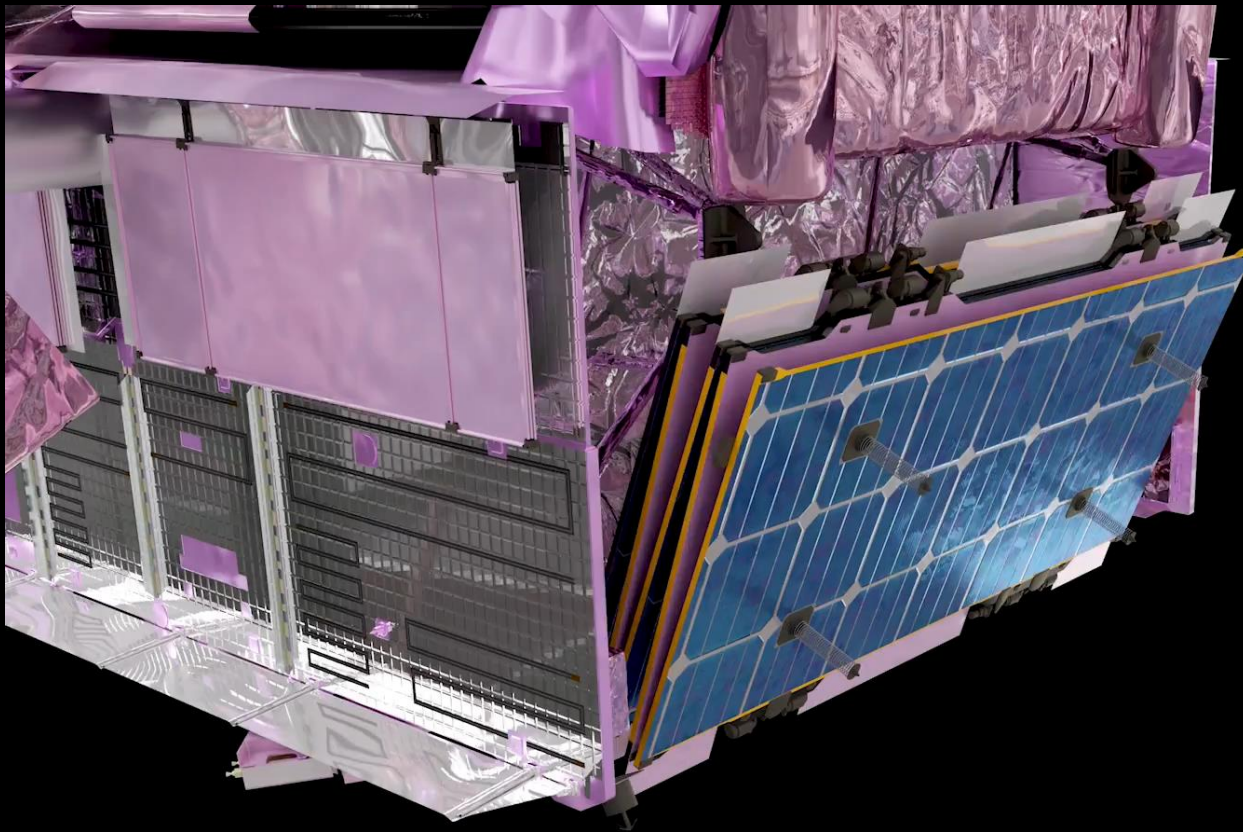




50 major deployments – all successful

- 178 release mechanisms – all worked
- Solar panel – deployed; providing nominal power
- High-gain antenna – deployed, turned on, and in use

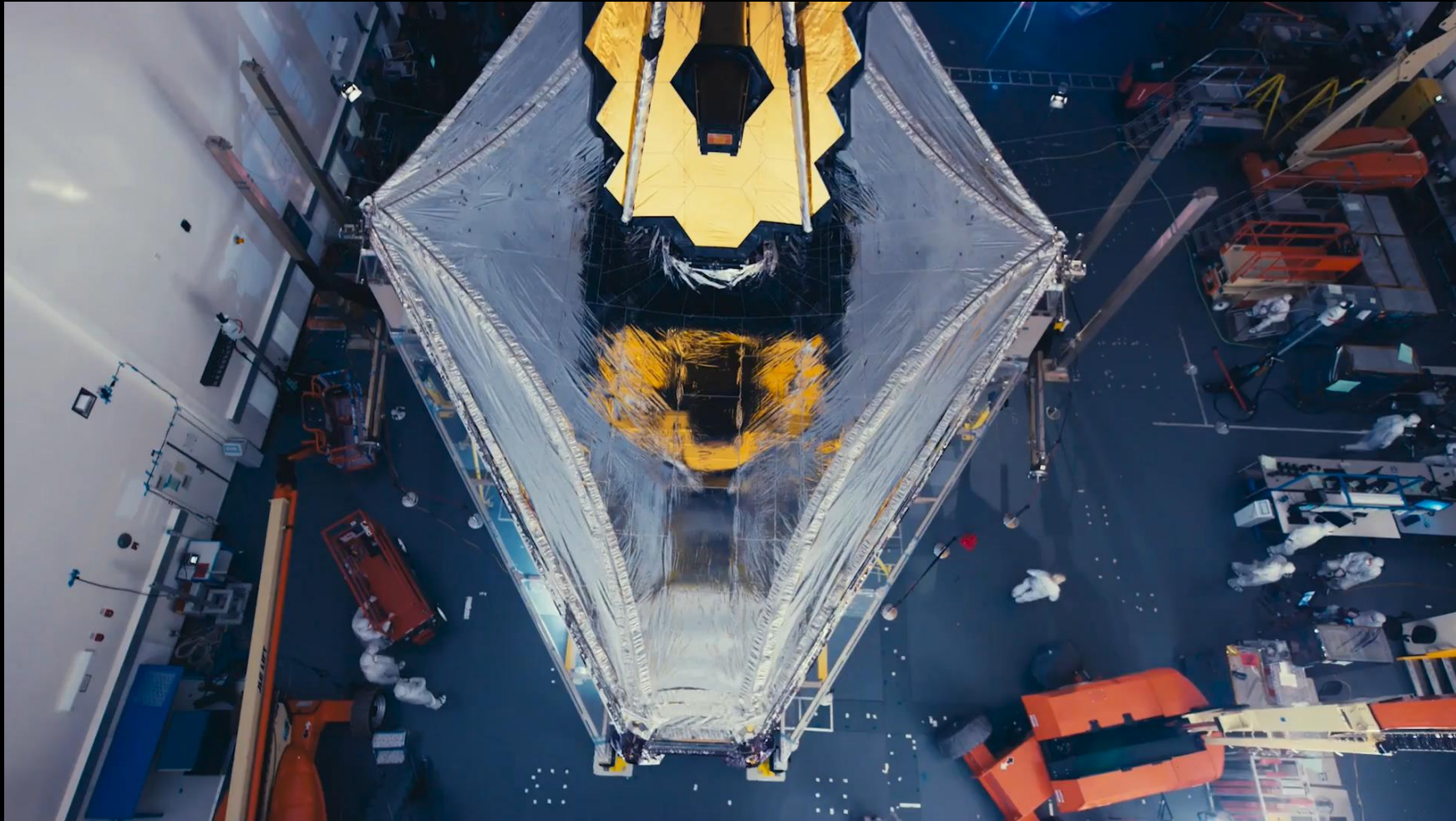
Mid-course corrections and station-keeping – all successful



Sunshield deployment

- 140 release mechanisms
- 70 hinge assemblies
- 8 deployment motors
- 400 pulleys
- 90 cables, totaling 400 meters

The sunshield was successfully deployed!

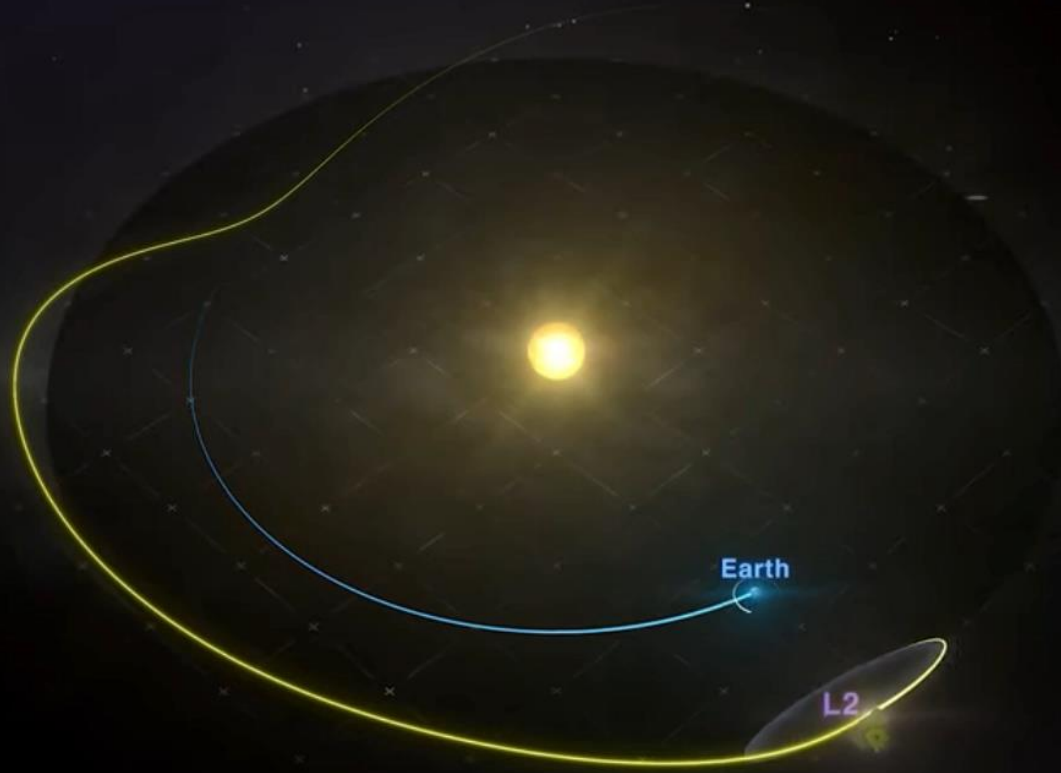


The Telescope:

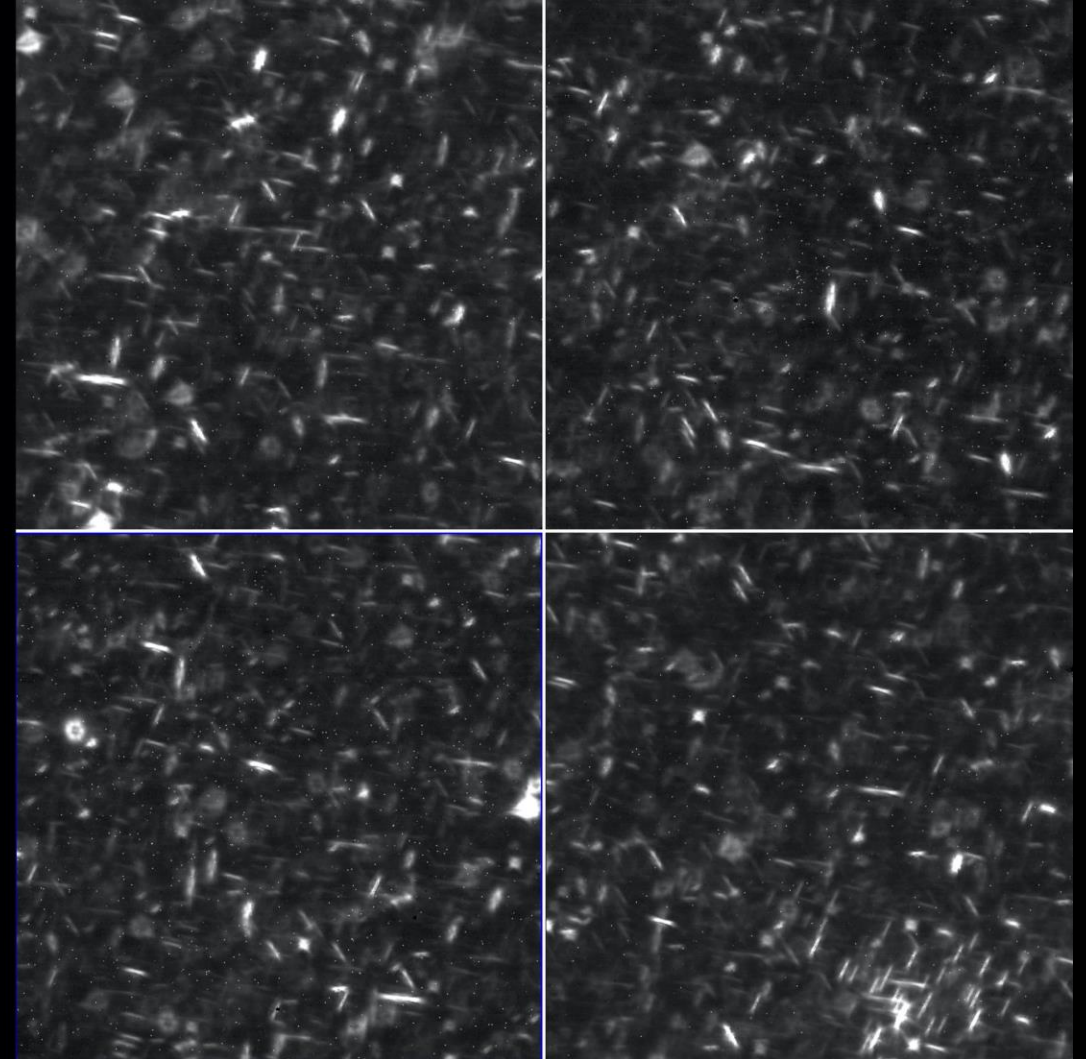
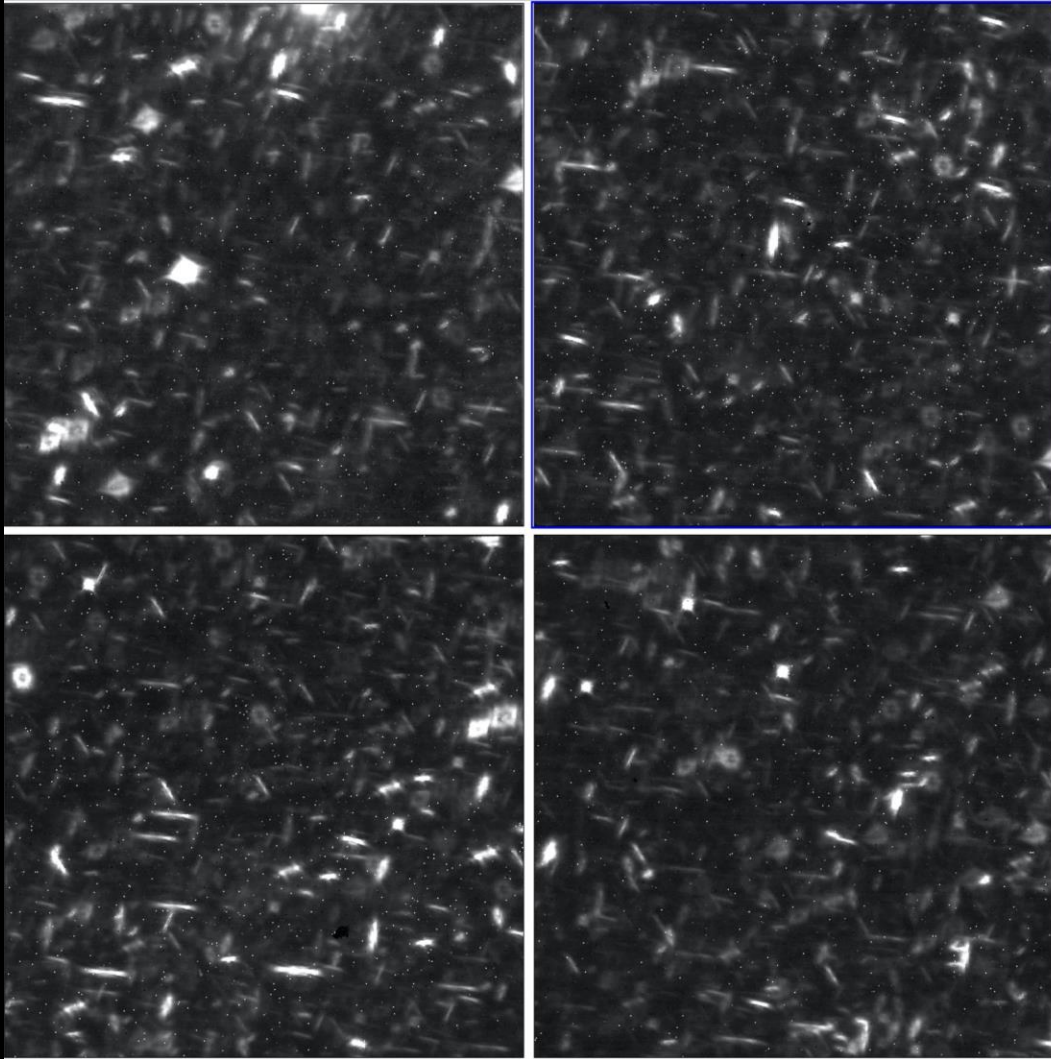
- Secondary Mirror
- Instrument Radiator
- Primary Mirror Wings
- Secondary & 18 Primary Mirror Segments



Where is Webb orbiting?

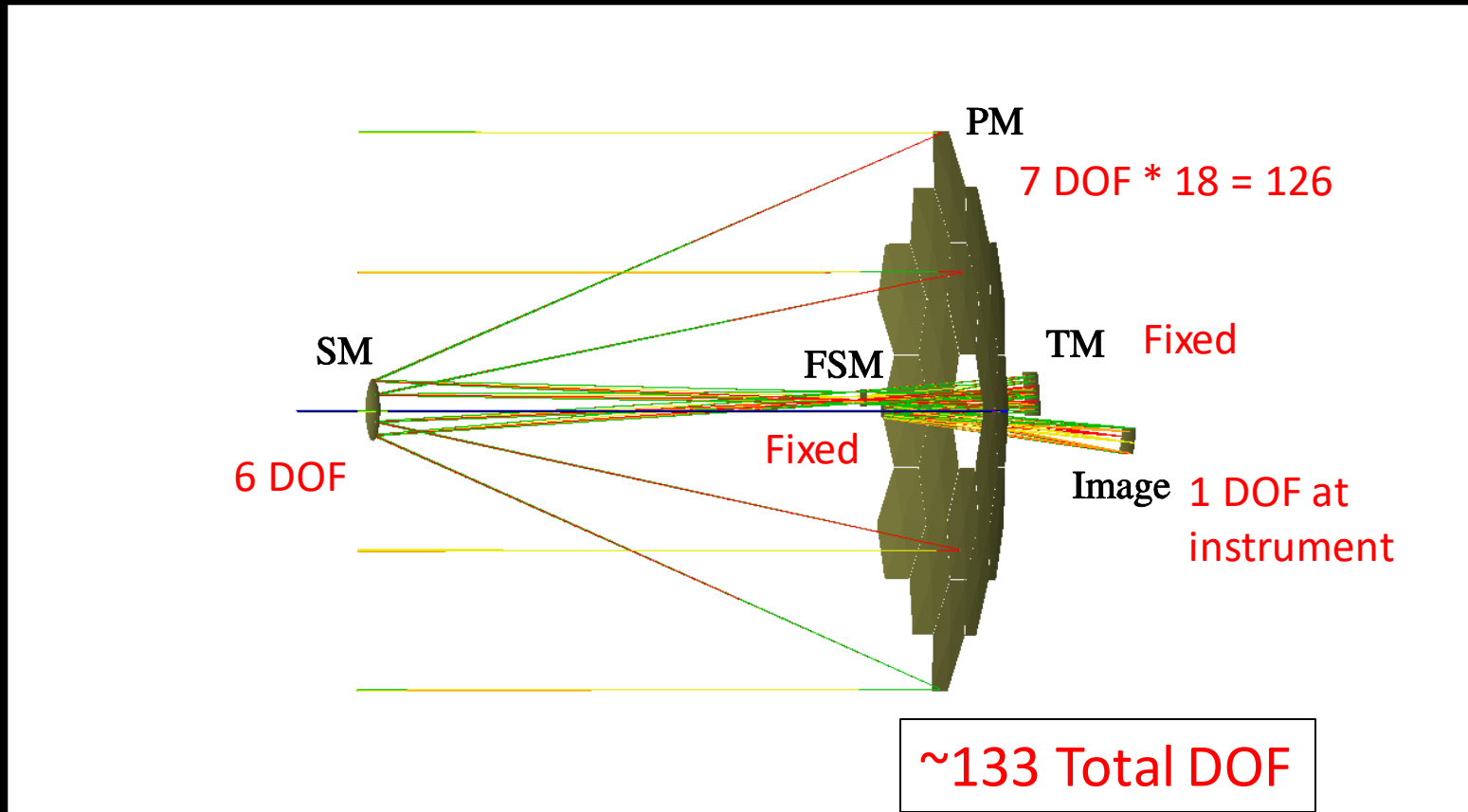


JWST First Test Image (NIRCam): Large Magellanic Cloud, Feb 2nd, 2022



NIRCam works! Now it is time to align the telescope!

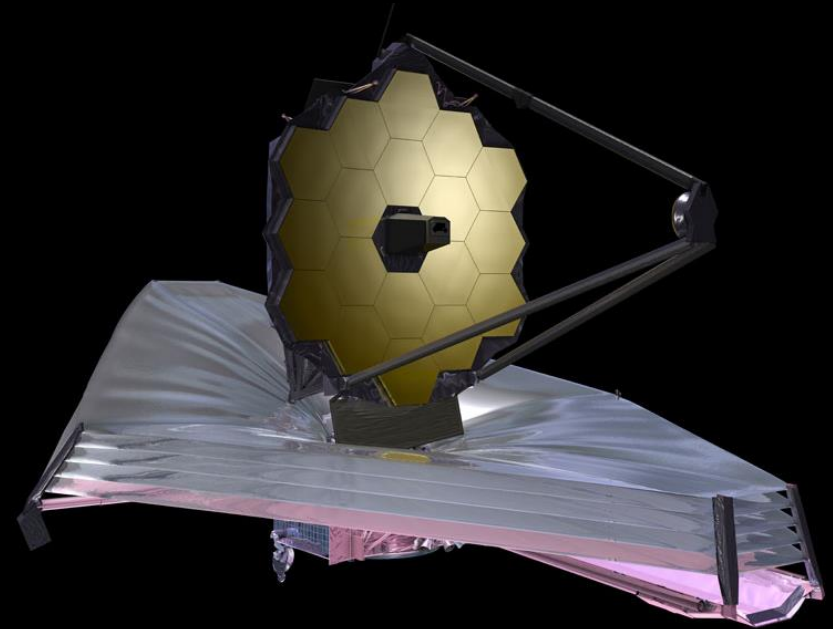
JWST Alignment degrees of freedom (DOF)



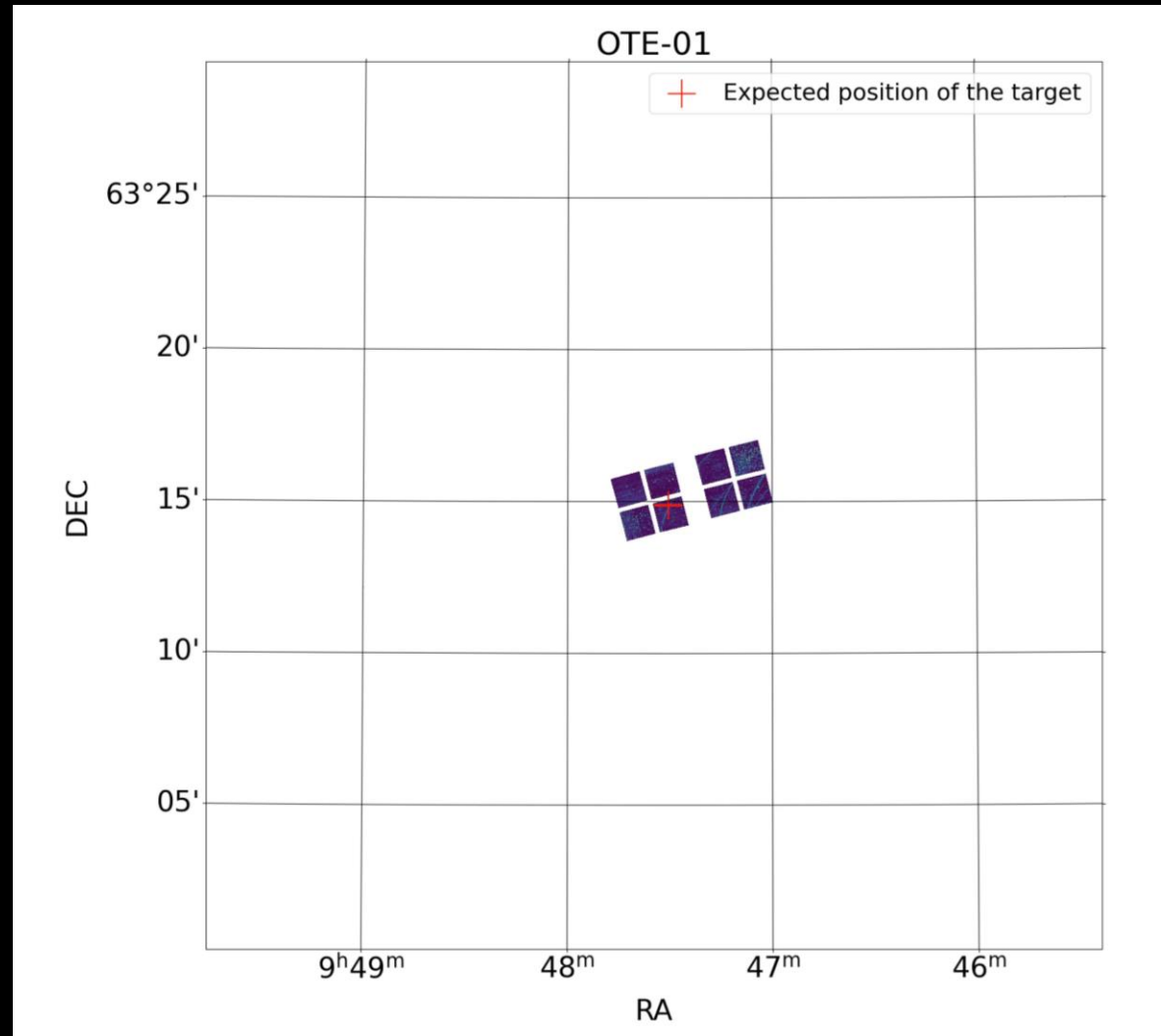
- Primary mirror segment: 6 DOF + radius
- Secondary mirror: 6 DOF
- Fast Steering Mirror: dynamic tip/tilt control for pointing stability
- Each instrument (except MIRI): Focus control

JWST Alignment procedure

1. Segment Image Identification
2. Segment Alignment
3. Image Stacking
4. Coarse Phasing
5. Fine Phasing
6. Telescope Alignment Over Instrument Fields of View
7. Iterate Alignment for Final Correction



1. Point to an isolated star to find segment images



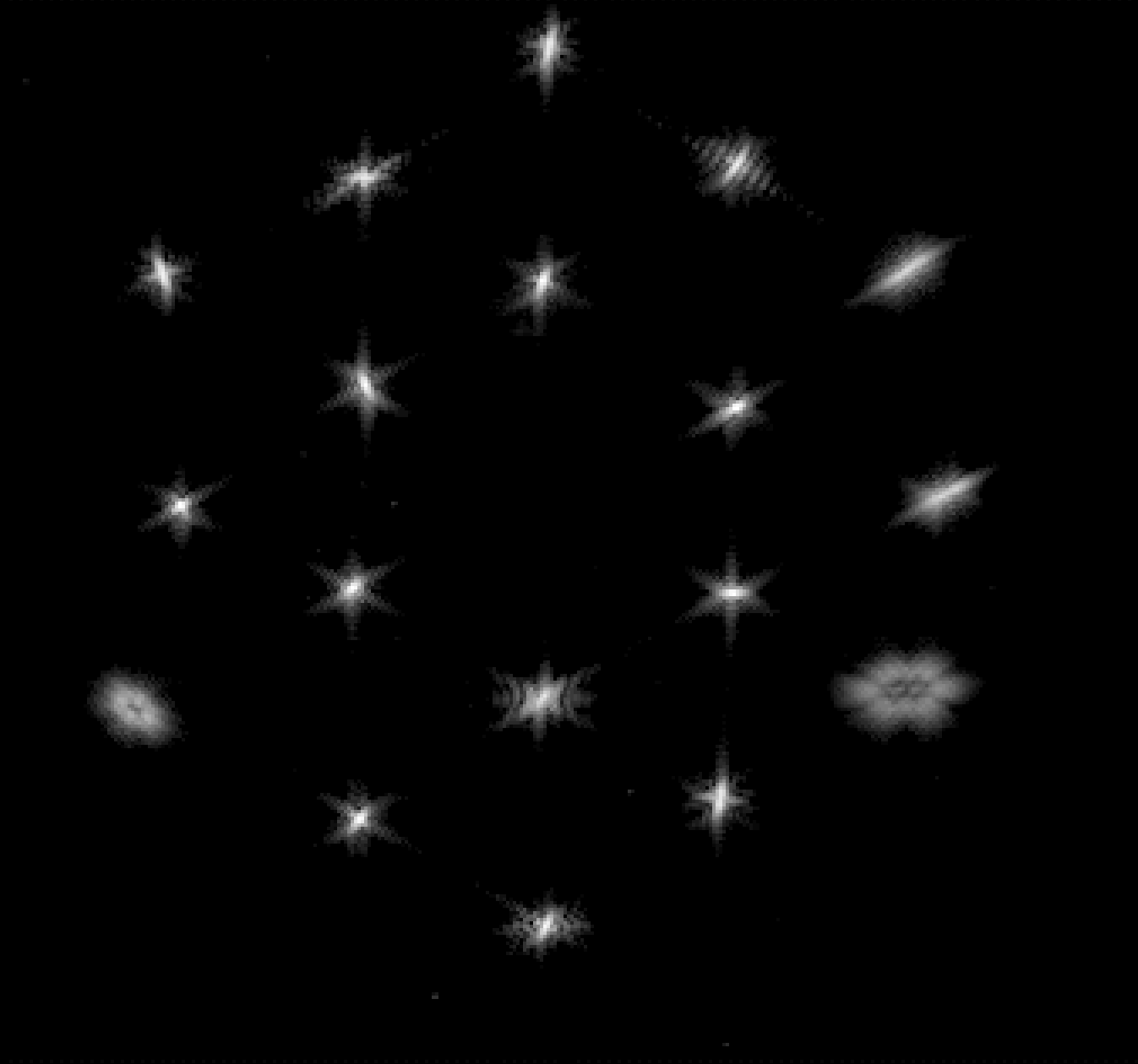
1

INITIAL ALIGNMENT MOSAIC





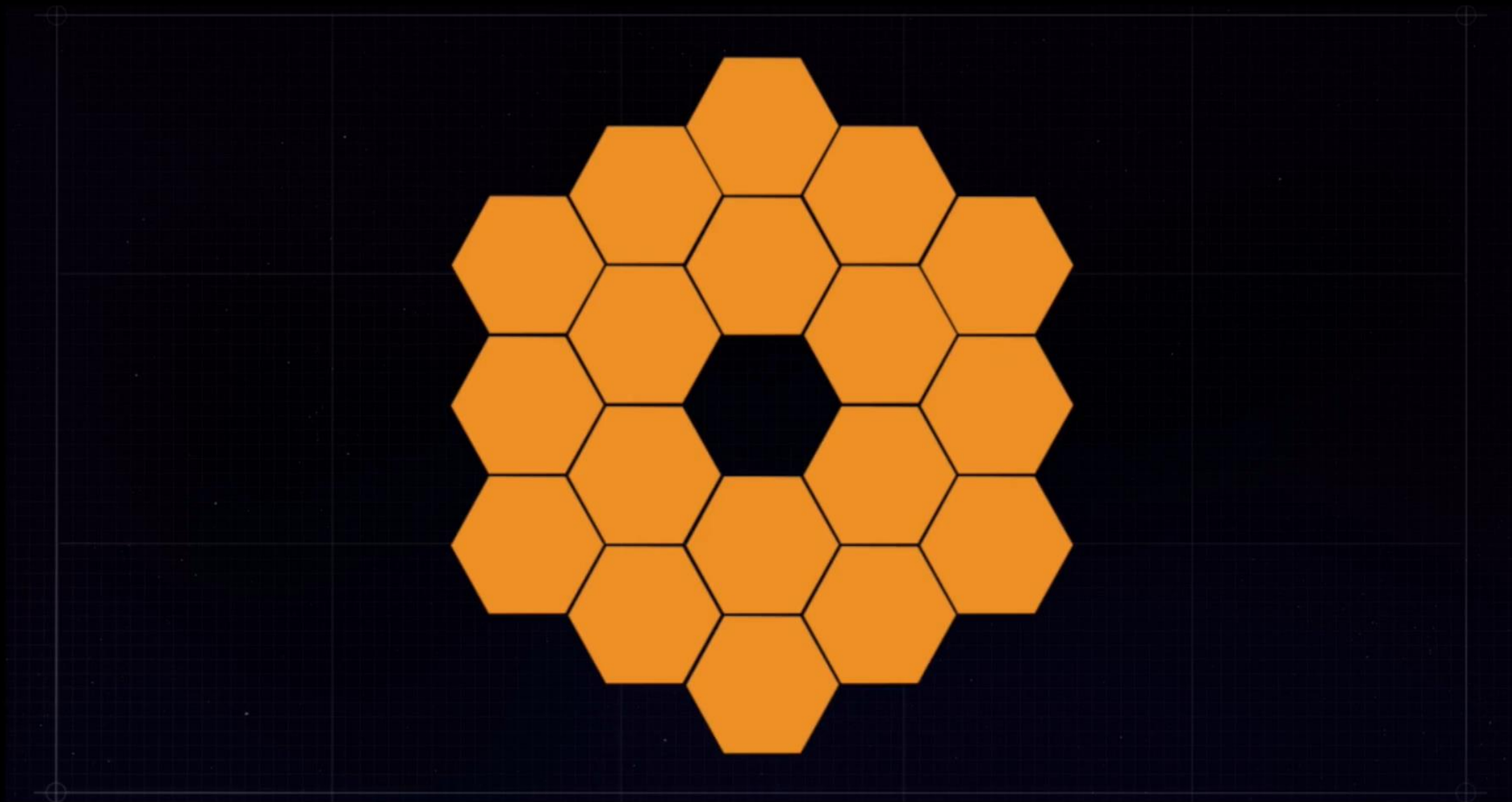
2 Segment Alignment



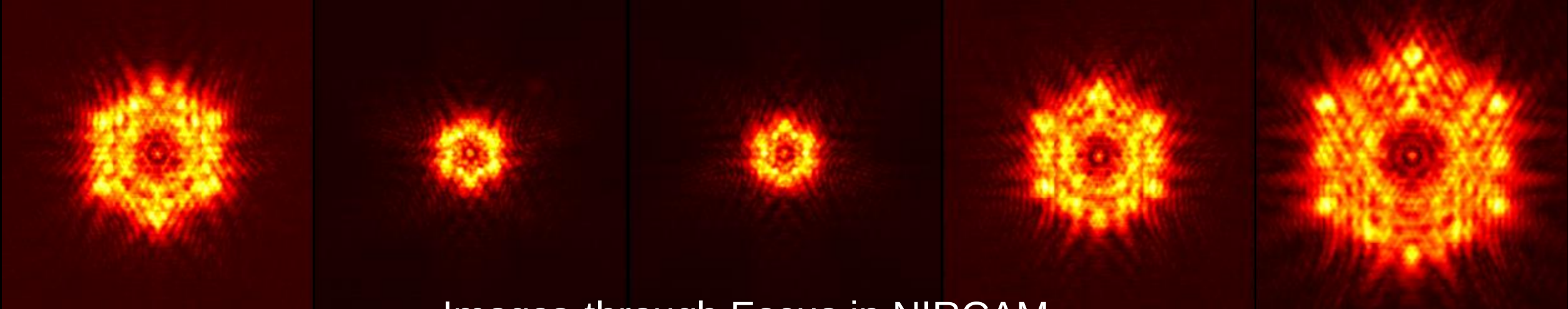
COMPLETED IMAGE STACKING



4 Coarse Phasing

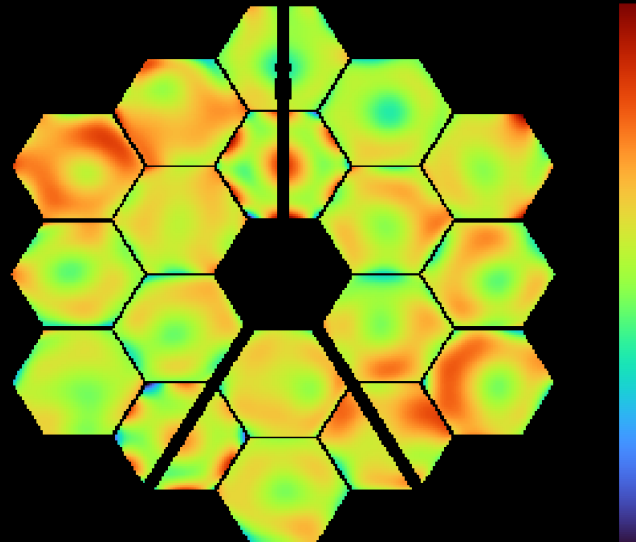


Fine Phasing: NIRCAM Weak Lens Data Phase Retrieval

 -8λ -4λ $+4\lambda$ $+8\lambda$ $+12\lambda$ 

Images through Focus in NIRCAM

Exit Pupil Phase Map





2-5 movie

Image Array

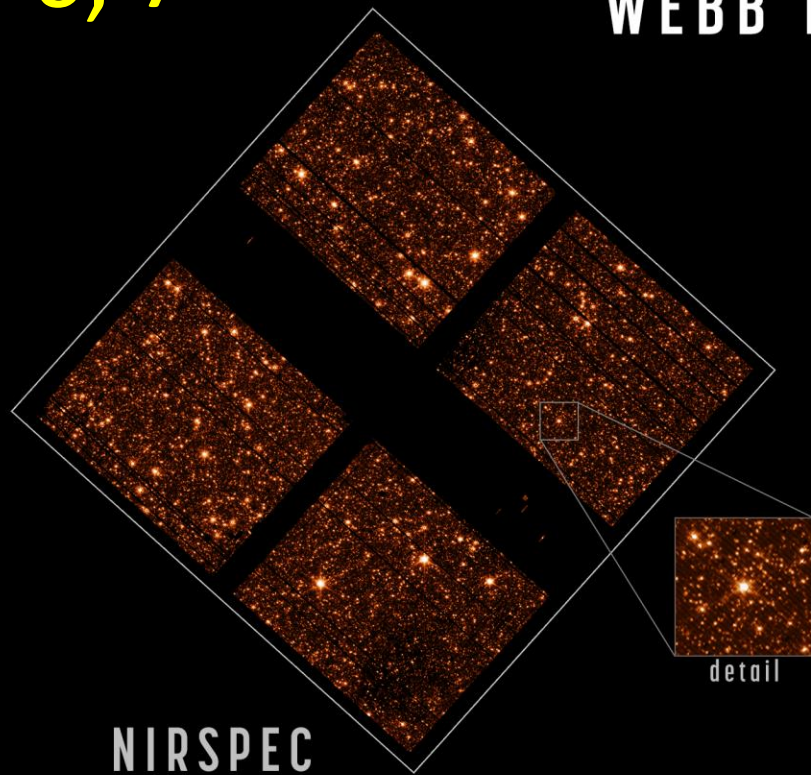


../OTE-06/jw01140001001_02101_00001_nrca3_cal.fits

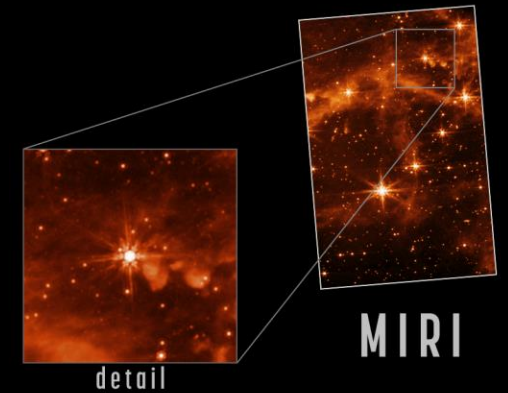
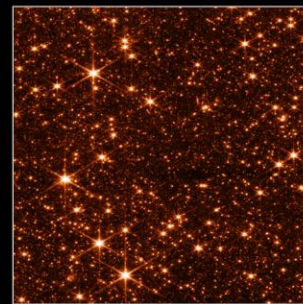
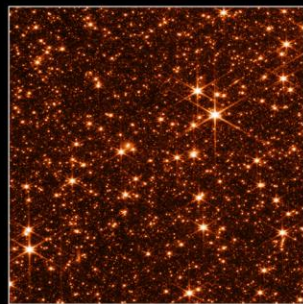


6, 7

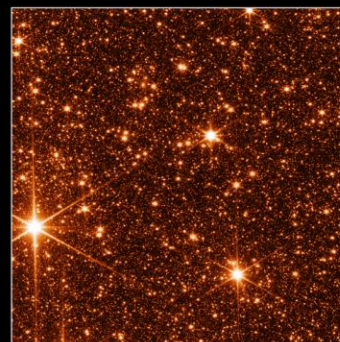
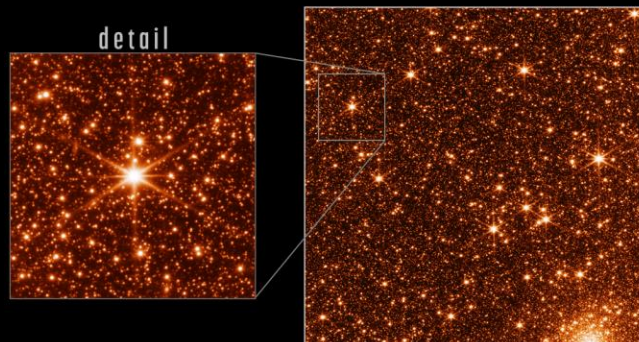
WEBB TELESCOPE IMAGE SHARPNESS CHECK



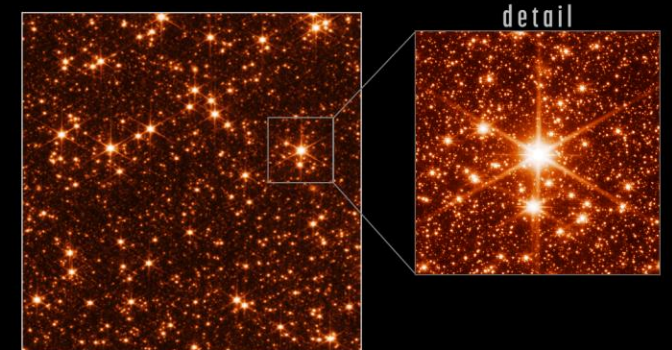
NIRCAM

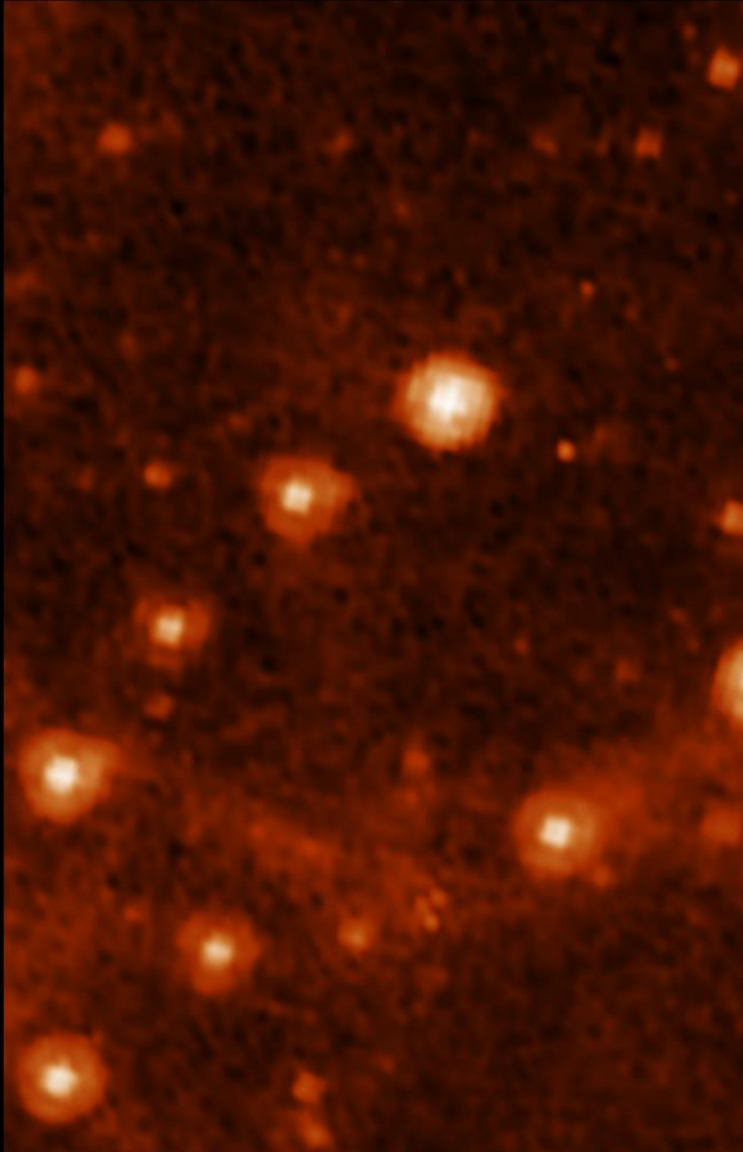


FINE GUIDANCE SENSOR

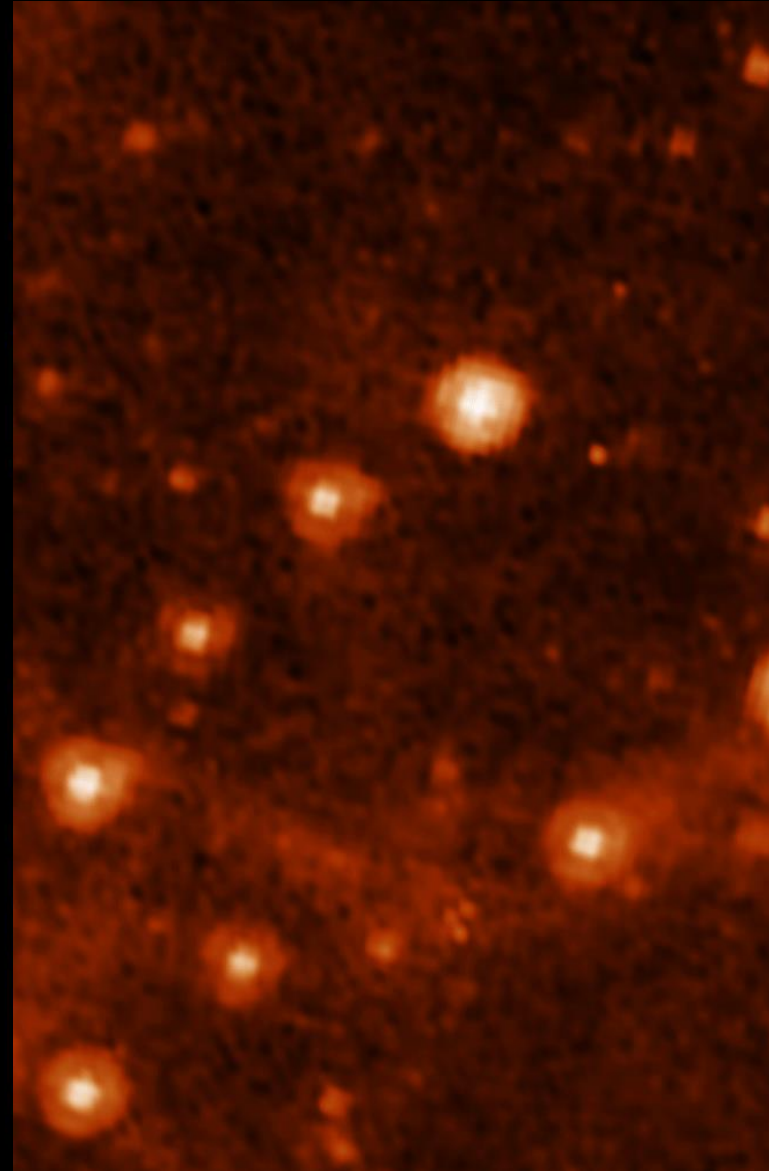


NIRISS



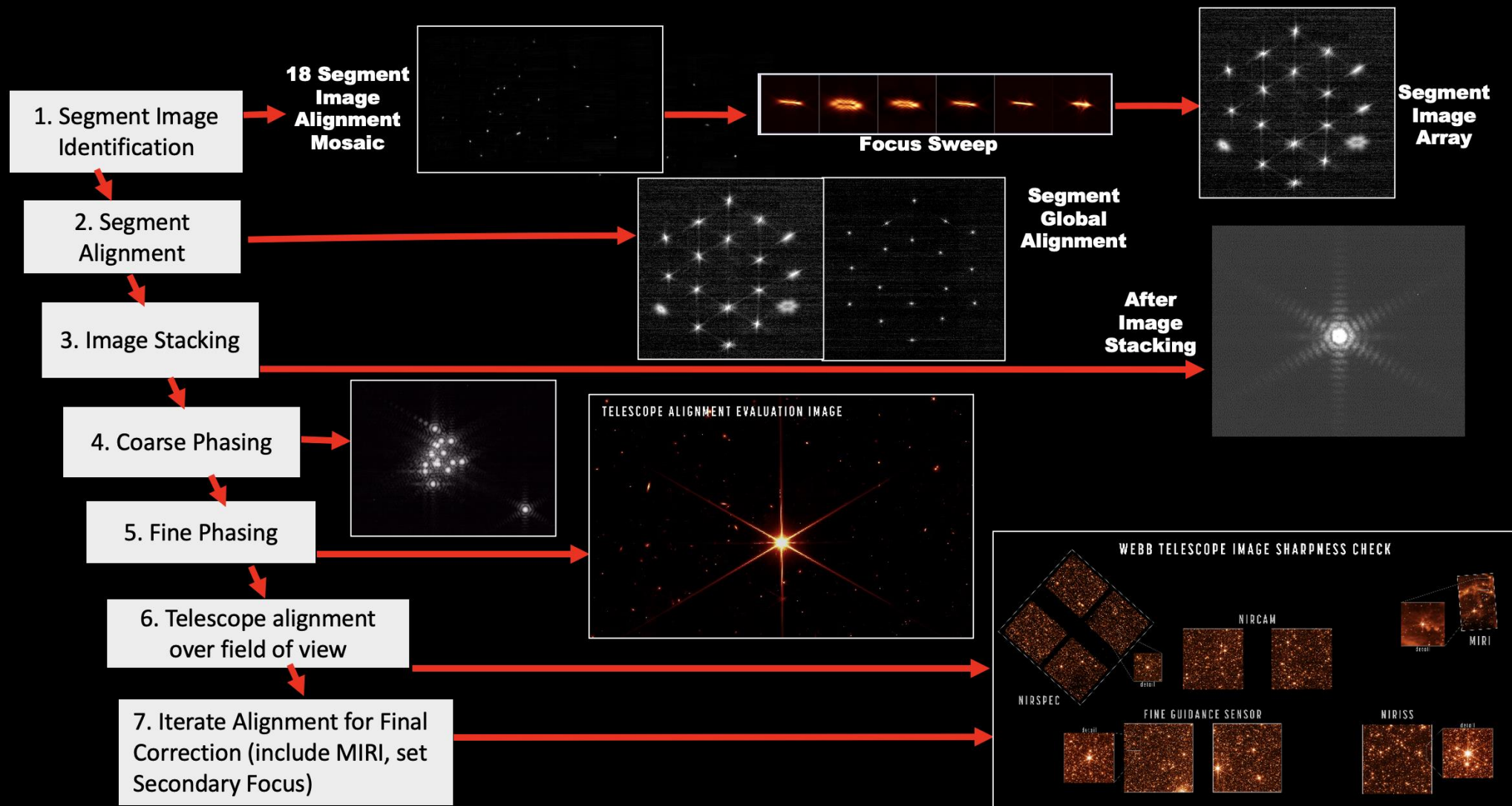


SPITZER IRAC 8.0 μ



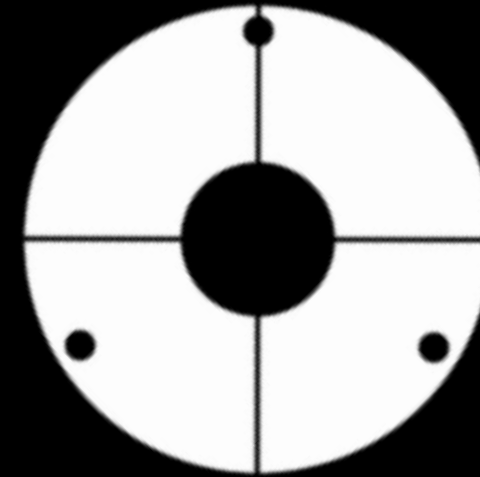
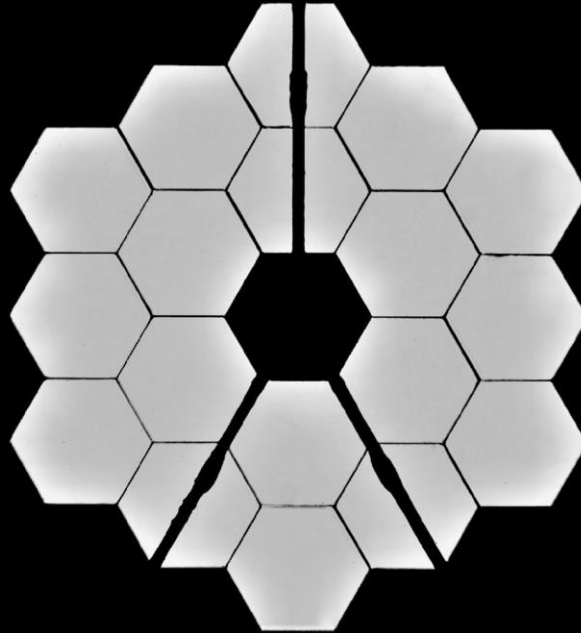
WEBB MIRI 7.7 μ

Alignment Summary: 3 months in one slide



Diffraction : WEBB vs Hubble

Pupil Image:

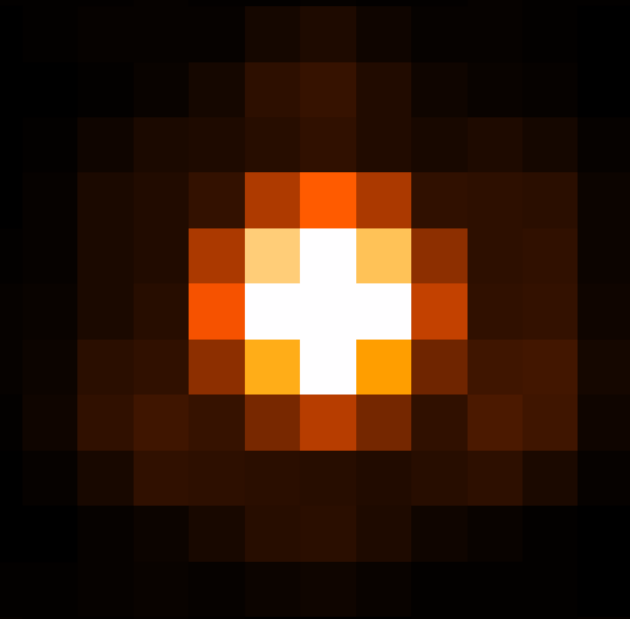
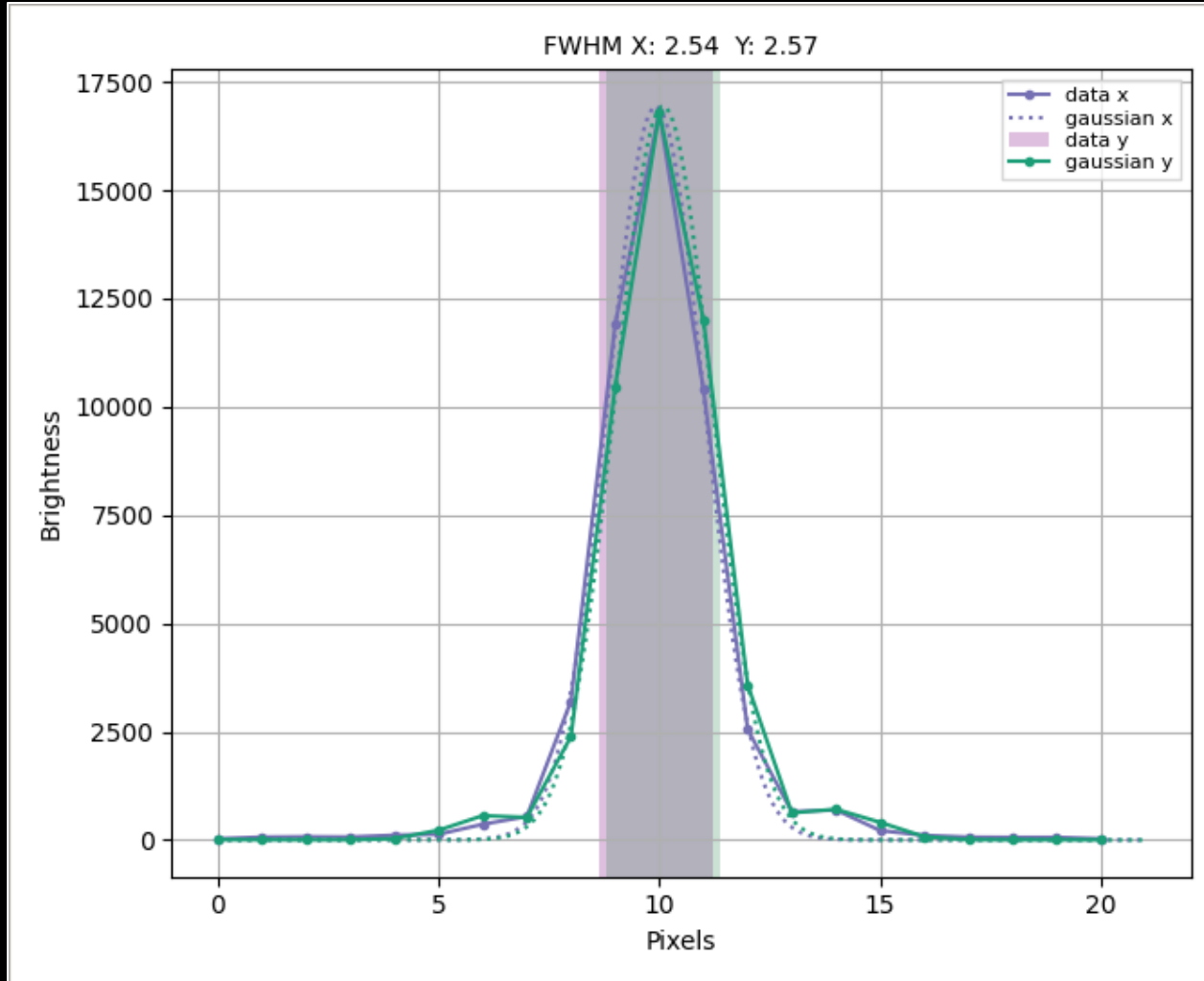


Star images

“point spread function”



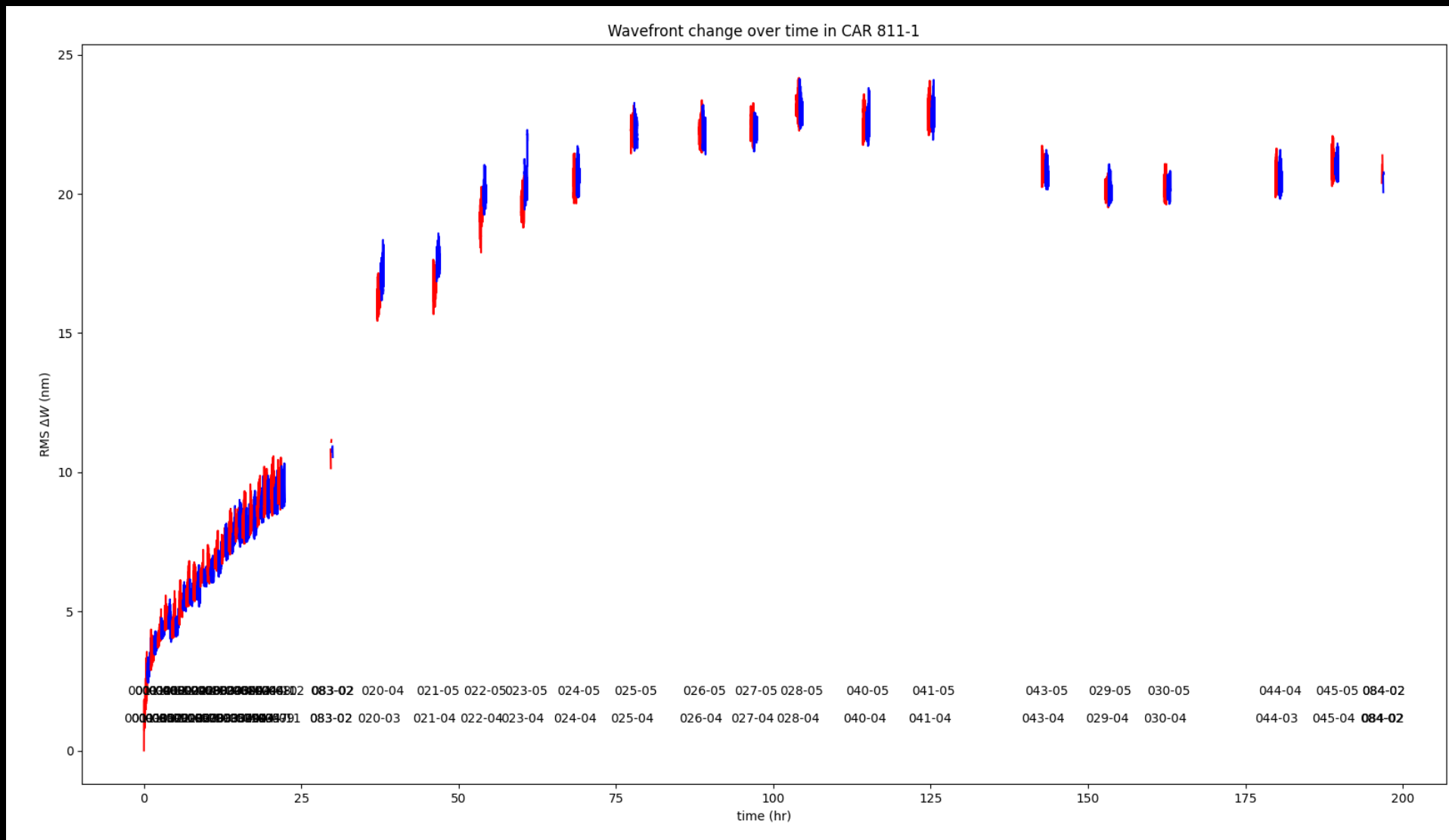
Webb Image Quality Assessment: Diff Limited!



Star is 77 milli-arcseconds wide
NIRCam, 2.12 microns wavelength



Stability check over 8 days: Fantastic!



JWST Engineers... time to celebrate!



Webb's First Science Images





Stephan's
Quintet

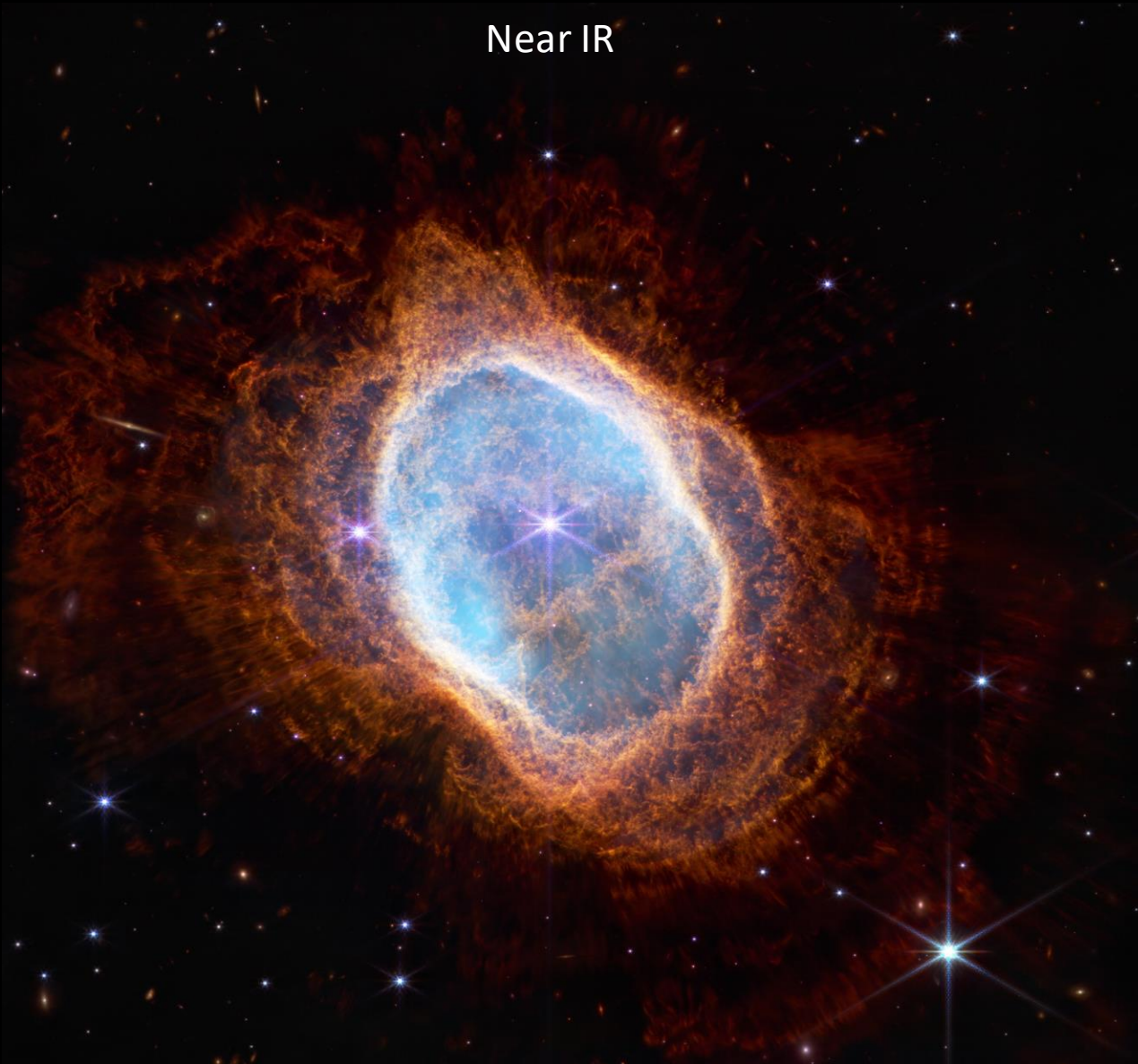


Deep Field
SMACS 0723

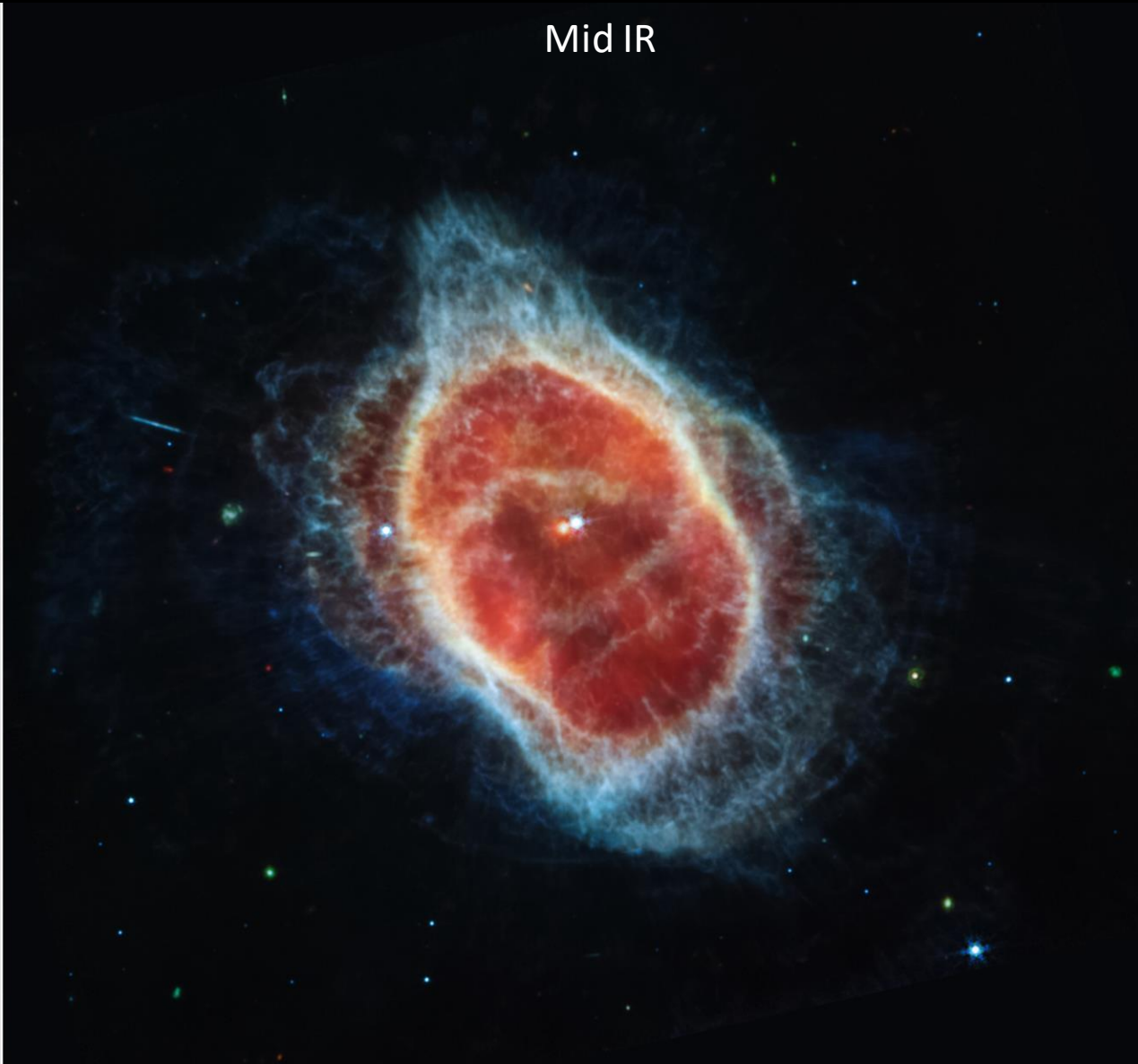
12.5 hours

Southern Ring Nebula

Near IR



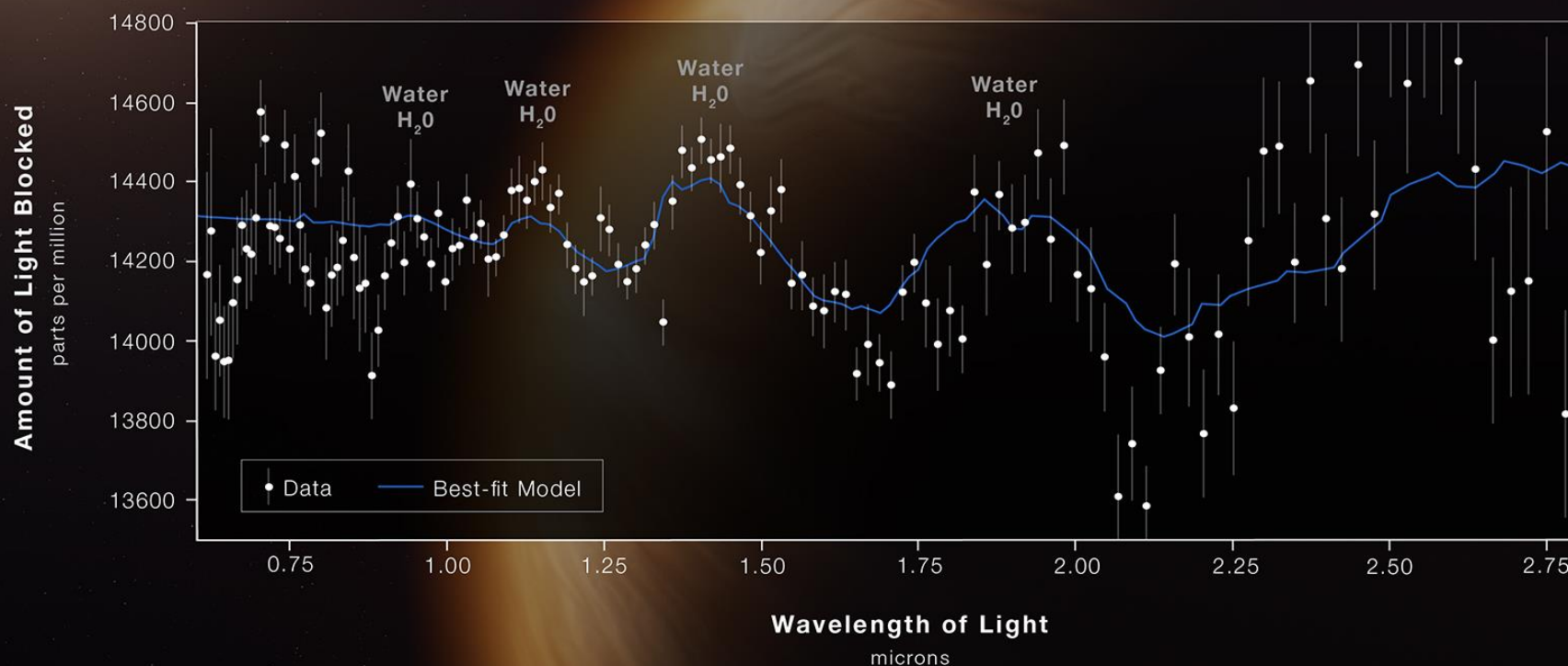
Mid IR



HOT GAS GIANT EXOPLANET WASP-96 b

ATMOSPHERE COMPOSITION

NIRISS | Single-Object Slitless Spectroscopy





Carina Nebula



JWST is for everyone !!



JWST User Documentation

[Home](#) [About](#) [Acronyms](#) [Helpdesk](#)

[Home](#) / [JWST Opportunities and Policies](#) / [JWST Call for Proposals for Cycle 2](#)

JWST Call for Proposals for Cycle 2

STScI solicits proposals for JWST Observing, Archival, and Theoretical Research. Downloadable PDF collections of these articles are provided as a courtesy, made available and updated when feasible. ***The online documentation is the authority***, and will be updated with the latest information.

Cycle 2 proposal deadline:
January 27, 2023 by 8:00pm US Eastern Standard Time

Over 20,000 engineers and scientists contributed to JWST...

NASA Goddard Space Flight Center



Ireland



Munich



Baltimore

Two decades of amazing teamwork!



Brush
Wellman/Materion



Ball



OTIS/JSC/Harris



StSci/Ball/GSFC



Tinsley



GSFC OTE/CoC Team



MSEC YRCE



Orbital ATK

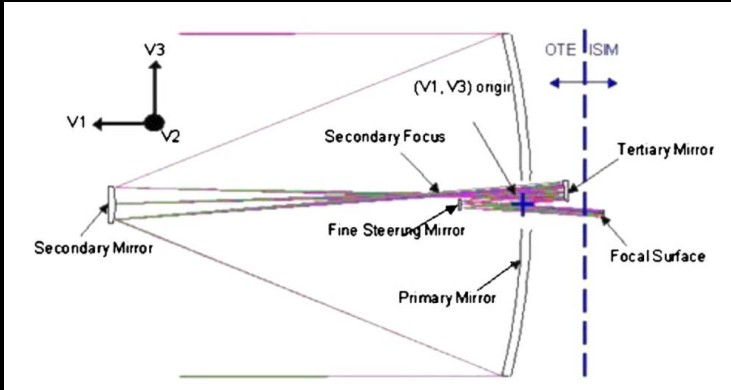


Axsys Technologies



QCI

It's like raising a kid!



THANK YOU!



WEBB

SPACE TELESCOPE



Questions?



Backup slides



Credits: NASA, ESA, CSA, and STScI

[View larger version of this image](#)

This landscape of “mountains” and “valleys” speckled with glittering stars is actually the edge of a nearby, young, star-forming region called NGC 3324 in the Carina Nebula. Captured in infrared light by NASA’s new James Webb Space Telescope, this image reveals for the first time previously invisible areas of star birth.

Called the Cosmic Cliffs, Webb’s seemingly three-dimensional picture looks like craggy mountains on a moonlit evening. In reality, it is the edge of the giant, gaseous cavity within NGC 3324, and the tallest “peaks” in this image are about 7 light-years high. The cavernous area has been carved from the nebula by the intense ultraviolet radiation and stellar winds from extremely massive, hot, young stars located in the center of the bubble, above the area shown in this image.



Credits: NASA, ESA, CSA, and STScI
[View larger version of this image](#)

Stephan's Quintet, a visual grouping of five galaxies, is best known for being prominently featured in the holiday classic film, "It's a Wonderful Life." Today, NASA's James Webb Space Telescope reveals Stephan's Quintet in a new light. This enormous mosaic is Webb's largest image to date, covering about one-fifth of the Moon's diameter. It contains over 150 million pixels and is constructed from almost 1,000 separate image files. The information from Webb provides new insights into how galactic interactions may have driven galaxy evolution in the early universe.

With its powerful, infrared vision and extremely high spatial resolution, Webb shows never-before-seen details in this galaxy group. Sparkling clusters of millions of young stars and starburst regions of fresh star birth grace the image. Sweeping tails of gas, dust and stars are being pulled from several of the galaxies due to gravitational interactions. Most dramatically, Webb captures huge shock waves as one of the galaxies, NGC 7318B, smashes through the cluster.



Credits: NASA, ESA, CSA, and STScI

[View larger version of this image](#)

Some stars save the best for last.

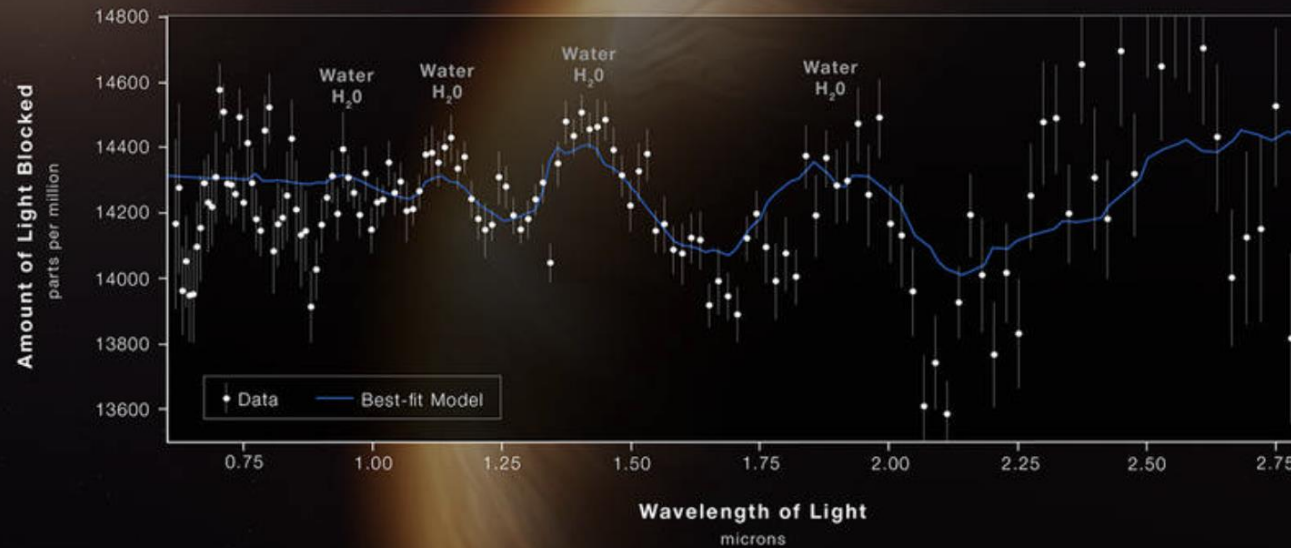
The dimmer star at the center of this scene has been sending out rings of gas and dust for thousands of years in all directions, and NASA's James Webb Space Telescope has revealed for the first time that this star is cloaked in dust.

Two cameras aboard Webb captured the latest image of this planetary nebula, cataloged as NGC 3132, and known informally as the Southern Ring Nebula. It is approximately 2,500 light-years away.

Webb will allow astronomers to dig into many more specifics about planetary nebulae like this one – clouds of gas and dust expelled by dying stars. Understanding which molecules are present, and where they lie throughout the shells of gas and dust will help researchers refine their knowledge of these objects.

HOT GAS GIANT EXOPLANET WASP-96 b ATMOSPHERE COMPOSITION

NIRISS | Single-Object Slitless Spectroscopy



WEBB
SPACE TELESCOPE

Credits: NASA, ESA, CSA, and STScI

[View larger version of this image](#)

NASA's James Webb Space Telescope has captured the distinct signature of water, along with evidence for clouds and haze, in the atmosphere surrounding a hot, puffy gas giant planet orbiting a distant Sun-like star.

The observation, which reveals the presence of specific gas molecules based on tiny decreases in the brightness of precise colors of light, is the most detailed of its kind to date, demonstrating Webb's unprecedented ability to analyze atmospheres hundreds of light-years away.

While the Hubble Space Telescope has analyzed numerous exoplanet atmospheres over the past two decades, capturing the first clear detection of water in 2013, Webb's immediate and more detailed observation marks a giant leap forward in the quest to characterize potentially habitable planets beyond Earth.



Credits: NASA, ESA, CSA, and STScI

[View larger version of this image](#)

NASA's James Webb Space Telescope has produced the deepest and sharpest infrared image of the distant universe to date. Known as Webb's First Deep Field, this image of galaxy cluster SMACS 0723 is overflowing with detail.

Thousands of galaxies – including the faintest objects ever observed in the infrared – have appeared in Webb's view for the first time. This slice of the vast universe covers a patch of sky approximately the size of a grain of sand held at arm's length by someone on the ground.

First, how does NASA decide what to spend \$ on?



- NASA engages with the world scientific community to determine priorities which will give the best return for the US taxpayer's investment.
- This is typically done once a decade and is led by a private non-profit society of distinguished scholars: the National Research Council of the National Academies.
- Established by an Act of Congress and signed by President Abraham Lincoln in 1863, the National Academies are charged with providing independent, objective advice to the nation on matters related to science and technology.



These are the Astrophysics decadal reports...

Astrophysics

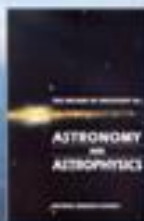
Decadal Survey Missions



1972
Decadal Survey
Hubble



1982
Decadal Survey
Chandra



1991
Decadal Survey
Spitzer



2001
Decadal Survey
Webb



2010
Decadal Survey
Roman



2021
Decadal Survey

?

1972: Hubble Space Telescope (HST)

- EPD: 2.4 m
- FOV: 14 arcmin radial
- F/#: 24
- λ : 0.12 - 2.5 μm
- Design: RC
- Launch 1990

EPD = Entrance Pupil Diameter

FOV = Field of View

F/# = Focal Ratio, focal length/EPD

λ = Wavelength Range, bandpass

RC = 2 mirror Ritchey-Chretien



1982: Chandra X-ray Telescope

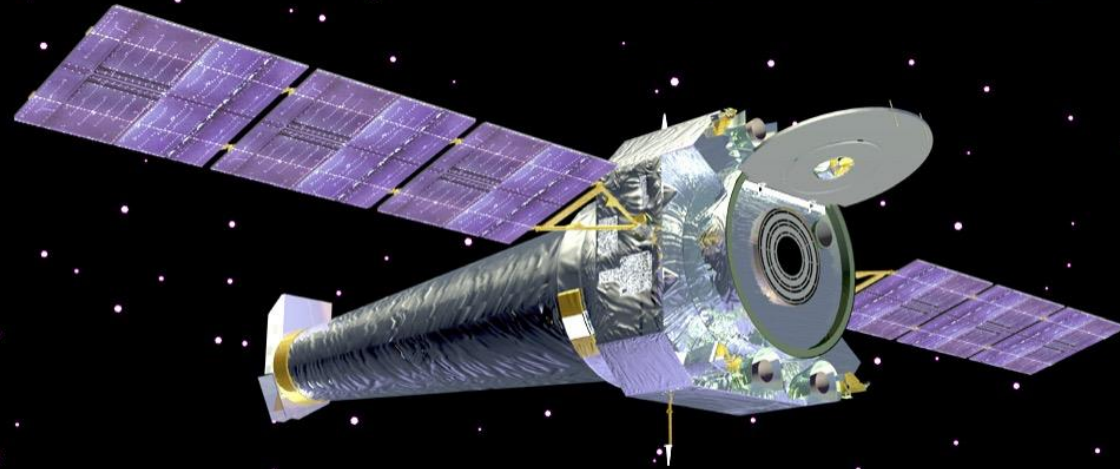
- EPD: 1.2 m
- FOV: 30 arcmin
- F/#: 8
- λ : 0.12 – 12 nm
- Design: Wolter type I
- Resolution: 0.5 arcsec
- Launch 1999

EPD = Entrance Pupil Diameter

FOV = Field of View

F/# = Focal Ratio, focal length/EPD

λ = Wavelength Range, bandpass



1991: SPITZER IR Telescope

- EPD: 0.85 m
- FOV: 60x30 arcmin
- F/#: 12
- λ : 3.6 – 160 μm
- Design: RC
- Launch 2003
- Mission complete: 30 Jan 2020

EPD = Entrance Pupil Diameter

FOV = Field of View

F/# = Focal Ratio, focal length/EPD

λ = Wavelength Range, bandpass

RC = Ritchey-Chretien



1991: SOFIA IR Telescope

- EPD: 2.5 m
- FOV: 60x30 arcmin
- F/#: 20
- λ : 2.5 – 5 μm
- Design: Cassegrain
- First Light 2007

EPD = Entrance Pupil Diameter

FOV = Field of View

F/# = Focal Ratio, focal length/EPD

λ = Wavelength Range, bandpass

RC = Ritchey-Chretien



Astrophysics

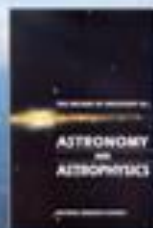
Decadal Survey Missions



1972
Decadal
Survey
Hubble



1982
Decadal
Survey
Chandra



1991
Decadal
Survey
Spitzer



2001
Decadal
Survey
Webb



2010
Decadal
Survey
Roman



2021
Decadal
Survey

?

Nancy Grace Roman Space Telescope

- EPD: 2.4 m
- FOV: 50x25 arcmin
- F/#: 8
- λ : 0.5 – 2.0 μm
- Design: 3-mirror
- Survey 2010, Launch 2027

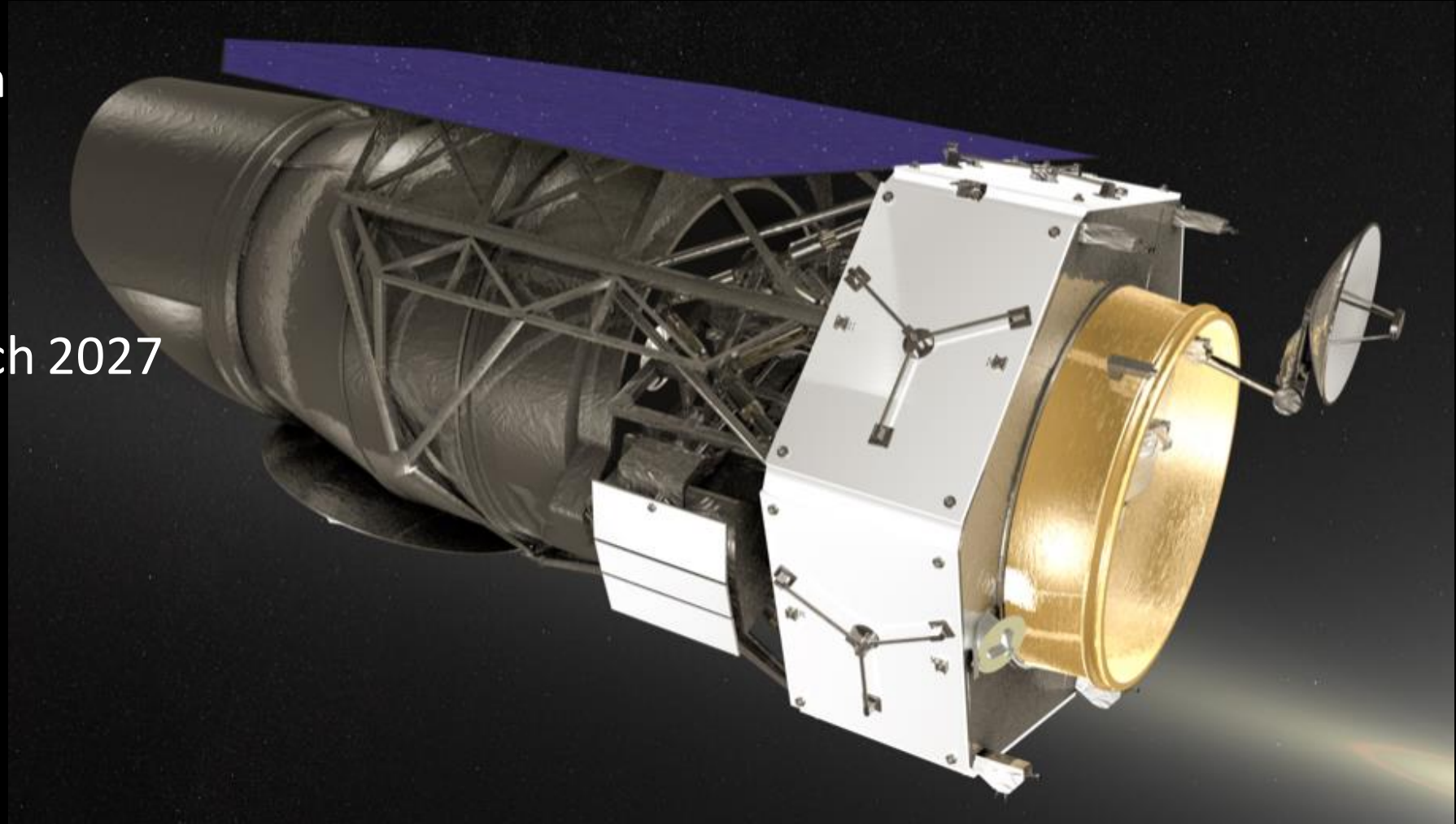
EPD = Entrance Pupil Diameter

FOV = Field of View

F/# = Focal Ratio, focal length/EPD

λ = Wavelength Range, bandpass

TMA = Three-Mirror Anastigmat



Who is Nancy Grace Roman?

This space-based observatory is named after Nancy Grace Roman (1925- 2018), NASA's first chief astronomer who paved the way for space telescopes focused on the broader universe.

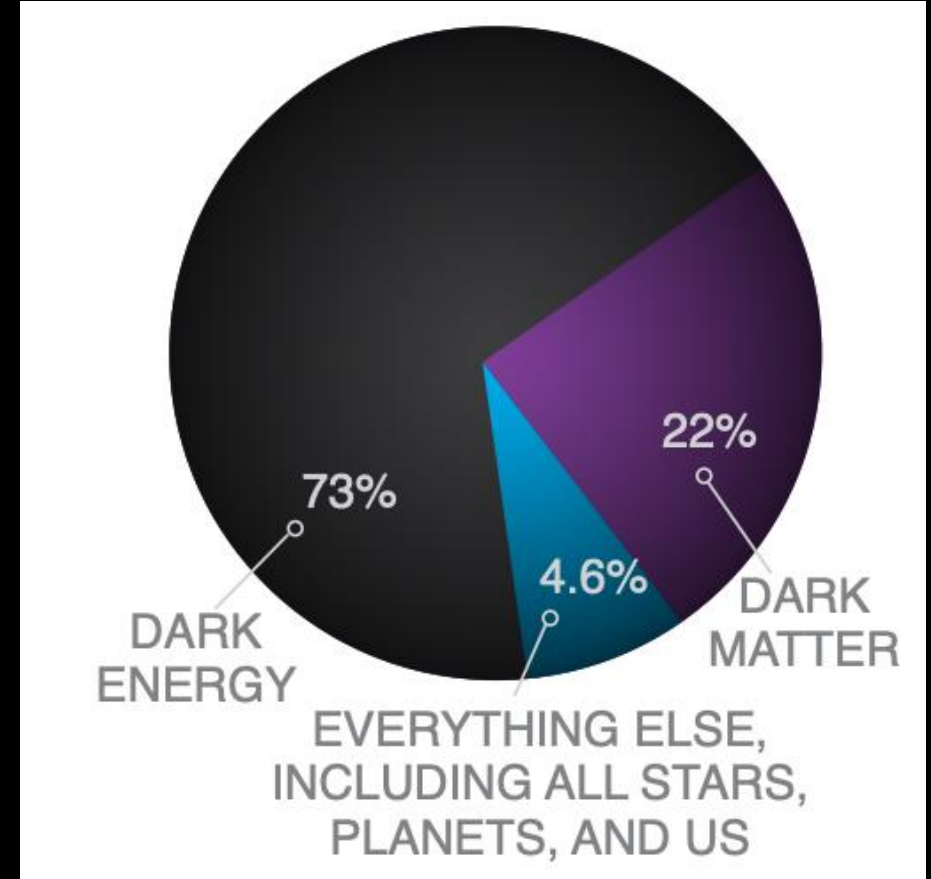
Considered the “mother” of NASA's Hubble Space Telescope, Roman tirelessly advocated for new tools that would allow scientists to study the broader universe from space



Dr. Roman at NASA's Goddard Space Flight Center in Greenbelt, Md., circa 1972. NASA

Roman will study Dark Energy

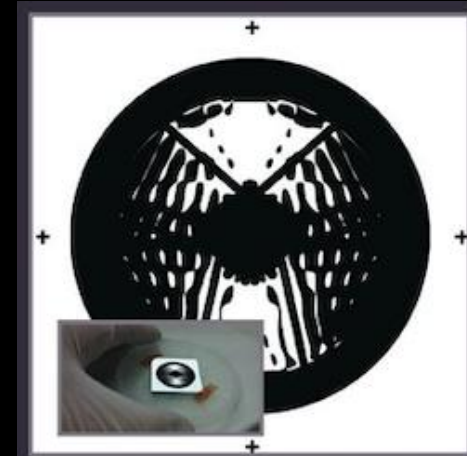
Astronomers have discovered that the expansion of the universe is accelerating. That is, that all galaxies in the universe are moving away from one another at greater and greater speeds. The cause for this expansion is not well understood. Astronomers have proposed that there is an additional, previously unknown energy, or “dark energy” responsible for the observed acceleration.



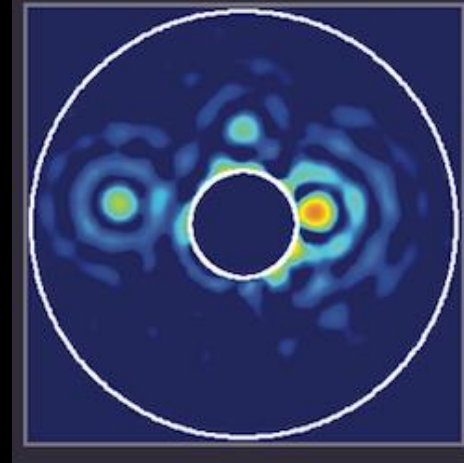
Roman will study Exoplanets

Microlensing takes advantage of two stars crossing paths in our line of sight to determine whether the star closest to us has planets.

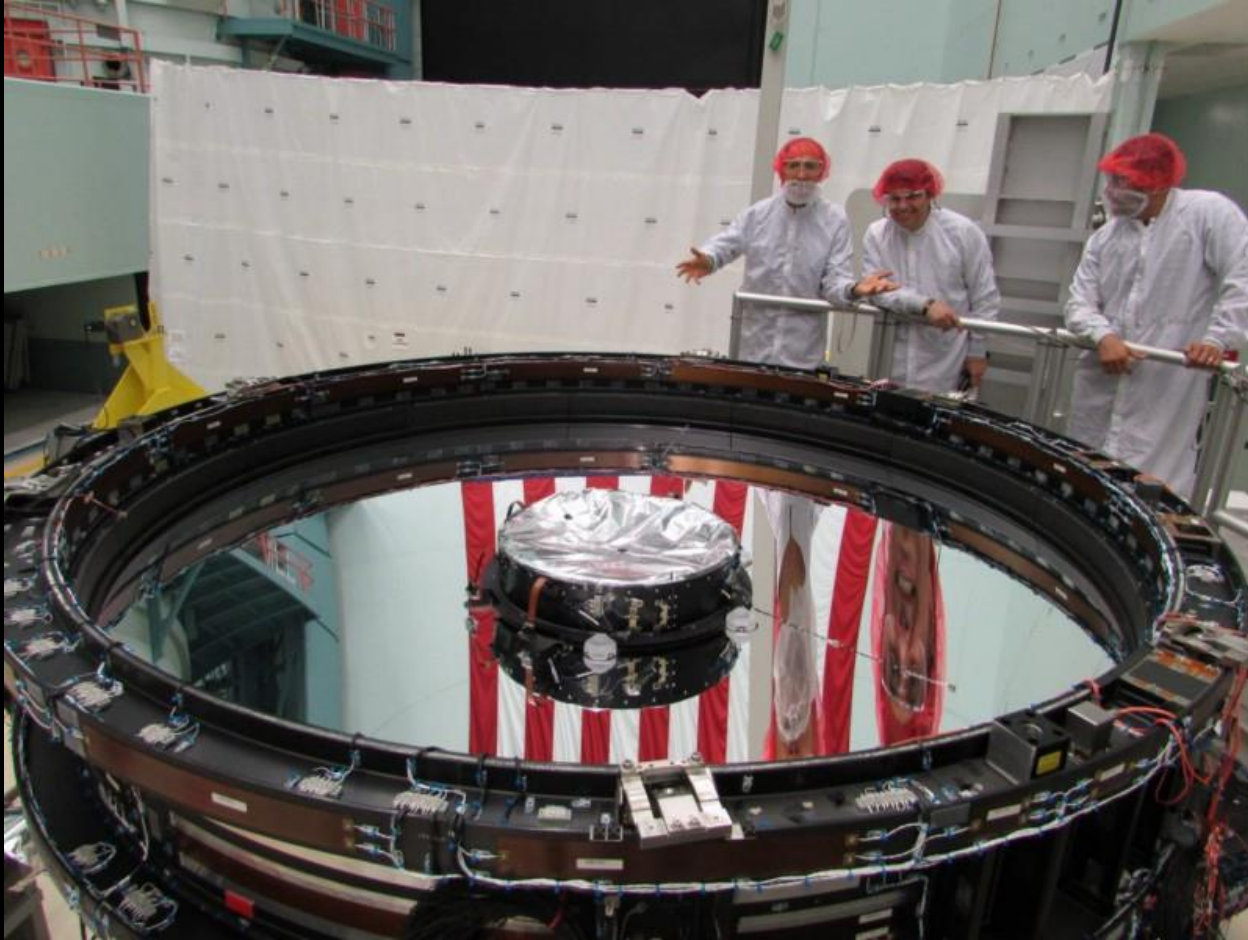
Coronagraph Instrument: A coronagraph blocks the light of a host star to directly image an exoplanet.



Advance coronagraph technology will enable the Roman Space Telescope to directly image exoplanets and study them.



Roman Space Telescope Hardware





Did NASA follow the 2010 recommendations?

Astro2010 Scorecard

Recommendation		Response / Status	
L	WFIRST	Roman Space Telescope in Phase C, launch by 2027	✓
L	Explorers: 4 AOs / decade	AOs in 2011, 2014, 2016, 2019, 2021, 2024	✓
L	LISA	Partnered with ESA on LISA, launch in mid-2030s	✓
L	IXO	Partnered with ESA on Athena, launch in early 2030s	✓
M	New worlds technology	Matured coronagraphs & starshades, CGI tech demo on Roman, precursor science (LBTI, NEID, EPRV, etc.)	✓
M	Inflation probe technology	Matured detectors in labs and on balloons	✓
S	R&A augmentations	R&A up 60% from FY10 to FY24; added RTF, TCAN, evolved XRP	✓
S	Mid-TRL technology	Initiated SAT, competed and directed technologies	✓
S	Suborbital-class missions	Added New Zealand, developed super-pressure balloon, added CubeSats, added Pioneers	✓
S	SPICA	Elected not to participate	✗



Astrophysics

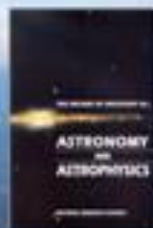
Decadal Survey Missions



1972
Decadal
Survey
Hubble



1982
Decadal
Survey
Chandra



1991
Decadal
Survey
Spitzer



2001
Decadal
Survey
Webb



2010
Decadal
Survey
Roman

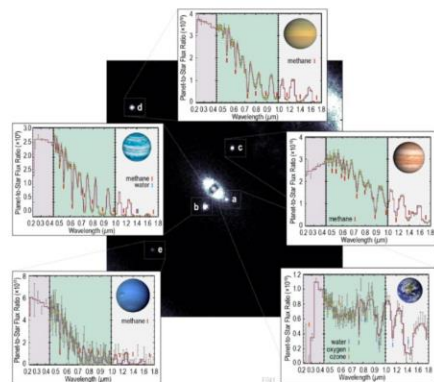


2021
Decadal
Survey

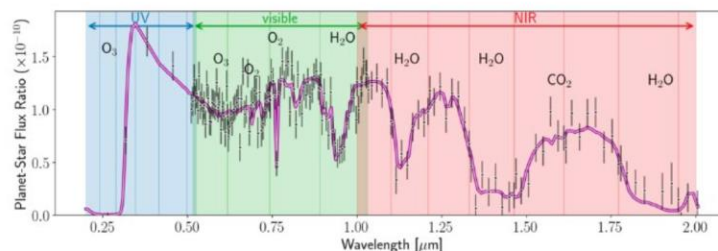
?

Astro 2021 recommendation:

A Future IR/Optical/UV Telescope Optimized for Observing Habitable Exoplanets and General Astrophysics



Simulated space-telescope image of a complete planetary system including a life-bearing Earth-like planet

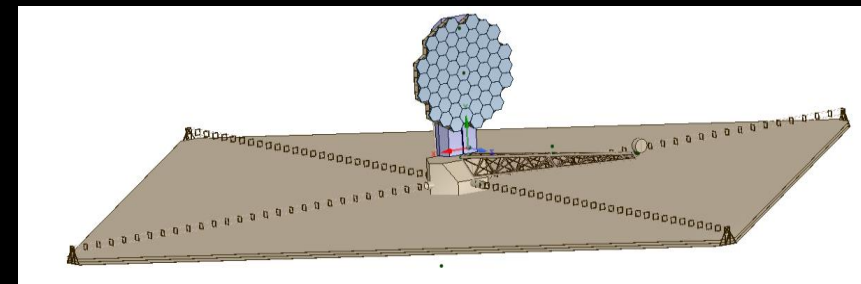
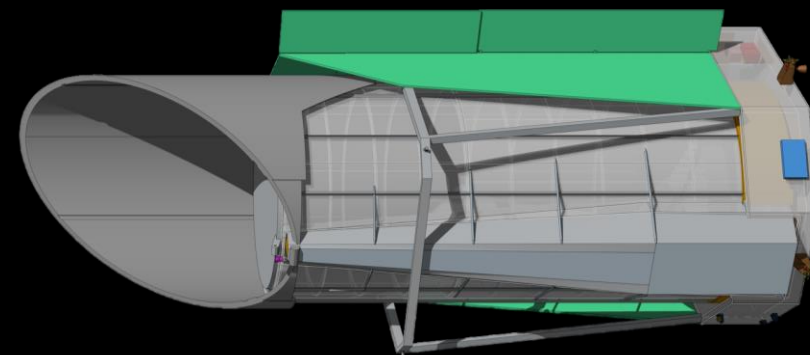


Simulated spectrum of an Earth-twin planet observed from the UV to near-IR by a space coronagraph

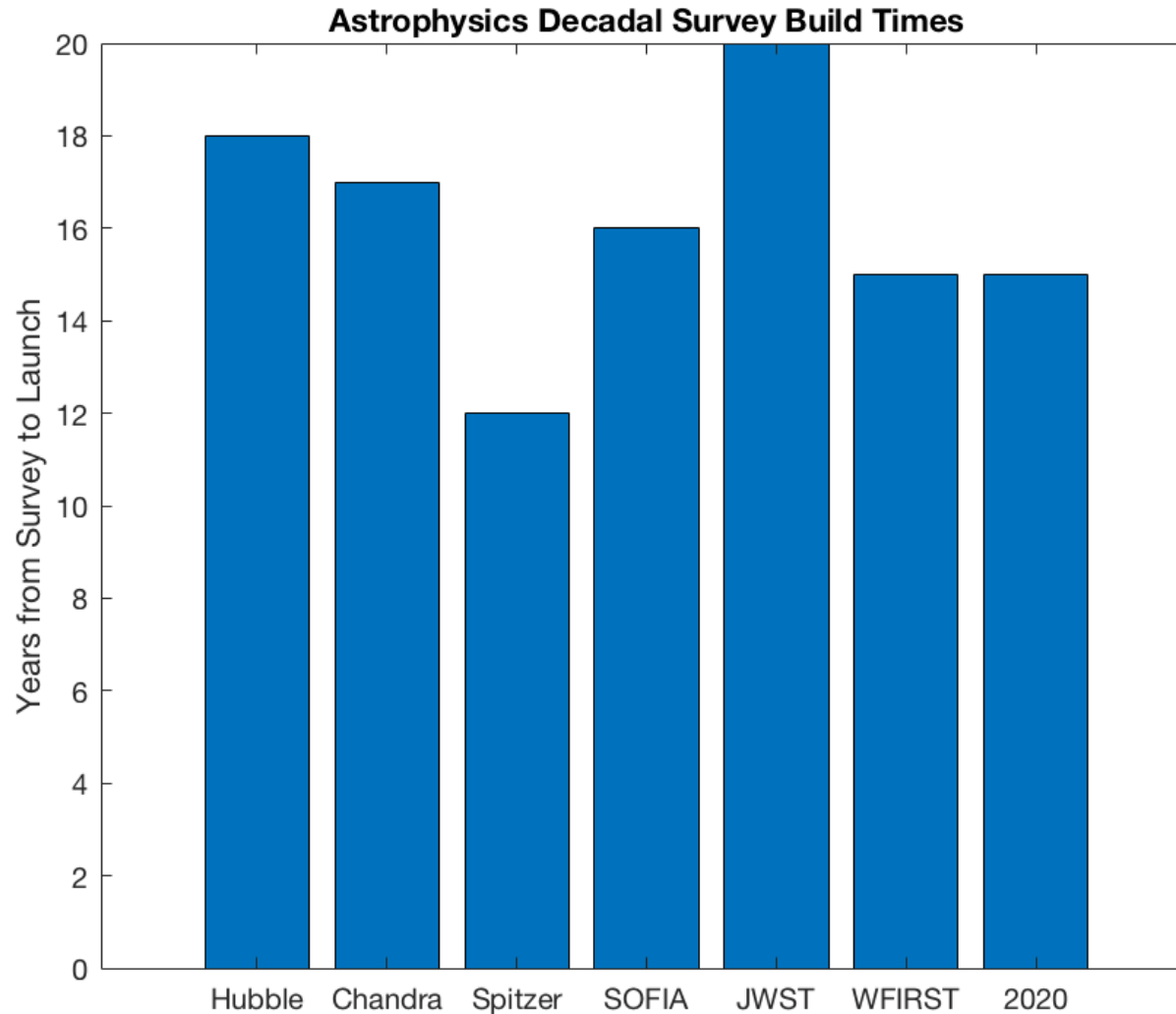
Recommendation: After a successful mission and technology maturation program, NASA should embark on a program to realize a mission to search for biosignatures from a robust number of about ~25 habitable zone planets and to be a transformative facility for general astrophysics. If mission and technology maturation are successful, as determined by an independent review, implementation should start in the latter part of the decade, with a target launch in the first half of the 2040's

IR/O/UV Telescope Characteristics

- ~6 m off-axis inscribed diameter provides robust sample of ~25 spectra of potentially habitable planets, and would be transformative for general astrophysics
- Estimated cost: 11B\$
- Target launch: first half of 2040's



Astrophysics Telescopes Build times





NIRCAM ALIGNMENT SELFIE

