National Aeronautics and Space Administration

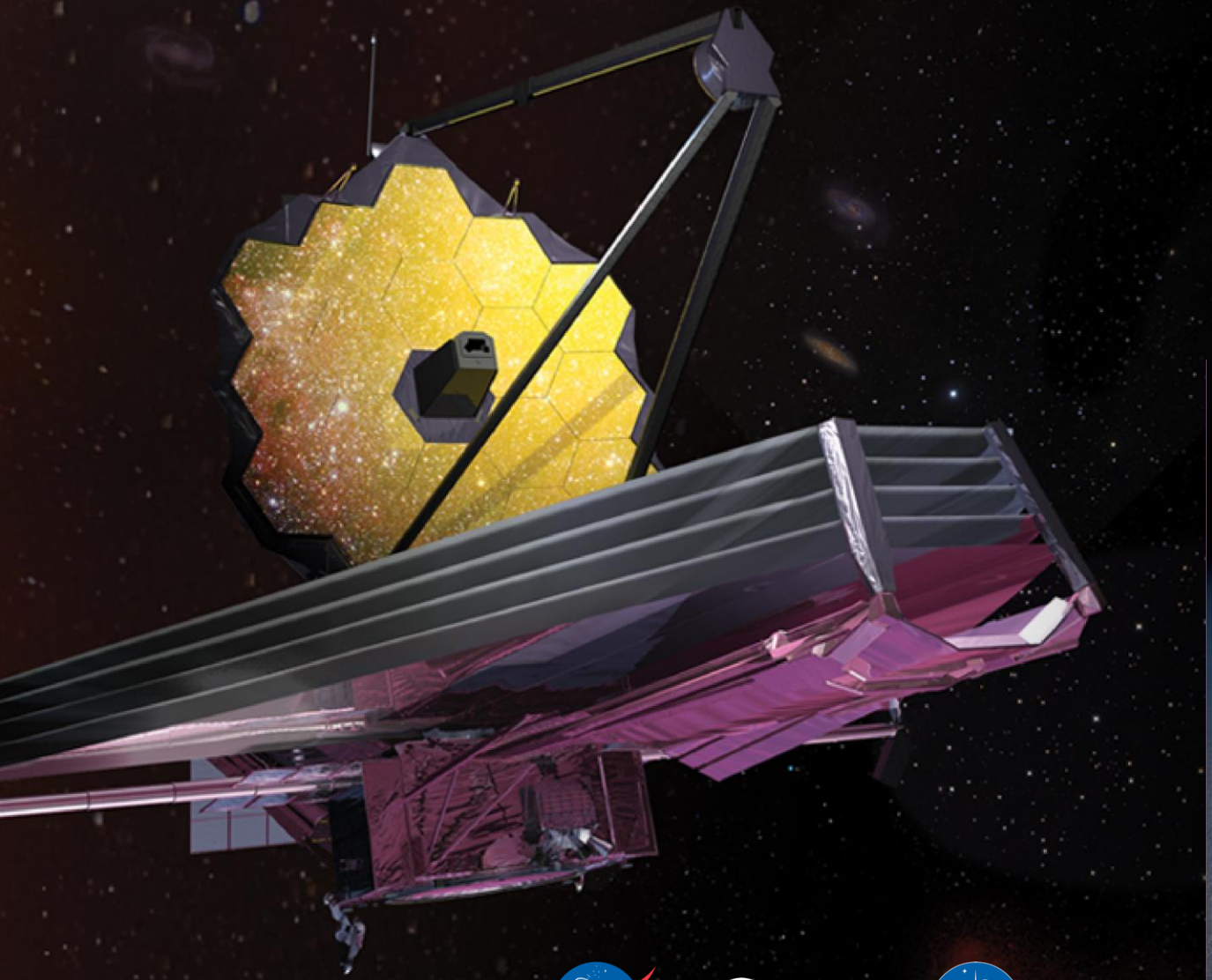
From the Hubble To the James Webb Space Telescopes: A Personal Journey

Hashima Hasan

Astrophysics Division
Science Mission Directorate
NASA Headquarters, Washington DC

February 2025

James Webb Space Telescope
Launched: 2021



National Aeronautics and
Space Administration

Hubble Space Telescope
Launched: 1990

Lucknow to AMU and Oxford

Loreto Convent Girls' High School, Lucknow (India)

Lucknow University (1966-1968)

- B. Sc. (Physics, Chemistry, Math)
- 5th position (1st position in Math)

Aligarh Muslim University

- M.Sc. (Physics)
- 1st position – Imdad Saifi Gold Medal (1970)
- M. Phil. (Physics) – 1972

Lady Margaret Hall, Oxford University

- D. Phil. (Theoretical Nuclear Physics) - 1976

Aligarh Muslim University

Lucknow University

Loreto Convent Girls' High School, Lucknow

Lady Margaret Hall, Oxford University

Road to NASA HQ took many turns

Tata Institute of Fundamental Research, Bombay

University of Poona, Pune (India)

Marriage to NIH scientist, Dr. Aftab Ansari (1979)

Duke University, Durham, NC (USA)

US Environmental Protection Agency, NC (USA)

Bhabha Atomic Research Center, Trombay (India)

Space Telescope Science Institute, Baltimore (1985)

NASA Headquarters, Washington DC (1994)

University of Poona, Pune

Tata Institute of Fundamental Research (TIFR), Bombay

Bhabha Atomic Research Center (BARC), Bombay

NASA Headquarters

Duke University, Durham NC, USA

STScI, Baltimore

nstitute in Baltimore, Maryland, is home to the science programs o
rchives of other NASA missions. ***CREDIT:*** *Zoltan G. Levay*

Missions Worked as Program Scientist

James Webb Space Telescope (Webb)

Nuclear Spectroscopic Telescope Array (NuSTAR)

Imaging Xray Polarimetry Explorer (IXPE)

W. M. Keck Observatory

Hubble Space Telescope (Hubble)

Stratospheric Observatory For Infrared Astronomy (SOFIA)

International Ultraviolet Explorer (IUE)

Extreme Utraviolet Explorer (EUVE)

Orbiting and Retrievable Far & Extreme Ultraviolet Explorer (ORFEUS-SPAS II)

Far Ultraviolet Spectroscopic Explorer (FUSE)

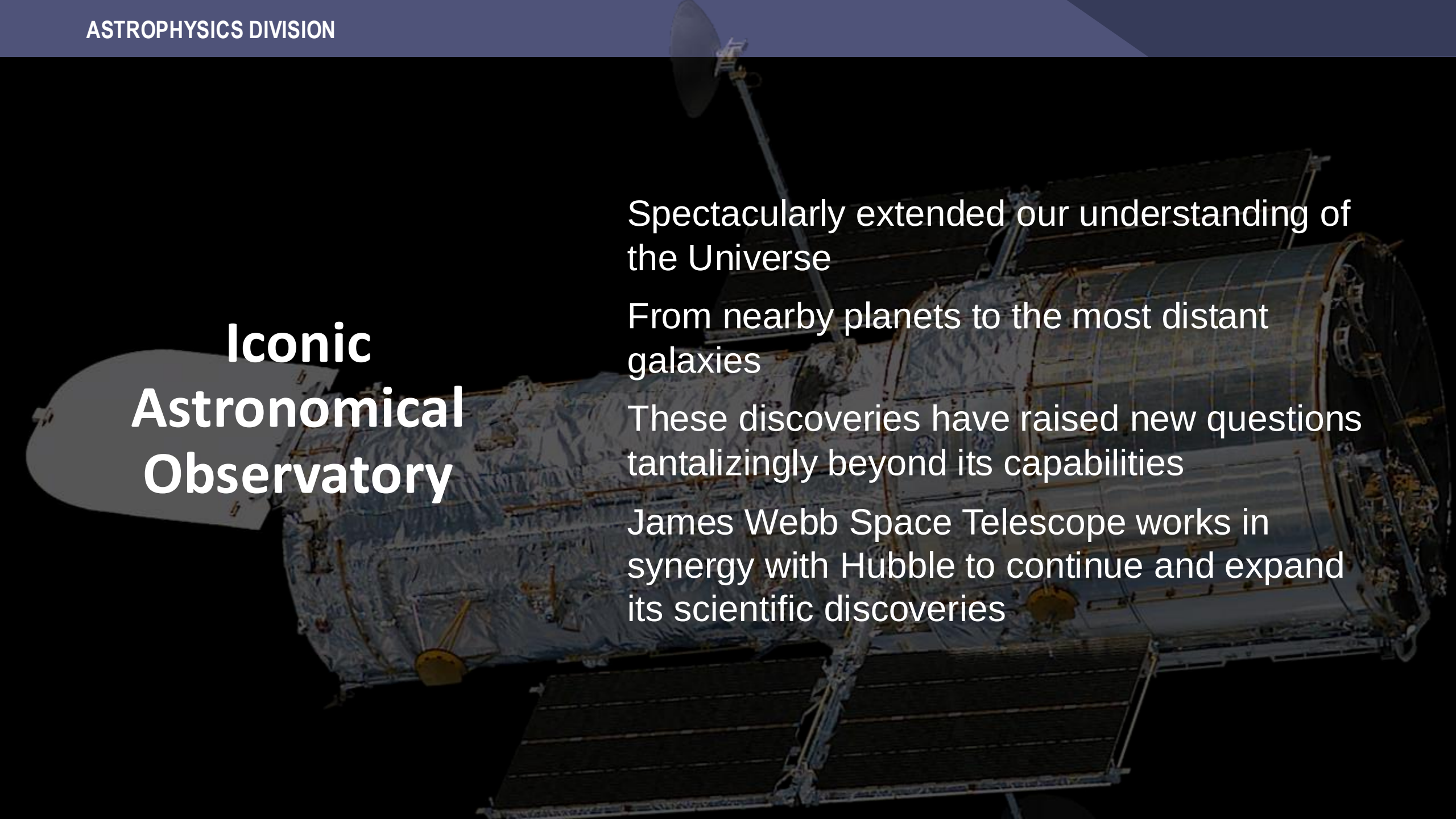
Galaxy Evolution Explorer (GALEX)

Wide-field Infrared Surveyor (WISE)

Gravity Probe – B (GP-B)

NASA Explorer Program

Hubble Space Telescope



Iconic Astronomical Observatory

Spectacularly extended our understanding of the Universe

From nearby planets to the most distant galaxies

These discoveries have raised new questions tantalizingly beyond its capabilities

James Webb Space Telescope works in synergy with Hubble to continue and expand its scientific discoveries

Lookback at Hubble

The bold vision for Hubble required it to be

- ➢Launched on the Space Shuttle
- ➢Be serviceable by astronauts
- ➢Science instruments be kept current by changing them out during servicing missions

Cassegrain telescope with 2.4 m hyperbolic primary mirror; hyperbolic secondary

Science instruments operating in UV, Visible, Near-Infrared

Hubble's Orbit

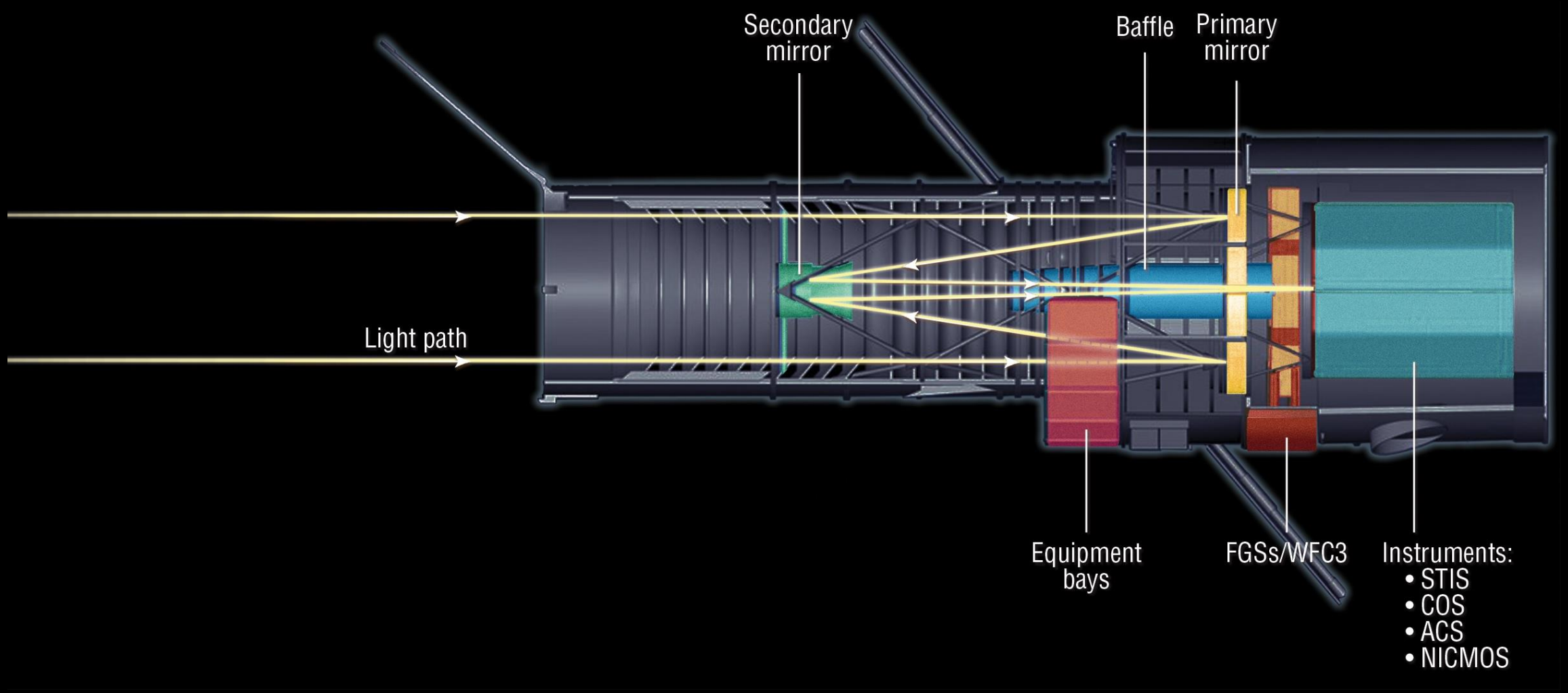
Launched on Space Shuttle STS 31
April 24, 1990

Hubble is in orbit around Earth at an altitude of about 332 mile (545 km) and its orbit is inclined with respect to the Earth's equator at angle of about 28.5 degrees.

It zooms along in its orbit at a speed of 17,000 mph (27,000 kph), meaning that it completes an entire orbit in just under 97 minutes.

Hubble Primary Mirror

- Lightweight glass – honeycomb structure (818 kg total weight)
- Aluminum and magnesium fluoride coating optimized to reflect UV light
- Smoothest mirror ground
- Edges ground to the wrong shape leading to spherical aberration



Hubble Ray Diagram

Hubble Suffers from Spherical Aberration

- Hubble first light images showed the telescope suffered from spherical aberration
- Additional focus changes were introduced by water desorption from graphite epoxy truss supporting the mirrors

Working on Hubble@STScI (1985-1995)

HASHIMA HASAN, AURA
INSTRUMENT SCI.- TELESCOPE

Publications of the Astronomical Society of the Pacific
107: 289–298, 1995 March

Telescope Image Modeling (TIM)

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Electronic mail: burrows@stsci.edu

Received 1994 September 7; accepted 1994 Dece

1990ApJ...361...69H

THE ASTROPHYSICAL JOURNAL, **361**:69–77, 1990 September 20

CHAOTIC ORBITS IN BARRED GALAXIES WITH CENTRAL MASS CONCENTRATIONS

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Space Telescope Science Institute
AND
COLIN NORMAN
Department of Physics and Astronomy, Johns Hopkins University; and Space Telescope Science Institute
Received 1989 November 14; accepted 1990 March 20

ABSTRACT

Publications of the Astronomical Society of the Pacific
105: 1184–1191, 1993 October

Focus History of the *Hubble Space Telescope*—Launch to May 1993[1]

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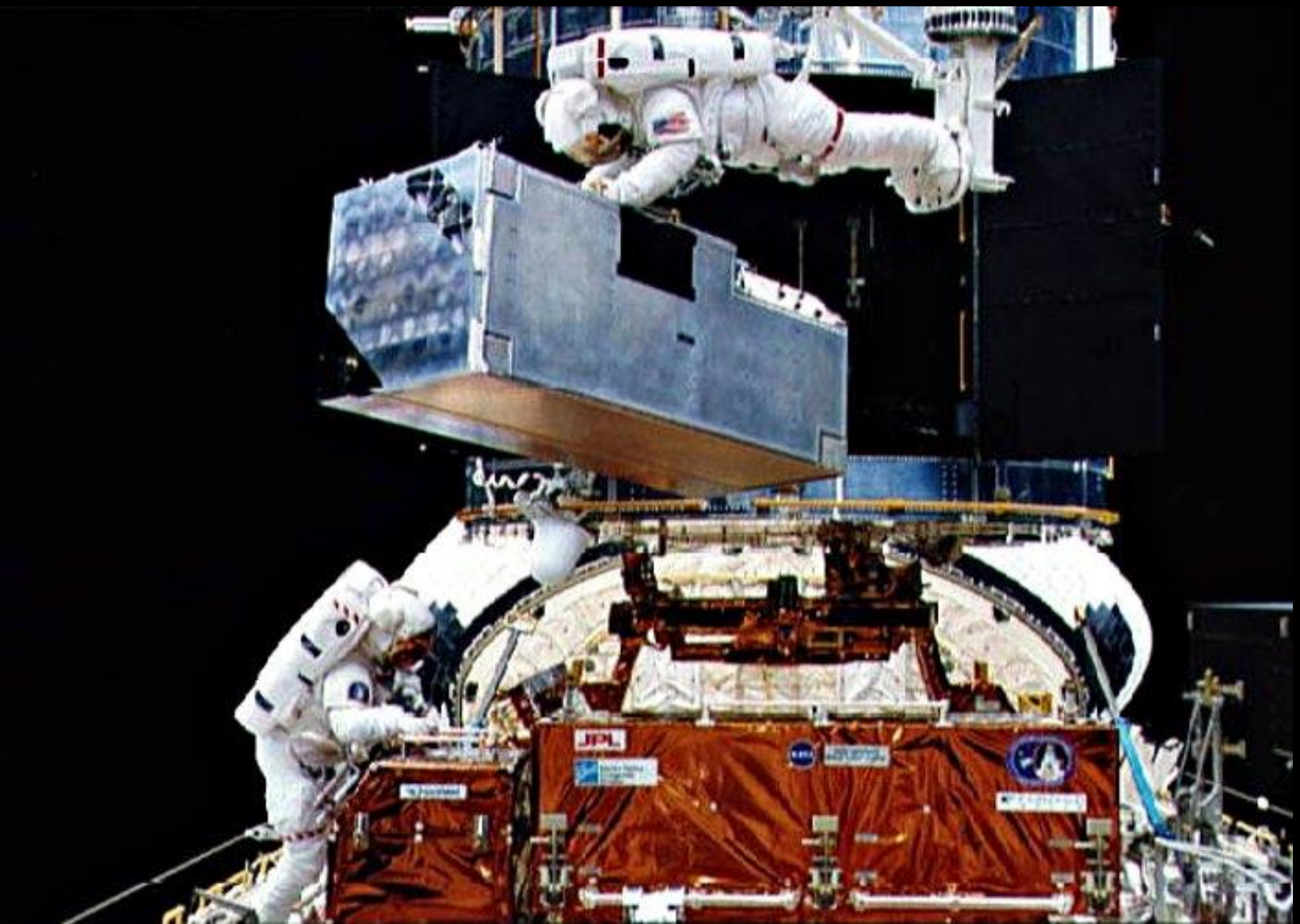
Received 1993 June 6; accepted 1993 July 22

ABSTRACT. Since the launch of the *Hubble Space Telescope* (*HST*) the secondary mirror of the

Hubble Optics Fixed in First Servicing Mission
December 2-13, 1993



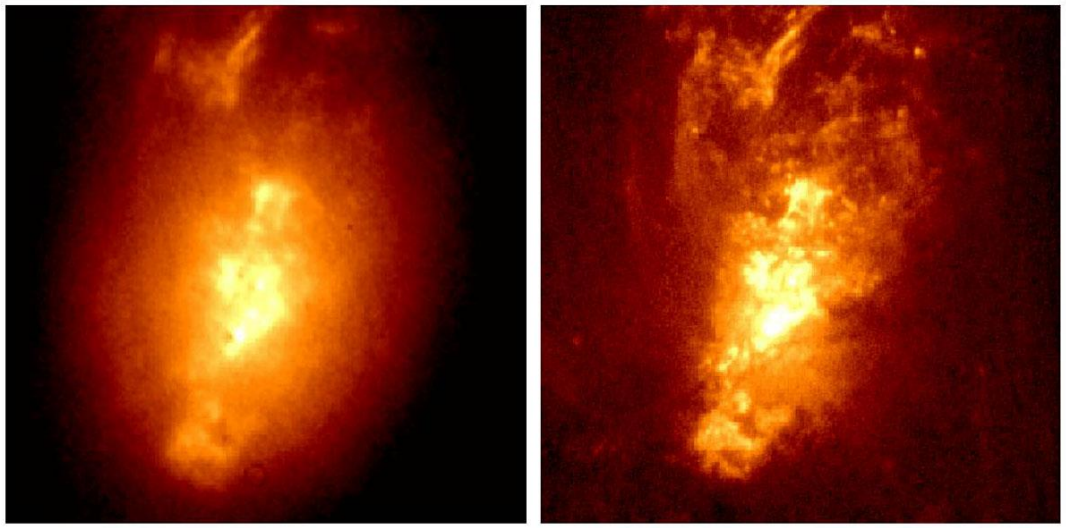
COSTAR - Corrective Optics Space Telescope Axial Replacement (COSTAR) installed to optically correct the effects of the primary mirror's aberration on the Faint Object Camera (FOC), Goddard High Resolution Spectrograph (GHRS) and Faint Object Spectrograph (FOS).

Before and After COSTAR images

The Central Region of the Active Galaxy NGC 1068

Hubble Space Telescope

Faint Object Camera



Pre-COSTAR

With COSTAR

M100 Galactic Nucleus

Hubble Space Telescope

Wide Field Planetary Camera 2

Wide Field Planetary Camera 1

Wide Field Planetary Camera 2

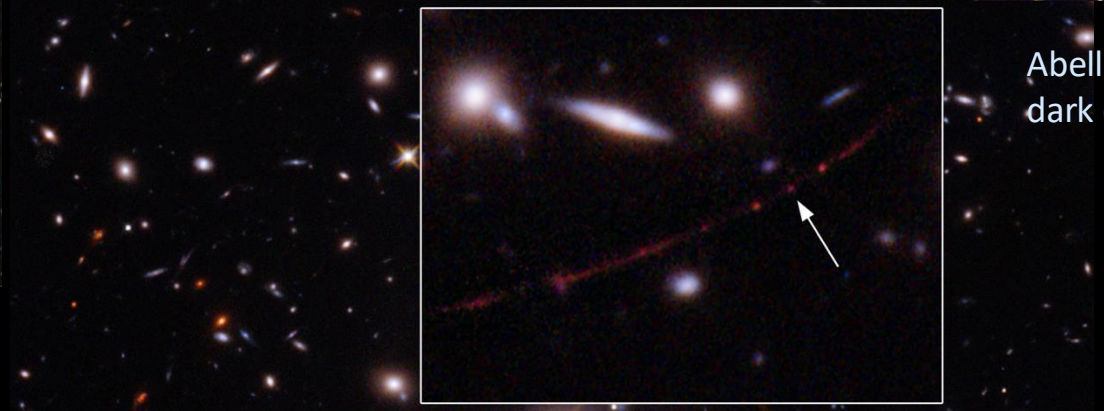
ASTROPHYSICS DIVISION

Hubble Science

Eagle Nebula's Pillars of Creation Jan 2015

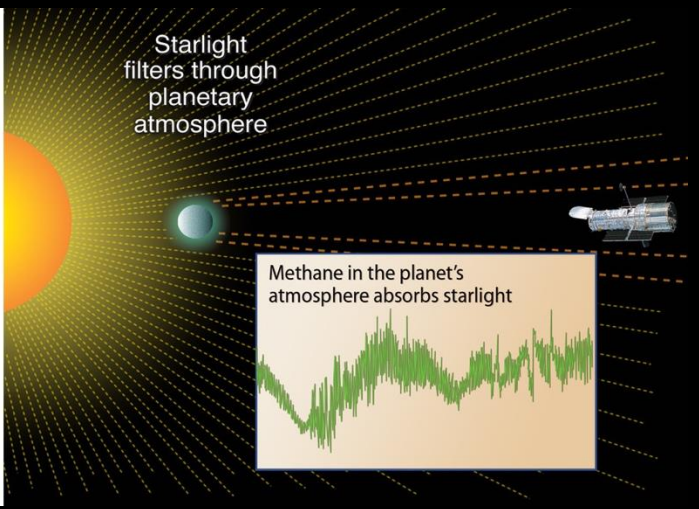
Abell 1689 – gravitational lensing used to determine dark energy Sep 2013

Frontier Field May 2017

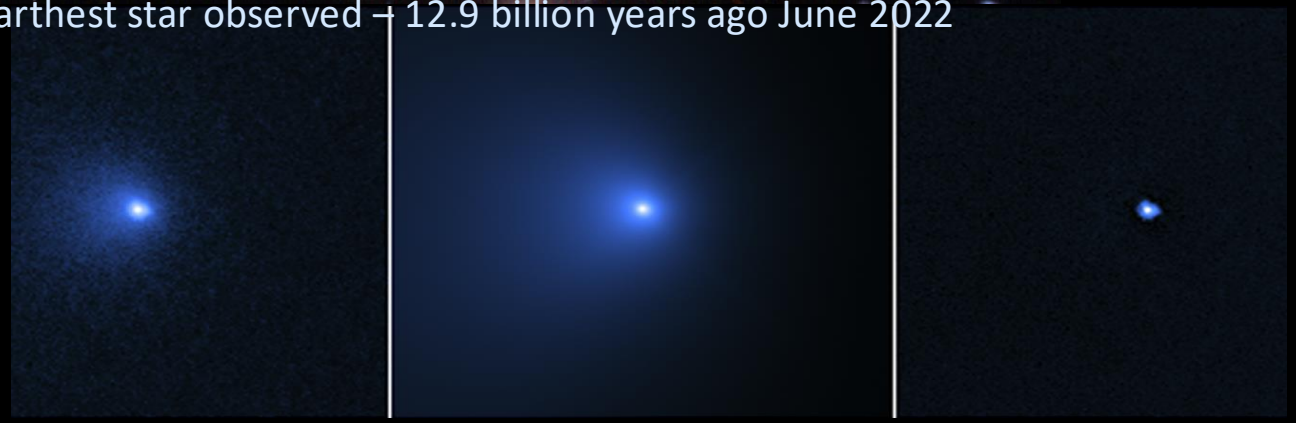


Farthest star observed – 12.9 billion years ago June 2022

Bullseye galaxy Feb. 2025



Methane in atmosphere of extrasolar planet March 2008



Largest comet nucleus ever seen (observation, coma model, nucleus) April 2022

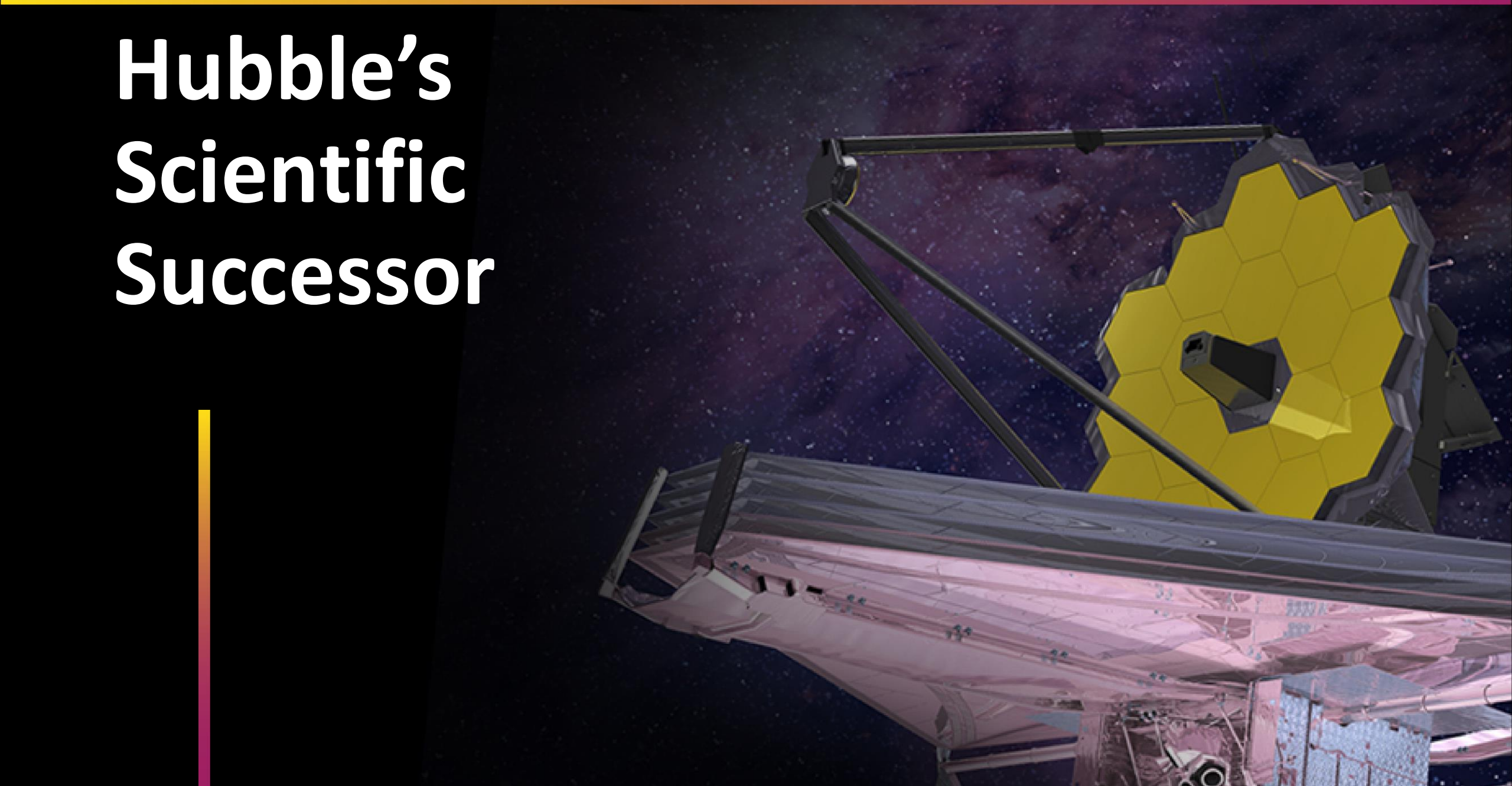
Hubble's Timeline of Development and Discoveries

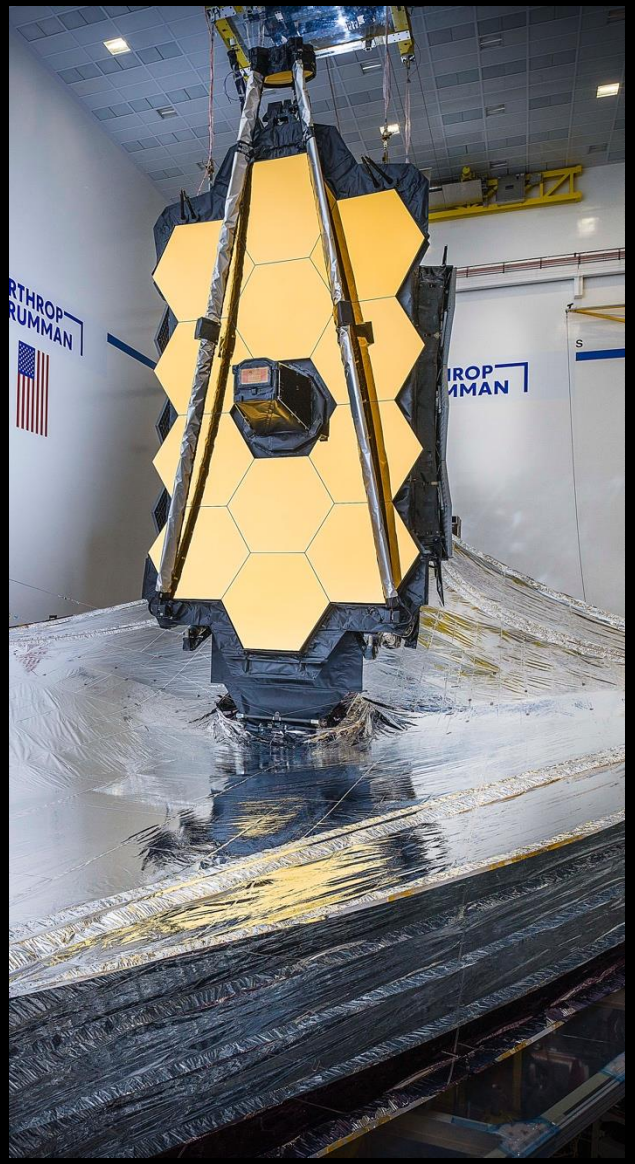
https://science.nasa.gov/mission/hubble/overview/hubble-timeline/

This timeline describes Hubble's history from the first proposal of a space telescope by Lyman Spitzer in 1946, through the completion of Hubble's five servicing missions in the 1990s and 2000s, and to many of the significant observations and discoveries Hubble has made during its years in orbit.

James Webb Space Telescope

Hubble's Scientific Successor





JWST is a technological wonder

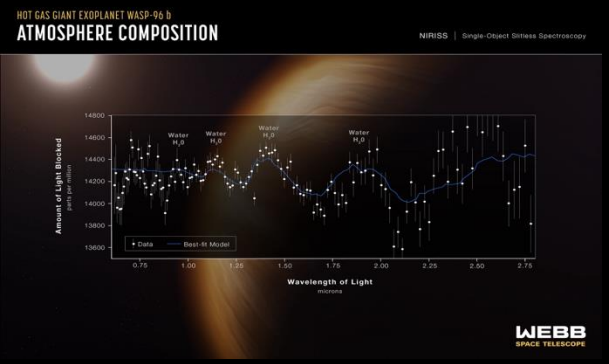
Its infrared capability enables humankind to unlock mysteries of formation of early Universe

Tribute to ingenuity and creativity of the human mind

With its 6.5 m primary mirror and four powerful science instruments it is beginning to study the first stars and galaxies, atmospheres of extrasolar planets, helping us learn where elements that form life came from and much more

Detect and study the formation of first stars and galaxies created 13.6 billion years ago, follow the evolution of galaxies, study black holes, by capturing the light from them that has stretched into the infrared.

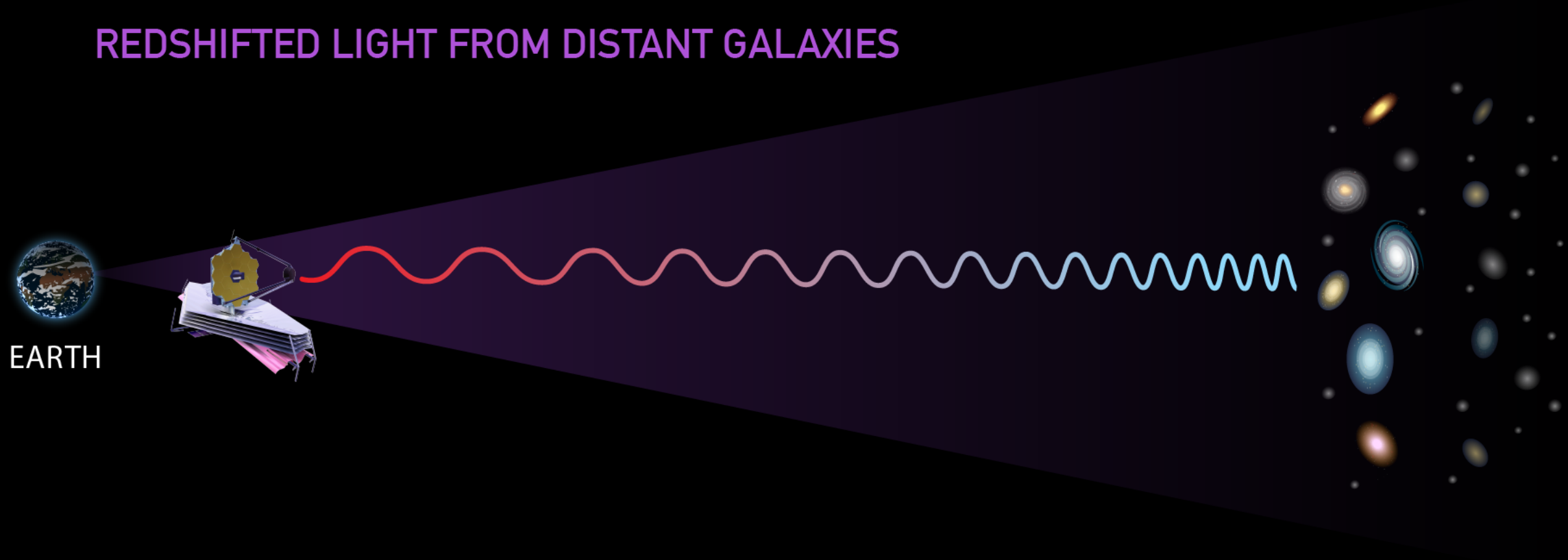
Use its infrared capability to see into the birthplaces of stars with unprecedented detail



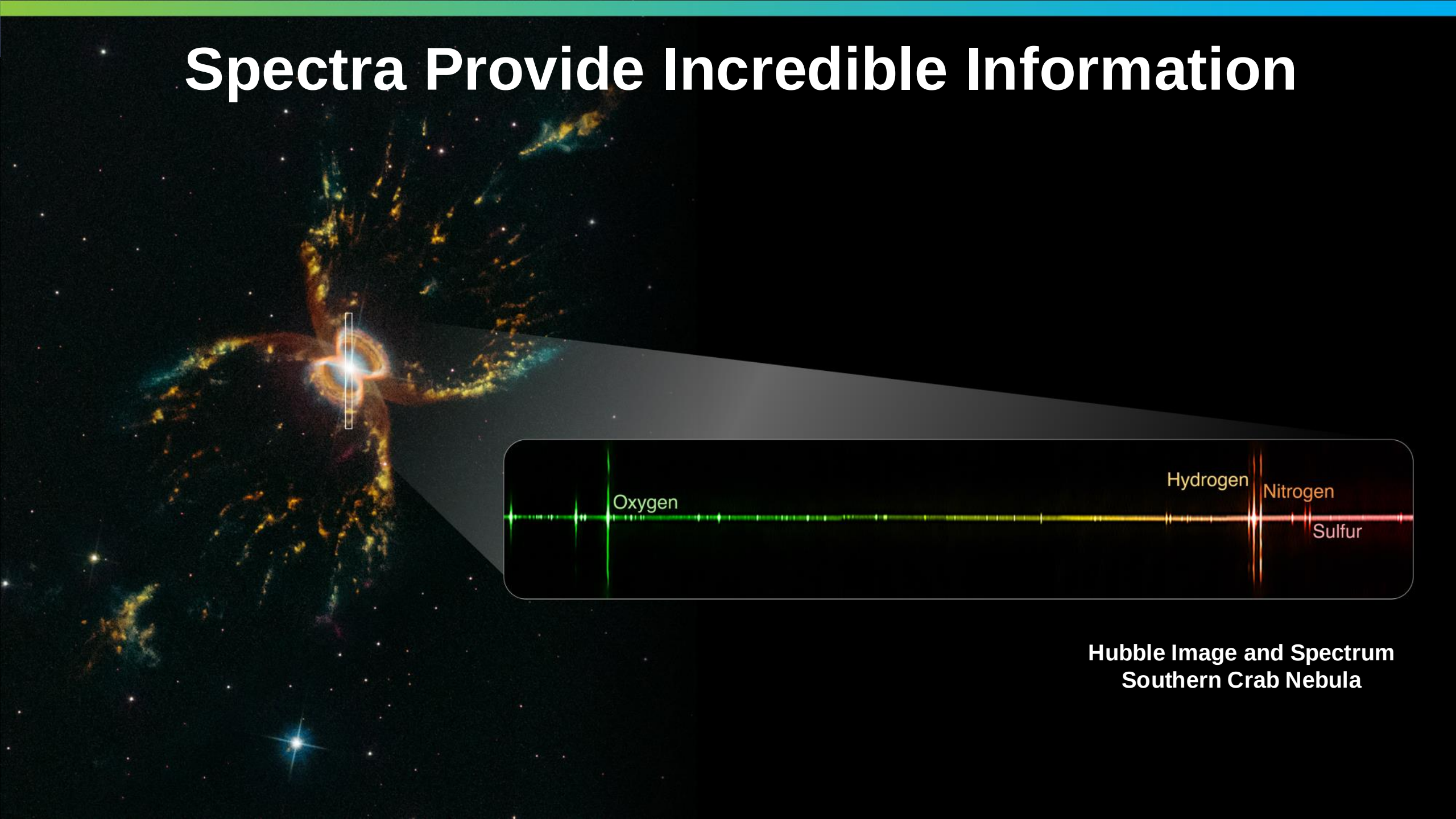
Study how planetary systems form and evolve; discover extrasolar planets; study their atmospheres and habitability.

Observe the giant gas planets in our own Solar System, study the seasonal weather and climate on them and their moons; and study the composition of asteroids and Kuiper belt objects.

Observing the Ancient Universe

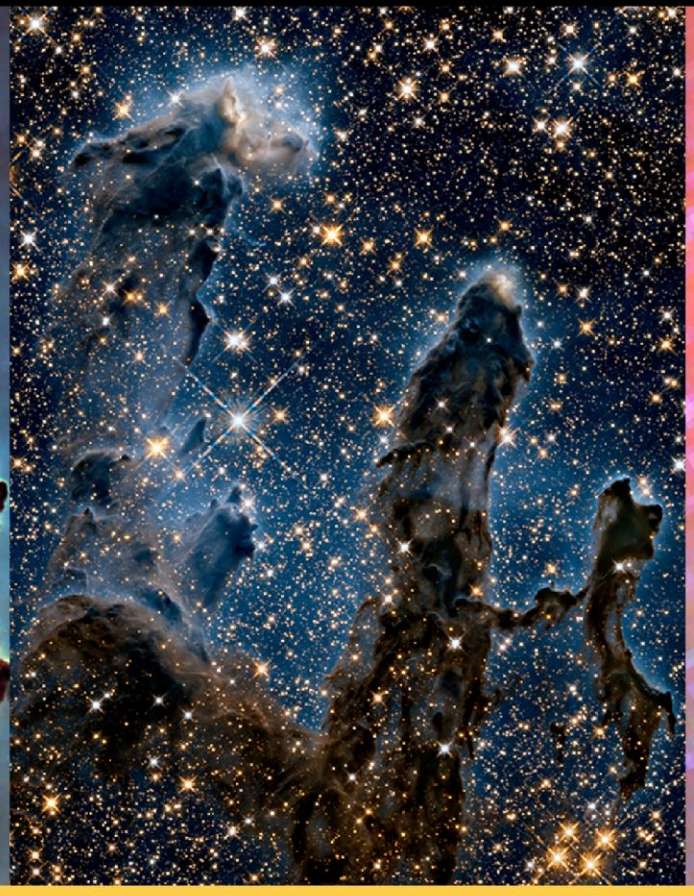


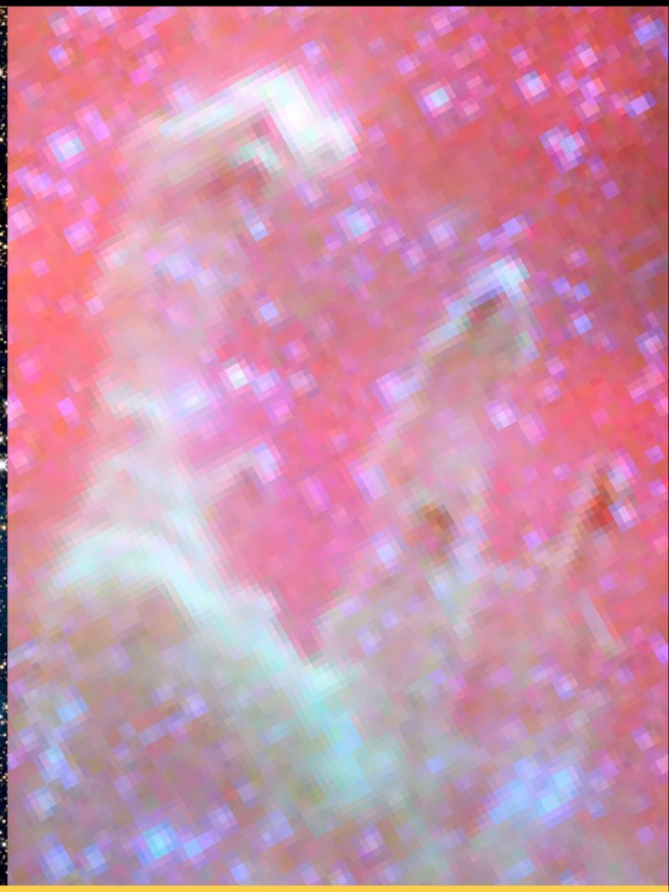
Spectra Provide Incredible Information



Hubble Image and Spectrum
Southern Crab Nebula

Peering Through *and* Examining Dust





Visible Light

Near-Infrared Light

Mid-Infrared Light

UNIVERSE THROUGH TIME

BIG BANG

Universe forms roughly 13.8 billion years ago

Recombination occurs 380,000 years after the big bang

DARK AGES

FIRST STARS form 200–400 million years after the big bang

FIRST GALAXIES

Reionization

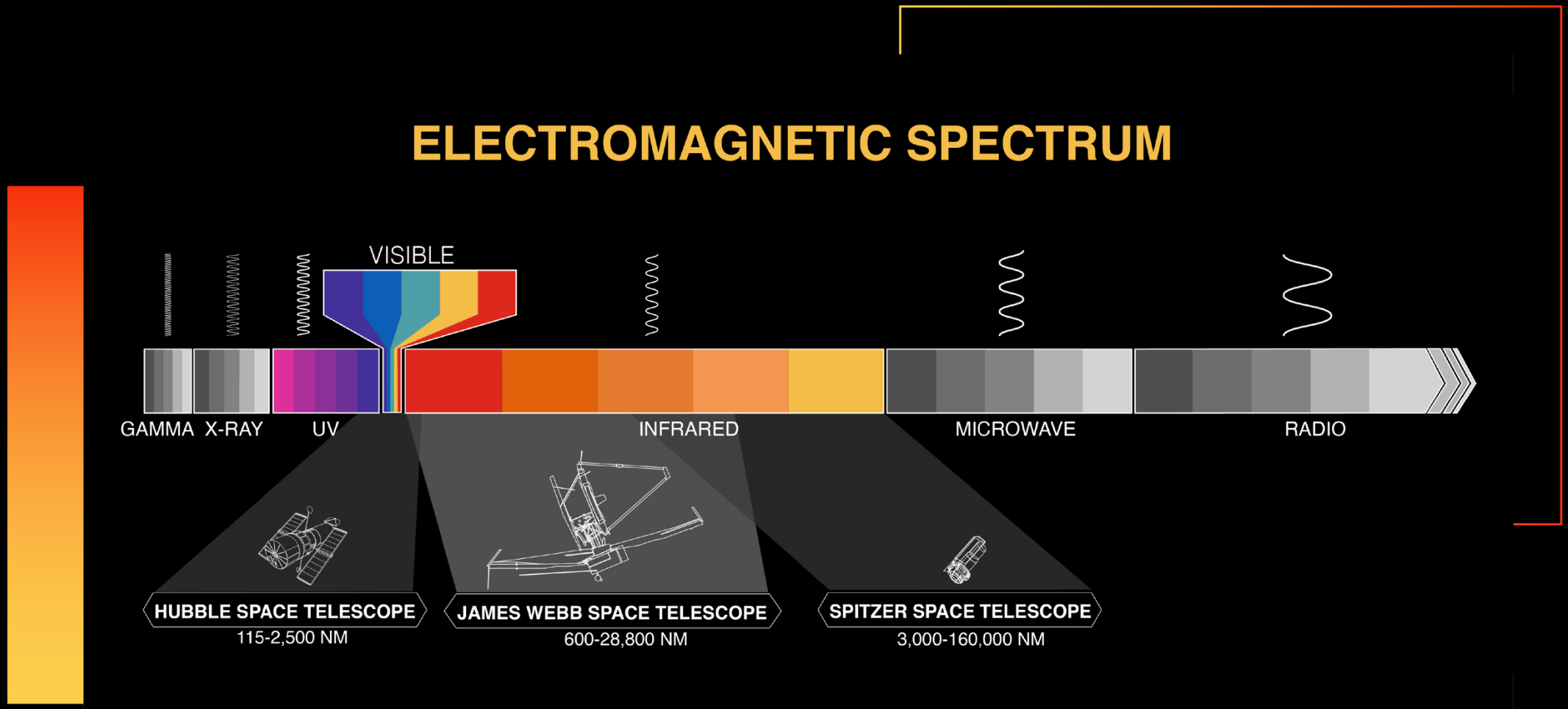
begins when the first stars start to shine

complete within 1 billion years after the big bang

MODERN UNIVERSE

SUN forms more than 9 billion years after the big bang

Webb's Specialization in Infrared Light



Scientific Highlights of JWST


Hubble

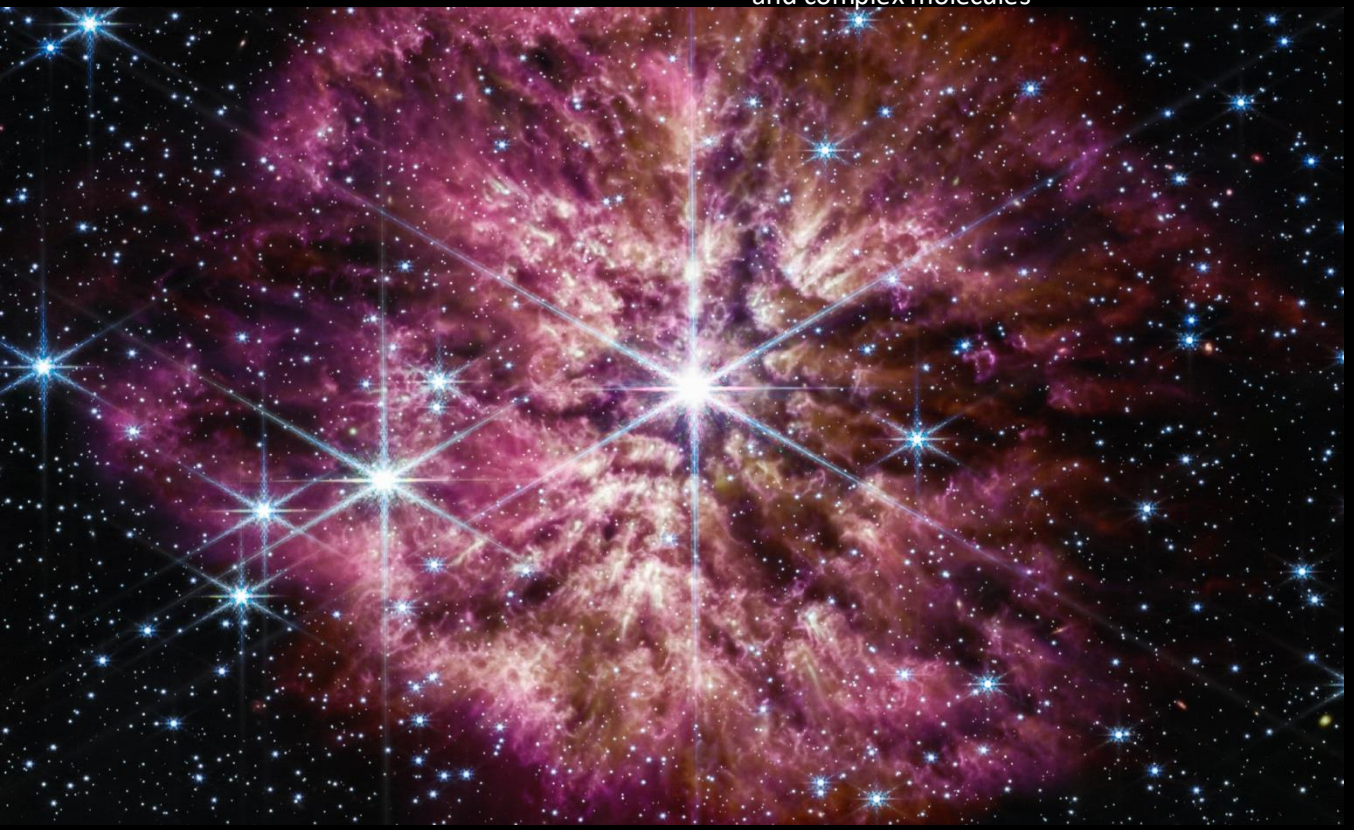
Planetary Nebula | Southern Ring Nebula

Near-Infrared Light
NIRCam Image

Mid-Infrared Light
MIRI Image

Wolf-Rayet Star WR124

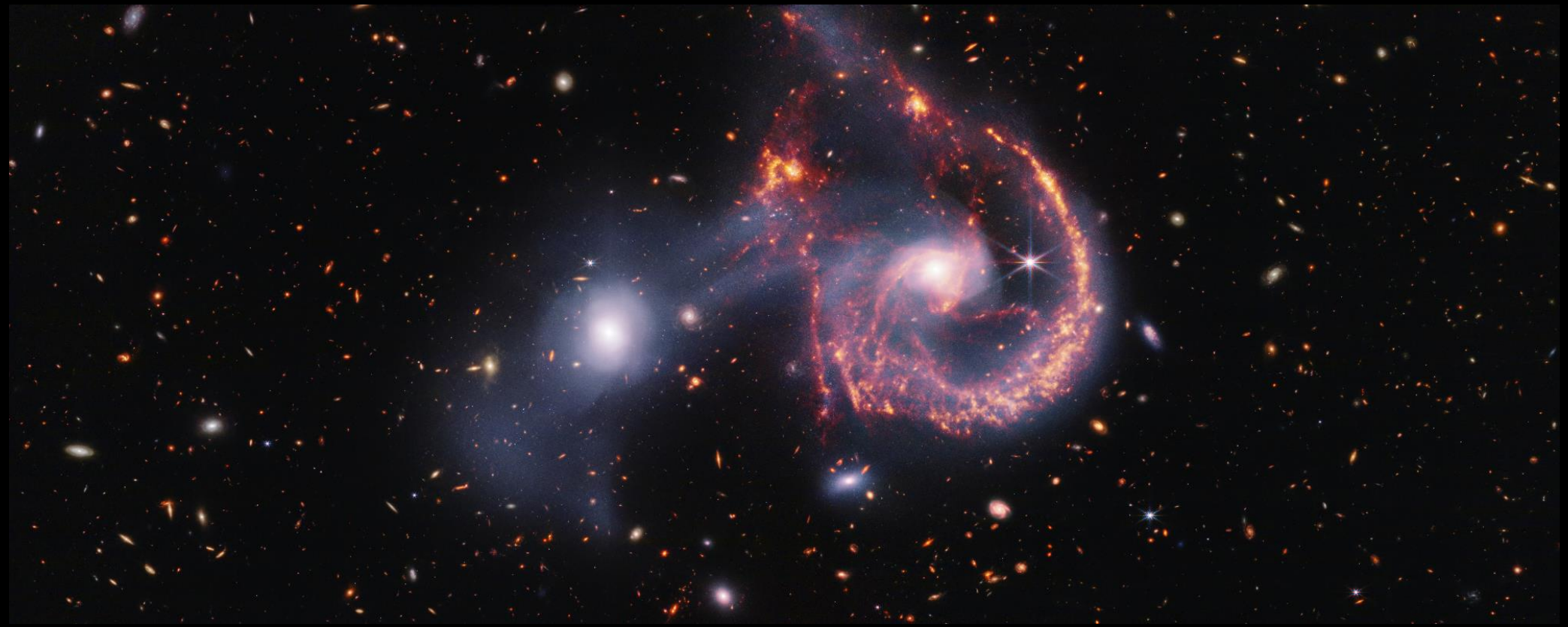
- WR 124's nebular structure created by material cast off from the aging star is displayed by the glow of the cooler cosmic dust in the mid infrared.
- This brilliant stage of mass loss precedes the star's eventual supernova, when nuclear fusion in its core stops and the pressure of gravity causes it to collapse in on itself and then explode.
- Webb will help astronomers to explore questions that were previously only left to theory – about how much dust stars like this create before exploding in a supernova, and how much of that dust is large enough to survive the blast and go on to serve as building blocks of future stars, planets, and complex molecules



L: NIRCAM/MIRI; r: MIRI

Photo Credits:NASA,ESA,CSA,STScI,Webb ERO Production Team

Direct impact is lab for star formation



Arp 107

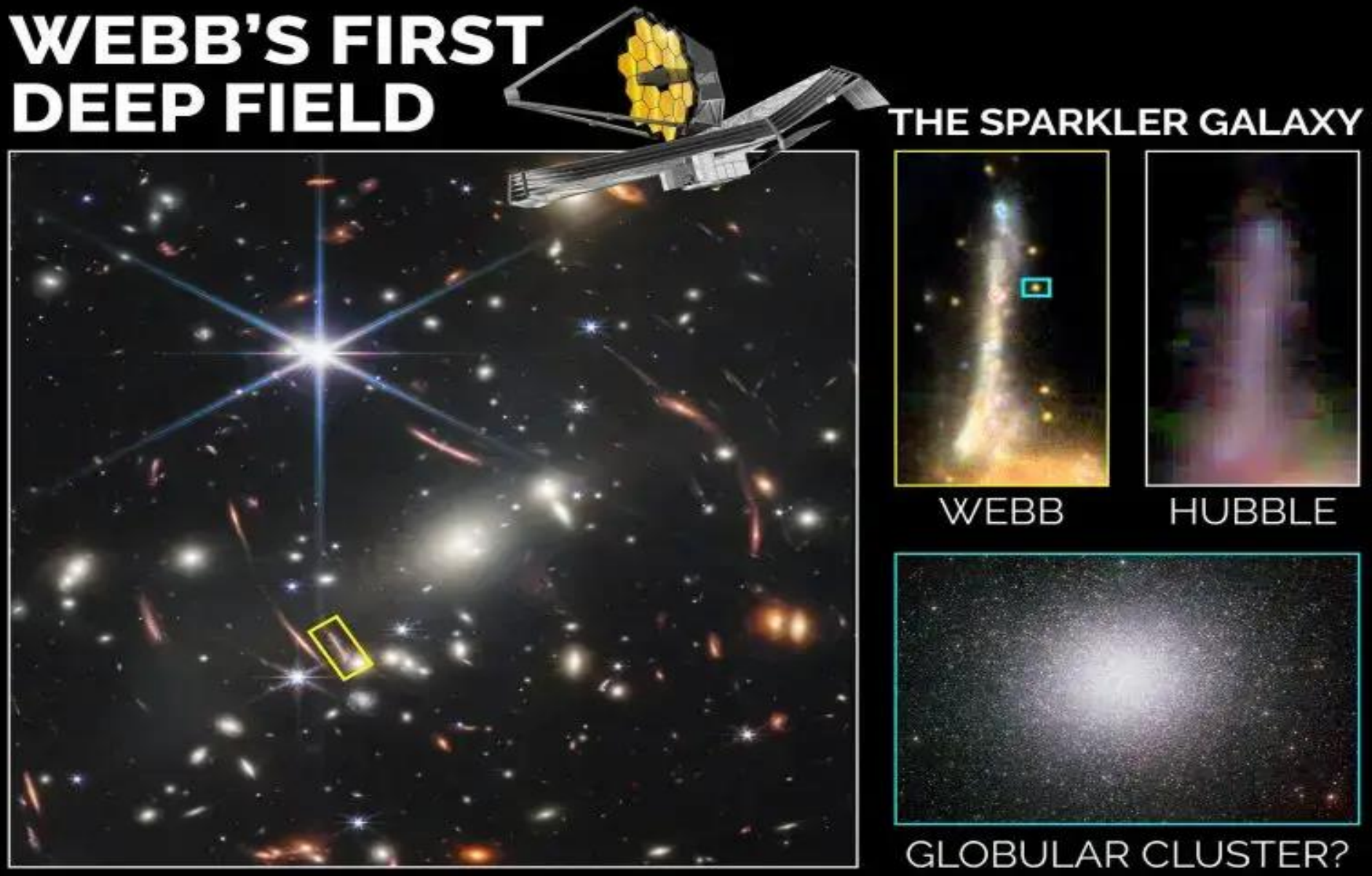
NASA, ESA, CSA, STScI

NIRCAM/MIRI

Seeking Some of the First Galaxies

Webb's First Deep Field
SMACS 0723

Near-Infrared Light
NIRCam Image

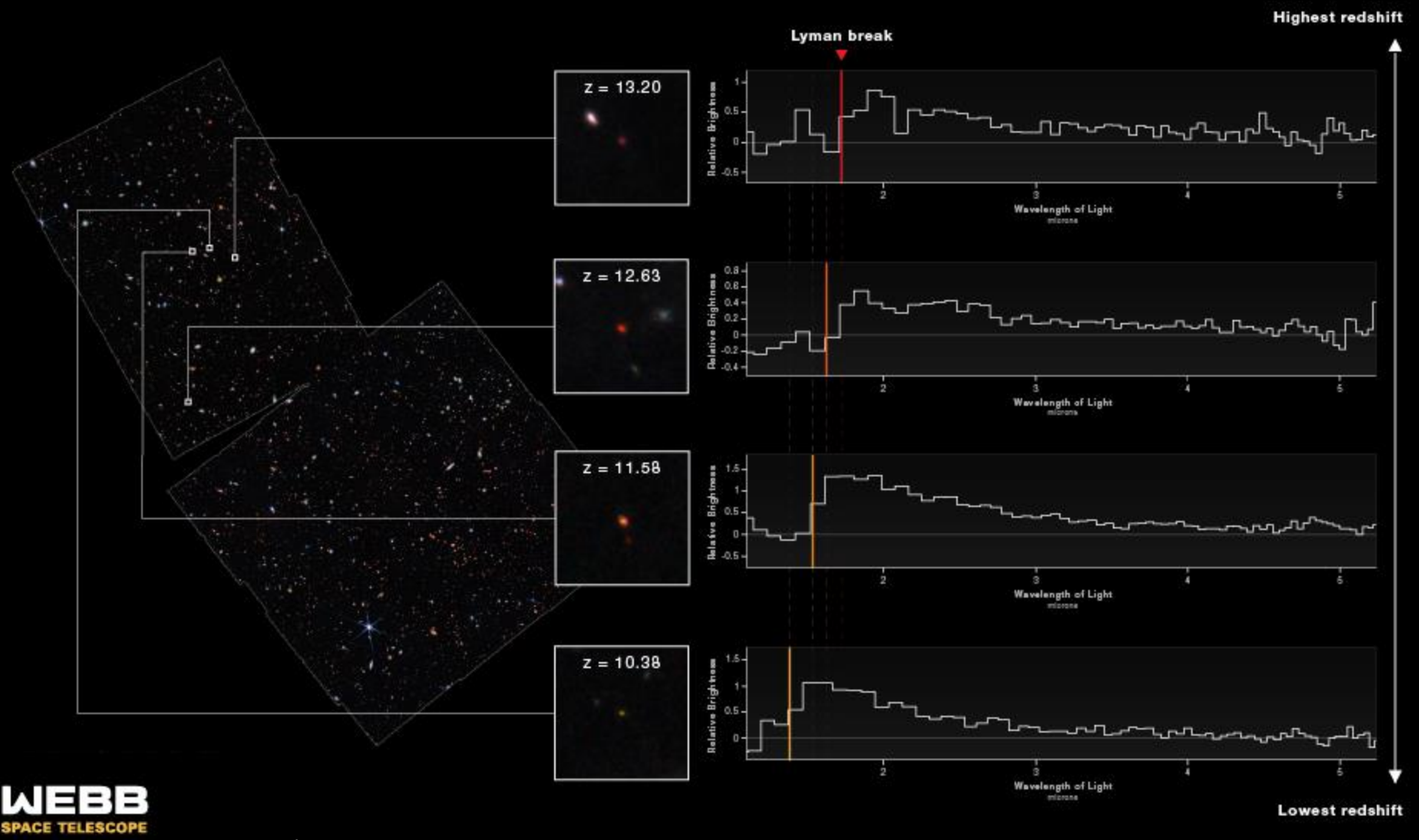


Credit: Image via Canadian Space Agency with images from NASA, ESA, CSA, STScI; Mowla, Iyer et al. 2022

JWST ADVANCED DEEP EXTRAGALACTIC SURVEY (JADES)

WEBB SPECTRA REACH NEW MILESTONE IN REDSHIFT FRONTIER

Of 250 galaxies, 4 at z > 10



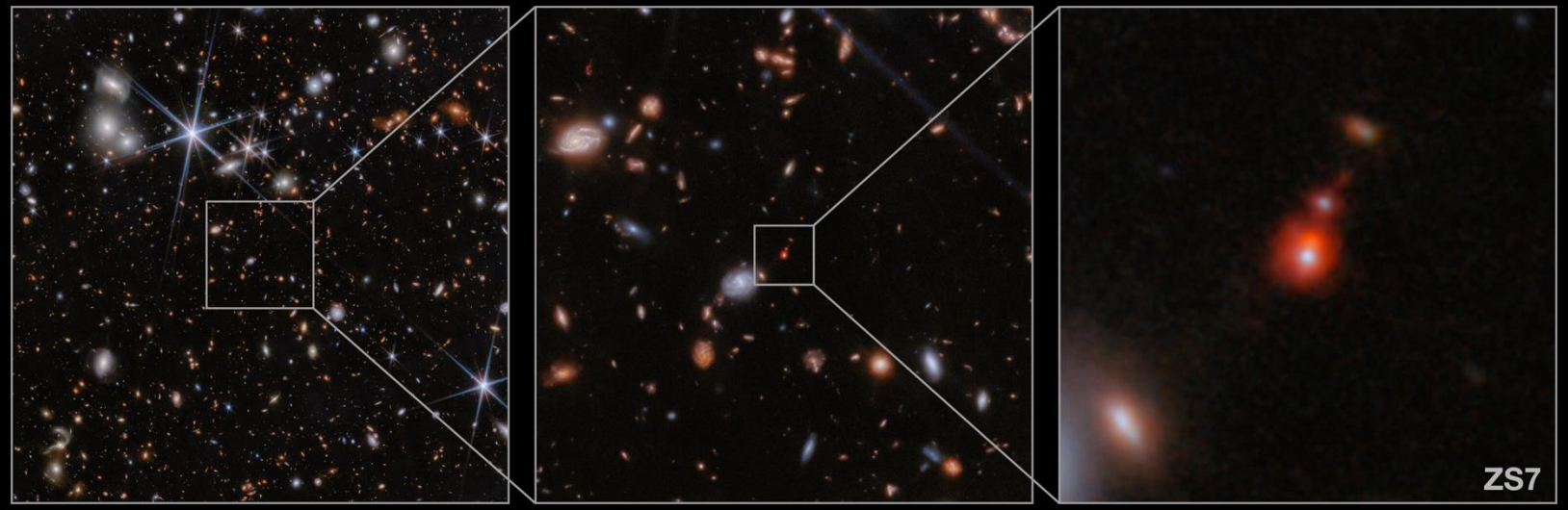
WEBB SPACE TELESCOPE

IMAGE: NASA, ESA, CSA, M. Zamani (ESA/Webb), Leah Hustak (STScI)

SCIENCE: Brant Robertson (UC Santa Cruz), S. Tacchella (Cambridge), E. Curtis-Lake (UOH), S. Carniani (Scuola Normale Superiore), JADES Collaboration

NGC628 = M74. Mid IR info reprocessed by Judy Schmidt. Image Credit: NASA/ESA/CSA/STSCI/JUDY SCHMIDT CC BY 2.0

Webb Detects Most Distant Black Hole Merger (May 2024)



ZS7 location in PRIMER image (NIRCam image)

the growth of black holes in the early Universe.

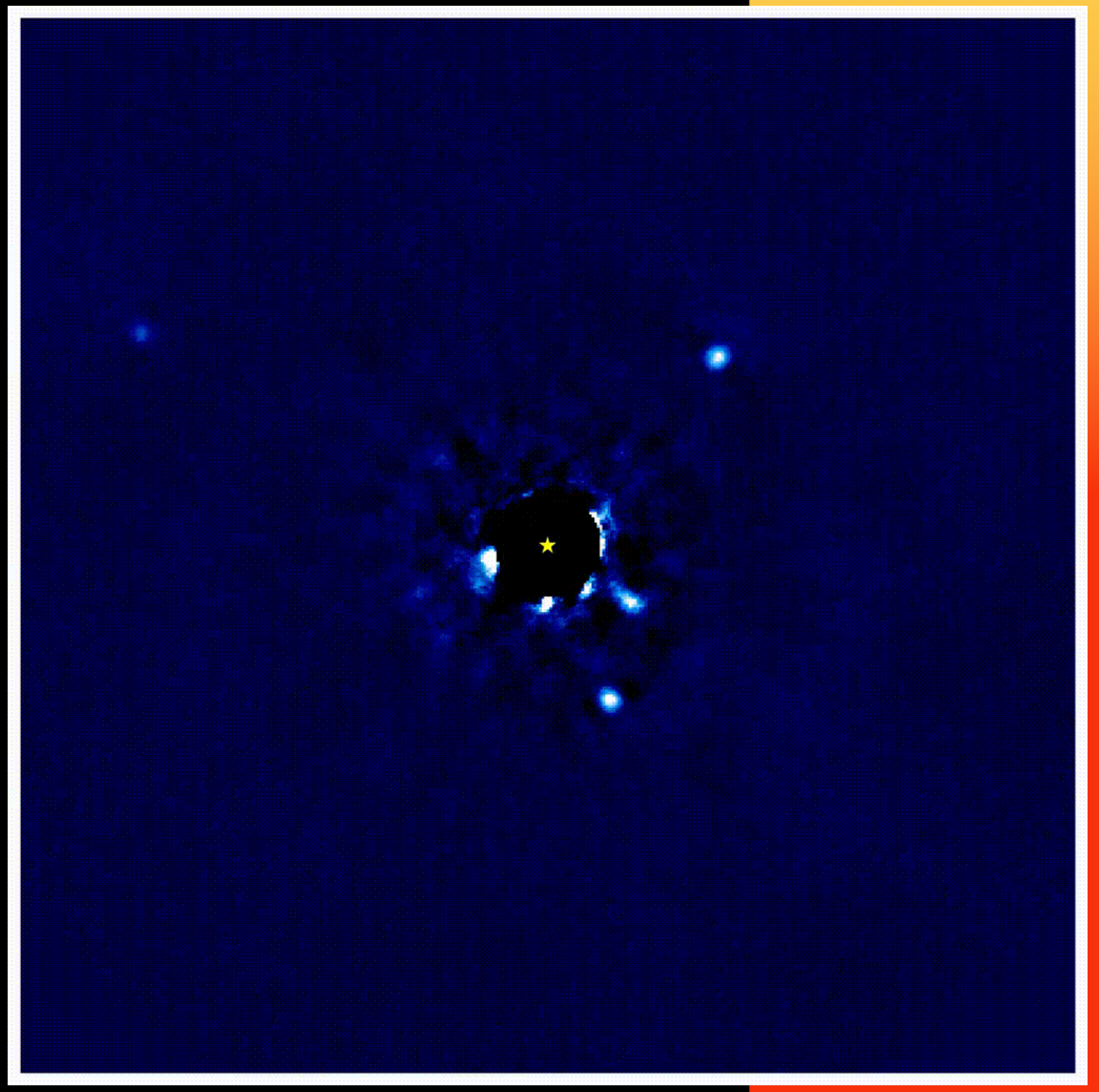
evidence for an ongoing merger of two galaxies and their massive black holes when the Universe was 740 million years old. The system is known as ZS7.

distinctive spectrographic features that enable astronomers to identify massive black holes that are actively accreting matter.

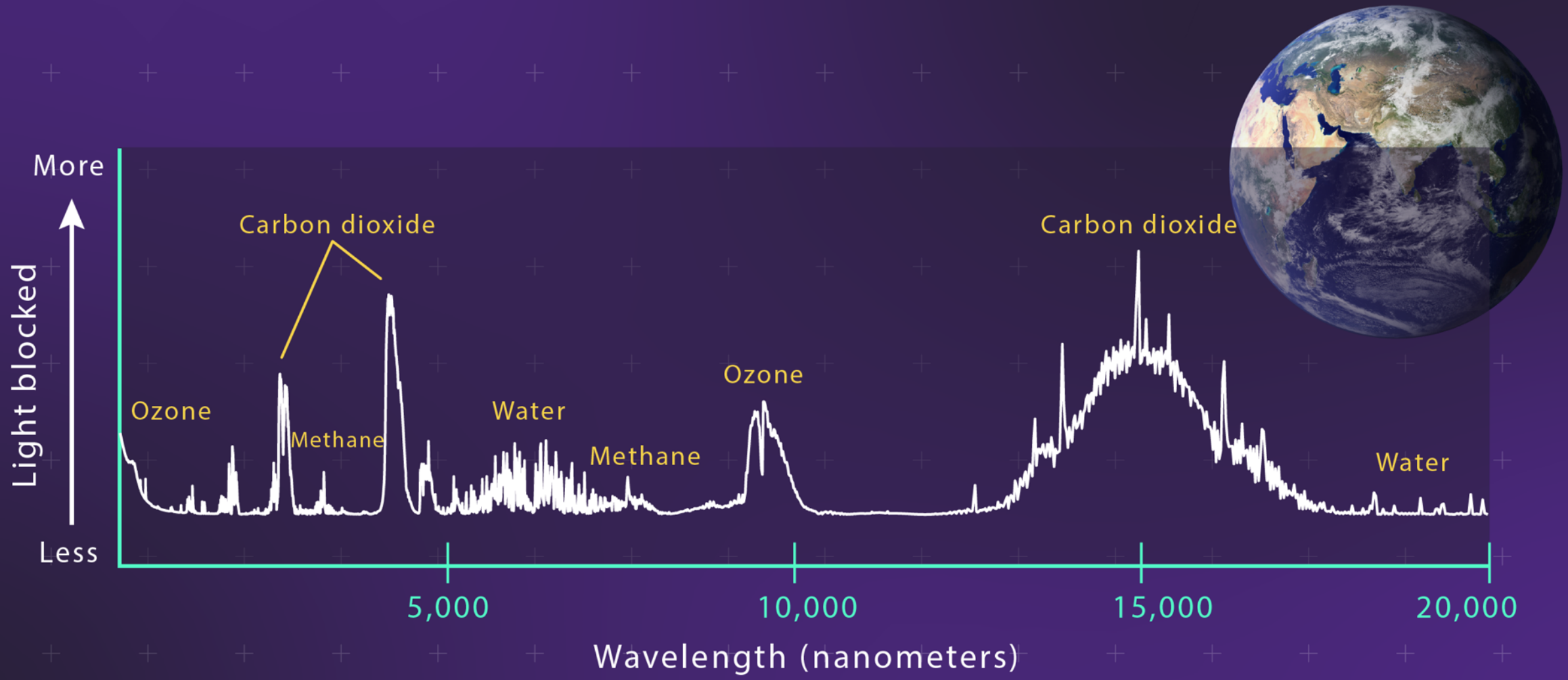
Evidence was found for very dense gas with fast motions in the vicinity of the black hole, as well as hot and highly ionized gas illuminated by the energetic radiation typically produced by black holes in their accretion episodes

NIRCam images allowed the team to spatially separate the two black hole.

Infrared Light Helps Us Find Distant Planets

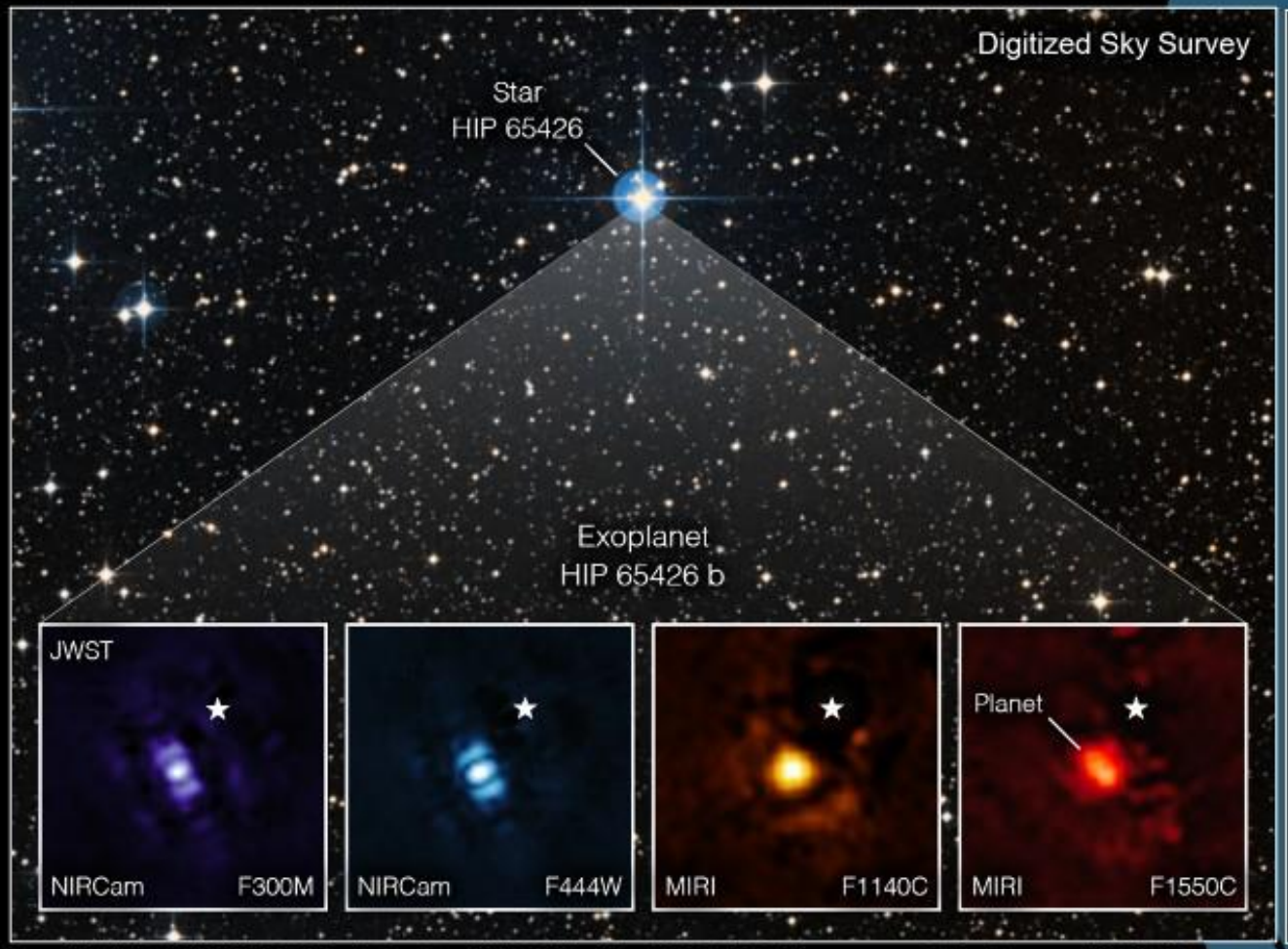


Decoding Planets' Atmospheres



NASA's Webb Takes Its First-Ever Direct Image of Distant World

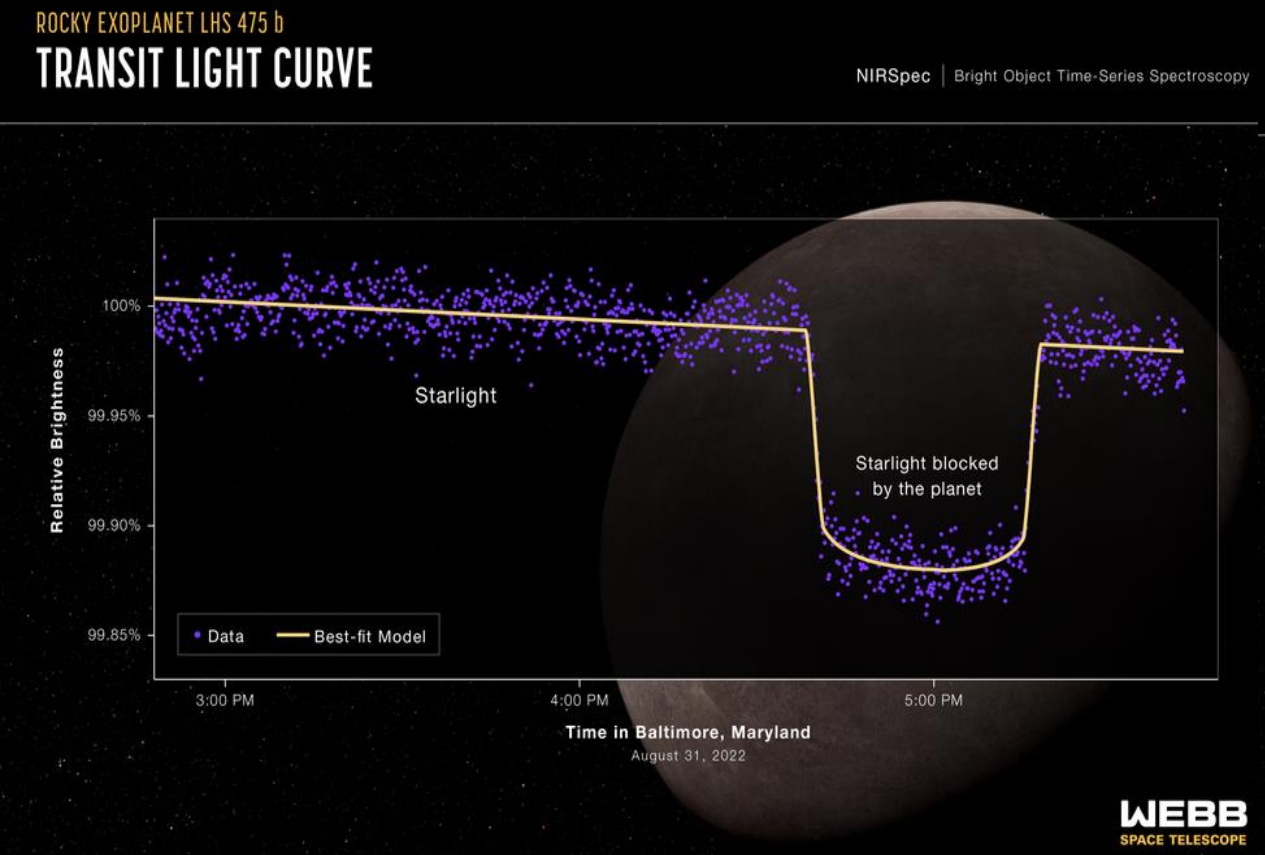
SCIENCE HIGHLIGHT

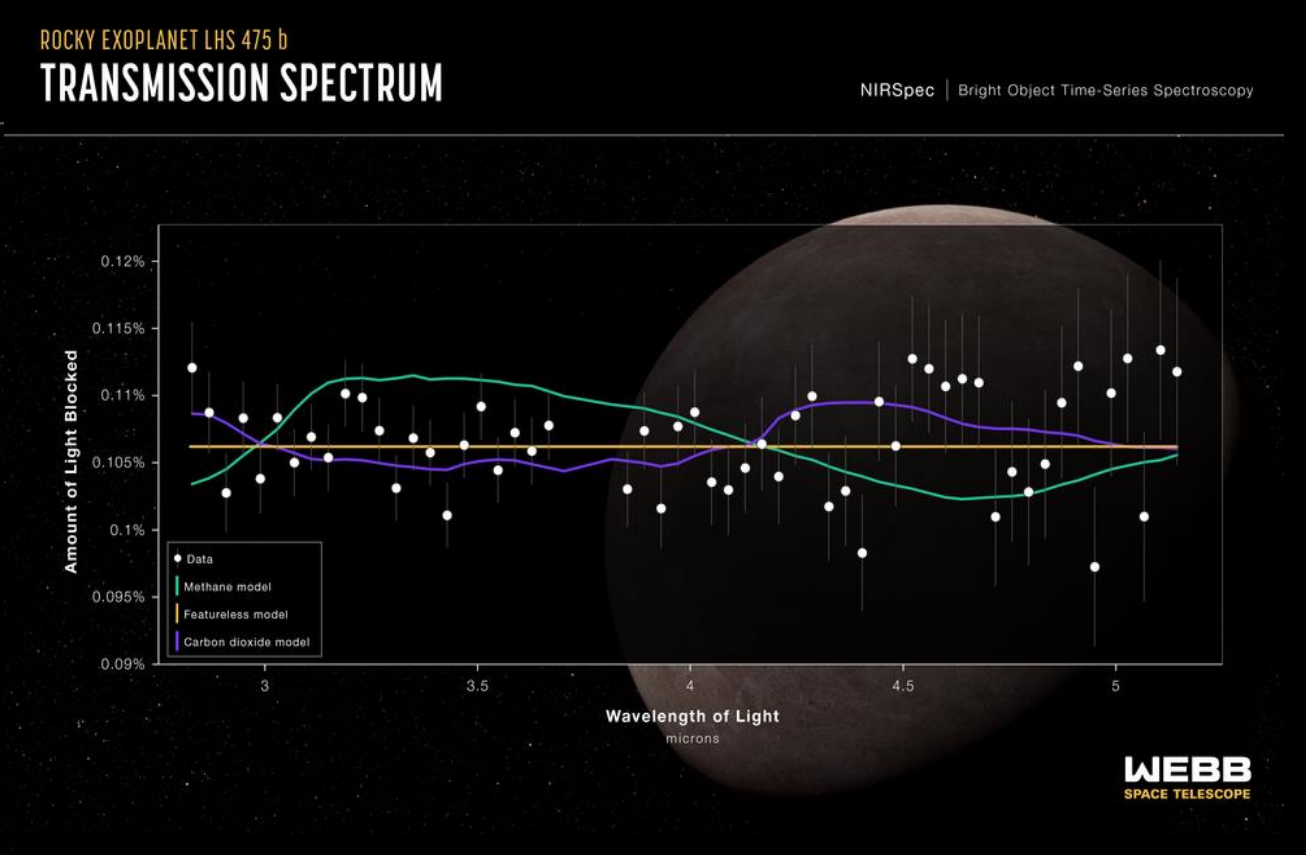


Credit: NASA/ESA/CSA, A Carter (UCSC), the ERS 1386 team, and A. Pagan (STScI).

- These JWST coronagrphic images shows the exoplanet HIP 65426 b in different infrared bands of infrared light.
  - NIRCam instrument's view at 3.00 μm (purple),
  - NIRCam instrument's view at 4.44 μm (blue),
  - MIRI instrument's view at 11.4 μm (yellow)
  - MIRI instrument's view at 15.5 μm (red)
- The small white star in each image marks the location of the host star HIP 65426, which has been subtracted using the coronagraphs and image processing. The bar shapes in the NIRCam images are artifacts of the telescope's optics, not objects in the scene.

Webb discovers Earth size rocky planet



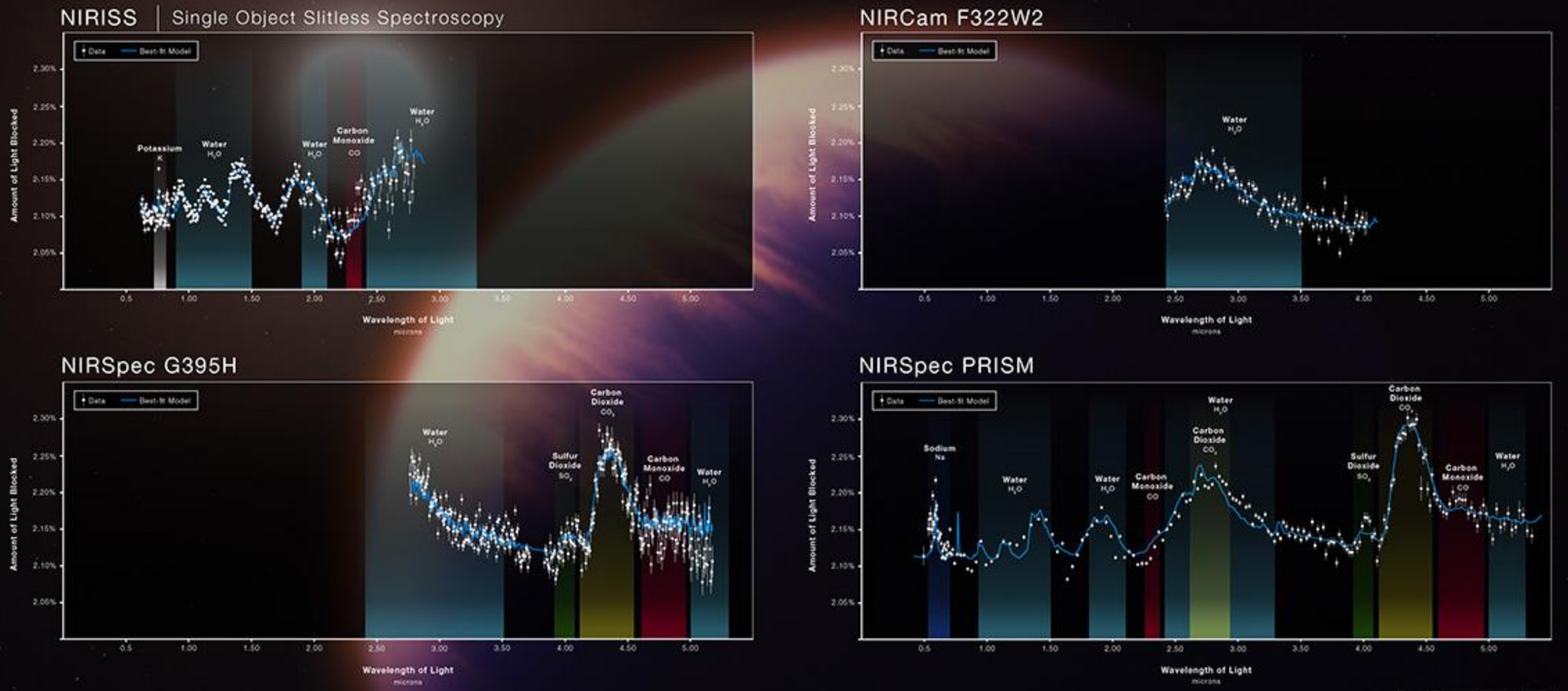


Credits: Illustration: NASA, ESA, CSA, L. Hustak (STScI); Science: K. Stevenson, J. Lustig-Yaeger, E. May (JHU/APL), G. Fu (JHU), and S. Moran(UoA)

HOT GAS GIANT EXOPLANET WASP-39 b

ATMOSPHERE COMPOSITION

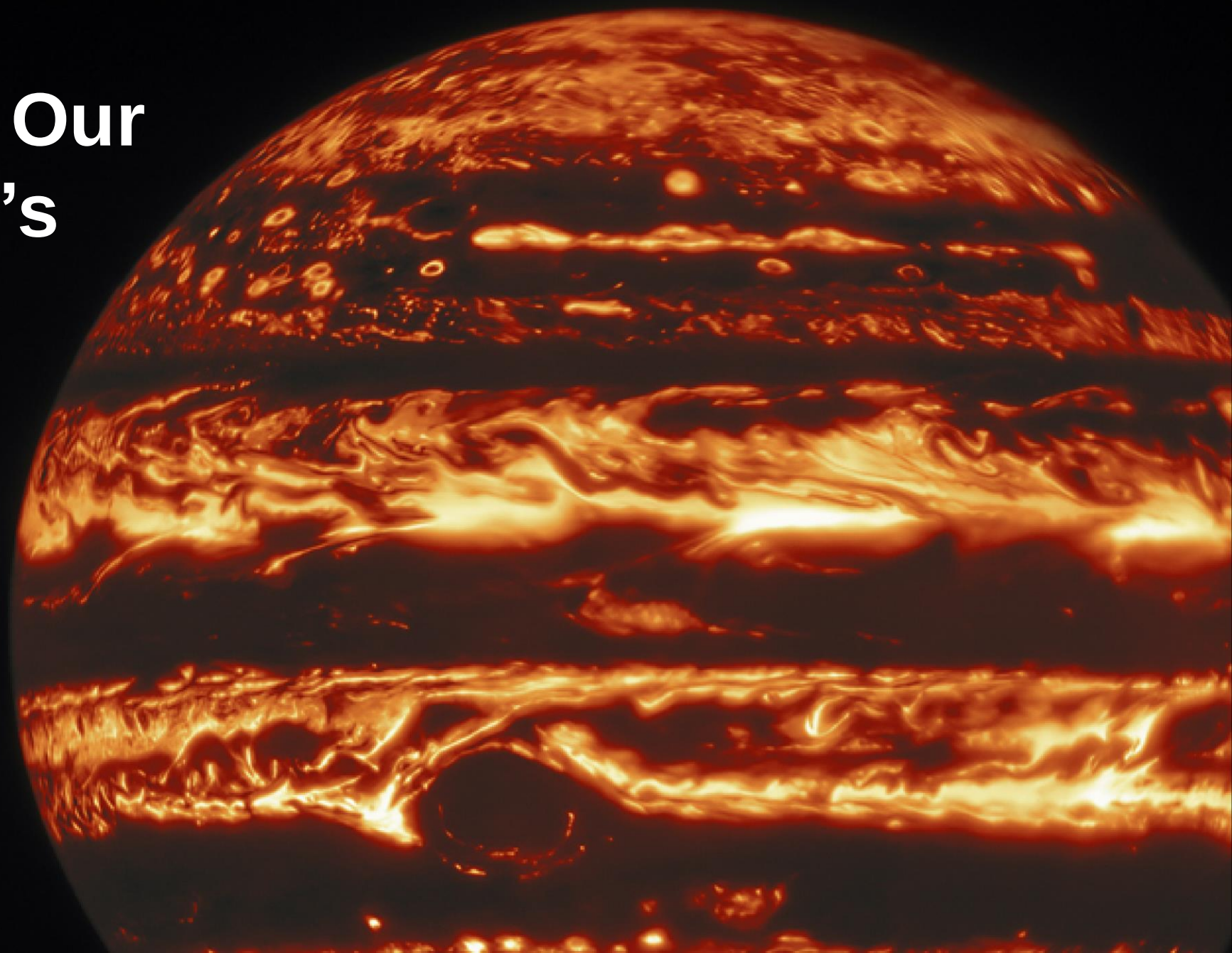
4 instruments show lines of Na, K, CO, CO_2, H_2O, SO_2



WEBB SPACE TELESCOPE

ILLUSTRATION: NASA, ESA, CSA, Joseph Olmsted (STScI)

Reexamining Our Solar System's Planets



Jupiter in Near-Infrared Light
(Gemini North)

Webb's View of Jupiter

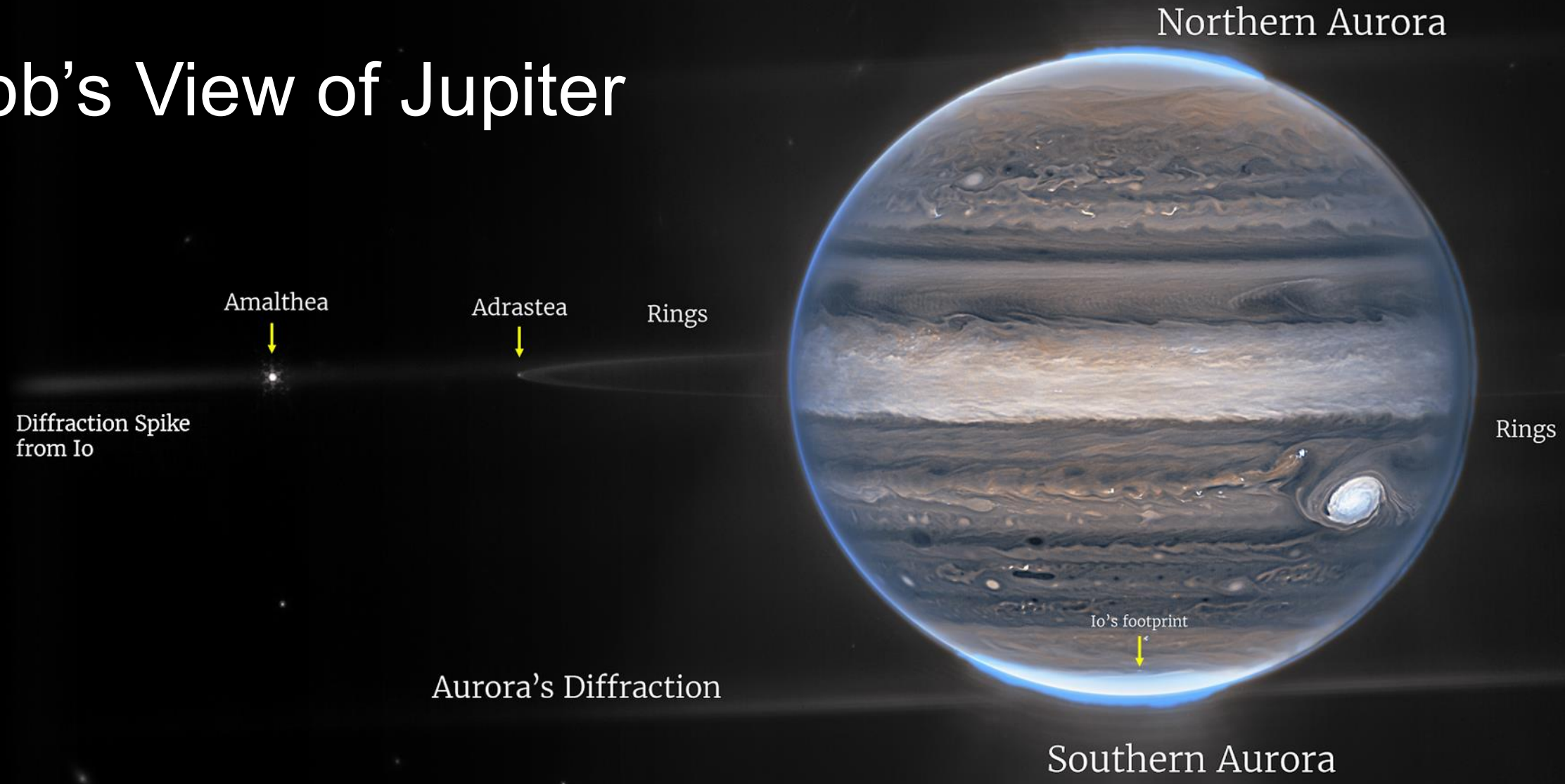
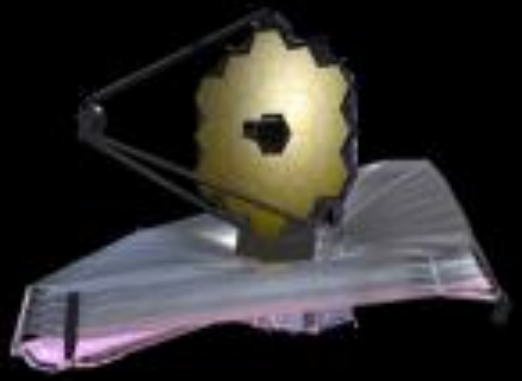


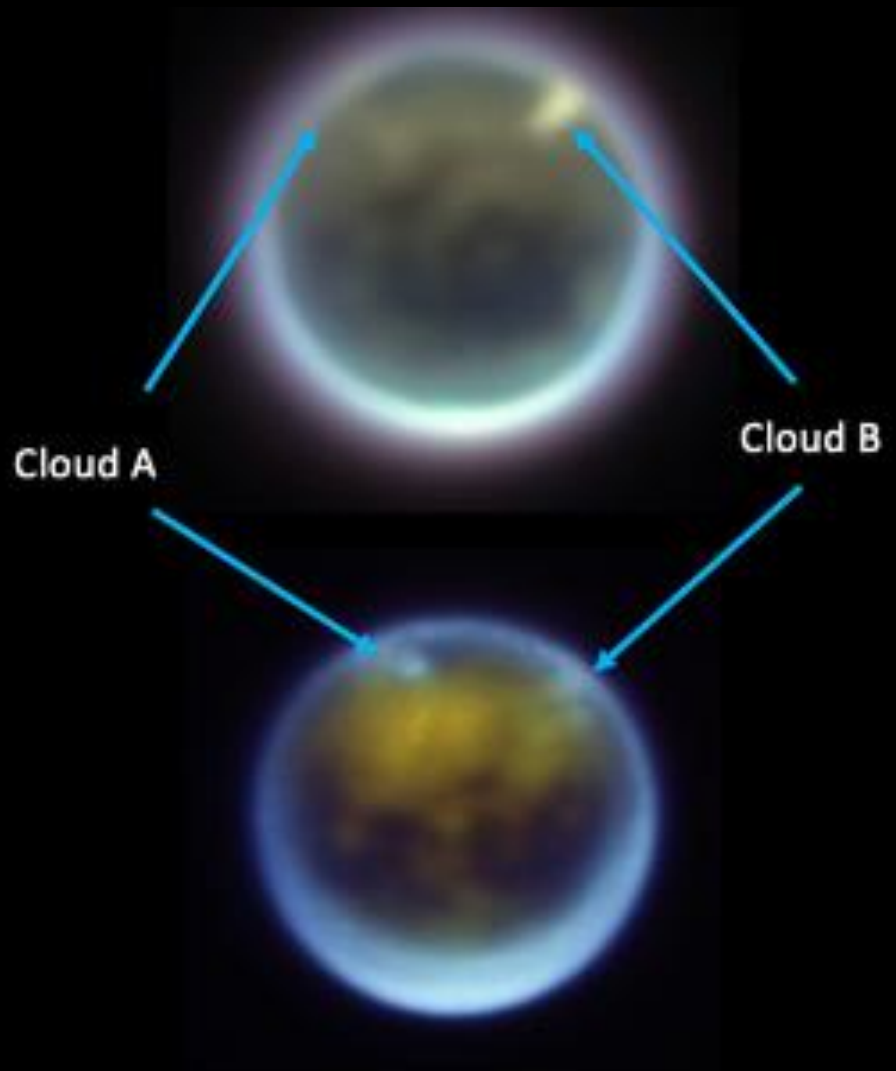
Image credit: NASA, ESA, Jupiter ERS Team; image processing by Ricardo Hueso (UPV/EHU) and Judy Schmidt

Saturn's Moon Titan

JWST NIRCam Nov 4th 2022

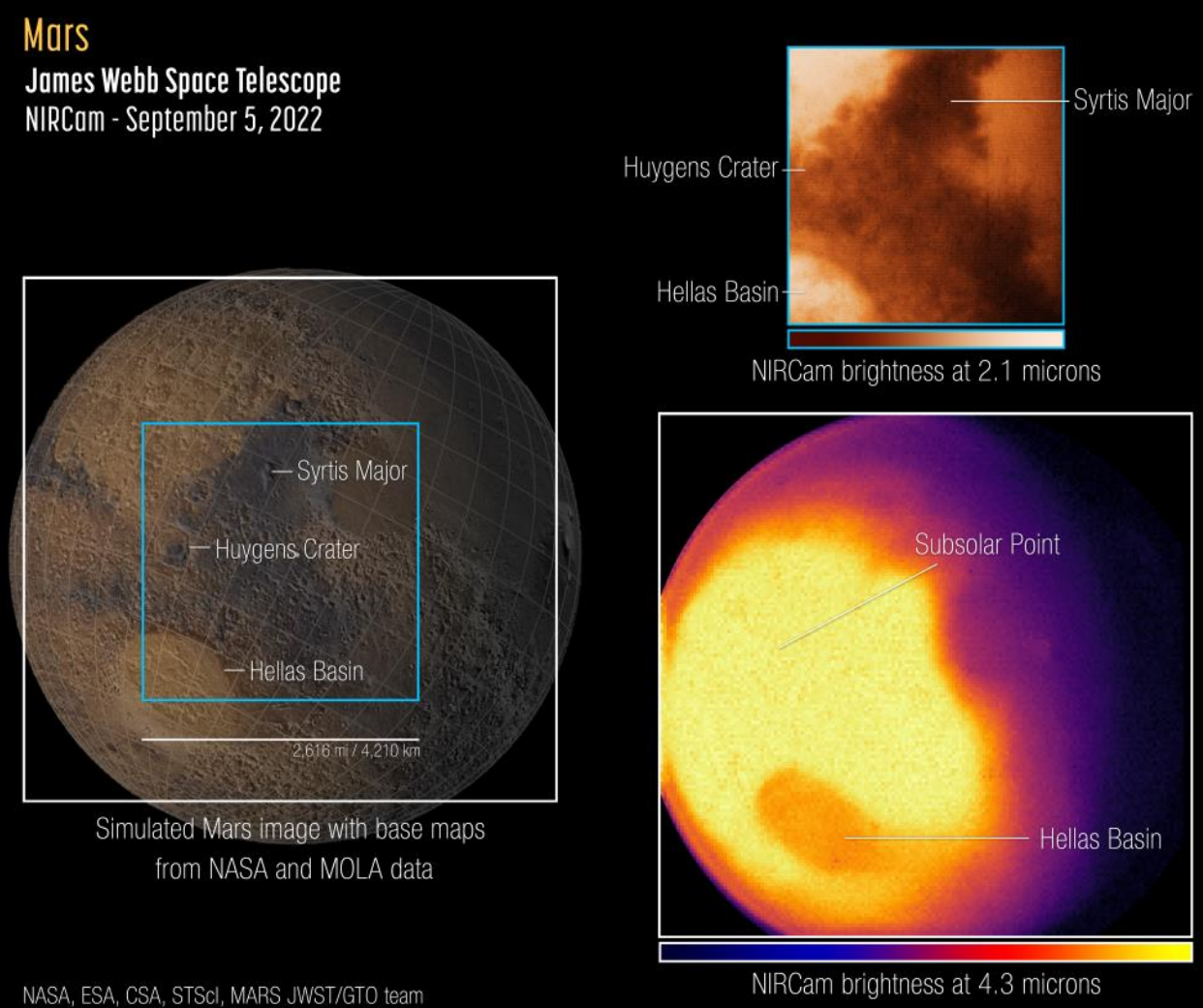


Keck NIRC-2 Nov 6th 2022

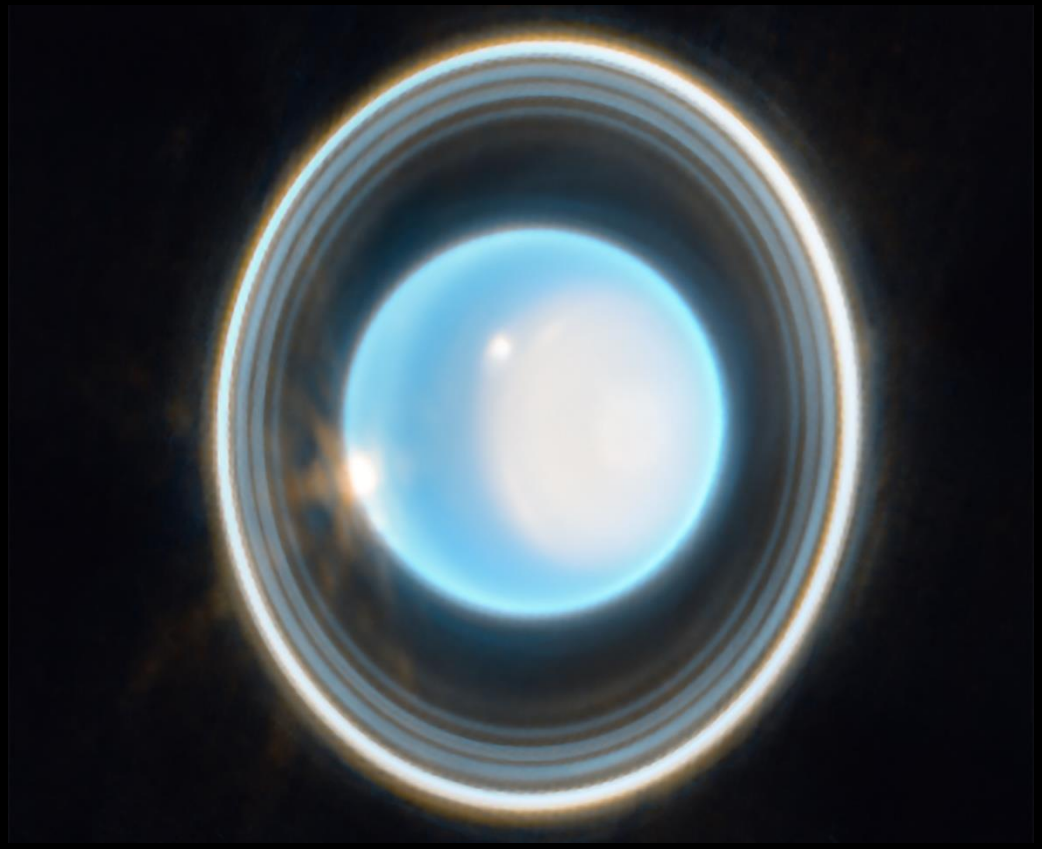


- Tracking clouds over Titan give insight into how air is flowing in Titan's atmosphere
- As the only moon in our solar system with a dense atmosphere as well as the only place besides Earth to have present-day liquid rivers, lakes, oceans, we hope to deepen our understanding of Titan's environment

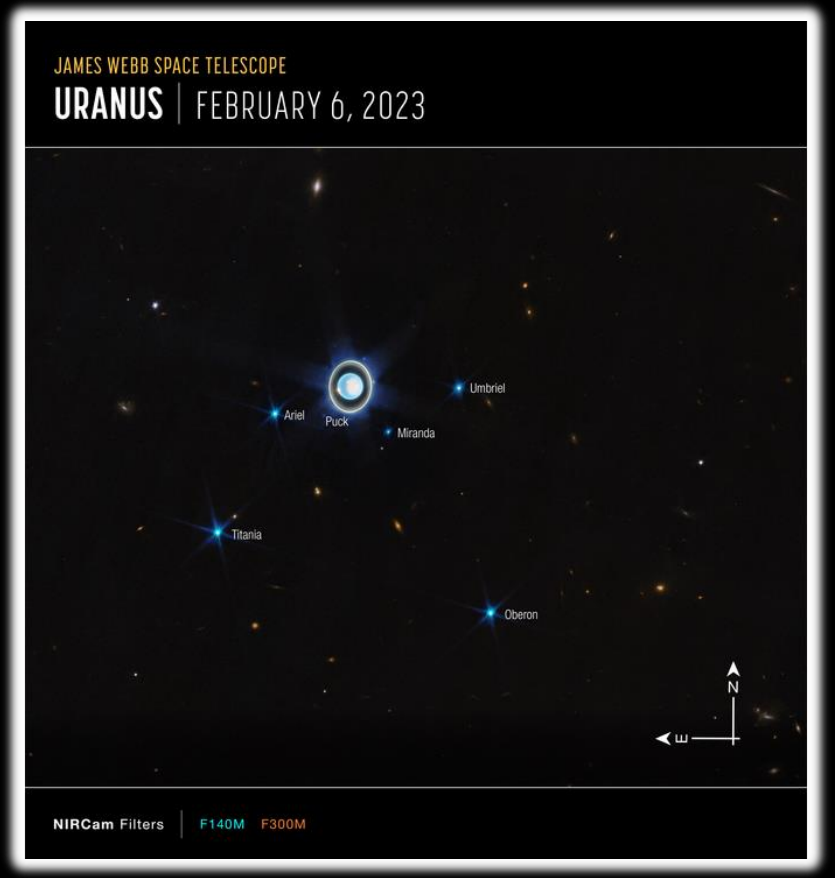
Webb's View of Mars



- Top right: dominated by reflected sunlight reveals details similar to visible image (left)
- Lower right: shows thermal emission. Brightest region is where sun is nearly overhead, decreasing towards polar regions.
- As light emitted by the planet passes through Mars' atmosphere, some gets absorbed by carbon dioxide (CO_2) molecules. The Hellas Basin – which is the largest well-preserved impact structure on Mars, spanning more than 1,200 miles (2,000 kilometers) – appears darker than the surroundings because of this effect.

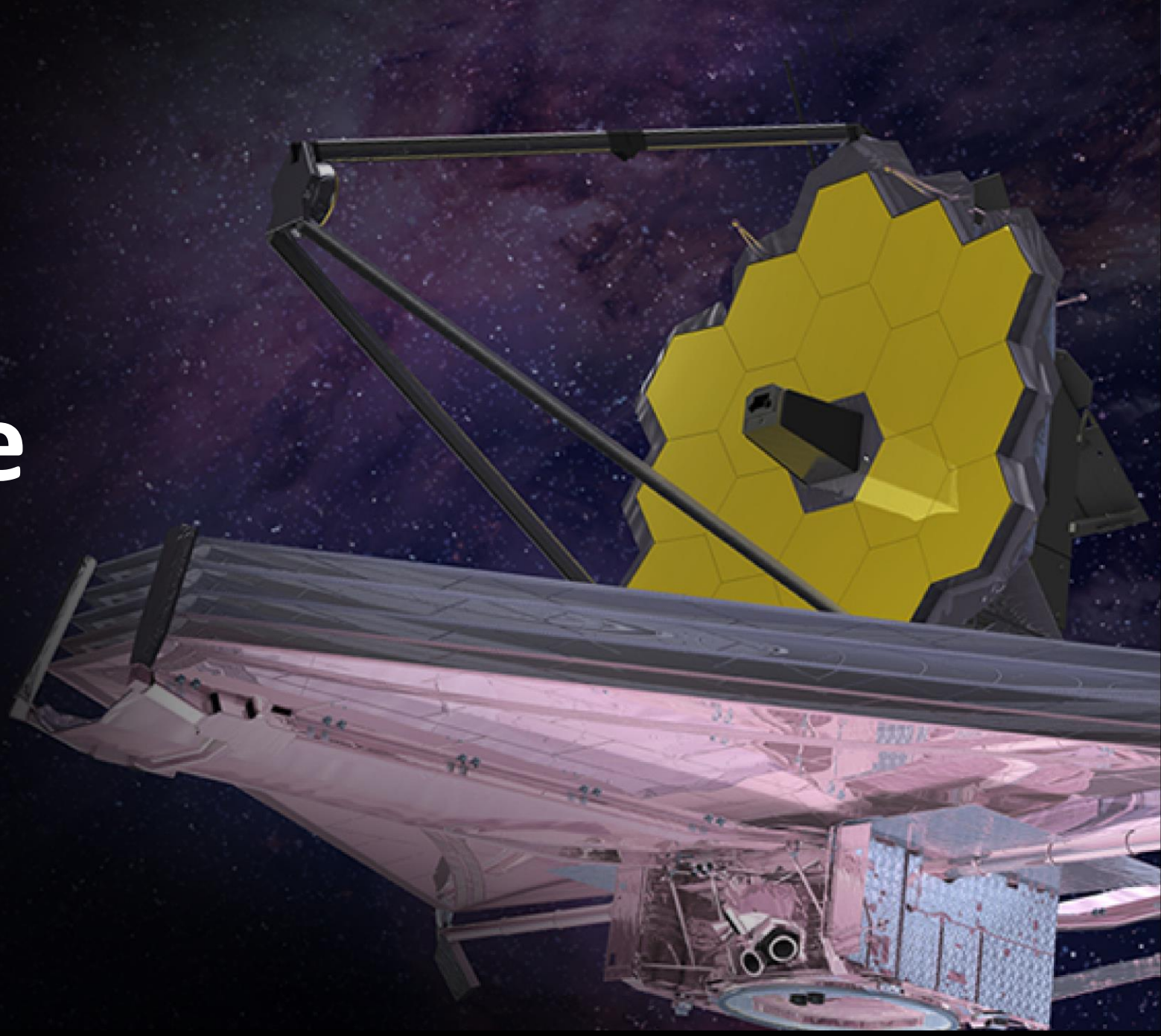


New Image of Uranus: A Ringed World



This wider view of the Uranian system with Webb's NIRCam instrument features the planet Uranus as well as six of its 27 known moons

All About the Telescope



James Webb Space Telescope (JWST)

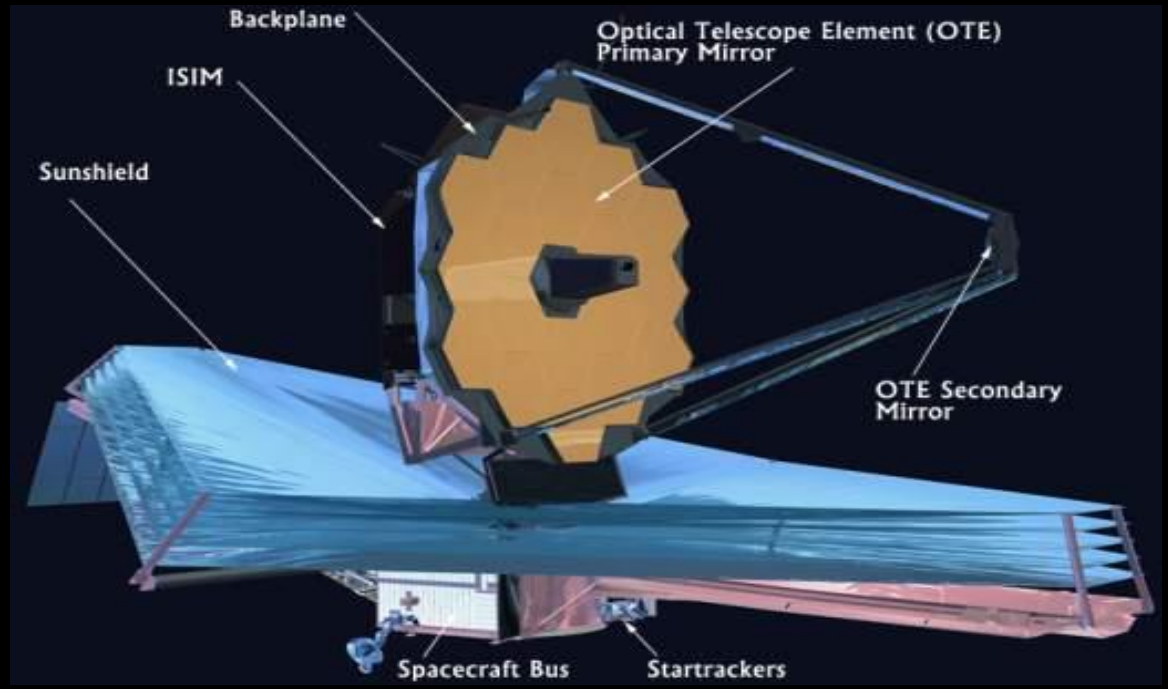
Organization

- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Contractor: Northrop Grumman Space Systems
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) and Near IR Imaging Slitless Spectrograph (NIRISS) – 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

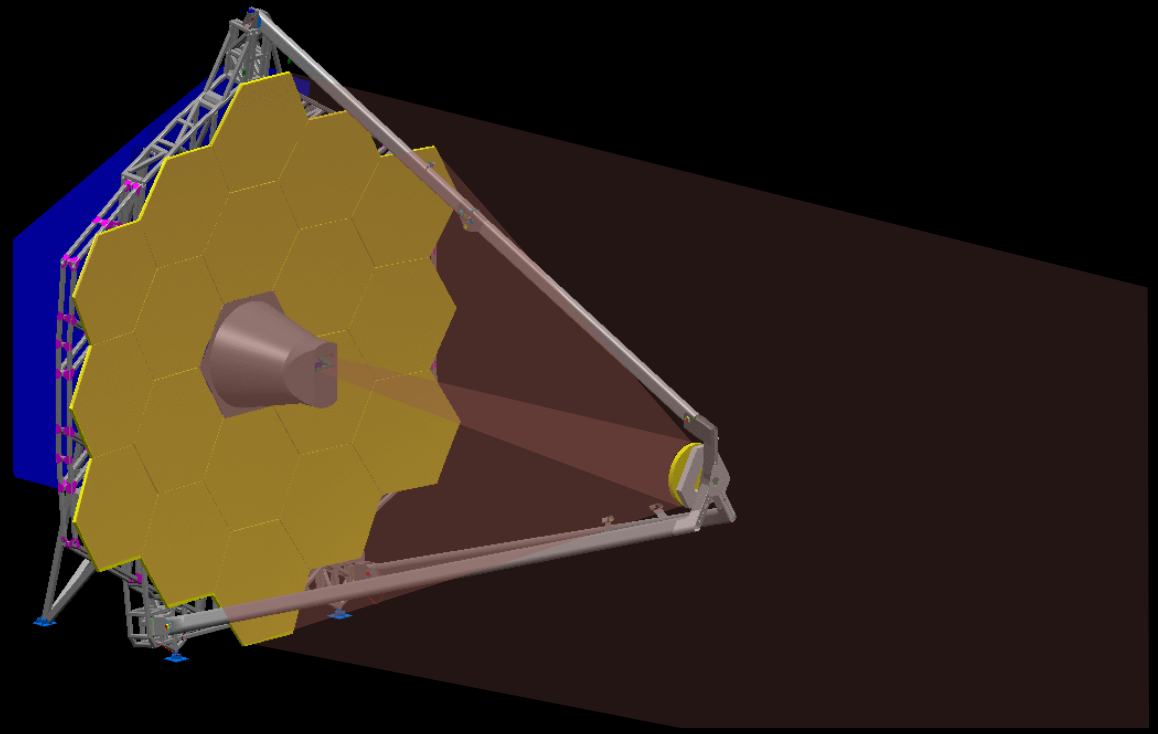
End of the dark ages: First light and reionization

The assembly of galaxies

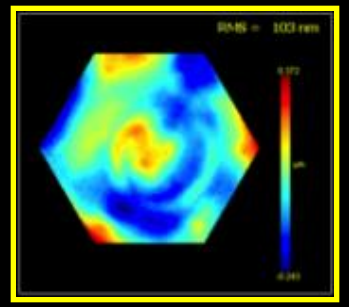
Birth of stars and proto-planetary systems

Planetary systems and the origin of life

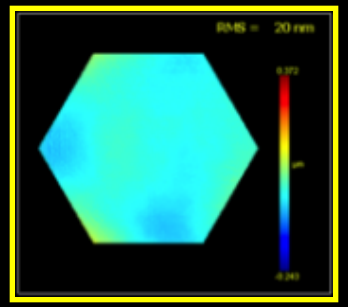
JWST's Telescope Design



- 18 primary mirror segments
- 6 degrees of freedom + ROC (radius of curvature) adjustments
- Beryllium mirrors, 2 mm thick, with ribs
- 40 K operation
- Polish to be correct shape when cold
- Long lead time fabrication



Ambient Surface



Cryo Surface

Elliptical f/1.2 Primary Mirror (PM)

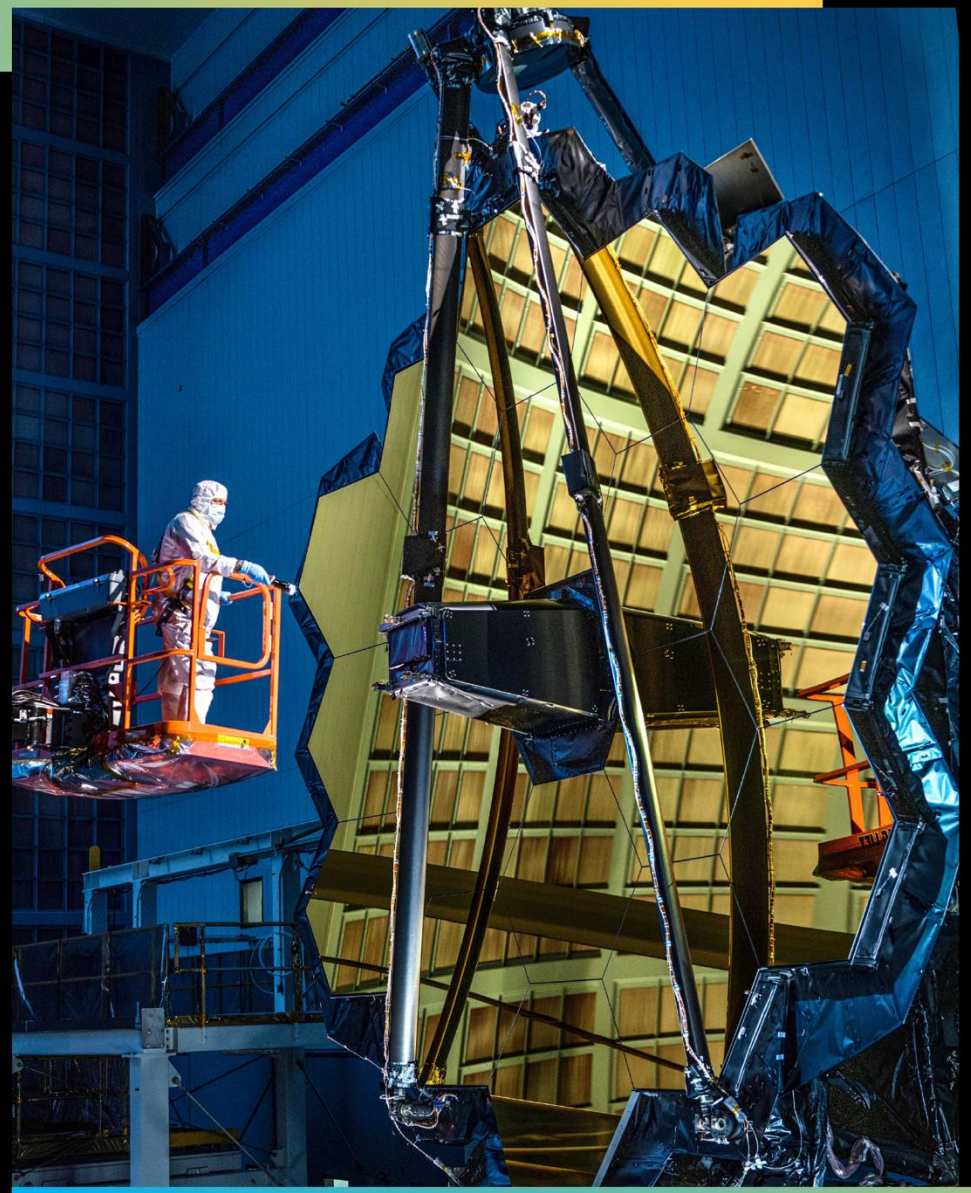
Hyperbolic Secondary Mirror (SM)

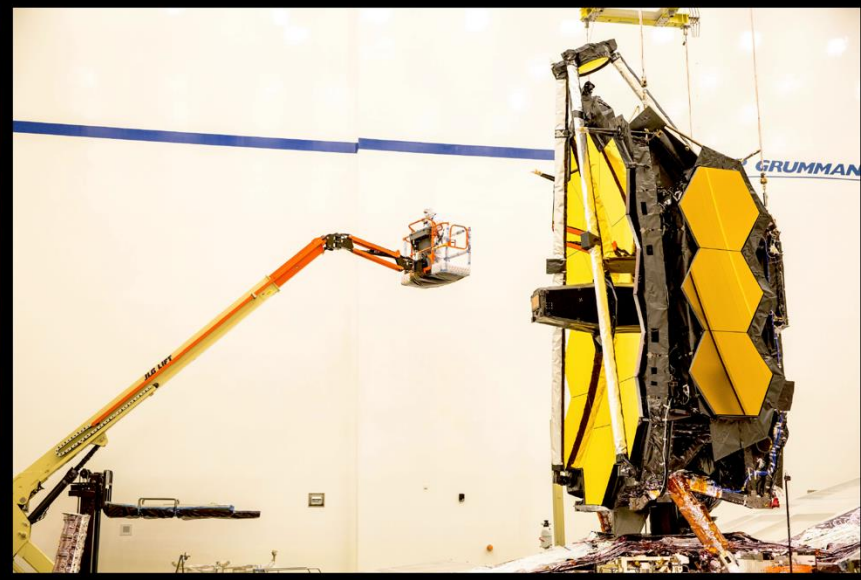
Elliptical Tertiary Mirror (TM)

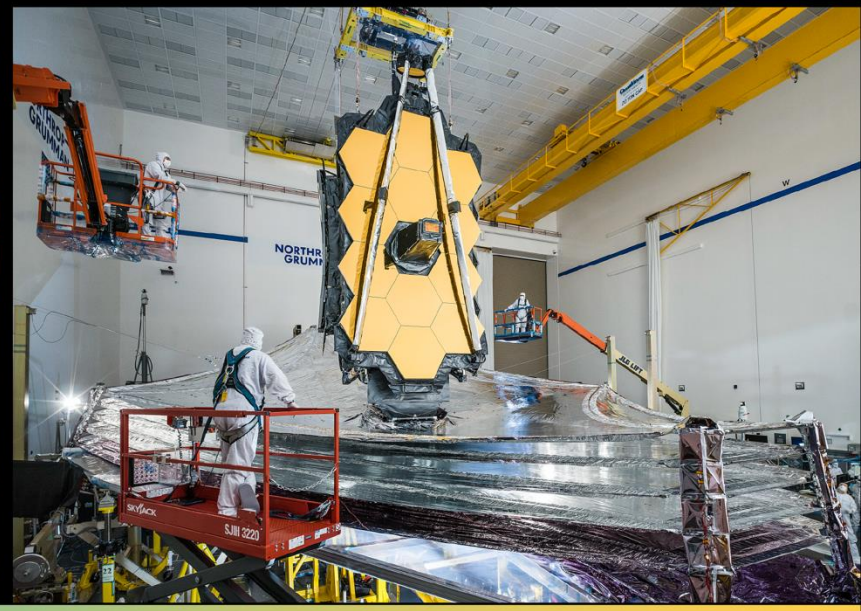
Fine Steering Mirror (FSM)

Diffraction-limited imaging at ≥ 2 µm [150 nm rms wavefront error @ NIRCam focal plane]

Webb Is a Feat of Engineering







JWST's 10 New Technologies 1996 - 2002

Near infrared detectors (NIR): HgCdTe, 2 flavors

Sidecar ASIC to run the NIR detectors

Mid infrared detectors (MIR)

MIRI cryocooler (pulse tube): unlimited lifetime

Microshutters (250,000)

Heat switch (not needed with cryocooler)

Sunshield membrane

Wavefront sensing & control (WFS&C): intentionally out of focus images + computer on ground

Primary mirror (12 contracts to learn how)

Cryogenic stable structures (invented high speed speckle interferometry)

The telescope mirrors are fabricated from Beryllium

Key physical properties of Beryllium:

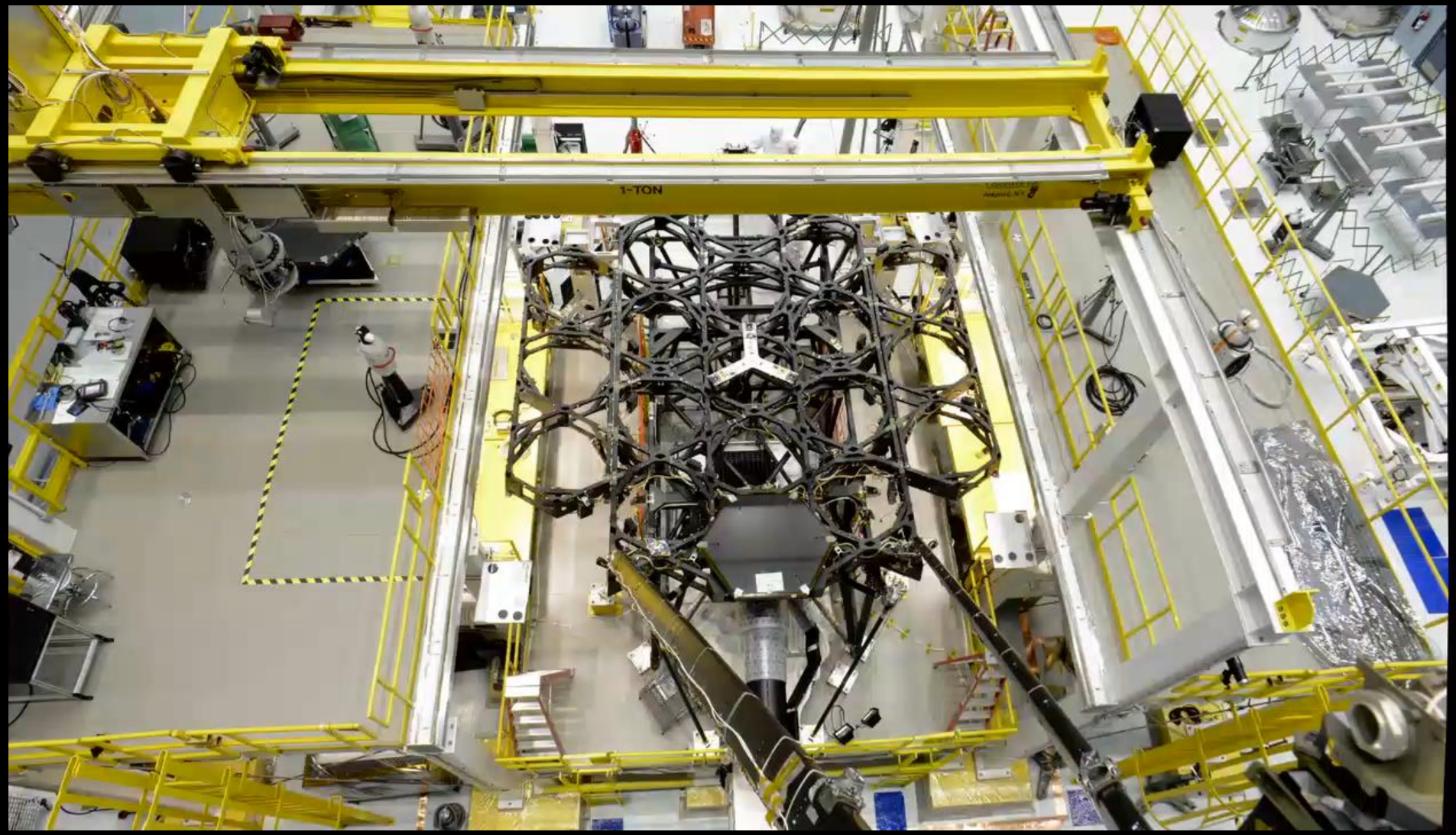
- low coefficient of thermal expansion at 50 K
- high thermal conductivity
- high stiffness to mass ratio

- Type O-30 spherical powder
  - uniform CTE, high packing density, low oxide content

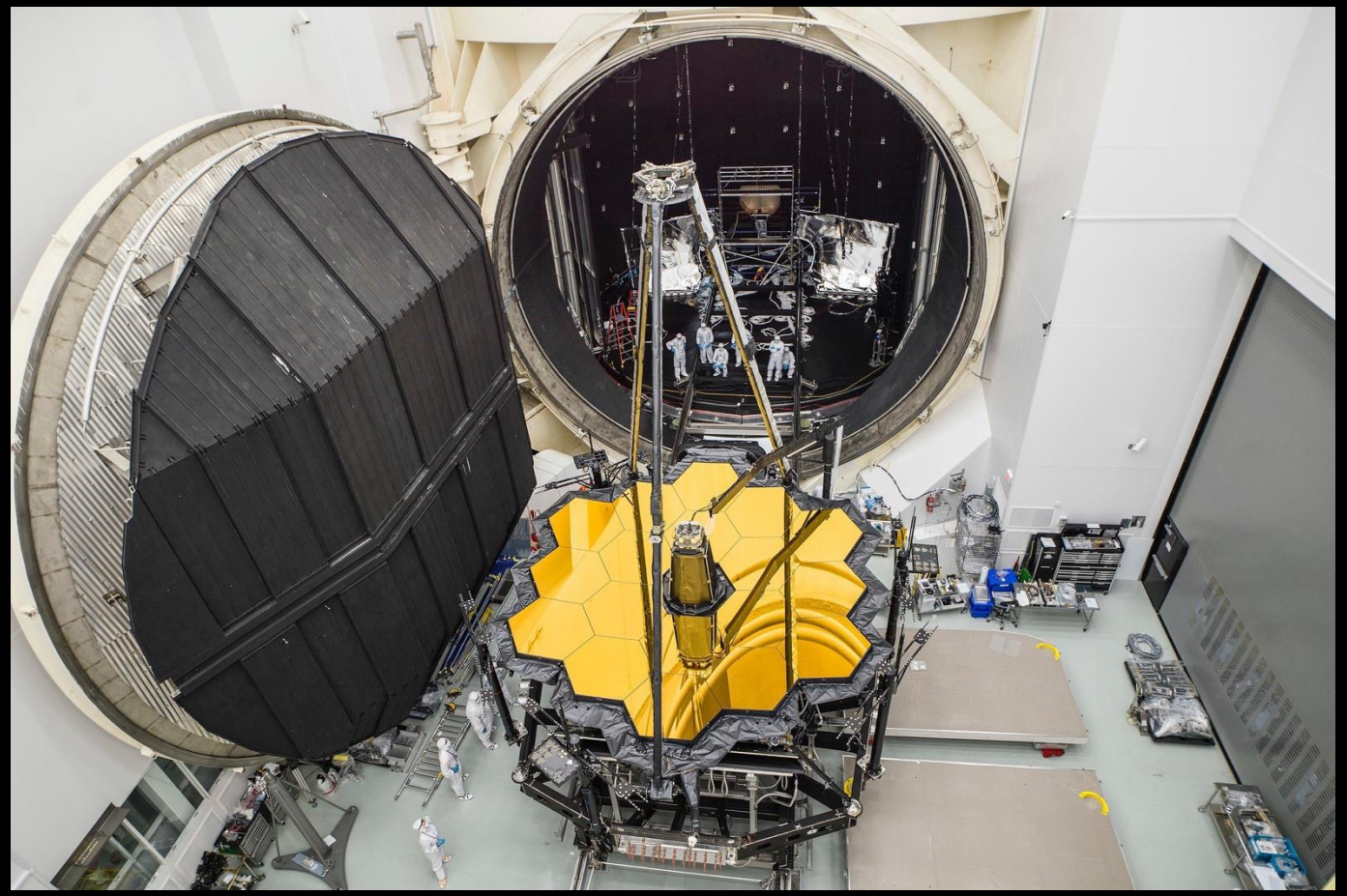
Primary mirror mass properties

- substrate: 21.8 kg
- segment assembly: 39.4 kg
- OTE area density: ~28 kg m^{-2}
  - HST (ULE) ~ 180 kg m^{-2} (~ 6X heavier)
  - Keck (Zerodur) ~ 2000 kg m^{-2} (~71X heavier)

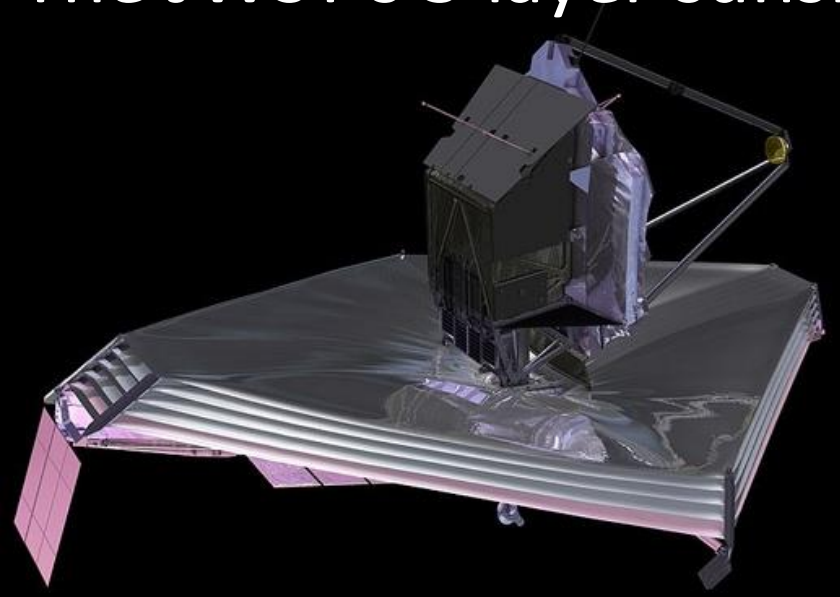
Robotics were used to integrate the flight telescope mirrors with the structure

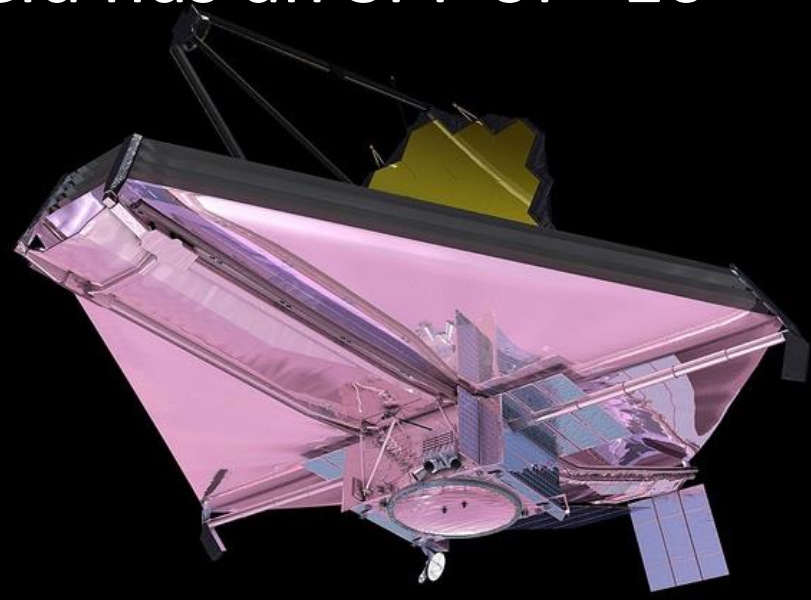


Telescope emerges after cryogenic testing at NASA/JSC



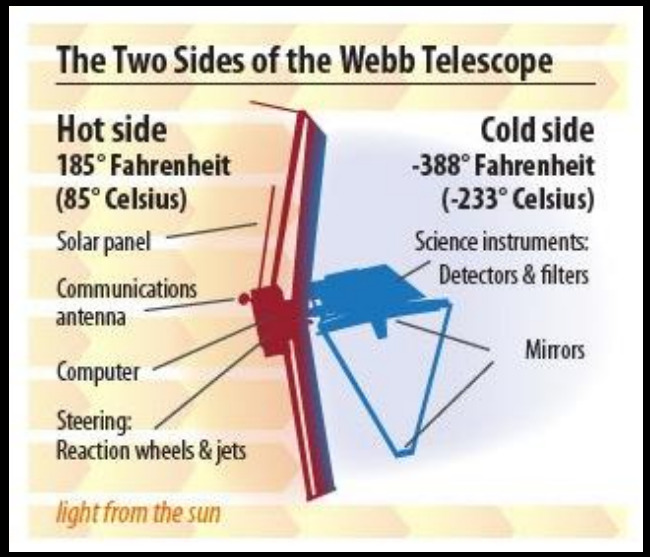
The JWST's 5 layer sunshield has an SPF of ~10^6



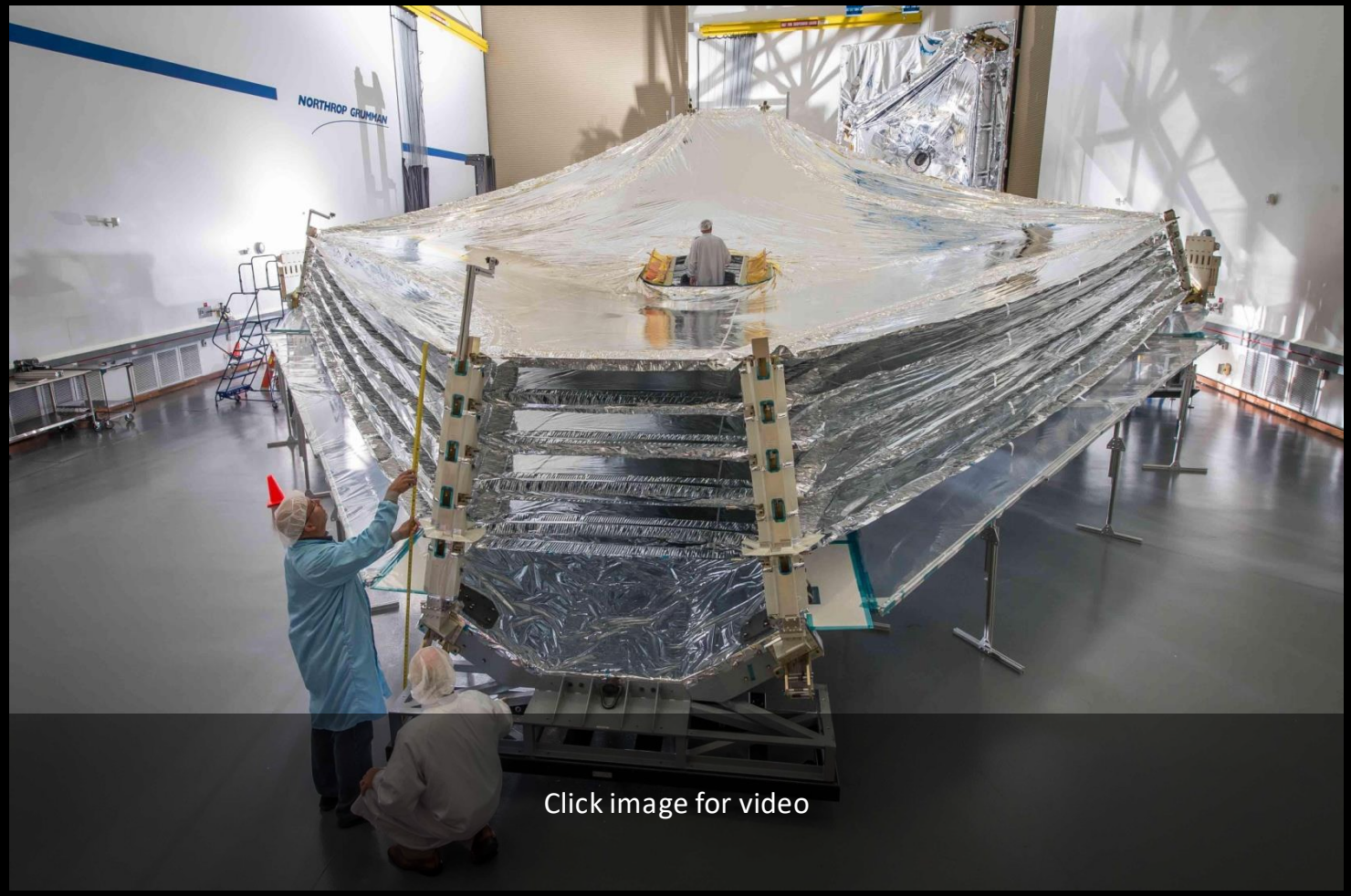


Sunshield Facts

- Measures 73 x 40 feet and has 5 layers
- Made of heat-resistant Kapton coated with silicon on sun side and aluminum on other surfaces
- Sun side reaches 358 K (85° C), dark side stays at 40 K (-233° C)
- Each of 5 layers consist of 50 pieces to form shape
- Seaming involves 7,000 inches of thermal welds
- Seam-to-seam accuracy ~ 0.05 inch with shape of (tennis court size) layers accurate to a few tenths of an inch

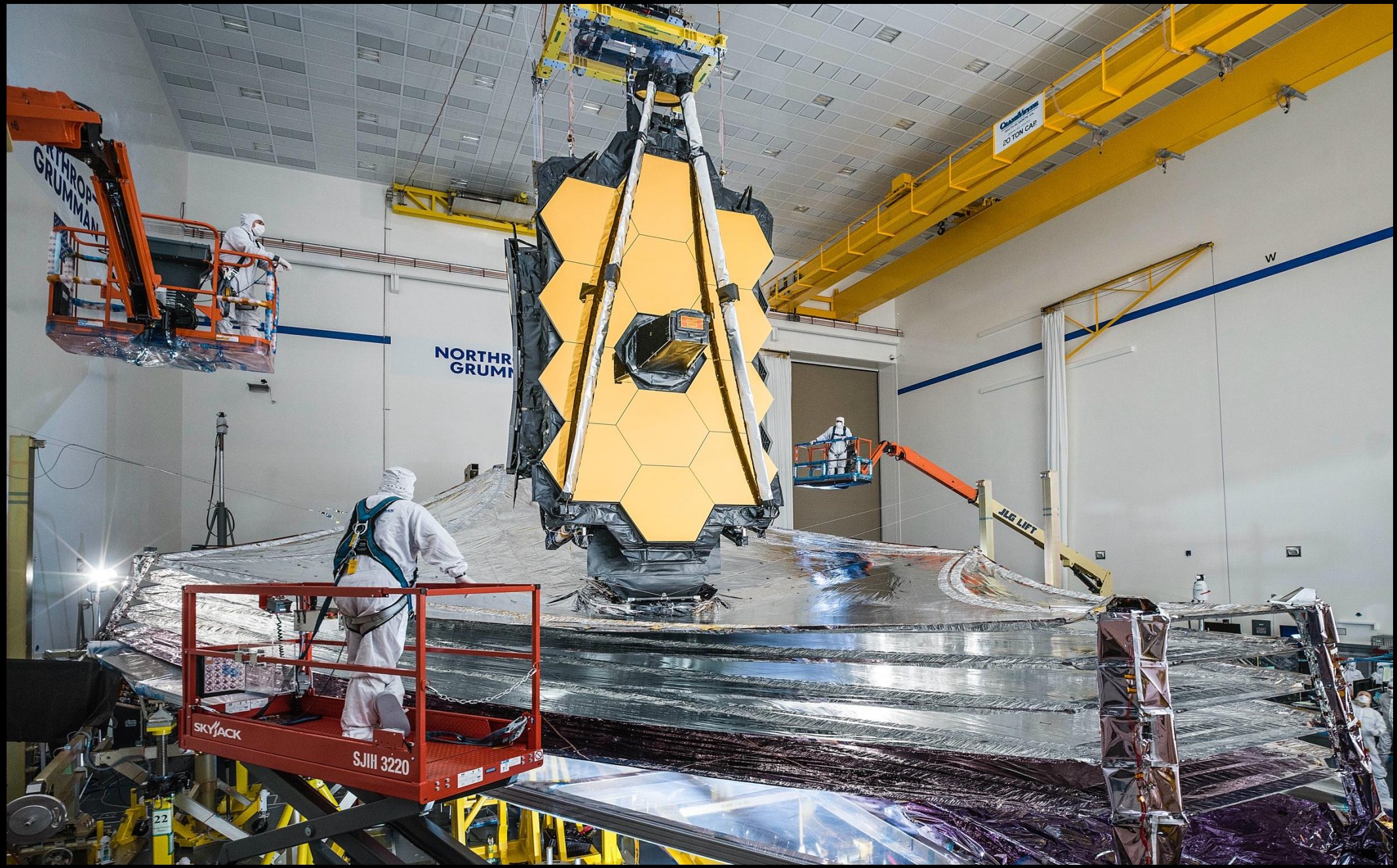


Engineering Model Sunshield Manual Deployment Test



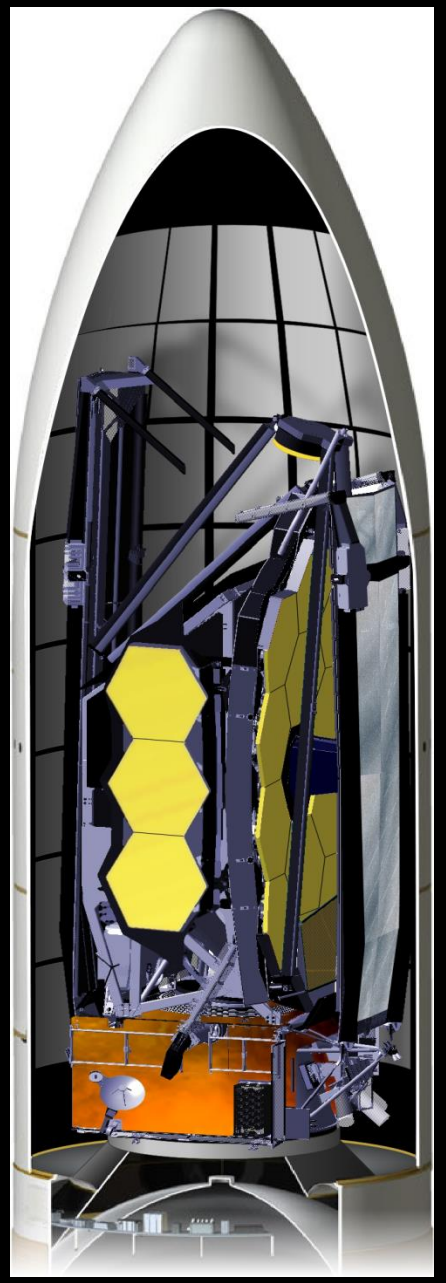
Click image for video

Optical Telescope Element integrated to Sunshield



The telescope required a segmented deployable mirror

Ariane 5 ECA



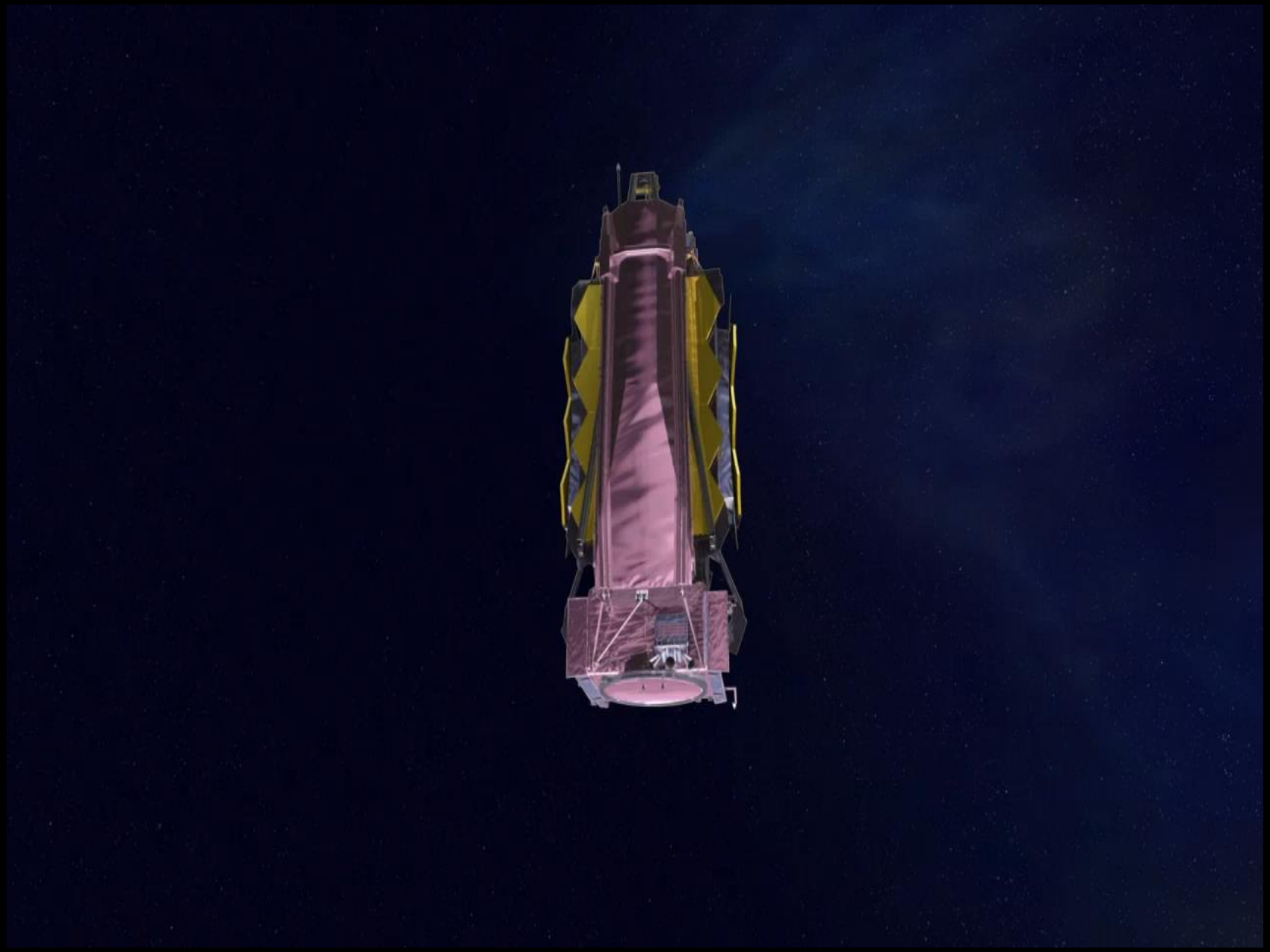
- Ariane V ECA launch vehicle
  5 m diameter fairing
- Launched from Kourou Launch Center (French Guiana) with direct transfer to L2 point.
- 6530 kg (14,396 lb) payload
- 40 deployable structures and 178 release devices

December 25, 2021

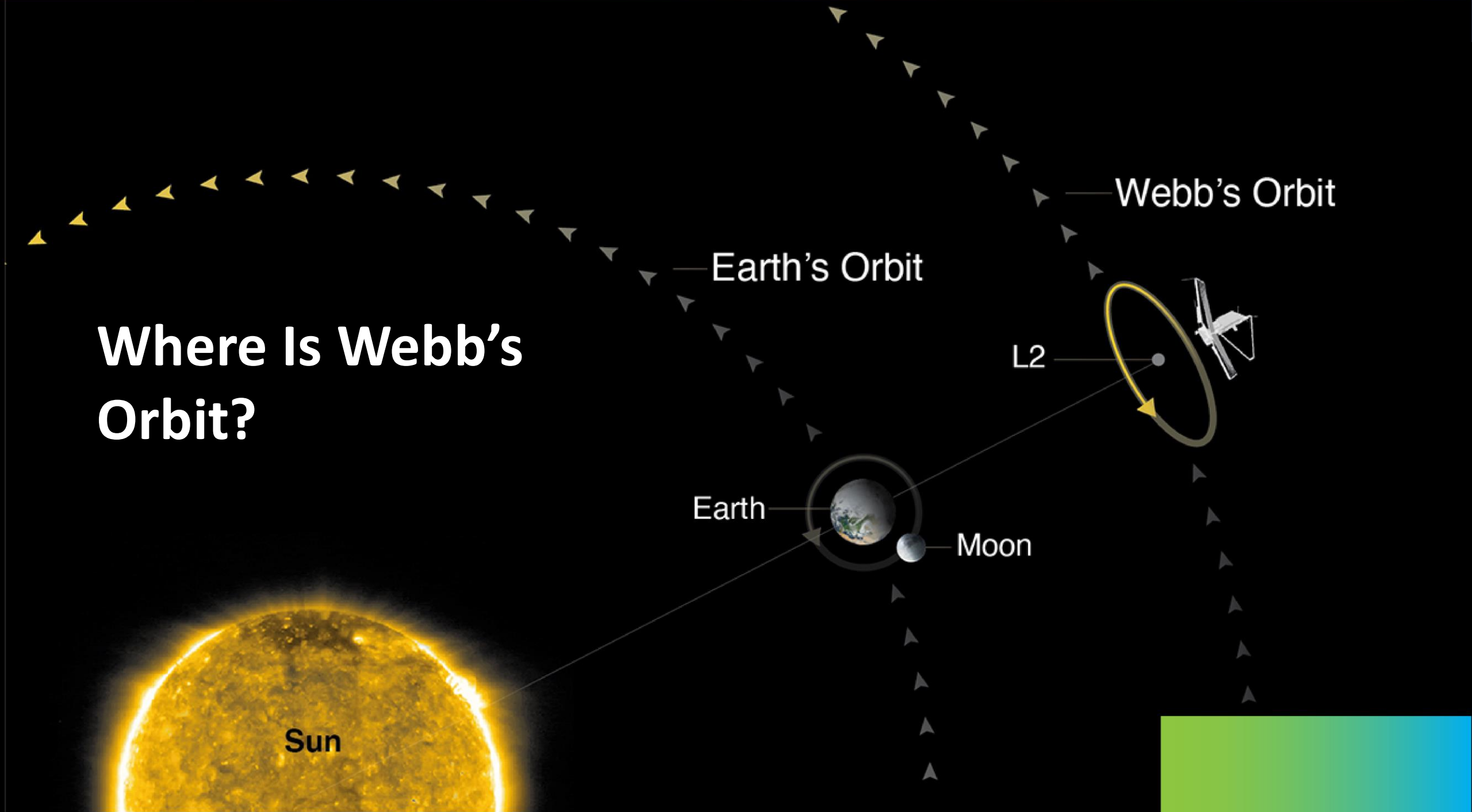
Arianne V launches into space taking Webb into a perfect orbit on its way to its final destination L2

At L2, a million miles from Earth, Webb will be far enough from the Sun and Earth for its 5-layer sunshield to keep it cold

Webb Unfolding

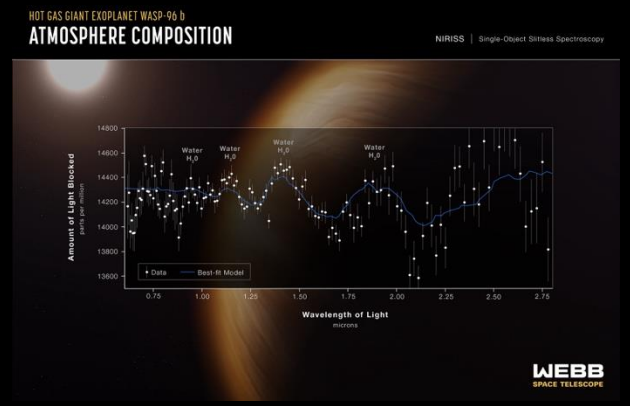


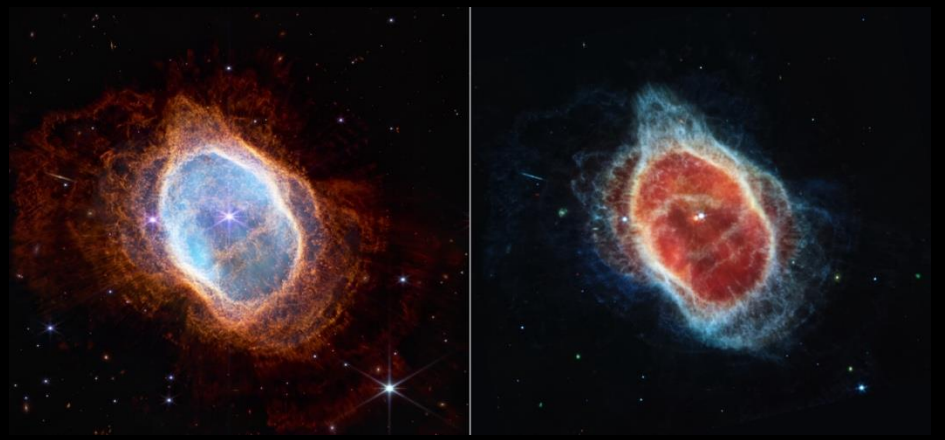
Where Is Webb's Orbit?




Launch
Sunshield deployment
Mirror deployments
Arrival at L2
Telescope cooling
Telescope alignment
Instruments calibration
First images and spectra

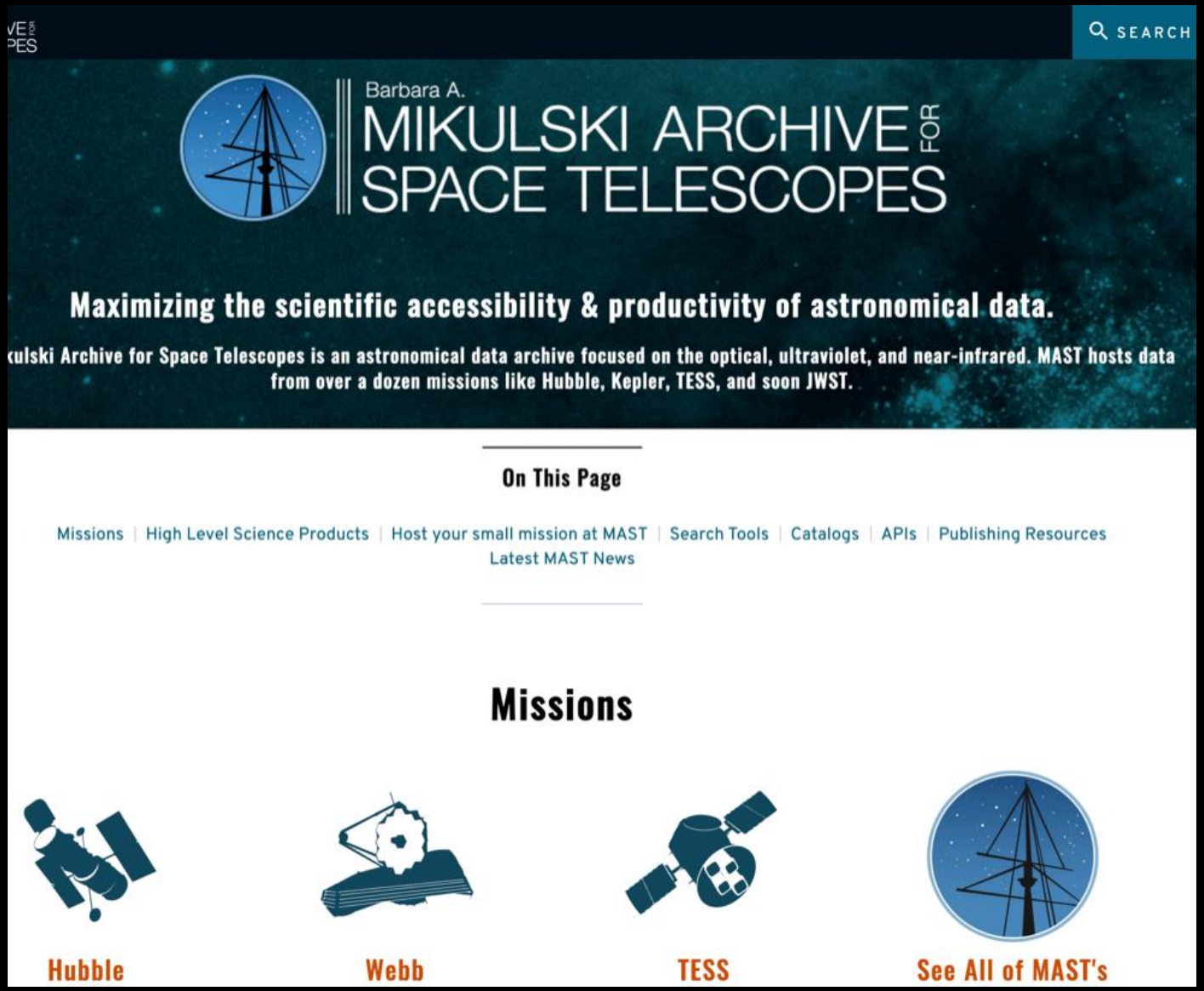
Webb First Release Images
July 12, 2022



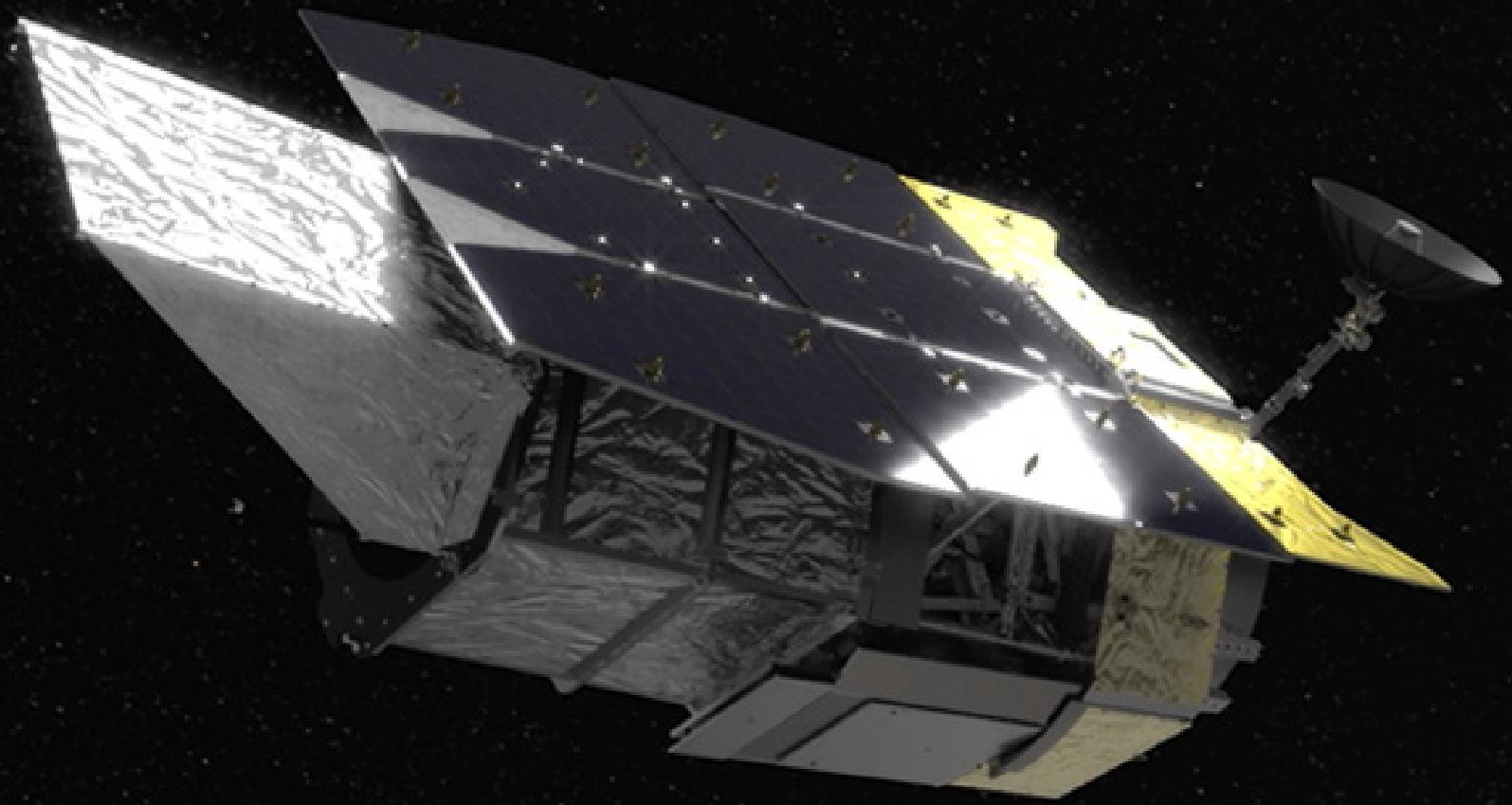


Webb data archived at MAST

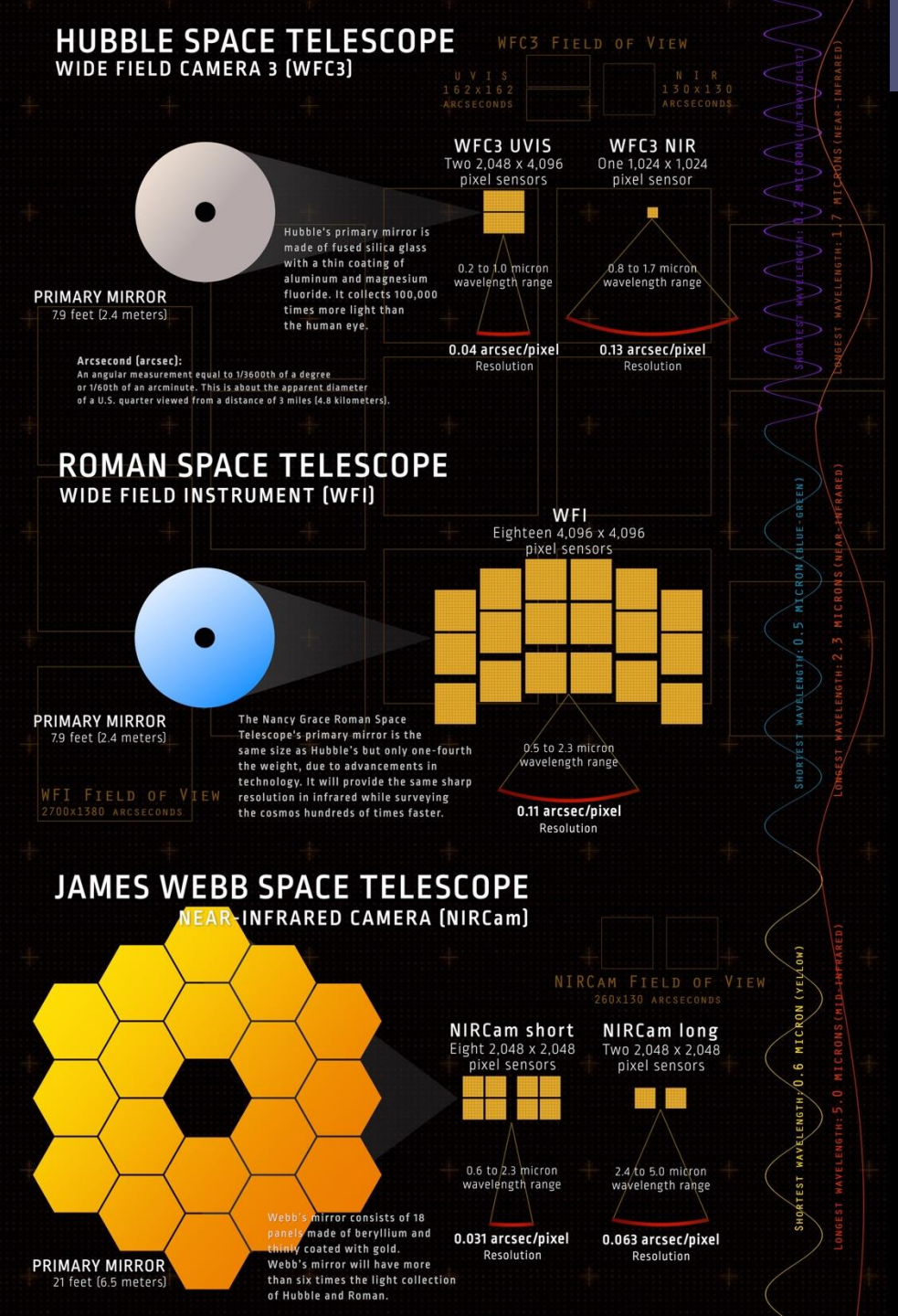
- Data will be available to the public
- Anyone can analyze Webb data



NANCY GRACE
ROMAN
SPACE TELESCOPE



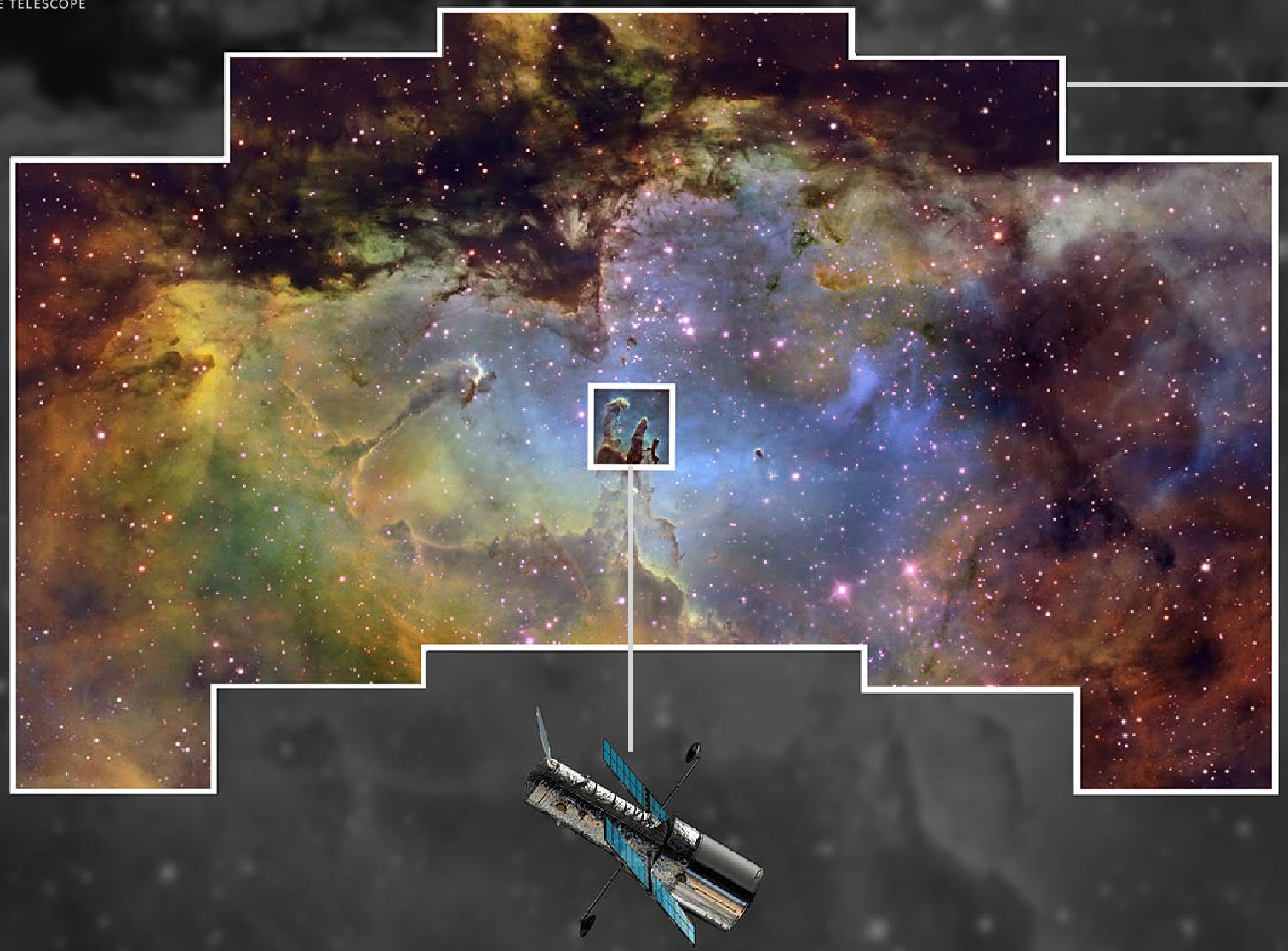
EXPANDING OUR VIEW

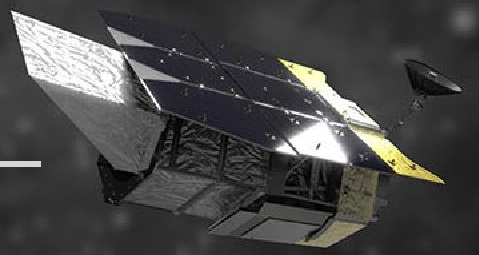


Hubble, Roman, Web

- **Hubble** views the cosmos in infrared, visible and ultraviolet light, providing a more comprehensive, high-resolution view of individual objects.
- The **Roman Space Telescope** will expand on Hubble's infrared observations specifically, using a much larger field of view to create enormous panoramas of the universe with the same high resolution.
- **Webb** also conducts high-resolution infrared observations, peering across farther stretches of space with a narrower field of view.

NANCY GRACE ROMAN SPACE TELESCOPE





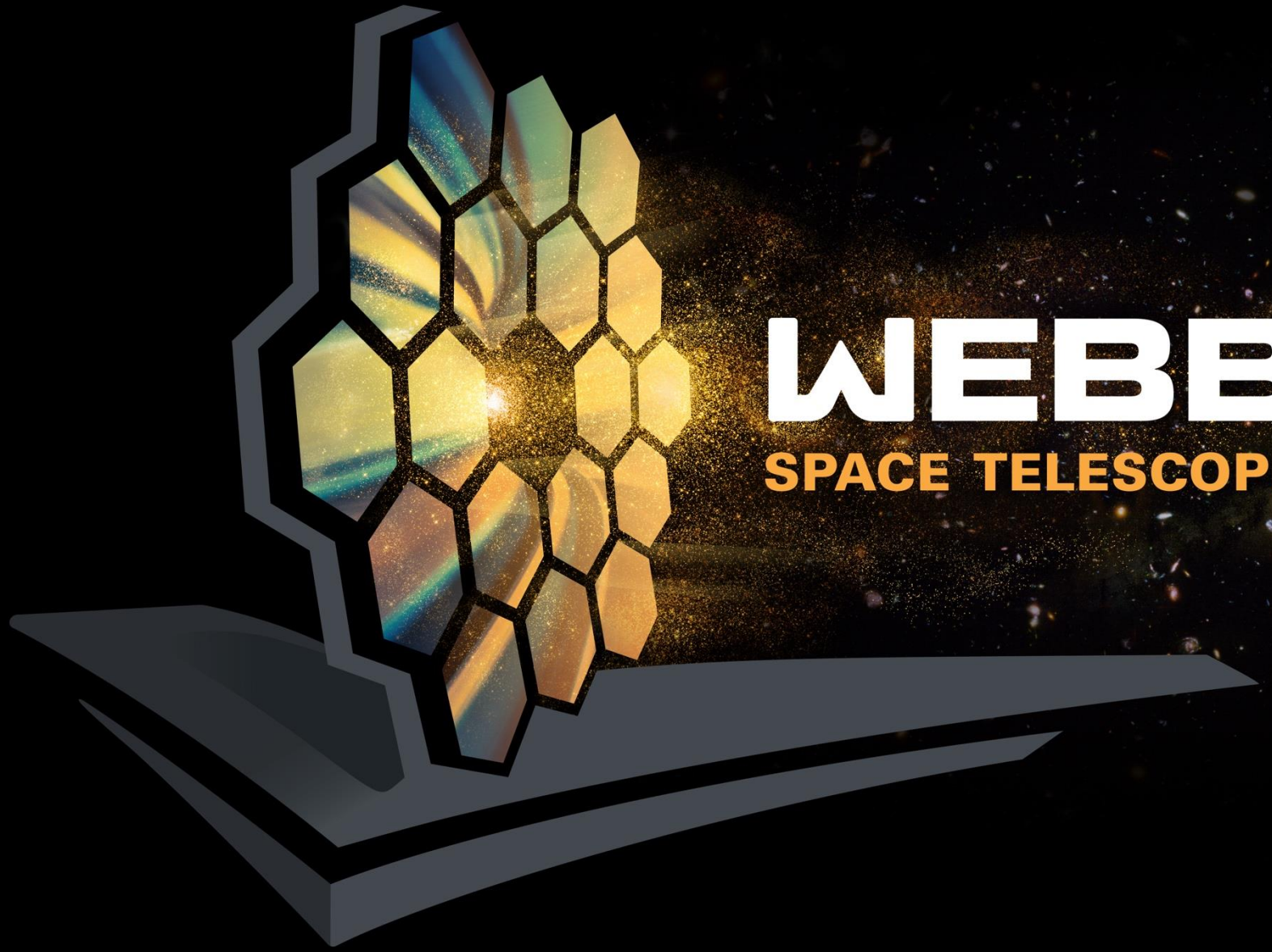
The Bigger Picture

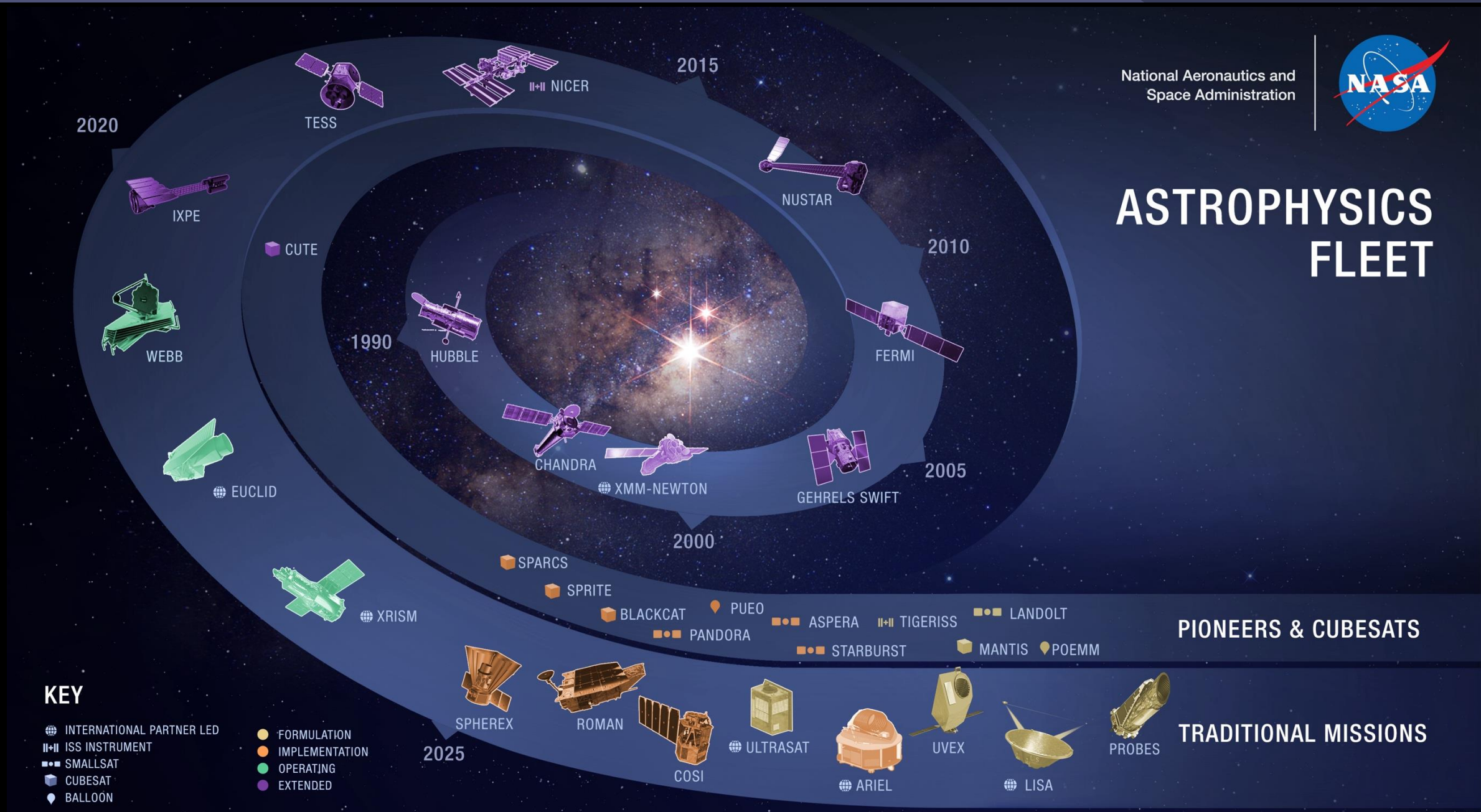
with the Roman Space Telescope

- Planets by the thousands
- Stars by the billions
- Galaxies by the millions
- Fundamental Physics
- The Unexpected


EXIT
HERMES
PARIS

Questions?

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BLACKCAT
PUEO
ASPERA
TIGERISS
LANDOLT
PANDORA
STARBURST
MANTIS
POEMM
PIONEERS & CUBESATS
SPHEREX
ROMAN
COSI
ULTRASAT
ARIEL
UVEX
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SMALLSAT
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