The Infrared Universe Beyond Hubble:

The James Webb Space Telescope in 2022 and 2023 !

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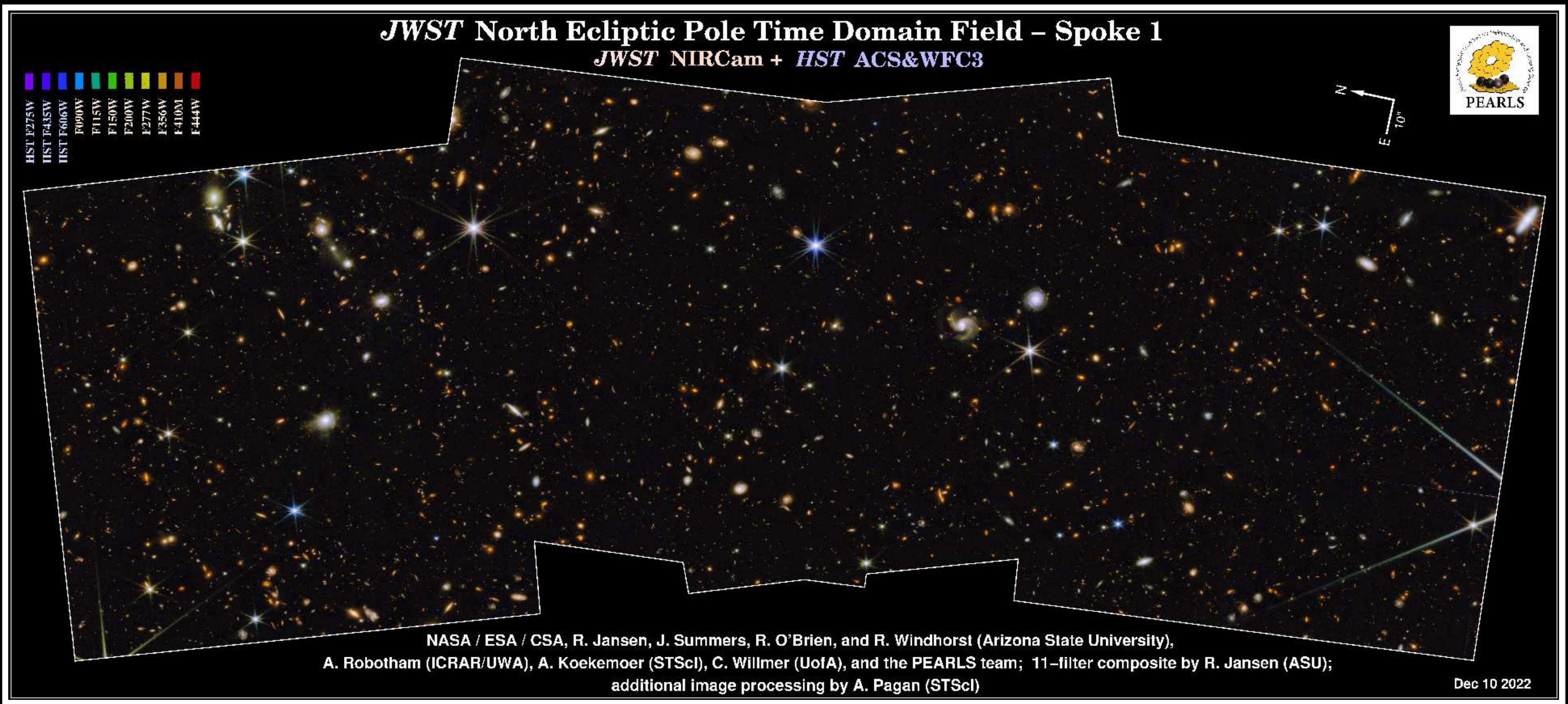
+ the PEARLS team: S. Cohen, R. Jansen, J. Summers, S. Tompkins, R. O'Brien, C. Conselice, S. Driver, H. Yan, D. Coe, B. Frye, N. Grogin, A. Koekemoer, M. Marshall, R. O'Brien, N. Pirzkal, A. Robotham, R. Ryan Jr., C. Willmer, J. Berkheimer, T. Carleton, J. Diego, W. Keel, et al.



Public Talk, Phoenix Astronomical Society, Phoenix, AZ (via Zoom); Thursday January 18, 2023

PDF on: `http://www.asu.edu/clas/hst/www/jwst/phoenixAS23_jwst.pdf`

North Ecliptic Pole (NEP) Time Domain Field (TDF) from PEARLS project:

(PEARLS = Prime Extragalactic Areas for Reionization and Lensing Science; Windhorst et al. 2023, Astron. J., 165, 13; astro-ph/2209.04119)

- The NEP TDF is unique: Webb can observe it 365 days per year!
- Some remarkable results in PEARLS and other recent JWST projects:
- (Old SED) tidal tails everywhere. Abundance of red (dusty) spirals.

Outline

- (1) Update on the James Webb Space Telescope (JWST), 2023.
- (2) Webb's first images: the "Cosmic Circle of Life"
- (3) Summary and Conclusions
- (4) What Hubble has done: Galaxy Assembly & SMBH Growth
  - (5) How can JWST measure Star-formation & Earth-like exoplanets?

Thank you, Europe & ESA, for your very significant work on JWST!

Arizona State University

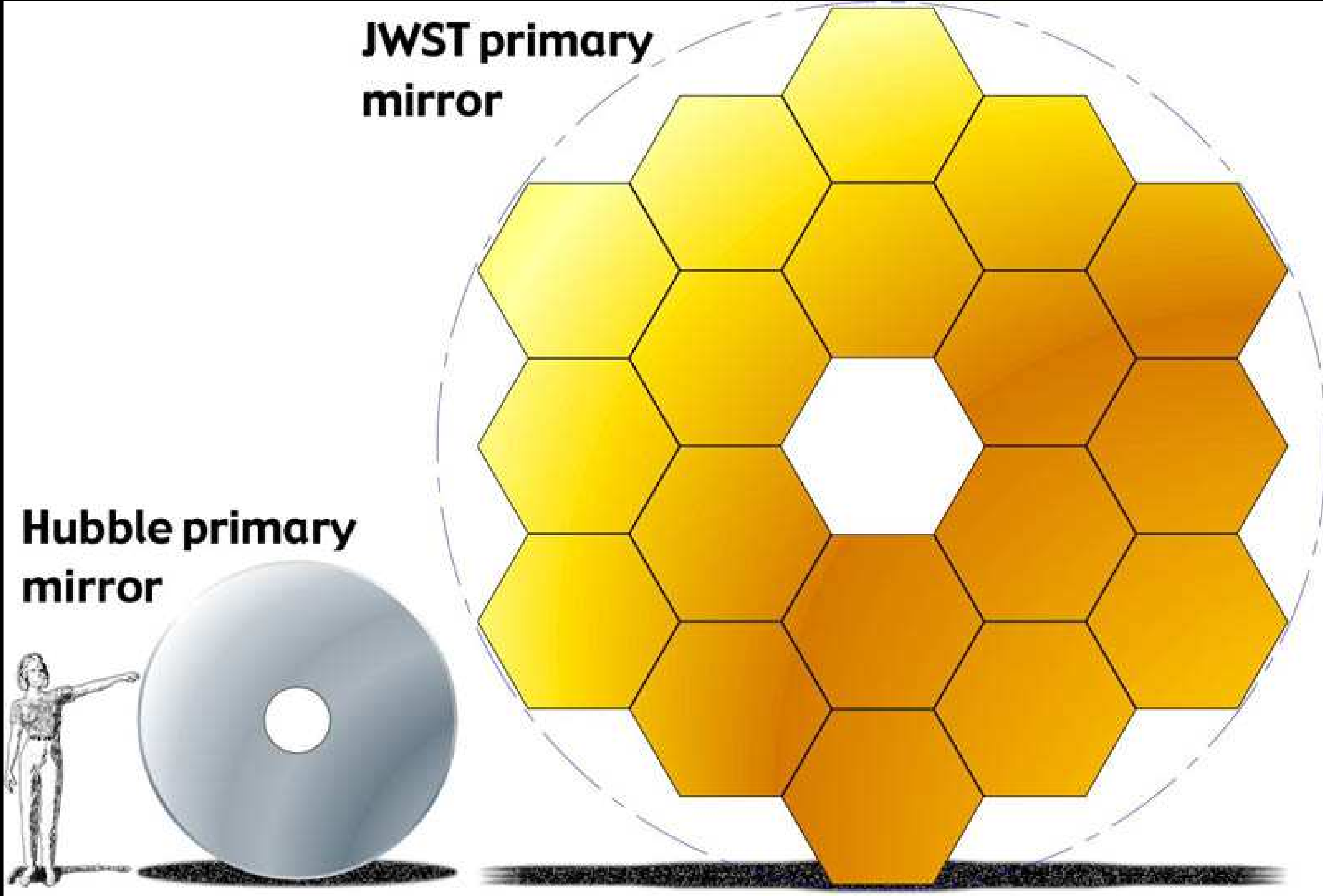
Sponsored by NASA/HST & JWST

Edwin P. Hubble (1889–1953) — Carnegie astronomer

James E. Webb (1906–1992) — Second NASA Administrator

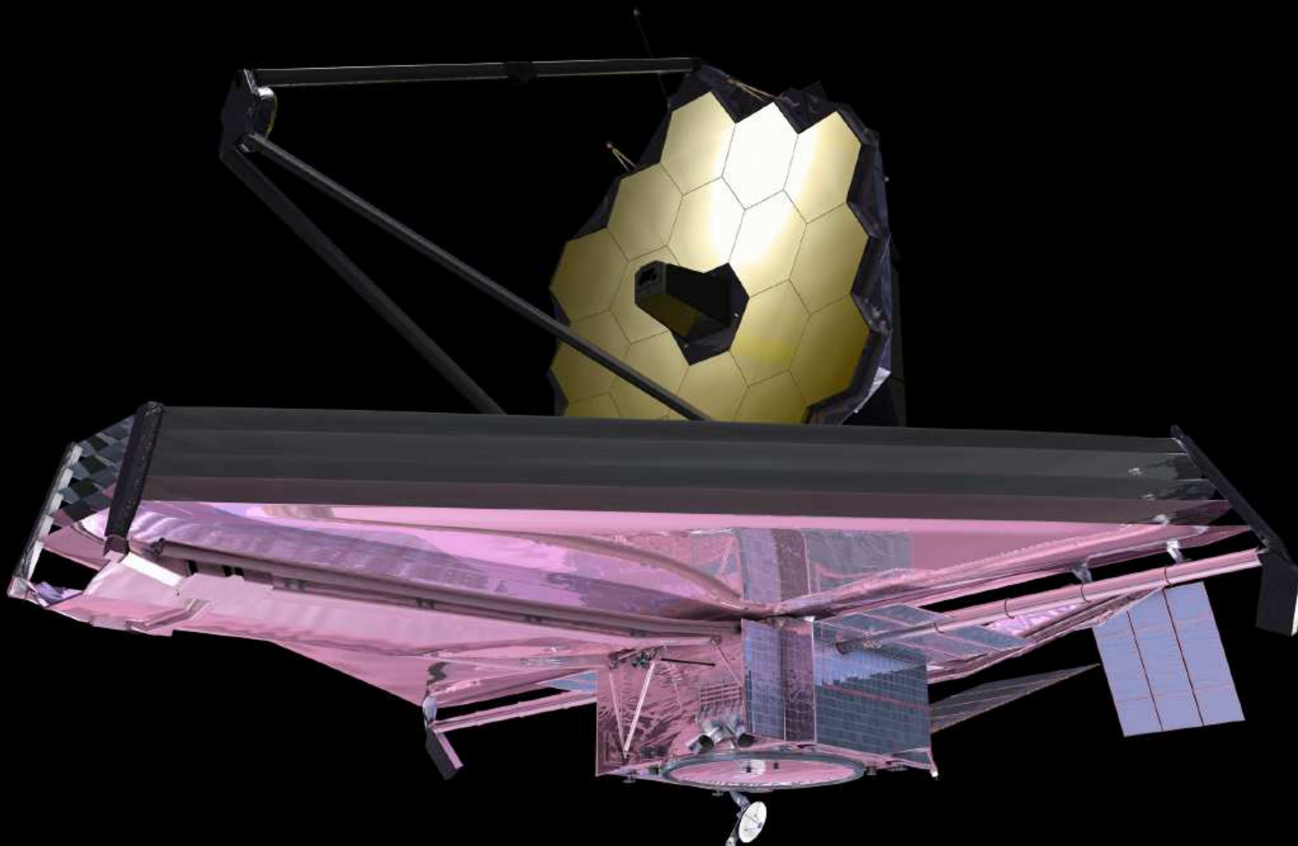
Hubble: Concept in 1970's; Made in 1980's; Operational 1990–$\gtrsim$2022?.

JWST: The infrared sequel to Hubble from 2021–2026 (–2031?).



JWST $\simeq$2.5$\times$ larger than Hubble, so at $\sim$2.5$\times$ larger wavelengths:
JWST has the same resolution in the near-IR as Hubble in the optical.

(1) Update of the James Webb Space Telescope as of 2022

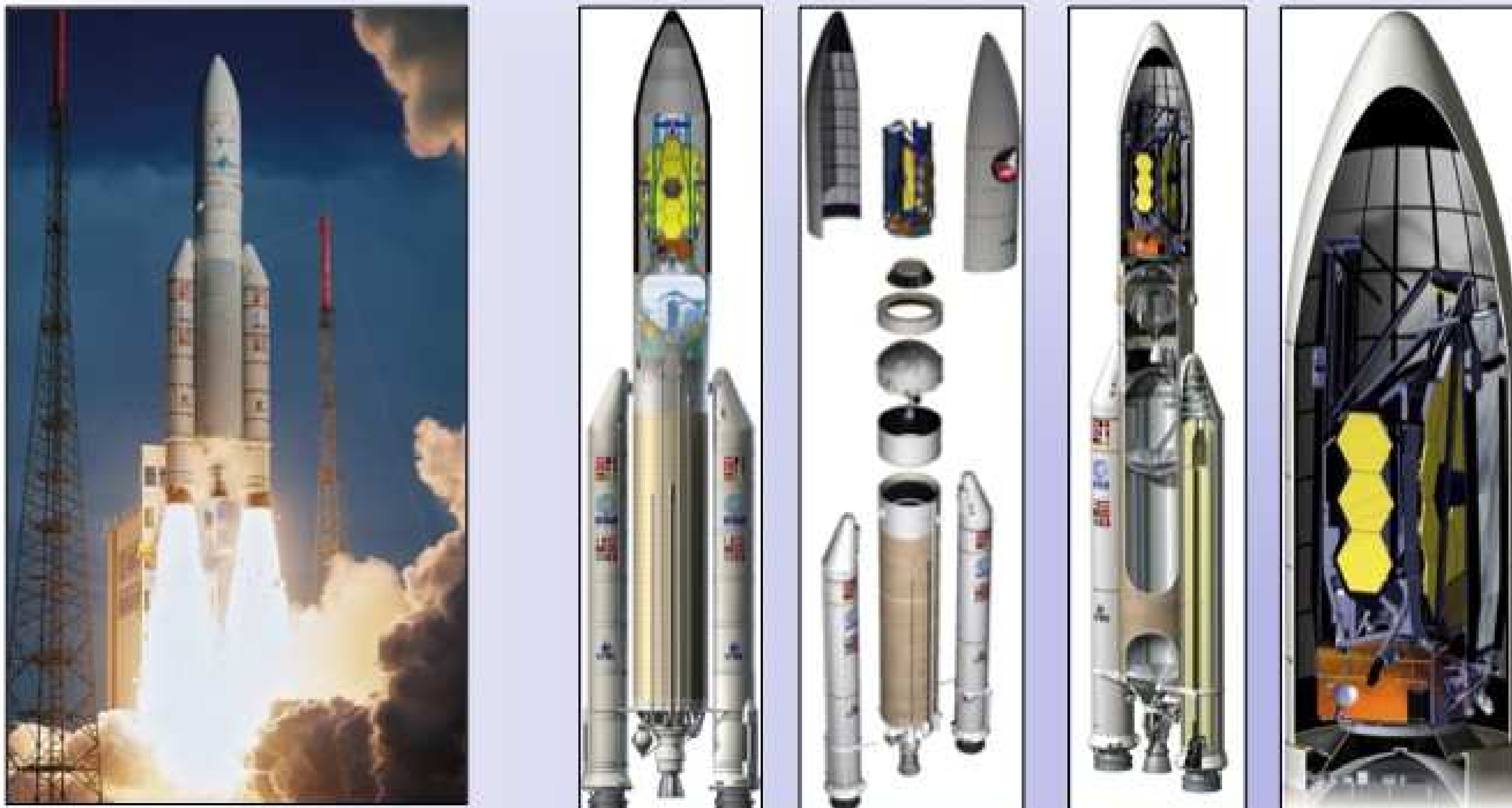


- A fully deployable 6.5 meter (25 m^2) segmented IR telescope for imaging and spectroscopy at 0.6–28 μm wavelength, launched Dec. 25, 2021.
- Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging (31.5 mag$\sim$1 FF from Moon), and spectroscopy.

The James Webb Space Telescope

JWST Launch

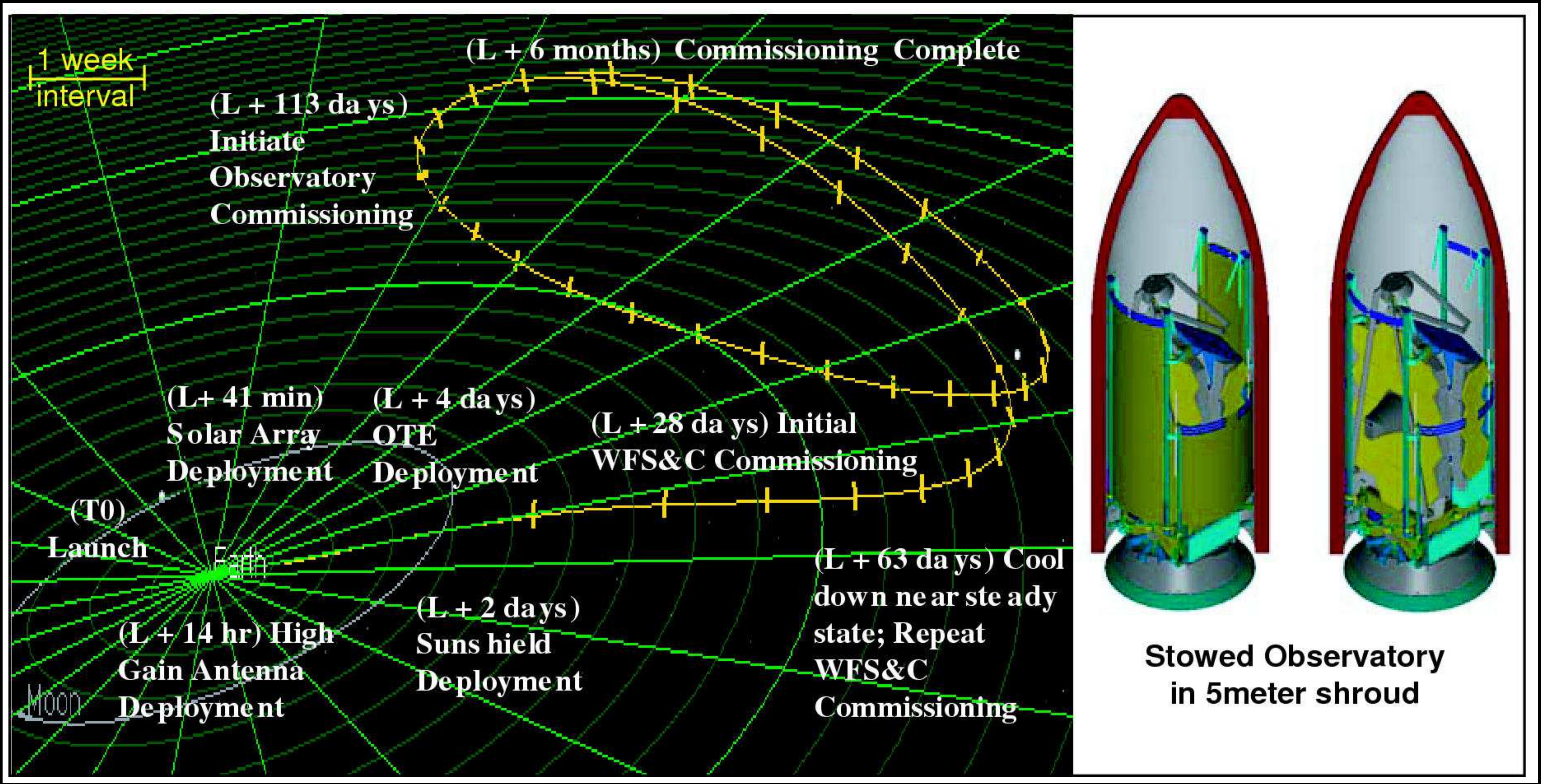
- Launch vehicle is an Ariane 5 rocket, supplied by ESA
- Site will be the Arianespace's ELA-3 launch complex near Kourou, French Guiana



ARIANESPACE – ESA - NASA

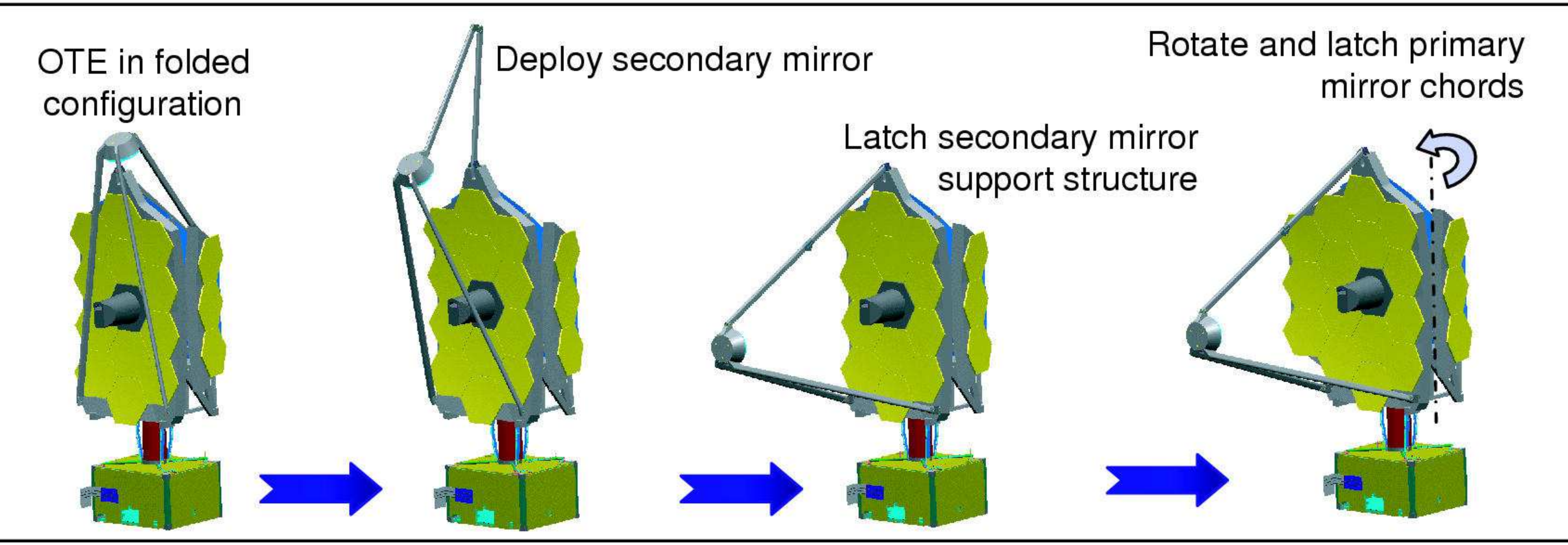
• The JWST launch weight is $\lesssim$6500 kg, and it was launched to L2 with an ESA Ariane-V launch vehicle from Kourou in French Guiana.

(1a) How did JWST travel to its L2 orbit?



- After launch on Dec. 25, 2022 with an ESA Ariane-V, JWST will orbit around the Earth–Sun Lagrange point L2, 1.5 million km from Earth.
- JWST can cover the whole sky in segments that move along with the Earth, observe $\gtrsim$70% of the time, and send data back to Earth every day.

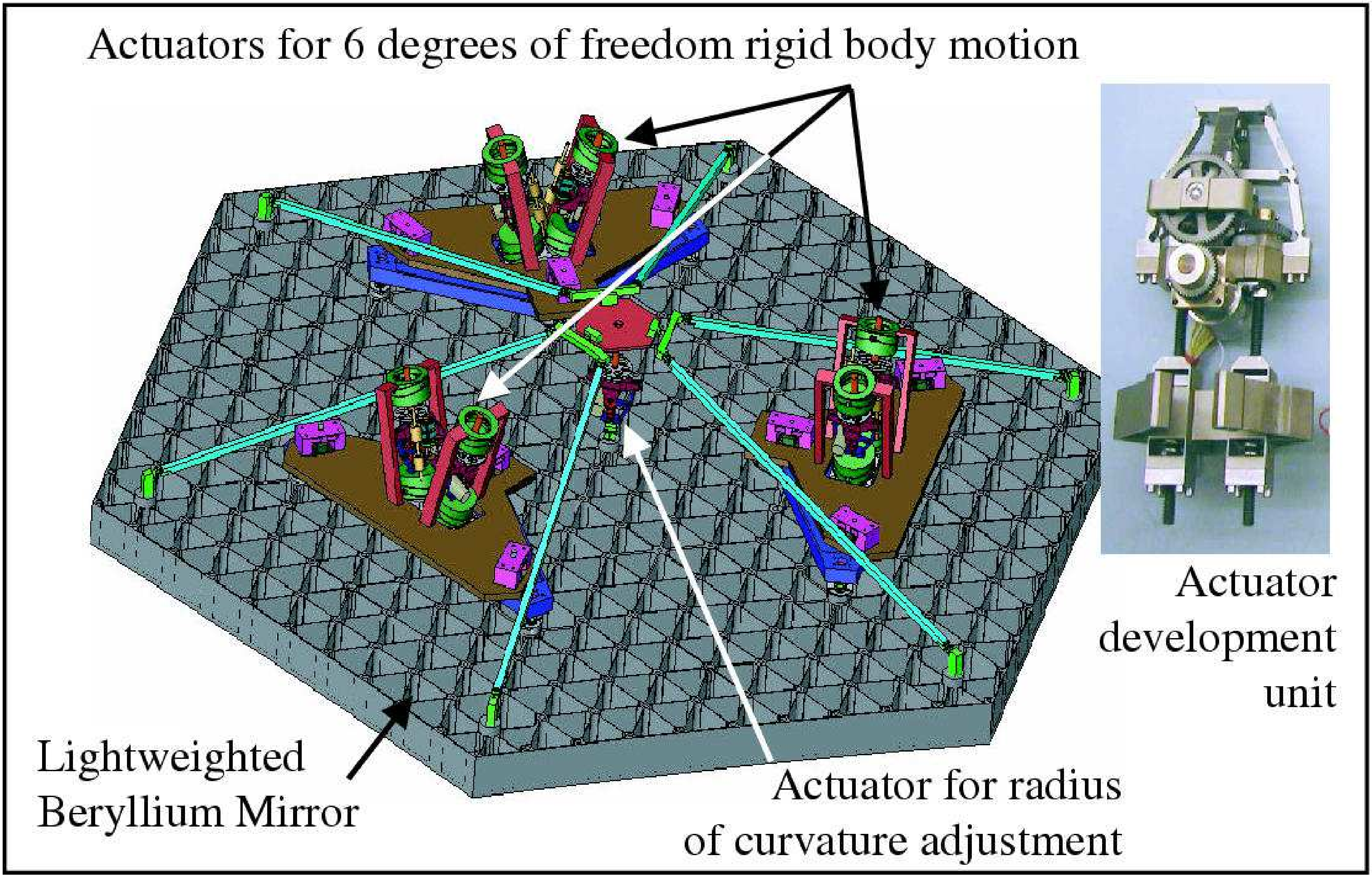
• (1b) How was JWST automatically deployed?



- During its two month journey to L2, JWST will be automatically deployed, its instruments will be cooled, and be inserted into an L2 orbit.

- The entire JWST deployment sequence is being tested several times on the ground — but only in 1-G: component and system tests in 2014–2019 at GSFC (MD), Northrop (CA), and JSC (Houston).

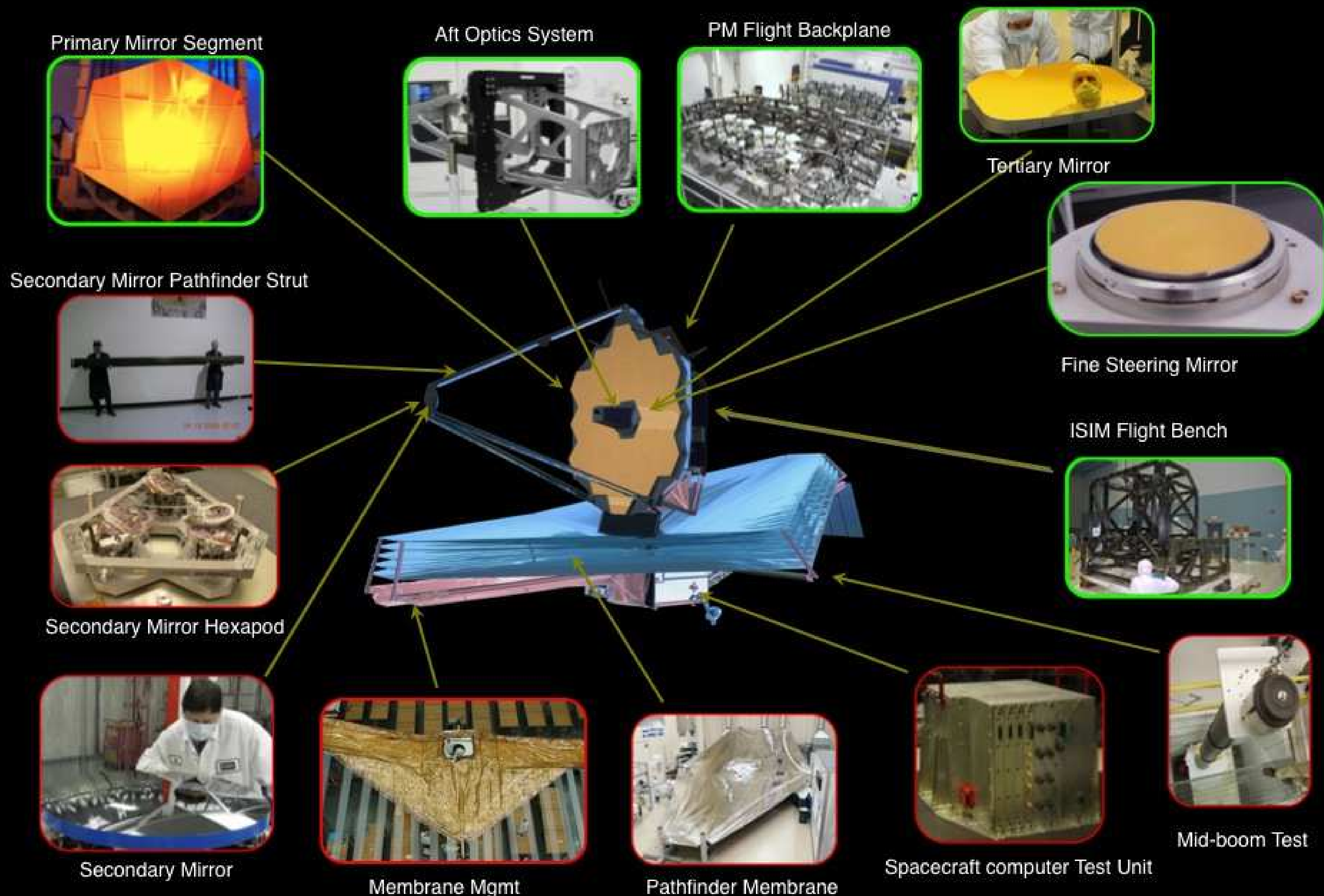
- Component fabrication, testing, & system integration: 18 out of 18 flight mirrors done in 2015, and meet the 40K specifications (2017).



Active mirror segment support through “hexapods”, similar to Keck.

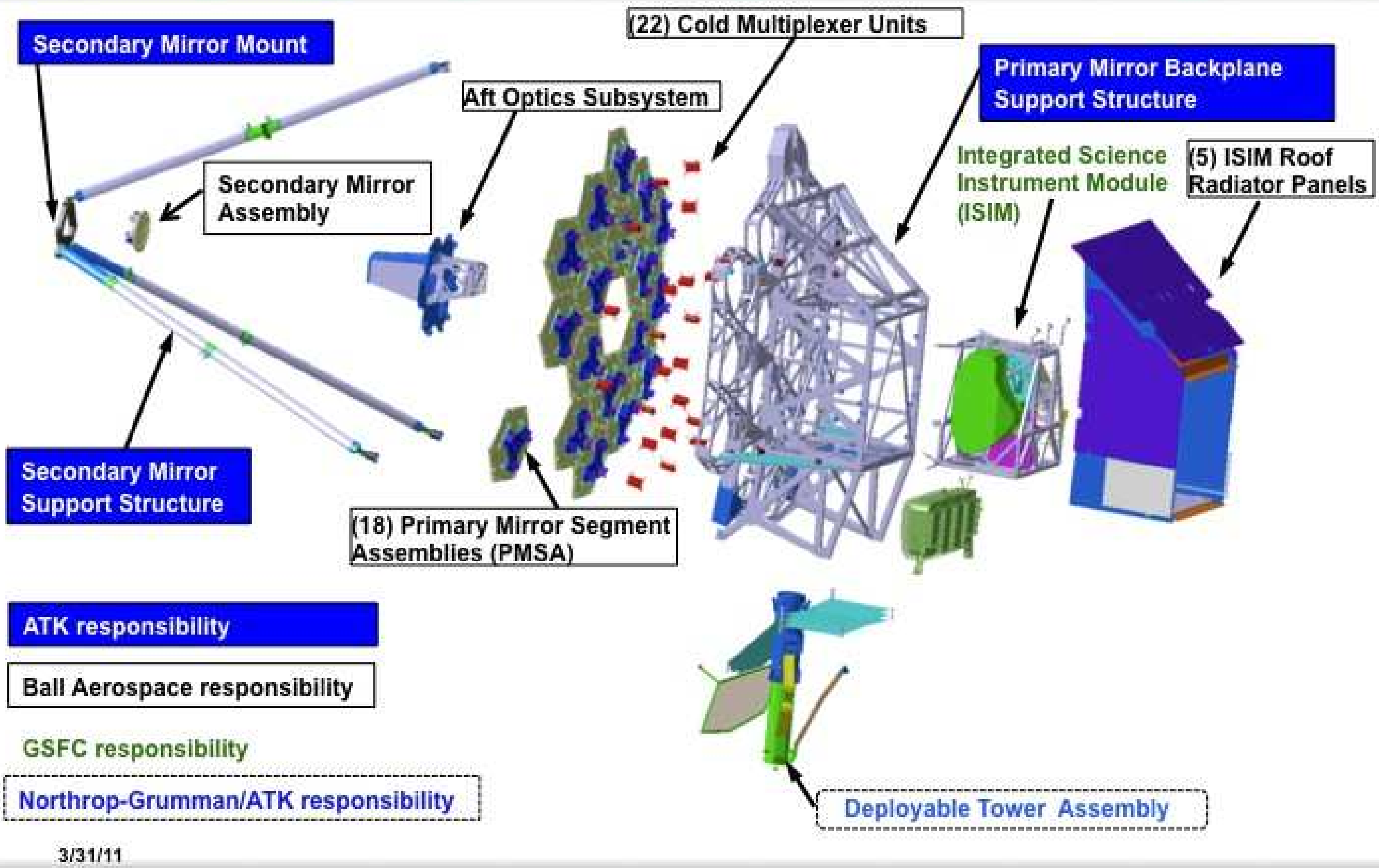
Redundant & doubly-redundant mechanisms, quite forgiving against failures.

JWST Hardware Status



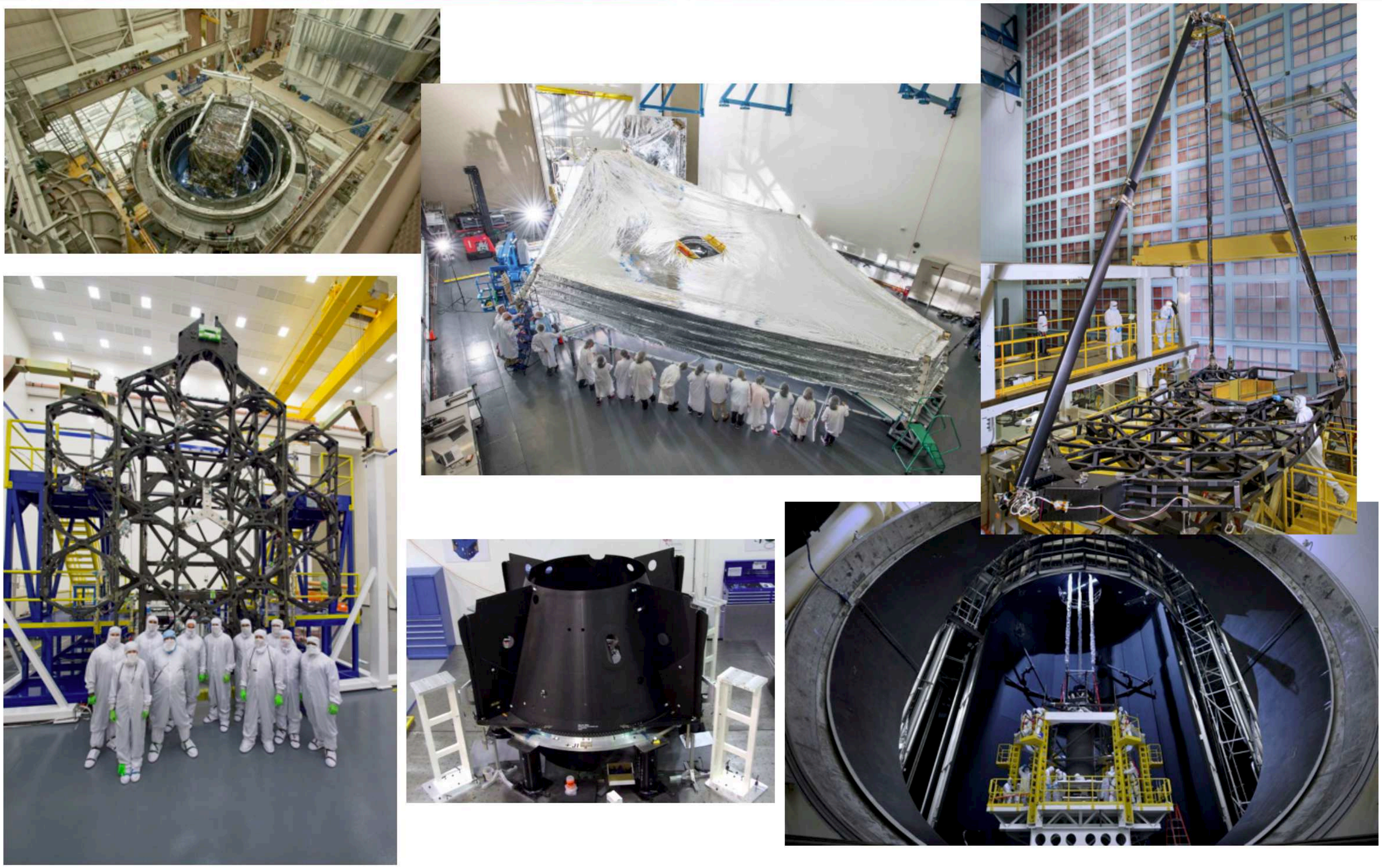
2021: 100% of launch mass designed and built (100% weighed).

TELESCOPE ARCHITECTURE



2014–2021: Complete system integration at GSFC and Northrop.

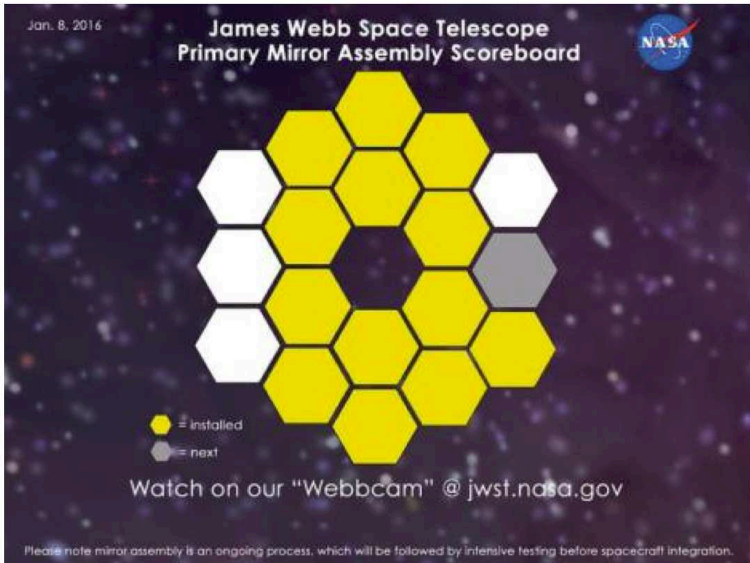
JWST Hardware Progress



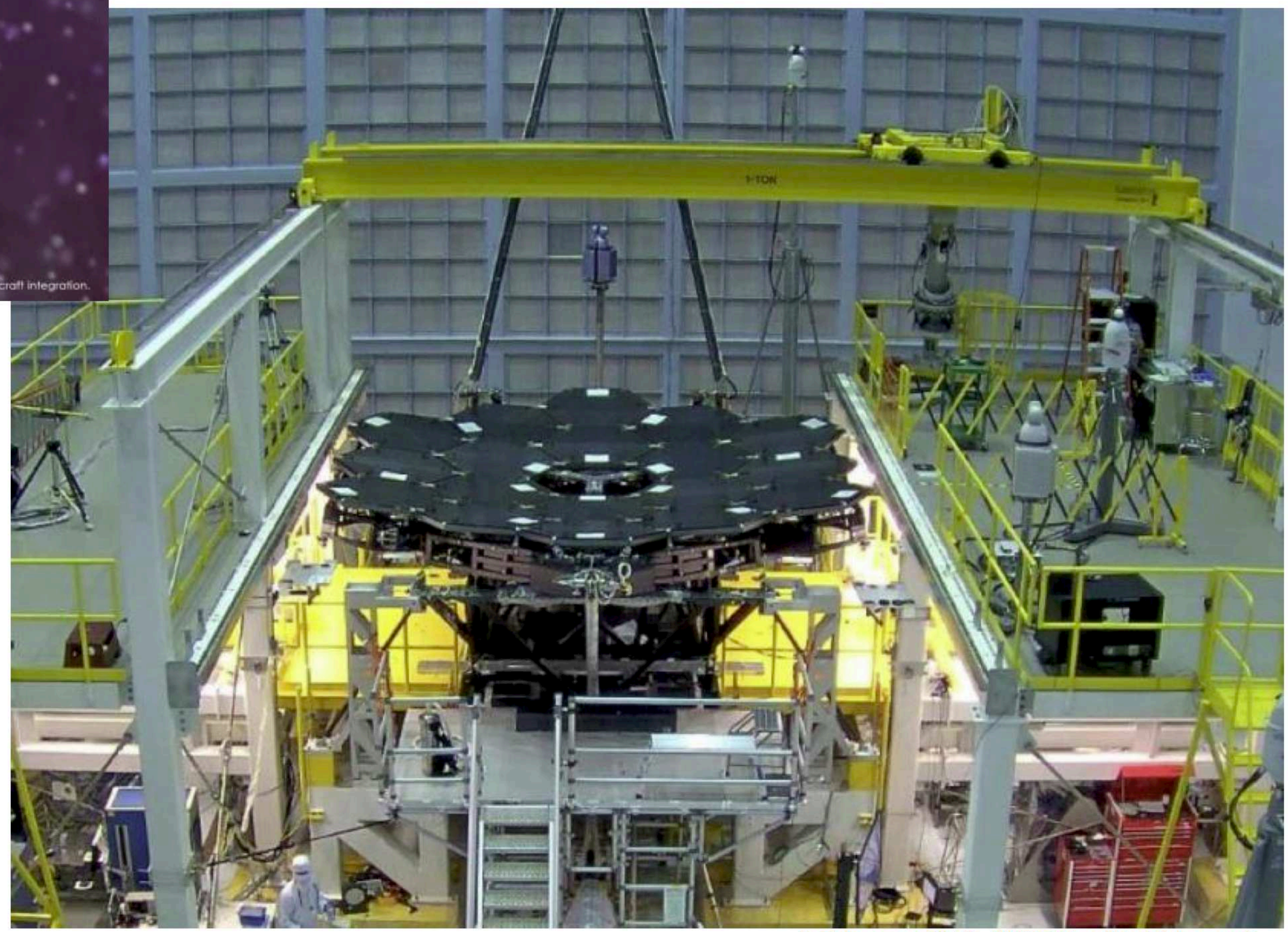
JWST remains on track for an October 2018 launch within its replan budget guidelines

July 2014: • Secondary Mirror Support deployment successfully tested.
2015: • Engineering sunshield successfully deployed at Northrop (CA).

Much progress has been made in OTE integration



← Where we were at last month's call



<u>Current</u>: all 18 PMSAs installed, liquid-shim-cured, & metrologized. Alignments meet specifications, and actuator motions verified →

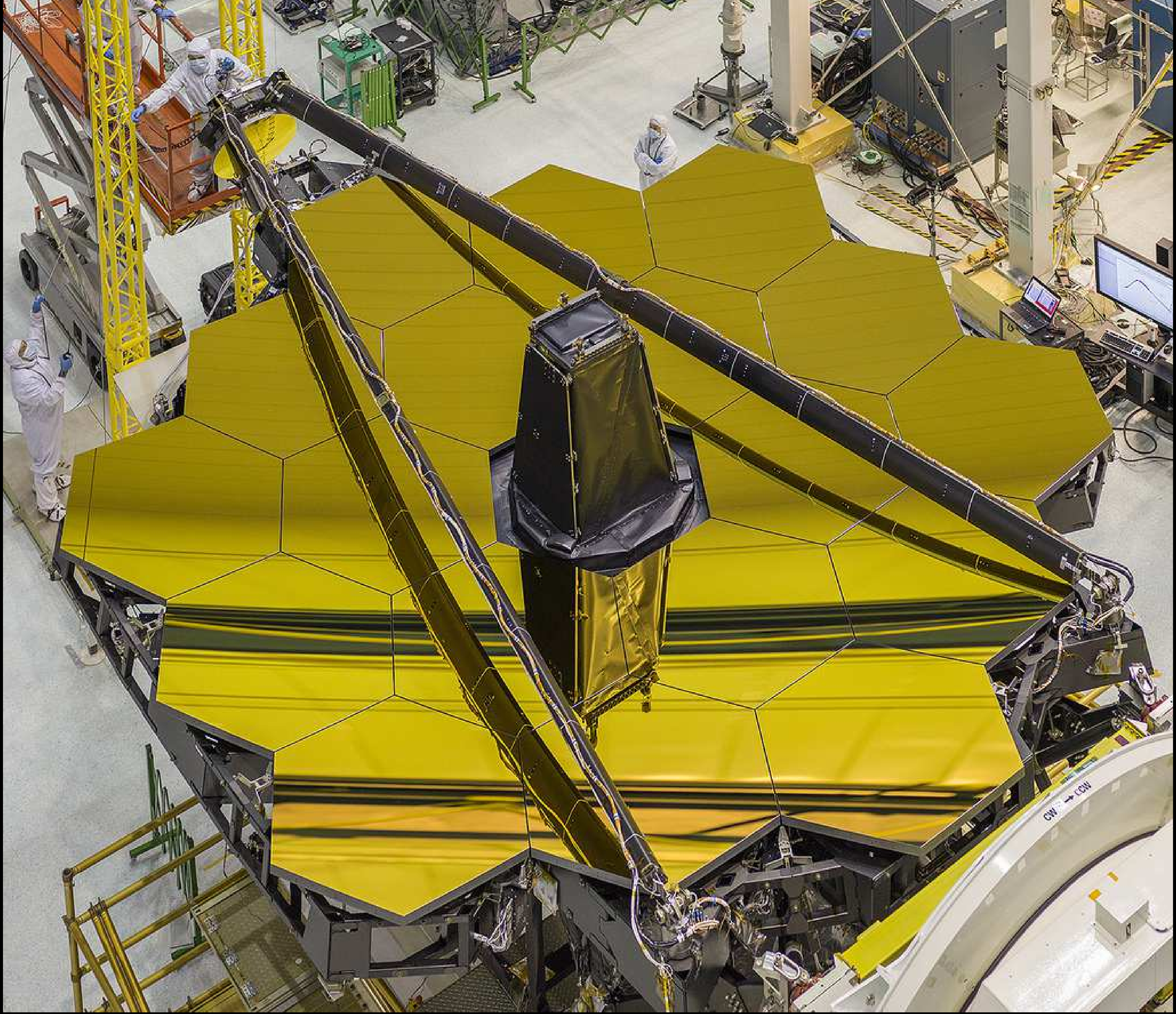
Big milestone!

JWST lifetime: Requirement: 5 yrs; Goal: 10 yrs; Propellant: 20^{+} yrs!

NASA team-work to take JWST mirror covers off!

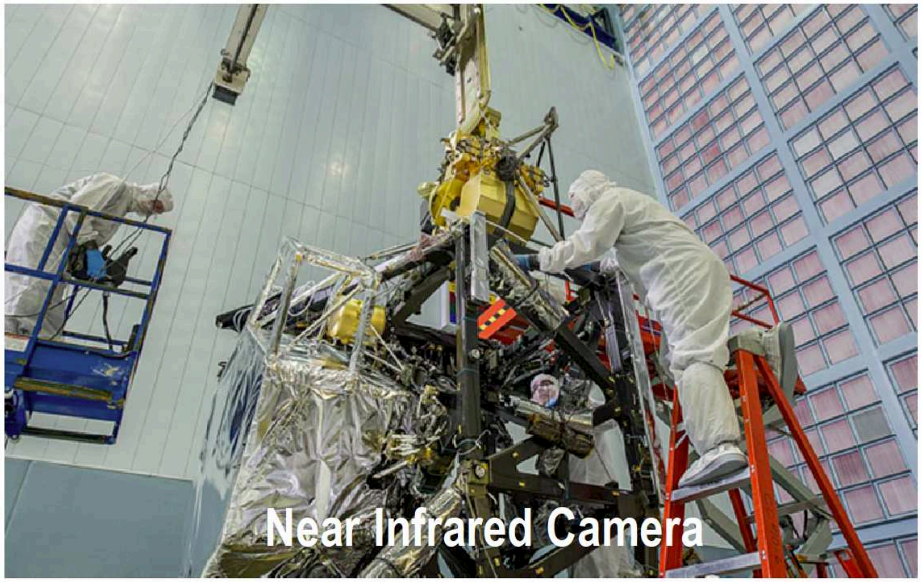
JWST being tilted into the right position

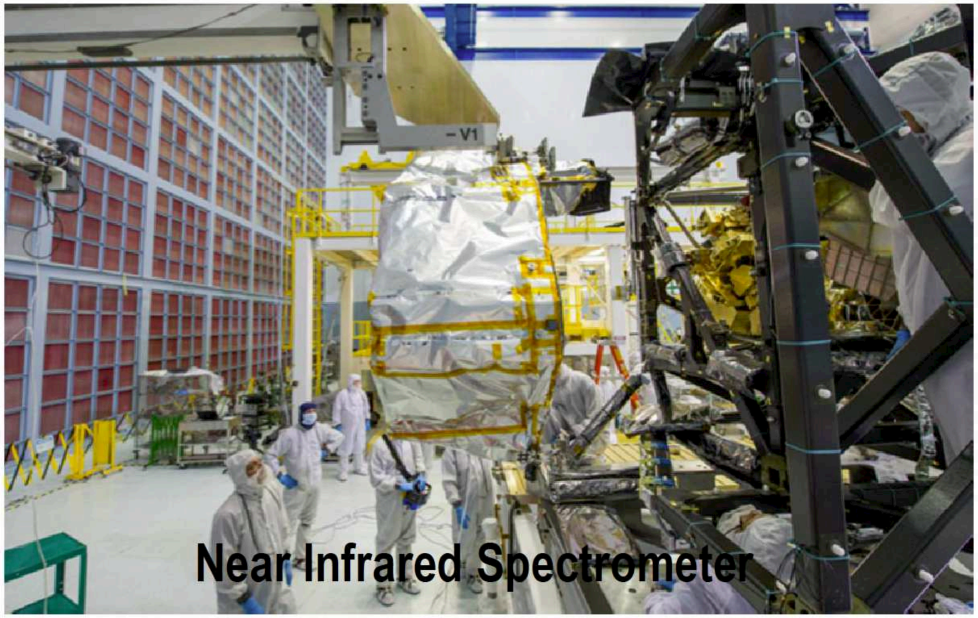
Webb mirrors finally mounted and ready!

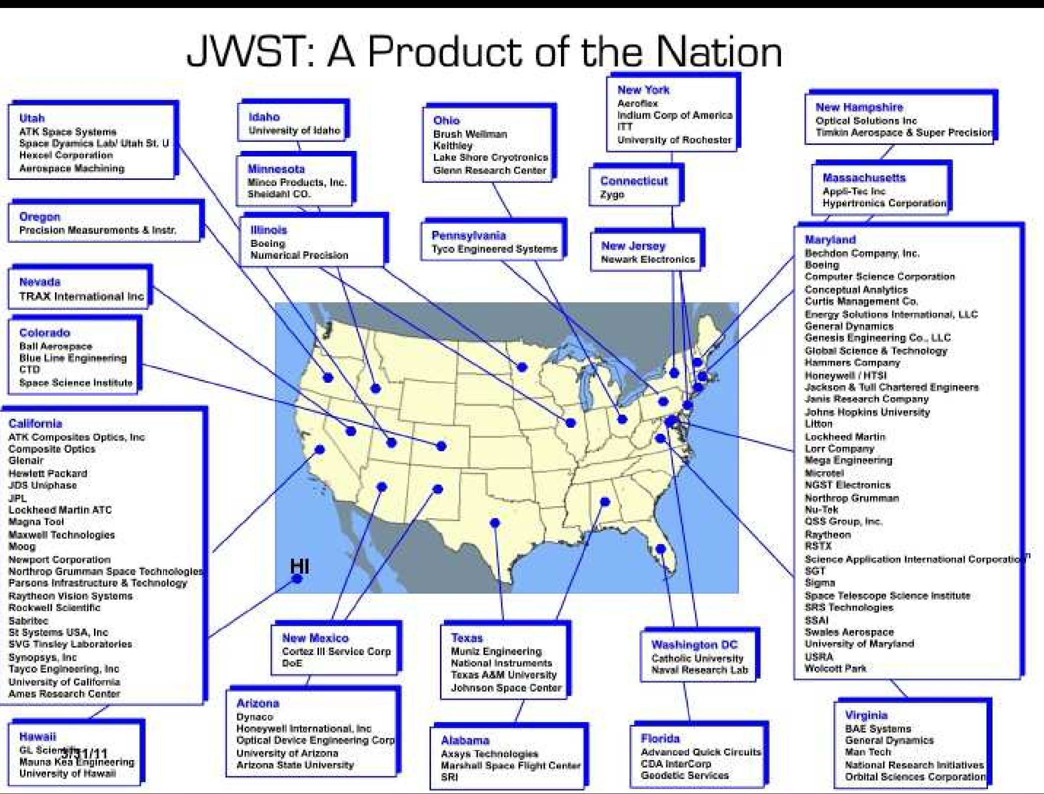


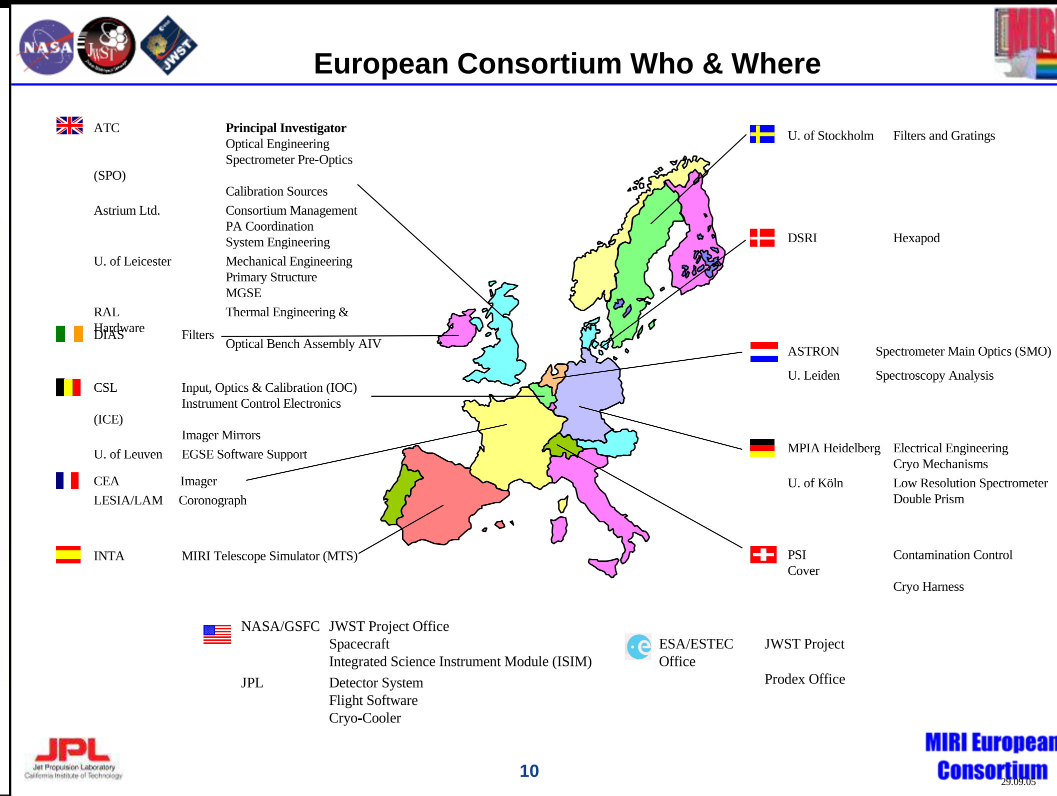
JWST stowed for further instrument mounting

All Instruments Integrated









- JWST hardware made in 27 US States: 100% of launch-mass finished.

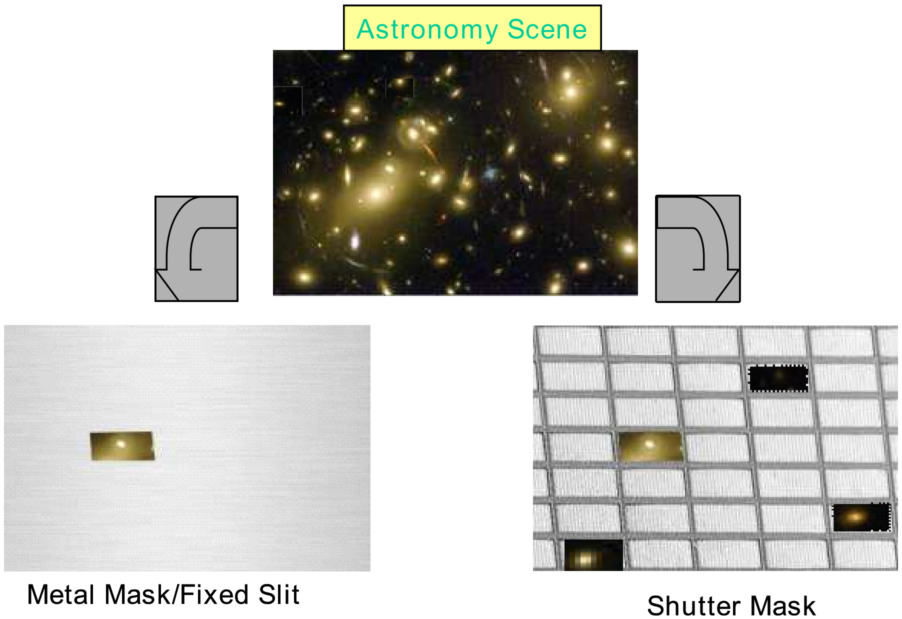
- Ariane V Launch & NIRSpec provided by ESA; & MIRI by ESA & JPL.

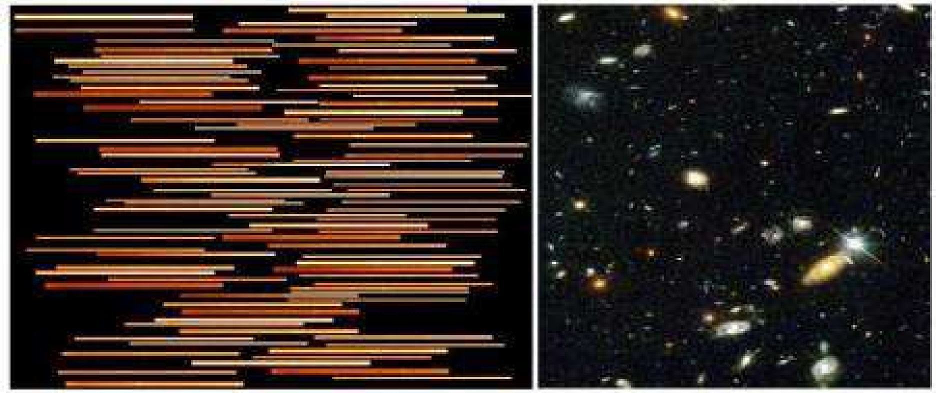
- JWST Fine Guider Sensor + NIRISS provided by Canadian Space Agency.

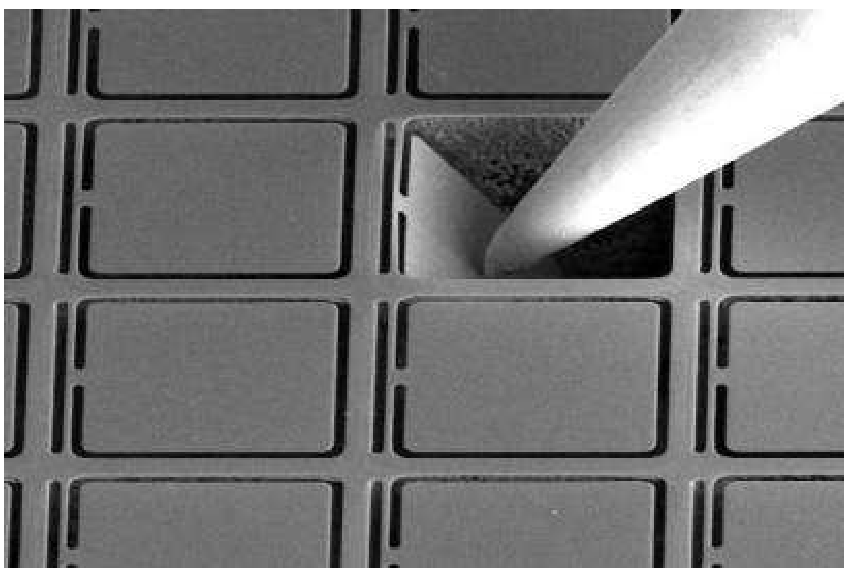
- JWST NIRCam made by UofA and Lockheed.

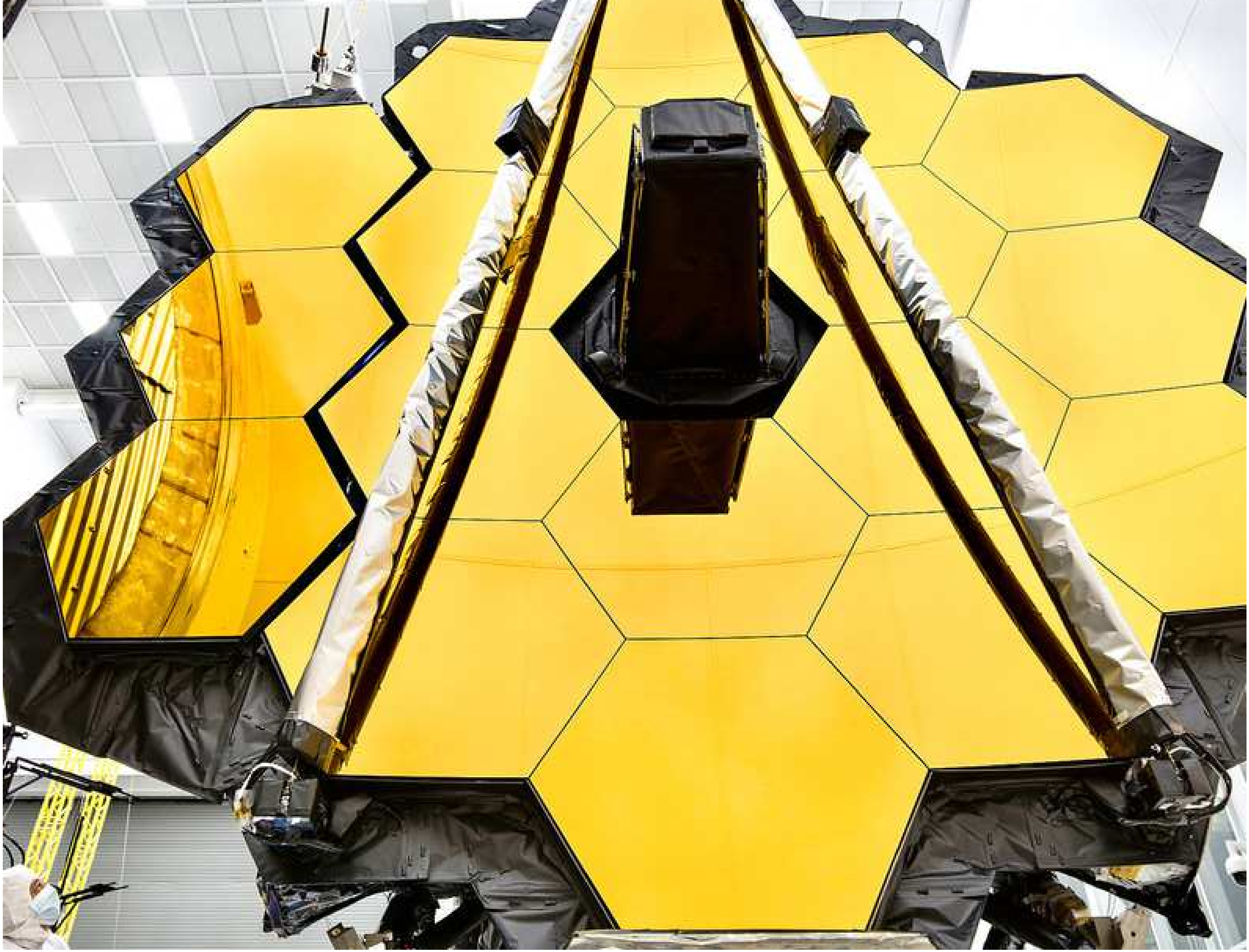
Thank you, Europe & ESA, for your very significant work on JWST!

Micro Shutters



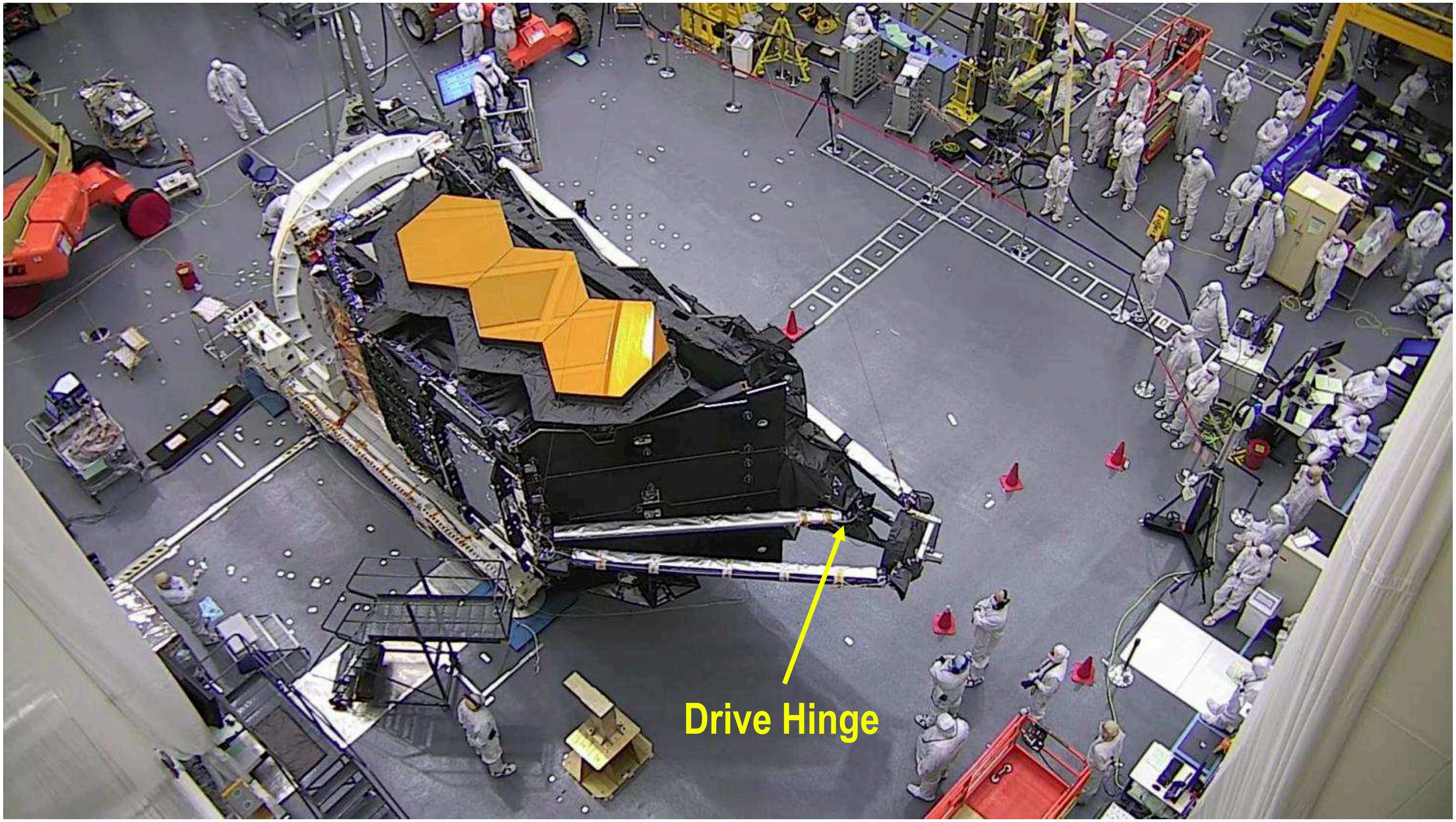






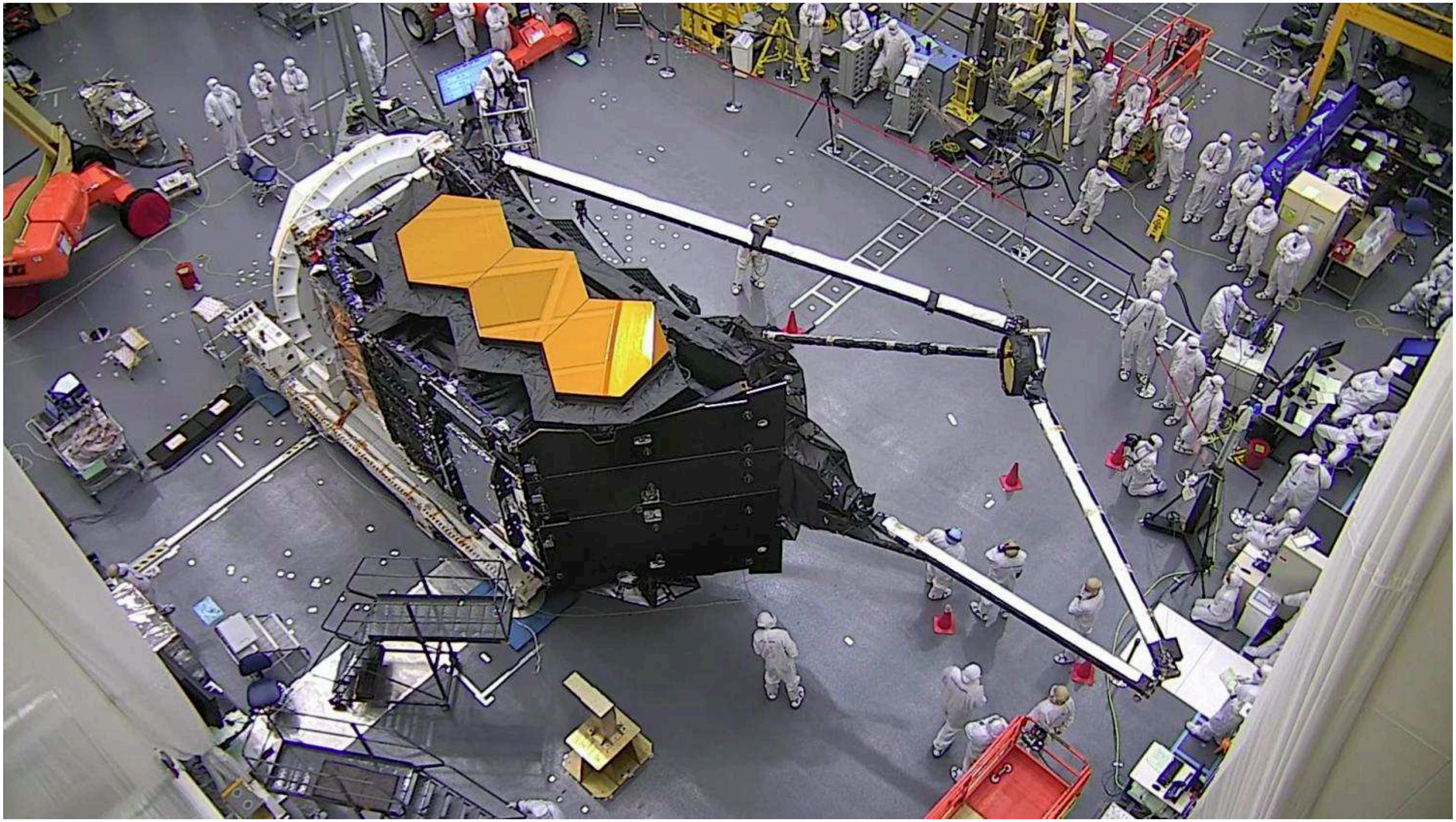
April 2017: Last portrait of JWST at Goddard Space Flight Center (MD).

SMSS Deployment Sequence (1)



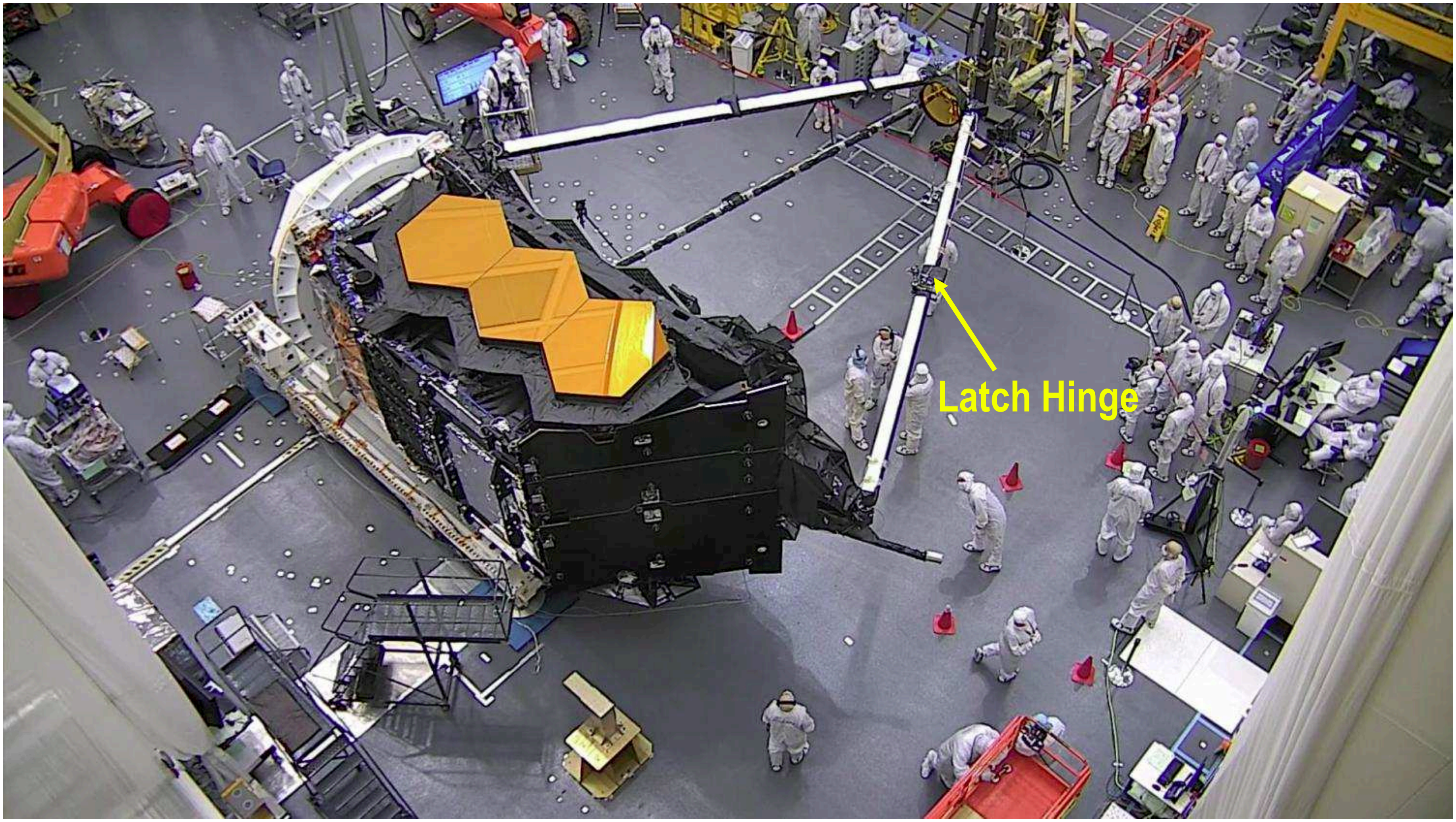
July 2019: Full 1-G deployment of JWST secondary mirror (SM) .

SMSS Deployment Sequence (2)



July 2019: Full 1-G deployment of JWST secondary mirror (SM) ..

SMSS Deployment Sequence (3)



July 2019: Full 1-G deployment of JWST secondary mirror (SM) ...

May 2017: JWST in enclosure at Johnson Space Center in Houston.

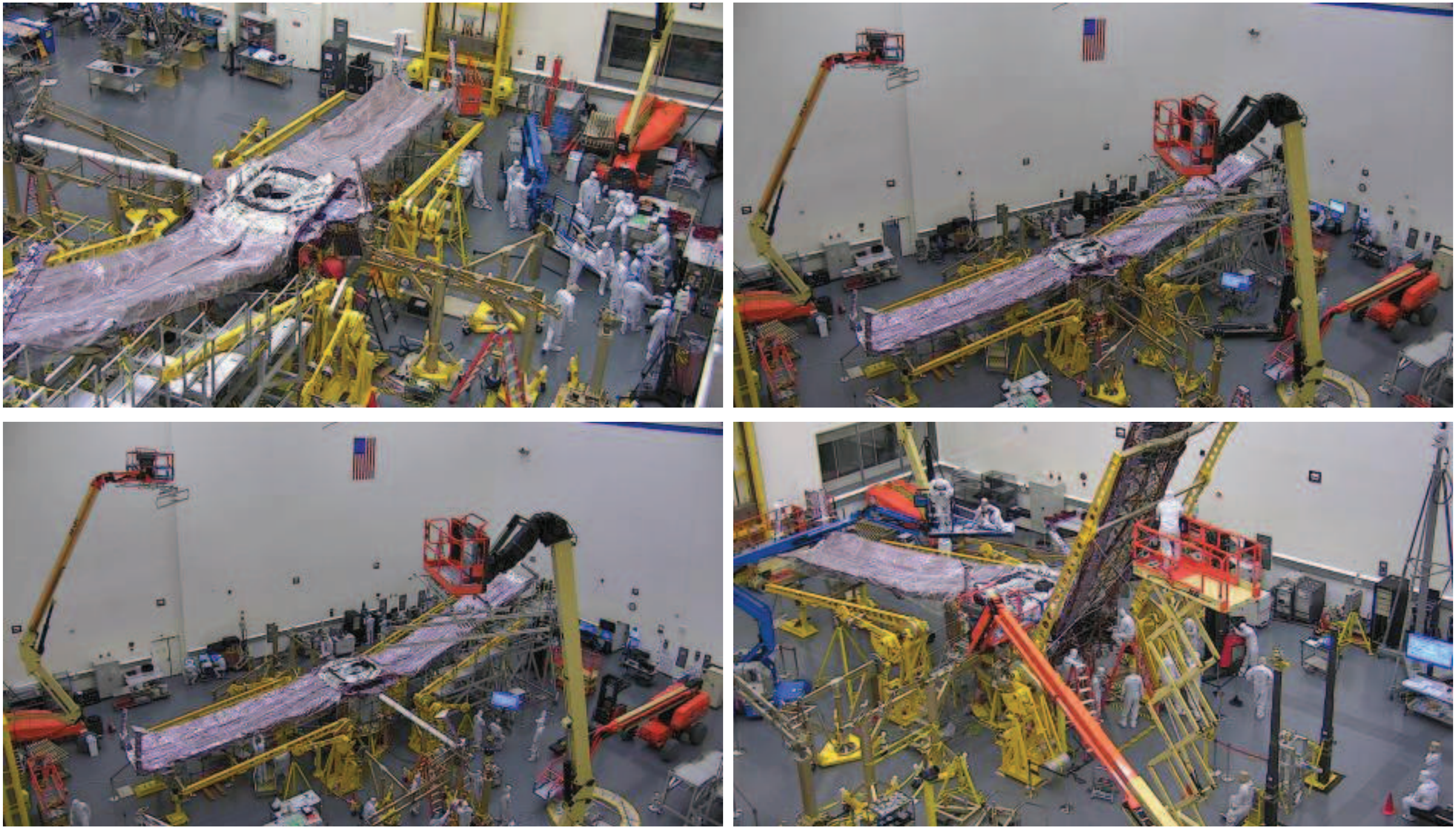
Program Update: OTIS

NORTHROP GRUMMAN

June 2017: JWST going into Chamber A at Johnson Space Center in Houston.

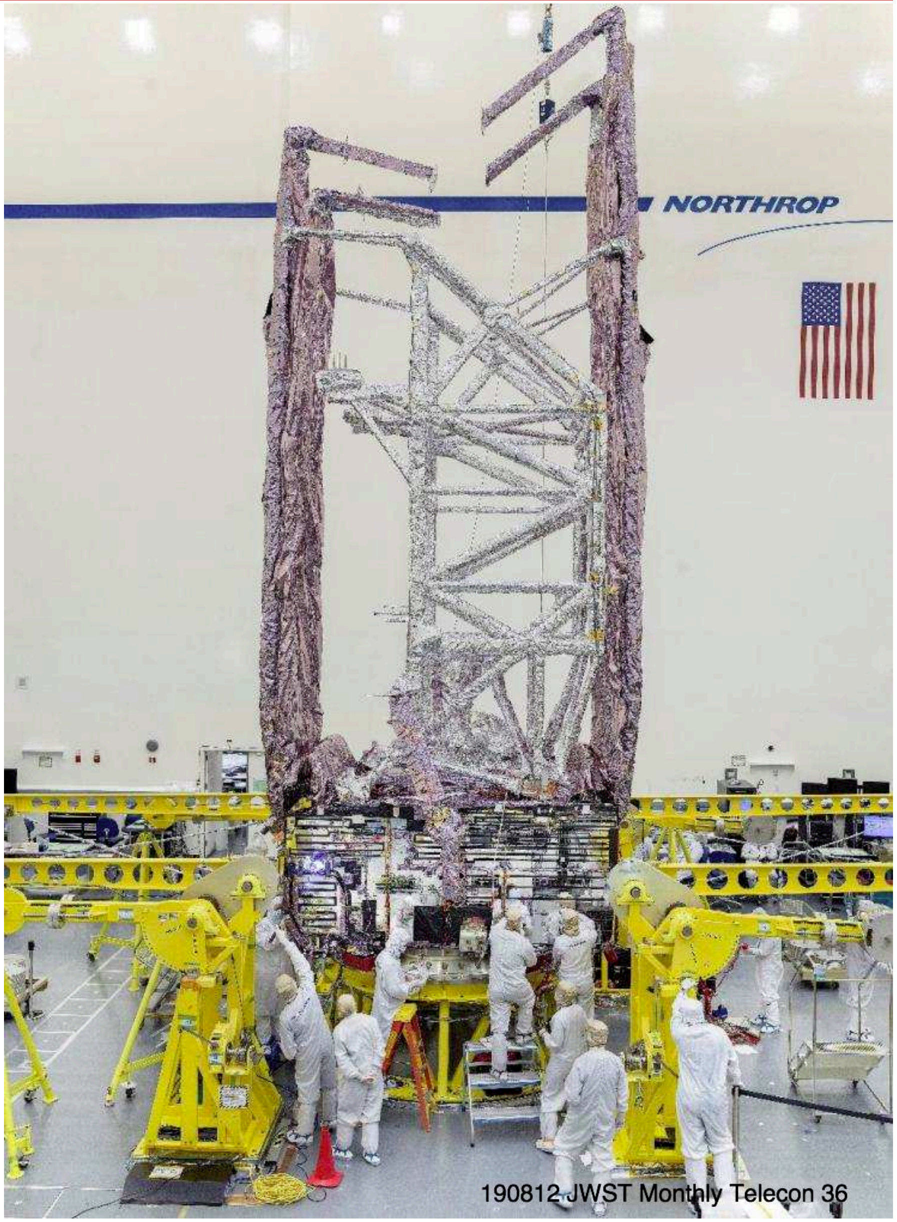
Program Updates: Spacecraft and Sunshield

NORTHROP GRUMMAN



2017–2018: JWST Flight Sunshield assembled and tested at Northrop.

SCE to Elephant Stand



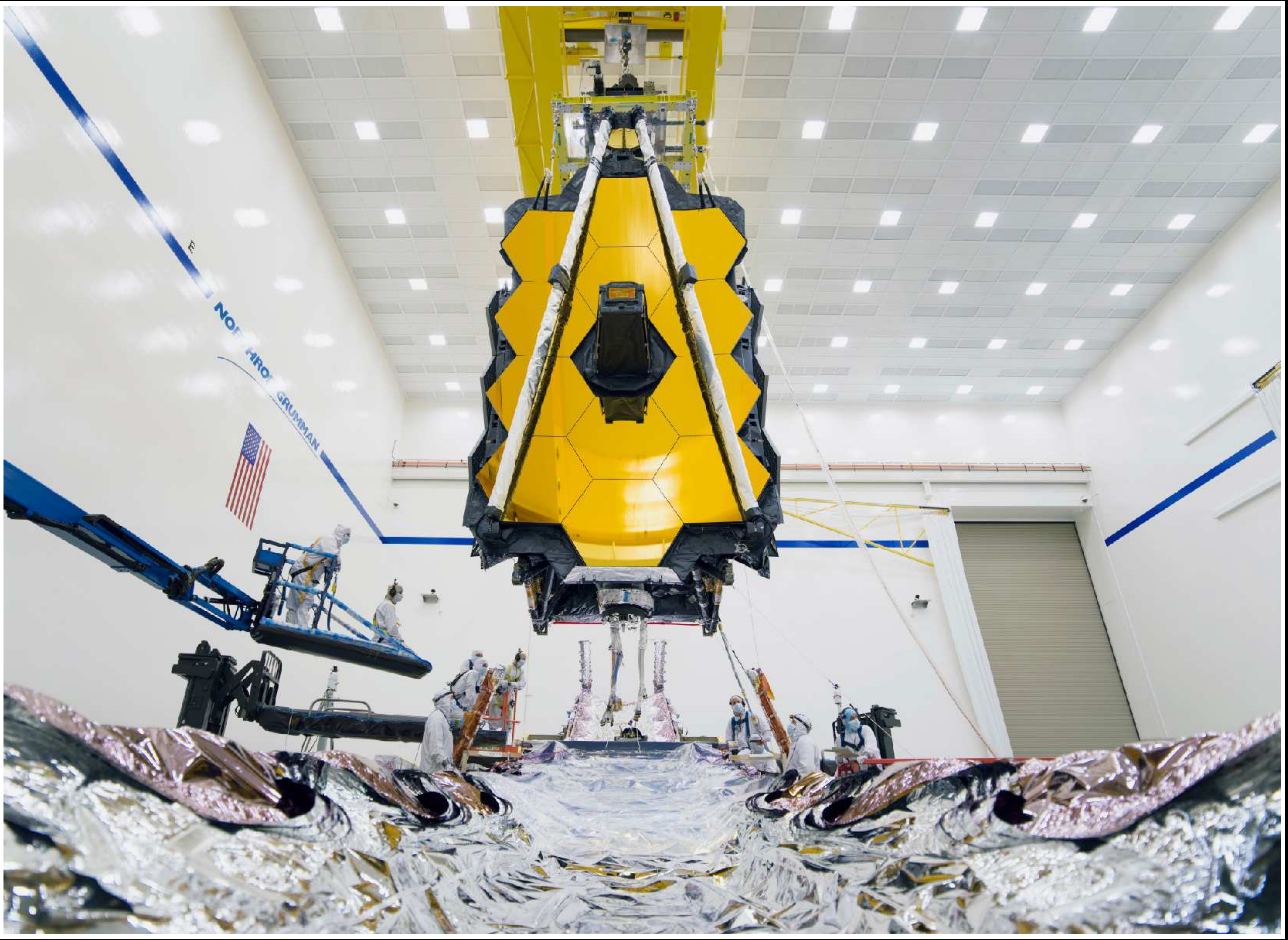
Aug. 2019: Stowed flight sunshield before integration with JWST OTE.

SMSS Deployment

NORTHROP GRUMMAN

190812 JWST Monthly Telecon 39

Aug. 2019: OTE before final integration with Sunshield & spacecraft.

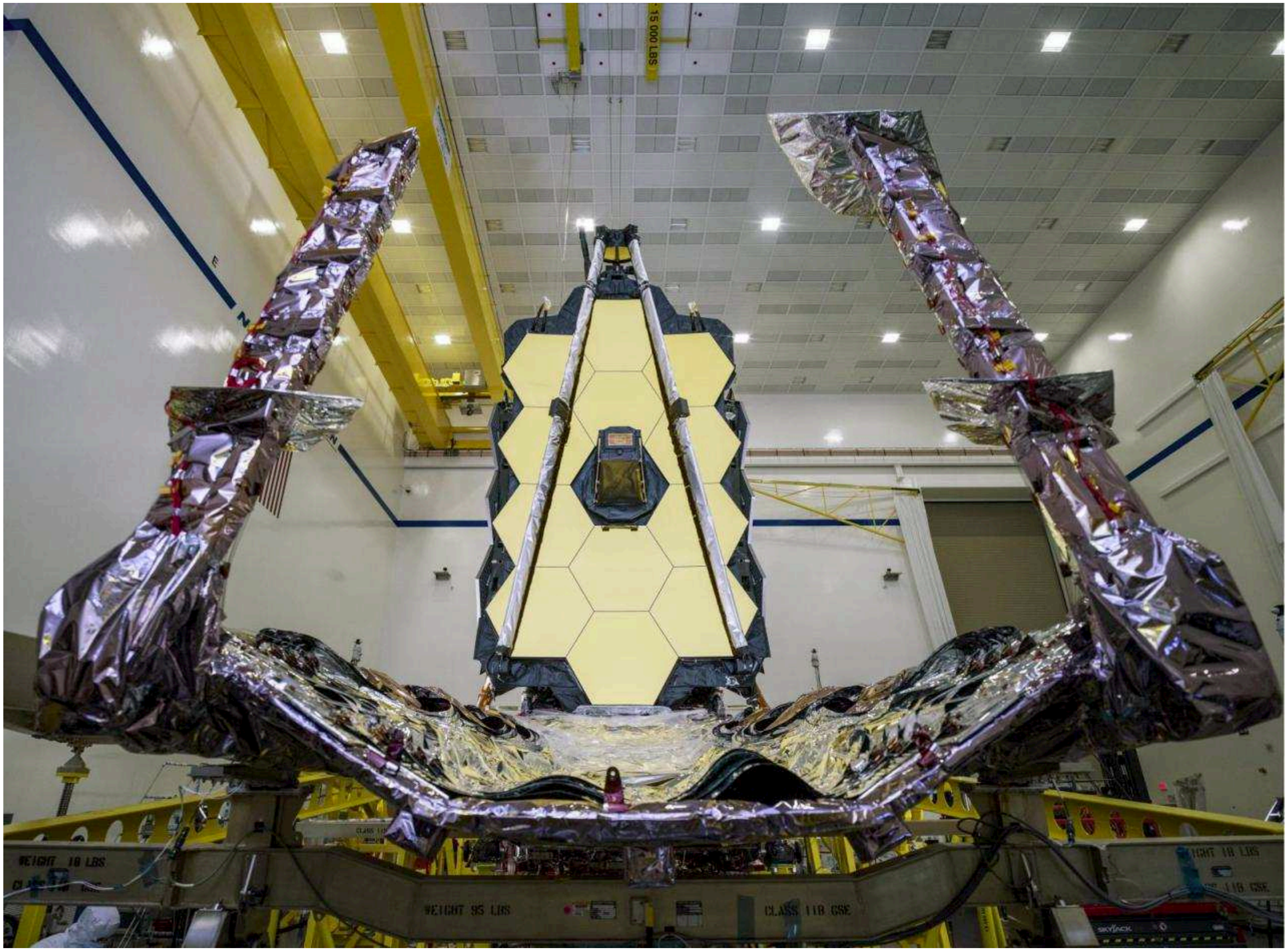


Aug. 2019: JWST OTE+ISIM lowered into Sunshield+Spacecraft

August 2019: JWST OTE+ISIM integrated with Sunshield+Spacecraft!

August 2019: JWST OTE+ISIM integrated with Sunshield and Spacecraft!

Meet the JWST Observatory 1



See NASA Press Release here:

https://www.nasa.gov/feature/goddard/2019/nasa-s-james-webb-space-telescope-has-been-assembled-for-the-first-time

August 2019: JWST OTE+ISIM integrated with Sunshield and Spacecraft!

Solar Array Deployment 1

May 2020: Ready for Solar Array deployment test

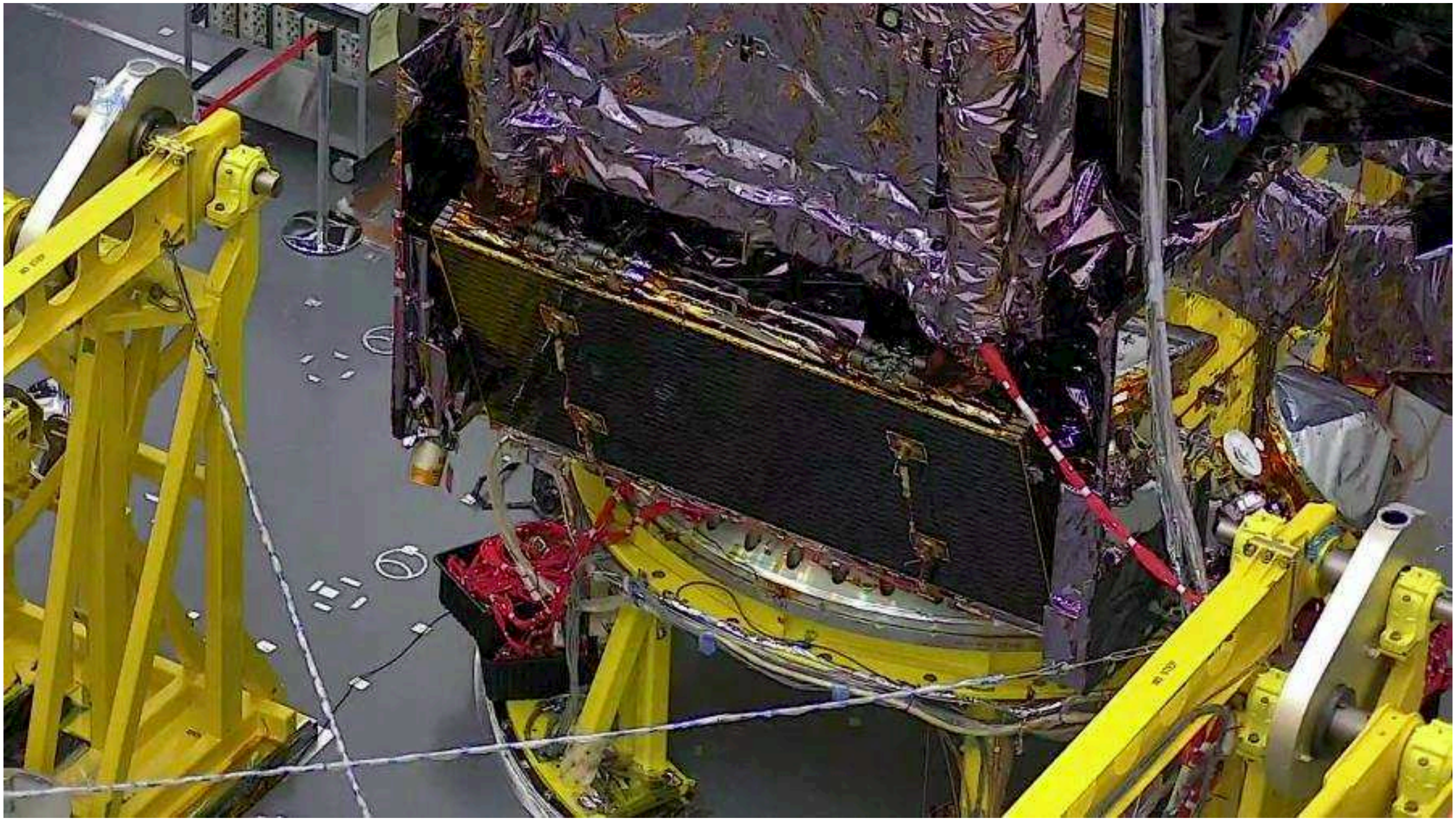
Solar Array Deployment 2

May 2020: Solar Array deployment with gravity off-loading

Solar Array Deployment 3

May 2020: Solar Array fully deployed and motor tested in 1G

7/26/20: Solar Array Installed for Environments



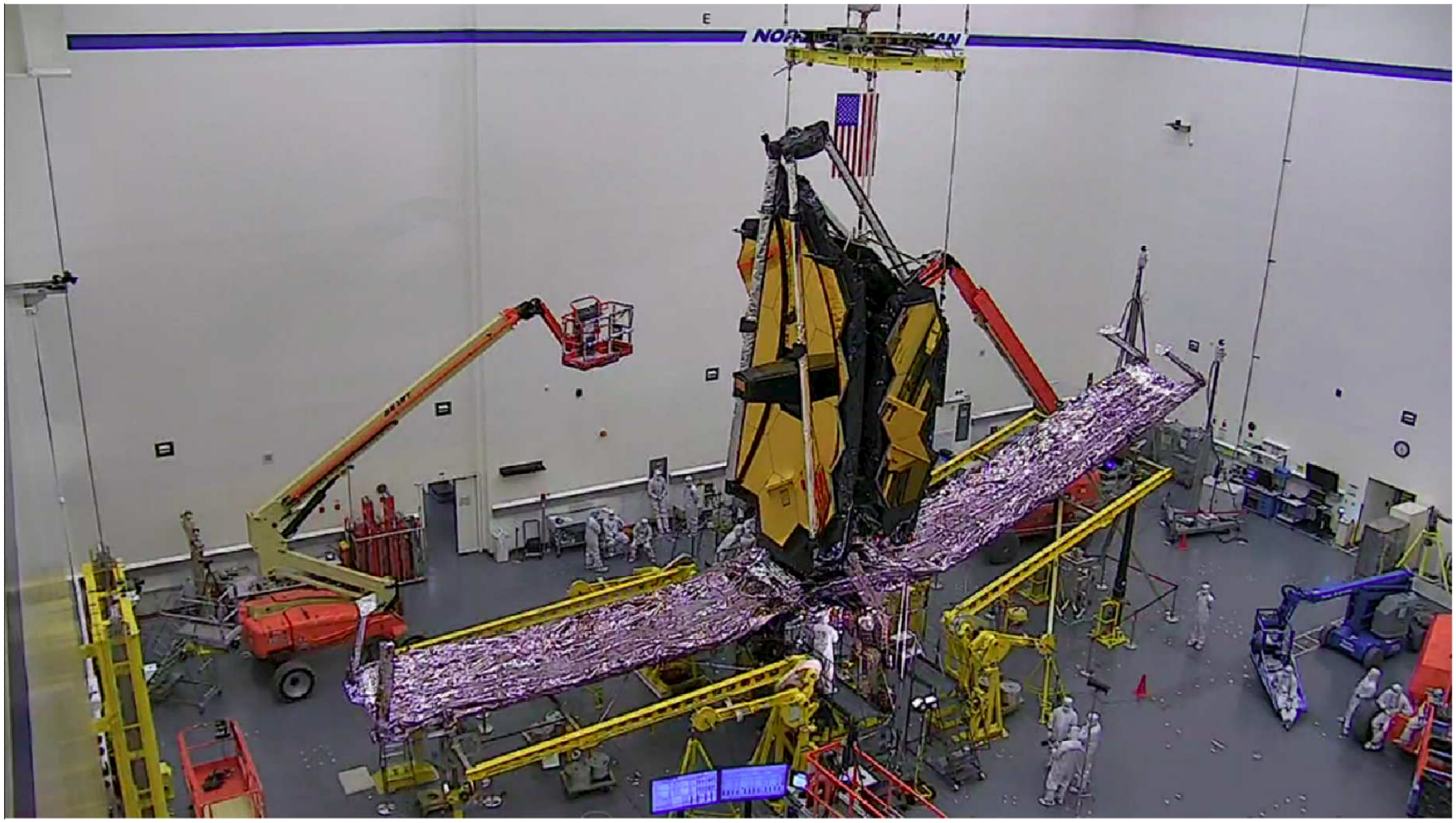
May 2020: Solar Array as installed on JWST Observatory

5/28/20: DTA Deployment

Approved for Public Release; NG20-106

June 2020: Deployable Tower Assembly test

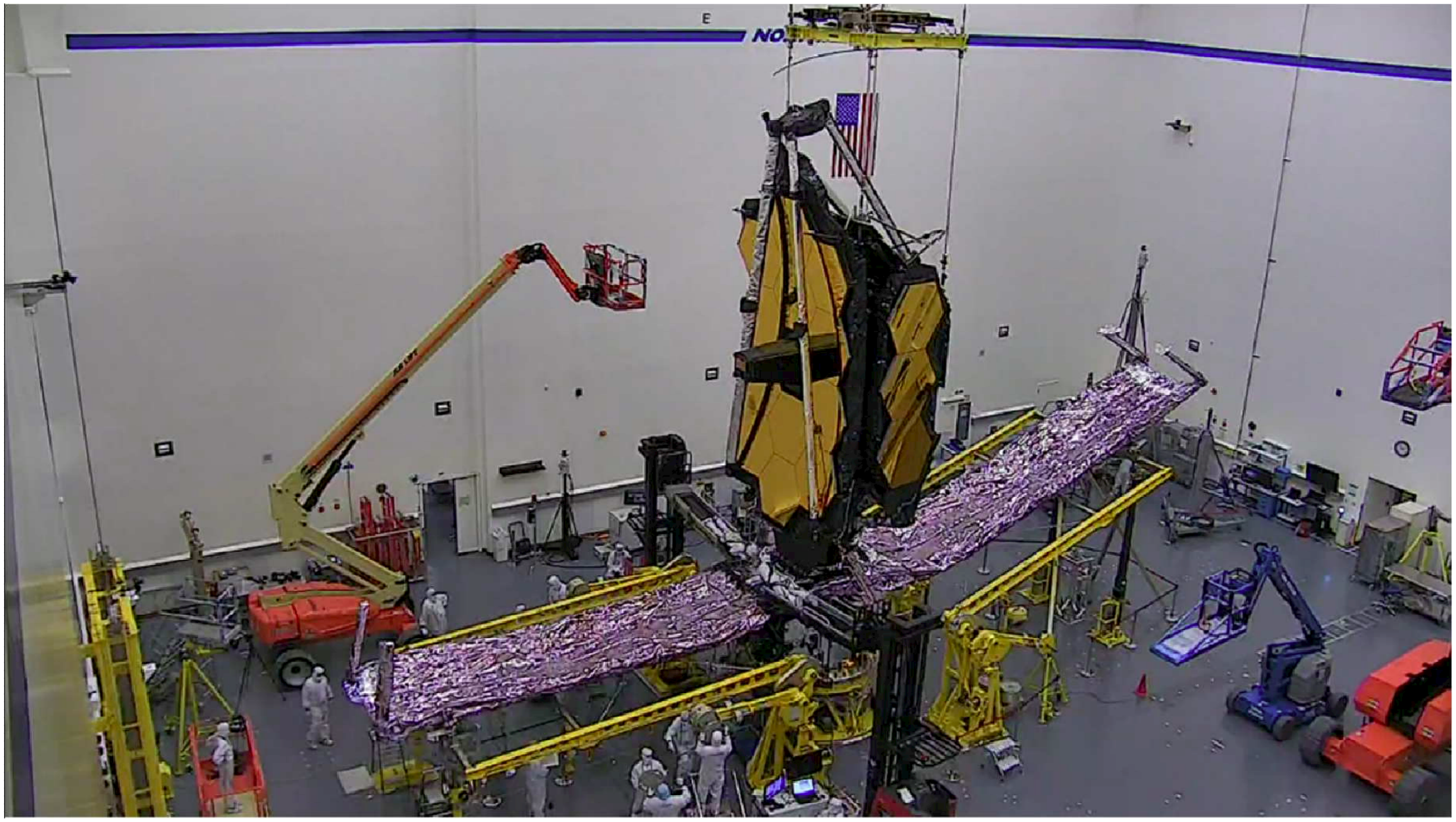
5/28/20: DTA Deployment



June 2020: Deployable Tower Assembly test with gravity off-loading.

NORTHROP GRUMMAN

5/29/20: DTA Deployment



Approved for Public Release; NG20-106

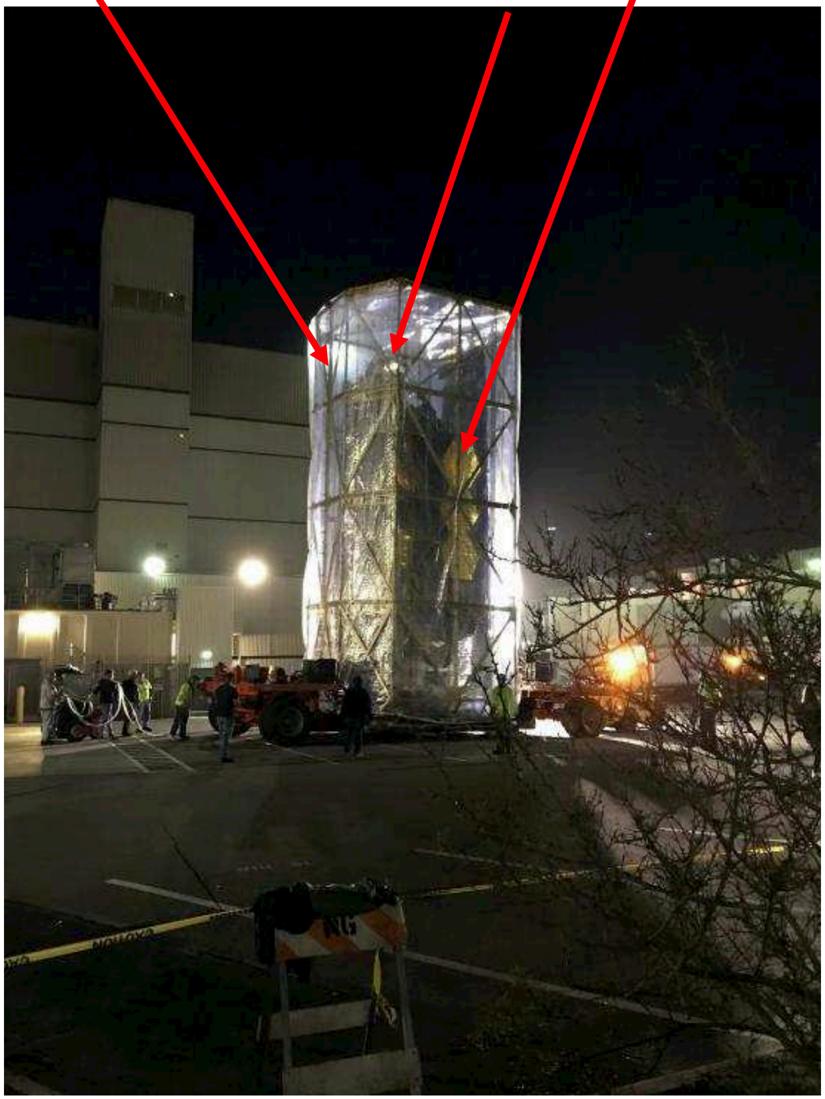
June 2020: Deployable Tower Assembly motor tested in 1G

Transport to the Large Acoustic Test Facility

Contamination Tent

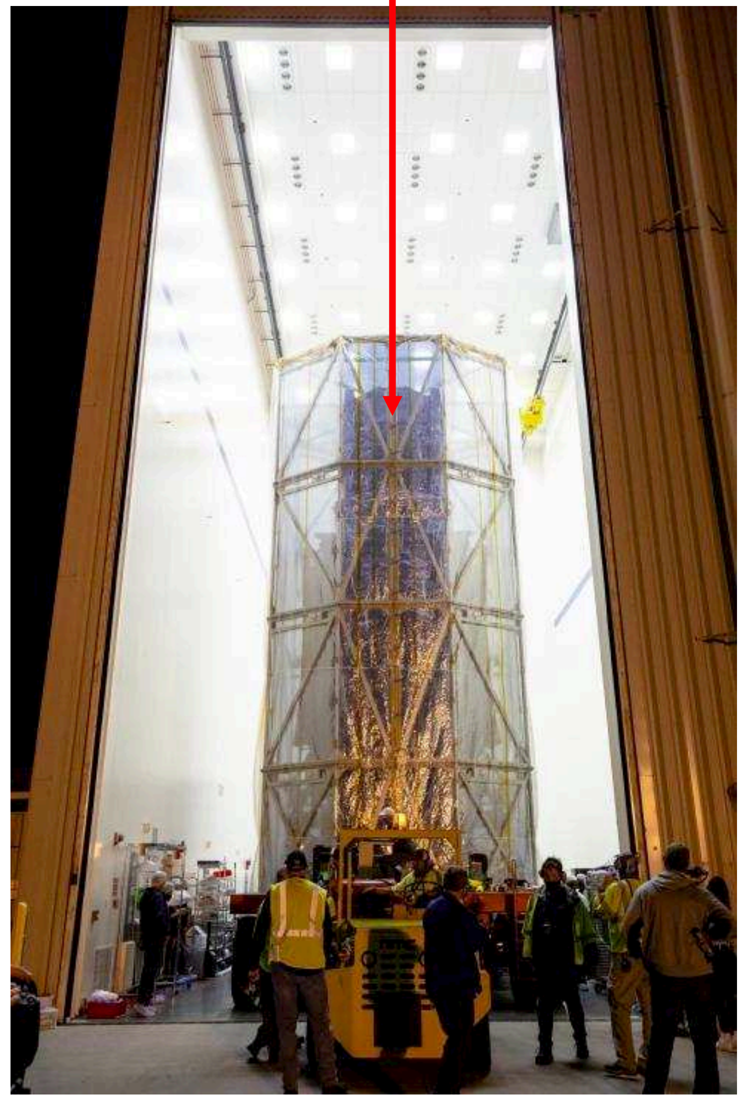
Secondary Mirror

Primary Mirror Wing



En route through the Space Park, Credit: NGSS

Unitized Pallet Structure



Arriving at the LATF Airlock, Credit: NGSS

Aug 2020: Transport of JWST into Northrop acoustic chamber

(beautiful)

The ^ James Webb Space Telescope

Stowed for Launch

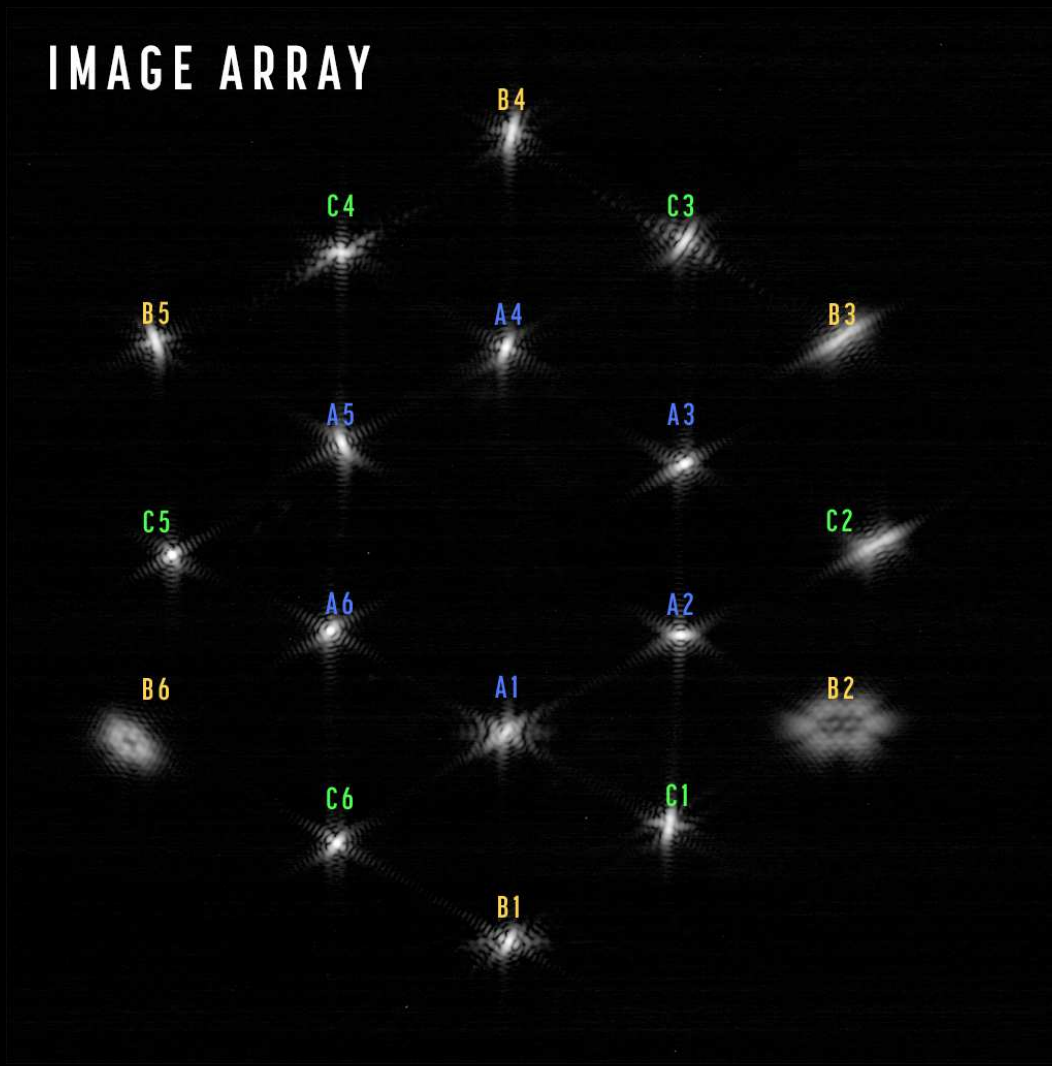
210913 JWST Monthly Telecon 18

Sept. 2021: JWST ready and stowed for shipping to Kourou

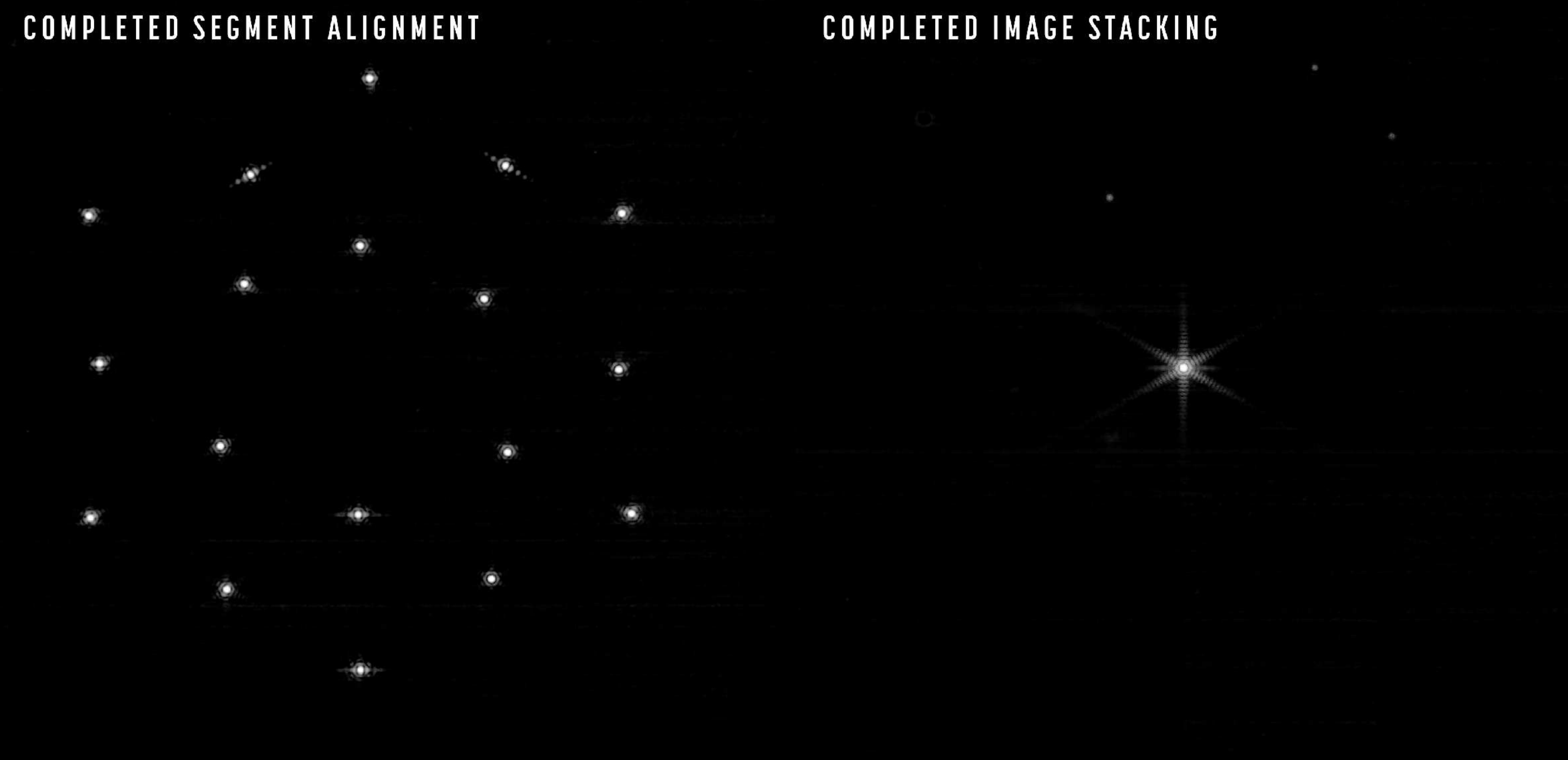
Dec. 9, 2021: JWST transport in Kourou to Ariane Rocket Assembly Building

Webb is finally launched from Kourou on December 25, 2021!

Feb. 2022: Webb seen shortly after launch over Africa using the Ariane V camera.



Feb. 2022: Webb's first selfie (left) and First Light raw image (right).

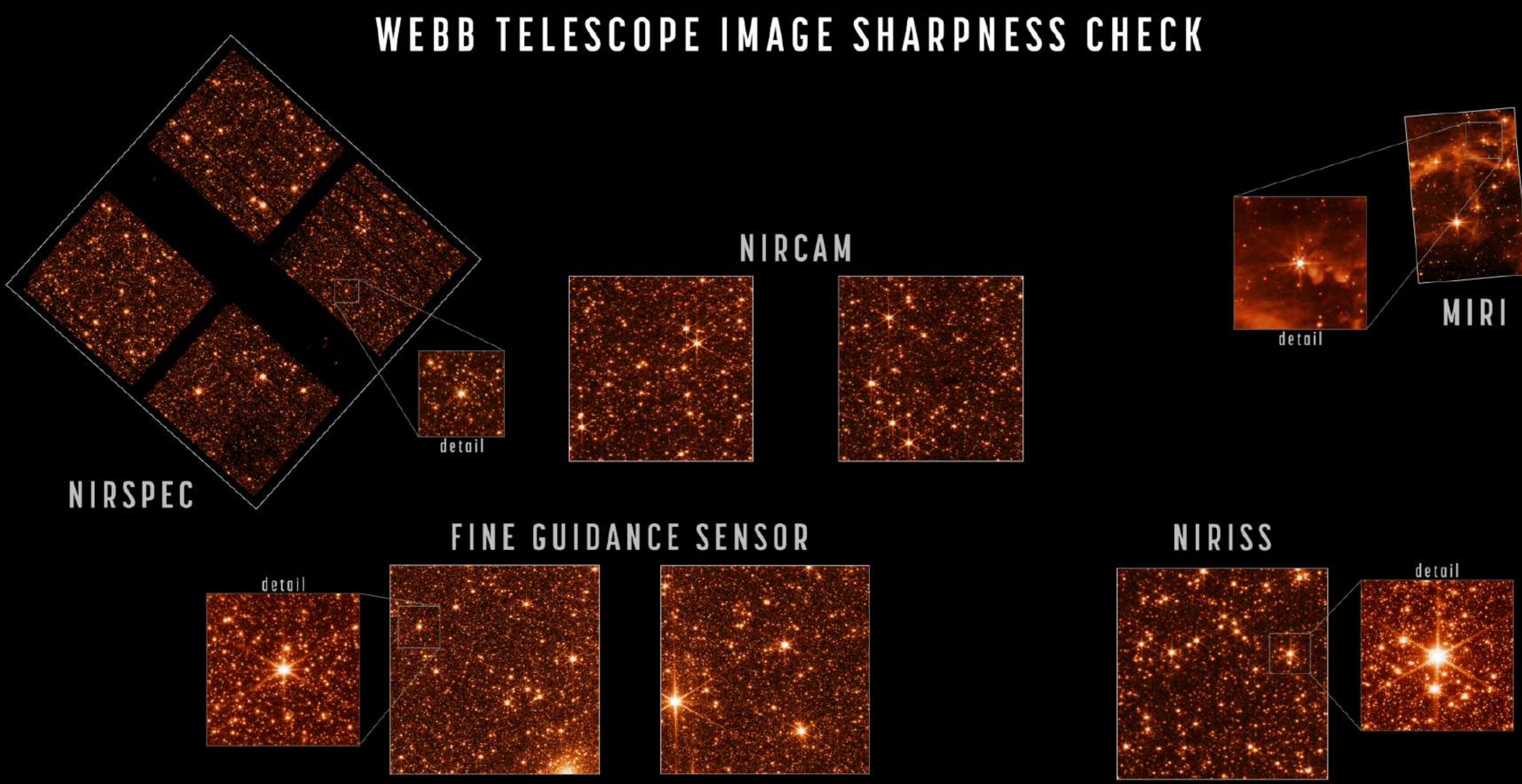


Webb's first segment alignment (left) and first image stack (right).

March 16, 2022: Webb's first fully focused image publicly released !!

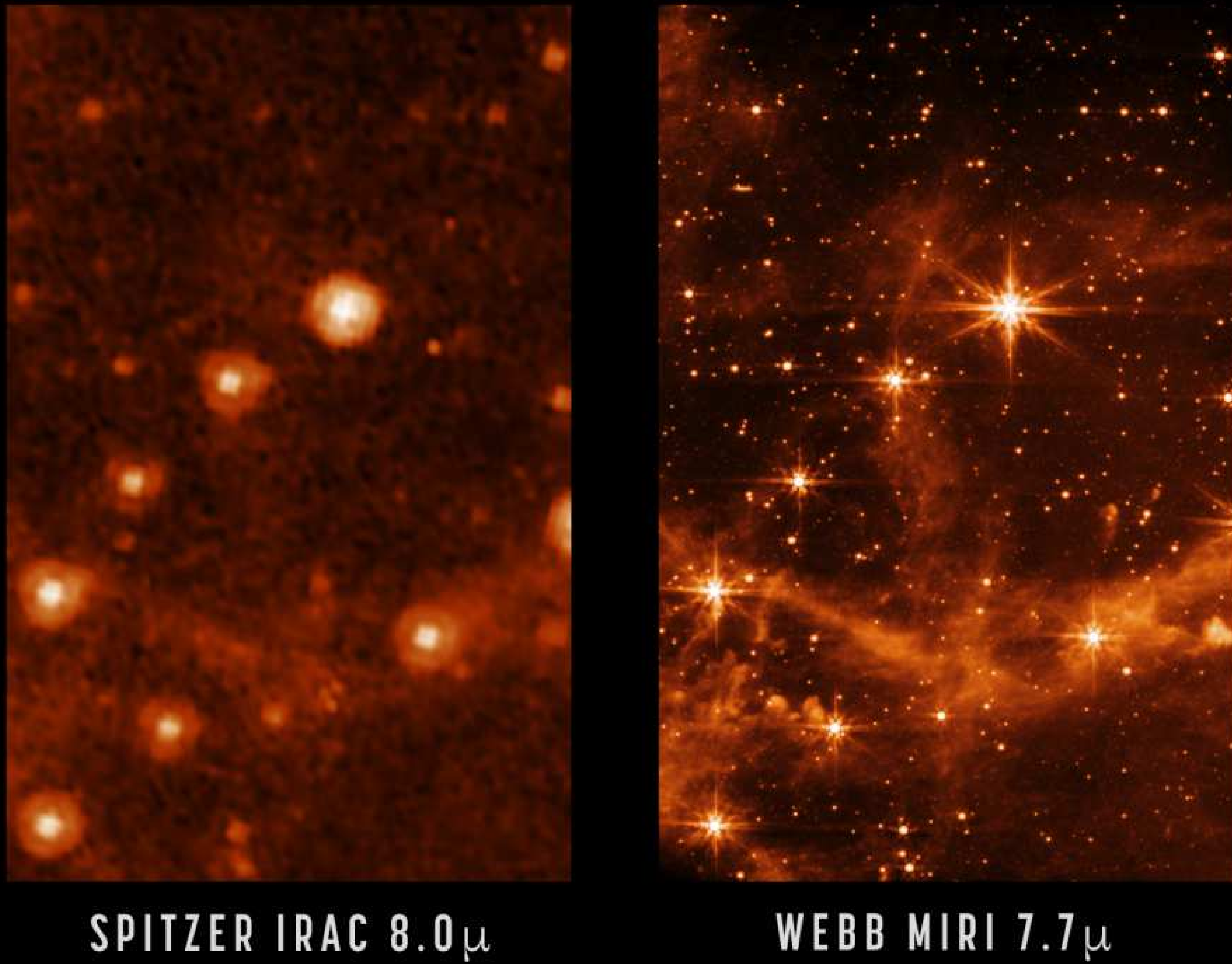
Note the plethora of faint galaxies — Webb's looking back in time!

`https://www.nasa.gov/press-release/nasa-s-webb-reaches-alignment-milestone-optics-working-successfully`



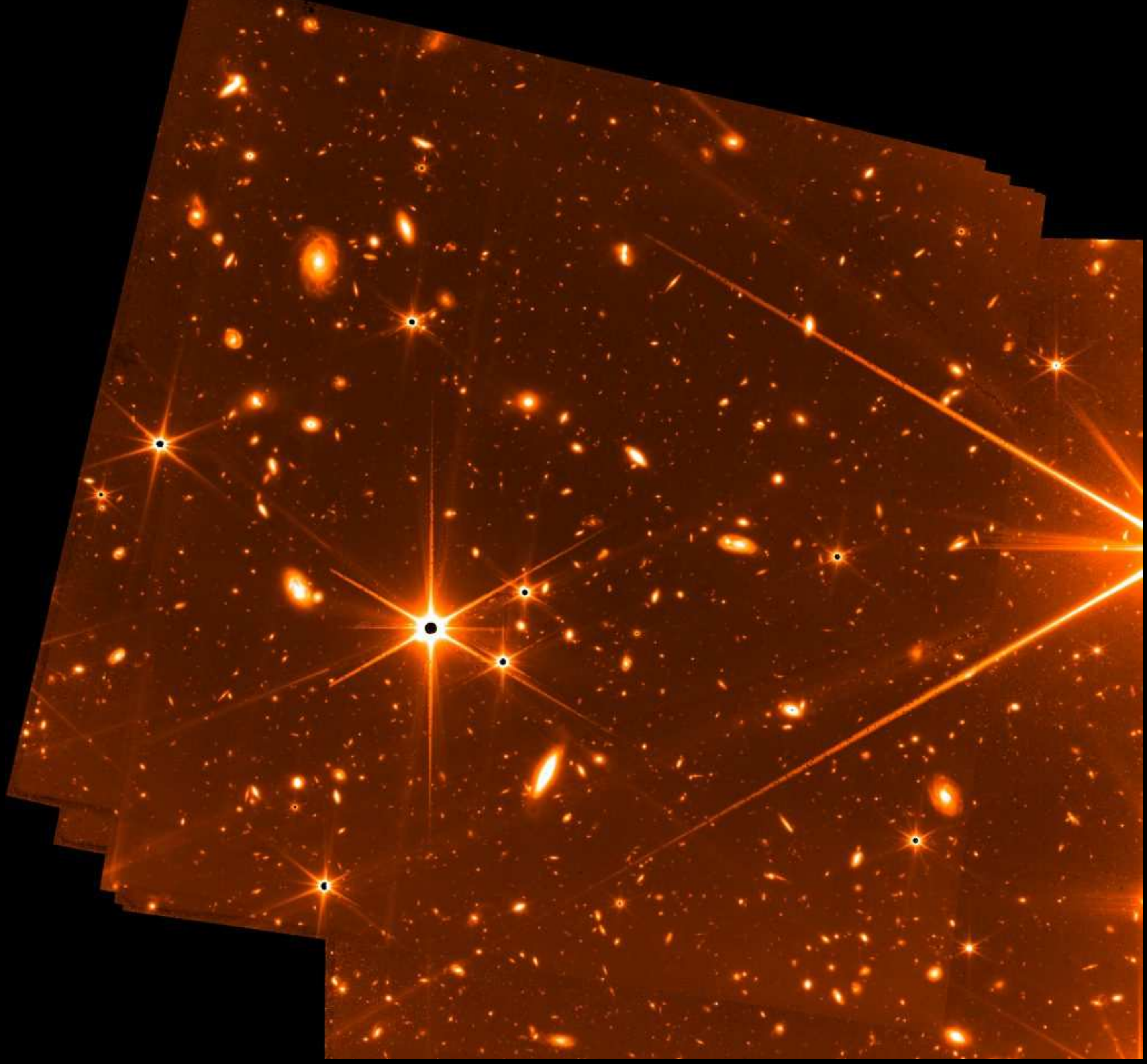
April 28, 2022: Webb's first fully focused images in all four instruments: a dense star field in the Large Magellanic Cloud in the South Ecliptic Pole! (NIRSpec: 1.1 μm; NIRISS: 1.5 μm; NIRCam: 2.0 μm; MIRI 7.7 μm).

https://blogs.nasa.gov/webb/2022/04/28/nasas-webb-in-full-focus-ready-for-instrument-commissioning/



May 9, 2022: Webb's 7.7. μm MIRI image compared to Spitzer 8.0 μm:
Same dense star field in the Large Magellanic Cloud in the South Ecliptic Pole

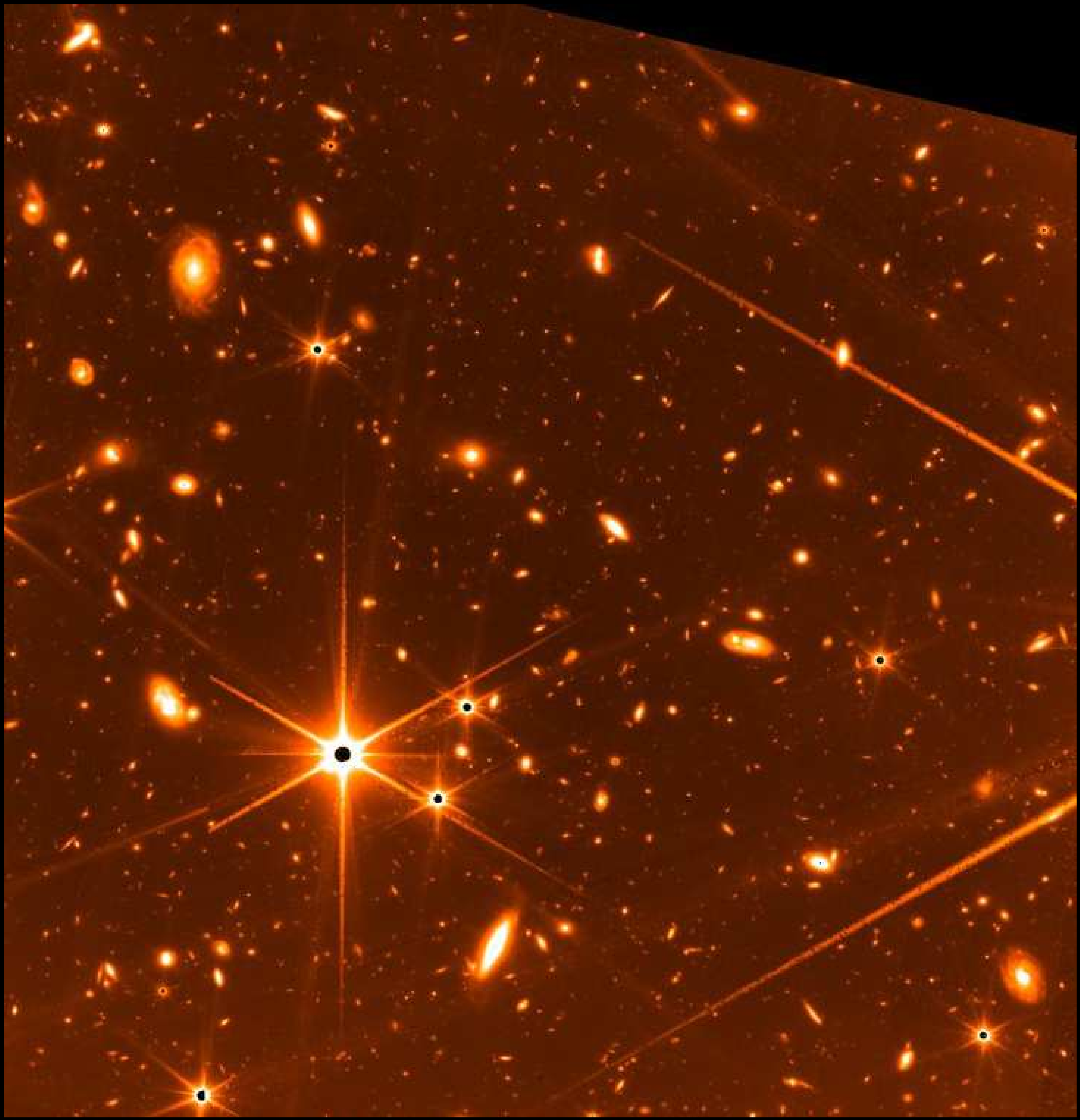
https://blogs.nasa.gov/webb/2022/05/09/miris-sharper-view-hints-at-new-possibilities-for-science/



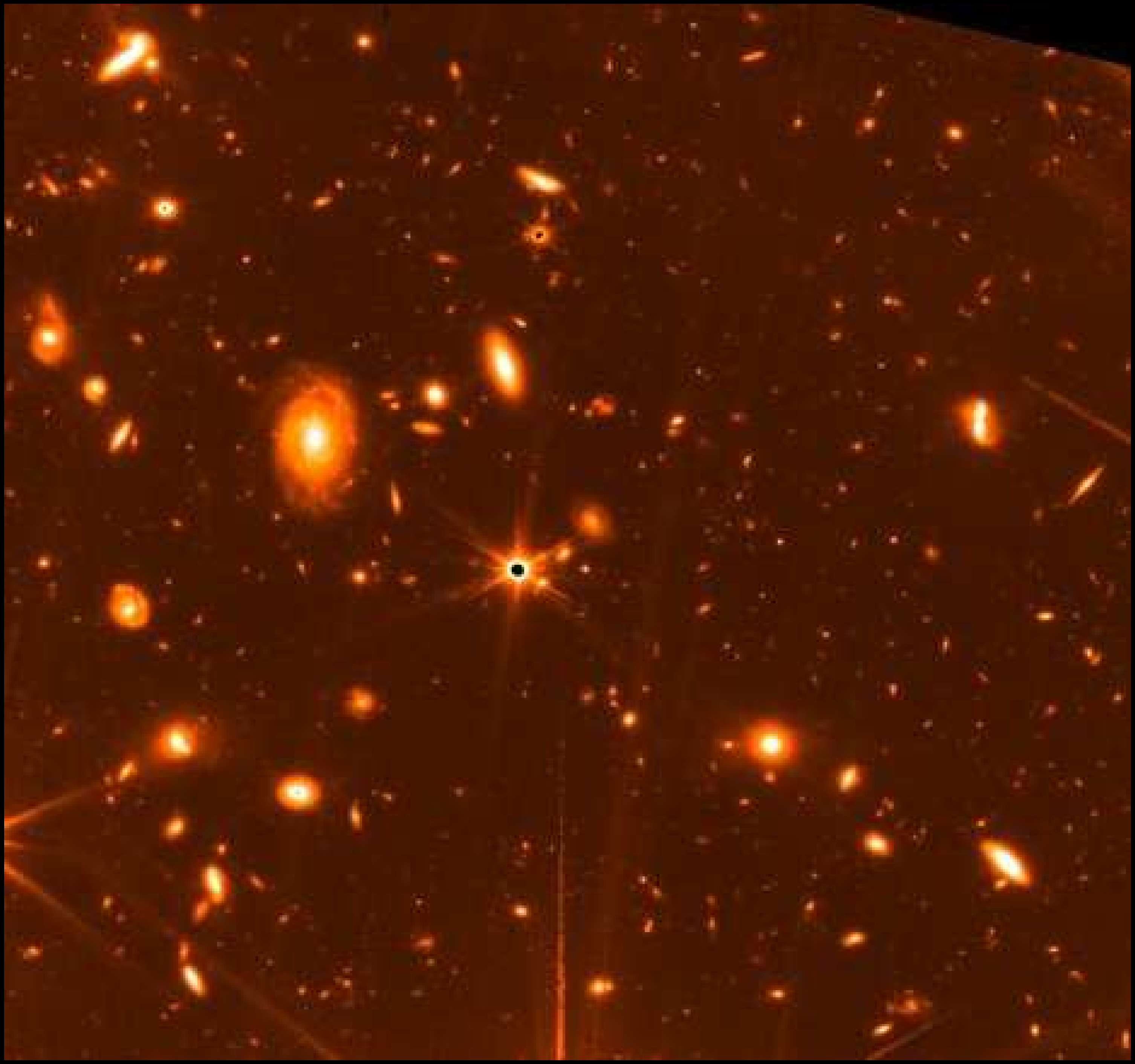
July 6, 2022: 32-hr Fine Guidance Sensor deepest wide-band near-IR image

(bright star: 9.2 mag 2MASS 16235798+2826079).

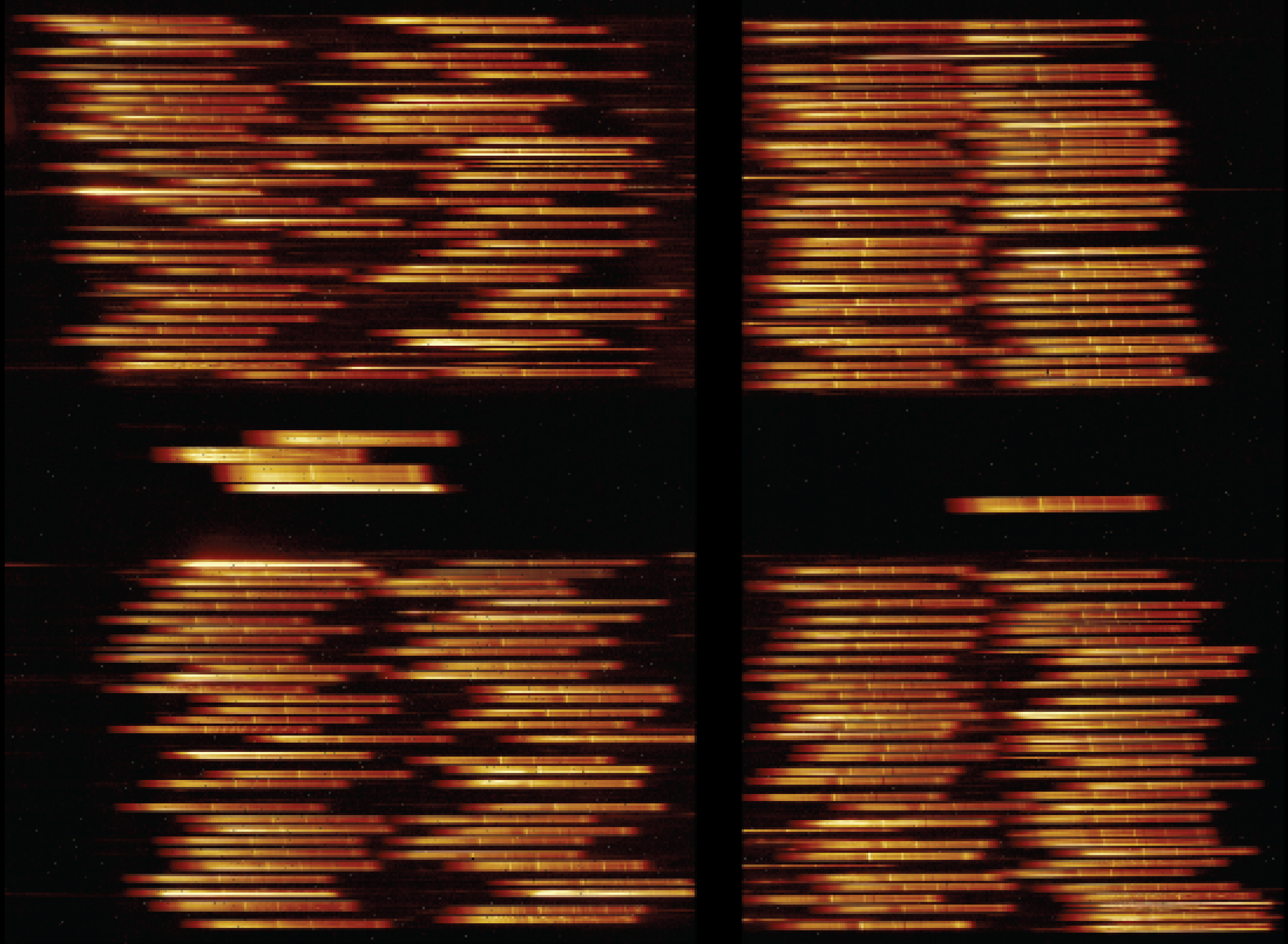
https://blogs.nasa.gov/webb/2022/07/06/webbs-fine-guidance-sensor-provides-a-preview/



... Webb reveals the faintest galaxies in the near-infrared!



Webb can see the faintest galaxies to the level where the universe has many many “billions and billions”!



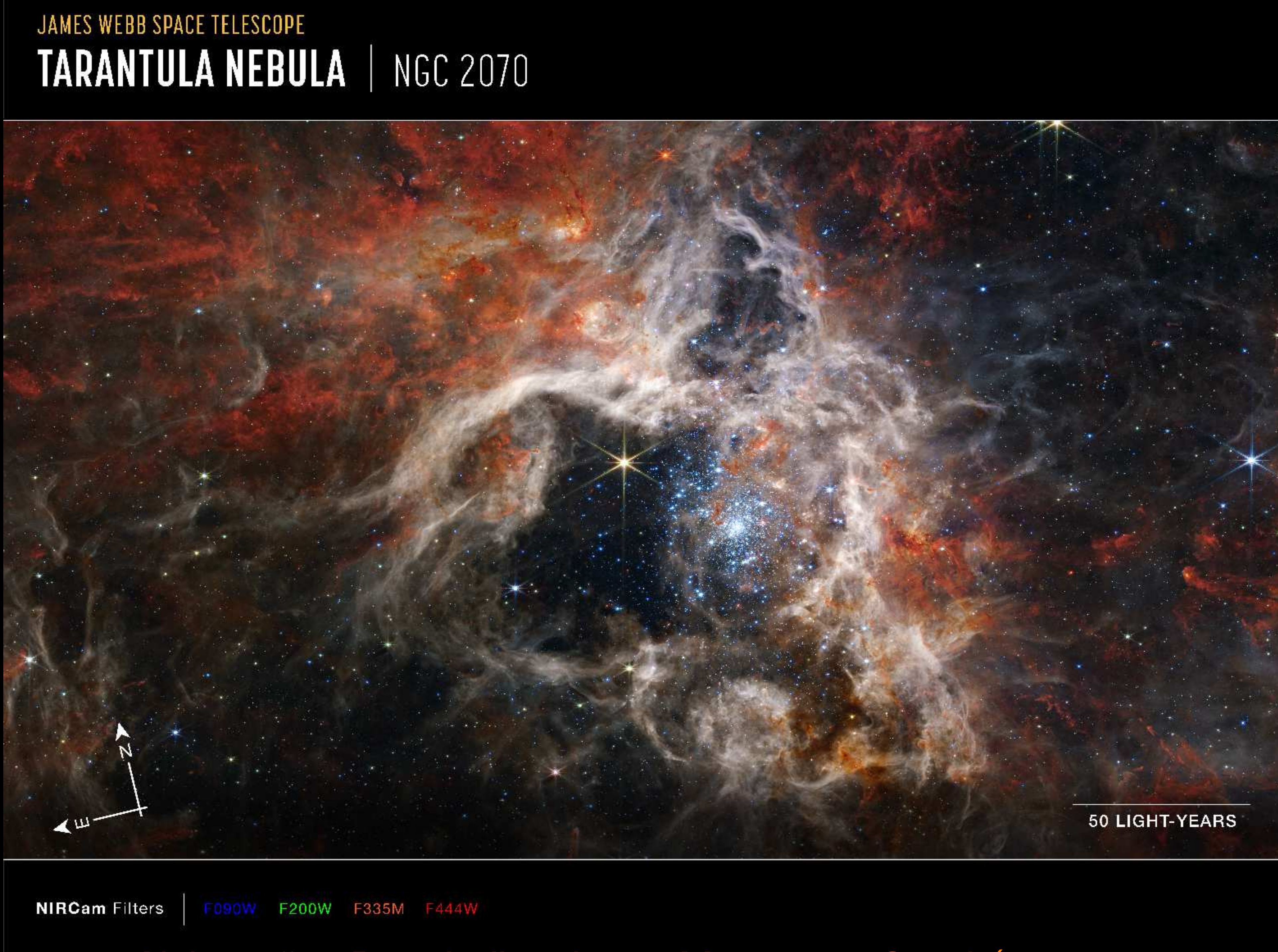
Webb first NIRSpec near-IR spectra of ∼100 faint stars near Galactic Center

Webb can take spectra of many 1000's of faint galaxies revealing their distances and chemical composition.

Hubble WFPC2 Eagle Nebula (1995) compared to JWST NIRCam (2022):

- The cradle of cosmic star-formation: NIRCam peers through the dust!
- The 1995 Hubble WFPC2 image (left) was made by Prof. Jeff Hester and Paul Scowen at ASU. It made it onto a US postage stamp!

Webb's MIRI shows the hauntingly beautiful cosmic dust pillars (8–15 μm)



Tarantula Nebula "30 Doradus" in Large Magellanic Cloud (163,000 lyrs away)

Cradle of cosmic star-formation: massive stars trigger formation of sun-like stars

JAMES WEBB SPACE TELESCOPE

TARANTULA NEBULA | NGC 2070

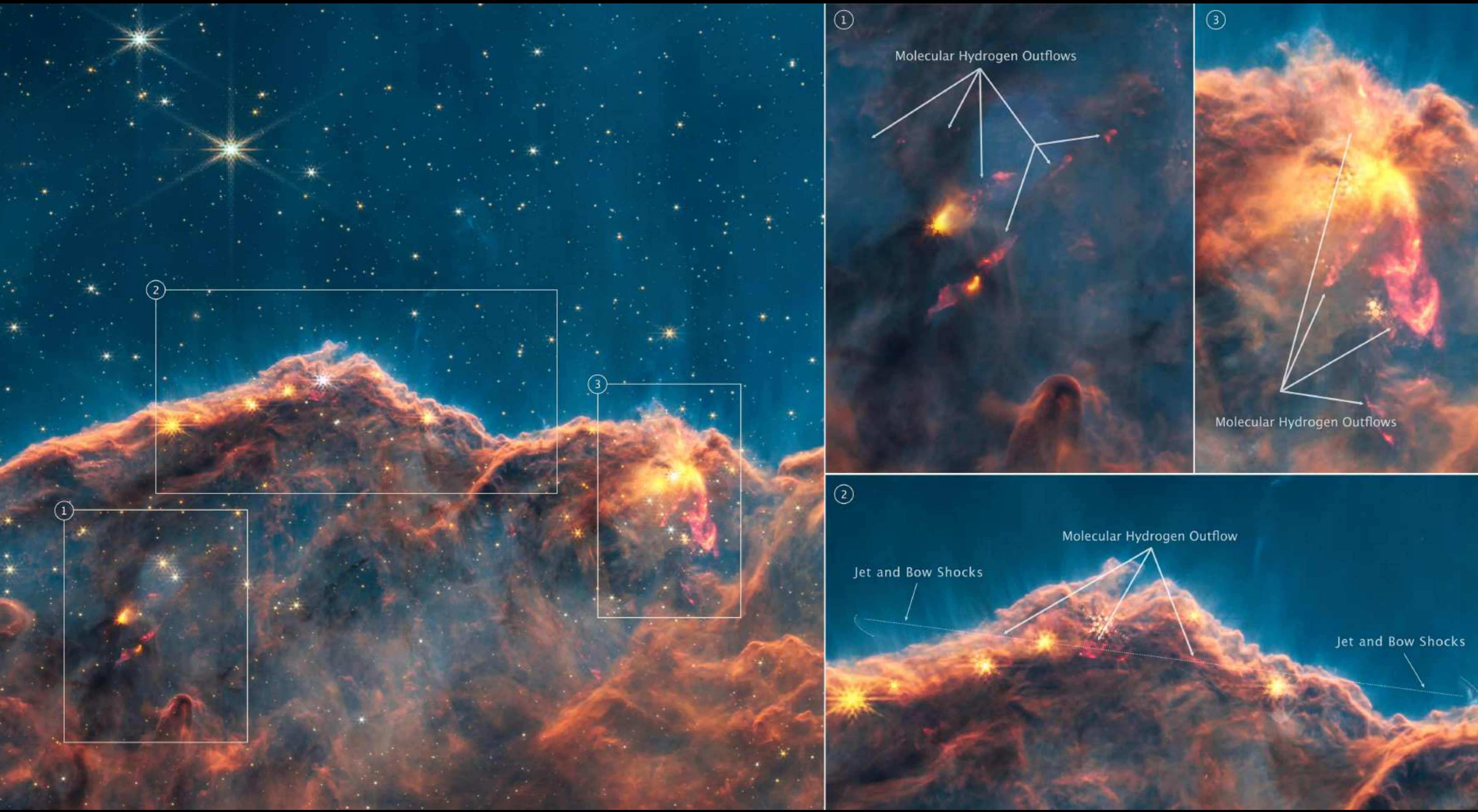
MIRI Filters F770W F1000W F1280W F1800W

mid-IR shows Poly-Aromatic Hydro-carbons: leftover from previous massive stars

Webb's MIRI shows the chemistry of star-formation: cosmic star-dust!

“Cosmic Cliffs” of star-formation in the Carina Nebula (NIR; 7600 light-years).

You will be witnessing the “Cosmic Circle of Life” ...



Where the action is: Composite of the Carina "Cosmic Cliffs"

- Red indicates molecular hydrogen outflowing from young forming stars.
- Young stars squirt out molecular jets that cause far-away bow-shocks.

Cosmic Cliffs of Star-formation in Carina Nebula (NIR+MIR).

Compared to optical+near-IR, mid-IR sees “Cradle of Cosmic Star-formation”

Deep inside the gas and dust, mid-IR reveals birth of young Sun-like stars.

NGC346: Star-forming region in Small Magellanic Cloud (200,000 lyrs)

- Pink is hot gas (18,000 F), while orange is old (300 F) H-gas.
- Many pillars of gas sculpted by young hotter stars are forming lower mass stars from this cooler Hydrogen gas.

Our birth, *e.g.*, : Protoplanetary "Hourglass Nebula" L1527 at 460 lyrs.

- A forming protostar with ∼30% of Sun's mass only 100,000 year old!
- The protostar has surrounding accreting gas, and a circumstellar disk.
- Eventually, L1527 will start shining as a star, and have its own planets.

Southern Ring Nebula (Near-IR+Mid-IR; 2500 light-years):

- You *are* witnessing the "Cosmic Circle of Life" here ...
- This is a Sun-like star expelling its outer layers in retirement ...
- It has exhausted its hydrogen and helium as nuclear fuel ...

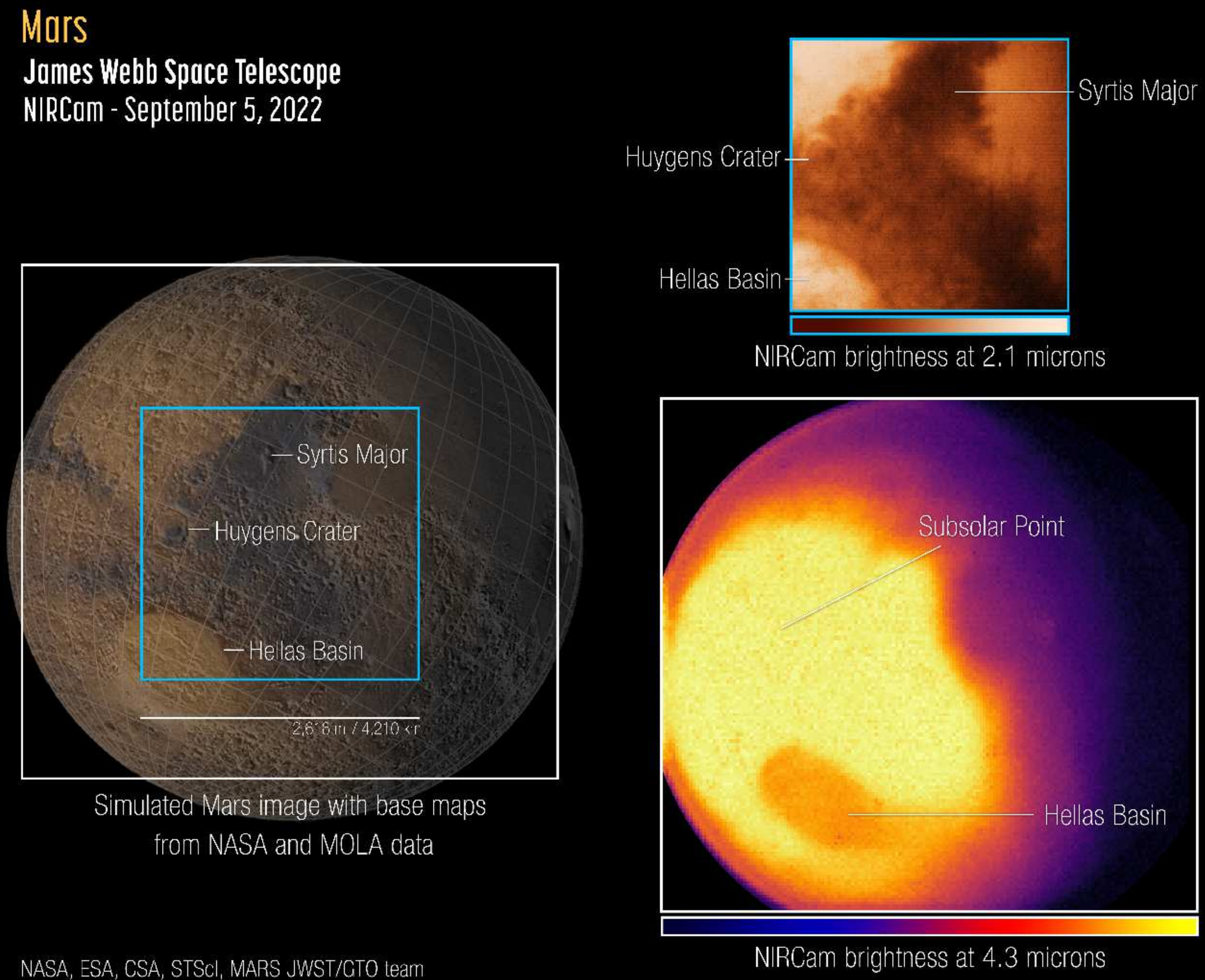
and expanded to 100× its current size, engulfing the Earth.

This is how our Sun *will* come to an end in 5 Billion years (near-IR).

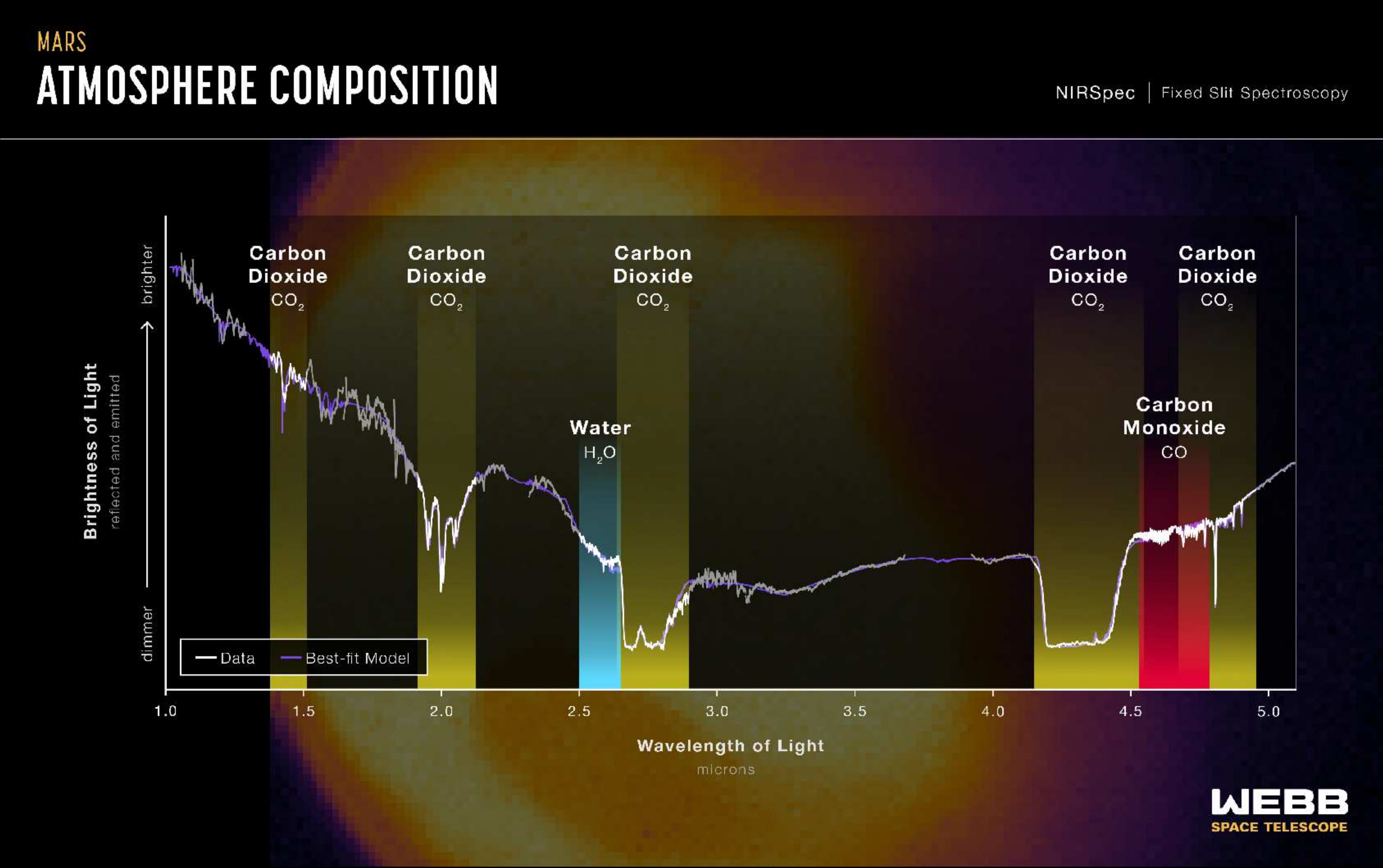
"... for dust thou art, and unto dust shalt thou return" (Genesis 3:19).

From gas expelled by previous sun-like stars, new stars are born (mid-IR).

And thanks to the dust they expelled, new stars will form with planets ...



Mars' surface with NIRCam: From "hot" to "cold" in the infrared!



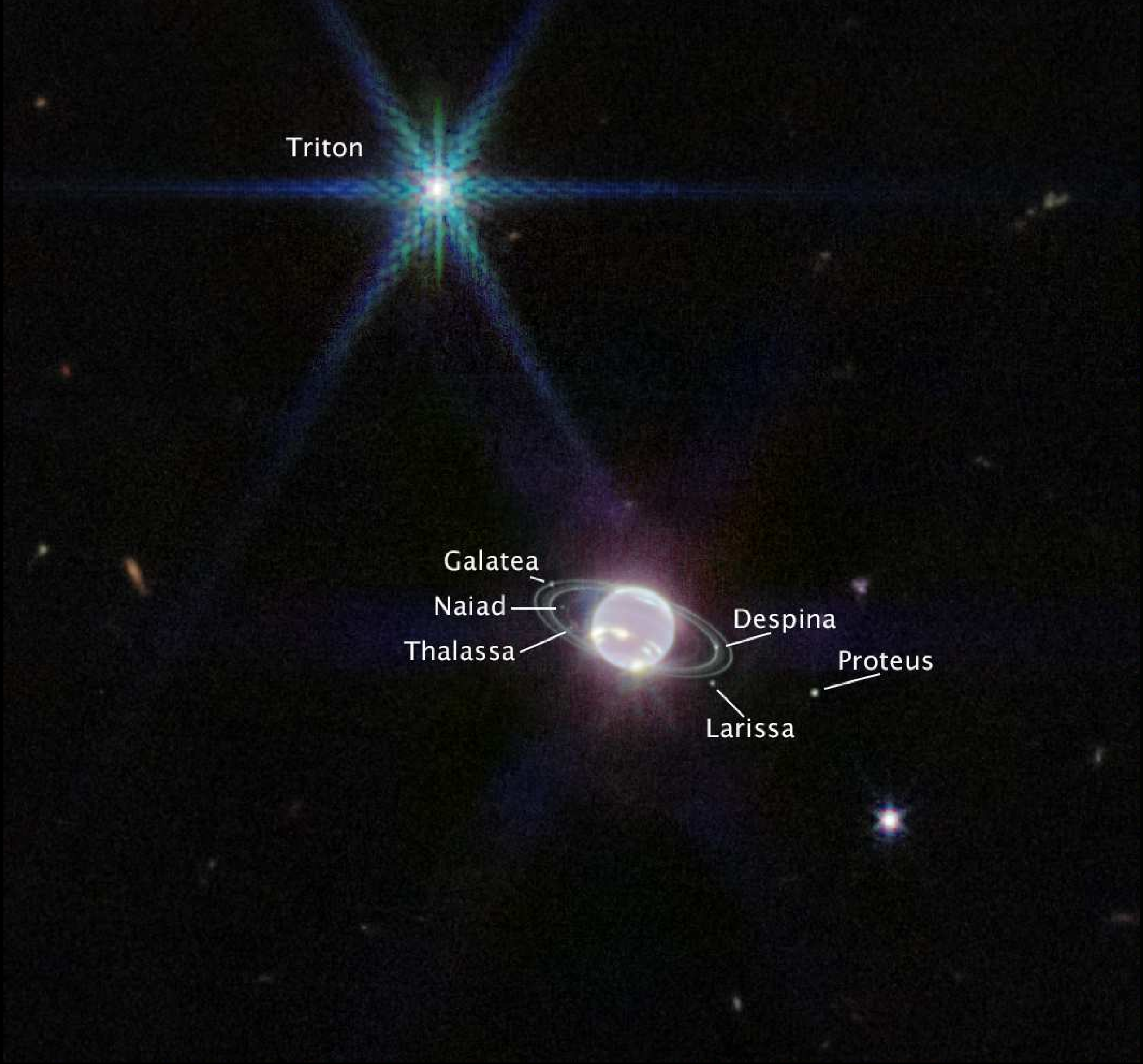
Mars atmosphere NIRSpec spectrum: Plenty of Carbon Dioxide ...
but the search is much harder for Water vapor and Carbon Monoxide

Aug. 2022: JWST NIRcam image of the planet Jupiter: it has beautiful aurorae at its North and South pole — very strong magnetic field!

The Great "Red" Spot: A giant 4-century storm 2×Earth's diameter.

Saturn's moon Titan: JWST NIRCam medium-band and color-composite.

- Bright clouds are visible in the near-IR, and they move with time!
- Kraken is a a methane sea — it rains methane on Titan!
- Belet is a darkly colored plane with sand dunes.

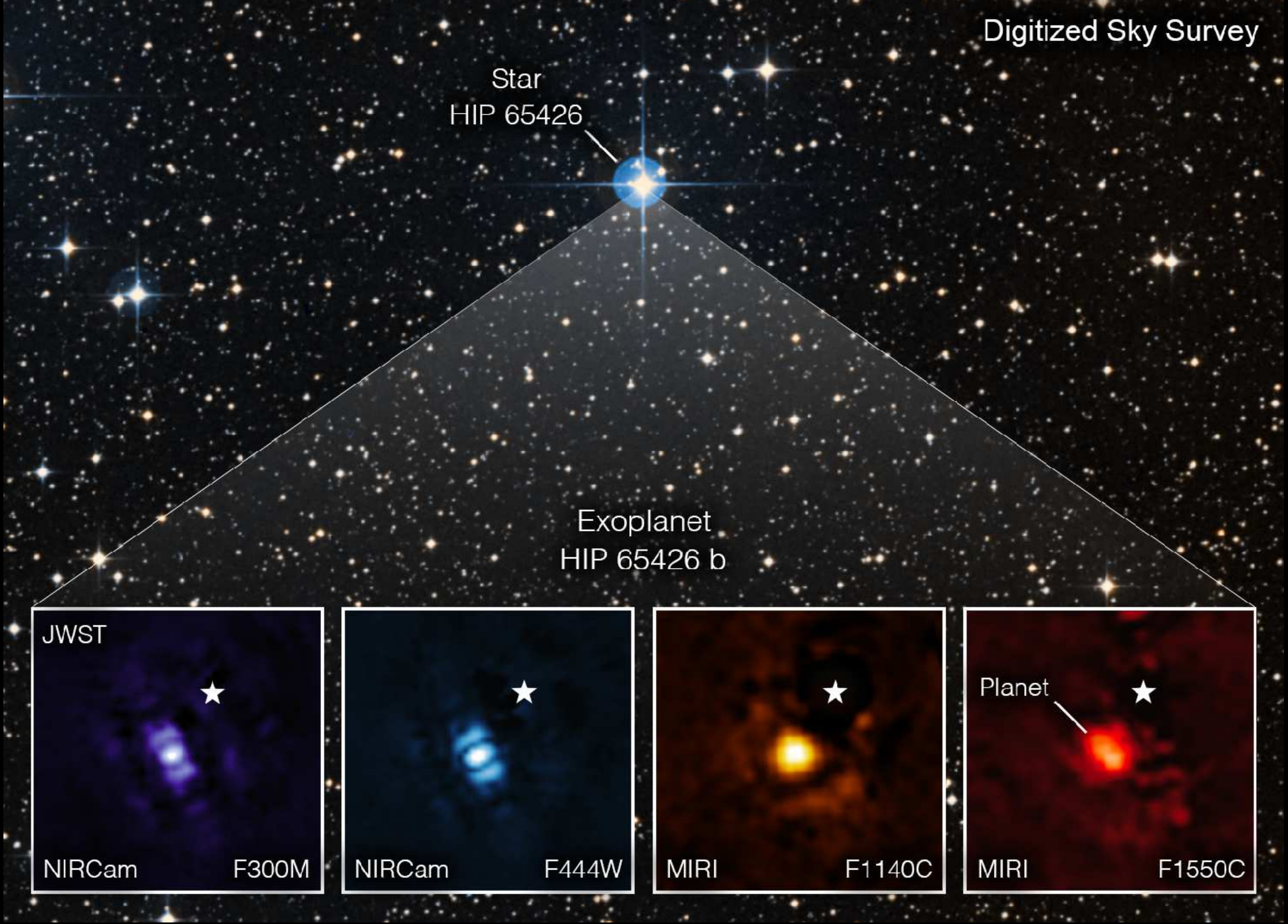


NIRCam family portrait of Neptune with 7 of its Moons

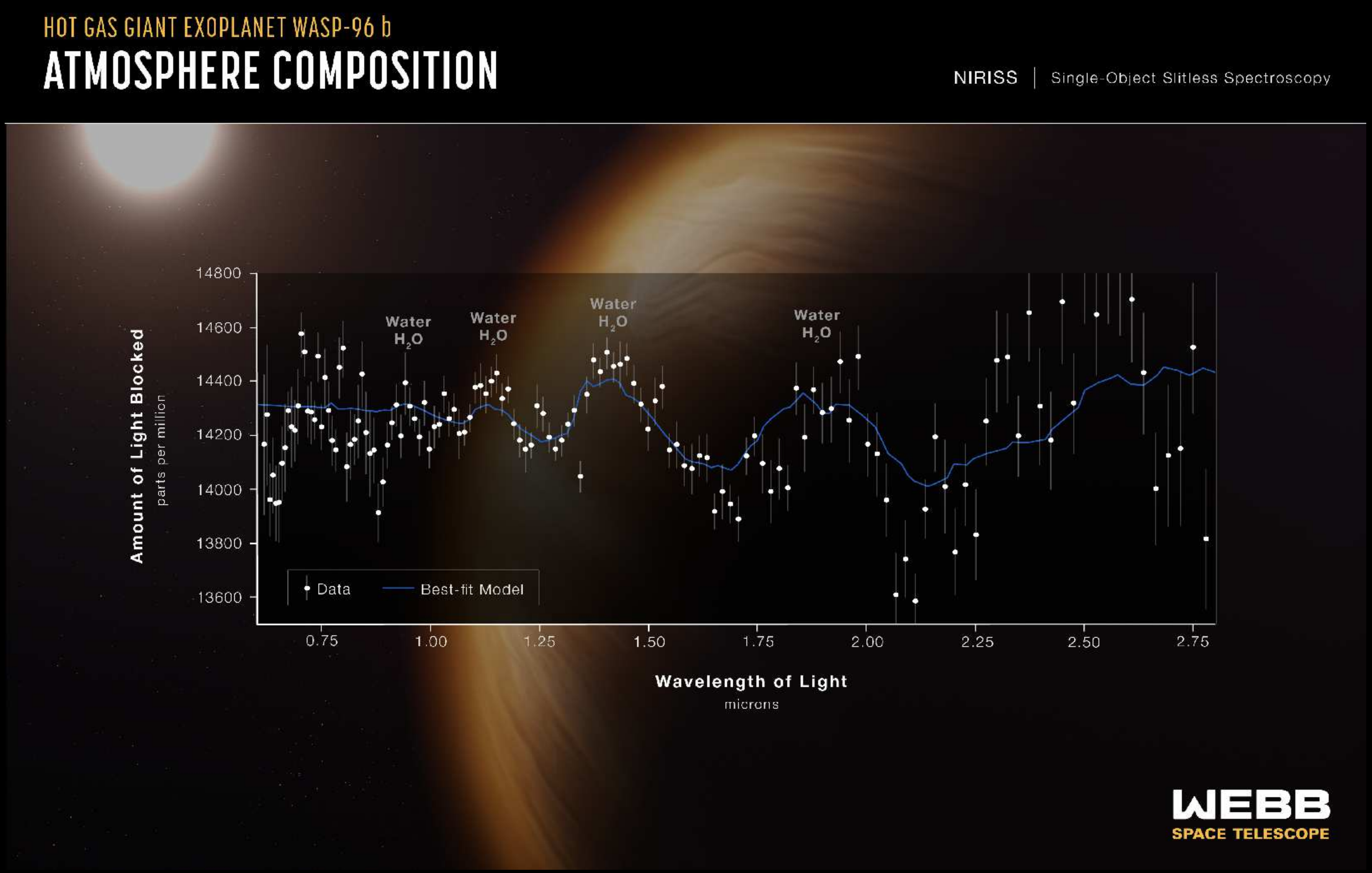
Moon Triton is brighter, since methane darkens Neptune's atmosphere

Closeup of planet Neptune with Webb's NIRCam

- Giant planets with (dim) rings more common those than without rings!



Webb 3–15 micron exoplanet images (10 Jupiter masses; 15 Myr young!)

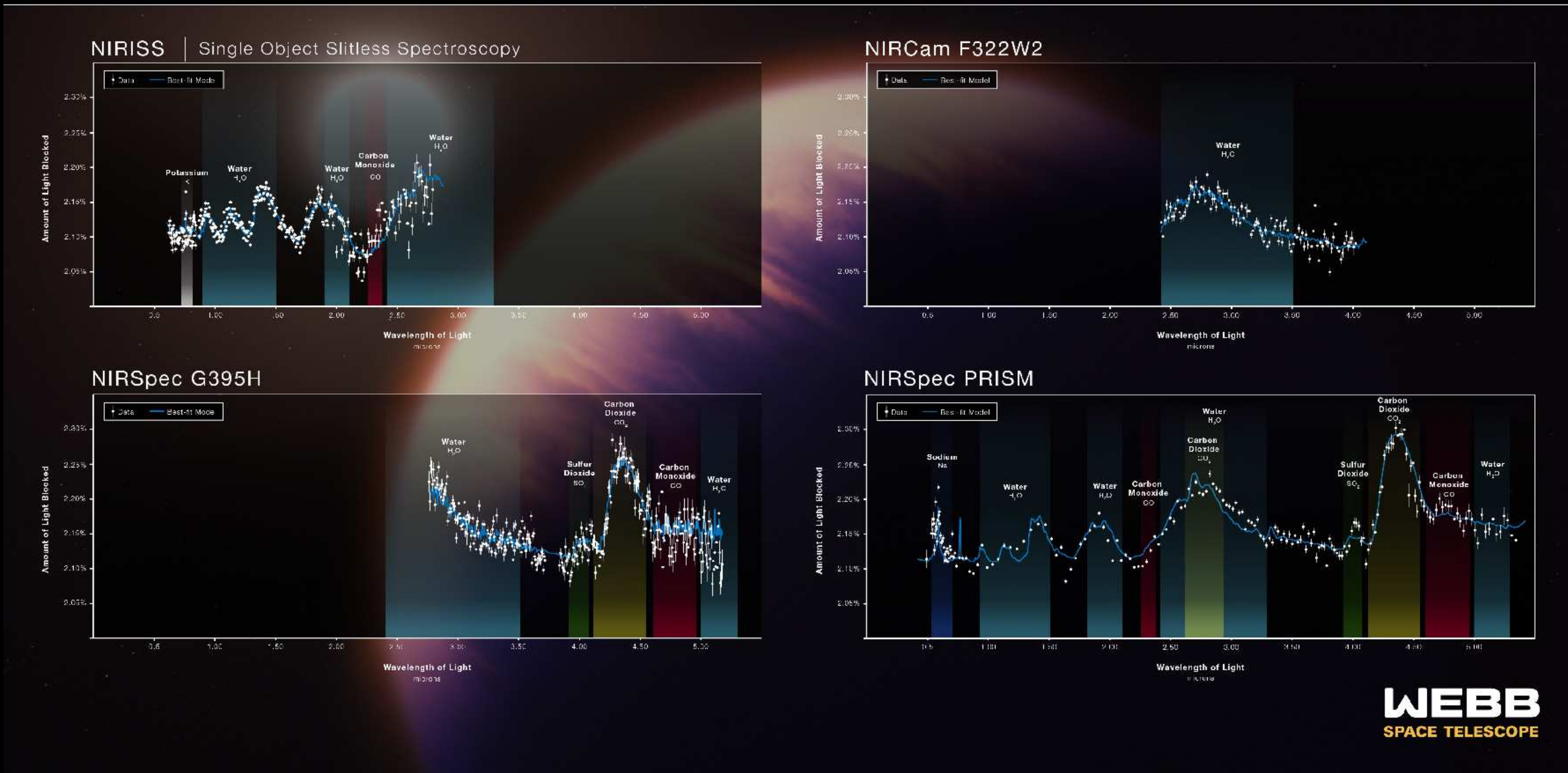


Hot exoplanet WASP-96b orbiting a Sun-like star (1150 light-years):

- Near-IR spectrum shows characteristic features of water (steam !).
- It has a temperature of 1000 F and is half Jupiter in mass.
- Webb will scan Earth-like exoplanets for building blocks of life.

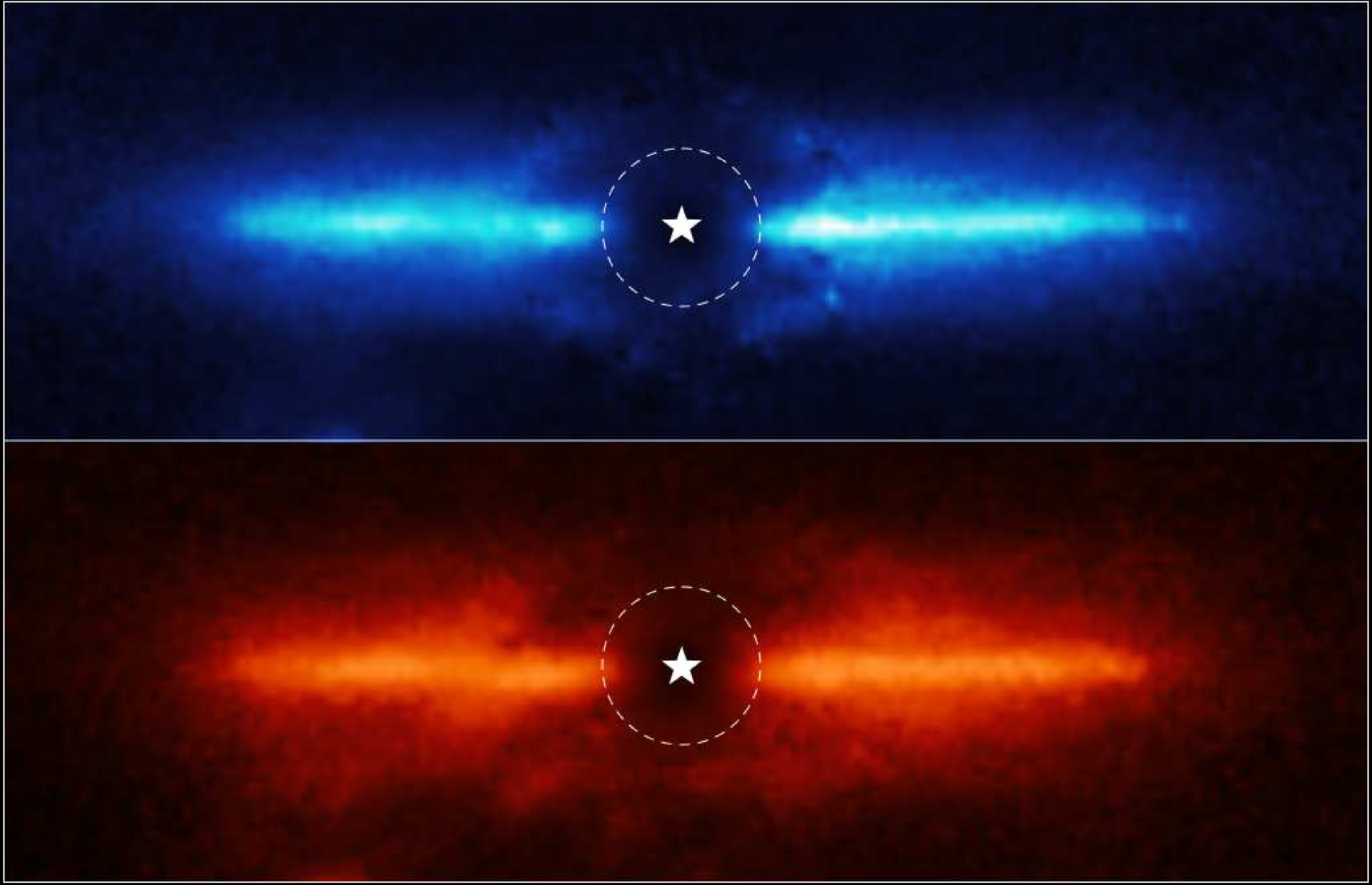
HOT GAS GIANT EXOPLANET WASP-39 b

ATMOSPHERE COMPOSITION



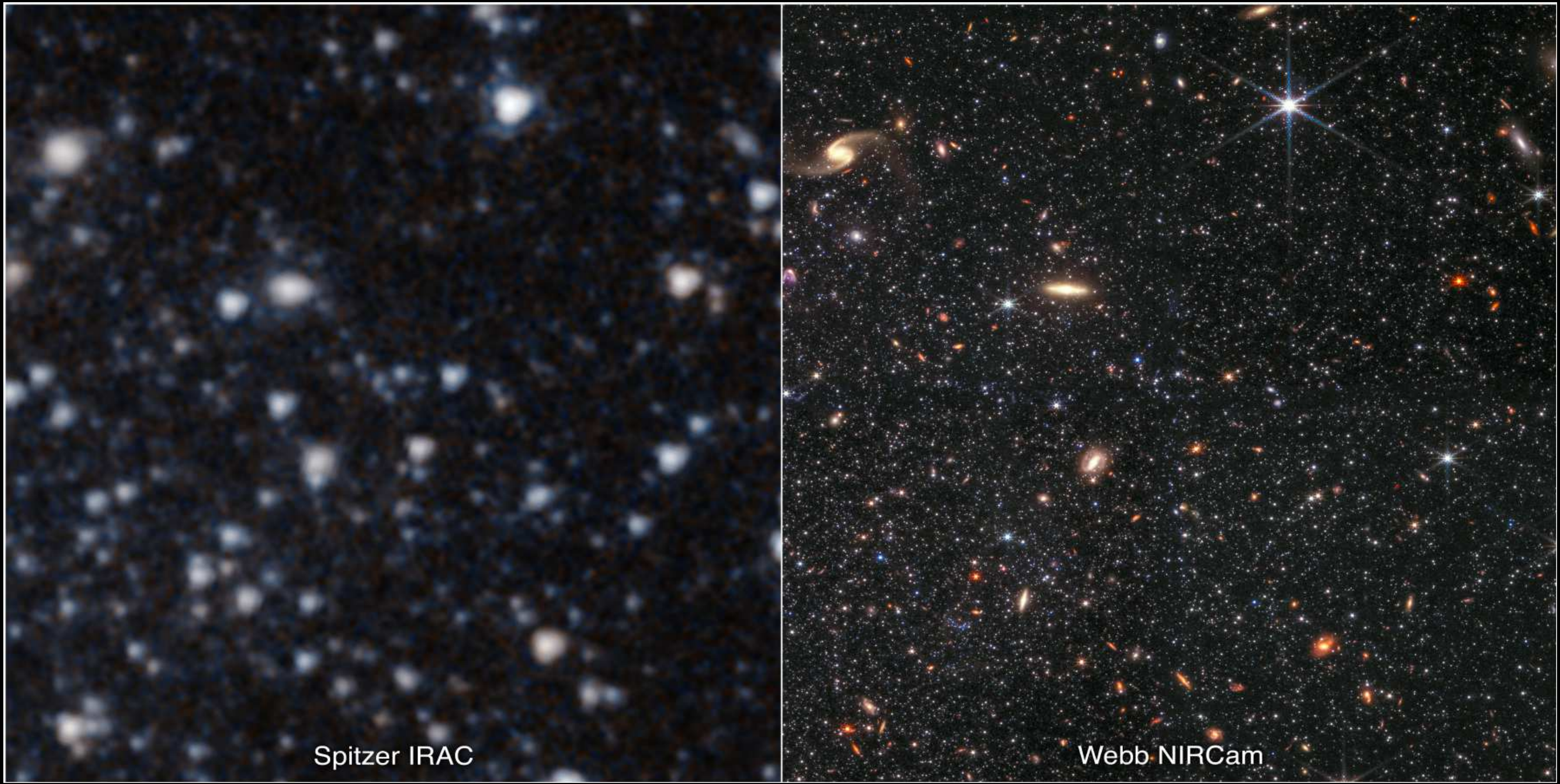
Hot exoplanet WASP-39b orbiting a Sun-like star (700 light-years):

- Near-IR spectrum shows characteristic features of water (steam !).
- It has a temperature of 1650 F and is about Saturn’s mass.
- Complex — and poisonous — Sulfur and Silicates atmosphere.



Dusty debris disk around red dwarf star AU Mic at 32 light-years.

- NIRCam's Coronagraph blocks the central star-light.
- Debris disk visible for 5–60 AU, *i.e.*, slightly larger than Solar System.



Dwarf Galaxy Wolf-Lundmark-Melotte (WLM): 3 Million light-years away.

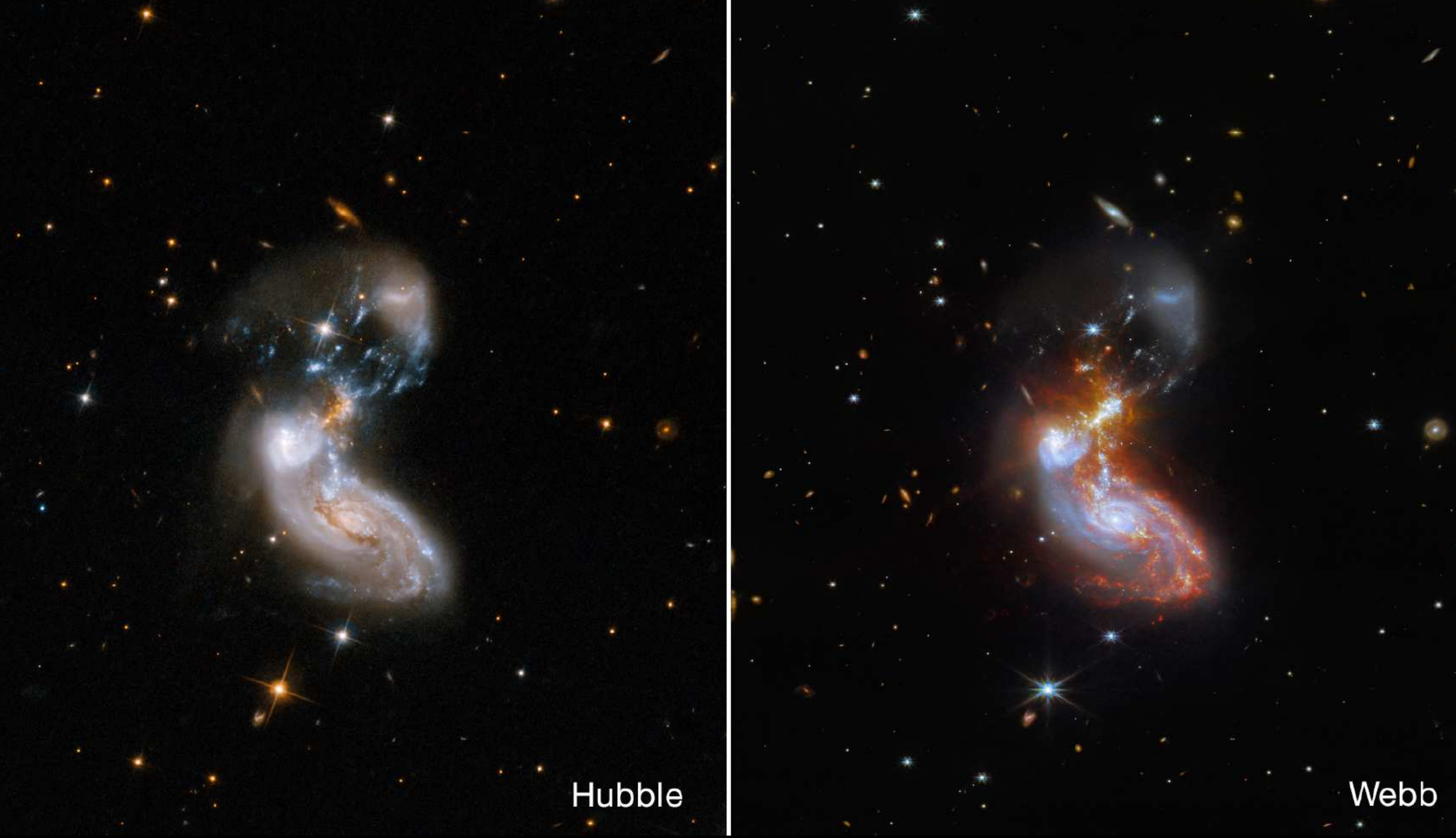
- A diffuse galaxy part of the Local Group: foreground stars *are* WLM!
- You're looking right through it, yet is is forming stars (H. Archer 2022).

Stephan's Quintet: 4 colliding galaxies (40 M-lyr; left spiral is foreground).

- These major "Cosmic Trainwrecks" are much more common in the past.
  - Sun-like stars formed in aftermath of minor "Cosmic Fender-benders".

Stephan's Quintet: 4 colliding galaxies at 40 million light-years (Mid-IR):

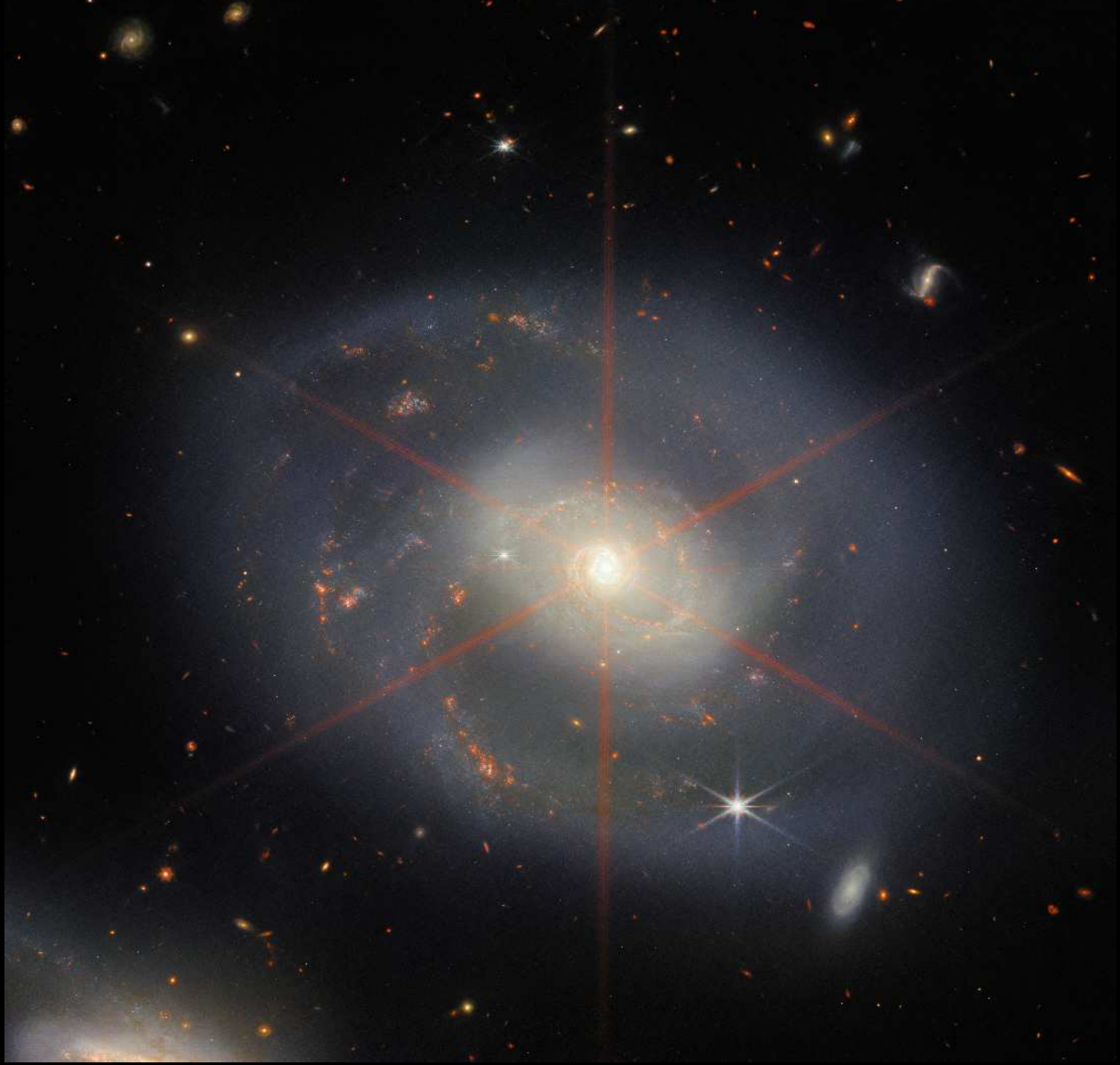
- Mid-IR shows molecular gas being pulled out during collision.
- Gravity from collision in top galaxy feeds the Beast: central black hole!



Galactic Merger: Hubble vs. Webb — a veritable cosmic train wreck!

- [Left]: Hubble sees the young star-forming regions and dust.
- [Right]: Webb sees also the warm dust in the infrared (orange filaments).

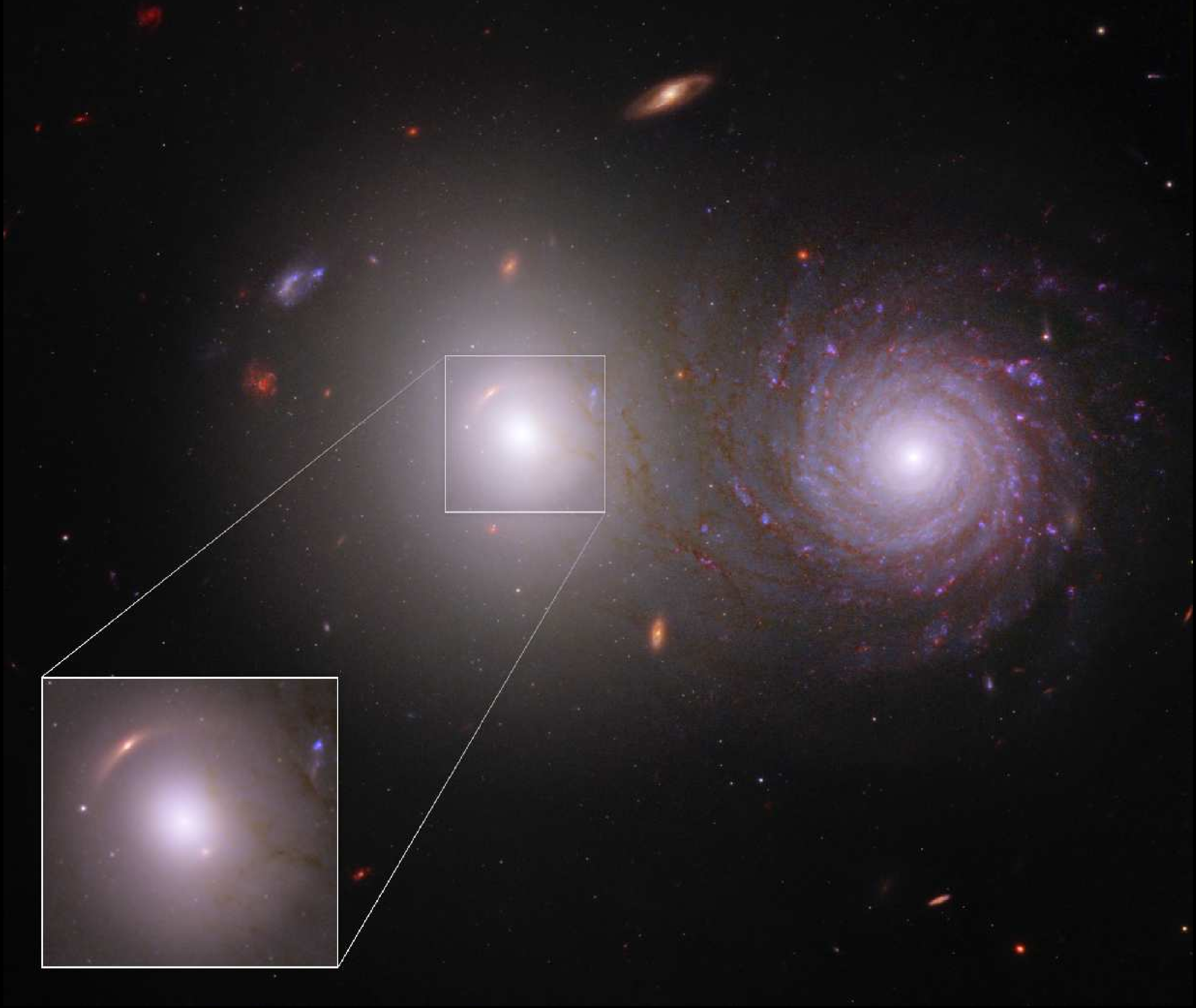
(First revealed by Vice President Harris & French President Macron; Dec. 2022)



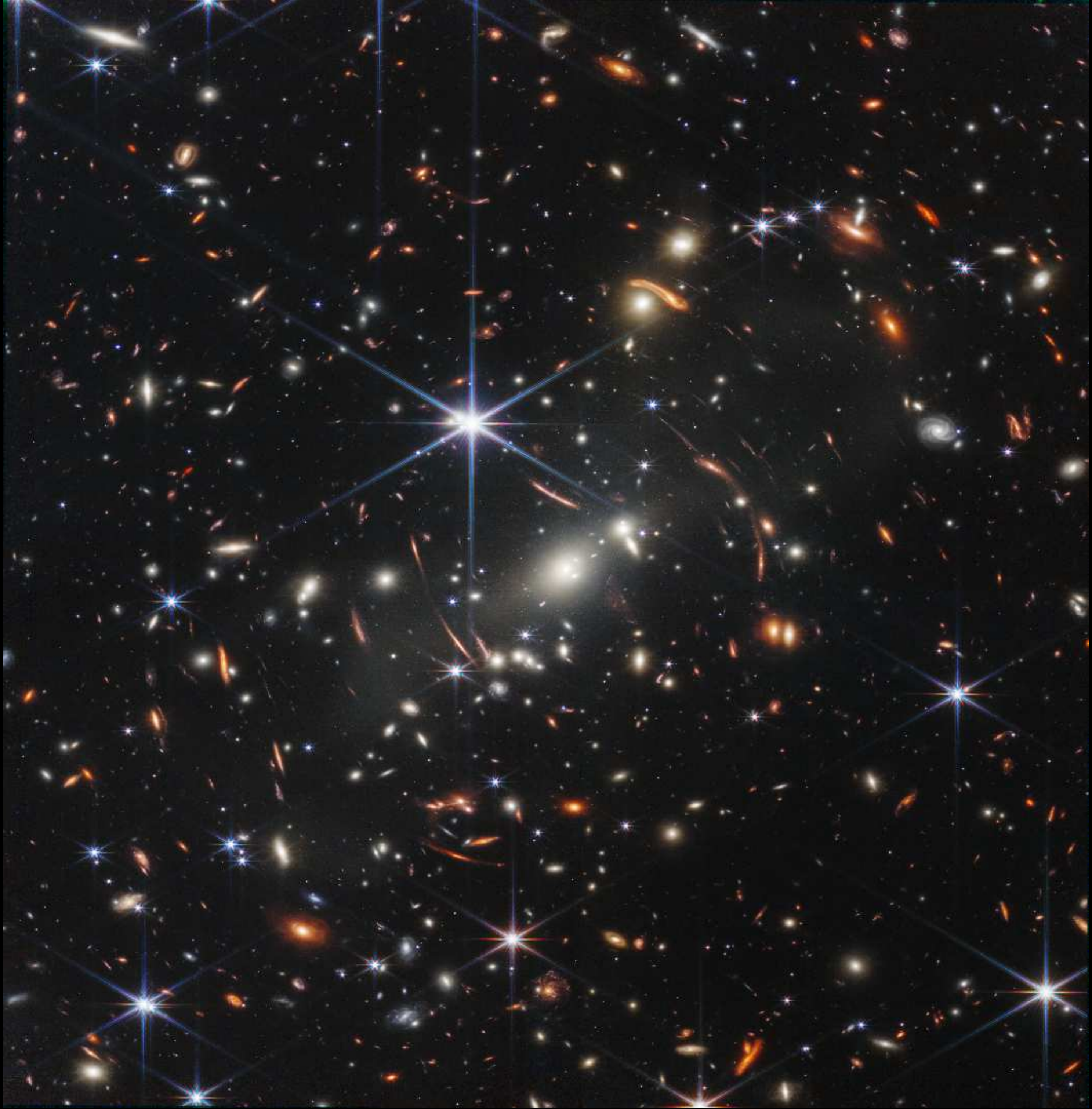
Don't feed the animals: NGC7469 a spiral galaxy at 220 million light-years:

- It has a supermassive black hole feasting on the in-falling gas!
- In area surrounding the SMBH, gas is expelled at very high speeds, and stars are forming in ambient cooler gas.

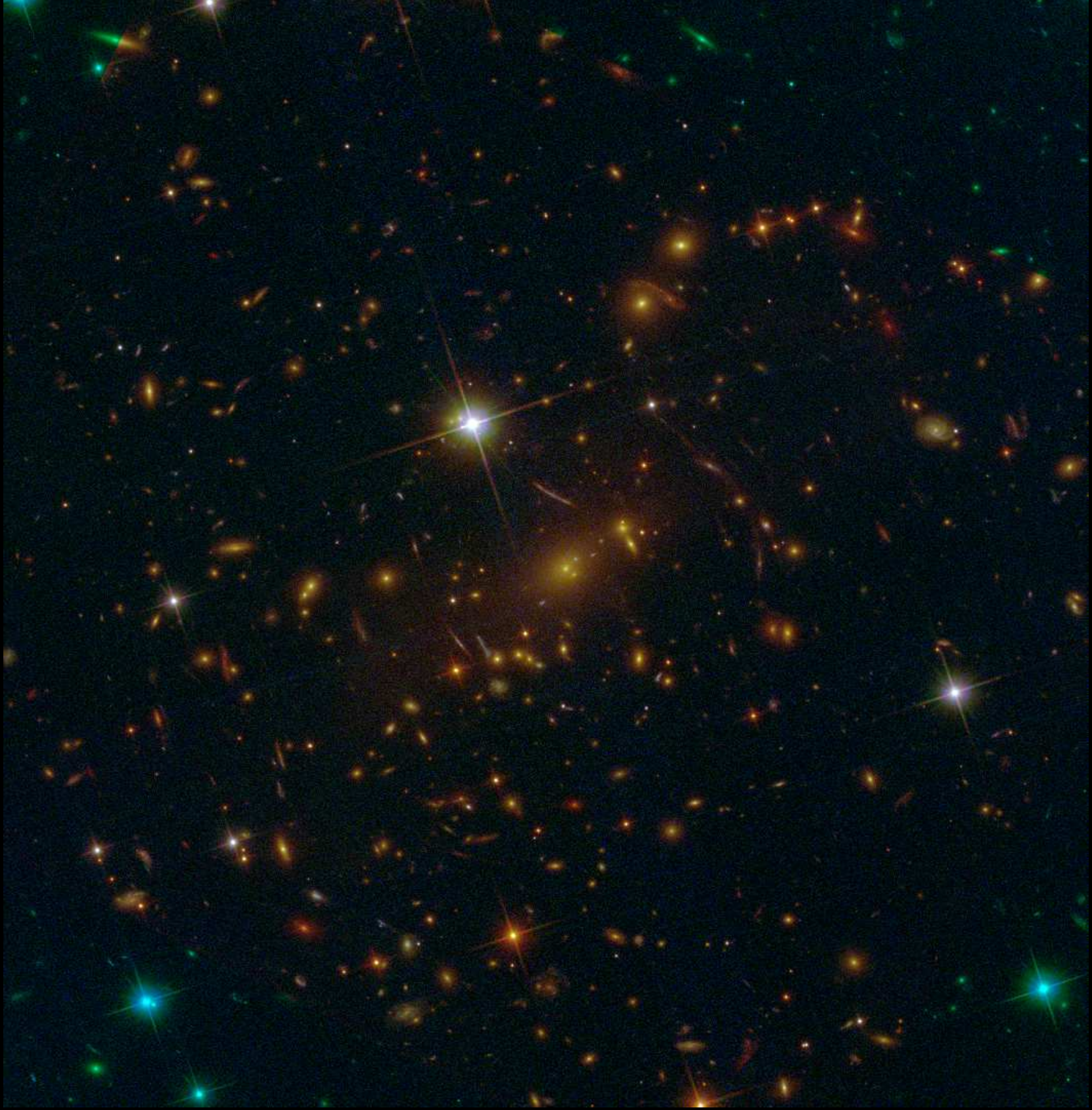
Spiral Galaxy overlapping Elliptical: Tracing cosmic dust (Keel^{+} 22) ...



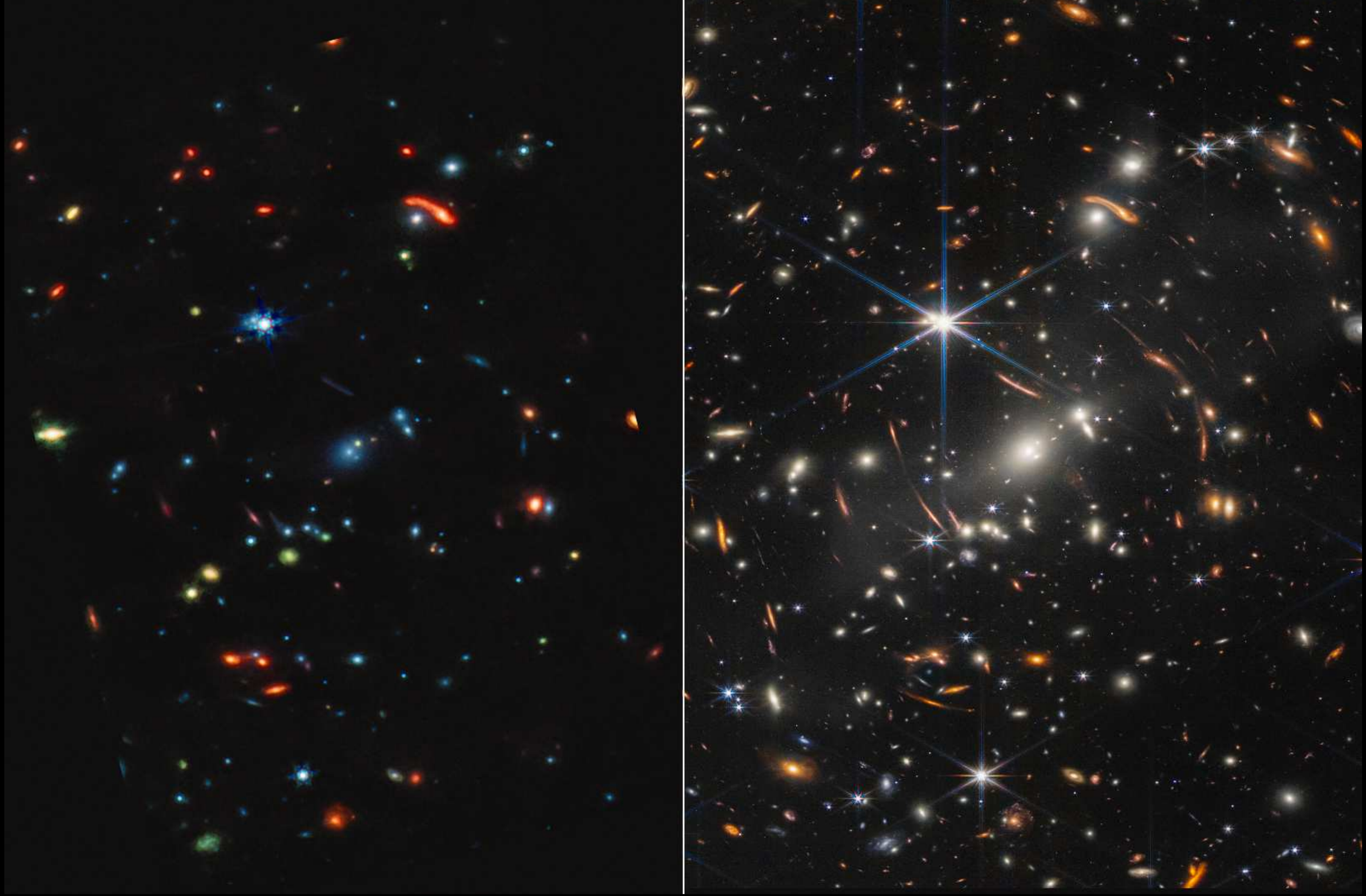
... and the elliptical also lenses a galaxy seen 2 Byrs after Big Bang!



July 11, 2022: 12-hr Webb Deep Field on galaxy cluster SMACS 0723



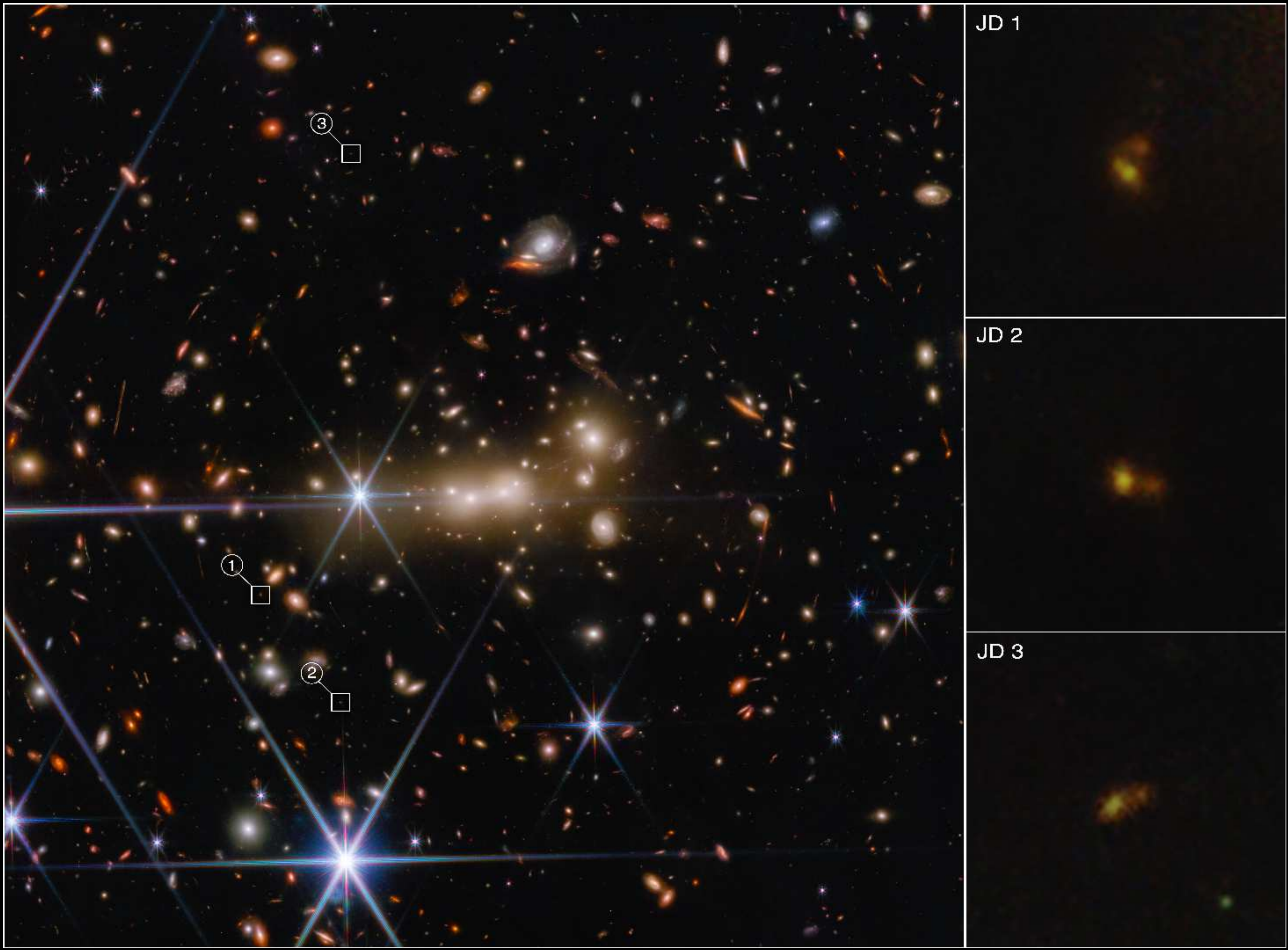
Hubble image of SMACS 0723 – Webb sees the dawn of galaxy formation!



Compared to near-IR (right), mid-IR sees some very red objects (left):

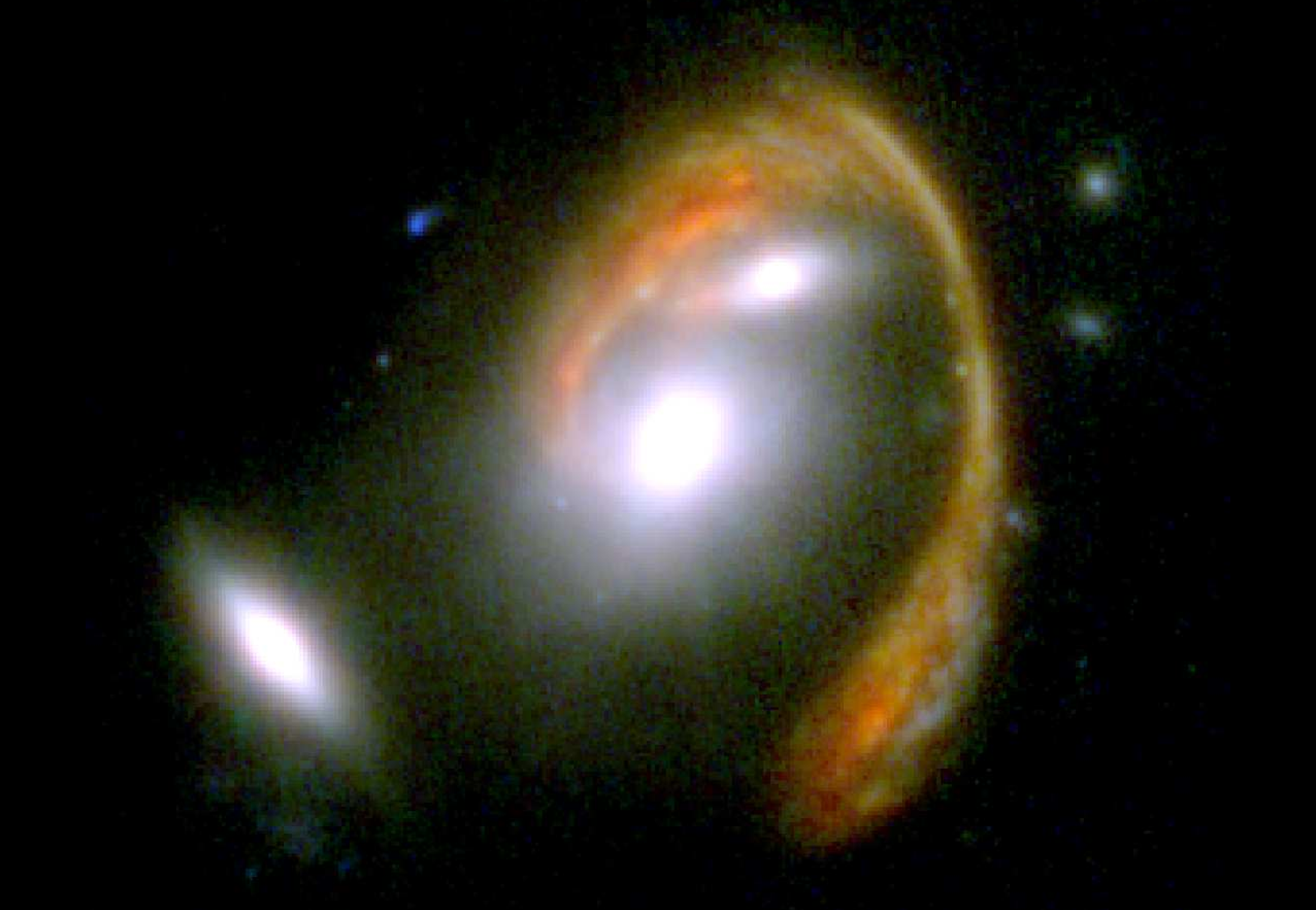
- These may be gravitationally lensed galaxies seen in the first 1–2 Byrs.
- Cluster galaxies already are ∼9 Byrs old, seen at 4.5 Blyr distance!

$\Longrightarrow$ Sun was just born when these *old* galaxies emitted their light!

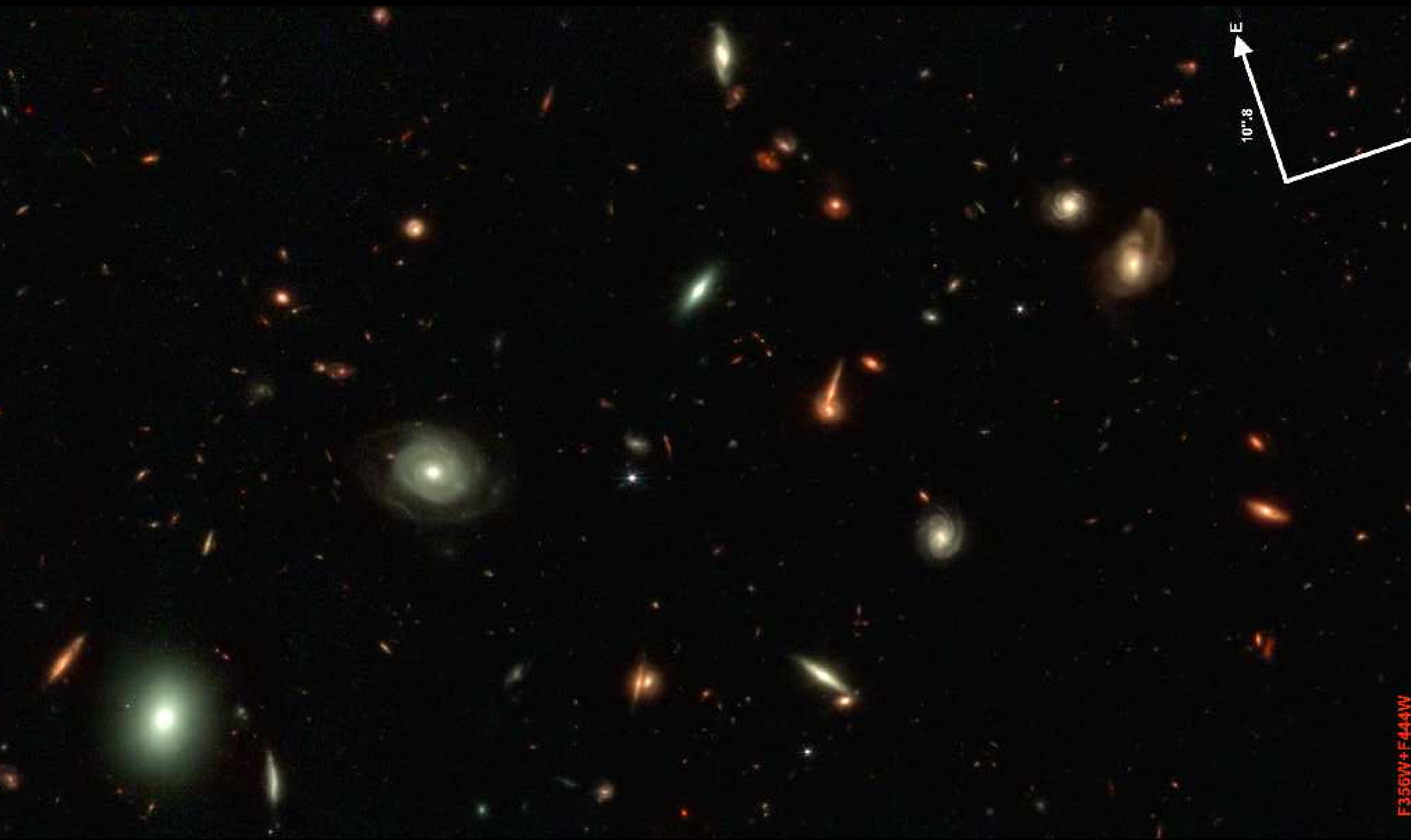


Cluster MACS0647 triply lensed a galaxy 0.4 Byrs after BB! (Hsiao, Coe^{+} 22)

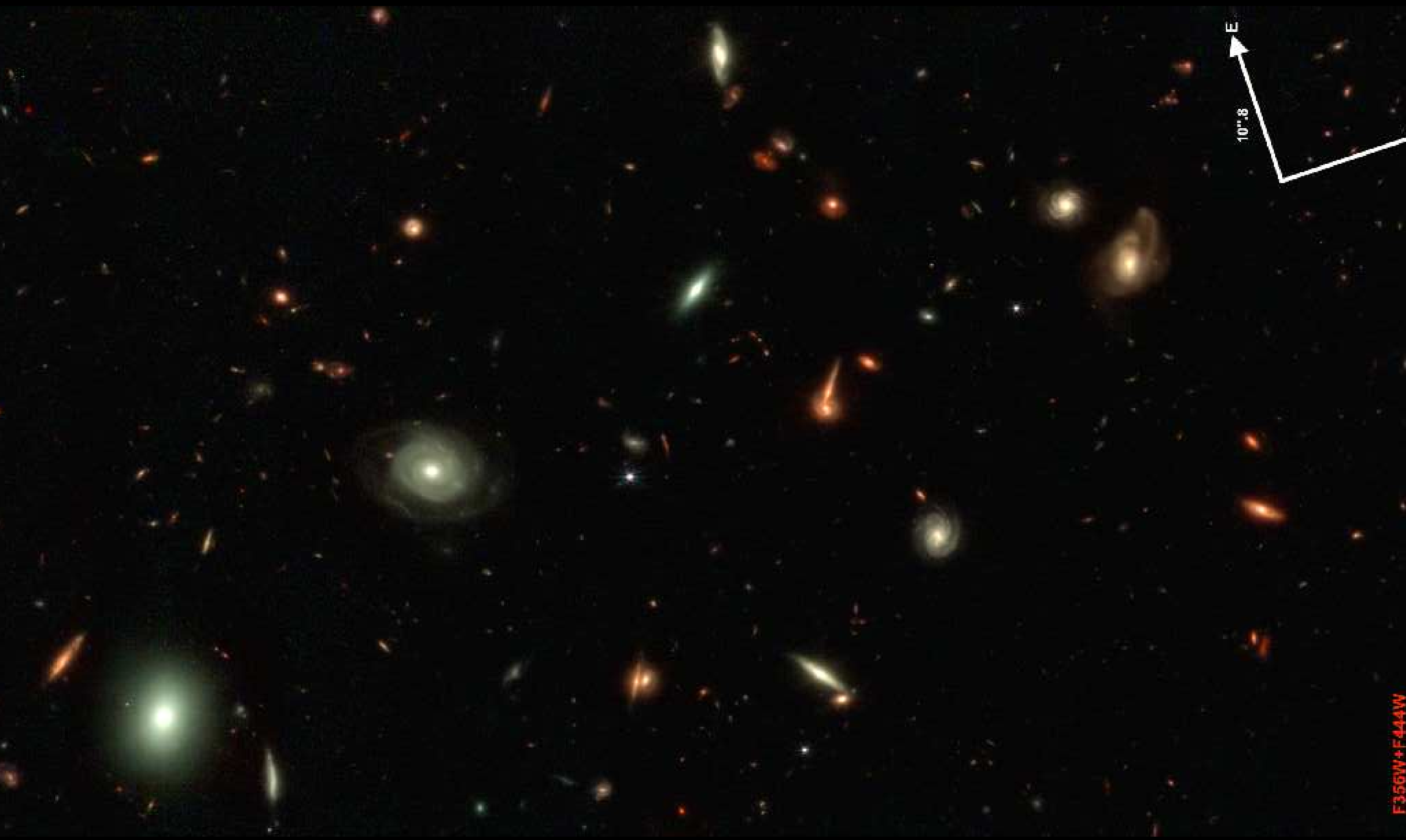
Monster cluster El Gordo distorts distant galaxies into “pencils” (Diego^{+}22)



and El Gordo makes a super-lens “El Anzuelo” — Einstein’s fishhook!



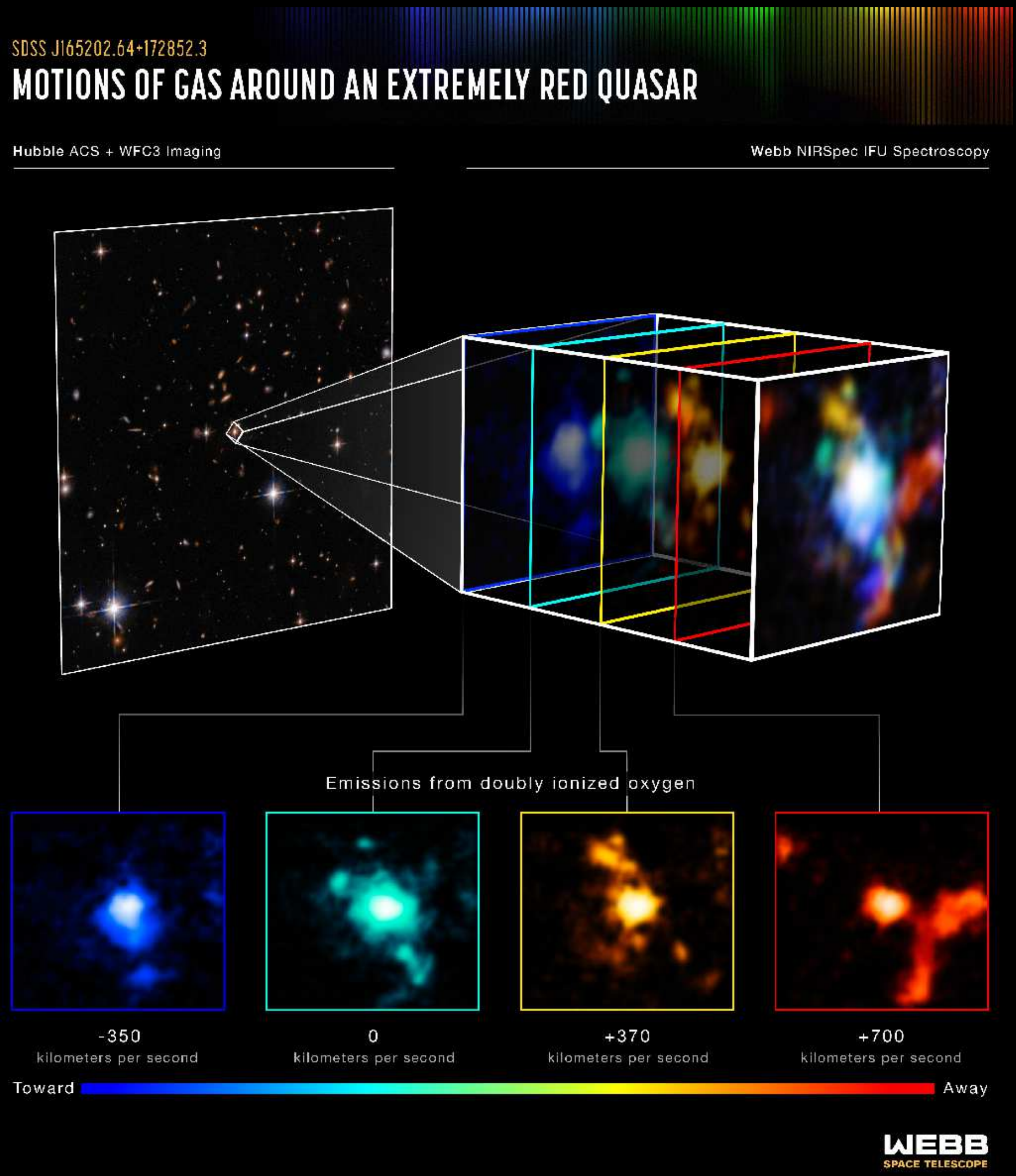
Many deep field galaxies have tidal tails ... galaxies torn by gravity ...
What can I say: Gravity bends!



Many deep field galaxies have tidal tails ... galaxies torn by gravity ...

What can I say: Gravity bends!

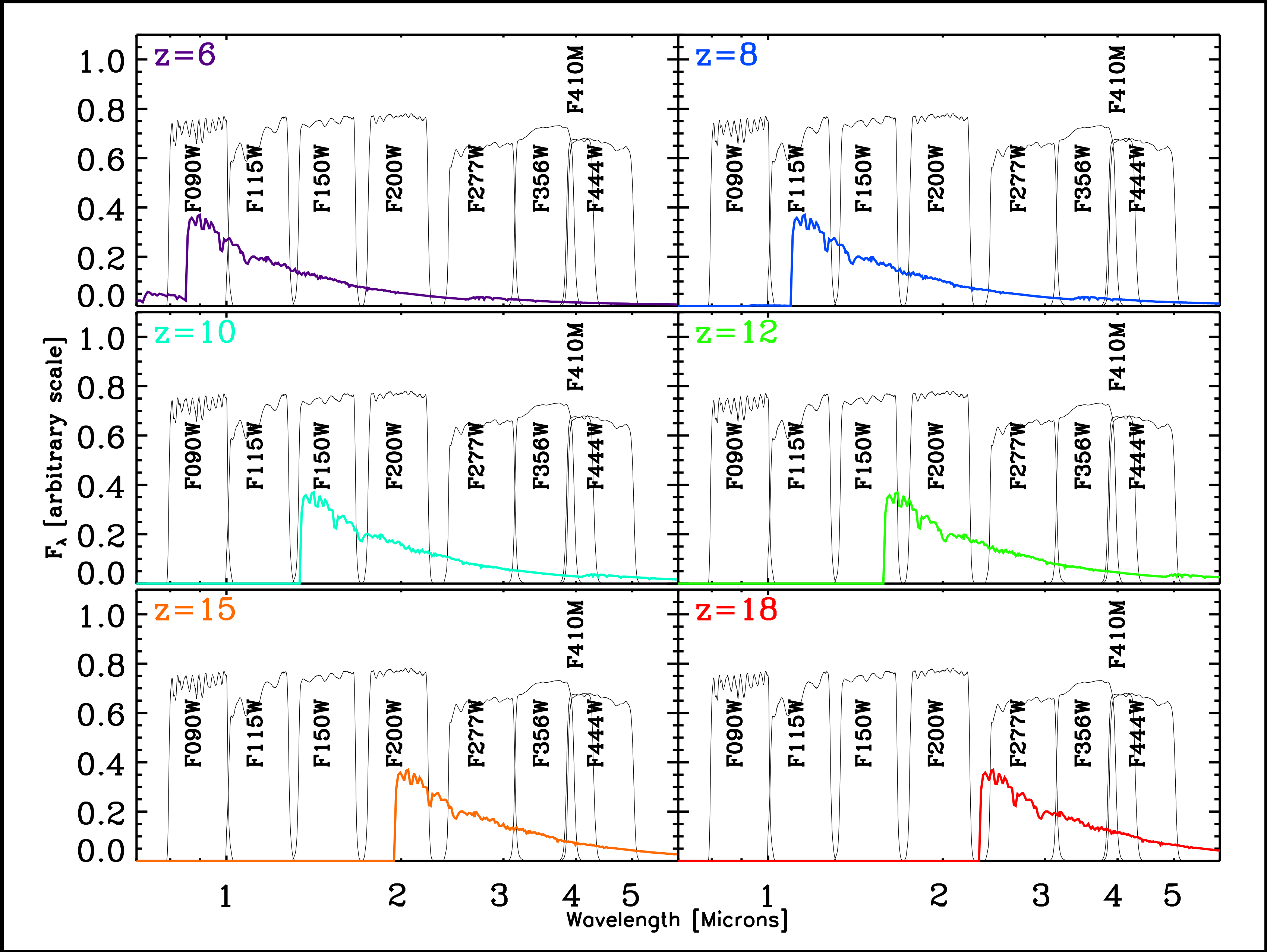
and black holes bend harder ... any black hole questions?



NIRSpec spectral cube of a luminous quasar seen 2.2 Byrs after Big Bang. Colors indicate 3 companion galaxies falling into the quasar host galaxy.

- In the first 2 billion years big galaxies were swallowing little ones!

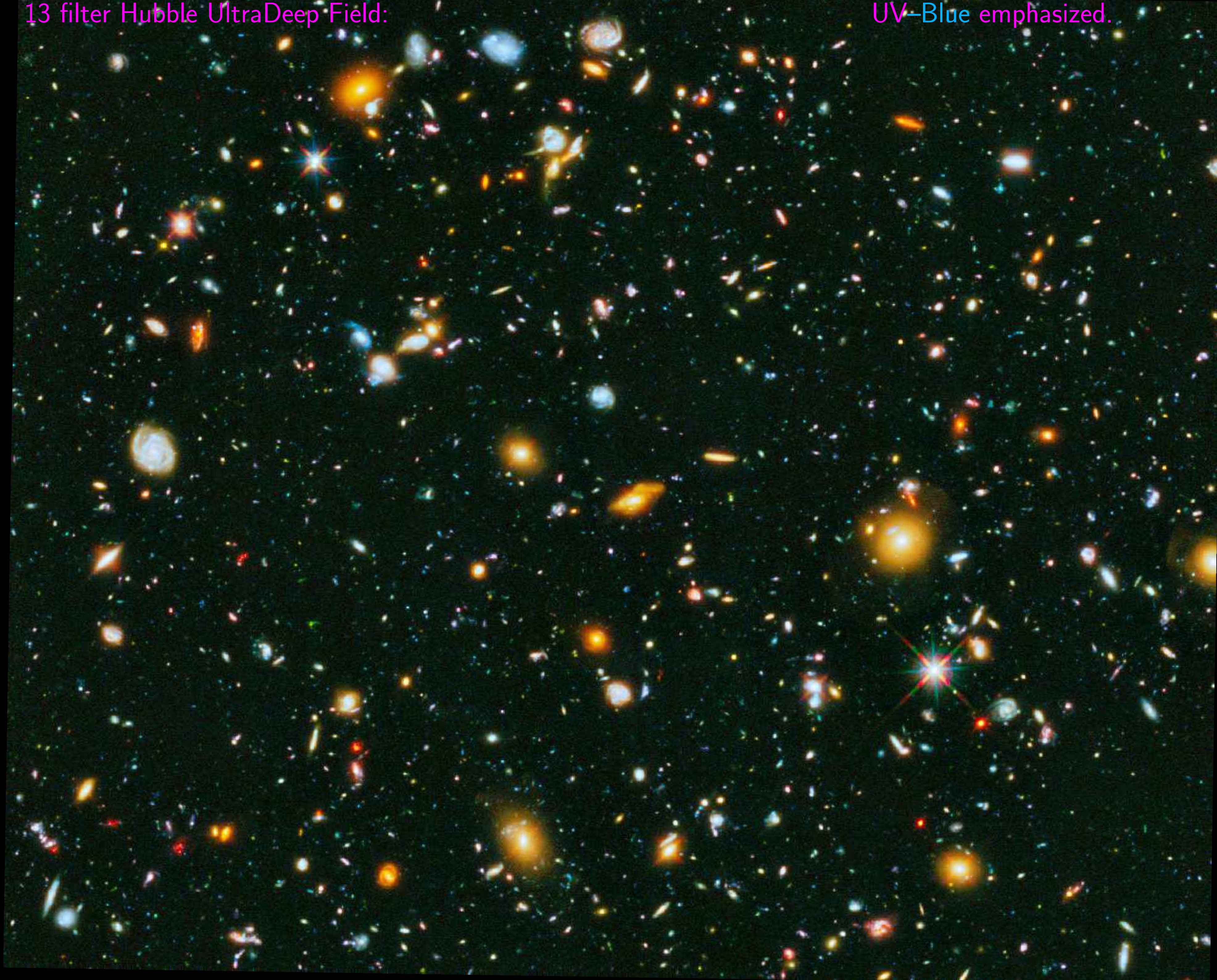
3) How can Webb measure First Light: What to expect in (Ultra)Deep Fields?



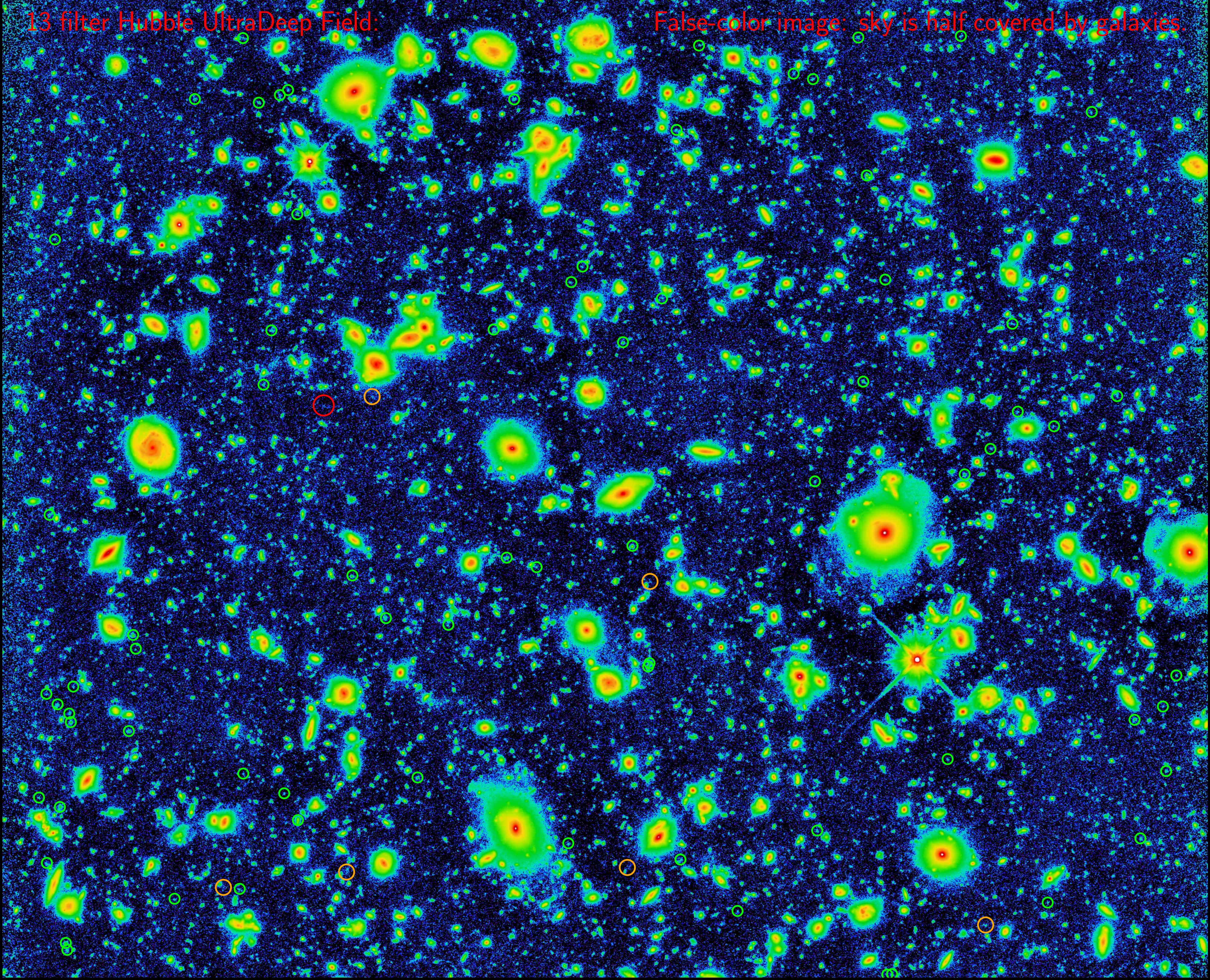
- Can't beat redshift: to see First Light, must observe near–mid IR.

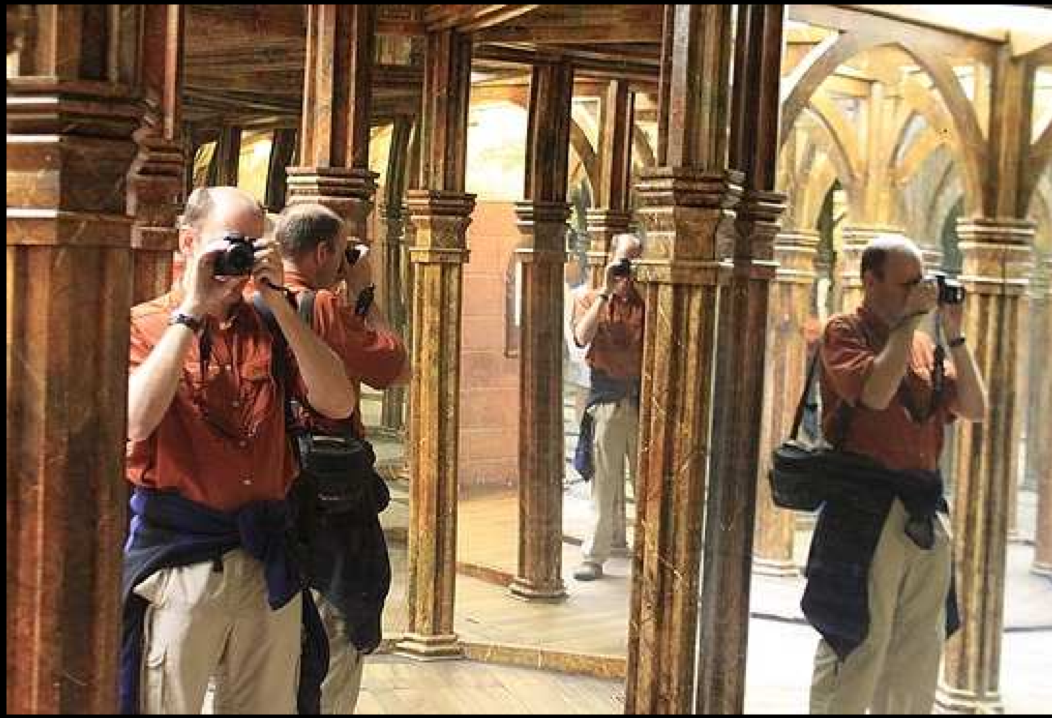
$\Rightarrow$ This is why JWST needs NIRCam at 0.8–5 μm and MIRI at 5–28 μm.

13 filter Hubble UltraDeep Field: UV–Blue emphasized.




o z=7–8, o z=9, O z=10–12.
Hubble UltraDeep Field: Red–IR emphasized.


13 filter Hubble UltraDeep Field:
False-color image: sky is half covered by galaxies.



Conclusion: JWST First Light strategy must consider three aspects:

(1) The earliest objects (first 0.5 Byr) are very rare and hard to find.

(2) Cannot-see-the-forest-for-the-trees effect ["Confusion" limit]:

Background objects blend into foreground objects because of their density.

(3) House-of-mirrors effect ["Gravitational Amplification"]:

- Lensing is needed to see what Einstein thought was impossible to observe!

(3) Summary and Conclusions

(1) Webb was successfully built, tested and finally launched in Dec. 2021.

(2) Webb was designed to map the epochs of First Light, Galaxy Assembly & Super Massive Black Hole-growth in detail:

- Formation of the first stars and star-clusters after 0.2 Byr.
- How galaxies formed and evolved over 13.5 Billion years.

(3) Webb's first images trace the "Cosmic Circle of Life":

- Formation and evolution of stars and dust over cosmic time.
- How dust helped form exoplanets and building blocks for life.

(4) Webb will have a major impact on astrophysics this decade:

- IR sequel to HST starting 2022: Training next generation researchers.

SPARE CHARTS

• References and other sources of material

Talk: http://www.asu.edu/clas/hst/www/jwst/aas241_143_JWST_PEARLS23.pdf

Data: https://sites.google.com/view/jwstpearls and http://skysurf.asu.edu/

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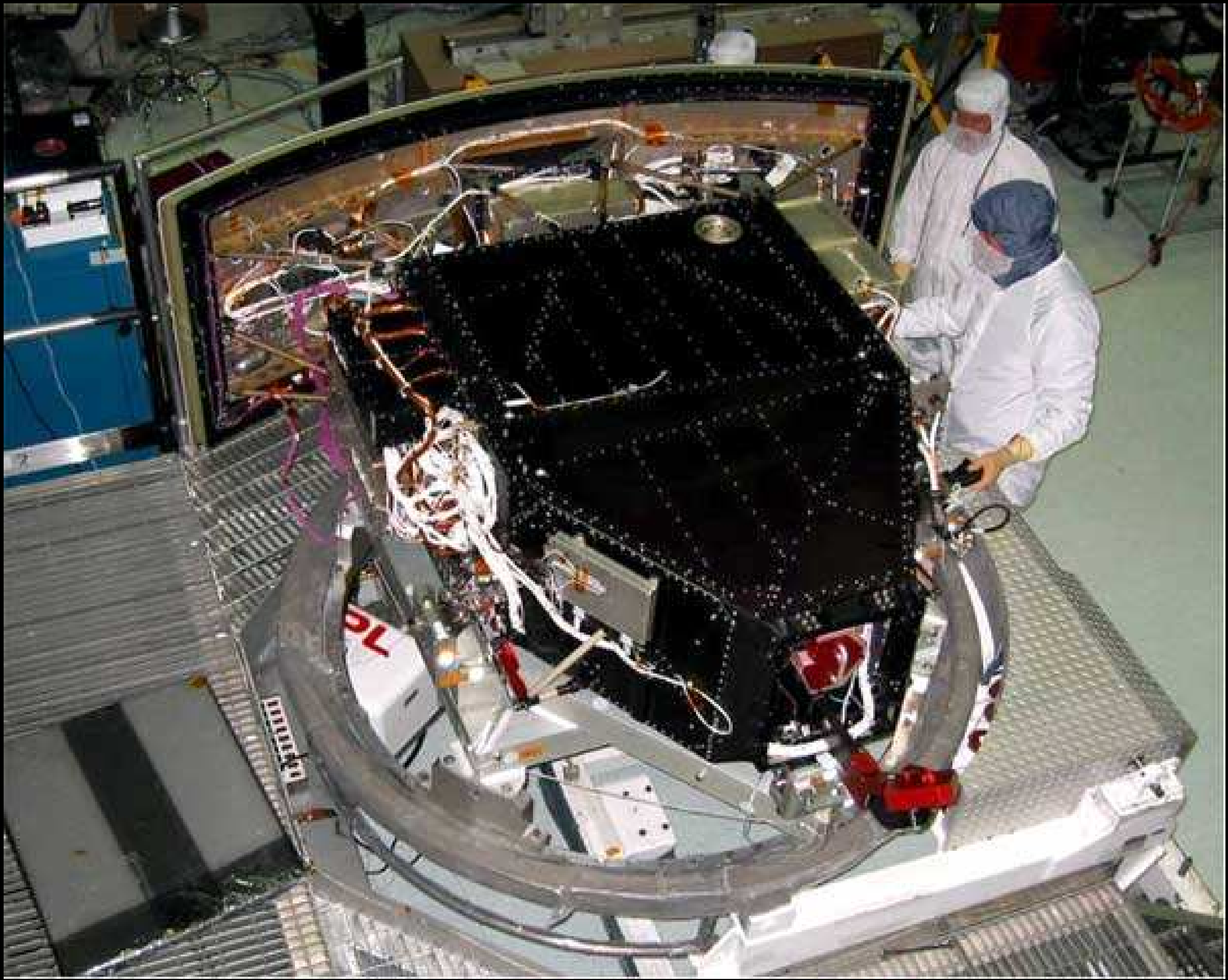
https://blogs.nasa.gov/webb/2022/12/14/webb-glimpses-field-of-extragalactic-pearls-studded-with-galactic-diamonds/

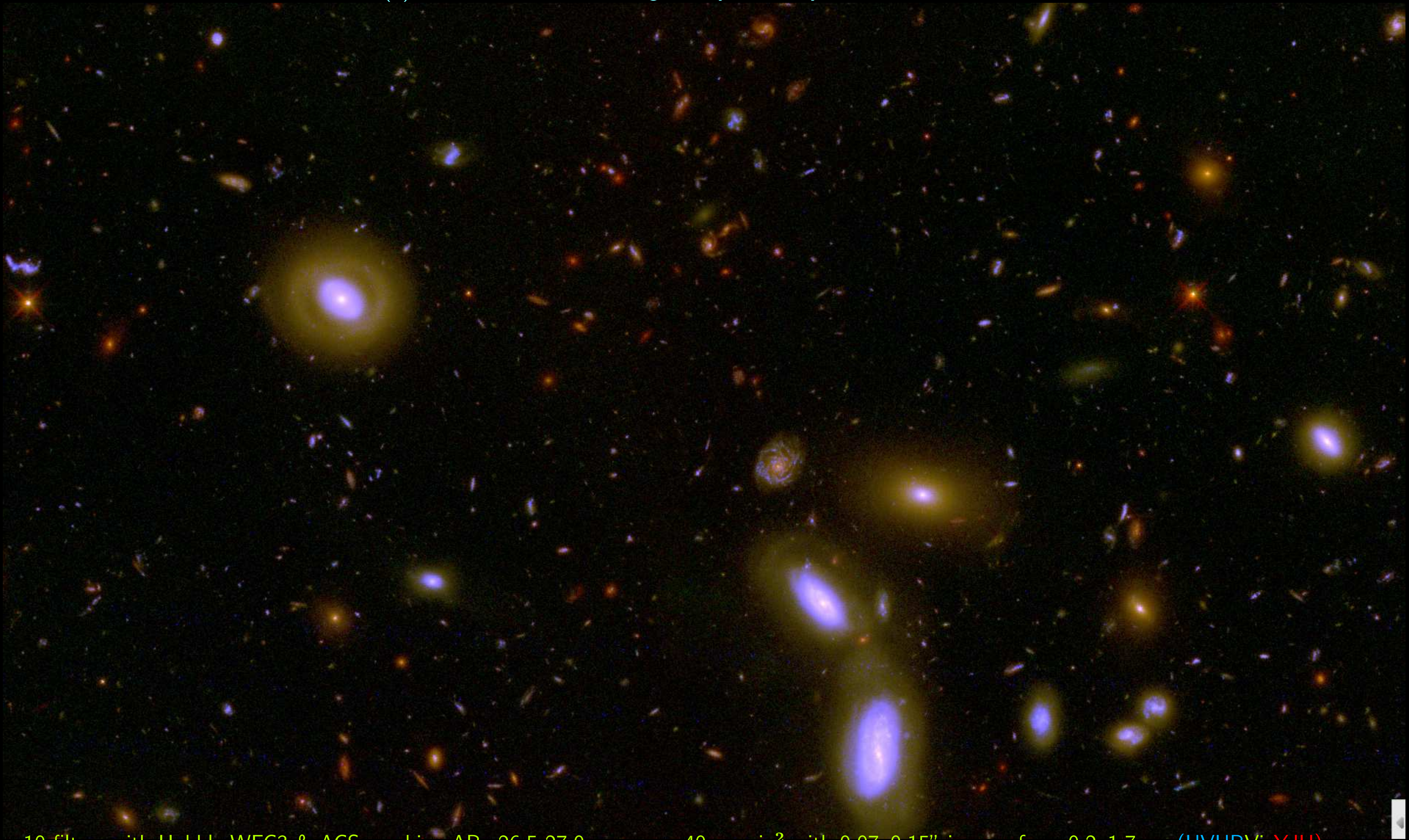
https://esawebb.org/images/pearls1/zoomable/

Any (space) mission is a balance between what science demands, what technology can do, and what budget & schedule allows ... (courtesy Prof. R. Ellis).



HST WFC3 and its IR channel: a critical pathfinder for JWST science.

(4) Hubble WFC3: Measuring Galaxy Assembly and SMBH Growth?



10 filters with Hubble WFC3 & ACS reaching AB=26.5-27.0 mag over 40 arcmin^2 with 0.07–0.15" images from 0.2–1.7μm (UVUBVizYJH).

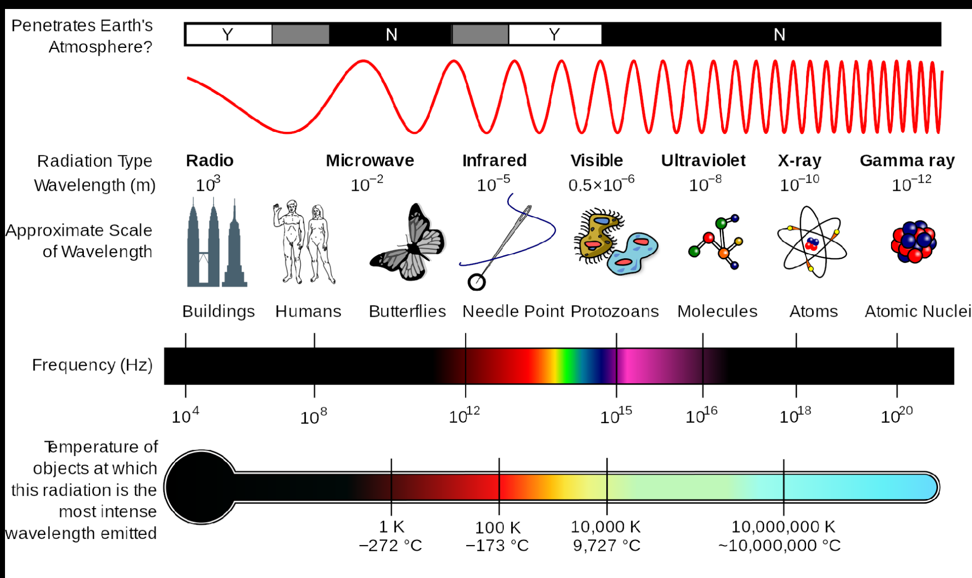
JWST adds 0.05–0.2" FWHM imaging to AB≃31.5 mag (1 FF) at 1–5μm, with 0.2–1.2" images at 5–29μm, tracing young+old stars & dust.

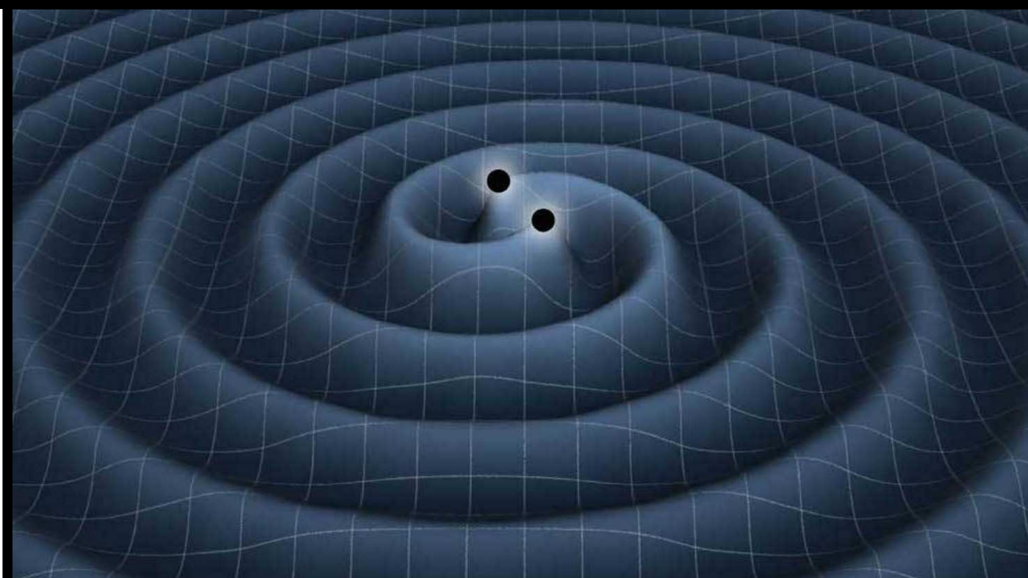
Black Hole growth — Waves that happen in Nature: 1) Sounds Waves:

In solids: Earthquakes

In liquids: Surf!

In gasses: Sound

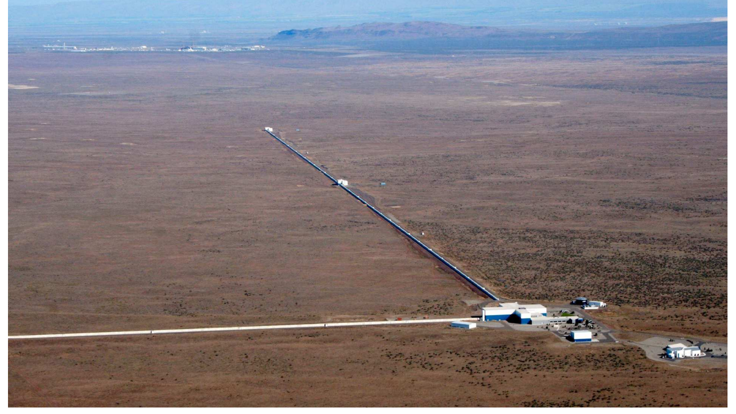


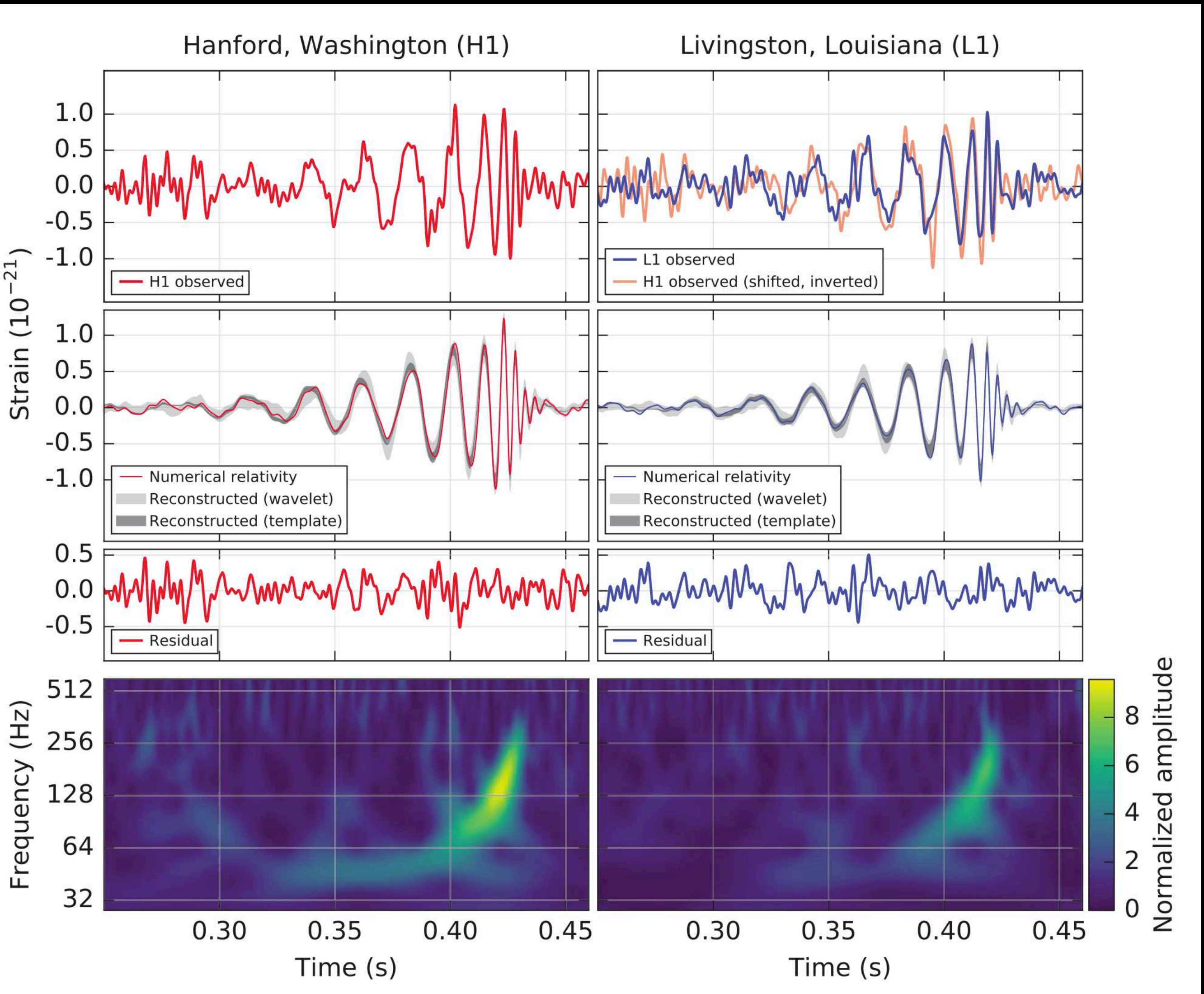


2) Electromagnetic Waves

3) In space-time: Gravity Waves

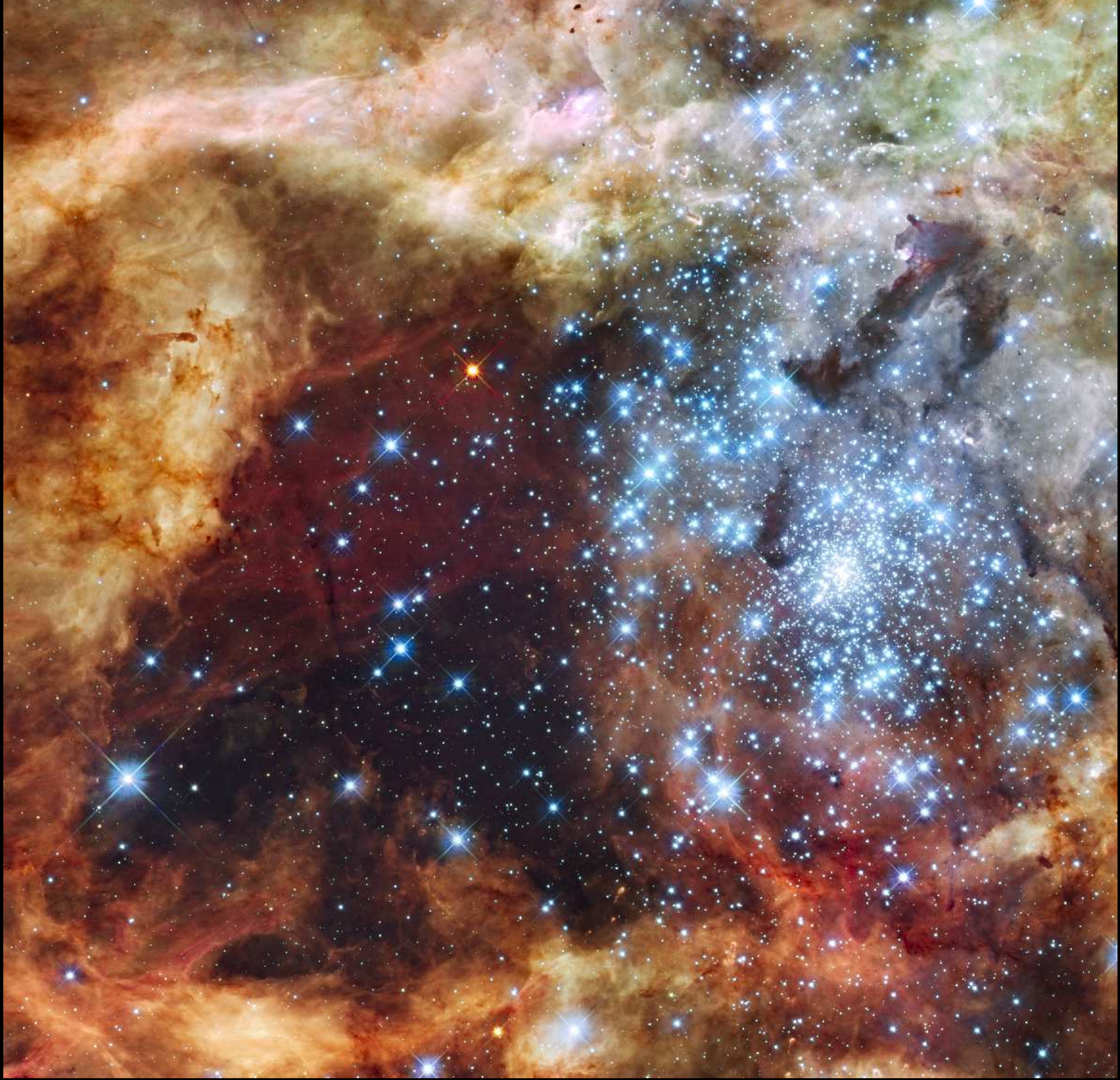
Sept. 2015: LIGO added Gravity Waves as a new way to observe Nature!



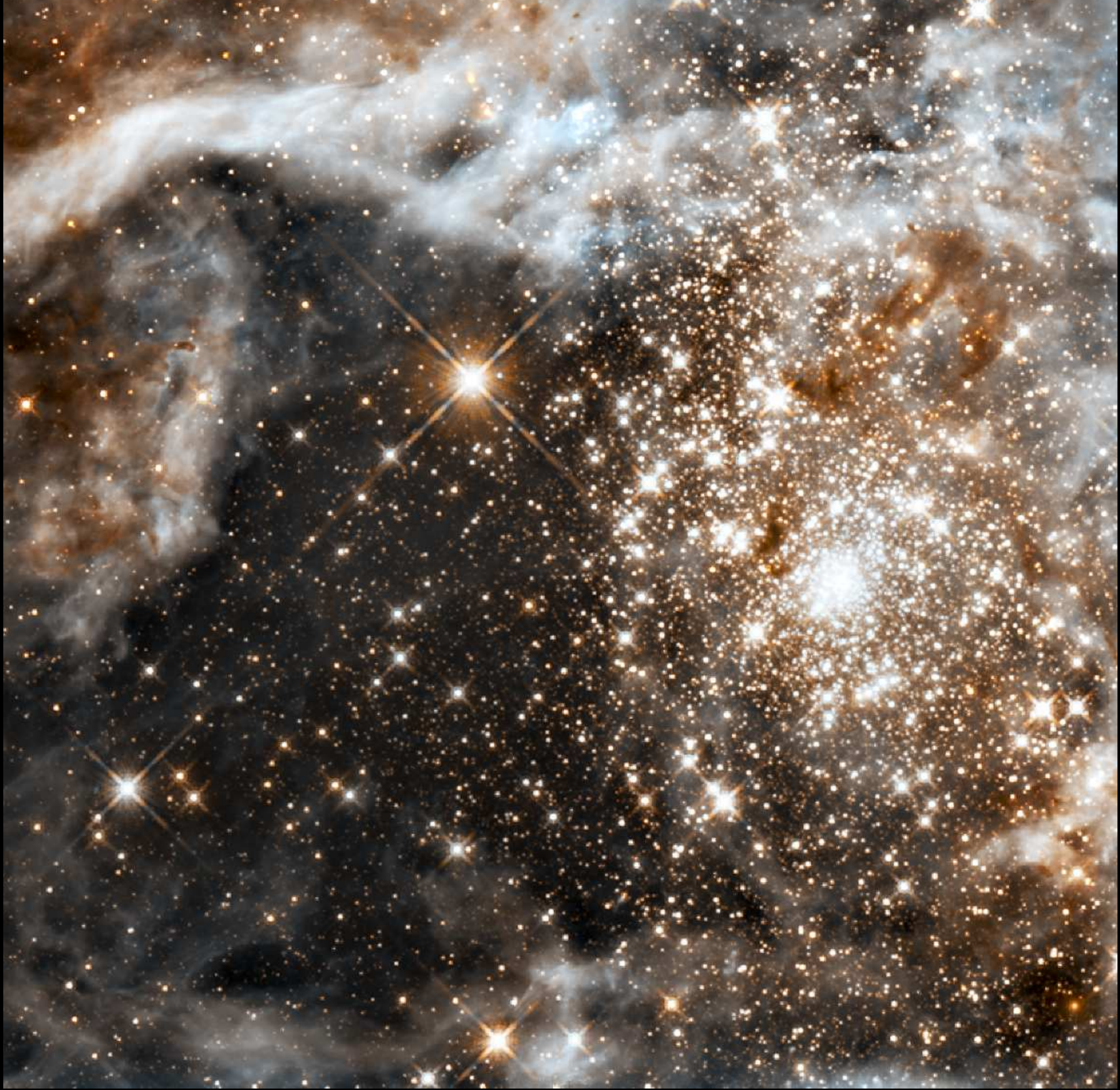


Hanford, Washington (H1)
Livingston, Louisiana (L1)
Strain (10^{-21})
H1 observed
L1 observed
H1 observed (shifted, inverted)
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
Residual
Frequency (Hz)
512
256
128
64
32
0.30
0.35
0.40
0.45
Time (s)
Normalized amplitude
1.0
0.5
0.0
-0.5
-1.0
8
6
4
2
0

30 Doradus: Giant young star-cluster in Large Magellanic Cloud (150,000 ly), triggering birth of Sun-like stars (and surrounding debris disks).



Ordinary massive stars (10–30 $M_{\odot}$) leave modest black holes ($\sim$3–10 $M_{\odot}$).



Ordinary massive stars (10–30 $M_{\odot}$) leave modest black holes ($\sim$3–10 $M_{\odot}$).

Conclusion 1: Most low-mass black holes today are small, slow eaters:

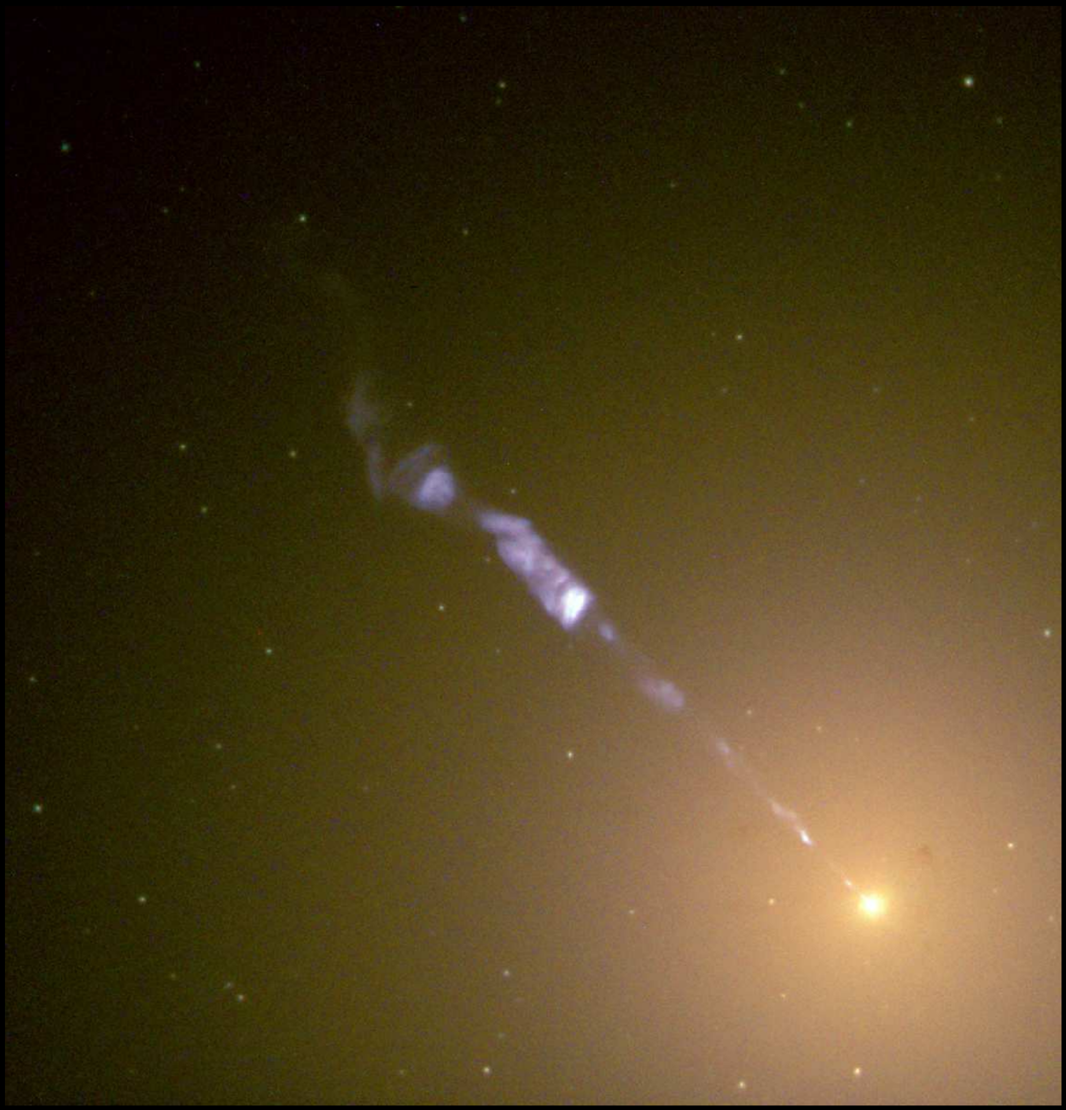
- 29–36 $M_\odot$ blackholes may be leftover from First Stars (first 500 Myr).

- Likely too massive to be leftover from ordinary Supernova explosions, ...

- How come only now seen merging by LIGO (12.5 Byr after BB)?

- They were likely not fast & efficient eaters, but slow and messy ...

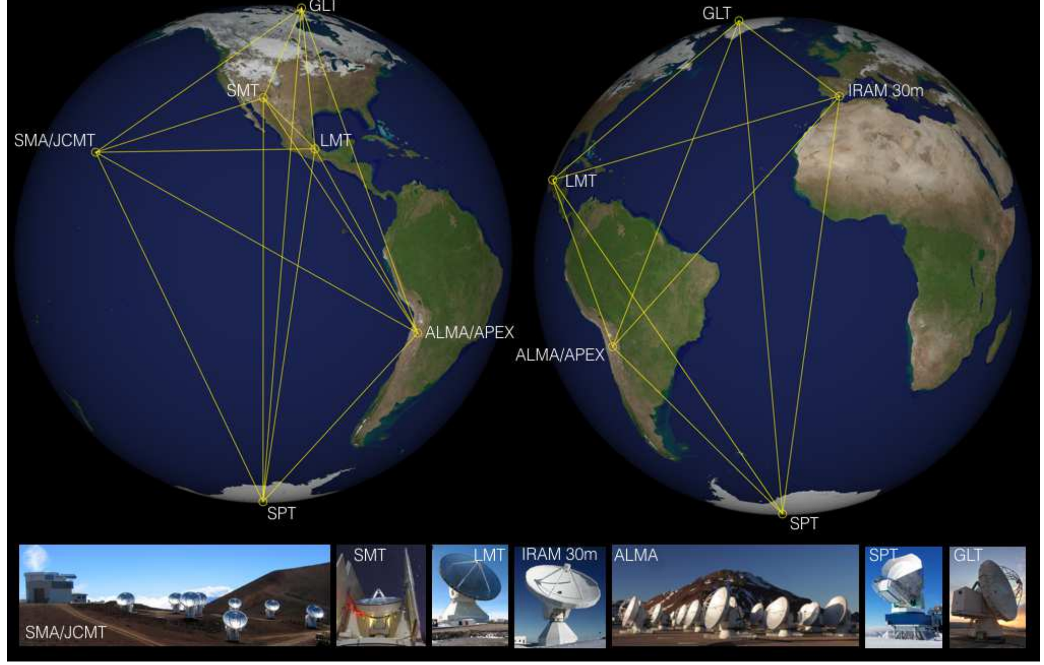
Elliptical galaxy M87 with Active Galactic Nucleus (AGN) and relativistic jet:

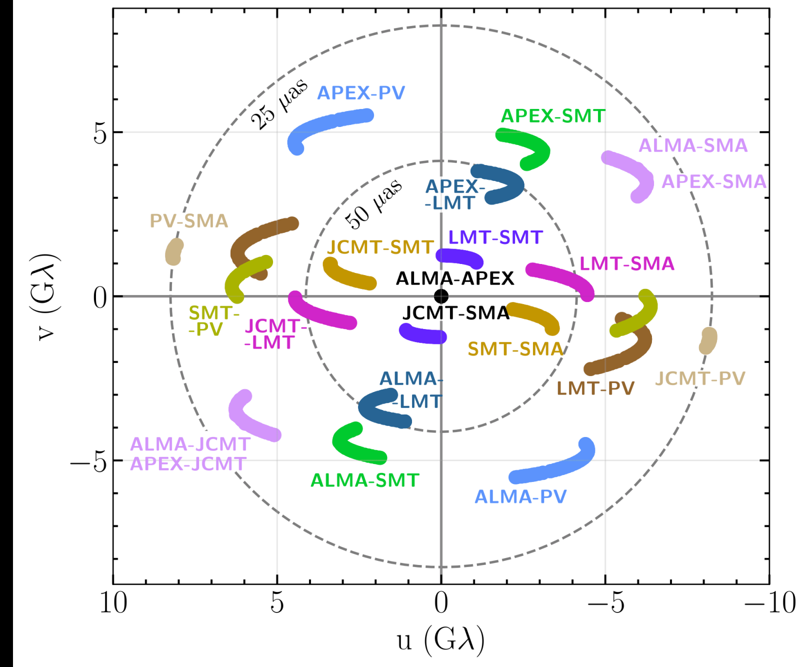


The danger of having Quasar-like devices too close to home ...

They are EXTREMELY bright sources if viewed "down-the-pipe".

$\sim$0.5% of the baryonic mass, but produce most of the photons!





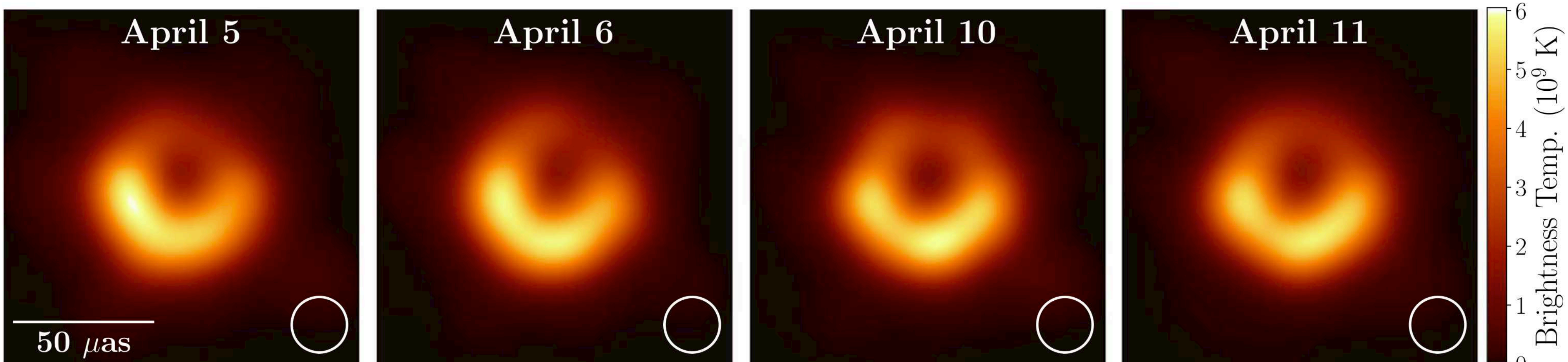
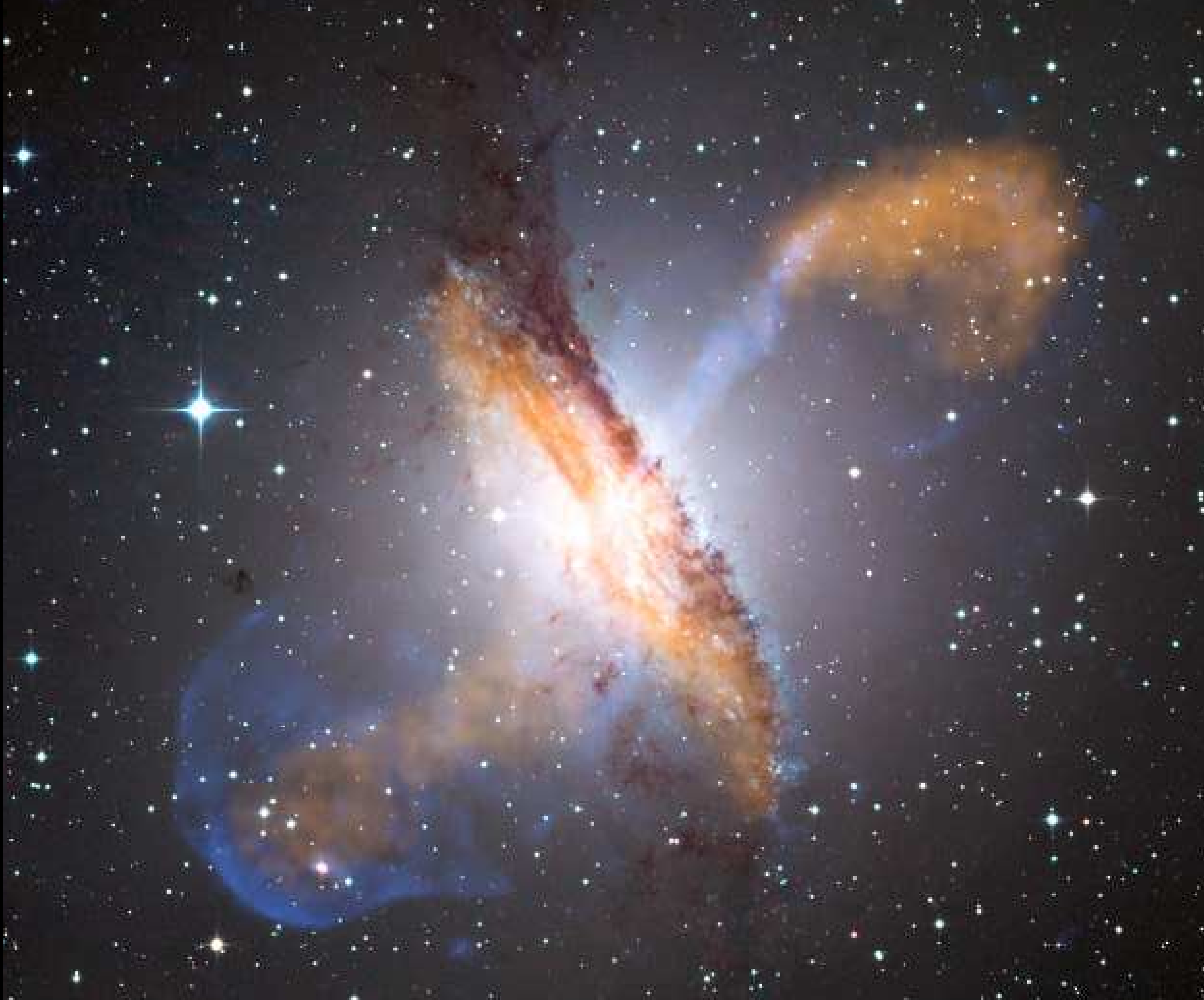


Figure 15. Averages of the three fiducial images of M87 for each of the four observed days after restoring each to an equivalent resolution, as in Figure 14. The indicated beam is 20 μas (i.e., that of `DIFMAP`, which is always the largest of the three individual beams).

2019 discovery of Black Hole Shadow in M87 by Event Horizon Telescope:

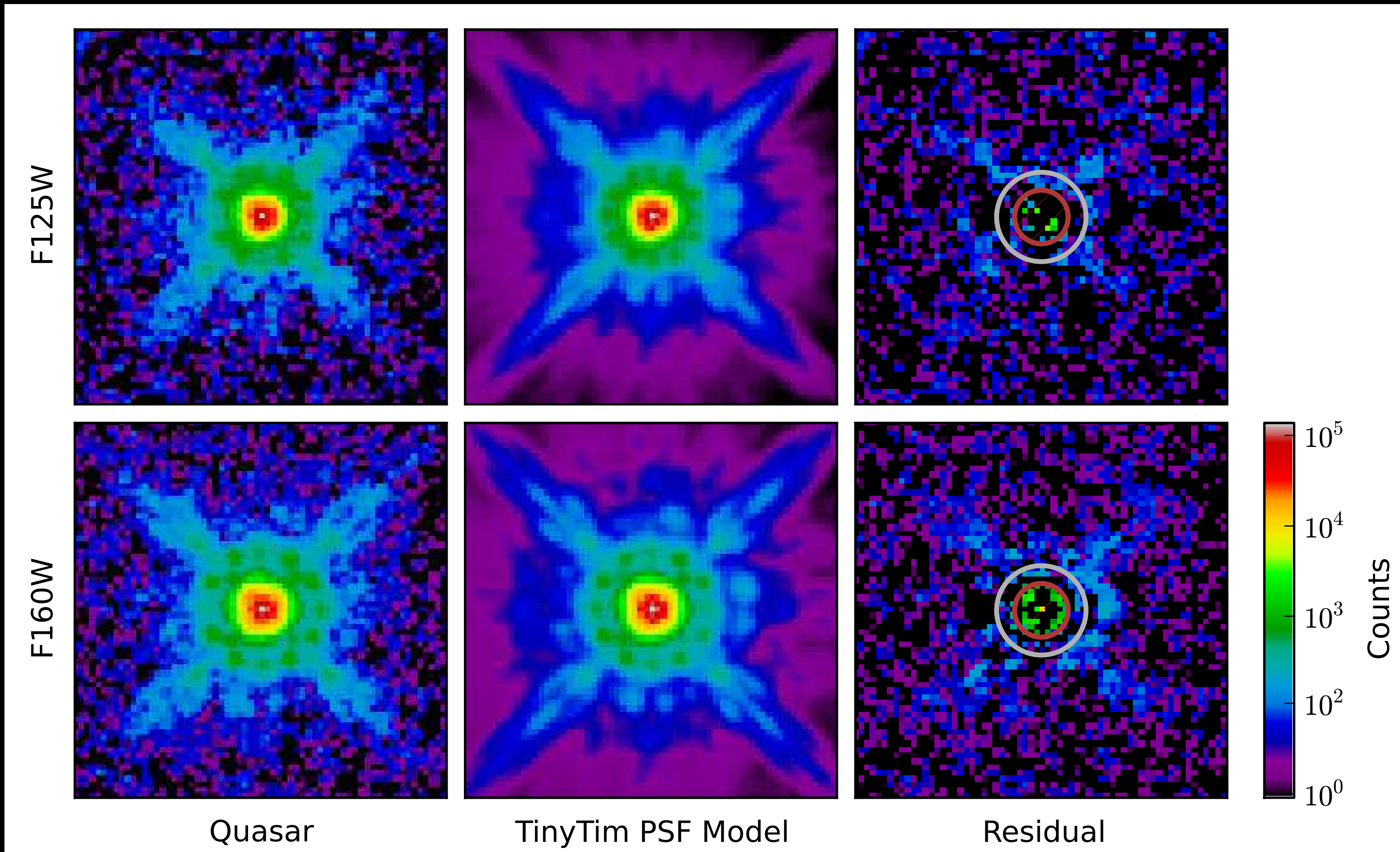
M87 at 55 Mlyr distance has a black hole mass of $\sim 6.5\times10^9$ $M_\odot$!


Centaurus A
NGC 5128
HST WFC3/UVIS
F225W+F336W+F438W
F487N Hβ
F502N [O III]
F547M y
F657N Hα+[N II]
F673N [S II]
F814W *I*
3000 light-years
1400 parsecs
56″
E
N



Blue=X-rays; White=Optical; Orange=Radio

• Quasars: Centers of galaxies with feeding supermassive blackholes:



- Hubble IR-images of the most luminous Quasar known in the universe.
- Seen at redshift 6.42 (universe 7.42× smaller than today), 900 Myr old!
- Contains 10^{14} solar luminosities within a region as small as Pluto's orbit!
- A feeding monster blackhole (>3×10^9 solar mass) 900 Myr after BB!

Conclusion 2: Supermassive black holes started early & were very rapid eaters:

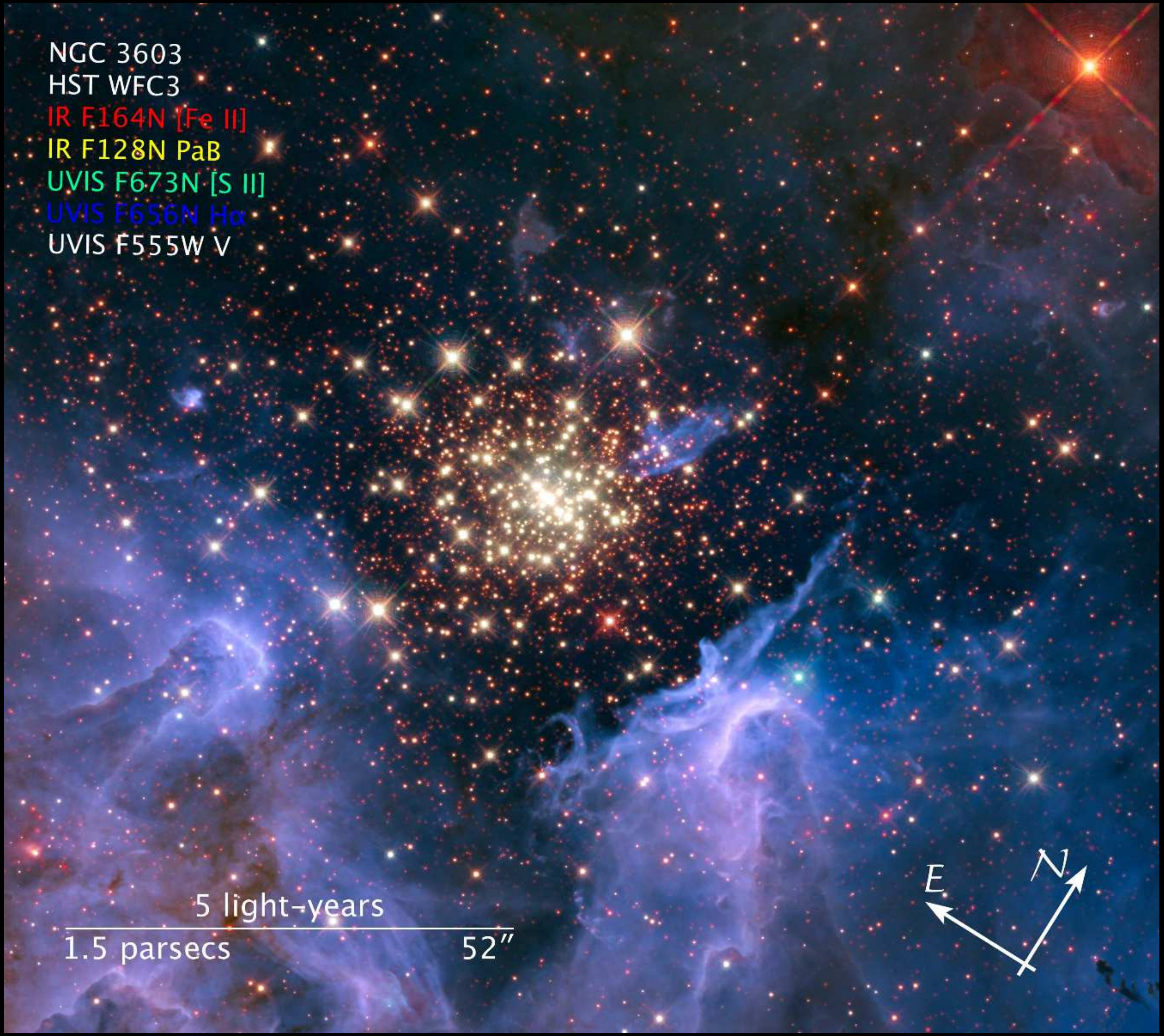
- Massive galaxies today contain a super-massive blackhole, no exceptions!

- Masses $\sim 3\times 10^9$ solar, leftover from the First Stars (first 500 Myr)?
- Must have fed enormously rapidly in the first 1 Byr after the Big Bang.
- Were eating cat-astrophically (and secretly) until they ran out of food ...
- JWST can image the First Quasars to z$\gtrsim$10 (*if* we can find them).

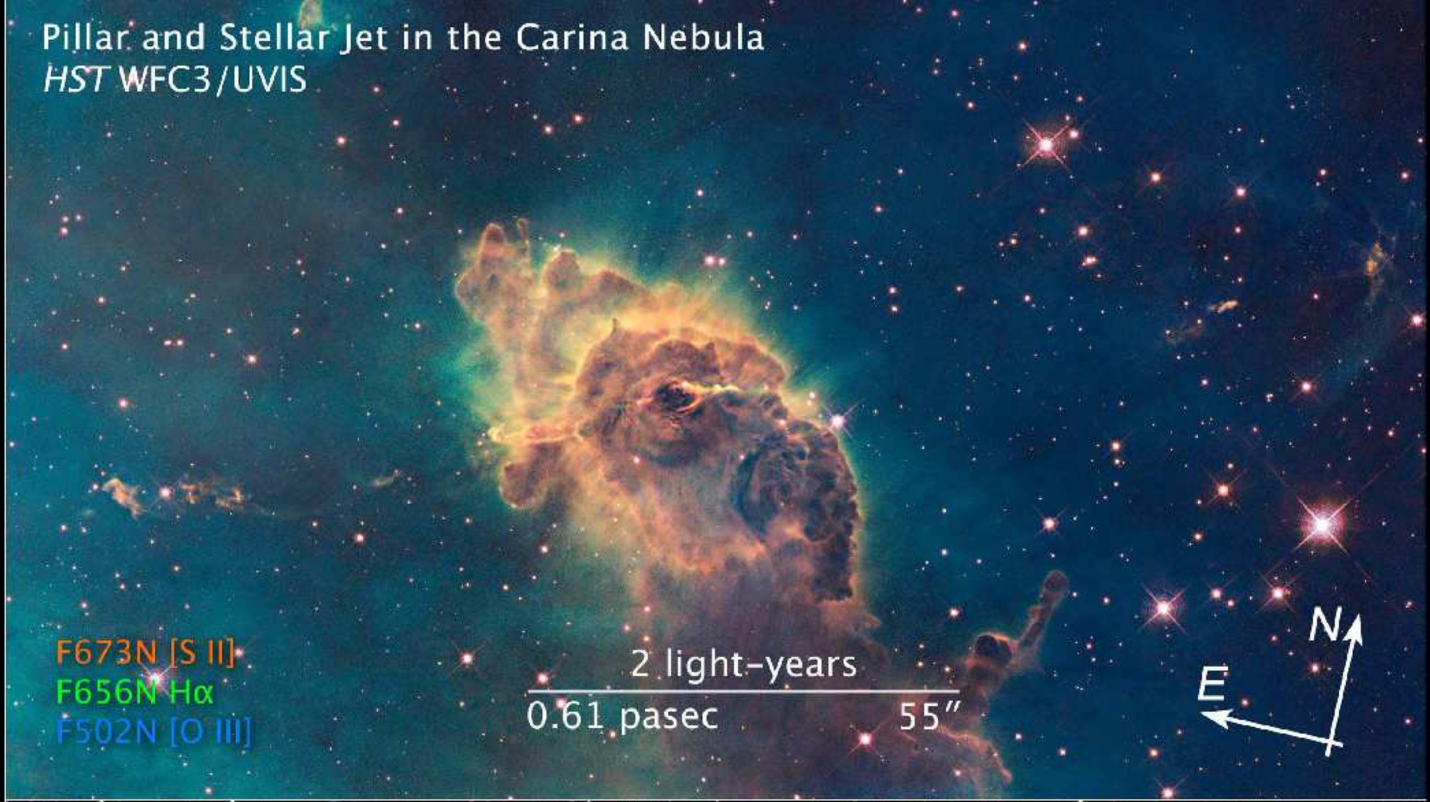
Illustration Sequence of the Milky Way
and Andromeda Galaxy Colliding

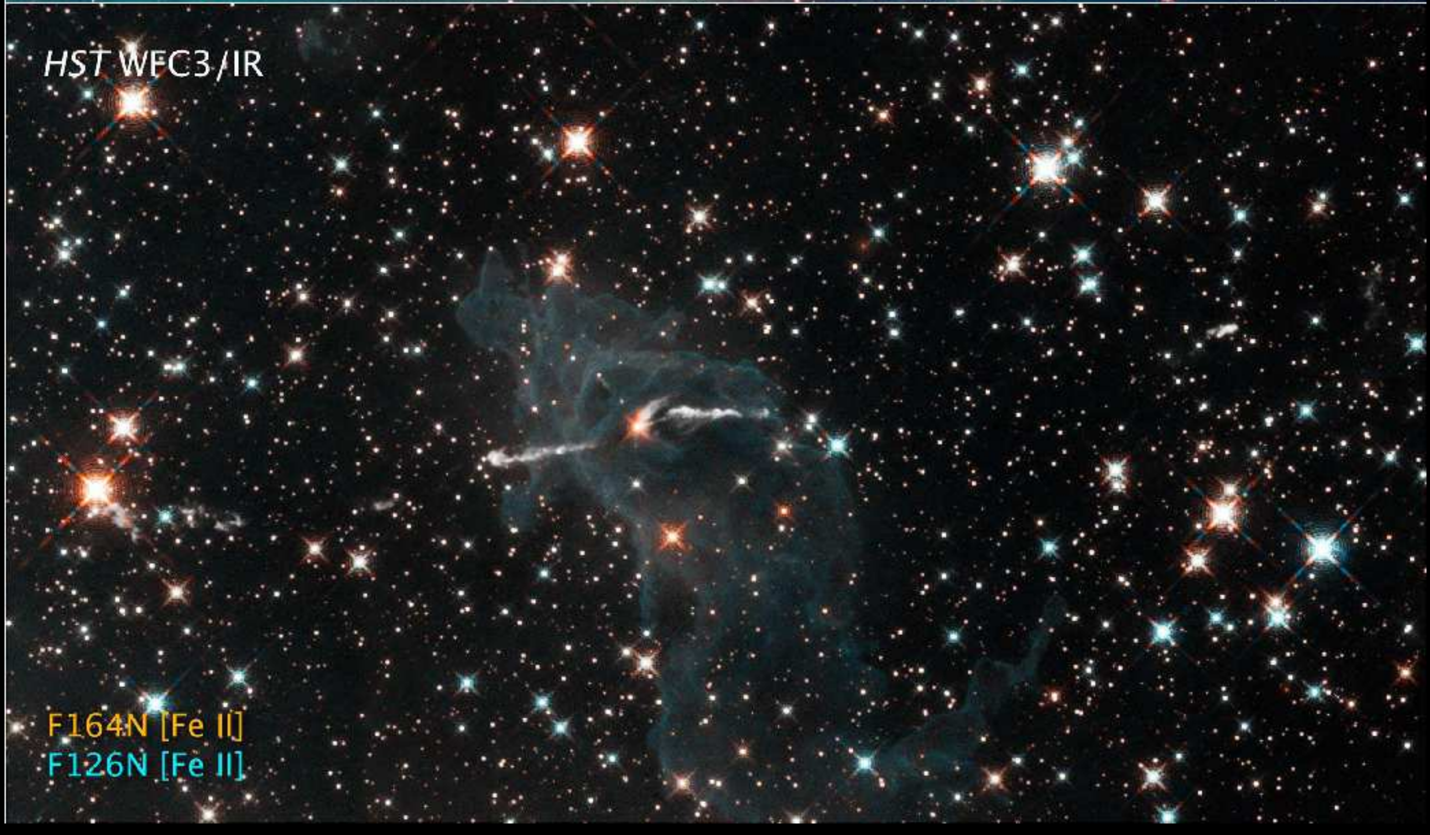
NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger ▪ STScI-PRC12-20b

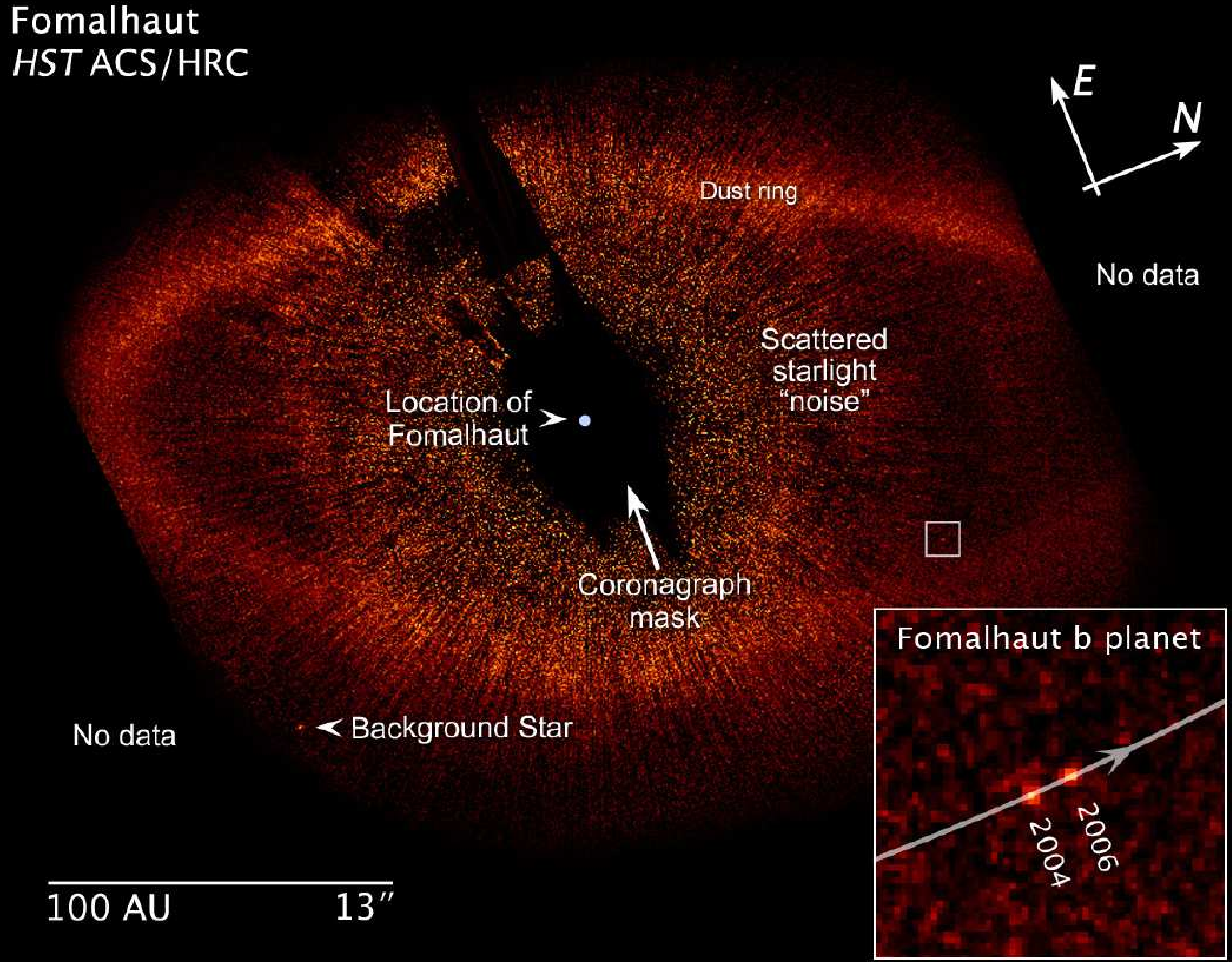
(5) How can JWST measure Star-Formation and Earth-like exoplanets?



NGC 3603: Young star-cluster triggering star-birth in "Pillars of Creation"

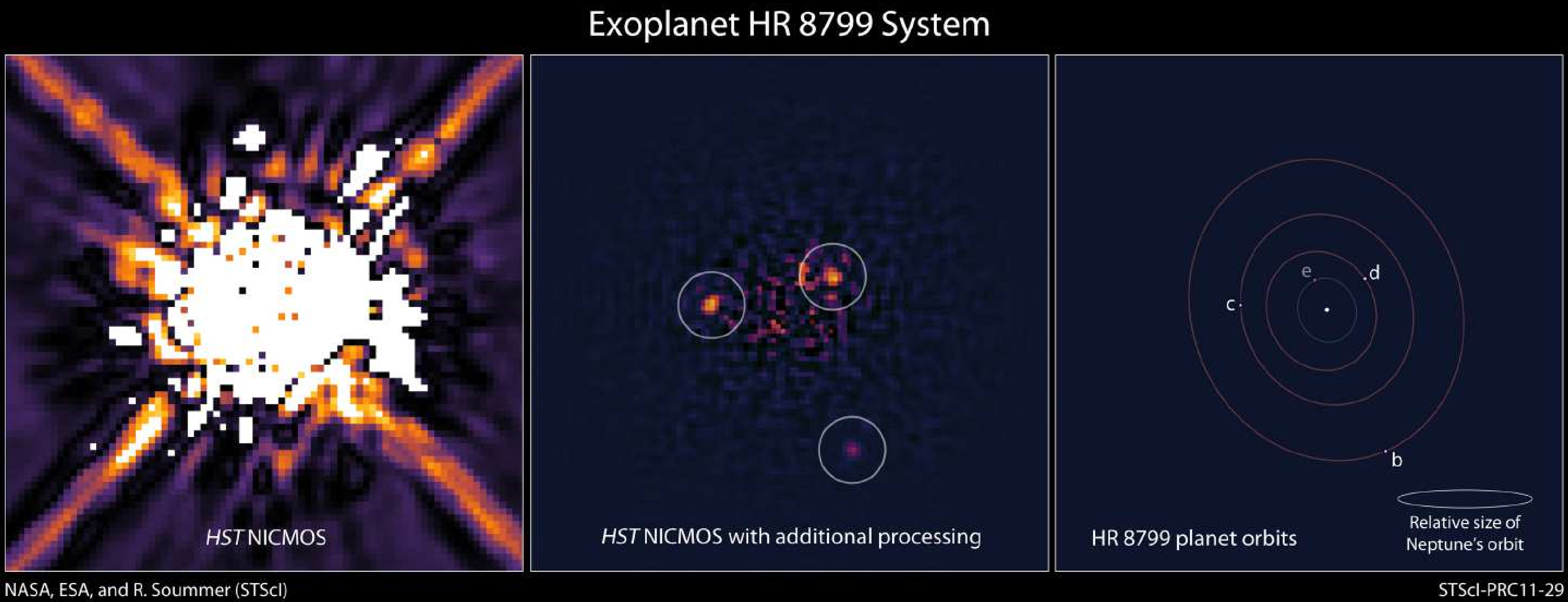

Pillar and Stellar Jet in the Carina Nebula
HST WFC3/UVIS
F673N [S II]
F656N Hα
F502N [O III]
2 light-years
0.61 pasec
55″
N
E


HST WFC3/IR
F164N [Fe II]
F126N [Fe II]



HST/ACS Coronagraph imaging of planetary debris disk around Fomalhaut: First direct imaging of a moving planet forming around a nearby star!

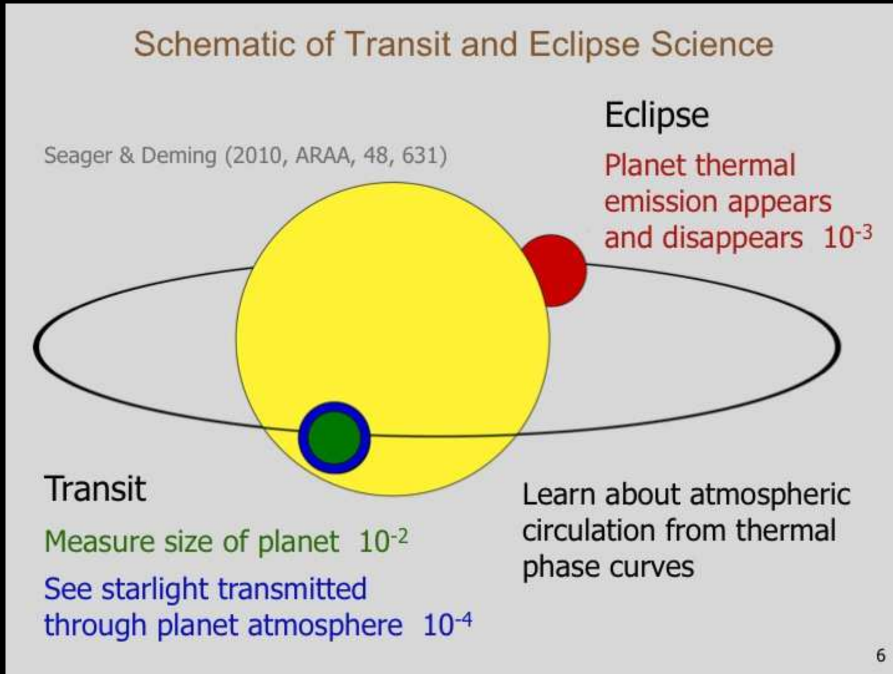
JWST can find such planets much closer in for much farther stars.

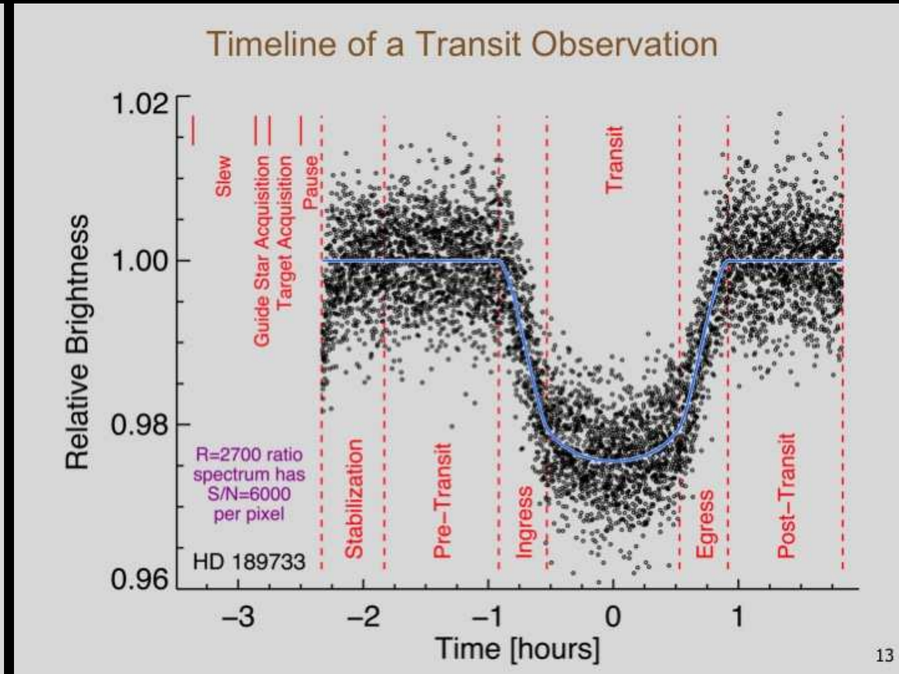


HST/NICMOS imaging of planetary system around the (carefully subtracted) star HR 8799: Direct imaging of planets around a nearby star.

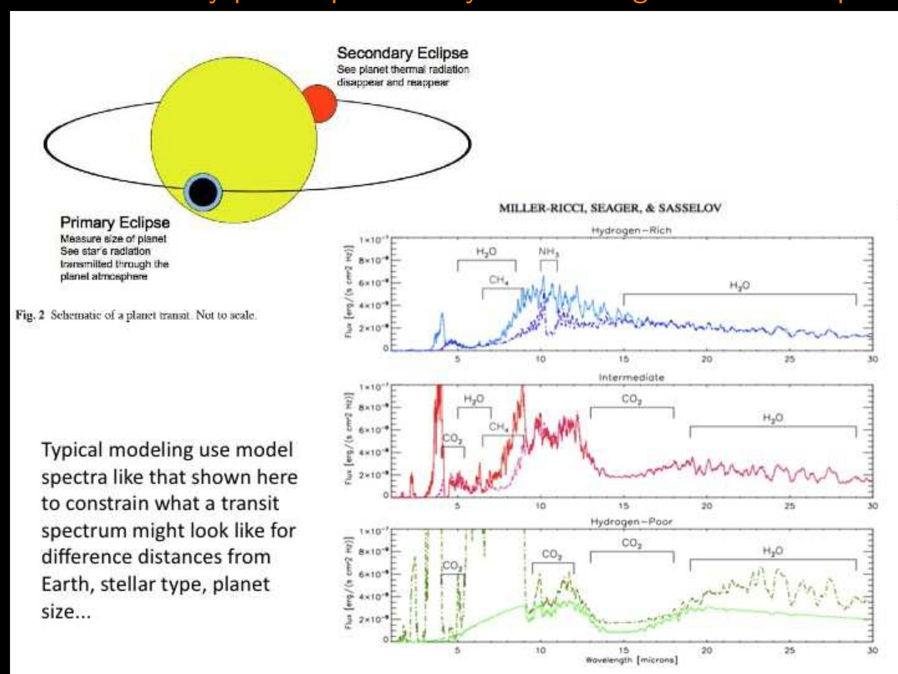
Press release: http://hubblesite.org/newscenter/archive/releases/2011/29/

JWST can find such planets much closer in for much farther-away stars.



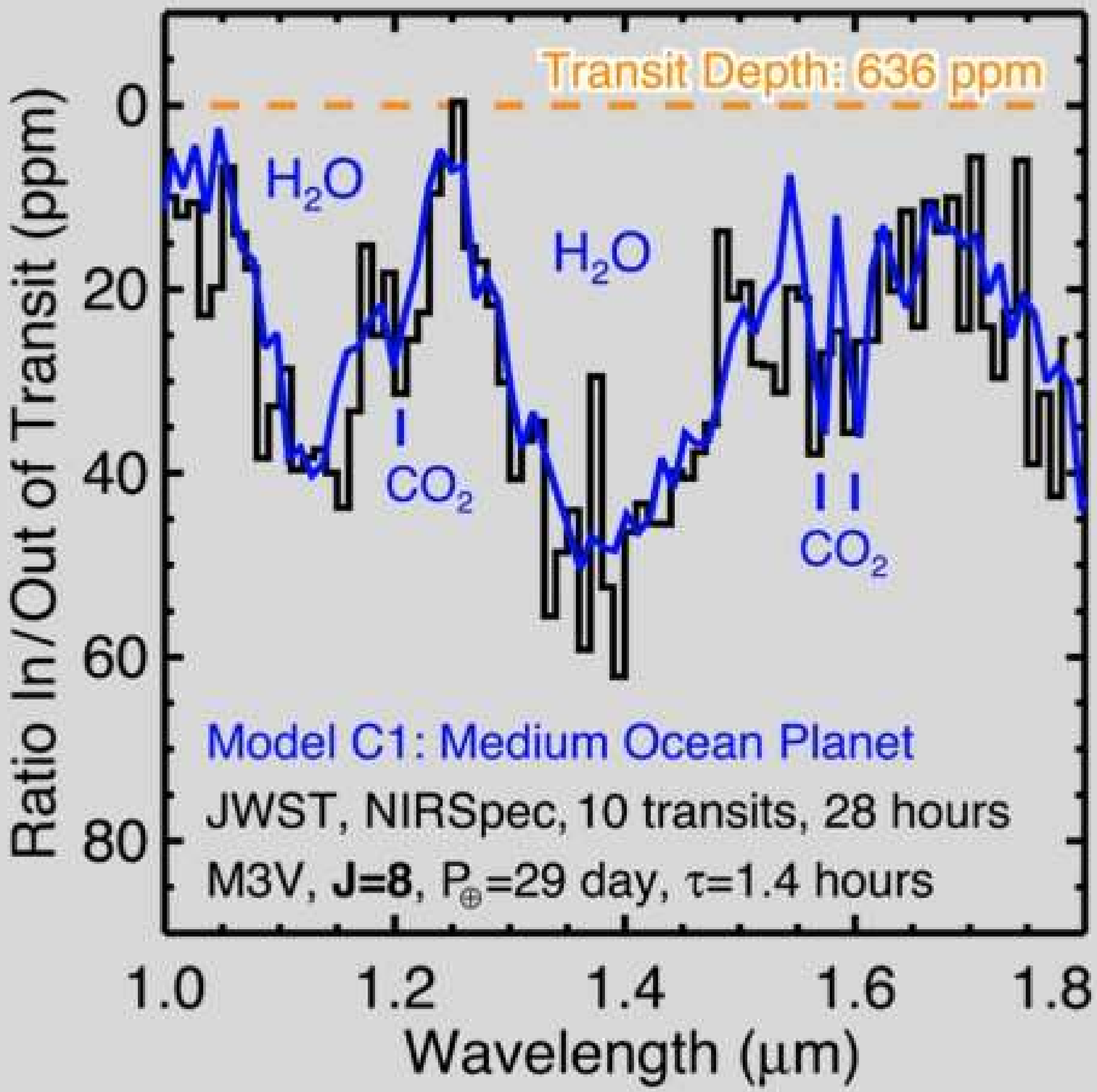


JWST can do very precise photometry of transiting Earth-like exoplanets.



JWST IR spectra can find water and CO_2 in (super-)Earth-like exoplanets.

Transit Spectrum of Habitable "Ocean Planet"



JWST IR spectra can find water and CO_2 in transiting Earth-like exoplanets.