The World of Webb, the Cosmic Circle of Life, and seeing through the Eyes of Einstein

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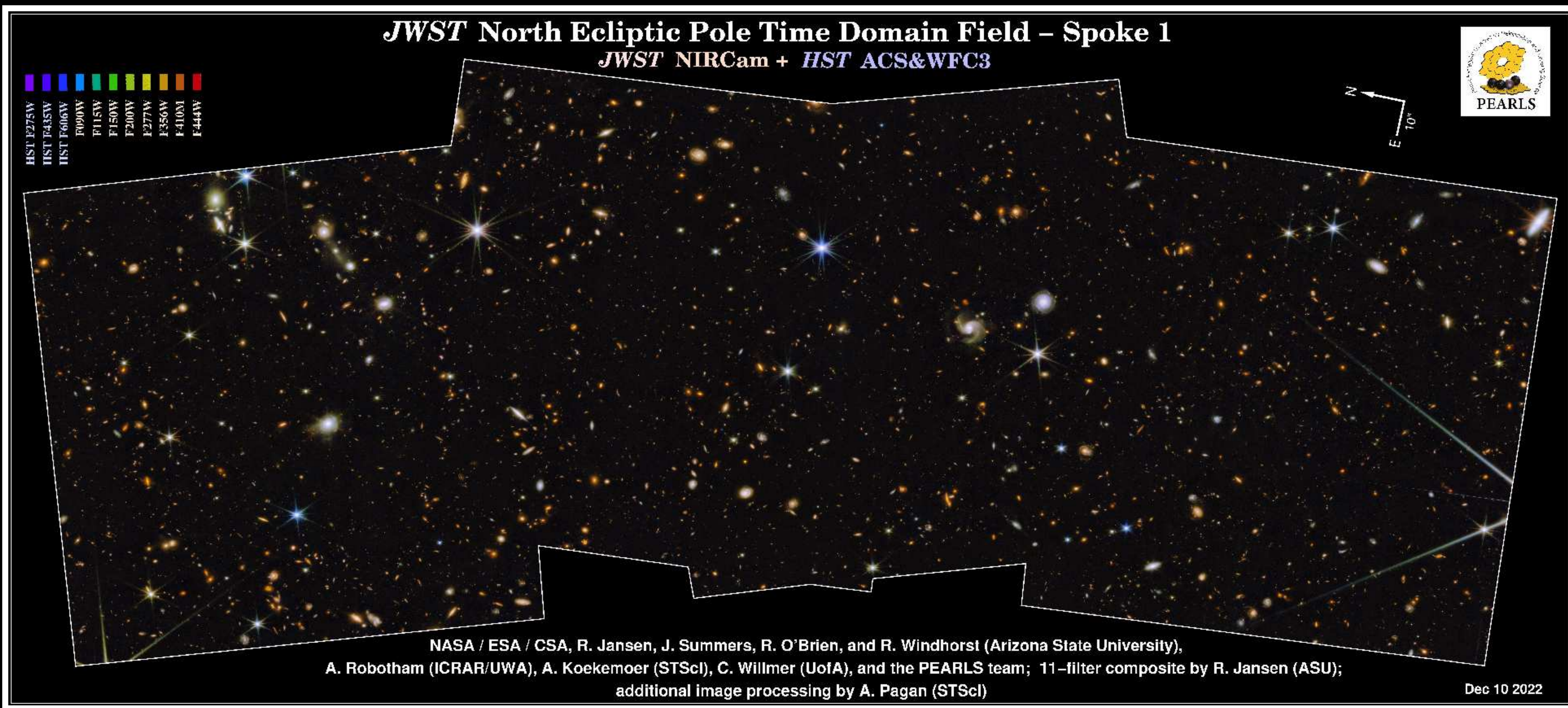


East Valley Astronomy Club, Gilbert Library, Arizona — Friday February 16, 2024

Outline

- (1) Update on the James Webb Space Telescope (JWST), 2024.
- (2) Webb's first images: the "Cosmic Circle of Life"
- (3) Viewing the Universe through the Eyes of Einstein"
- (4) Summary and Conclusions
- (5) What Hubble has done: Galaxy Assembly & SMBH Growth
- (6) How can JWST measure Earth-like exoplanets?

Sponsored by NASA/HST & JWST

Arizona State University

Talk is on: http://www.asu.edu/clas/hst/www/evac24_jwst.pdf

WARNING: asking NASA for Hubble images is like drinking from a fire-hydrant;

WARNING: asking NASA for Hubble images is like drinking from a fire-hydrant;

asking NASA for Webb images is like taking a sip from Niagara Falls!

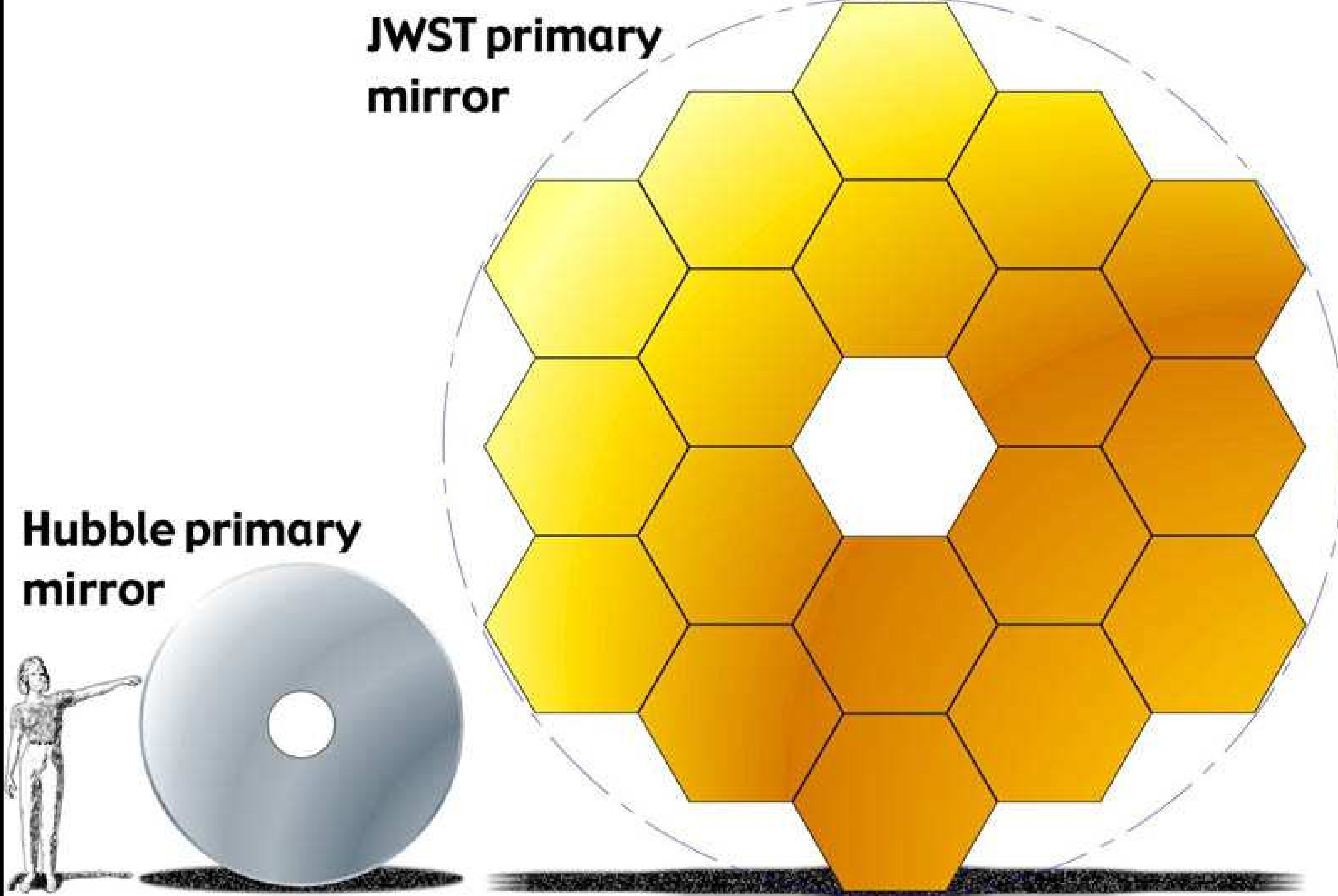
Children: Please don't do this at home!! :)

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

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

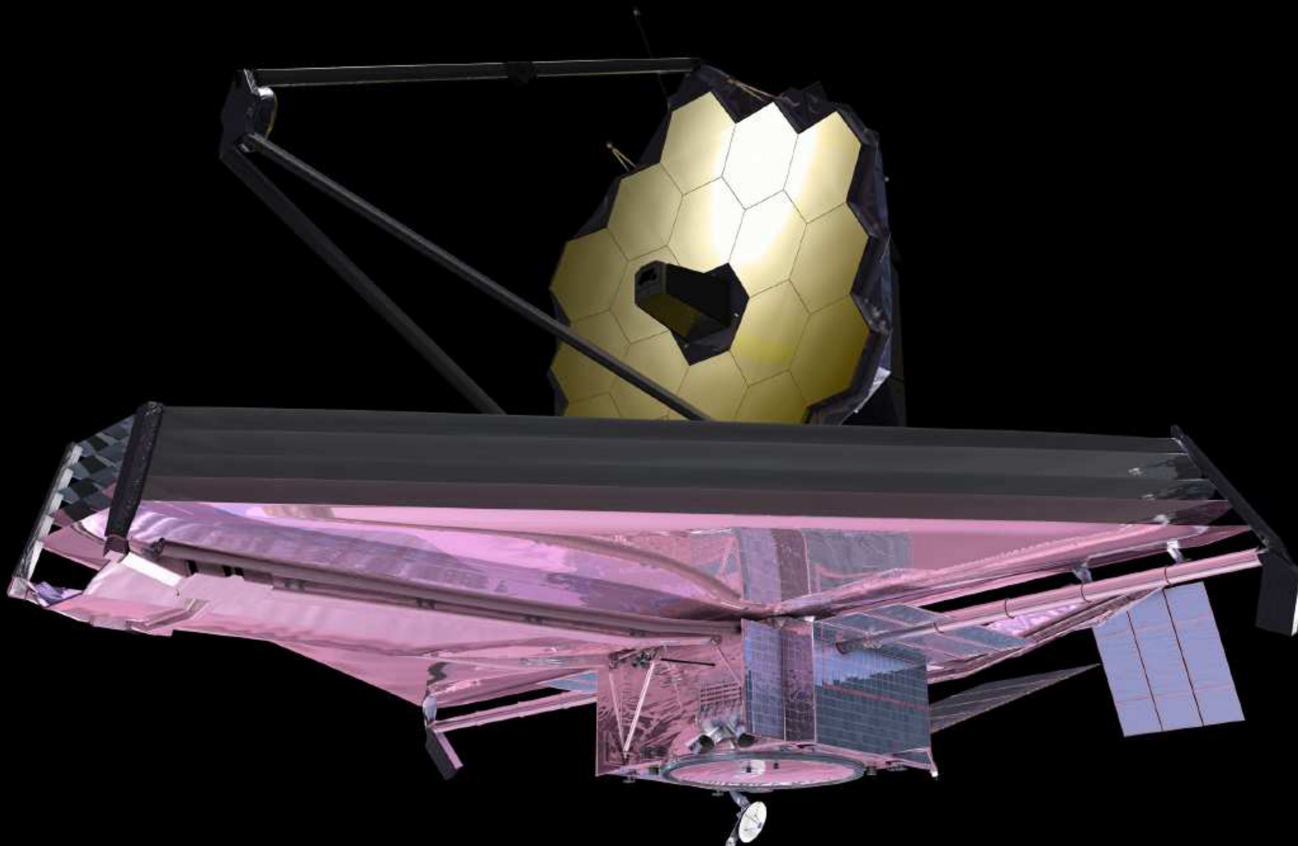
Hubble: Concept in 1970's; Made in 1980's; Operational 1990–$\gtrsim$2025?

JWST: The infrared sequel to Hubble from 2021–2026 (–$\gtrsim$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 2024

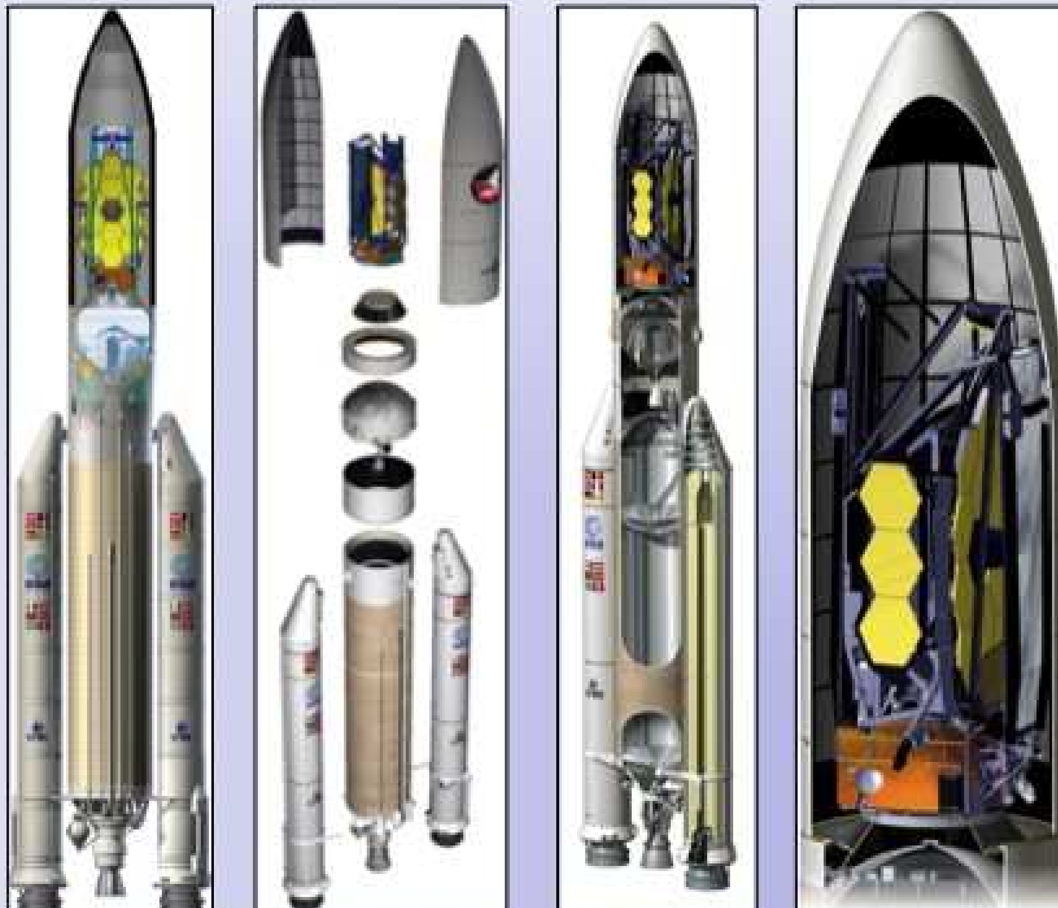


- A fully deployable 6.5 meter (25 m^2) segmented IR telescope for imaging and spectroscopy at 0.6–28 μm wavelength, launched Dec. 25, 2021.
- Nested array of sun-shields to keep ambient temperature at 40 K, allowing faint imaging (31.5 mag$\simeq$1 firefly from Moon), & spectroscopy.

The James Webb Space Telescope

JWST Launch

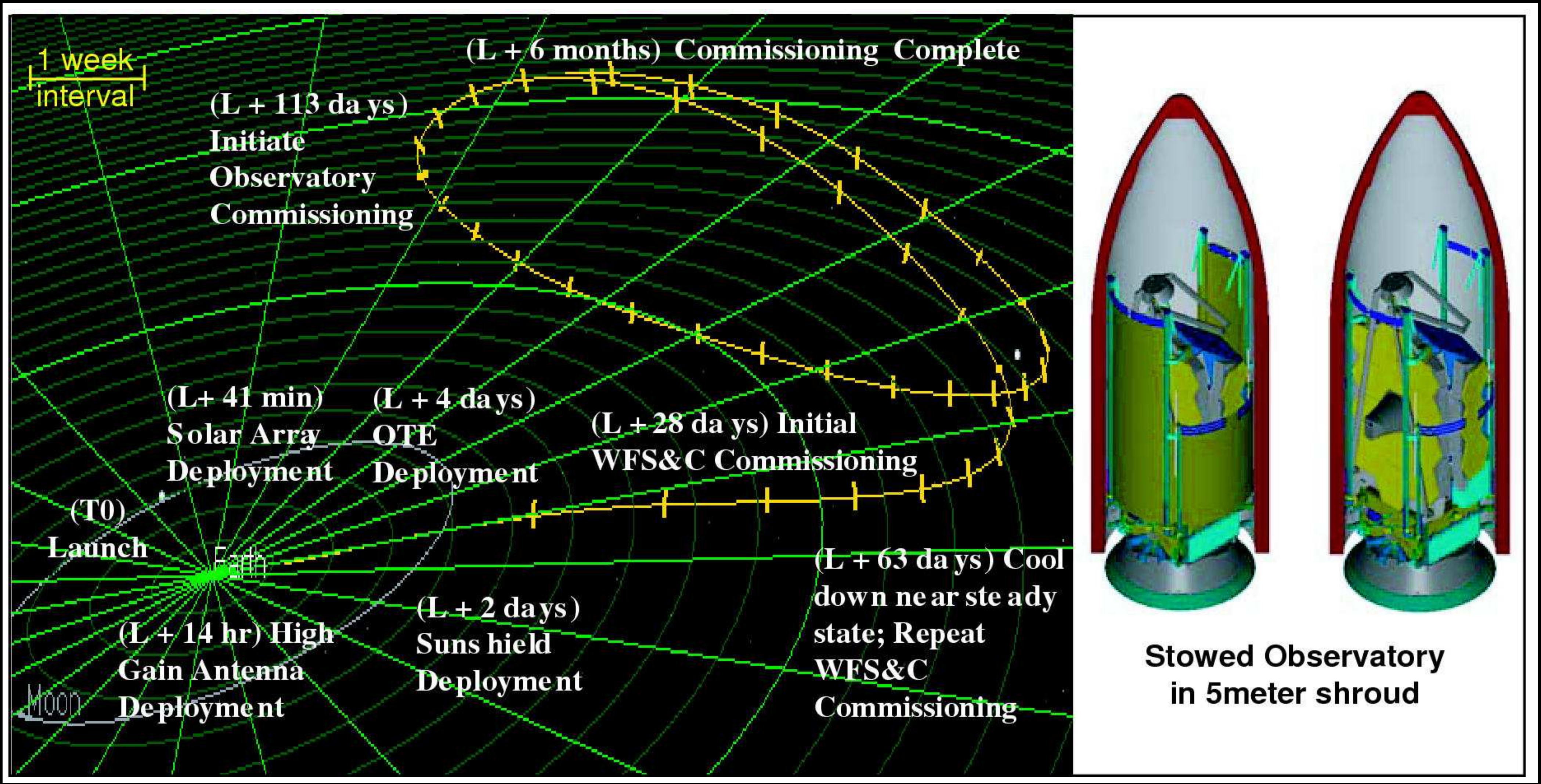
- Launch vehicle is an Ariane 5 rocket, supplied by ESA
- Site will be the Arianespace's ELA-3 launch complex near Kourou, French Guiana



Arianespace – ESA - NASA

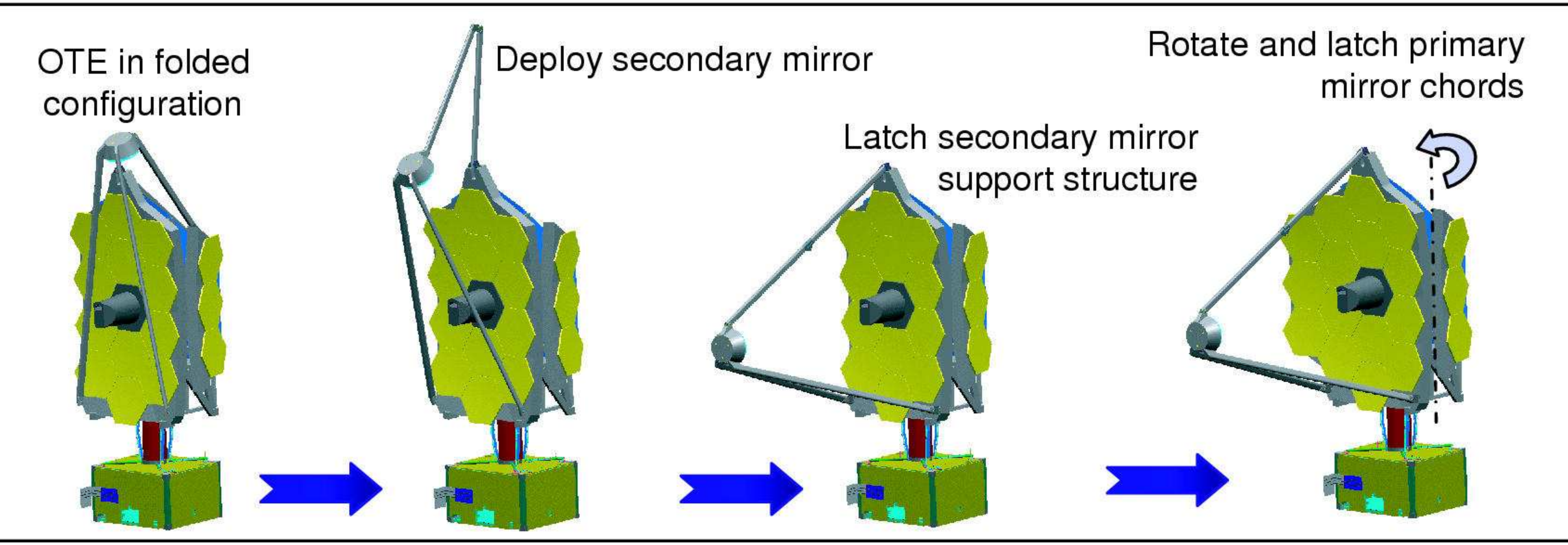
- The JWST launch weight is $\lesssim$6500 kg, and it was launched to L2 with an ESA Ariane-V launch vehicle from Kourou in French Guiana.

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



- After launch on Dec. 25, 2021 with an ESA Ariane-V, JWST orbits 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.

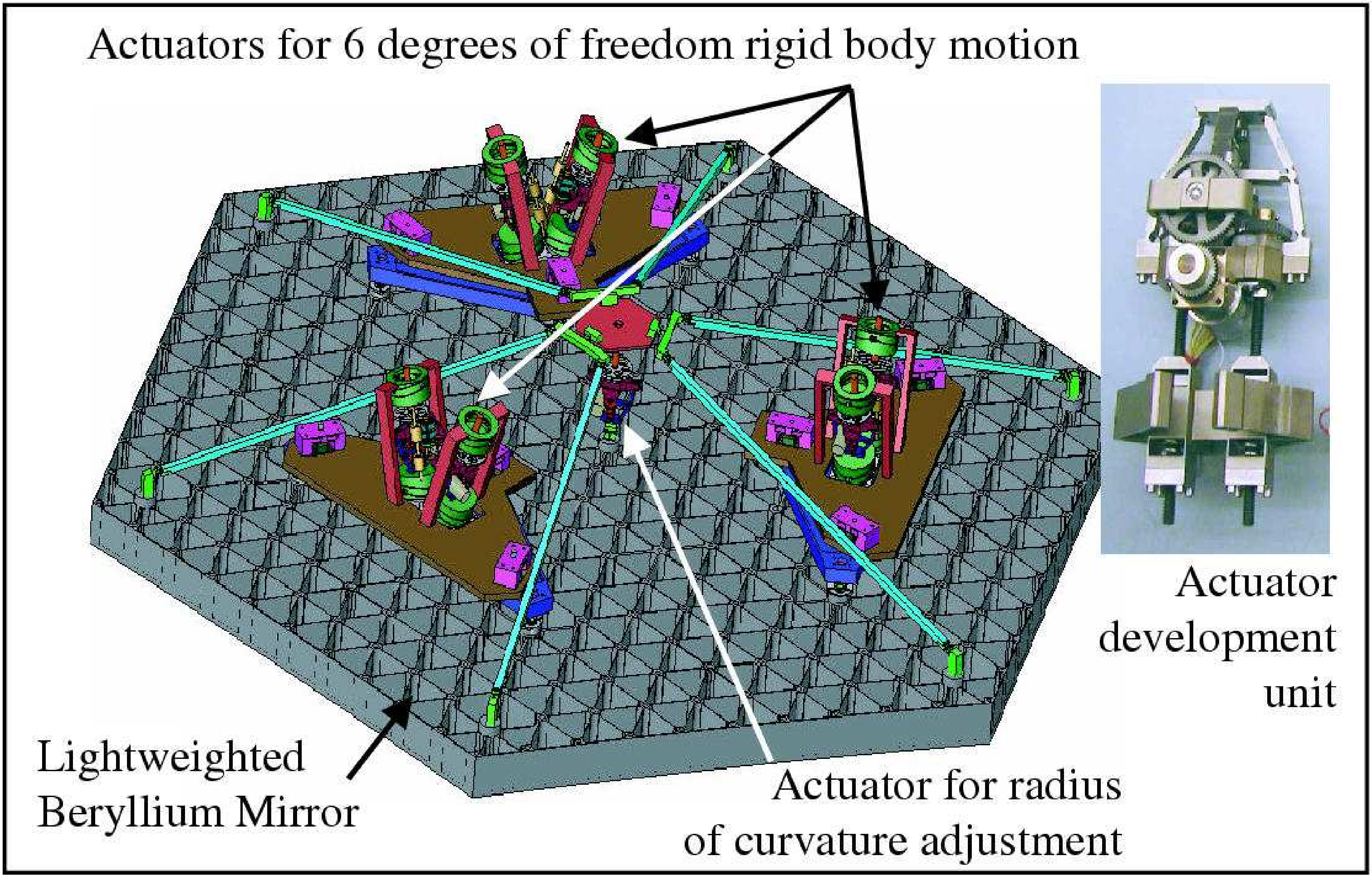
• (1b) How was JWST automatically deployed?



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

• The entire JWST deployment sequence was 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).

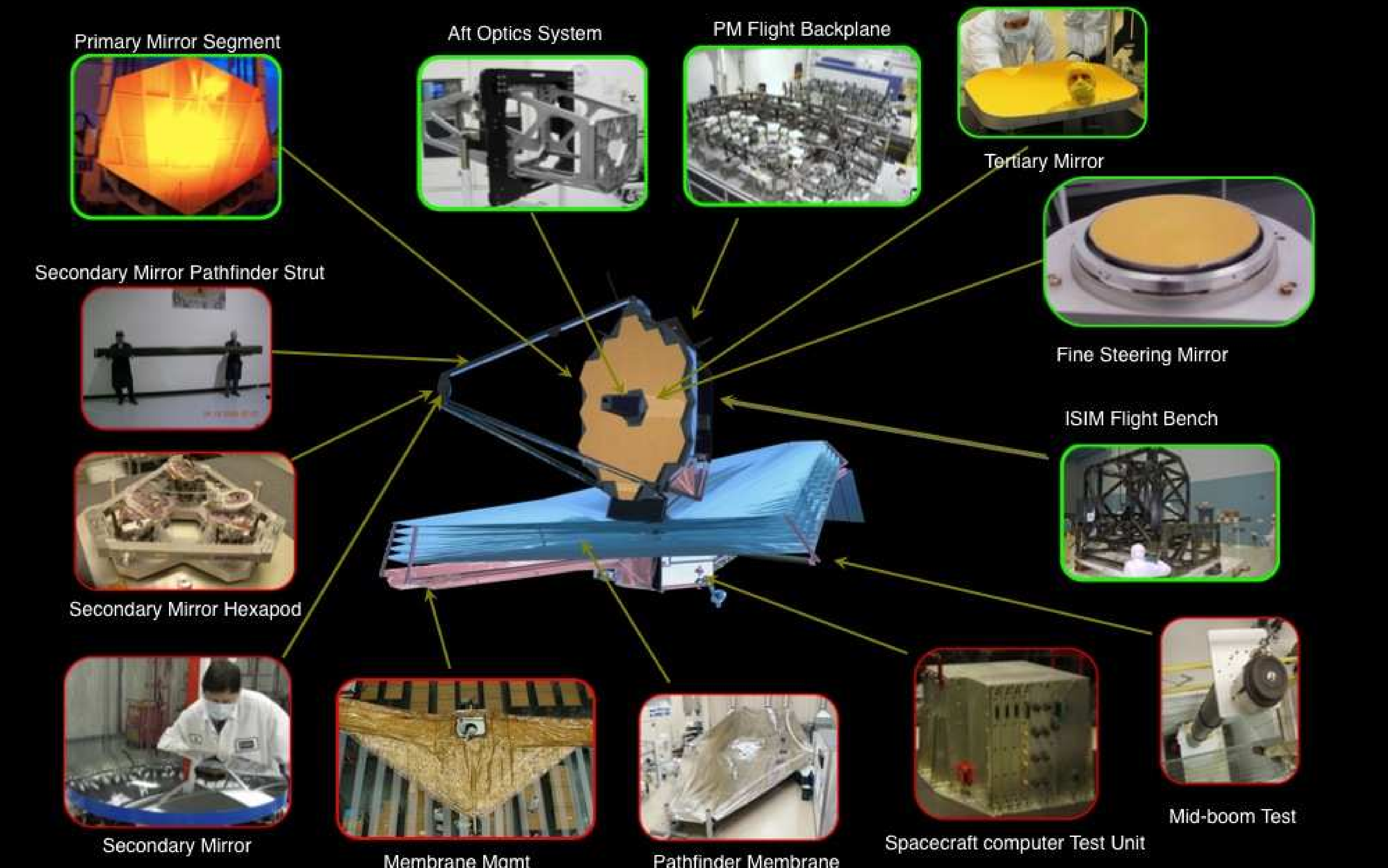
• Component fabrication, testing, & system integration: 18 out of 18 flight mirrors completed in 2015, and meet the 40K specifications (2017).



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

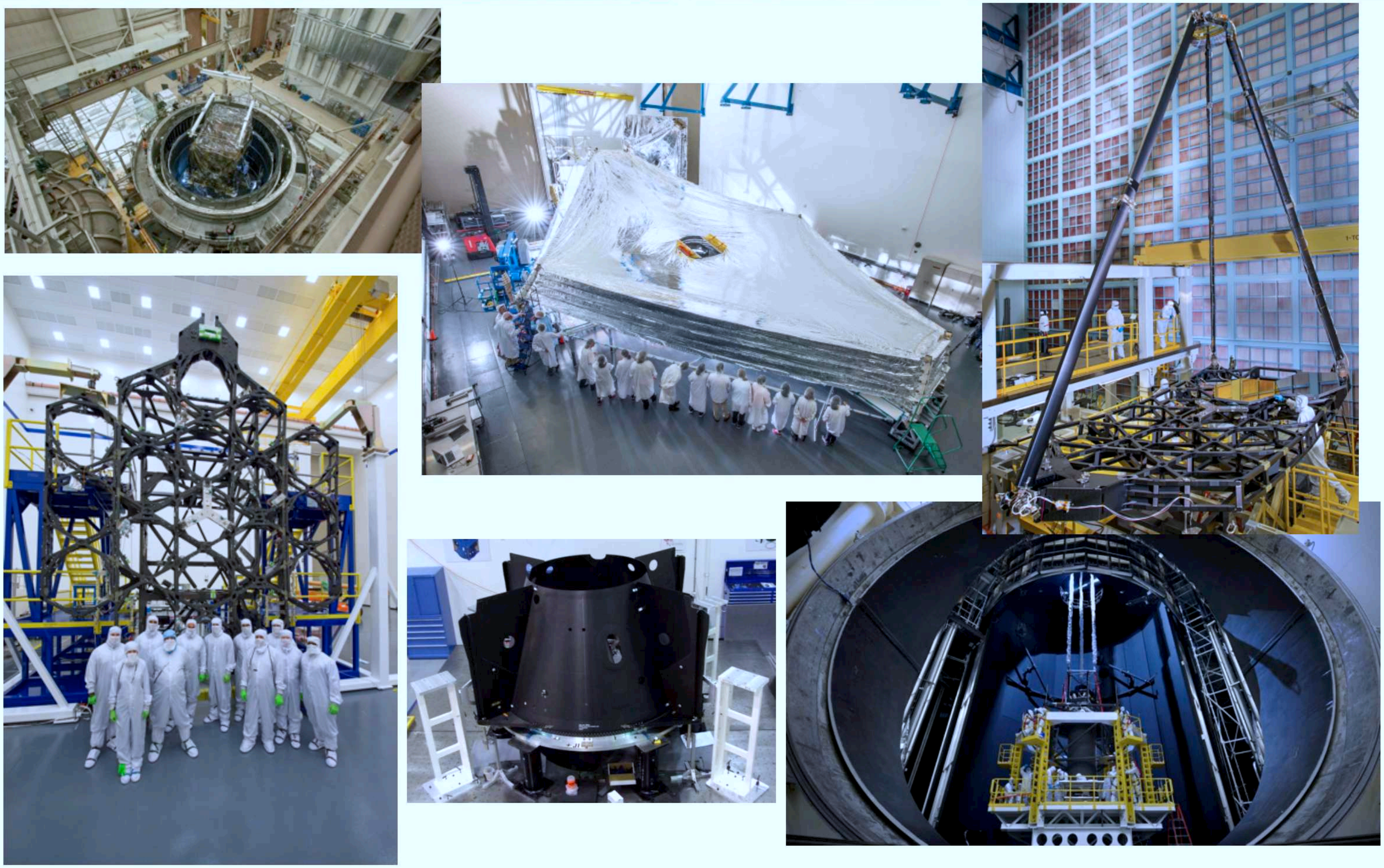
Redundant & doubly-redundant mechanisms, quite forgiving against failures.

JWST Hardware Status



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

JWST Hardware Progress

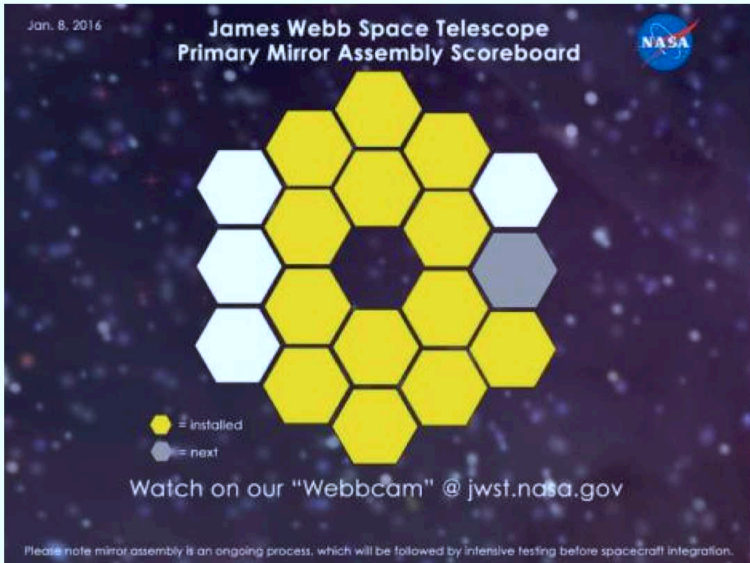


JWST remains on track for an October 2018 launch within its replan budget guidelines

July 2014: • Secondary Mirror Support deployment successfully tested.

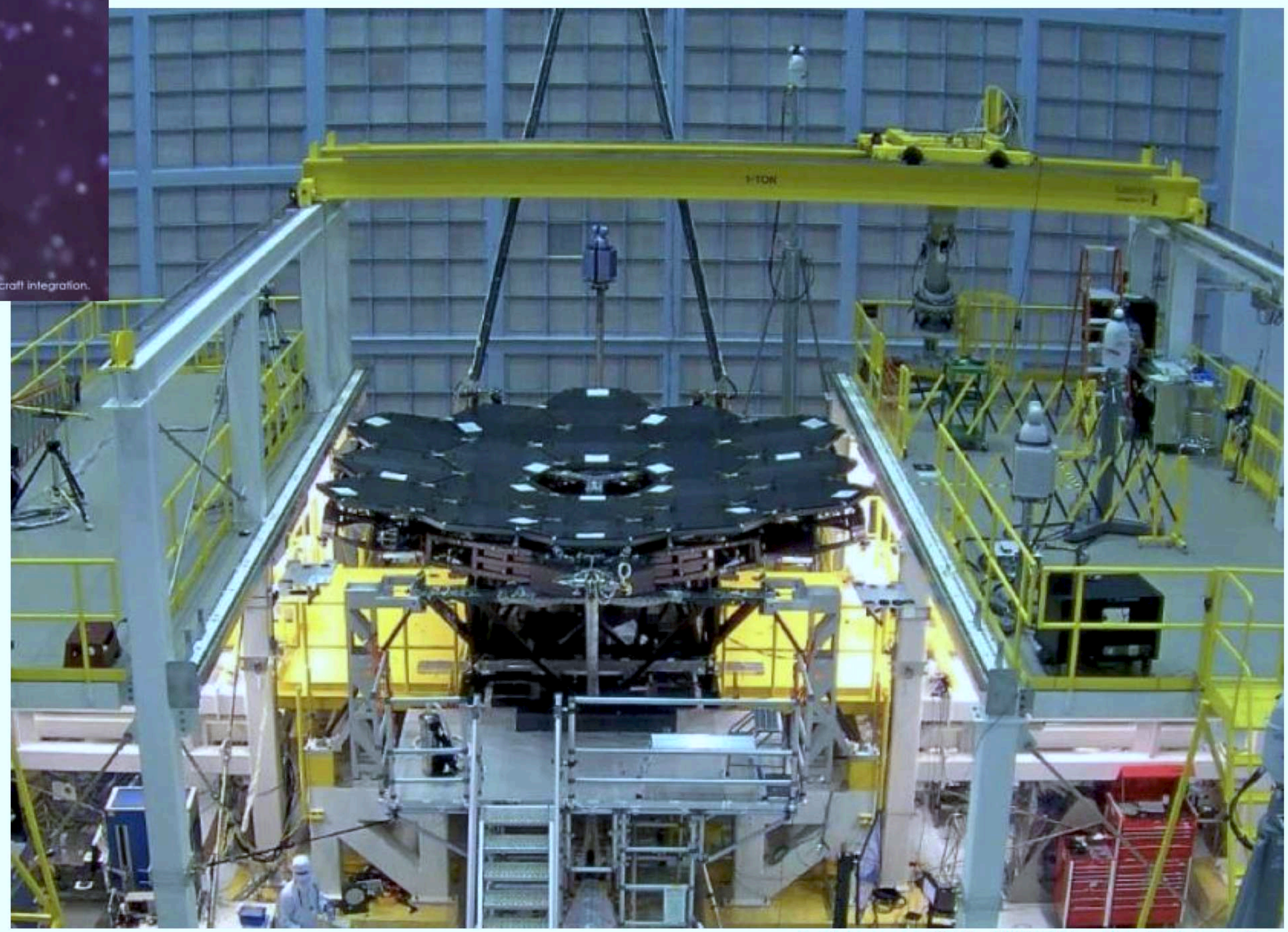
2015: • Engineering sunshield successfully deployed at Northrop (CA).

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. Align-ments meet specifi-cations, and actuator motions verified
Big milestone! →

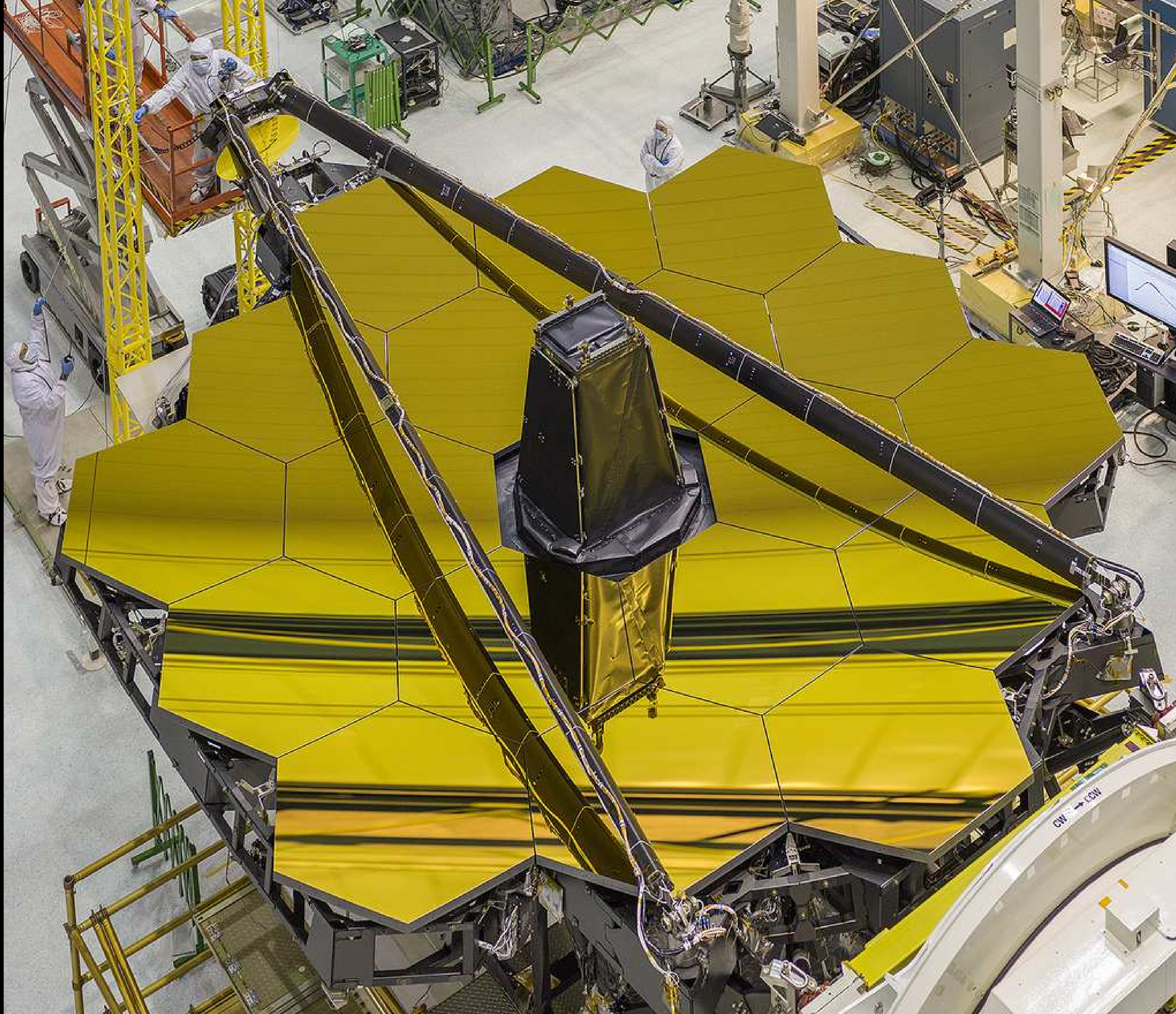


JWST lifetime: Requirement: 5 yrs; Goal: 10 yrs; Propellant: 20^{+} yrs!

NASA team-work to take JWST mirror covers off!

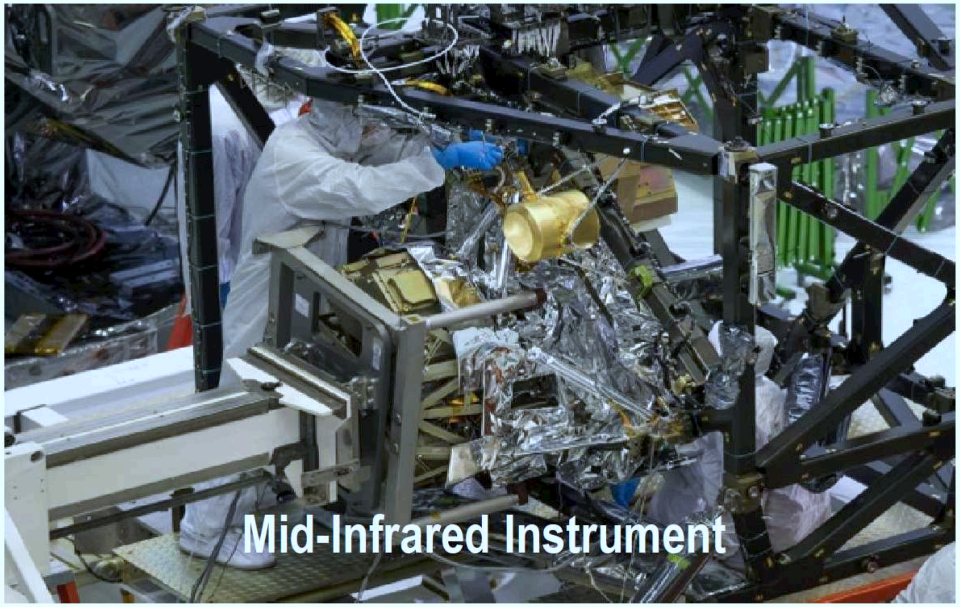
JWST being tilted into the right position

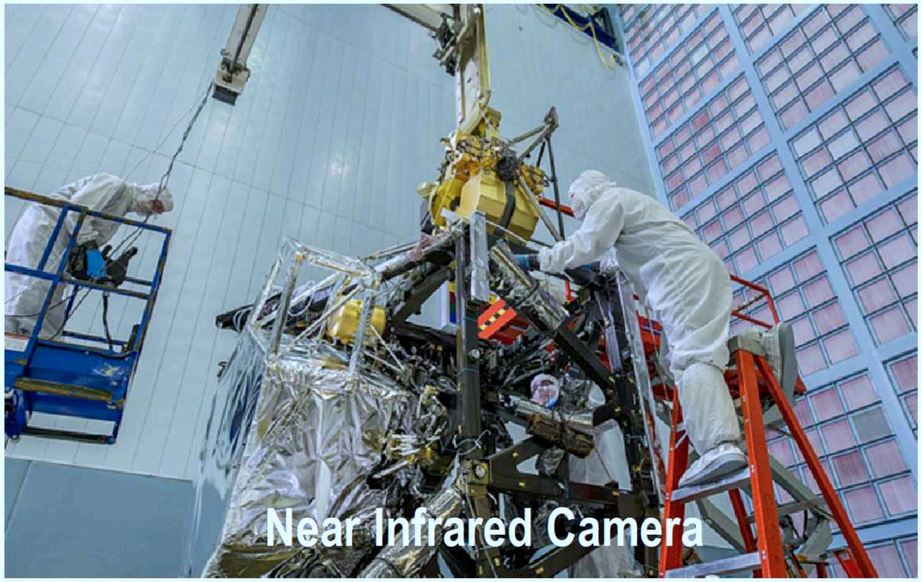
Webb mirrors finally mounted and ready!

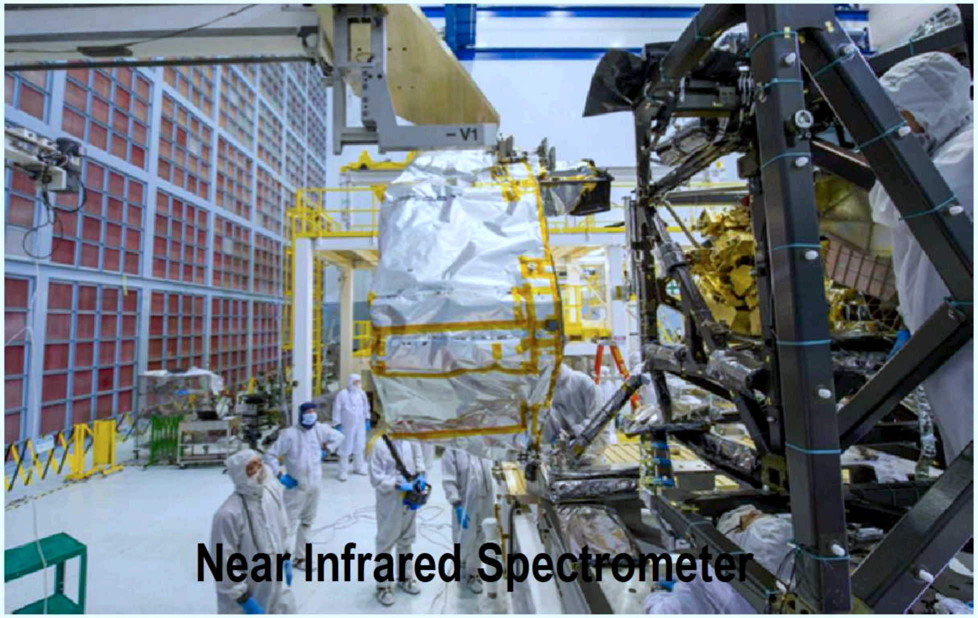


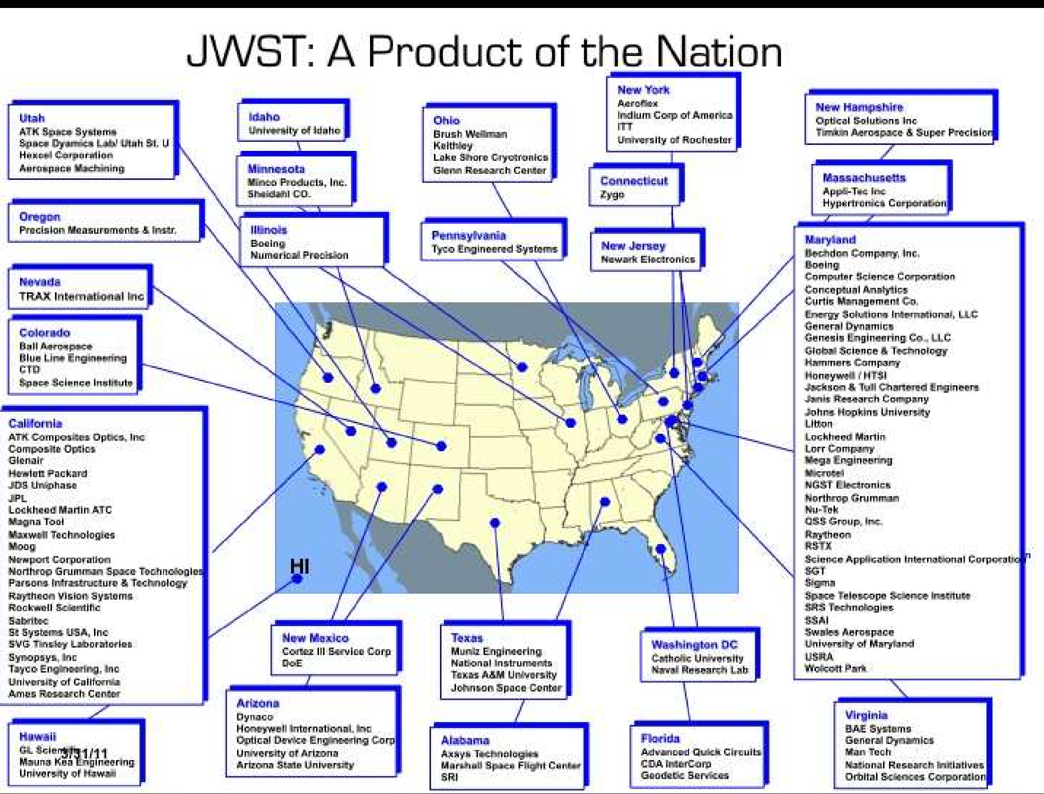
JWST stowed for further instrument mounting

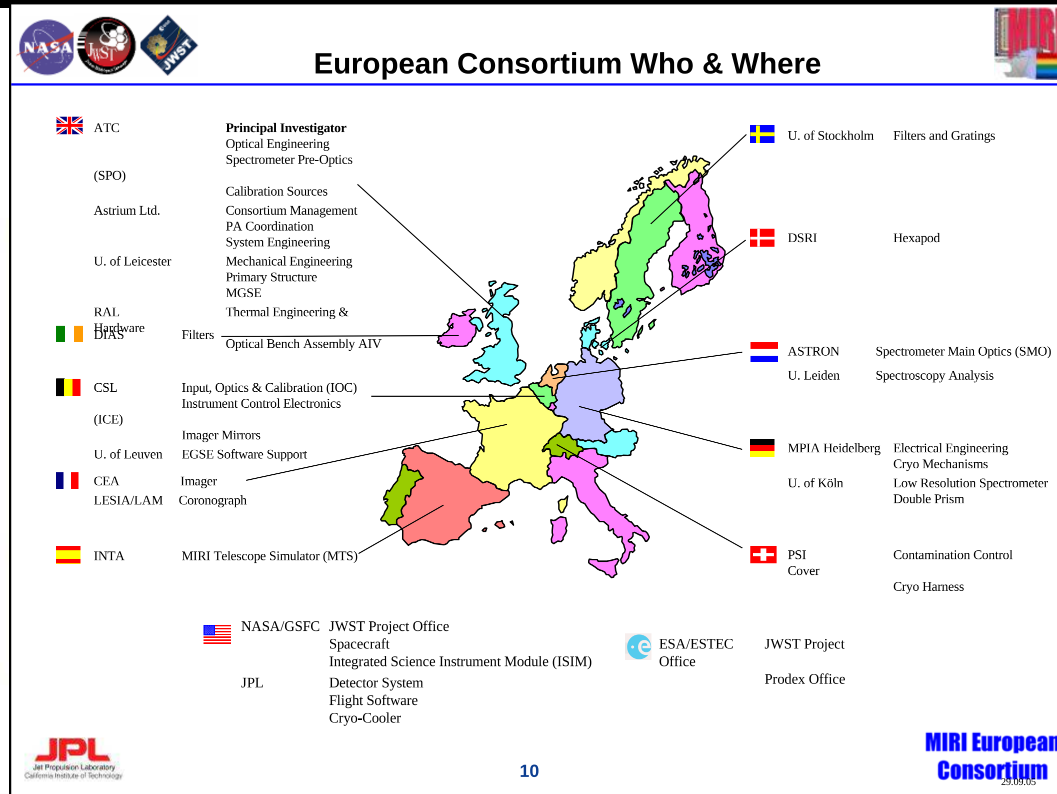
All Instruments Integrated





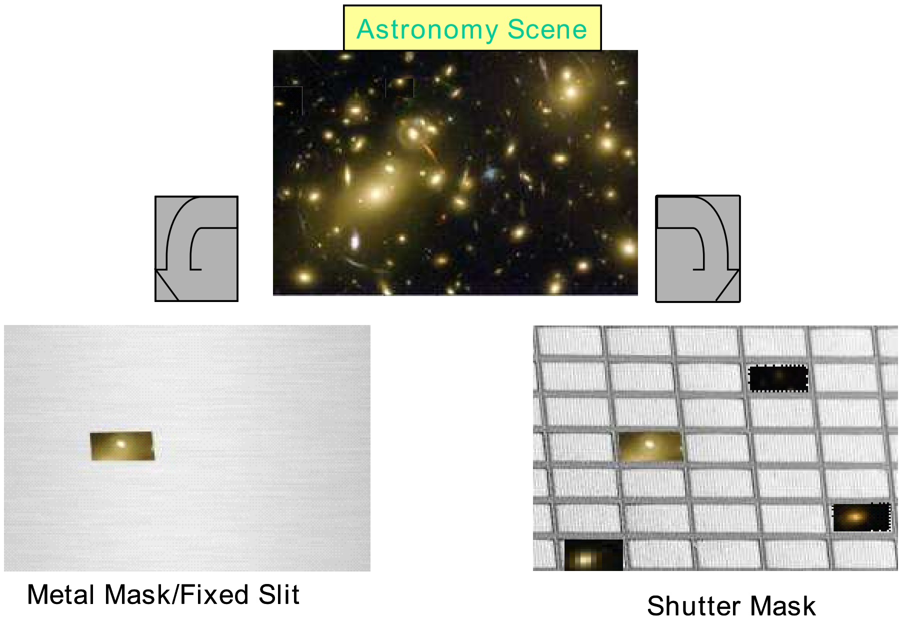


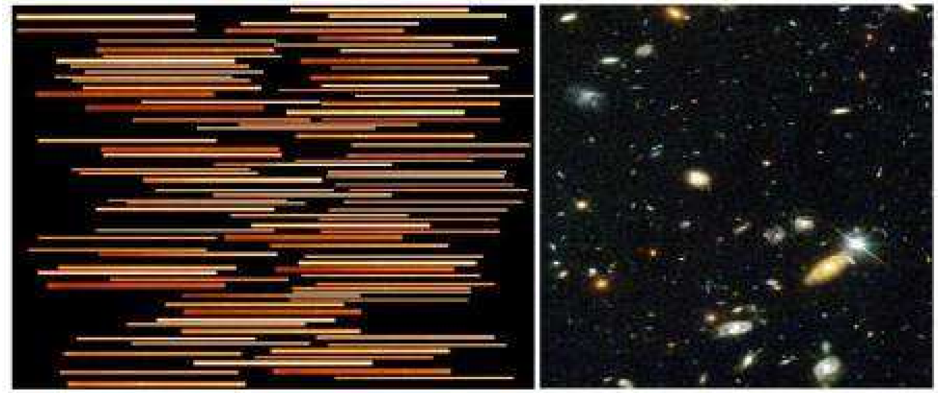


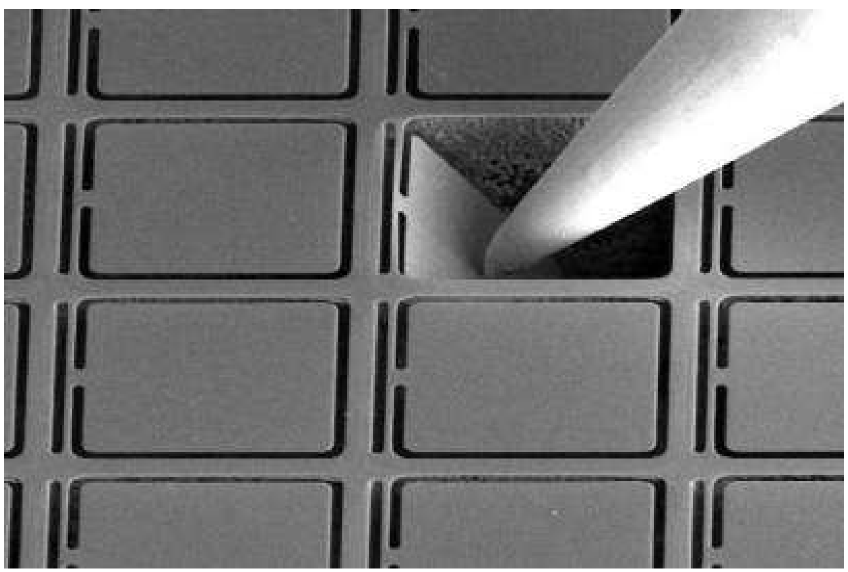


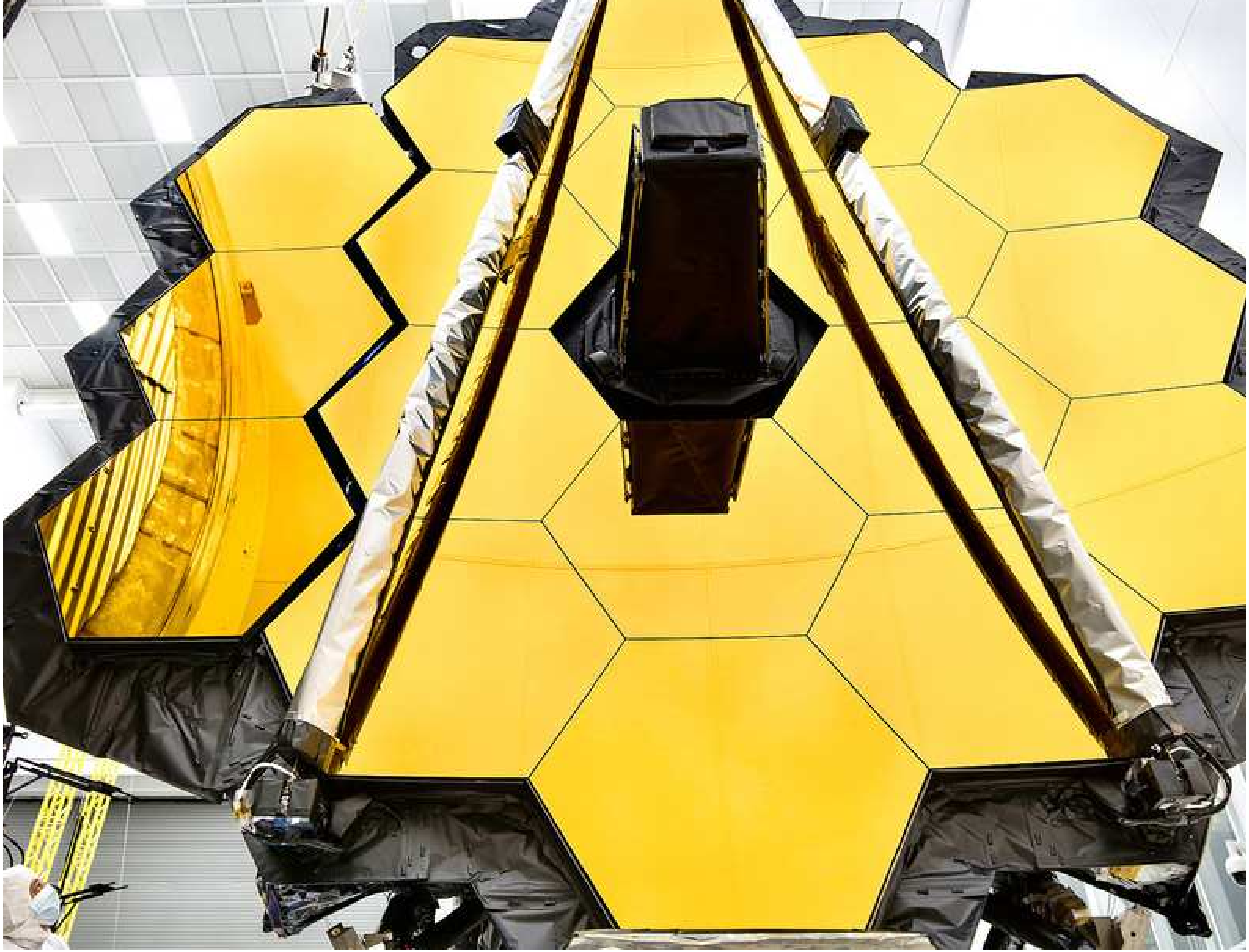
- JWST hardware made in 27 US States: 100% of launch-mass finished.
- Ariane V Launch & NIRSpec provided by ESA; & MIRI by ESA & JPL.
- JWST Fine Guider Sensor + NIRISS provided by Canadian Space Agency.
- JWST NIRCam made by UofA and Lockheed.

Micro Shutters



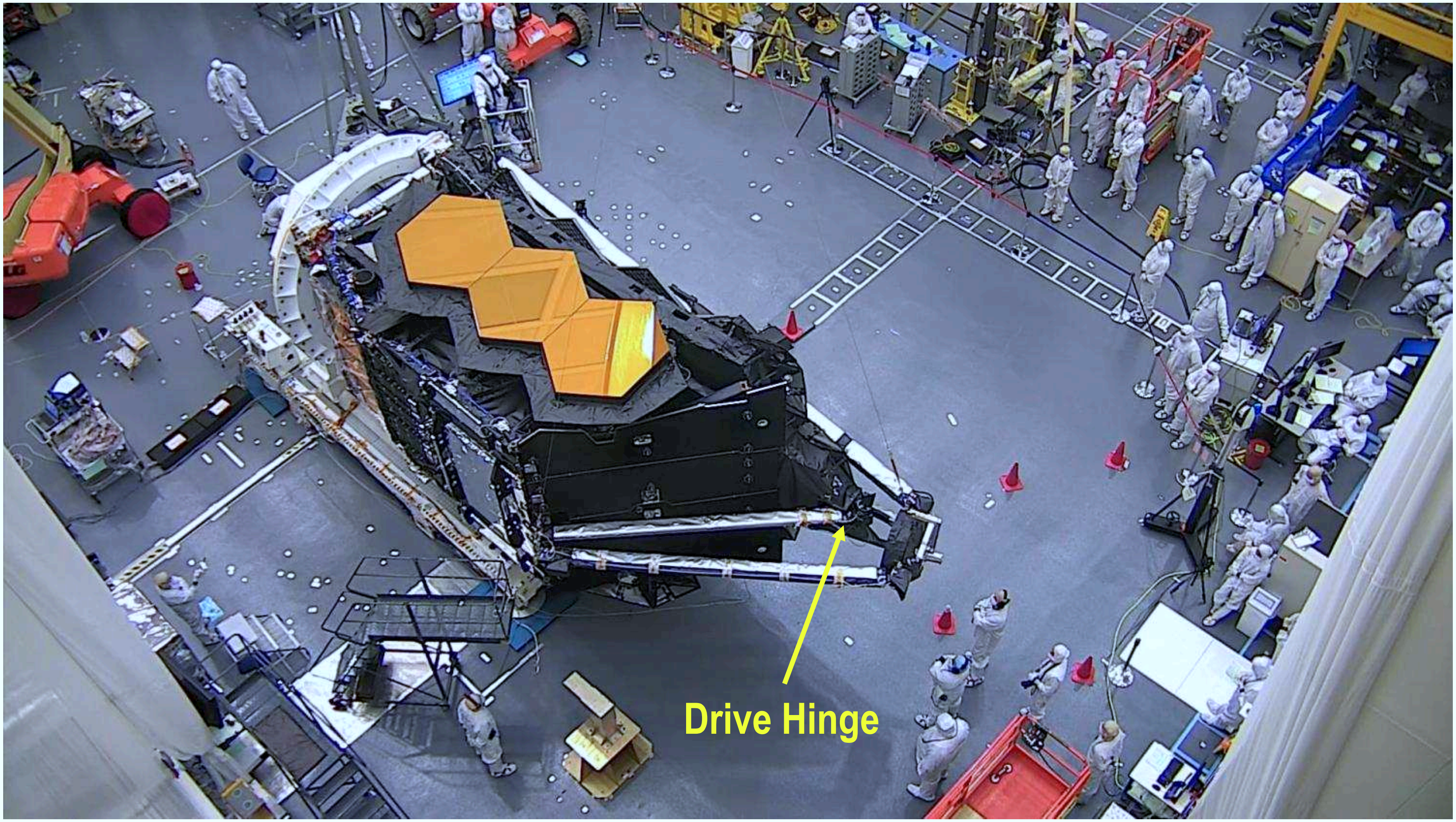






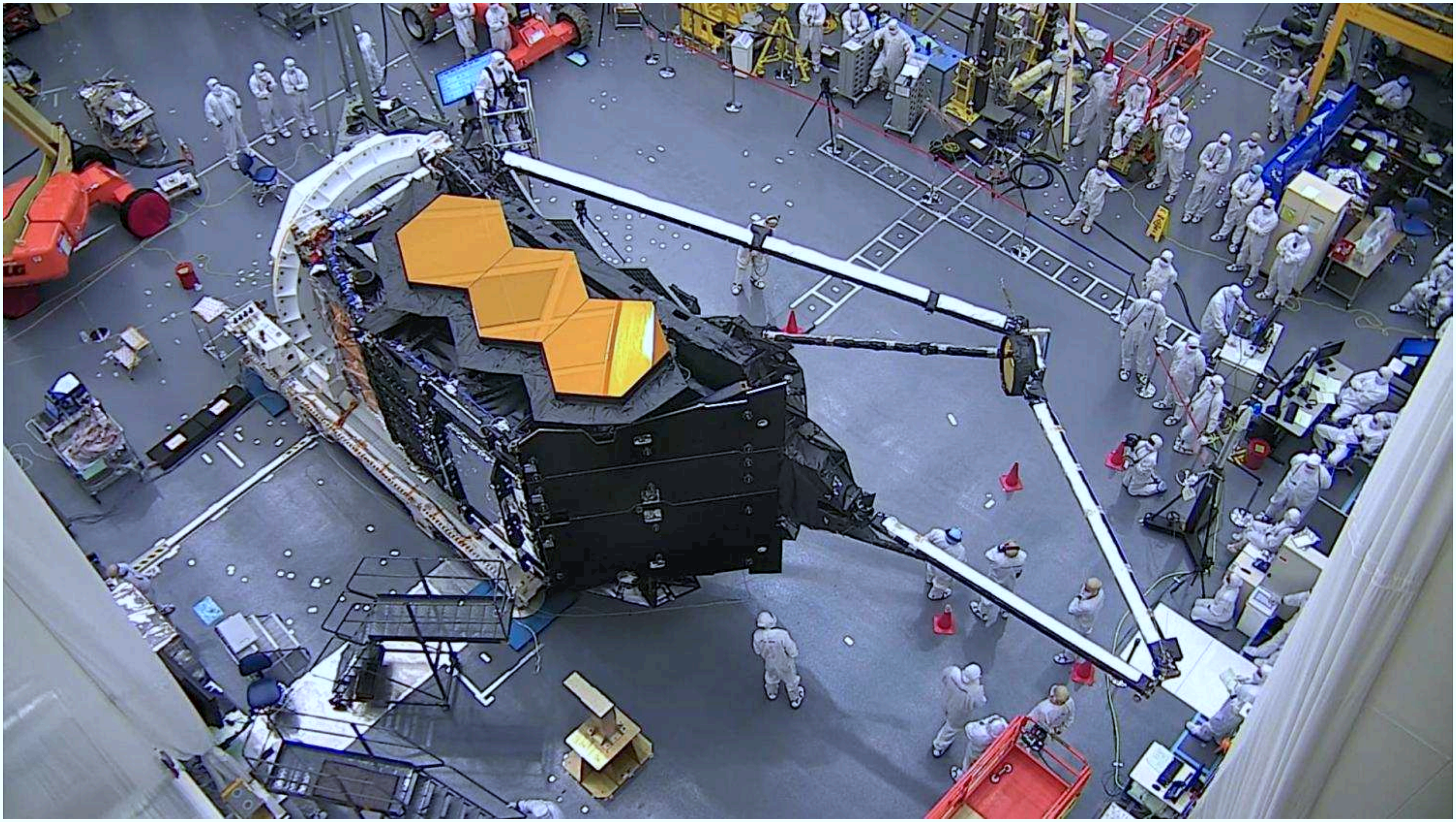
April 2017: Last portrait of JWST at Goddard Space Flight Center (MD).

SMSS Deployment Sequence (1)



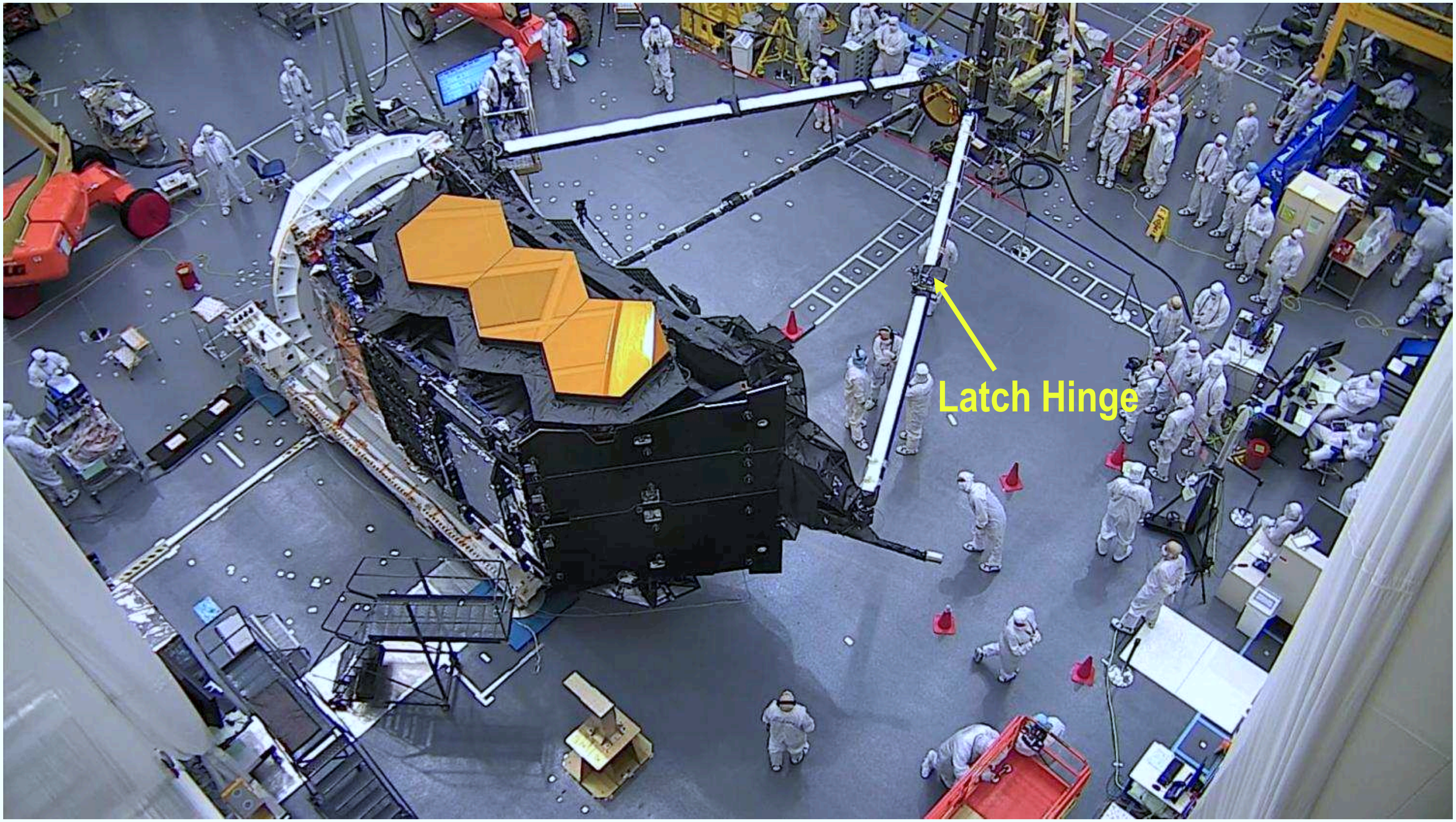
July 2019: Full 1-G deployment of JWST secondary mirror (SM) .

SMSS Deployment Sequence (2)



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

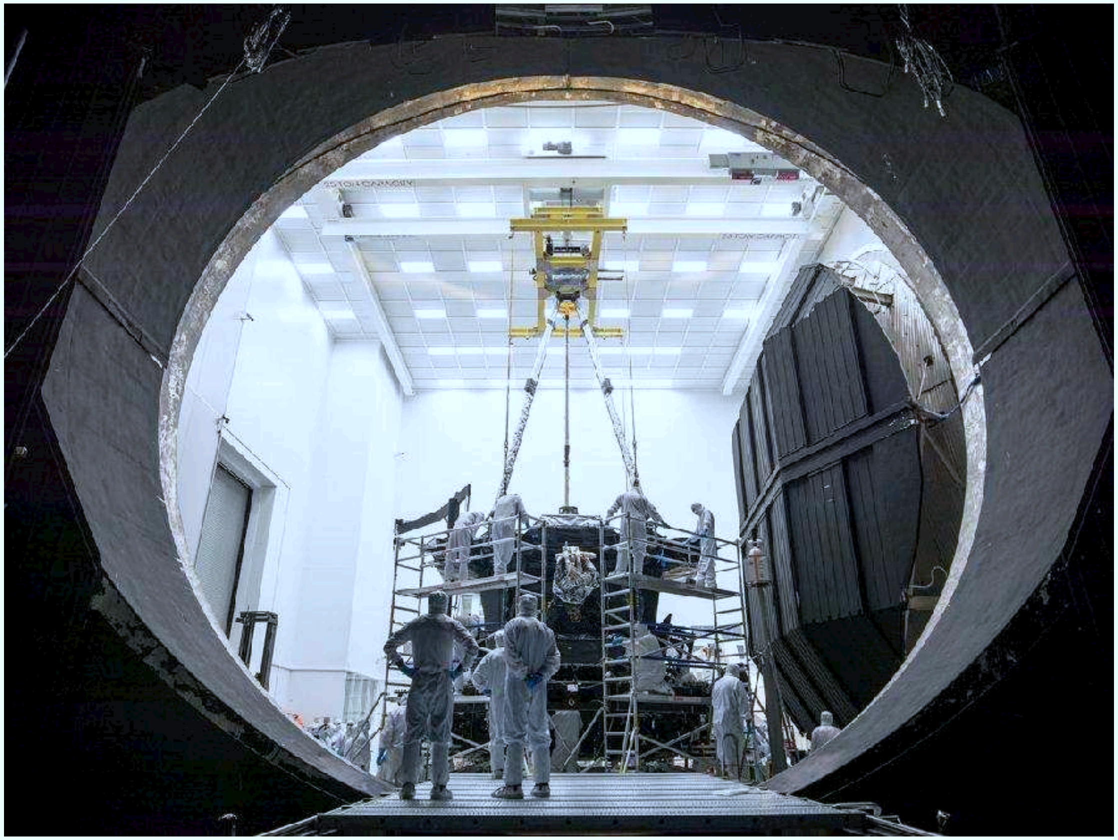
SMSS Deployment Sequence (3)

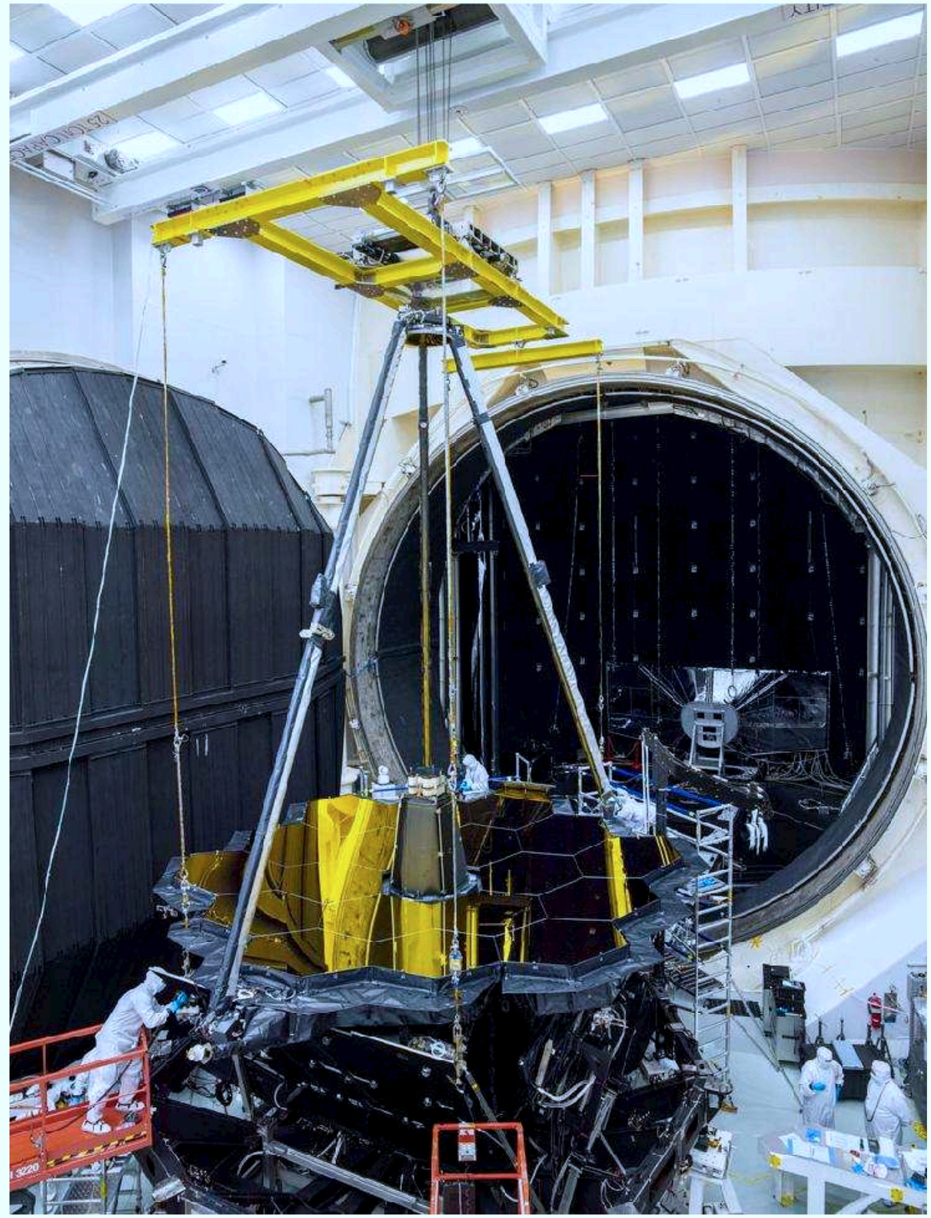


July 2019: Full 1-G deployment of JWST secondary mirror (SM) ...

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

Program Update: OTIS

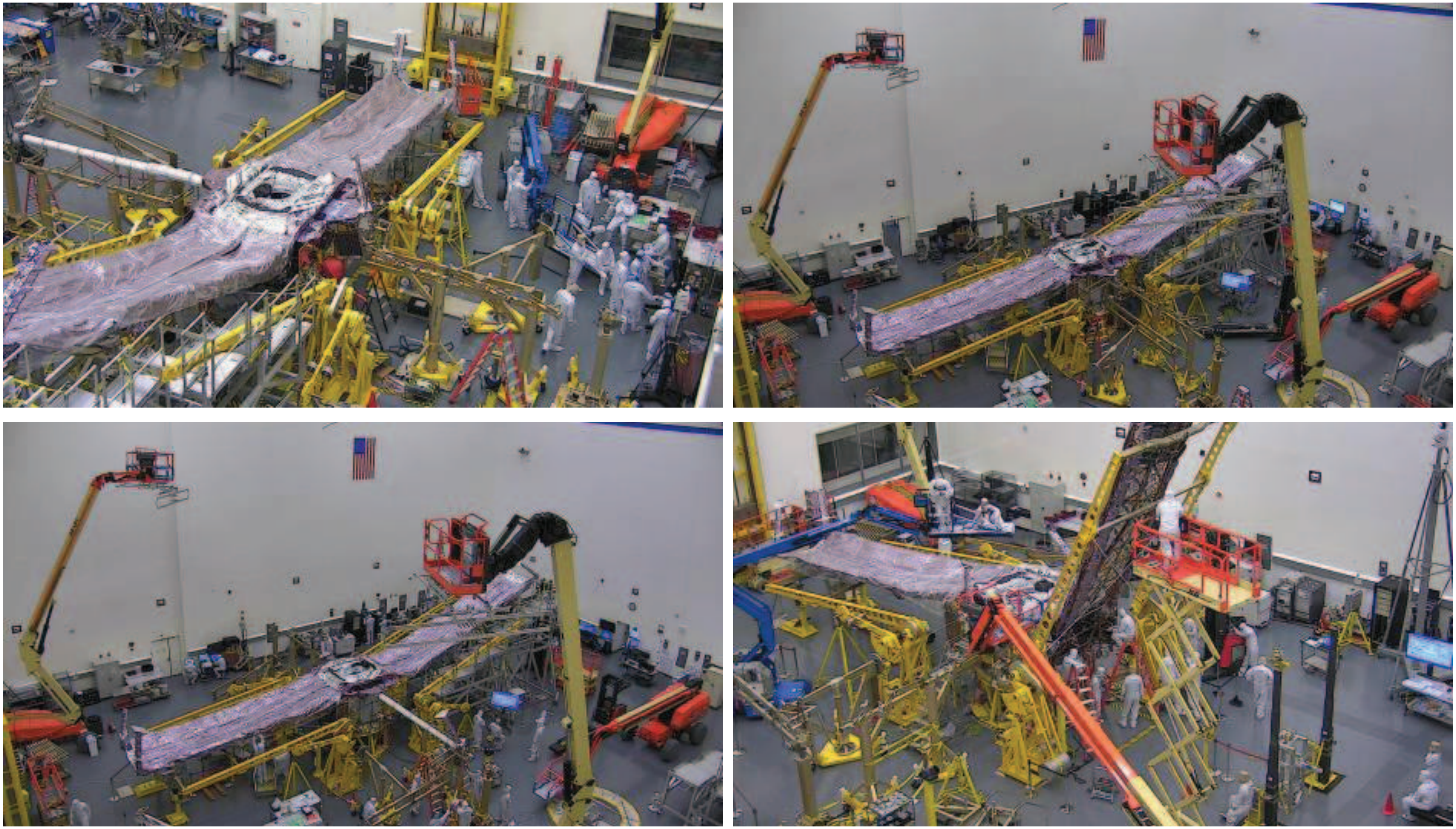




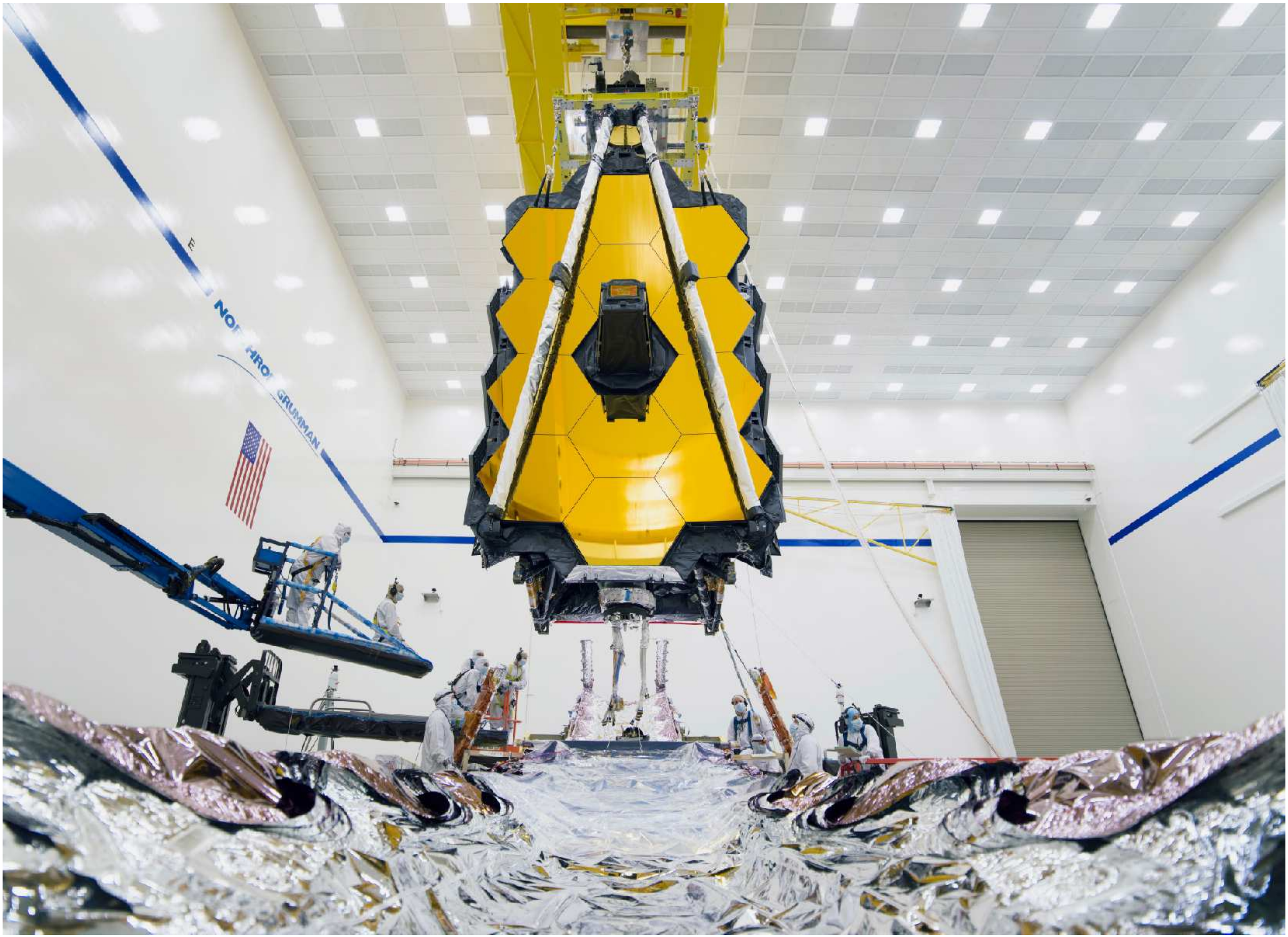
June 2017: JWST going into Chamber A at Johnson Space Center in Houston.

Program Updates: Spacecraft and Sunshield

NORTHROP GRUMMAN

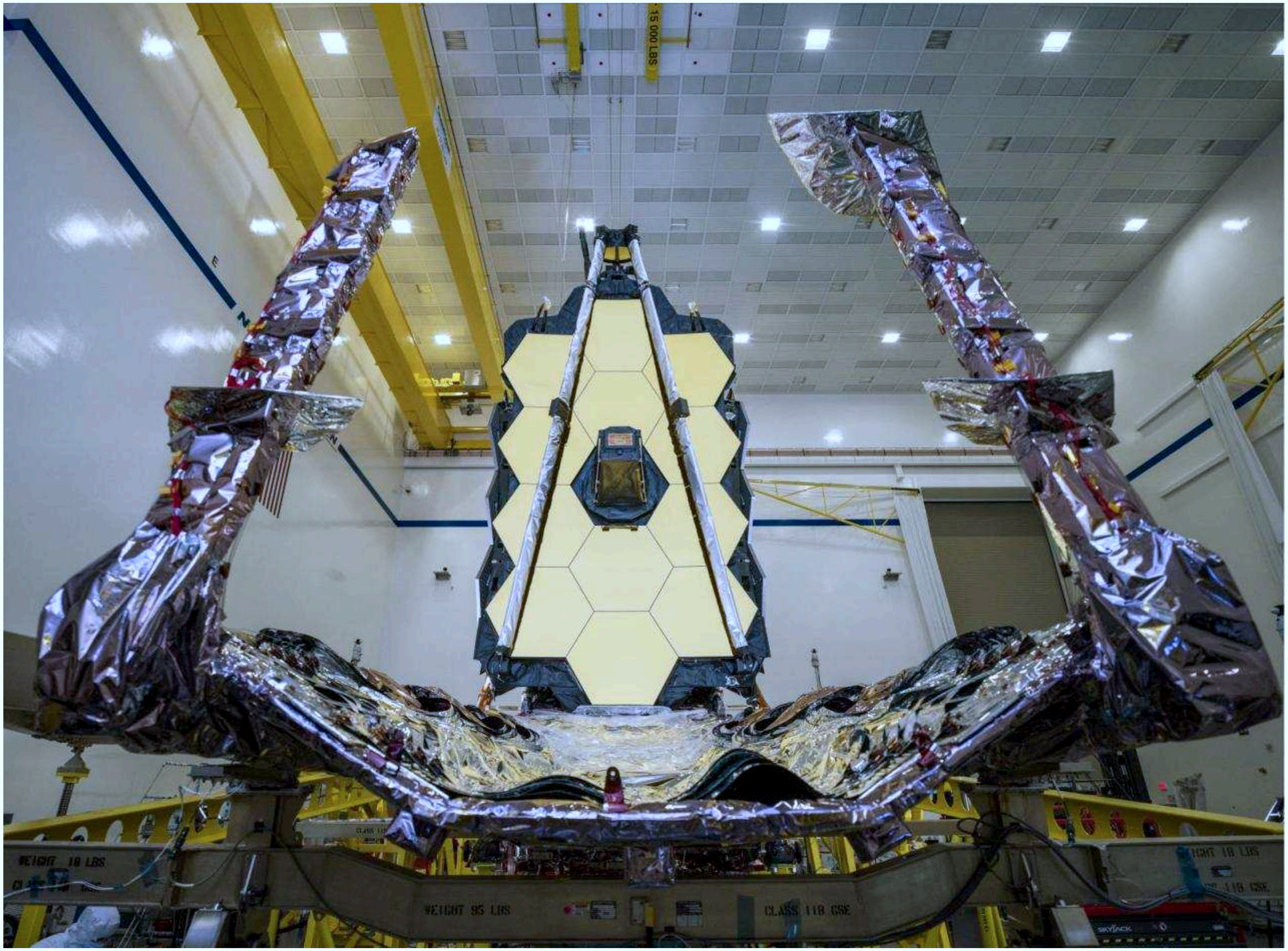


2017–2018: JWST Flight Sunshield assembled and tested at Northrop.



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

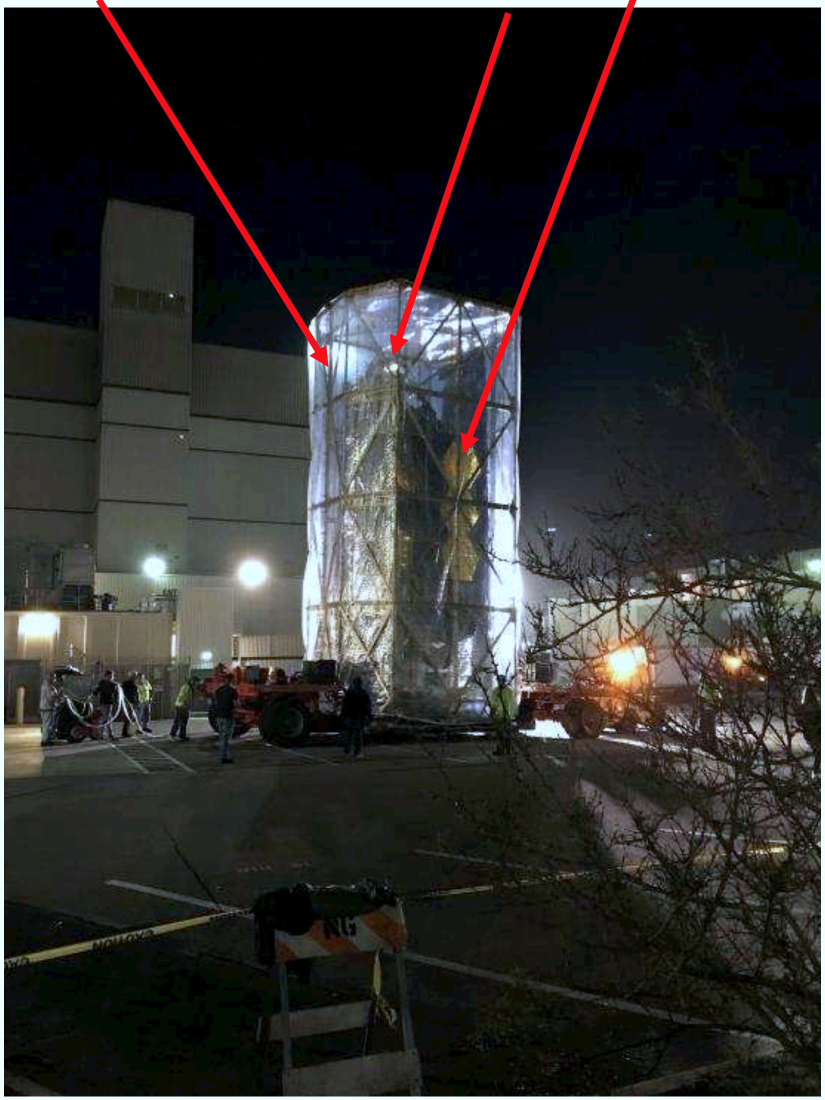
Meet the JWST Observatory 1



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!

Transport to the Large Acoustic Test Facility



En route through the Space Park, Credit: NGSS

Arriving at the LATF Airlock, Credit: NGSS

Aug 2020: Transport of JWST into Northrop acoustic chamber

(beautiful)
The ^ James Webb Space Telescope

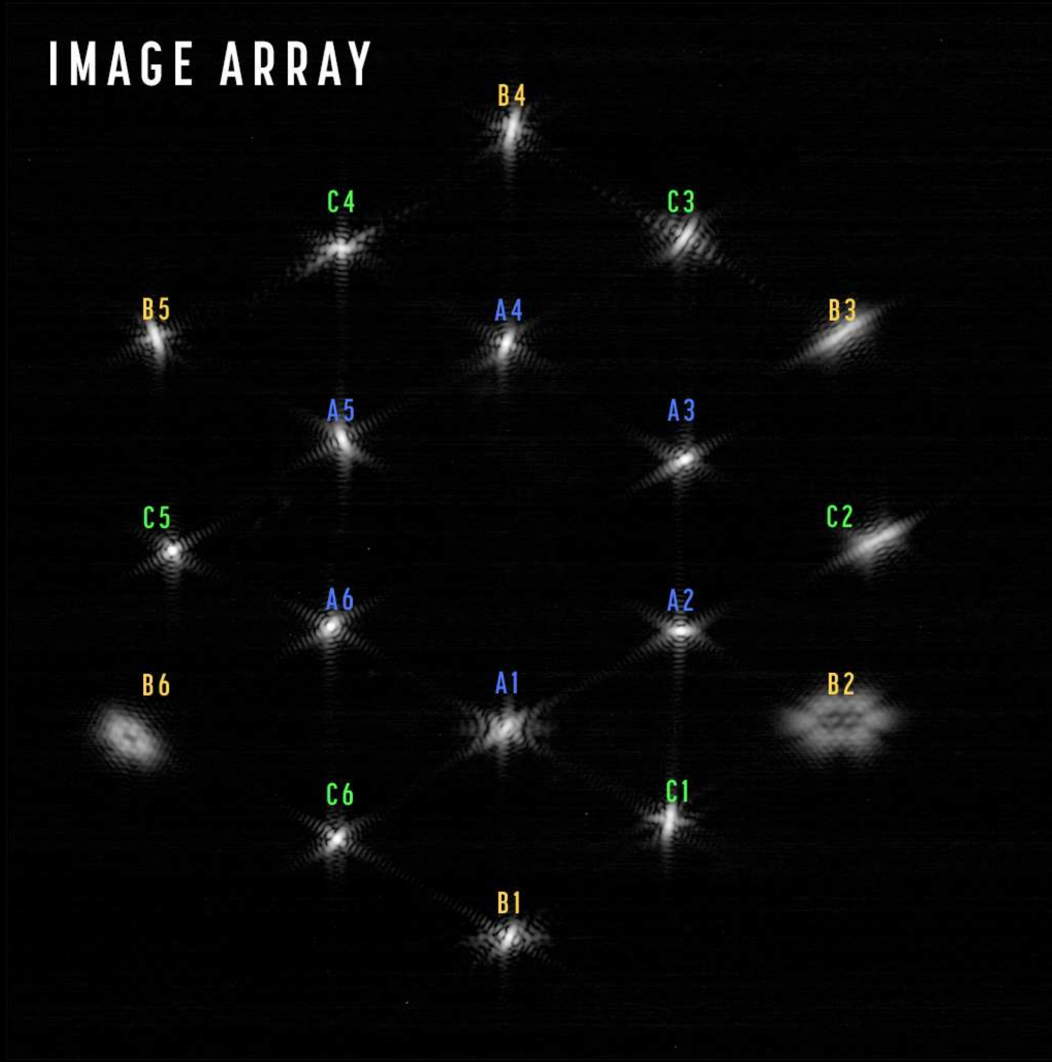
Stowed for Launch

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

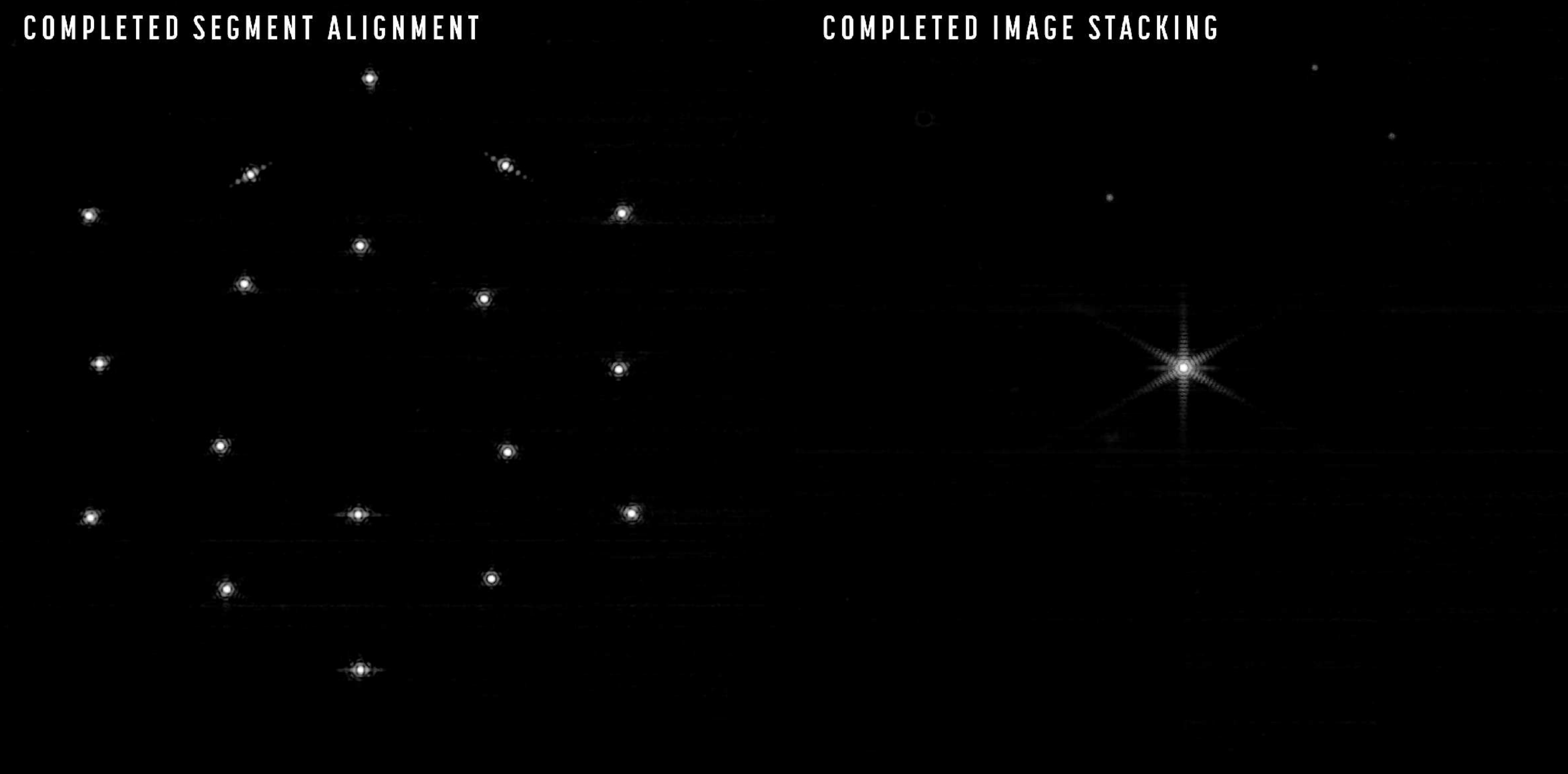
Dec. 9, 2021: JWST transport in Kourou to Ariane Rocket Assembly Building

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

Dec. 25, 2021: Webb seen shortly after launch over Africa using the Ariane V on-board camera.



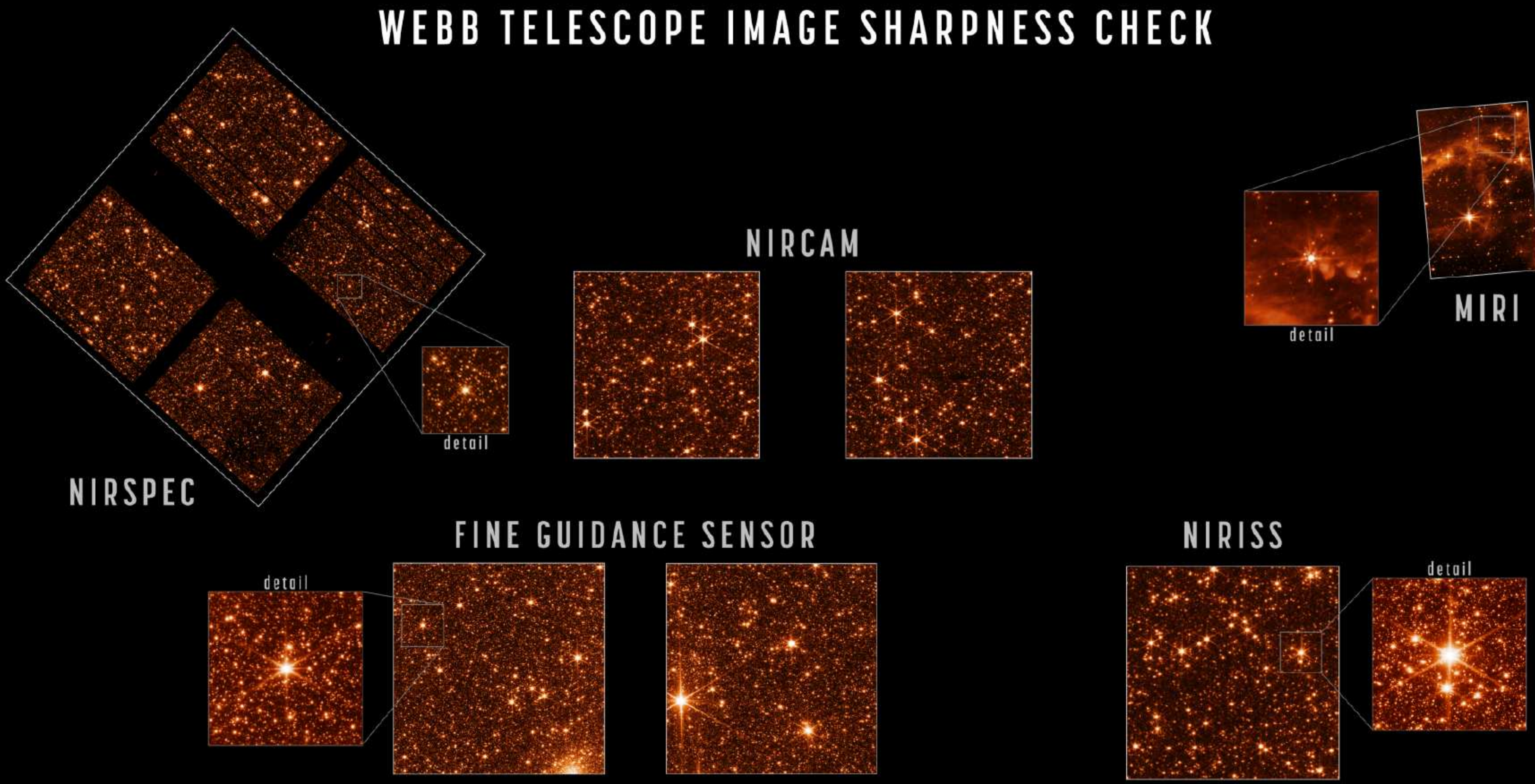
Feb. 2022: Webb's first selfie (left) and First Light raw image (right).



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

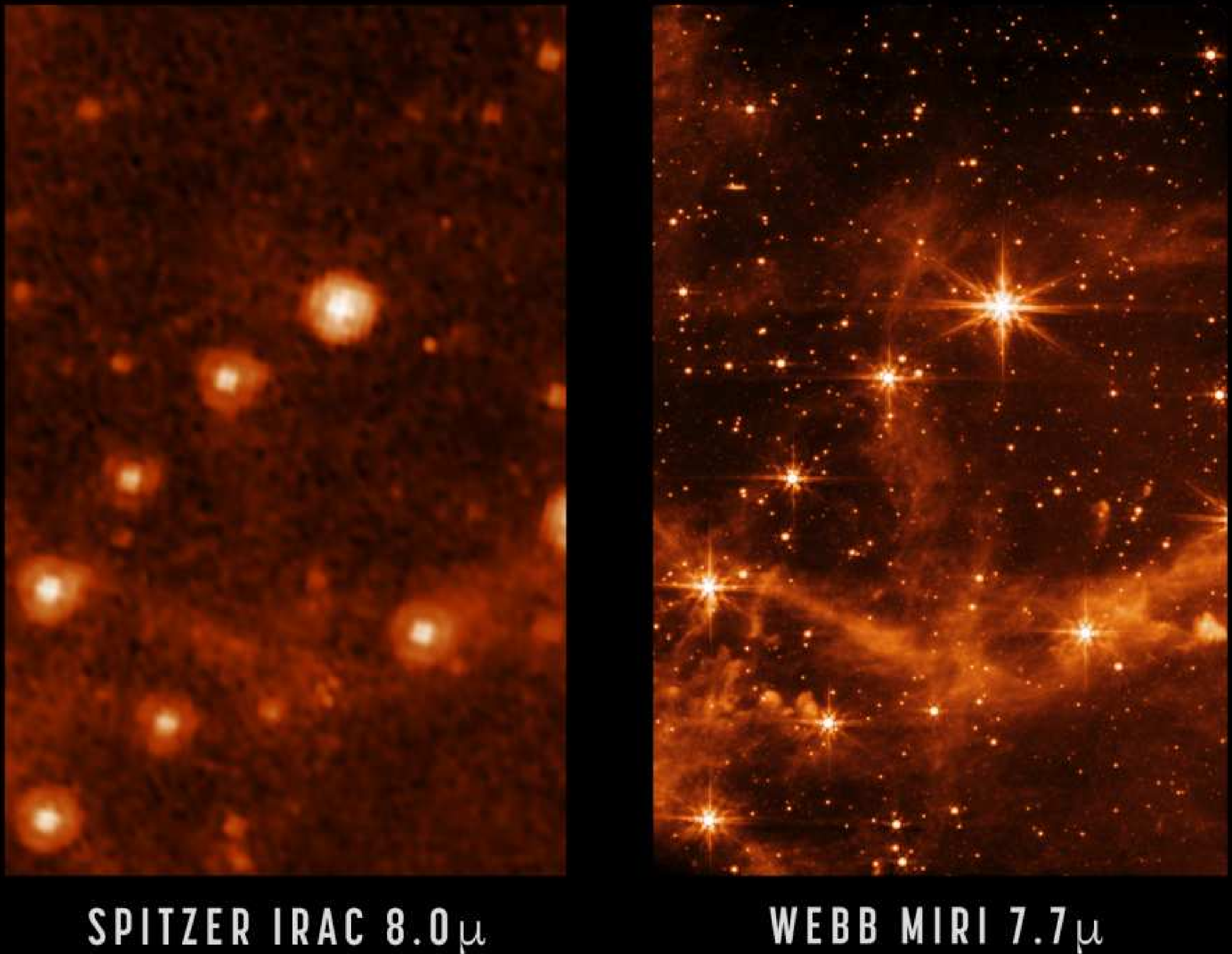
March 16, 2022: Webb's first fully focused image publicly released !!
Note the plethora of faint galaxies — Webb's looking back in time!

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



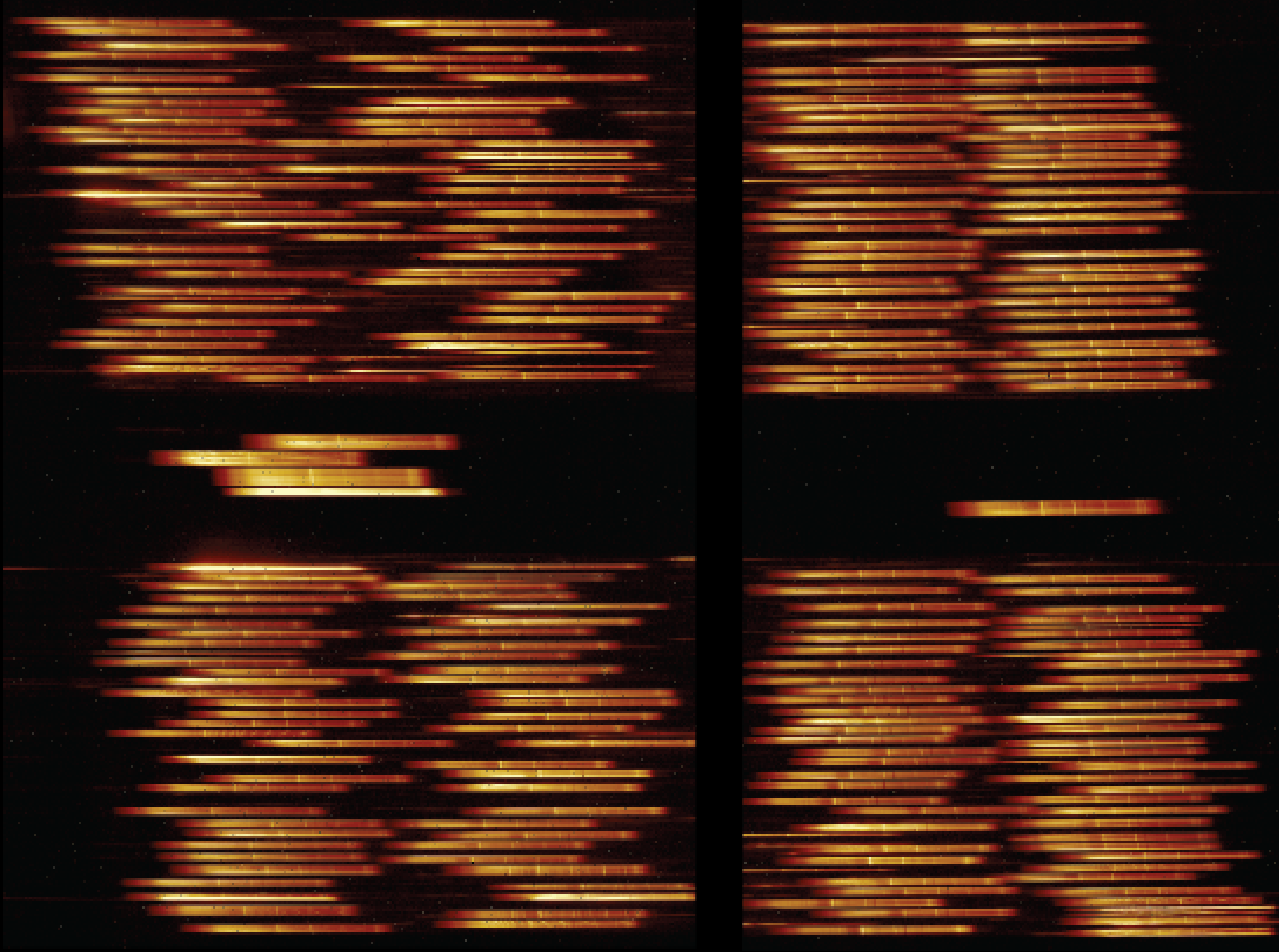
April 28, 2022: Webb's first fully focused images in all four instruments: a dense star field in the Large Magellanic Cloud in the South Ecliptic Pole! (NIRSpec: 1.1 μm; NIRISS: 1.5 μm; NIRCam: 2.0 μm; MIRI 7.7 μm).

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/

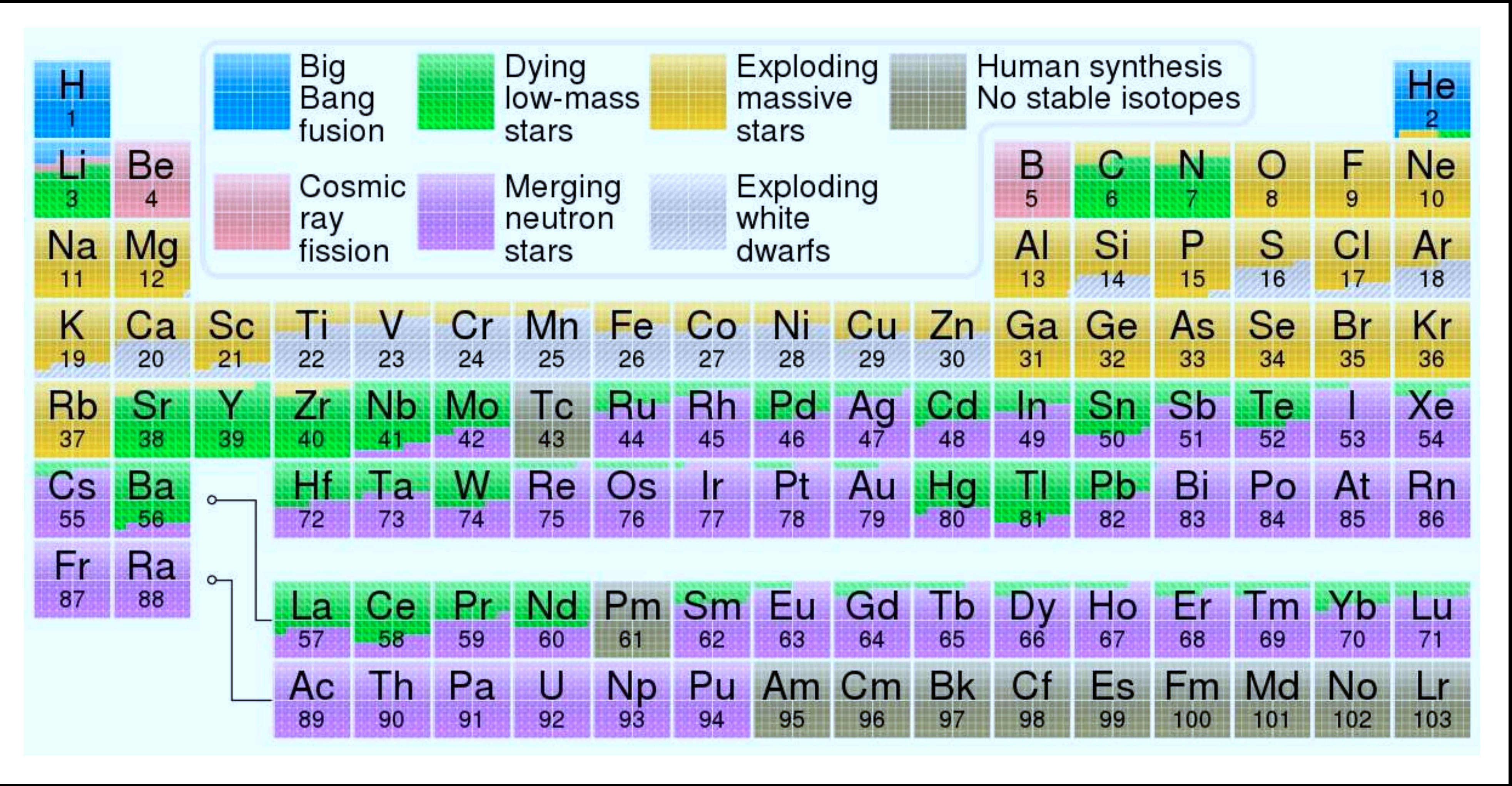


Webb first NIRSpec near-IR spectra of ∼100 faint stars near Galactic Center

Webb can take spectra of many 100's of faint galaxies revealing their distances and chemical composition.

Before getting to the cosmic circle of life, let's get this straight:

- This Periodic Table you learned in highschool is **NOT** the real one!:



(1) Hydrogen & Helium: the *only* chemical elements made in the Big Bang!

(2) All heavier elements made by (dying) stars: • Low mass stars ejecting their outer shells; • Supernova explosions; & • neutron star mergers.

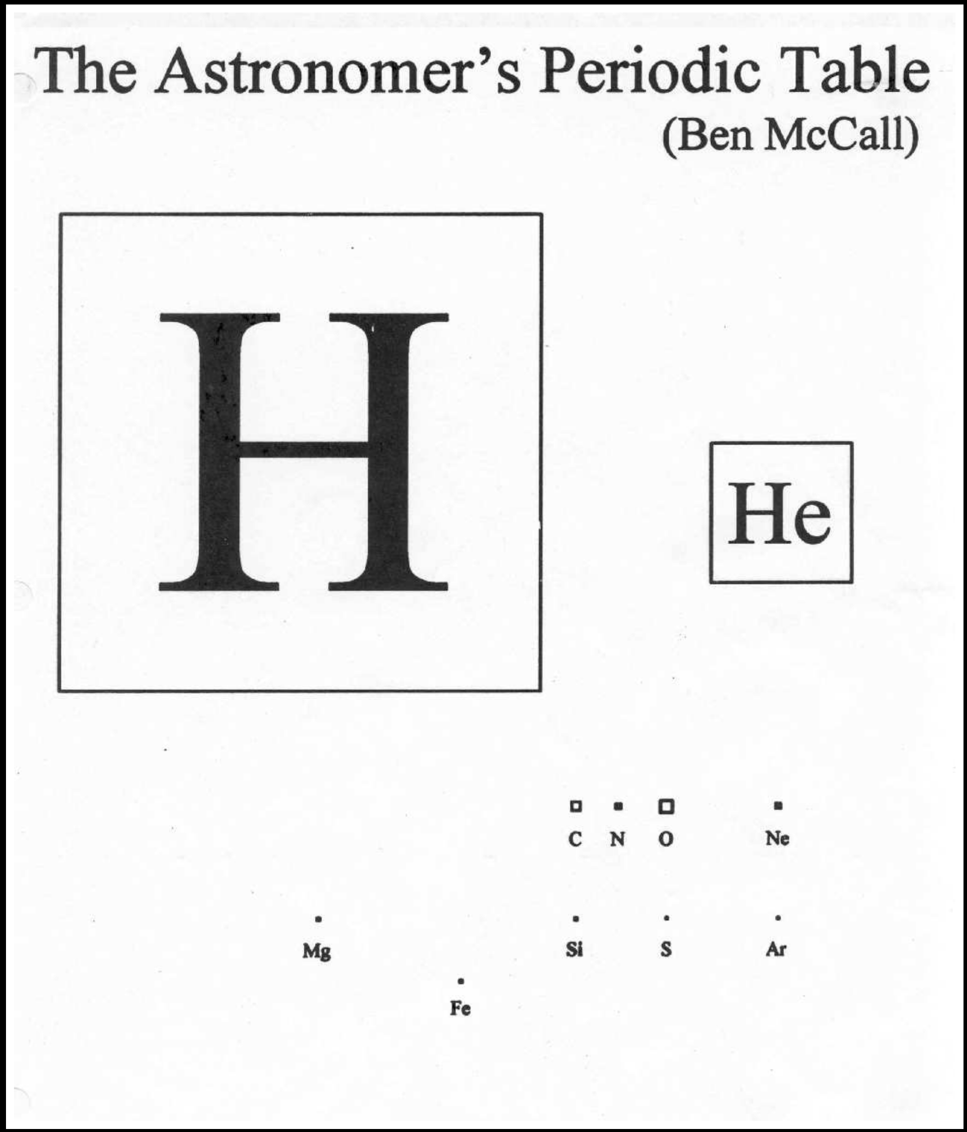
Here is the real Astronomical Periodic Table:

(1) Hydrogen (76%) & Helium (24%) are the only chemical elements made in the Big Bang.

(2) All heavier chemical elements ($\lesssim$1%) made by (dying) stars:

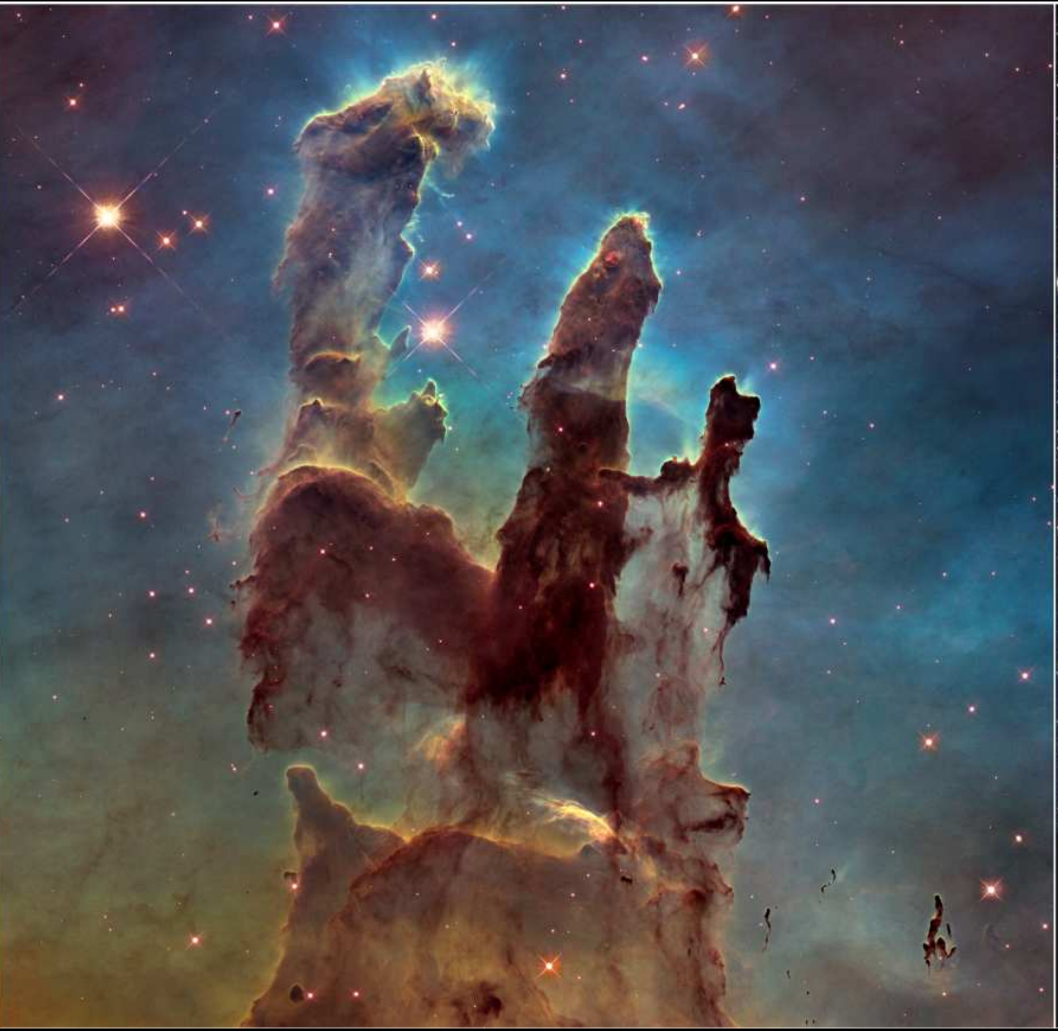
- Late stages of stellar evolution, Supernova explosions & white dwarfs, and neutron star mergers distribute these throughout the universe.

$\Longrightarrow$ Planets and people are literally made from stardust!



- This is the real Periodic Table with cosmic abundance included!

• (2) Webb's first images: the "Cosmic Circle of Life"

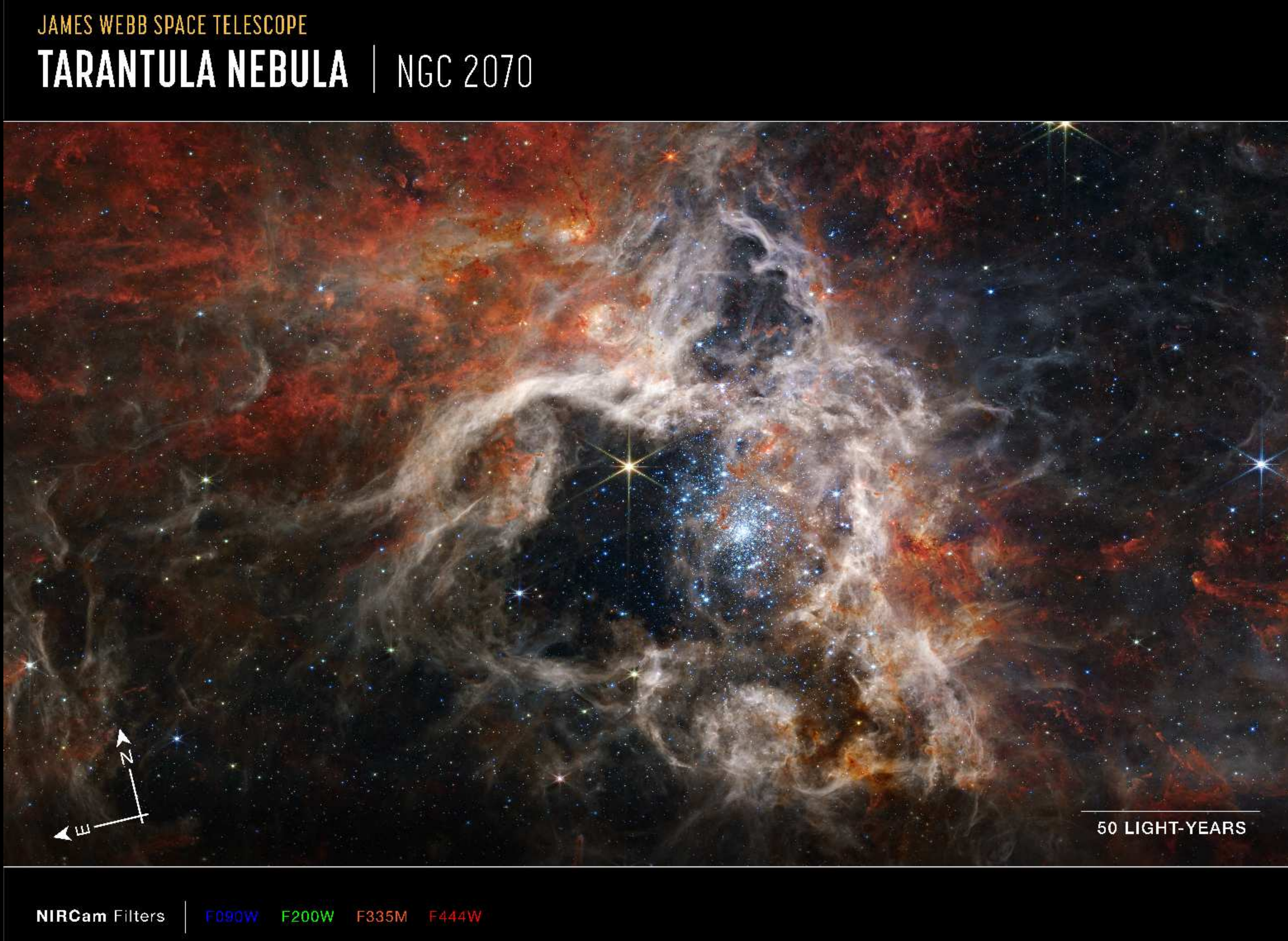


Hubble WFPC2 Eagle Nebula (1995) compared to JWST NIRCam (2022):

• 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

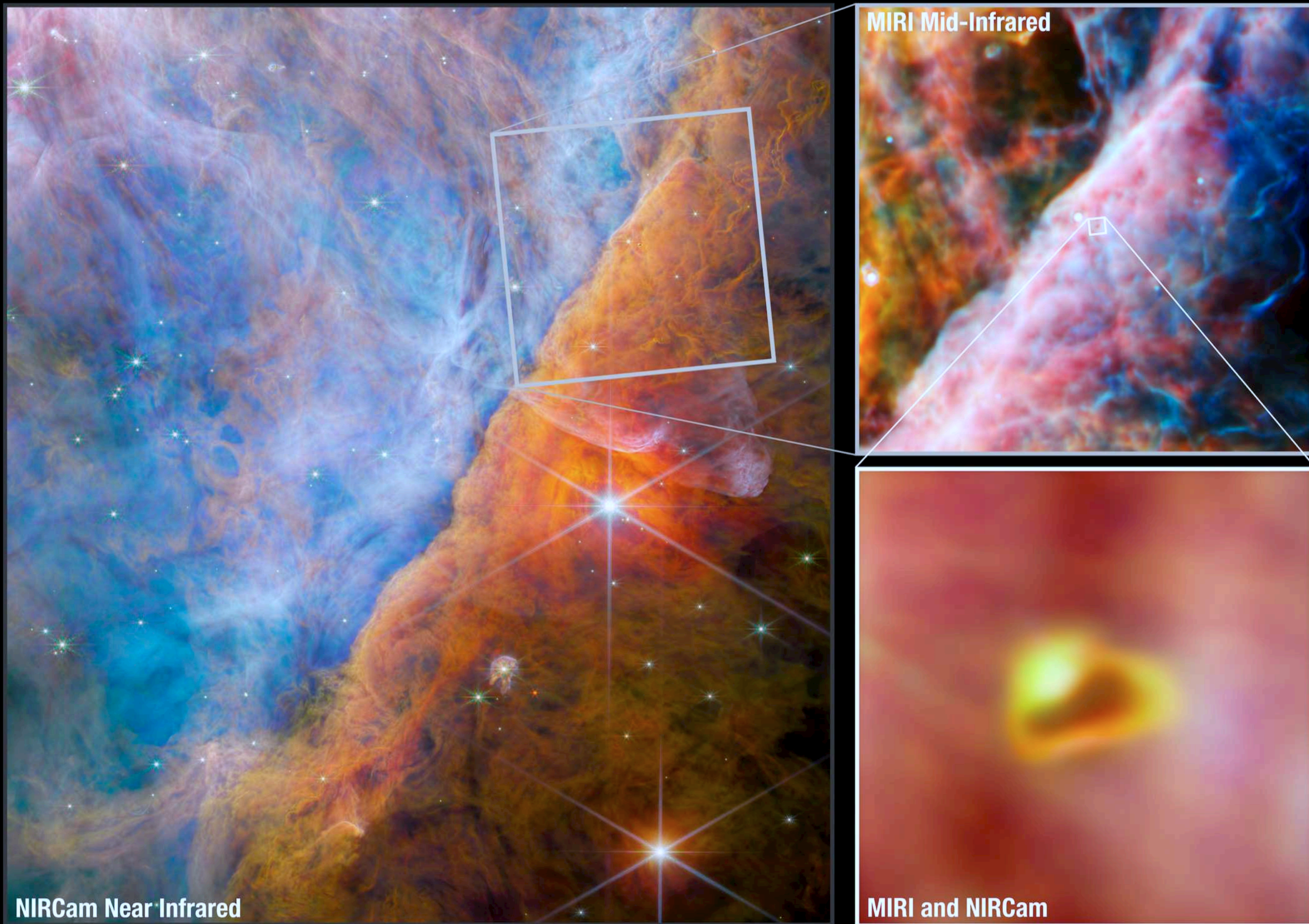
“Cosmic Cliffs” of star-formation in the Carina Nebula (NIR; 7600 light-years).

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

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.



JWST NIRCam+MIRI: Cosmic Cliff-like in Orion's Trapezium (1344 lyrs):

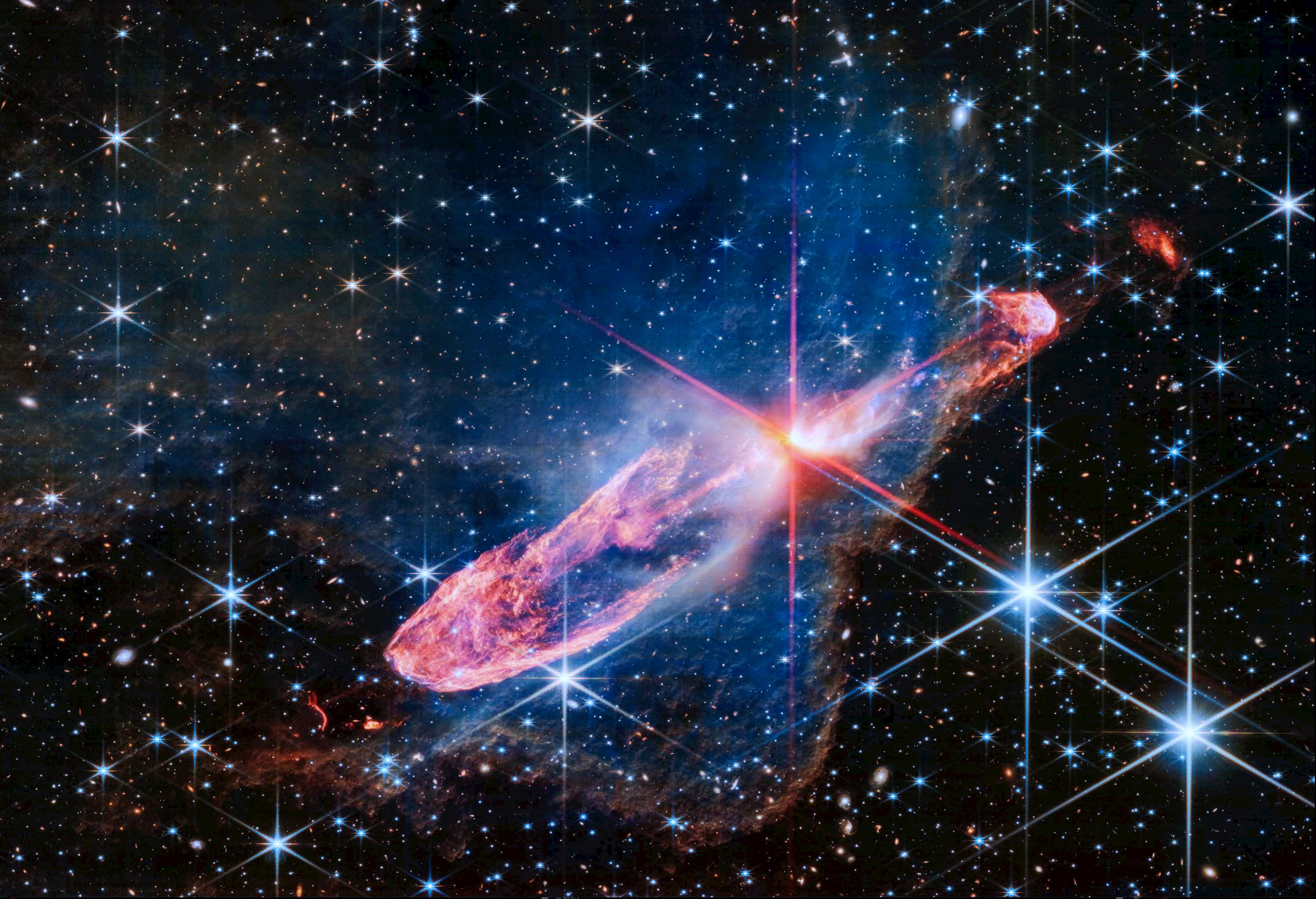
- New stars are forming containing the carbon chain "Methyl Cation"

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

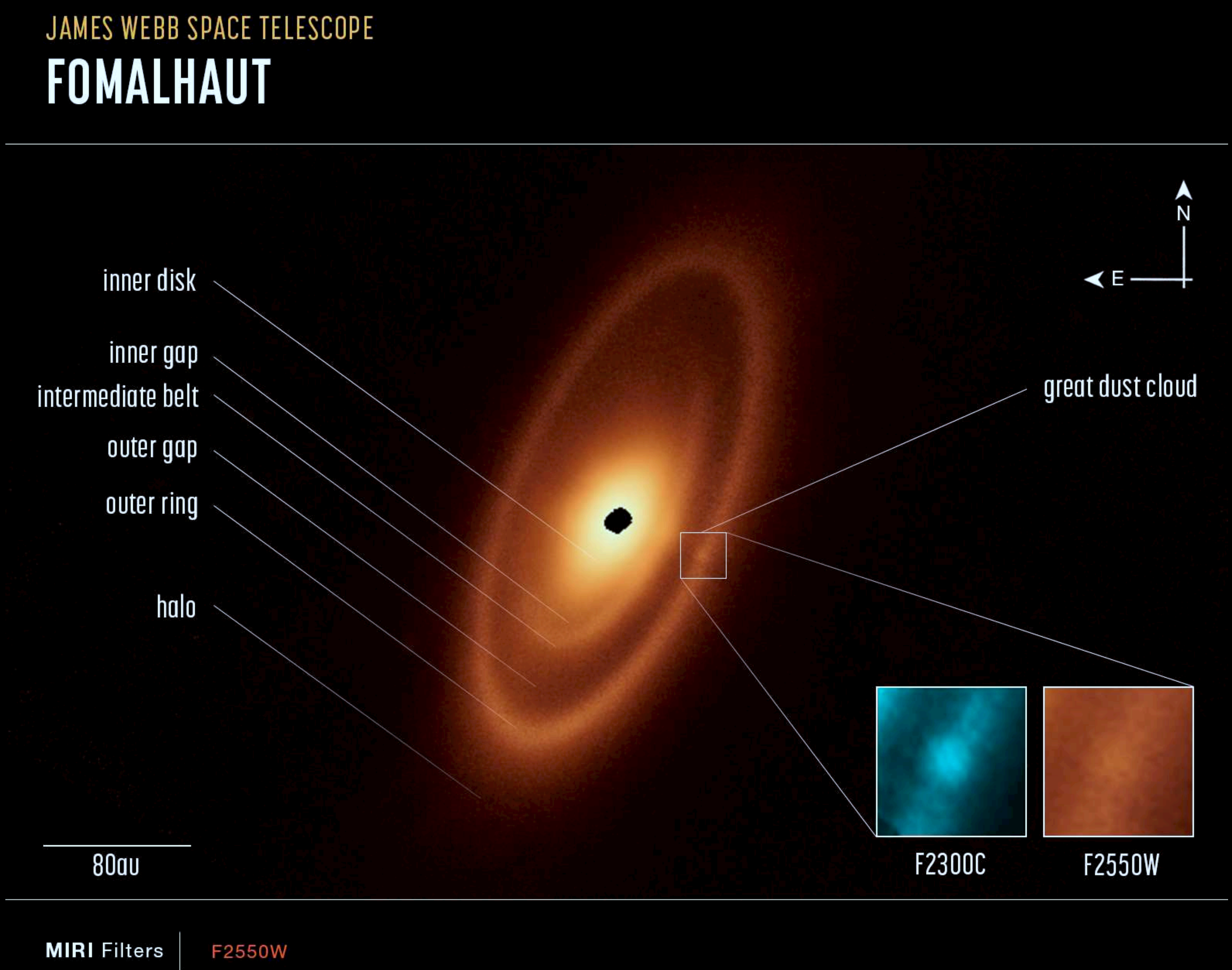
- A forming protostar with ∼30% of Sun's mass only 100,000 year old!
- The protostar has surrounding accreting gas, and a circumstellar disk.
- Eventually, L1527 will start shining as a star, and have its own planets.

NIRCam+MIRI: ρ Ophiuchi dark cloud (closest stellar nursery at 456 lyrs):

- Cradle of star-formation contains Polycyclic Aromatic Hydrocarbons!

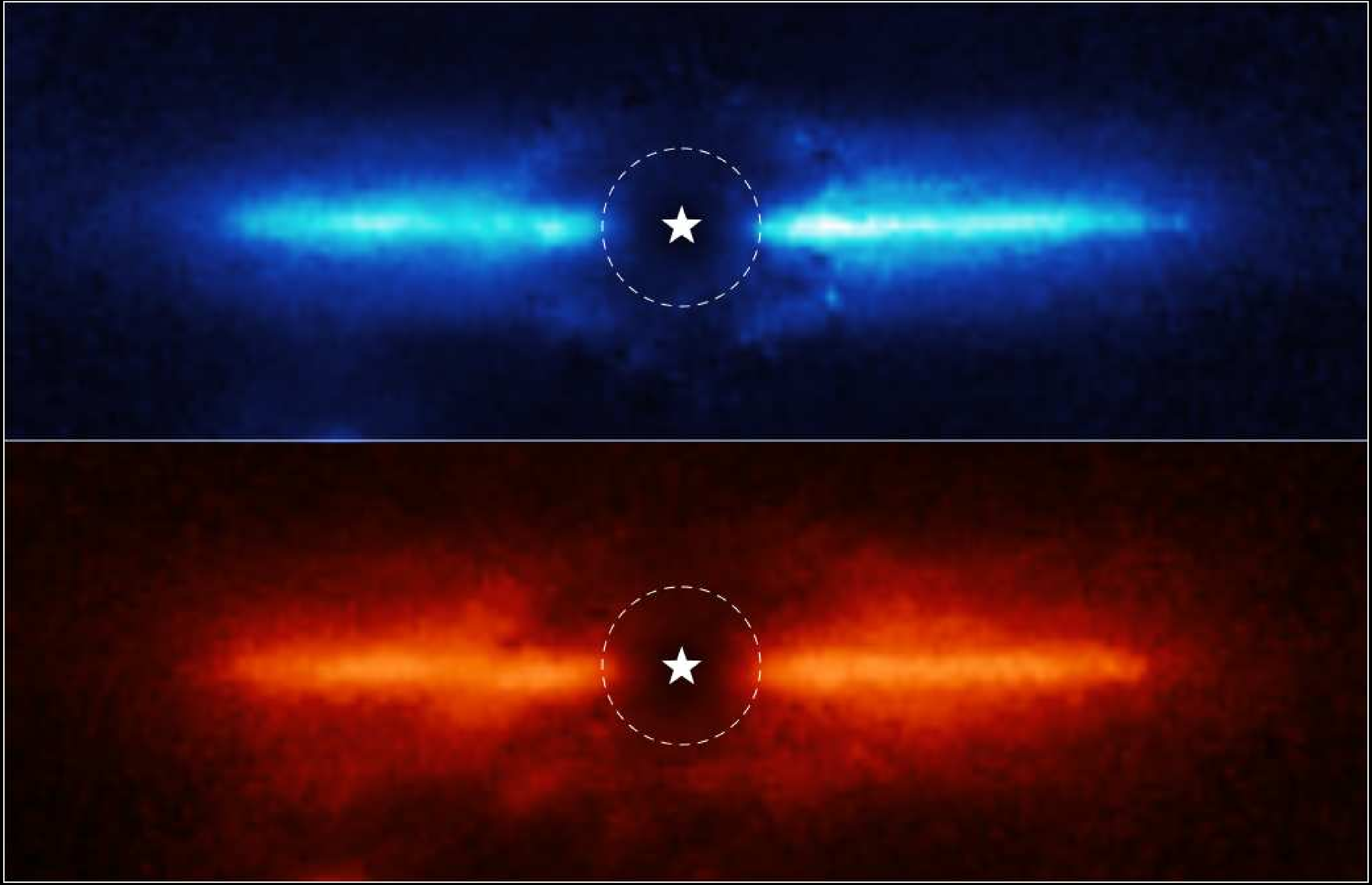


Newly forming stars Herbig-Haro 46/47 with jet-expelled material (1470 lyrs):
Formation of Sun-like stars is messy: inflow and outflow of gas & dust!



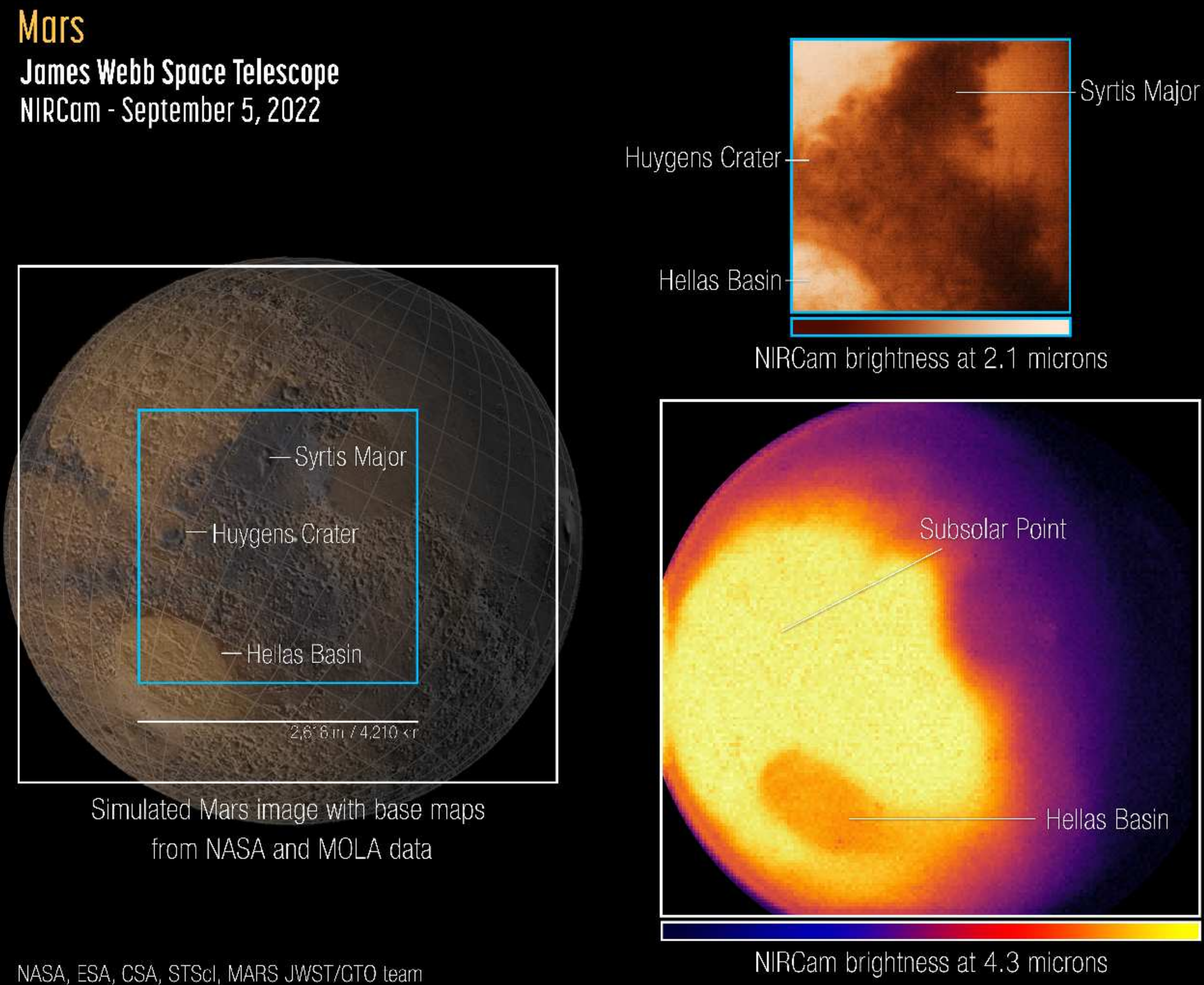
JWST MIRI Coronagraph: Debris disk around nearby star Fomalhaut:

- This is how the giant planets and terrestrial planets formed around our Sun

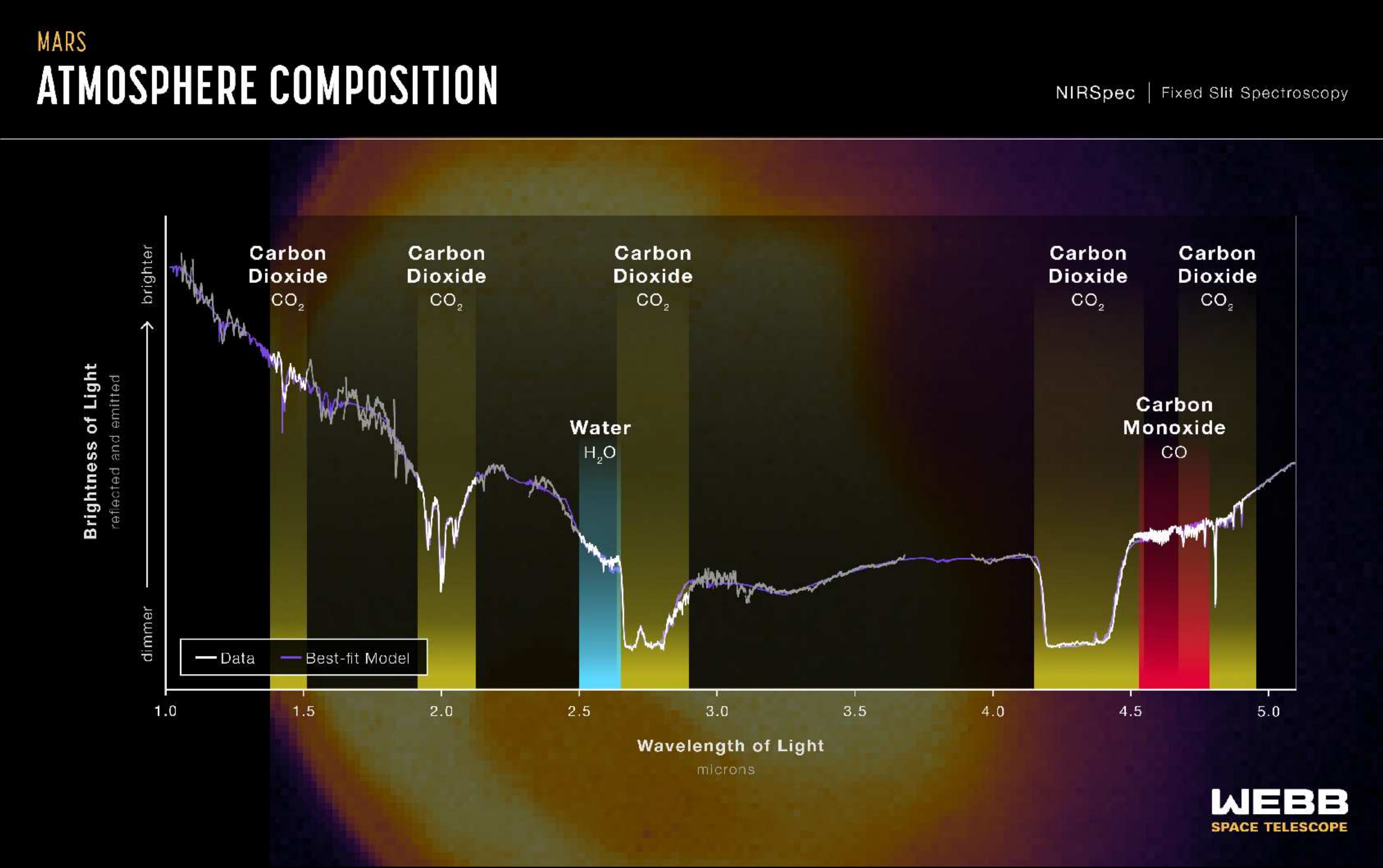


Dusty debris disk around red dwarf star AU Mic at 32 light-years:

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



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

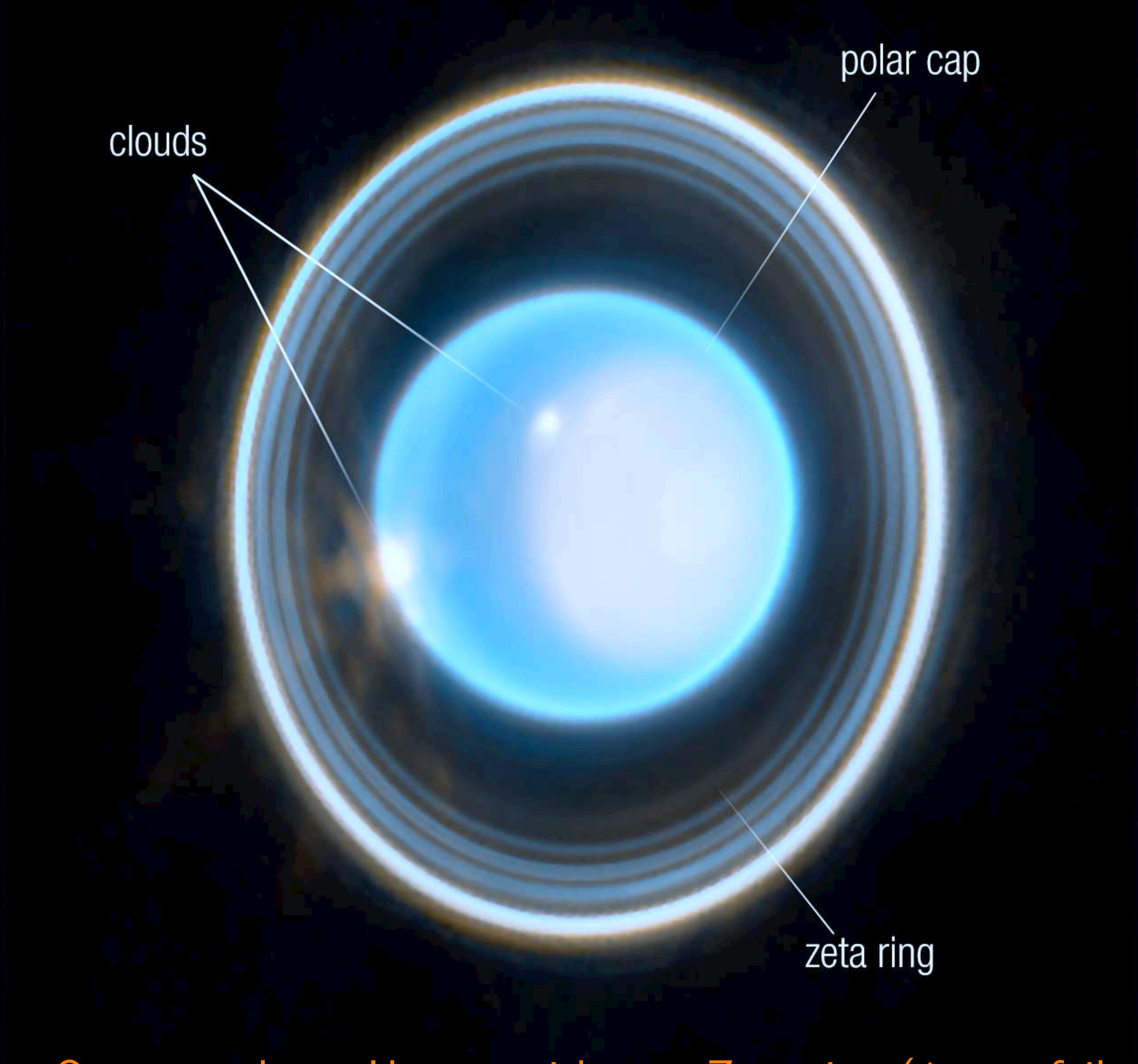
Aug. 2022: JWST NIRcam image of the planet Jupiter:

Beautiful aurorae at its North and South pole: very strong magnetic field!

- The Great “Red” Spot: A giant 4-century storm $2\times$Earth’s diameter!

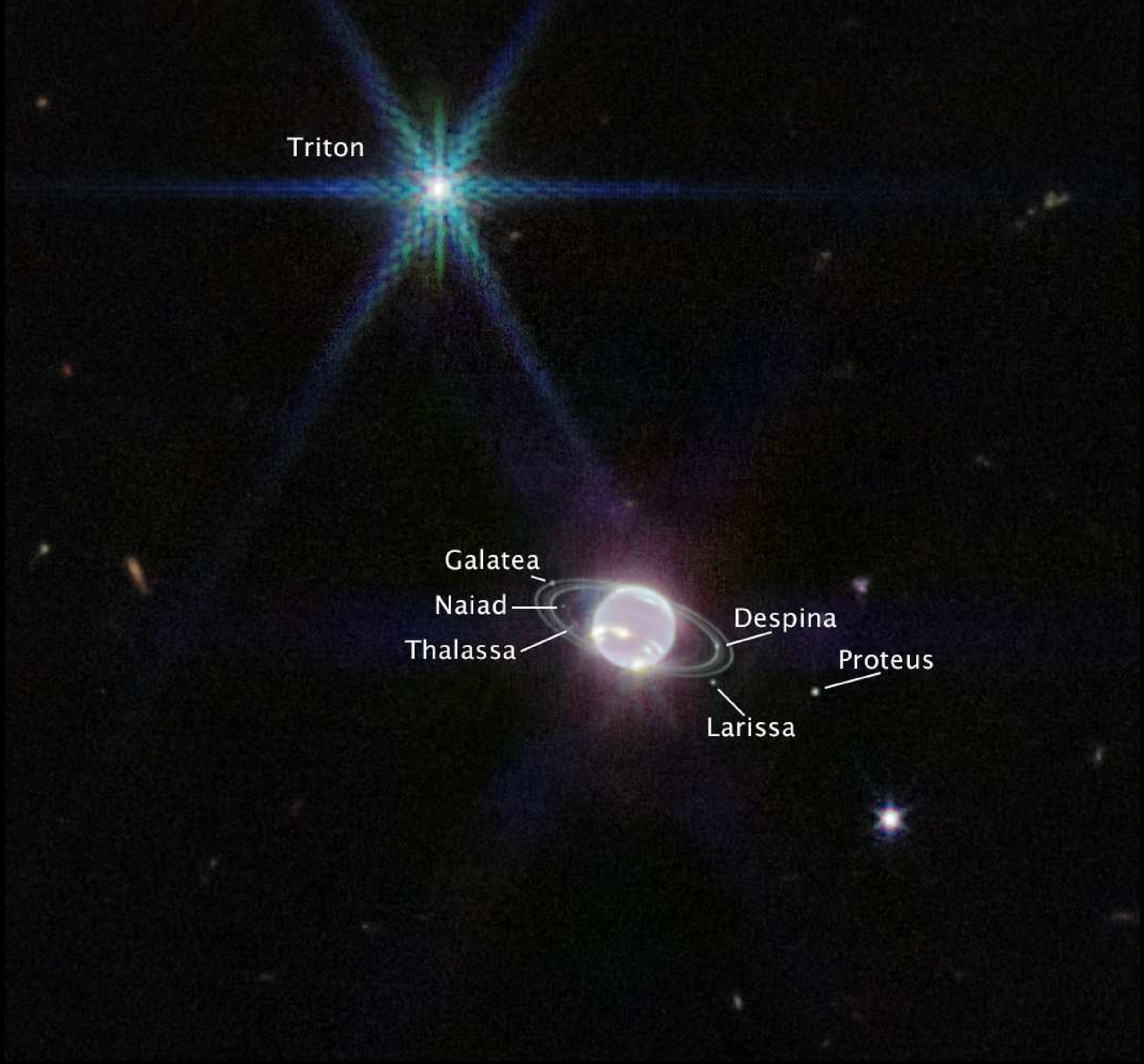
JWST NIRCam: Our own planet Saturn with its moons and rings:

- Planetary rings are "failed moons" due to planet's strong tidal forces.



NIRCam: Our own planet Uranus with new Zeta ring (*i.e.*, a failed moon)

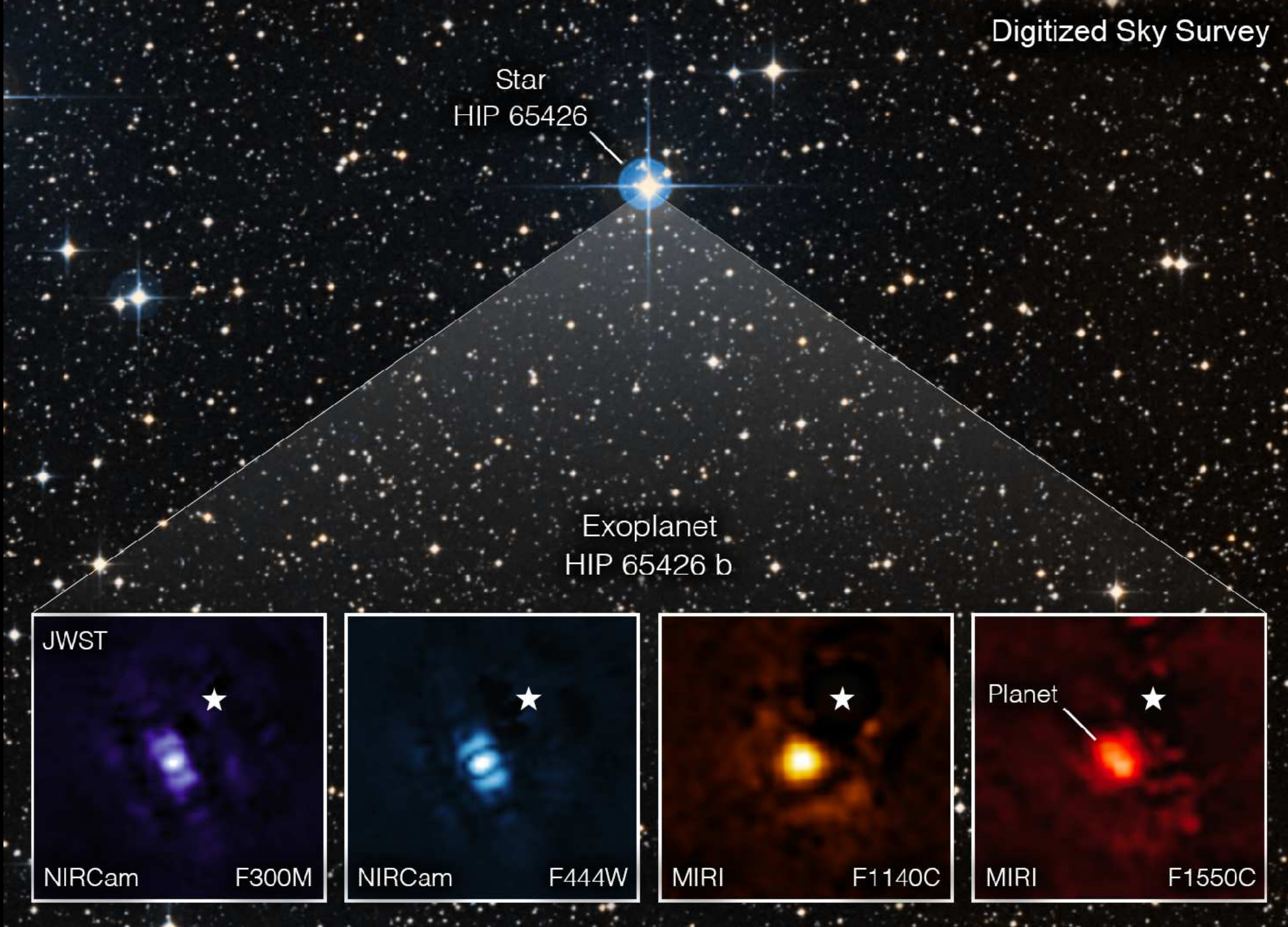
- Polar cap: warmest point on Uranus for half its 84-year orbit!



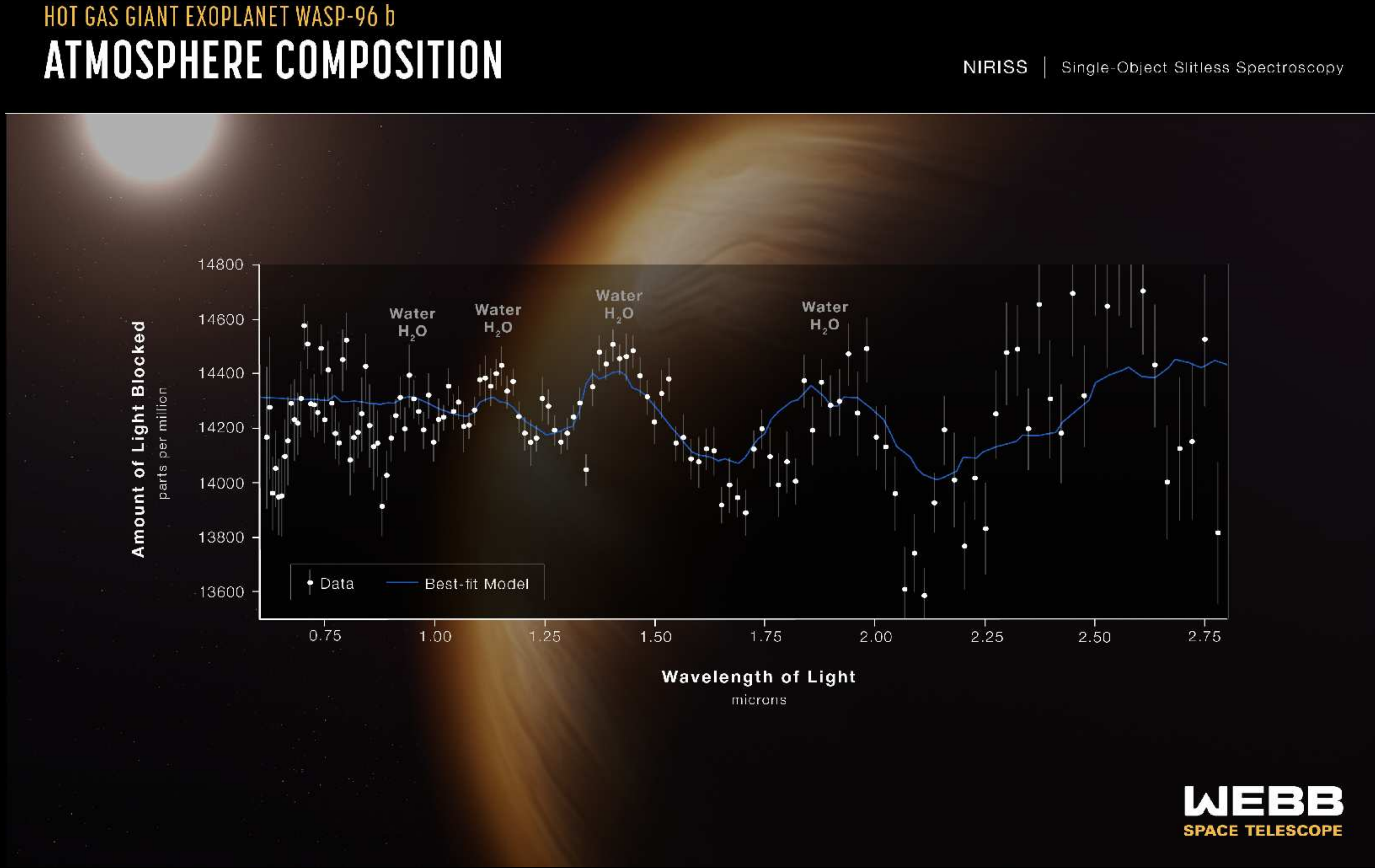
NIRCam family portrait of Neptune with 7 of its Moons:
Moon Triton is brighter, since methane darkens Neptune's atmosphere

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.

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 $>>100\times$ 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).

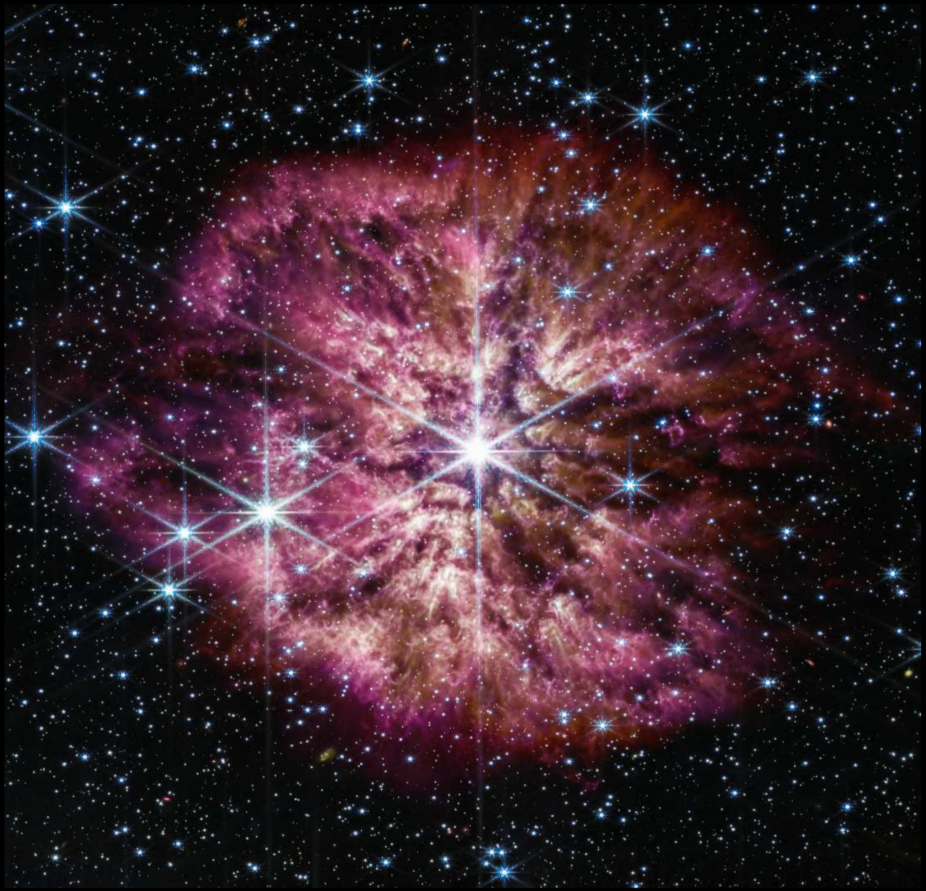
And thanks to the dust they expelled, new stars will form with planets ...


Webb images of THE Northern Ring Nebula in Lyra:

[Left] NIRCam & [Right] MIRI: mass loss in Asymptotic Giant Branch stage.

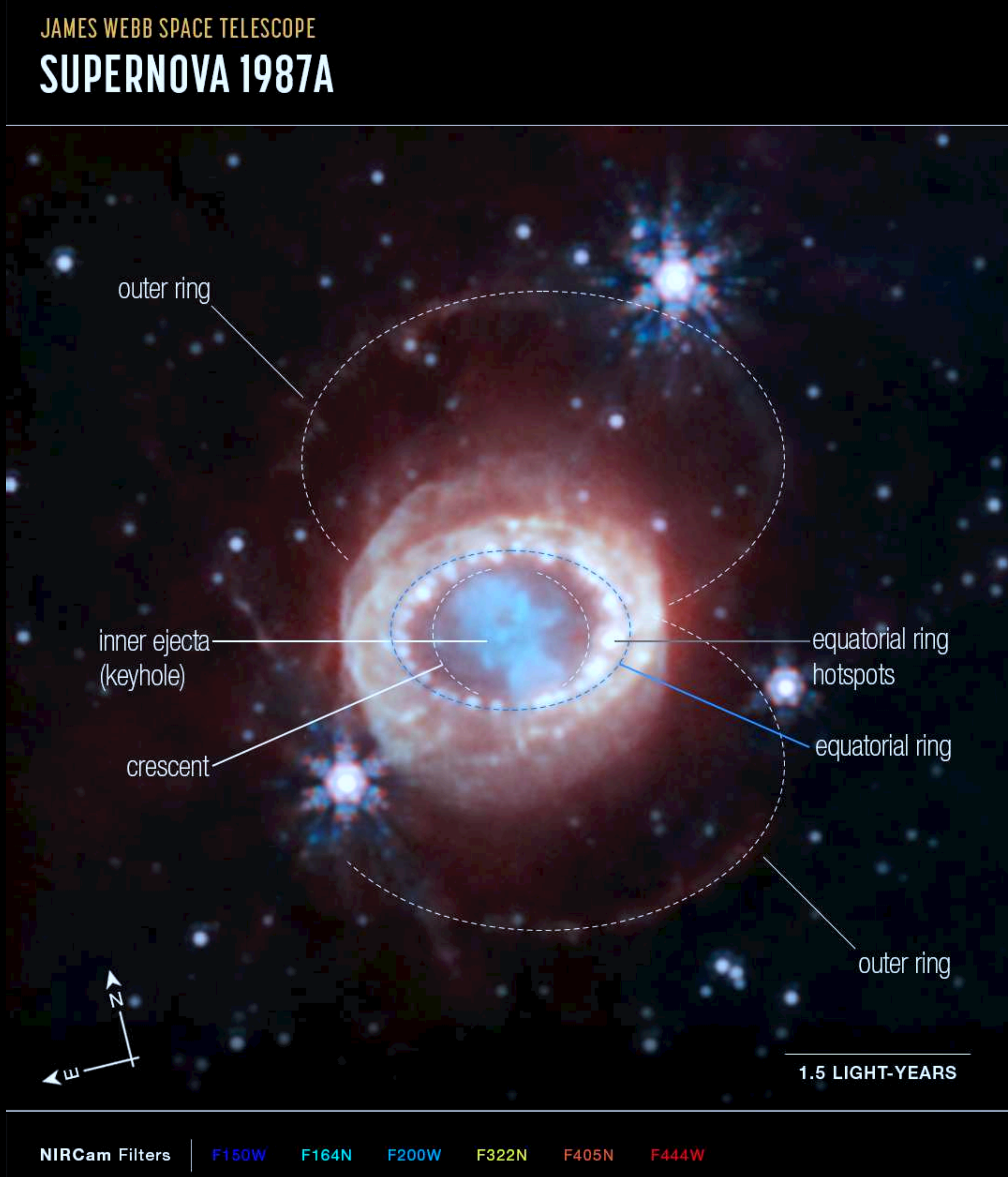
- This is how our Sun *will* come to an end in 5 Billion years ...

and leave an ultra hot dim white dwarf star behind in the center.

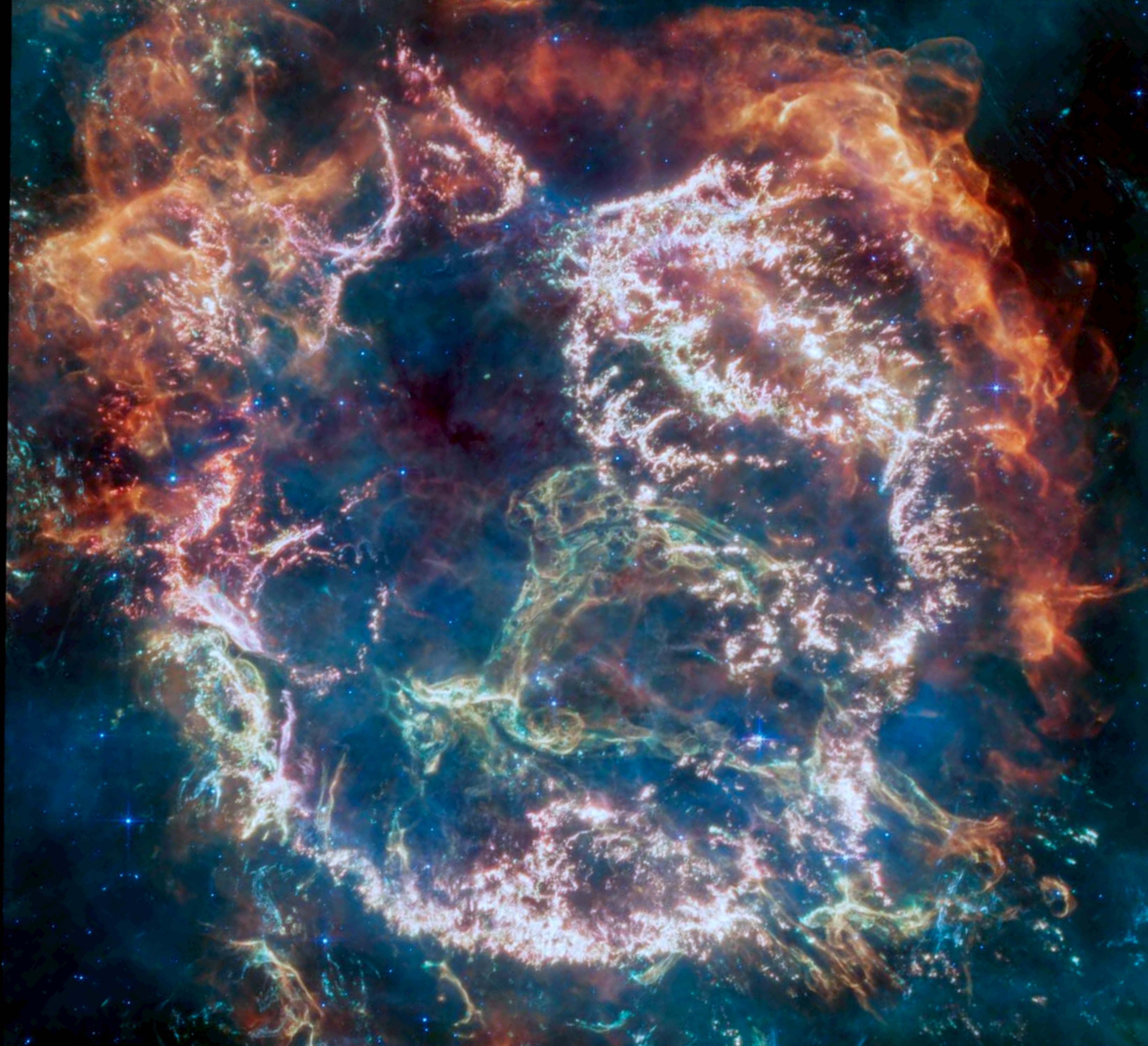
30 solar mass Wolf Rayet star WR124 shortly before it turns Supernova ...

- [Left] NIRCam and [Right] MIRI — both showing recent mass loss.
- Prelude stage to Supernova also releases a lot of (dusty) mass!

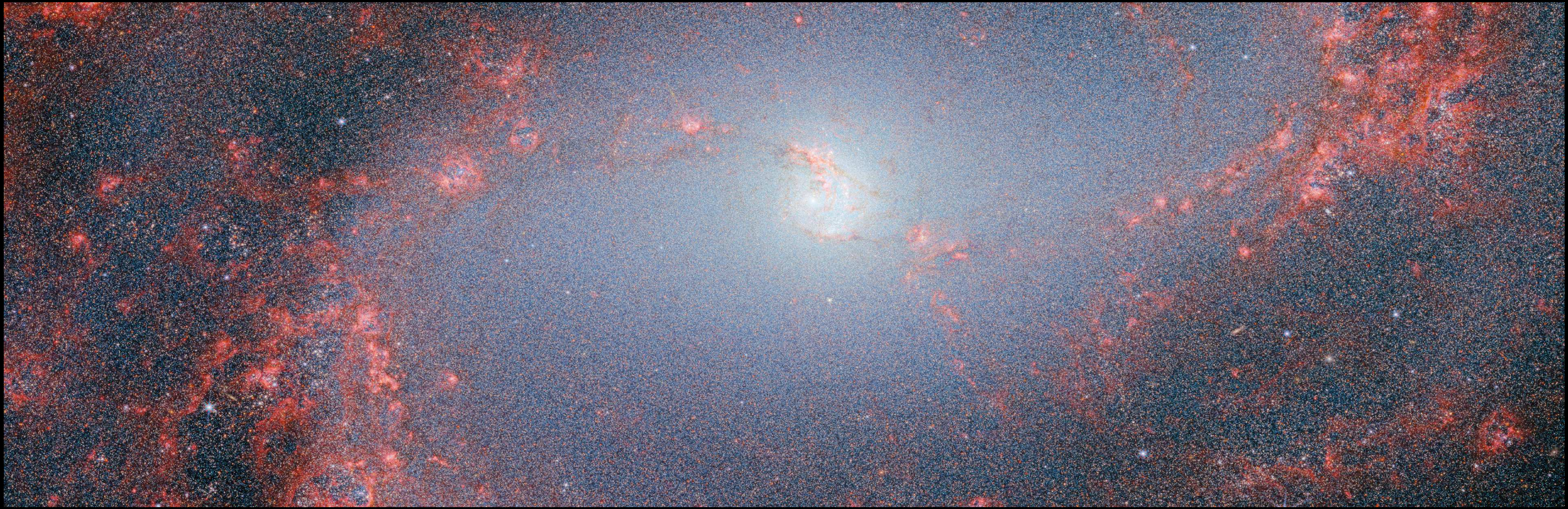


NIRCam: Remnants of Supernova 1987A seen in Large Magellanic Cloud

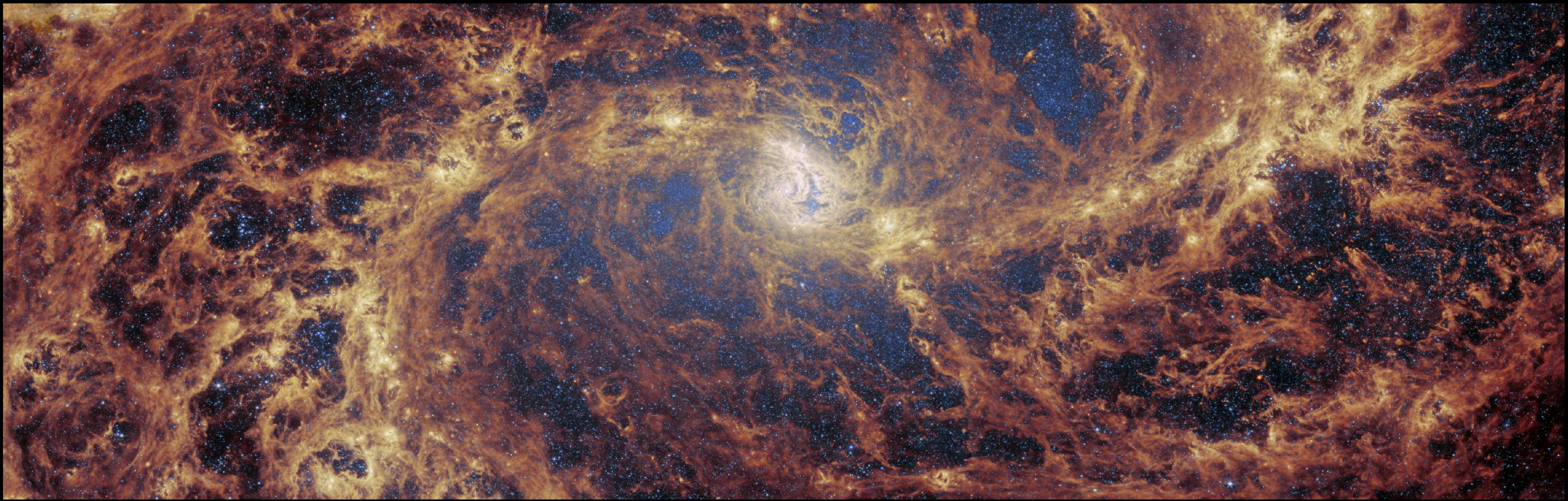
- Shells outflowing over the decades caused hour-glass shaped bubbles



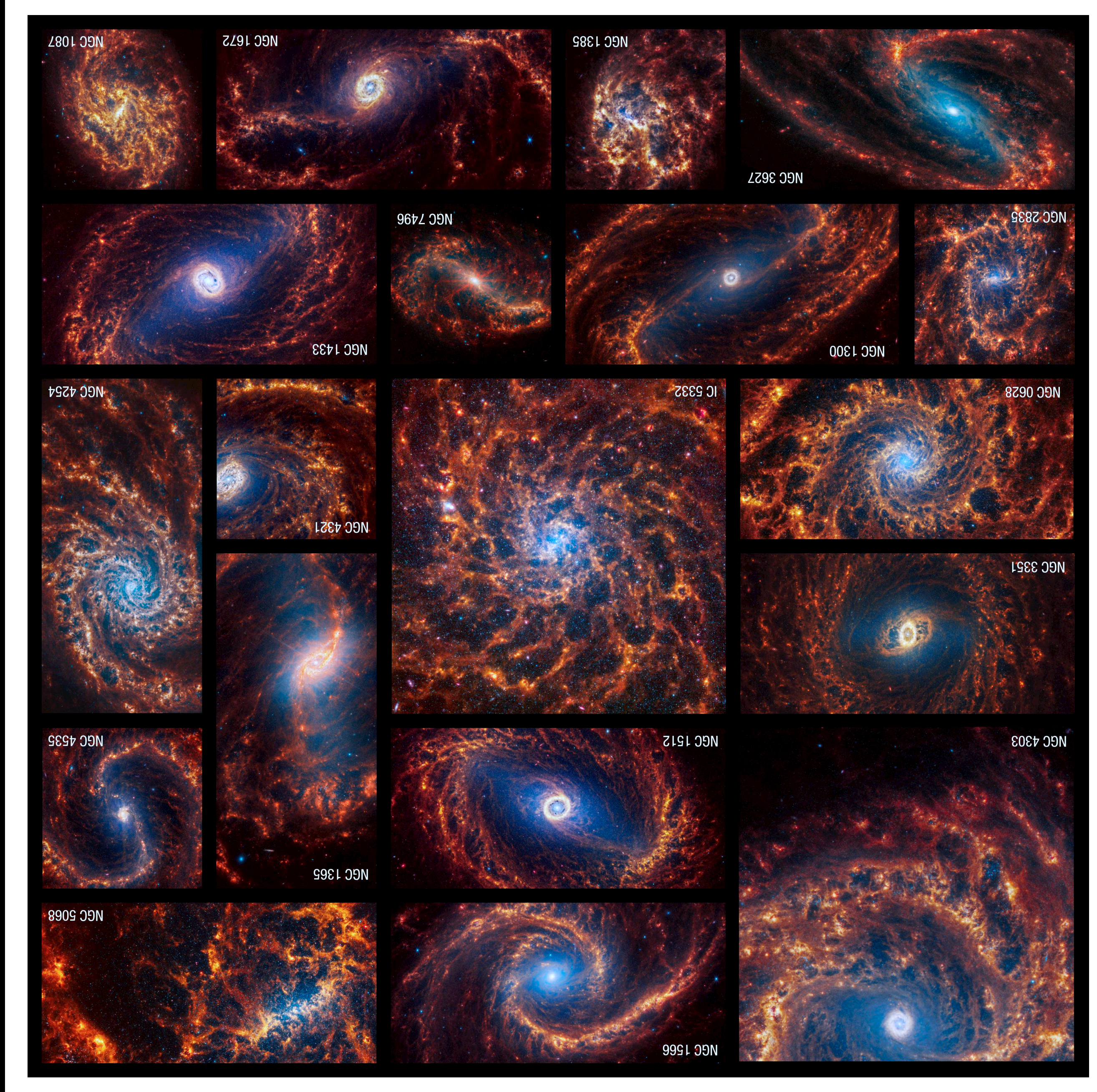
JWST MIRI: Supernova Remnant Cassiopeia-A expelling dust



M83 spiral galaxy NIRCam (near-IR): Through dust thou art made, stars!

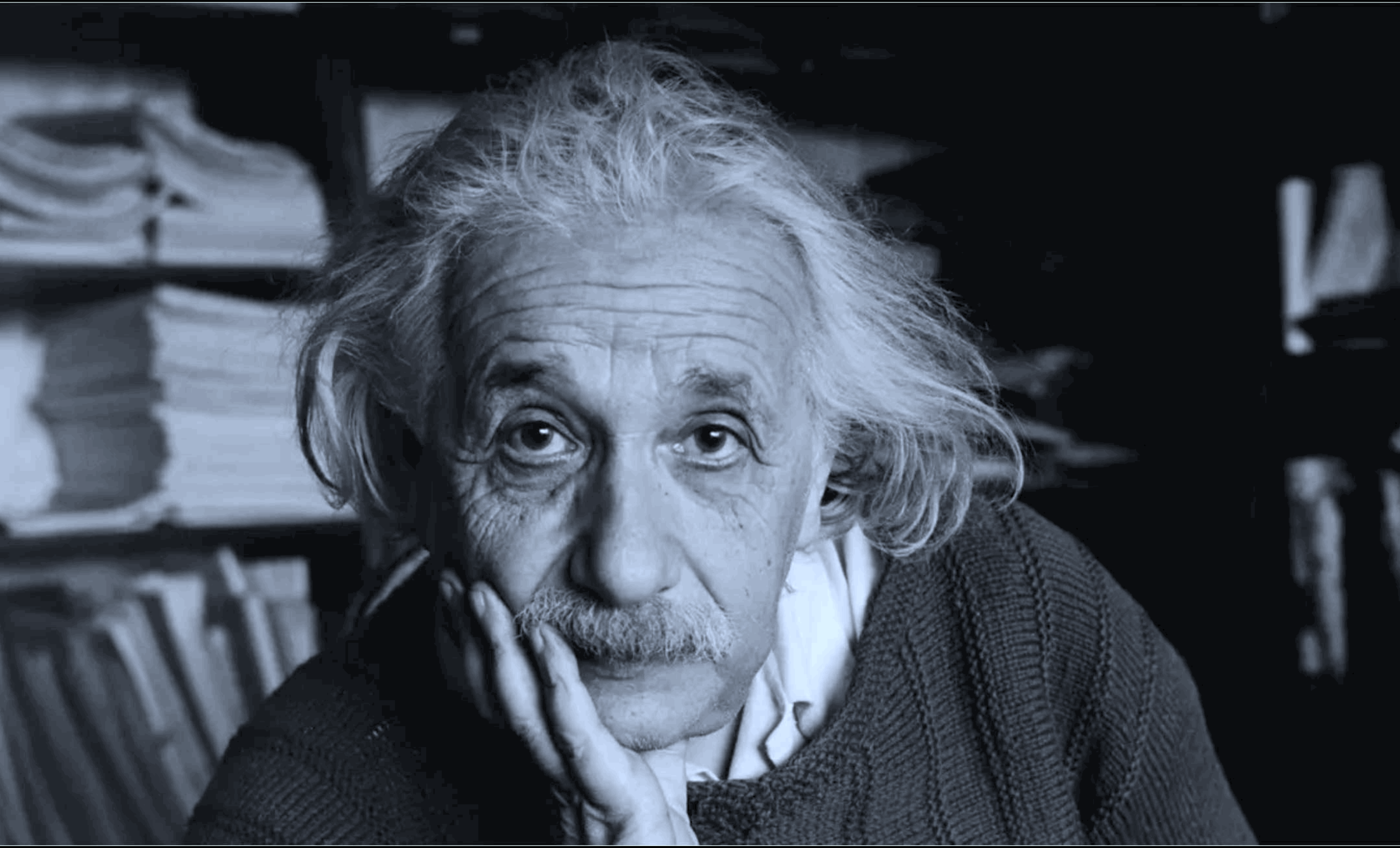


M83 spiral galaxy MIRI (mid-IR): ... and dust thou shalt return, stars!



Webb NIRCam and MIRI images of nearby galaxies:
Cosmic star-formation and dust production ubiquitous throughout the universe!
The “Cosmic Circle of Life” rules throughout the universe!

• (3) Viewing the Universe through the "Eyes of Einstein"



Webb is observing many things Einstein correctly predicted, yet doubted:
Gravitational lensing, Black Holes, the Hubble Expansion, ...

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".

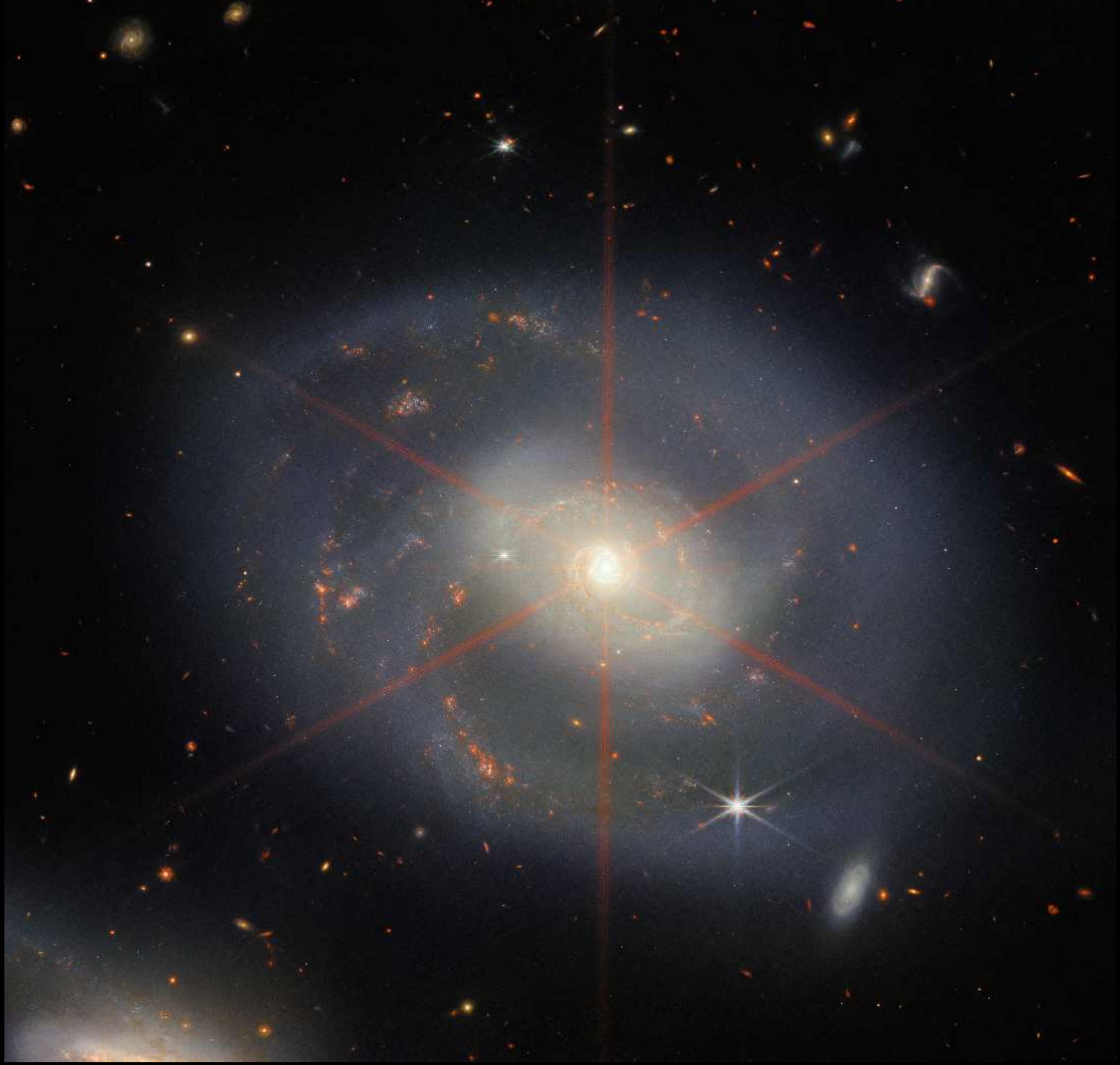
Stephan's Quintet: 4 colliding galaxies at 40 million light-years (Mid-IR):

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

NGC1433 a galaxy with dusty spiral arms at 48 million light-years

NGC7496 a galaxy with dusty spiral arms at 24 million light-years:

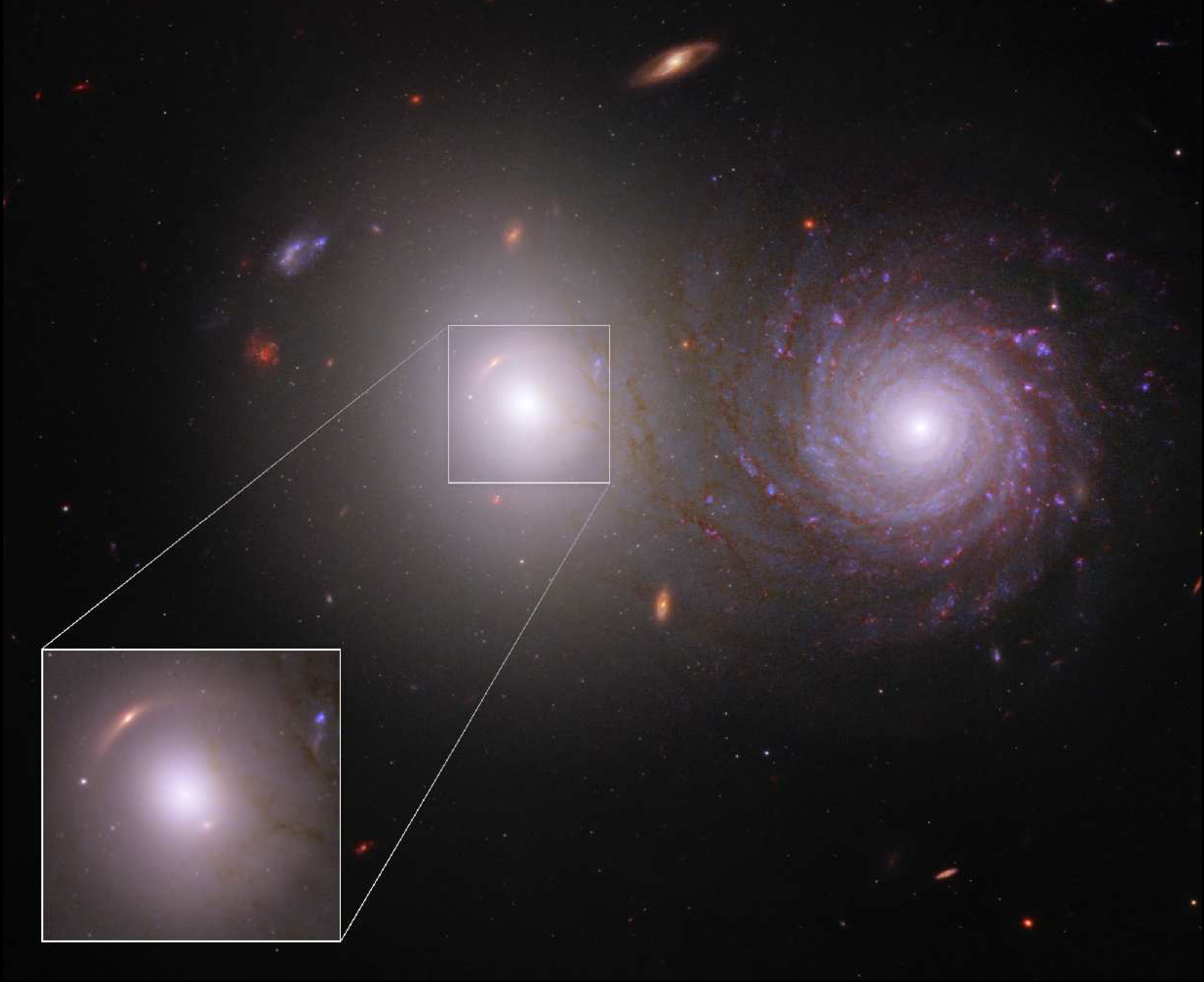
- Inner spiral arms feed the central monster (black hole!)



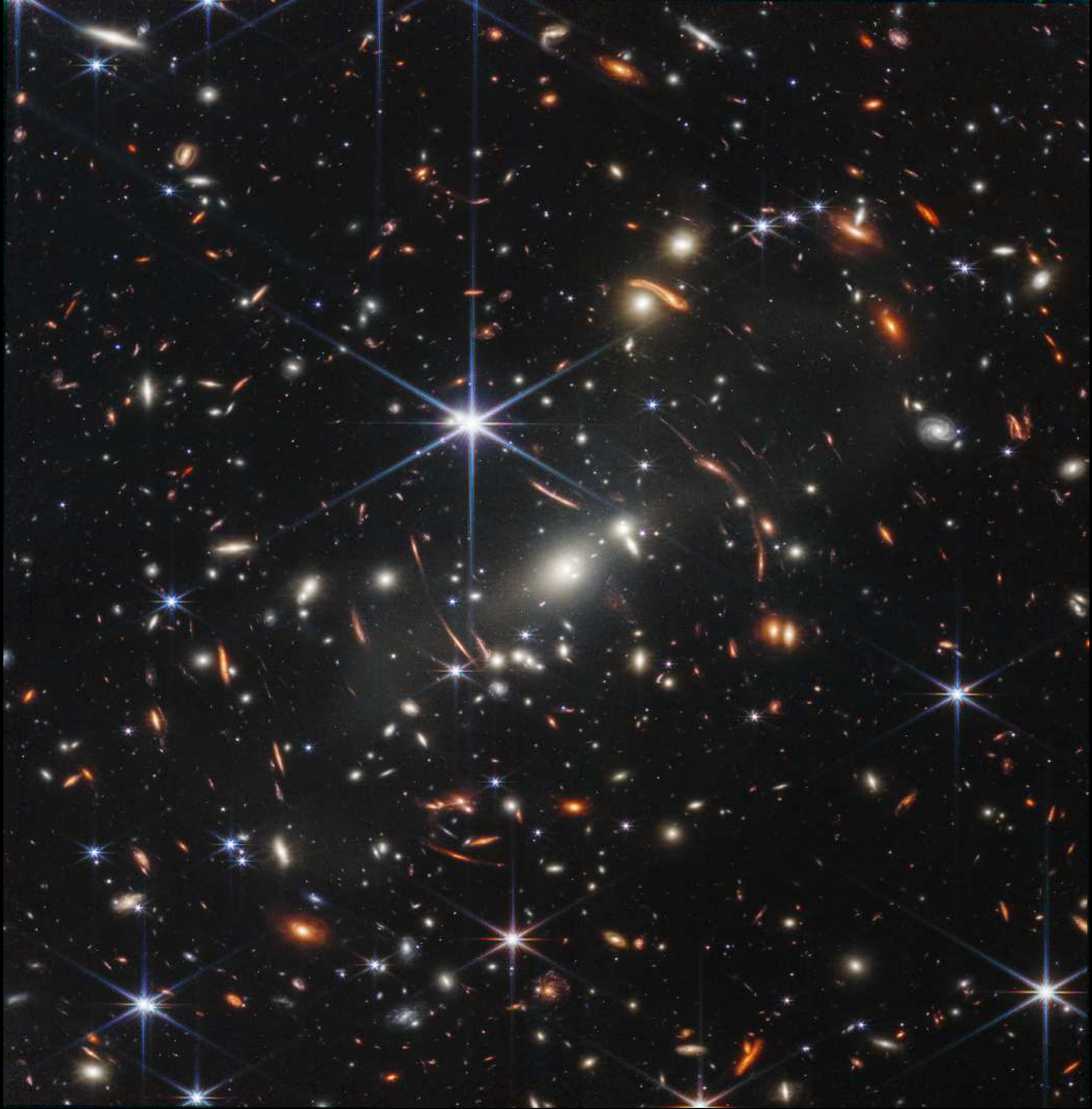
Don't feed the animals: NGC7469, a spiral galaxy at 220 million light-years:

- It has a supermassive black hole (SMBH) 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 $\longrightarrow$ very bright nucleus (quasar).

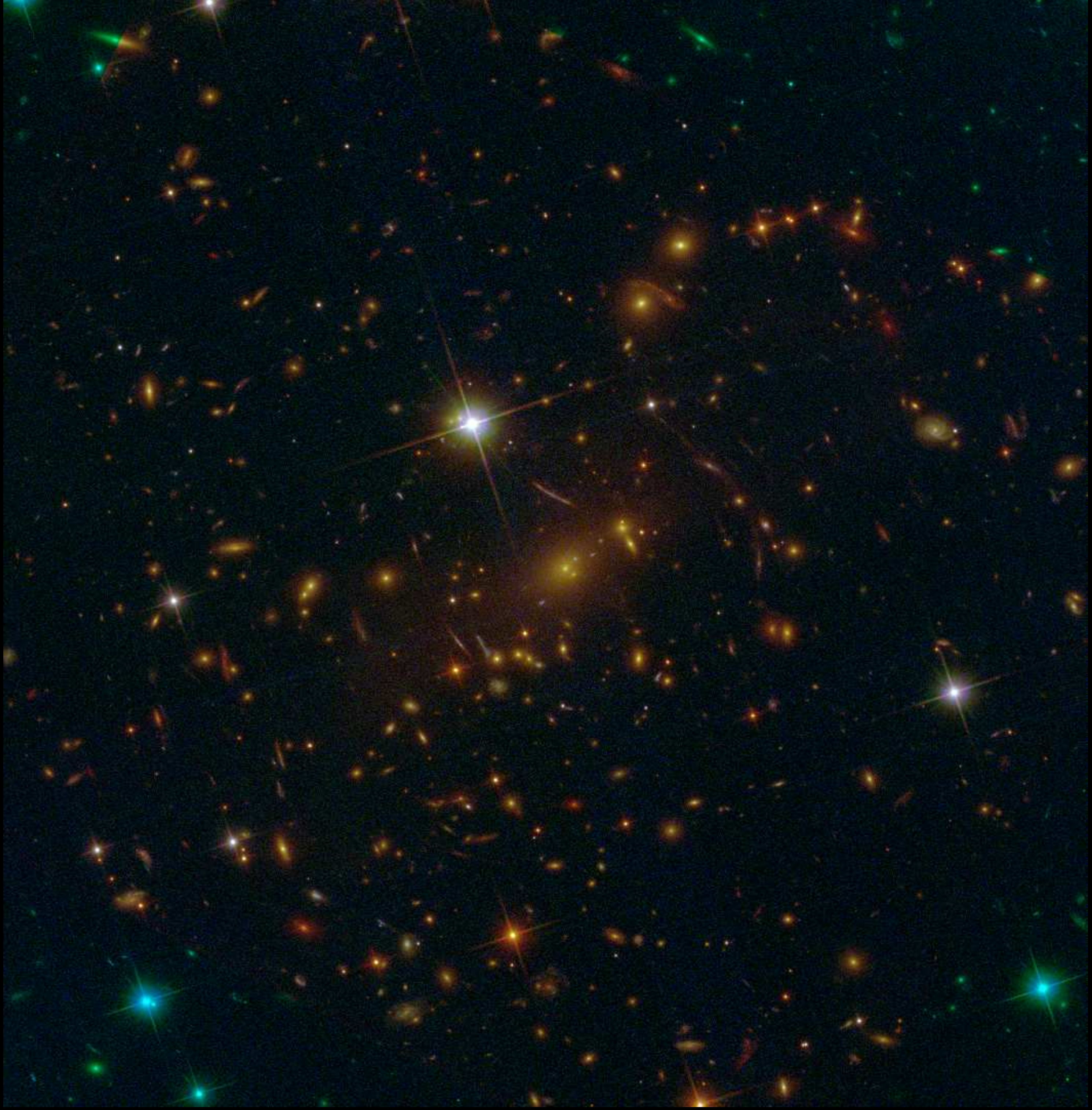
- Spiral overlapping Elliptical: Trace cosmic dust: small grains! (Keel^{+} 2023).
- 100's of Globular Clusters in Elliptical at z=0.0513 (J. Berkheimer^{+} 2024).



The z=0.0513 elliptical also lenses a background galaxy seen ∼6 Byrs after the BB (Keel⁺ 2023, AJ, 165, 16)!

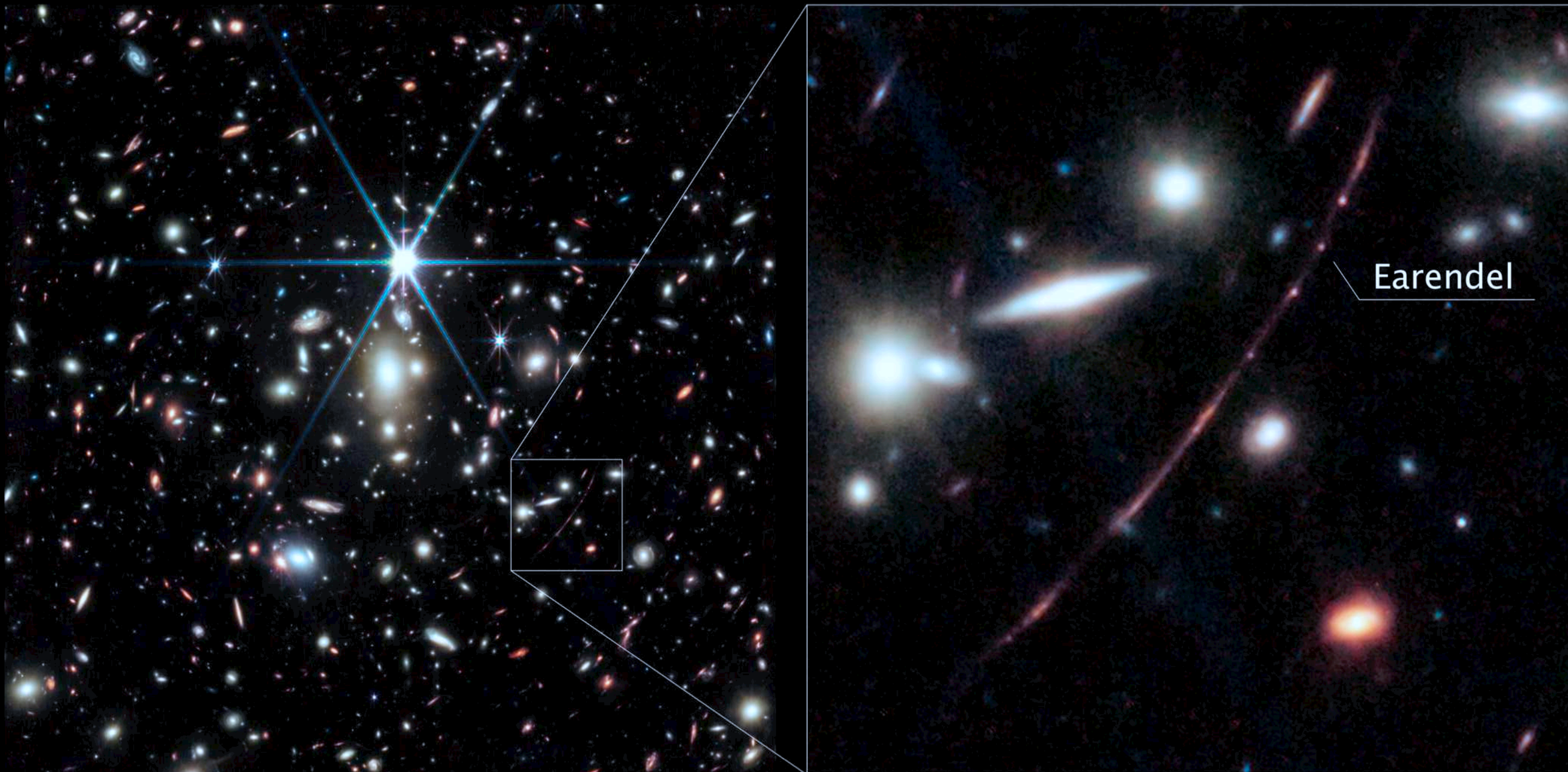


July 11, 2022: 12-hr Webb Deep Field on galaxy cluster SMACS 0723



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

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

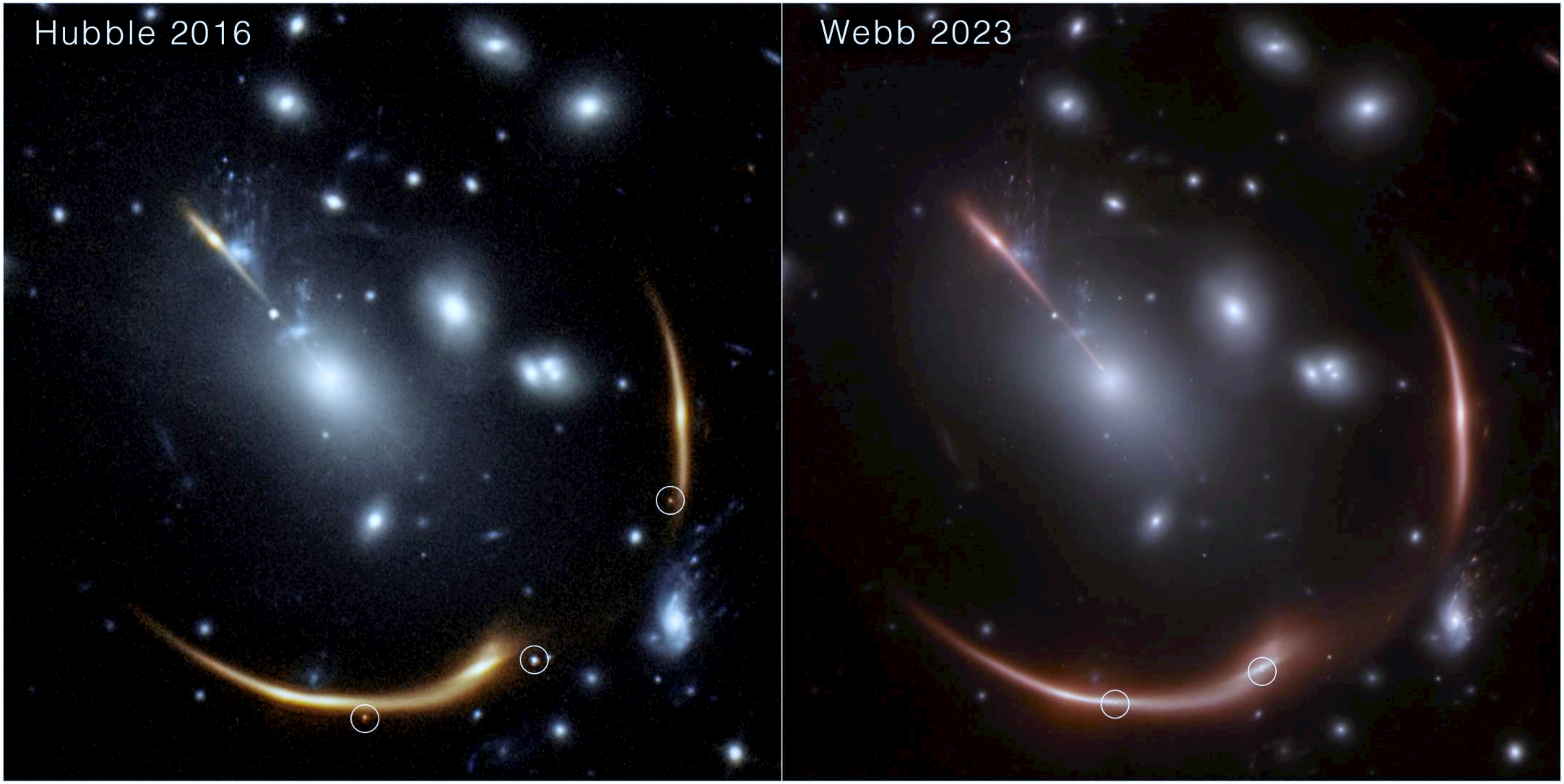


NIRCam: Lensing cluster WHL0137-08 with highly lensed arc at z=6.2

• Earendel: a highly magnified (double-)star seen in the first billion years after the Big Bang — the most distant star ever observed directly!

JWST image of most luminous far-IR Planck cluster G165 at z=0.35 found: Distant Supernova Ia at z=1.78 $\longrightarrow$ measure $\boldsymbol{H_0}$ 10 Byrs ago (Frye$^+$23)!

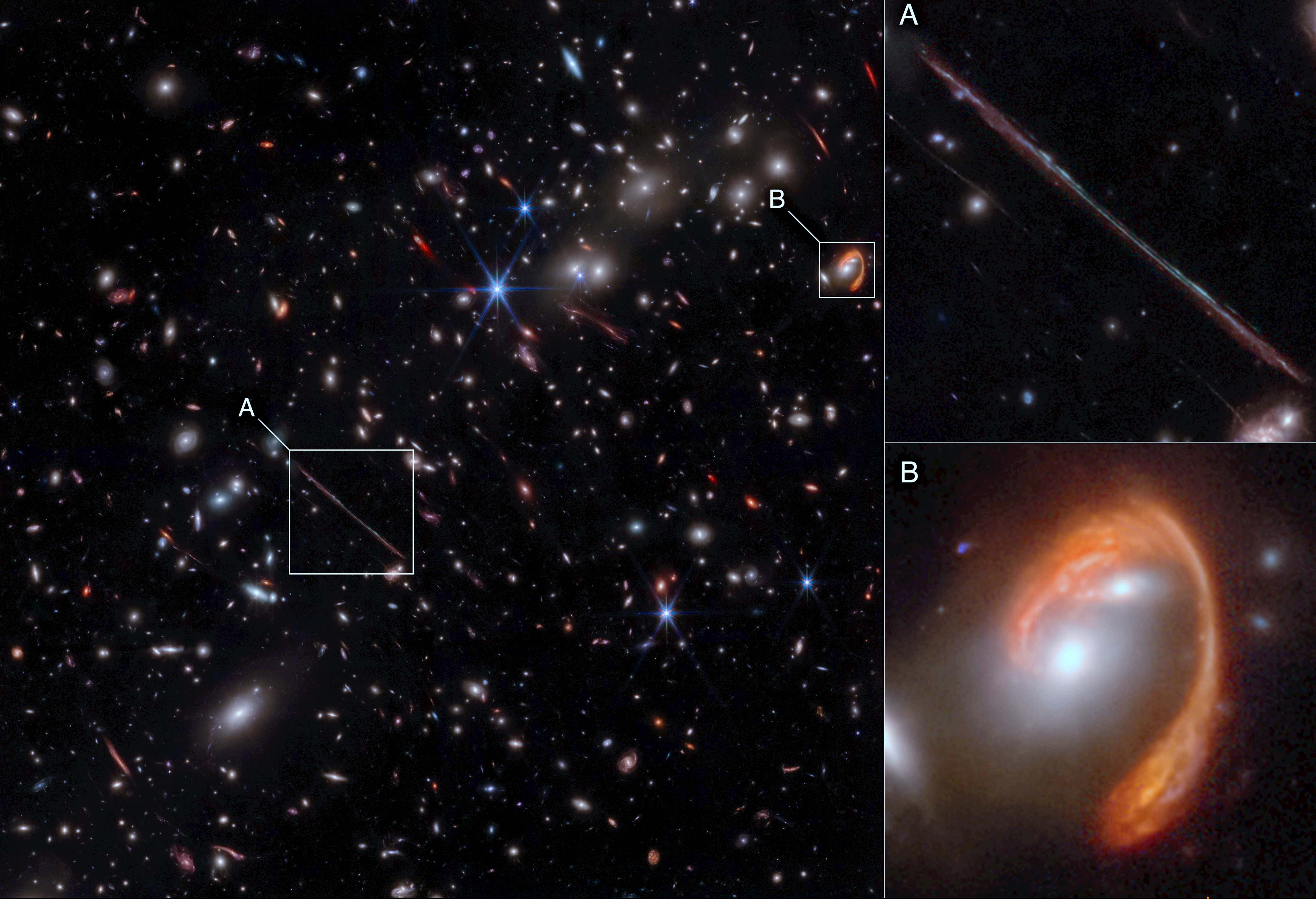
https://bigthink.com/starts-with-a-bang/triple-lens-supernova-jwst/



Hubble saw a lensed Supernova Ia behind this galaxy cluster in 2016:

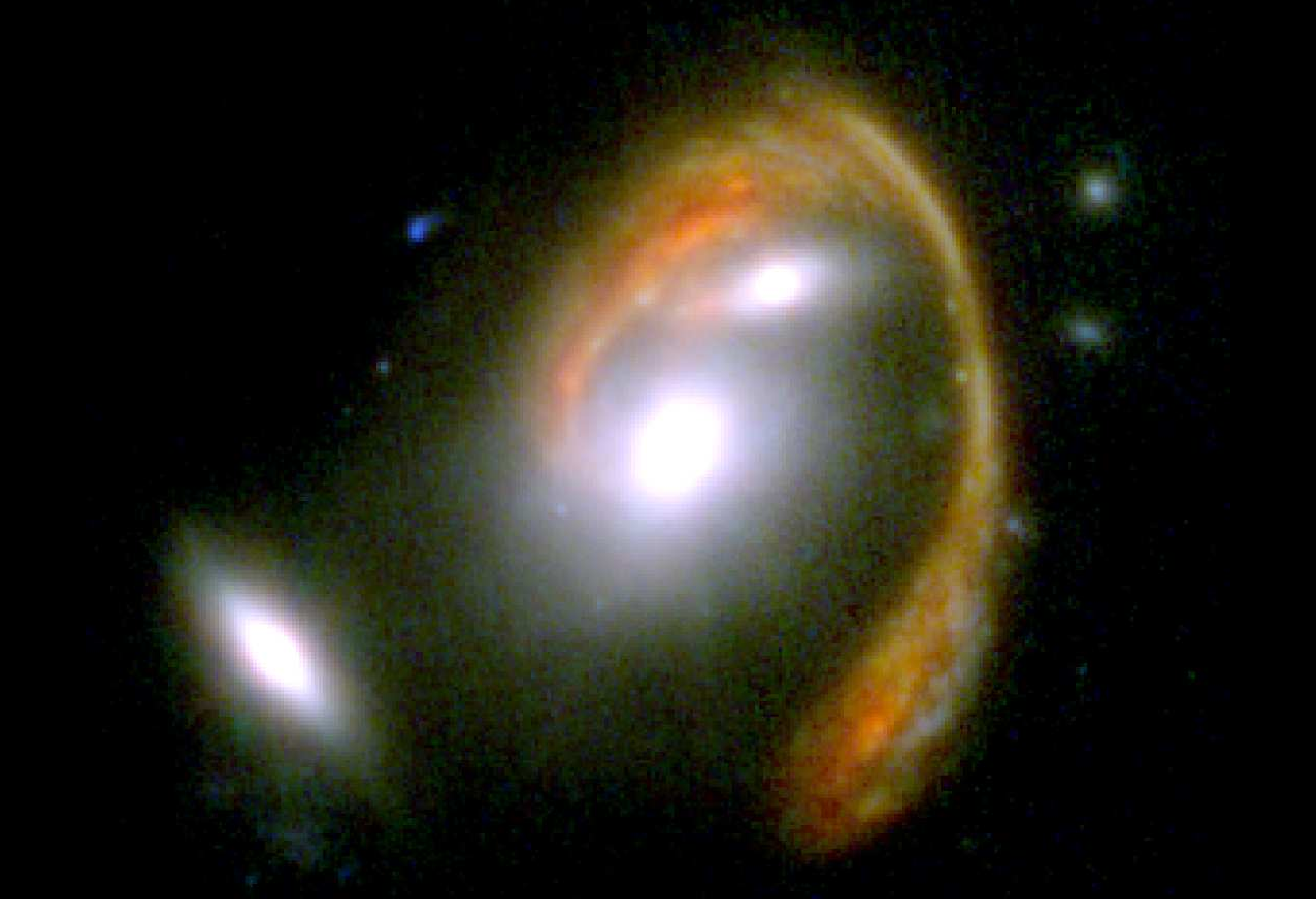
Webb saw more distant lensed Supernova at z=1.9 (age 3.5 Byrs) in 2023!

$\Longrightarrow$ "SN Encore": Lensing is the gift that keeps on giving!



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

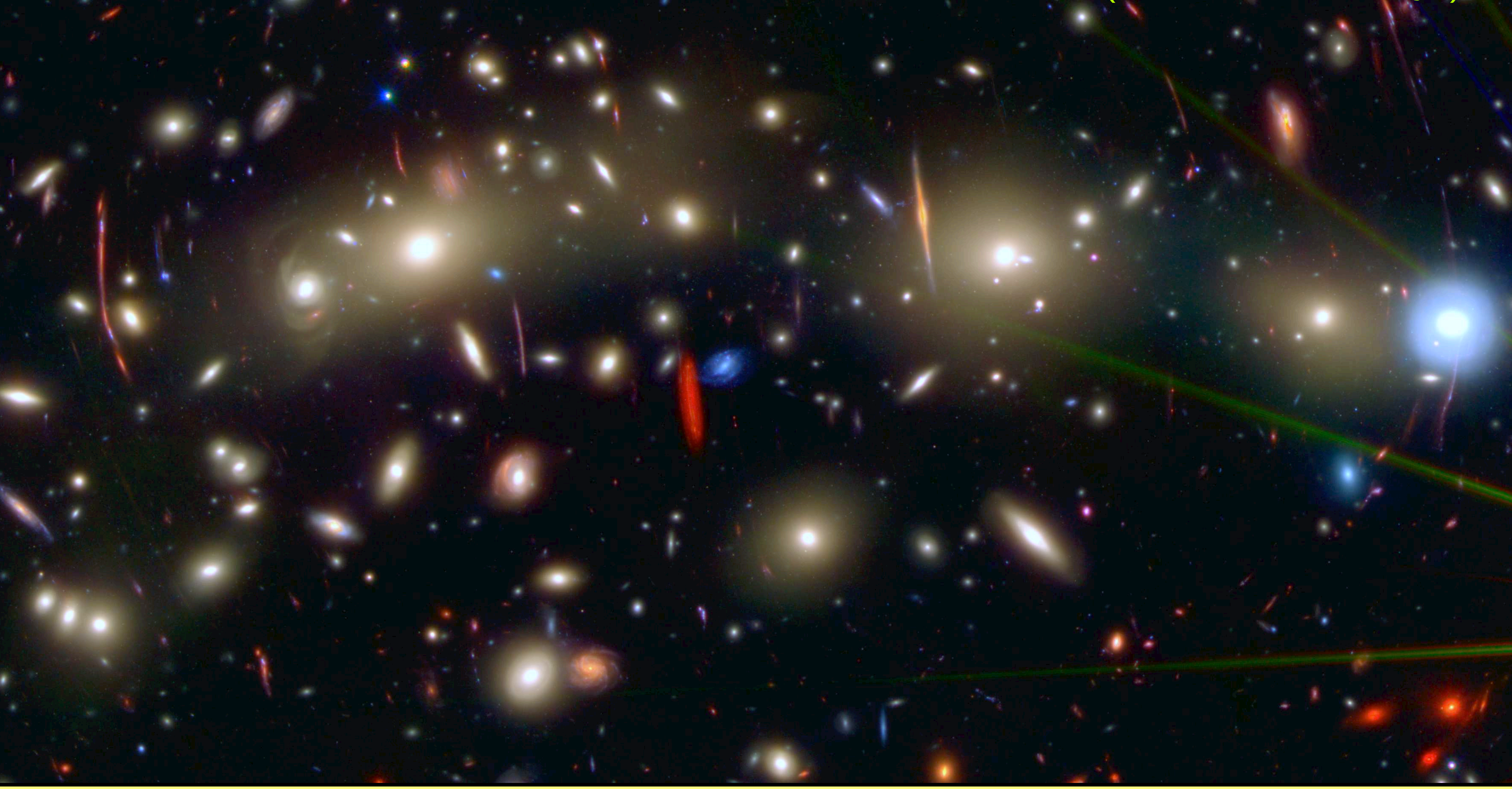
https://news.asu.edu/20230801-jwsts-gravitational-lens-reveals-distant-objects-behind-el-gordo-galaxy-cluster



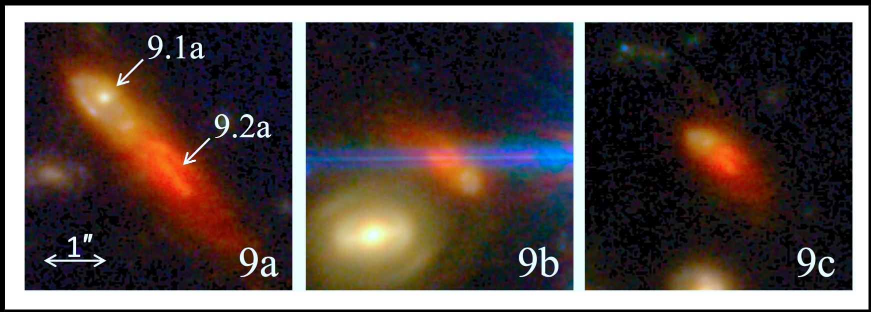
and El Gordo makes a super-lens “El Anzuelo” — Einstein’s fishhook!

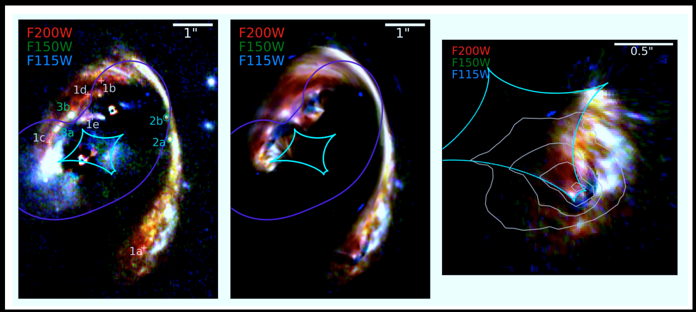
https://webbtelescope.org/contents/news-releases/2023/news-2023-119

22 hr JWST on Hubble Frontier Field cluster MACS0416 (z=0.397; 4.3 Blyr)



JWST: Lensed Dusty sources behind El Gordo in first few Byrs (P. Kamieneski$^+$; astro-ph/2303.05054):

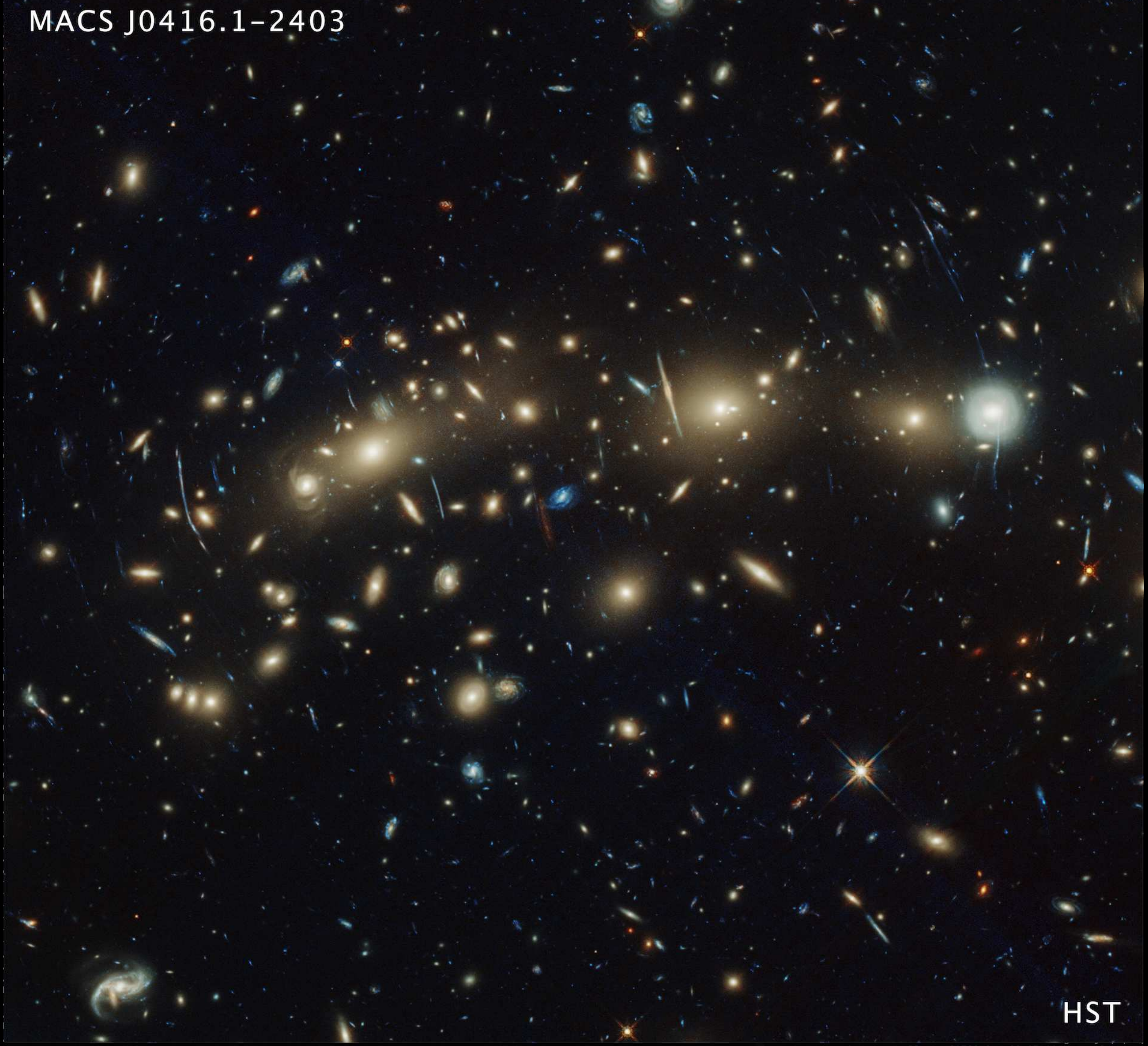




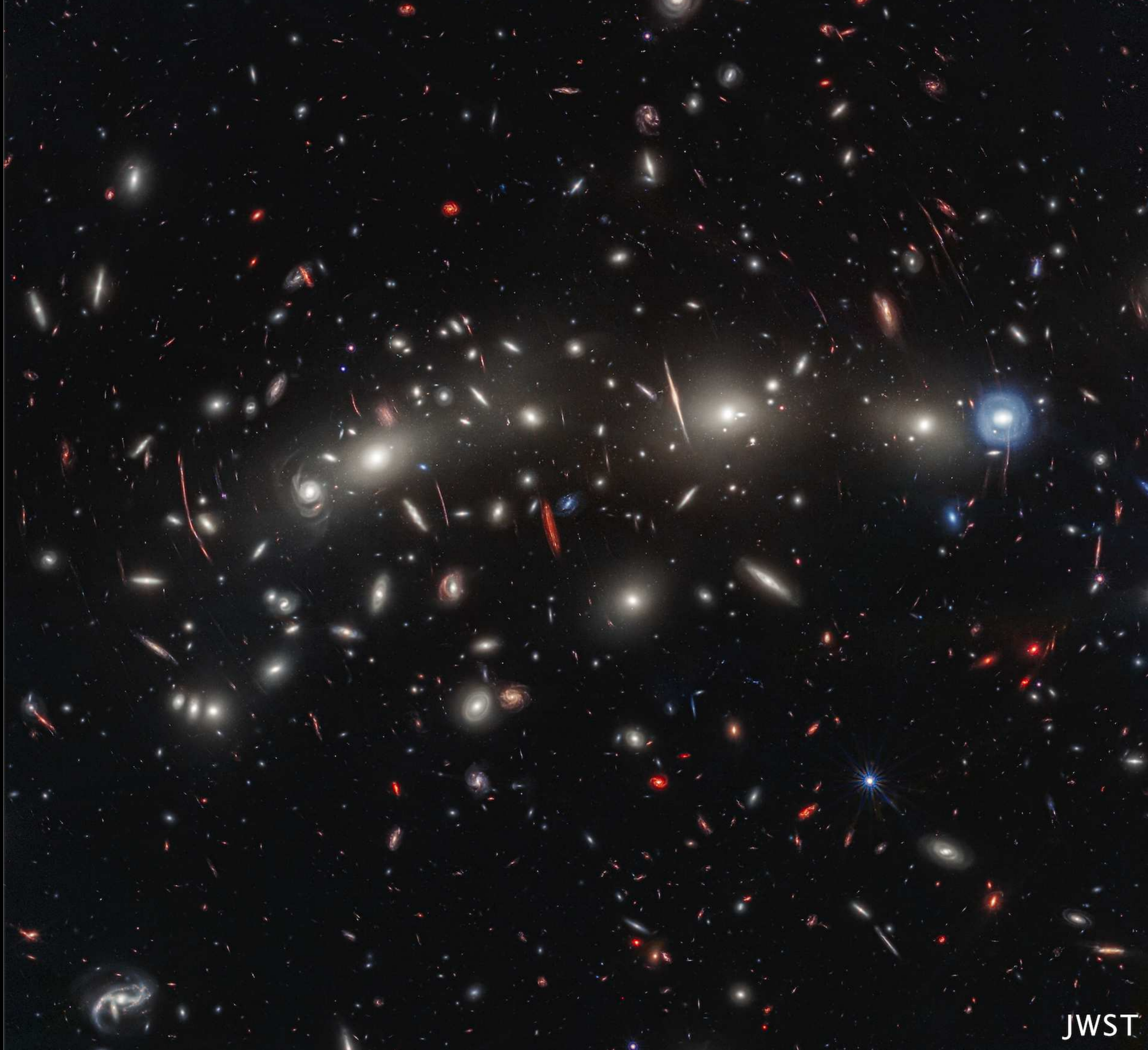
122 hr HST + 22 hr JWST on Frontier Field cluster MACS0416 (4.3 Blyr)

- The power of Two Telescopes: Webb collects 6× more light than Hubble!

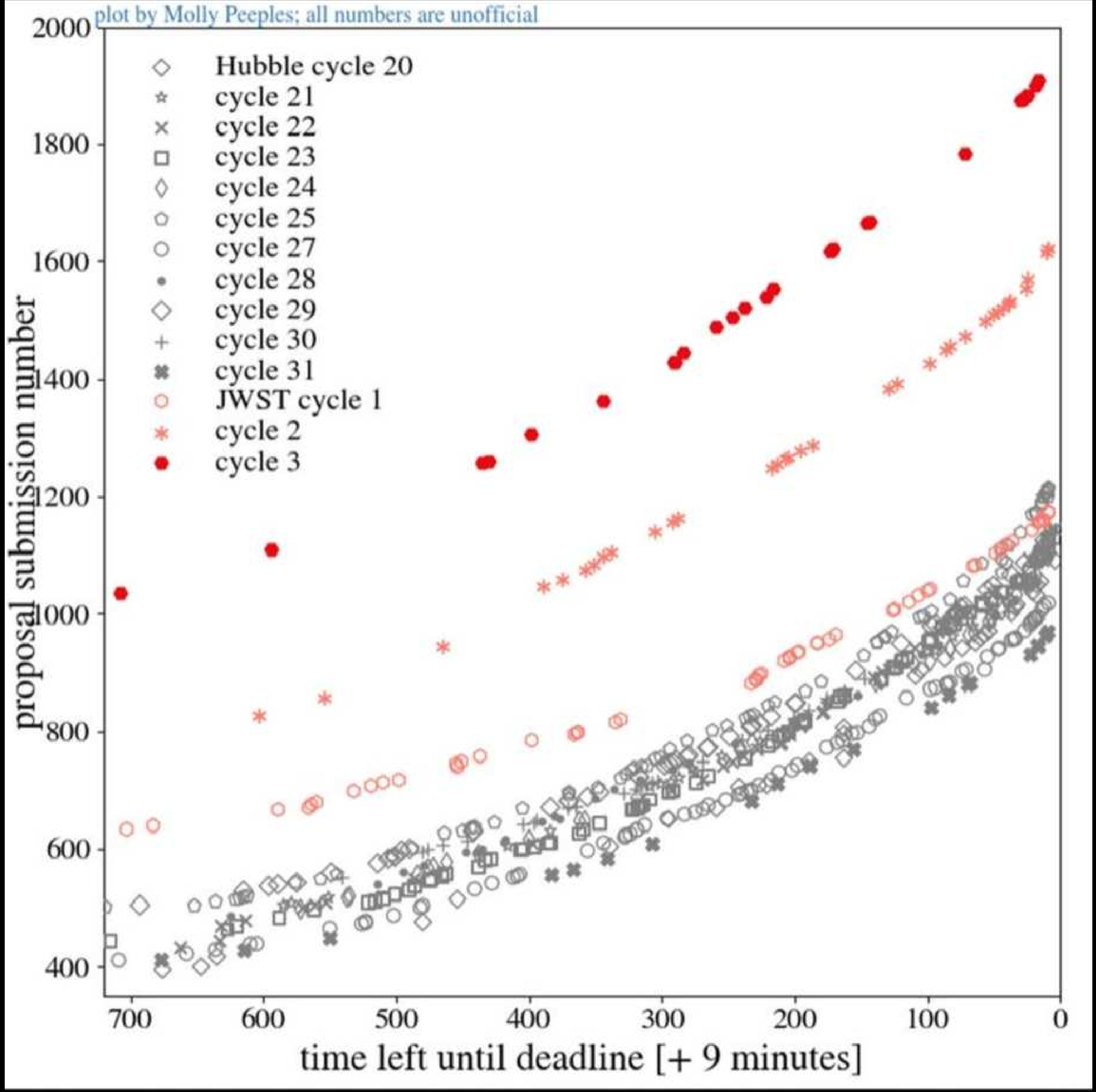
NASA press release for Nov. 9, 2023: https://webbtelescope.org/contents/news-releases/2023/news-2023-146



122 hr HST on Hubble Frontier Field cluster MACS0416 (z=0.397; 4.3 Blyr)



22 hrs JWST on Hubble Frontier Field cluster MACS0416 (z=0.397; 4.3 Blyr)



Oct 2023: Webb is now THE highest-in-demand NASA Flagship mission ever!

(4) Summary and Conclusions

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

(2) Webb is observing the epochs of First Light, Galaxy Assembly & Super Massive Black Hole-growth in detail (much through lensing):

- 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 has a major impact on astrophysics this decade and beyond:

- 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/asuSES502grads_jwst23.pdf Data: https://sites.google.com/view/jwstpearls

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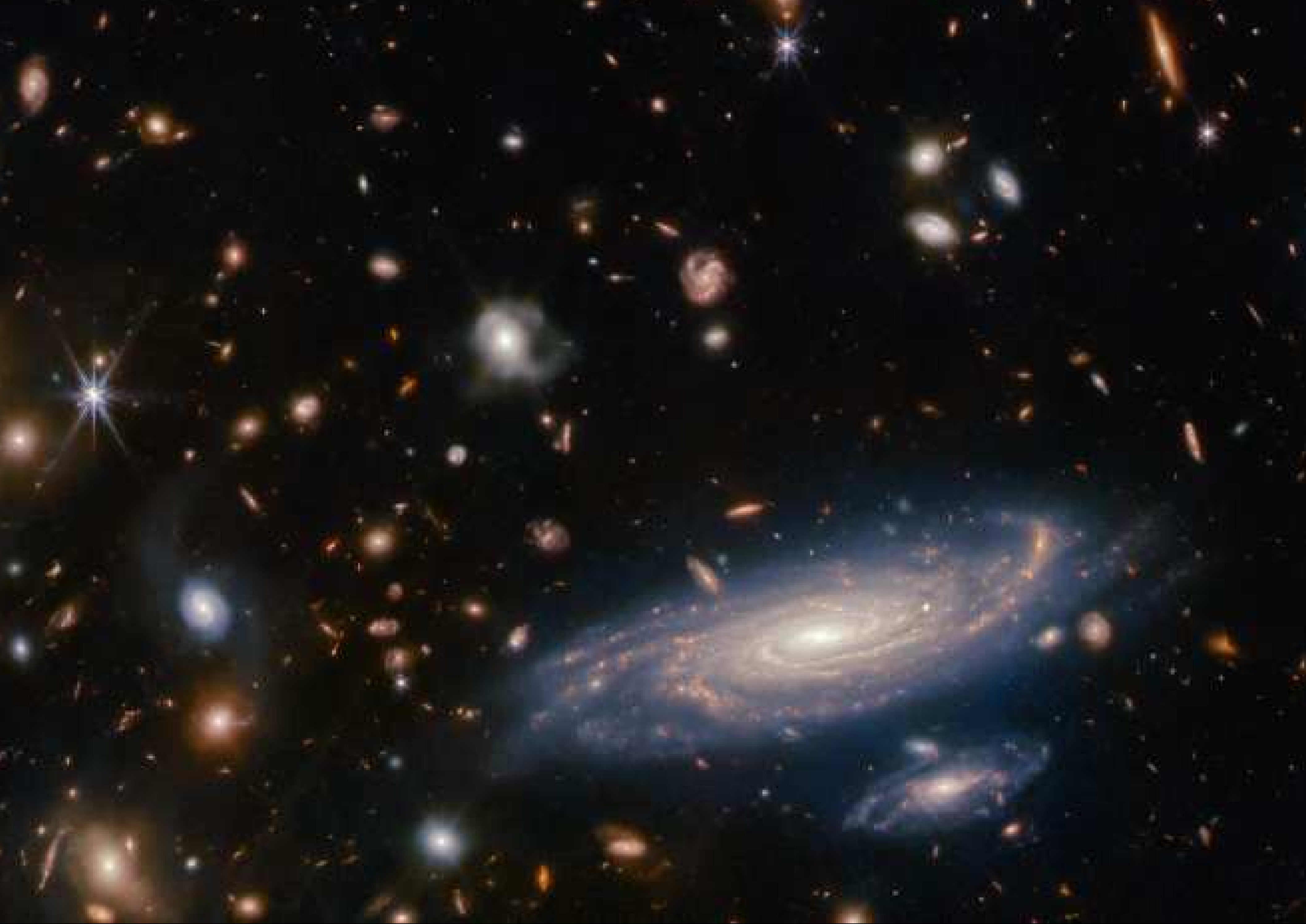
https://webbtelescope.org/contents/news-releases/2023/news-2023-119

https://news.asu.edu/20230801-jwsts-gravitational-lens-reveals-distant-objects-behind-el-gordo-galaxy-cluster

https://webbtelescope.org/contents/news-releases/2023/news-2023-146

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

LEDA-2046648: a beautiful galaxy pair observed with NIRISS 1 Blyr away



LEDA-2046648: Andromeda will collide will Milky Way like this in 4–5 Byrs.

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

Will this ever happen to our own Galaxy?

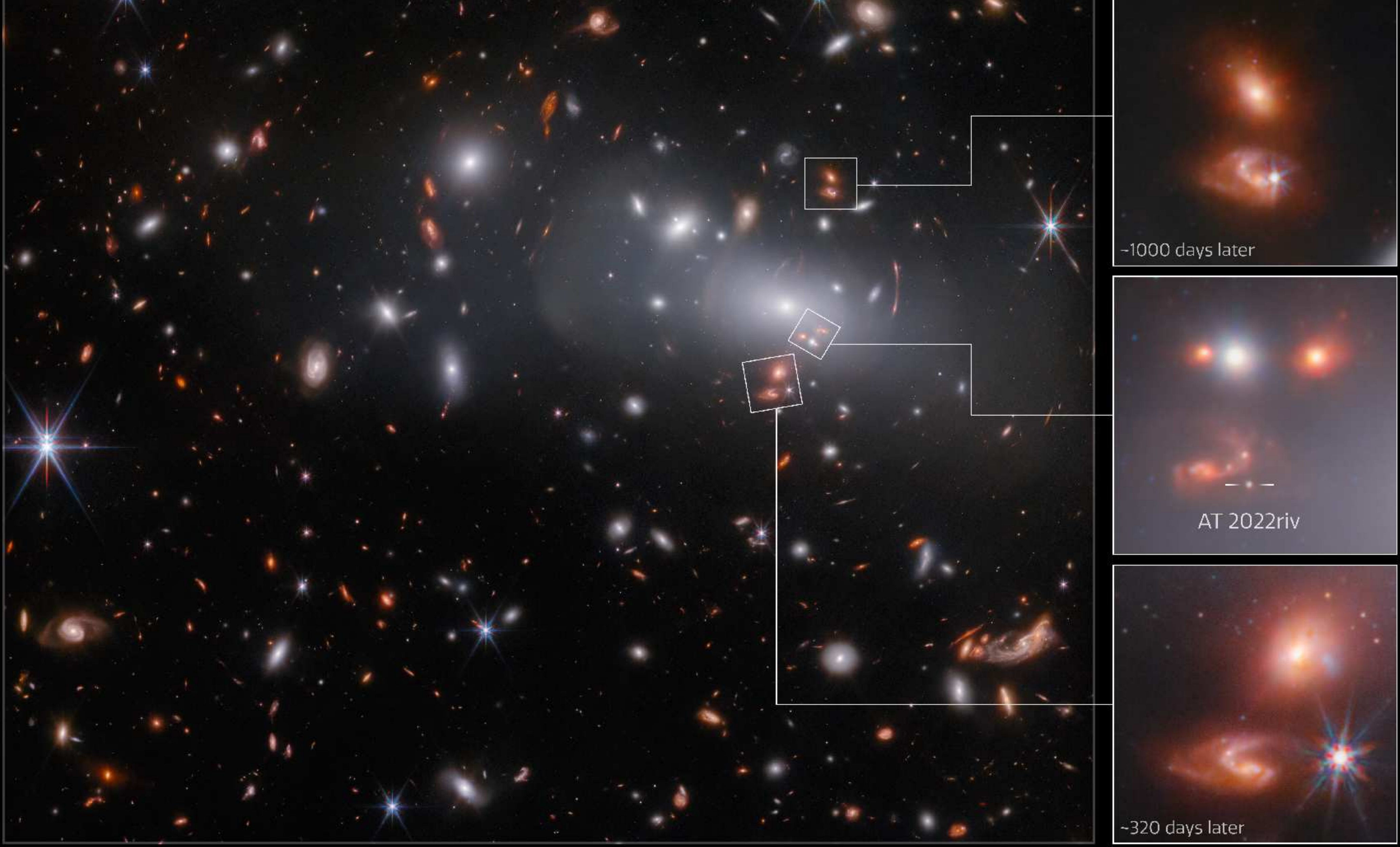
YES! Hubble showed no lateral motion of Andromeda:

Approaches at –110 km/s.

Hence, Andromeda will merge with Milky Way!

The two blackholes (10^6–10^7 suns) will also merge!

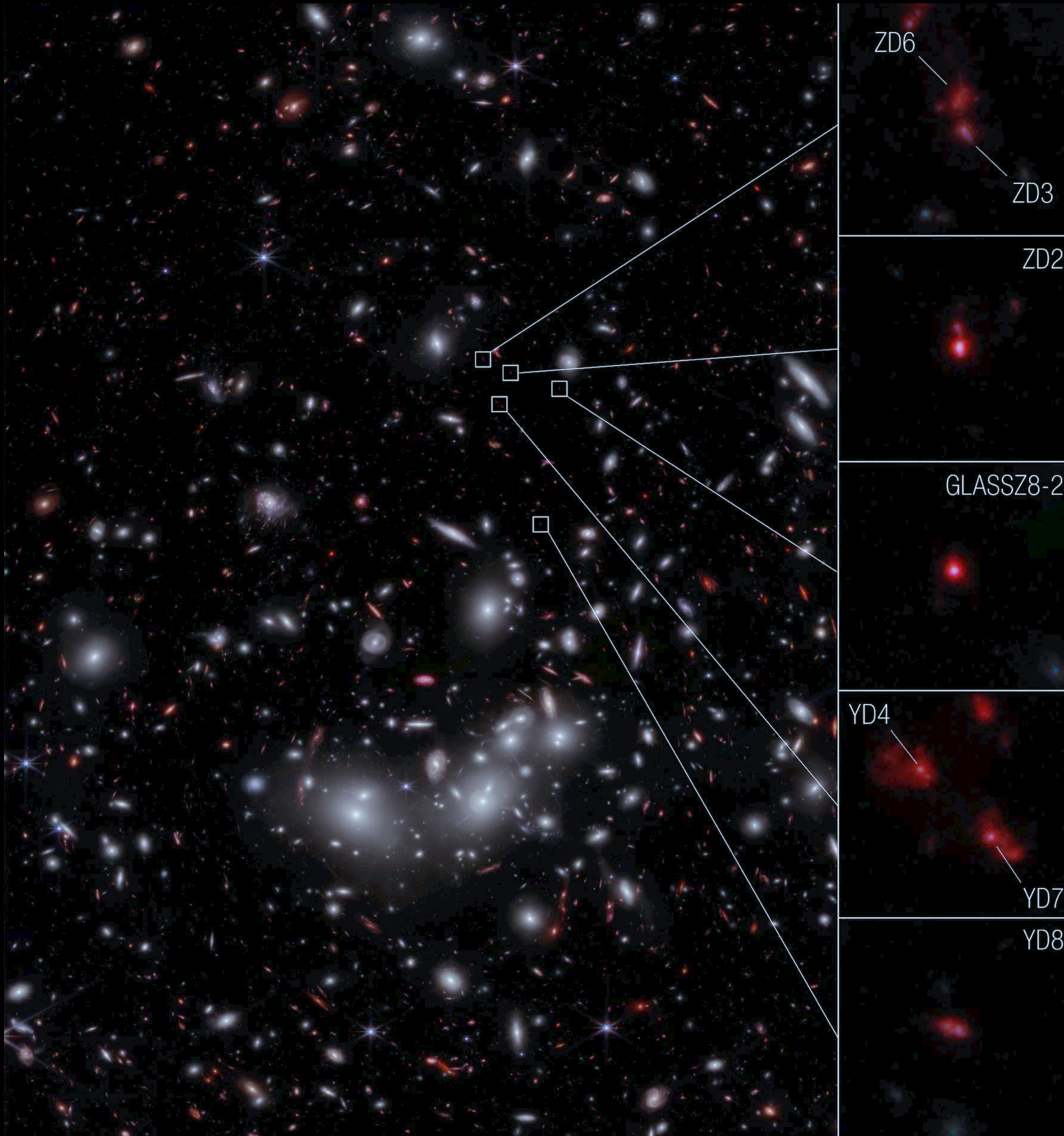
Not to worry: only 4–5 Byr from today!



Cluster RXJ2129 with triply lensed Supernova at 2.9 billion lyrs distance

- SN only seen in middle panel sampling the earliest observation

https://esawebb.org/images/potm2302a/



Massive lensing cluster Abell 2744:

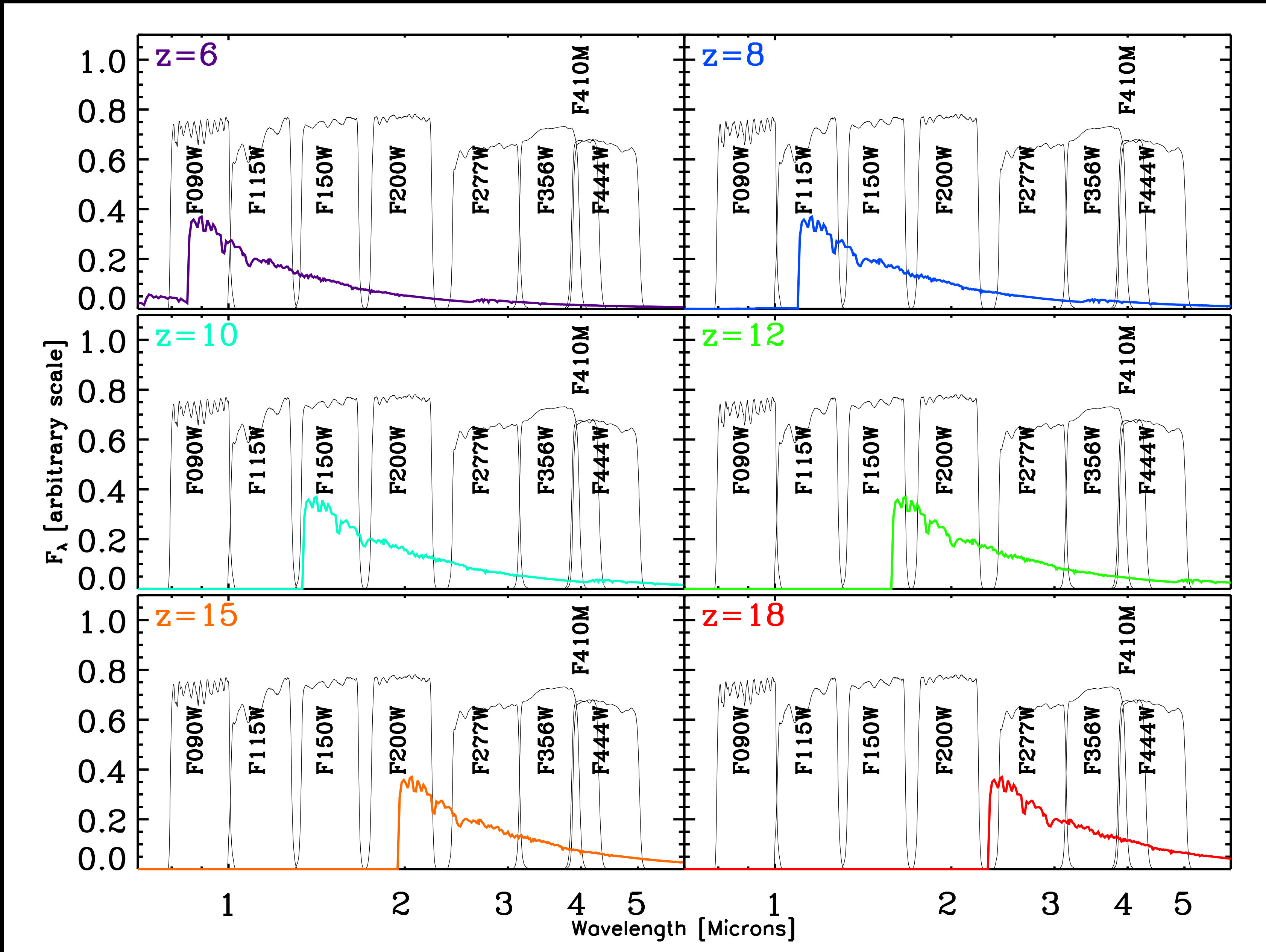
Over $\mathbf{10^{15}}$ solar masses seen 4 billion years ago:

Its gravity lenses 5 young galaxies at redshift z≃7.88,

i.e., / magnifying objects seen 13 billion years ago.

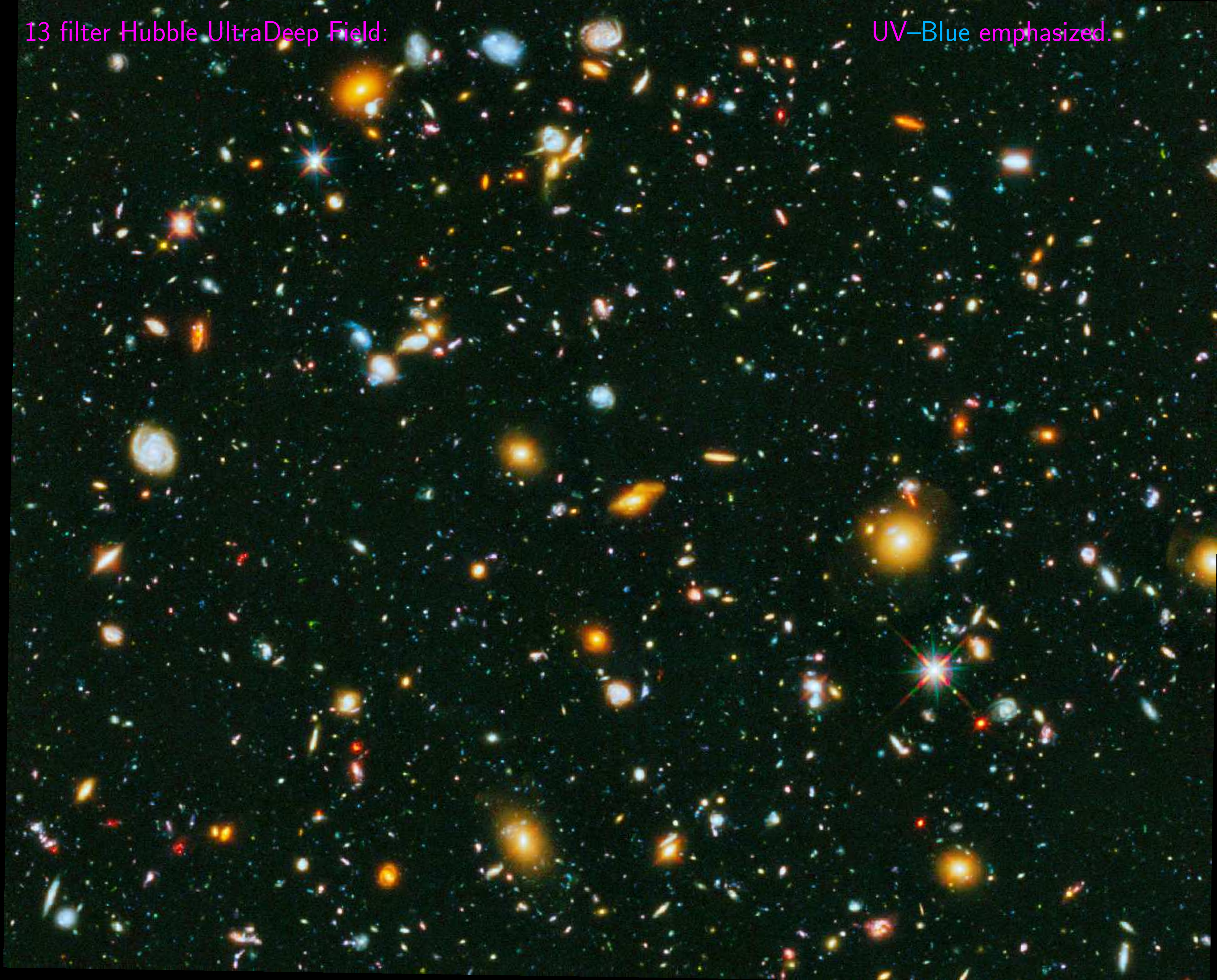
Webb is looking back to 650 million years after Big Bang!

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

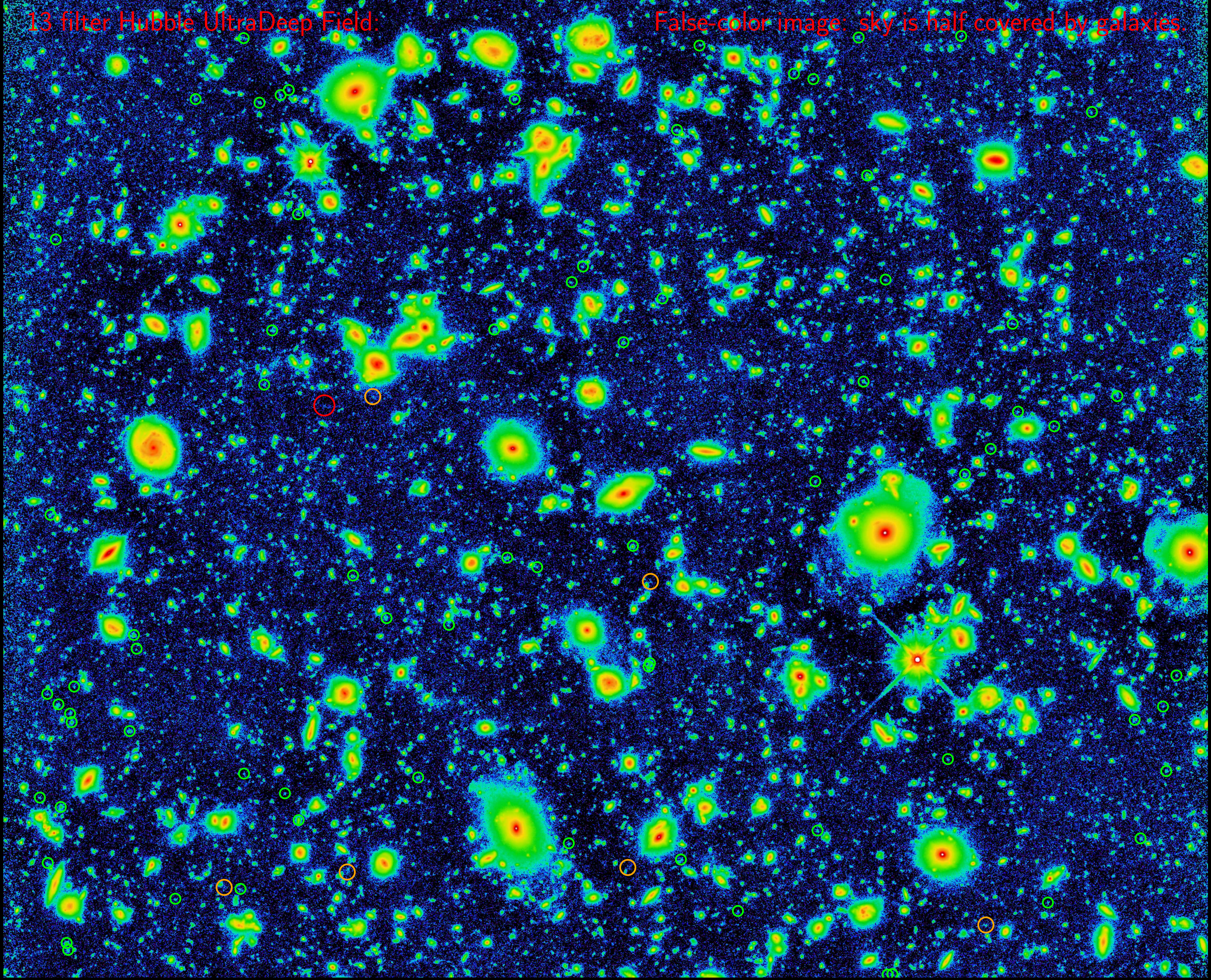


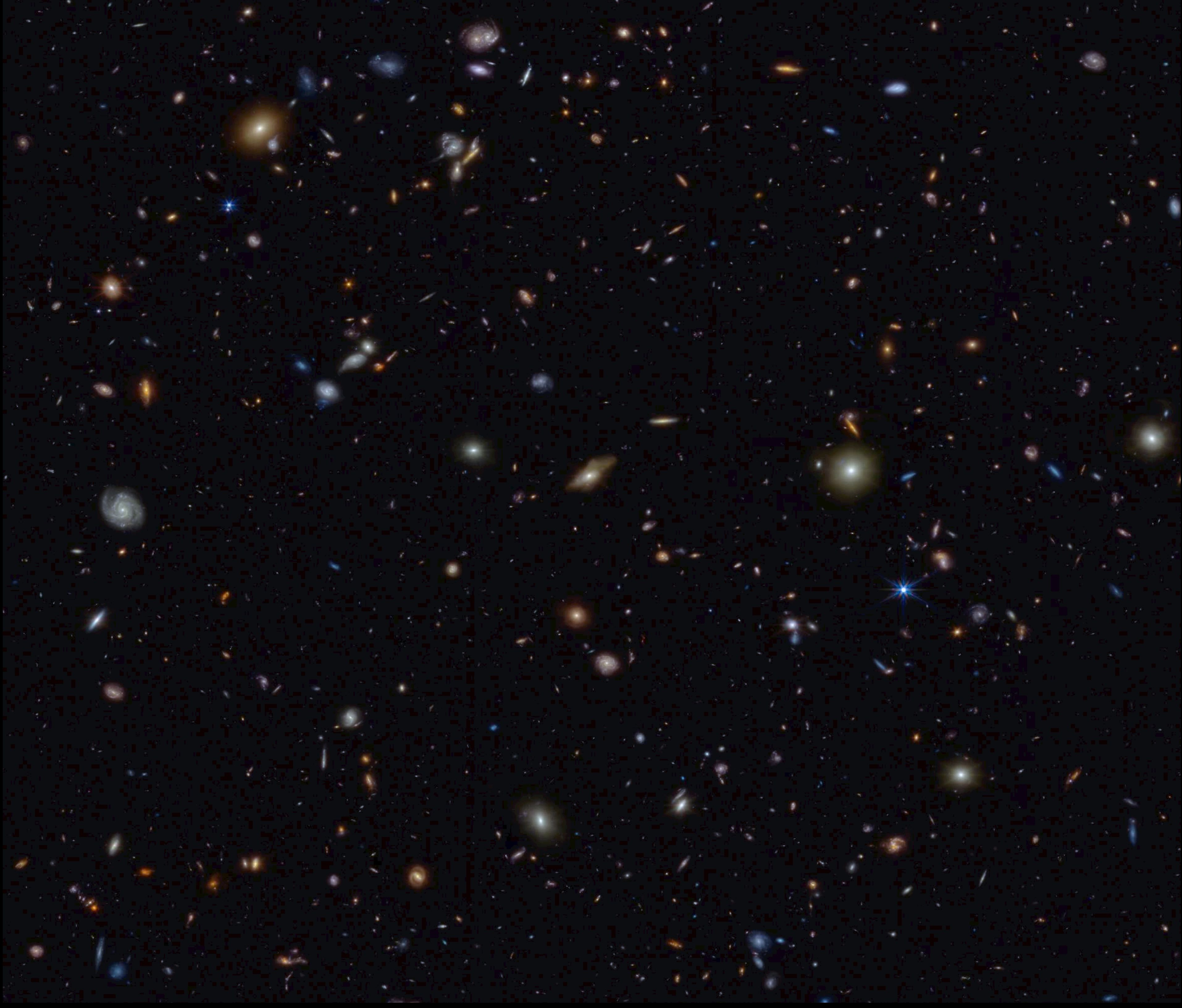
- Can't beat redshift: to see First Light, must observe near–mid IR.

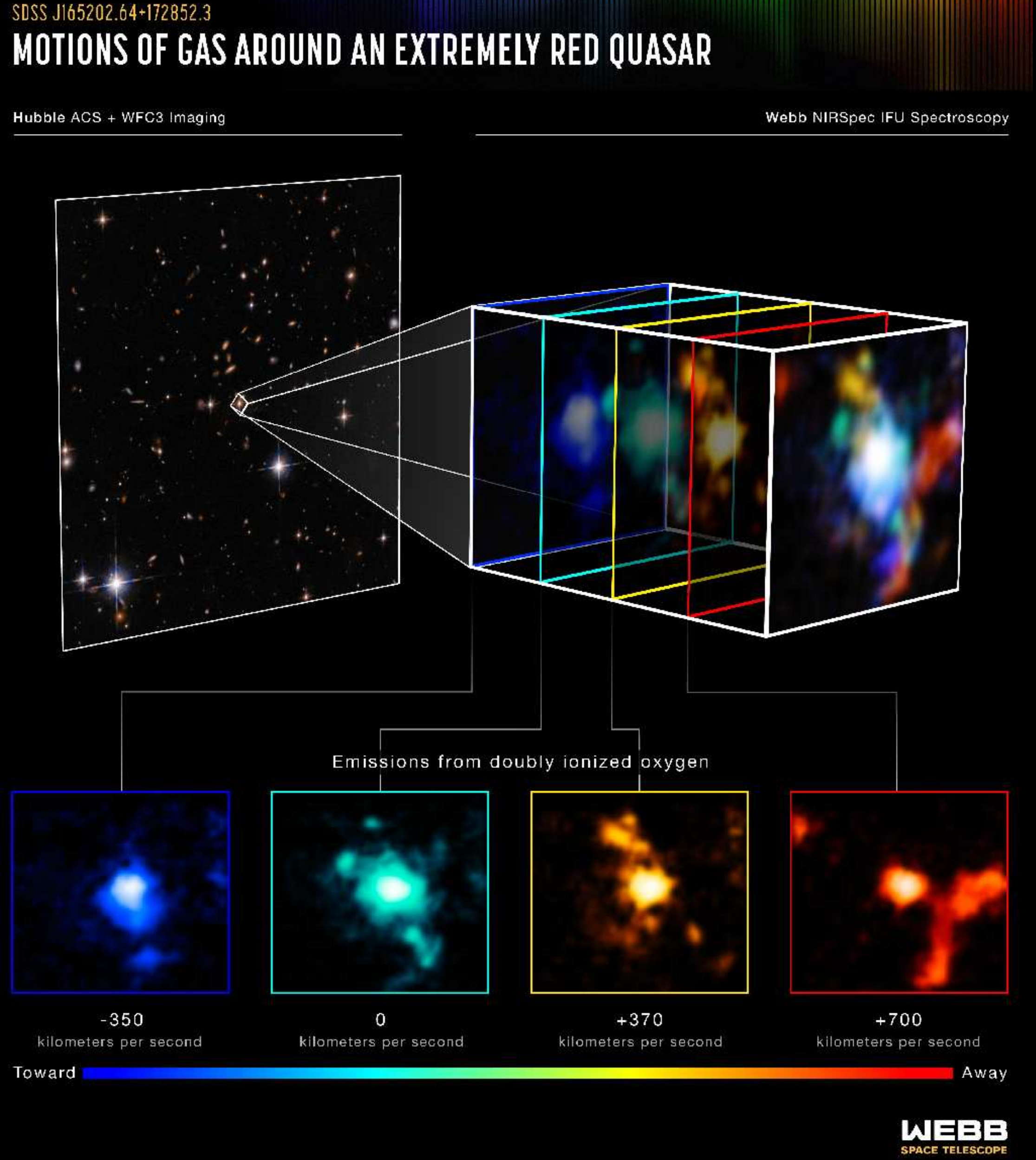
⇒ This is why JWST needs NIRCam at 0.8–5 μm and MIRI at 5–28 μm.


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.



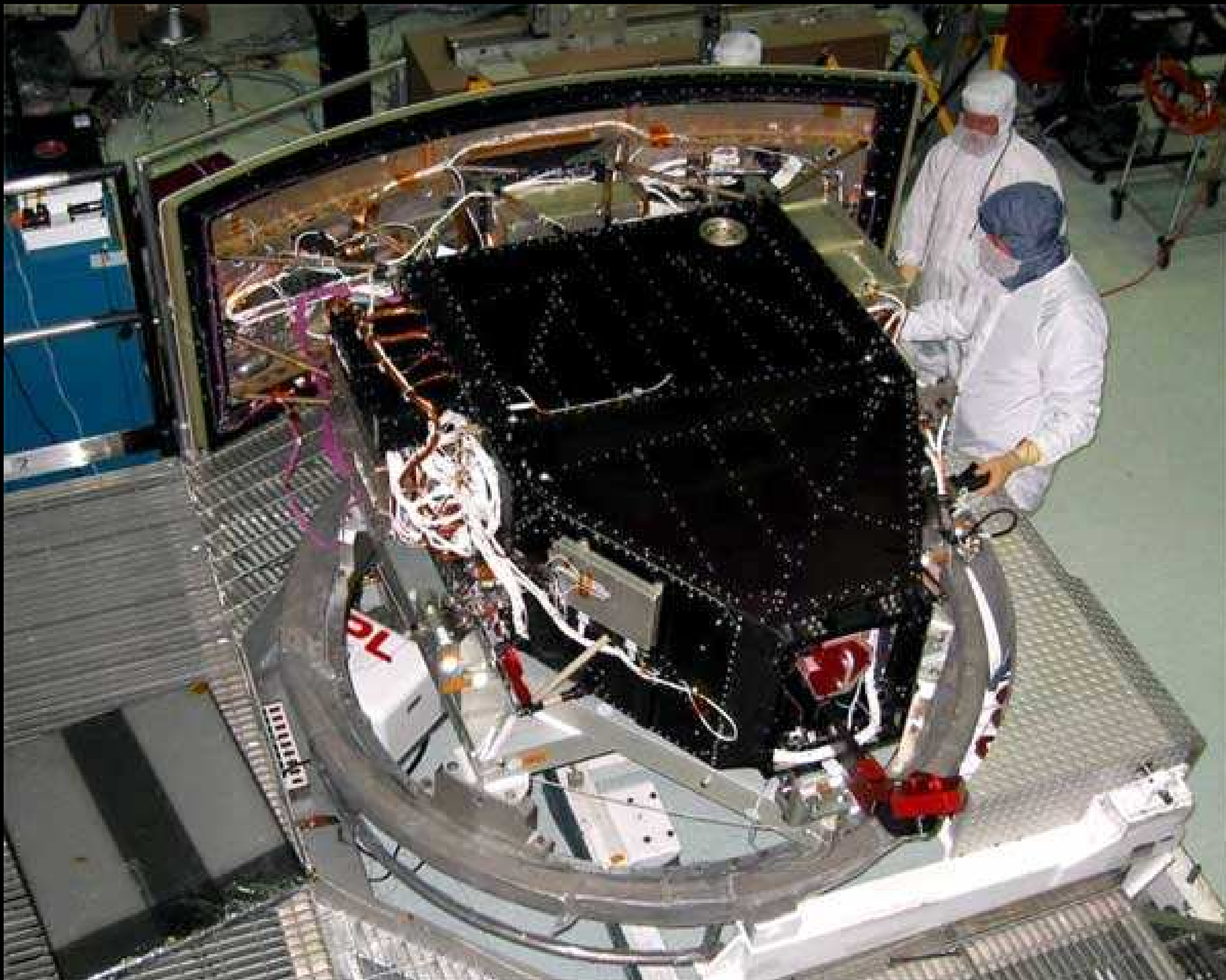


NIRSpec spectral cube of a luminous quasar seen 2.2 Byrs after Big Bang.

Colors indicate 3 companion galaxies falling into the quasar host galaxy.

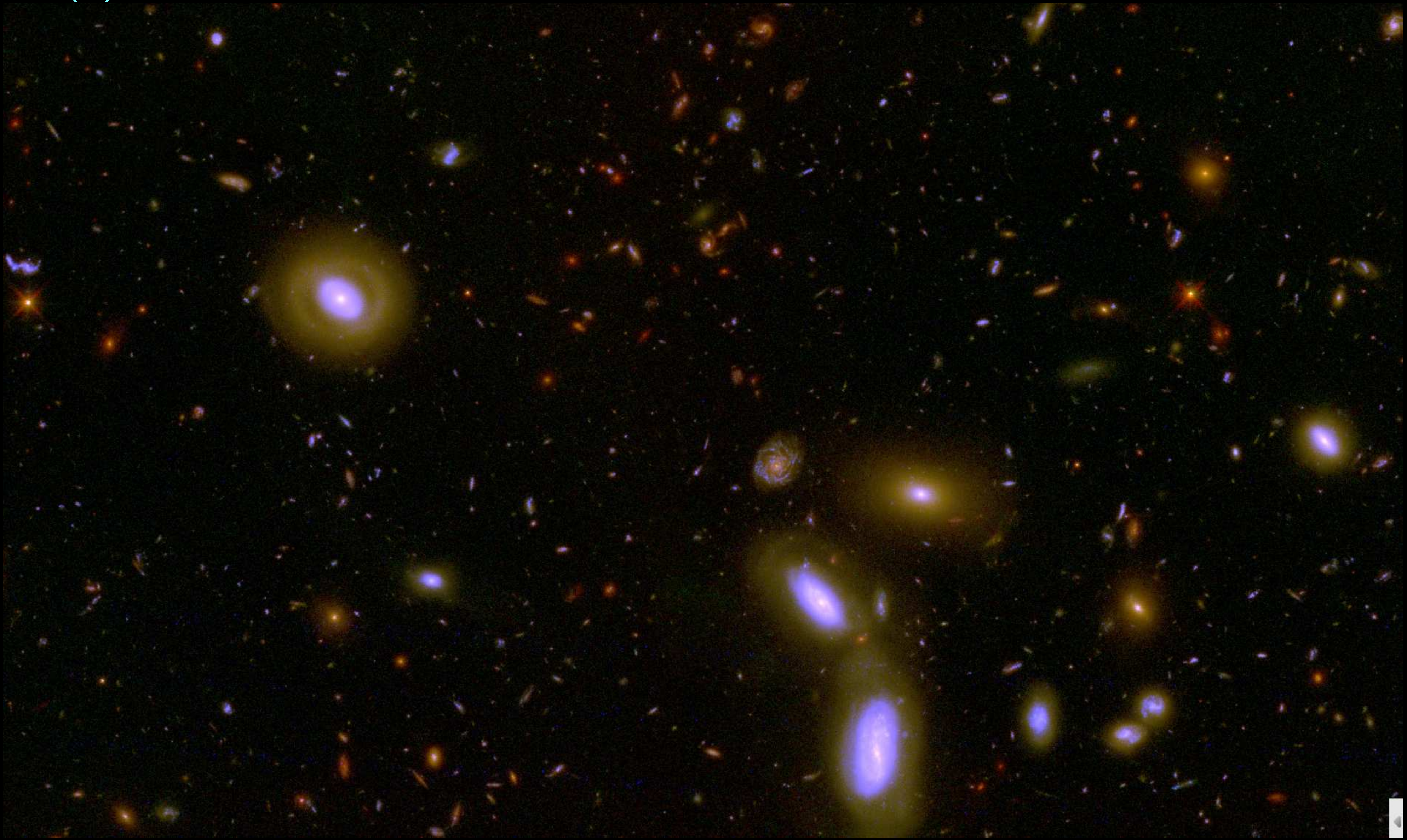
- In the first 2 billion years big galaxies were swallowing little ones!

(5) What Hubble has done: Panchromatic High-Throughput Camera



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

(5) 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).

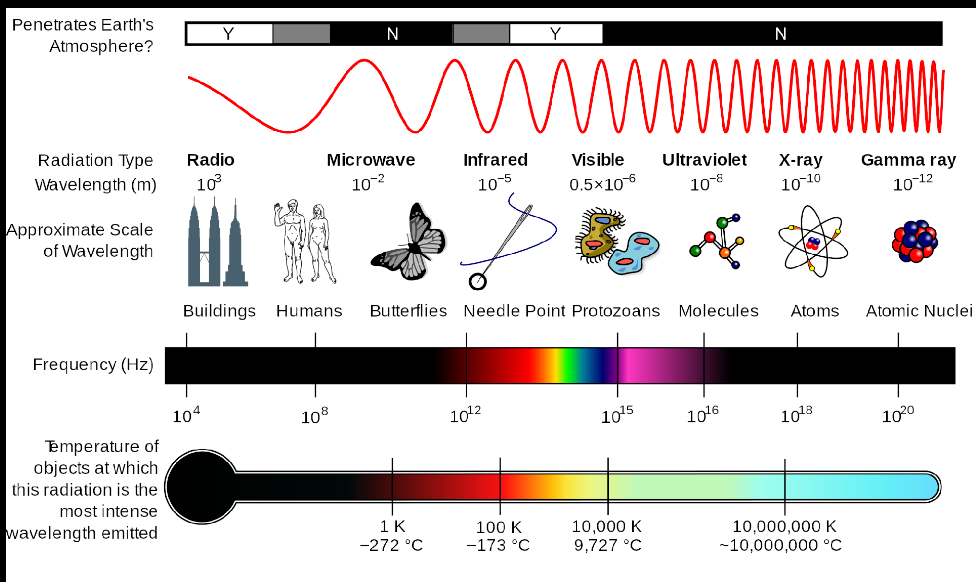
JWST adds 0.05–0.2" FWHM imaging to AB$\simeq$31.5 mag (1 FF) at 1–5μm, with 0.2–1.2" images at 5–29μm, tracing young+old stars & dust.

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

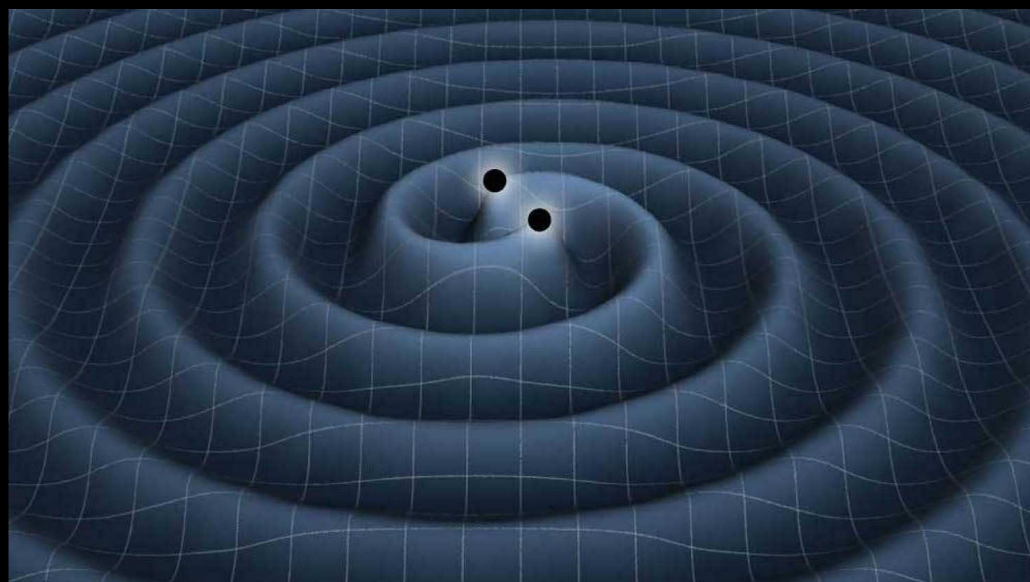
In solids: Earthquakes

In liquids: Surf!

In gasses: Sound

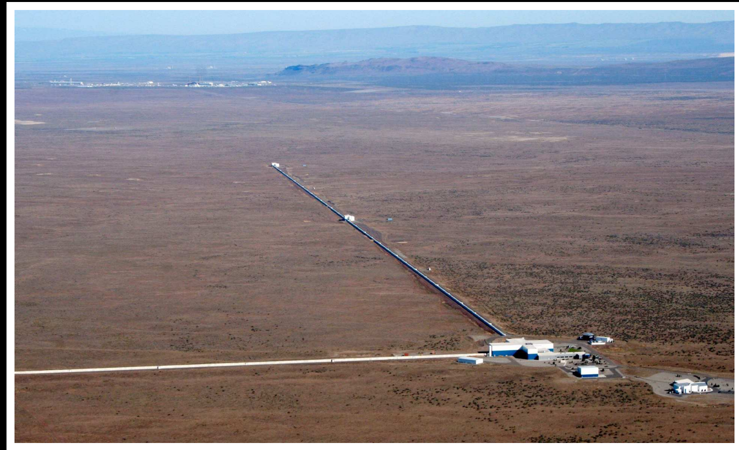


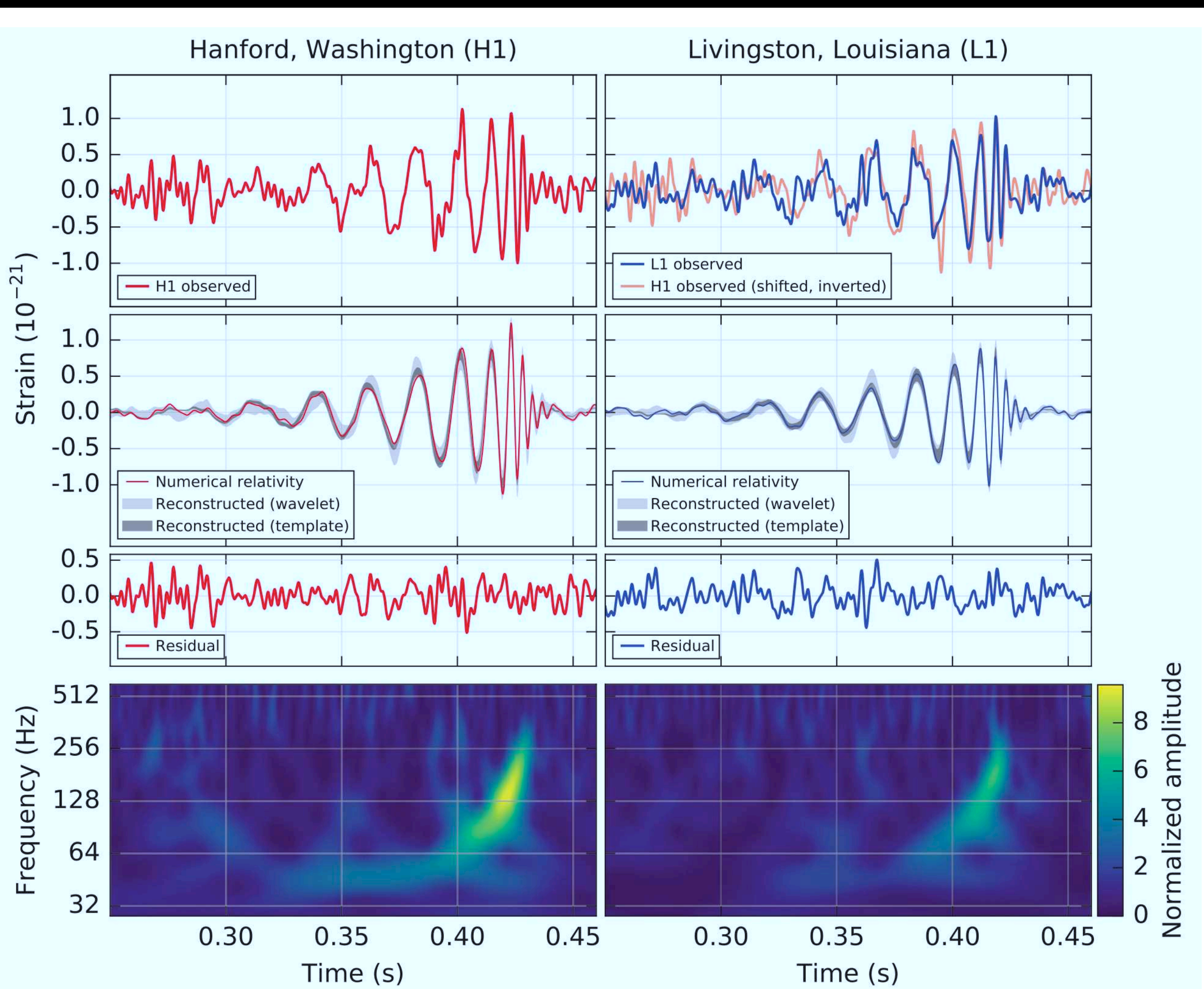
2) Electromagnetic Waves



3) In space-time: Gravity Waves

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

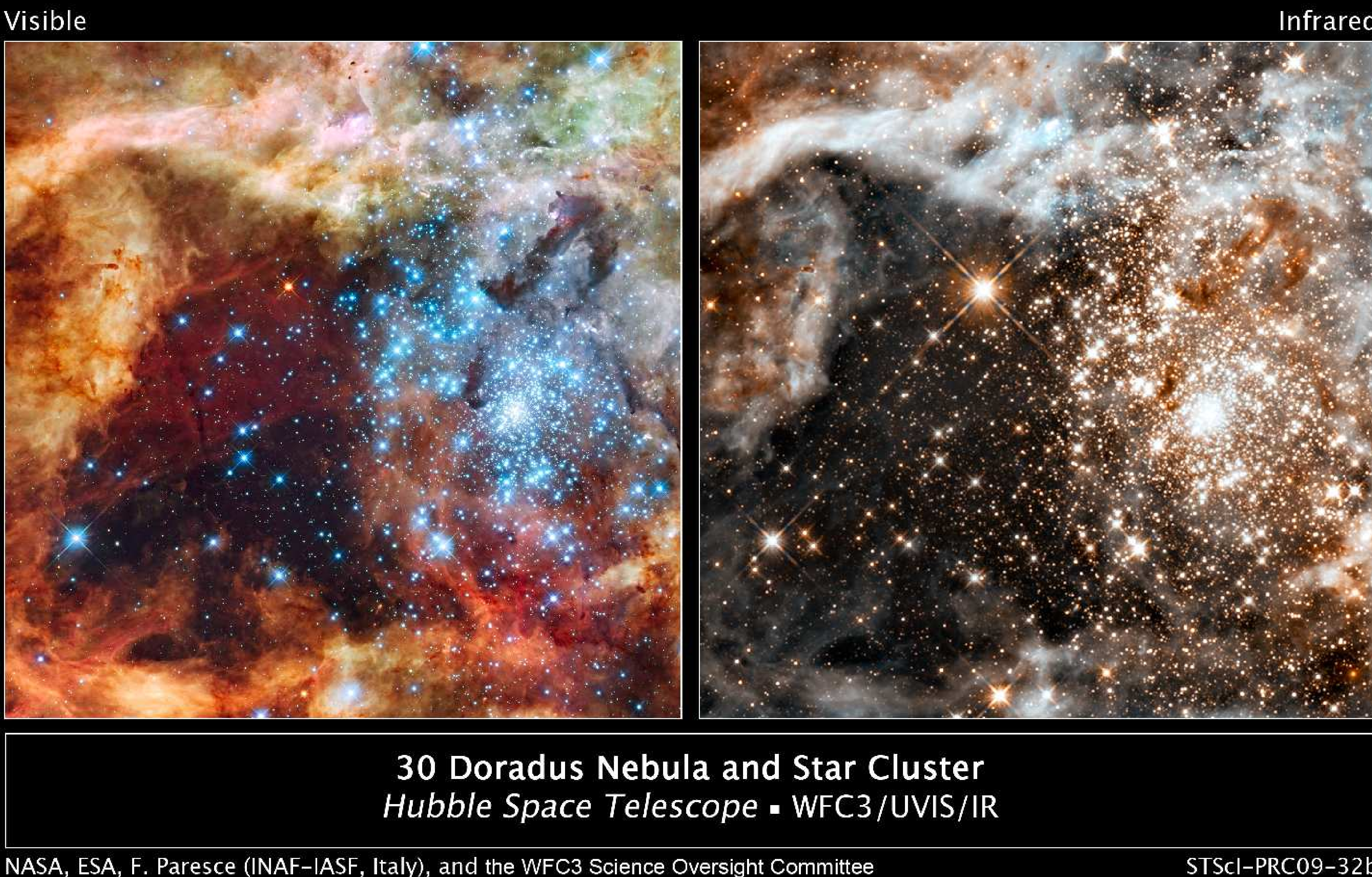




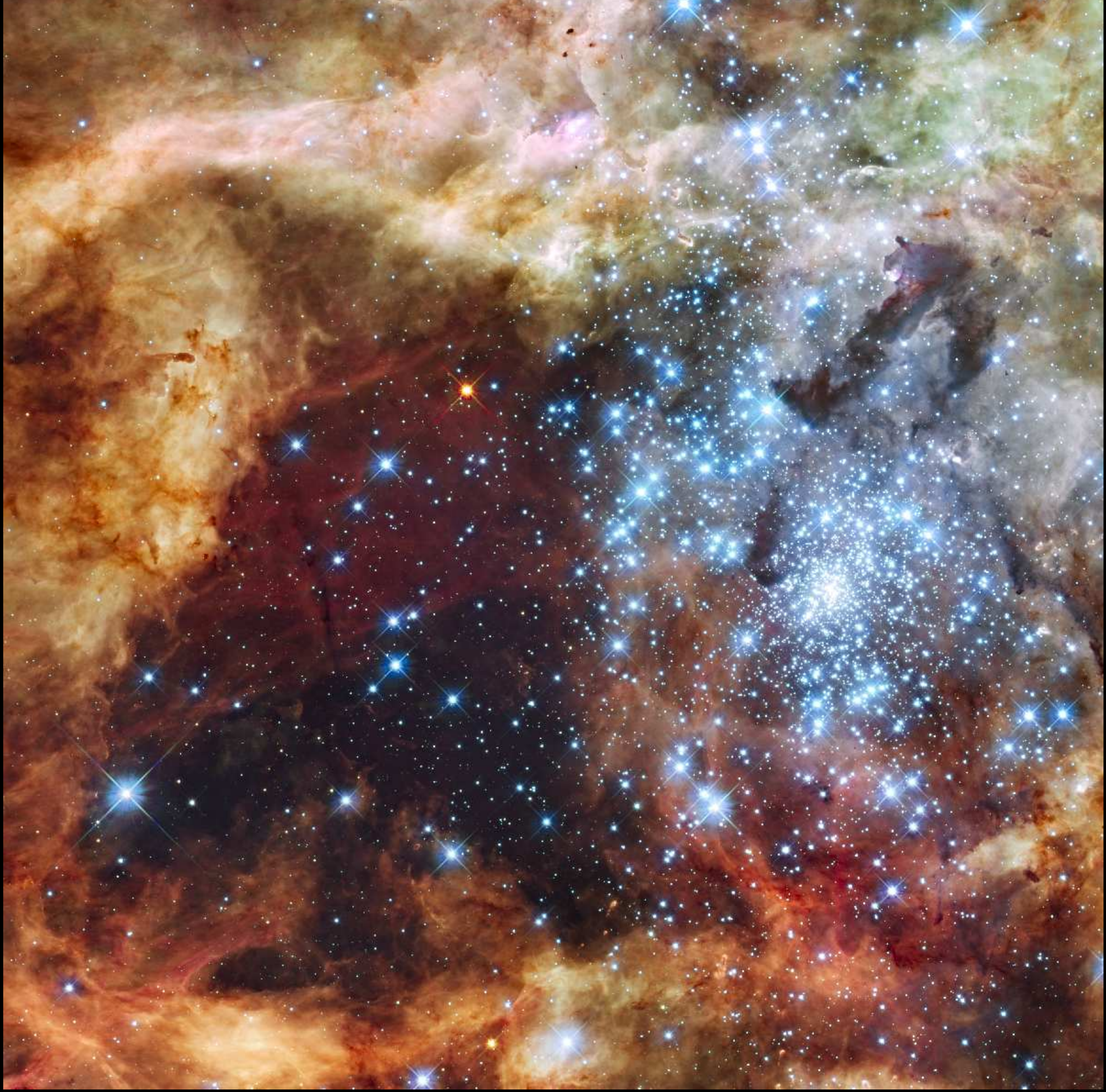
(1) LIGO first observed Gravitational Waves on Sept. 14, 2015.

(2) These were caused by two merging (29+36 $M_\odot$) black holes about 1 Gyr ago!

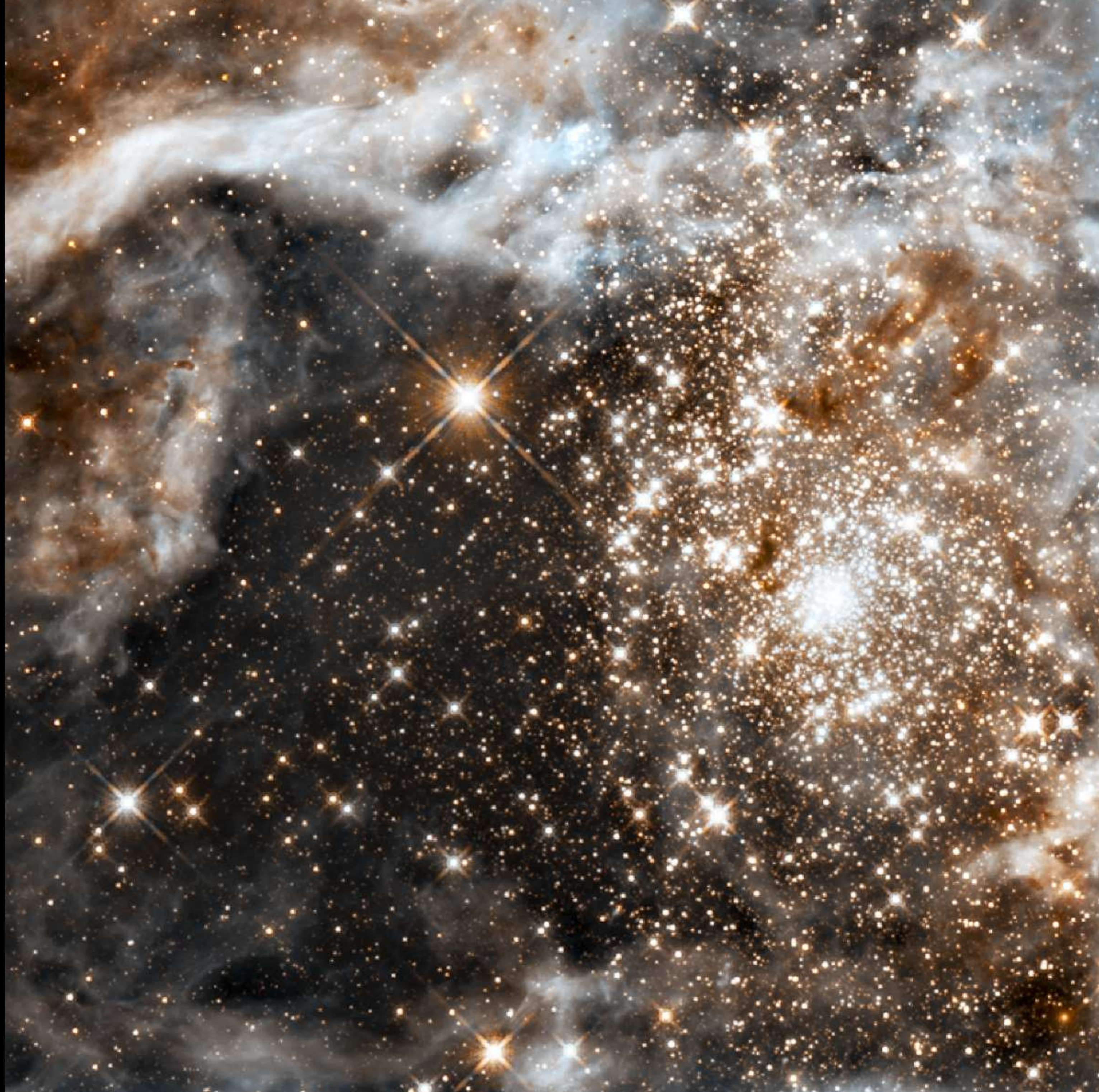
• $E=Mc^2$: 3 $M_\odot$ was converted to energy in a fraction of a second!



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 $M_{\odot}$).

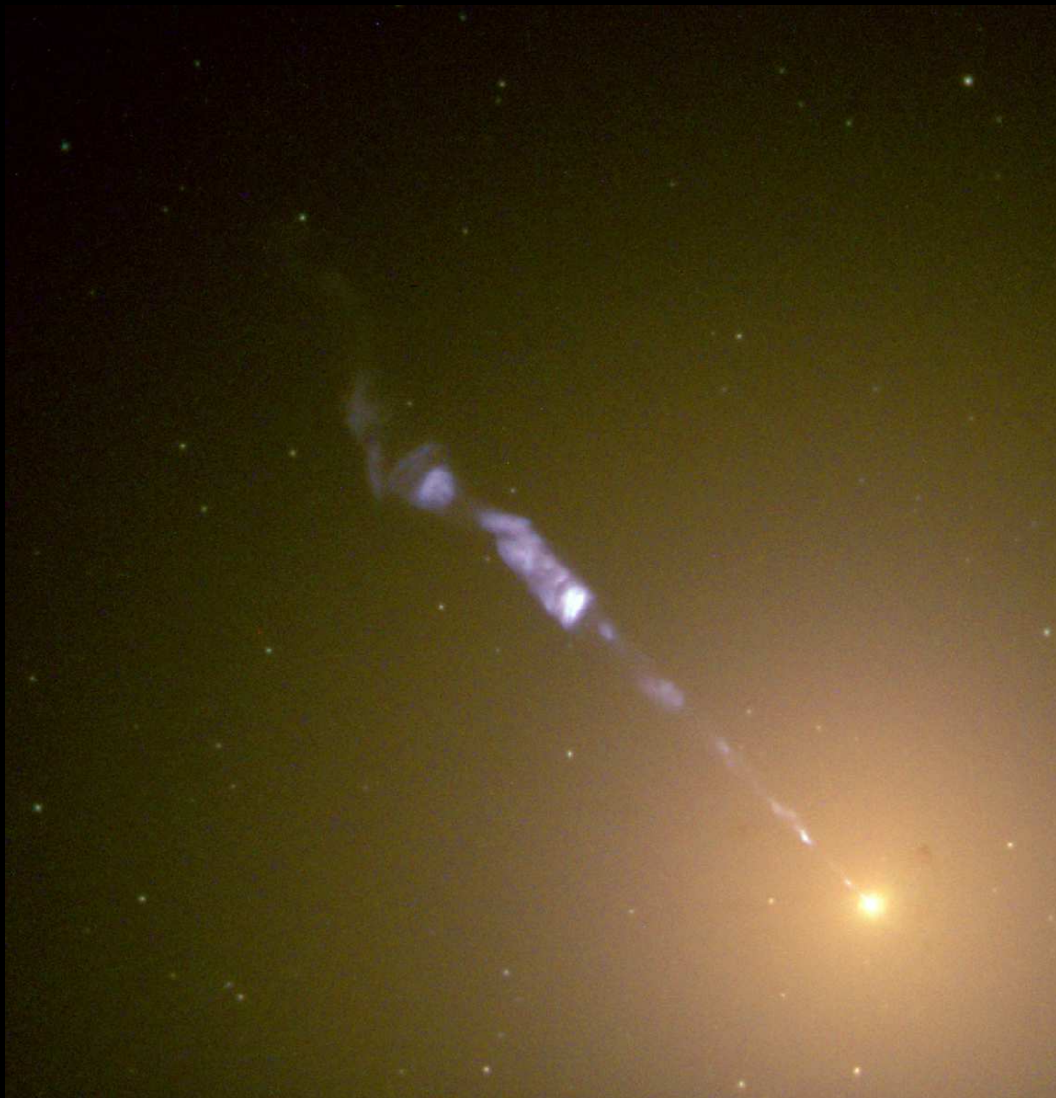


Ordinary massive stars (10–30 $M_{\odot}$) leave modest black holes ($\sim$3–10 $M_{\odot}$).

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:

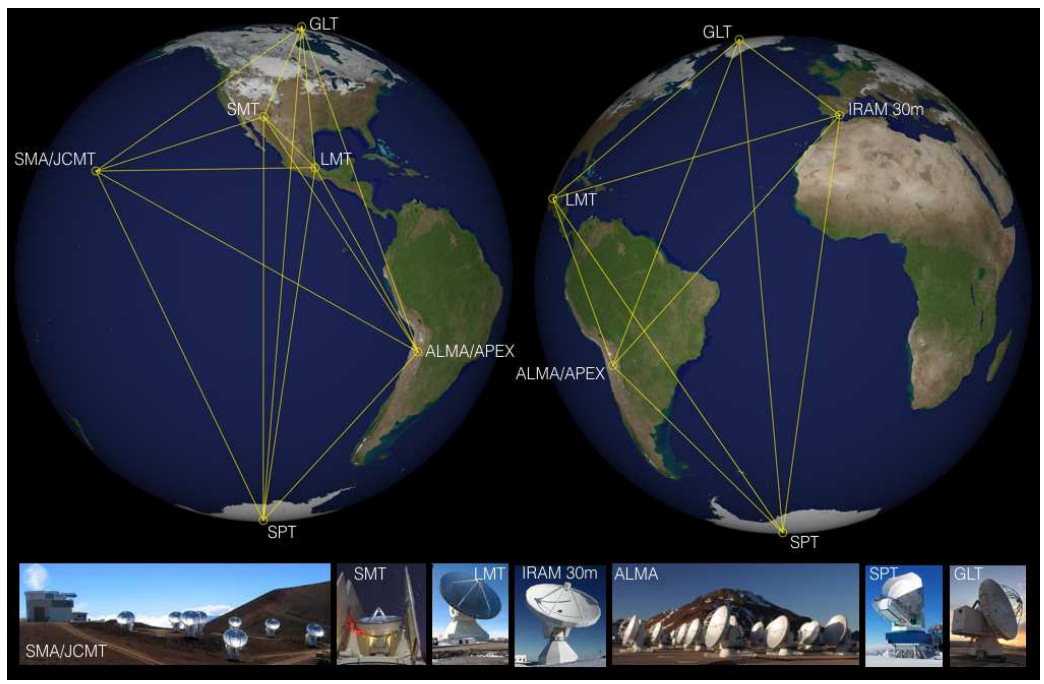


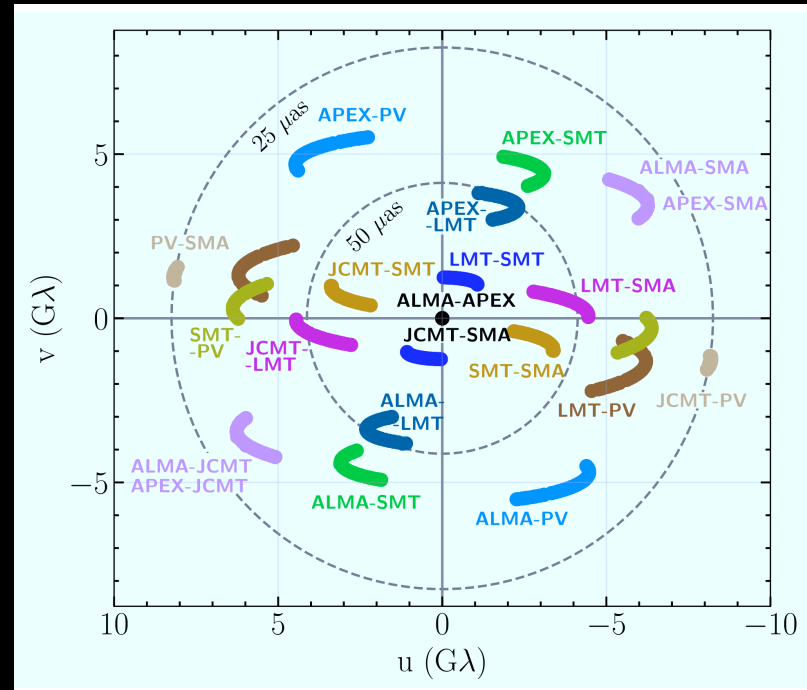
"For God's sake, Edwards. Put the laser pointer away."

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!





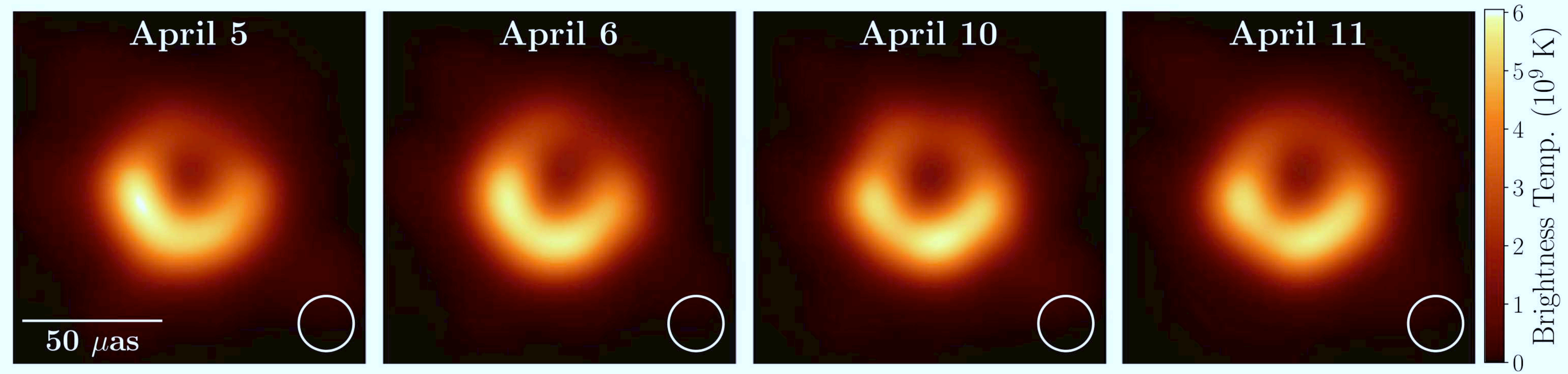
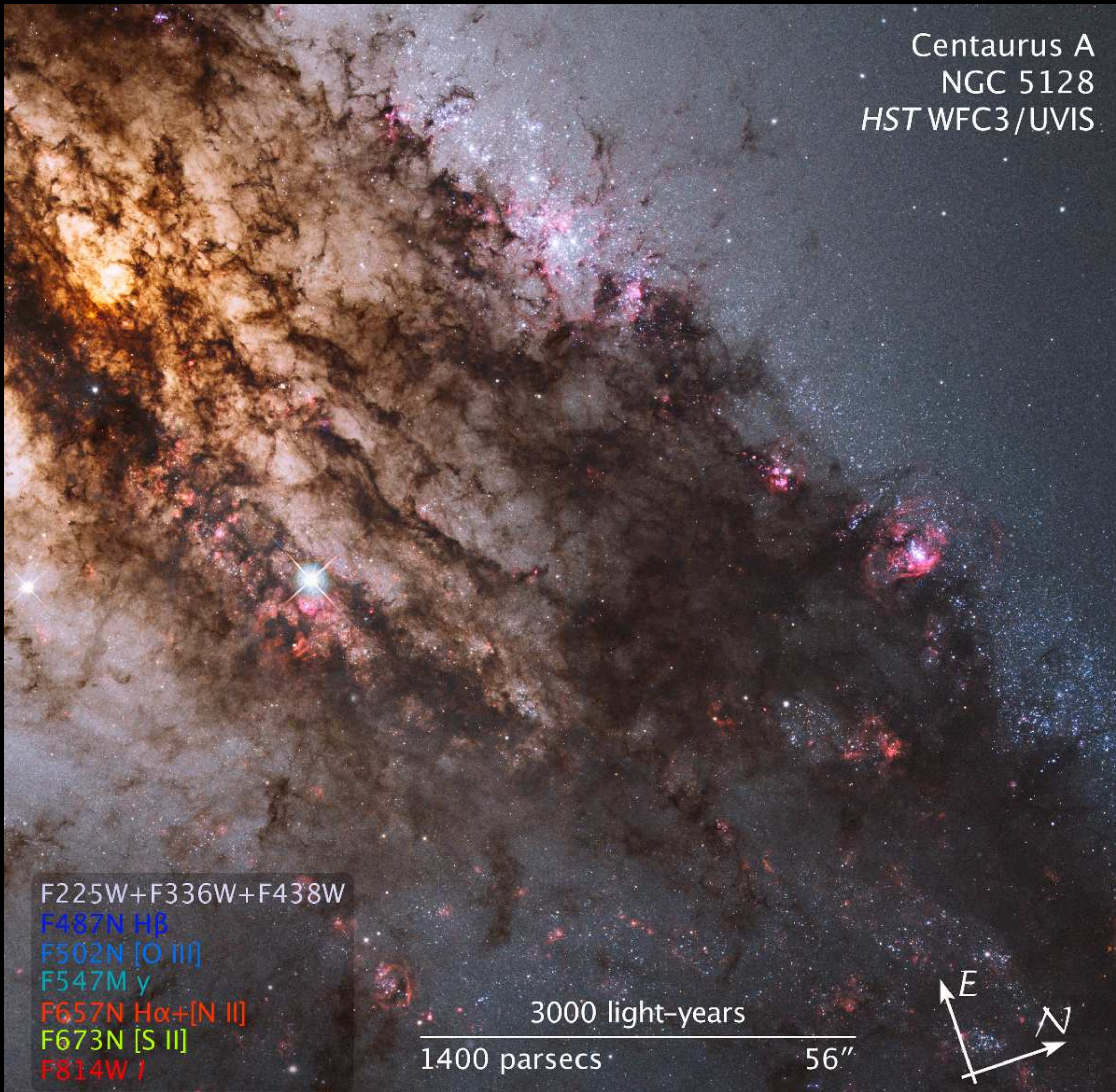
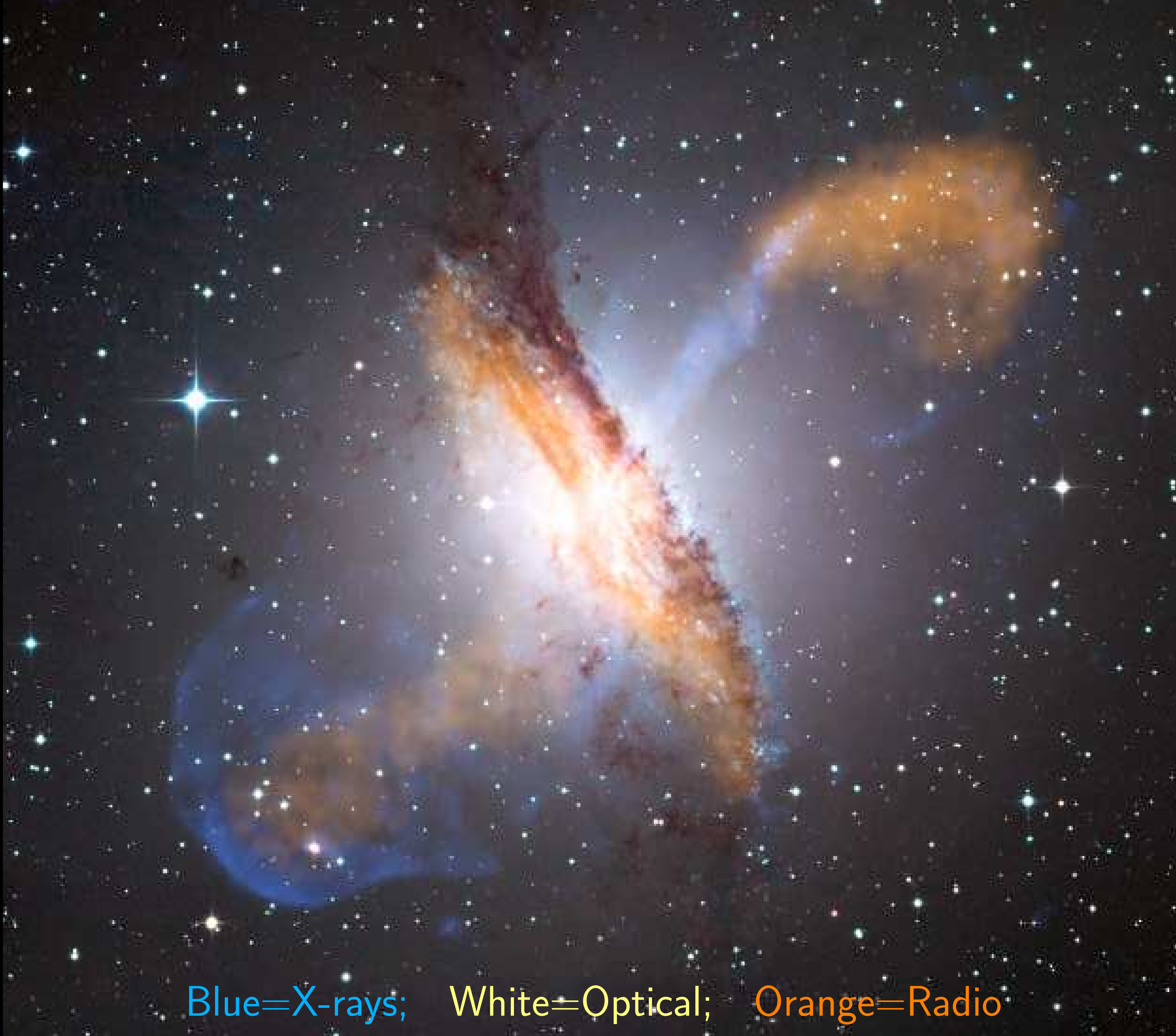


Figure 15. Averages of the three fiducial images of M87 for each of the four observed days after restoring each to an equivalent resolution, as in Figure 14. The indicated beam is 20 μas (i.e., that of DIFMAP, which is always the largest of the three individual beams).

2019 discovery of Black Hole Shadow in M87 by Event Horizon Telescope:
M87 at 55 Mlyr distance has a black hole mass of $\sim 6.5 \times 10^9\ M_\odot$!

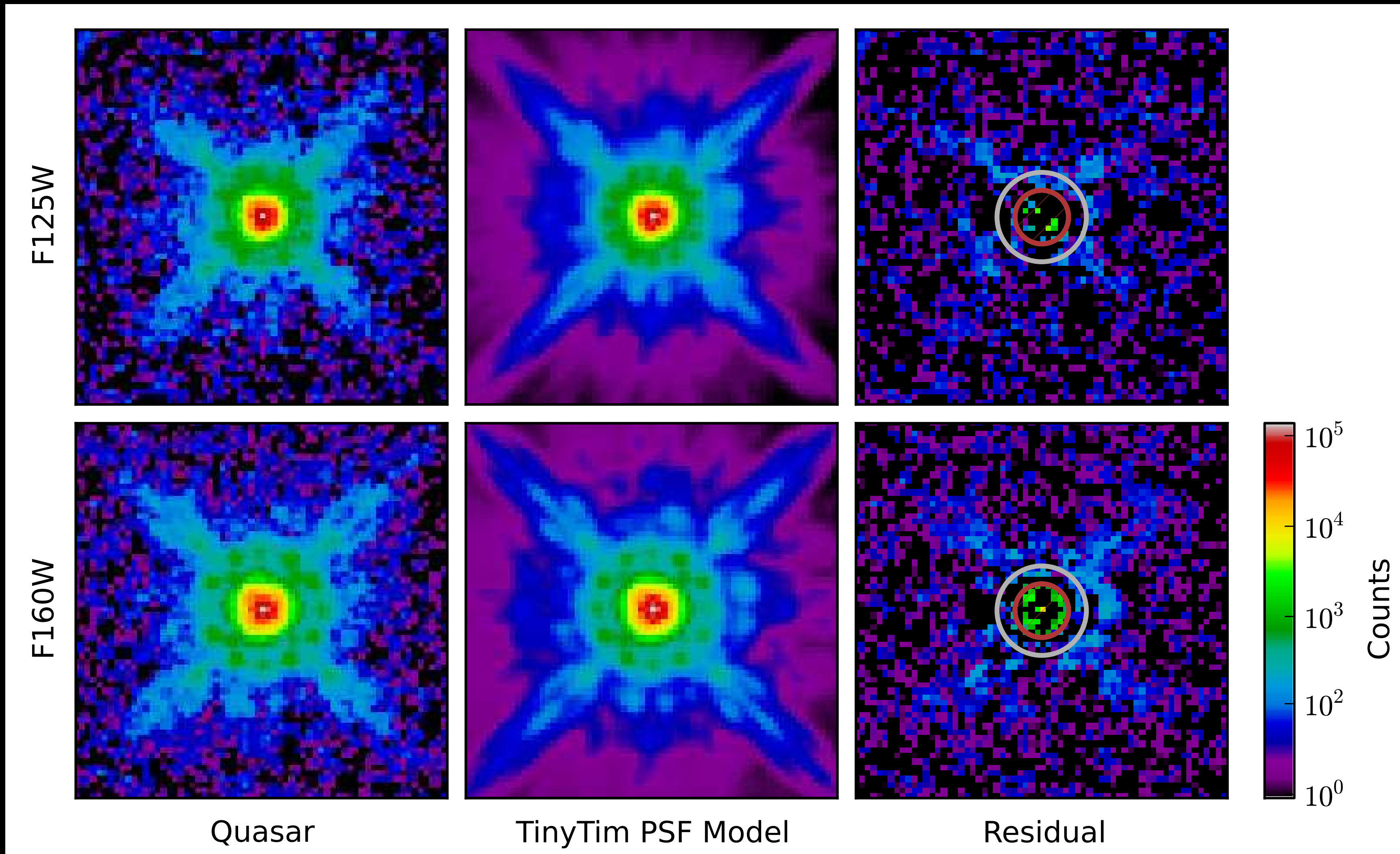

Centaurus A
NGC 5128
HST WFC3/UVIS
F225W+F336W+F438W
F487N Hβ
F502N [O III]
F547M y
F657N Hα+[N II]
F673N [S II]
F814W I
3000 light-years
1400 parsecs
56″
E
N


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

JWST NIRcam+MIRI: nearby actively star-forming galaxy Arp 220:

- Copious amounts of inflowing gas and dust feed the central monster!

• Quasars: Centers of galaxies with feeding supermassive blackholes:

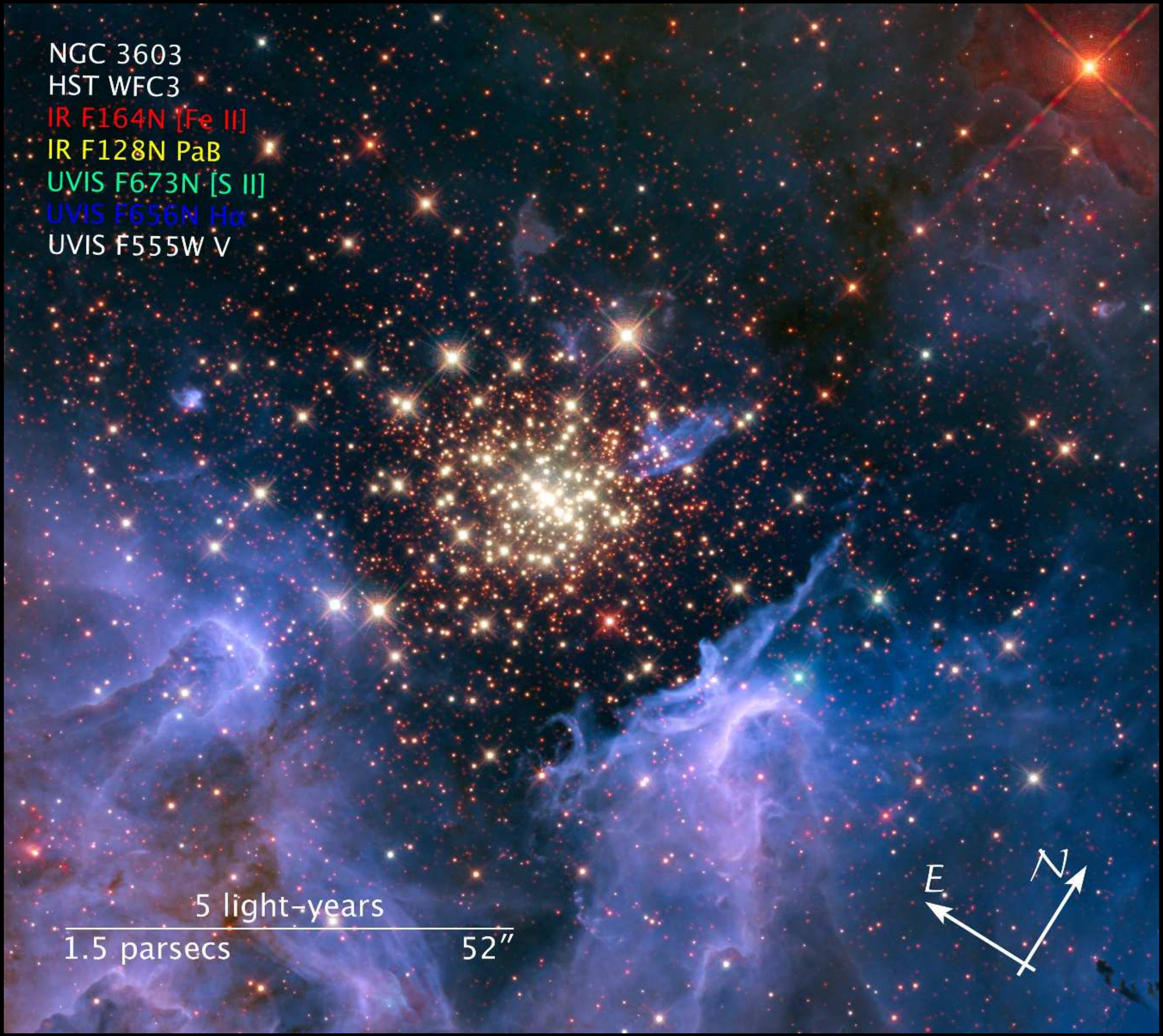


- Hubble IR-images of the most luminous Quasar known in the universe.
- Seen at redshift 6.42 (universe 7.42× smaller than today), 900 Myr old!
- Contains 10^{14} solar luminosities within a region as small as Pluto's orbit!
- A feeding monster blackhole (>3×10^9 solar mass) 900 Myr after BB!

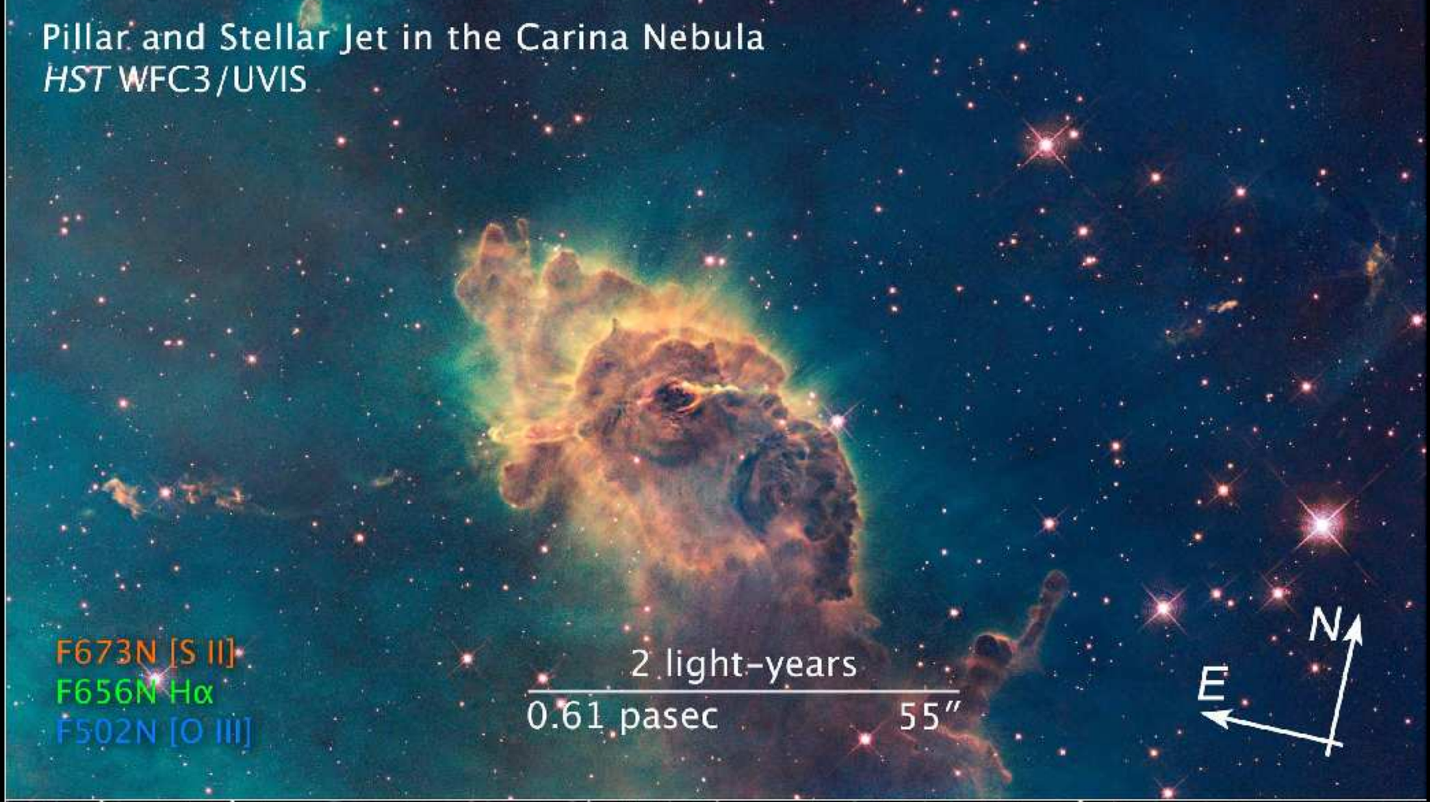
Conclusion 2: Supermassive black holes started early & were very rapid eaters:

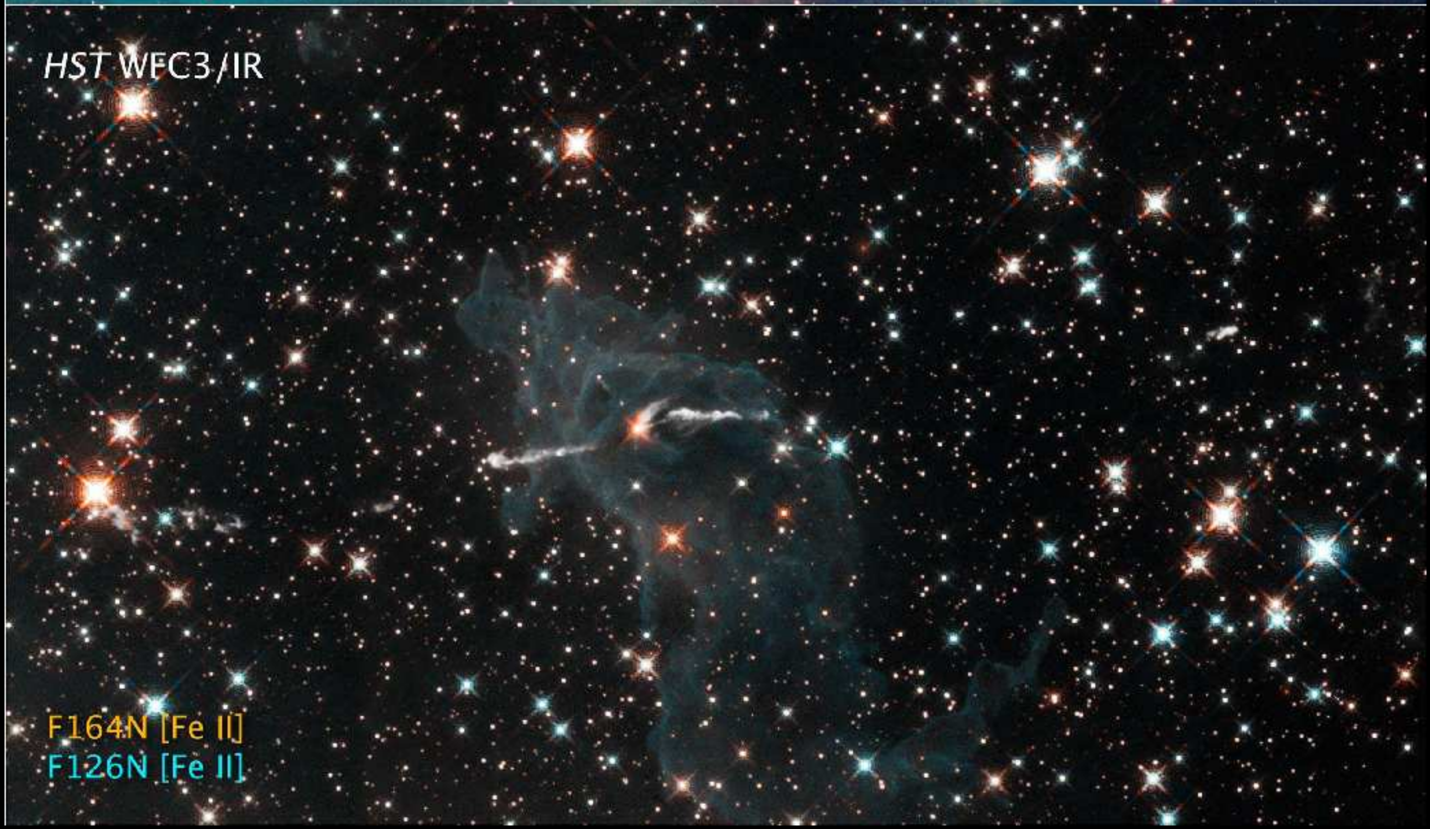
- Massive galaxies today contain a super-massive blackhole, no exceptions!
- Masses $\sim 3 \times 10^9$ solar, leftover from the First Stars (first 500 Myr)?
- Must have fed enormously rapidly in the first 1 Byr after the Big Bang.
- Were eating cat-astrophically (and secretly) until they ran out of food ...
- JWST can image the First Quasars to z$\gtrsim$10 (*if* we can find them).

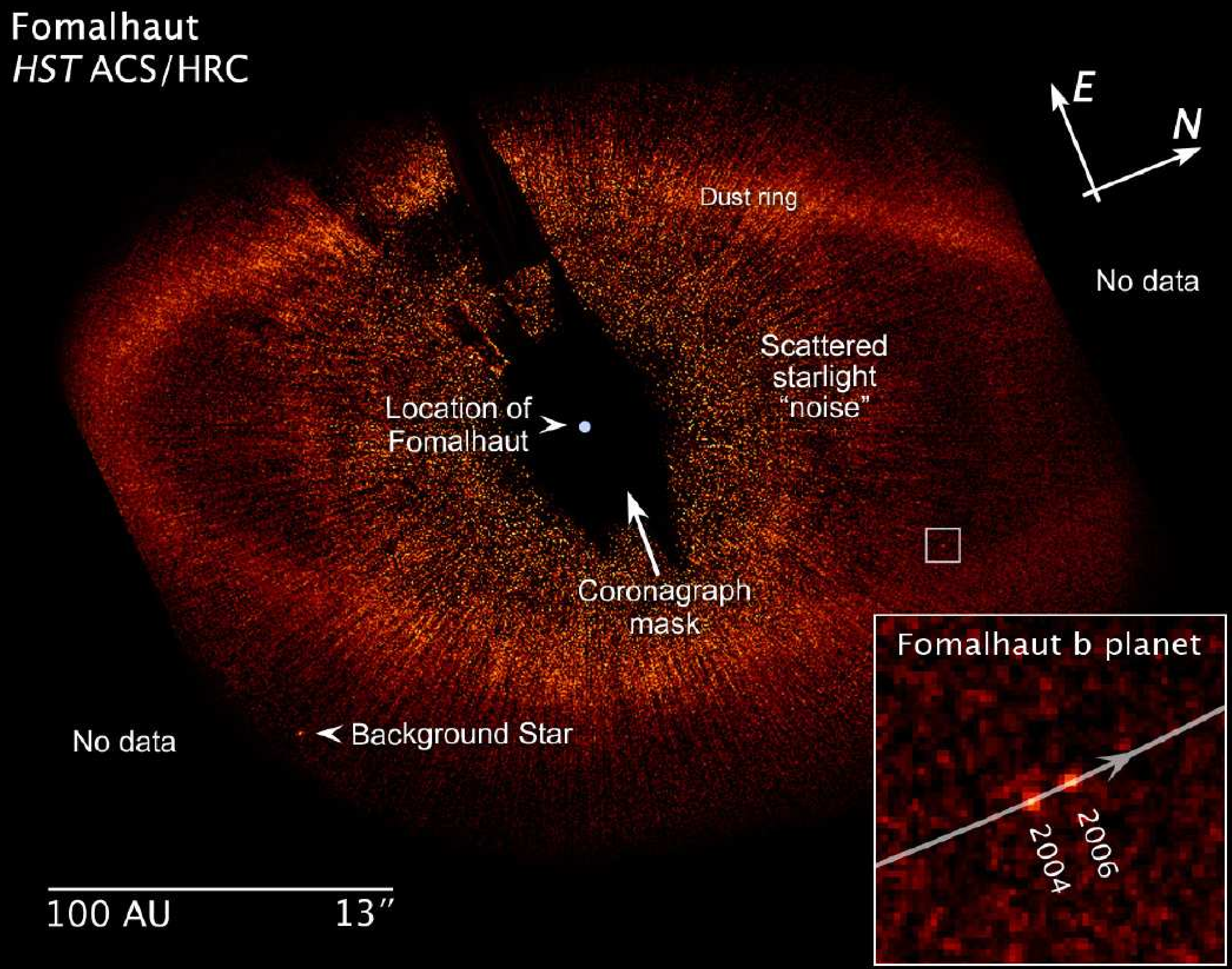
(6) How can JWST measure Earth-like exoplanets?



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

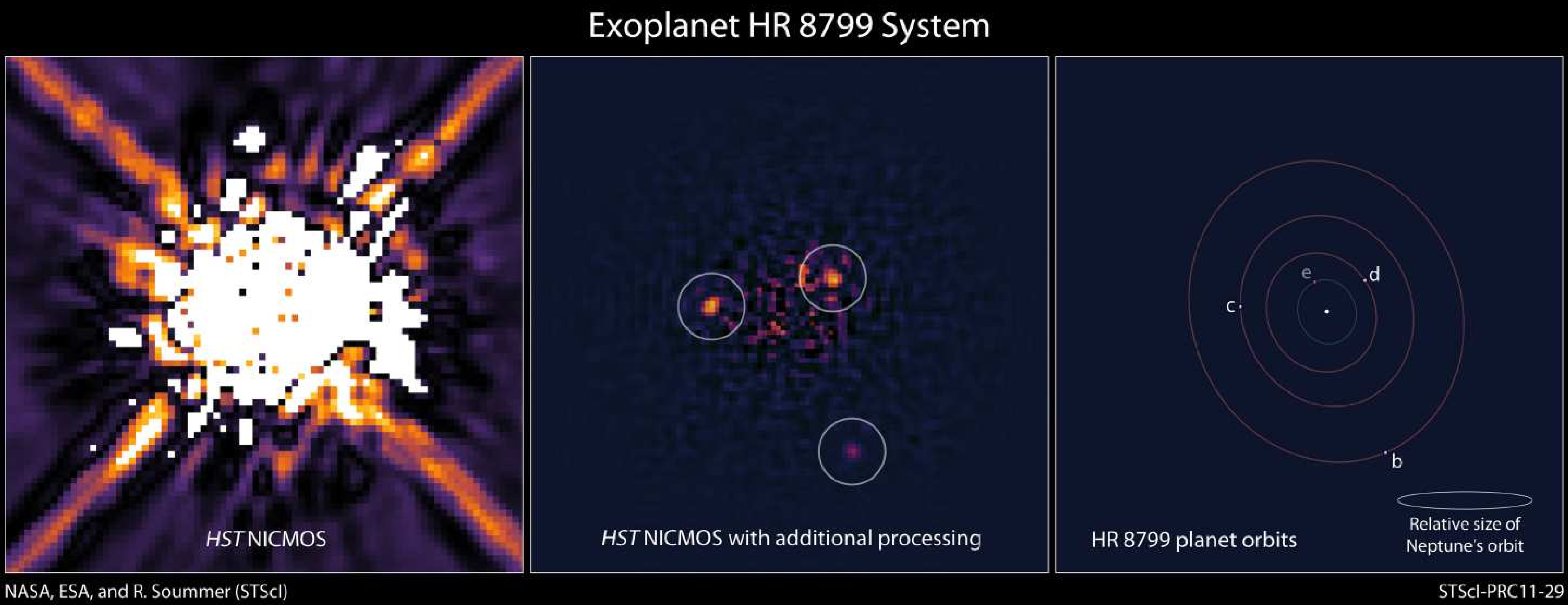

Pillar and Stellar Jet in the Carina Nebula
HST WFC3/UVIS
F673N [S II]
F656N Hα
F502N [O III]
2 light-years
0.61 pasec
55″
N
E


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!

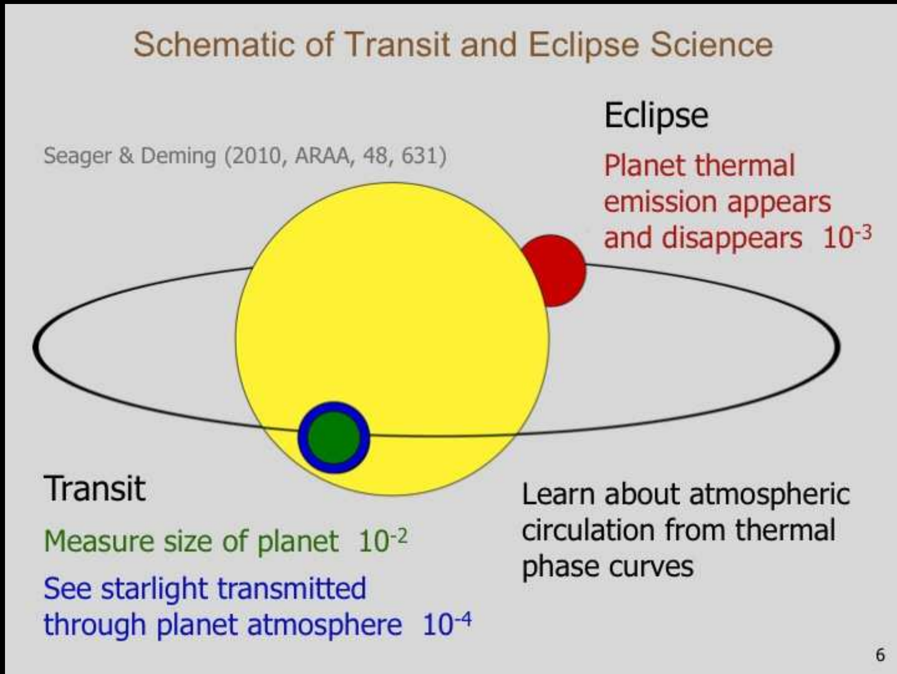
JWST can find such planets much closer in for much farther stars.

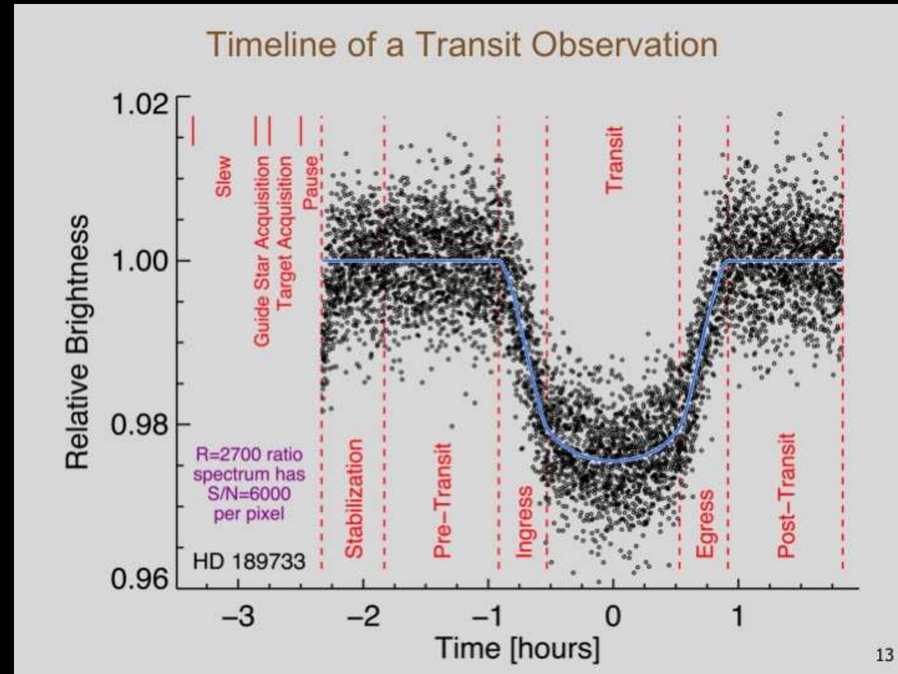


HST/NICMOS imaging of planetary system around the (carefully subtracted) star HR 8799: Direct imaging of planets around a nearby star.

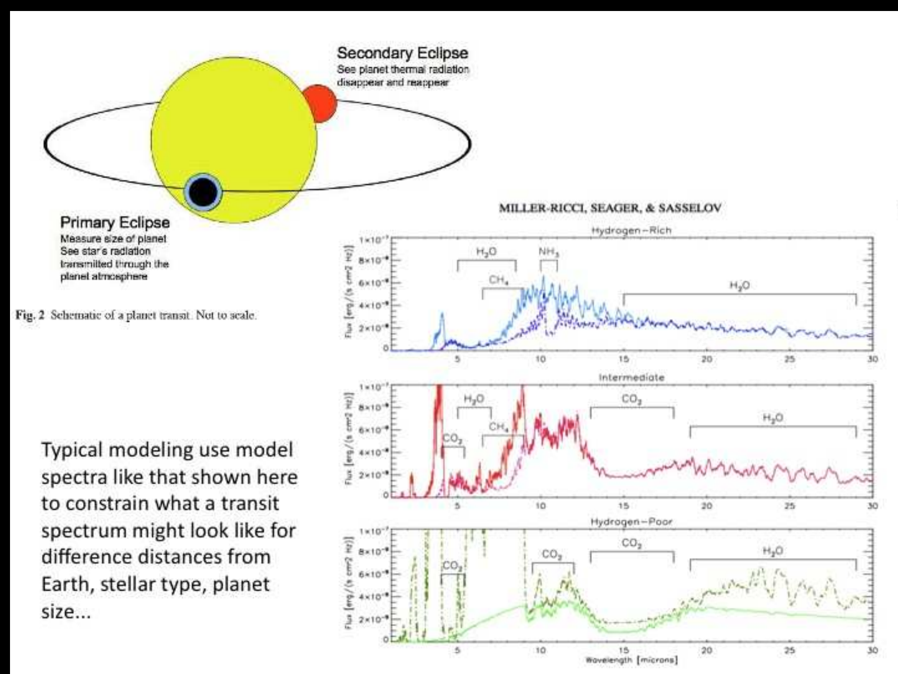
Press release: http://hubblesite.org/newscenter/archive/releases/2011/29/

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



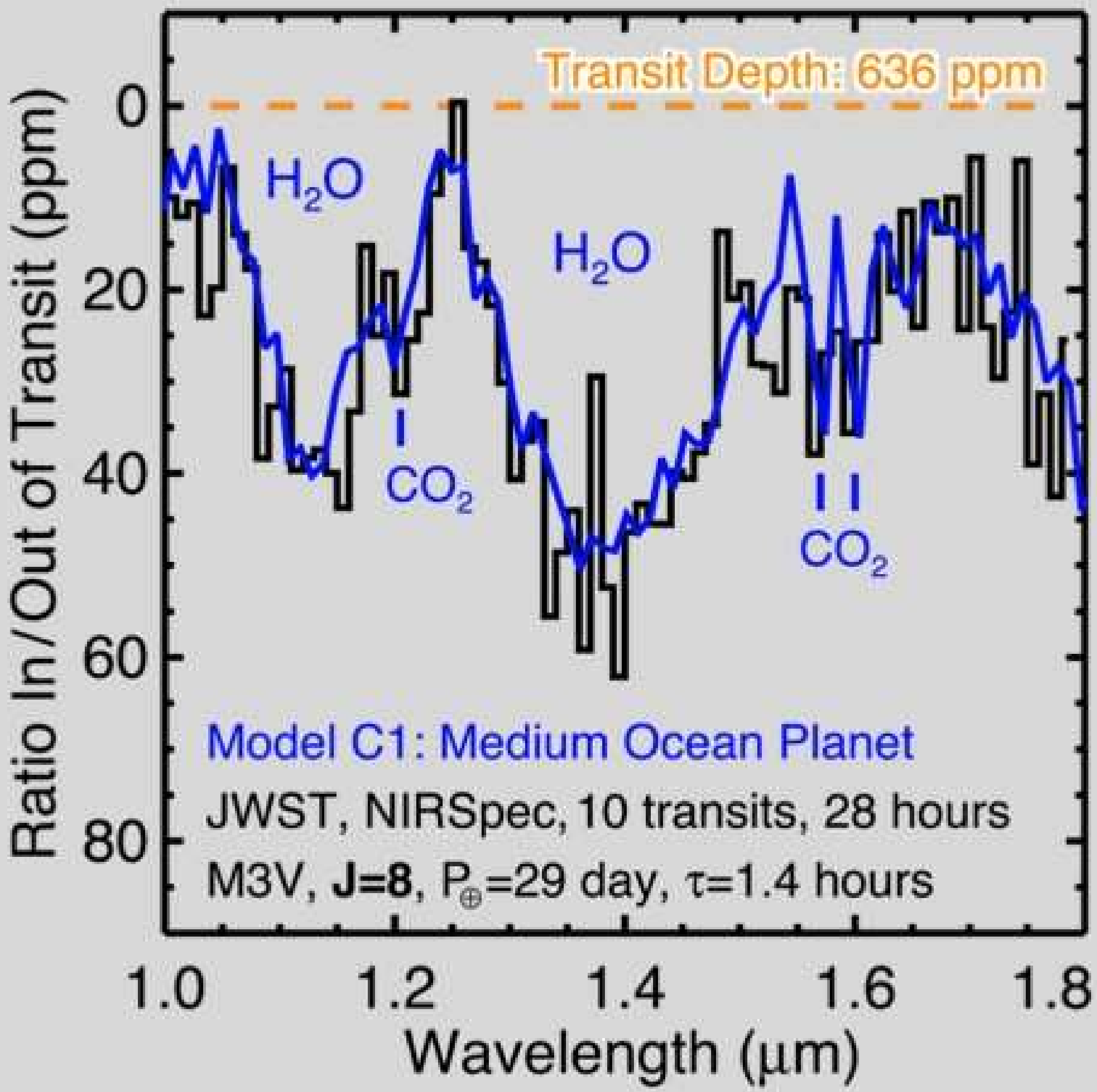


JWST can do very precise photometry of transiting Earth-like exoplanets.



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.

Some of our ASU grad students do important outreach events:

Annual Girl Scout Stargazing at the White House South lawn (July 2015).

Our own Amber Straughn (right; now at NASA GSFC working for Nobel Laureate Dr. John Mather) informs the Obama's about NASA.