The Infrared Universe Beyond Hubble:
The James Webb Space Telescope — July 2022!

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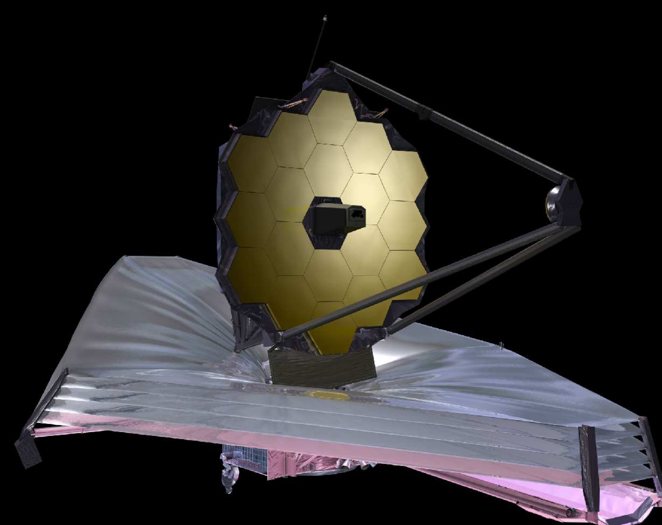
+ the PEARLS team of 75 scientists world-wide



1973∼2025$^+$; 1996∼2042;

Talk to the Dutch Consul and "Onze Landgenoten" in Arizona; (ASU, Tempe)

Wednesday Aug. 3, 2022. All presented materials are ITAR-cleared.

Outline

- (1) Update on the James Webb Space Telescope (JWST), 2022.
- (2) How can JWST measure the Epochs of First Light & Galaxy Assembly, and Supermassive Black-Hole Growth?
- (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!

Sponsored by NASA/HST & JWST

ARIZONA STATE UNIVERSITY

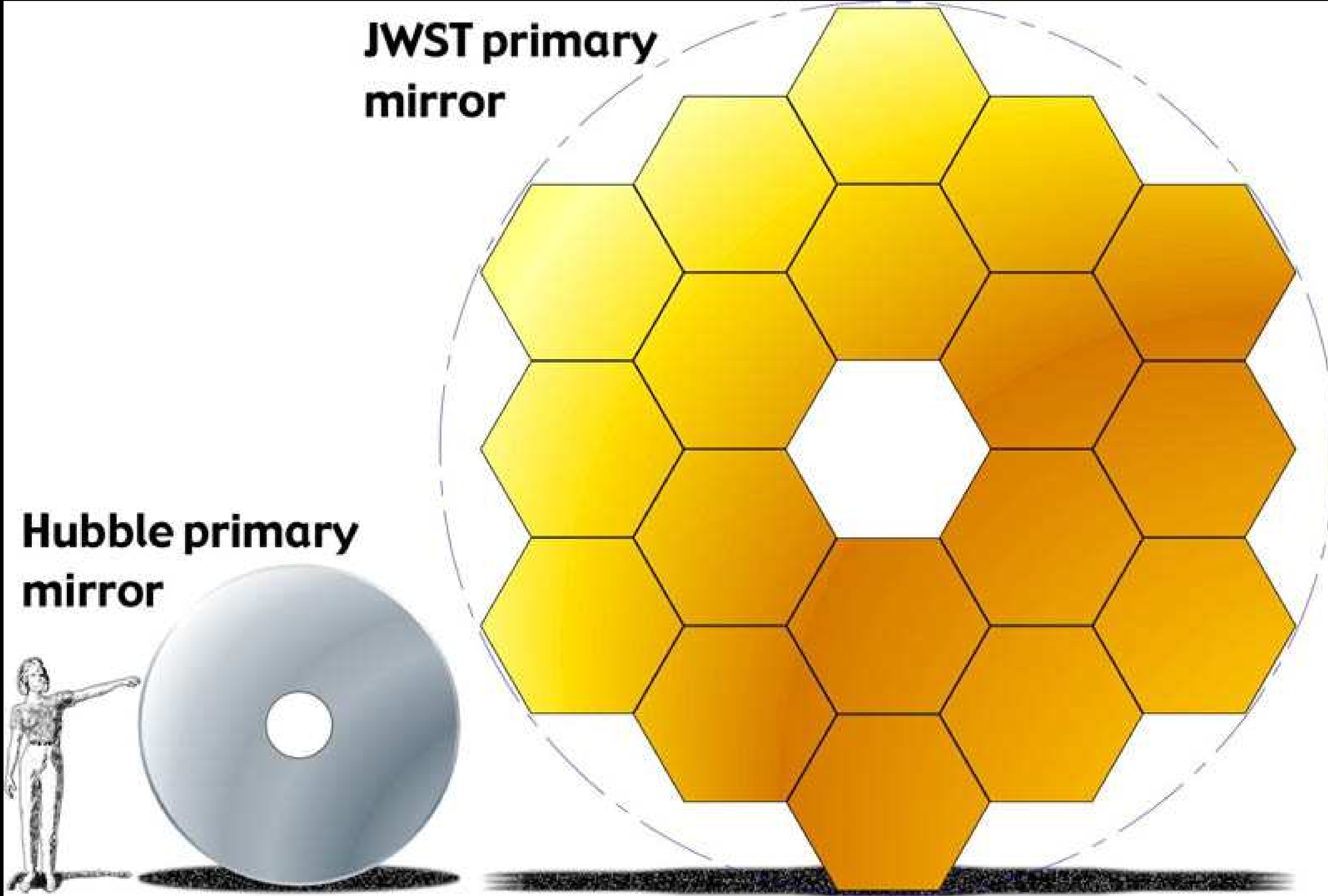
Talk is on: http://www.asu.edu/clas/hst/www/jwst/jwsttalks/nl_embassy_jwst_aug22.pdf

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?.

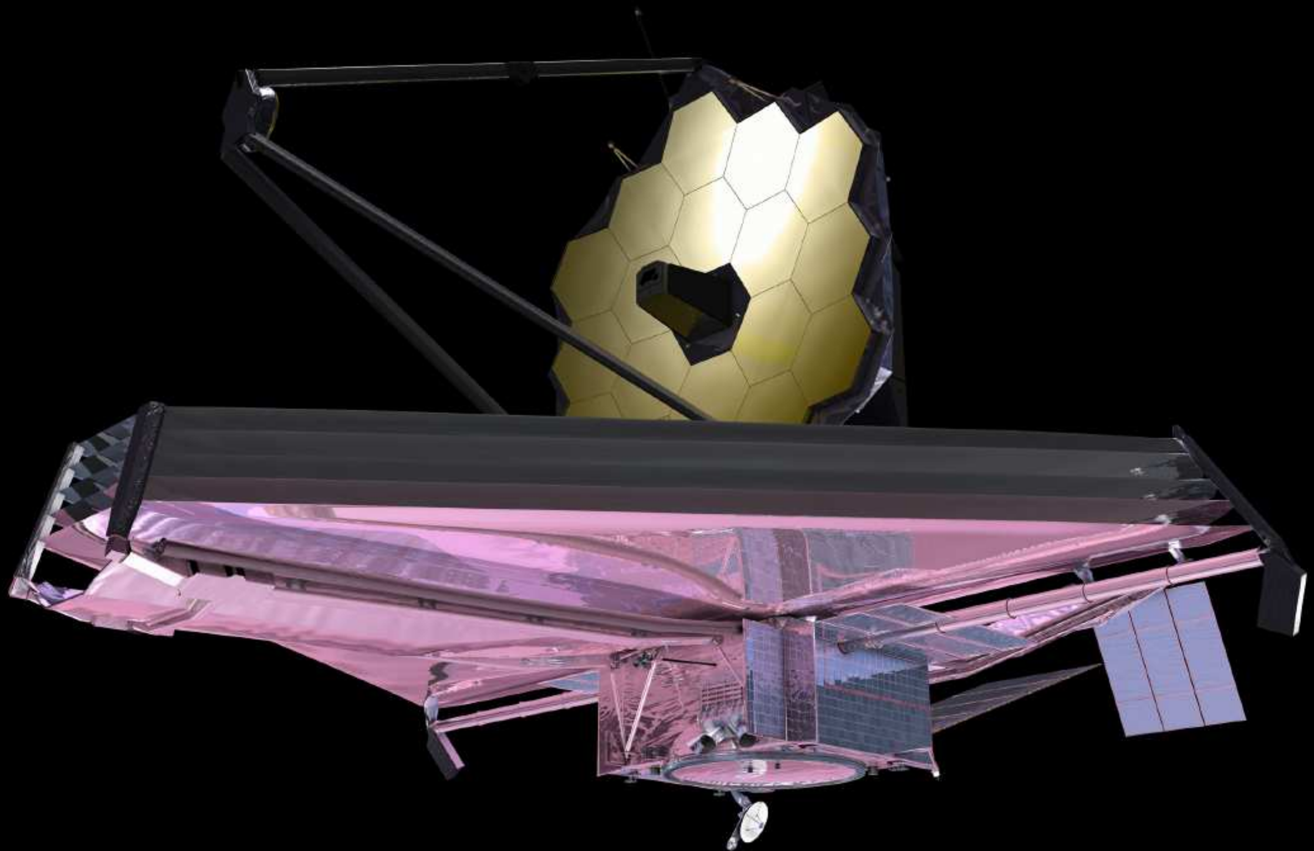
JWST: The infrared sequel to Hubble from 2021–2026 (–2031?).



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

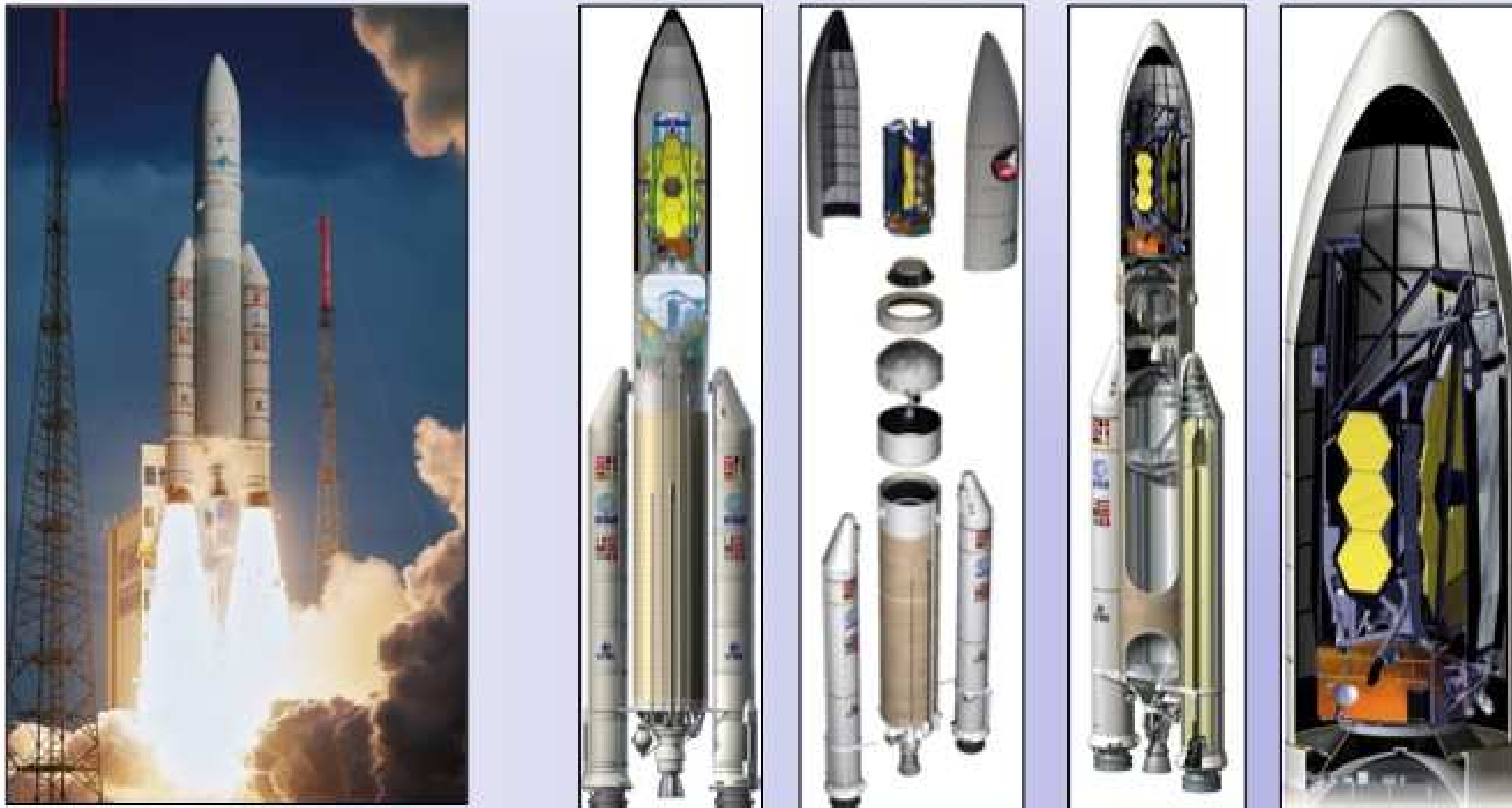


- A fully deployable 6.5 meter (25 m^2) segmented IR telescope for imaging and spectroscopy at 0.6–28 μm wavelength, launched Dec. 25, 2021.
- Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging (31.5 mag$\sim$1 FF from Moon), and spectroscopy.

The James Webb Space Telescope

JWST Launch

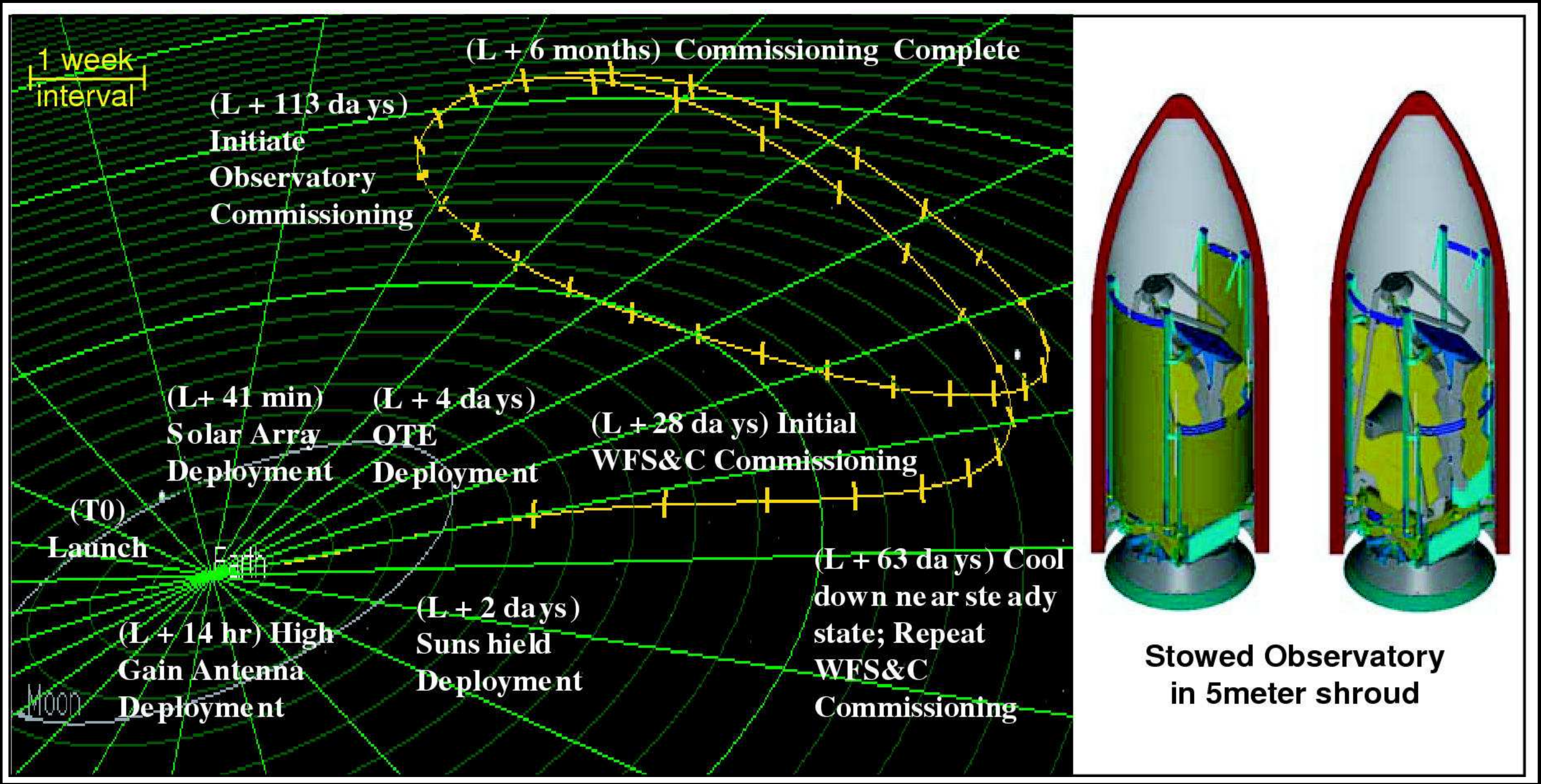
- Launch vehicle is an Ariane 5 rocket, supplied by ESA
- Site will be the Arianespace's ELA-3 launch complex near Kourou, French Guiana



Arianespace – ESA - NASA

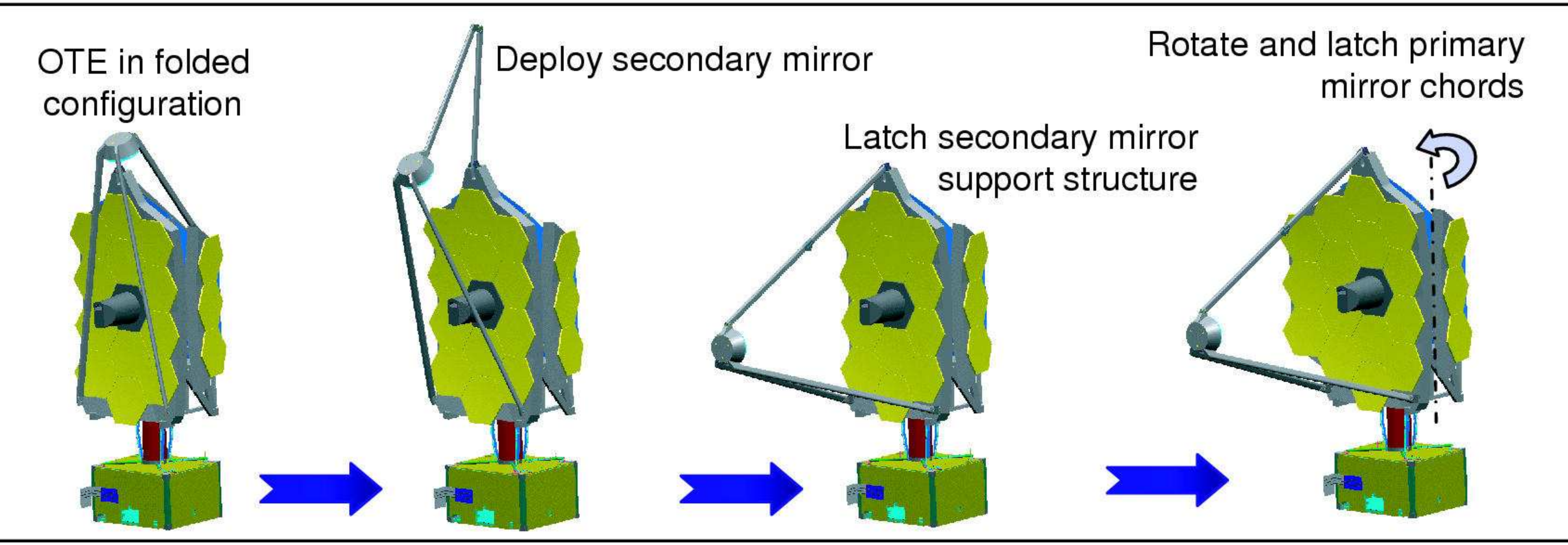
- The JWST launch weight is $\lesssim$6500 kg, and it was launched to L2 with an ESA Ariane-V launch vehicle from Kourou in French Guiana.

(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.

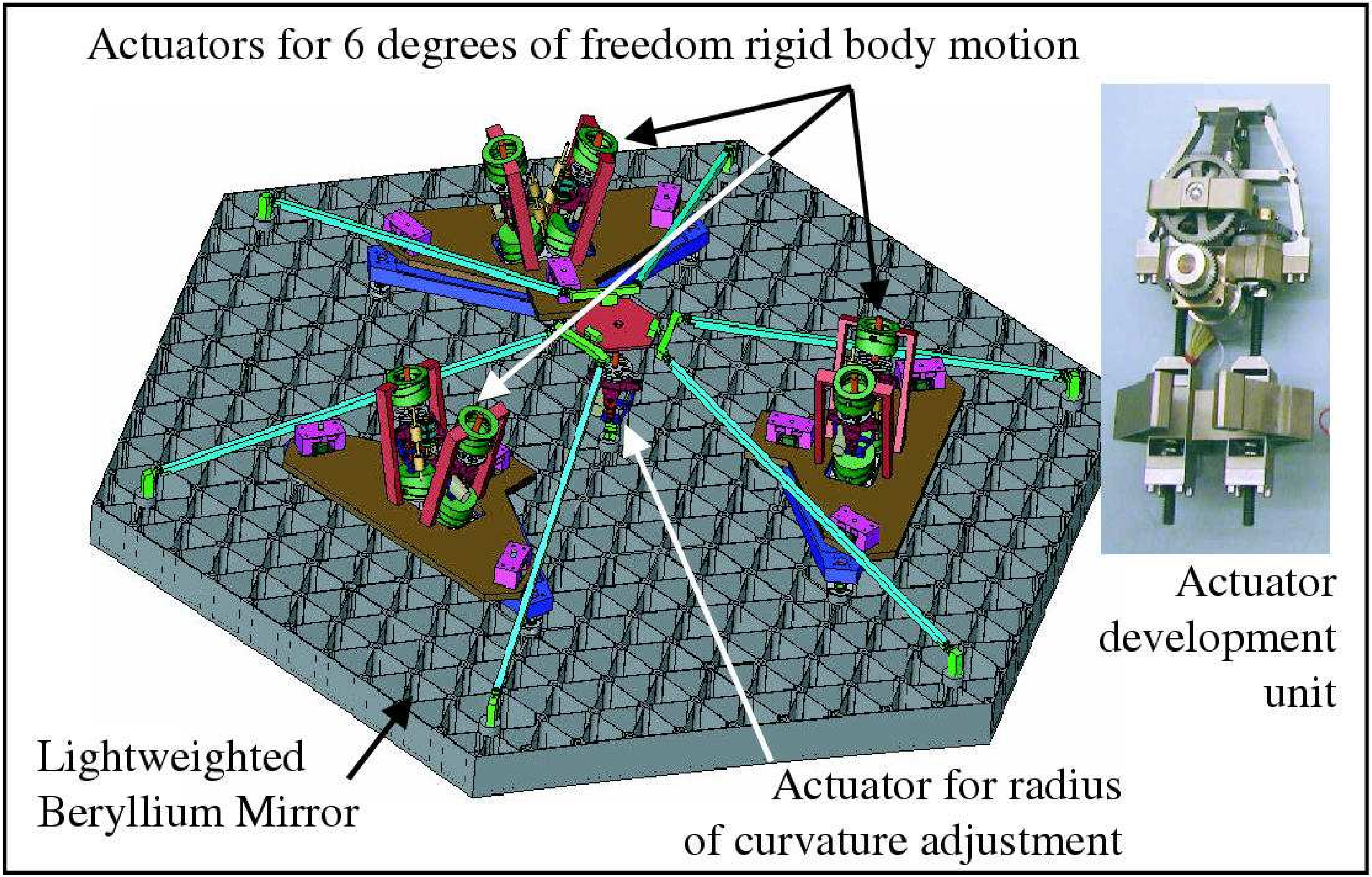
• (1b) How was JWST automatically deployed?



• 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).

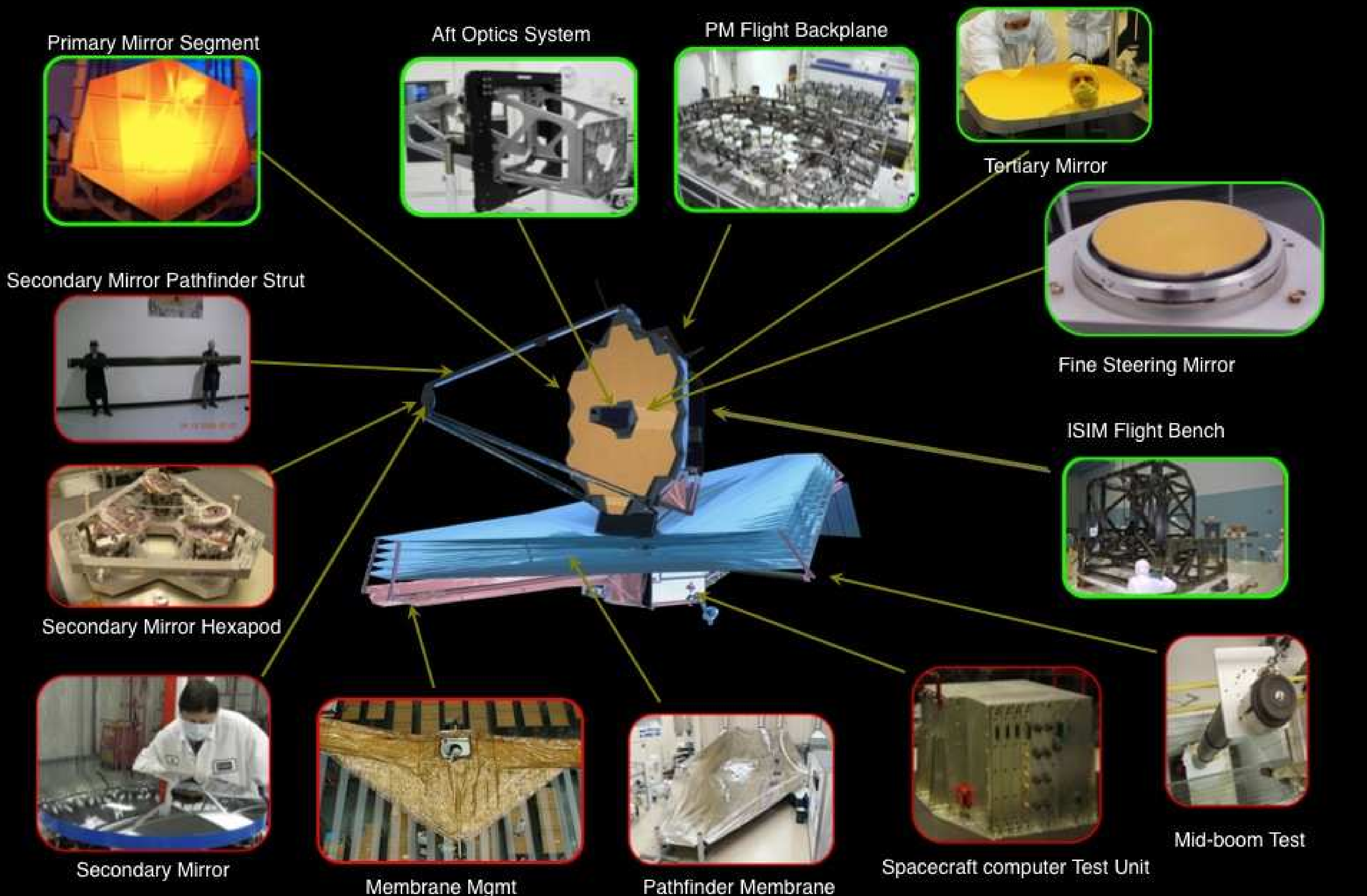
• Component fabrication, testing, & system integration: 18 out of 18 flight mirrors done in 2015, and meet the 40K specifications (2017).



Active mirror segment support through "hexapods", similar to Keck.

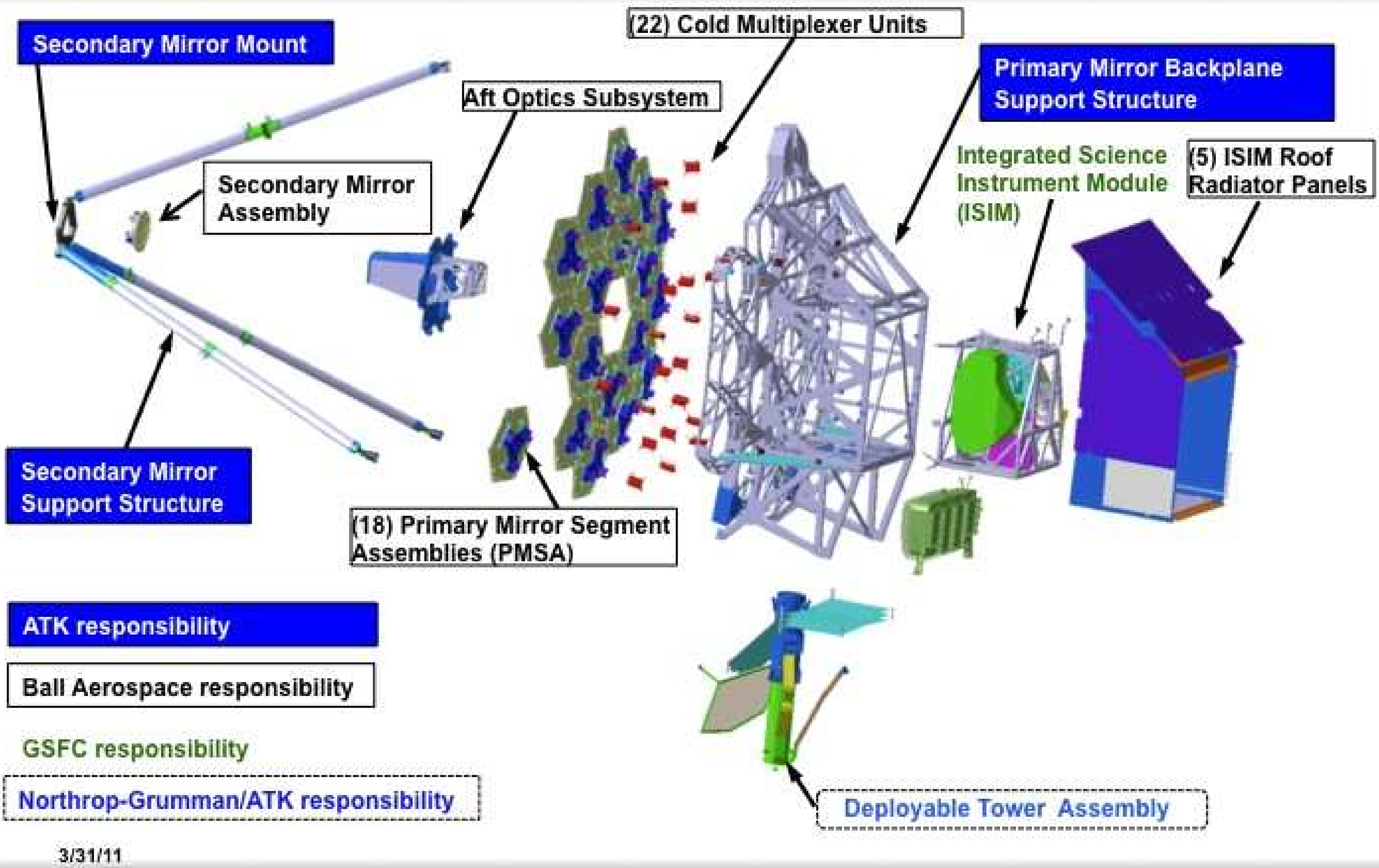
Redundant & doubly-redundant mechanisms, quite forgiving against failures.

JWST Hardware Status



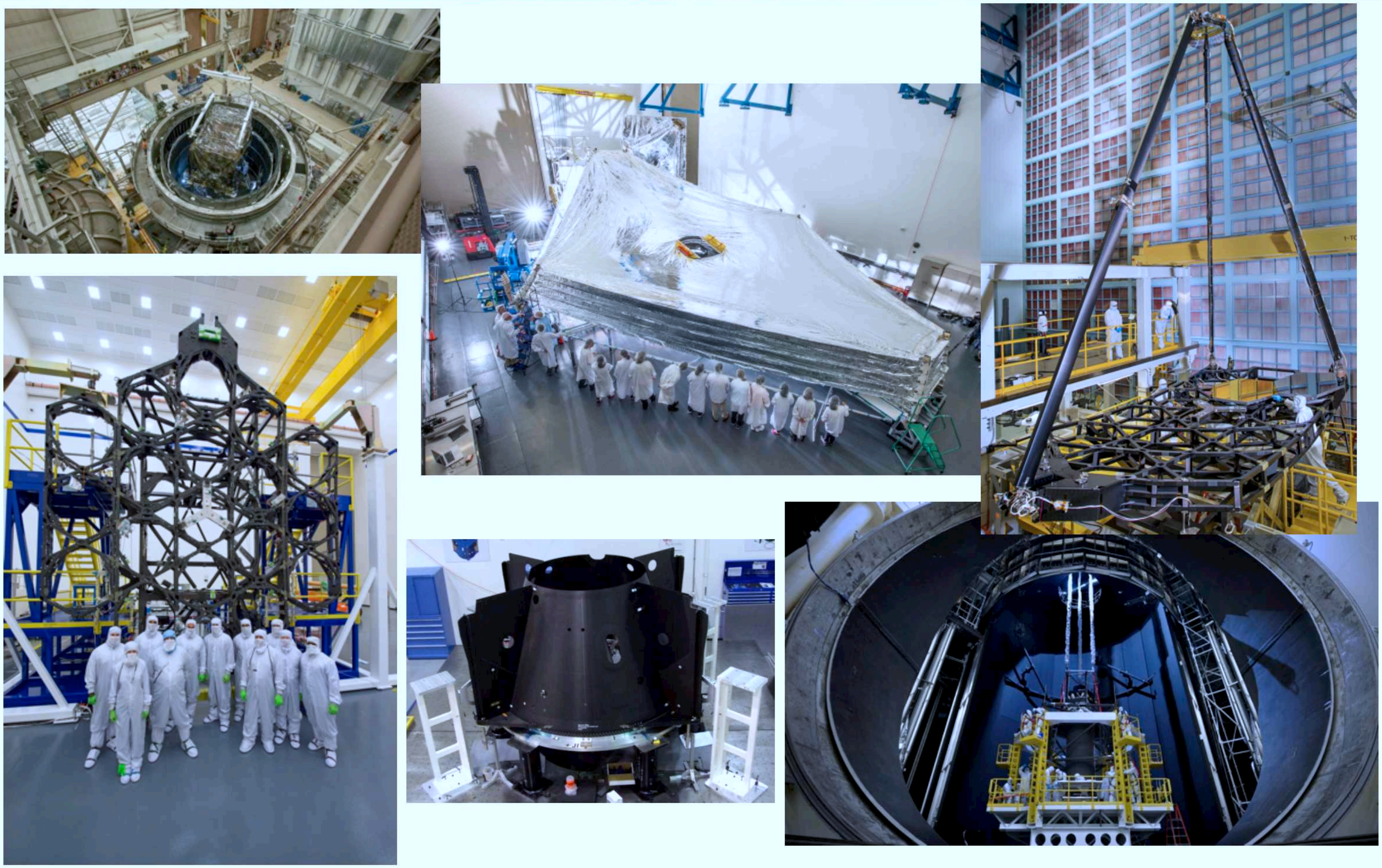
2021: 100% of launch mass designed and built (100% weighed).

TELESCOPE ARCHITECTURE



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

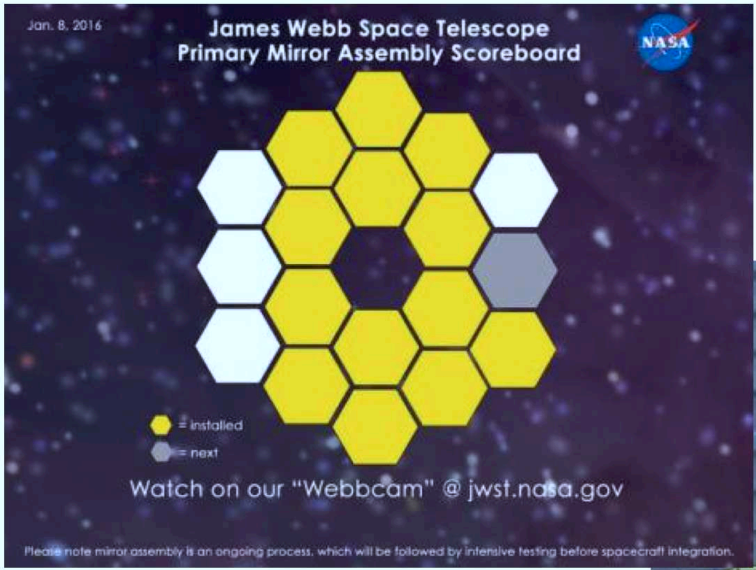
JWST Hardware Progress



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

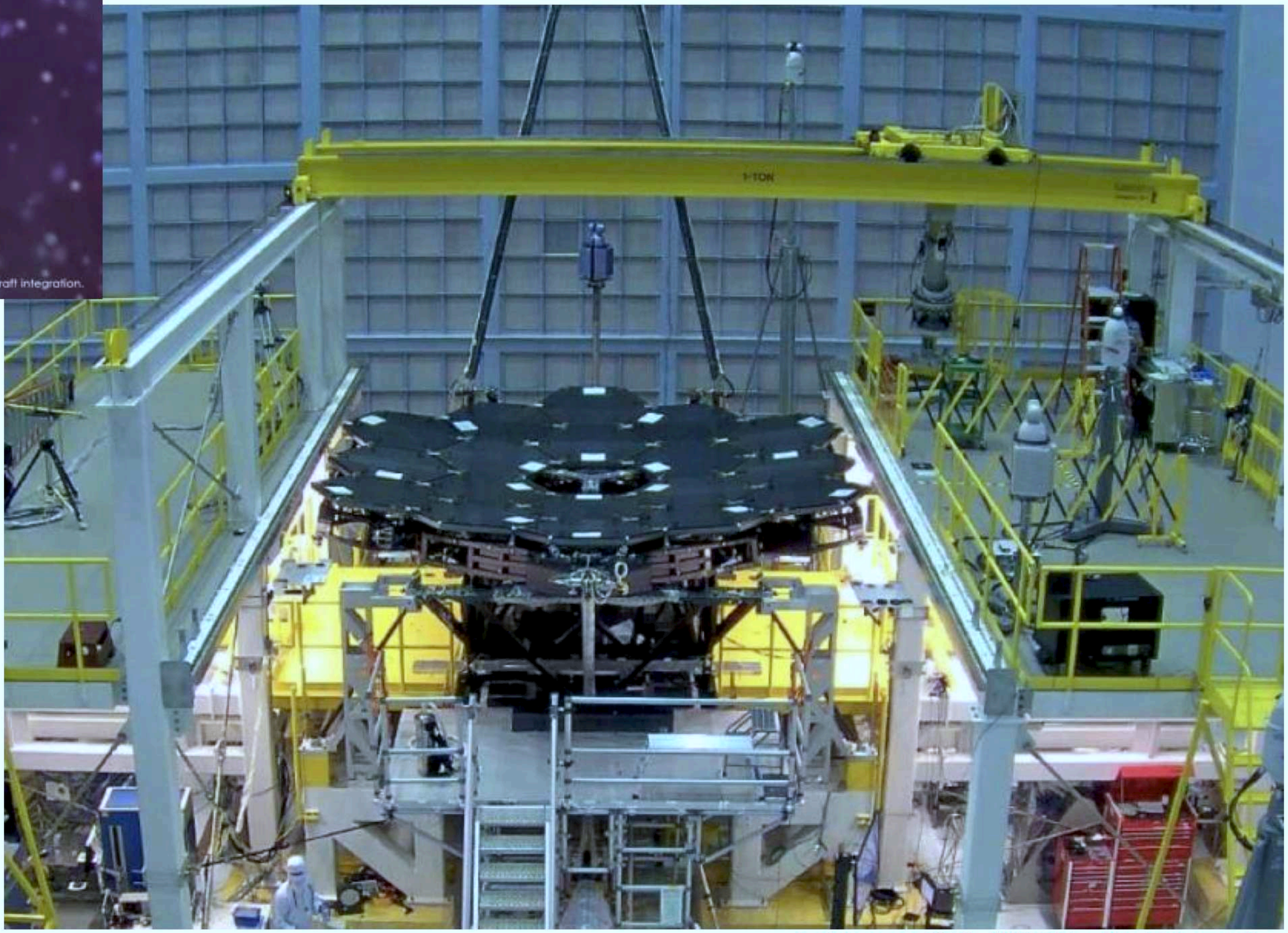
July 2014: • Secondary Mirror Support deployment successfully tested.
2015: • Engineering sunshield successfully deployed at Northrop (CA).

Much progress has been made in OTE integration



← Where we were at last month's call

Current: all 18 PMSAs installed, liquid-shim-cured, & metrologized. Alignments meet specifications, and actuator motions verified
Big milestone! →

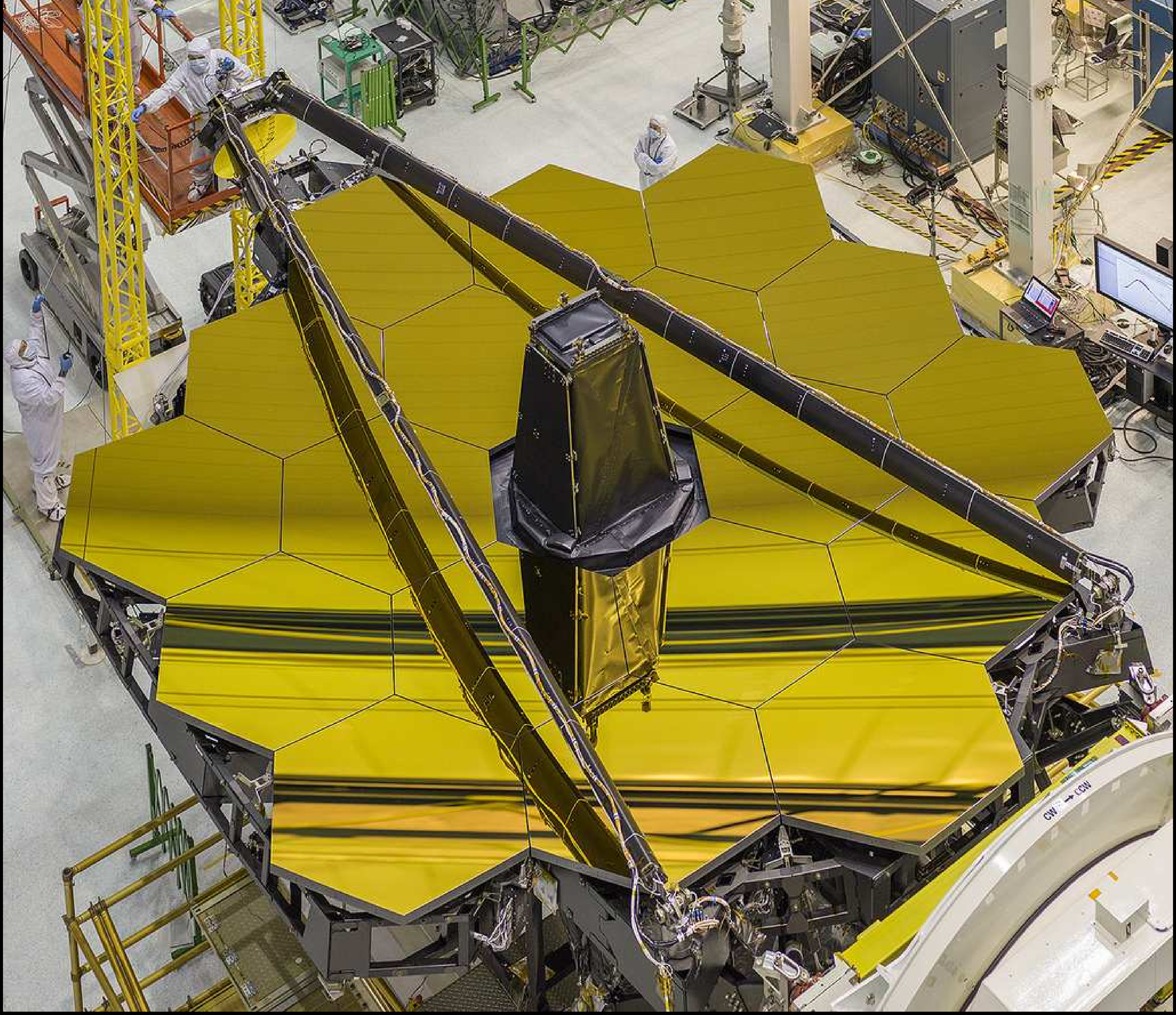


JWST lifetime: Requirement: 5 yrs; Goal: 10 yrs; Propellant: 20^{+} yrs!

NASA team-work to take JWST mirror covers off!

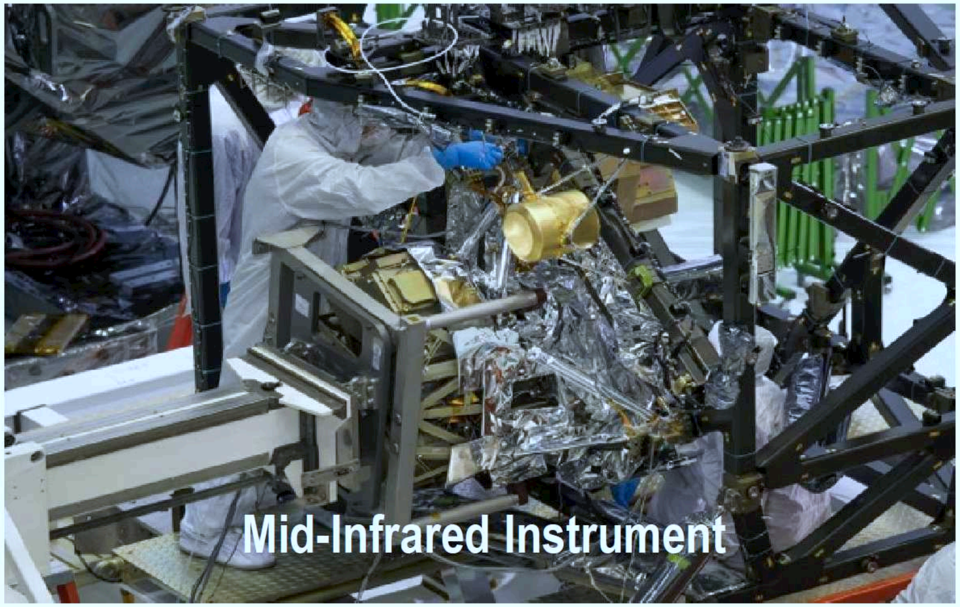
JWST being tilted into the right position

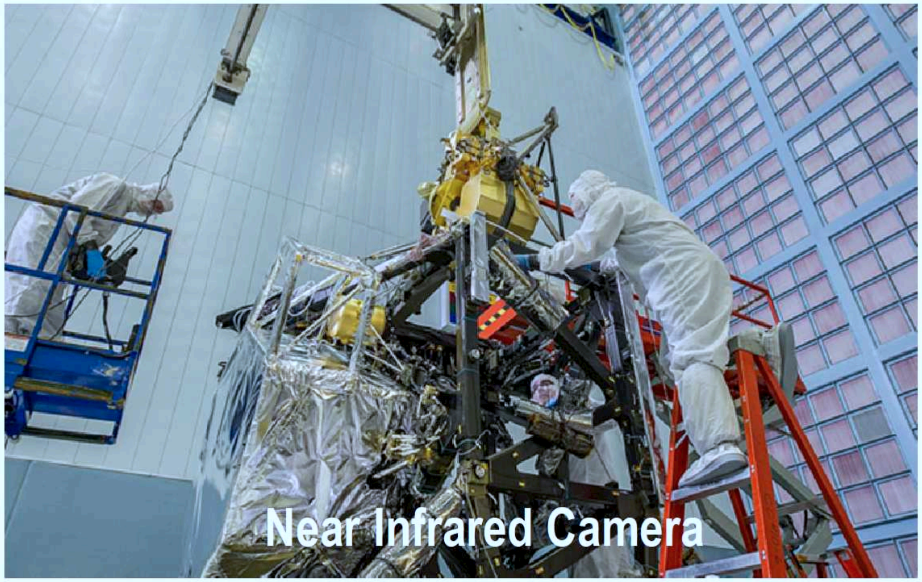
Webb mirrors finally mounted and ready!

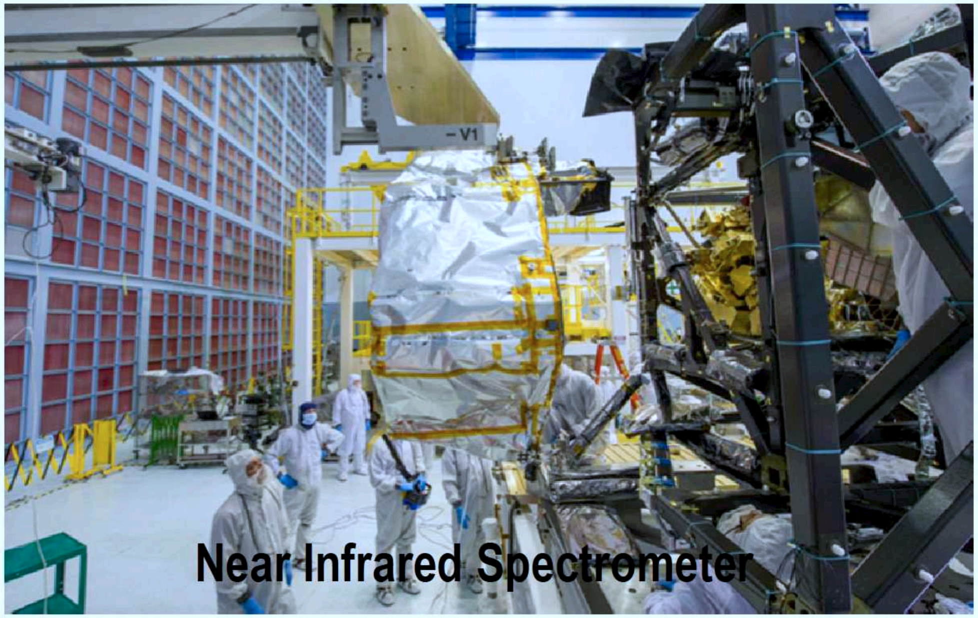


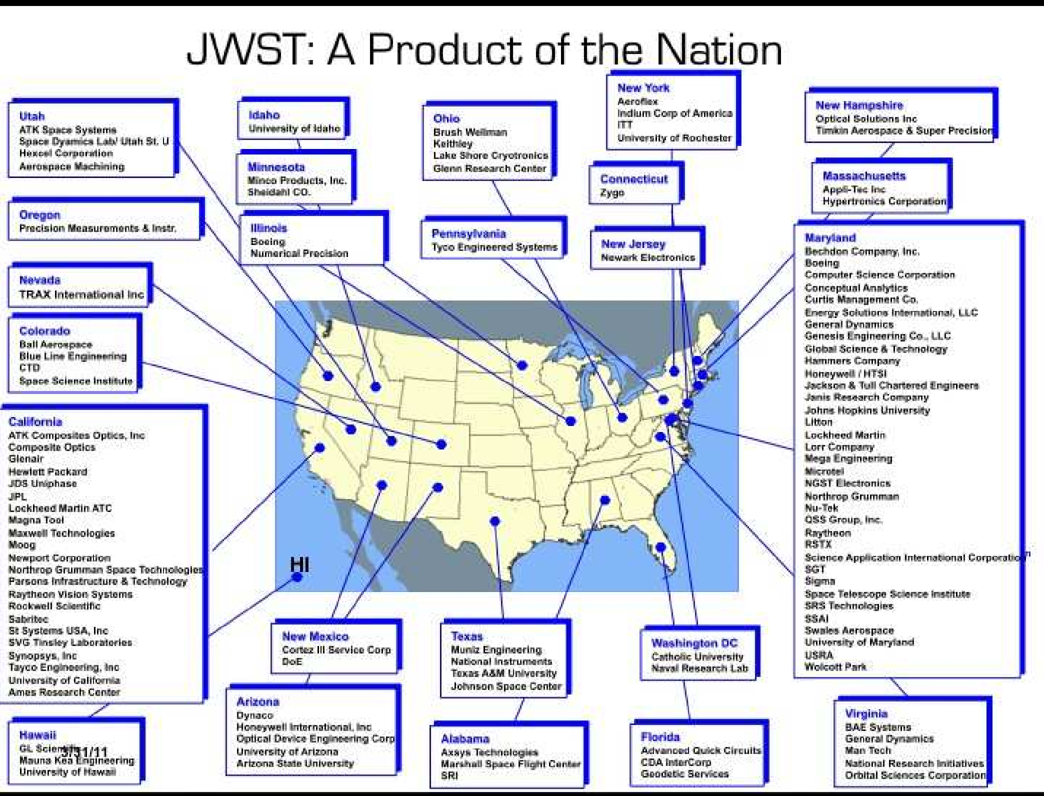
JWST stowed for further instrument mounting

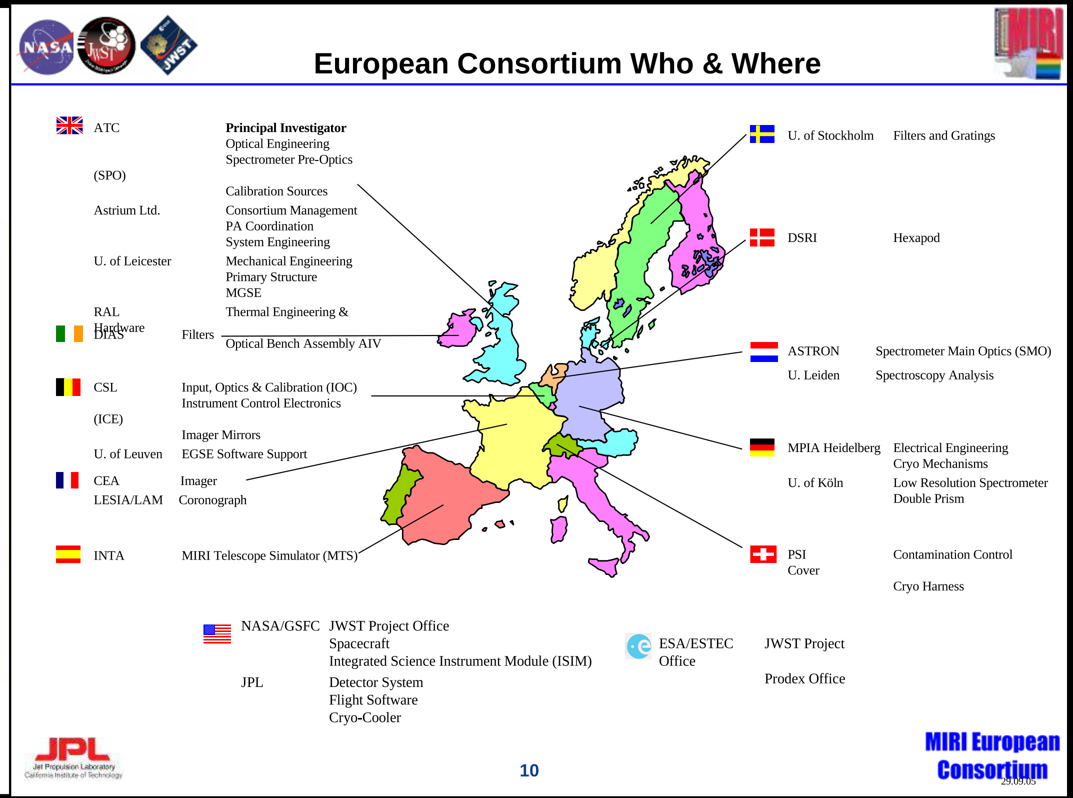
All Instruments Integrated











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

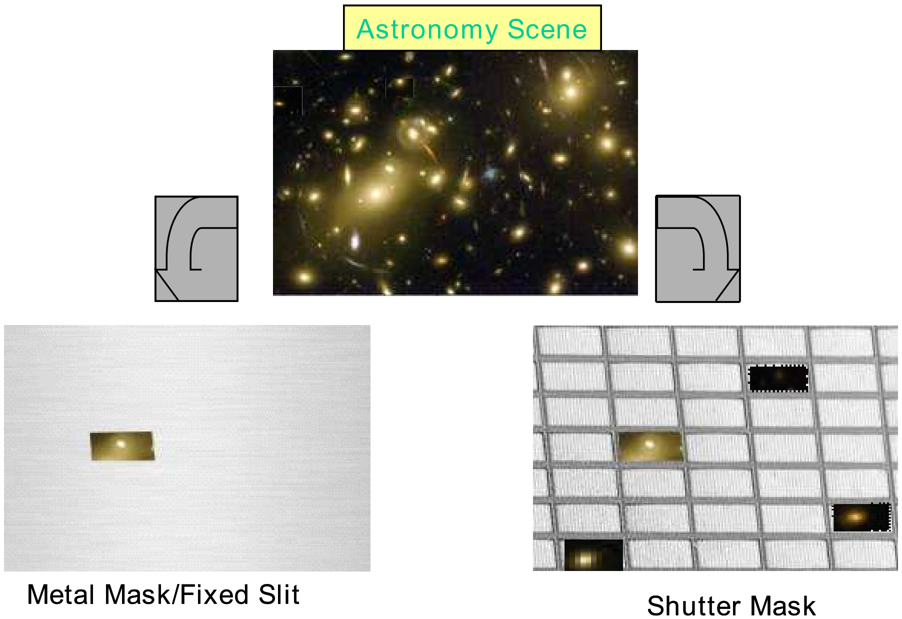
- Ariane V Launch & NIRSpec provided by ESA; & MIRI by ESA & JPL.

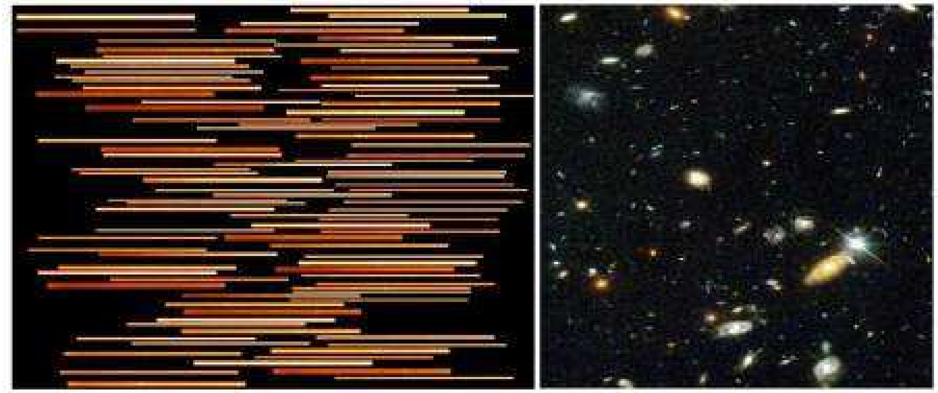
- JWST Fine Guider Sensor + NIRISS provided by Canadian Space Agency.

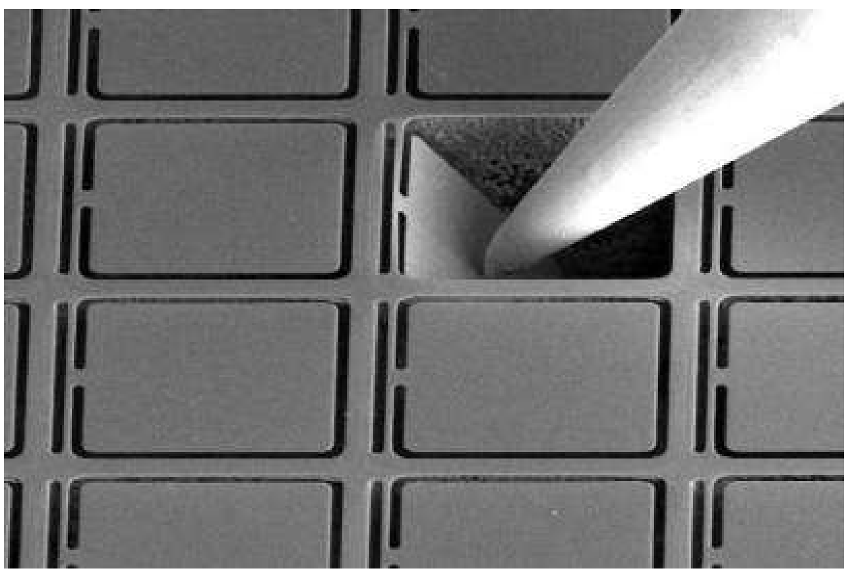
- JWST NIRCam made by UofA and Lockheed.

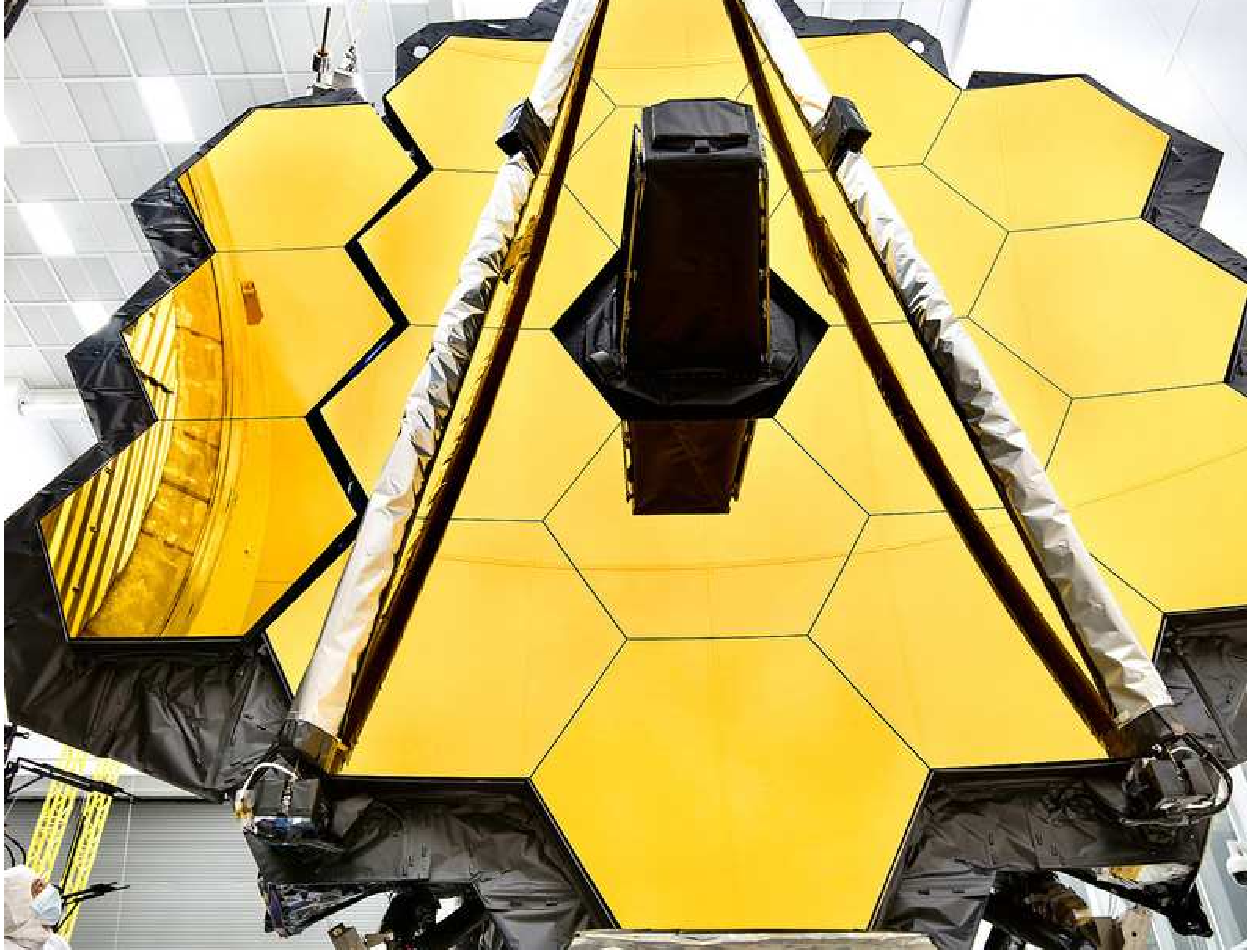
Thank you, Europe & ESA, for your very significant work on JWST!

Micro Shutters



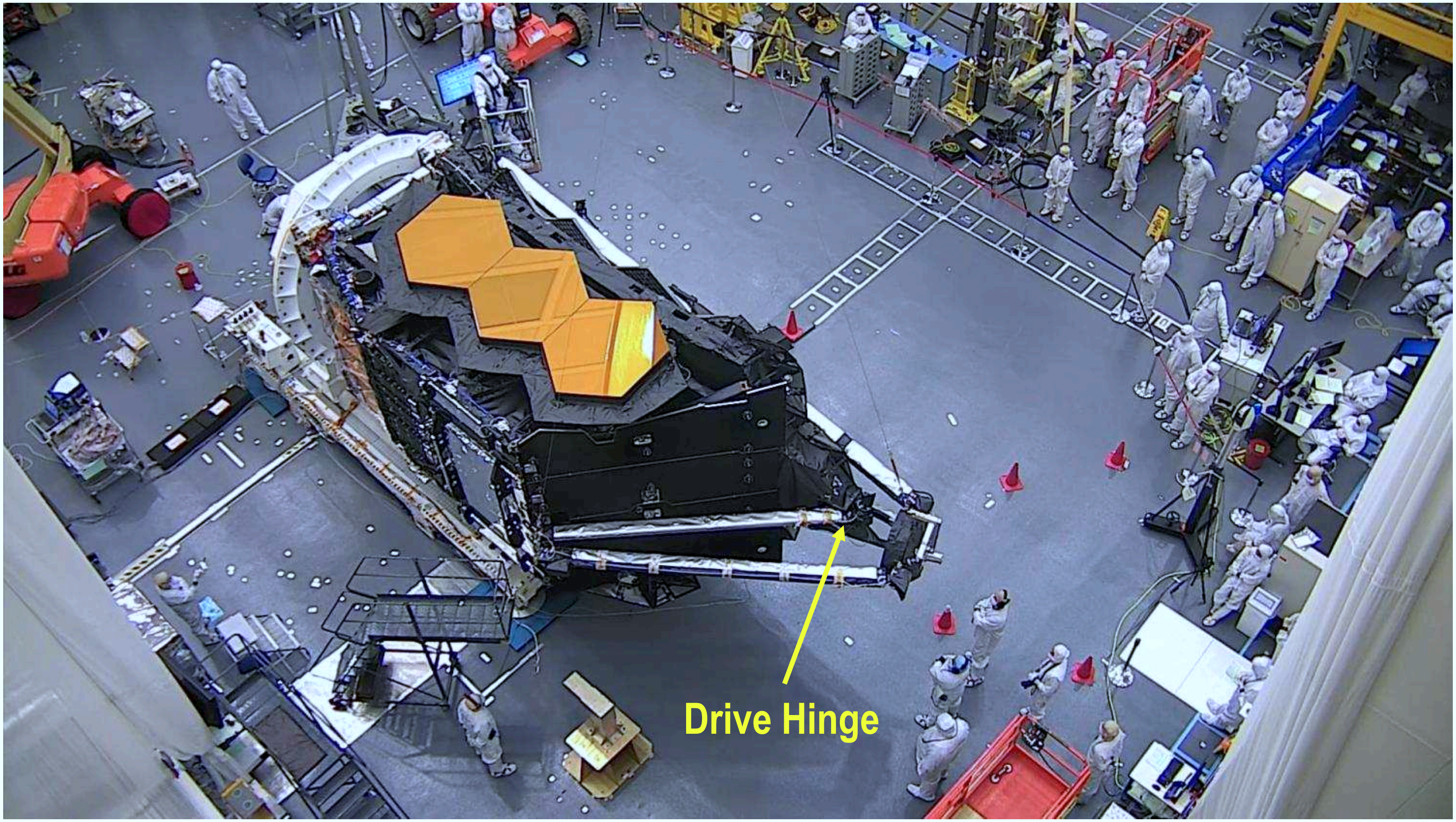






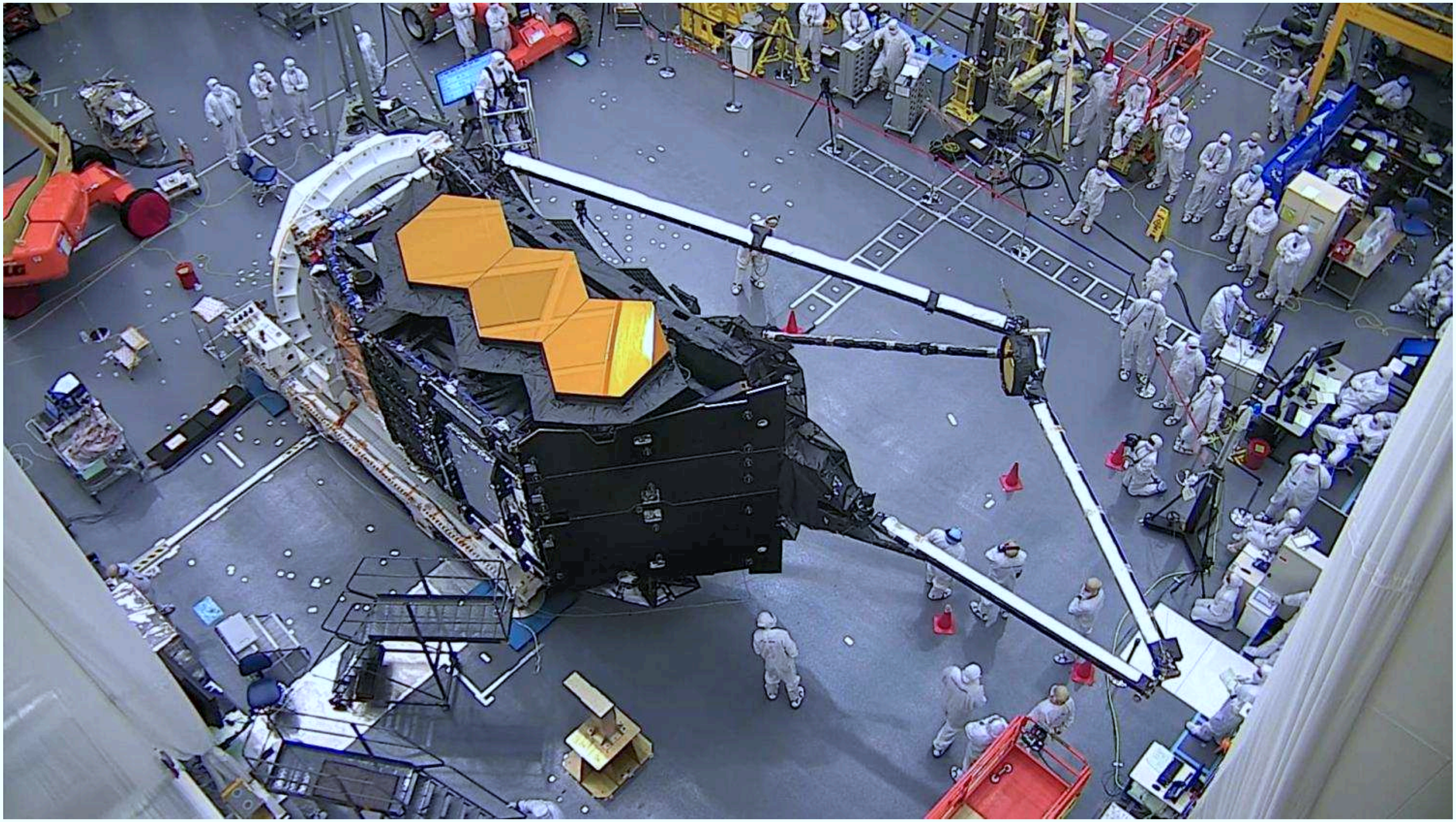
April 2017: Last portrait of JWST at Goddard Space Flight Center (MD).

SMSS Deployment Sequence (1)



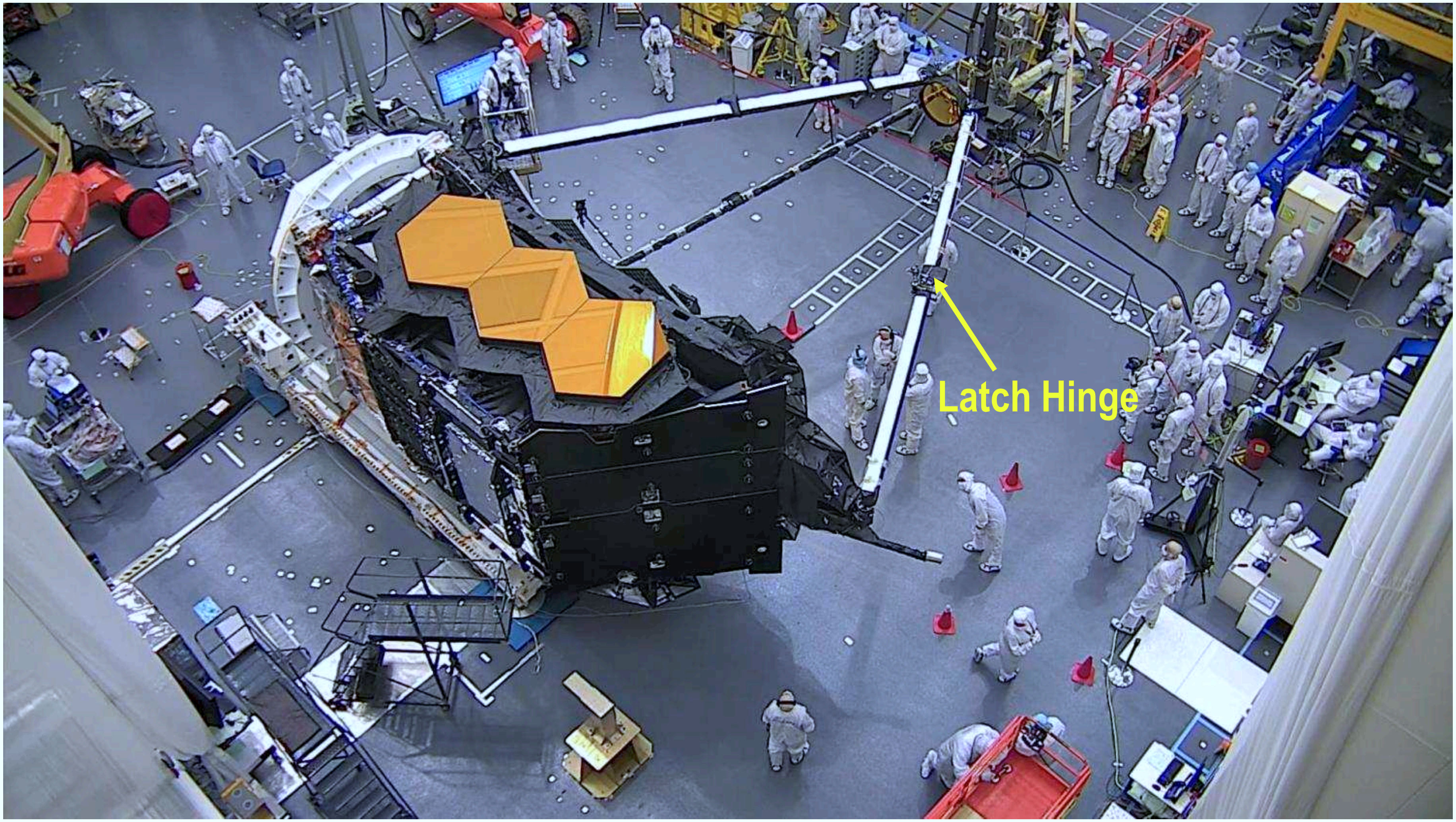
July 2019: Full 1-G deployment of JWST secondary mirror (SM) .

SMSS Deployment Sequence (2)



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

SMSS Deployment Sequence (3)

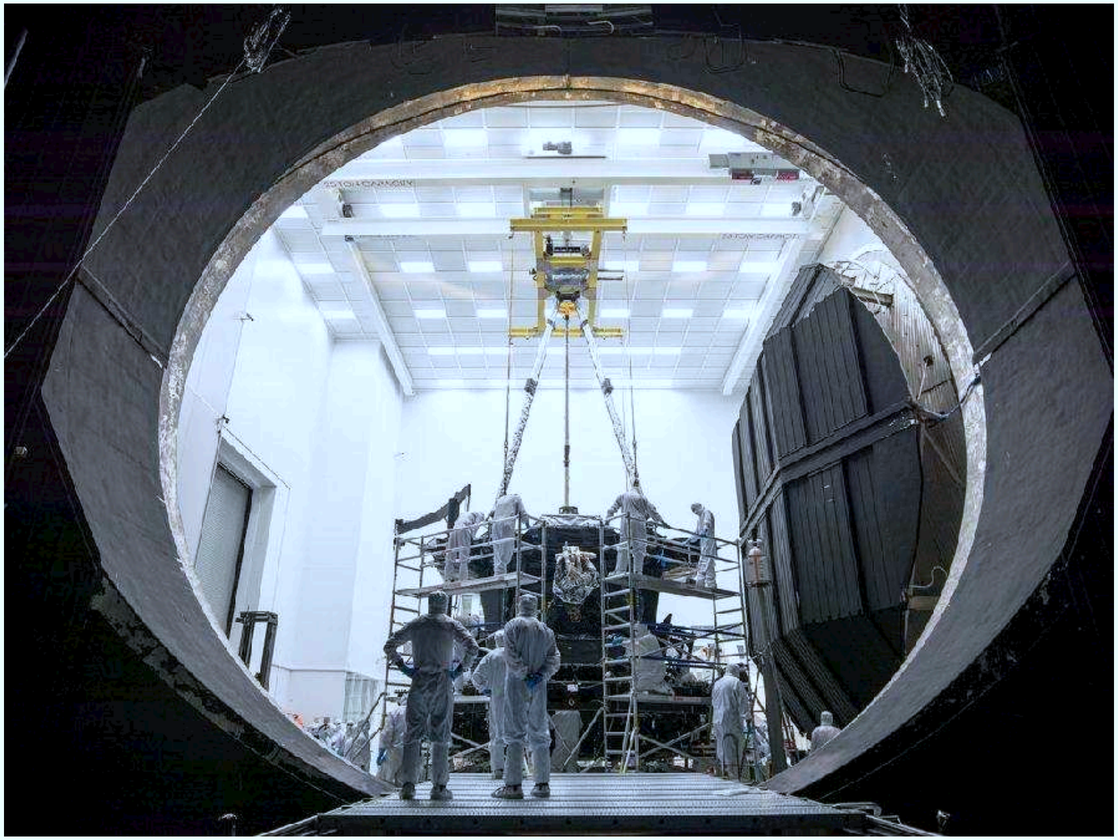


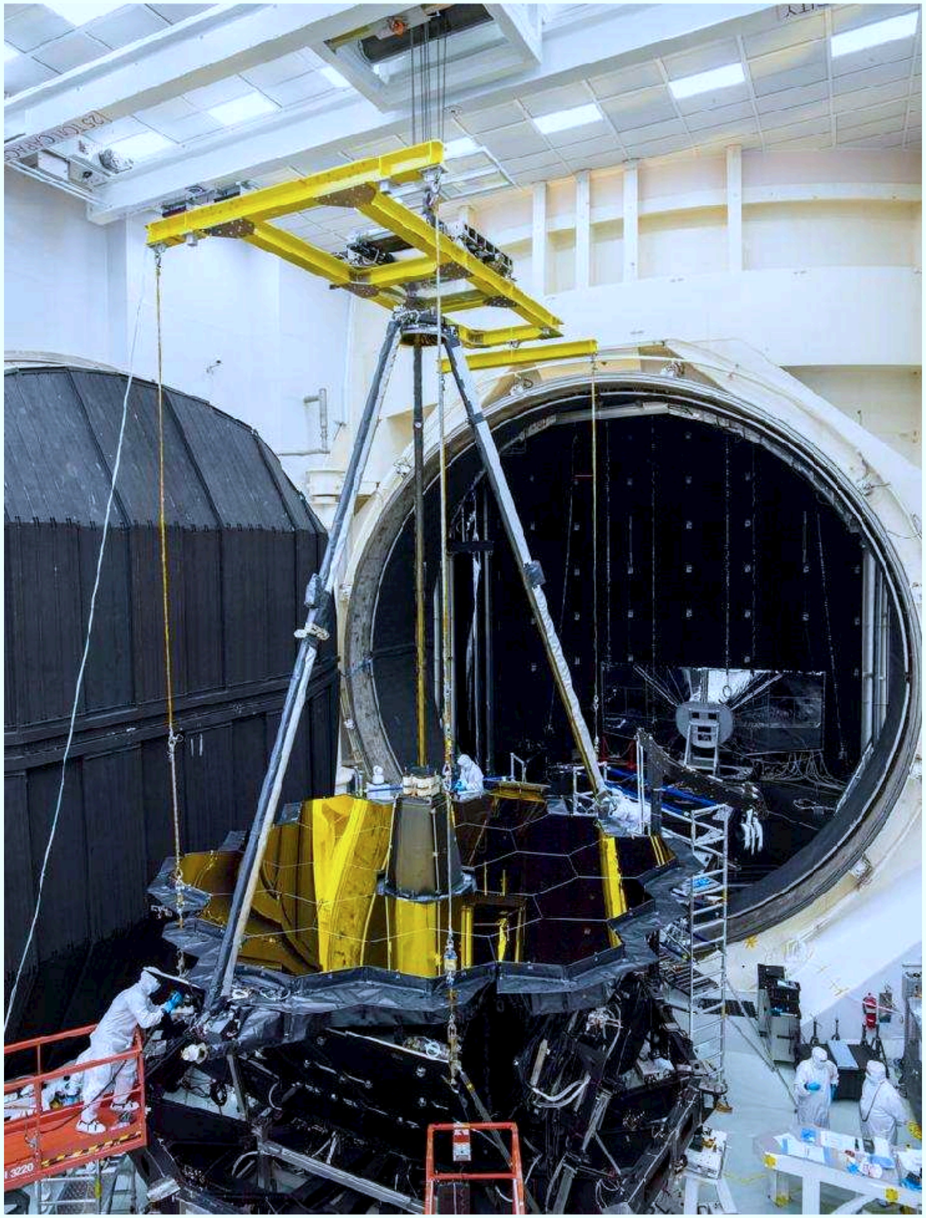
July 2019: Full 1-G deployment of JWST secondary mirror (SM) ...

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

Program Update: OTIS

NORTHROP GRUMMAN

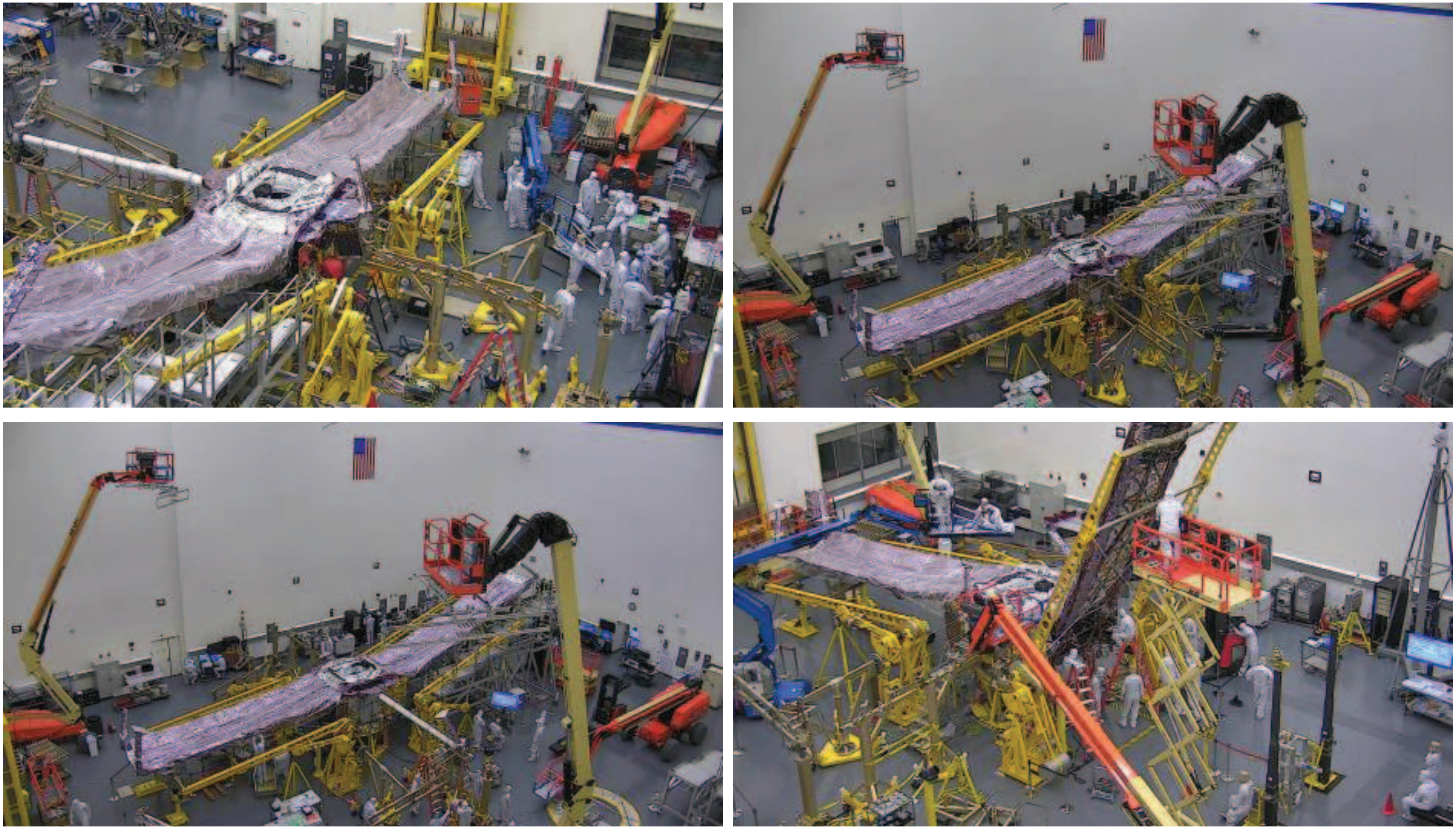




June 2017: JWST going into Chamber A at Johnson Space Center in Houston.

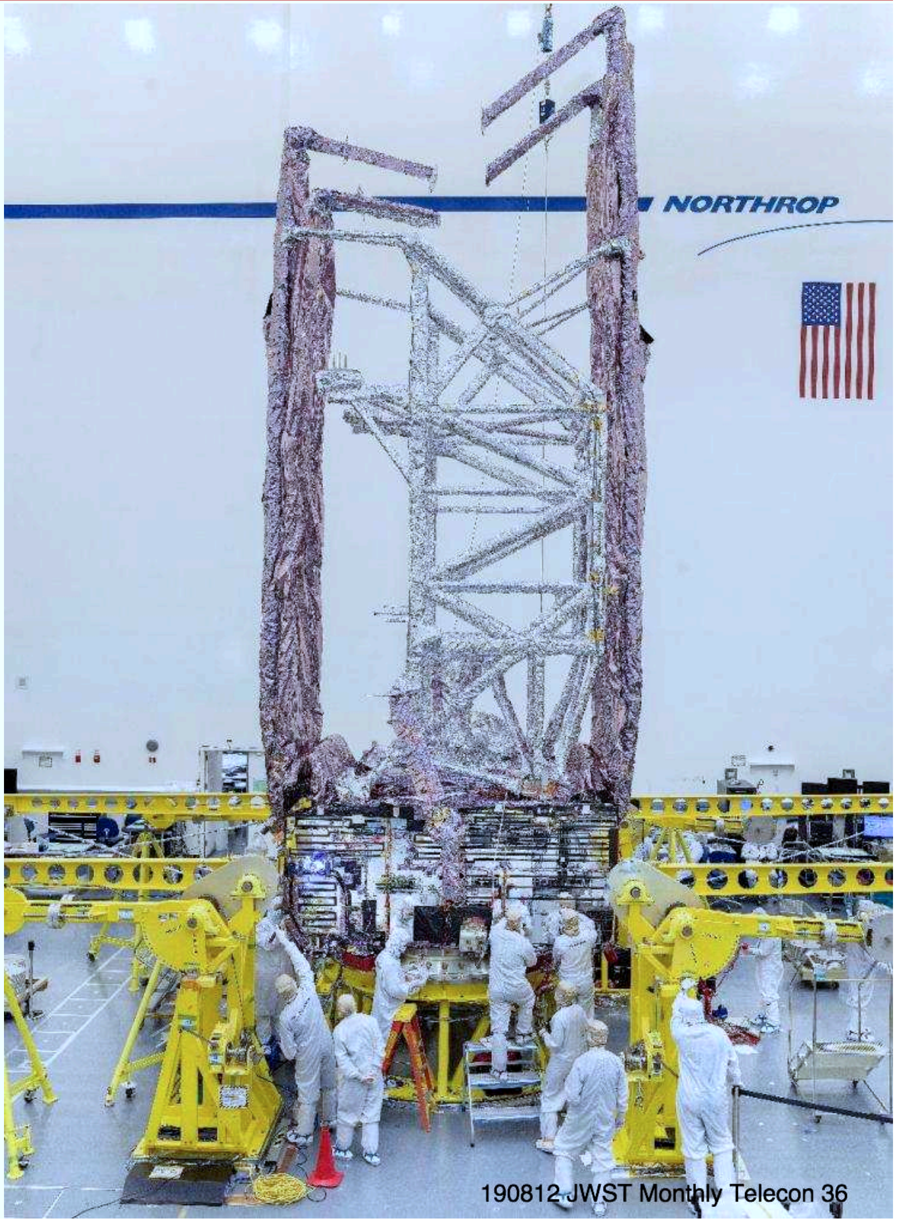
Program Updates: Spacecraft and Sunshield

NORTHROP GRUMMAN



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

SCE to Elephant Stand

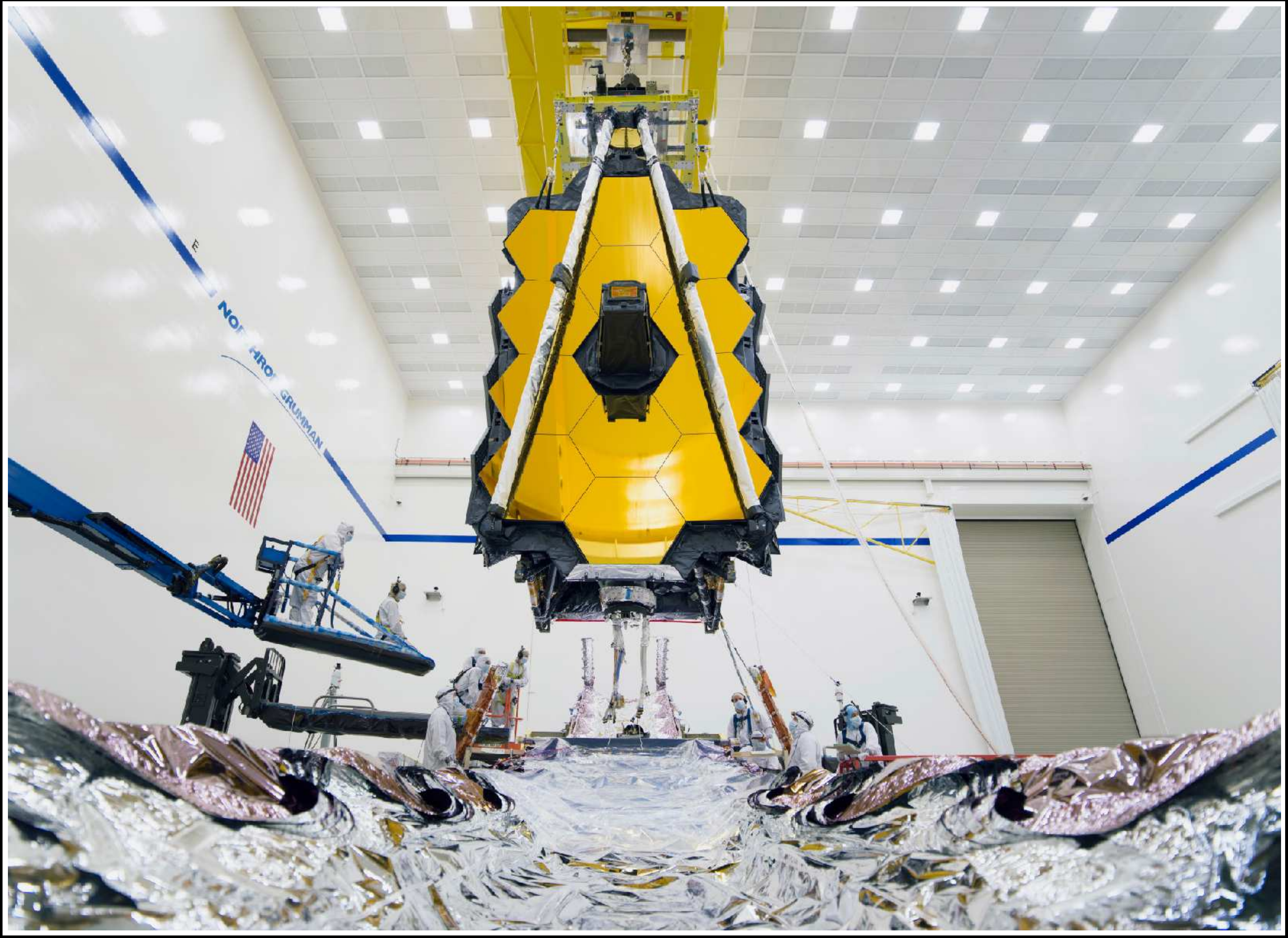


Aug. 2019: Stowed flight sunshield before integration with JWST OTE.

SMSS Deployment

NORTHROP GRUMMAN

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

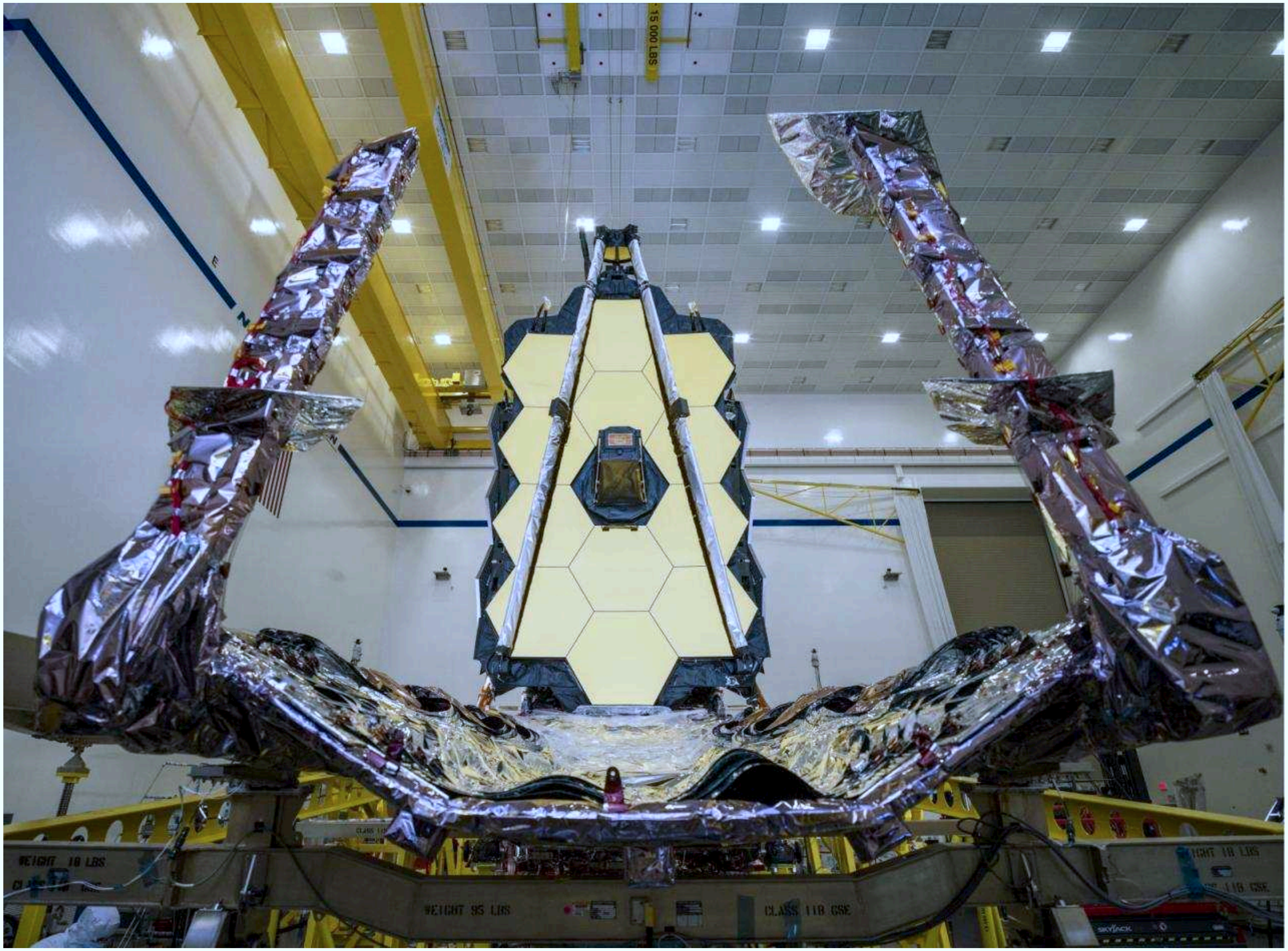


Aug. 2019: JWST OTE+ISIM lowered into Sunshield+Spacecraft

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

200511 JWST Monthly Telecon 12

May 2020: Ready for Solar Array deployment test

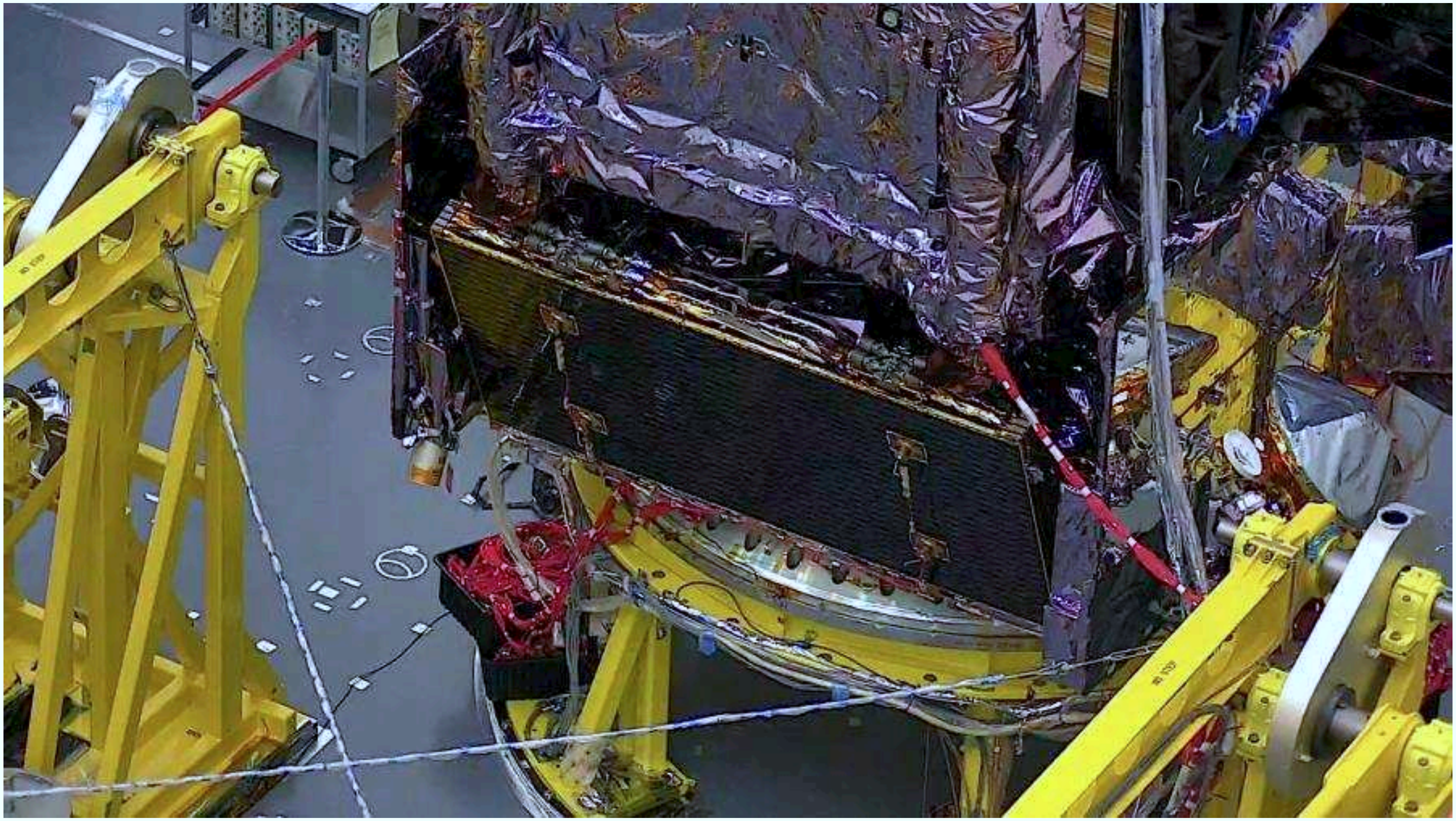
Solar Array Deployment 2

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

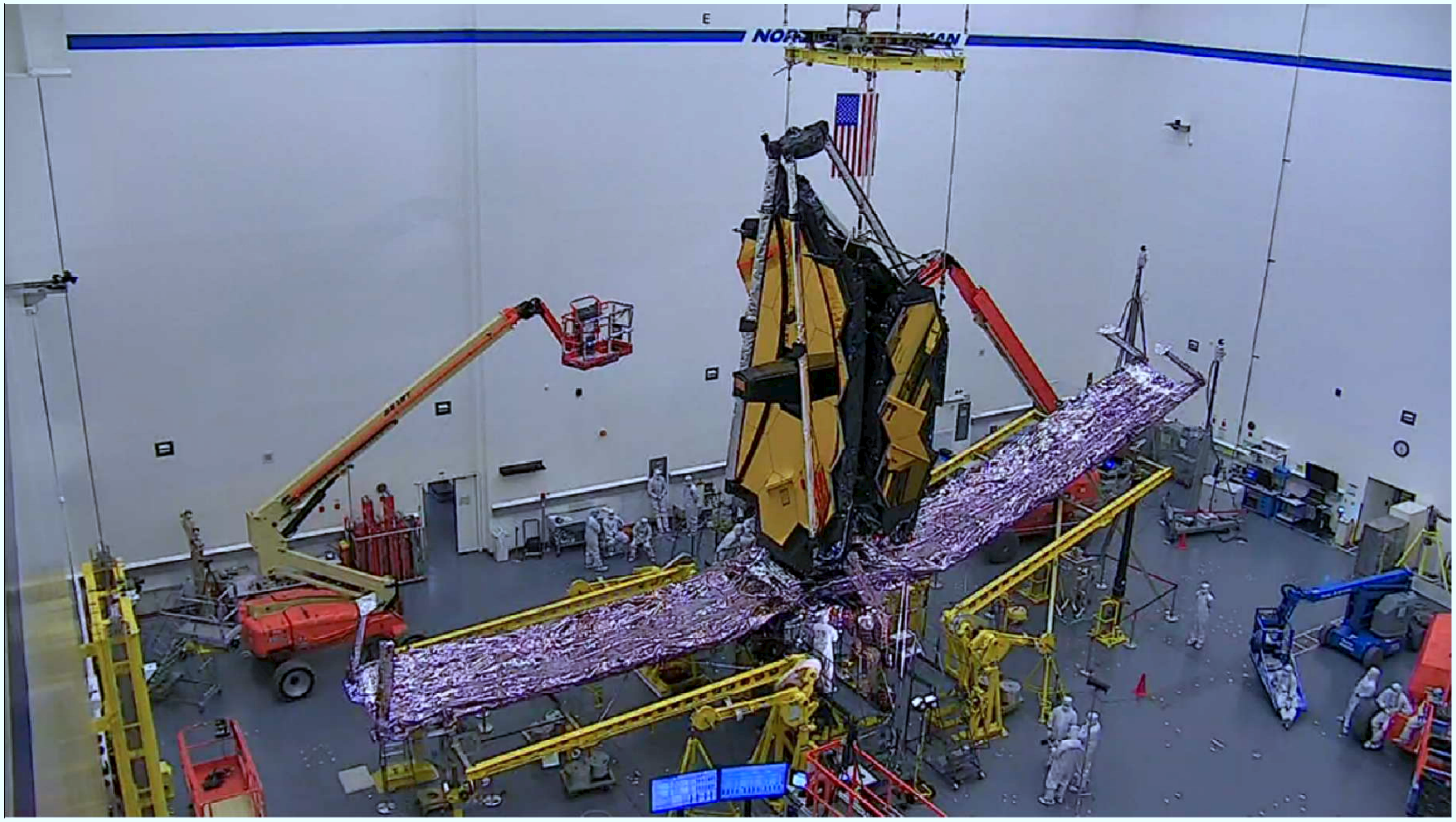
NORTHROP GRUMMAN

5/28/20: DTA Deployment

June 2020: Deployable Tower Assembly test

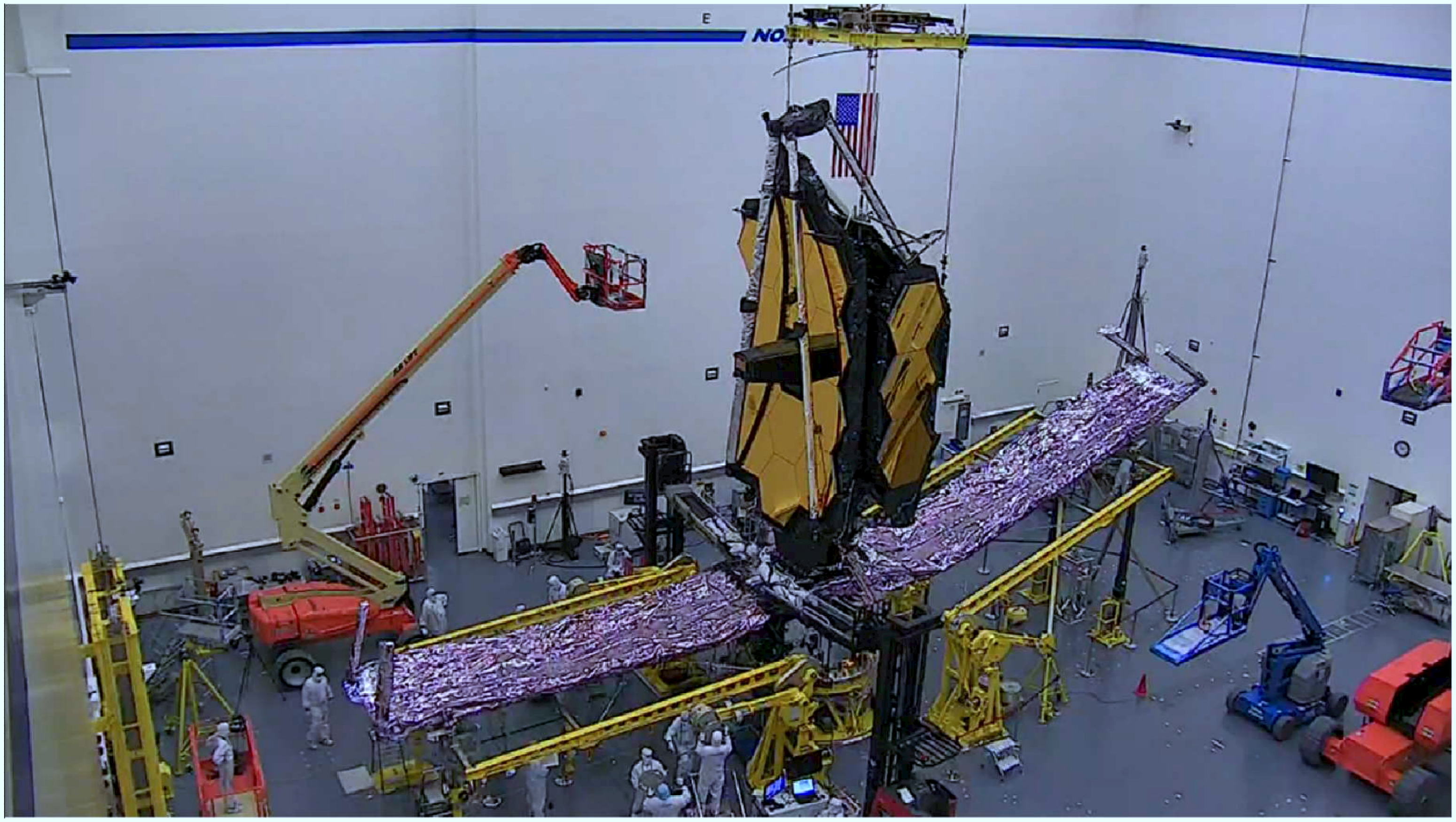
NORTHROP GRUMMAN

5/28/20: DTA Deployment



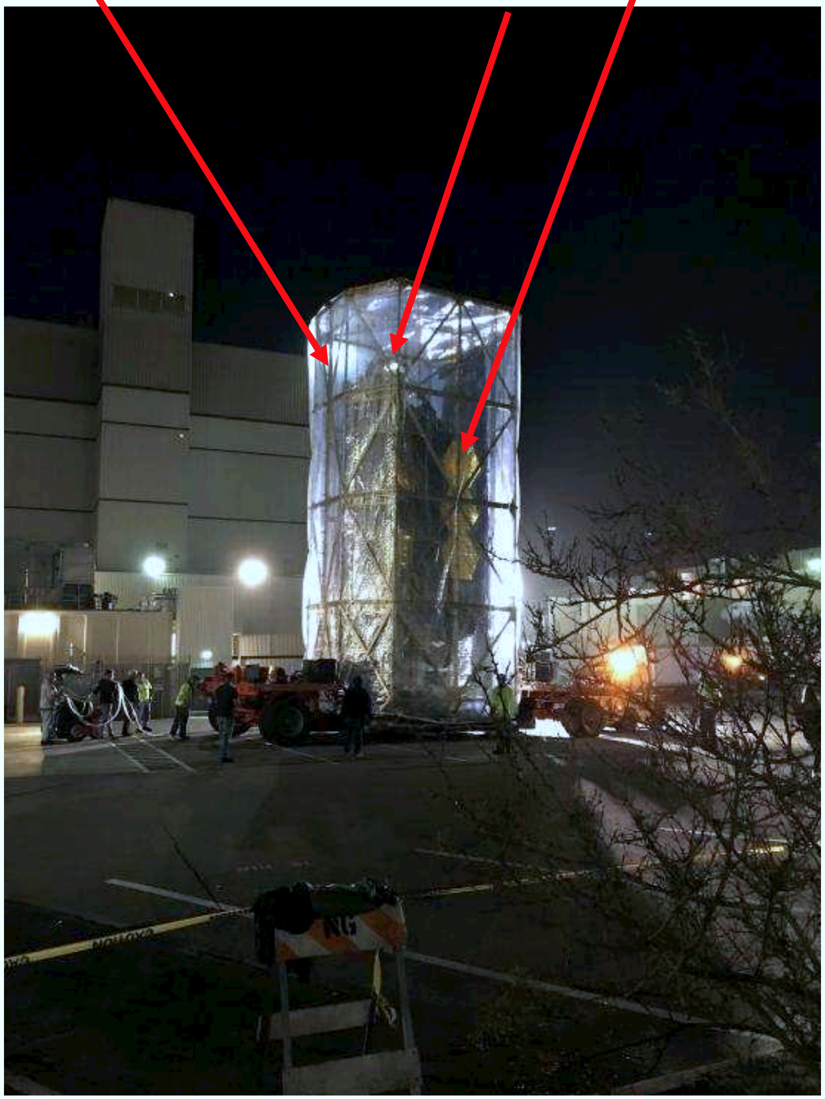
June 2020: Deployable Tower Assembly test with gravity off-loading.

5/29/20: DTA Deployment

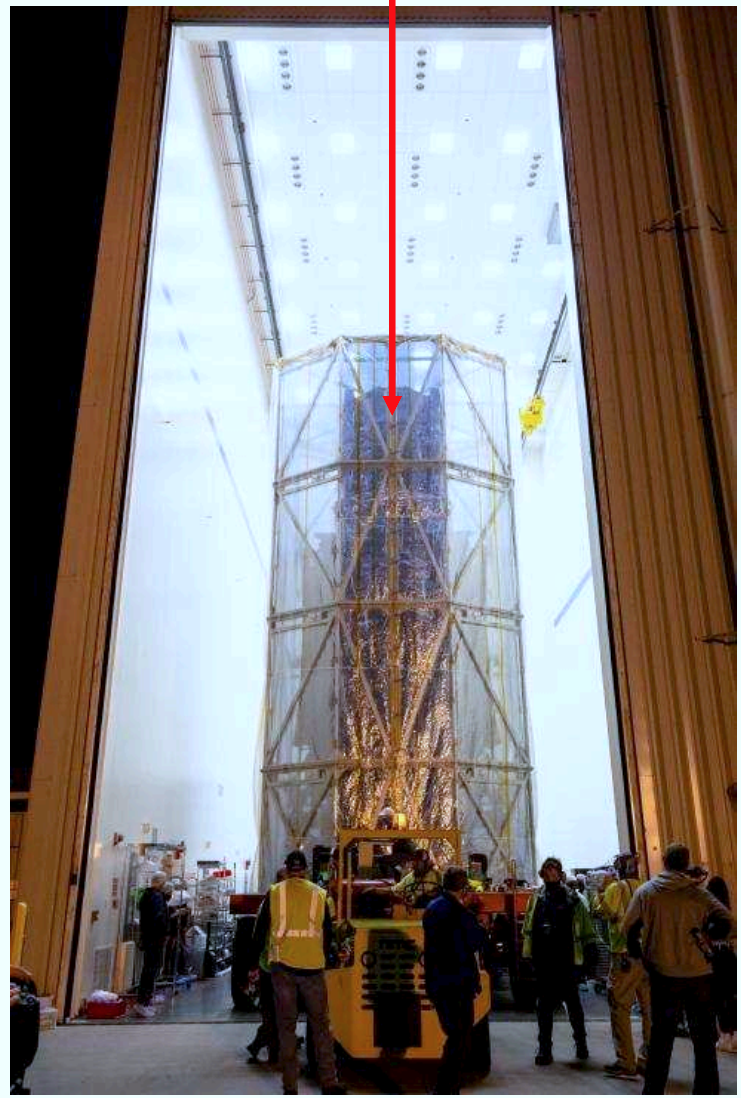


June 2020: Deployable Tower Assembly motor tested in 1G

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

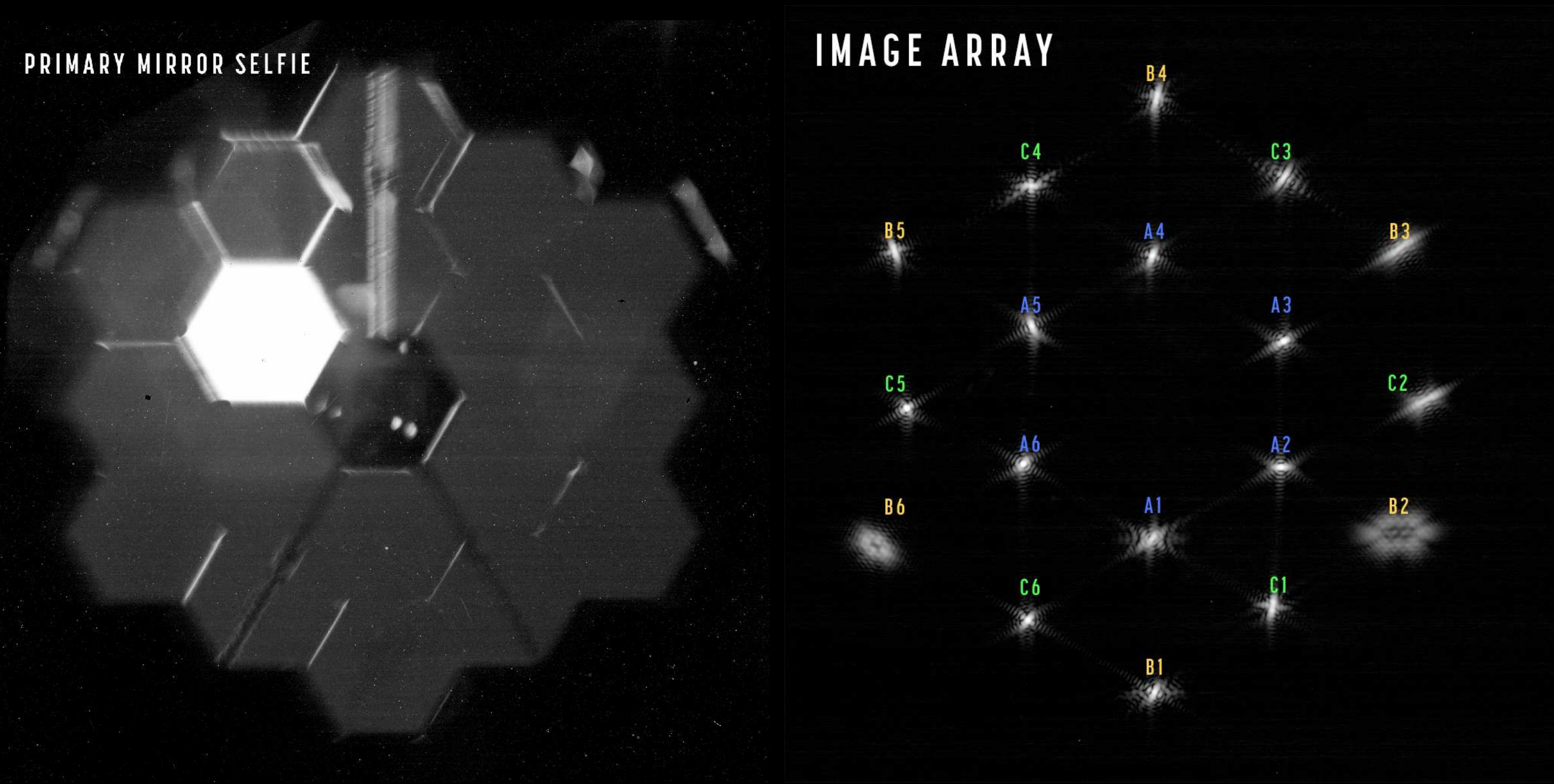
210913 JWST Monthly Telecon 18

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

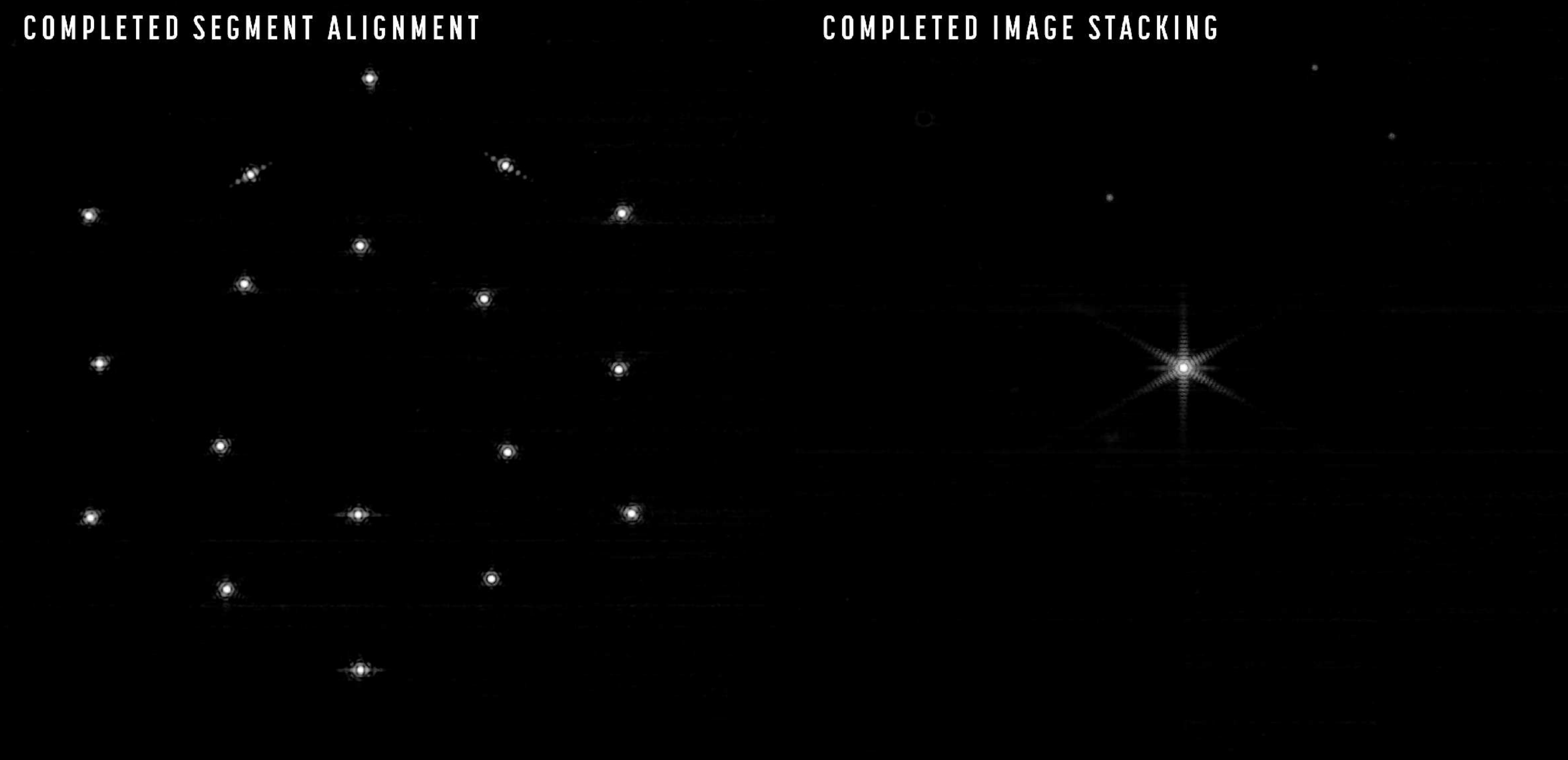
Dec. 9, 2021: JWST transport in Kourou to Ariane Rocket Assembly Building

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

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



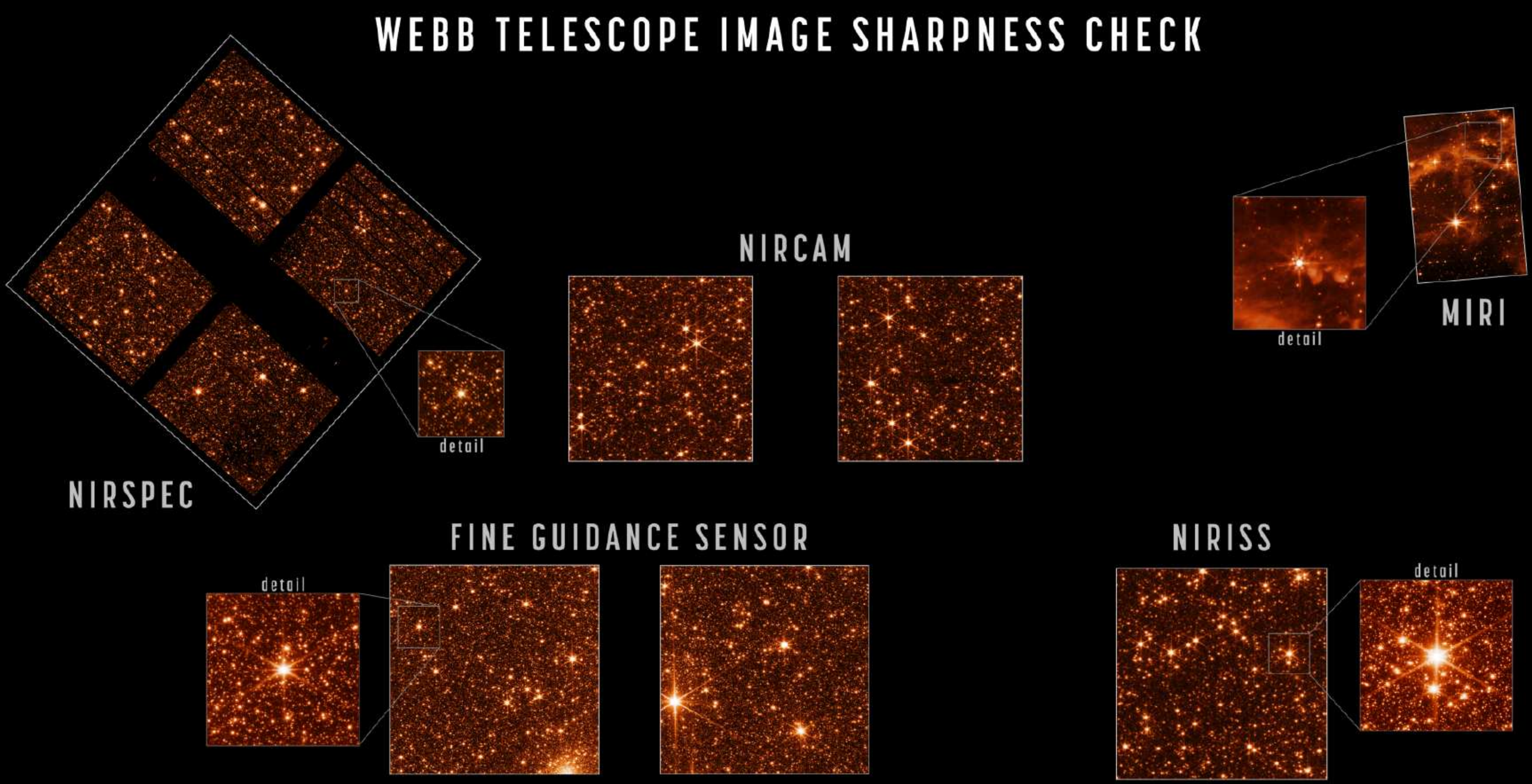
Feb. 2022: Webb's first selfie (left) and First Light raw image (right).



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

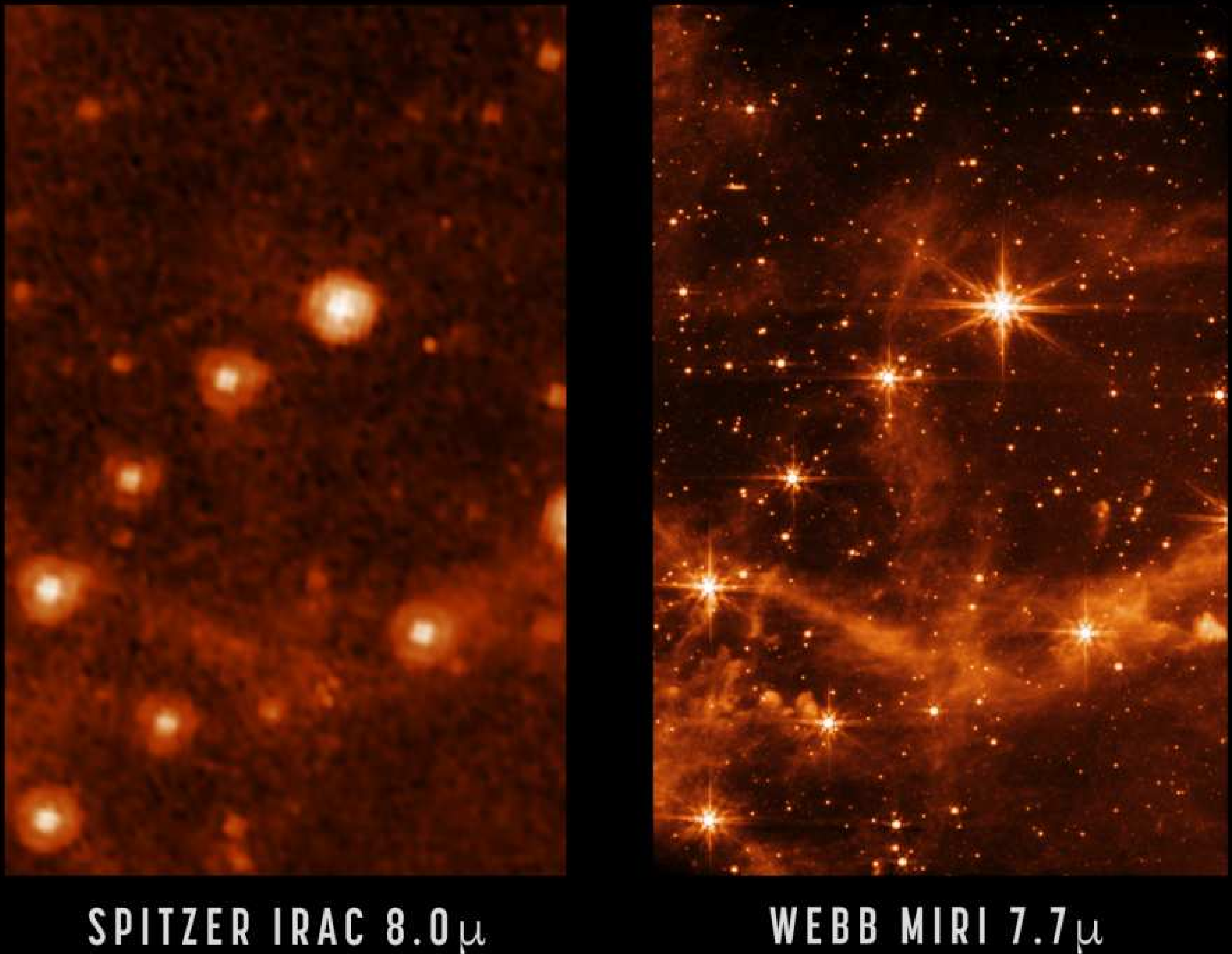
March 16, 2022: Webb's first fully focused image publicly released !!
Note the plethora of faint galaxies — Webb's looking back in time!

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



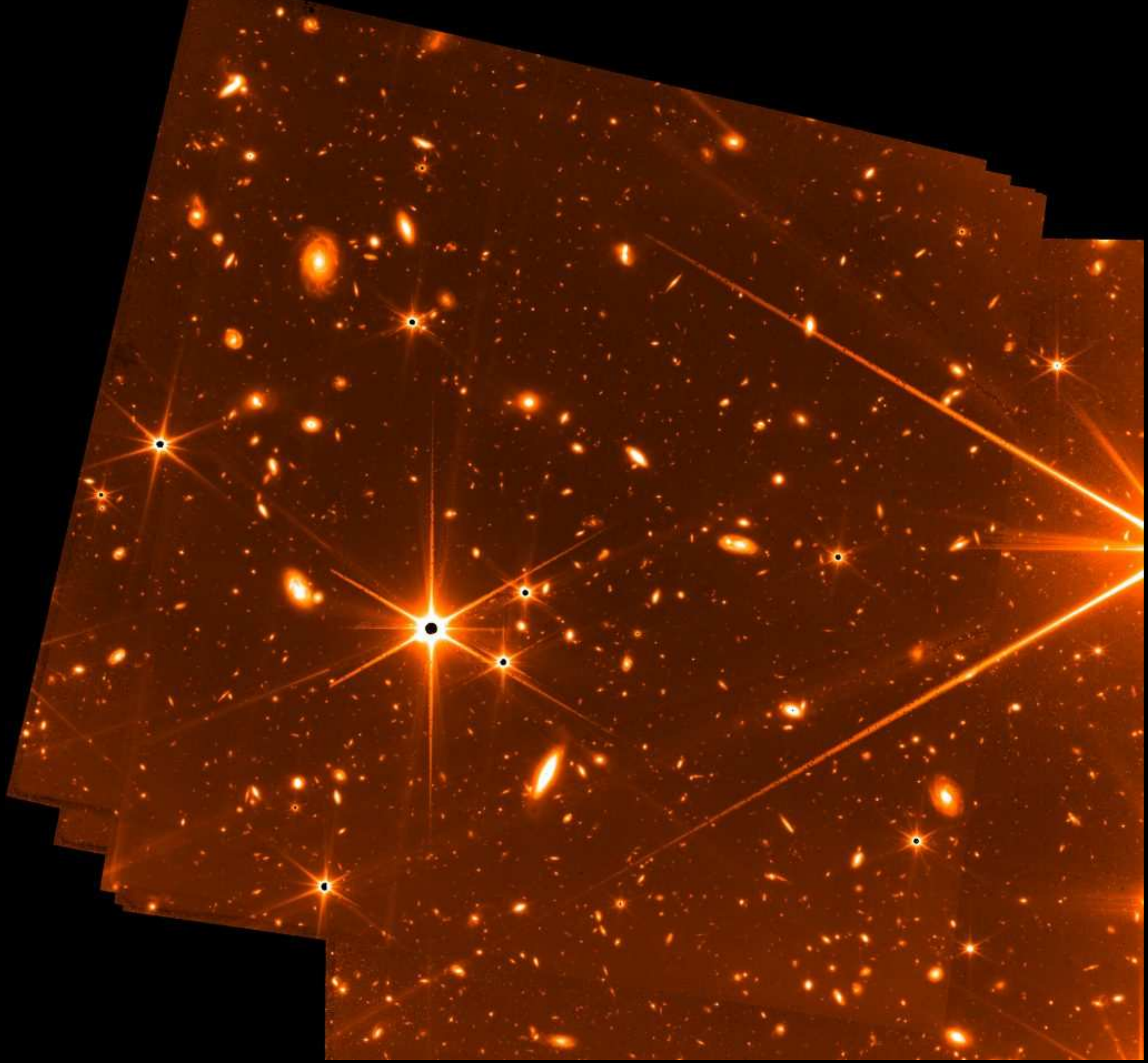
April 28, 2022: Webb's first fully focused images in all four instruments: a dense star field in the Large Magellanic Cloud in the South Ecliptic Pole! (NIRSpec: 1.1 μm; NIRISS: 1.5 μm; NIRCam: 2.0 μm; MIRI 7.7 μm).

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

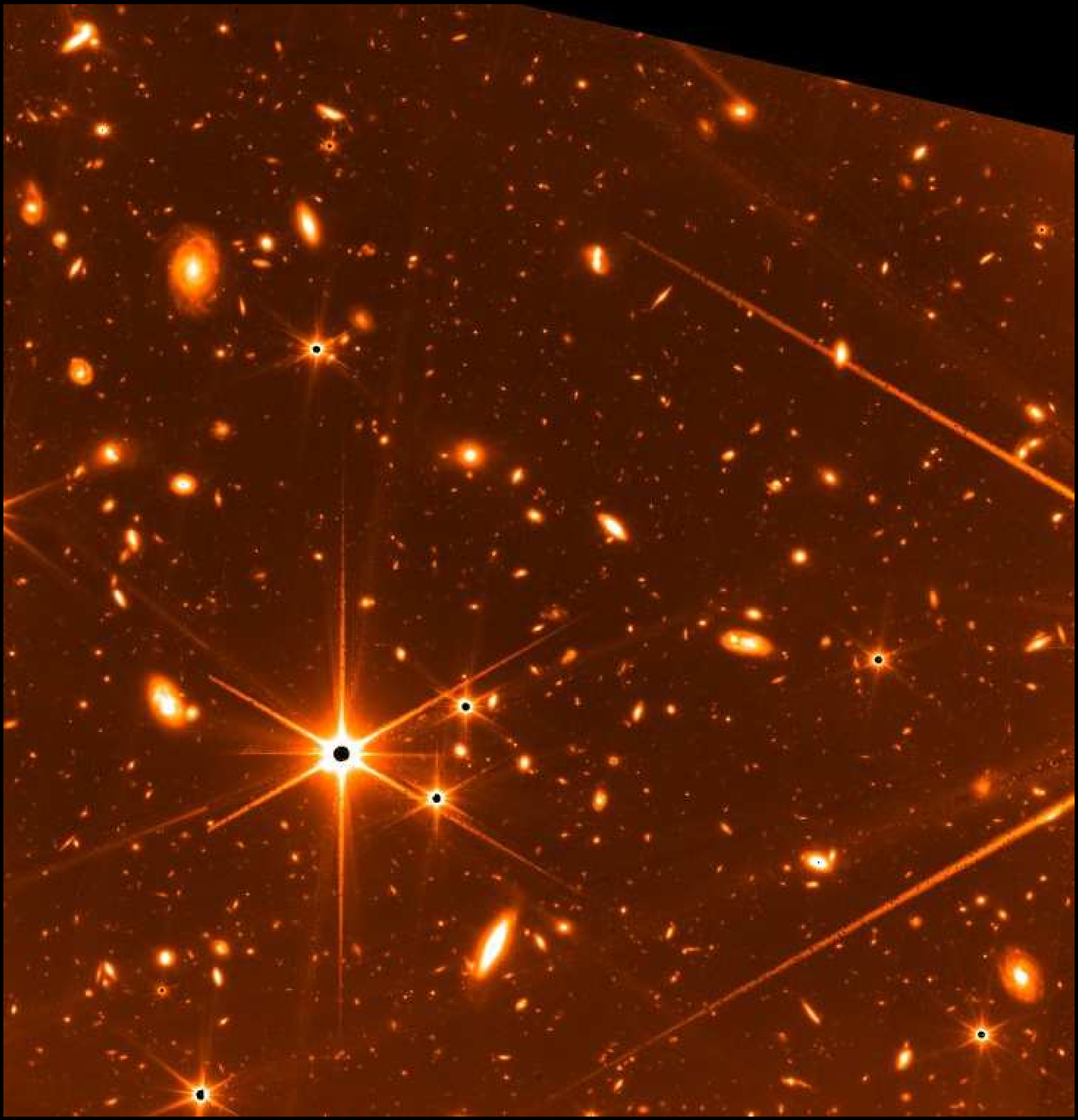
https://blogs.nasa.gov/webb/2022/05/09/miris-sharper-view-hints-at-new-possibilities-for-science/



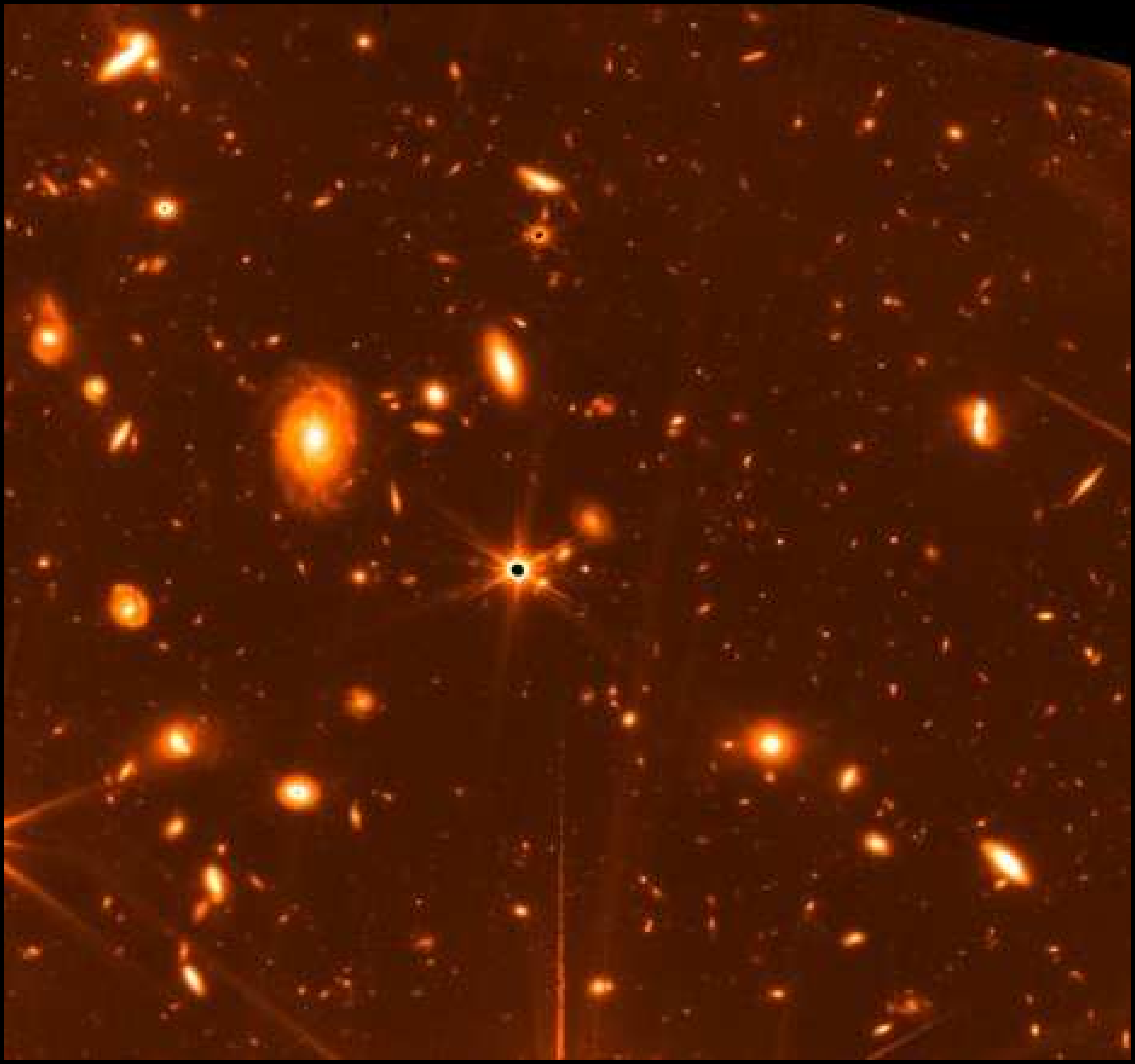
July 6, 2022: 32-hr Fine Guidance Sensor deepest wide-band near-IR image

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

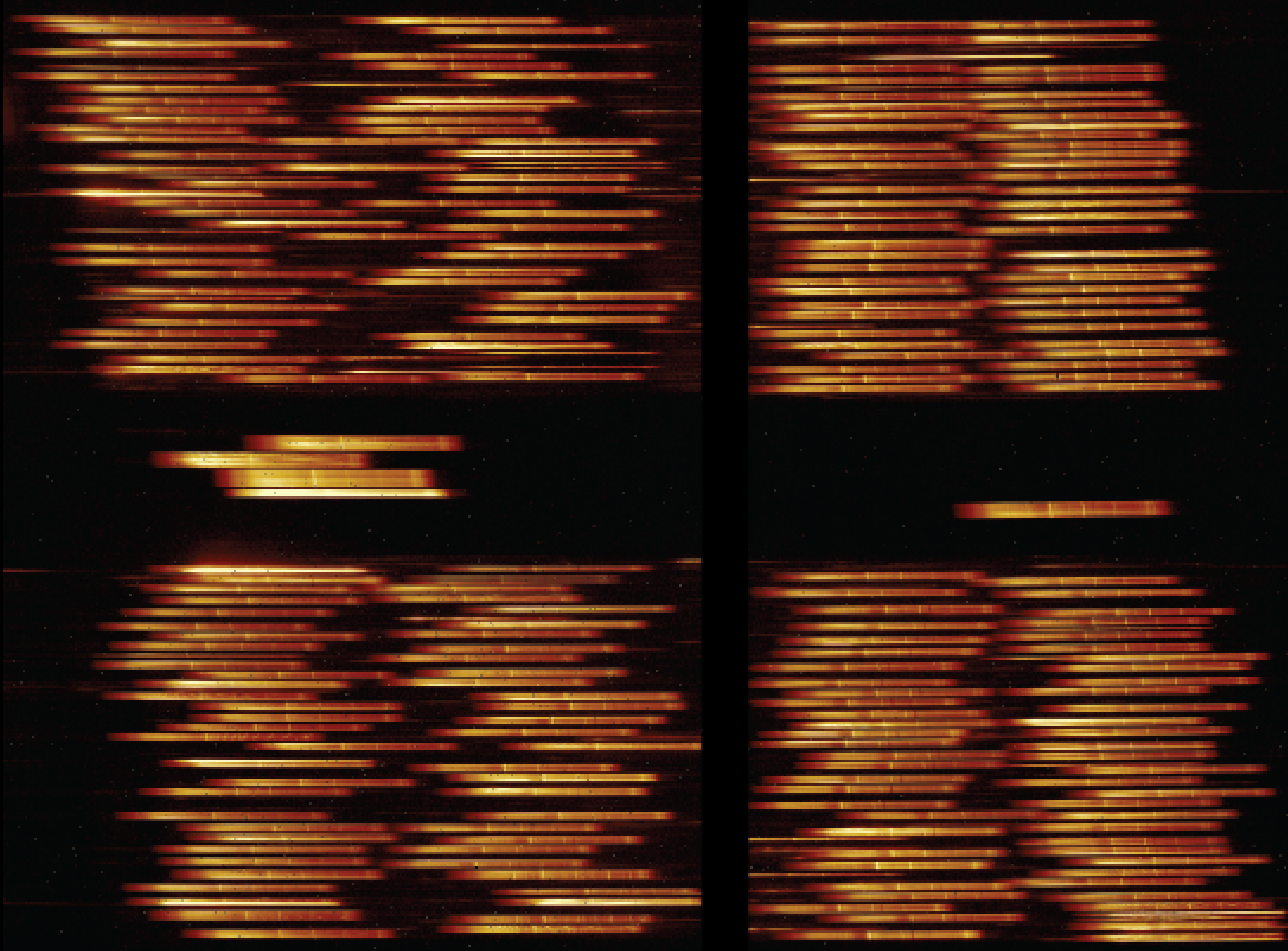
https://blogs.nasa.gov/webb/2022/07/06/webbs-fine-guidance-sensor-provides-a-preview/



… 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.

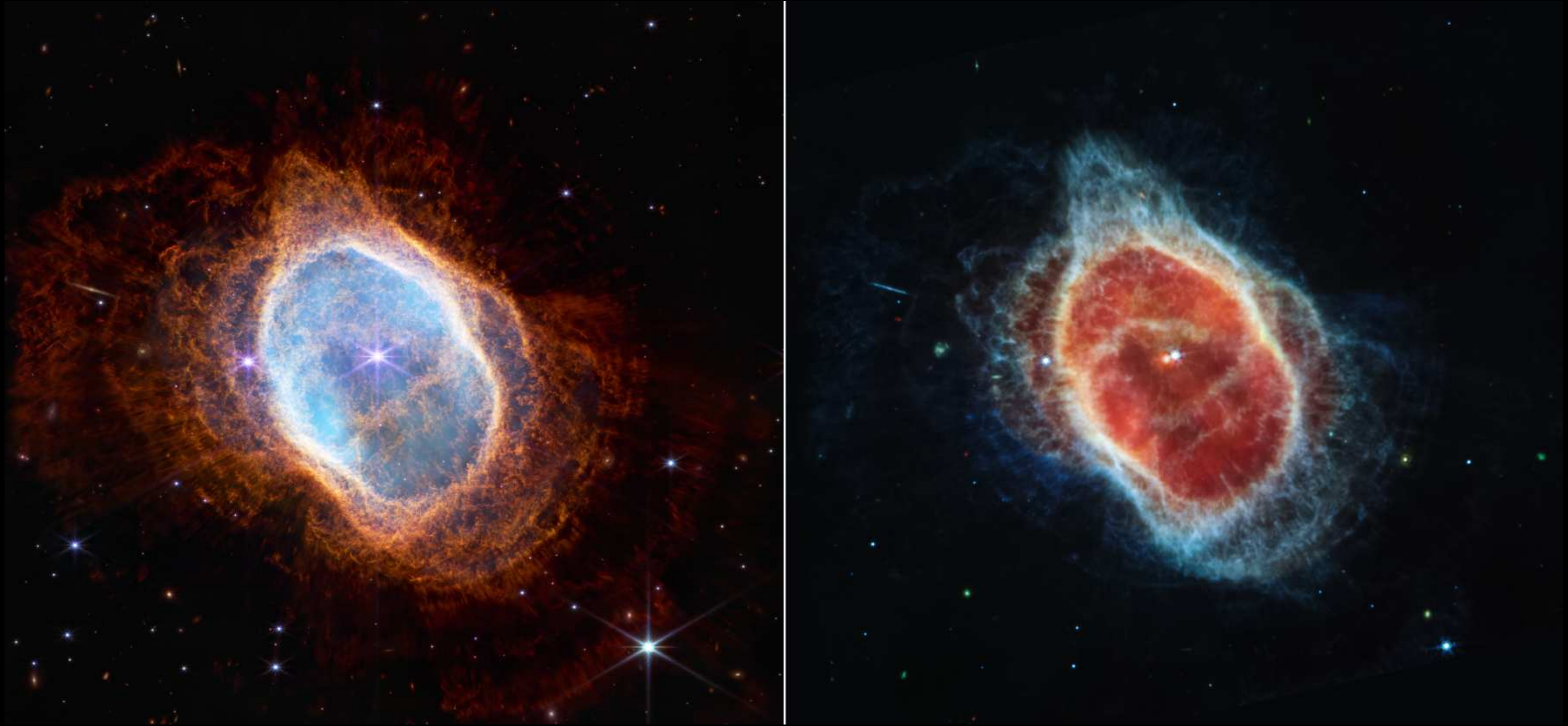
“Cosmic Cliffs” of star-formation in the Carina Nebula (NIR; 7600 light-years).

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.



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 ...

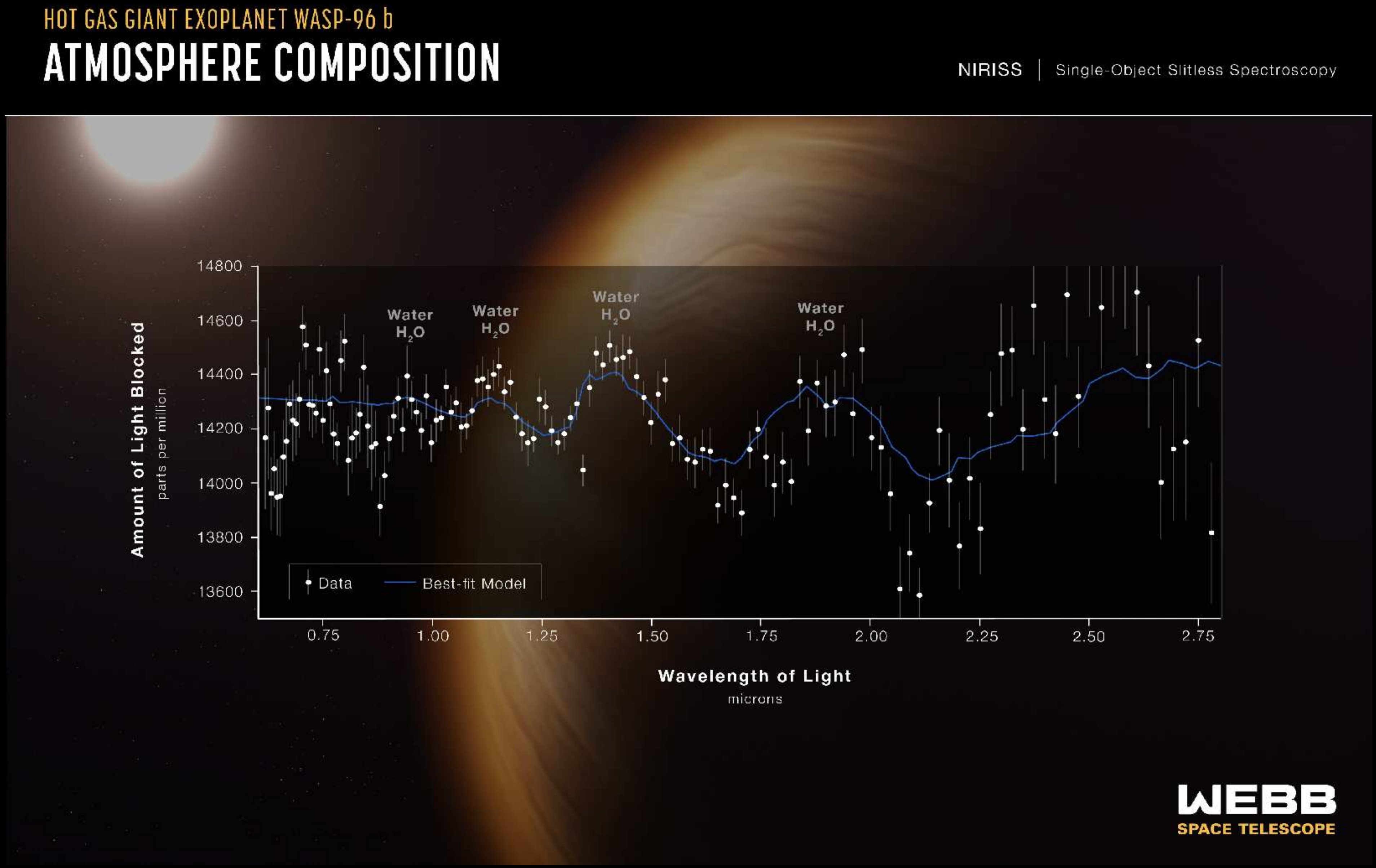
and expanded to 100$\times$ its current size, engulfing the Earth.

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 ...



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

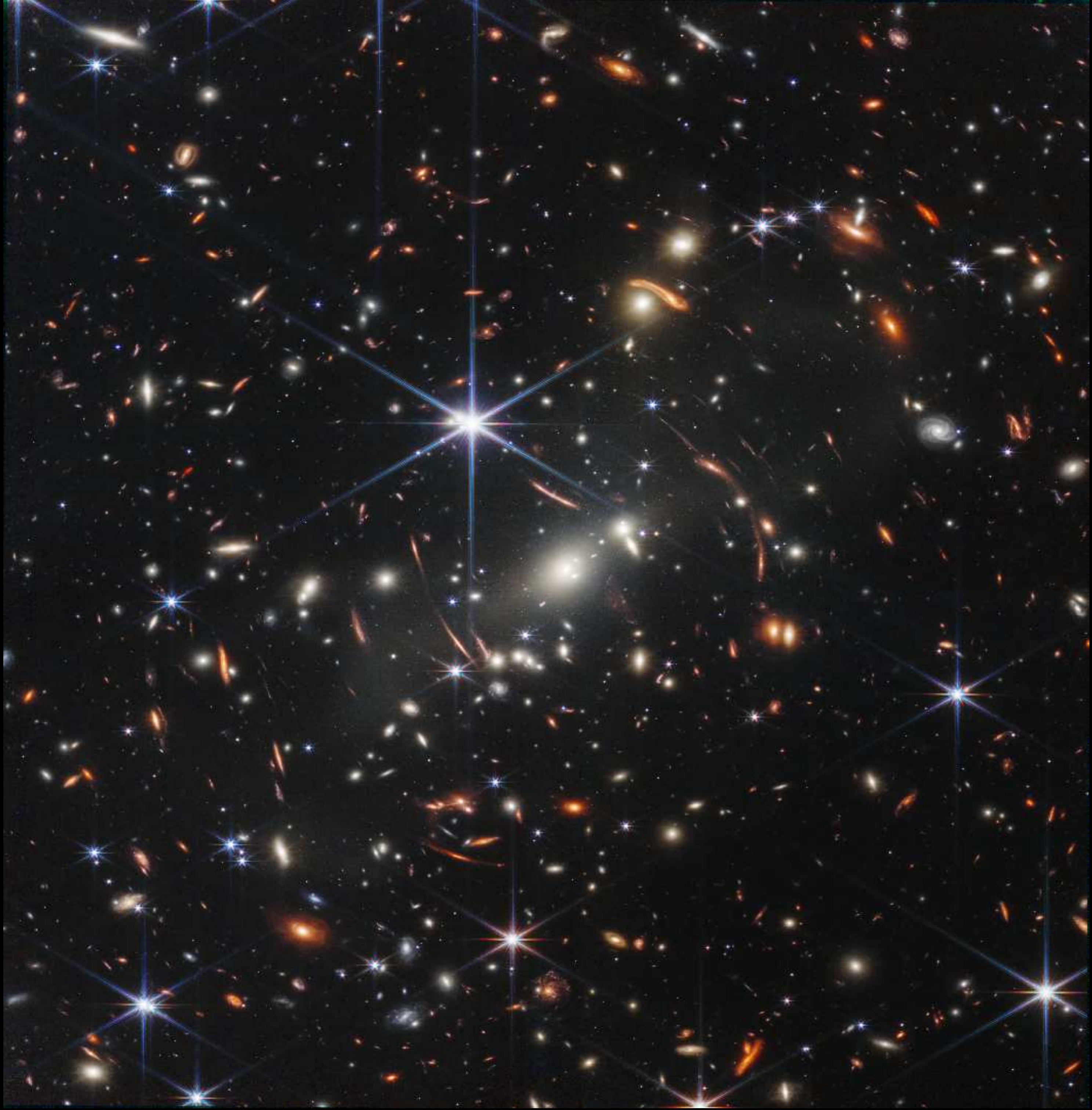
- Near-IR spectrum shows characteristic features of water (steam !).
- It has a temperature of 1000 F and is half Jupiter in mass.
- Webb will scan Earth-like exoplanets for building blocks of life.

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

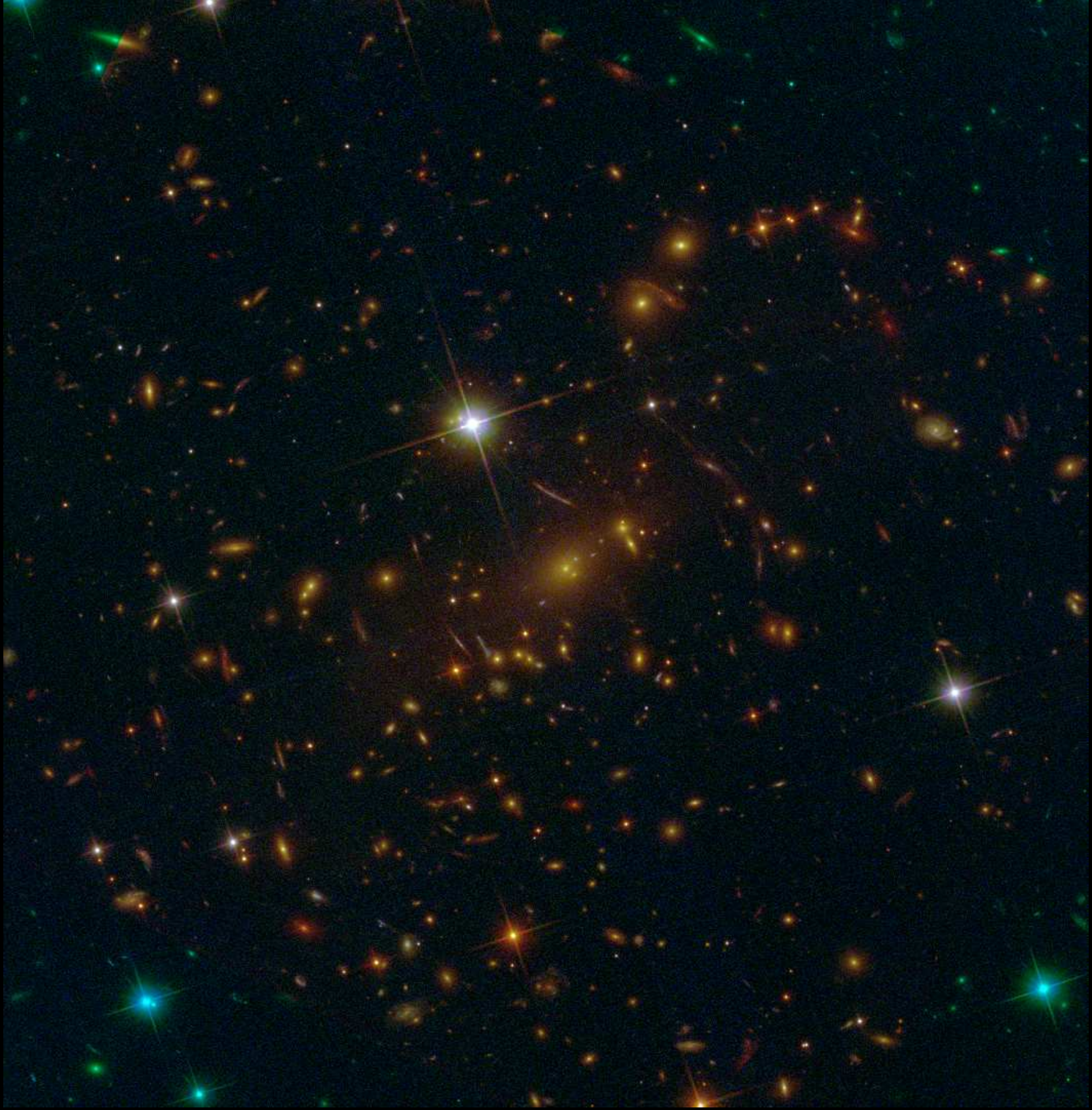
- These major "Cosmic Trainwrecks" are much more common in the past.
  - Sun-like stars formed in aftermath of minor "Cosmic Fender-benders".

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

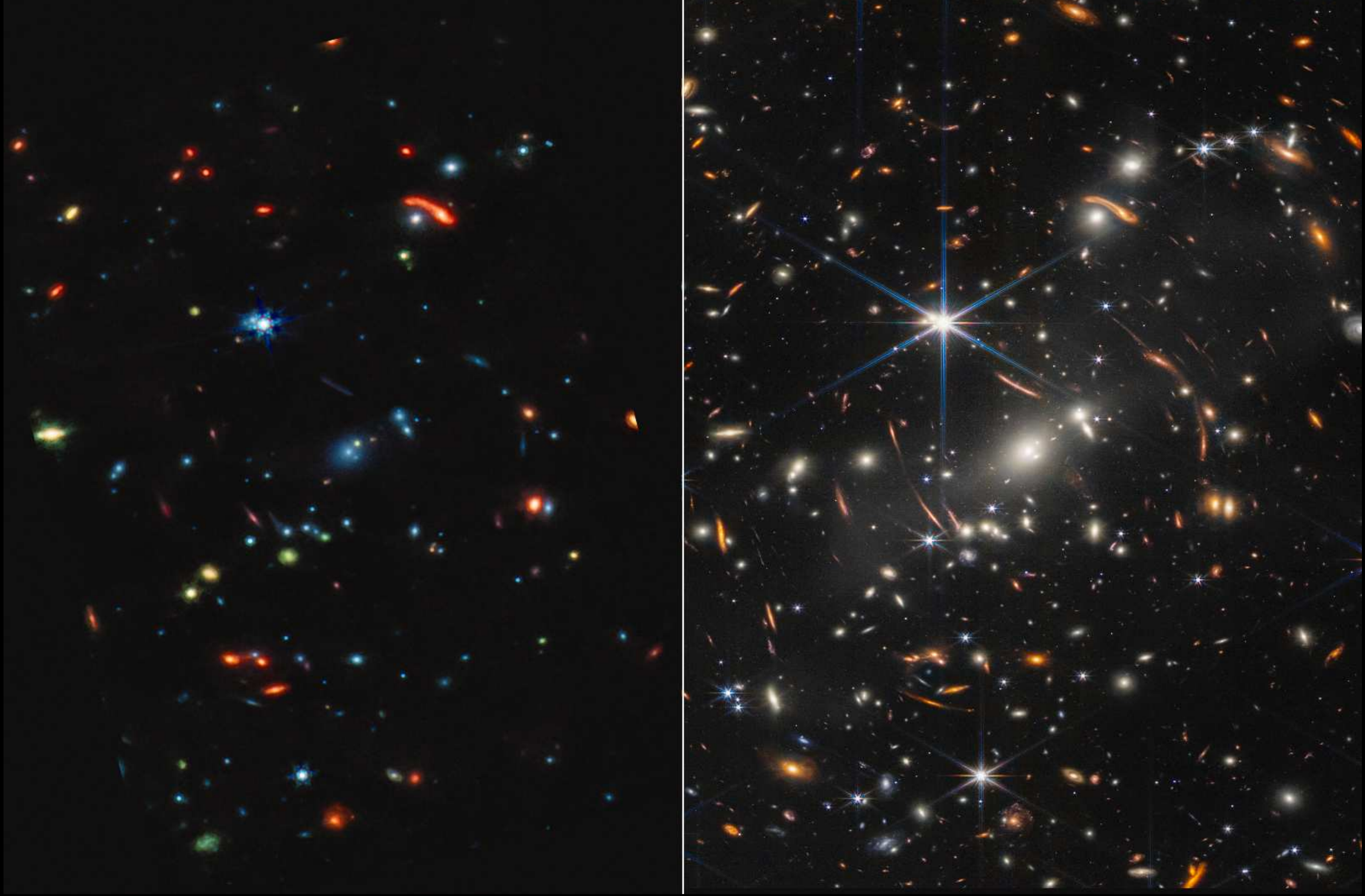
- Mid-IR shows molecular gas being pulled out during collision.
- Gravity from collision in top galaxy feeds the Beast: the central SMBH!



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!

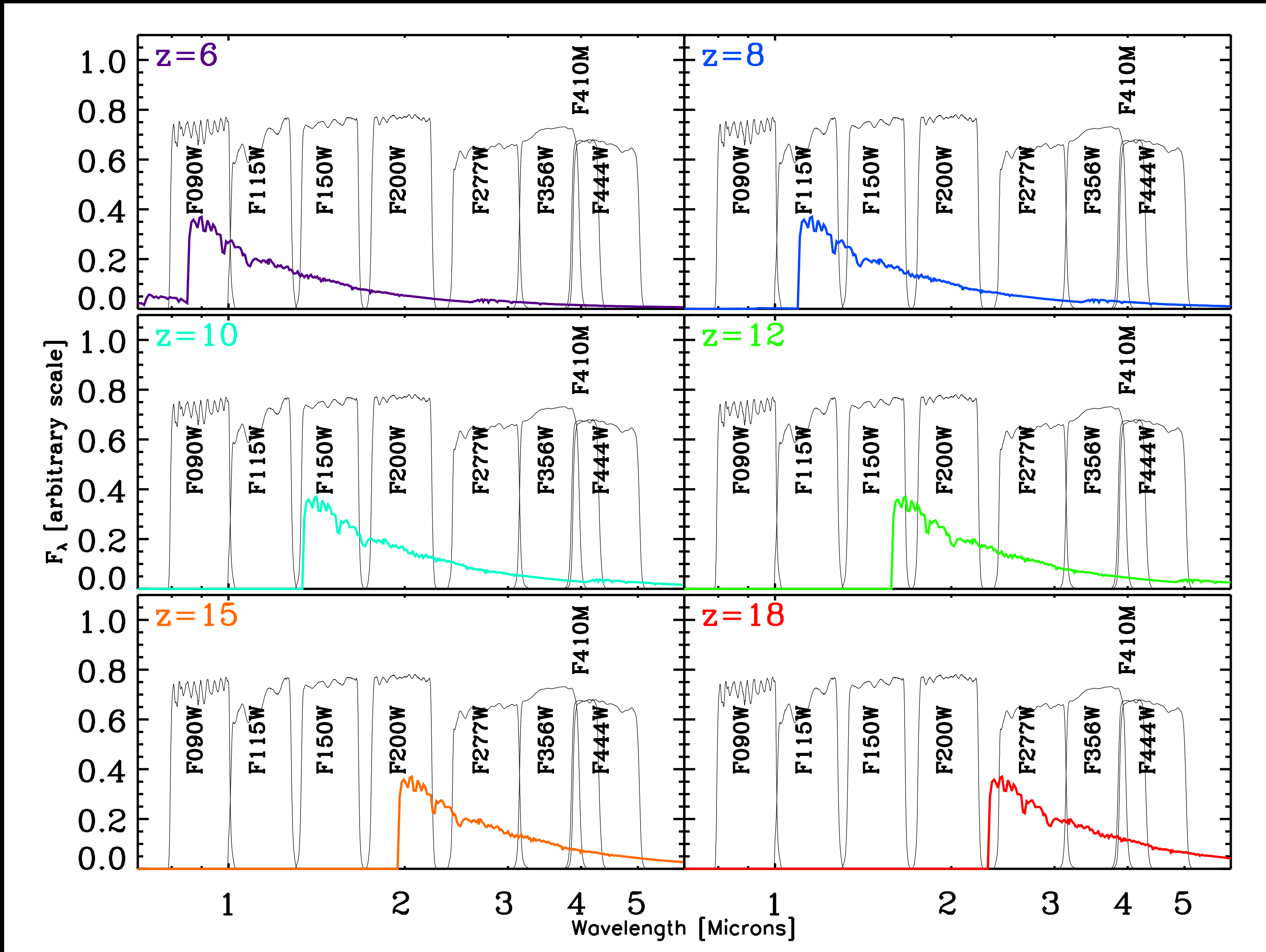


Compared to near-IR (right), mid-IR sees some very red objects (left):

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

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

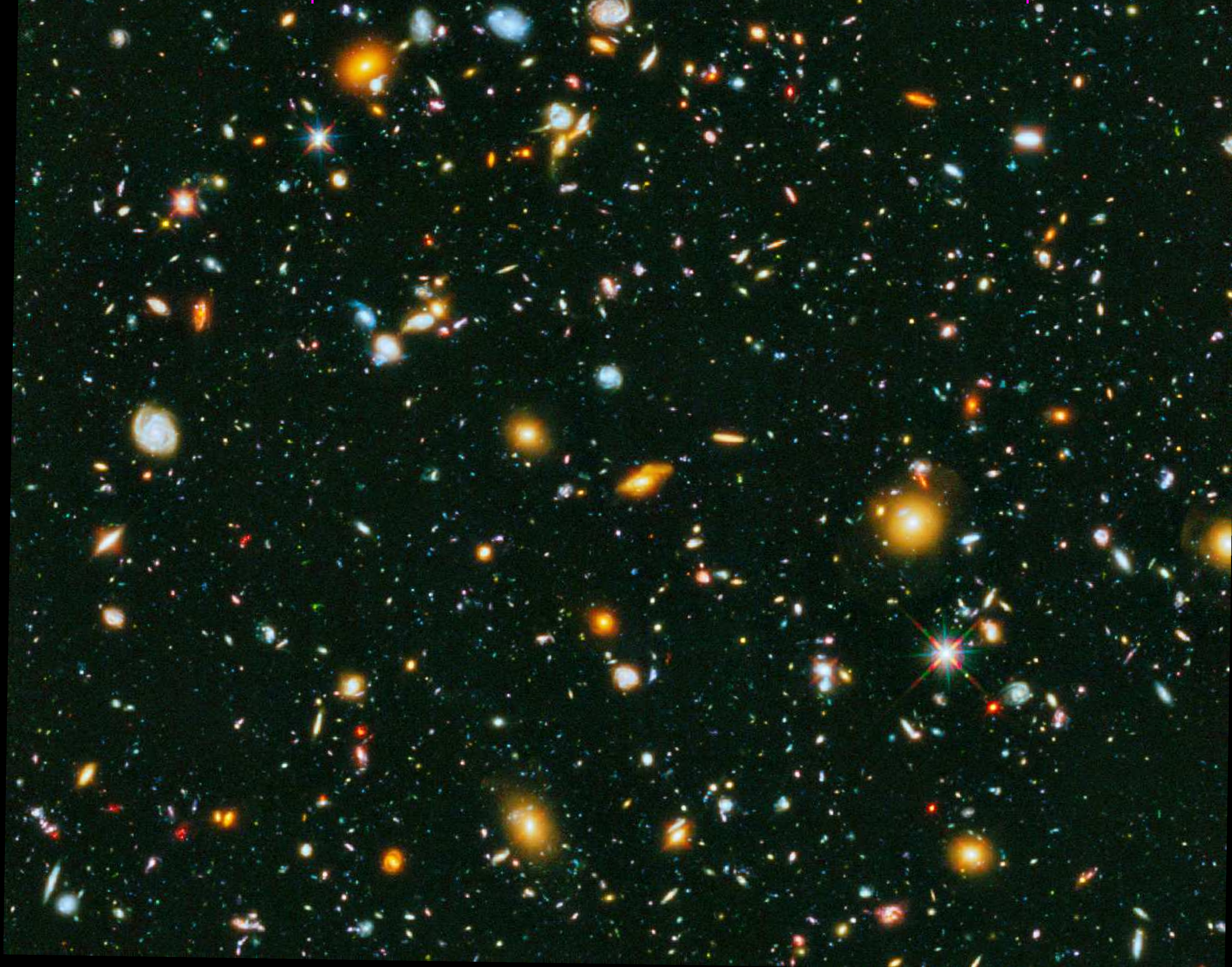
3) How can Webb measure First Light: What to expect in (Ultra)Deep Fields?



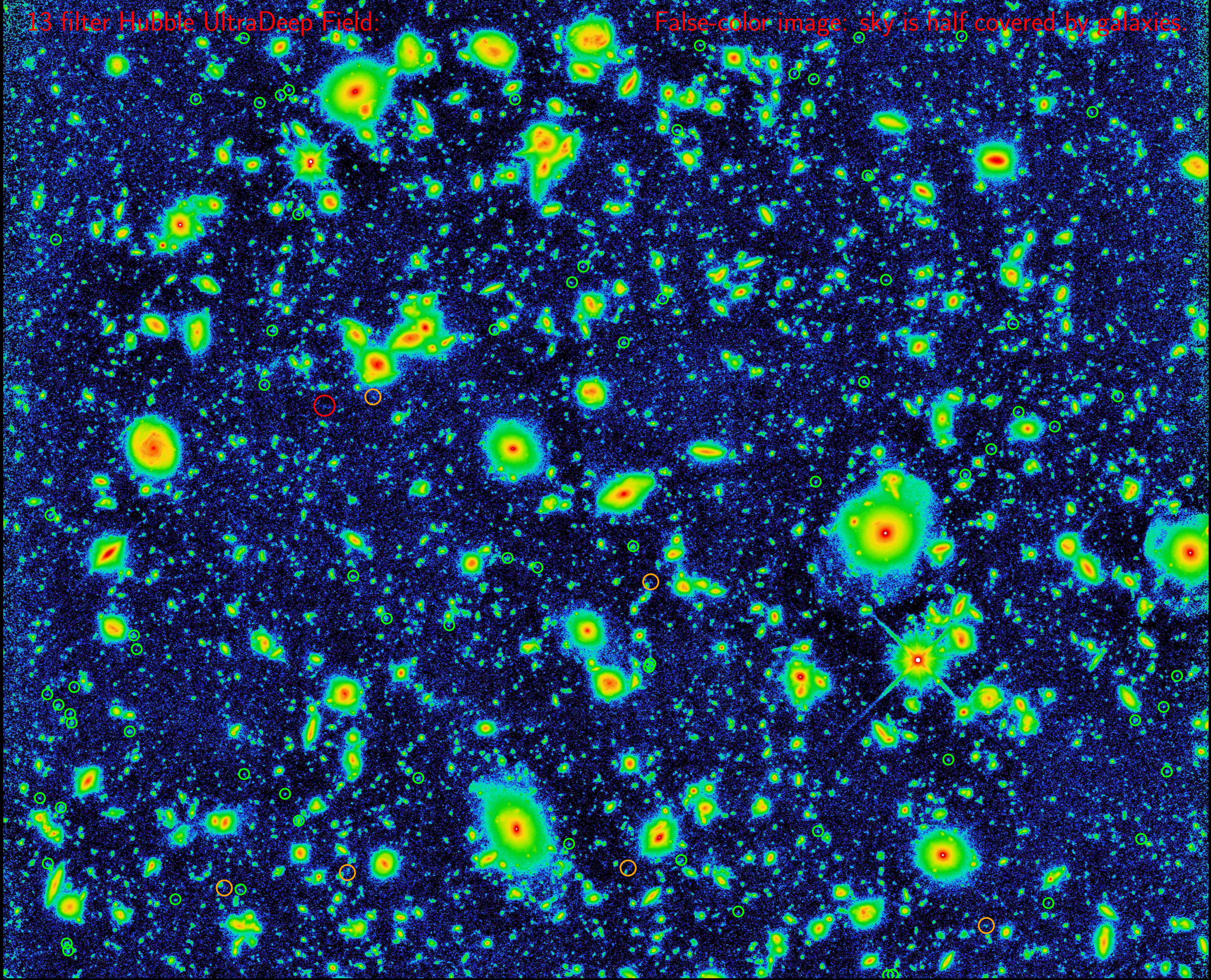
- Can't beat redshift: to see First Light, must observe near–mid IR.

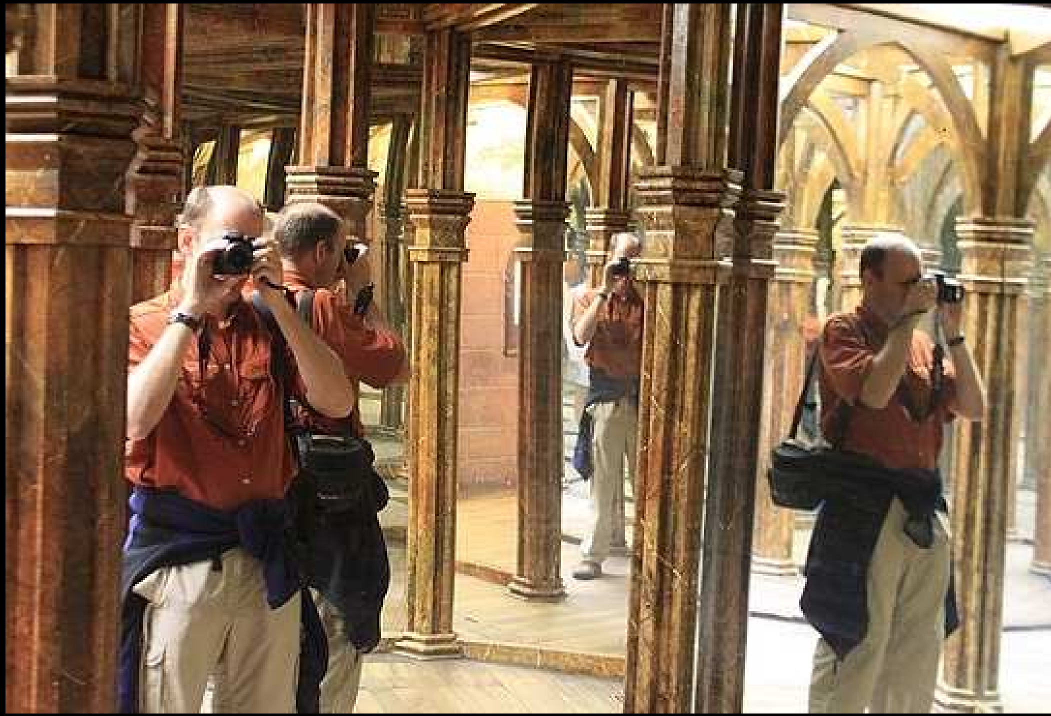
⇒ This is why JWST needs NIRCam at 0.8–5 μm and MIRI at 5–28 μm.

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.



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) HST set stage to measure galaxy assembly in the last 12.7-13.0 Gyrs.

(2) JWST passed Preliminary & Critical Design Reviews in 2008 & 2010.

- 100% built in 2017; Final testing: meets/exceeds specs.

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

(3) JWST is designed to map the epochs of First Light, Reionization, and Galaxy Assembly & SMBH-growth in detail. JWST will determine:

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

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

- IR sequel to HST starting 2022: Training next generation researchers.
- JWST will define the next frontier to explore: the Dark Ages.

SPARE CHARTS

- References and other sources of material shown:

http://ahah.asu.edu/ [Appreciating Hubble at Hyperspeed]

http://ahah.asu.edu/download.html [Download Java–tool]

http://ahah.asu.edu/clickonHUDF/index.html [Clickable map]

http://www.jwst.nasa.gov/ & http://www.stsci.edu/jwst/

https://blogs.nasa.gov/webb/

http://https://www.nasa.gov/webbfirstimages

http://www.webbcompare.com/index.html

Gardner, J. P., et al. 2006, Space Science Reviews, 123, 485–606

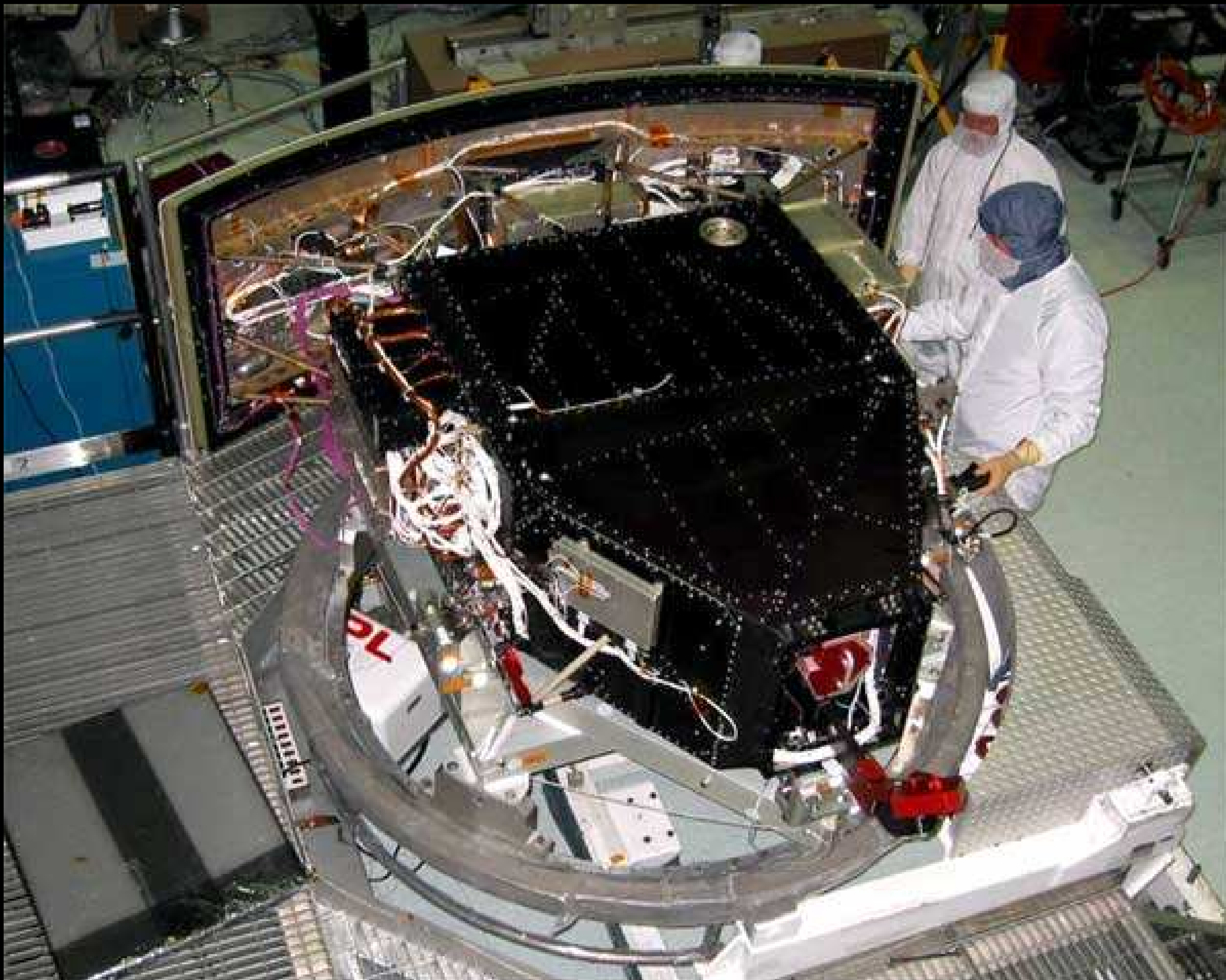
Mather, J., & Stockman, H. 2000, Proc. SPIE Vol. 4013, 2

Windhorst, R., et al. 2008, Advances in Space Research, 41, 1965

Windhorst, R., et al., 2011, ApJS, 193, 27 (astro-ph/1005.2776).

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

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



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).

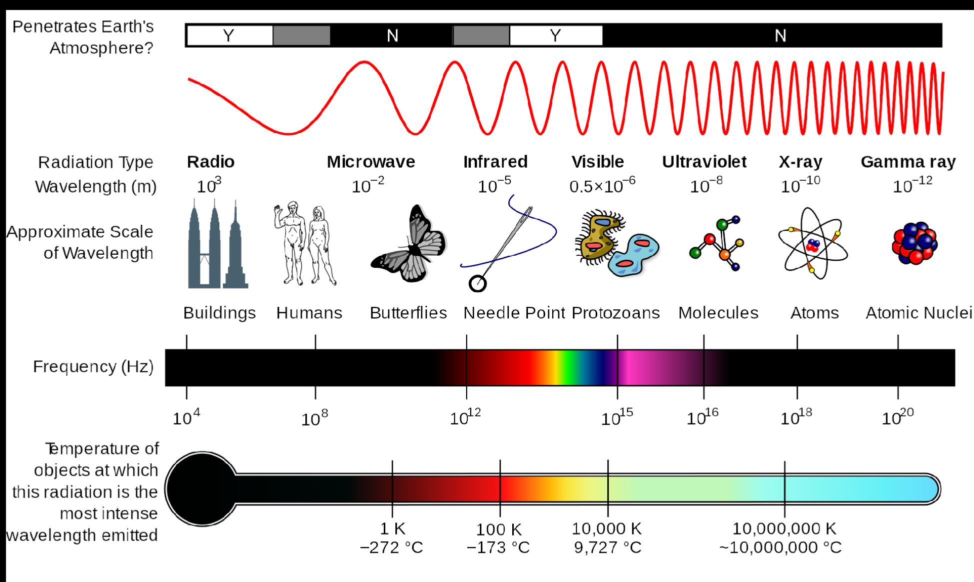
JWST adds 0.05–0.2" FWHM imaging to AB$\simeq$31.5 mag (1 FF) at 1–5μm, with 0.2–1.2" images at 5–29μm, tracing young+old stars & dust.

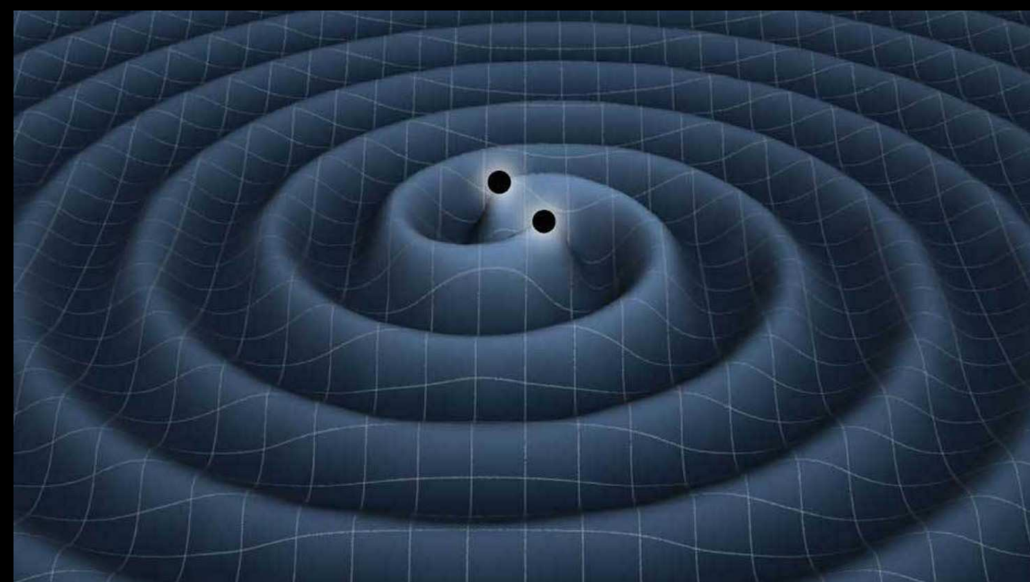
Black Hole growth — Waves that happen in Nature: 1) Sounds Waves:

In solids: Earthquakes

In liquids: Surf!

In gasses: Sound

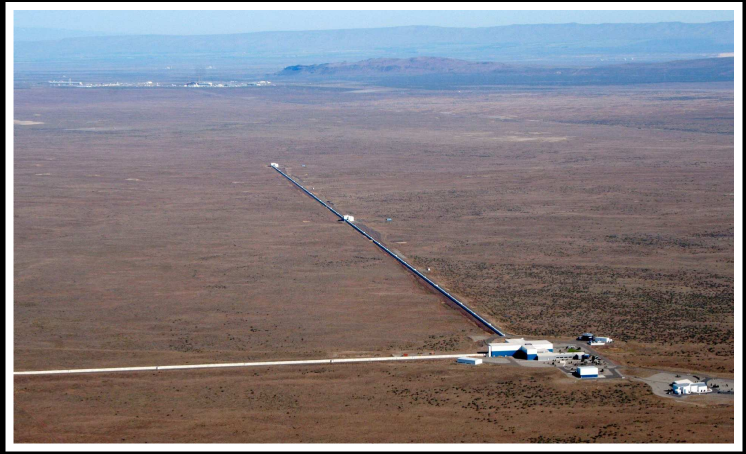


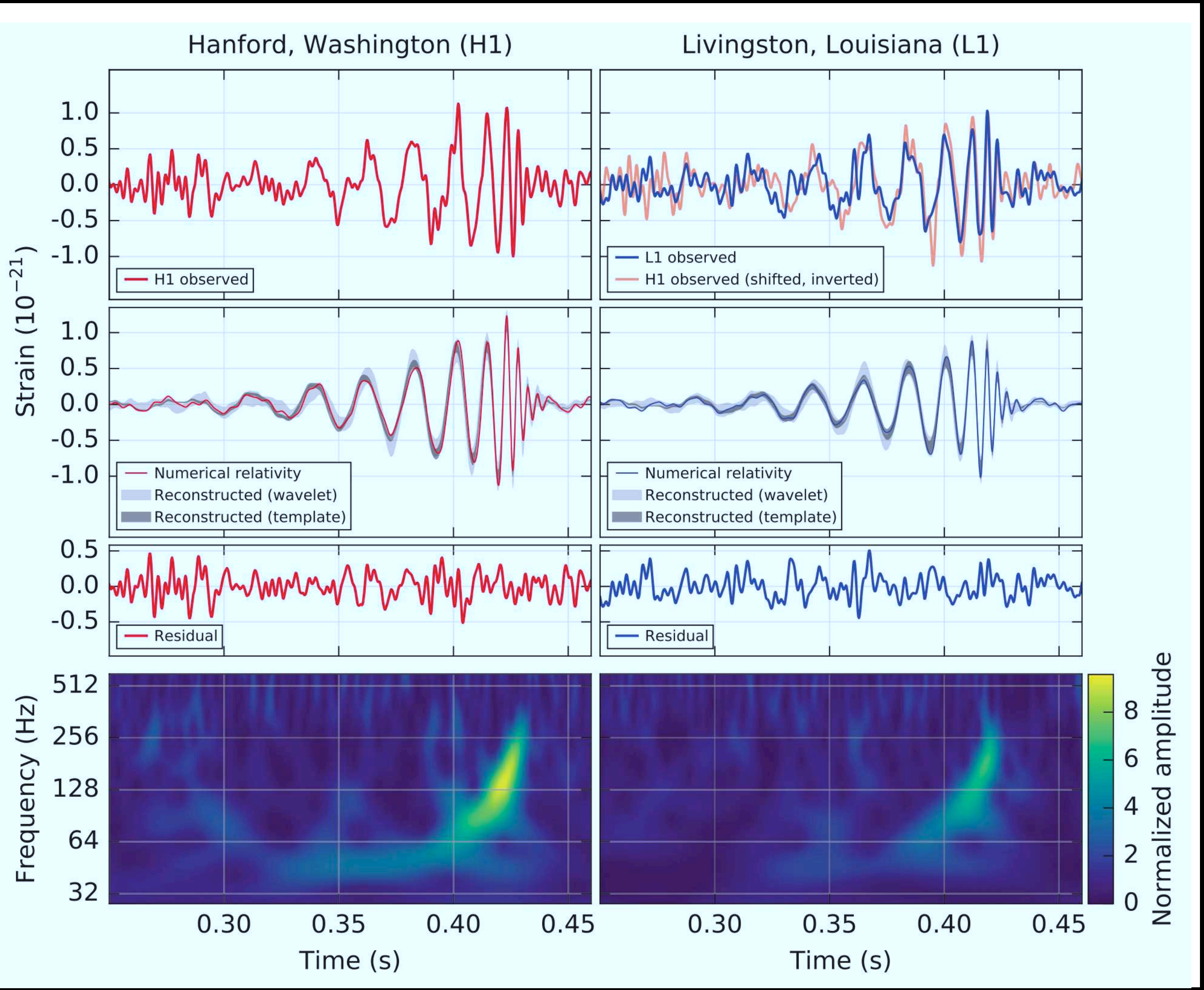


2) Electromagnetic Waves

3) In space-time: Gravity Waves

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

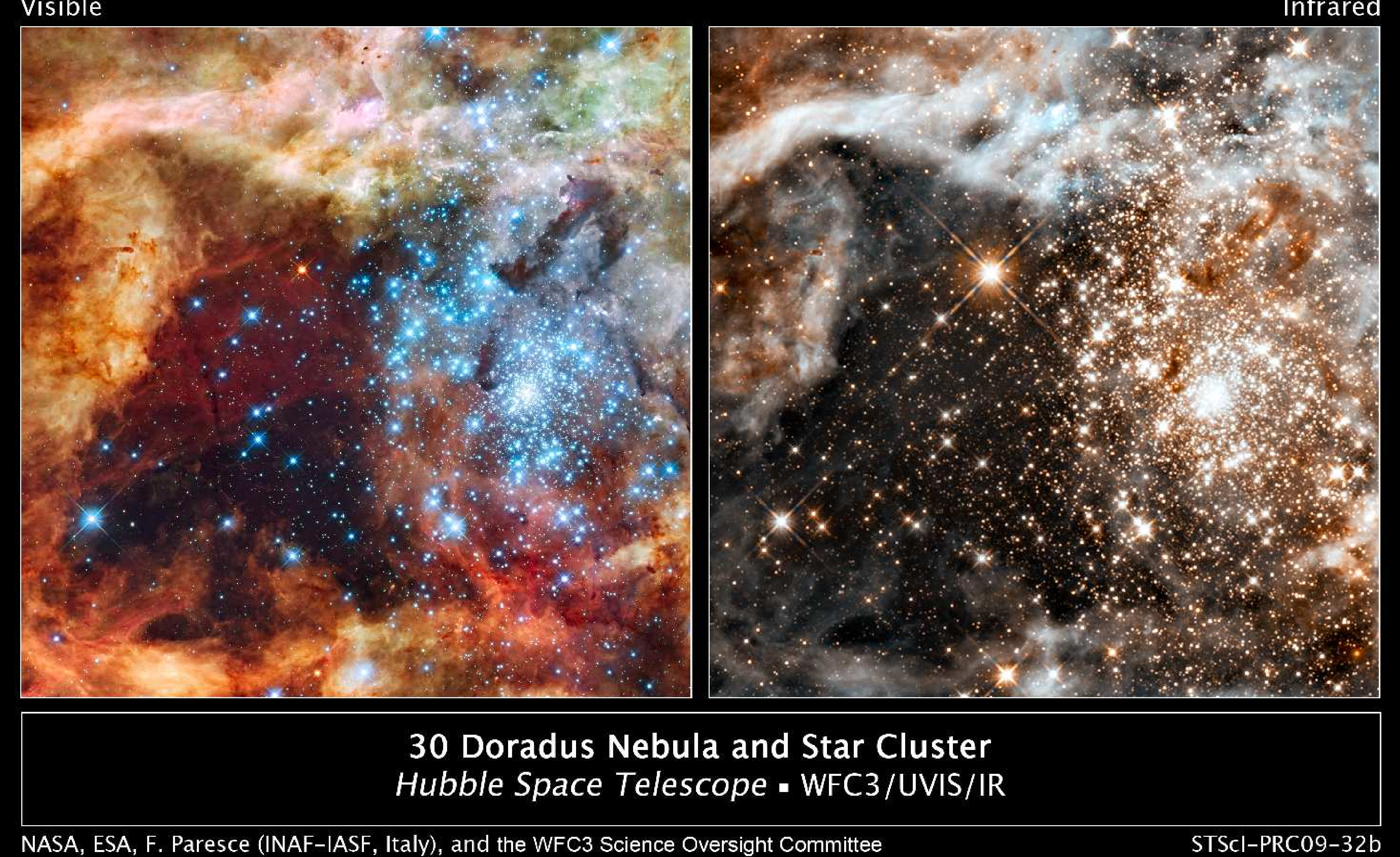




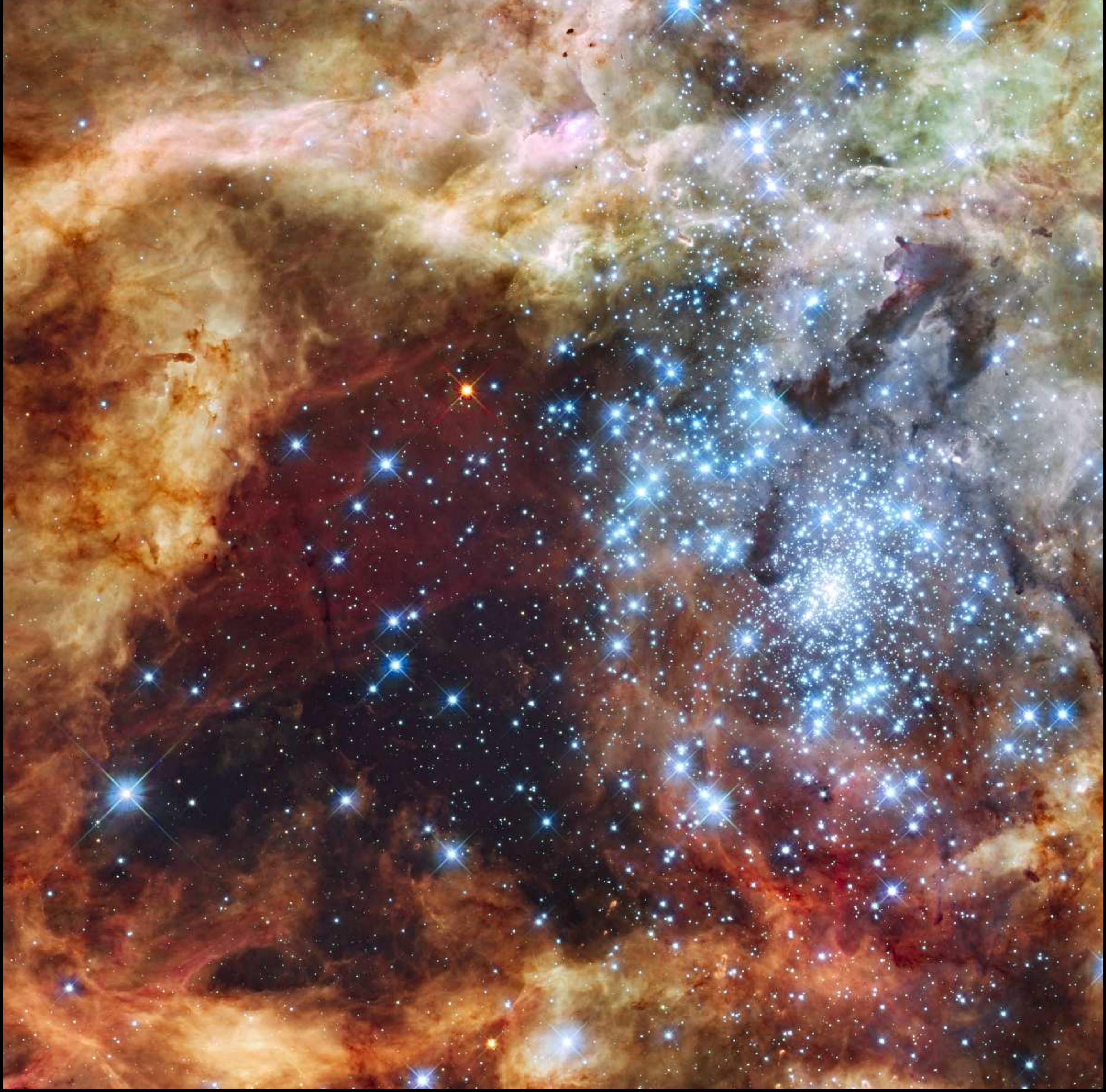
(1) LIGO first observed Gravitational Waves on Sept. 14, 2015.

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

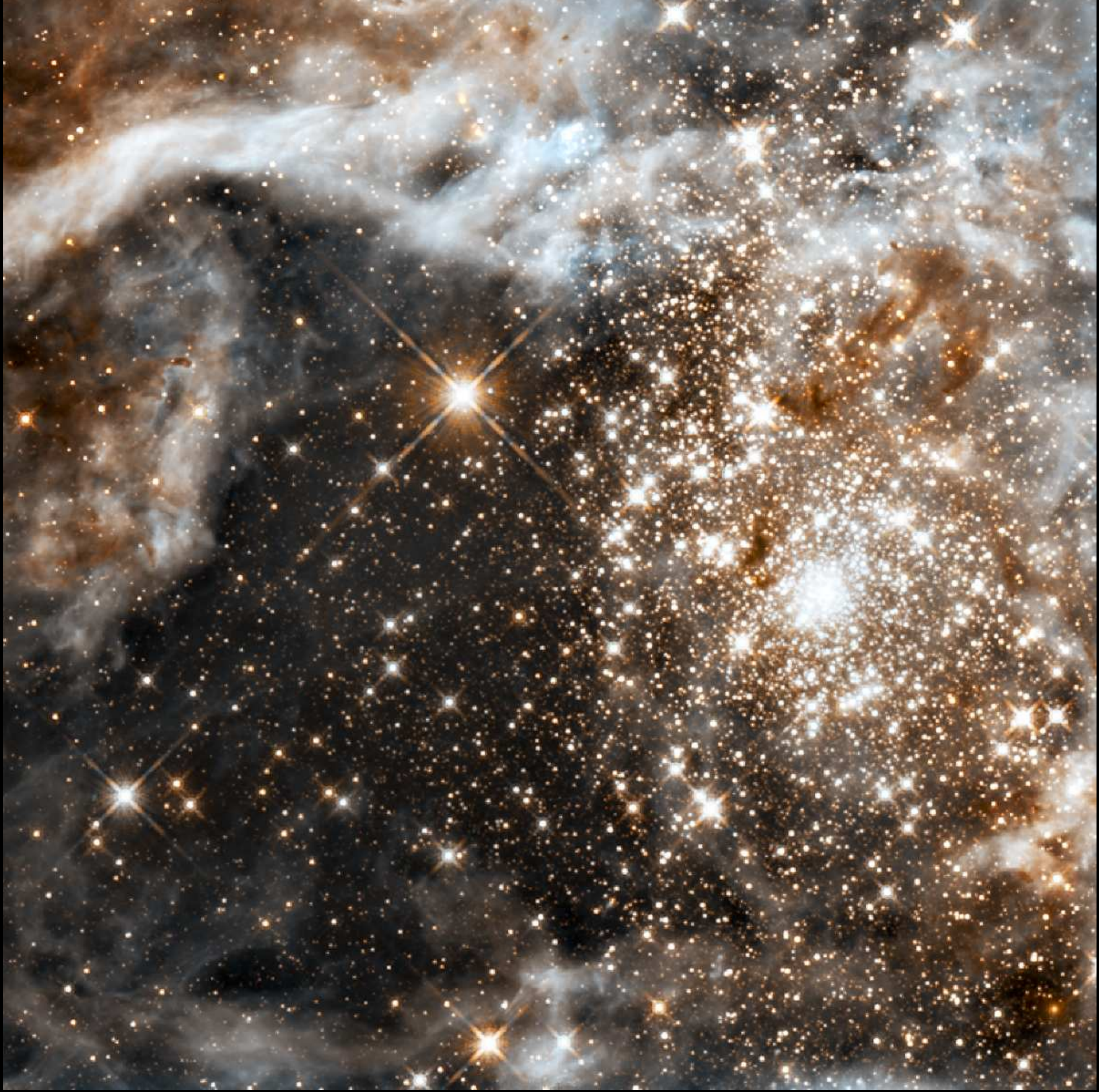
- $E=Mc^2$: 3 $M_{\odot}$ was converted to energy in a fraction of a second!



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 $M_\odot$).

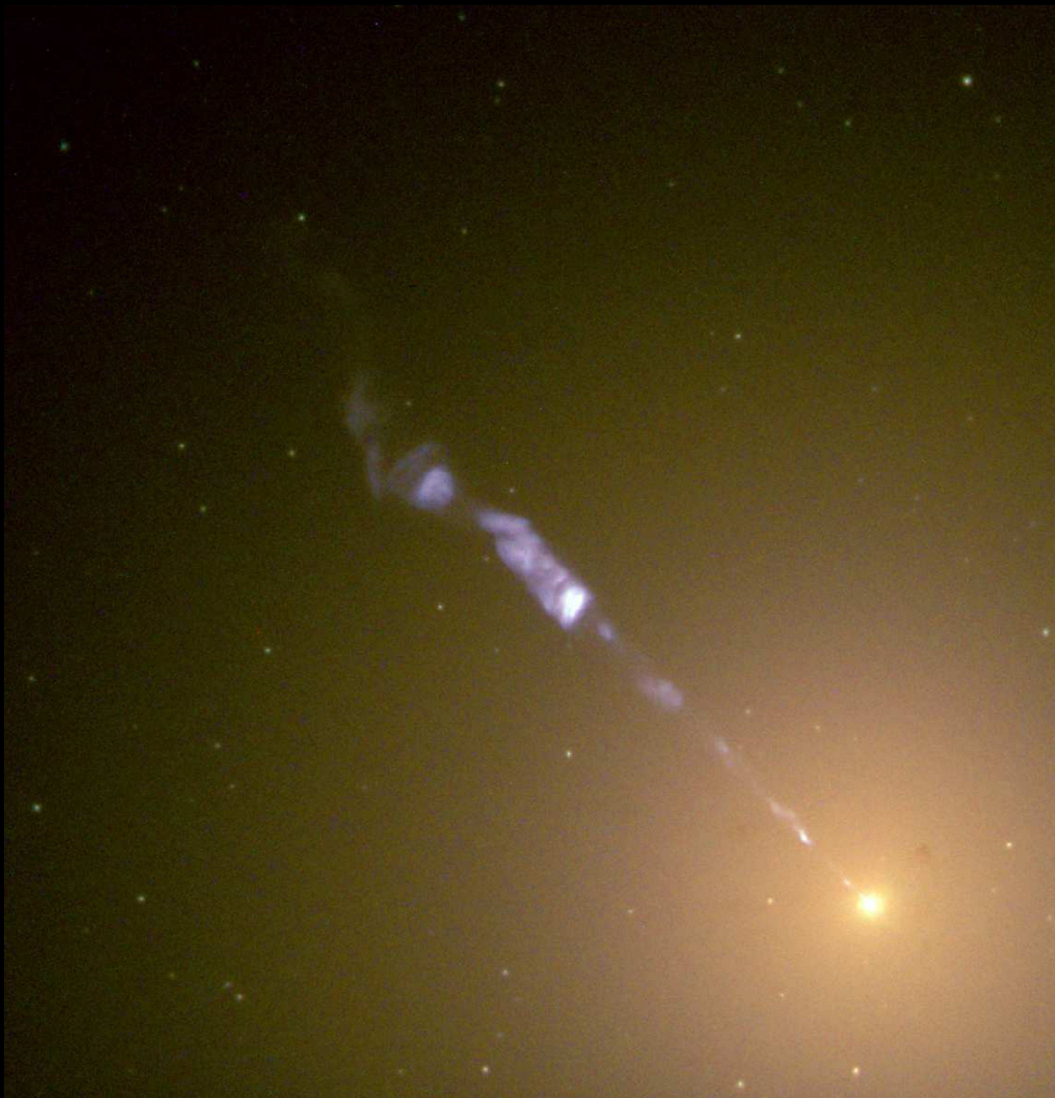


Ordinary massive stars (10–30 $M_\odot$) leave modest black holes ($\sim$3–10 $M_\odot$).

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 ...

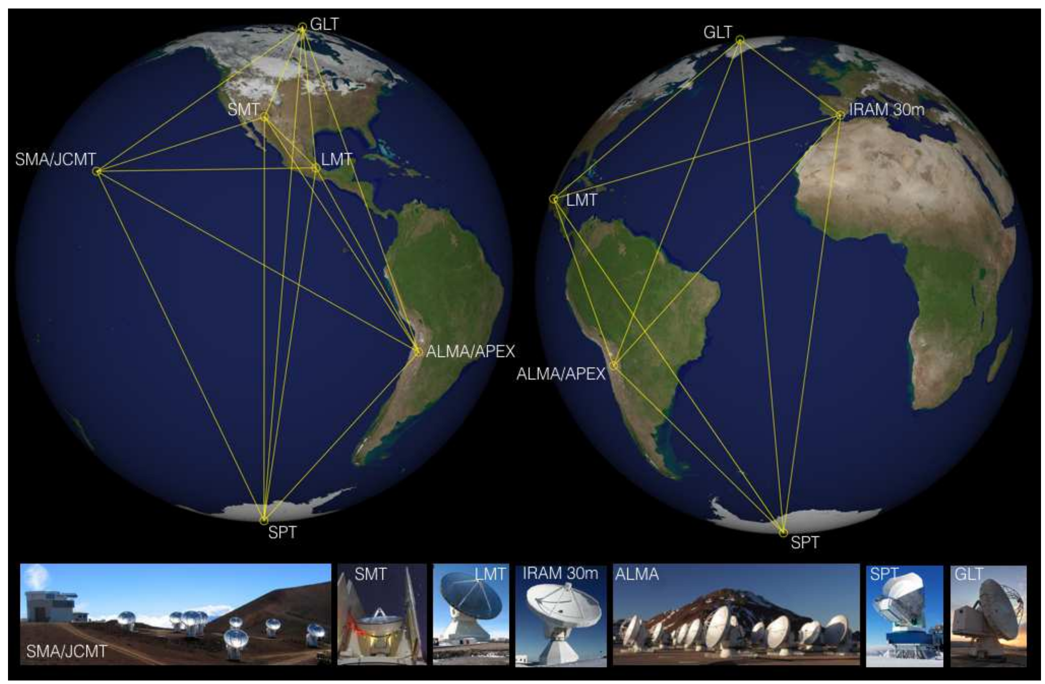
Elliptical galaxy M87 with Active Galactic Nucleus (AGN) and relativistic jet:

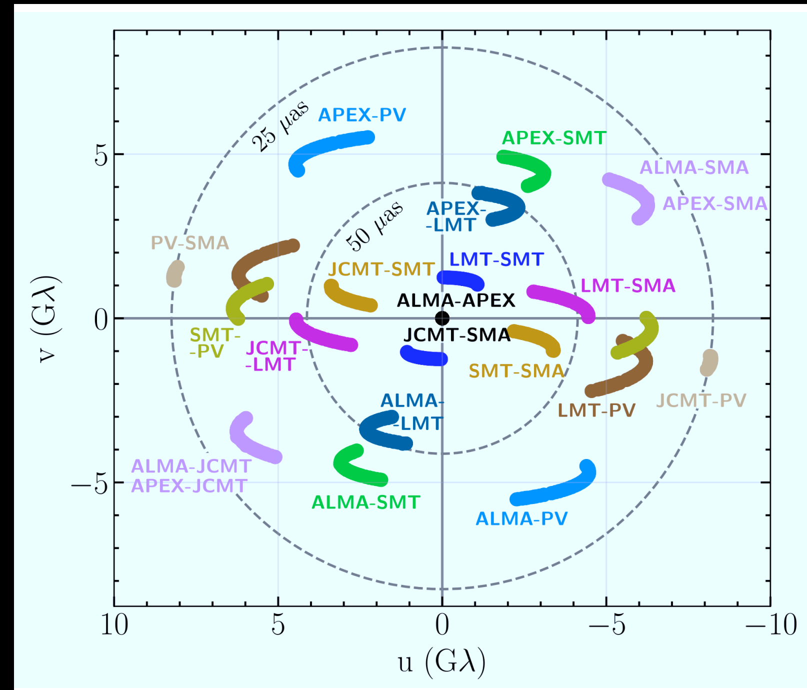


The danger of having Quasar-like devices too close to home ...

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

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





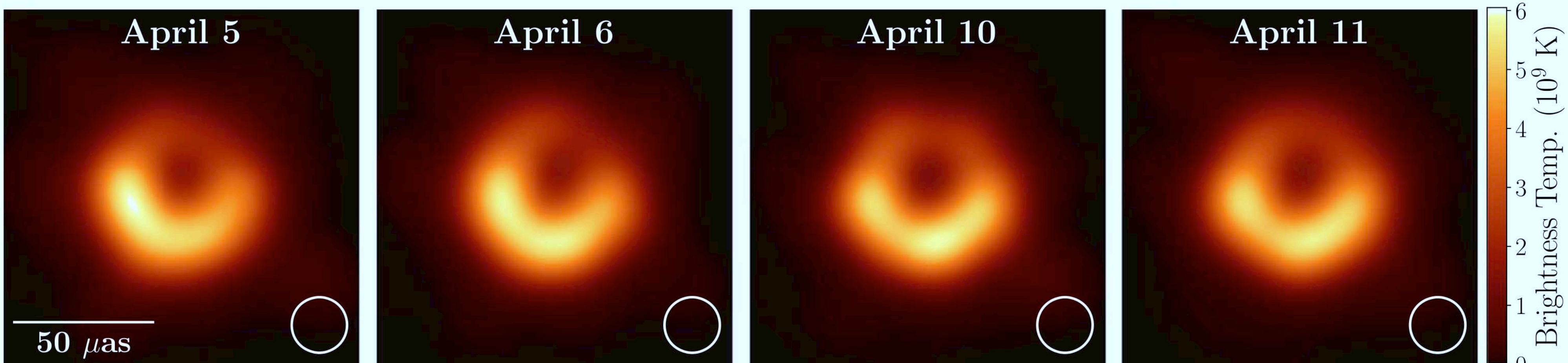
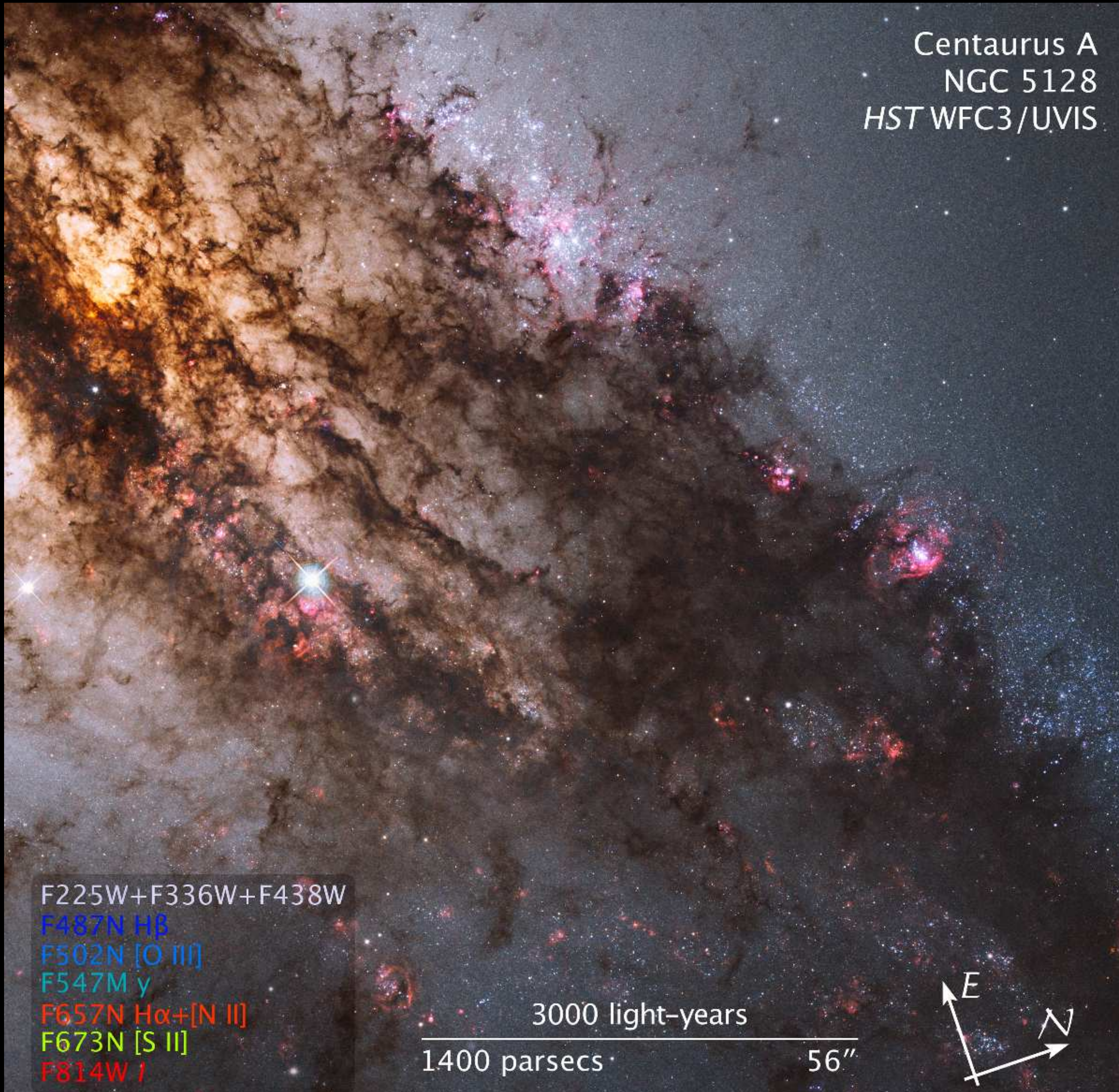
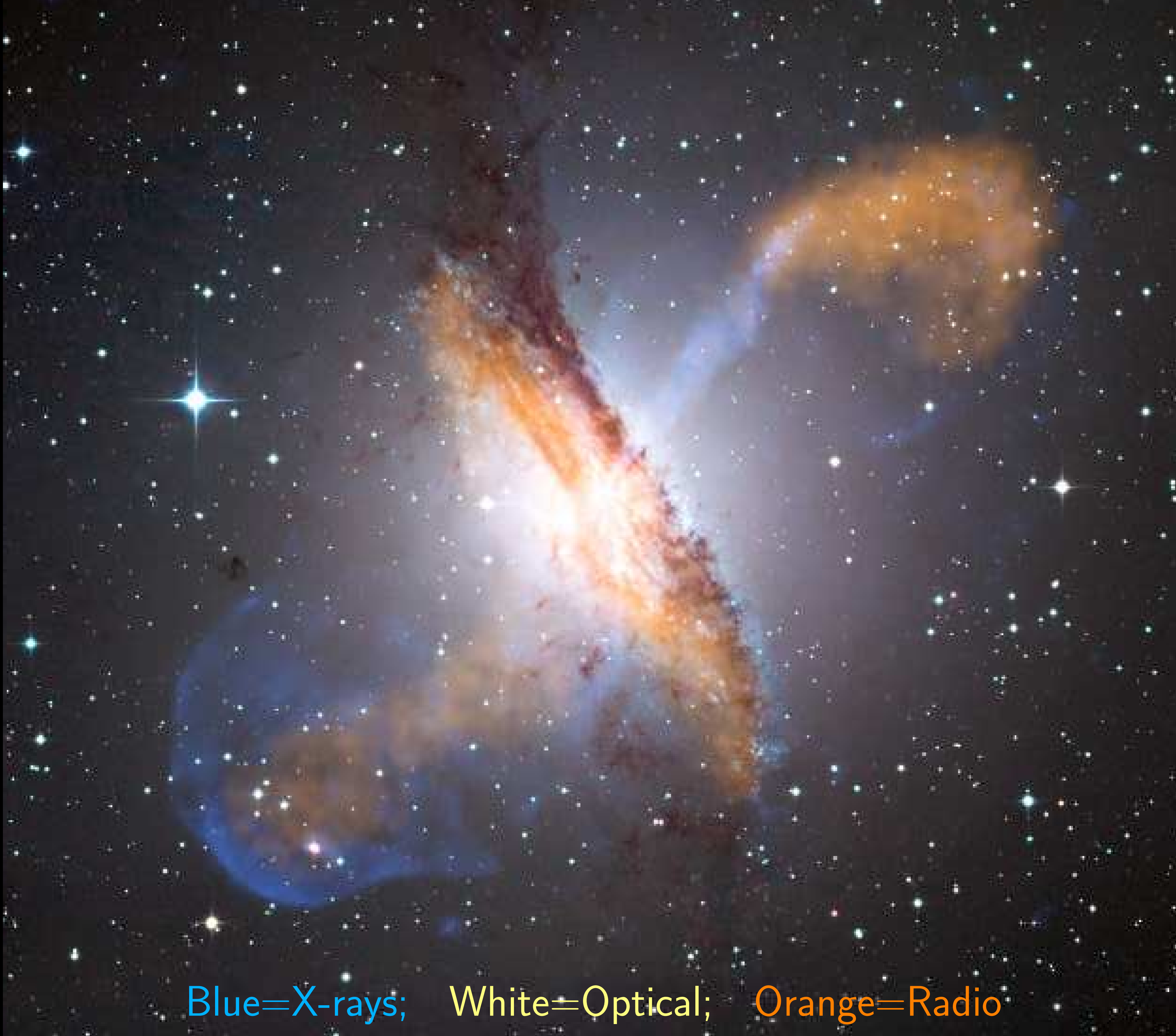


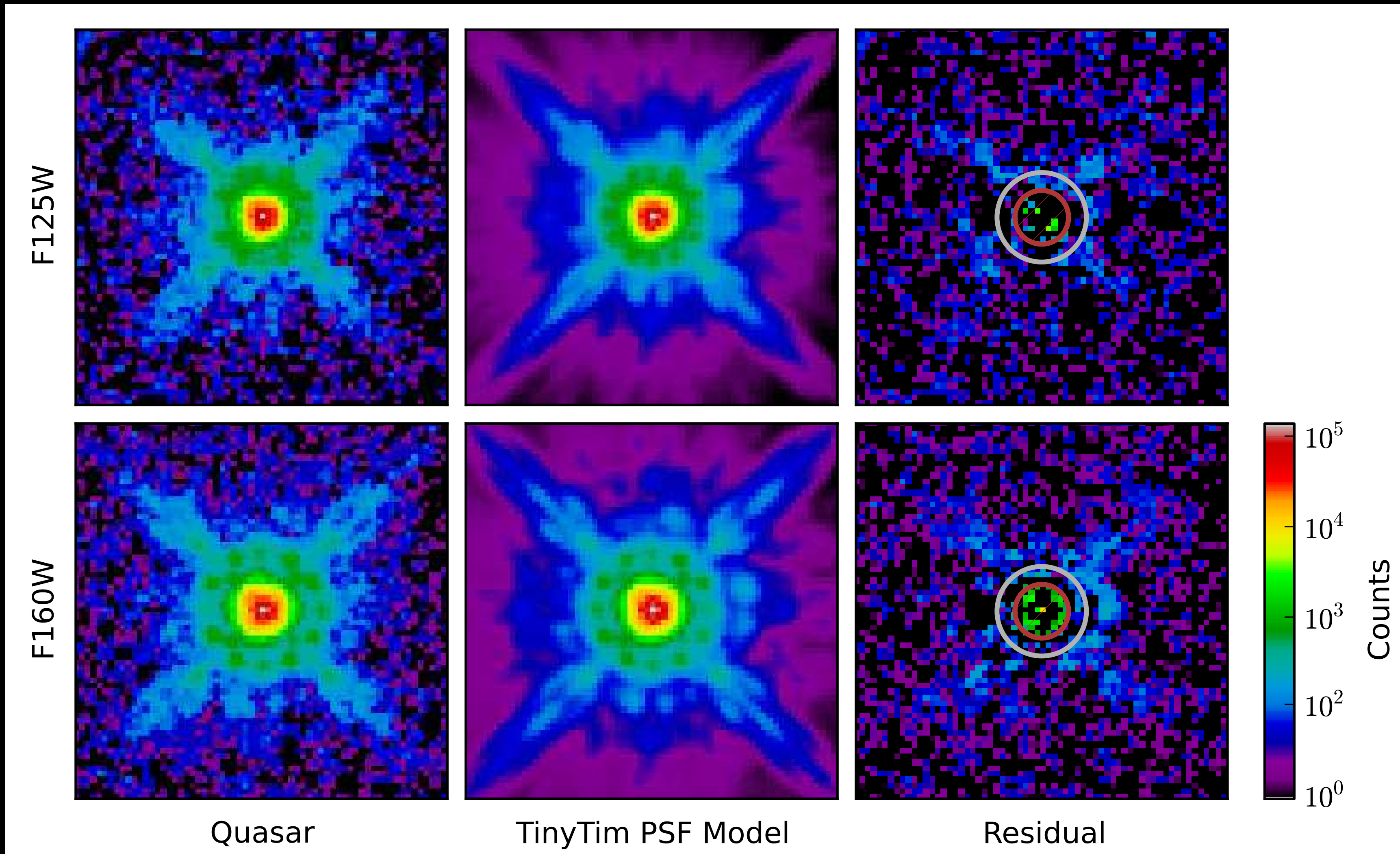
Figure 15. Averages of the three fiducial images of M87 for each of the four observed days after restoring each to an equivalent resolution, as in Figure 14. The indicated beam is 20 μas (i.e., that of DIFMAP, which is always the largest of the three individual beams).

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$\times$ smaller than today), 900 Myr old!
- Contains 10^{14} solar luminosities within a region as small as Pluto's orbit!
- A feeding monster blackhole ($>3\times10^9$ 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 $\sim 3\times10^{9}$ 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

Will this ever happen to our own Galaxy?

YES! Hubble showed no lateral motion of Andromeda:

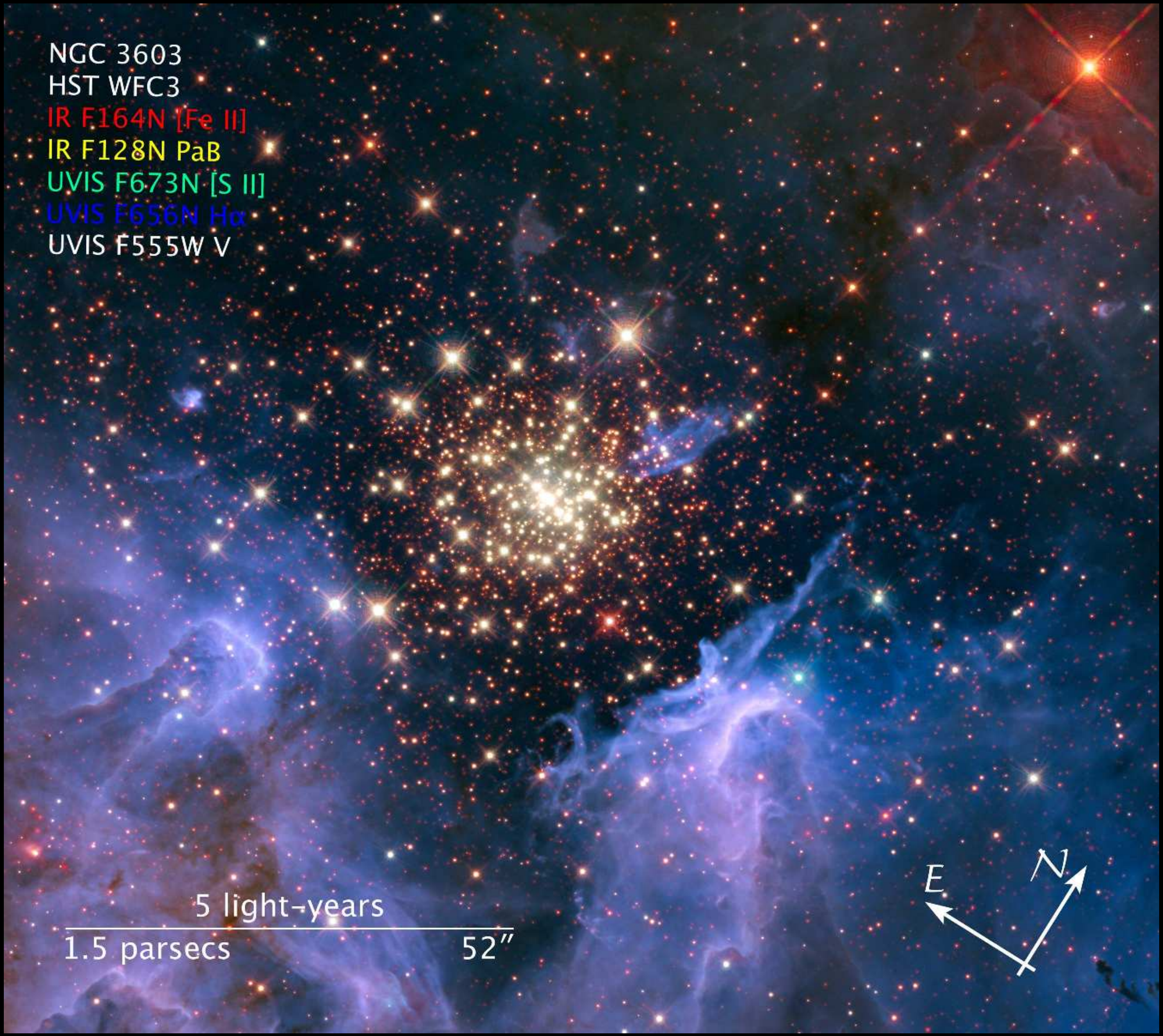
Approaches at –110 km/s.

Hence, Andromeda will merge with Milky Way!

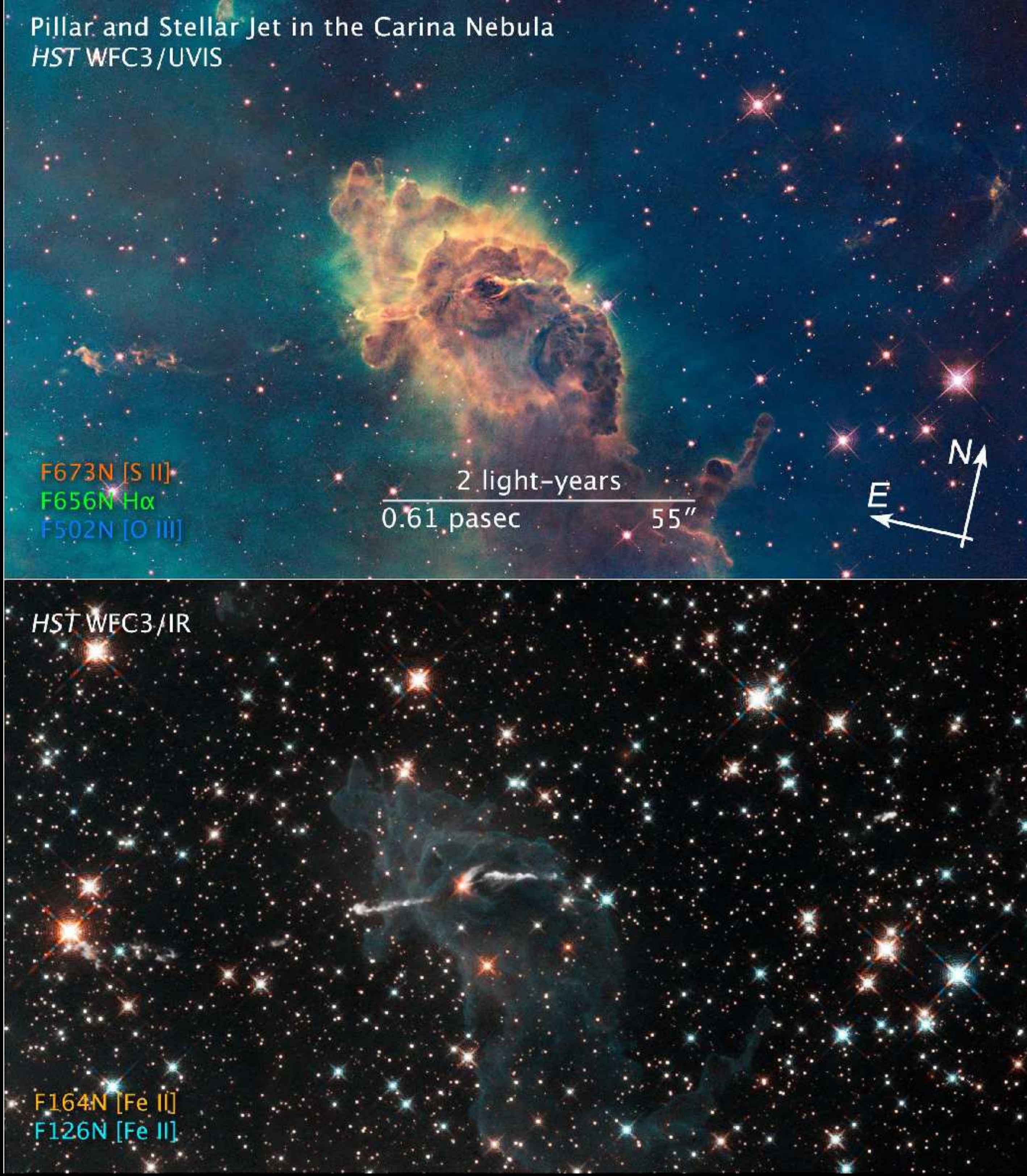
The two blackholes (10^6–10^7 suns) will also merge!

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

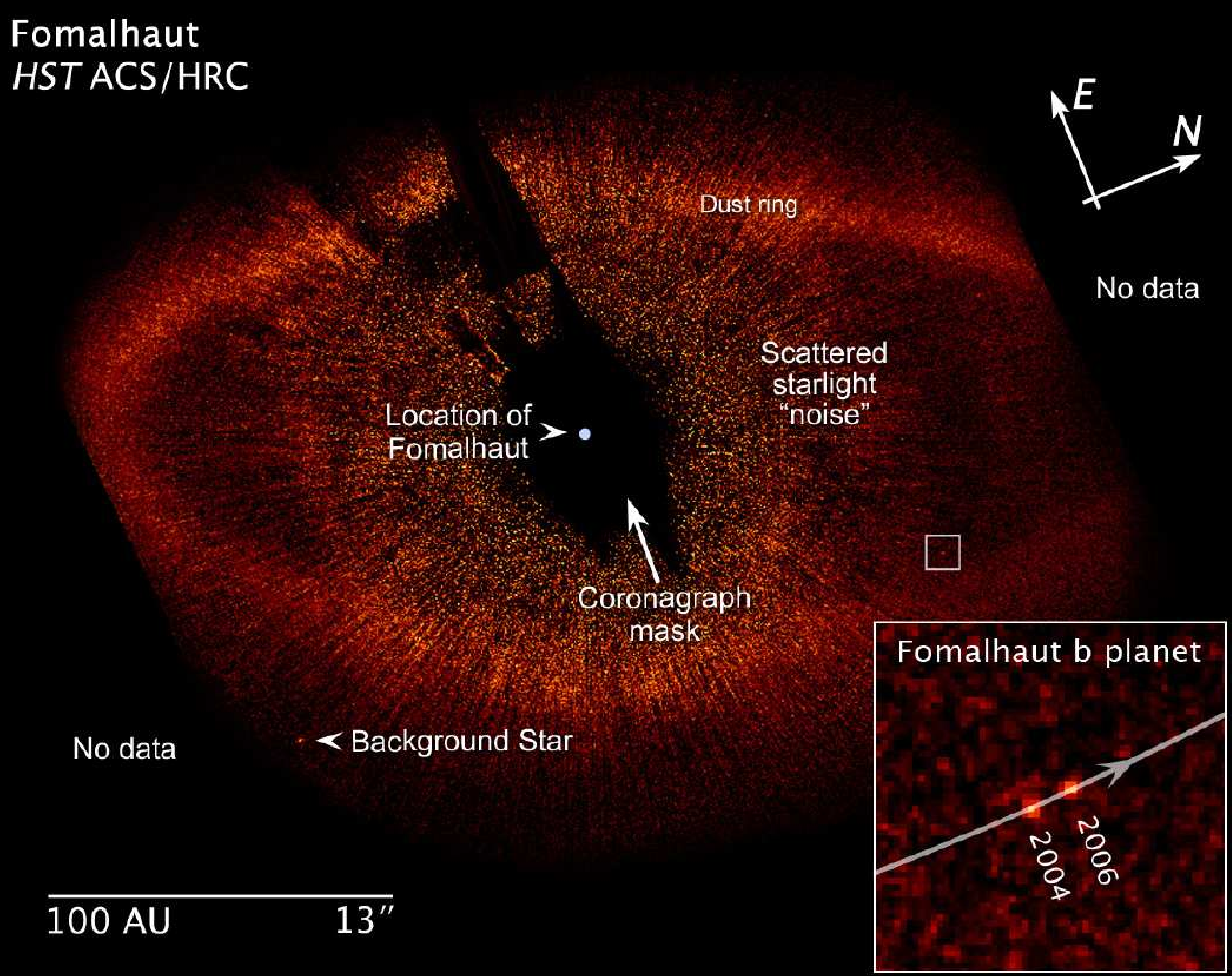
(5) How can JWST measure Star-Formation and Earth-like exoplanets?



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

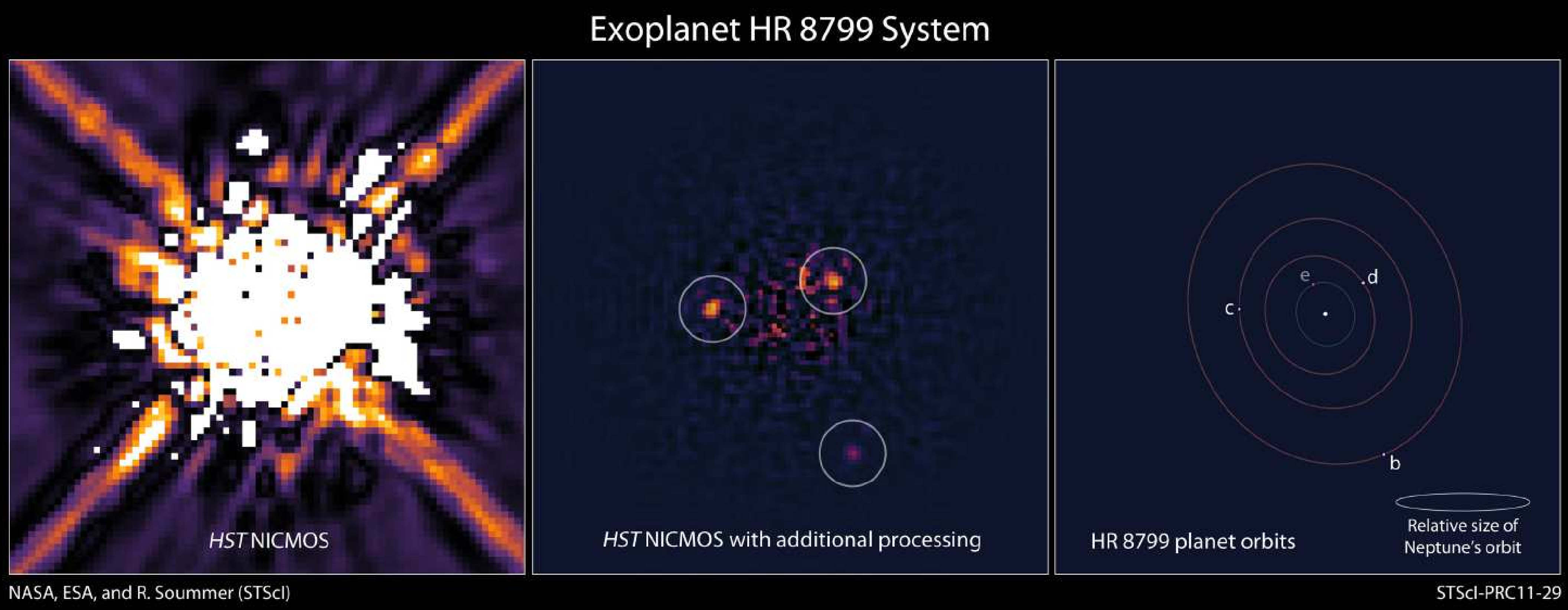


Pillar and Stellar Jet in the Carina Nebula
HST WFC3/UVIS
F673N [S II]
F656N Hα
F502N [O III]
2 light-years
0.61 pasec
55″
N
E
HST WFC3/IR
F164N [Fe II]
F126N [Fe II]



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

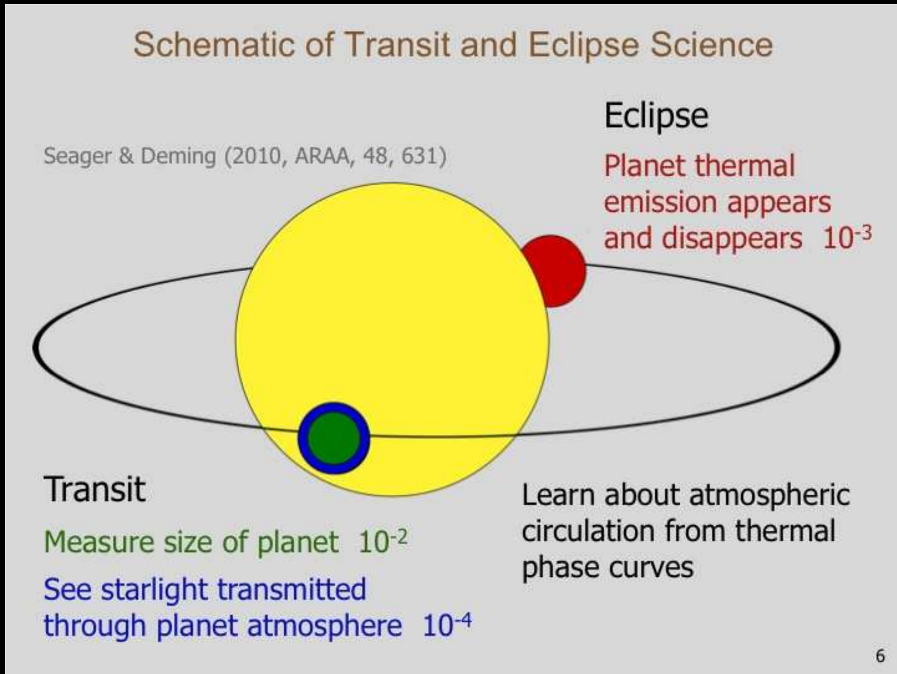
JWST can find such planets much closer in for much farther stars.

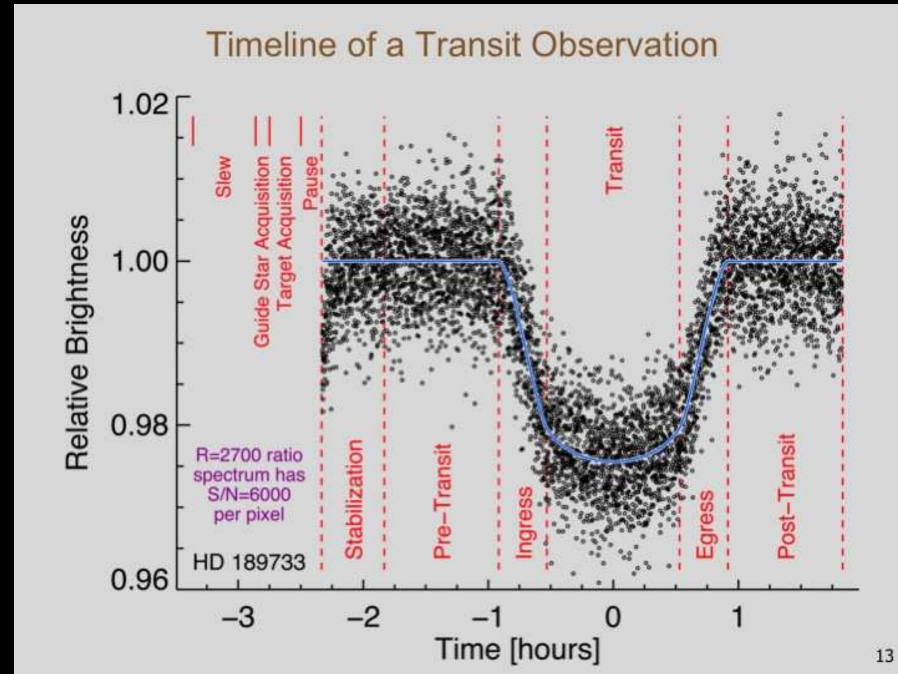


HST/NICMOS imaging of planetary system around the (carefully subtracted) star HR 8799: Direct imaging of planets around a nearby star.

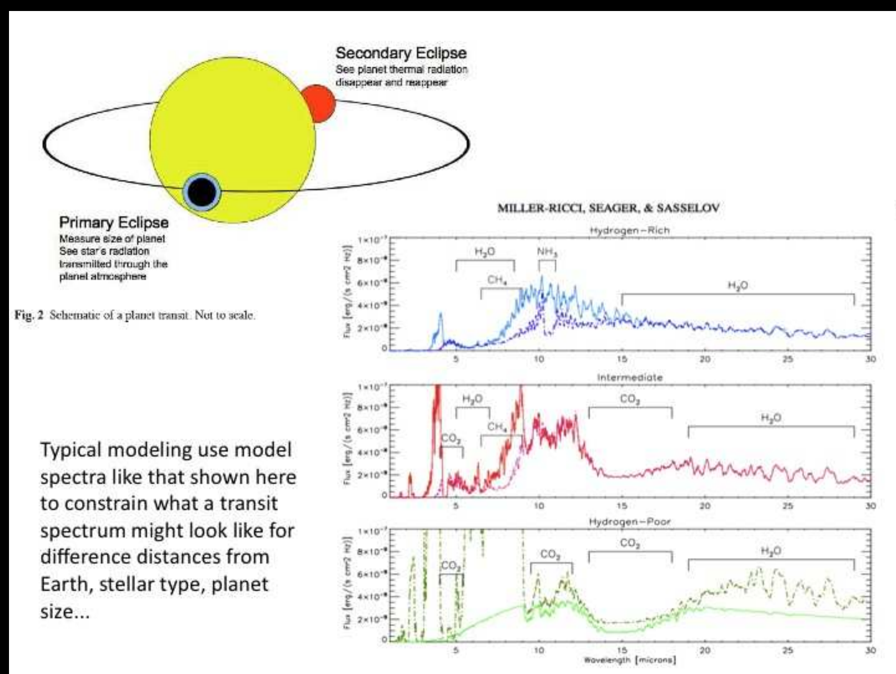
Press release: http://hubblesite.org/newscenter/archive/releases/2011/29/

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



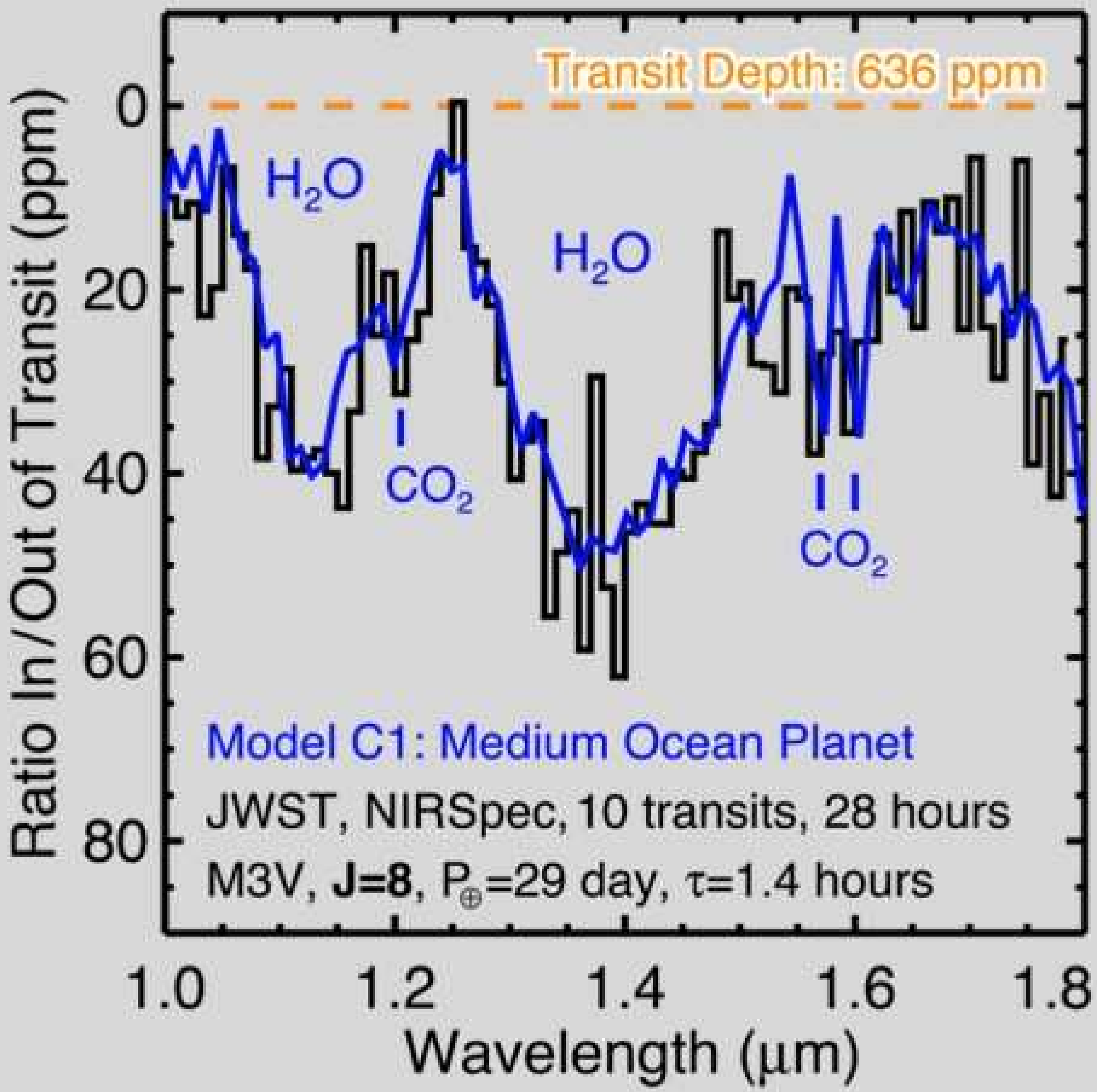


JWST can do very precise photometry of transiting Earth-like exoplanets.



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.