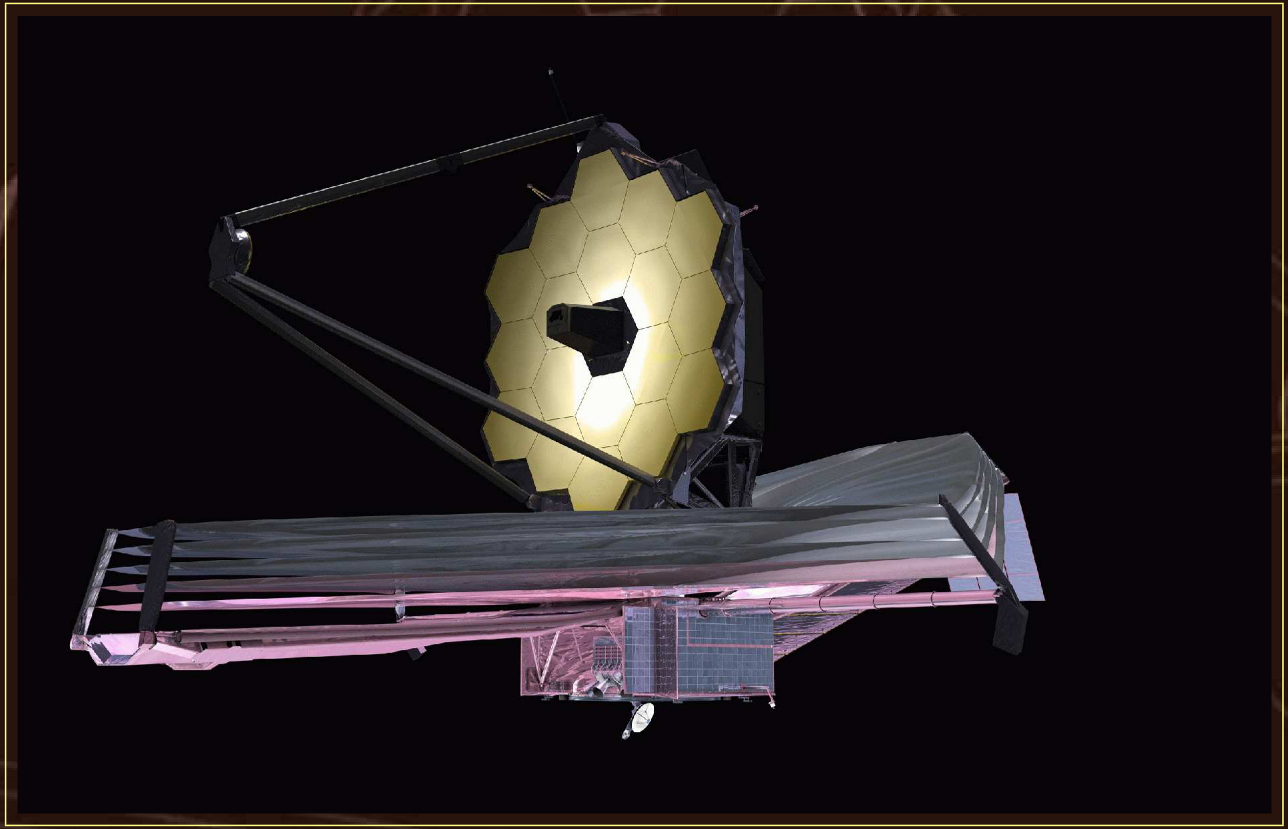
The Search for First Light

An Exciting Future with the *James Webb Space Telescope* after *Hubble*



Dr. Rolf A. Jansen (Arizona State University, SESE)

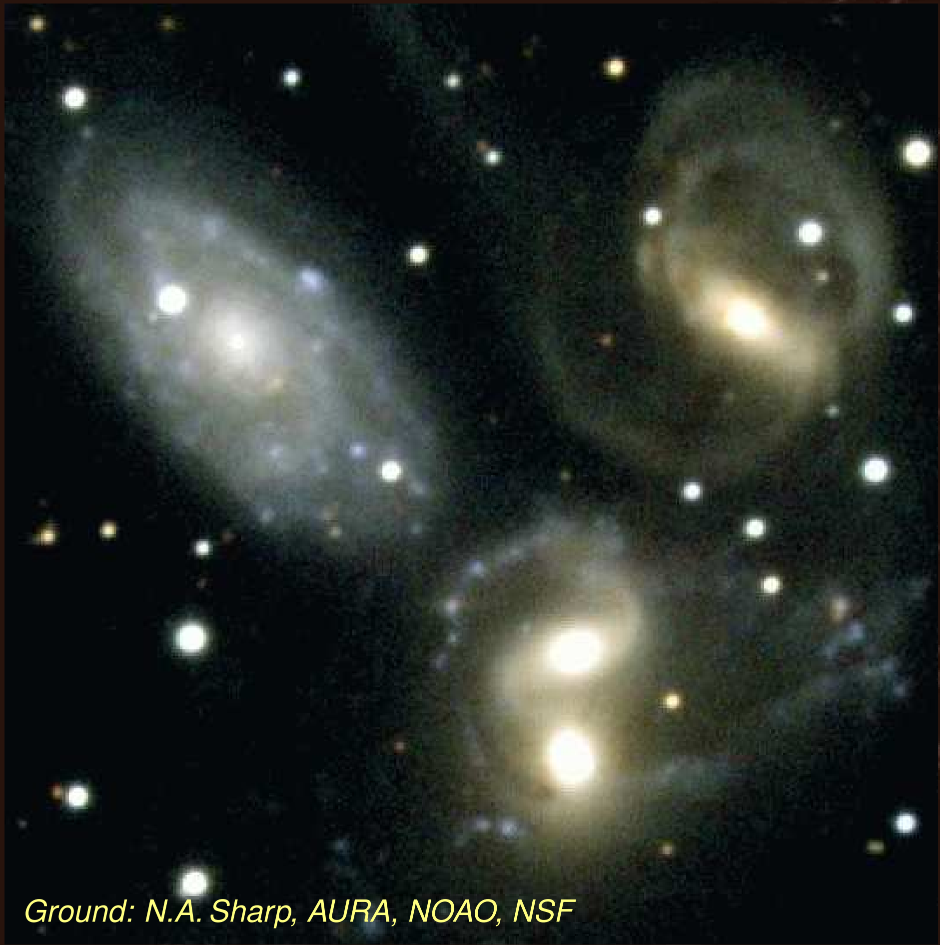
in collaboration with Dr. Rogier Windhorst & the *JWST* WMDFs GTO team

Valley Engineering, Science and Technology (VEST) Club — Sun City West, AZ — June 1, 2018

Outline

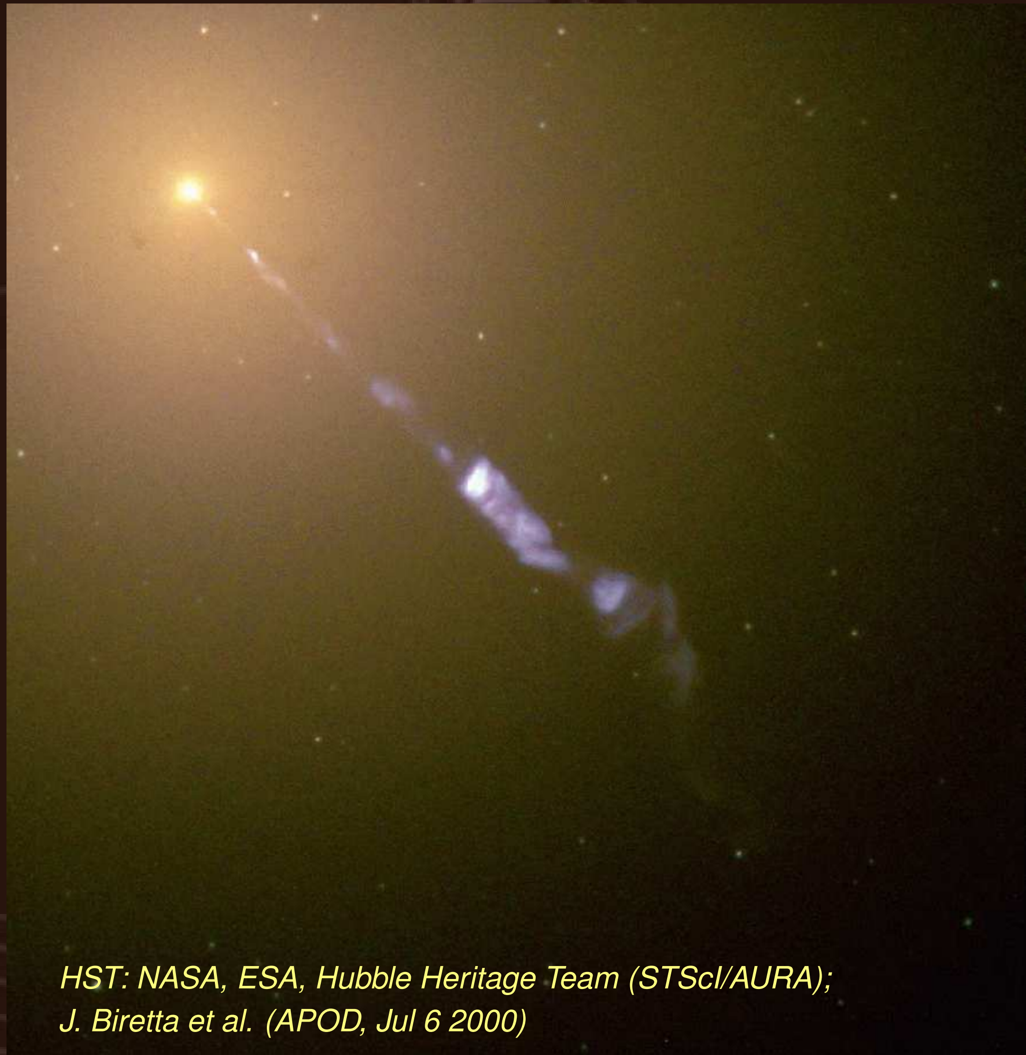
- The *Hubble Space Telescope*'s astronomical revolution
- The search for First Light: what we have learned from *HST*
- Beyond *HST*: How the *James Webb Space Telescope* can explore the Epoch of First Light
- Update on the current status of *JWST*
- The long journey of assembling *JWST*

The *HST*'s Astronomical Revolution



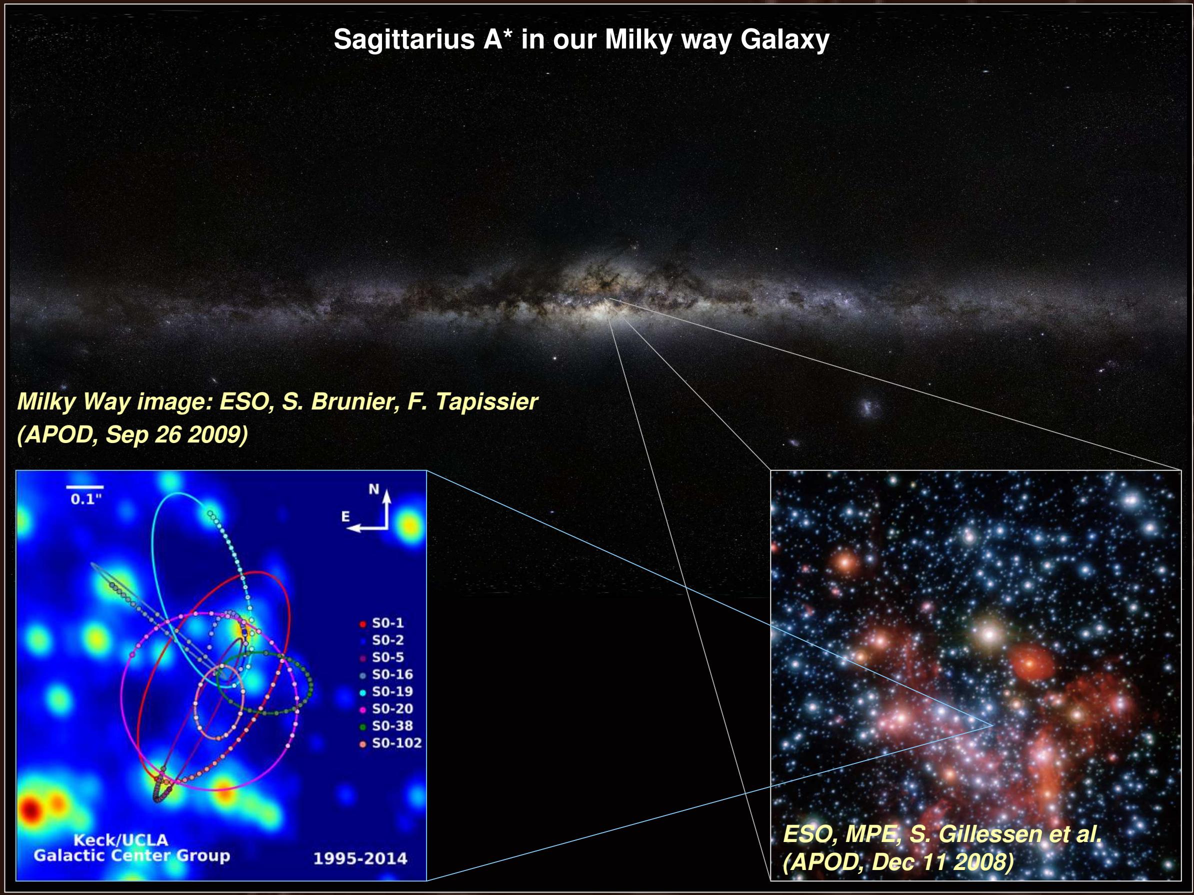
- The *Hubble Space Telescope* provides darker sky background, higher resolution, and access to wavelengths inaccessable from the ground (absorbed by Earth's atmosphere)

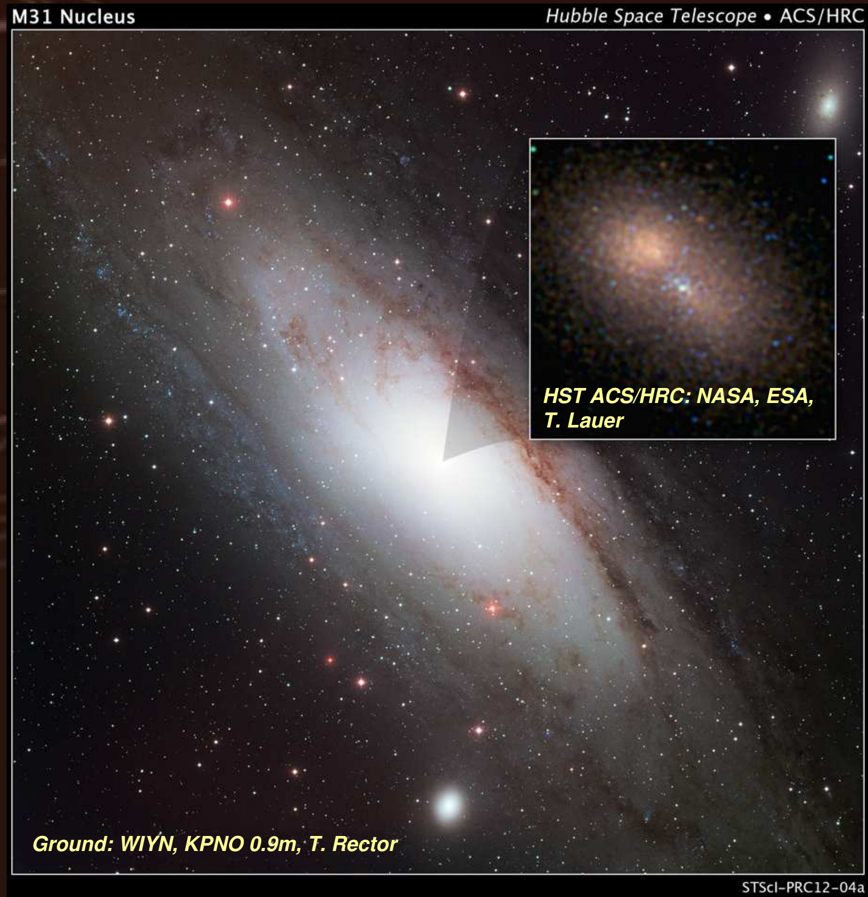
The *HST*'s Astronomical Revolution



- *HST* discovered that ***all*** large galaxies have a supermassive black hole (SMBH) at their center...

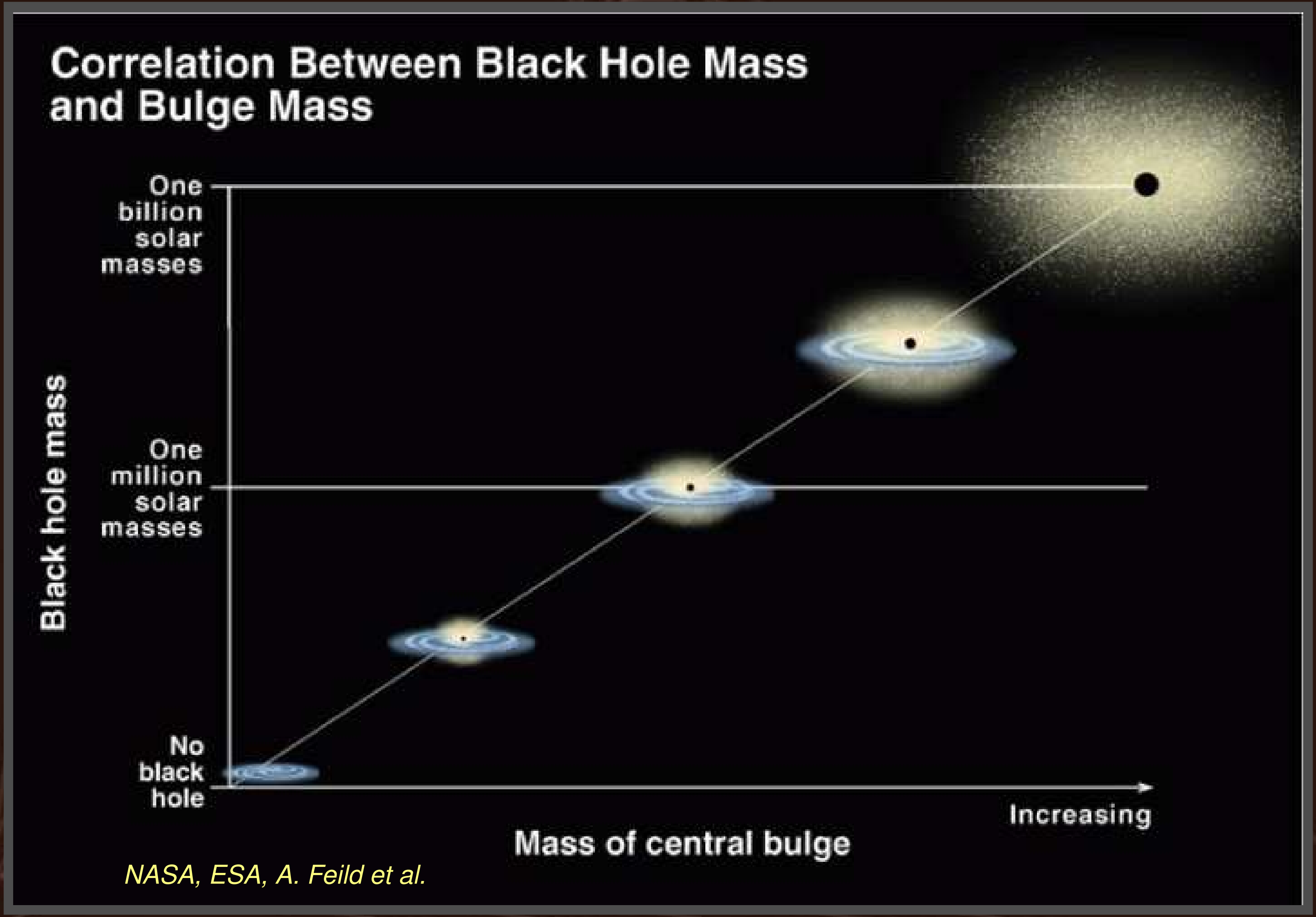
The *HST*'s Astronomical Revolution





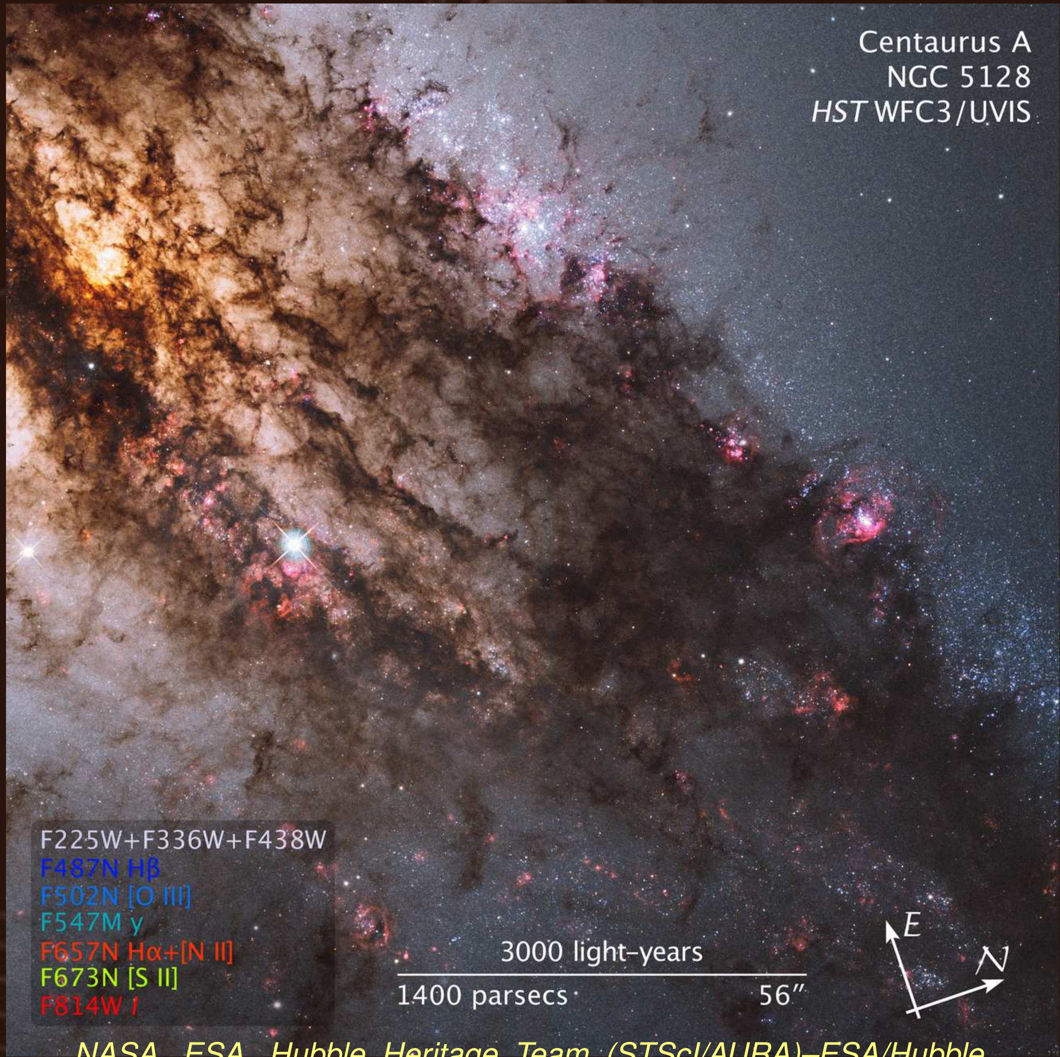
- ... even our own Milky Way Galaxy and our nearest big neighbor, M 31, the Andromeda Galaxy

The *HST*’s Astronomical Revolution



- *HST* imaging + ground-based spectroscopy showed that the mass of the central SMBH is proportional to the mass of a galaxy’s stellar bulge.

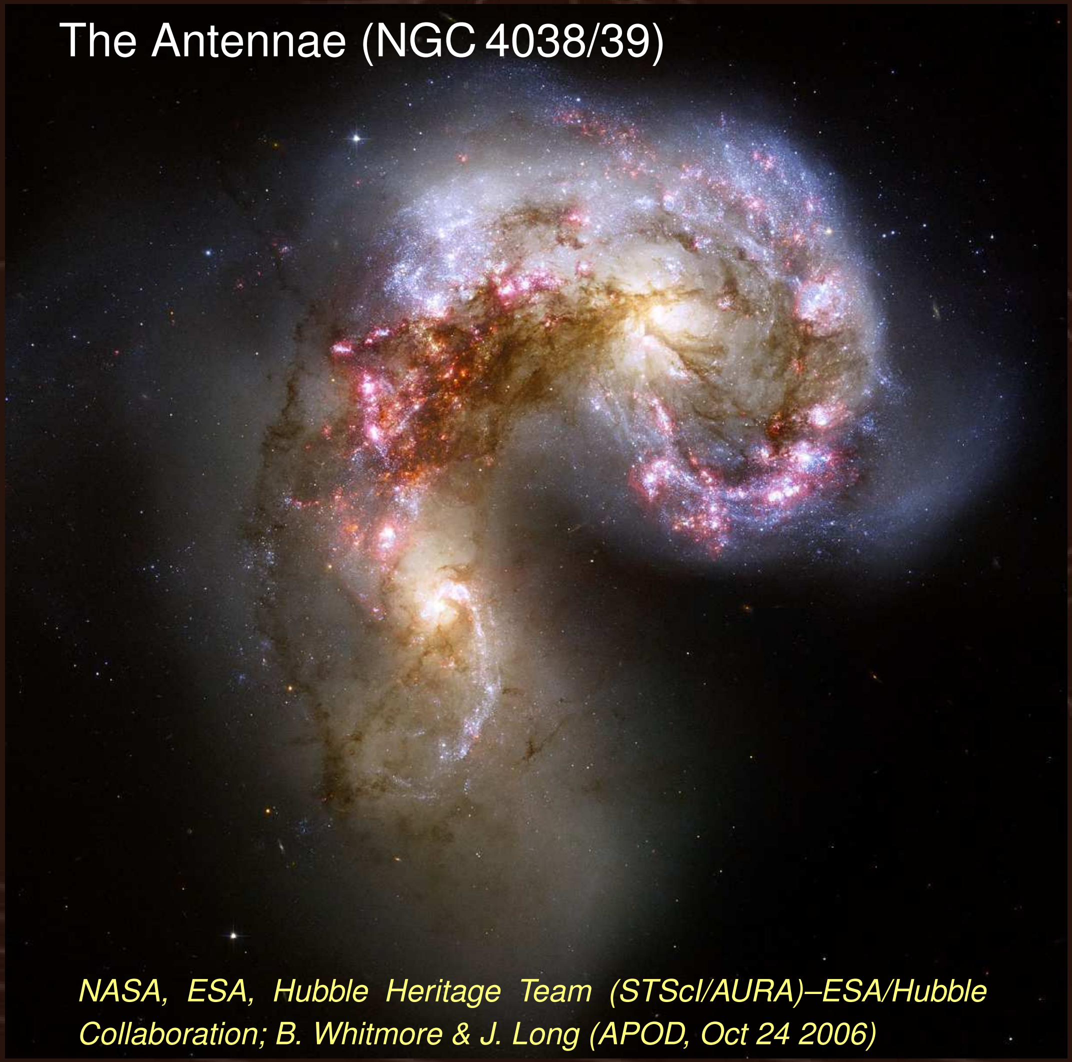
The *HST*'s Astronomical Revolution



NASA, ESA, Hubble Heritage Team (STScI/AURA)–ESA/Hubble Collaboration; R. O'Connell (APOD, Nov 29 2011)

- *HST* gave us sharp views of star bursting galaxies, interacting galaxies, ...

The *HST*'s Astronomical Revolution



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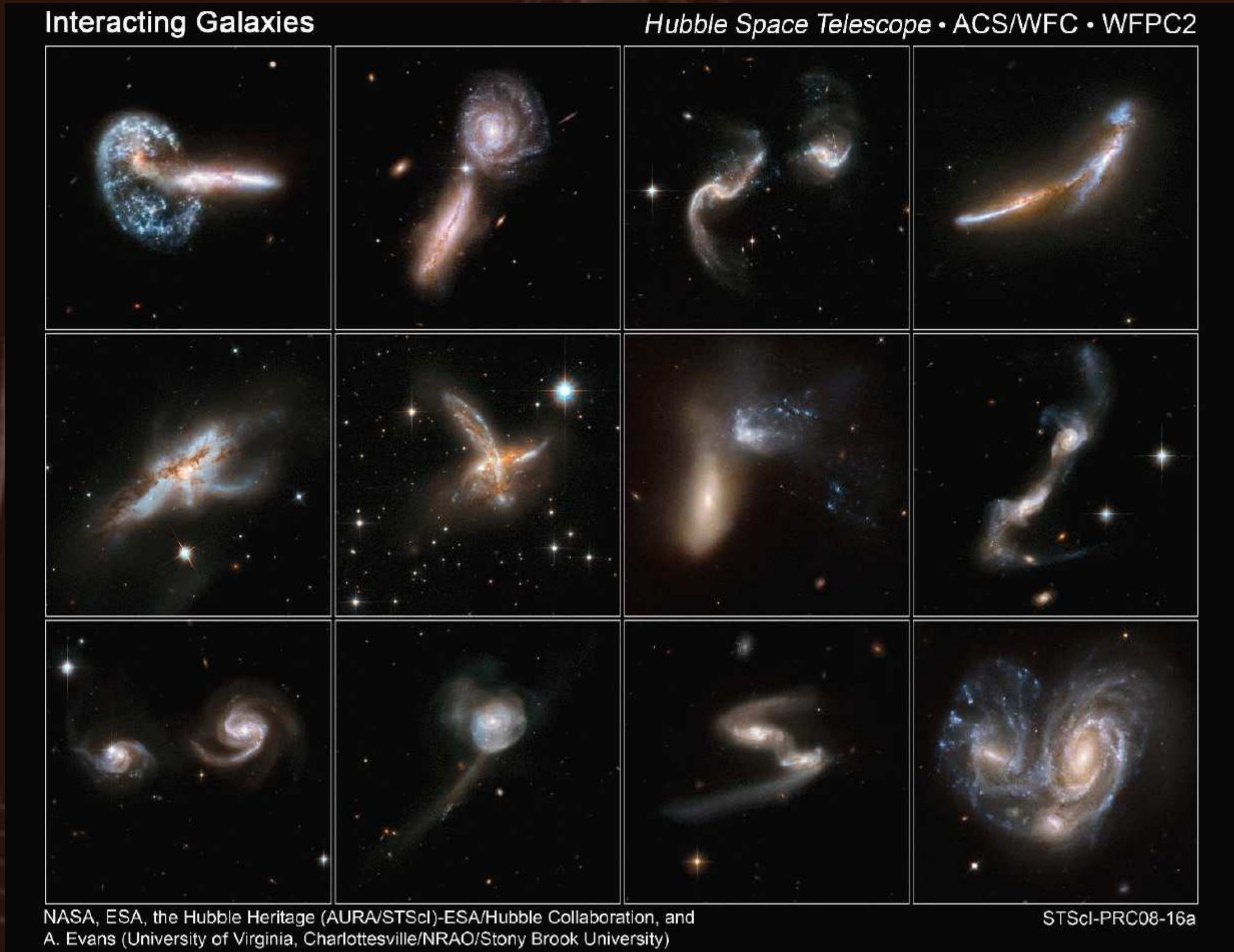
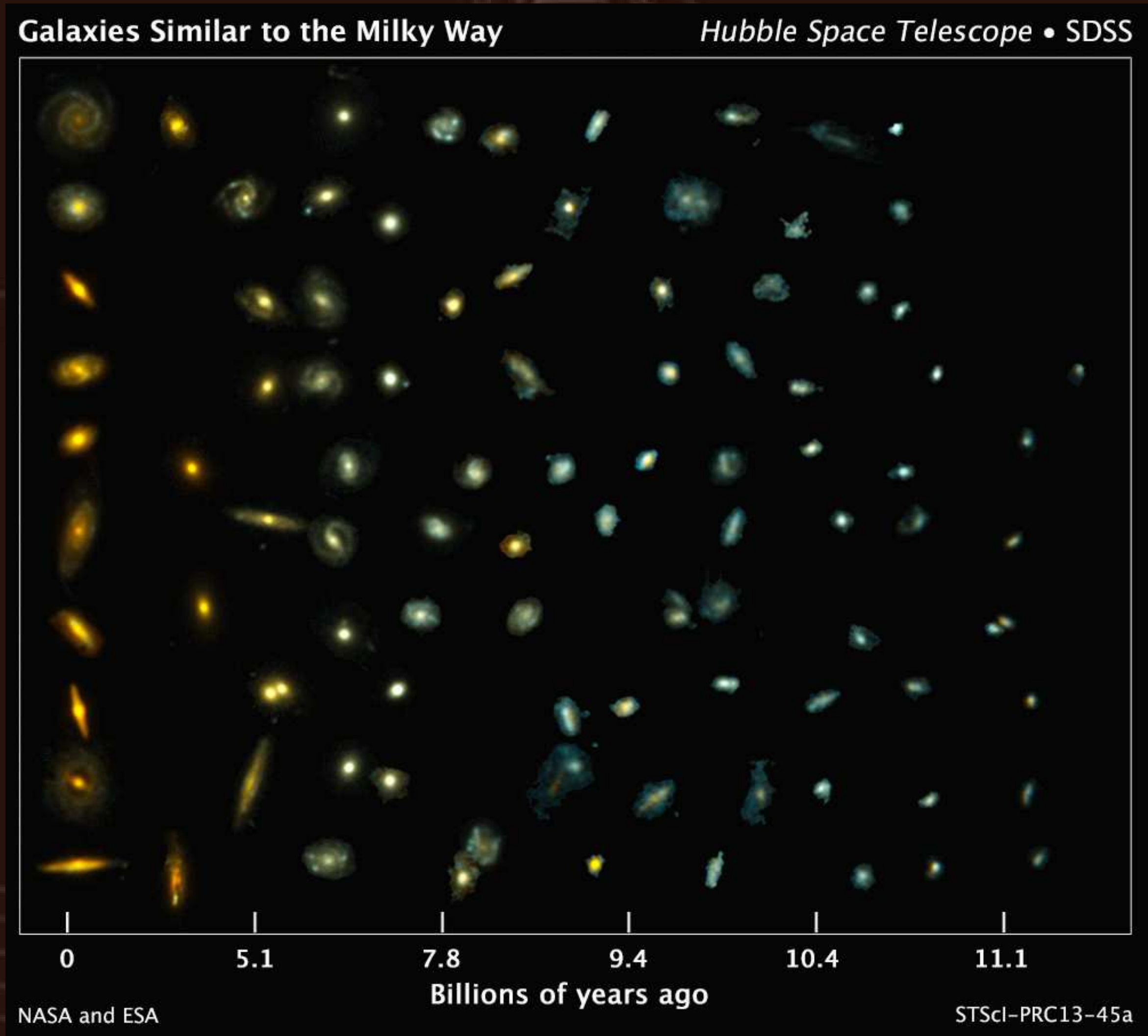
The *HST*'s Astronomical Revolution



- ... and allowed us to trace galaxy assembly and subsequent evolution over the past 12 billion years

The *HST*'s Astronomical Revolution



NASA, ESA, P. van Dokkum et al.

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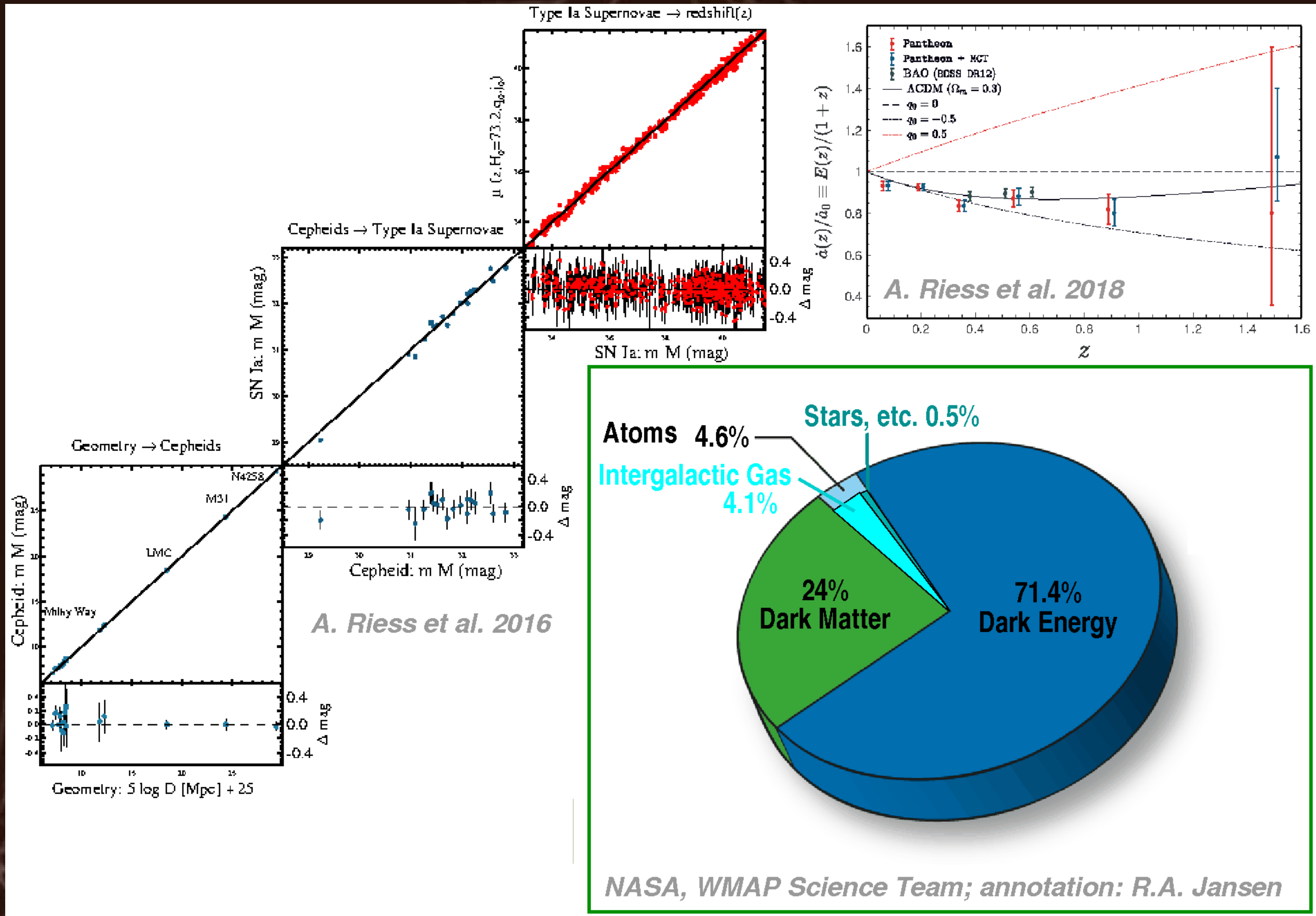
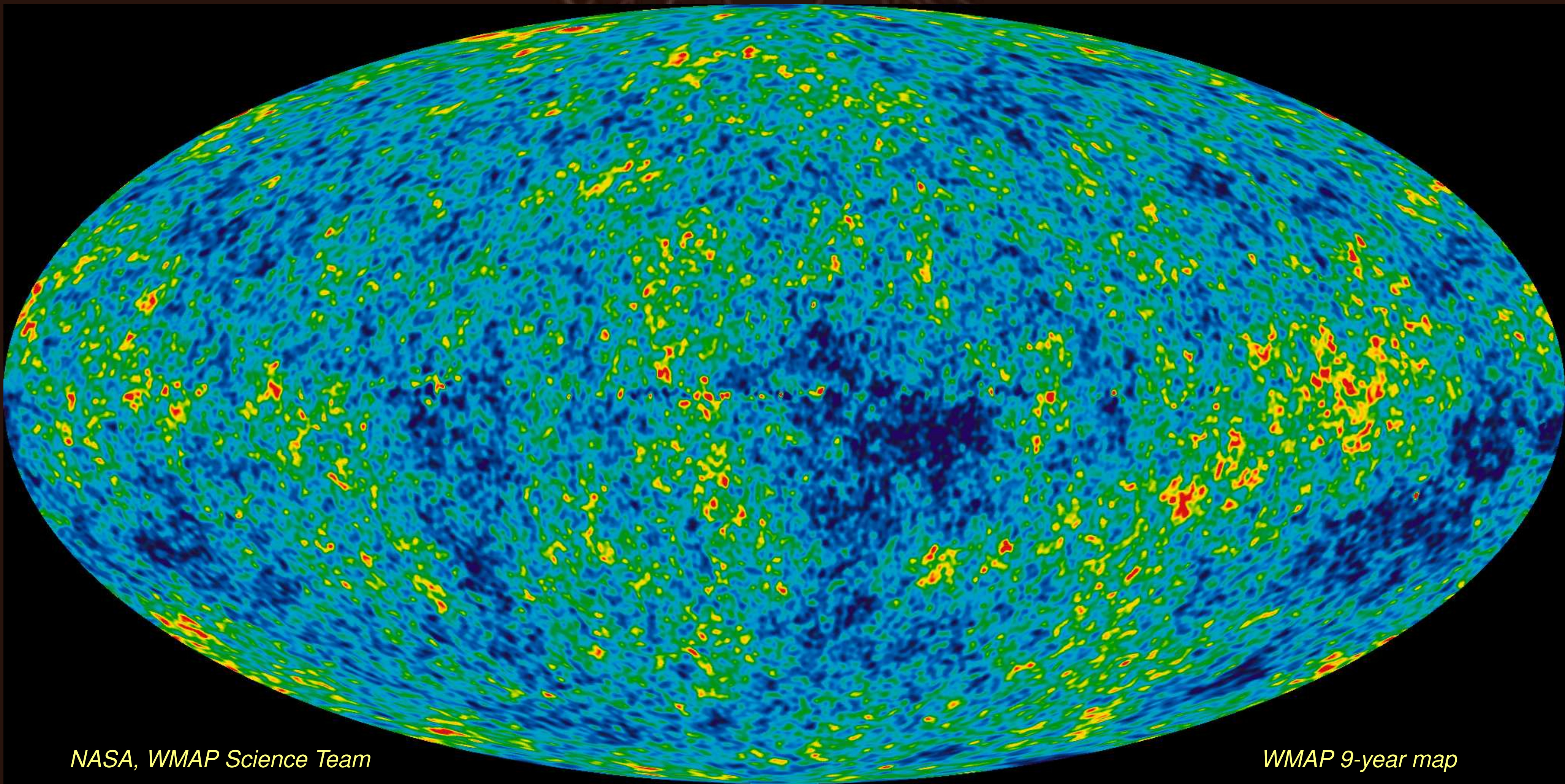
The *HST*'s Astronomical Revolution



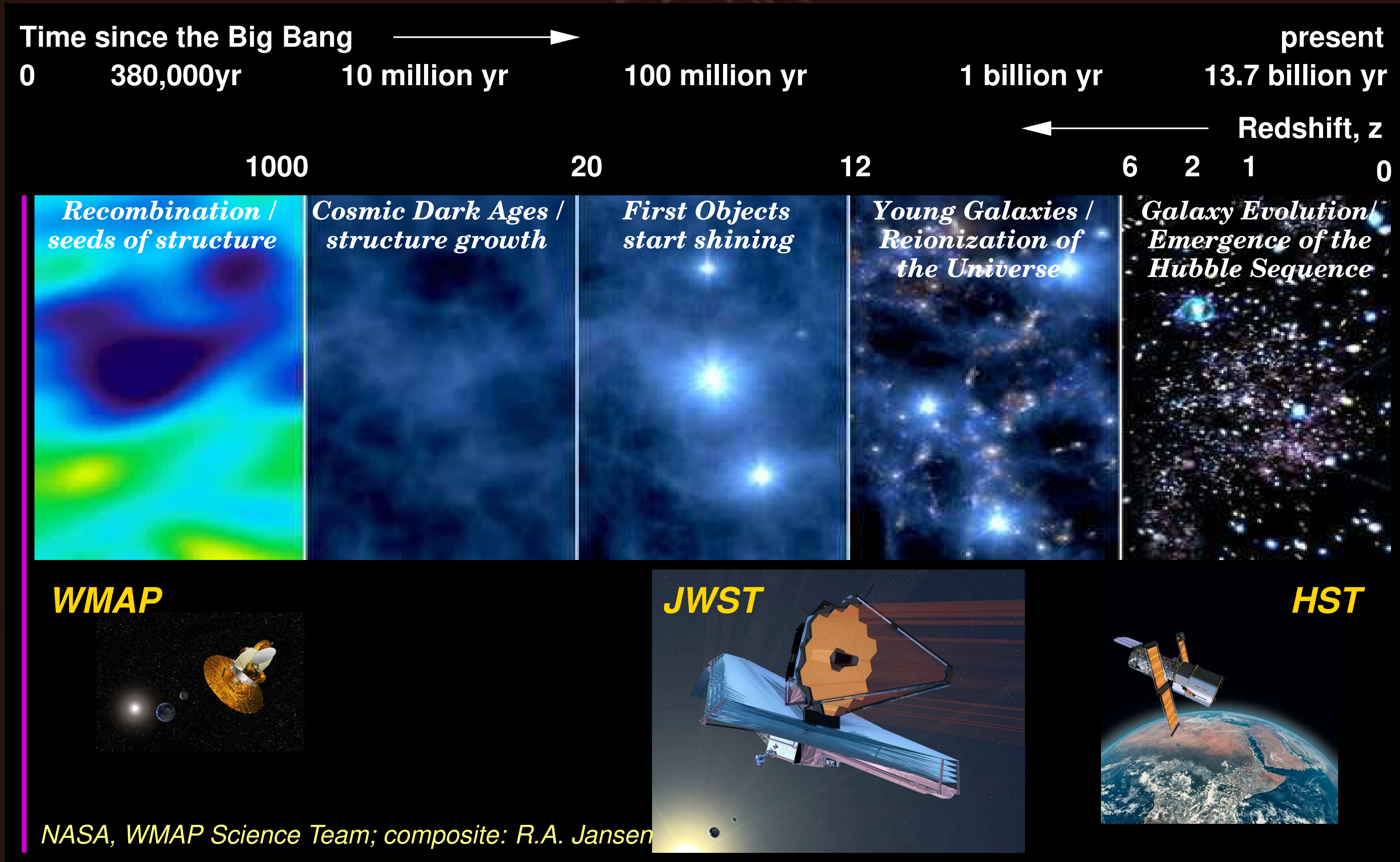
- Recipe for a Universe ... *Dark Energy* ⟶ 2011 Nobel Prize in Physics

HST (and *WMAP*)'s Astronomical Revolution



- Start with a Big Bang, inflate, let simmer until transparent ($\sim$380,000 yr)

HST (and *WMAP*)'s Astronomical Revolution



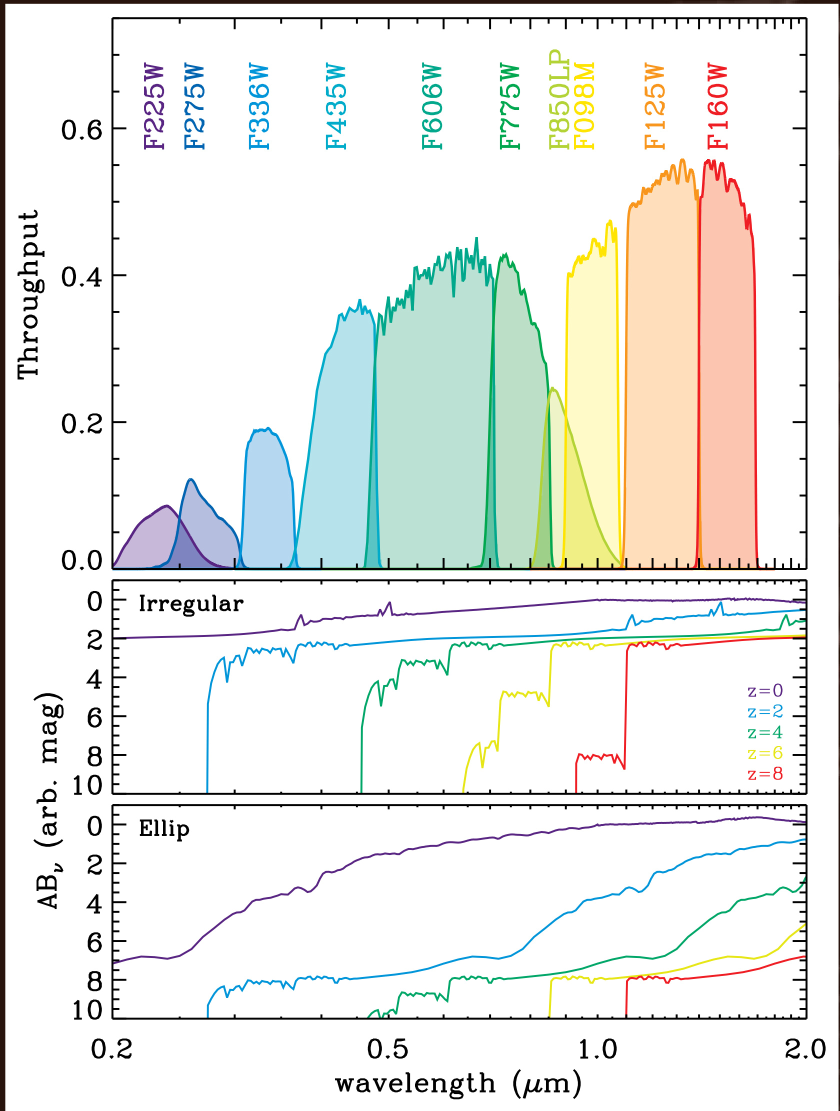
- Let rise and cool through the Dark Ages until stars and quasars ignite, producing first elements heavier than H, He and Li; the IGM gets reionized

The *HST*'s Astronomical Revolution

color composite by M. Mechtley (ASU)

- 12 billion years of cosmic history in one *HST* picture; galaxies at $z > 7$ difficult to find (dim, red, tiny) and very rare

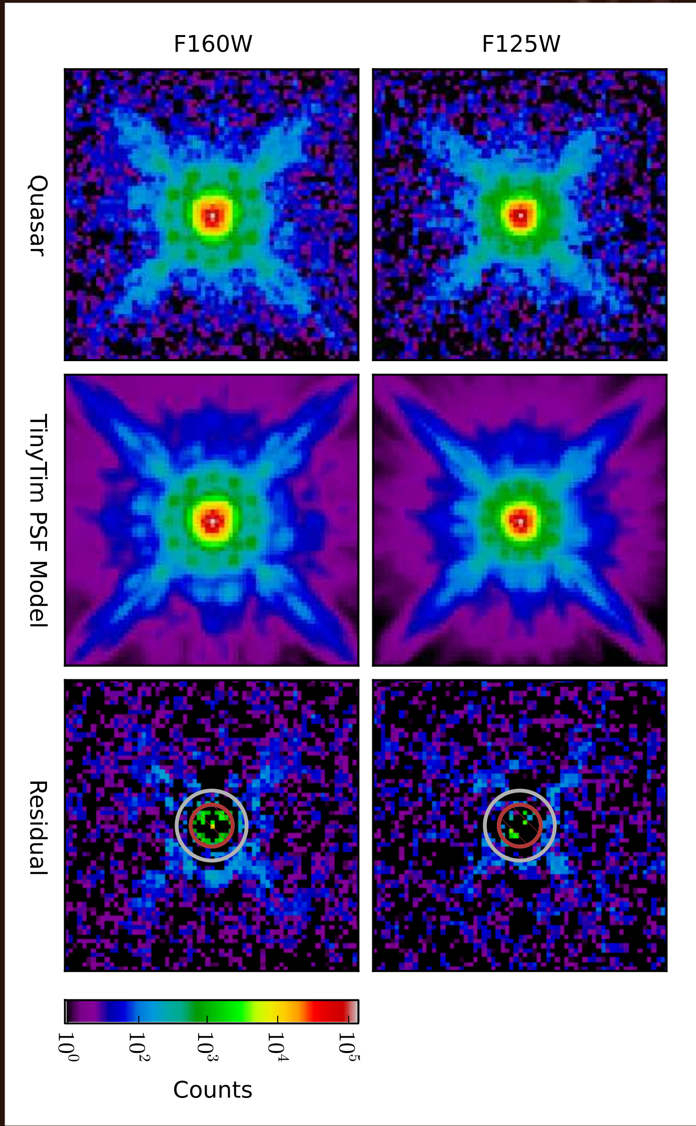
The search for First Light with *HST*



- Final Servicing Mission (SM4) of *HST* in 2009: WFC3/IR channel opened major new parameter space with filters sampling near-IR wavelengths up to 1.75 μm, designed to study star-formation and galaxy assembly to $z \sim 8$ (to when the age of the Universe was $\lesssim$700 Myr).

➤ Surprise: ground-based follow-up (e.g., ALMA) shows evidence for abundant 'metals' (elements heavier than He) — objects are not pristine!

The search for First Light with *HST*



- *HST* WFC3/IR observations of a bright ($m \simeq$ 18.5 mag) quasar at z = 6.42 (age $\lesssim$1 Gyr), with careful contemporaneous PSF-star observations to subtract the quasar light (Mechtley et al. 2012).

➤ Surprise: the most luminous quasar in the universe has NO detectable underlying host galaxy! — failure of SMBH and host galaxy stellar spheroid to grow in lock-step?

But ...

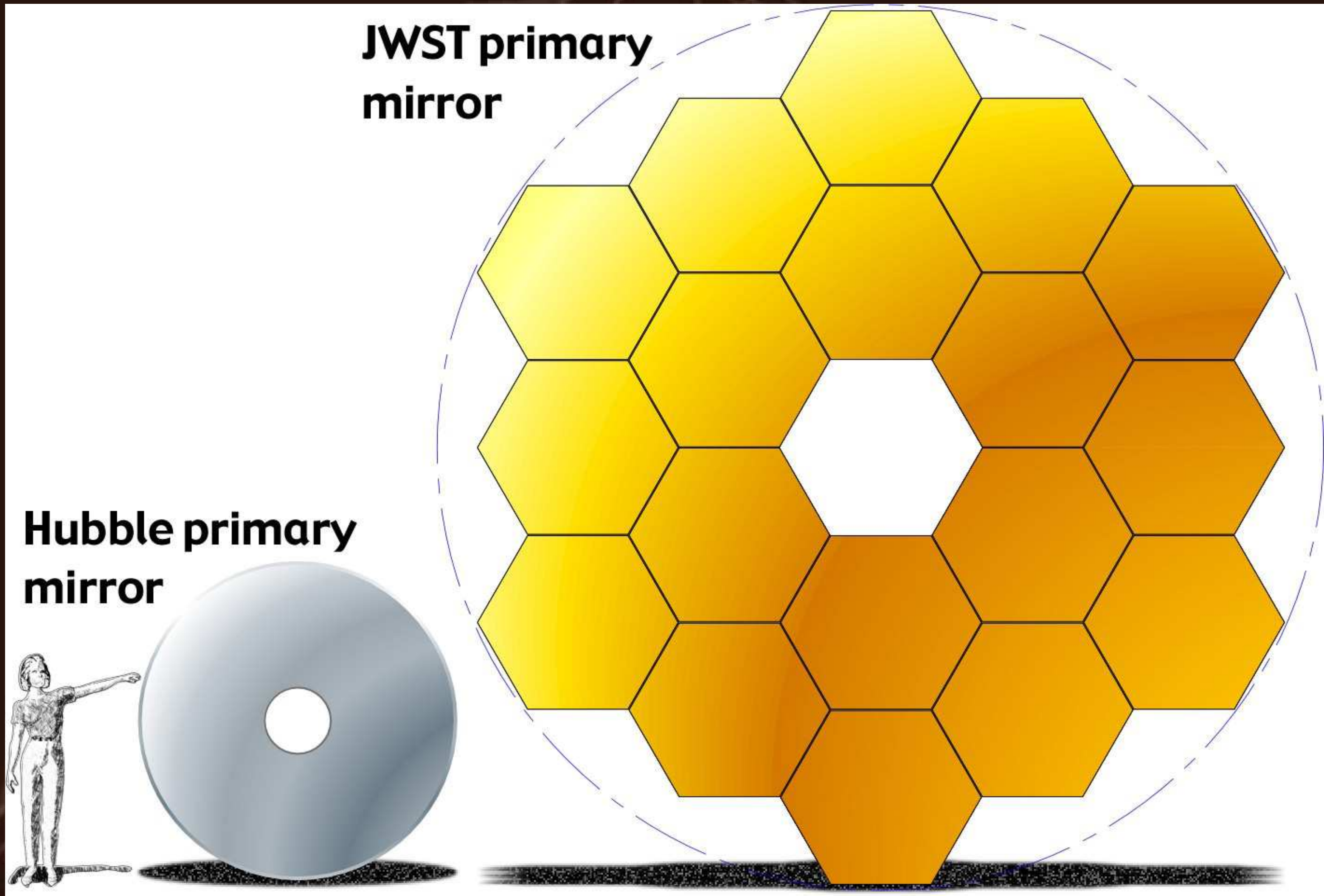
- *HST* is blind at wavelengths further into the near- and mid-infrared (cannot see light emitted by the first stars and proto-galactic clumps, or peer into dense star forming regions)
- *HST* is not big enough to detect the faint light from the first stars (even if it could see at longer wavelengths), and not big enough to characterize the atmospheres of Earth-like exoplanets in Earth-like orbits around their parent star.

The *James Webb Space Telescope*

- ➤ Enter *Hubble*'s successor: The *James Webb Space Telescope* (*JWST*), to be launched in May 2020.

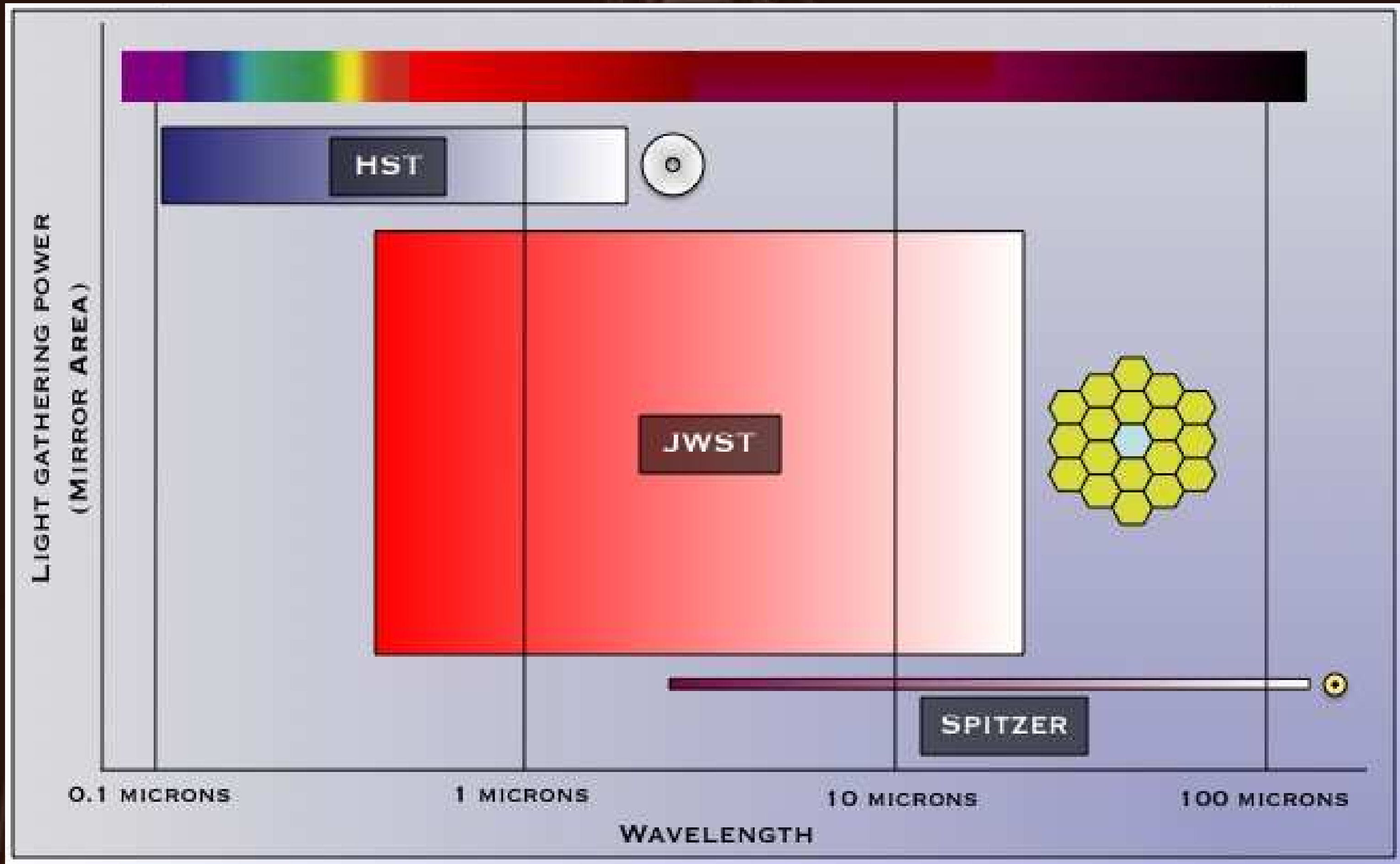
- ● *JWST* (then called the *Next Generation Space Telescope*) was the top-priority recommendation of the NRC's 2000 *Decadal Survey in Astronomy & Astrophysics* (2010 *Decadal Survey* recommendations assume *JWST*)
  - ➤ designed to detect light from the first stars and to trace the evolution of galaxies from their formation to the present
  - ➤ designed to characterize the nearest Earth-like exoplanets and their atmospheres (presence of water vapor!)
  - ➤ designed as a multi-purpose observatory (NASA Flagship mission) for the entire astronomical community
    - ✓ allows rapid response to new discoveries, use for science not imagined in the design stages of the mission (*HST*'s biggest discoveries were not the science for which it was built; same will be true for *JWST*)

Comparison of *JWST* and *HST*



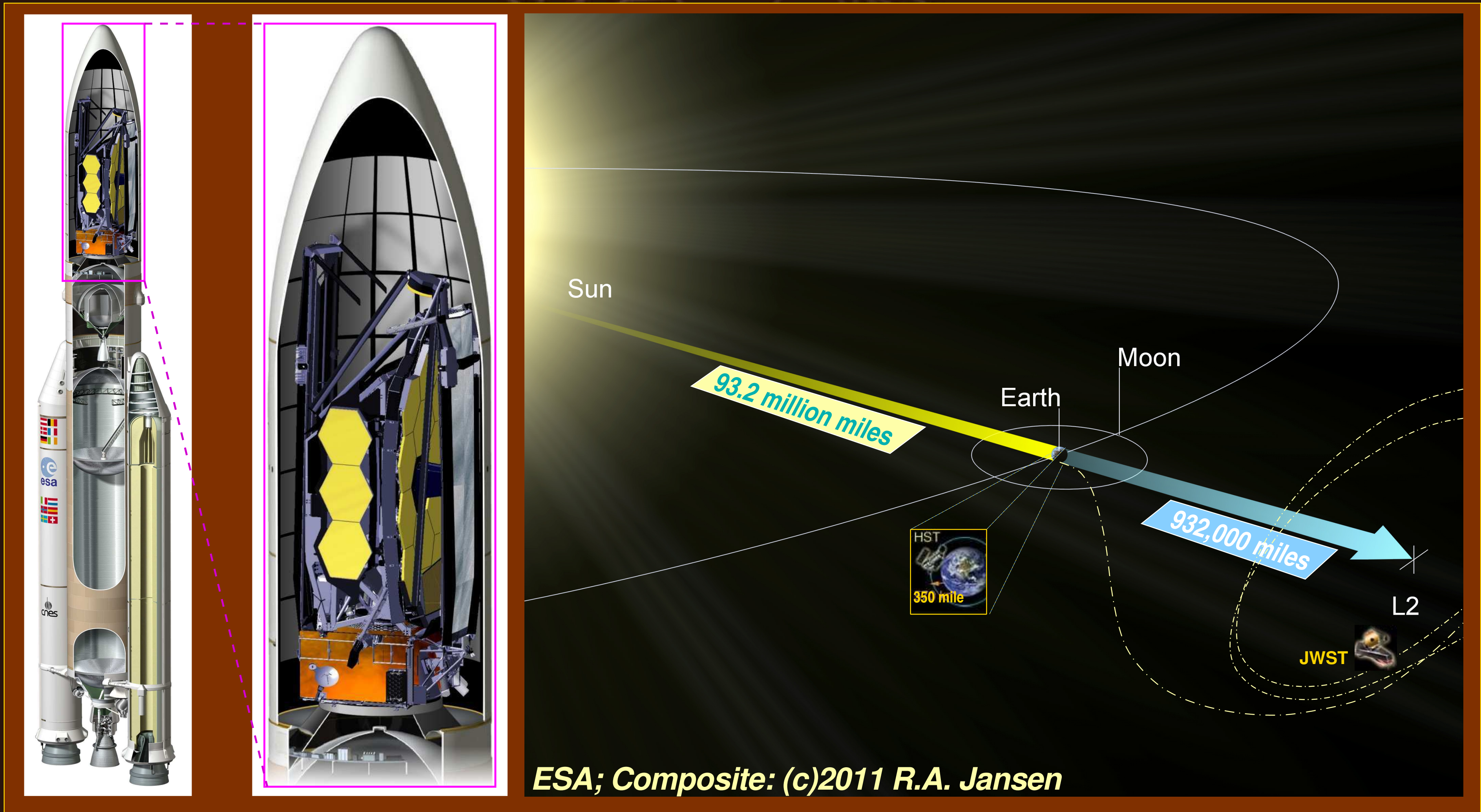
- Sizes: 7.9 ft (2.4 m; *HST*) versus 21.3 ft (6.5 m; *JWST*)

Comparison of *JWST* and *HST* and *Spitzer*



- Light gathering power: 4.5 m^2 (*HST*) vs. 25 m^2 (*JWST*) vs. 0.6 m^2 (*Spitzer*)
- Operational wavelength range: 0.2–1.7 μm (*HST*) vs. 0.7–28 μm (*JWST*) vs. 3.5–160 μm (*Spitzer*)

Comparison of *JWST* and *HST*

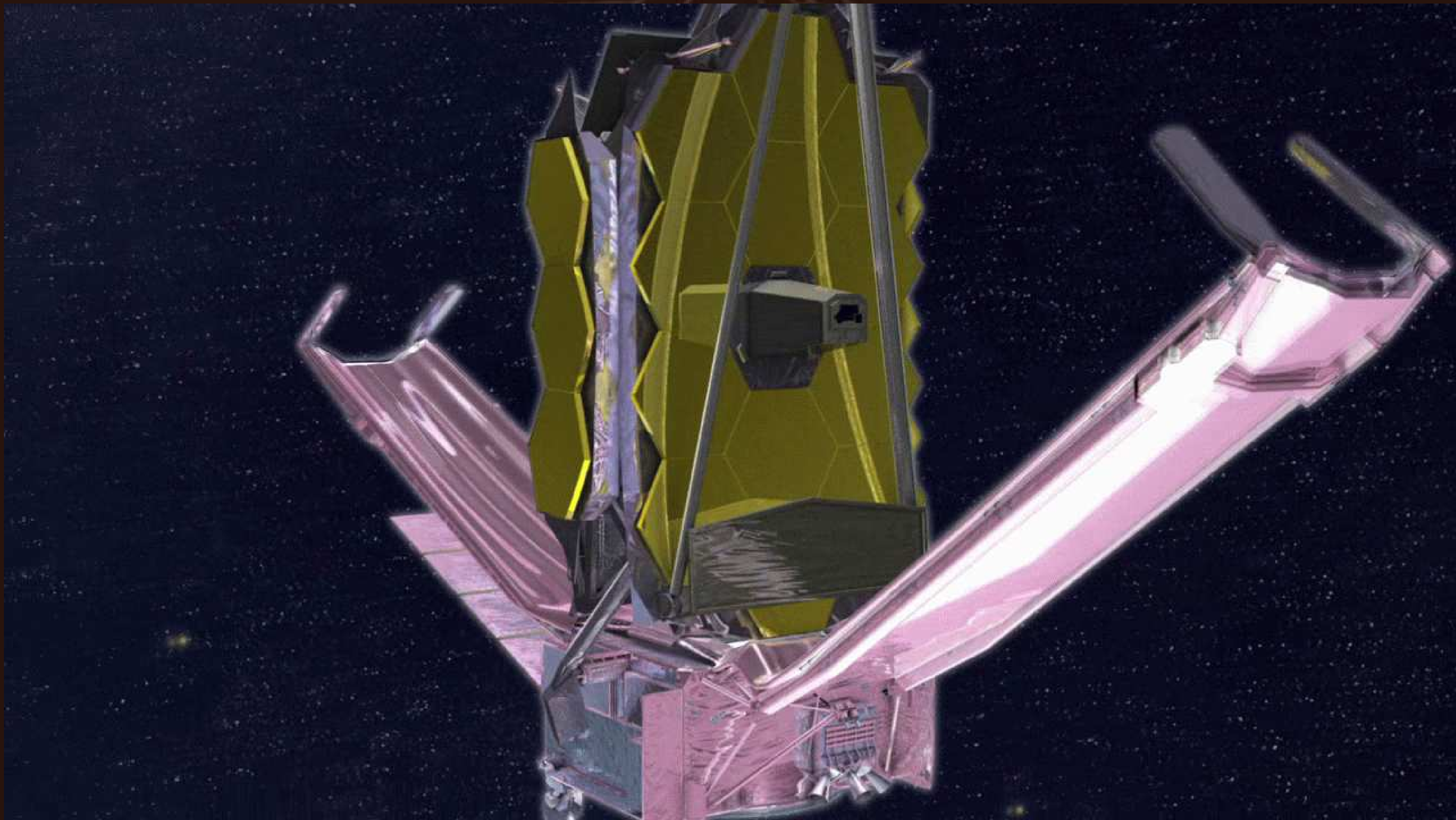


- Orbit: 350 miles (*HST*) vs. 932,000 miles (*JWST*); launch to L2 by Ariane 5

JWST deployment: advanced origami

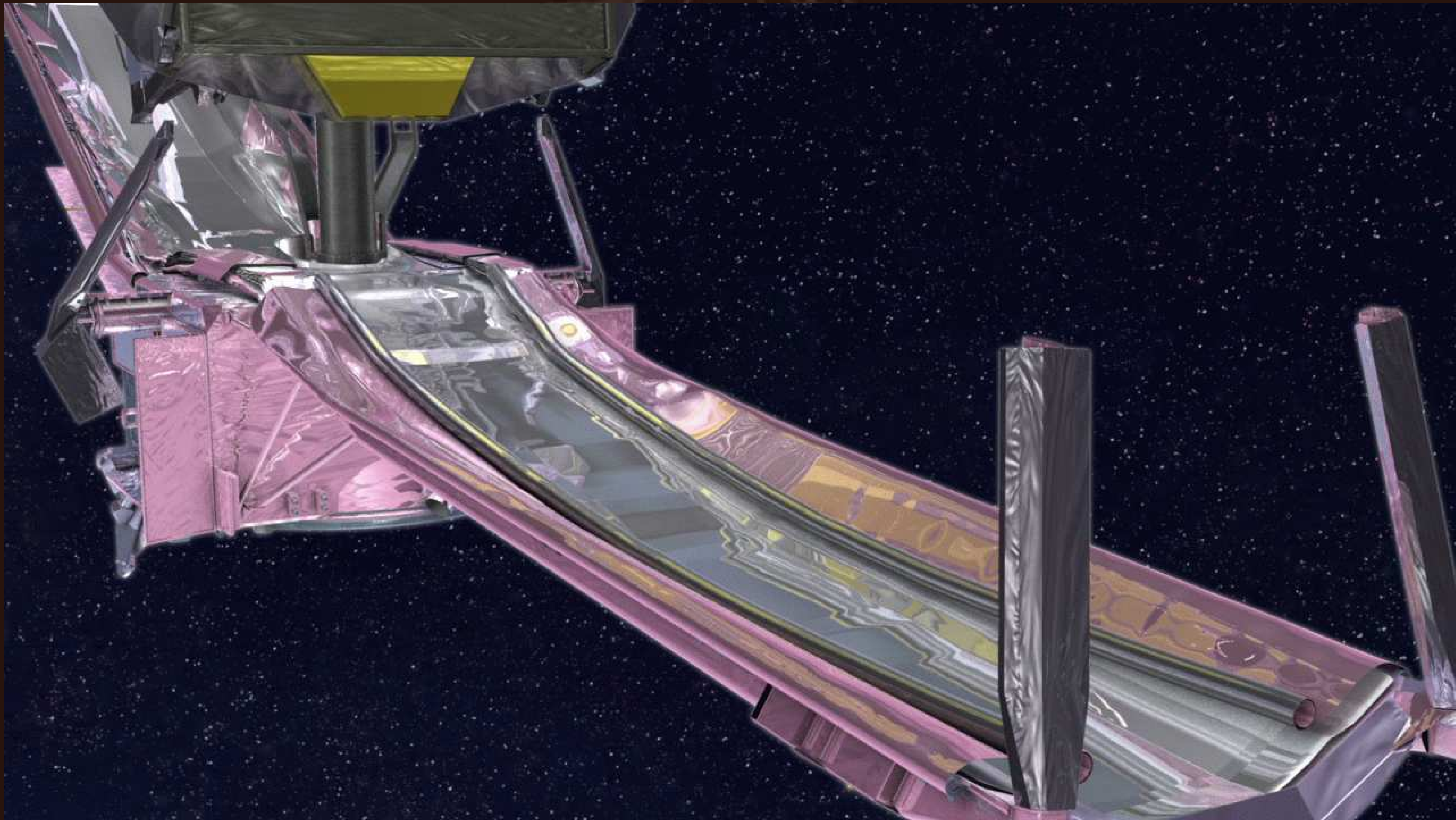
Unfolding the *JWST* – 1

JWST deployment: advanced origami



Unfolding the *JWST* – 2

JWST deployment: advanced origami

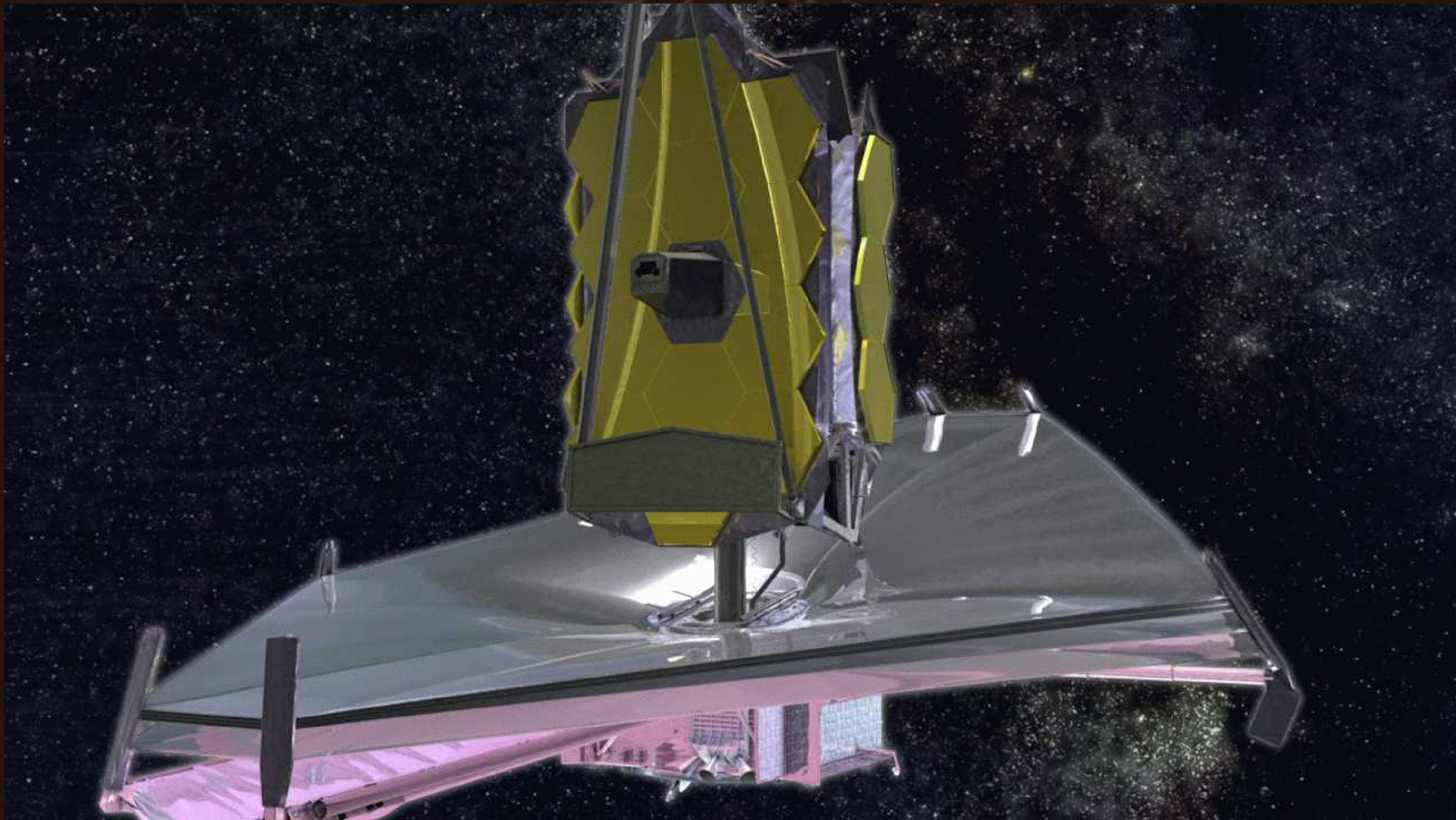


Unfolding the *JWST* – 3

JWST deployment: advanced origami

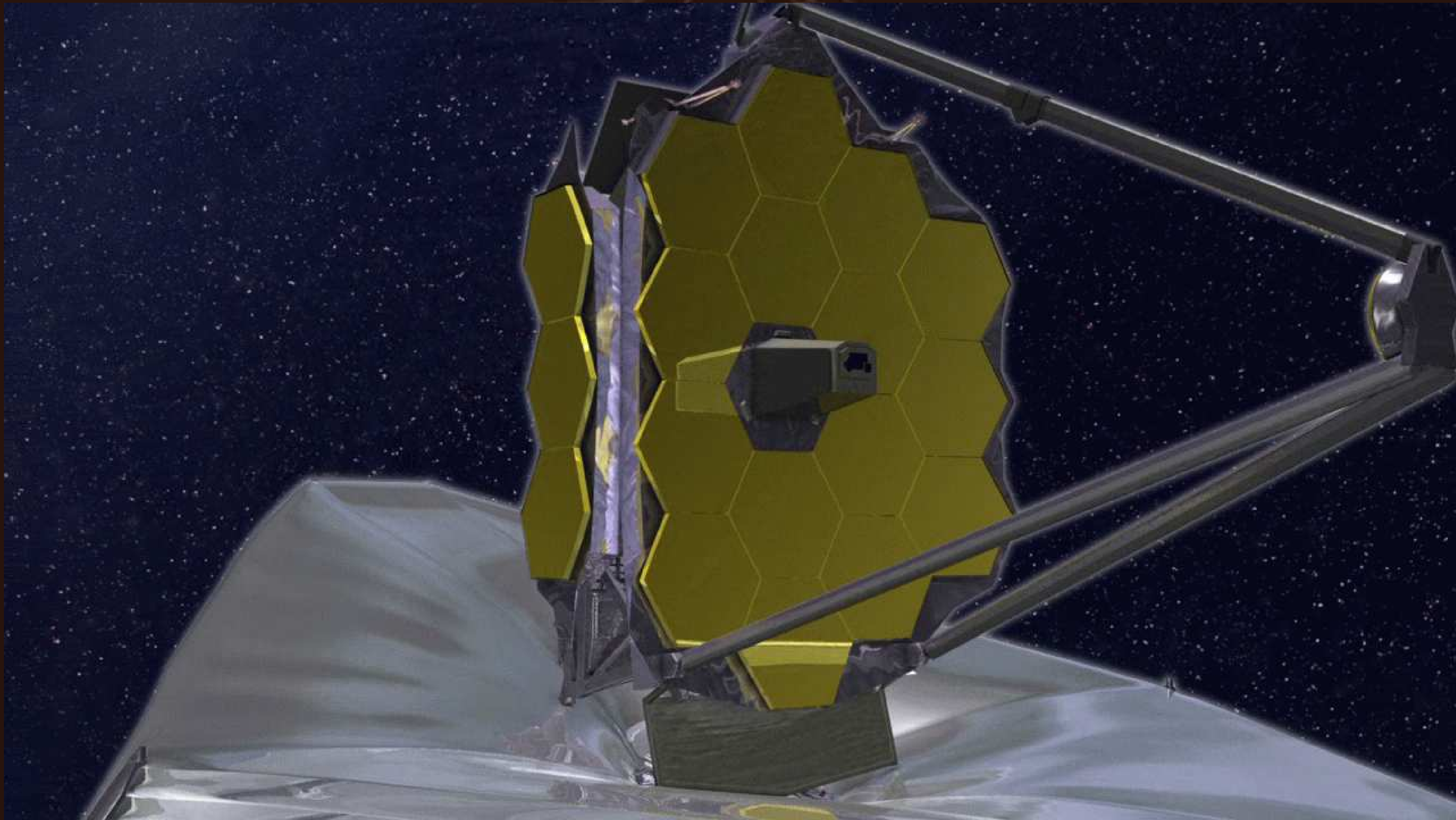
Unfolding the *JWST* – 4

JWST deployment: advanced origami



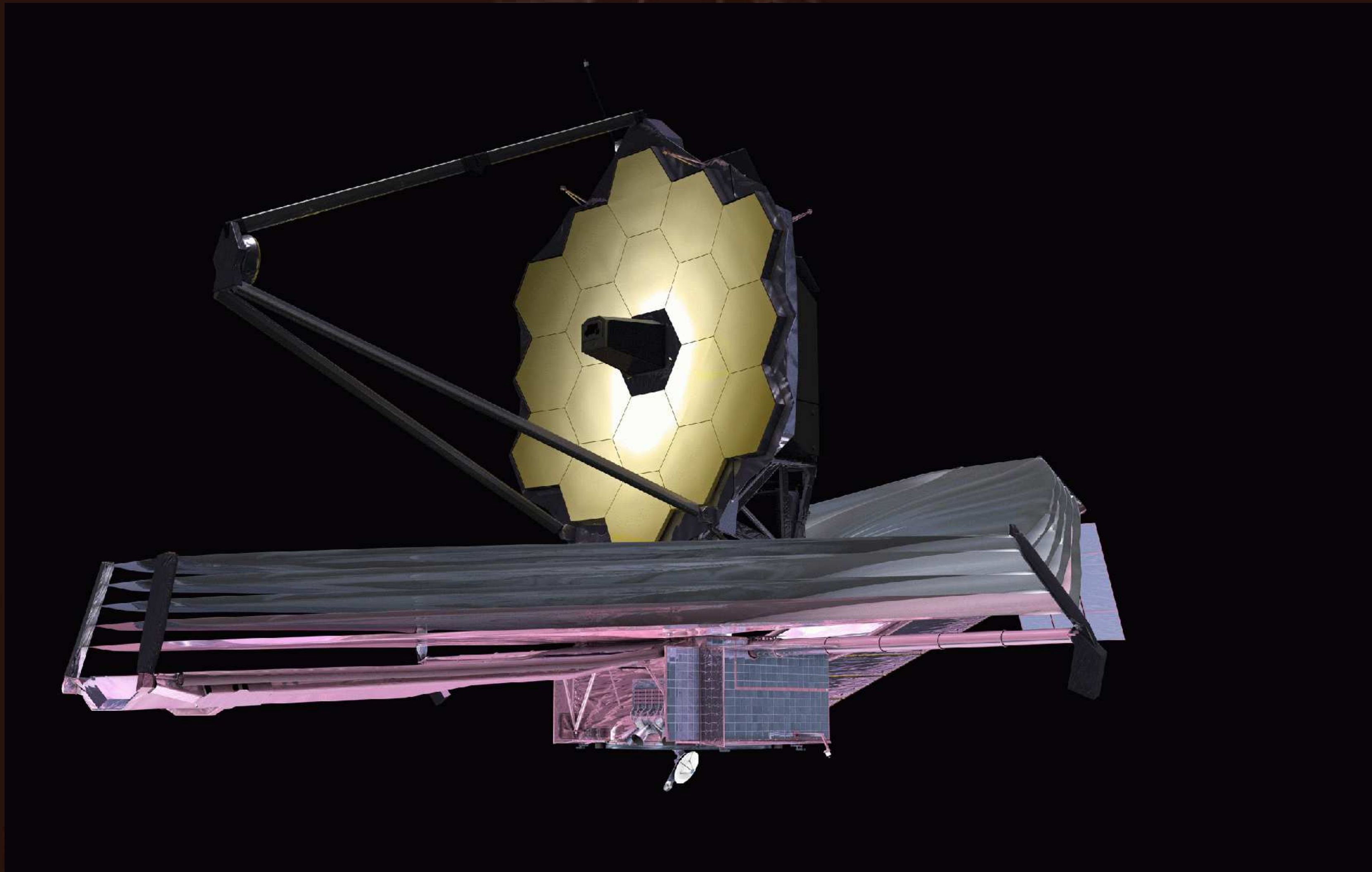
Unfolding the *JWST* – 5

JWST deployment: advanced origami



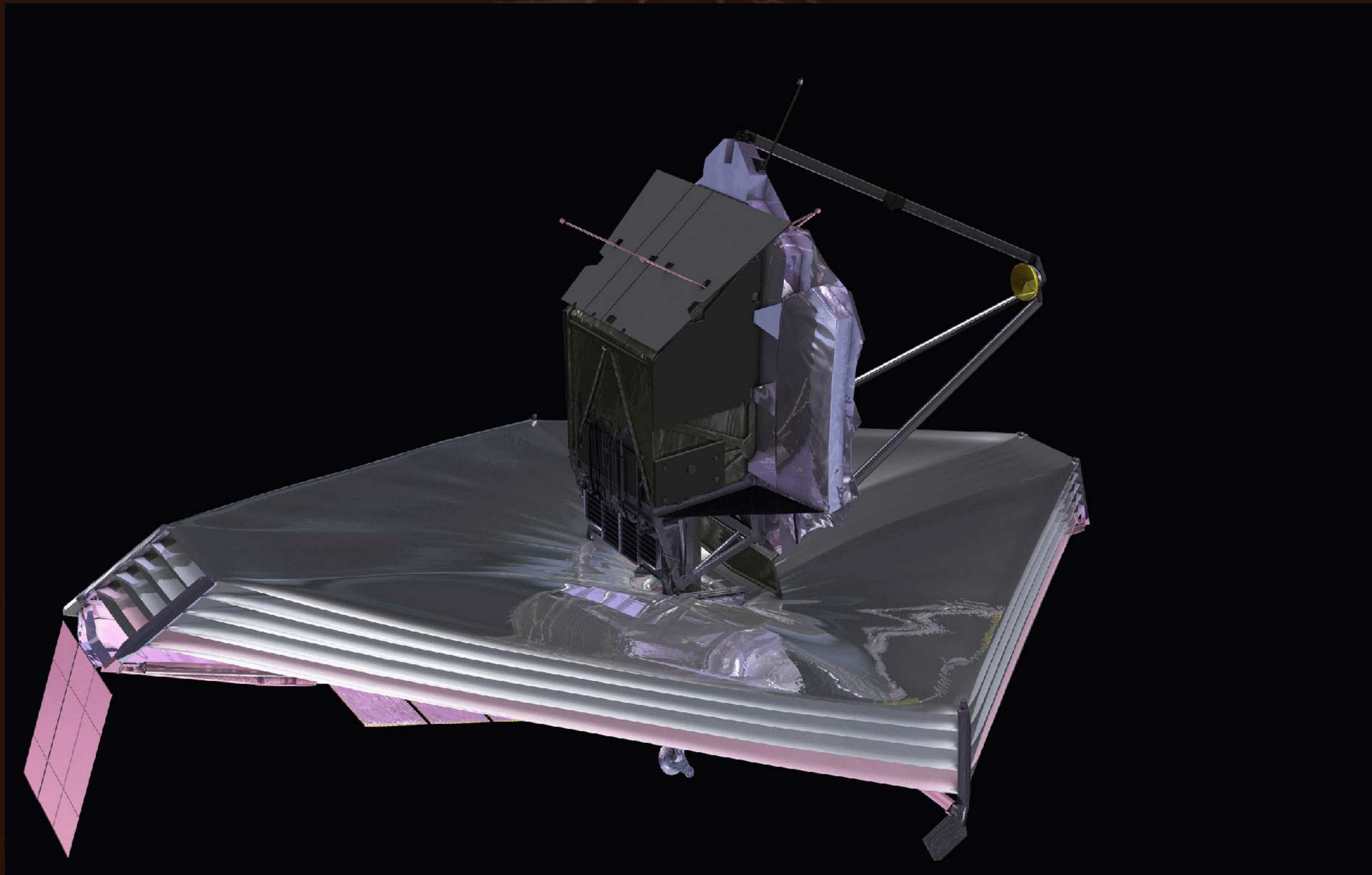
Unfolding the *JWST* – 6

What will *JWST* look like?



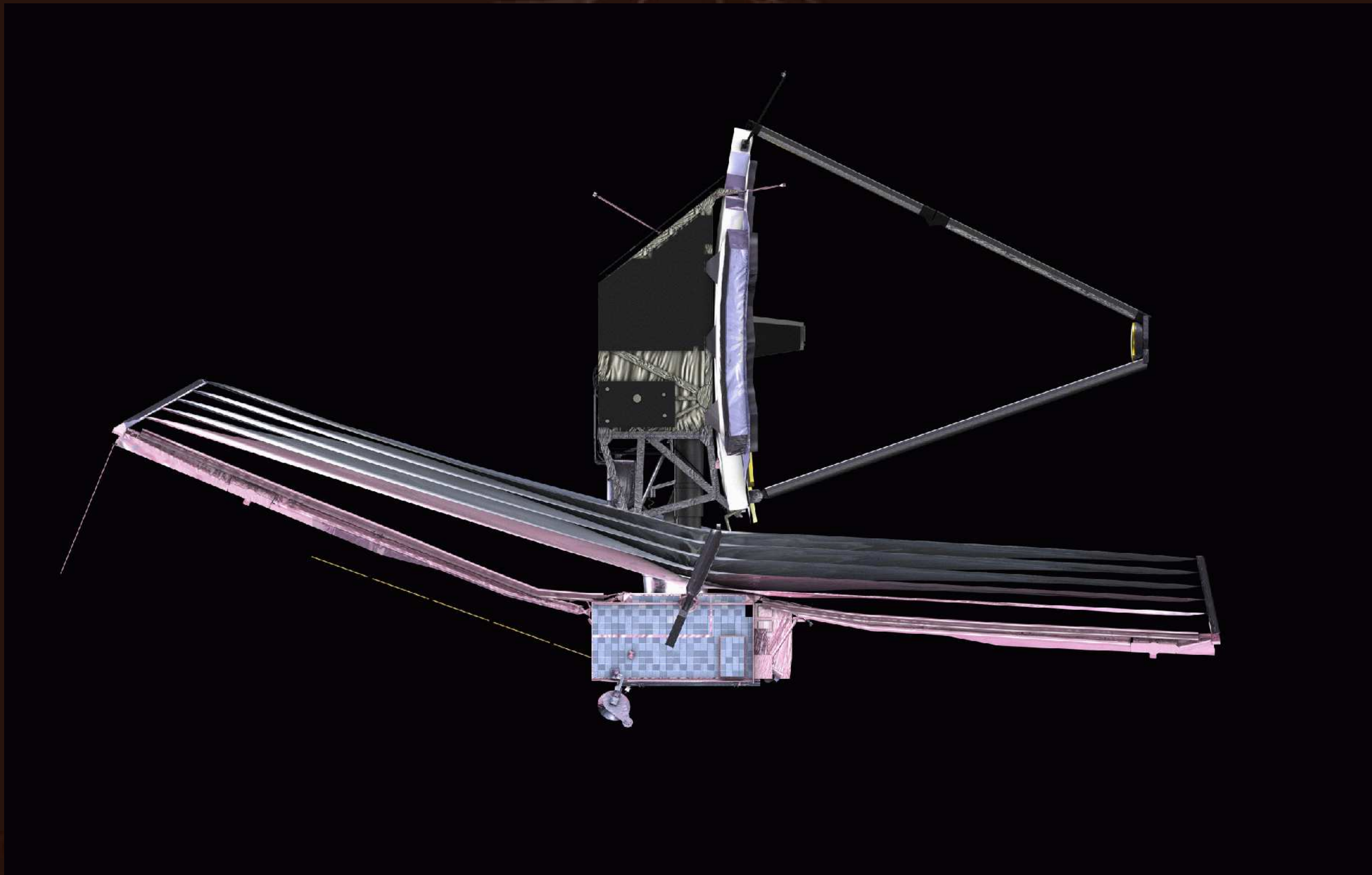
Rendering of the fully deployed *JWST*

What will *JWST* look like?



Perspective view from the rear of the fully deployed *JWST*

What will *JWST* look like?

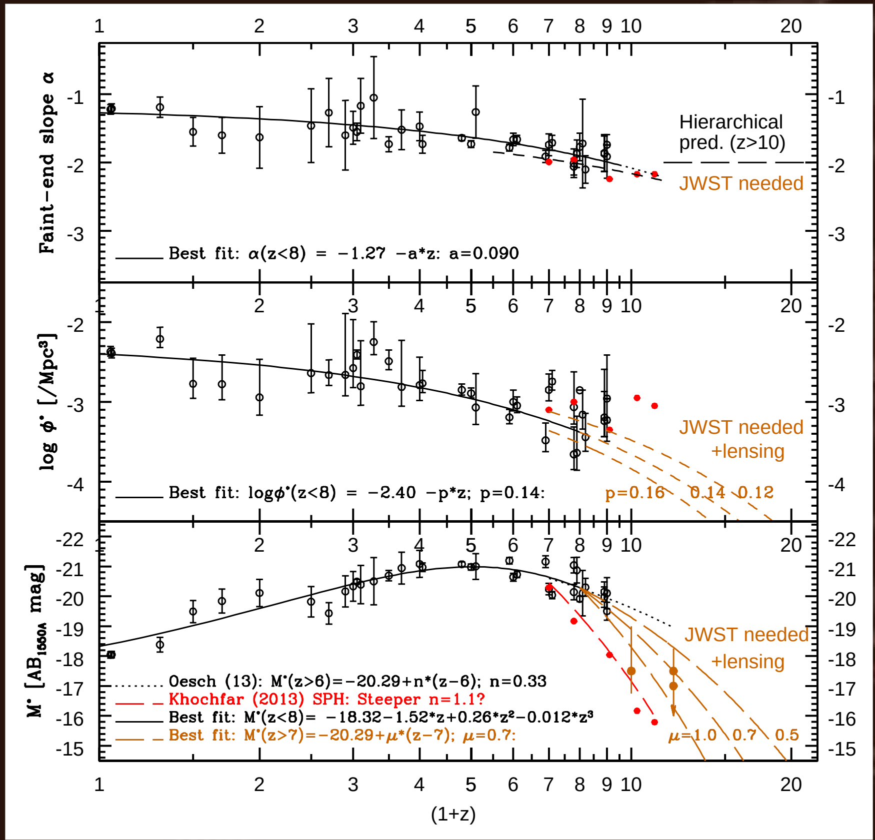


View from the side of the fully deployed *JWST*

What will *JWST* look like?

- Nested array of 5 sunshield layers keeps *JWST*'s telescope and instrument package at 40 K ($-388\,^{\circ}$F), allowing 0.7–28 μm imaging and spectroscopy of faint ($m \sim 31.5$ mag) objects

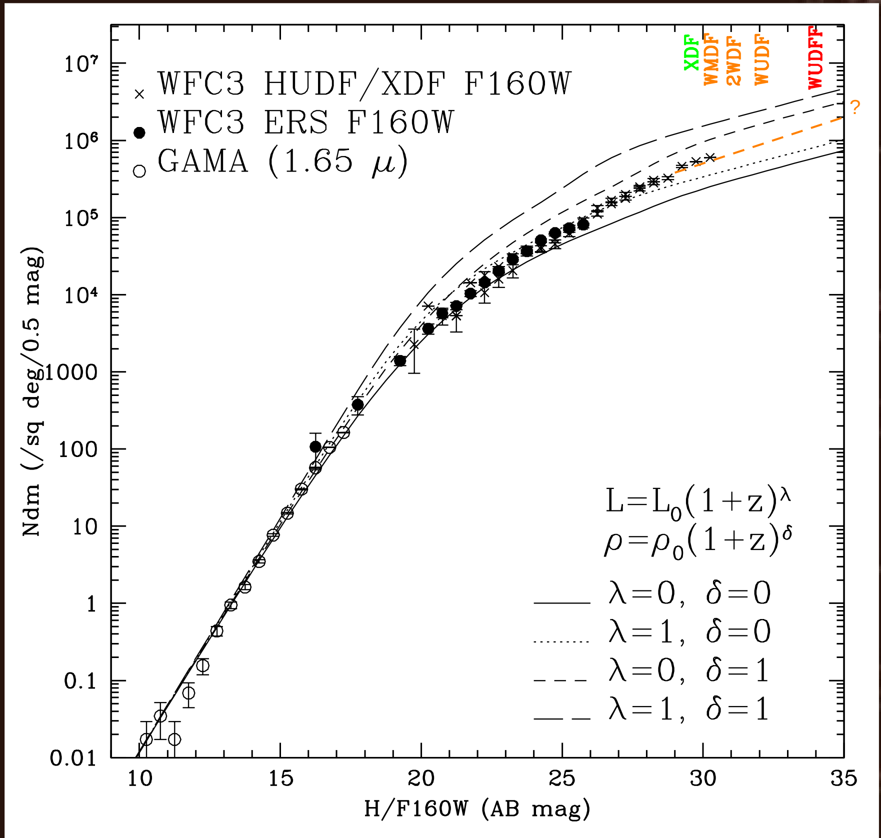
How can *JWST* best observe First Light

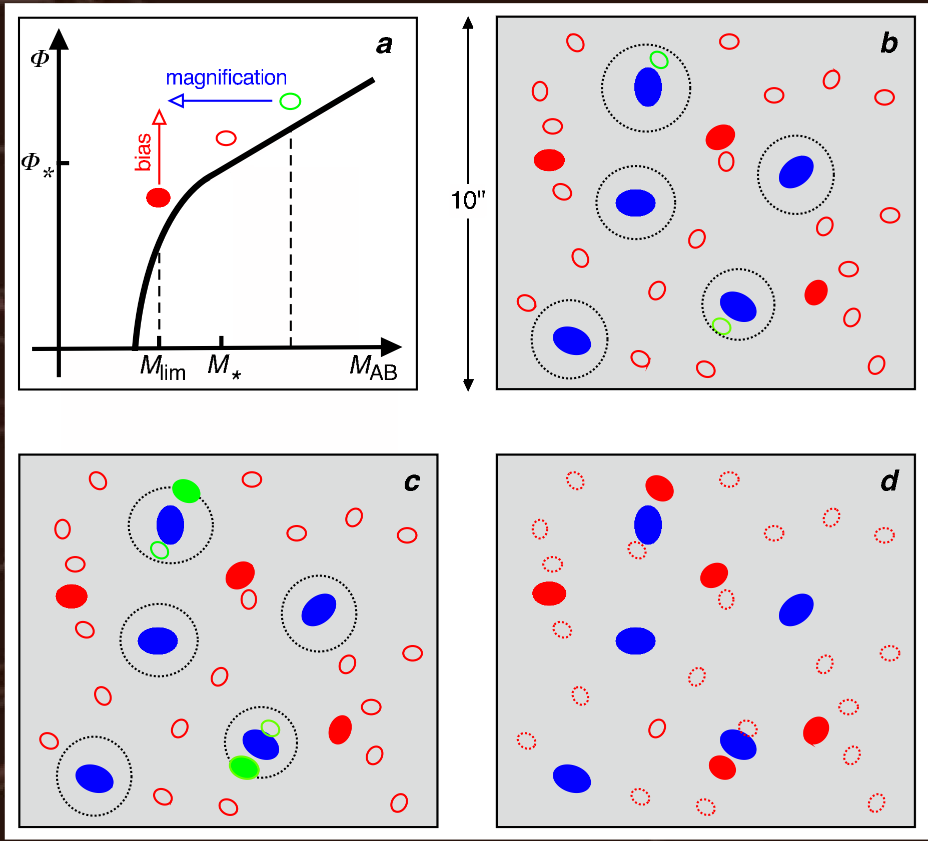


- *HST* surveys have shown strong evolution of the UV galaxy luminosity function at $z > 6$
  - ➤ faint-end slope $\alpha(z) \lesssim -2$, galaxy volume density $\Phi^\star(z) \lesssim 10^{-3}$ Mpc^{-3}, and characteristic galaxy magnitude $M^\star(z) \gtrsim -17.5$ mag
  - ➤ Number of detectable $z > 8$ objects per deg^2 likely *very* low!

- Even *JWST* may not be sensitive enough to find many First Light sources in deep, blank survey fields...

How can *JWST* best observe First Light

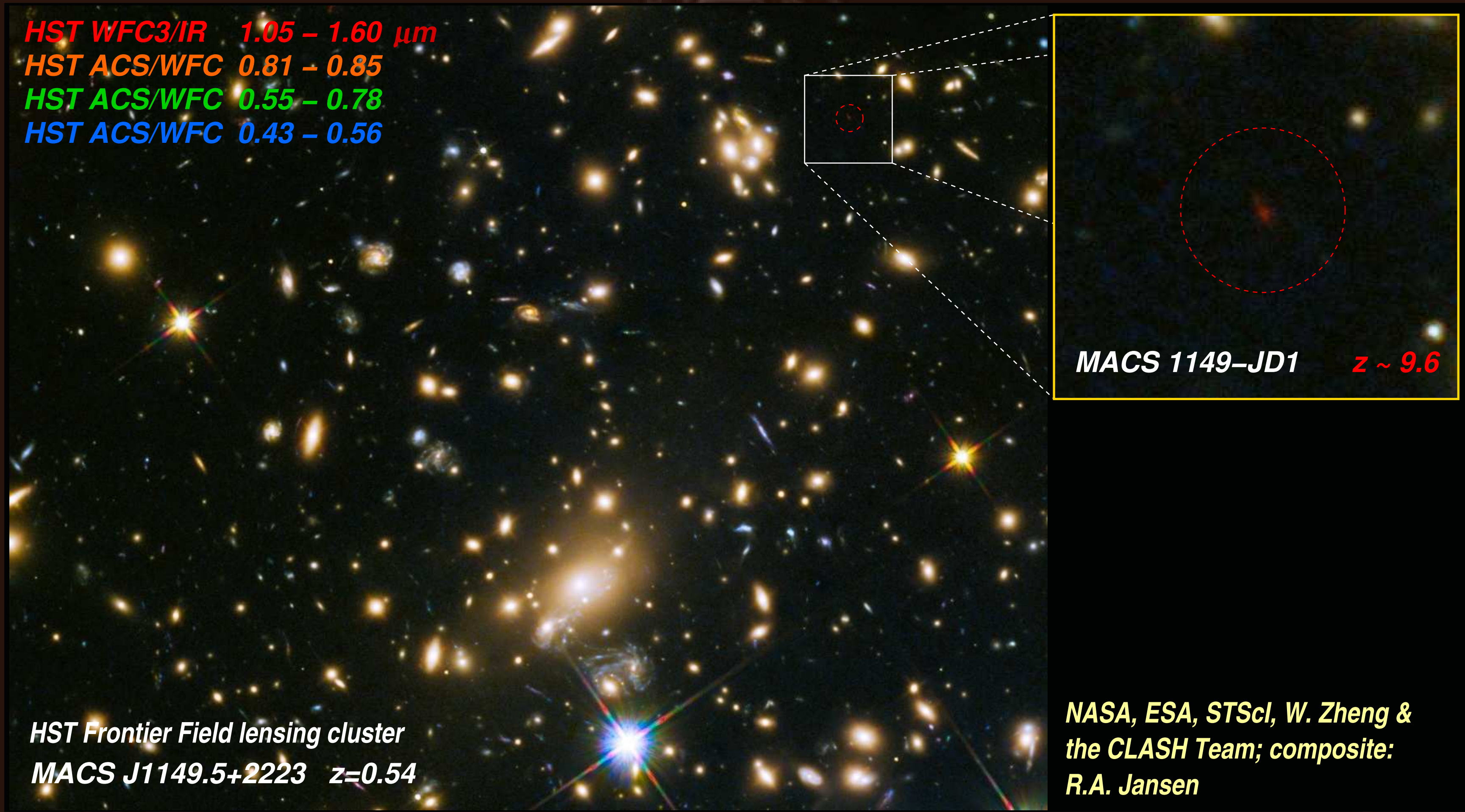




R. Windhorst, S. Wyithe, et al. 2018

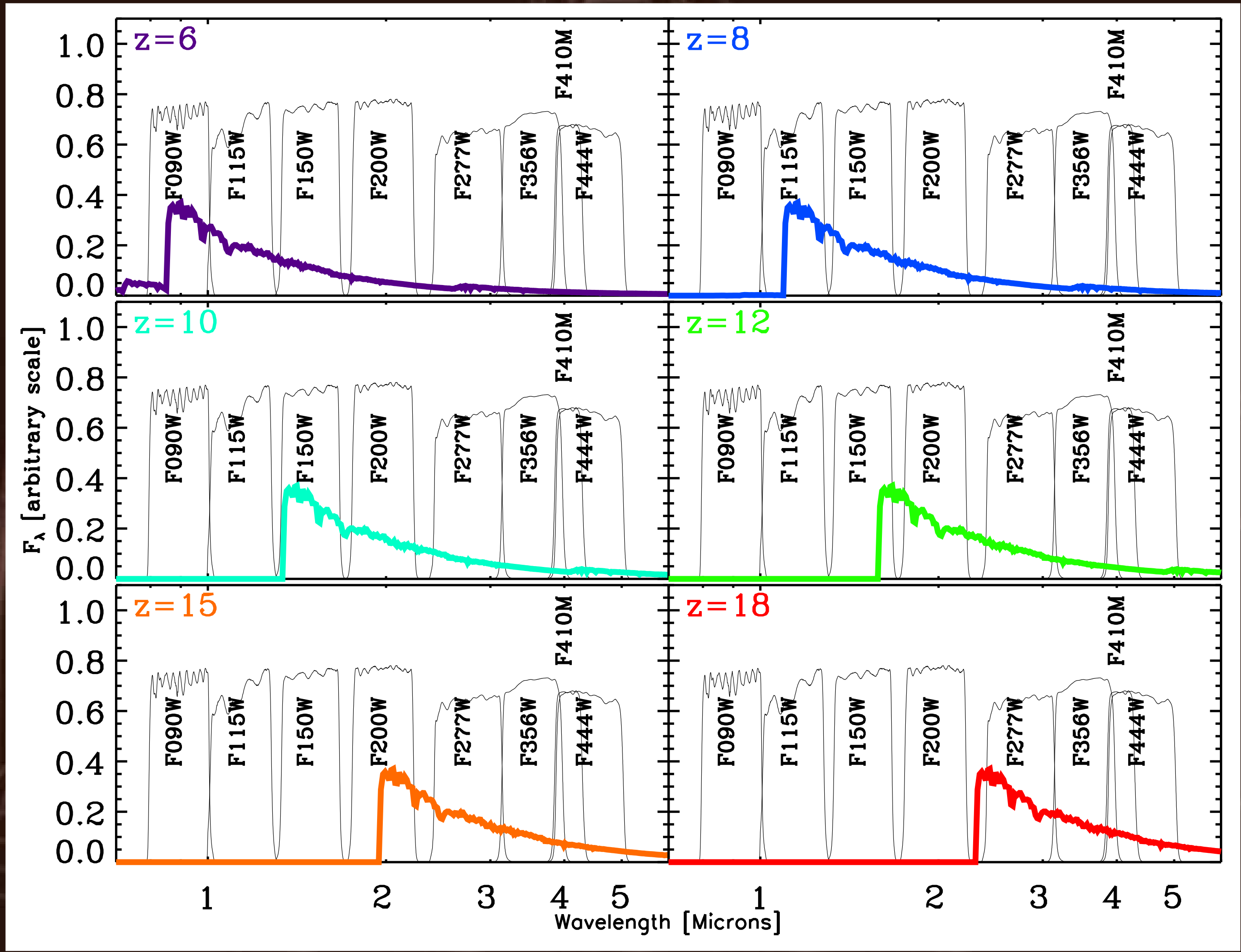
- Faint-end of near-IR galaxy counts has a steep slope
- Gravitational lensing boosts faint galaxies above the detection limit
  - ➤ Deep *JWST* surveys of lensing cluster targets will detect First Light objects ($m \sim 32$ mag, $z > 10$)

How can *JWST* best observe First Light



- *HST* already hints this strategy works: MACS J1149-JD1, is a $z \sim 9.6$ object. Its light was boosted by a factor ∼15 by the massive lensing cluster MACS J1149+2223 in the foreground.

How can *JWST* best observe First Light



- You can't beat redshift: to see First Light objects, one *must* observe in the near–mid-IR

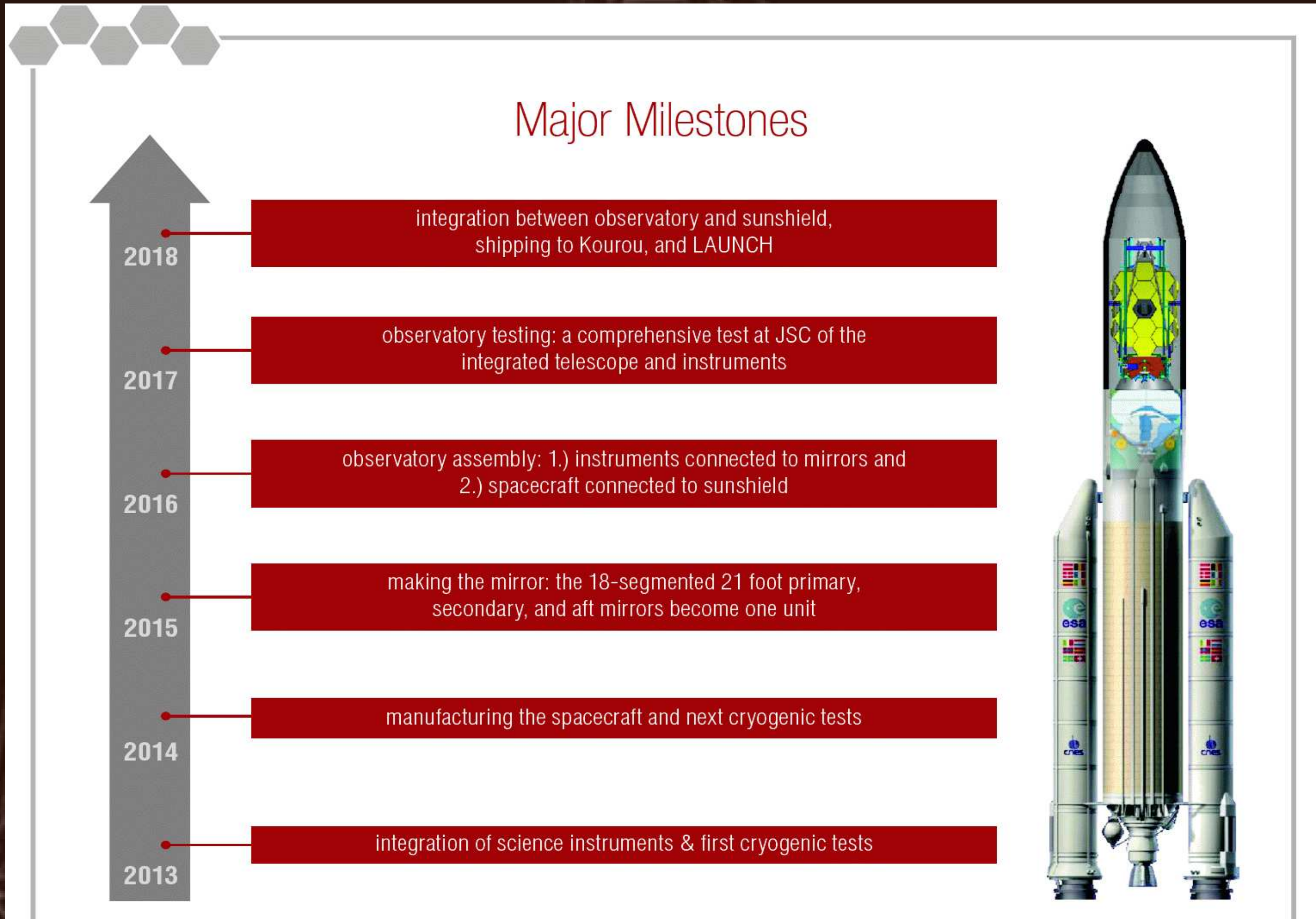
How can *JWST* best observe First Light

- *JWST*/NIRCam can observe at 0.7–5 μm to detect *and* characterize the UV-continuum of star-forming galaxies at redshifts up to $\sim$20 (a cosmic age of a mere $\sim$180 Myr)

- *Planck* (2016) constraints on the Epoch of Reionization and First Light:
  - if instantaneous: $z \simeq 8.2 \pm 0.9$
  - if inhomogenous and drawn out: starting at $z \gtrsim 12$, peaking at $z \sim 8$, ending at $z \simeq 6$–7.

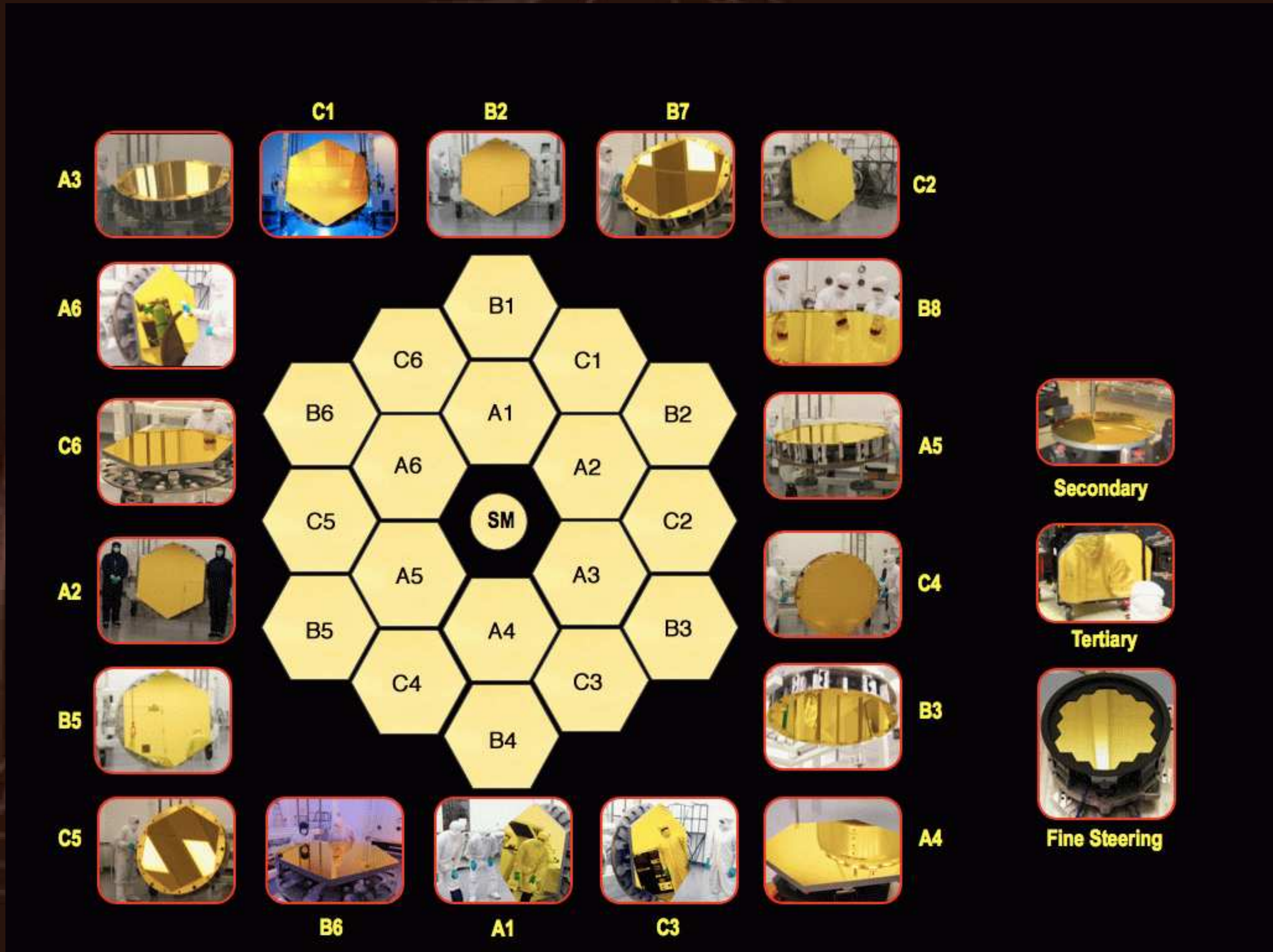
- First Light sources are within *JWST*'s wavelength range, but it is unclear how many reionizing sources *JWST* should expect to see at $z \simeq 10$–15.

Current Status of *JWST*



- ➤ Currently at Northrop Grumman (CA) in Integration & Testing of the entire *JWST* spacecraft bus + sunshield + observatory (telescope + instruments)

Assembling *JWST*



21 gold-coated beryllium mirrors (18 primary segments) to form the telescope

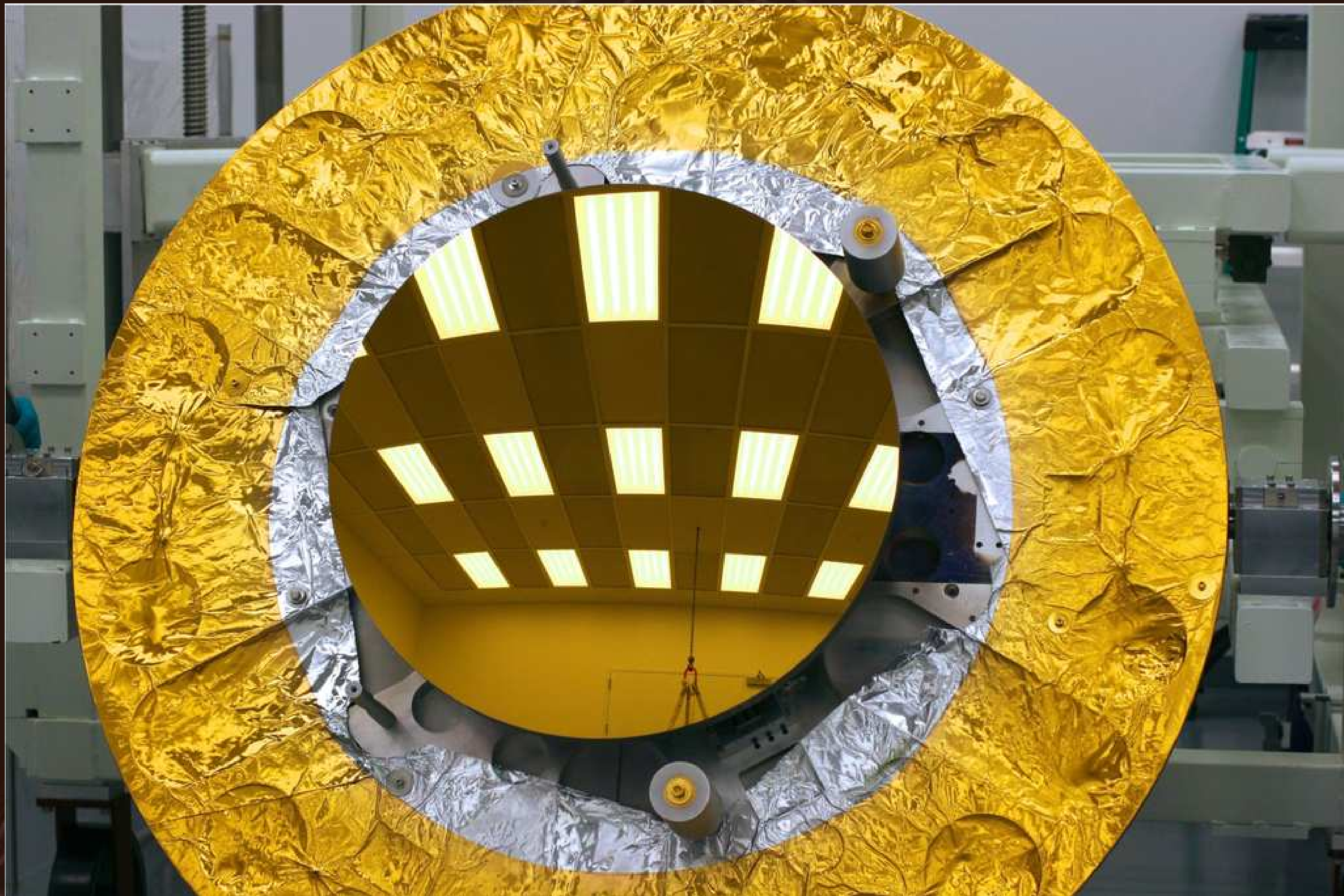
Assembling *JWST*

A light-weighted 4.2 ft (1.3 m) bare beryllium primary mirror segment, seen from the rear – Jul 20, 2010

Assembling *JWST*

The gold-coated tertiary mirror at GSFC – Jun 22, 2010

Assembling *JWST*



The gold-coated secondary mirror at GSFC – Jul 19, 2011

Assembling *JWST*

18 gold-coated beryllium primary mirror segments in their delivery canisters at GSFC – Aug 10, 2012

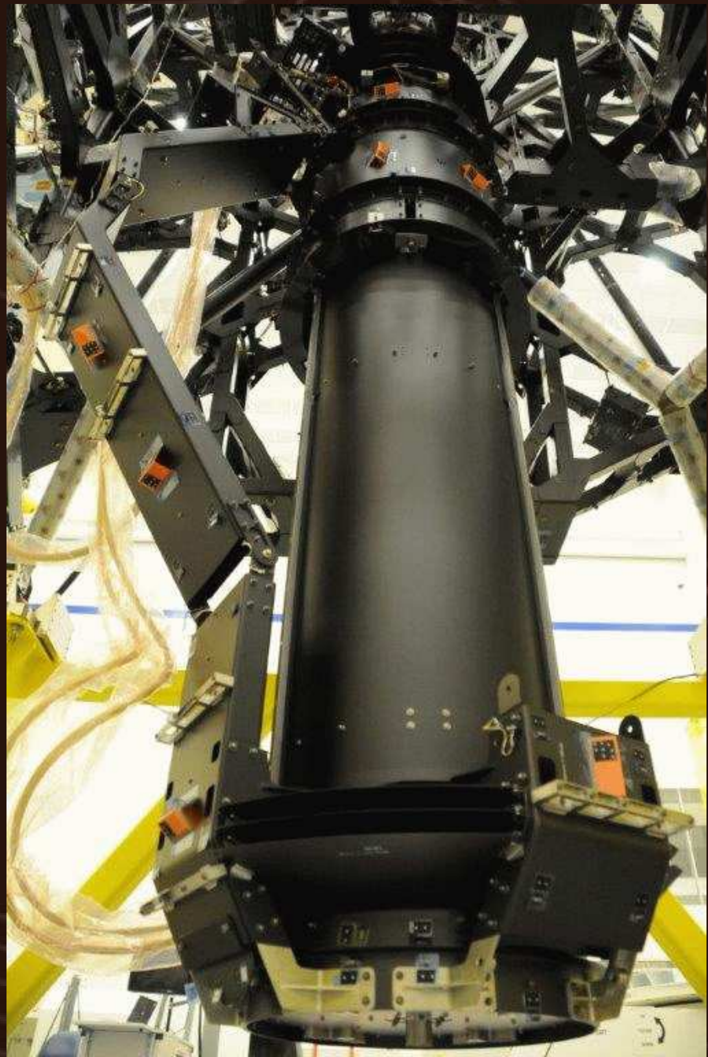
Assembling *JWST*

Inspection of one such gold-coated beryllium primary mirror segment at GSFC – Sep 19, 2012

Assembling *JWST*

Unfolding test of the 5-layer sunshield at Northrop-Grumman – Jul 10, 2014

Assembling *JWST*

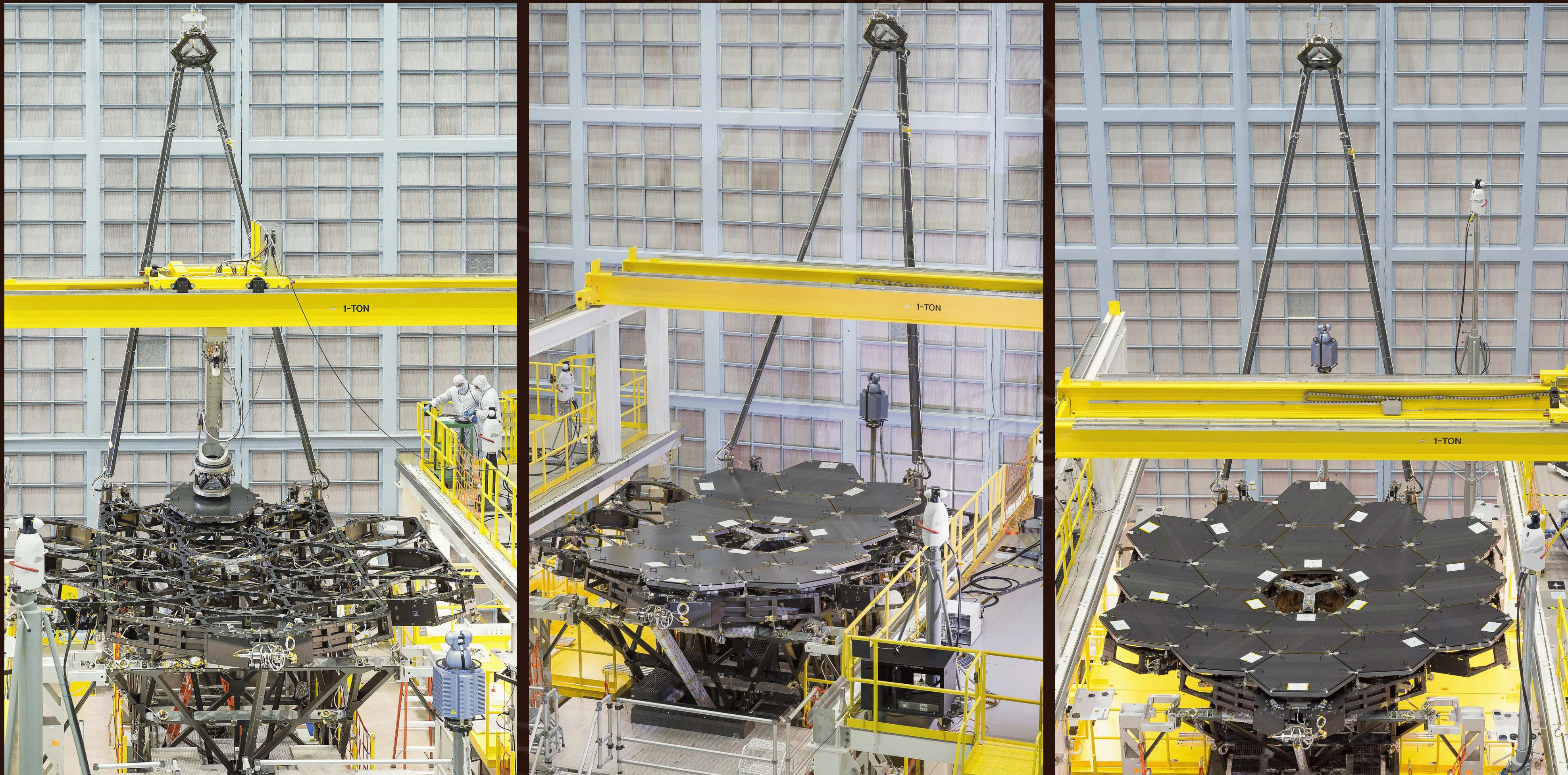


Deployable Tower Assembly, designed to raise the telescope off the spacecraft bus after launch, at Northrop-Grumman – Sep 9, 2015

Assembling *JWST*

The telescope structure (backplane) at GSFC – Nov 12, 2015

Assembling *JWST*



Installation of the primary mirror segments (covered) onto the mirror support structure at GSFC – Nov 22, 2015; Jan 3, 2016; Feb 8 2016

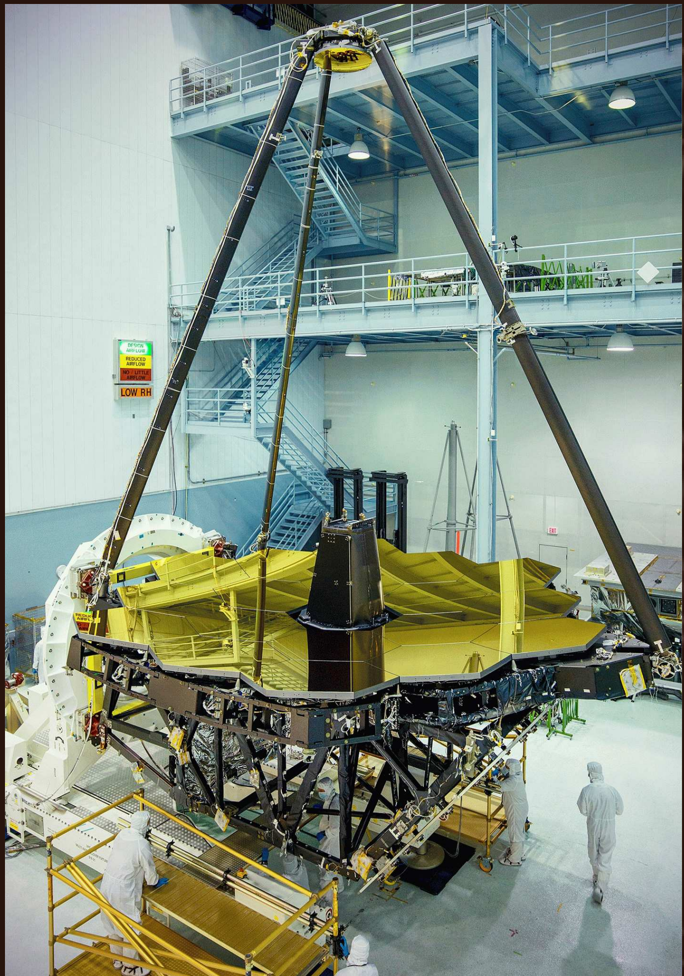
Assembling *JWST*

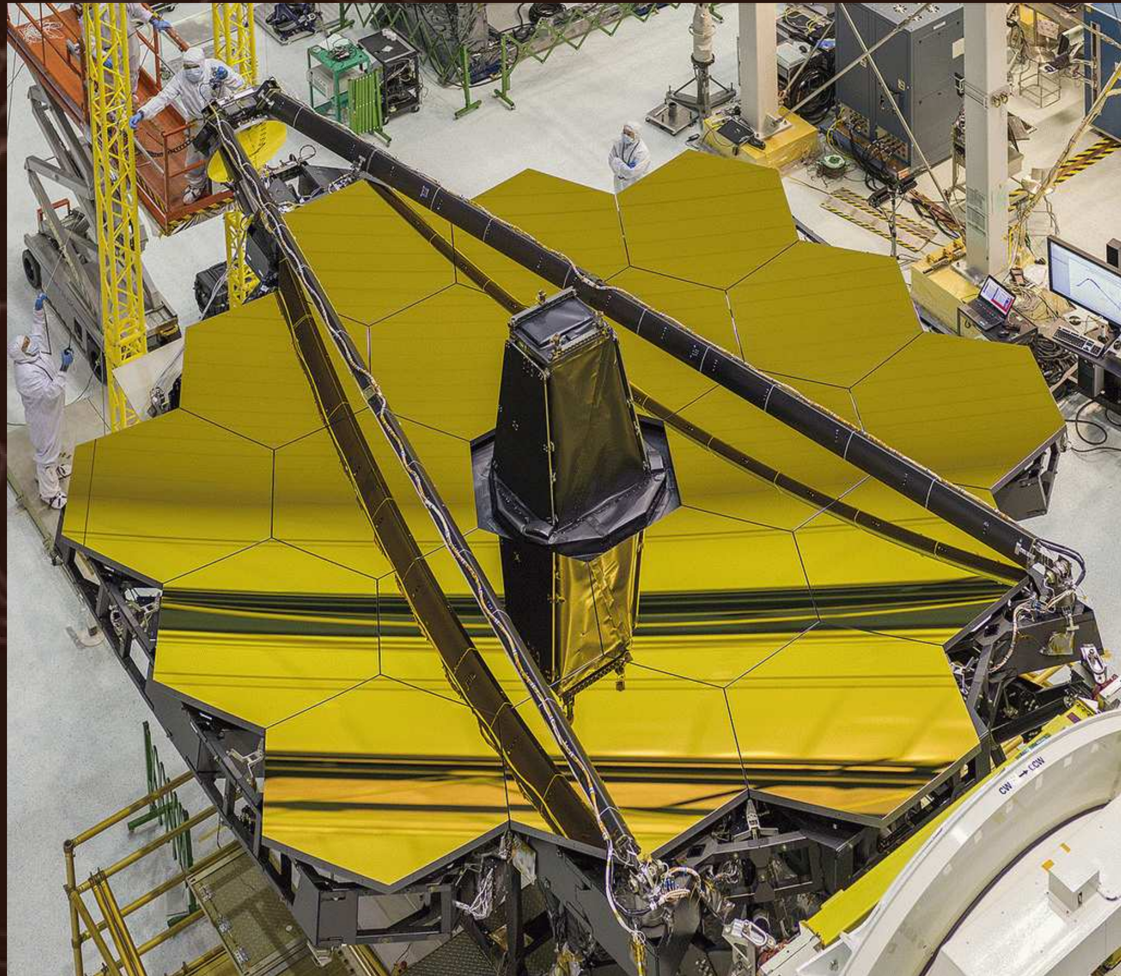
Installation of the secondary mirror at GSFC – Feb 27, 2016

Assembling *JWST*

NASA team-work to take the protective mirror covers off at GSFC – April 2016

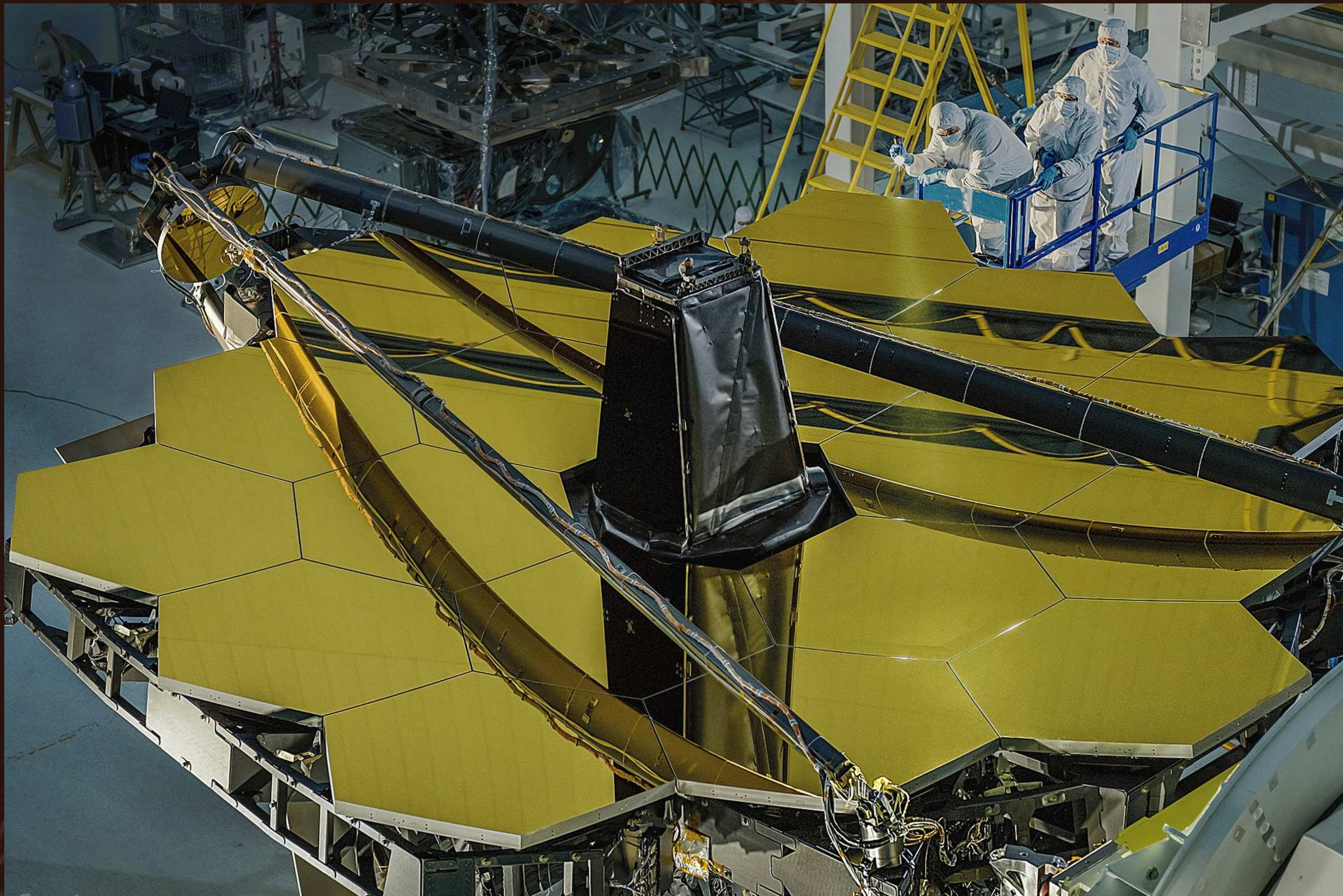
Assembling *JWST*





Fully assembled primary mirror array unveiled at GSFC – Apr 26-27, 2016

Assembling *JWST*

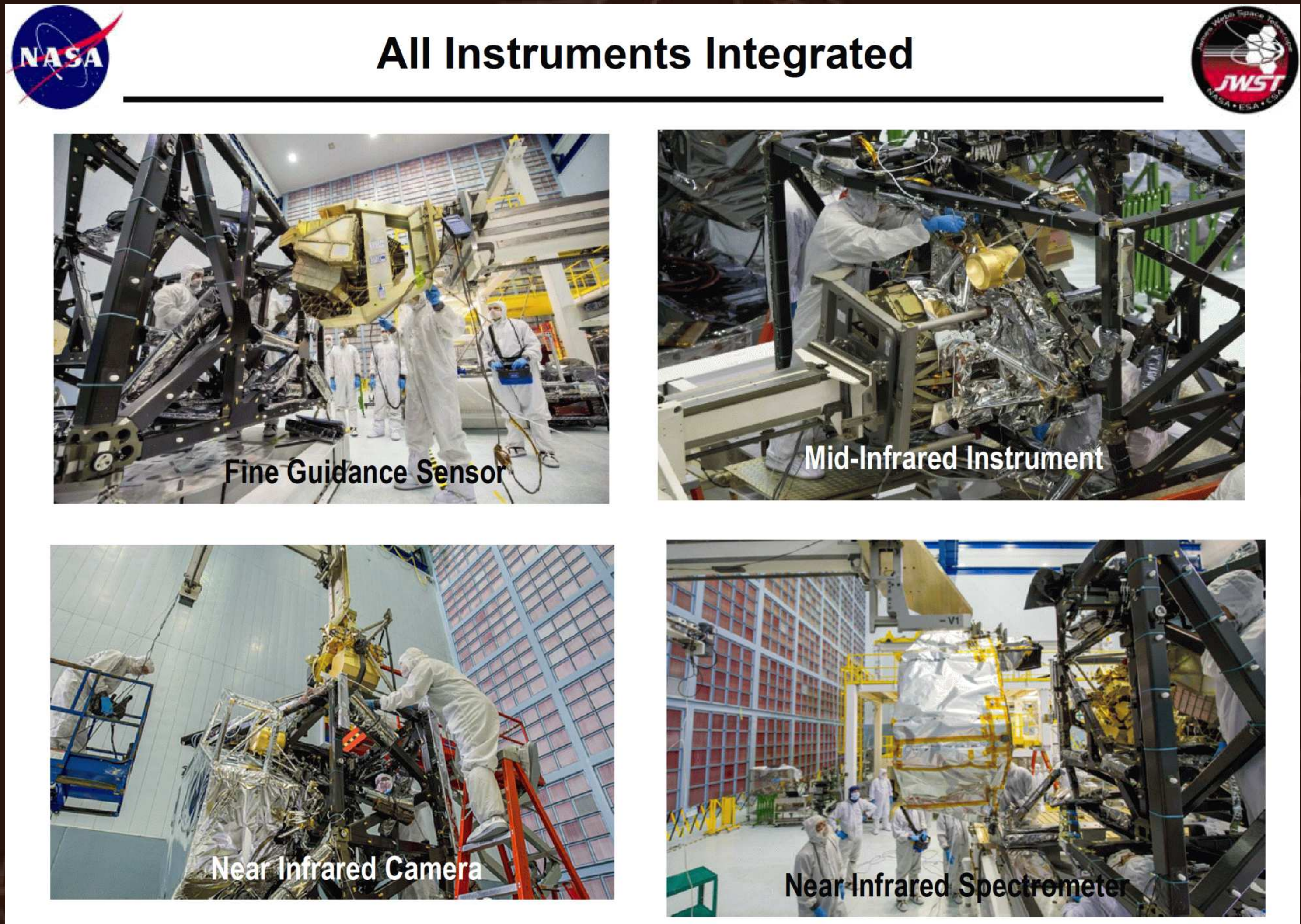


Secondary support stowed in preparation installation of the instrument module – May 2, 2016

Assembling *JWST*

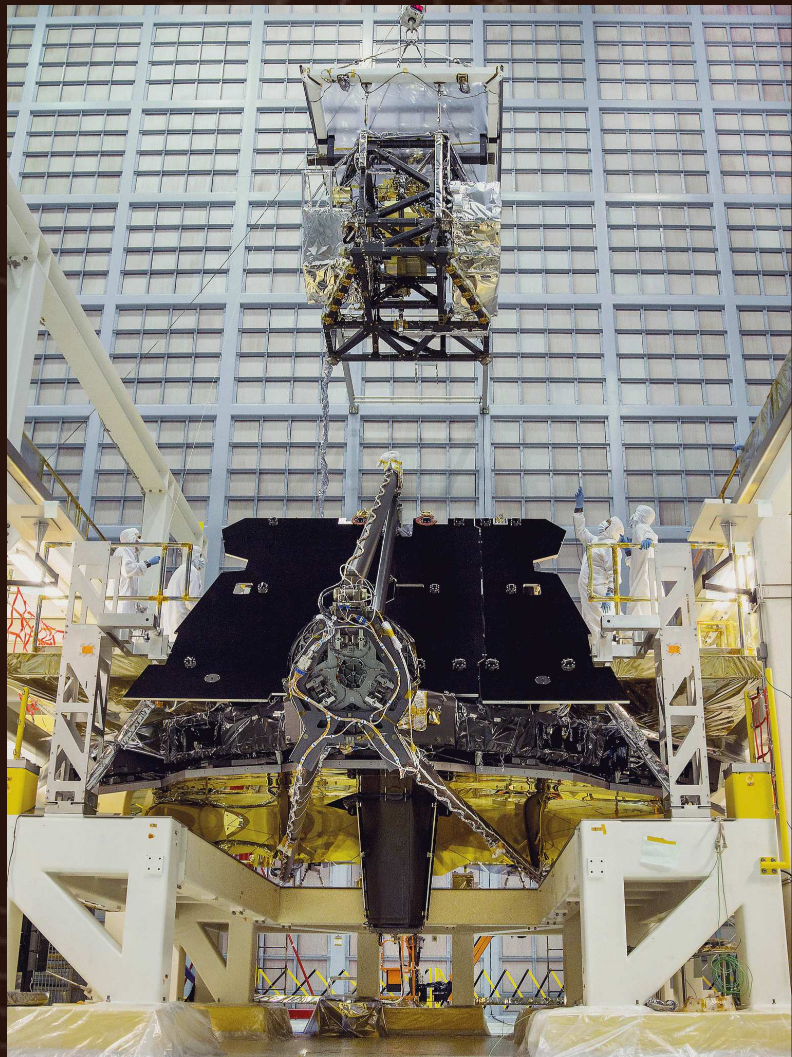
Selfie with Nobel laureate and *JWST* Senior Scientist Dr. John Mather from the public gallery at GSFC – May 4, 2016

Assembling *JWST*



Integration of the *JWST* instruments into the instrument module (ISIM) at GSFC – April 2016

Assembling *JWST*



Integration of the *JWST* optical telescope assembly (OTA) with the instrument module (ISIM) at GSFC – May 19, 2016

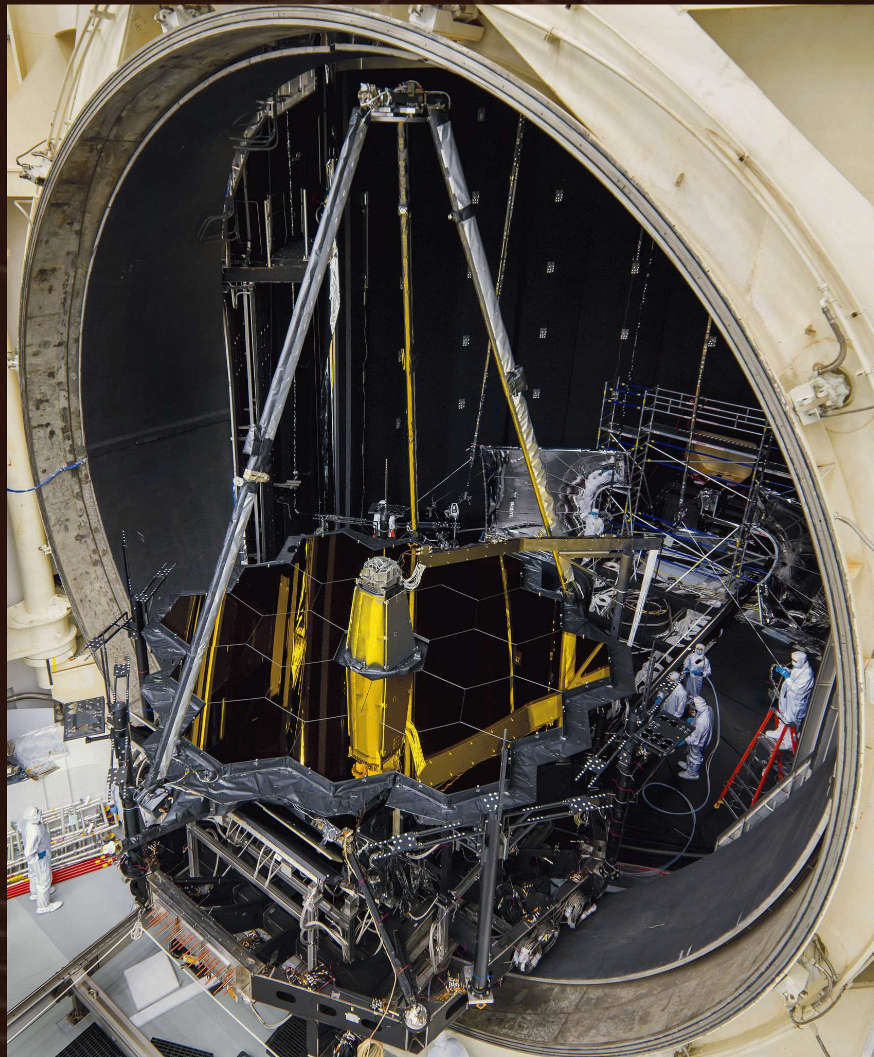
Assembling *JWST*

After integration with the instrument module and installation of the frill (baffle) behind and around the primary mirror array – Oct 3, 2016

Assembling *JWST*

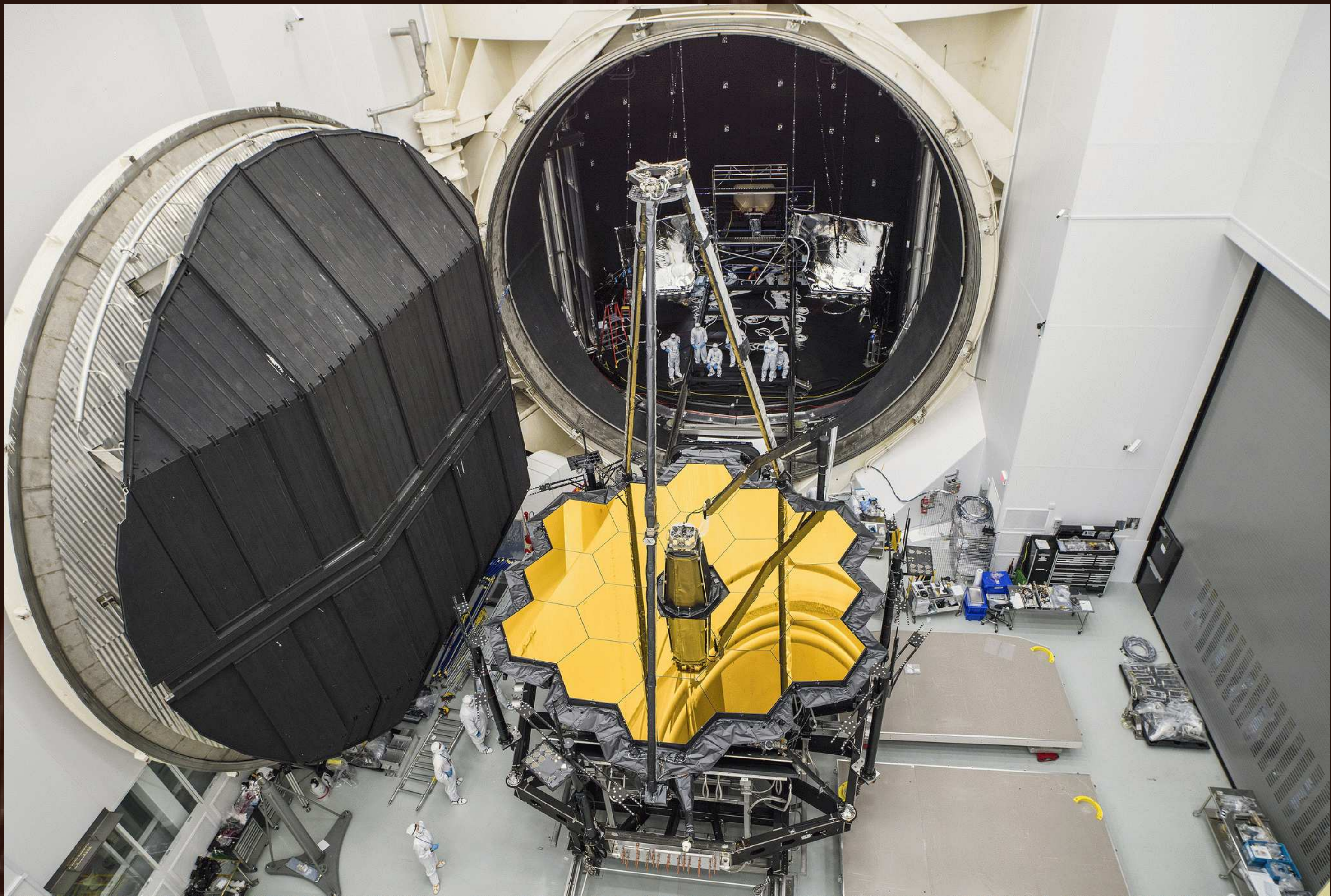
A farewell to GFSC as the *JWST* telescope is prepared for shipping to NASA’s Johnson Space Center – May 13, 2017

Assembling *JWST*



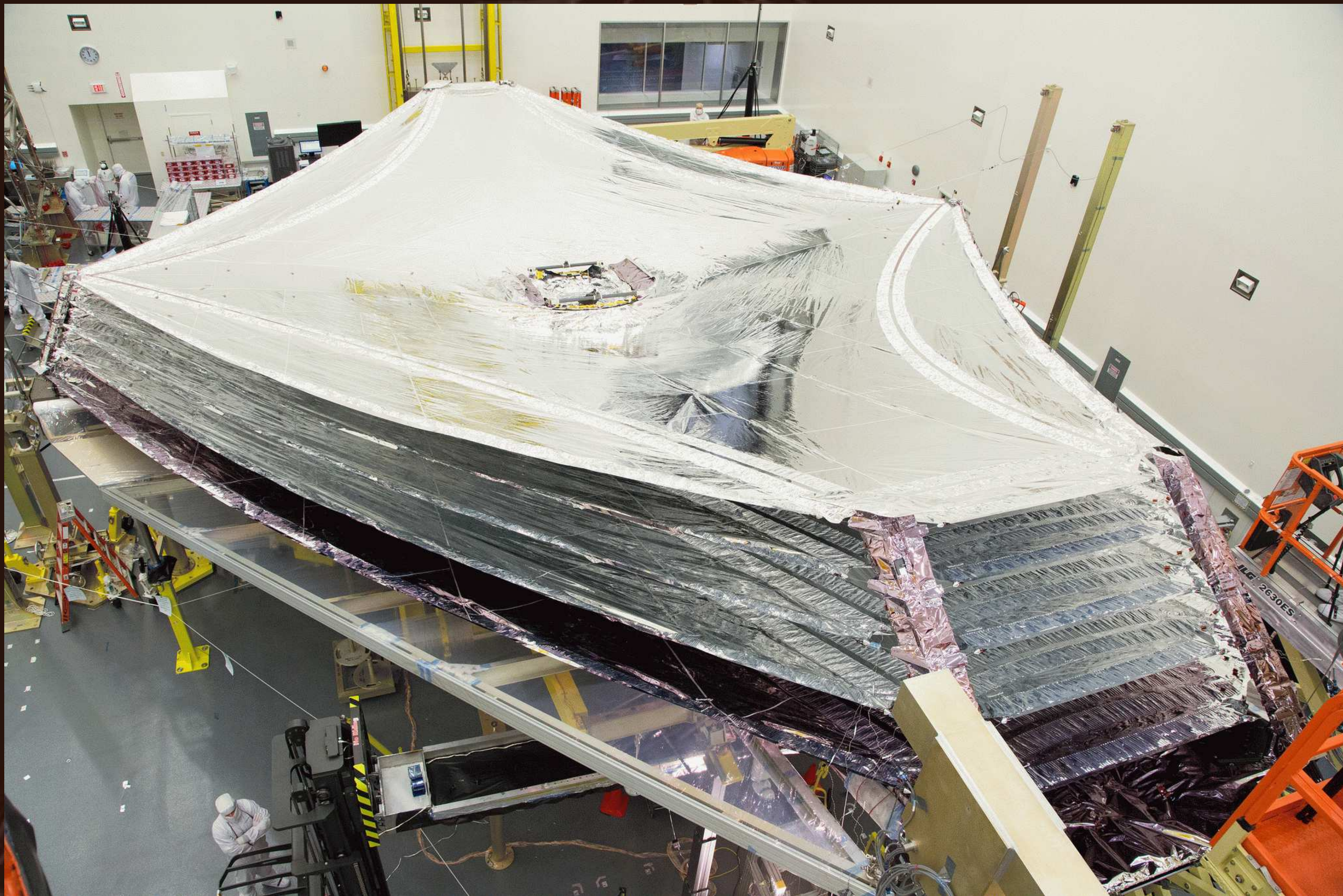
The integrated *JWST* telescope and instrument package is prepared for cryovacuum testing at JSC – Jun 20, 2017

Assembling *JWST*



The integrated *JWST* telescope and instrument package emerges from the cryovacuum tank at JSC, having successfully passed testing – Dec 12, 2017

Assembling *JWST*



The flight version of the stack of sunshield membranes after unfolding and tensioning at Northrop Grumman – Oct 23, 2017

Assembling *JWST*

- 11 new technologies invented from scratch early in *JWST*'s development; $\gtrsim$99.5% of flight hardware built
- Problem emerged with leaky spacecraft thruster valves due to improper cleaning at Northrop Grumman in May 2017
- Problem emerged with a flight sunshield unfolding and tensioning test at Northrop Grumman in Oct 2017
- Problem emerged after environmental (accoustic) testing of the spacecraft at Northrop Grumman in Apr 2018

➤ We do these tests here on the ground *precisely* so we can catch and fix any issues, so they won't happen during or after launch in space

➤ To ensure a realistic schedule for integration and testing of the integrated spacecraft + sunshield + telescope, NASA postponed the launch of *JWST* to May 2020.

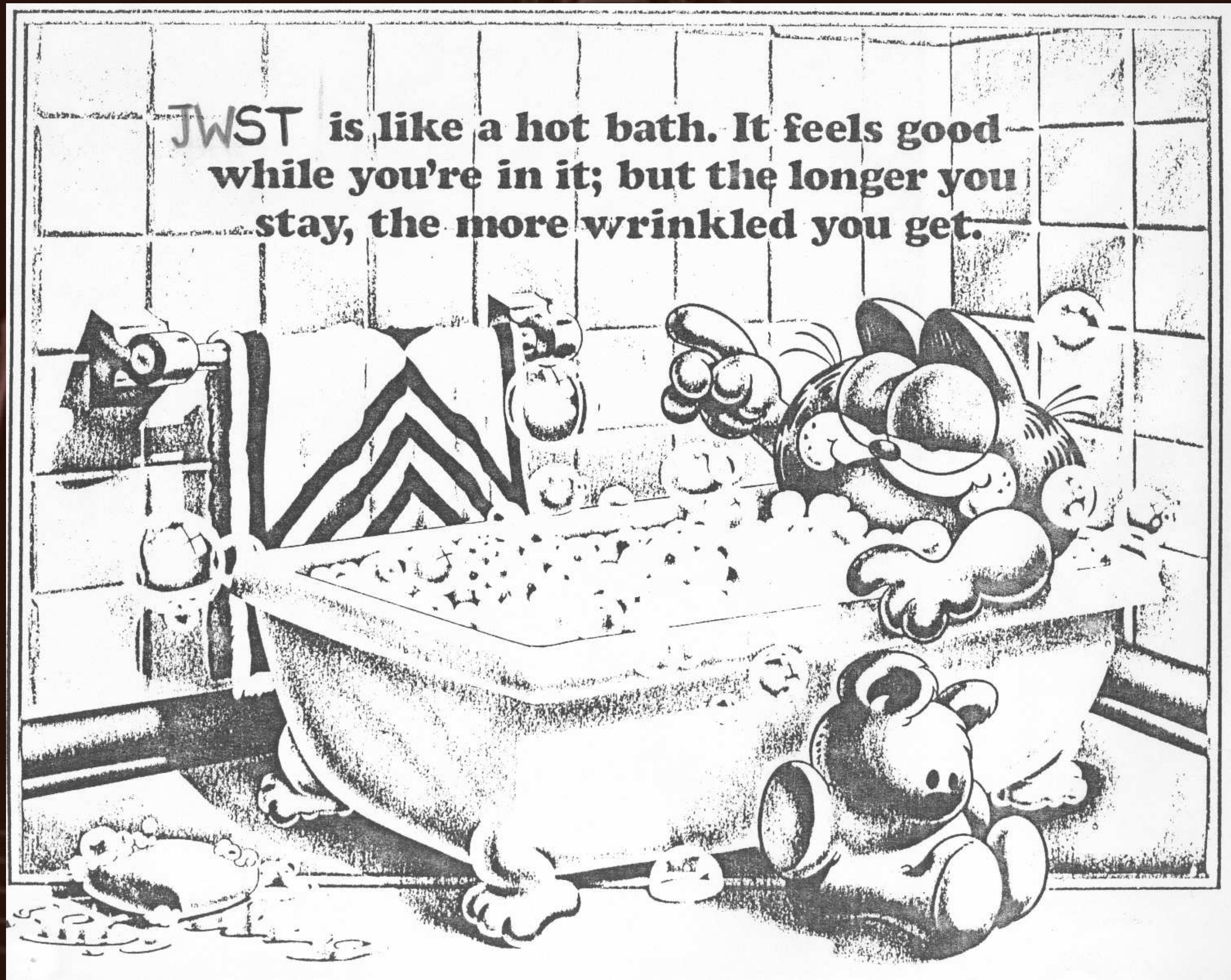
Current Status of *JWST*

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

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

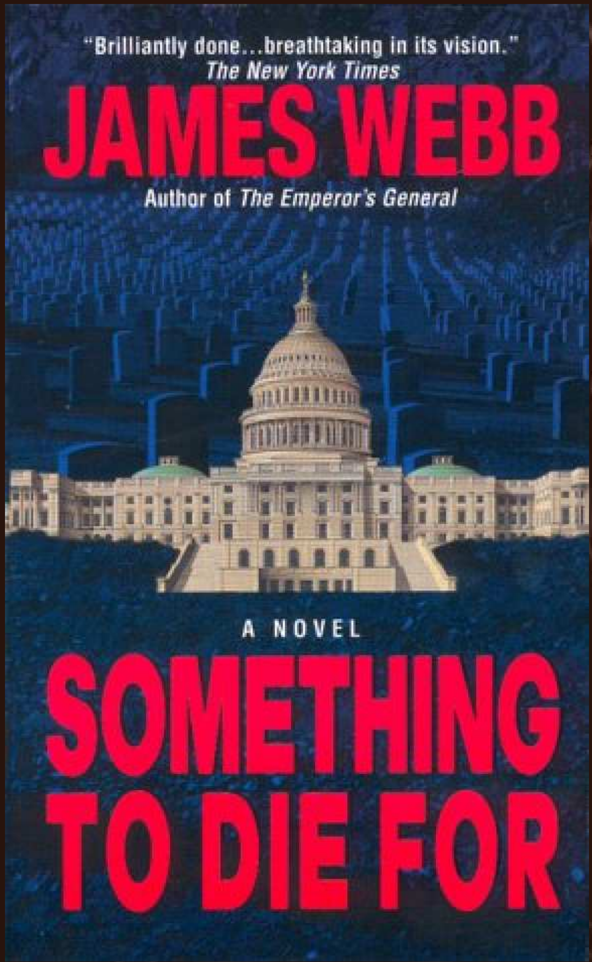
- *Hubble Space Telescope*: concept in 1970's, built in 1980's, operational 1990–2025?
- *James Webb Space Telescope*: concept in 1990's, built in 2000's–2010's, operational 2020–2030(–2034)?

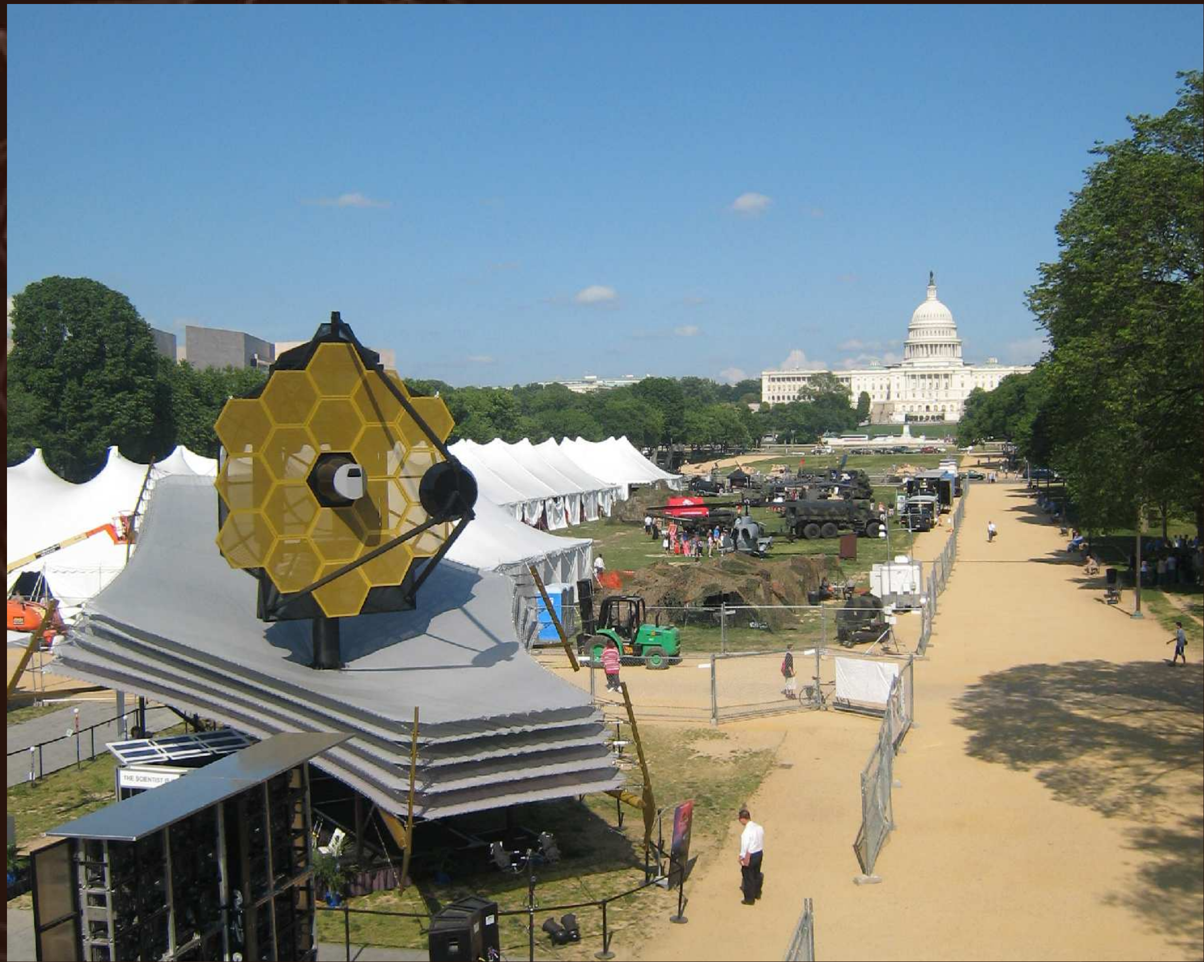
Current Status of *JWST*



- WARNING: both *Hubble* and *JWST* are 30–40$^+$ year projects from conception to fruition: you will be wrinkled before you know it...

Current Status of *JWST*





- ... but starting in 2020 students and (professional and citizen) scientists can start exploring *JWST* observations... It'll be worth it!

Thank you!

- Recommended 2:54 minute video clip on 'Where Do Galaxies Come From?':
  https://www.youtube.com/watch?v=kif4ON6QOPE
- *James Webb Space Telescope* web(b)-sites:
  https://jwst.nasa.gov/ and https://jwst.stsci.edu/