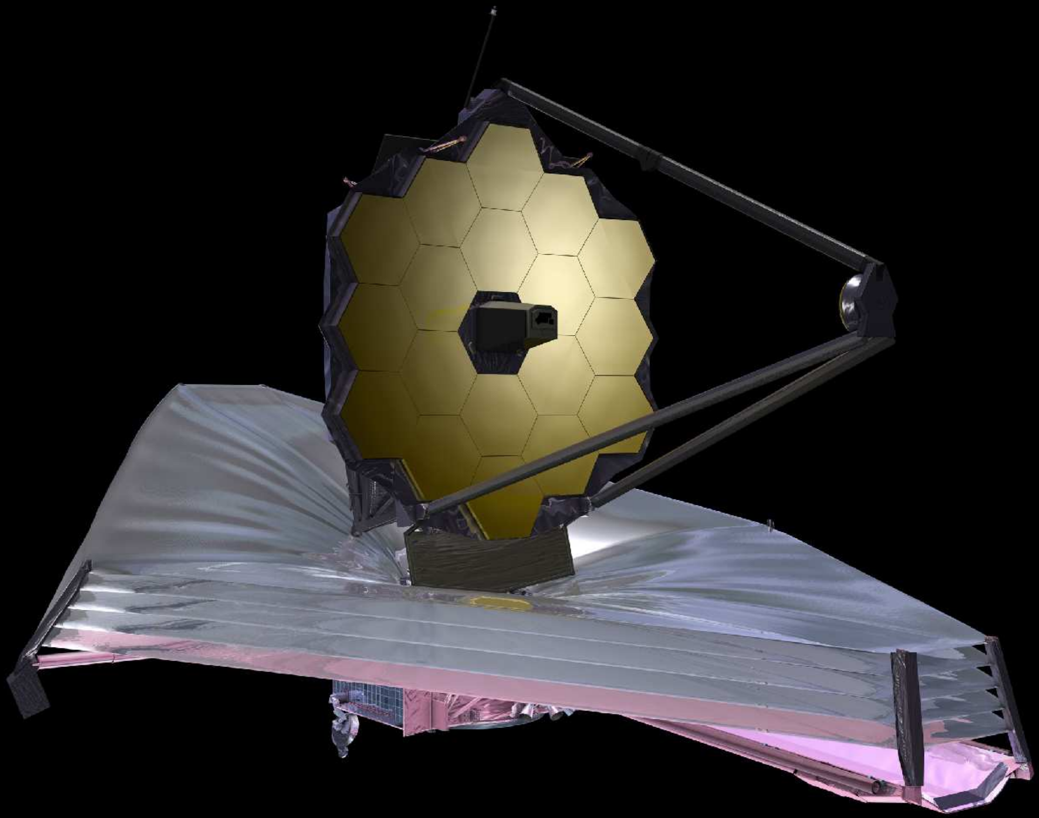
How will JWST measure First Light, Reionization, and Galaxy Assembly: Science and Project Update as of 2012.

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

Collaborators: S. Cohen, R. Jansen (ASU), C. Conselice, S. Driver (UK), & H. Yan (Carnegie)

(Ex) ASU Grads: N. Hathi, H. Kim, M. Mechtley, R. Ryan, M. Rutkowski, A. Straughn, & K. Tamura



Colloquium at Jet Propulsion Laboratories, Pasadena, CA, Thursday April 12, 2012

All presented materials are ITAR-cleared. These are my opinions only, not ASU's.

The scientist's perspective, presented to project managers and engineers ...

... our deep gratitude for your work on MIRI and its Cryocooler.

Outline

- (1) Recent key aspects of the Hubble Space Telescope (HST) project.
- (2) Measuring Galaxy Assembly and Supermassive Black-Hole Growth.
- (3) What is the James Webb Space Telescope (JWST)?
- (4) How can JWST measure the Epochs of First Light & Reionization?
- (5) Summary and Conclusions.
- (6) How can JWST measure Earth-like exoplanets?
- (7) Update of JWST programmatics as of 2011/2012.

Sponsored by NASA/HST & JWST

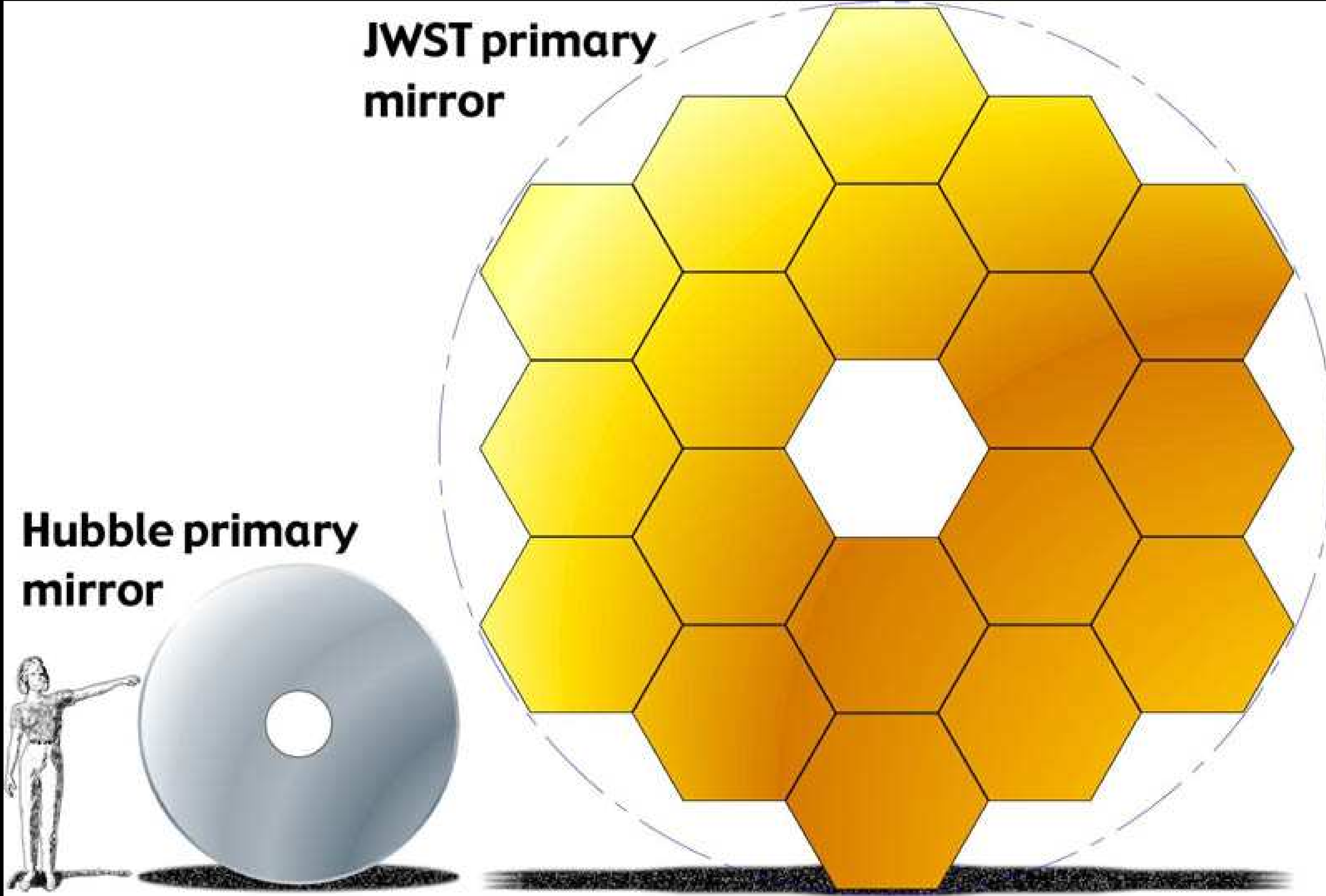
Arizona State University

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

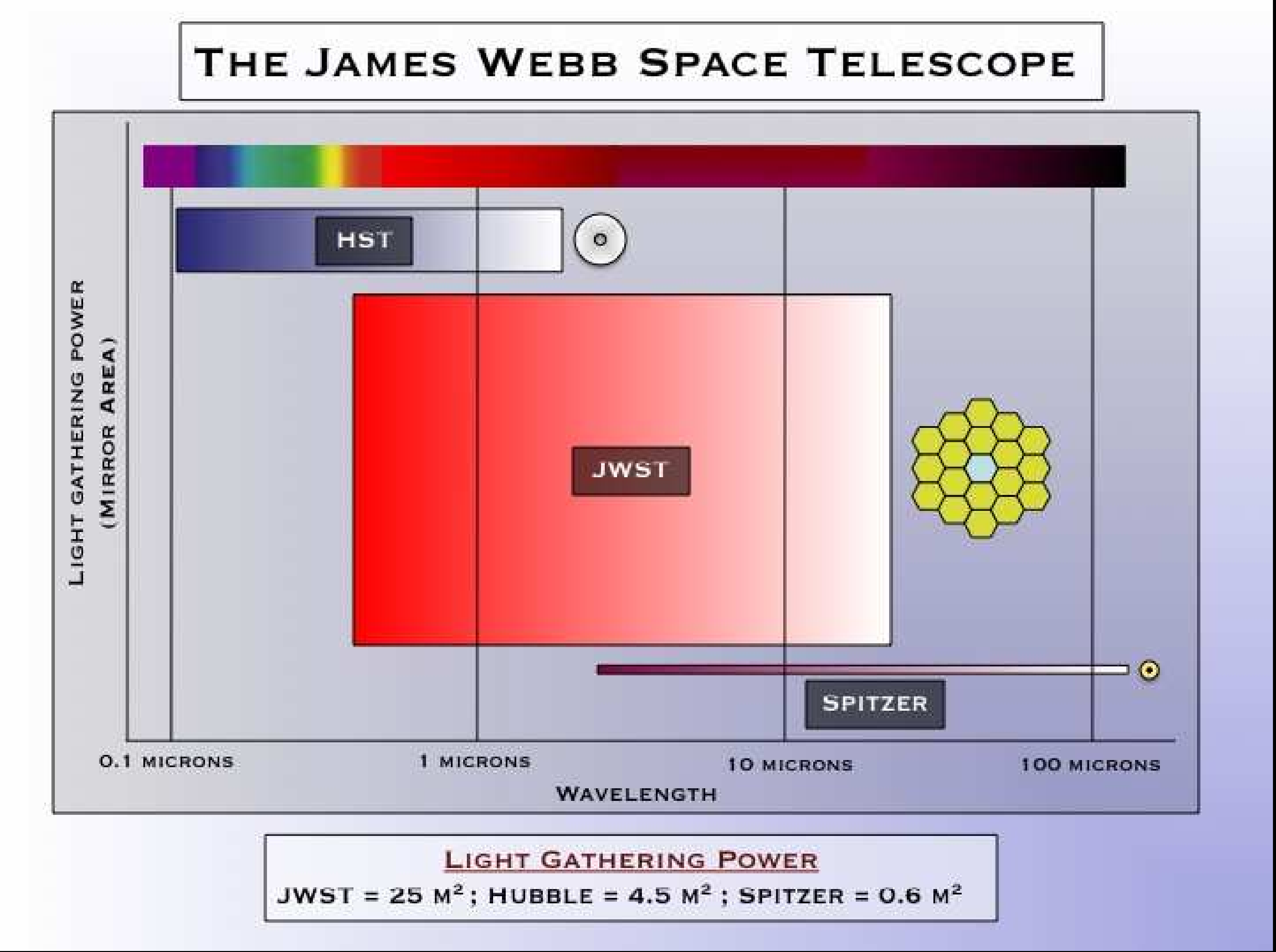
James E. Webb (1906–1992) — Second NASA Administrator

Hubble: Concept in 1970's; Made in 1980's; Operational 1990–$\gtrsim$2014.

JWST: The infrared sequel to Hubble from 2018–2023 (–2029?).



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.

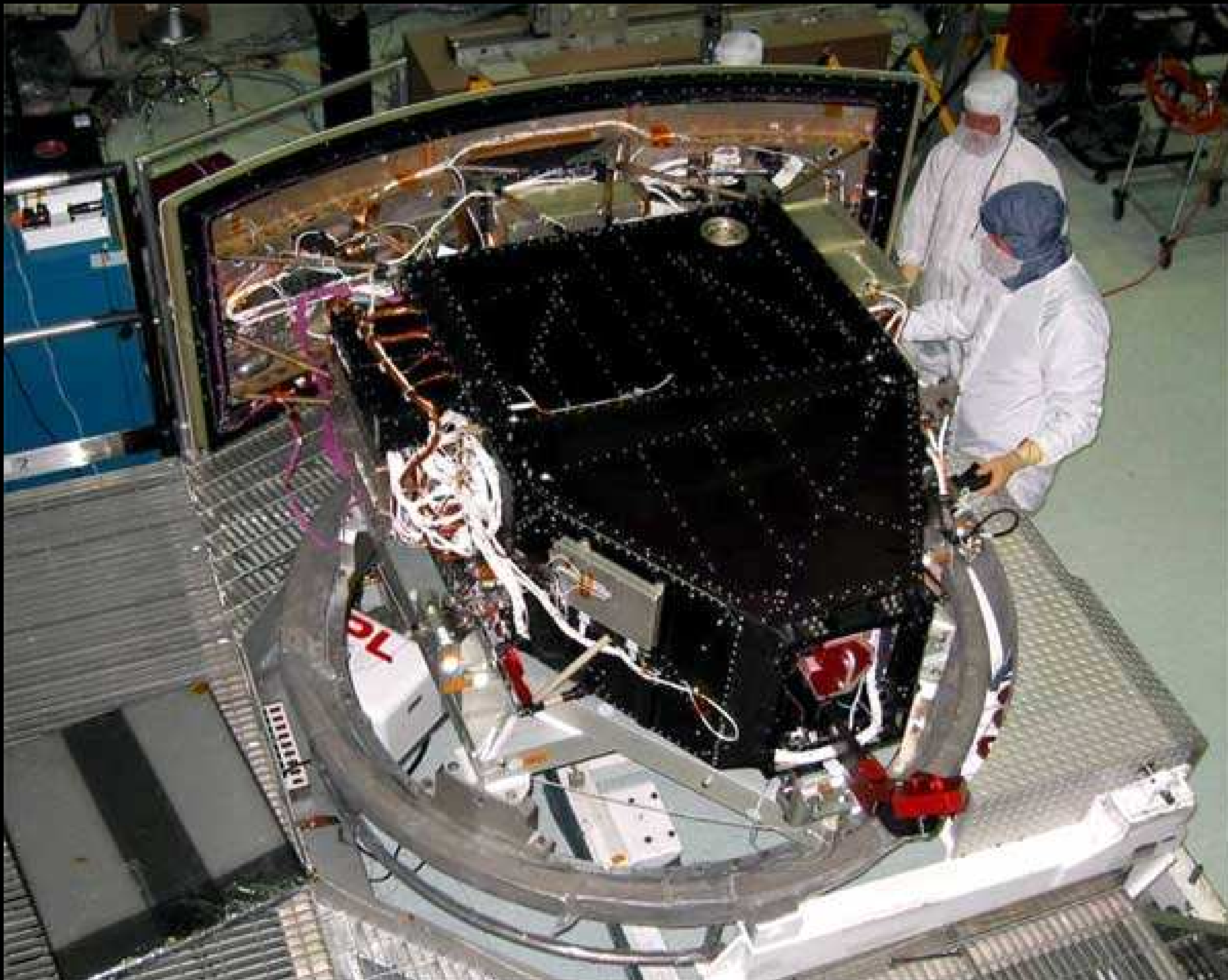


JWST is the perfect near–mid-IR sequel to HST and Spitzer:

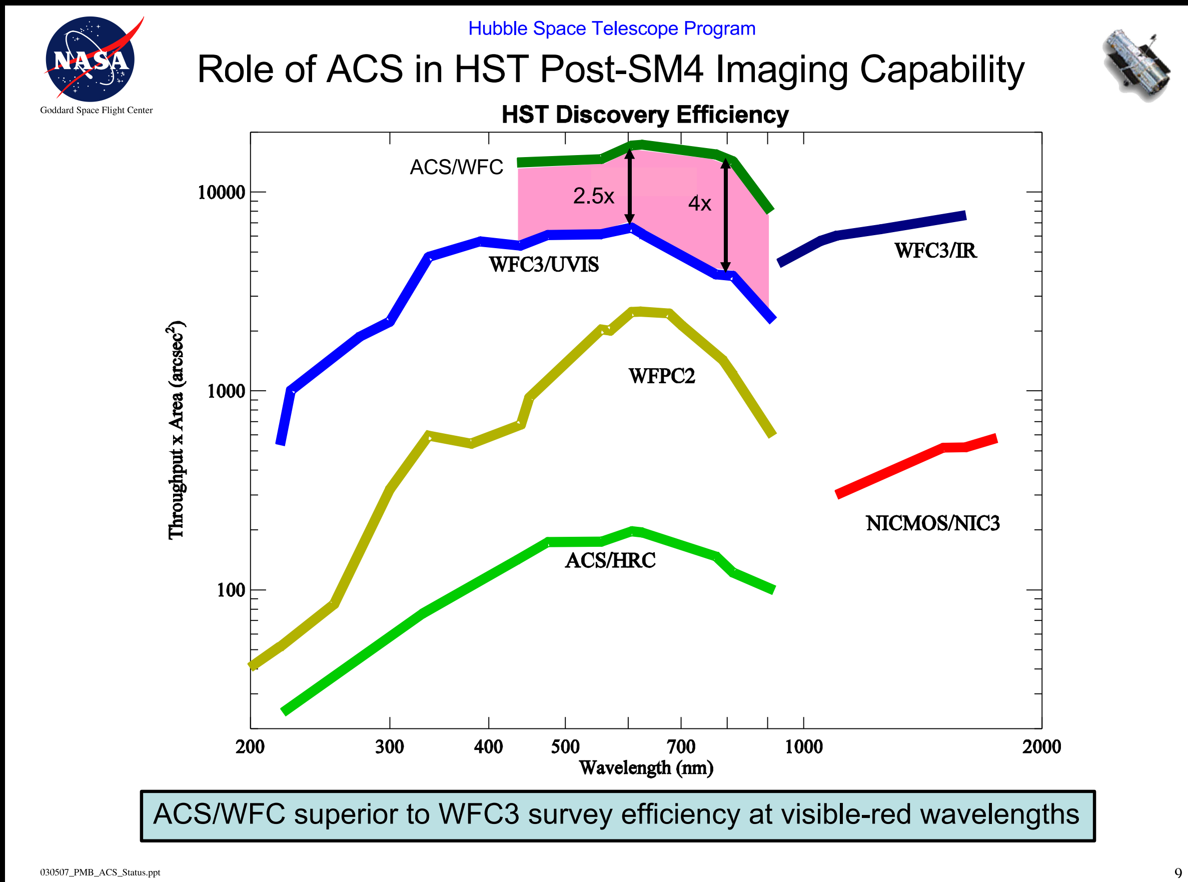
- Vastly larger $A \times \Omega$ than HST in UV-optical and Spitzer in mid-IR.

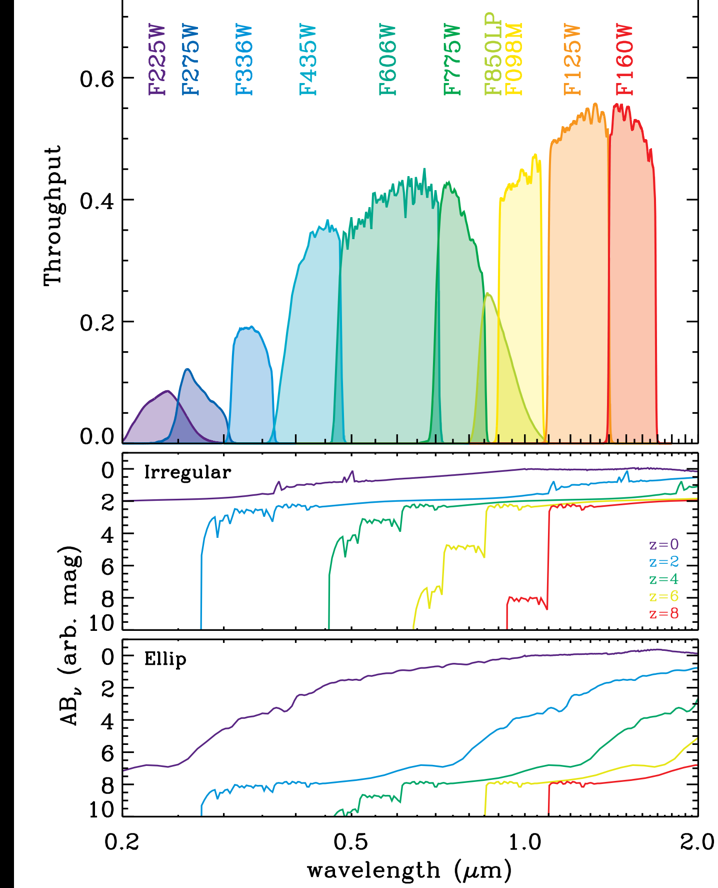
(1) Recent key aspects of the Hubble Space Telescope (HST) project:

WFC3: Hubble's new Panchromatic High-Throughput Camera



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





WFC3/UVIS channel unprecedented UV–blue throughput & areal coverage:

- QE$\gtrsim$70%, 4k$\times$4k array of 0.″04 pixel, FOV $\simeq$ 2.′67 $\times$ 2.′67.

WFC3/IR channel unprecedented near–IR throughput & areal coverage:

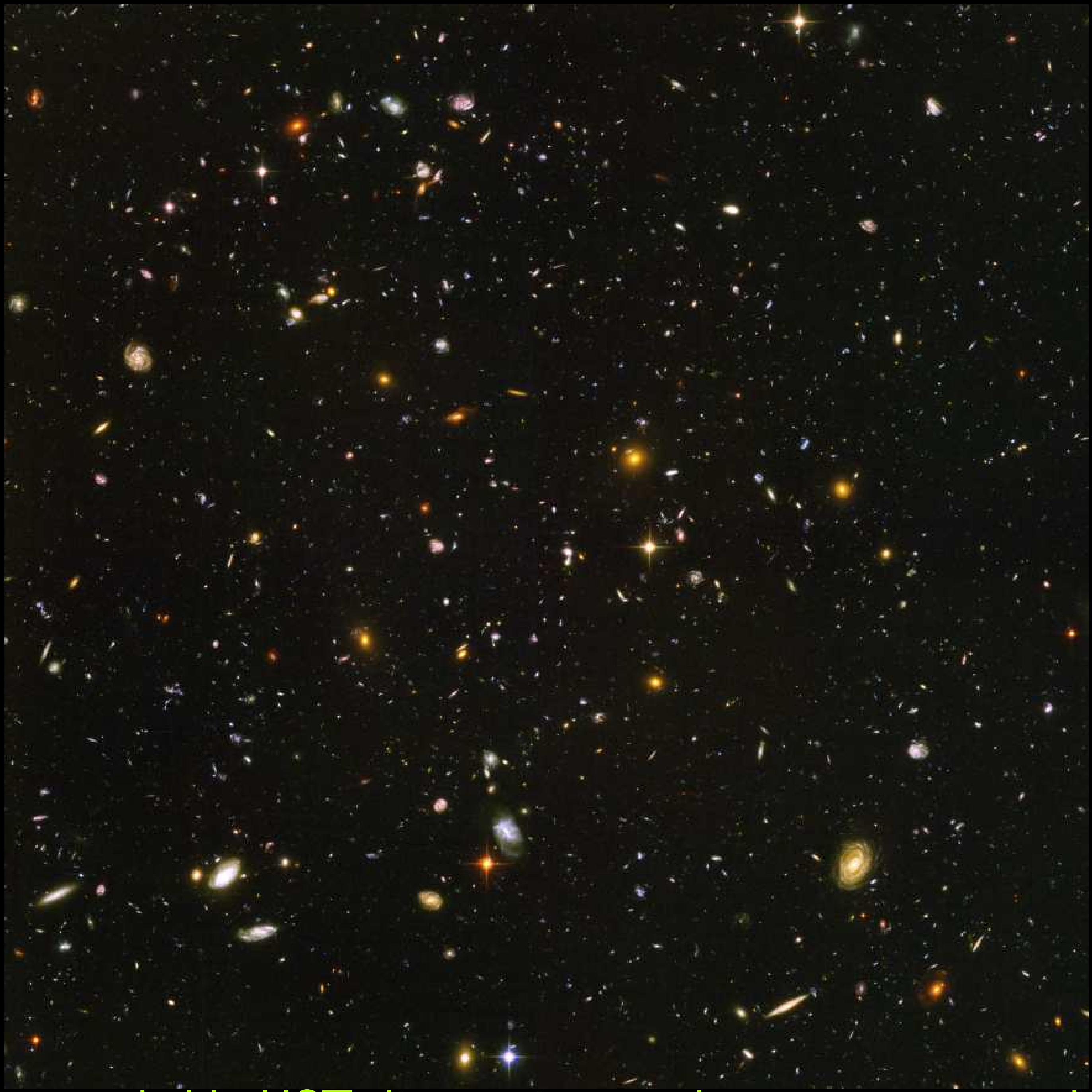
- QE$\gtrsim$70%, 1k$\times$1k array of 0.″13 pixel, FOV $\simeq$ 2.′25 $\times$2.′25.

WFC3 filters designed for star-formation and galaxy assembly at z$\simeq$1–8:

Thank you, John Trauger's group, for providing the best filters in the world!!

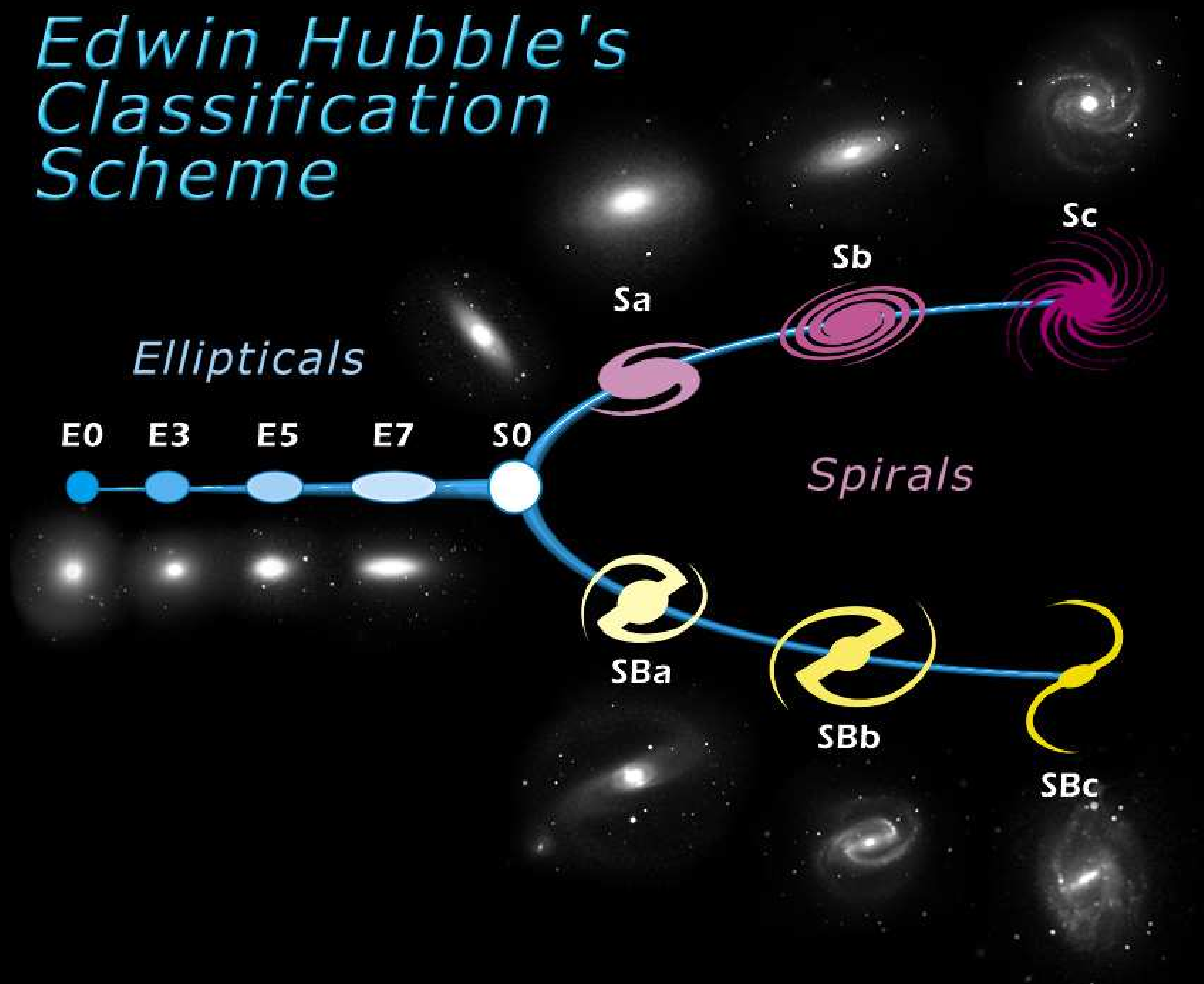
- HST WFC3 and its IR channel a critical pathfinder for JWST science.

(2) Measuring Galaxy Assembly and Supermassive Black-Hole Growth.



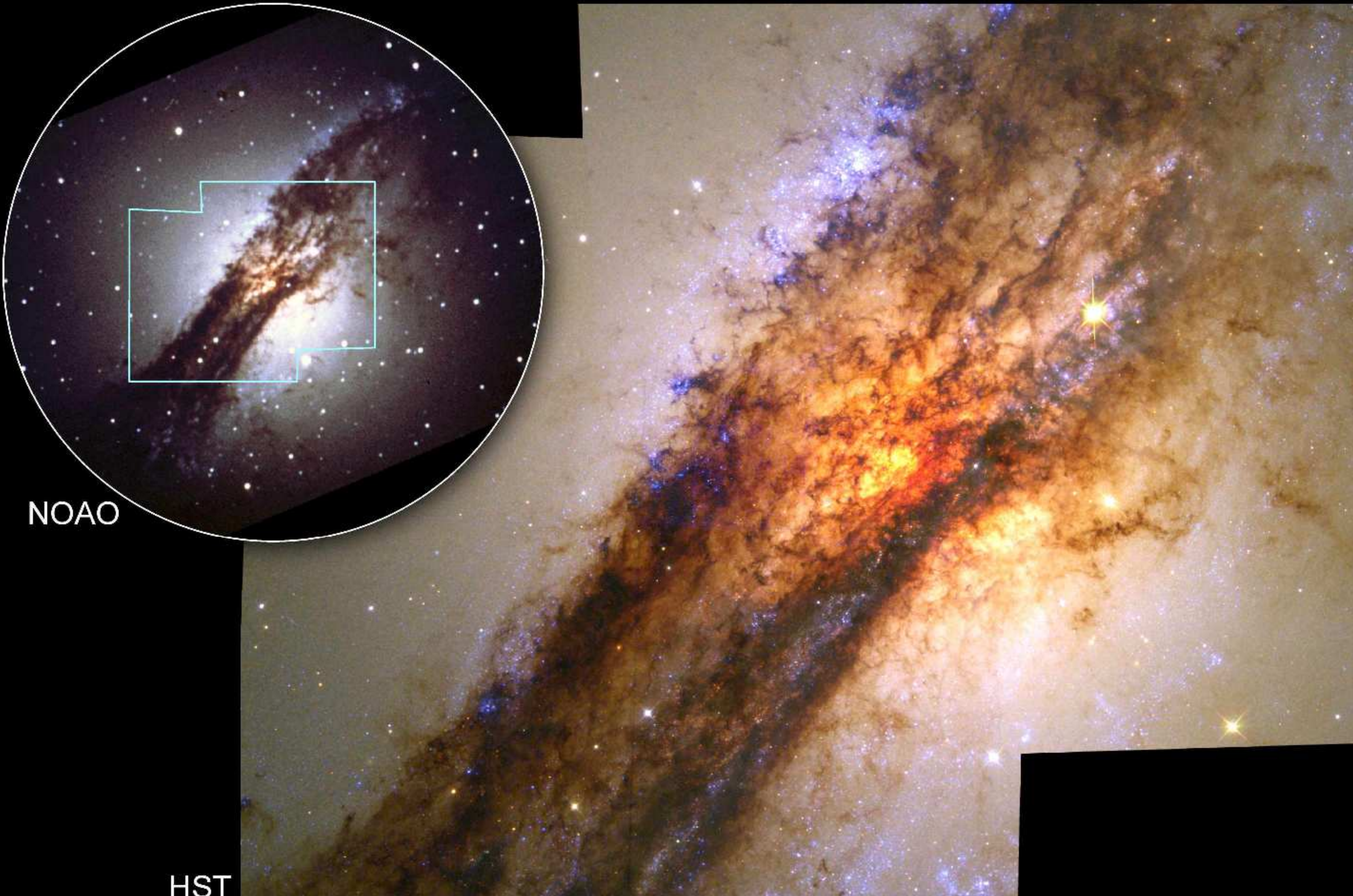
One of the remarkable HST discoveries was how numerous and small faint galaxies are: The building blocks of giant galaxies seen today.

(2) HST turned the classical Hubble sequence upside down!



Who (when)	Cosmic Epoch	Ellipticals	Spirals	Irr's/mergers
Hubble (1920's)	z=0 (13.73 Gyr)	$\sim$40%	$\gtrsim$50%	$\lesssim$10%
HST (1990's)	z$\simeq$1–2 (3–6 Gyr)	$\lesssim$15%	$\sim$30%	$\gtrsim$55% !

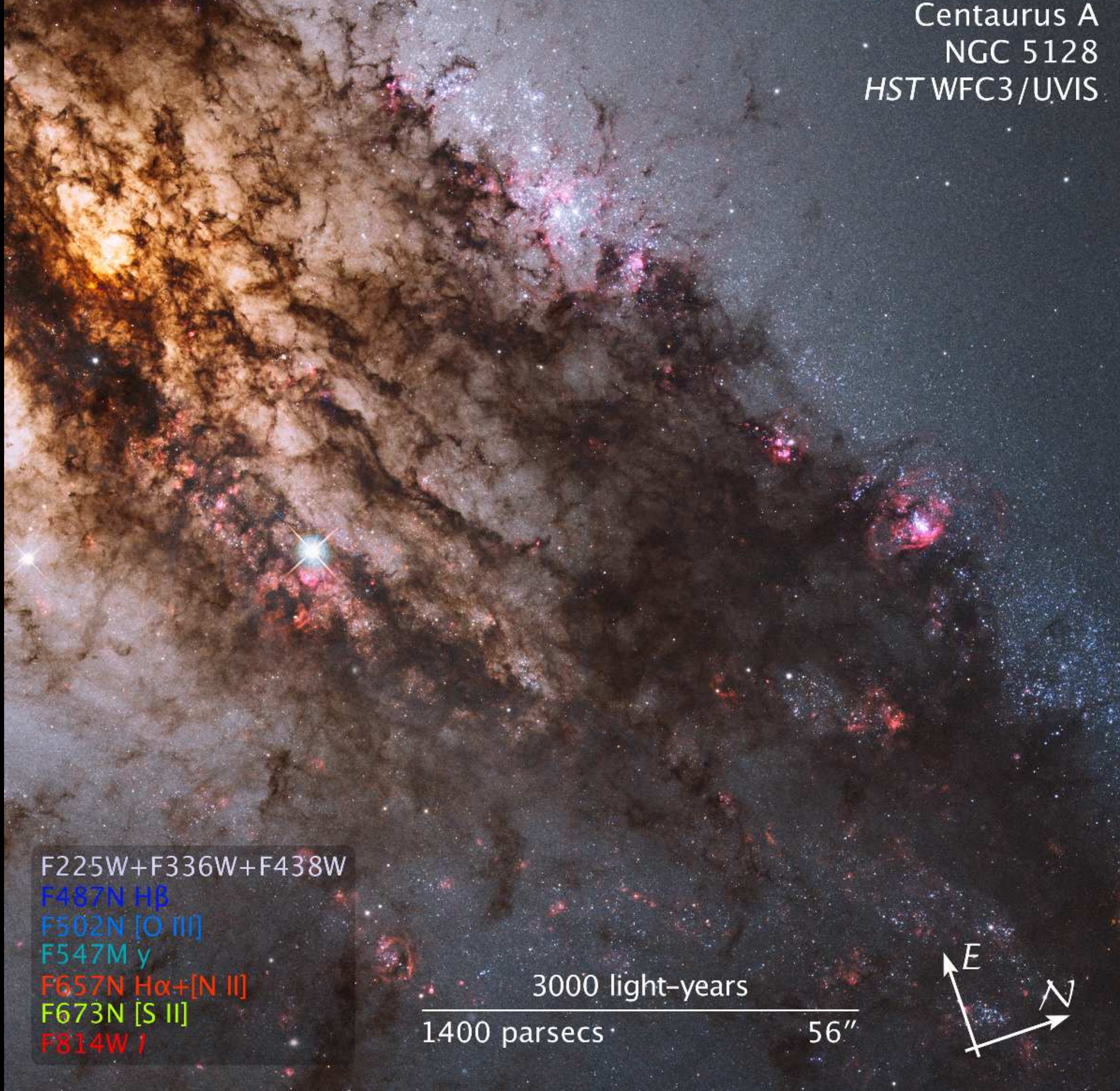
M. Rutkowski (2012, ApJS, 199, 3).



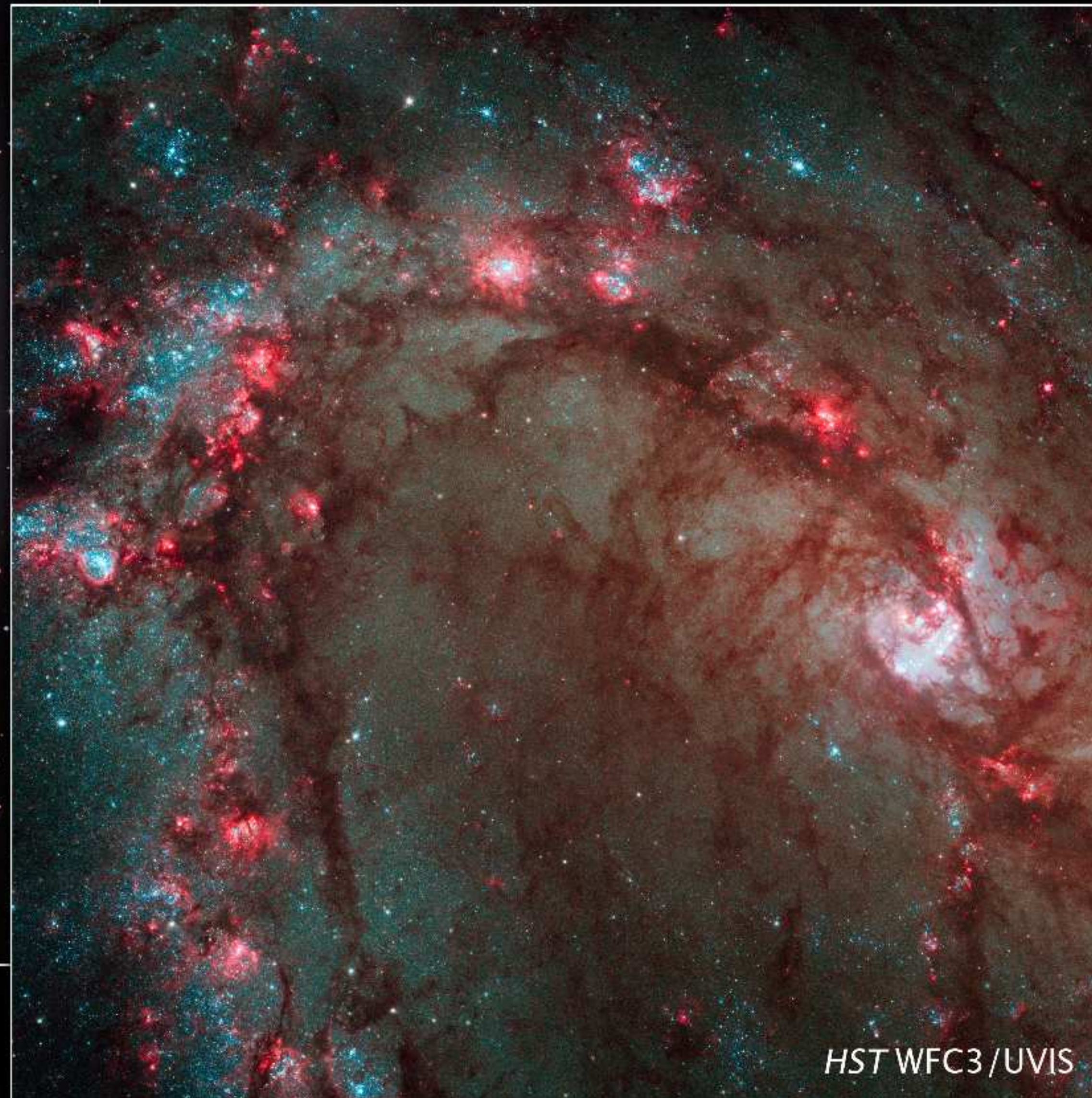
Active Galaxy Centaurus A

Hubble Space Telescope • Wide Field Planetary Camera 2

PRC98-14a • ST ScI OPO • May 14, 1998 • E. Schreier (ST ScI) and NASA


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

H. Kim (2012 ApJS & Dissertation)

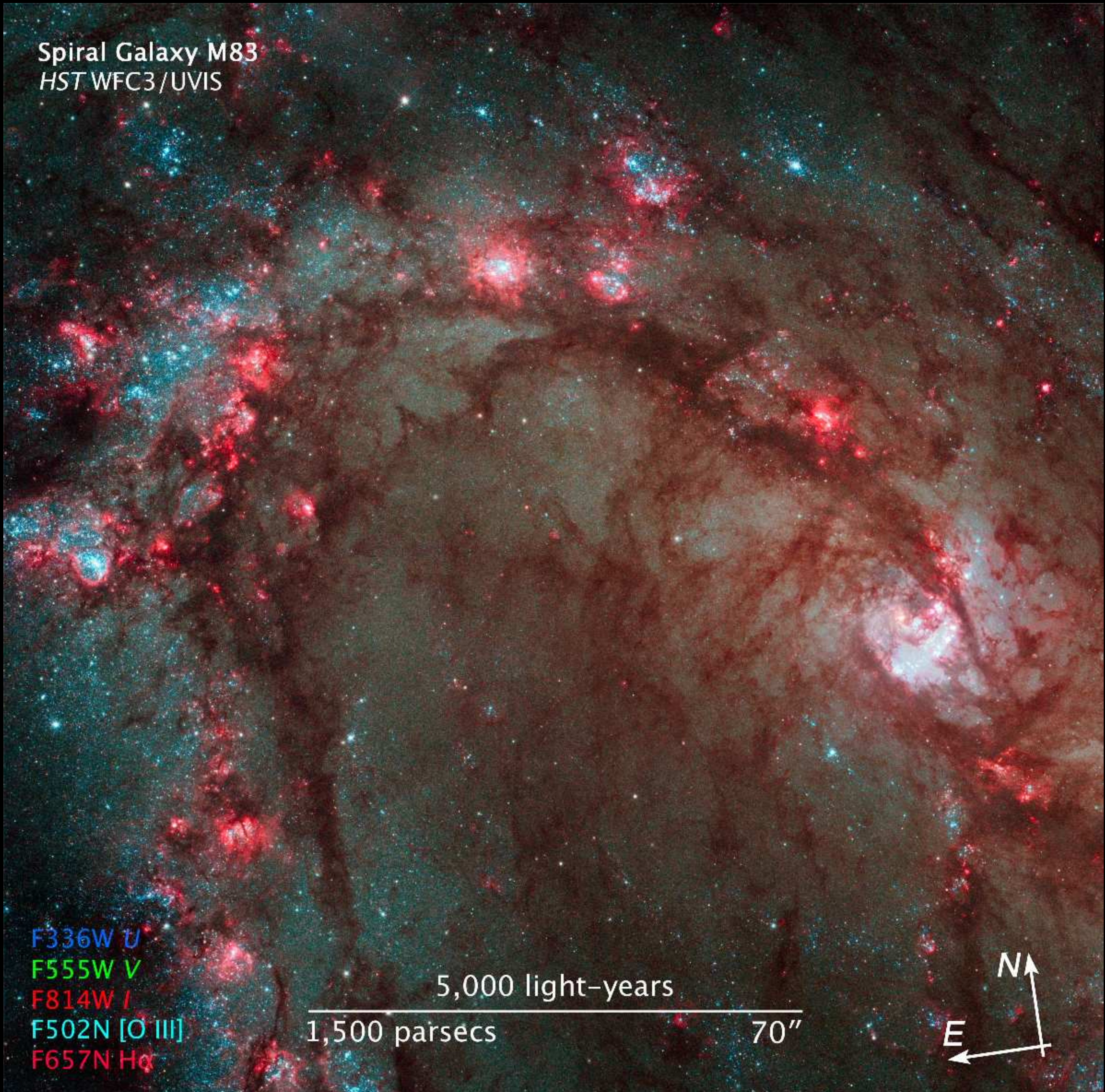


Spiral Galaxy M83

Hubble Space Telescope ▪ WFC3/UVIS

NASA, ESA, R. O'Connell (University of Virginia), the WFC3 Science Oversight Committee, and ESO

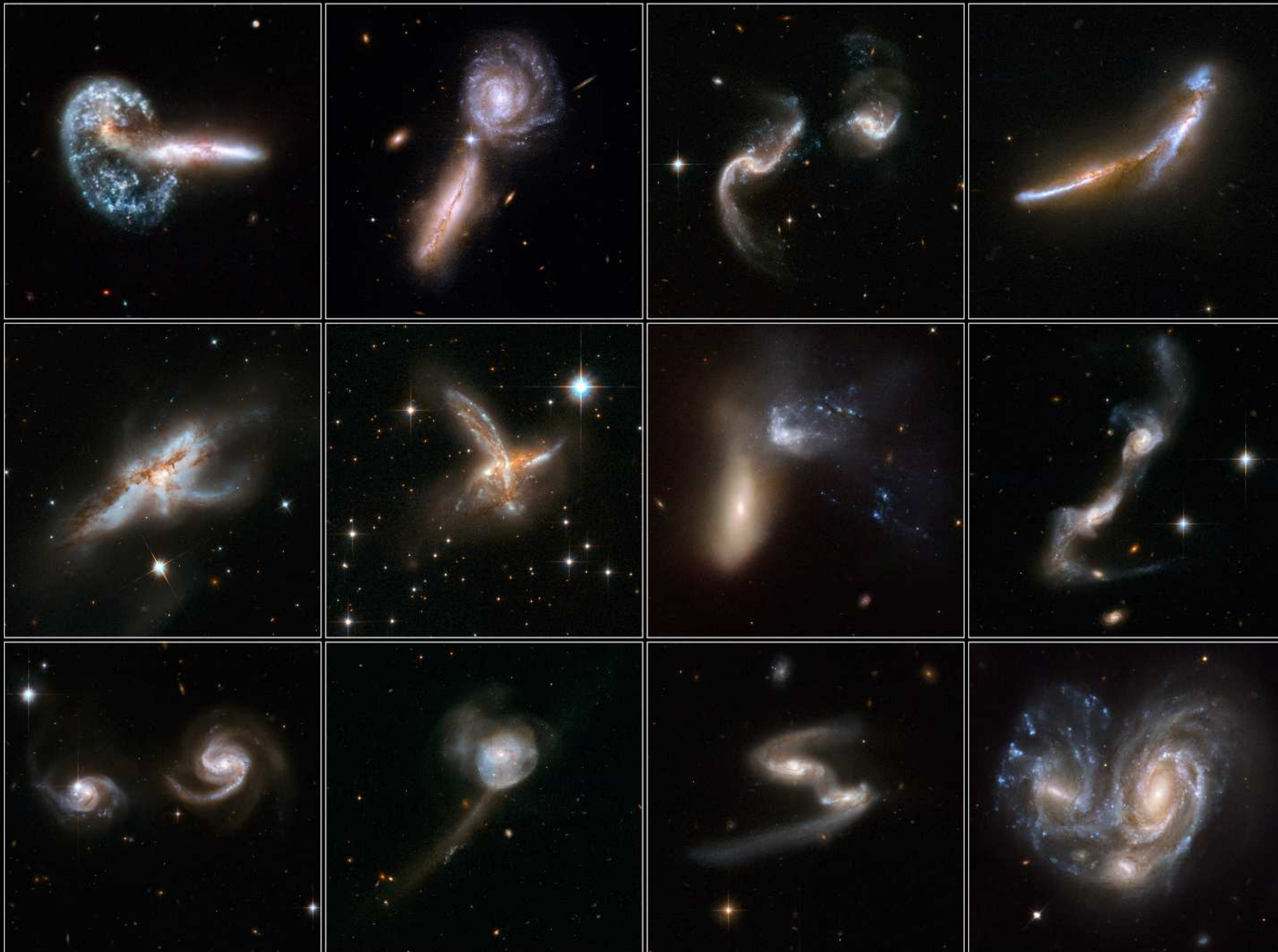
STScI-PRC09-29


Spiral Galaxy M83
HST WFC3/UVIS
F336W U
F555W V
F814W I
F502N [O III]
F657N Hα
5,000 light-years
1,500 parsecs
70″
N
E

HST Antenna galaxy: Prototype of high redshift, star-forming, major merger?

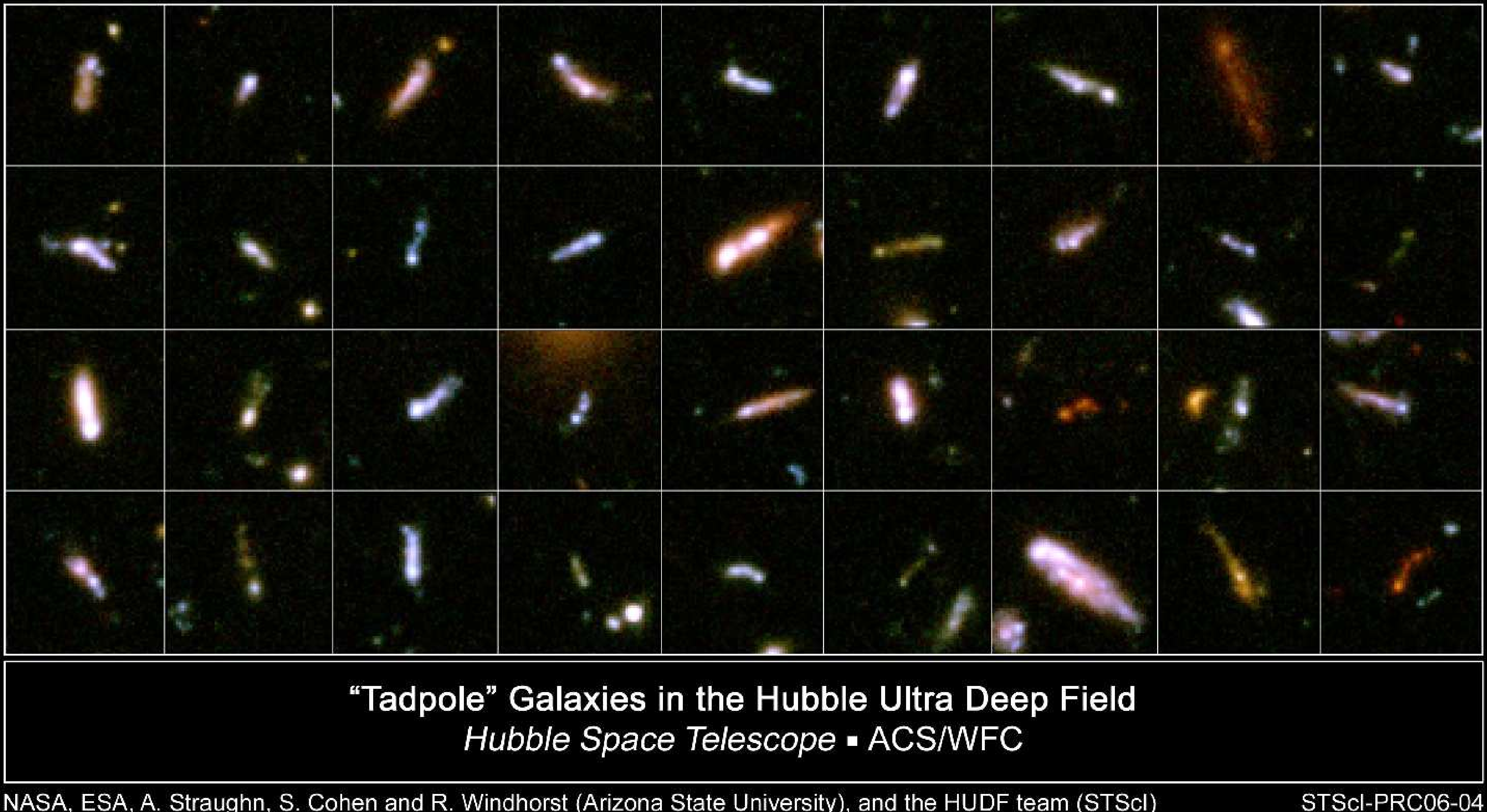
Interacting Galaxies

Hubble Space Telescope • ACS/WFC • WFPC2



NASA, ESA, the Hubble Heritage (AURA/STScI)-ESA/Hubble Collaboration, and
A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

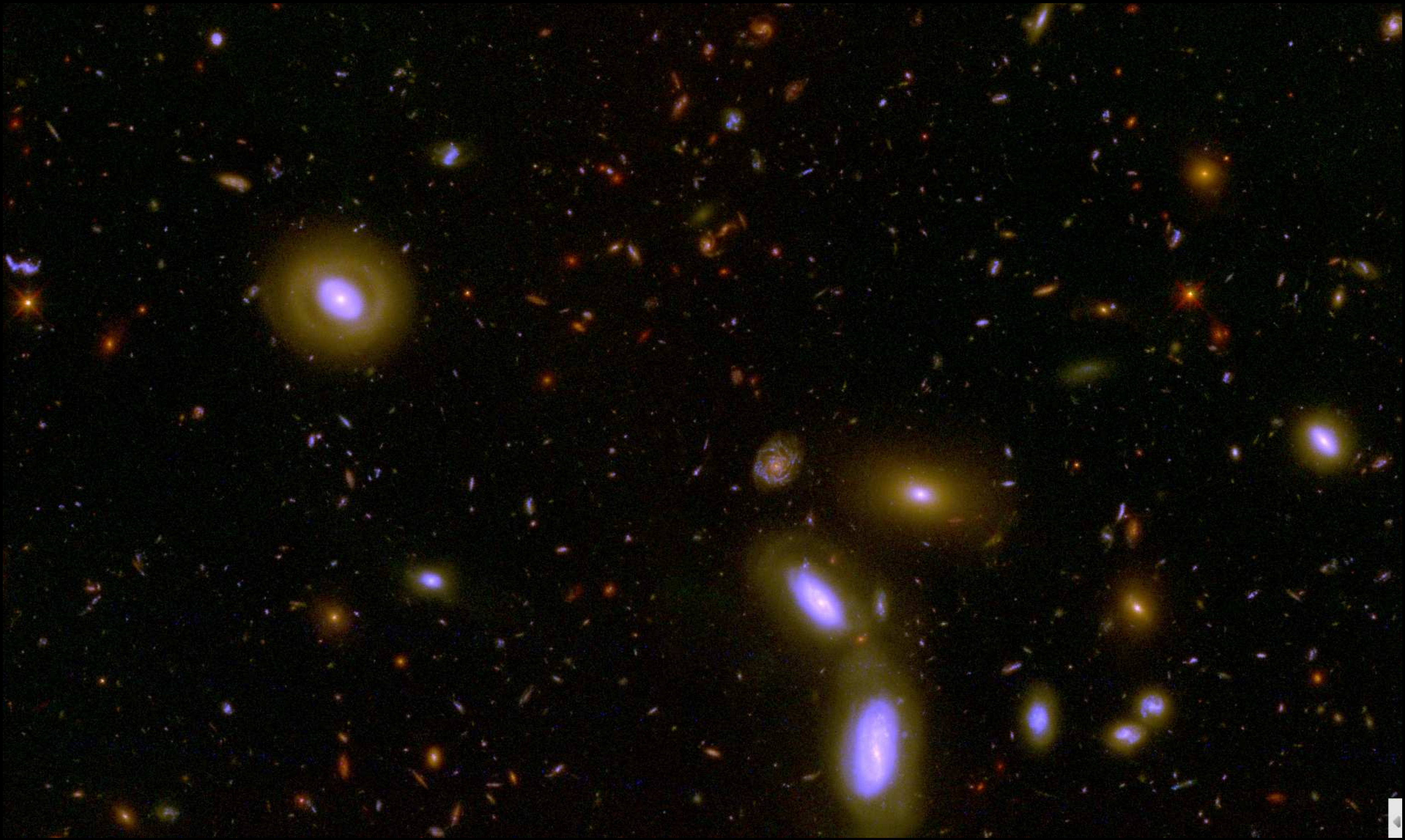
STScI-PRC08-16a



Merging galaxies constitute $\lesssim$1% of Hubble sequence today (age$\gtrsim$12.5 Gyr).

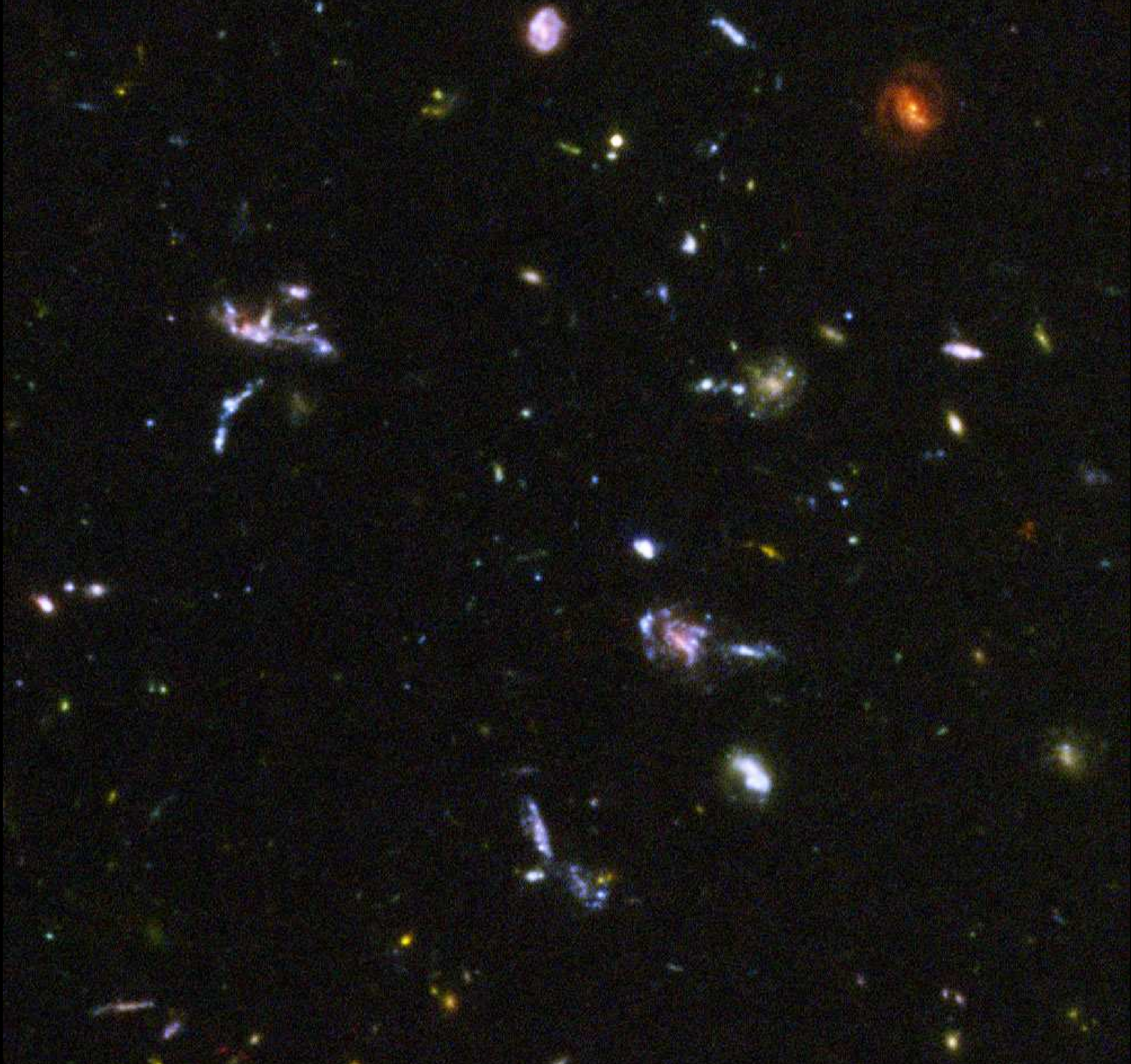
Tadpole galaxies are early stage mergers, very common at z$\gtrsim$2 (age$\lesssim$3 Gyr).

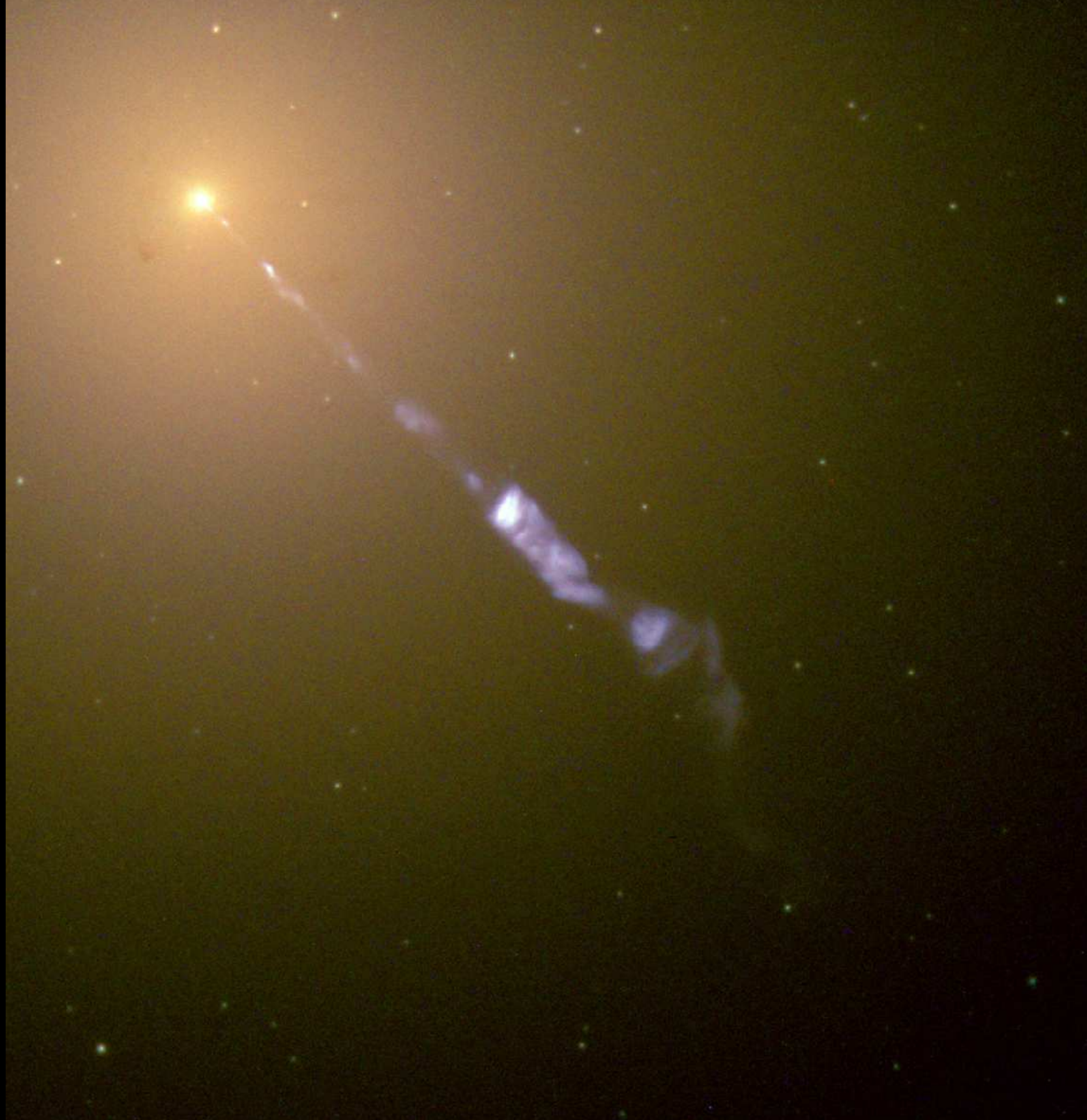
JWST will measure Galaxy Assembly to z$\lesssim$20 (cosmic age $\gtrsim$0.2 Gyr).



HST/WFC3 & ACS reach AB=26.5-27.0 mag ($\sim$100 fireflies from Moon) over 0.1$\times$full Moon area in 10 filters from 0.2–2μm wavelength.

JWST has 3$\times$sharper imaging to AB$\simeq$31.5 mag ($\sim$1 firefly from Moon) at 1(–29)μm wavelengths, tracing young and old stars + dust.

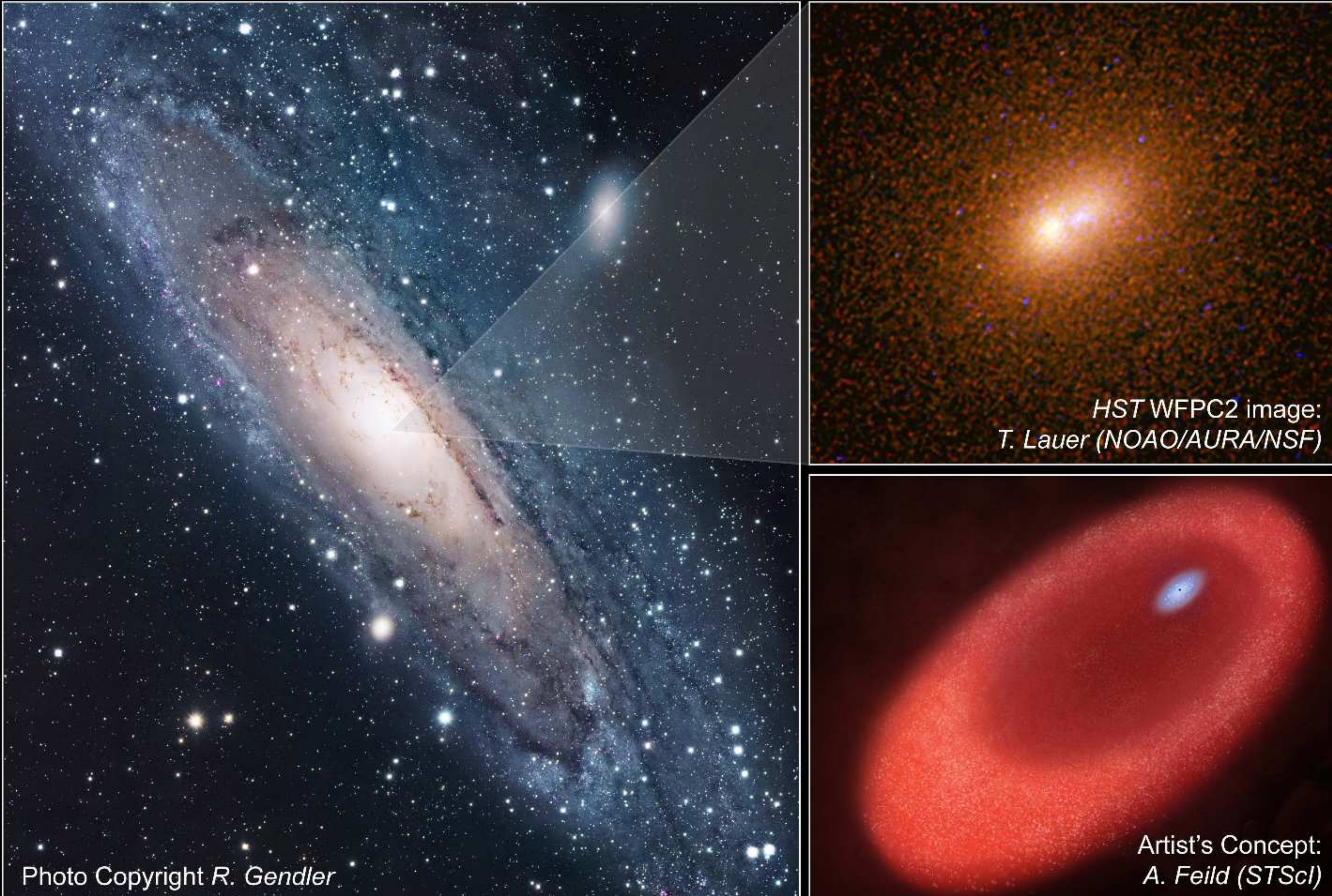




Elliptical galaxy M87 with Active Galactic Nucleus (AGN) and relativistic jet.

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

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



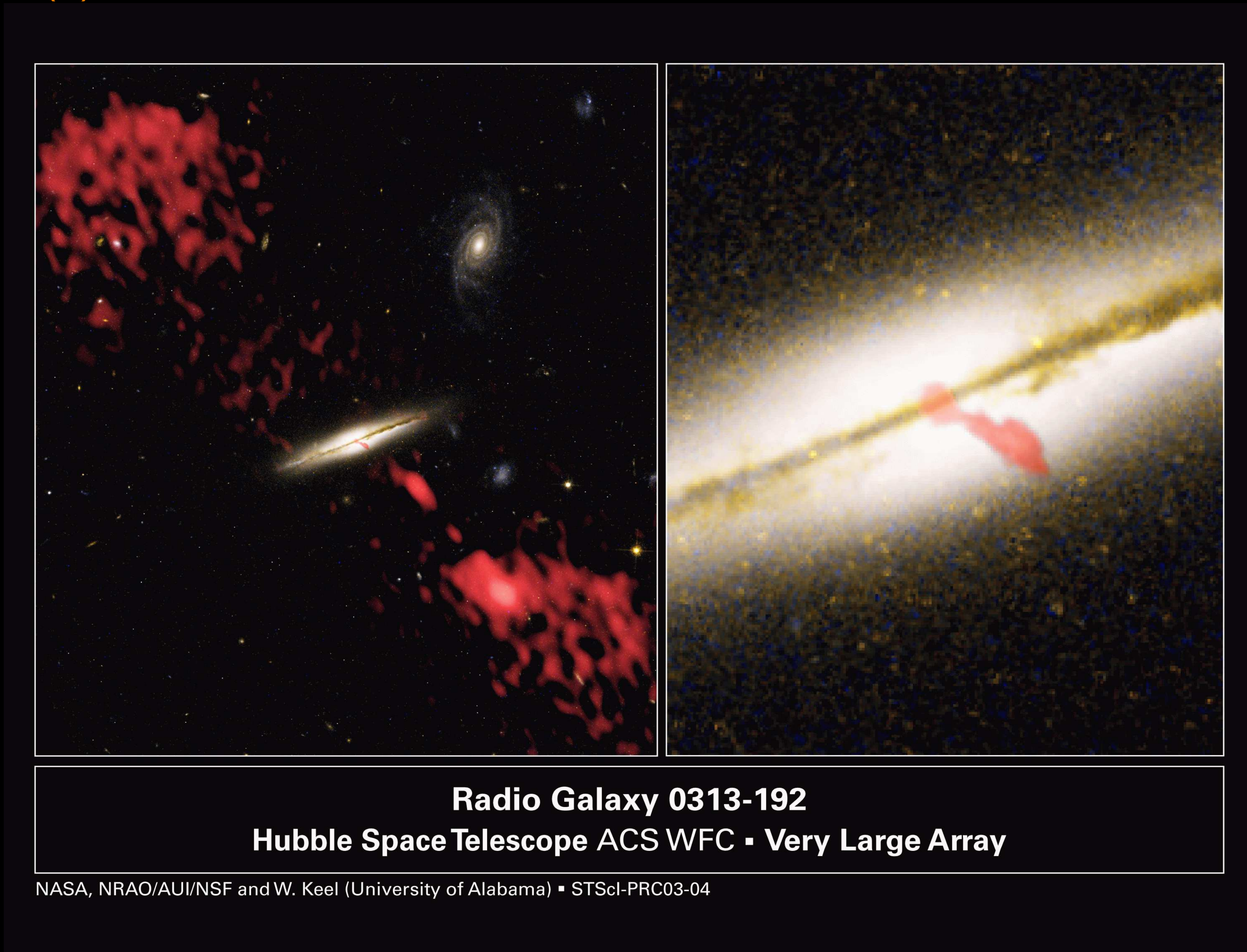
Andromeda Galaxy Nucleus ▪ M31

Hubble Space Telescope ▪ WFPC2

NASA, ESA, R. Gendler, T. Lauer (NOAO/AURA/NSF), and A. Feild (STScI)

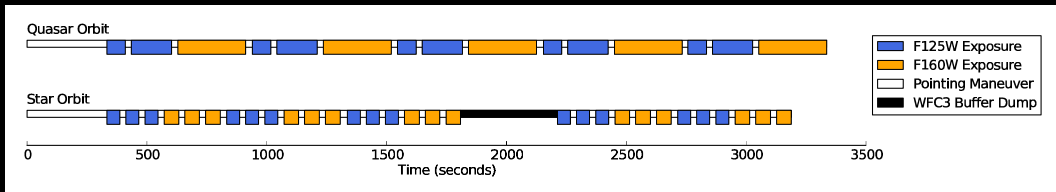
STScI-PRC05-26

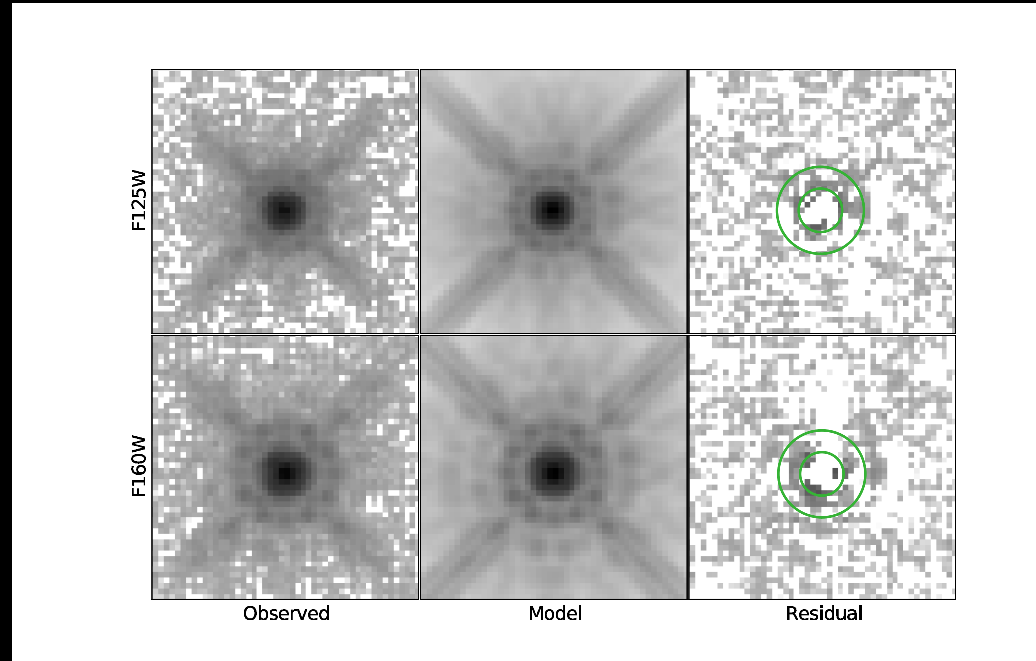
(2) Measuring Galaxy Assembly & Supermassive Blackhole Growth



Does galaxy assembly go hand-in-hand with supermassive blackhole growth?

HST WFC3 observations of Quasar Host Galaxies at $z \simeq 6$ (age$\sim$1 Gyr)





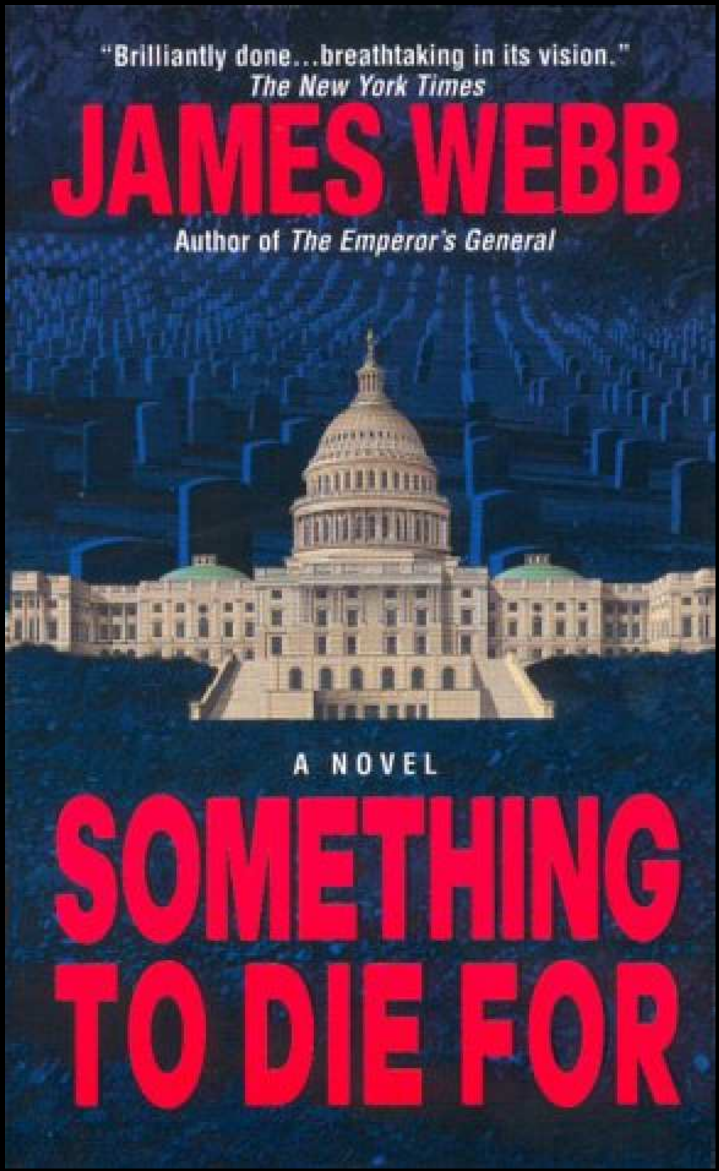
- Careful contemporaneous orbital PSF-star subtraction: Removes most of HST "OTA spacecraft breathing" effects (Mechtley et al. 2012).

- PSF-star (AB=15 mag) subtracts Quasar (18.5 mag) nearly to the noise limit: NO host galaxy detected 100$\times$fainter (AB$\gtrsim$23.5 mag; r$\gtrsim$0$''$.3).

THE most luminous Quasars in the Universe: Are all their host galaxies faint? $\Rightarrow$ Major implications for Galaxy Assembly–SMBH Growth!

- JWST Coronagraphs can do this 10–100$\times$ fainter (and for z$\lesssim$20) — but need JWST diffraction limit at 2.0μm and clean PSF to do this!

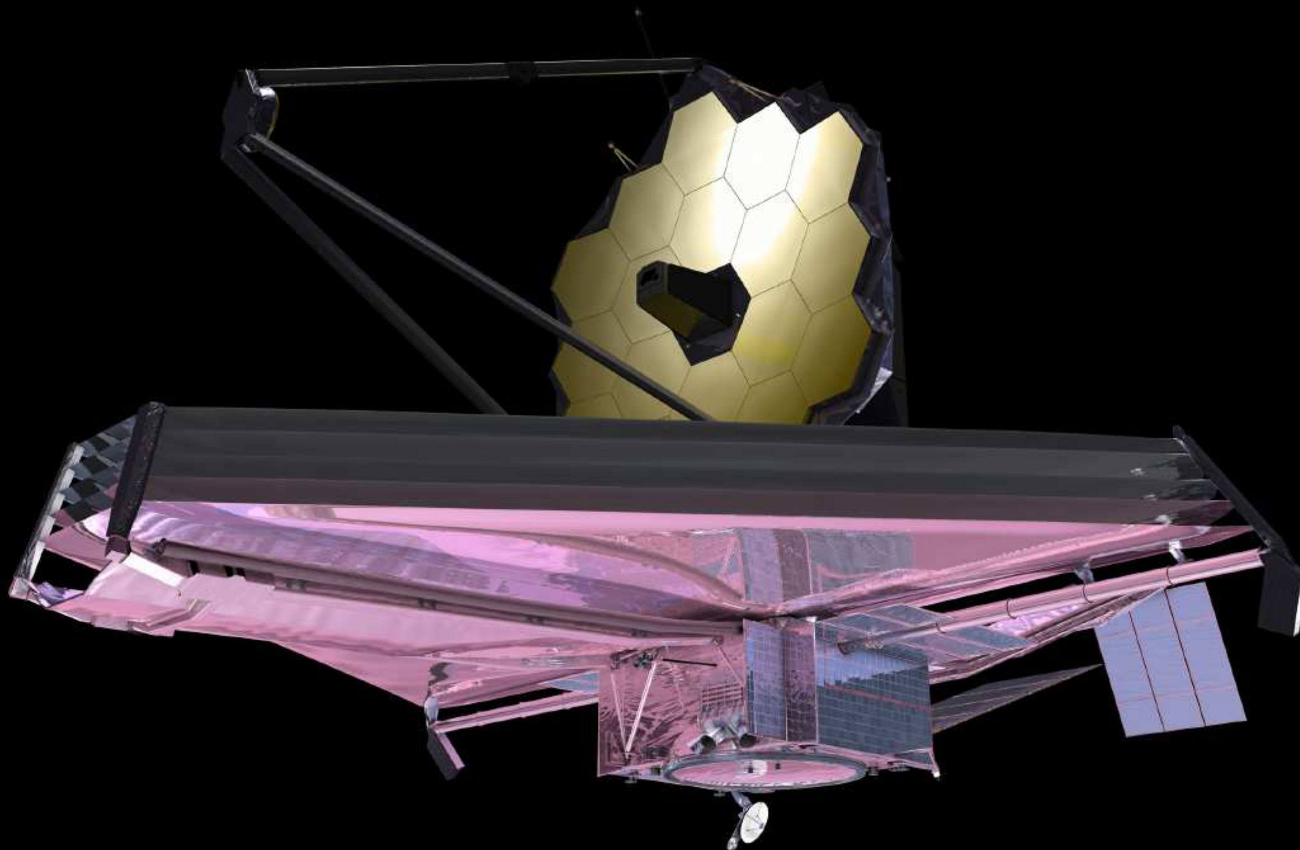
(3) What is the James Webb Space Telescope (JWST)?



Need young generation of students & scientists after 2018 ... It'll be worth it!

(RIGHT) Life-size JWST prototype on the Capitol Mall, May 2007 ...

(3) What is the James Webb Space Telescope (JWST)?

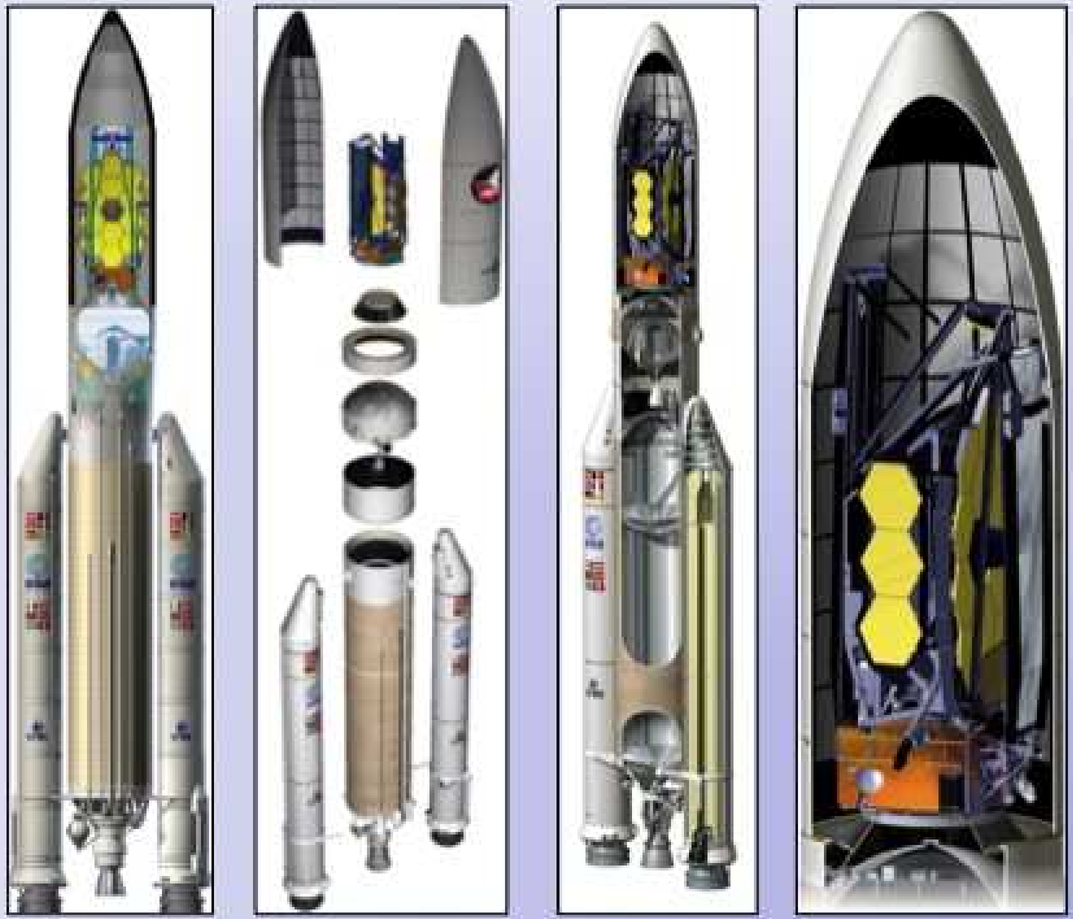


- A fully deployable 6.5 meter (25 m^2) segmented IR telescope for imaging and spectroscopy at 0.6–28 μm wavelength, to be launched in Fall 2018.
- Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging (31.5 mag = firefly from Moon!) and spectroscopy.

The James Webb Space Telescope

JWST Launch

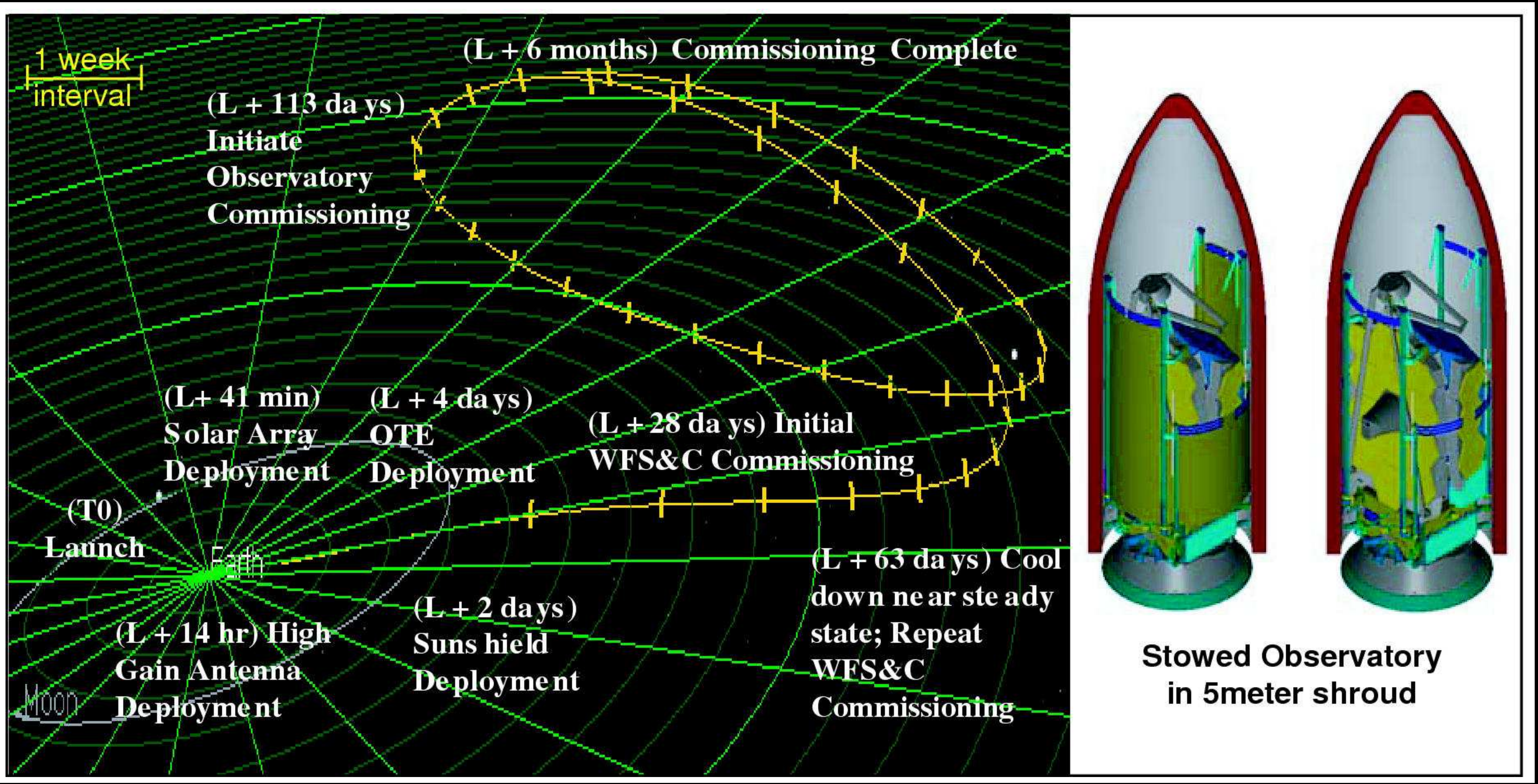
- Launch vehicle is an Ariane 5 rocket, supplied by ESA
- Site will be the Arianespace's ELA-3 launch complex near Kourou, French Guiana



Arianespace – ESA - NASA

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

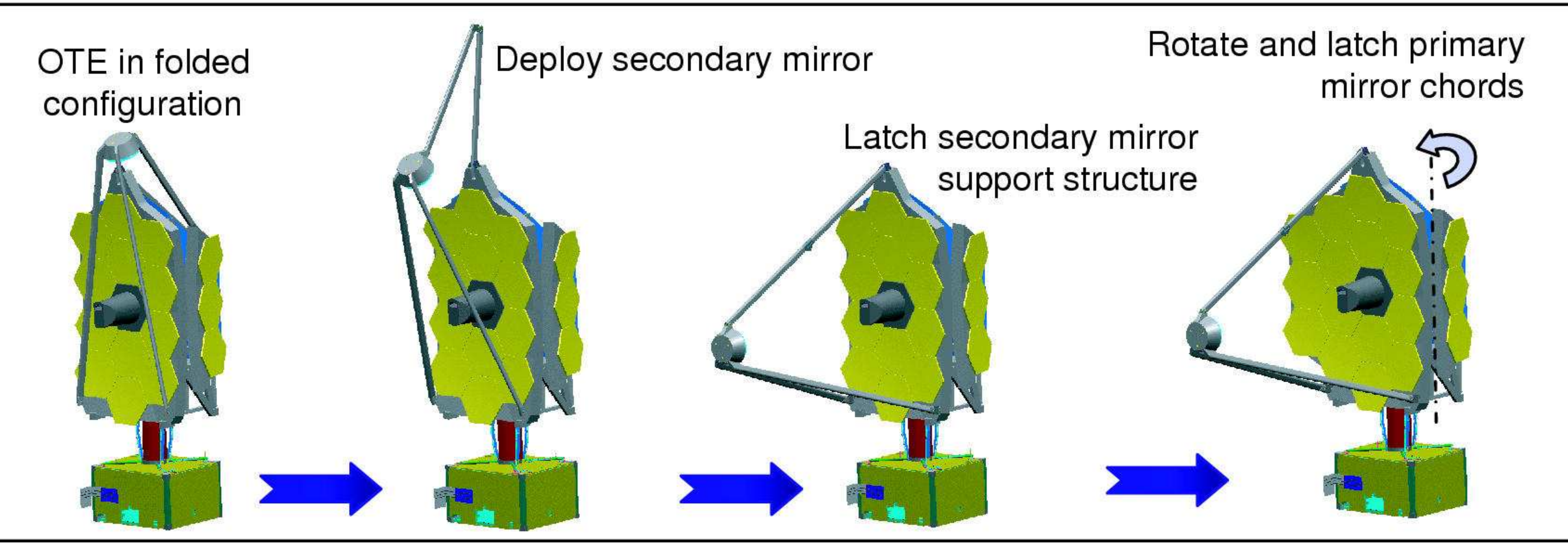
(3a) How will JWST travel to its L2 orbit?



• After launch in 2018 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.

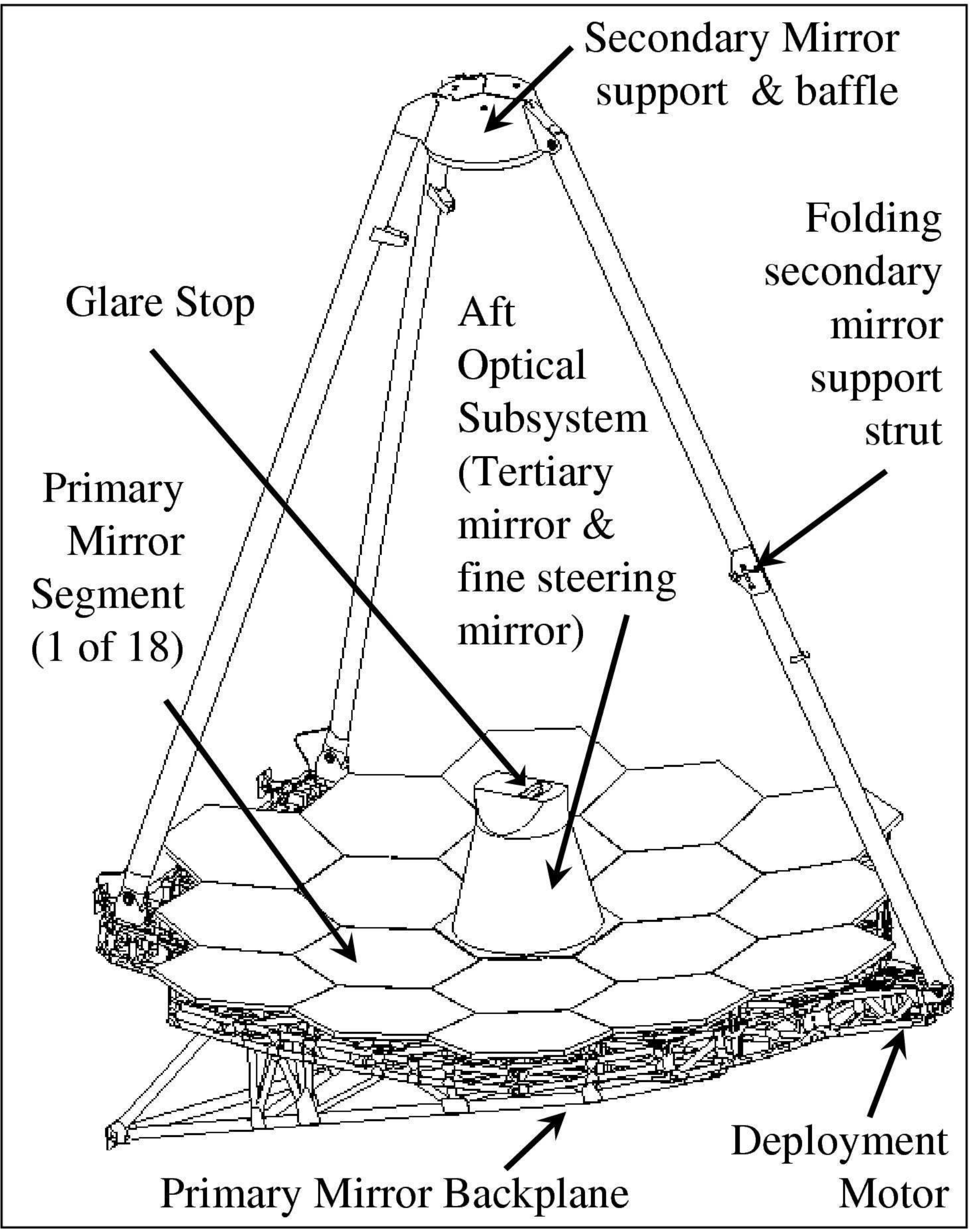
• (3b) How will JWST be automatically deployed?



- 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 will be tested several times on the ground — but only in 1-G: Component and system tests in Houston.

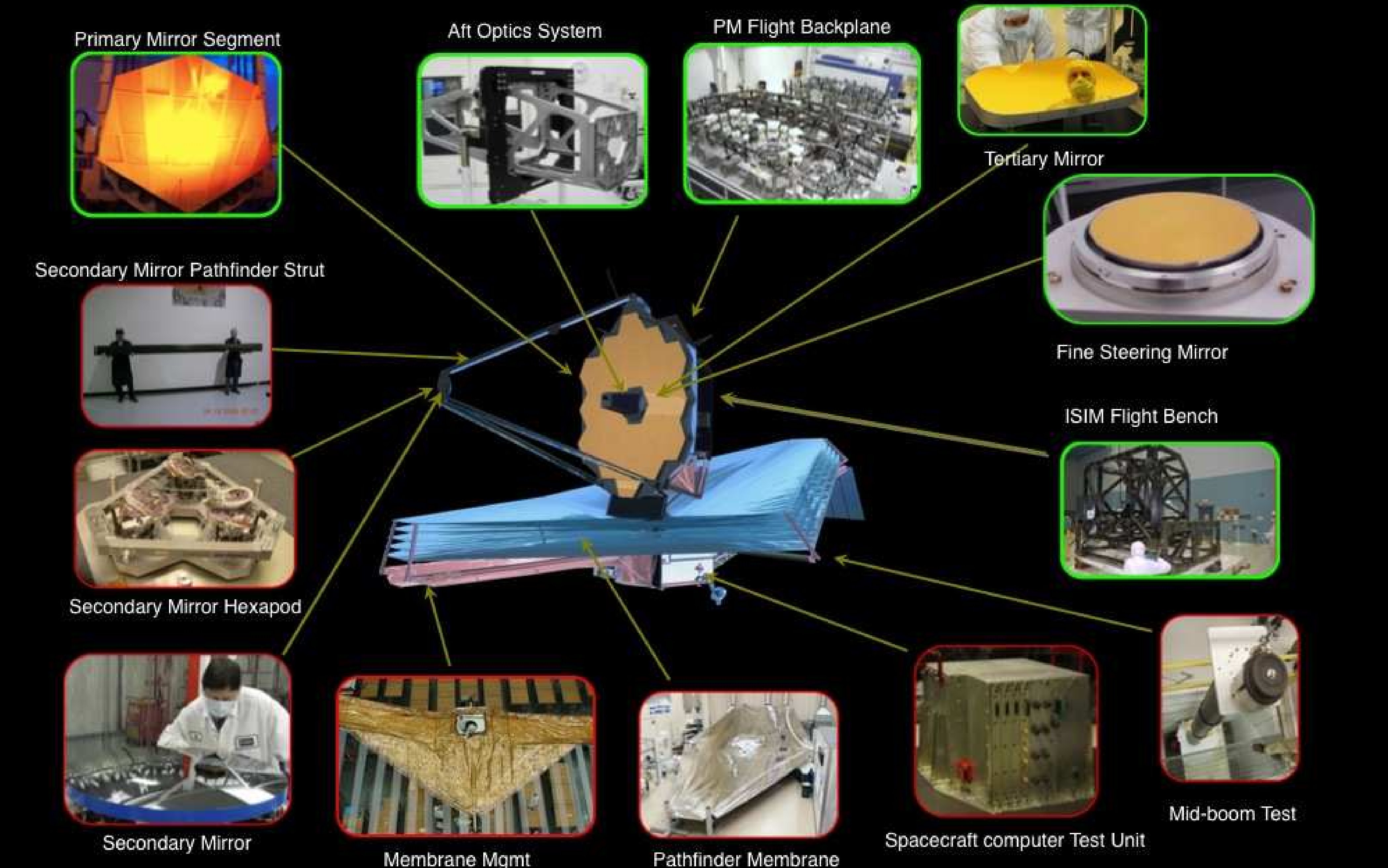
- Component fabrication, testing, & integration is on schedule: 18 out of 18 flight mirrors completely done, and meet the 40K specifications!



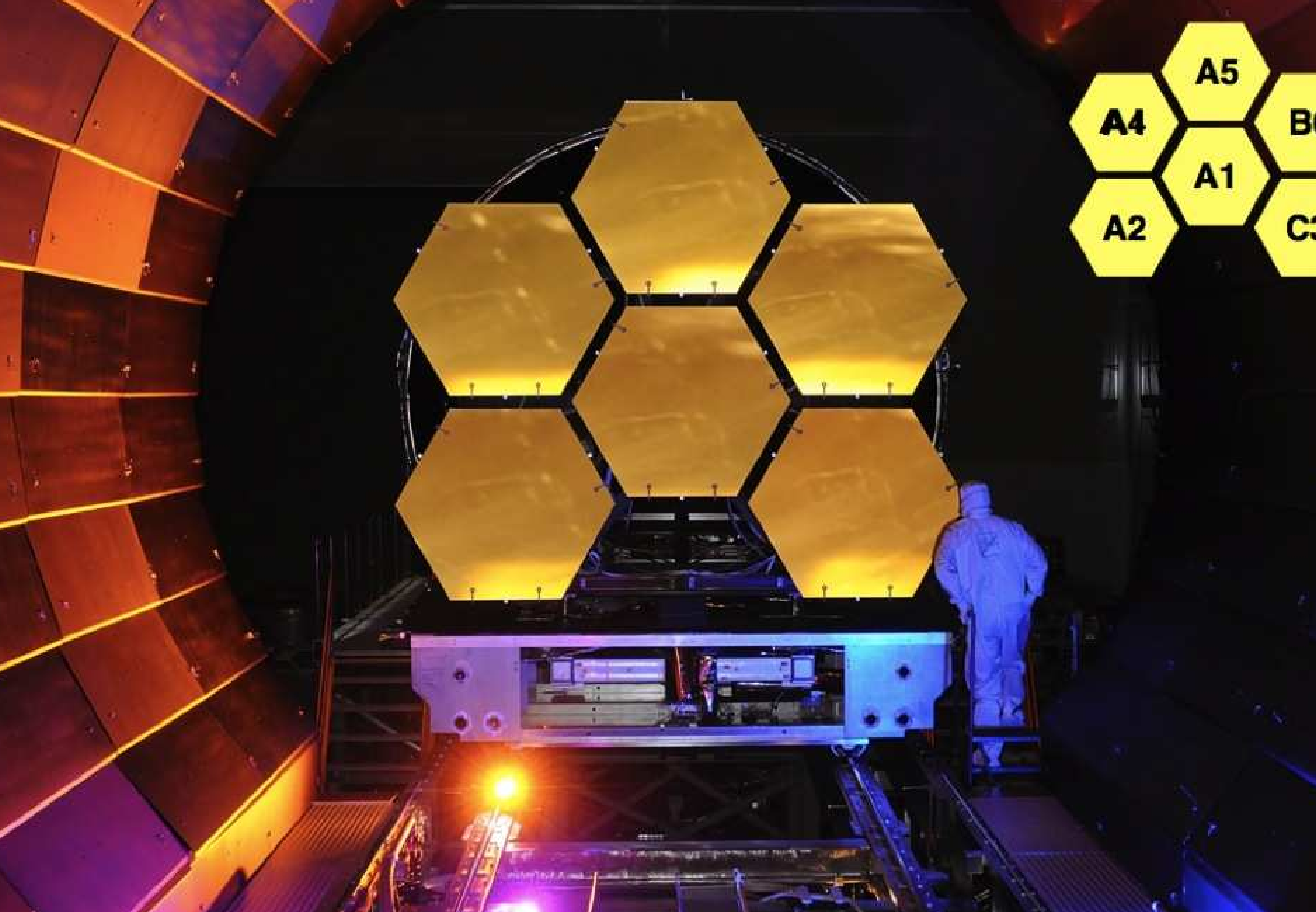
Wave-Front Sensing tested hands-off at 40 K in 1-G at JSC in 2015-2016.

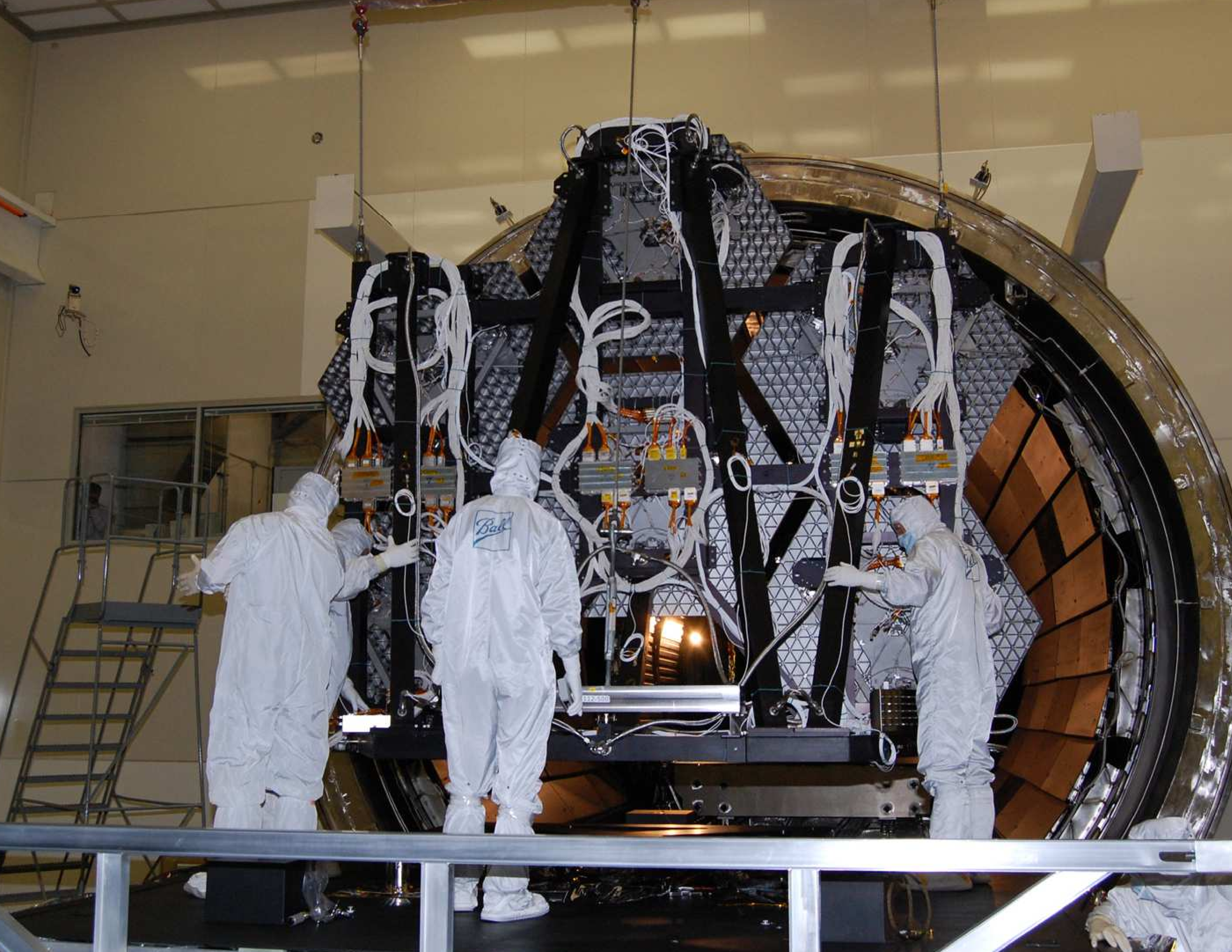
Ball 1/6 scale-model for WFS: produces diffraction-limited 2.0 μm images.

JWST Hardware Status

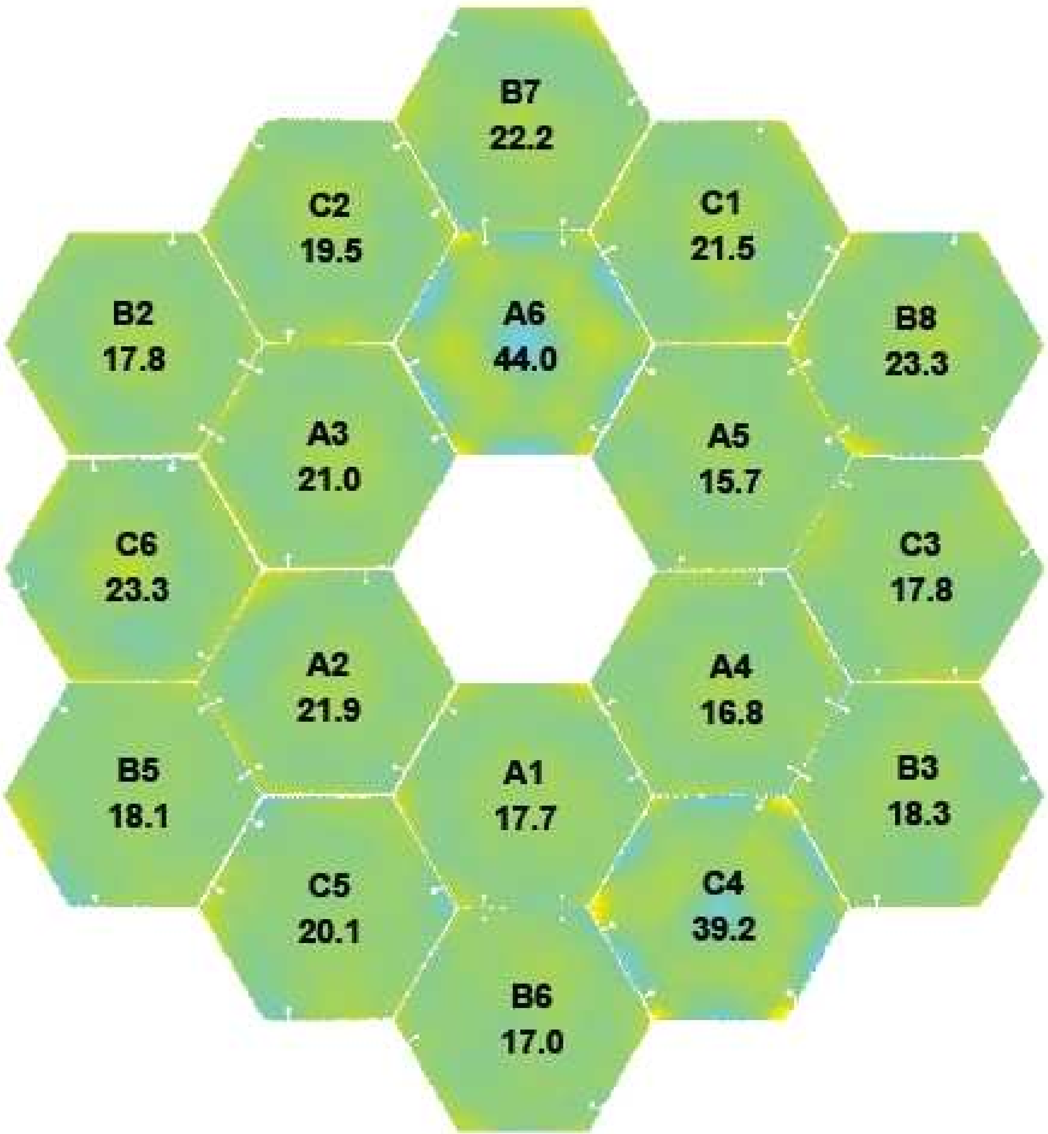


Mirror Acceptance Testing



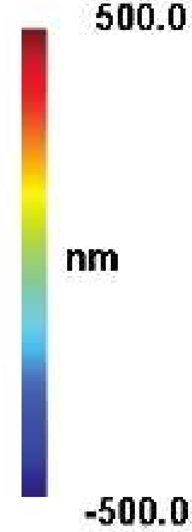

Ball

Primary Mirror Composite

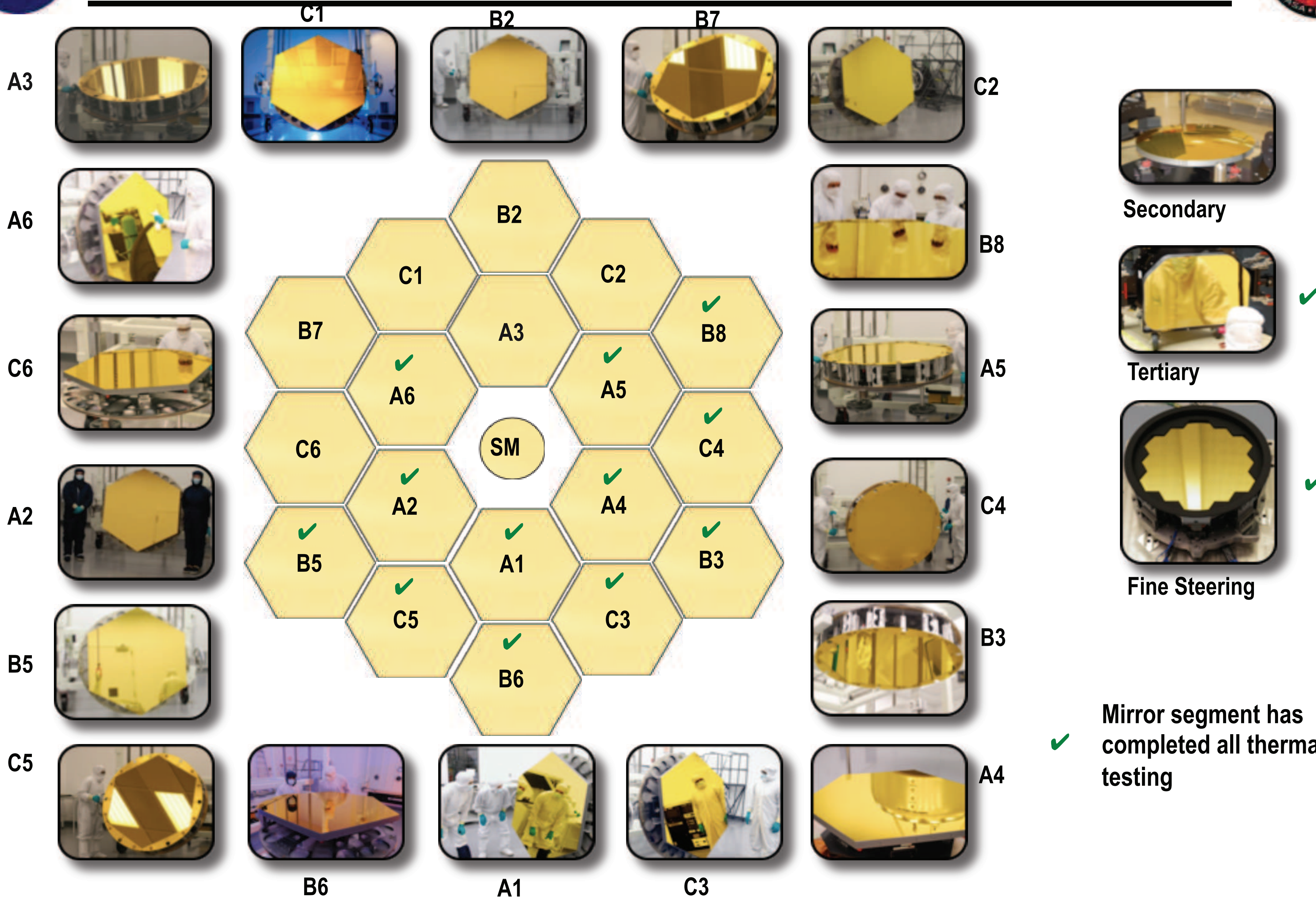


RMS: 23.2 nm

PV: 515.5 nm



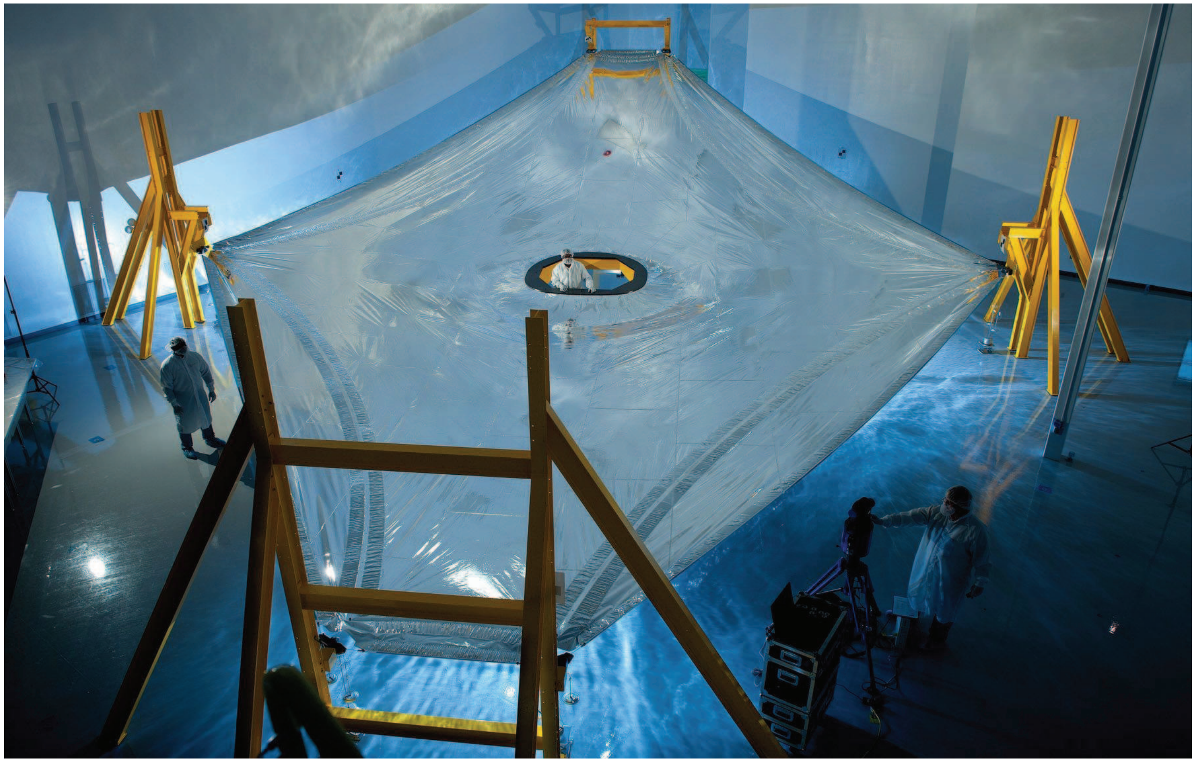
Family Portrait



✔ Mirror segment has completed all thermal testing

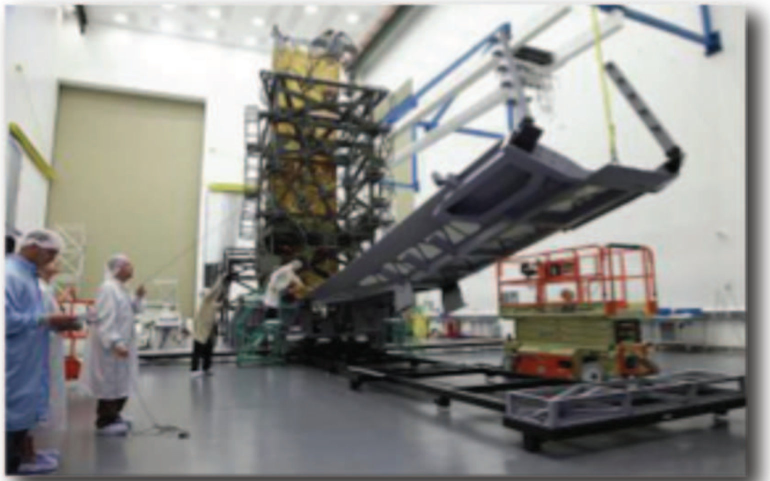
Sunshield

- **Template membrane build to flight-like requirements for verification of:**
  - Shape under tension to verify gradients and light line locations
  - Hole punching & hole alignment for membrane restraint devices (MRD)
  - Verification of folding/packing concept on full scale mockup
  - Layer 3 shape measurements completed



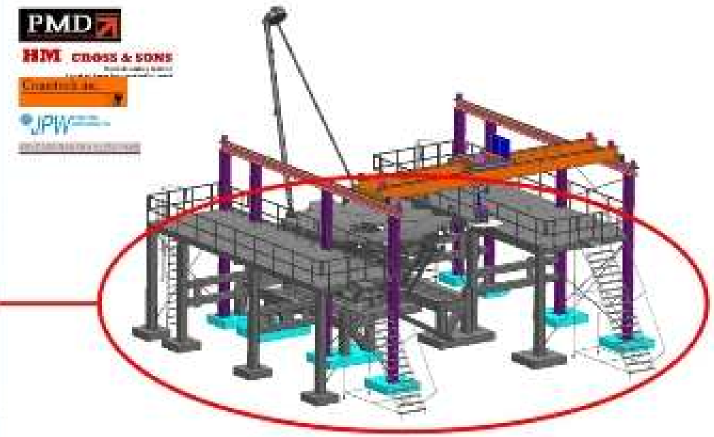
←Layer-3 template membrane under tension for 3-D shape measurements at Mantech

Full-scale JWST mockup with sunshield pallette ↓



Telescope Assembly Ground Support Equipment

Ambient Optical Alignment Stand



Hardware has been installed at GSFC approximately 8 weeks ahead of schedule

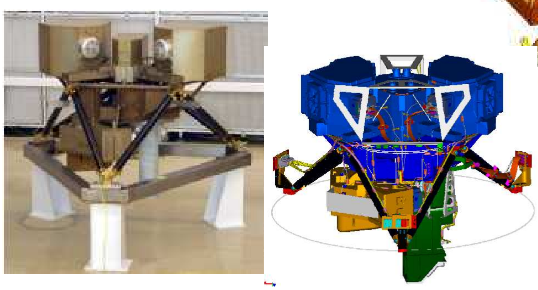
Landing a mirror onto backplane simulator

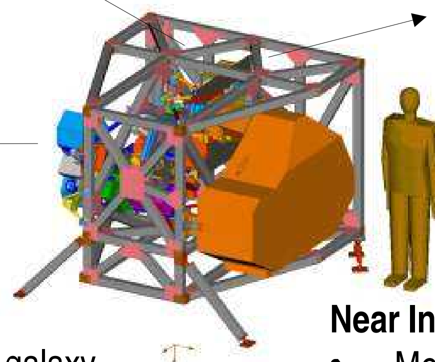
(3b) JWST instrument update: US (UofA, JPL), ESA, & CSA.

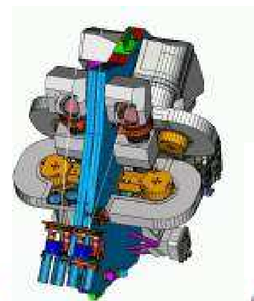
Instrument Overview

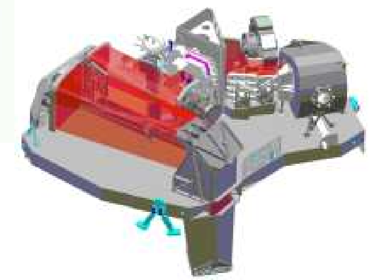
Fine Guidance Sensor (FGS)
- Ensures guide star availability with >95% probability at any point in the sky
- Includes Narrowband Imaging Tunable Filter
- Developed by Canadian Space Agency & COM DEV

Near Infra-Red Camera (NIRCam)
- Detects first light galaxies and observes galaxy assembly sequence
- 0.6 to 5 microns
- Supports Wavefront Sensing & Control
- Developed by Univ. of AZ & LMATC





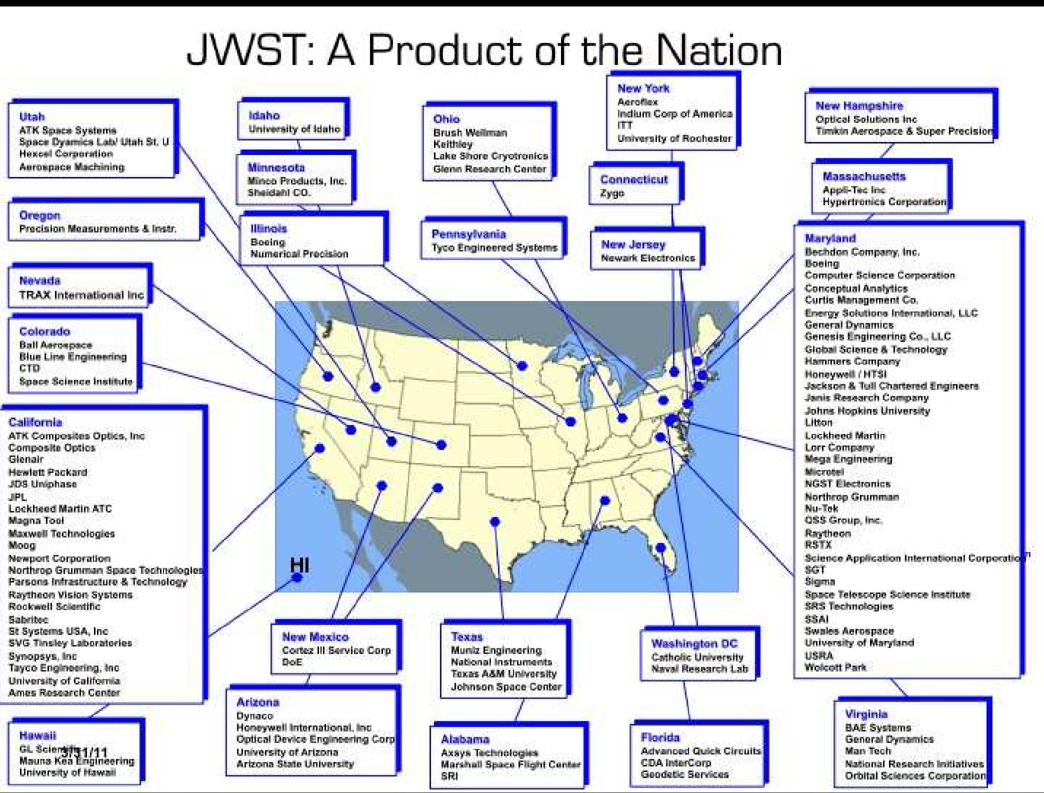


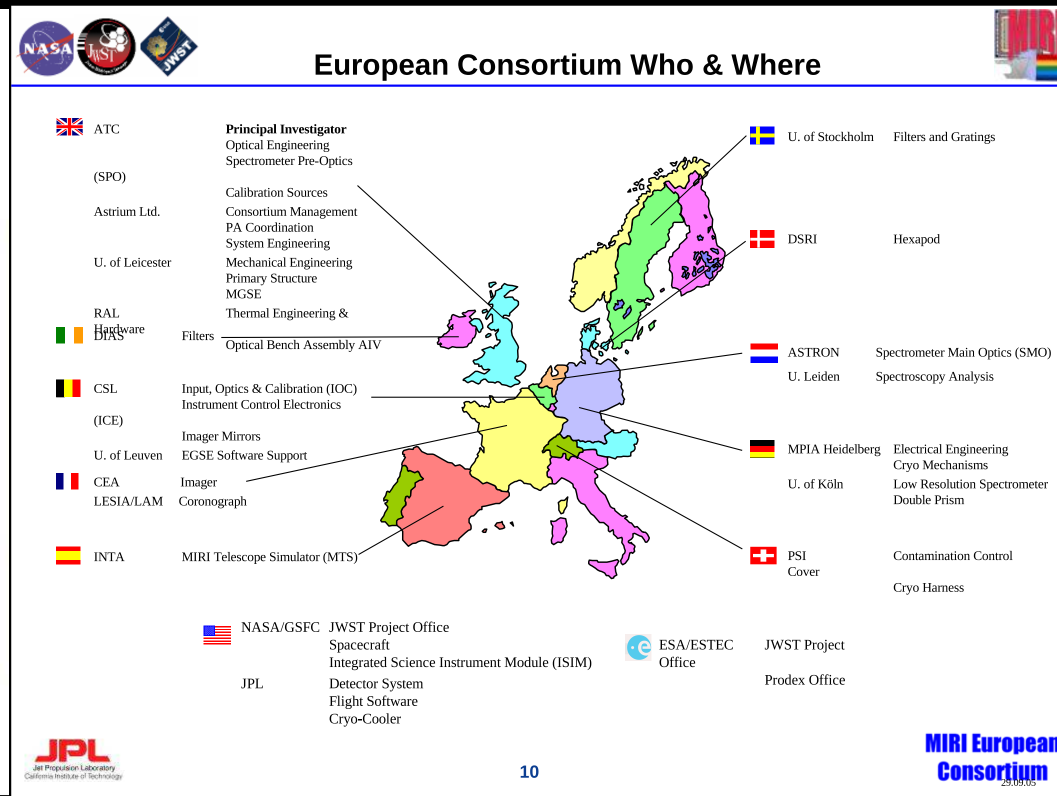


Mid-Infra-Red Instrument (MIRI)
- Distinguishes first light objects; studies galaxy evolution; explores protostars & their environs
- Imaging and spectroscopy capability
- 5 to 27 microns
- Cooled to 7K by Cyro-cooler
- Combined European Consortium/JPL development

Near Infra-Red Spectrograph (NIRSpec)
- Measures redshift, metallicity, star formation rate in first light galaxies
- 0.6 to 5 microns
- Simultaneous spectra of >100 objects
- Developed by ESA & EADS with NASA/ GSFC Detector & Microshutter Subsystems

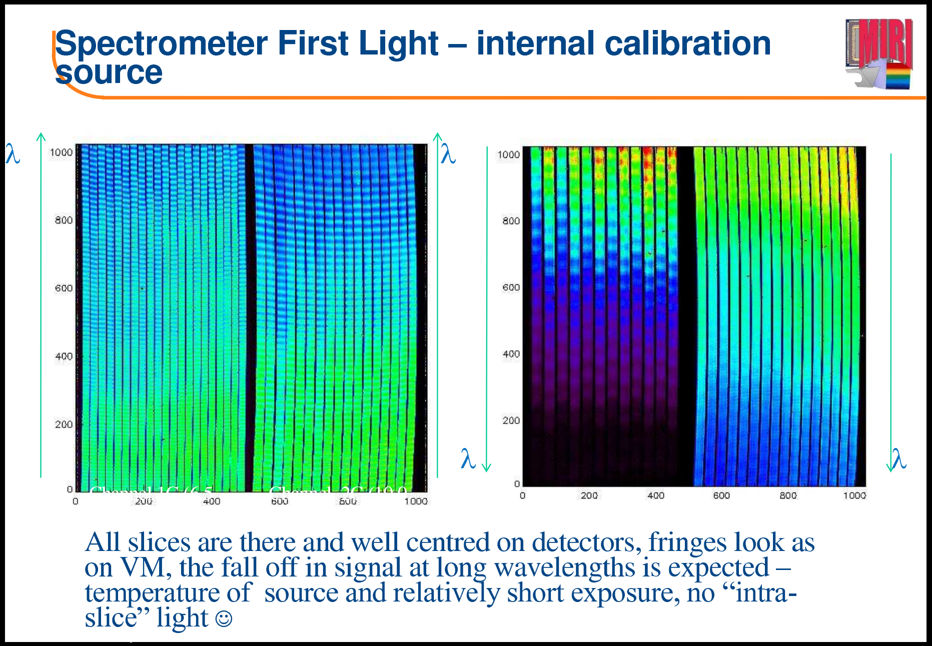
MIRI delivery 05/12; NIRCam 09/12; NIRSpec & FGS early 2013.





- JWST hardware made in 27 US States: $\gtrsim$75% 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.

Flight MIRI



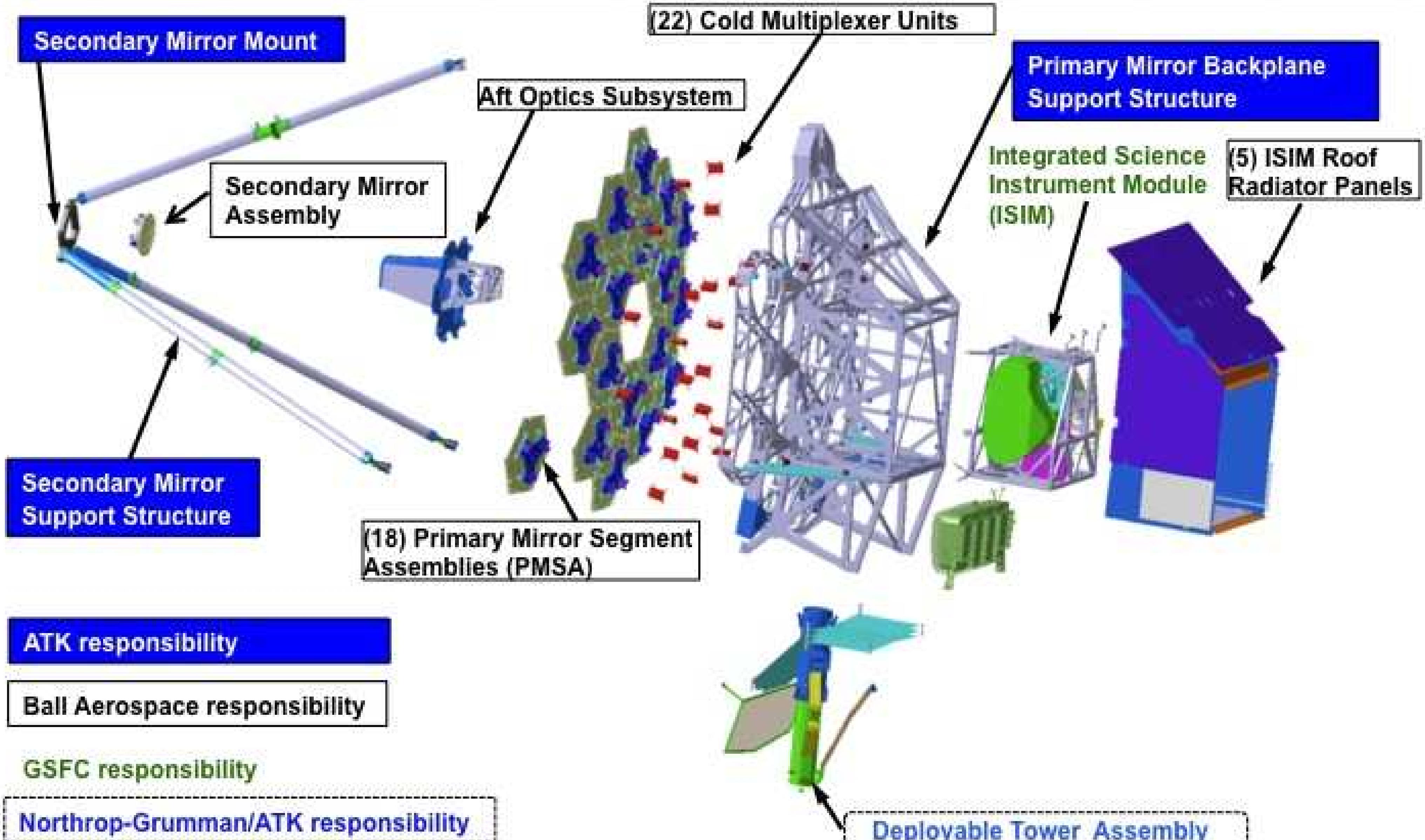
JWST's mid-infrared (5–29μm) camera and spectrograph:

- MIRI — built by ESA consortium of 10 ESA countries & NASA JPL.
- Fight build completed and tested with First Light in July 2011.

Final MIRI delivery to NASA/GSFC in early May 2012.

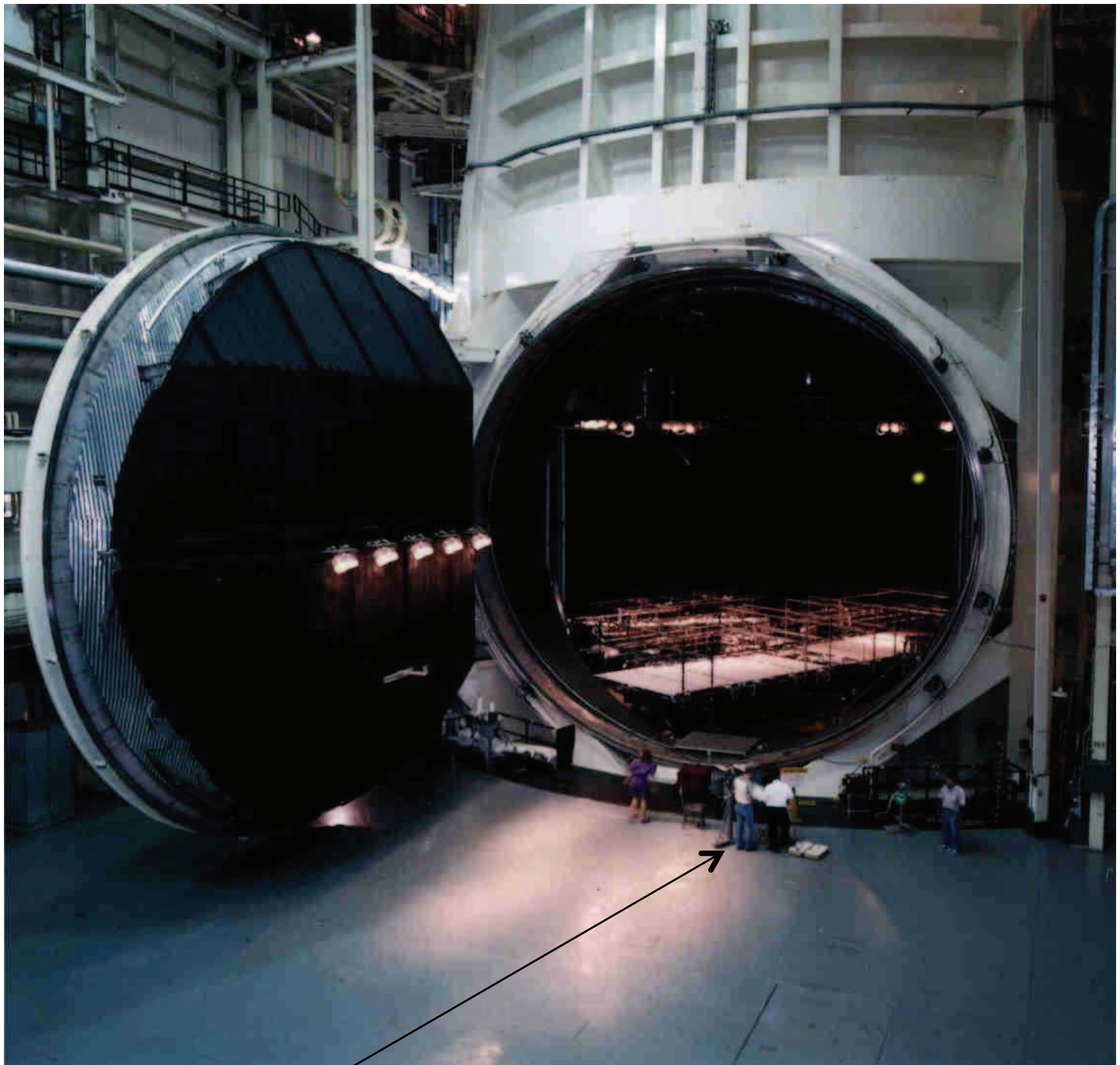
11-Apr-2012: Here is where your MIRI inside ISIM will be tested soon!

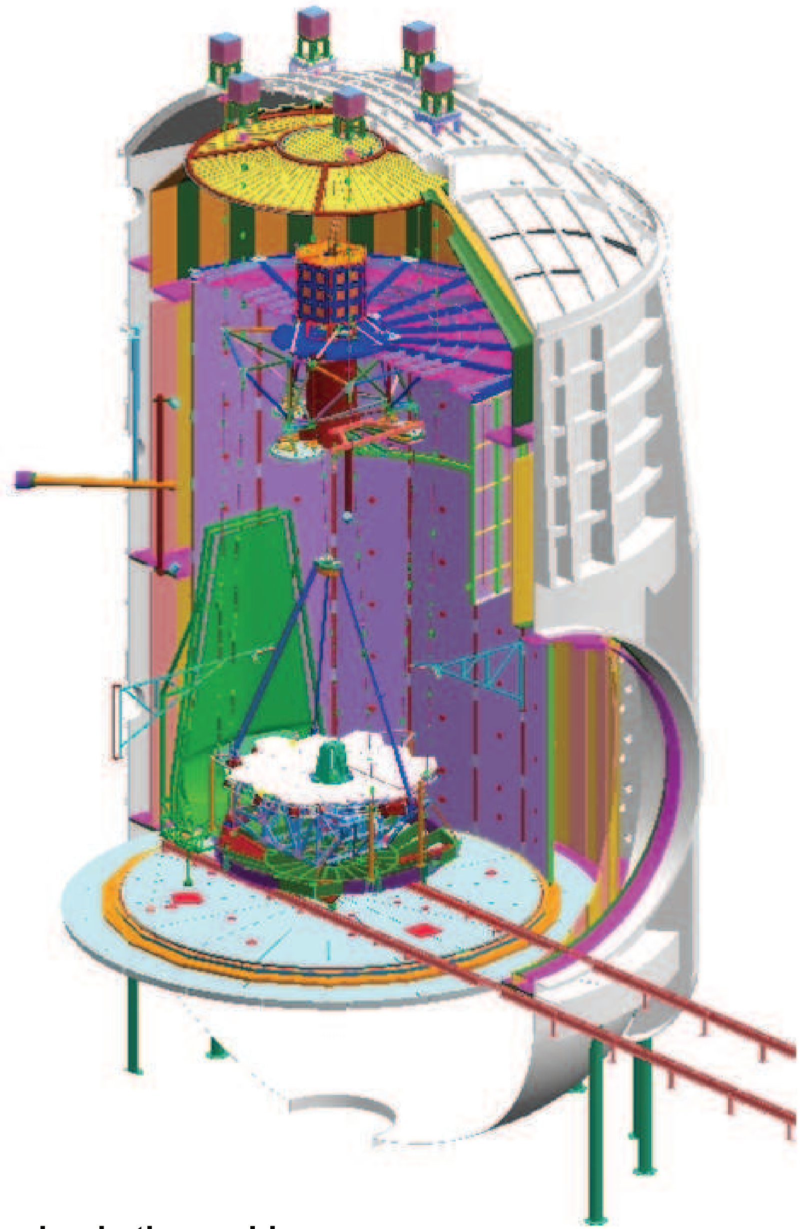
TELESCOPE ARCHITECTURE



3/31/11

OTE Testing – Chamber A at JSC

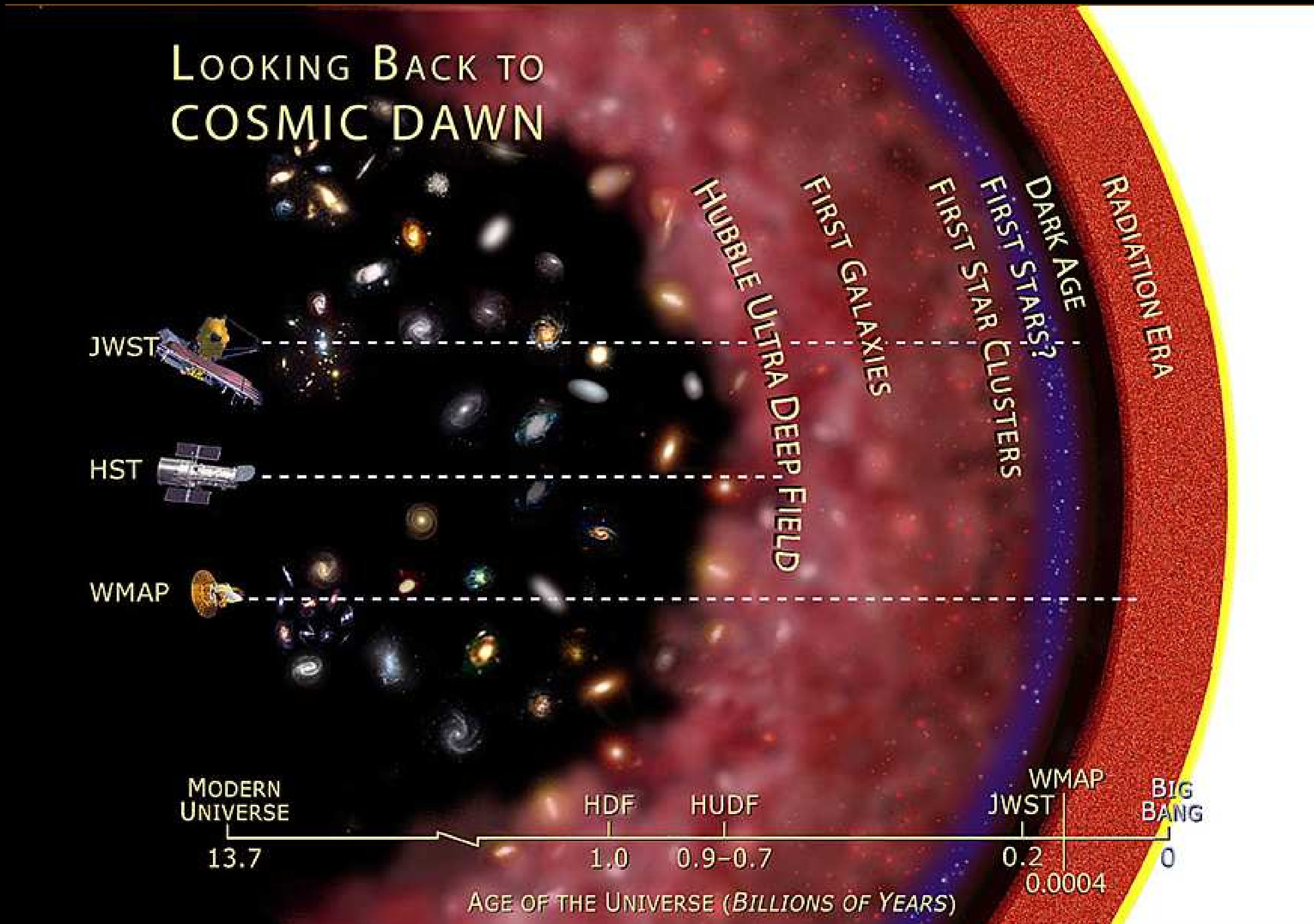




Notice people for scale

Will be the largest cryo vacuum test chamber in the world

(4) What is First Light, Reionization, and Galaxy Assembly?

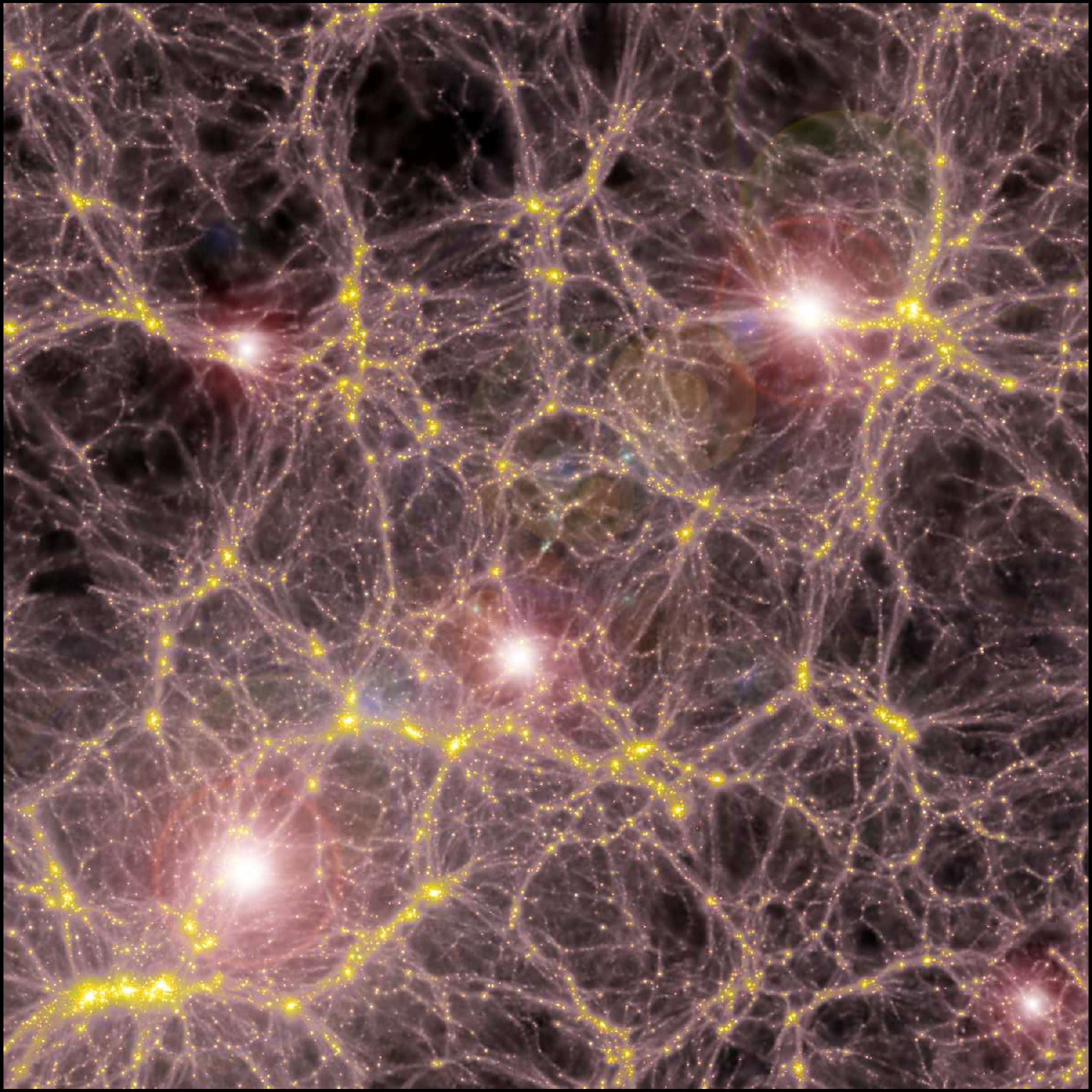


HST: Hubble sequence & galaxy evolution at z$\lesssim$7–8 (age$\gtrsim$0.7 Gyr).

JWST: First Light, Reionization, & Galaxy Assembly z$\gtrsim$8-20 (0.2-0.7 Gyr).

WMAP: Neutral Hydrogen first forms at z=1090 (cosmic age$\simeq$0.38 Myr).

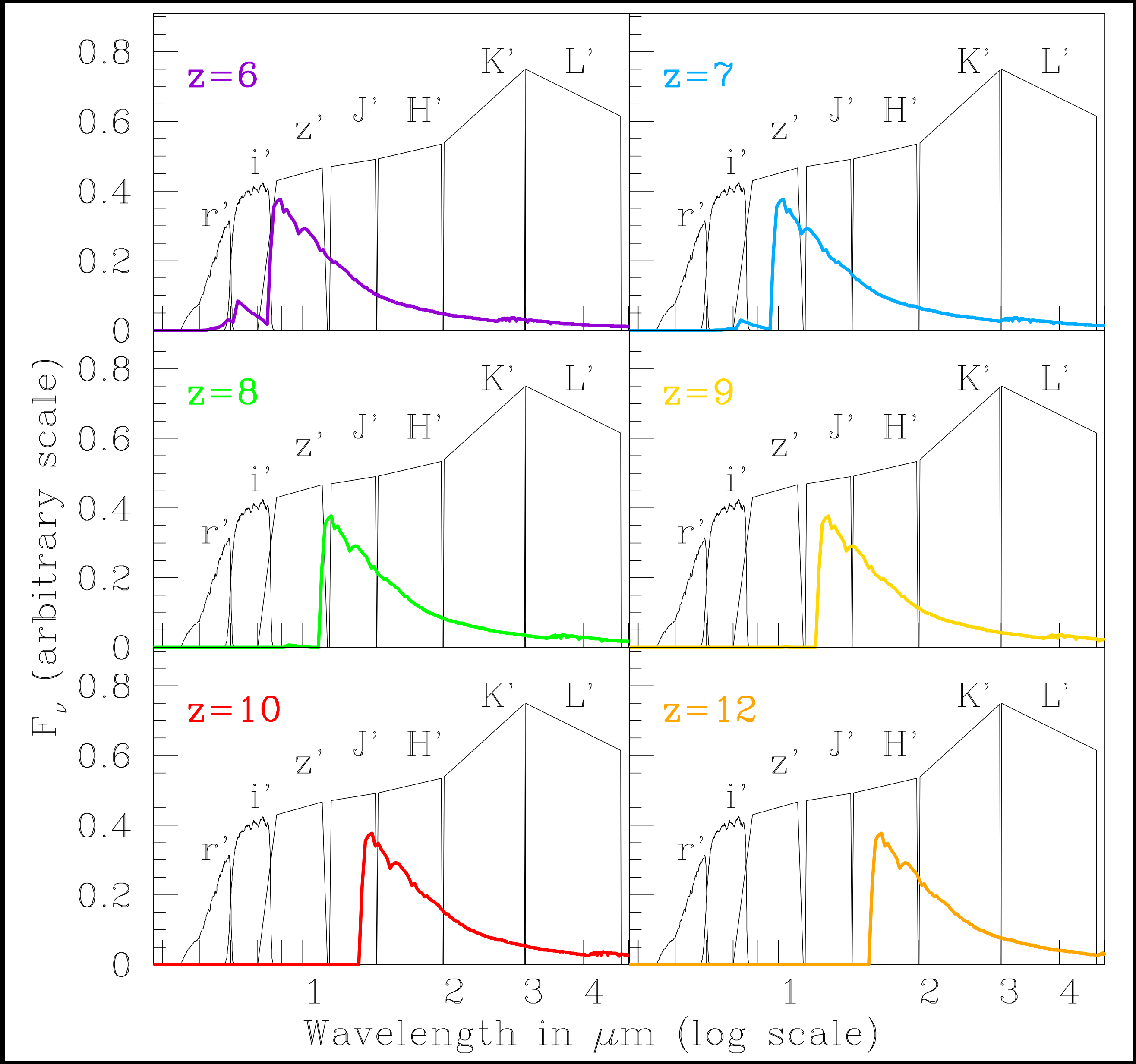
(4a) How will JWST Observe First Light and Reionization?



• Detailed hierarchical models (Dr. V. Bromm) show that formation of Pop III stars reionized universe for the first time at z$\simeq$10–30 (First Light, age$\simeq$500–100 Myr).

• This should be visible to JWST as the first massive stars and surrounding star clusters, and perhaps their extremely luminous supernovae at z$\simeq$10$\longrightarrow$30.

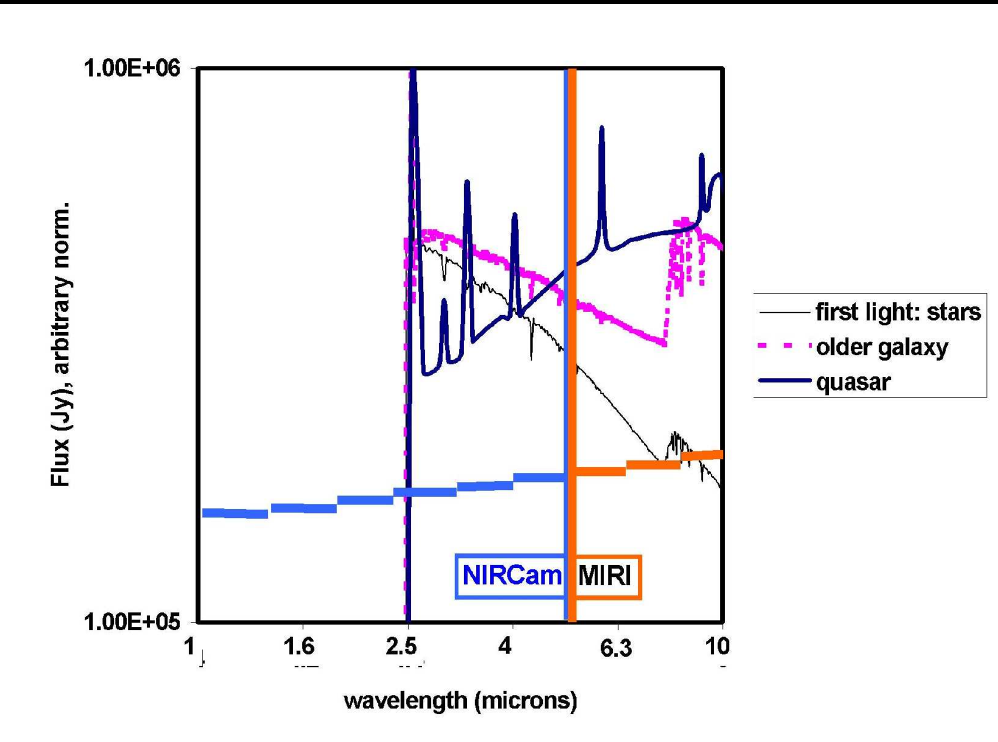
(4) How will JWST measure First Light & Reionization?

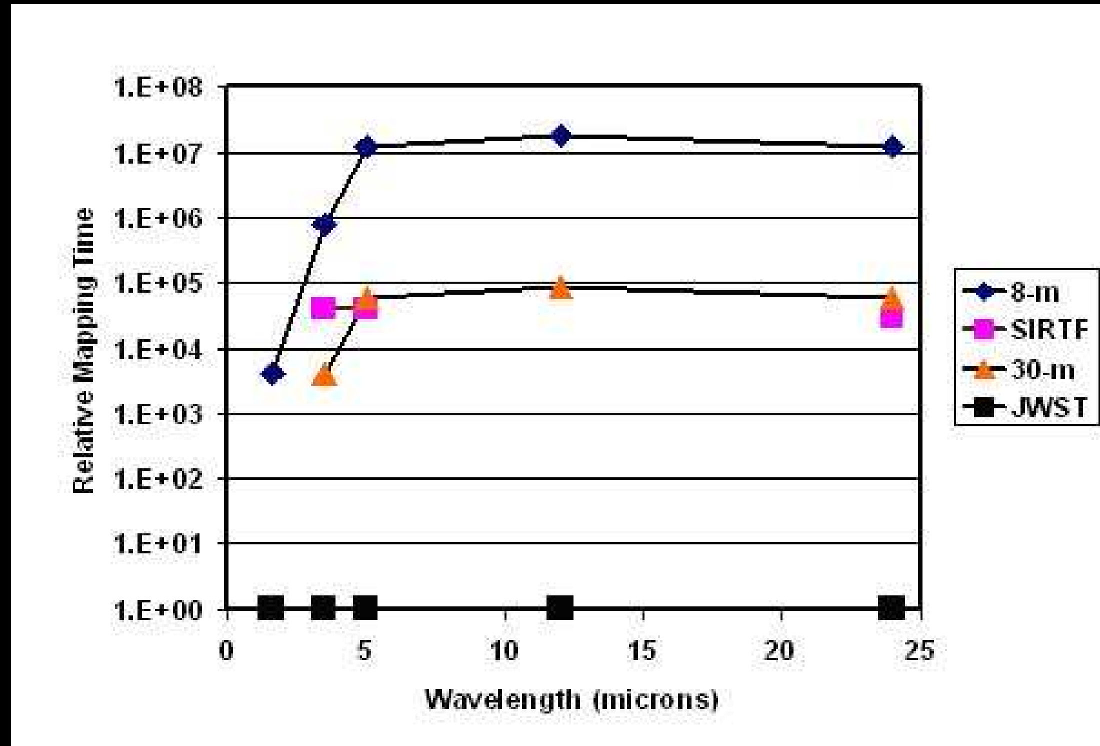


- Can't beat redshift: to see First Light, must observe near–mid IR.

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

• (4) What sensitivity will JWST have?



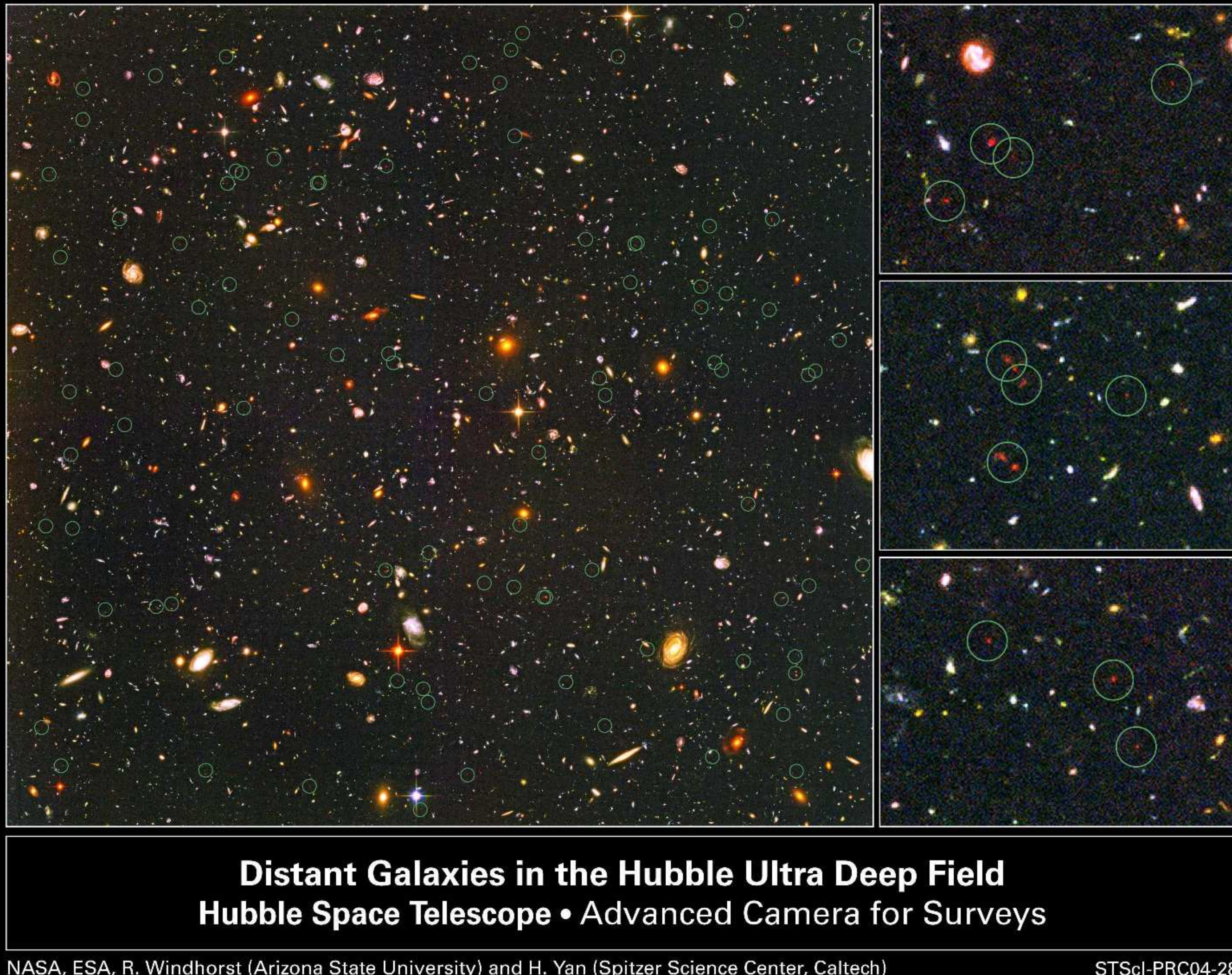


NIRCam and MIRI sensitivity complement each other, straddling $\lambda \simeq 5\ \mu$m.

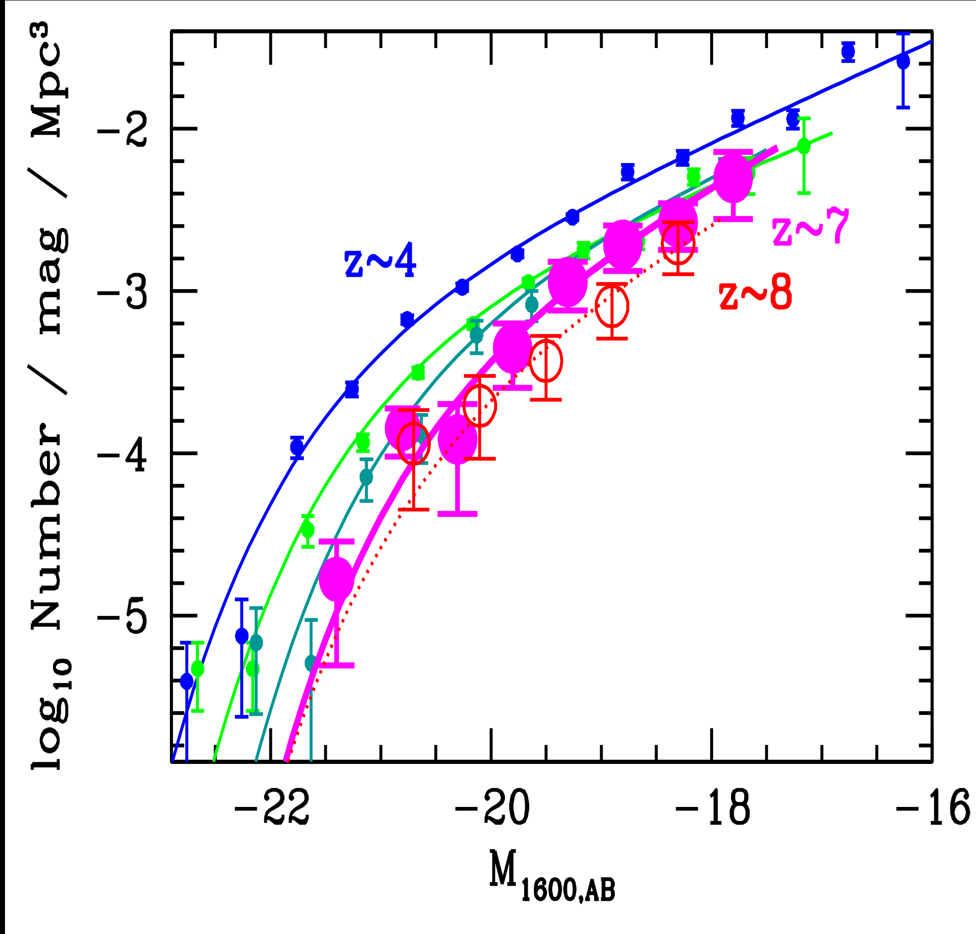
Together, they allow objects to be found to z=15–20 in $\sim 10^5$ sec (28 hrs).

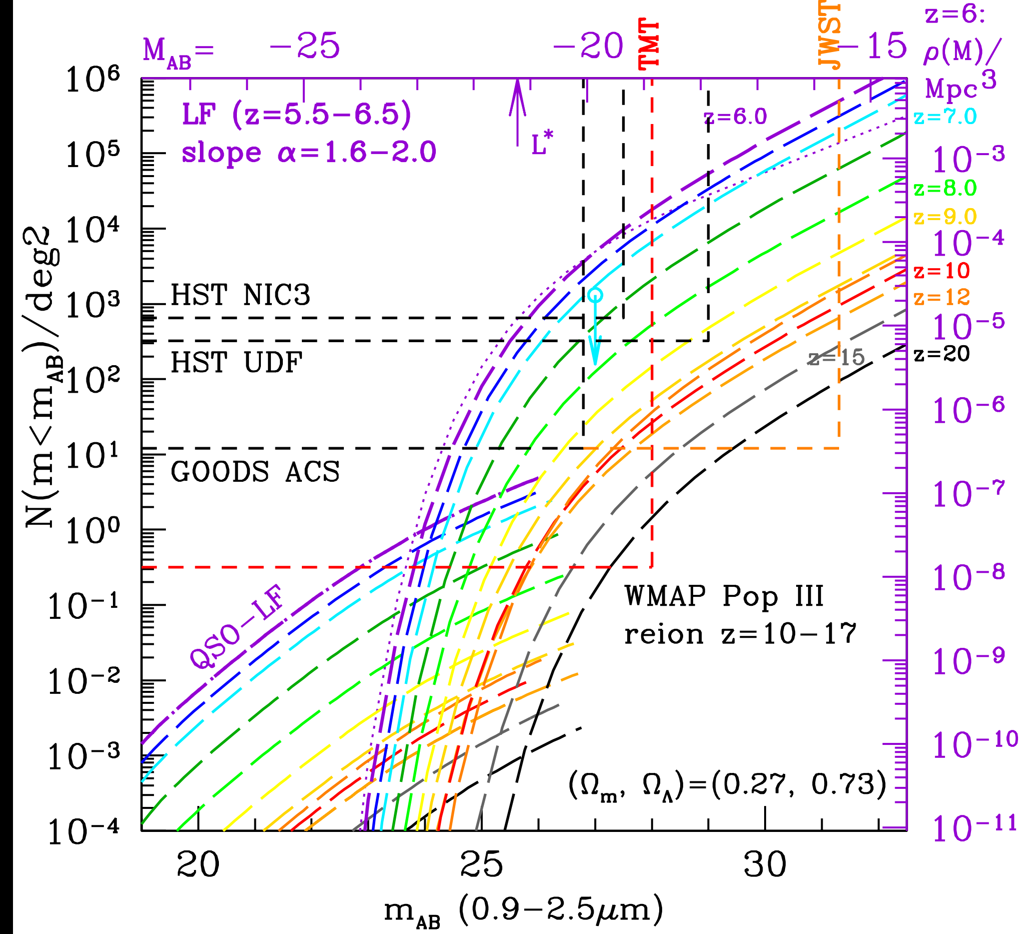
LEFT: NIRCam and MIRI broadband sensitivity to a Quasar, a "First Light" galaxy dominated by massive stars, and a 50 Myr "old" galaxy at z=20.

RIGHT: Relative survey time vs. λ that Spitzer, a ground-based IR-optimized 8-m, and a 30-m telescope would need to match JWST.



Hubble UltraDeep Field: Dwarf galaxies at z≃6 (age≃1 Gyr; Yan & Windhorst 2004), many confirmed by spectra at z≃6 (Malhotra et al. 2005).

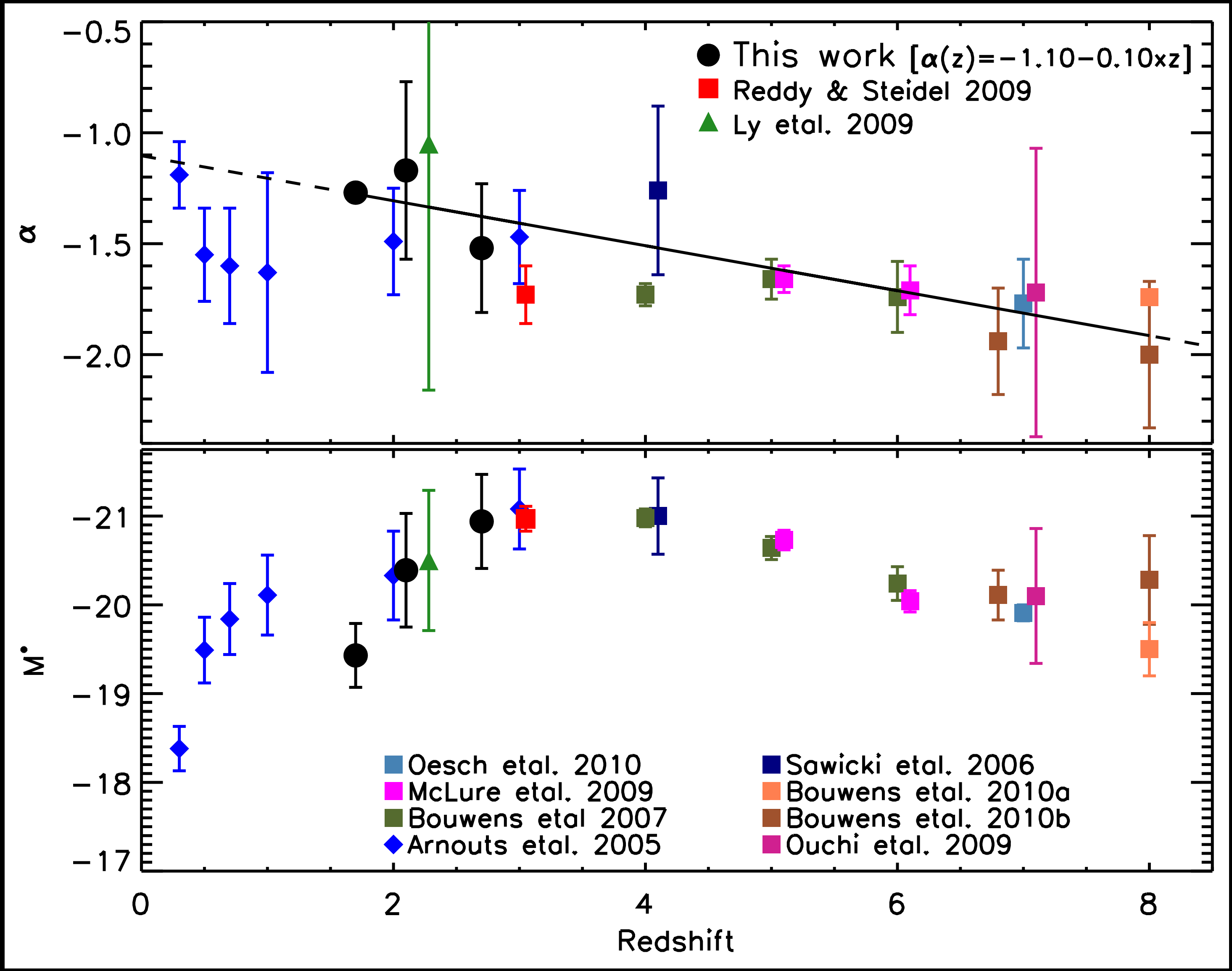




The "Cosmic Stock Market chart of galaxies: Very few big bright objects in the first Gyr, but lots of dwarf galaxies at z$\gtrsim$6 (age$\lesssim$1 Gyr).

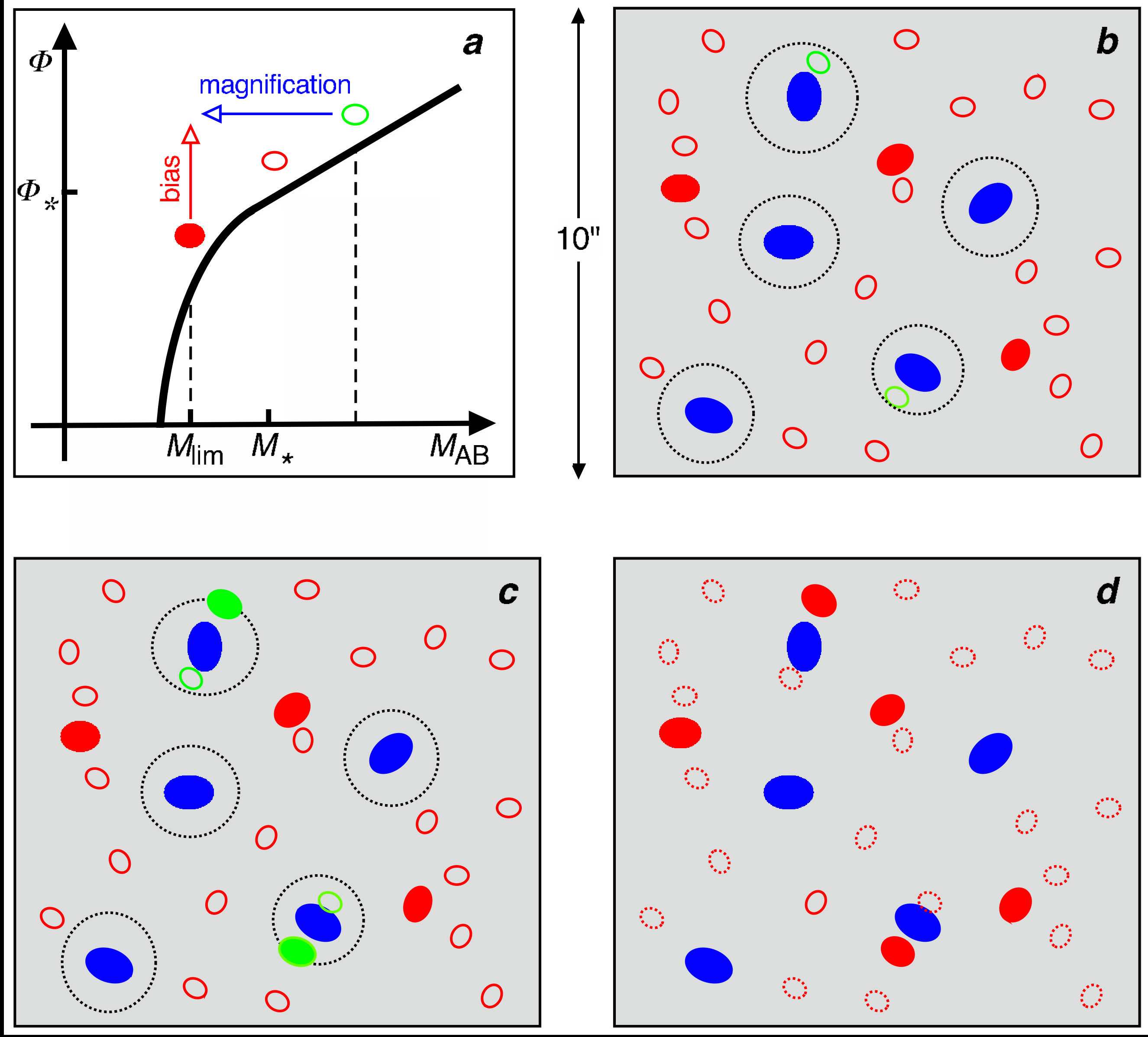
- With proper survey strategy (area AND depth), JWST can trace the entire reionization epoch and detect the first star-forming objects.

- JWST Coronagraphs can also trace Super-Massive Black Holes as faint Quasars in young galaxies: JWST needs 2.0μm diffraction limit for this!



Measured faint-end LF slope evolution (top) and characteristic luminosity evolution (bottom) from Hathi^{+} 2010, ApJ, 720, 1708 (arXiv:1004.5141v2).

- In the JWST regime at z$\gtrsim$8, expect faint-end LF slope $\alpha \simeq$2.0!
- In the JWST regime at z$\gtrsim$8, expect characteristic luminosity $M^* \gtrsim$–19!



Hard to see the forest for the trees in the first 0.5 Gyrs?:

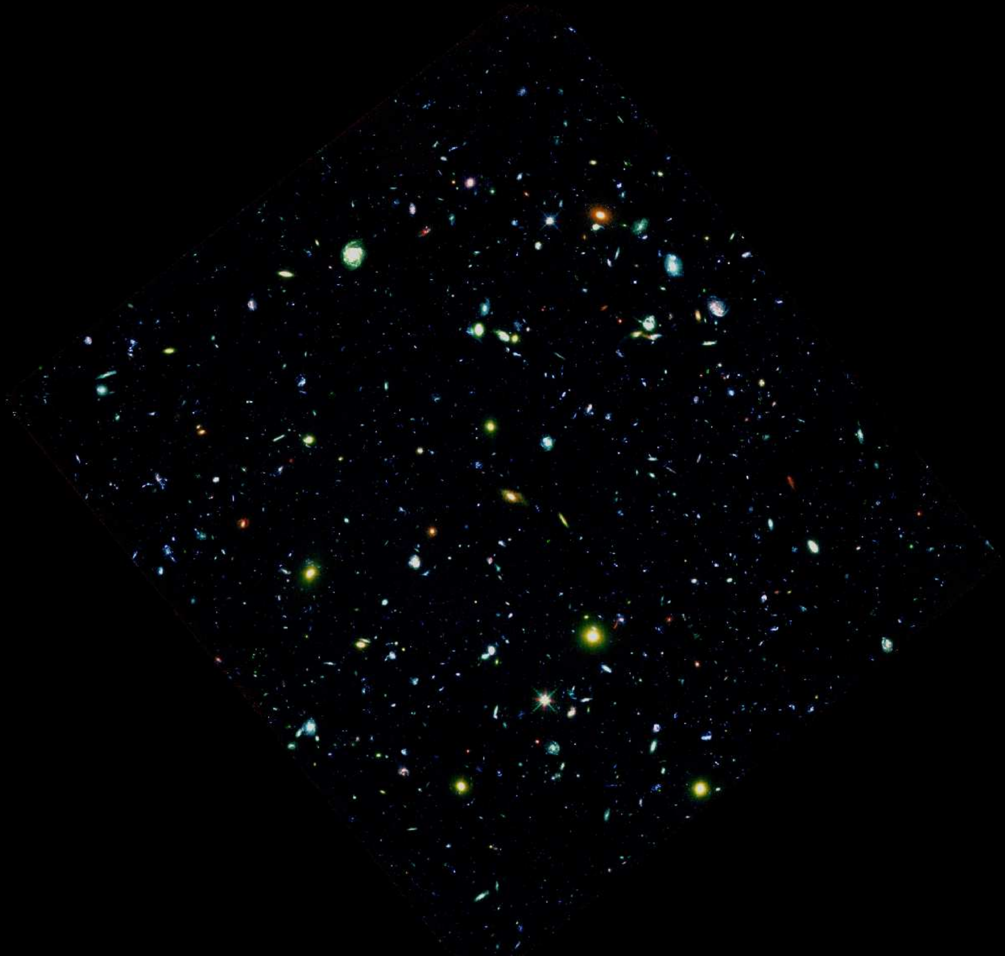
- Foreground galaxies ($z \simeq 1$–2 or age$\simeq$3–6 Gyr) may gravitationally lens or amplify galaxies at $z \gtrsim 8$–10 (cosmic age$\lesssim$0.5 Gyr; Wyithe et al. 2011).
- This could change the landscape for JWST observing strategies.

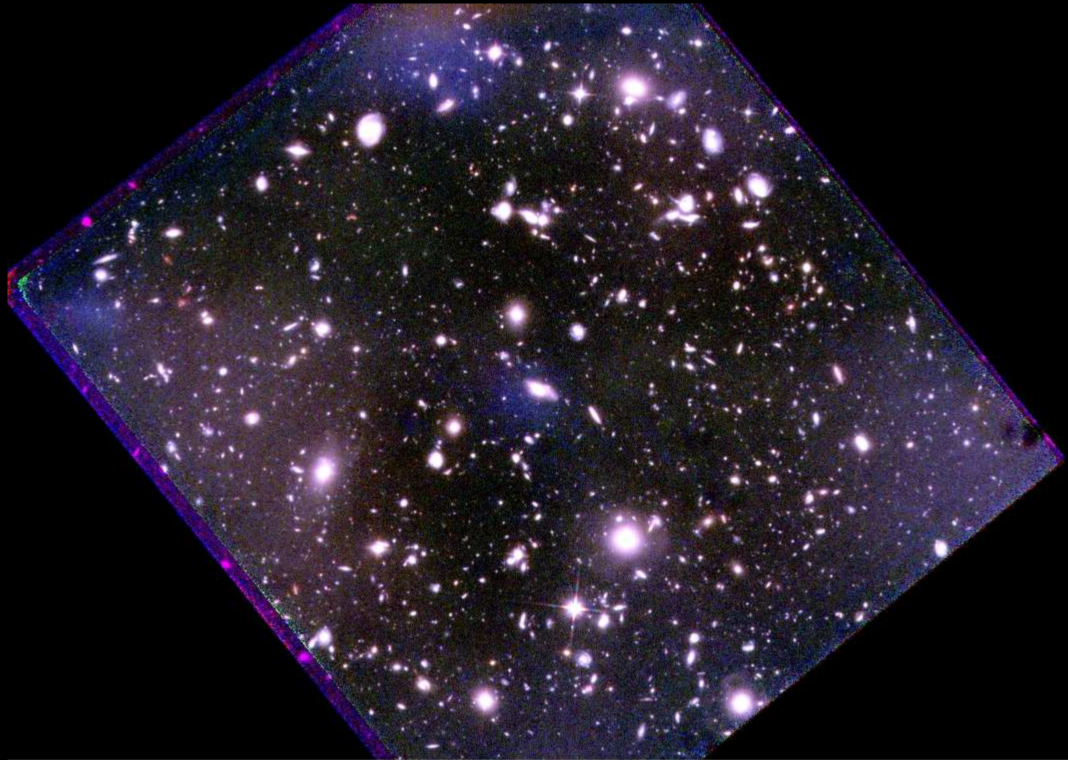
Two fundamental limitations determine ultimate JWST image depth:

(1) Cannot-see-the-forest-for-the-trees effect: Background objects blend into foreground neighbors $\Rightarrow$ Need multi-$\boldsymbol{\lambda}$ deblending algorithms!

(2) House-of-mirrors effect: (Many?) First Light objects can be gravitationally lensed by foreground galaxies $\Rightarrow$ Must model/correct for this!

- Proper JWST 2.0μm PSF and straylight specs essential to handle this!





(Left) 100-hr HST/WFC3 IR-mosaic in HUDF at 1–1.6μm (YJH filters; Bouwens et al 2010; Yan et al. 2010).

(Right) Same WFC3 IR-mosaic, but stretched to $\lesssim 10^{-3}$ of Zodical sky!!

- The CLOSED-TUBE HST has residual low-level systematics: Imperfect removal of detector artifacts, flat-fielding errors, and/or faint straylight.

$\Rightarrow$ The open JWST architecture needs very good baffling and rogue path mitigation to do ultradeep JWST fields (JUDF's) to 10^{-4} of sky.

(5) Conclusions

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

- Today's Hubble sequence formed 7–10 Gyrs ago.

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

Replan in 2011. No technical showstoppers: your MIRI work is paying off!

- More than 75% of JWST H/W built or in fab, & meets/exceeds specs.

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

- Formation and evolution of the first star-clusters after 0.2 Gyr.
- How dwarf galaxies formed and reionized the Universe after 1 Gyr.
- How to find water and CO_2 in transiting Earth-like exoplanets.

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

- IR sequel to HST after 2018: Training the next generation researchers.

SPARE CHARTS

- References and other sources of material shown:

http://www.asu.edu/clas/hst/www/jwst/ [Talk, Movie, Java-tool]

http://www.asu.edu/clas/hst/www/ahah/ [Hubble at Hyperspeed Java–tool]

http://www.asu.edu/clas/hst/www/jwst/clickonHUDF/ [Clickable HUDF map]

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

http://ircamera.as.arizona.edu/nircam/

http://ircamera.as.arizona.edu/MIRI/

http://www.stsci.edu/jwst/instruments/nirspec/

http://www.stsci.edu/jwst/instruments/fgs

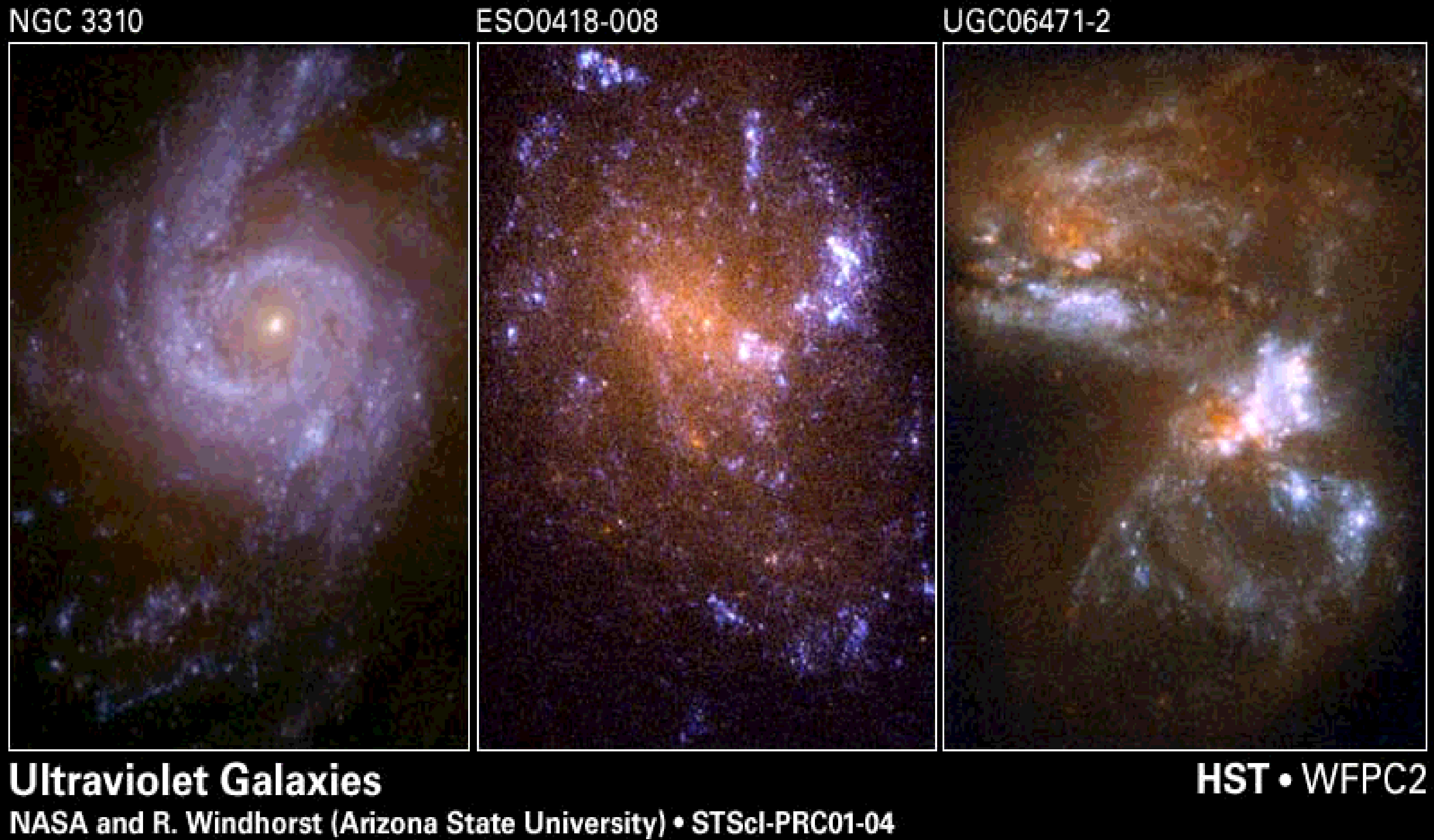
Gardner, J. P., et al. 2006, Space Science Reviews, 123, 485–606

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)

(4b) Predicted Galaxy Appearance for JWST at redshifts z≃1–15

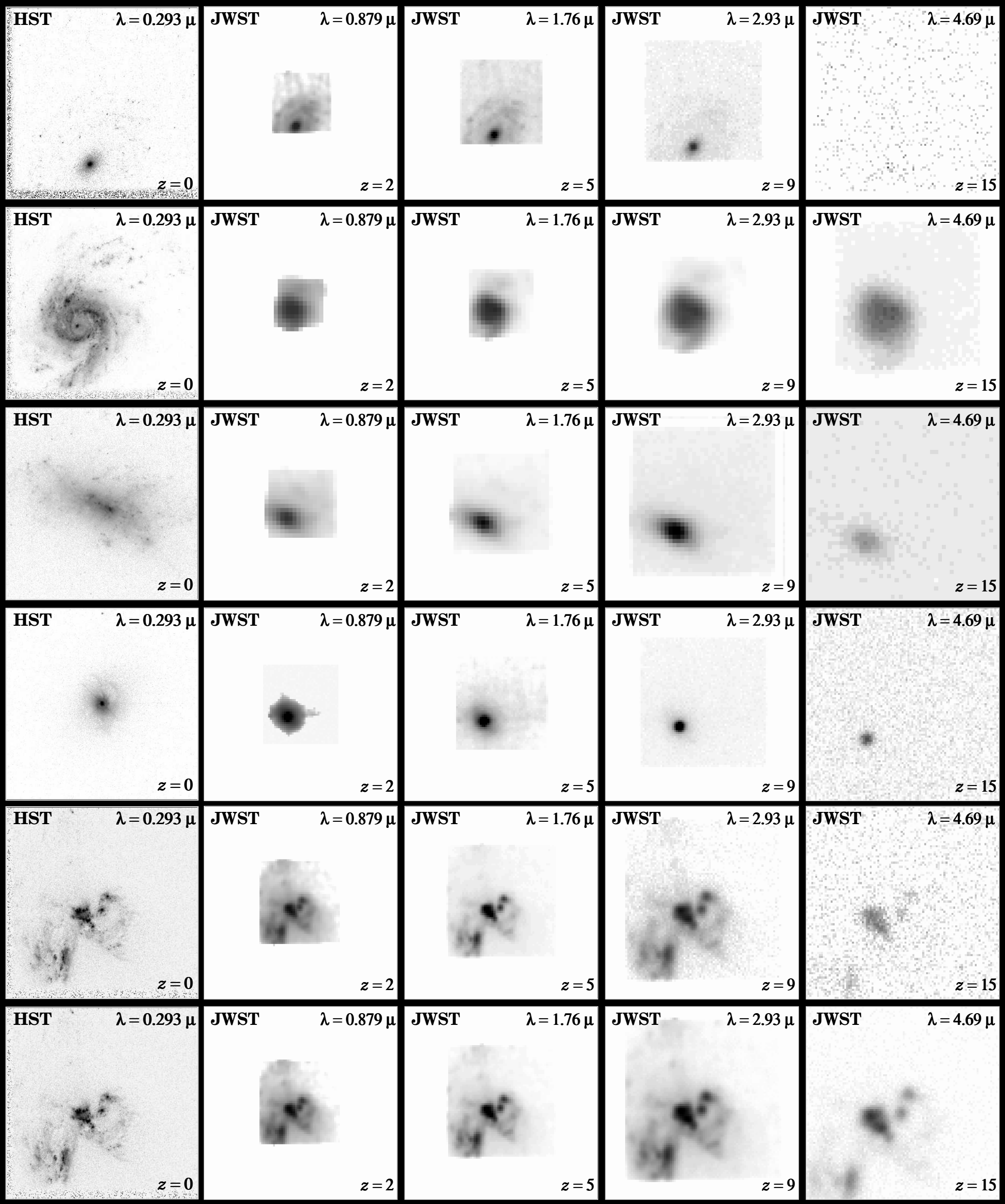


- The rest-frame UV-morphology of galaxies is dominated by young and hot stars, with often significant dust imprinted (Mager-Taylor et al. 2005).

- High-resolution HST ultraviolet images are benchmarks for comparison with very high redshift galaxies seen by JWST.

(4b) Predicted Galaxy Appearance for JWST at redshifts z≃1–15

HST z=0 JWST z=2 z=5 z=9 z=15



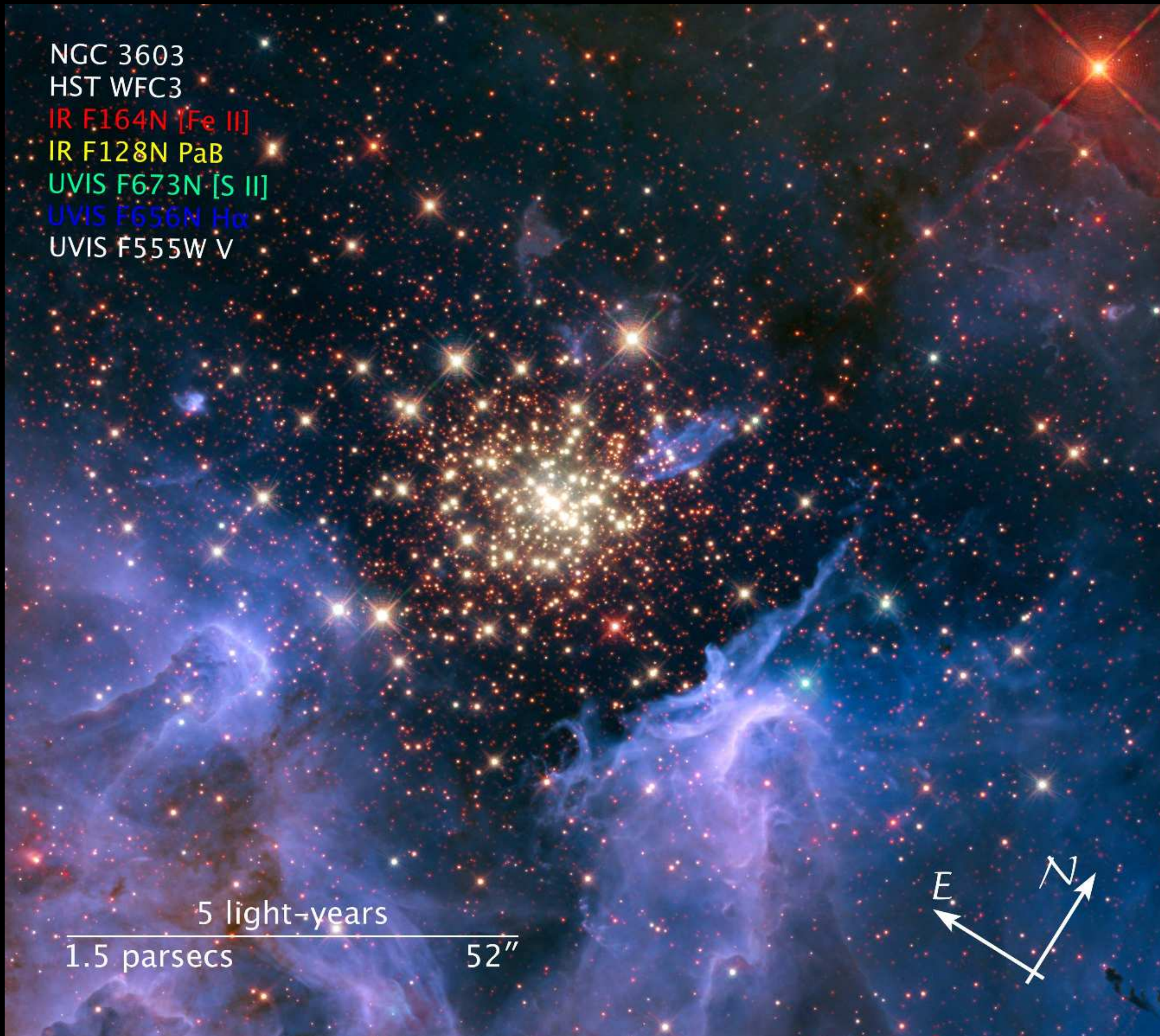
With Hubble UV-optical images as benchmarks, JWST can measure the evolution of galaxy structure & physical properties over a wide range of cosmic time:

- (1) Most spiral disks will dim away at high redshift, but most formed at z≲1–2.

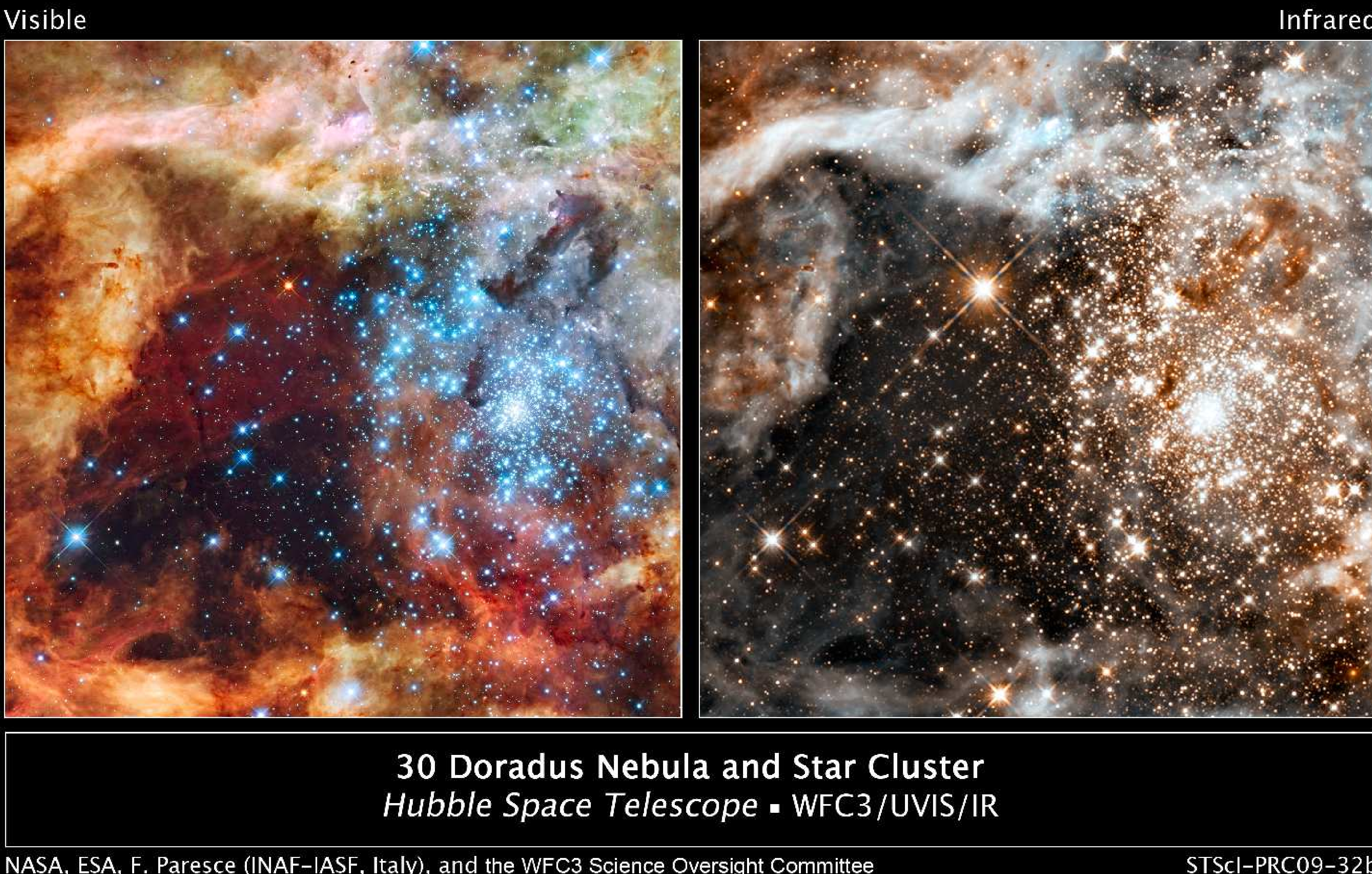
Visible to JWST at very high z are:

- (2) Compact star-forming objects (dwarf galaxies).
- (3) Point sources (QSOs).
- (4) Compact mergers & train-wrecks.

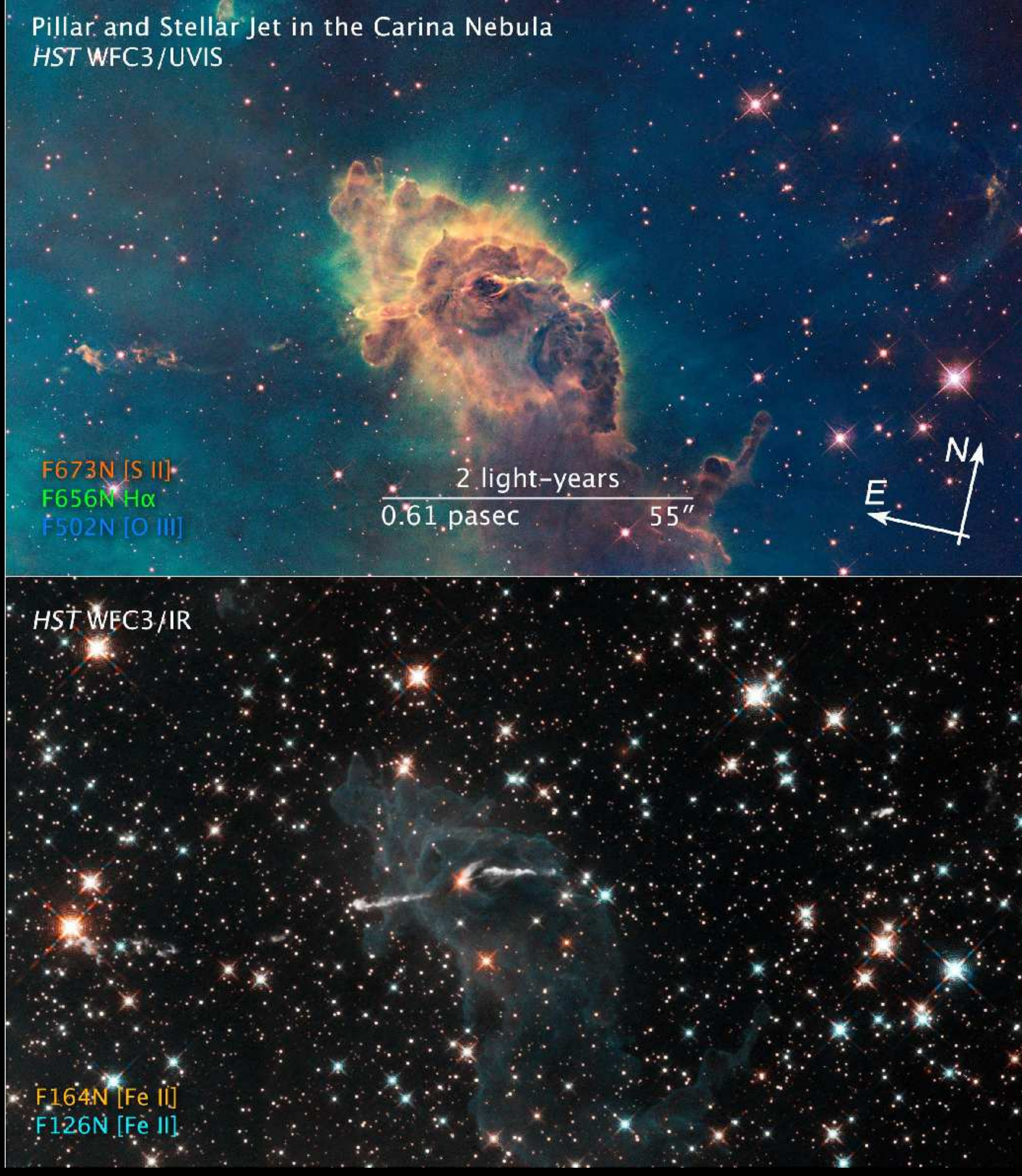
(6) How can JWST measure Earth-like exoplanets?

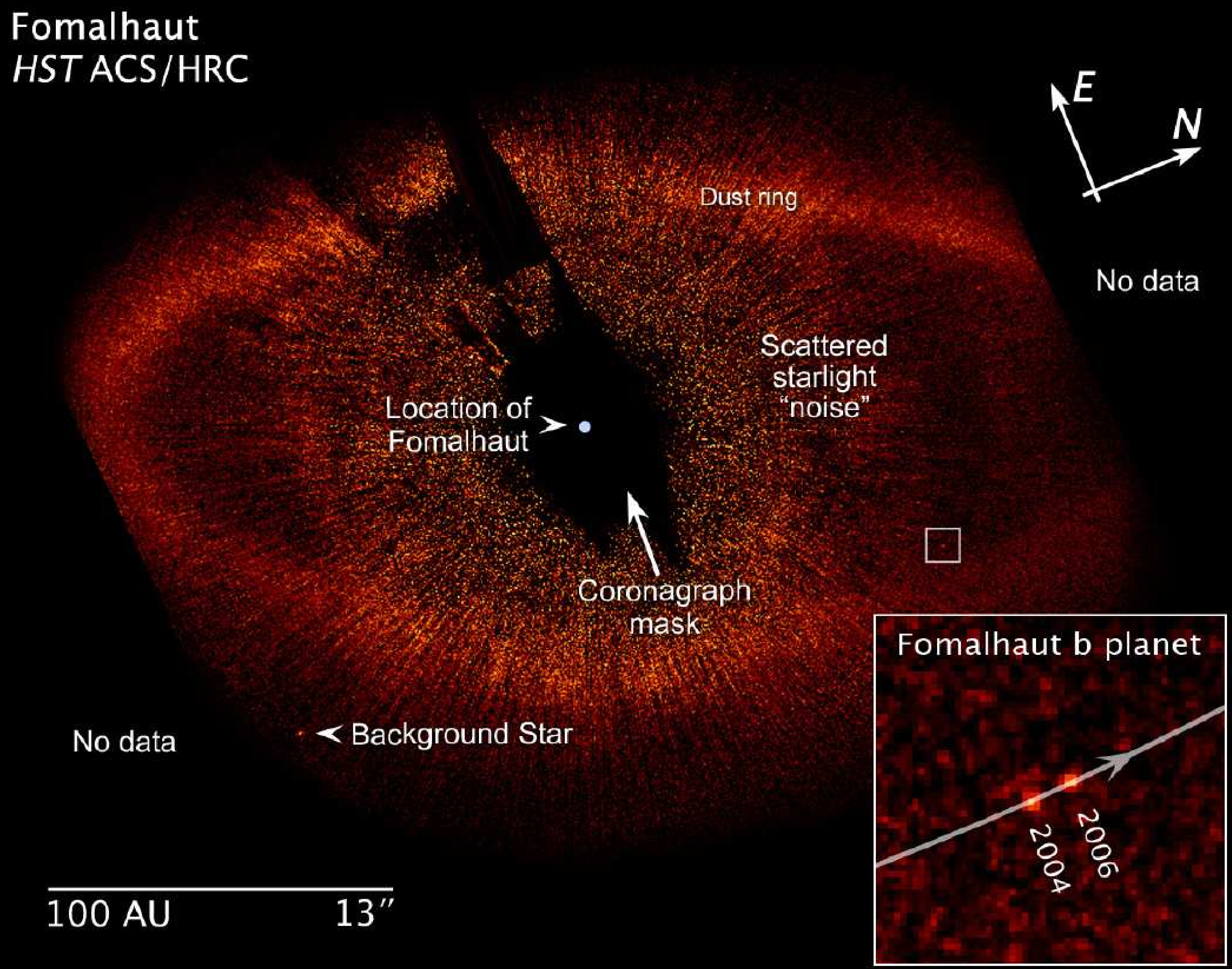


NGC 3603: Young star-cluster triggering star-birth in "Pillars of Creation"



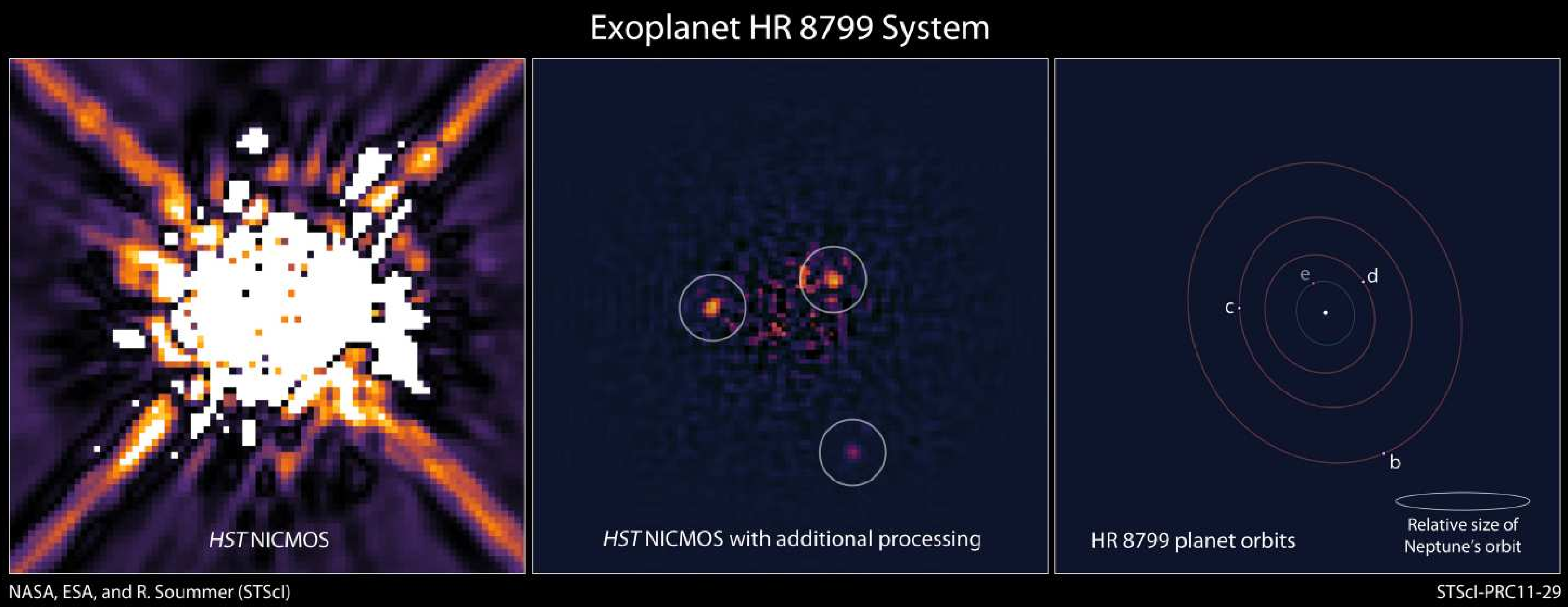
30 Doradus: Giant young star-cluster in Large Magellanic Cloud (150,000 ly), triggering birth of Sun-like stars (and surrounding debris disks).


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!

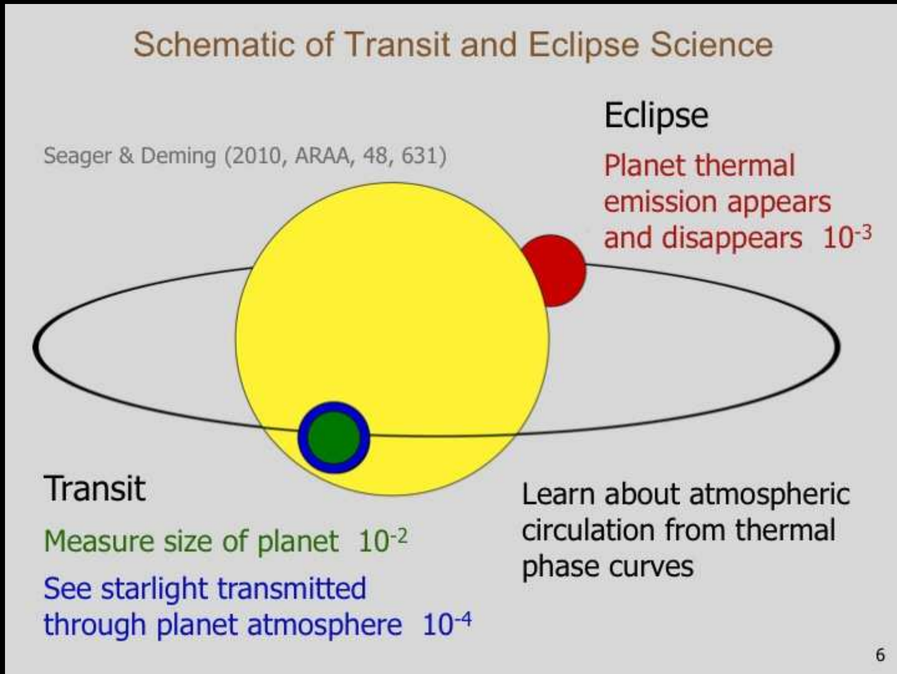
JWST can find such planets much closer in for much farther stars.

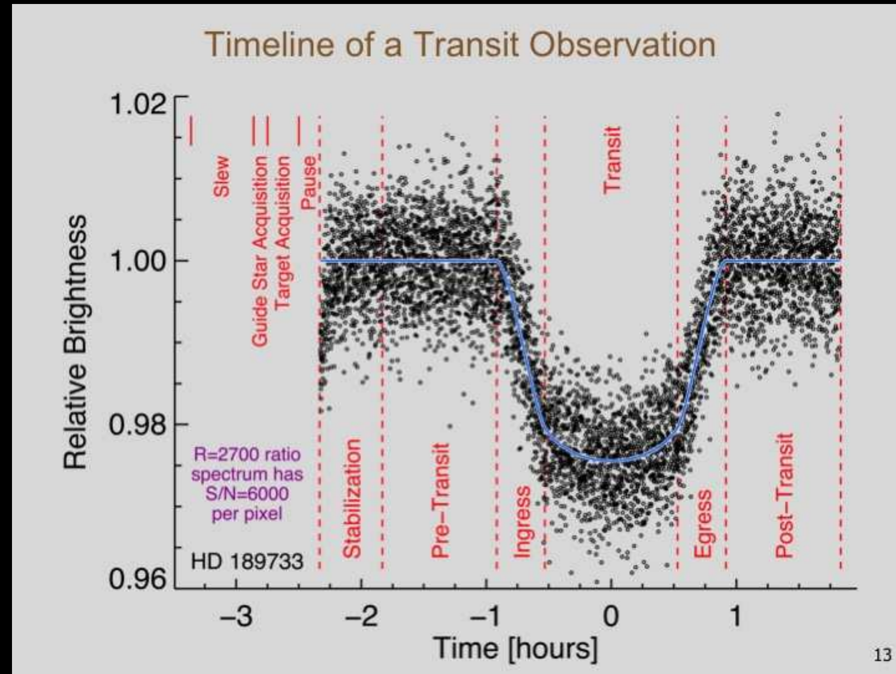


HST/NICMOS imaging of planetary system around the (carefully subtracted) star HR 8799: Direct imaging of planets around a nearby star!

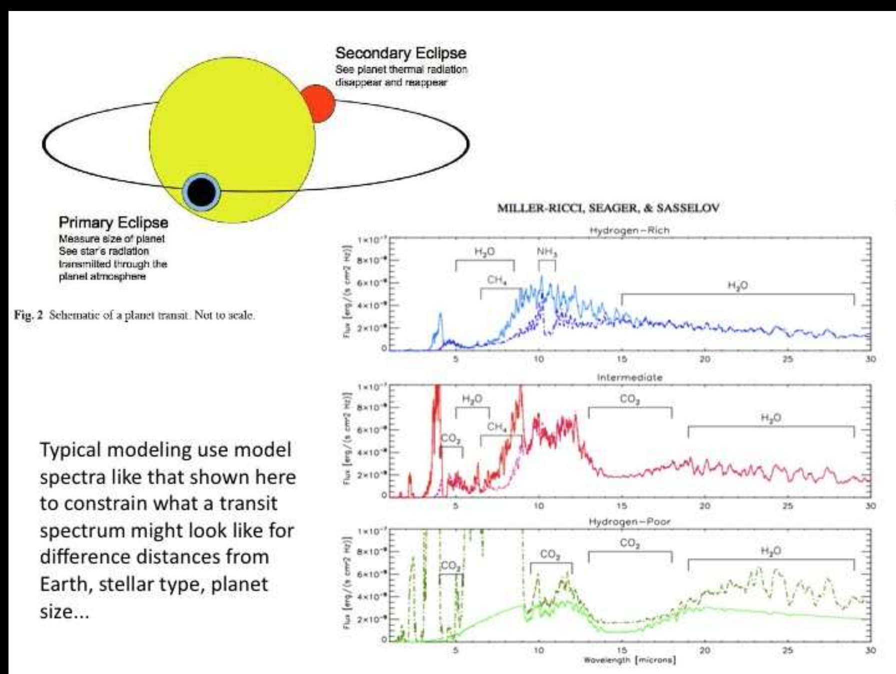
Press release: http://hubblesite.org/newscenter/archive/releases/2011/29/

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



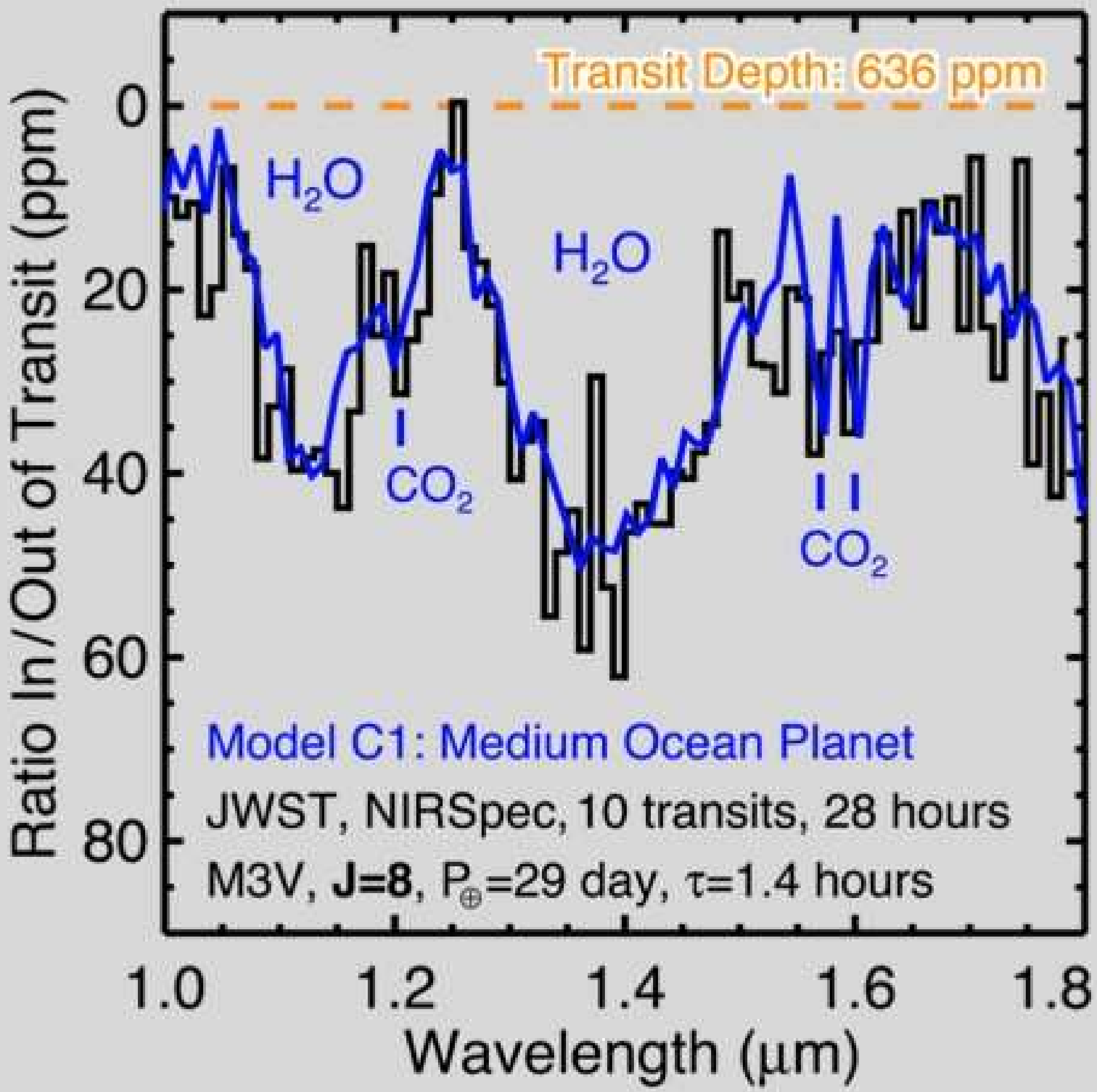


JWST can do very precise photometry of transiting Earth-like exoplanets.



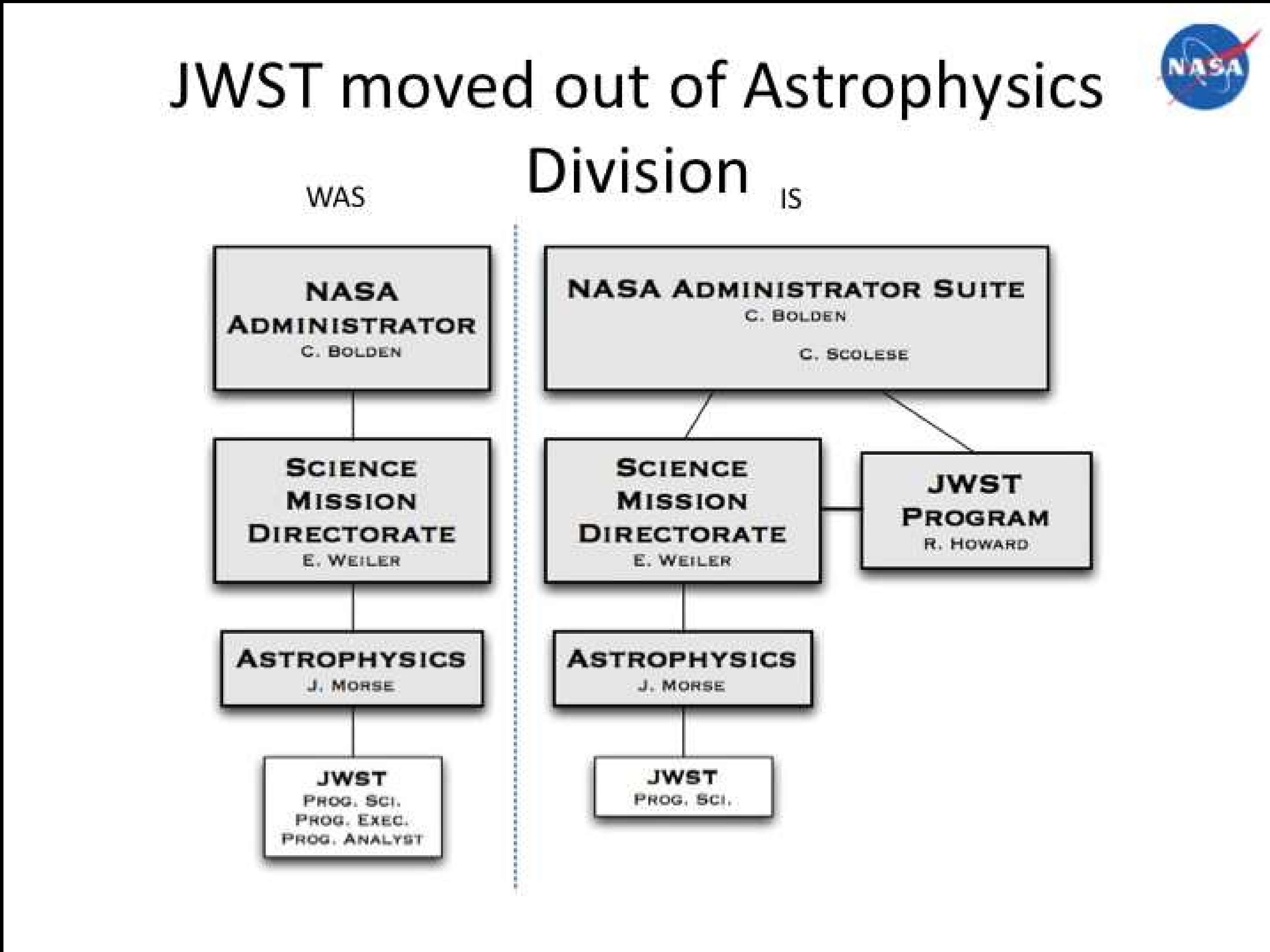
JWST IR spectra can find water and CO_2 in (super-)Earth-like exoplanets.

Transit Spectrum of Habitable "Ocean Planet"



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

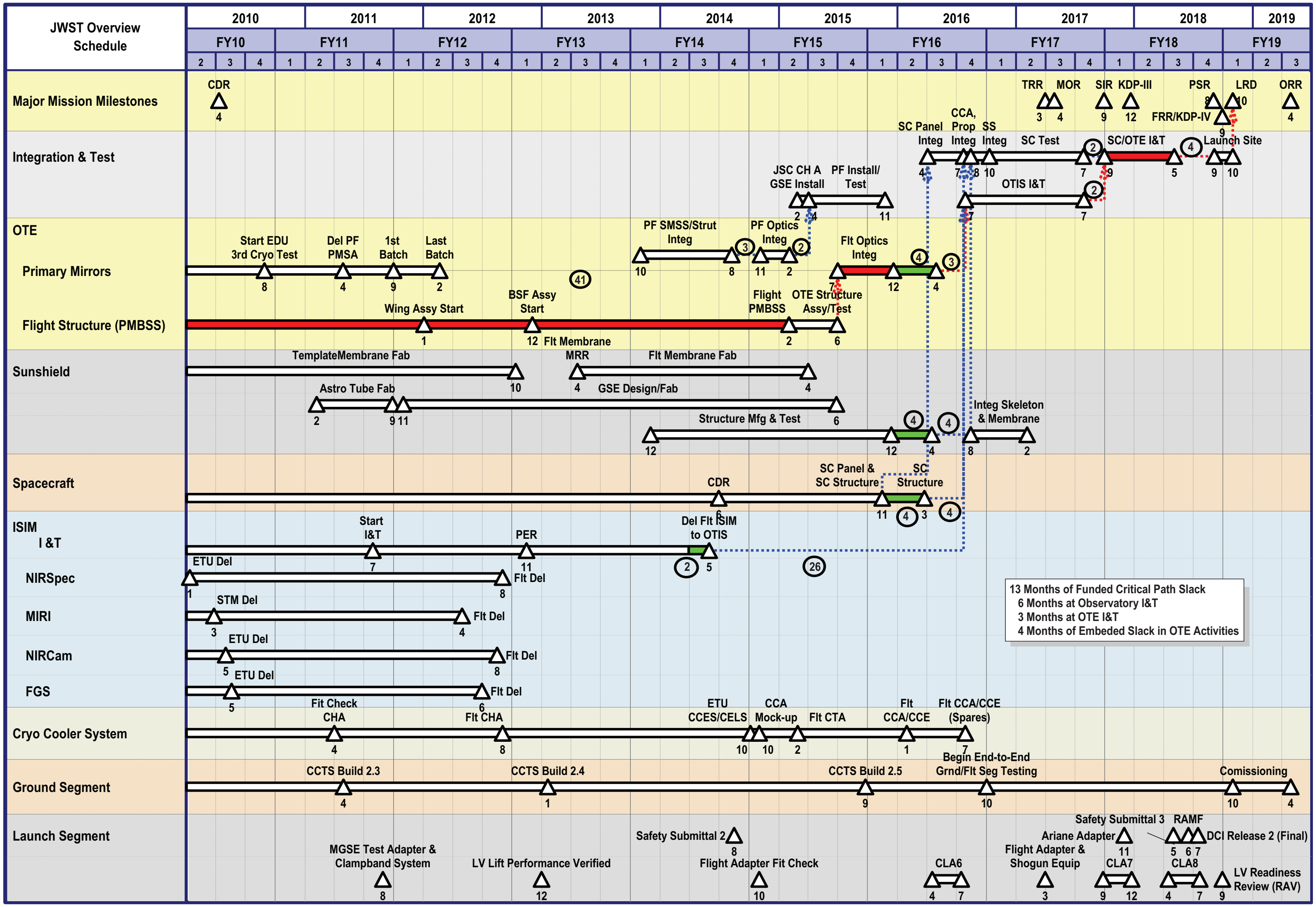
(7) Update of JWST programmatics as of 2011/2012:



NASA HQ Reorg: JWST budget no longer comes directly from SMD/Ap.

(7) Update of JWST programmatics as of 2011/2012:

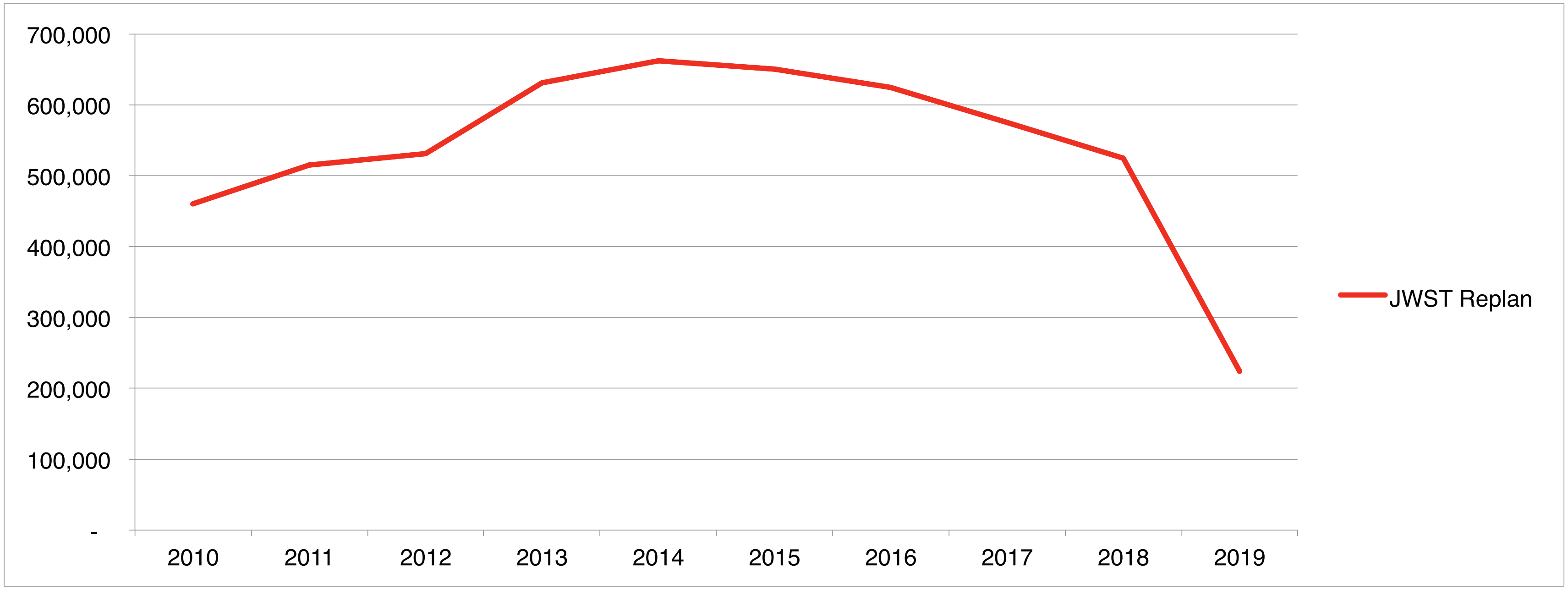
JWST Master Schedule



JWST schedule replan for FY12–18 as of 2011 (W. Ochs; NASA GSFC).

(7) Update of JWST programmatics as of 2011/2012:

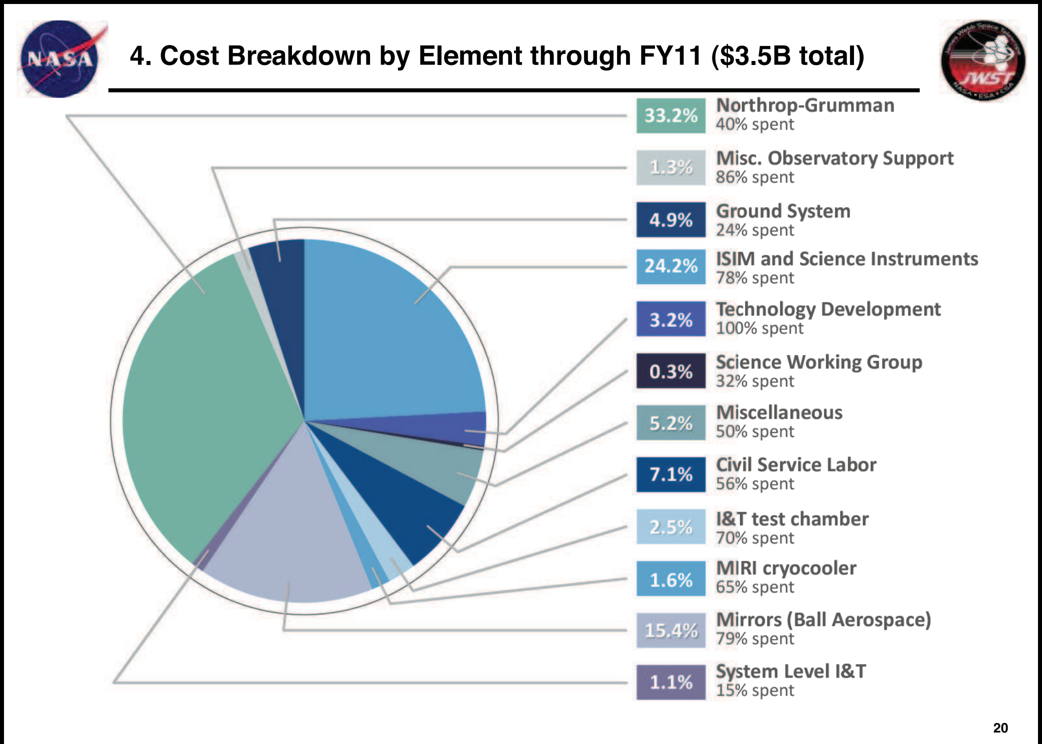
JWST Budget Profile (July 2011)

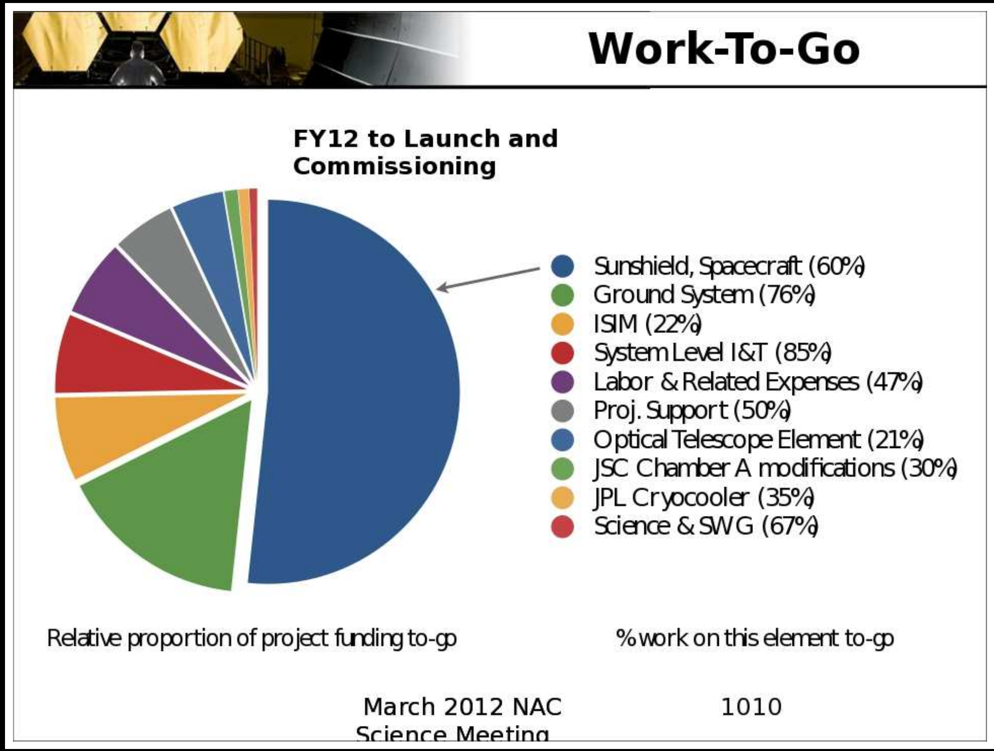


- **The replan addresses the findings of the SRB and the ICRP report**
  - Avoids making the mistakes identified by ICRP by providing adequate funding in early years
  - Provides a profile that can retire risk earlier by accelerating critical activities

JWST budget replan for FY12–19 as of 2011 (R. Howard; NASA HQ).

(7) Update of JWST programmatics as of 2011/2012:





Outcome of 2010 TAT & ICRP reviews and 2011 Project replan (JCL):

(Left) Cost breakdown through FY$\leq$11 on each element (as fraction of total Project cost + part thereof spent as of FY11);

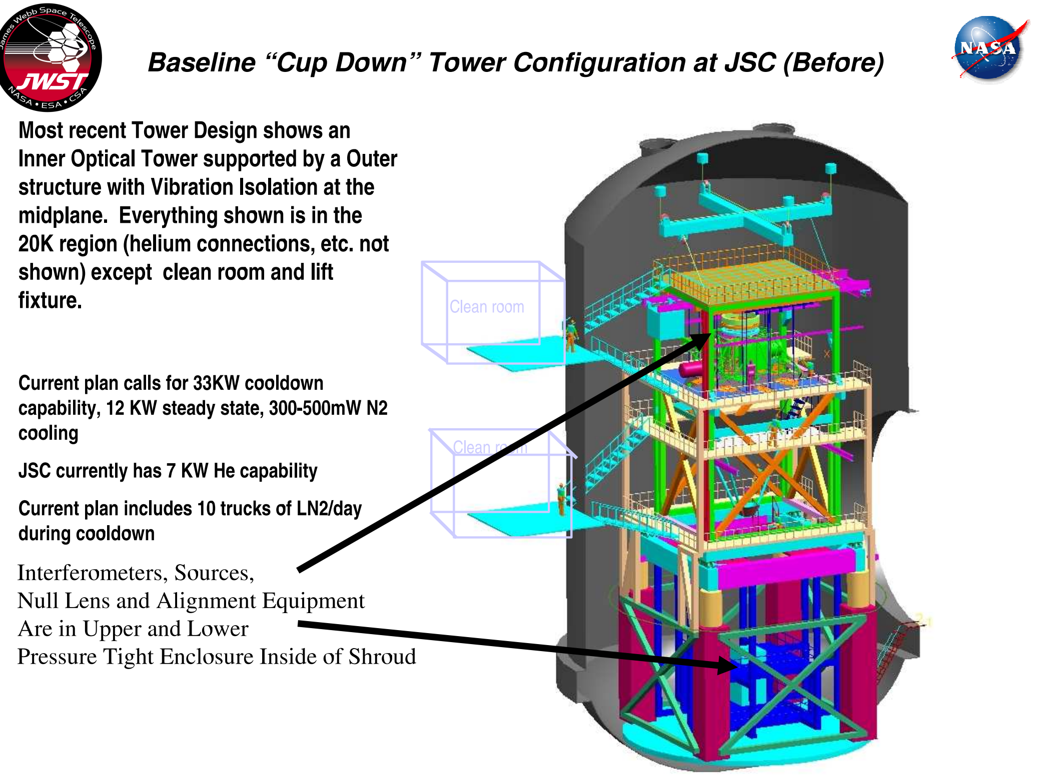
(Right) Work-to-go: FY12–FY19 work replanned for each element (as fraction of total cost of each element over length of Project).

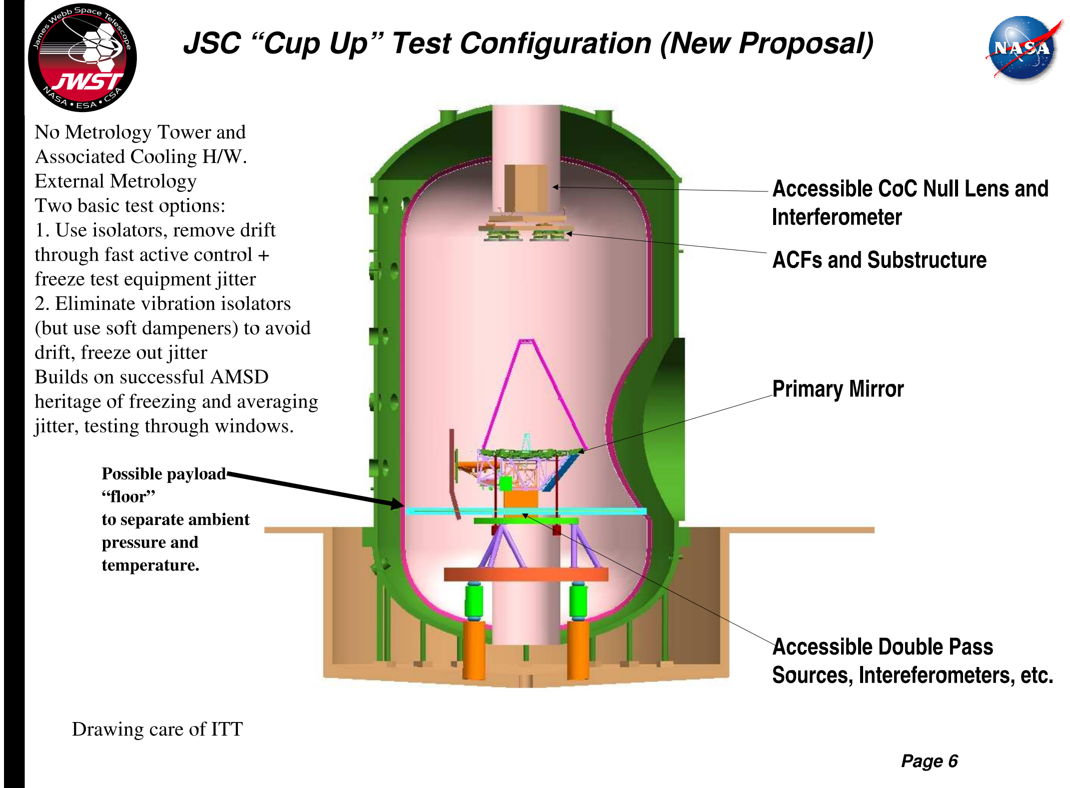
- After its 2011 replan, JWST now has a viable path to its 2018 launch.

Northrop Grumman Expertise in Space Deployable Systems

- Over 45 years experience in the design, manufacture, integration, verification and flight operation of spacecraft deployables
- 100% mission success rate, comprising over 640 deployable systems with over 2000 elements





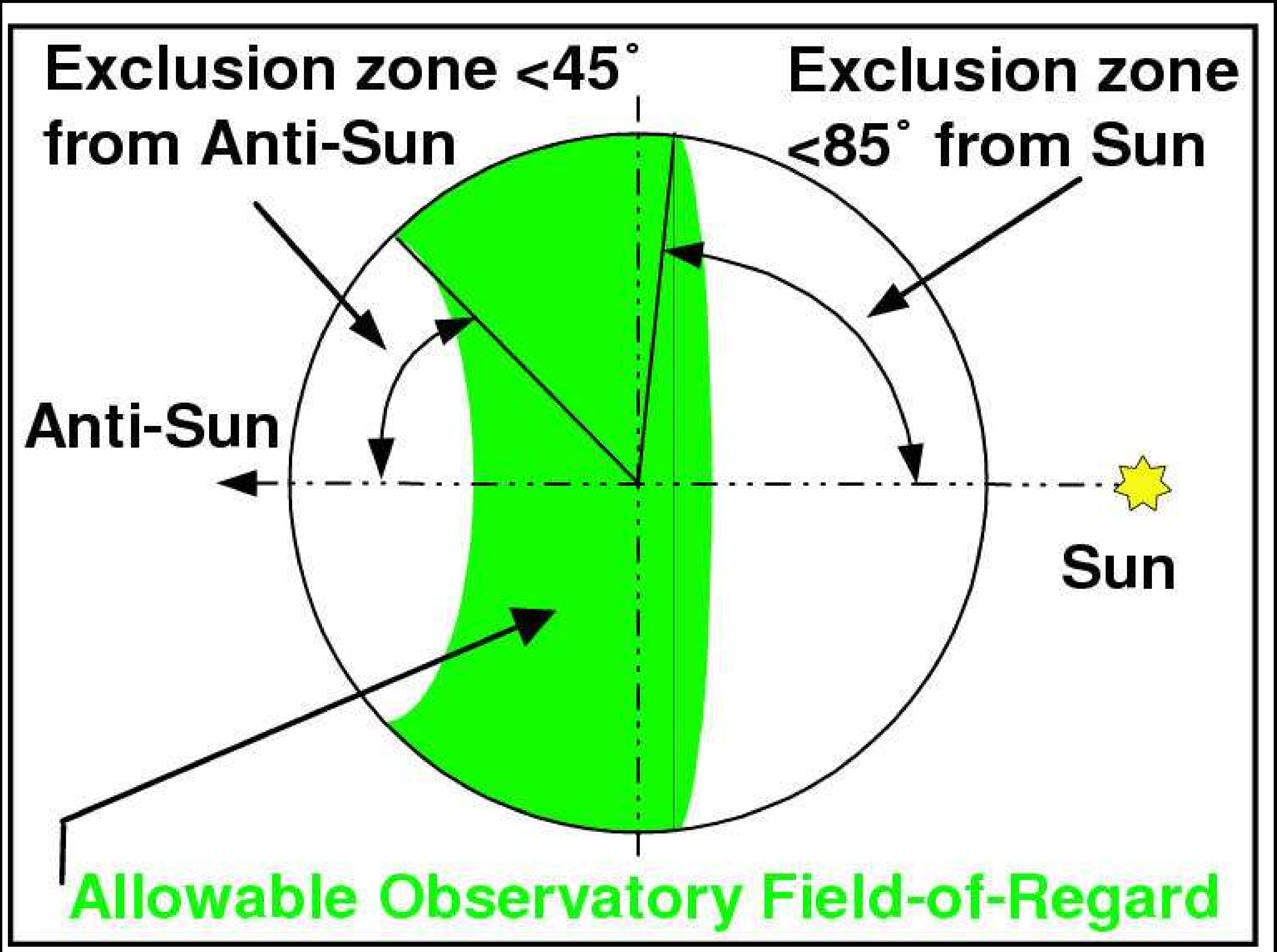


JWST underwent several significant replans and risk-reduction schemes:

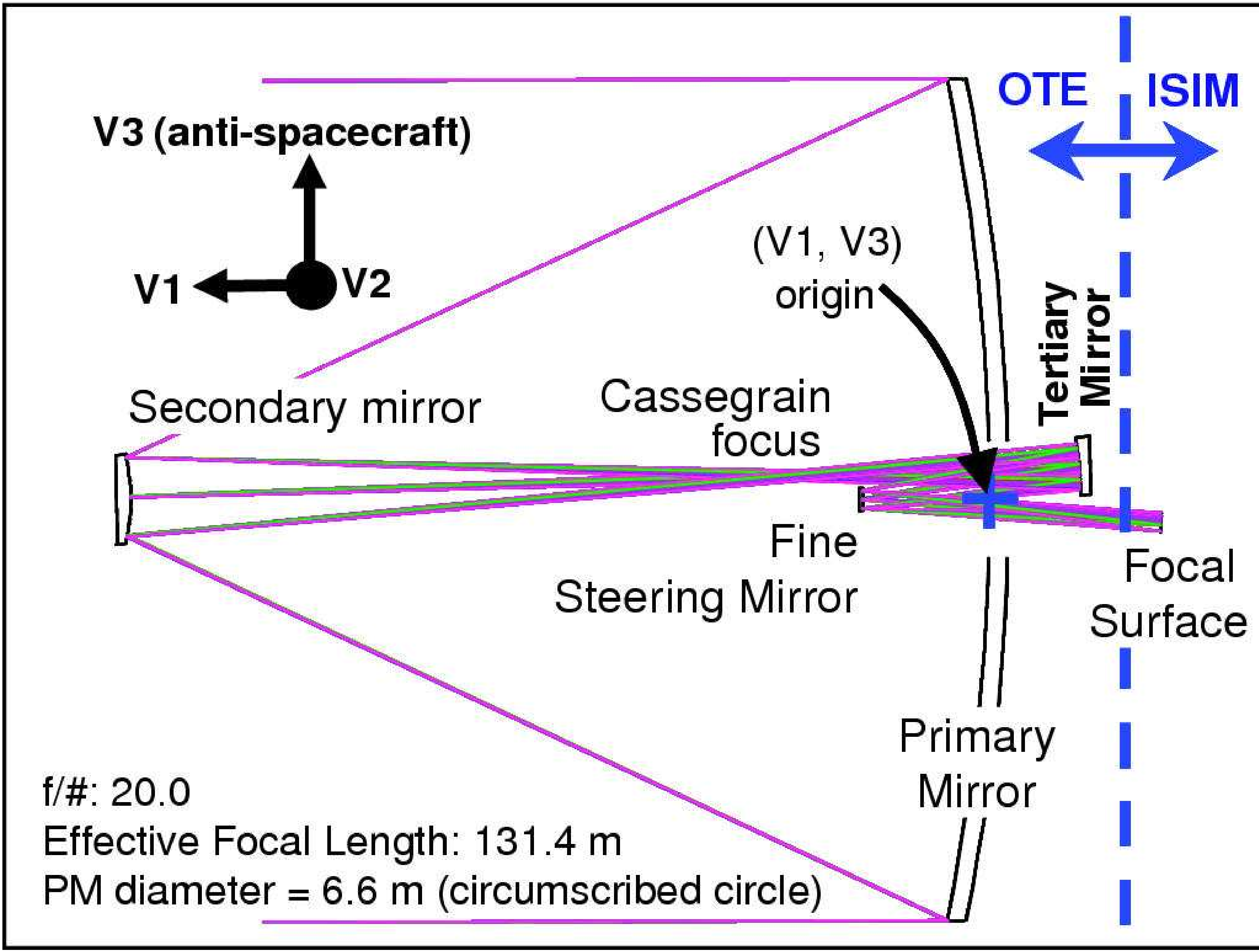
- $\lesssim$2003: Reduction from 8.0 to 7.0 to 6.5 meter. Ariane-V launch vehicle.
- 2005: Eliminate costly 0.7-1.0 μm performance specs (kept 2.0 μm).
- 2005: Simplification of thermal vacuum tests: cup-up, not cup-down.
- 2006: All critical technology at Technical Readiness Level 6 (TRL-6).
- 2007: Further simplification of sun-shield and end-to-end testing.
- 2008: Passes Mission Preliminary Design & Non-advocate Reviews.
- 2010: Passes Mission Critical Design Review — Replan Int. & Testing.

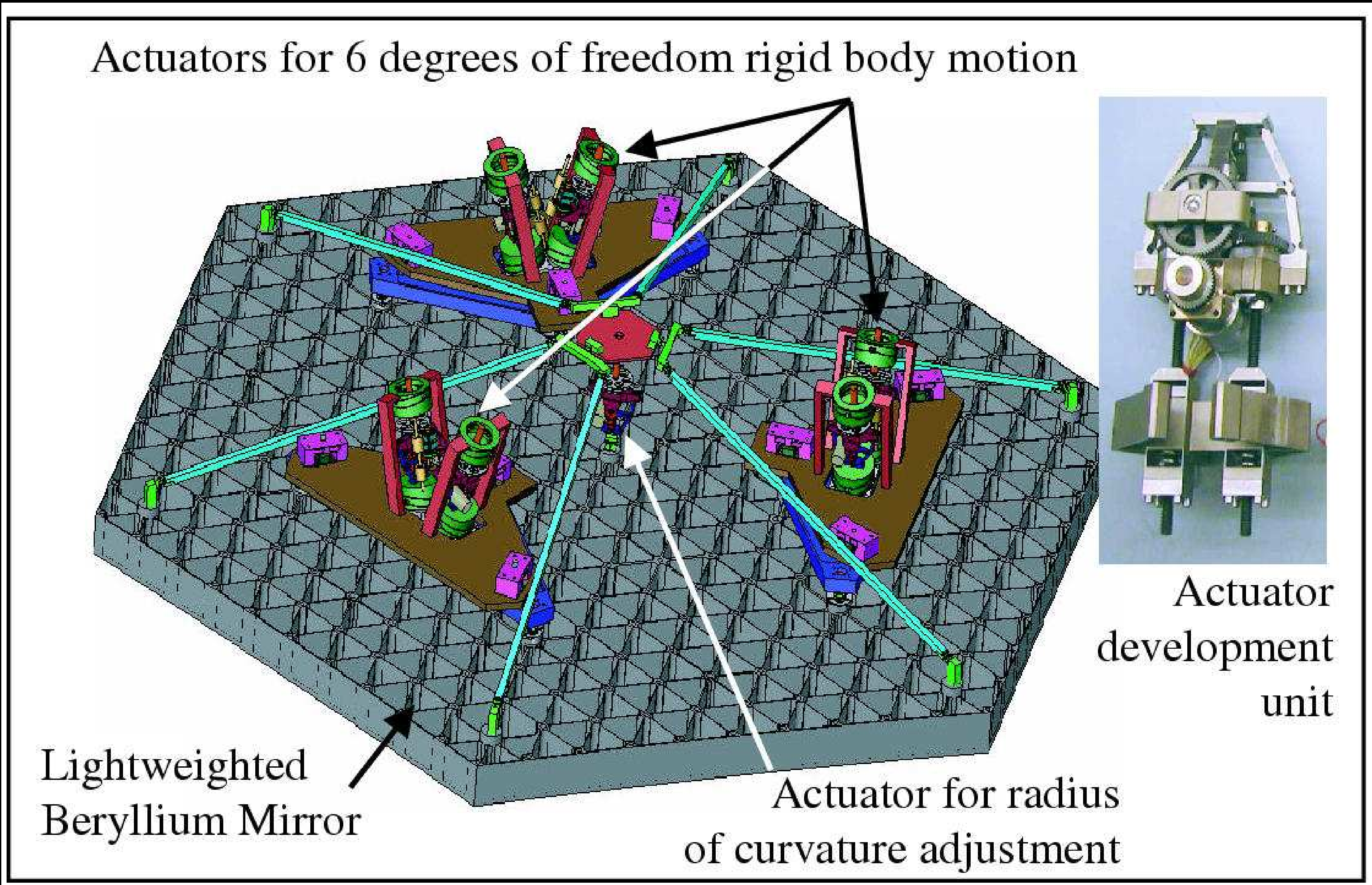
Life-sized JWST model, at NASA/GSFC with the whole JWST Project ...

Life-sized JWST model, at NASA/GSFC Friday afternoon after 5 pm ...



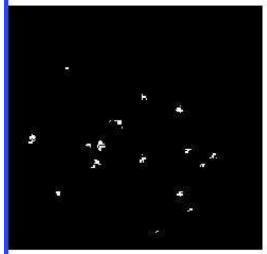
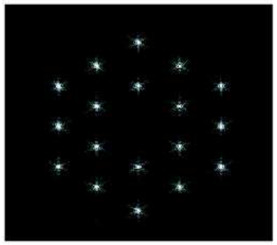
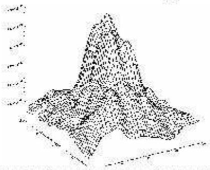
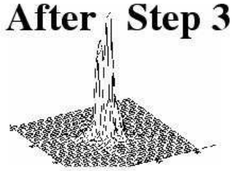
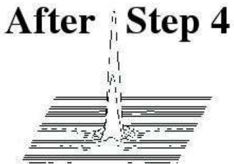
JWST can observe segments of sky that move around as it orbits the Sun.


OTE
ISIM
V3 (anti-spacecraft)
V1
V2
(V1, V3)
origin
Tertiary
Mirror
Secondary mirror
Cassegrain
focus
Fine
Steering Mirror
Focal
Surface
Primary
Mirror
f/#: 20.0
Effective Focal Length: 131.4 m
PM diameter = 6.6 m (circumscribed circle)



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

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

		Initial Capture	Final Condition
First light NIRCam  1. Segment Image Capture	**After Step 1** 	18 individual 1.6-m diameter aberrated sub-telescope images PM segments: < 1 mm, < 2 arcmin tilt SM: < 3 mm, < 5 arcmin tilt	PM segments: < 100 μm, < 2 arcsec tilt SM: < 3 mm, < 5 arcmin tilt
2. Coarse Alignment Secondary mirror aligned Primary RoC adjusted	**After Step 2** 	Primary Mirror segments: < 1 mm, < 10 arcsec tilt Secondary Mirror : < 3 mm, < 5 arcmin tilt	WFE < 200 μm (rms)
3. Coarse Phasing - Fine Guiding (PMSA piston)	**After Step 3** 	WFE: < 250 μm rms	WFE < 1 μm (rms)
4. Fine Phasing	**After Step 4** 	WFE: < 5 μm (rms)	WFE < 110 nm (rms)
5. Image-Based Wavefront Monitoring	**After Step 5** 	WFE: < 150 nm (rms)	WFE < 110 nm (rms)

JWST's Wave Front Sensing and Control is similar to the Keck telescope.

In L2, need WFS updates every 10 days depending on scheduling/illumination.

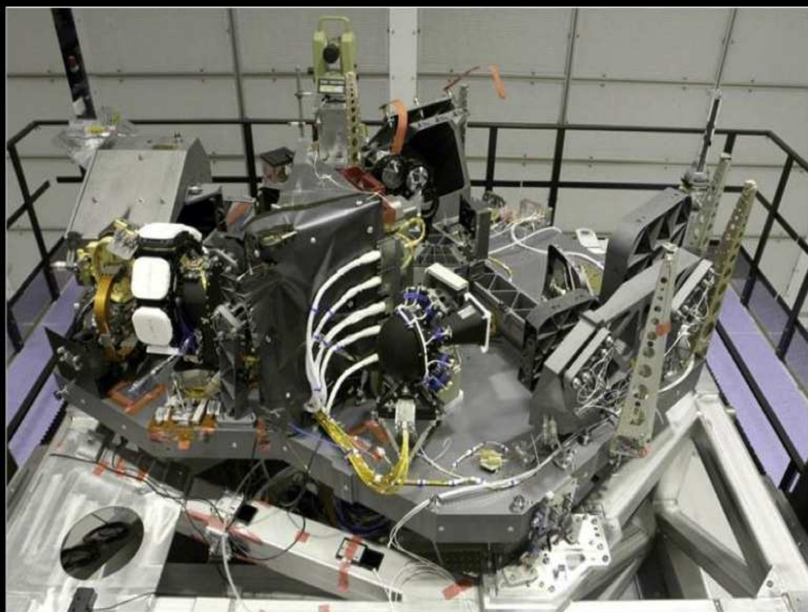
ETU NIRCam

Flight Fine Guidance Sensor

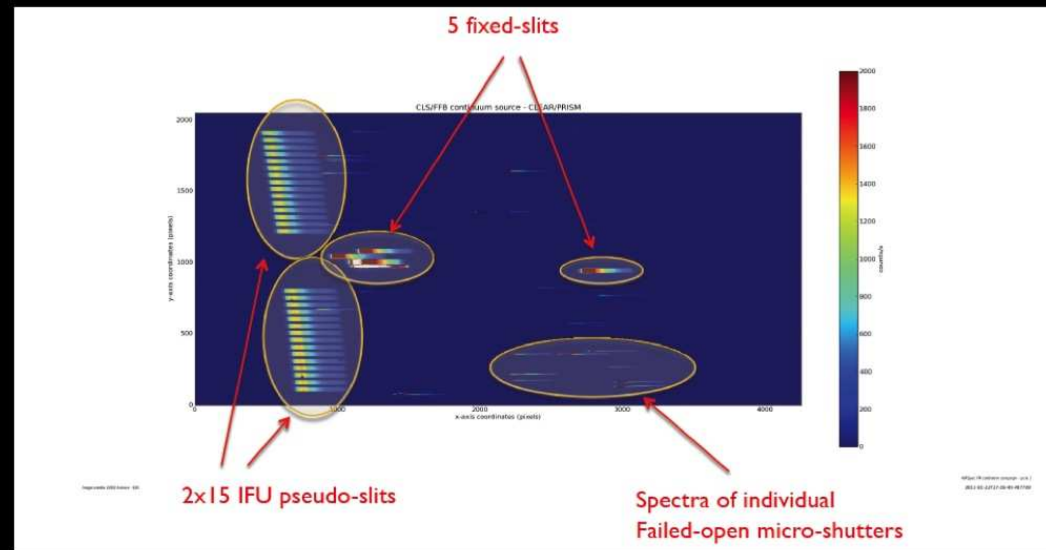
JWST's short-wavelength (0.6–5.0μm) imagers:

- NIRCam — built by UofA (AZ) and Lockheed (CA).
- Fine Guidance Sensor (& 1–5 μm grisms) — built by CSA (Montreal).
- NIRCam scheduled for delivery to GSFC Fall 2011, FGS early 2013.

FLIGHT NIRSpec



Flight NIRSpec First Light

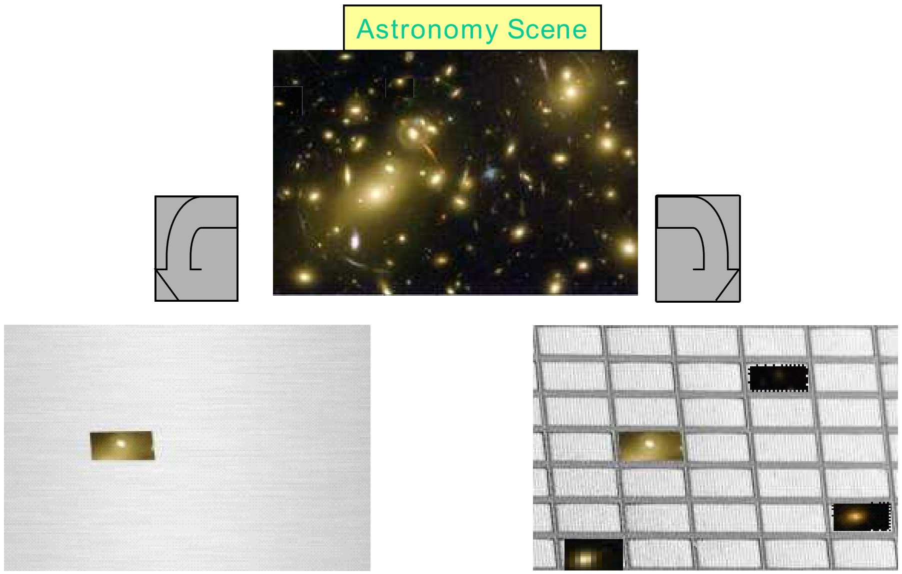


JWST's short-wavelength (0.6–5.0μm) spectrograph:

- NIRSpec — built by ESA/ESTEC and Astrium (Munich).
- Fight build completed and tested with First Light in Spring 2011.

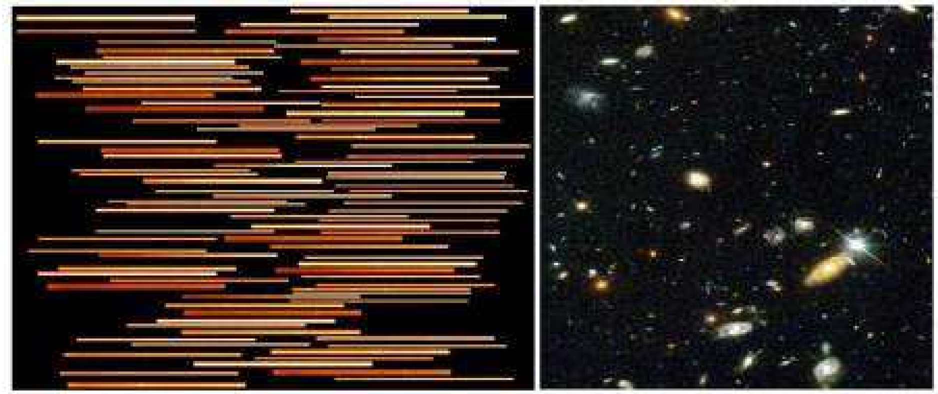
Final NIRSpec delivery to NASA/GSFC in early 2013.

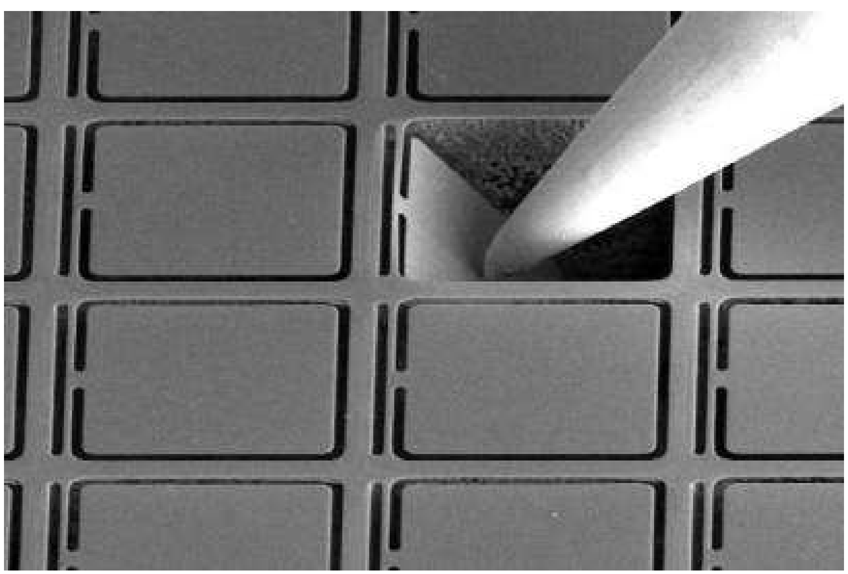
Micro Shutters

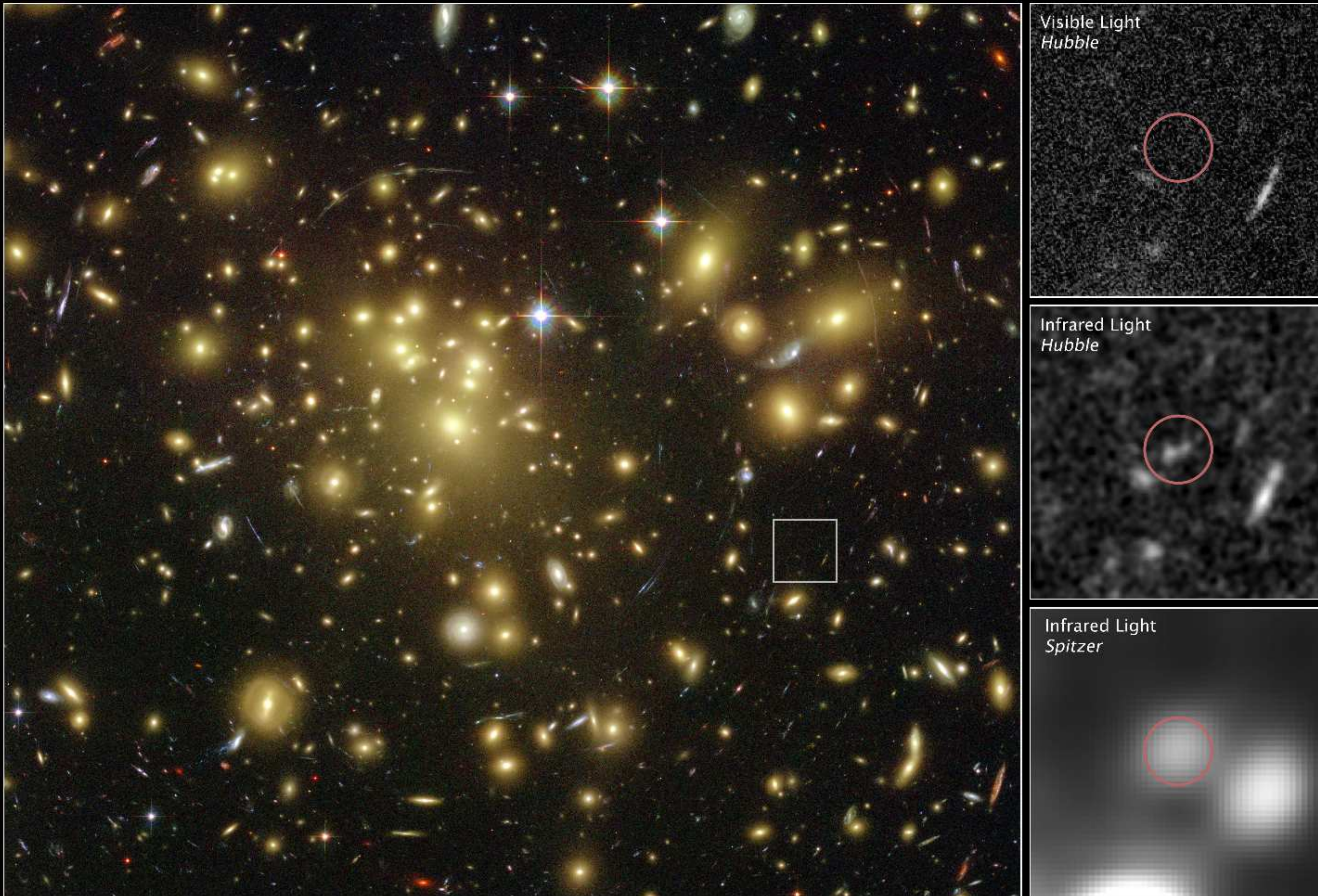


Metal Mask/Fixed Slit

Shutter Mask







Distant Gravitationally Lensed Galaxy ▪ Galaxy Cluster Abell 1689

Hubble Space Telescope ▪ ACS/WFC NICMOS

NASA, ESA, and L. Bradley (JHU), R. Bouwens (UCSC), H. Ford (JHU), and G. Illingworth (UCSC)

STScI-PRC08-08a

(0) Intro: Cosmic Expansion and Contents of the Universe

Expansion $\Rightarrow$ redshift $\lambda_{obs} = \lambda_{rest} \,.\, (1+z)$

Hubble's Law: $D \simeq v \,/\, H_o \simeq (c/H_o) \,.\, z = R_o \,.\, z$

Cosmic Content: inside $R_0=(c/H_0) \simeq 13.73$ Glyr:

[$t_{univ} = (211 \pm 1\,!) \,.\, (t_{dino}=65$ Myr)]

Photons (light): $N_{h\nu} \sim 10^{89}$

Baryons (atoms): $N_b \sim 10^{80}$

η=Photons/Baryons $\eta \sim 10^{9} \Rightarrow$ He/H ratio $= 0.235$

Energy Density: as fraction of critical closure density:

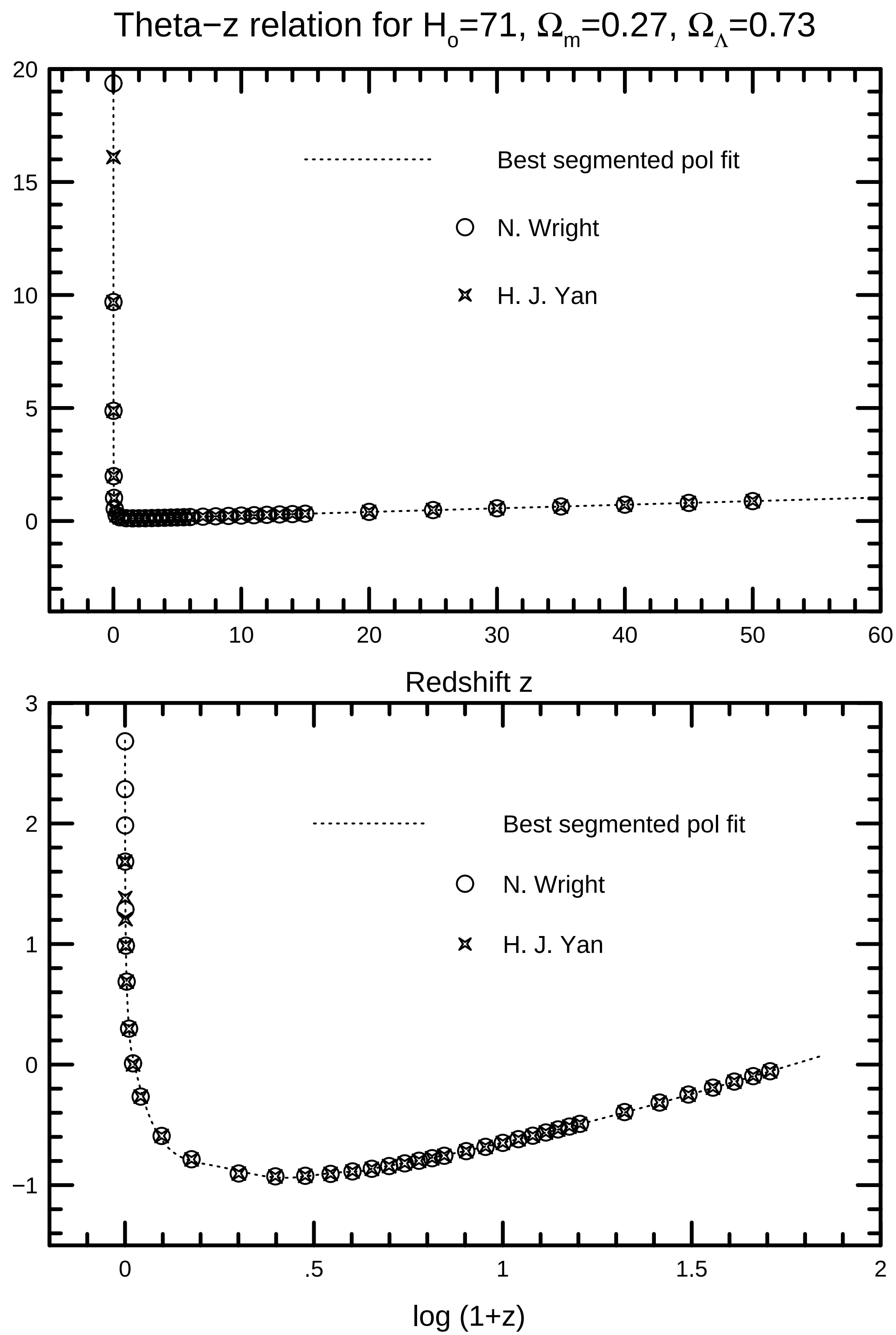
Baryons (atoms): $\Omega_b = \rho_b/\rho_{crit} \simeq 0.042$

Dark Matter: $\Omega_d = \rho_d/\rho_{crit} \simeq 0.20$

Dark Energy (Λ): $\Omega_\Lambda = \rho_\Lambda/\rho_{crit} \simeq 0.76$

(Supermassive) black holes: $\rho_{smbh}/\rho_{crit} \simeq 0.0001$

Total $\Omega_{tot}=\rho_{tot}/\rho_{crit} \simeq 1.00 \pm 0.02$



Angular size θ vs. redshift z in Lambda cosmology:

$H_0 = 73$ km/s/Mpc,
$\Omega_m = 0.24$, $\Omega_\Lambda = 0.76$.

- $\theta \propto 1/z$ for $z \lesssim 0.05$ (small angle approximation).
- $\theta \propto z$ for $z \gtrsim 3$!!
- Objects appear larger with redshift for $z \gtrsim 1.65$!!

But angular sizes of rigid rods are nearly constant for all redshifts $0.5 \lesssim z \lesssim 10$!

JWST — Web-links:

http://capwiz.com/supportjwst/home/

http://www.whitehouse.gov/contact

http://www.facebook.com/SaveJWST

http://twitter.com/#!/saveJWST or http://goo.gl/iAR4I

http://savethistelescope.blogspot.com/

http://www.change.org/petitions/do-not-cancel-funding-for-the-james-webb-space-telescope

General JWST Information:

http://www.aura-astronomy.org/news/news.asp?newsID=264

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

http://www.asu.edu/clas/hst/www/jwst/ [Talk, Movie, Java-tool]

Thank you for your time and hard work!