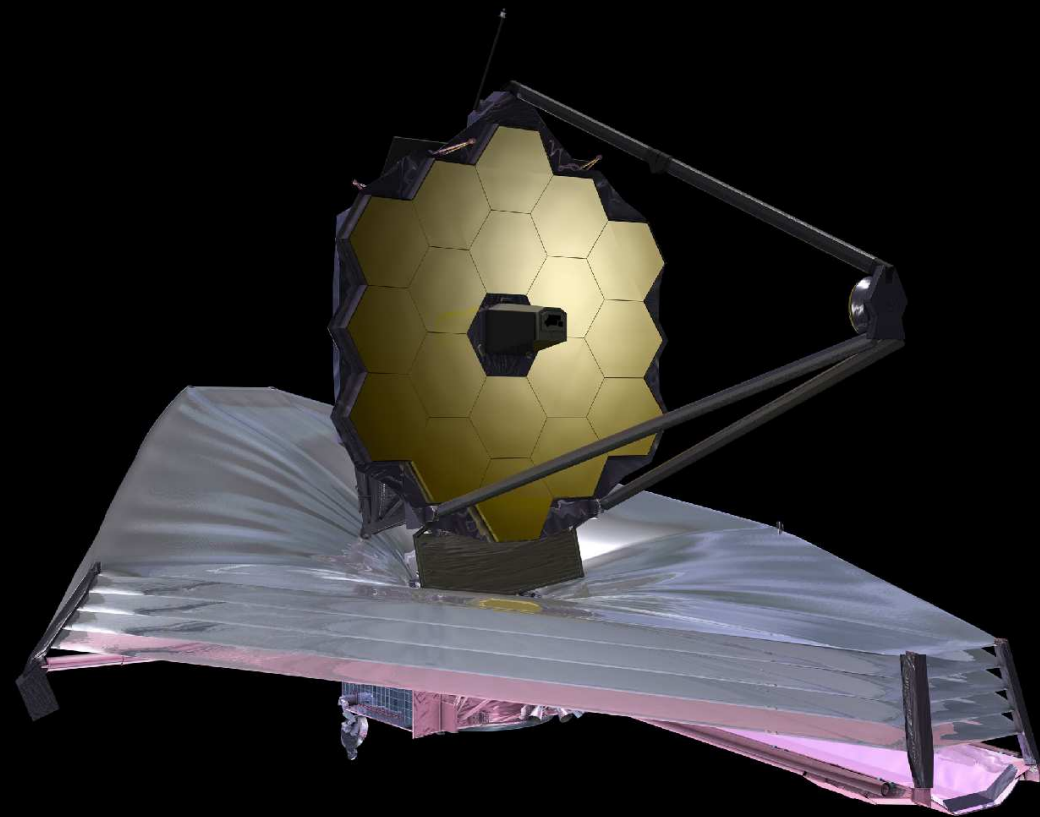


How will JWST measure First Light, Reionization, and Galaxy Assembly: Science and Project Update as of 2012.

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



Talk at IPAC/Caltech, Pasadena, CA, Wednesday April 11, 2012

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

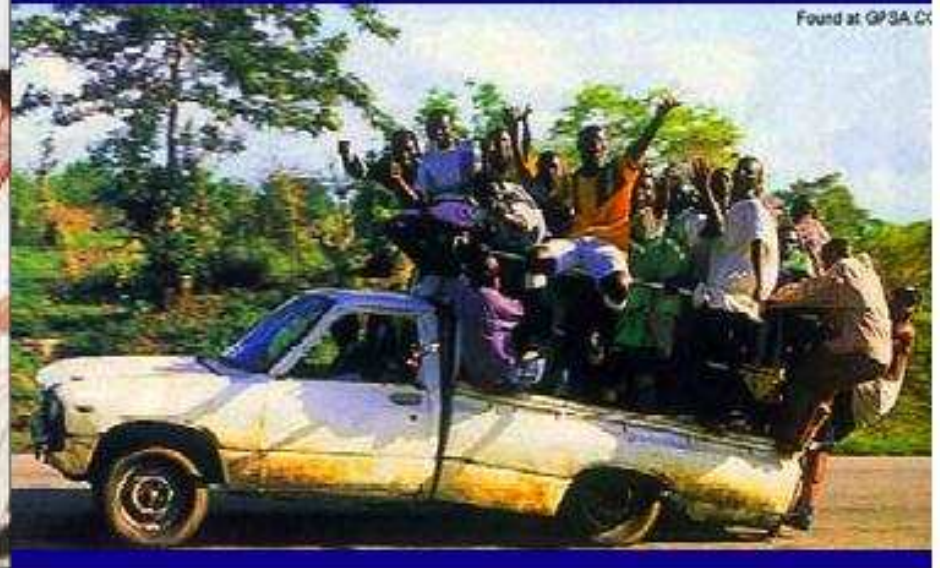
What the Scientists See:



What the Project Manager Sees:



The Happy Balance



Found at GP3A.CX

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

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.



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

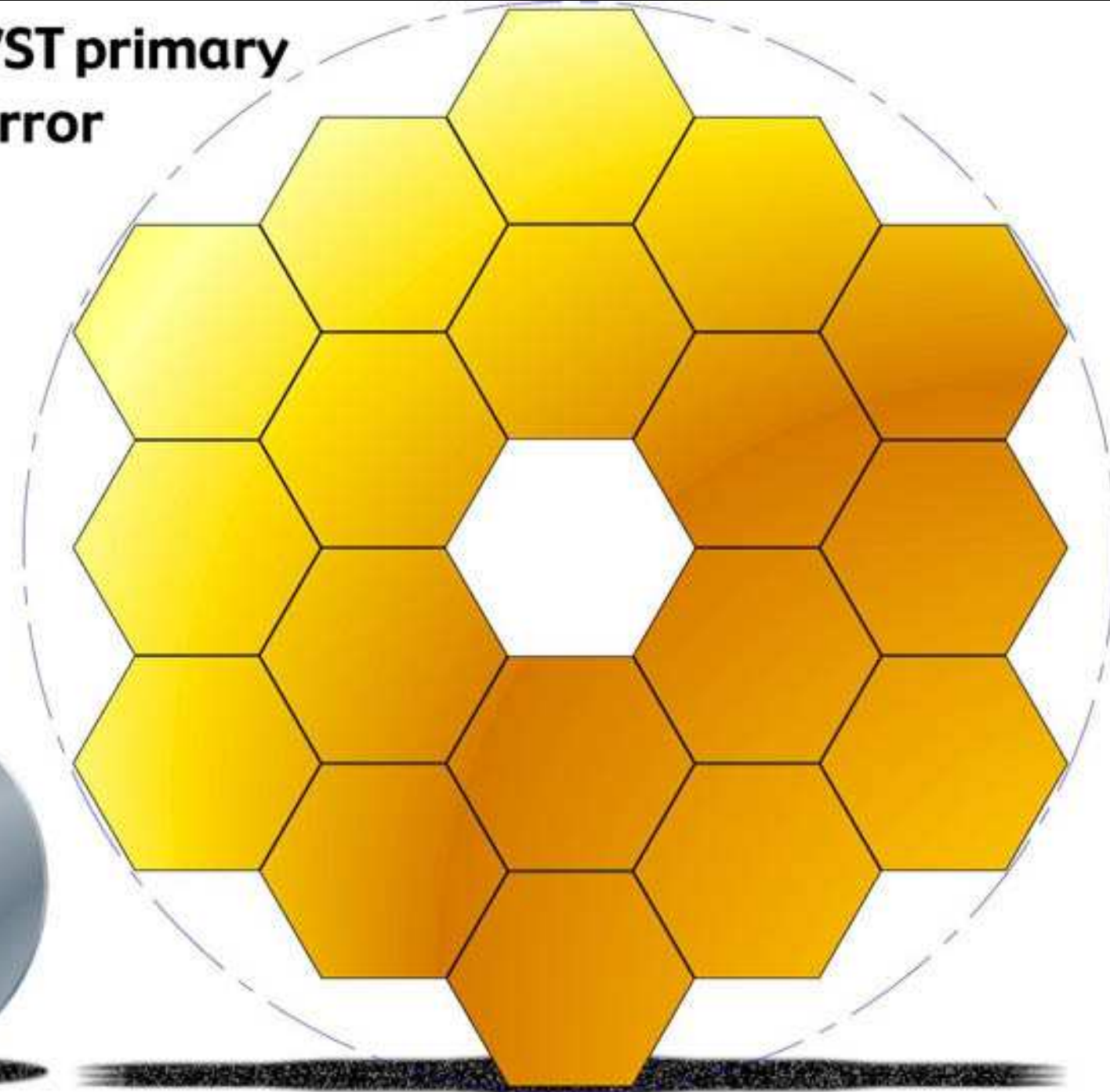


James E. Webb (1906–1992) — Second NASA Administrator

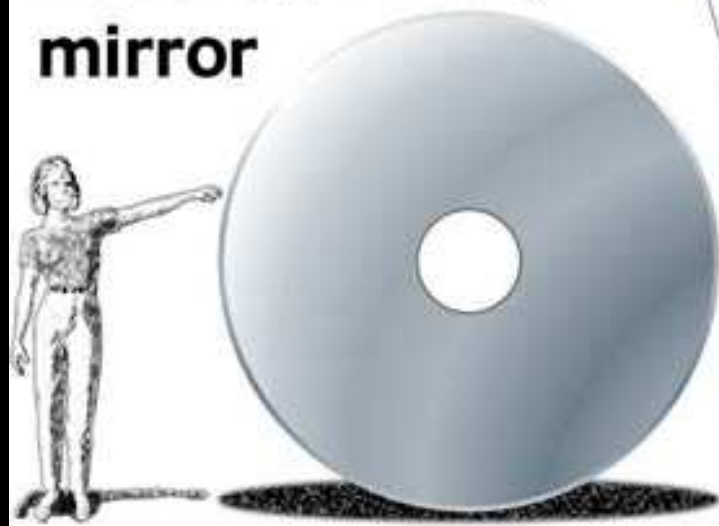
Hubble: Concept in 1970's; Made in 1980's; Operational 1990– \gtrsim 2014.

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

**JWST primary
mirror**

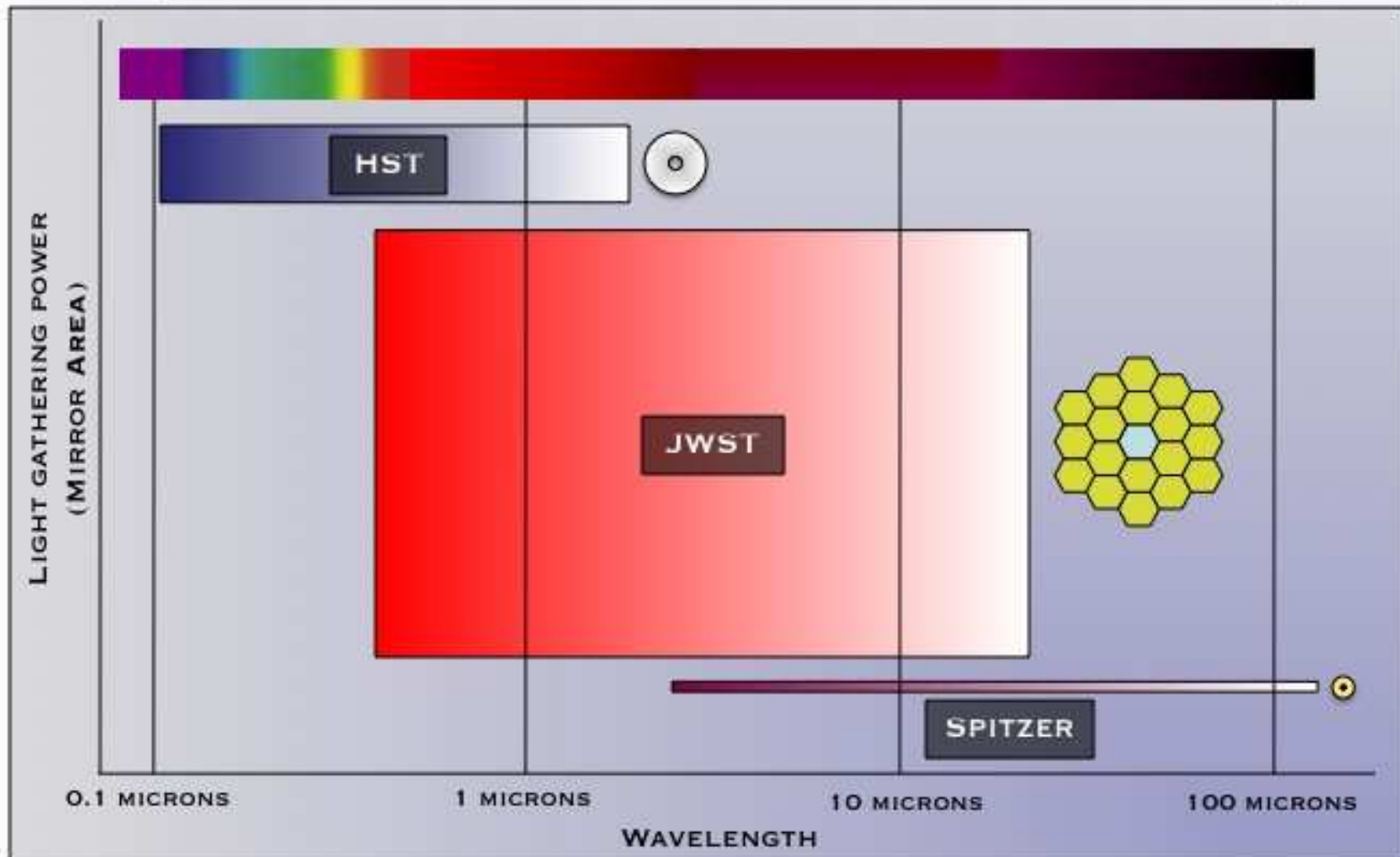


**Hubble primary
mirror**



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.

THE JAMES WEBB SPACE TELESCOPE



LIGHT GATHERING POWER
JWST = 25 M² ; HUBBLE = 4.5 M² ; SPITZER = 0.6 M²

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:

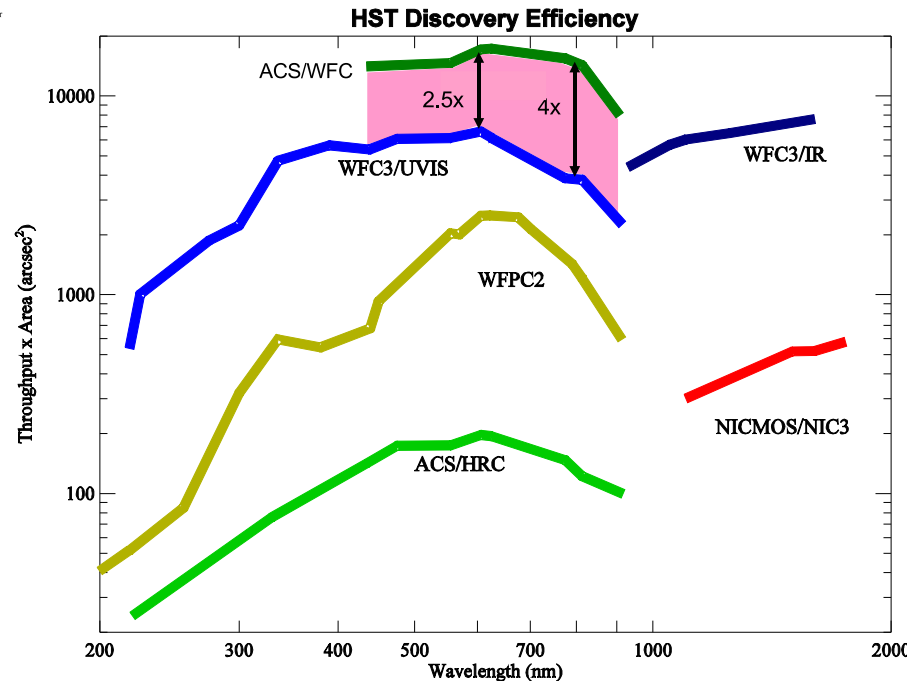


WFC3: Hubble's new Panchromatic High-Throughput Camera

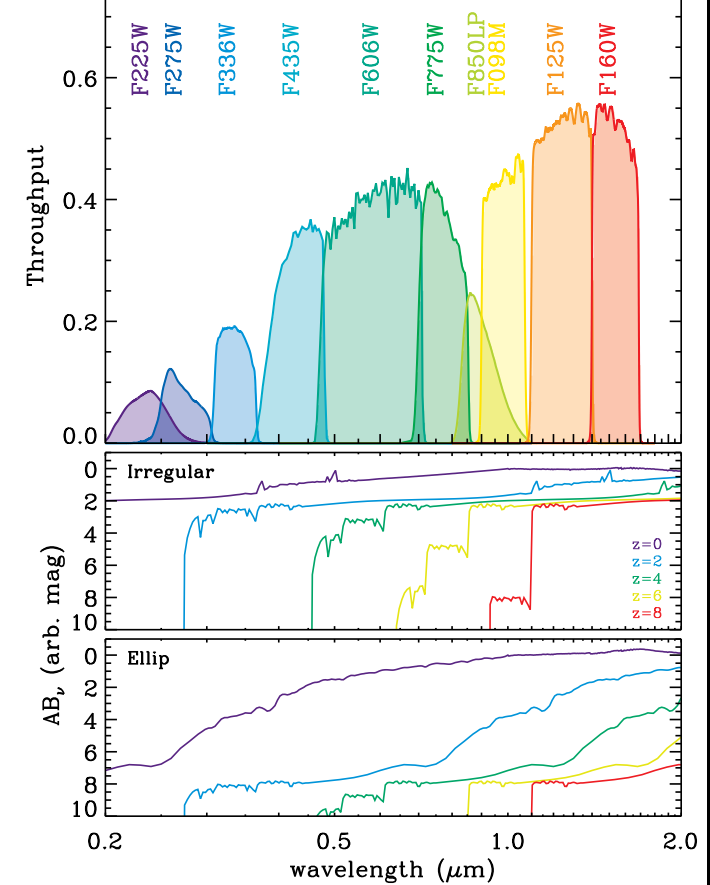


HST WFC3 and its **IR channel**: a critical pathfinder for JWST science.

Role of ACS in HST Post-SM4 Imaging Capability



ACS/WFC superior to WFC3 survey efficiency at visible-red wavelengths



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:

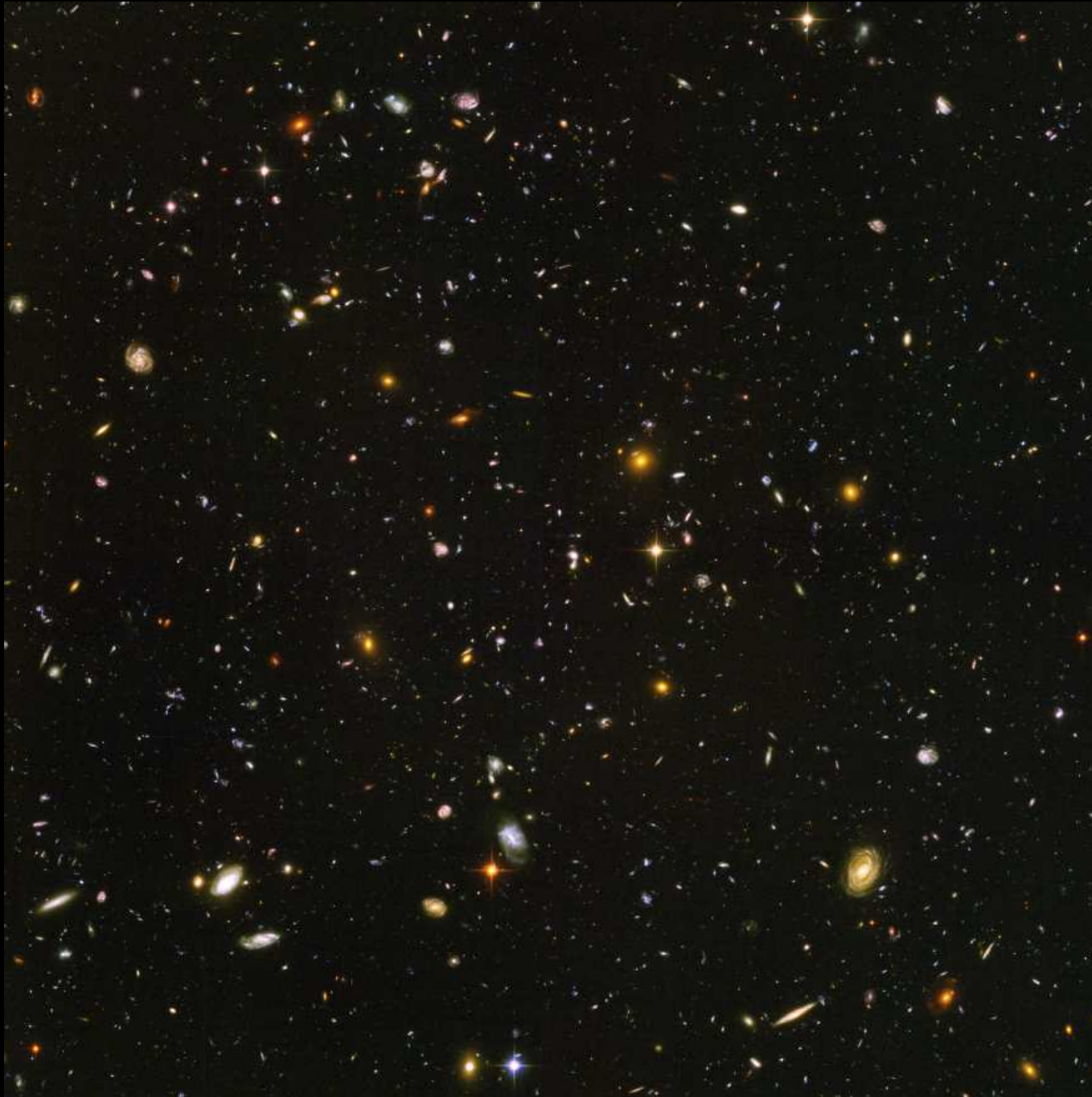
- $QE \gtrsim 70\%$, $1k \times 1k$ array of $0''.13$ pixel, $FOV \simeq 2'.25 \times 2'.25$.

⇒ WFC3 opened major new parameter space for astrophysics in 2009:

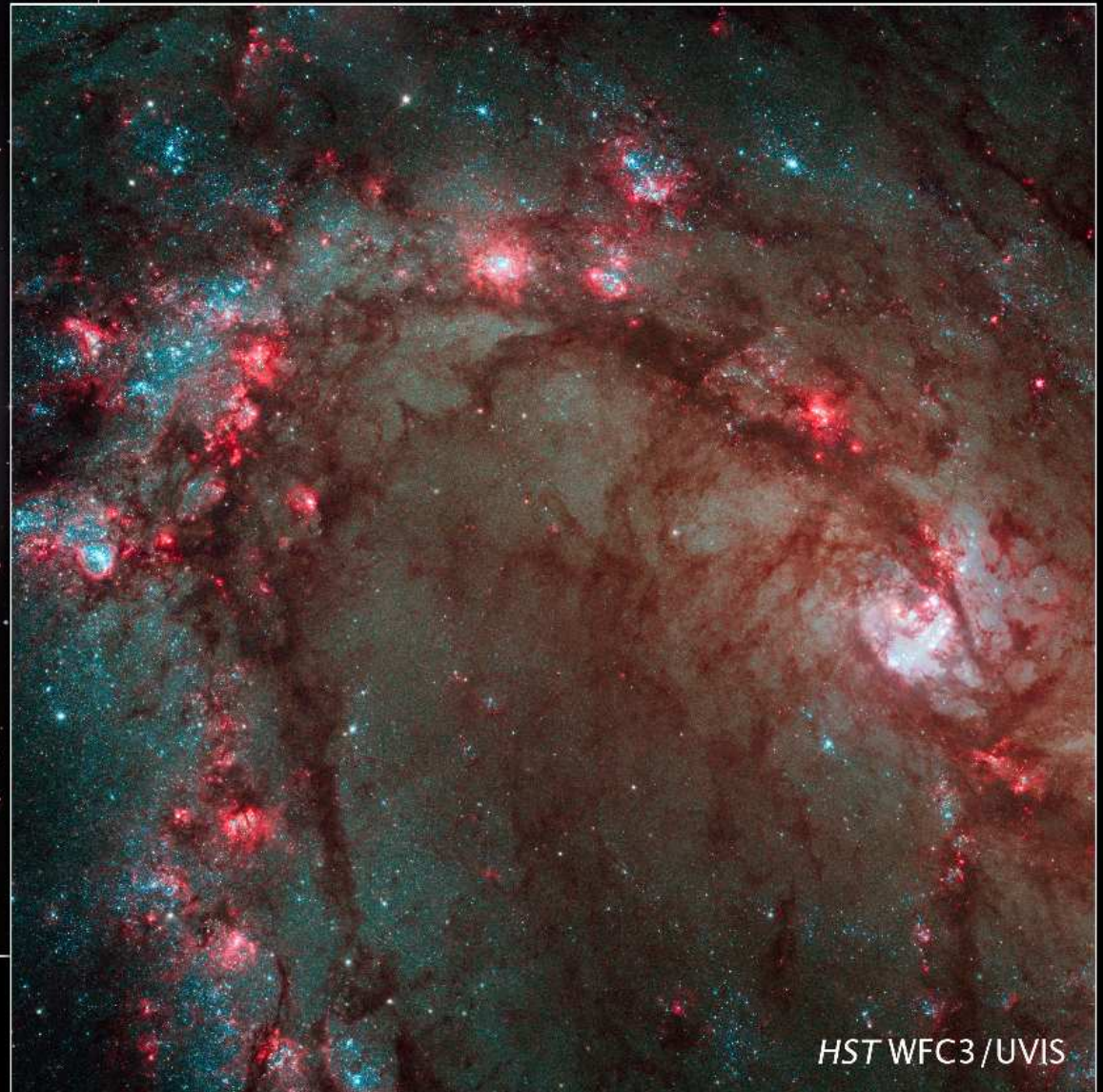
WFC3 filters designed for star-formation and galaxy assembly at $z \simeq 1-8$.

- 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.



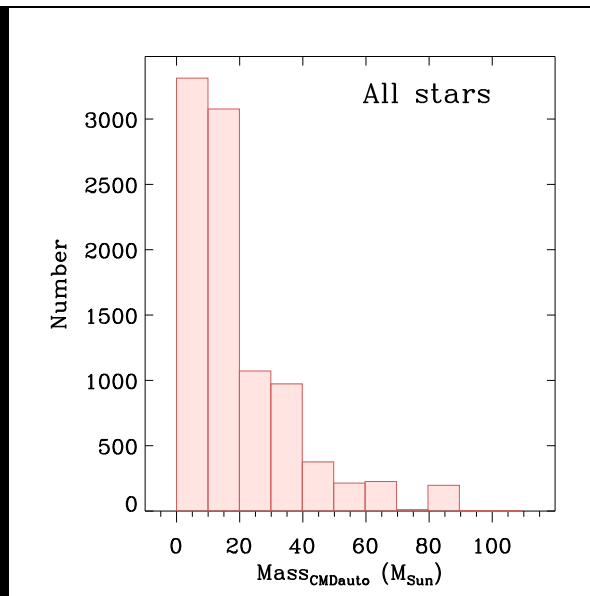
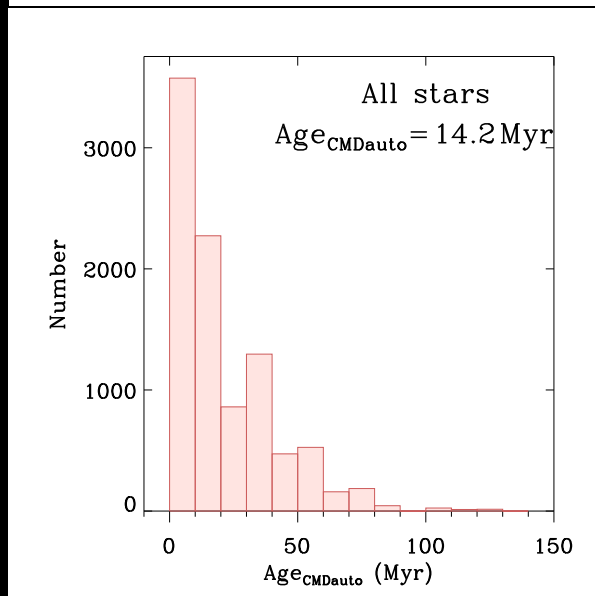
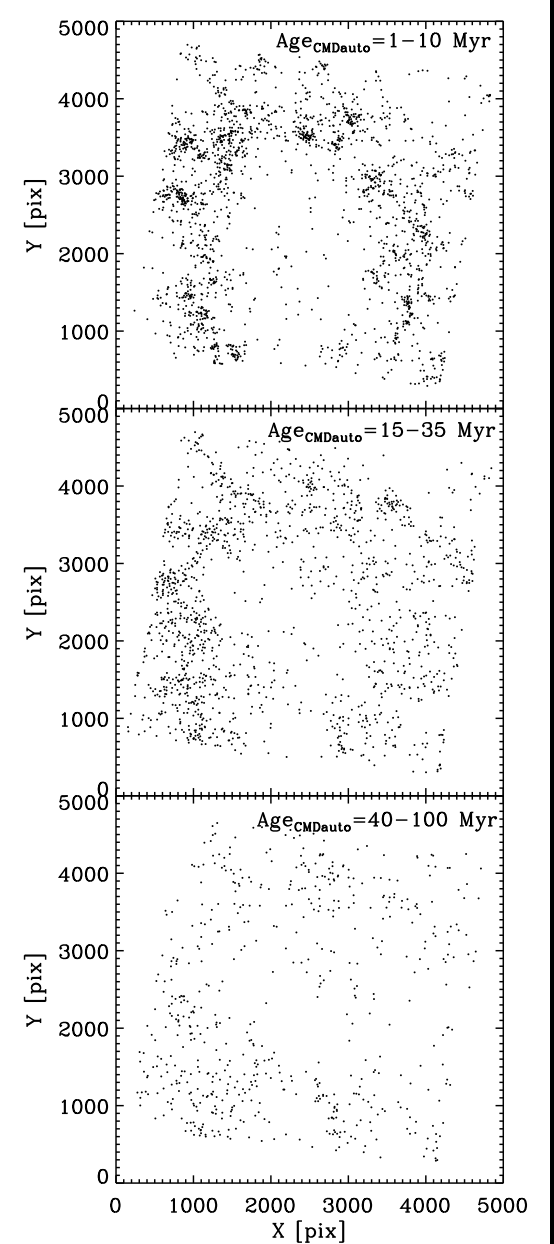
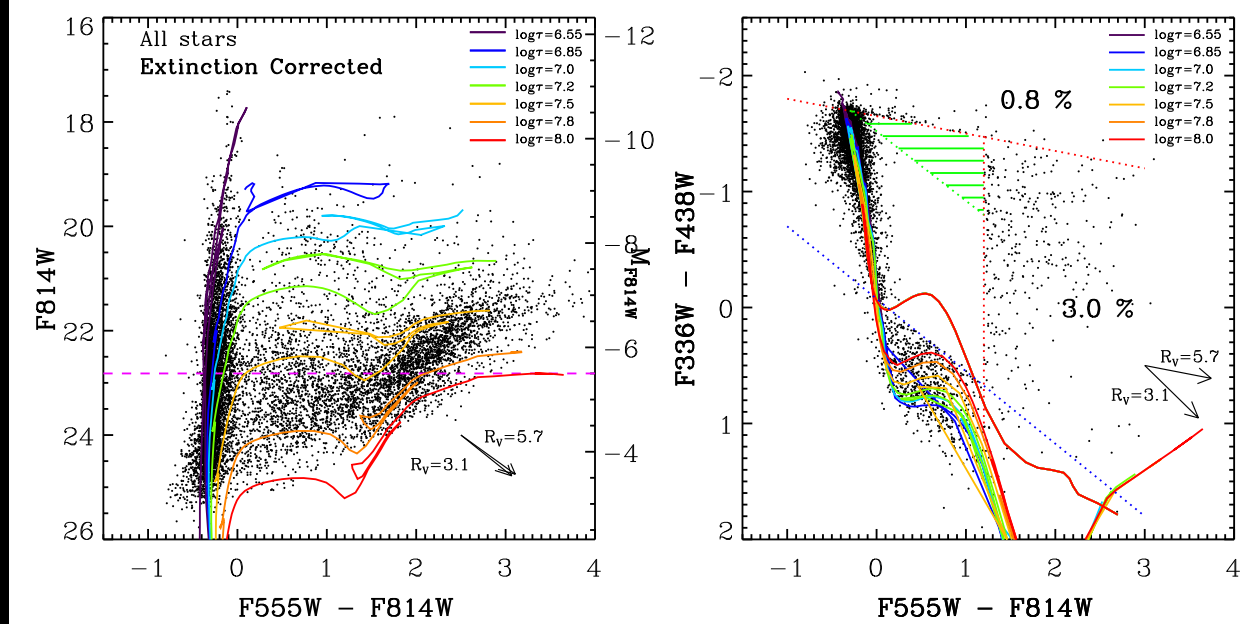
Spiral Galaxy M83
Hubble Space Telescope ■ WFC3/UVIS

Spiral Galaxy M83
HST WFC3/UVIS

F336W U
F555W V
F814W I
F502N [O III]
F657N H α

5,000 light-years
1,500 parsecs 70''

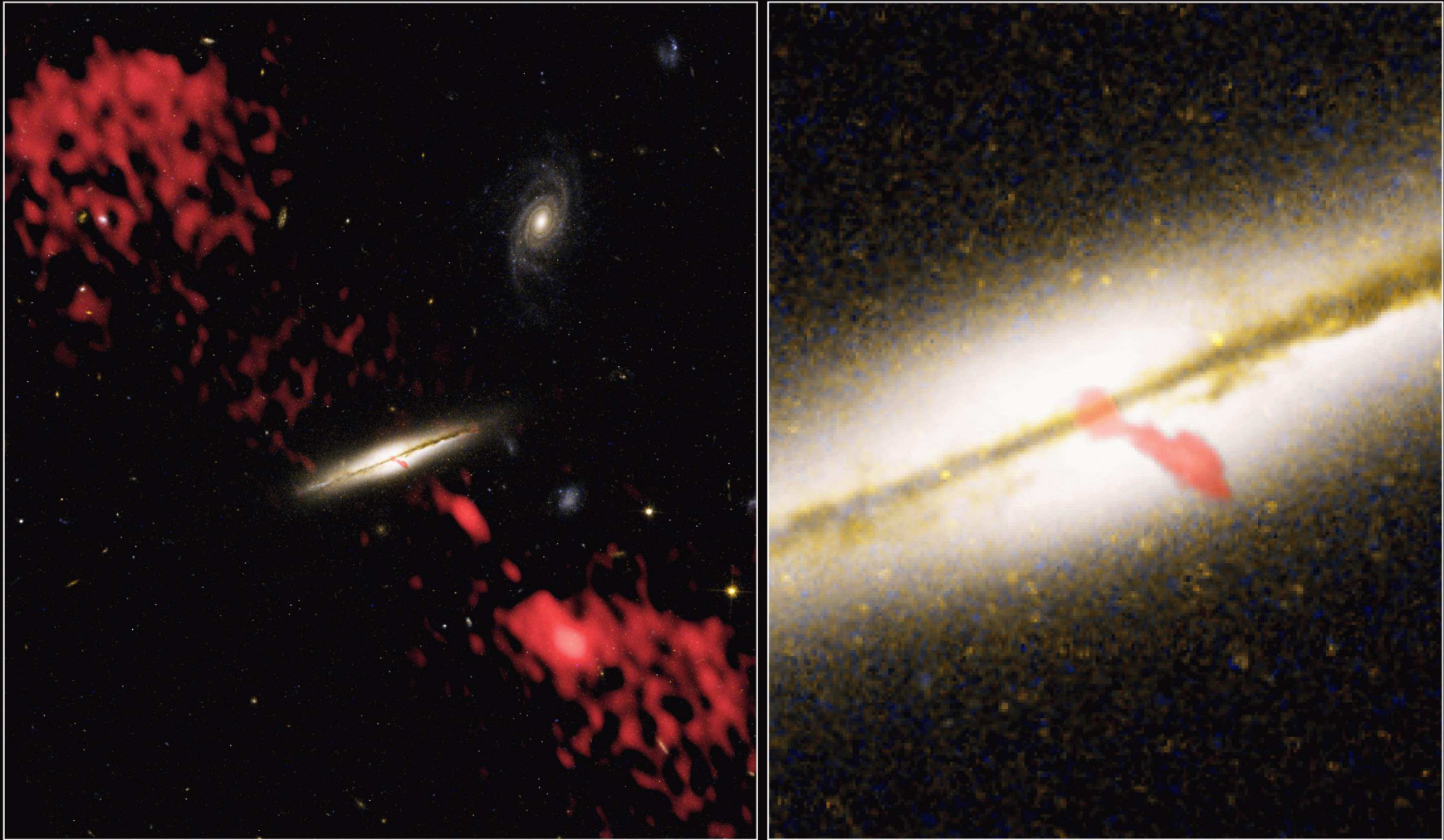




Well determined dust-corrected ages for stars in M83, with formation and dissipation along/across spiral arms (Hwihyun Kim et al. 2012, ApJS).

JWST can do this in much dustier environments and for older stellar populations. But must do all we can with HST in UV-blue before JWST flies!

(2) Measuring Galaxy Assembly & Supermassive Blackhole Growth



Radio Galaxy 0313-192
Hubble Space Telescope ACS WFC • Very Large Array

NASA, NRAO/AUI/NSF and W. Keel (University of Alabama) • STScI-PRC03-04

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



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

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

Centaurus A
NGC 5128
HST WFC3/UVIS

F225W+F336W+F438W

F487N H β

F502N [O III]

F547M γ

F657N H α + [N II]

F673N [S II]

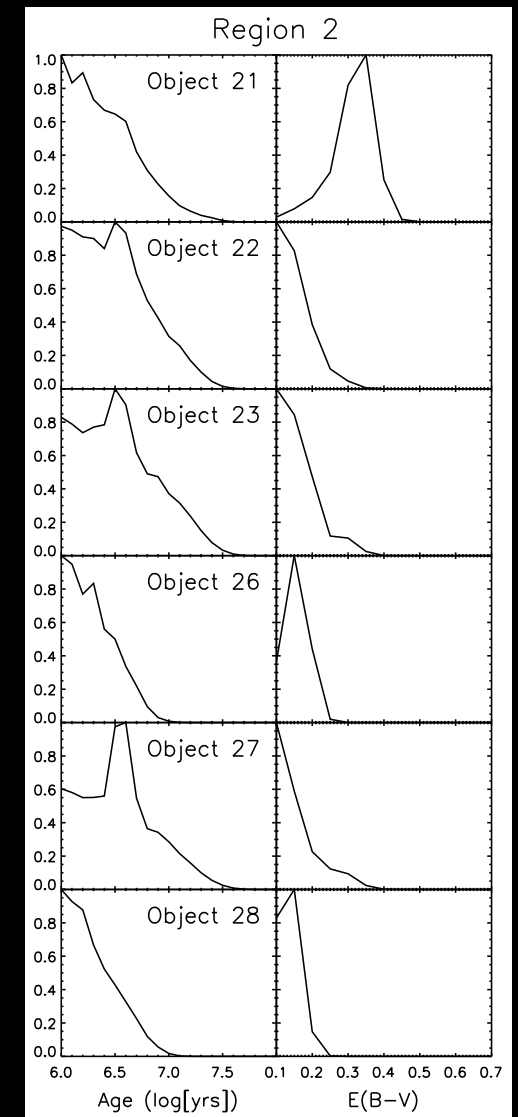
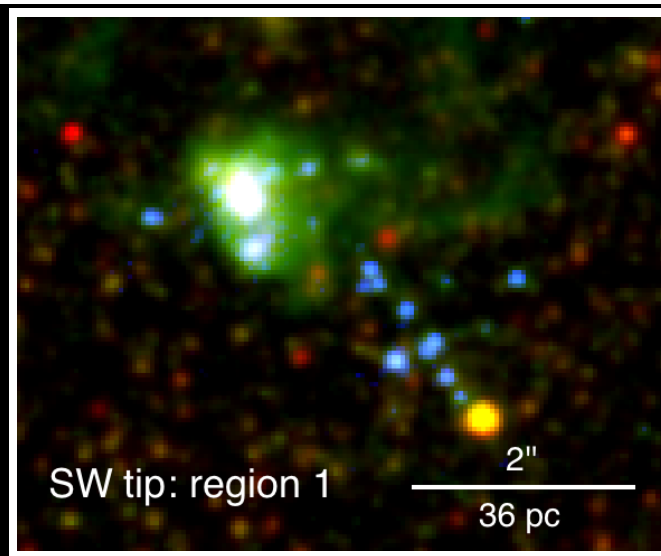
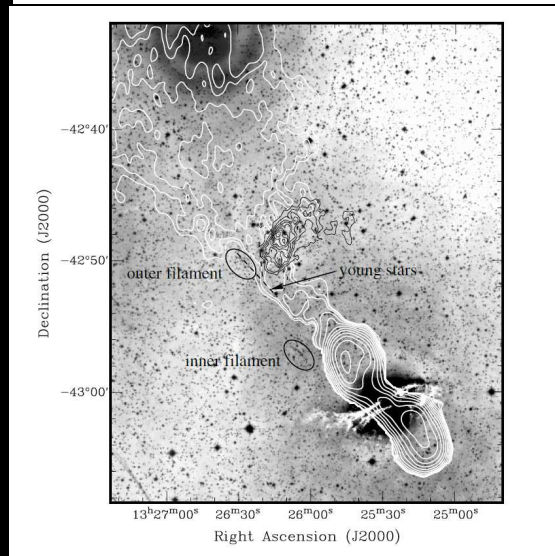
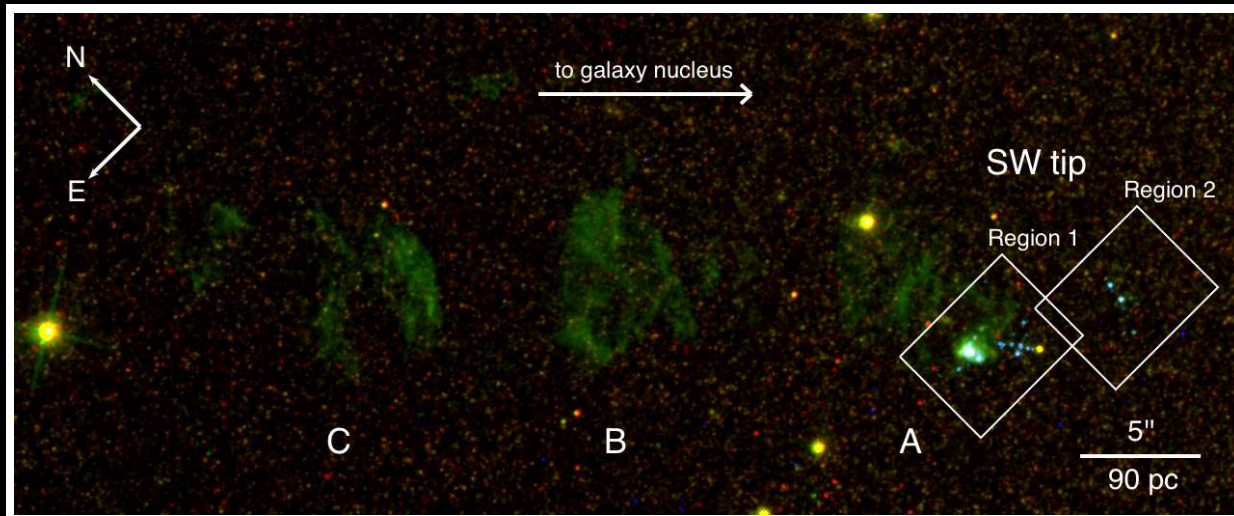
F814W I

3000 light-years

1400 parsecs

56''

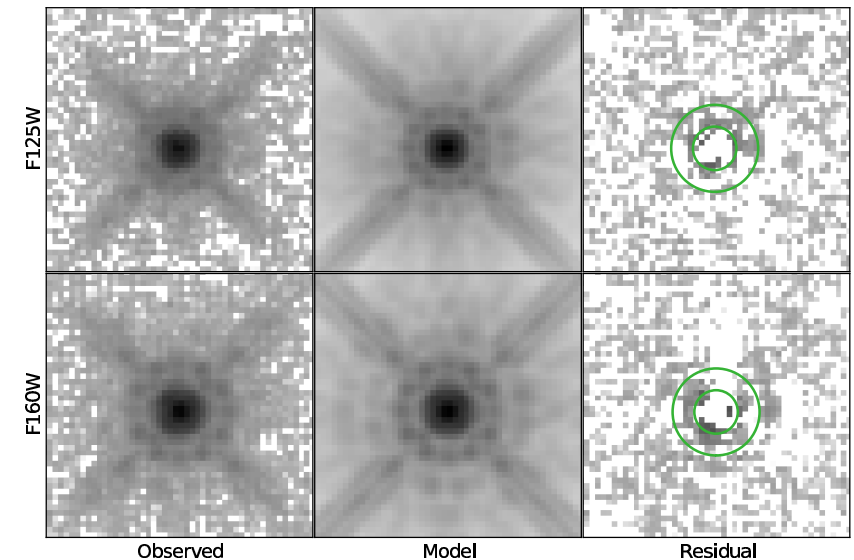
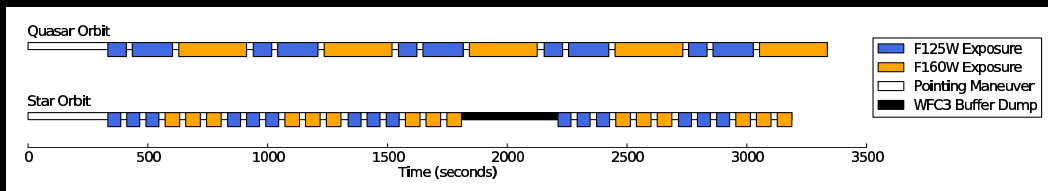




Well determined ages for young (~ 2 Myr) stars in Centaurus A jet, with star-formation in jet's wake (Crockett et al. 2012, MNRAS, 421, 1602).

JWST can do this in much dustier environments (and for older stars). We must do all we can with HST in UV-blue before JWST flies.

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



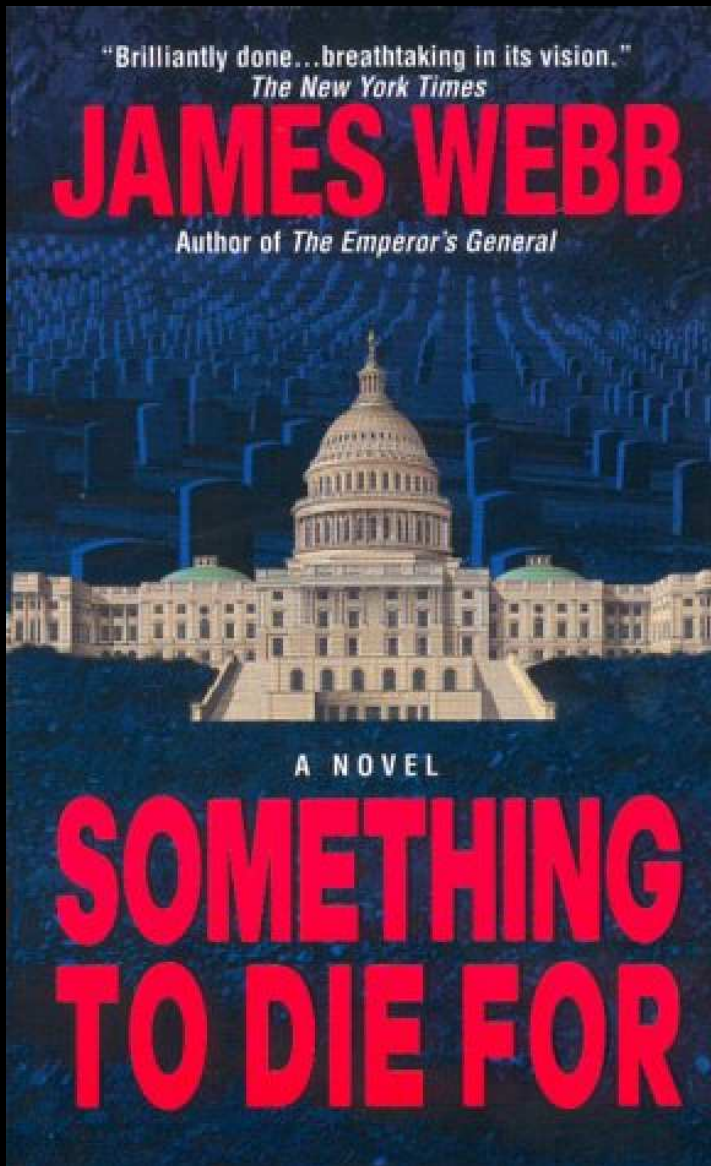
- Careful contemporaneous orbital PSF-star subtraction: Removes most of HST “OTA spacecraft breathing” effects (Mechtley et al. 2012).

- 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 at $r \gtrsim 0.3$).

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 $10\text{--}100\times$ fainter (and for $z \lesssim 20$) — but need JWST diffraction limit at $2.0\mu\text{m}$ and clean PSF to do this.

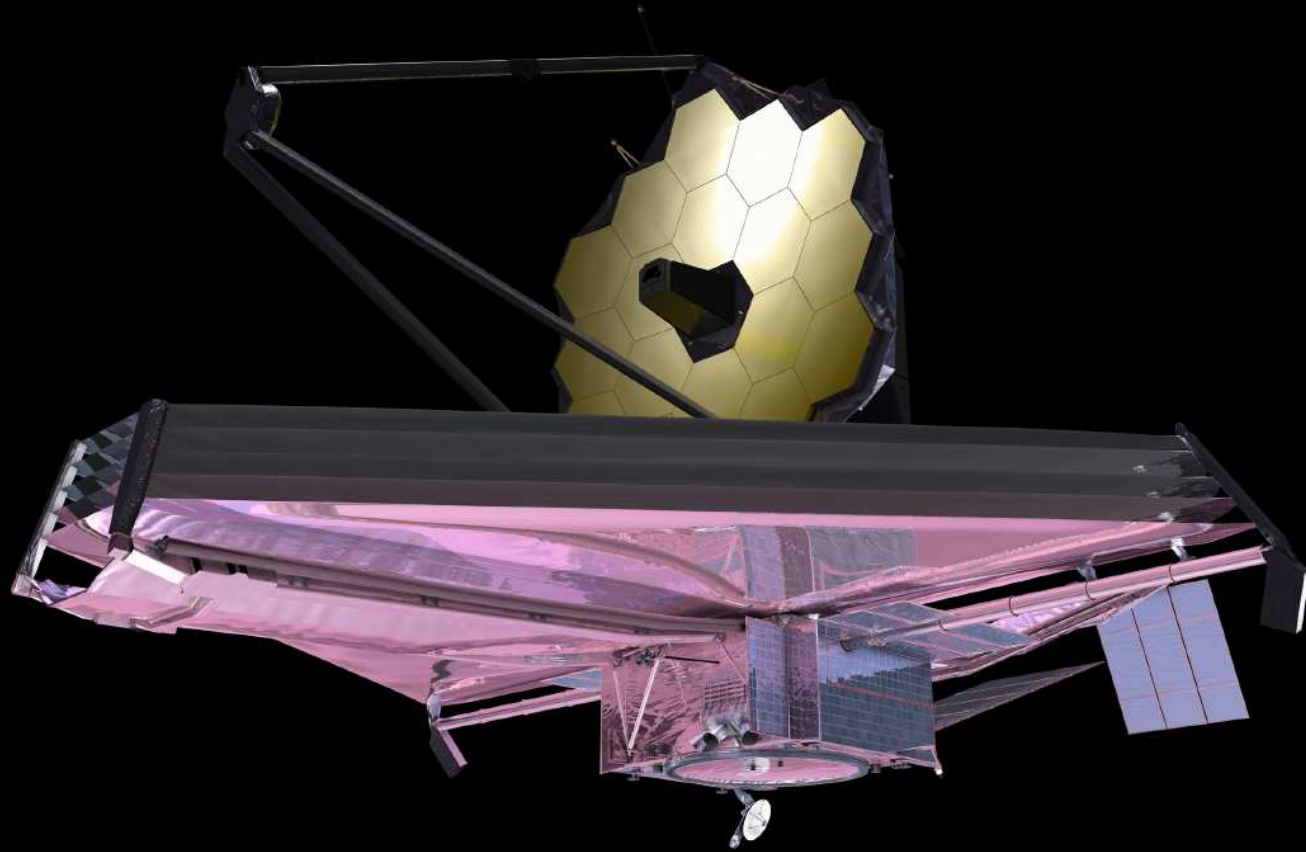
(3) What is the James Webb Space Telescope (JWST)?



To be used by 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 $0.6\text{--}28 \text{ }\mu\text{m}$ wavelength, to be launched in Fall 2018.
- Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging ($\text{AB}=31.5 \text{ mag}$) and spectroscopy.

THE JAMES WEBB SPACE TELESCOPE

JWST LAUNCH

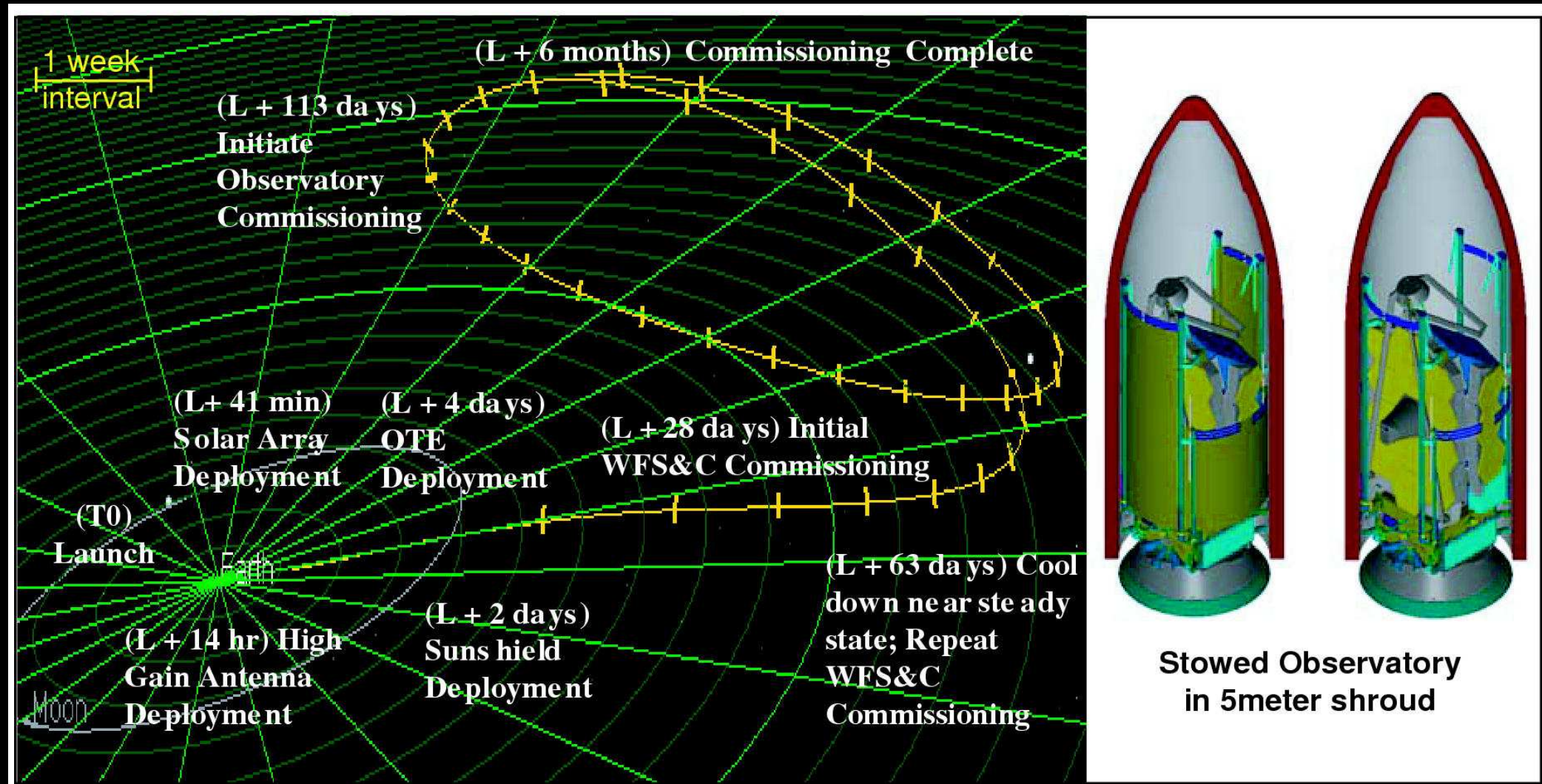
- LAUNCH VEHICLE IS AN ARIANE 5 ROCKET, SUPPLIED BY ESA
- SITE WILL BE THE ARIANESPACE'S ELA-3 LAUNCH COMPLEX NEAR KOUROU, FRENCH GUIANA



ARIANESPACE - ESA - NASA

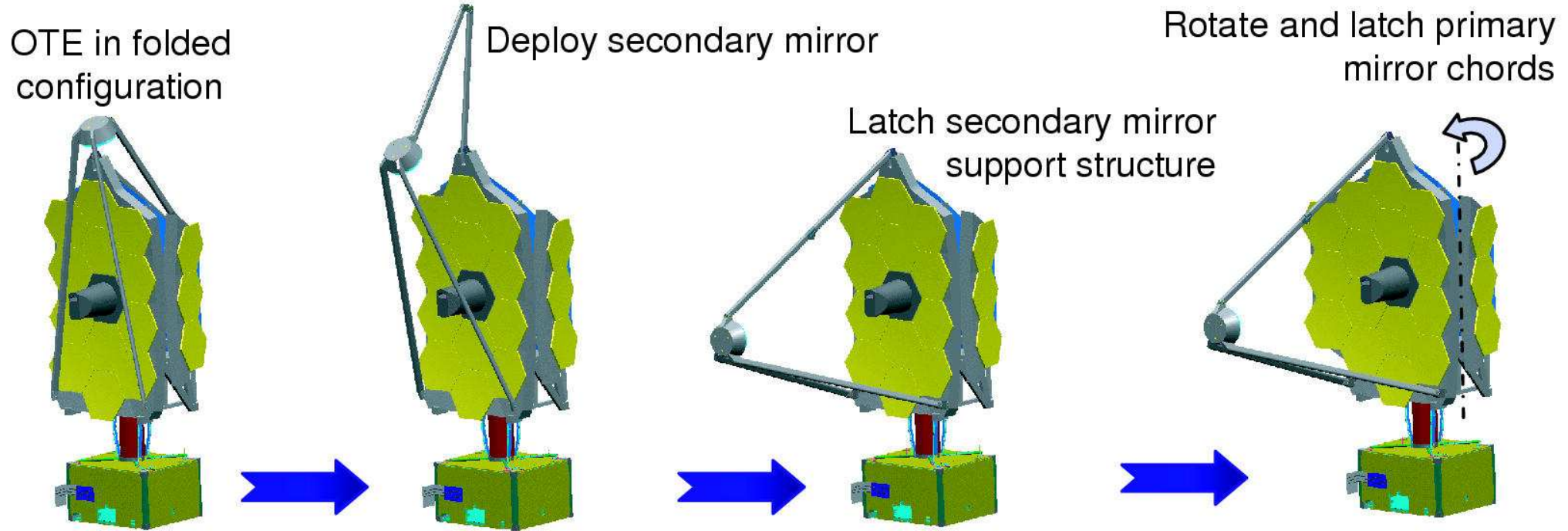
- The JWST launch weight will be $\lesssim 6500$ kg, and it will be launched to L2 with an ESA Ariane-V launch vehicle from Kourou in French Guiana.

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

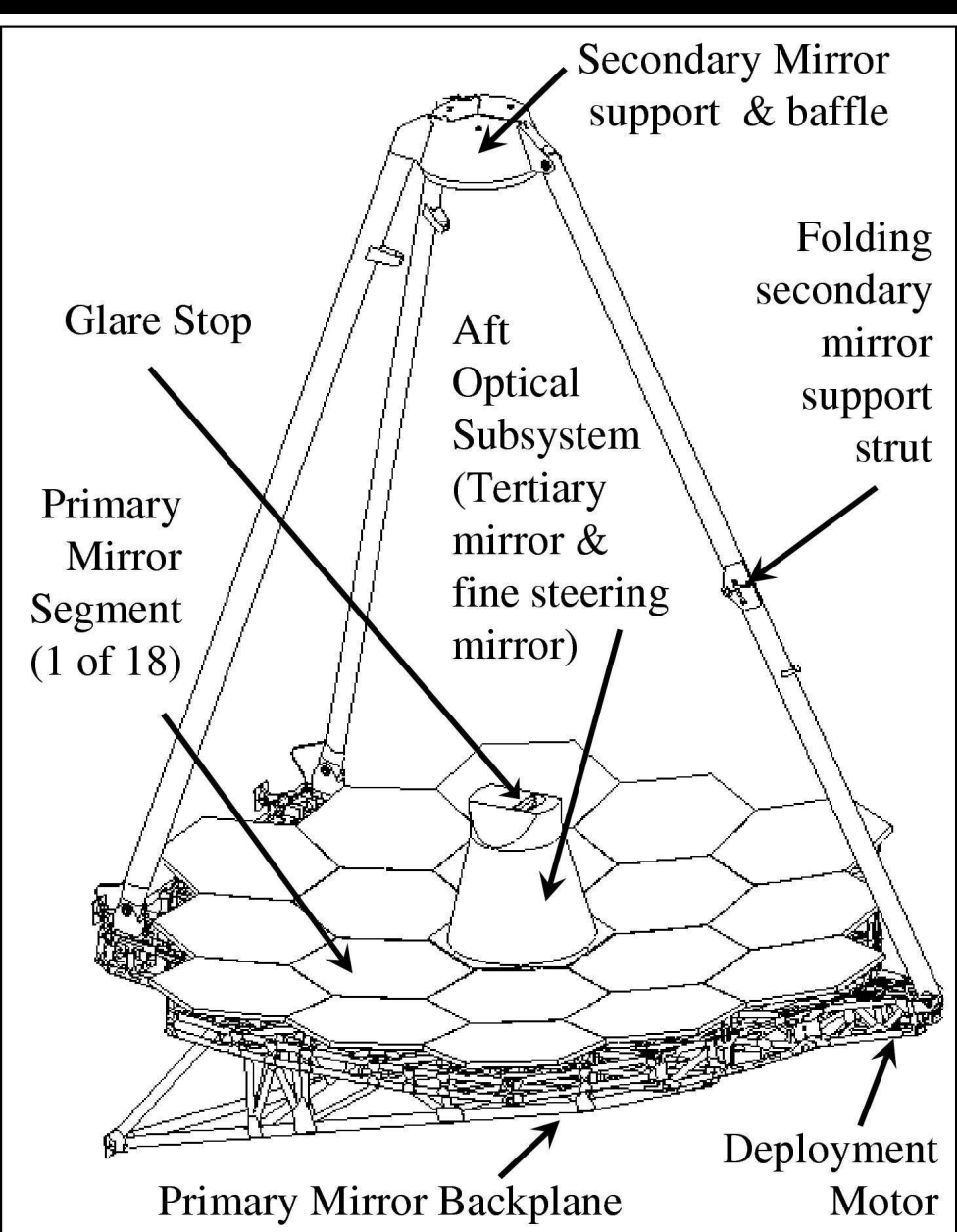


- After launch in 2018 with an ESA Ariane-V, JWST will orbit around the Earth–Sun Lagrange point L2, 1.5 million km from Earth.
- JWST can cover the whole sky in segments that move along with the Earth, observe $\gtrsim 70\%$ of the time, and send data back to Earth every day.

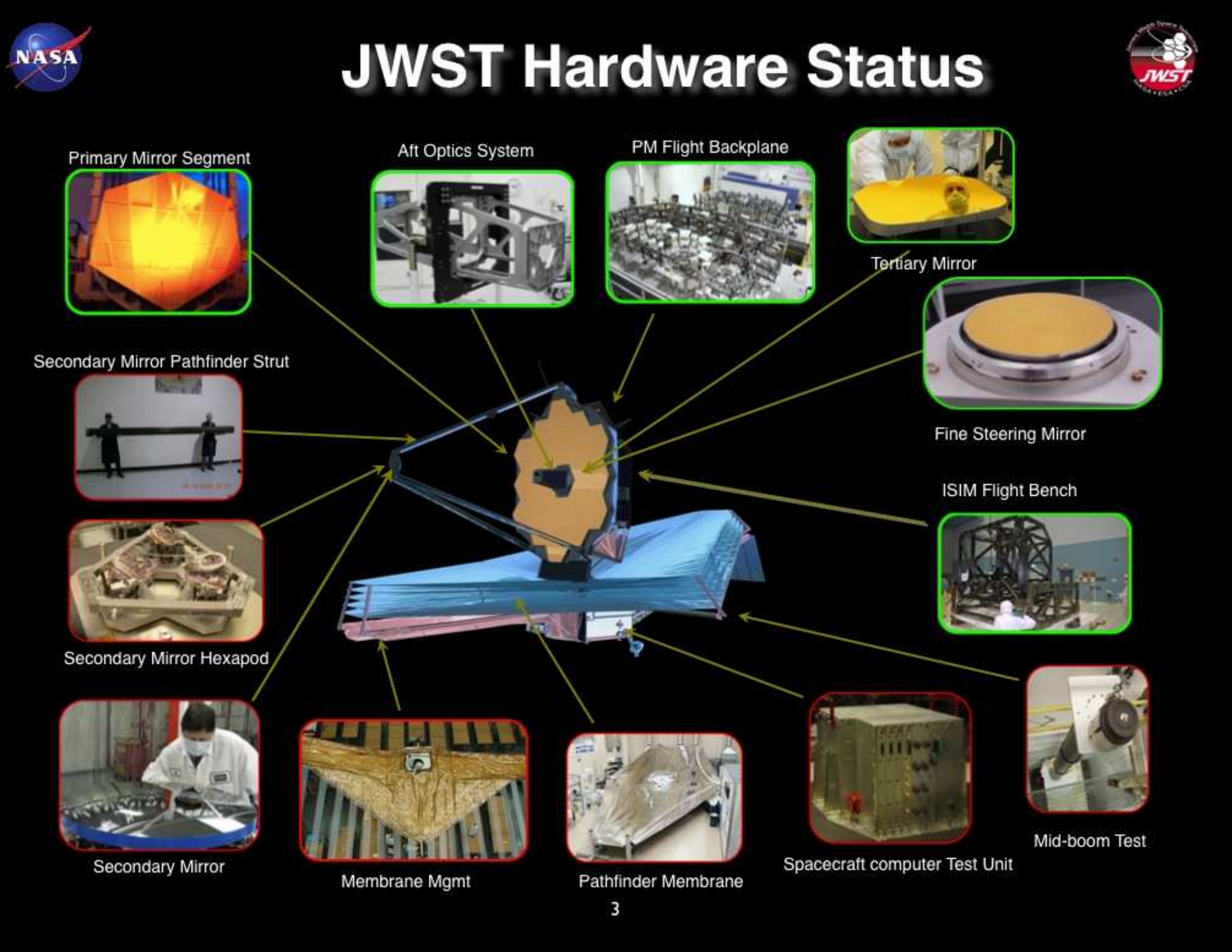
- (3b) How will JWST be automatically deployed?



- 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.

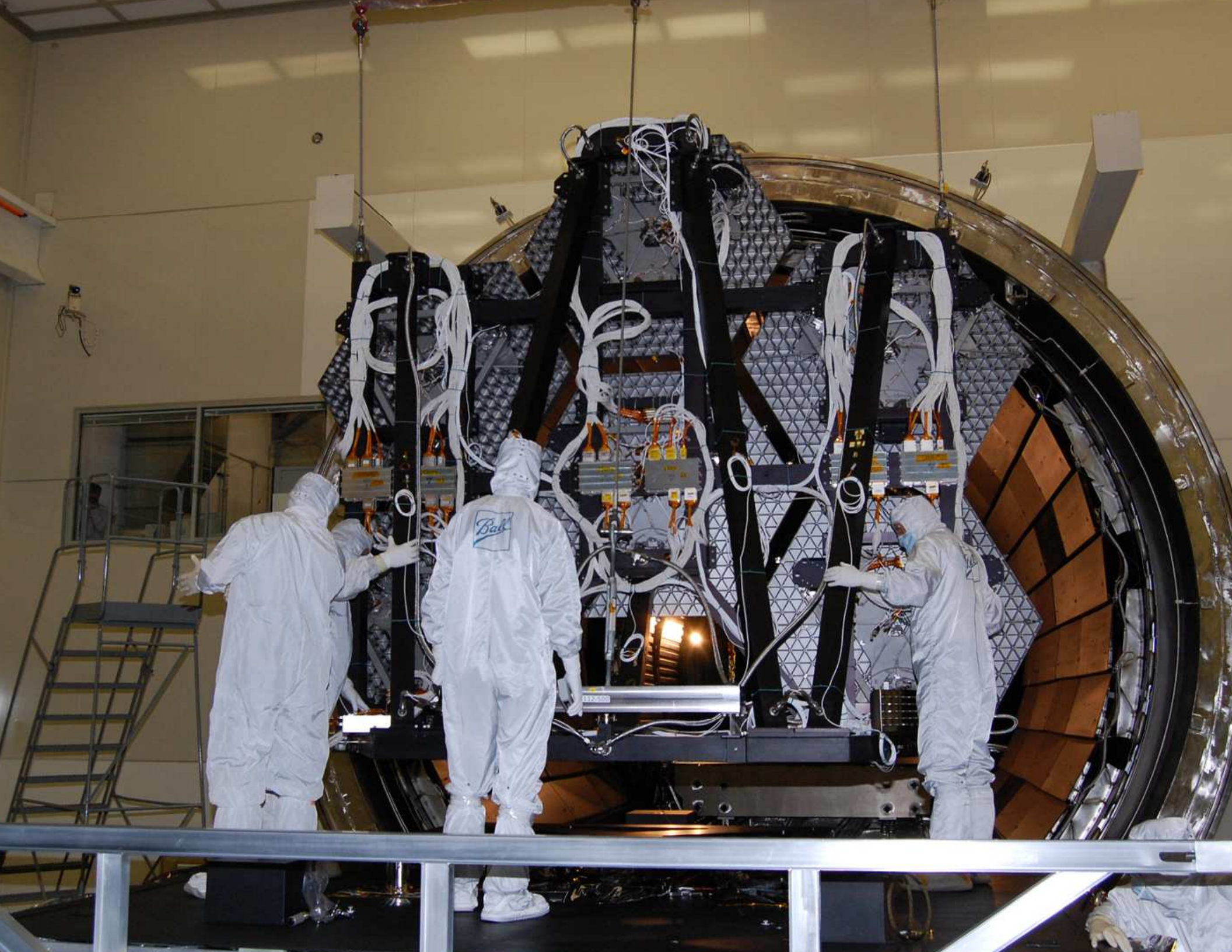


Wave-Front Sensing tested hands-off at 40 K in 1-G at JSC in 2015-2016.
Ball 1/6 scale-model for WFS: produces diffraction-limited $2.0 \mu\text{m}$ images.



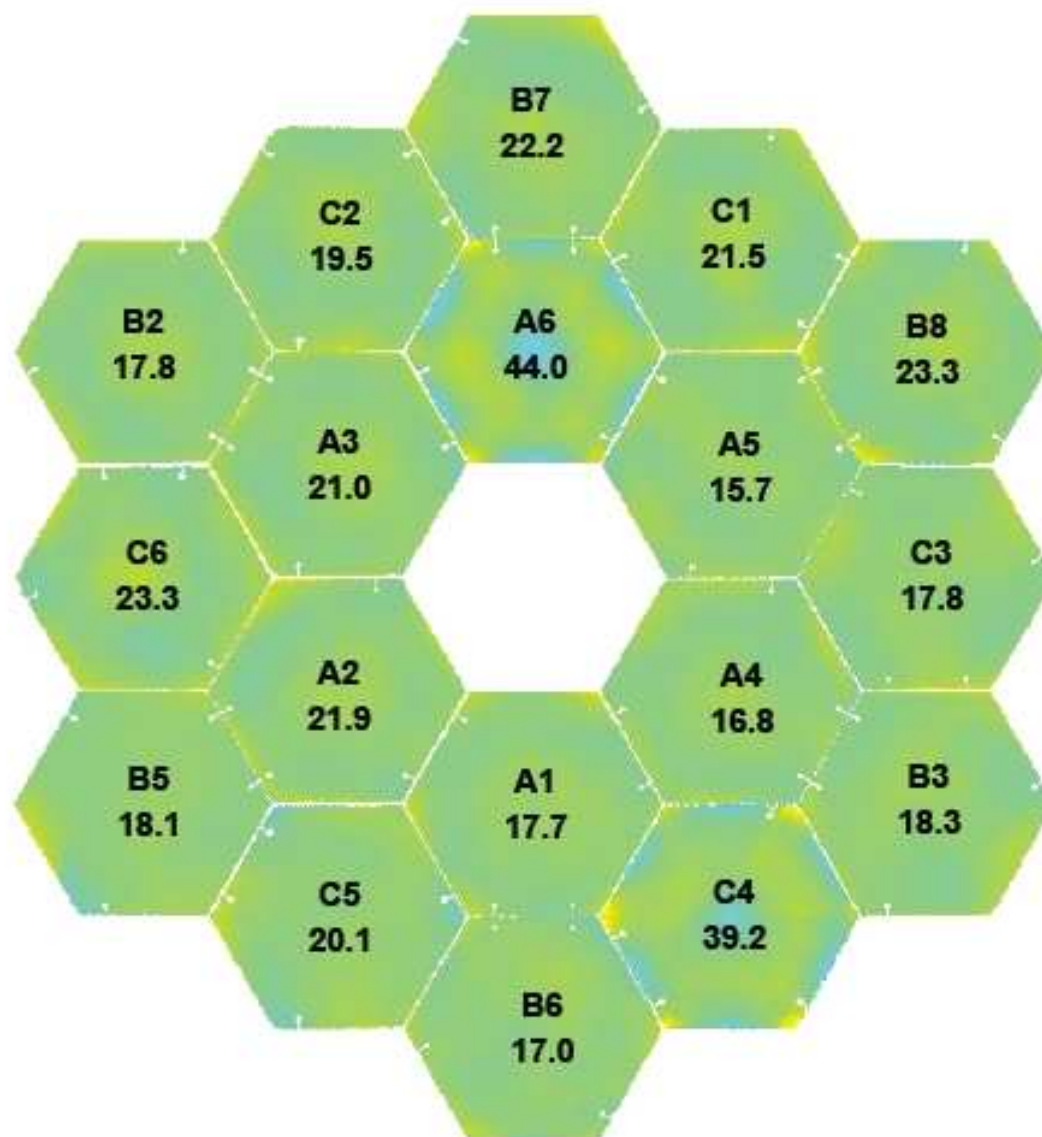
Mirror Acceptance Testing







Primary Mirror Composite



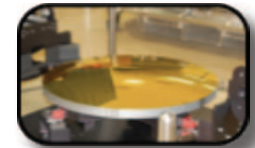
RMS: **23.2 nm**

PV: **515.5 nm**





Family Portrait



Secondary

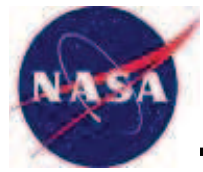


Tertiary



Fine Steering

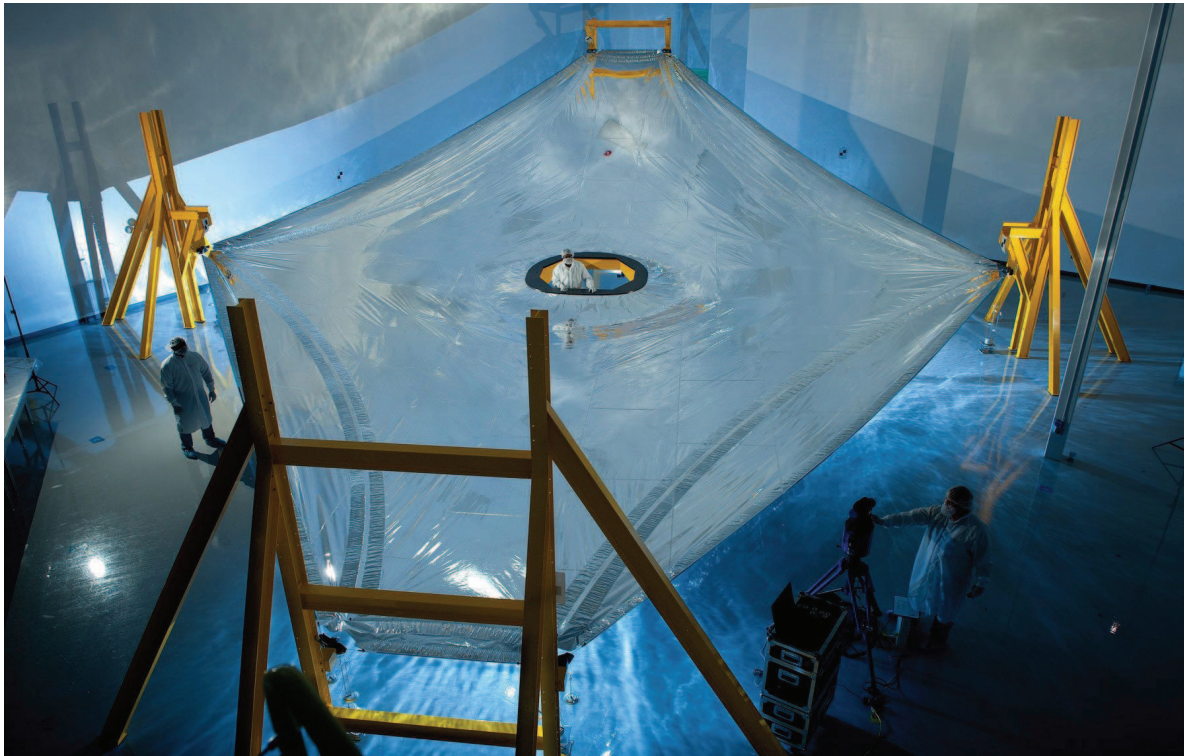
✓ Mirror segment has completed all thermal testing



Sunshield

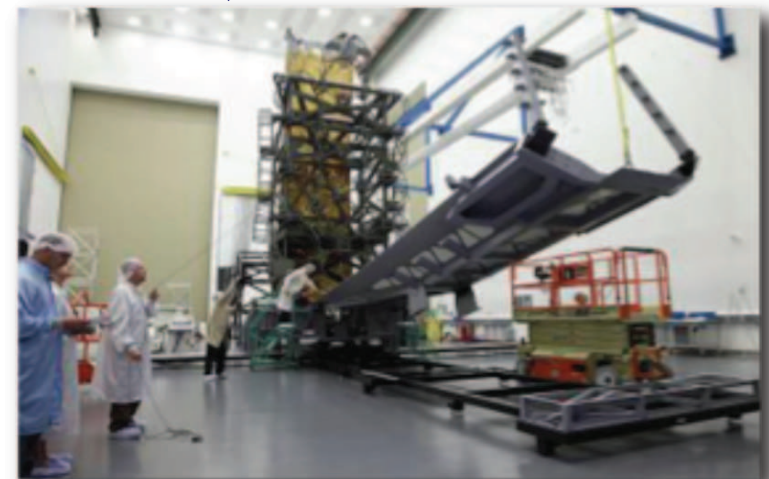


- **Template membrane build to flight-like requirements for verification of:**
 - Shape under tension to verify gradients and light line locations
 - Hole punching & hole alignment for membrane restraint devices (MRD)
 - Verification of folding/packing concept on full scale mockup
 - Layer 3 shape measurements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



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

Full-scale JWST mockup with sunshield palette



Telescope Assembly Ground Support Equipment



Ambient Optical Alignment Stand



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



March 2012 NAC
Science Meeting



Landing a mirror onto
backplane simulator

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



Instrument Overview

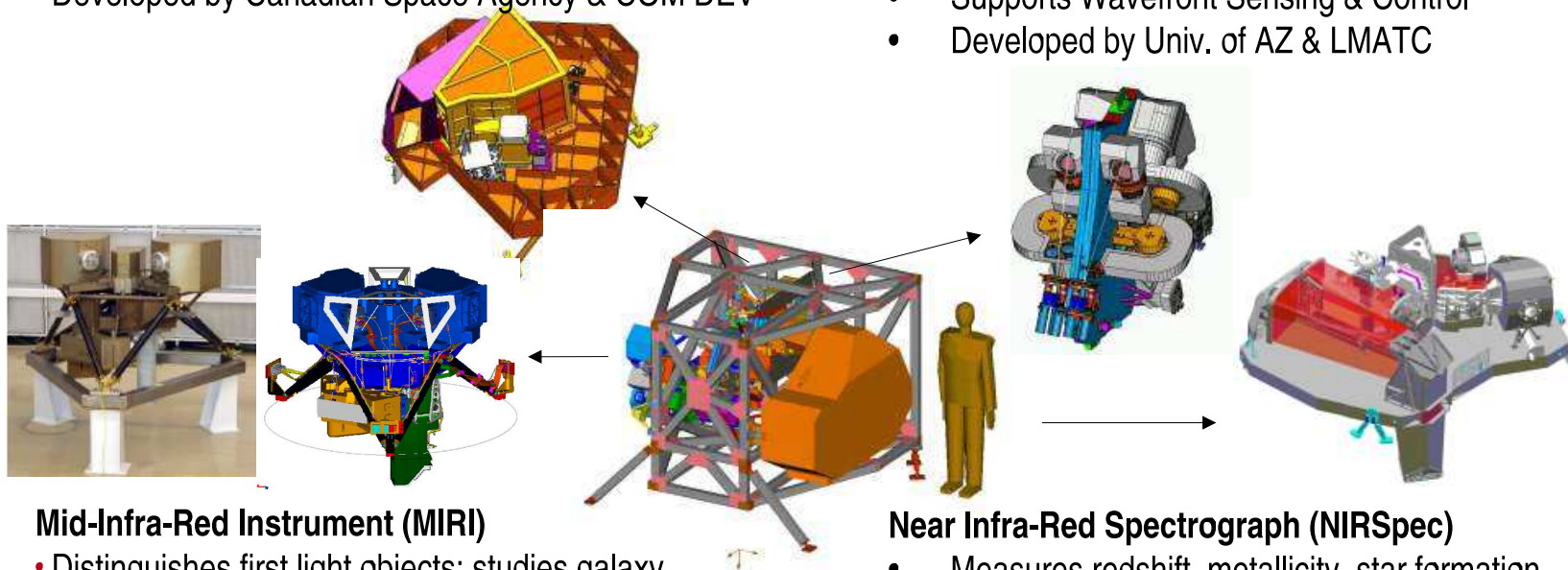


Fine Guidance Sensor (FGS)

- 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)

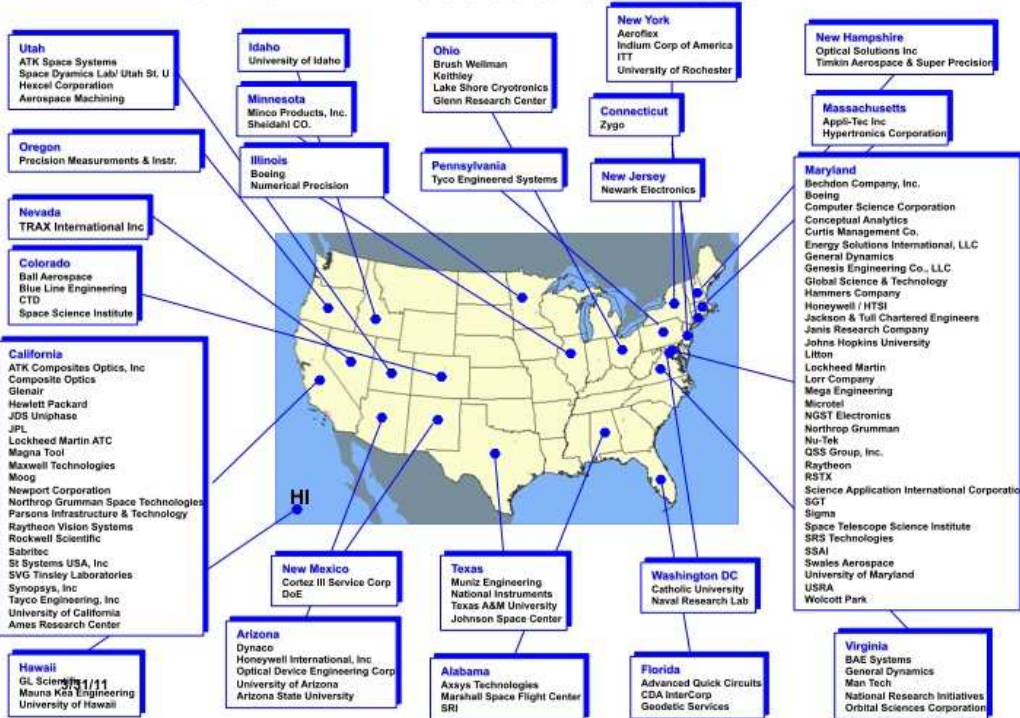
- Distinguishes first light objects; studies galaxy evolution; explores protostars & their environs
- Imaging and spectroscopy capability
- 5 to 27 microns
- Cooled to 7K by Cyro-cooler
- Combined European Consortium/JPL development

Near Infra-Red Spectrograph (NIRSpec)

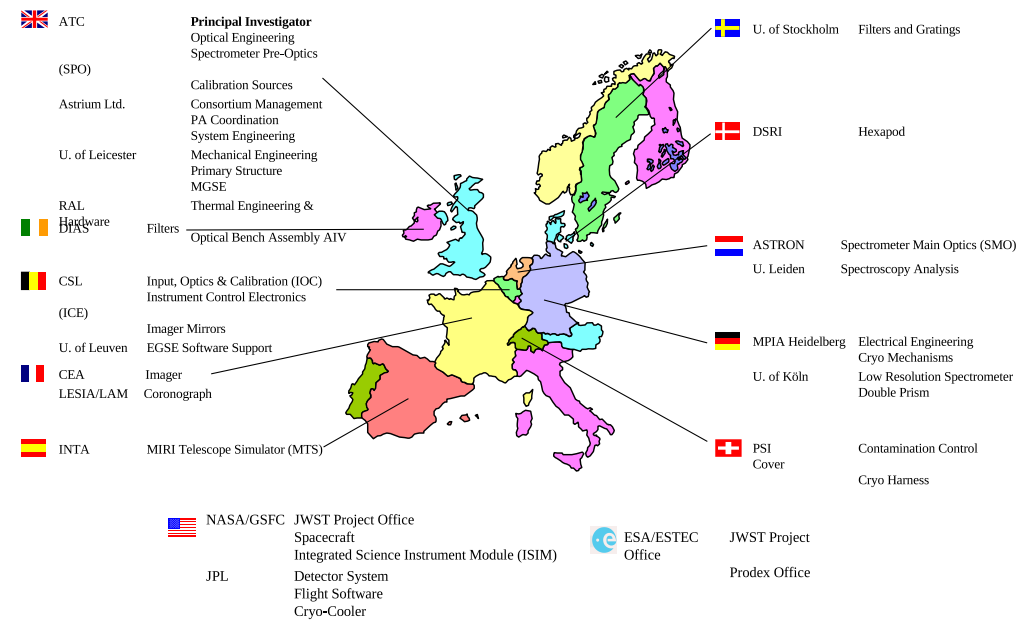
- Measures redshift, metallicity, star formation rate in first light galaxies
- 0.6 to 5 microns
- Simultaneous spectra of >100 objects
- Developed by ESA & EADS with NASA/ GSFC Detector & Microshutter Subsystems

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

JWST: A Product of the Nation



European Consortium Who & Where



10

MIRI European Consortium
23.05.03

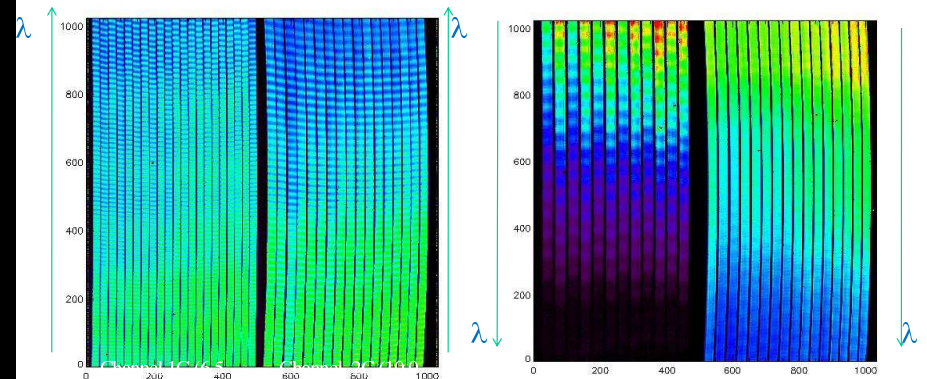
- JWST hardware made in 27 US States: $\geq 75\%$ of launch-mass finished.
- Ariane V Launch & NIRSpec provided by ESA; & MIRI by ESA & JPL.
- JWST Fine Guider Sensor + NIRISS provided by Canadian Space Agency.
- JWST NIRCам made by UofA and Lockheed.



Flight MIRI



Spectrometer First Light – internal calibration source



All slices are there and well centred on detectors, fringes look as on VM, the fall off in signal at long wavelengths is expected – temperature of source and relatively short exposure, no “intra-slice” light ☺

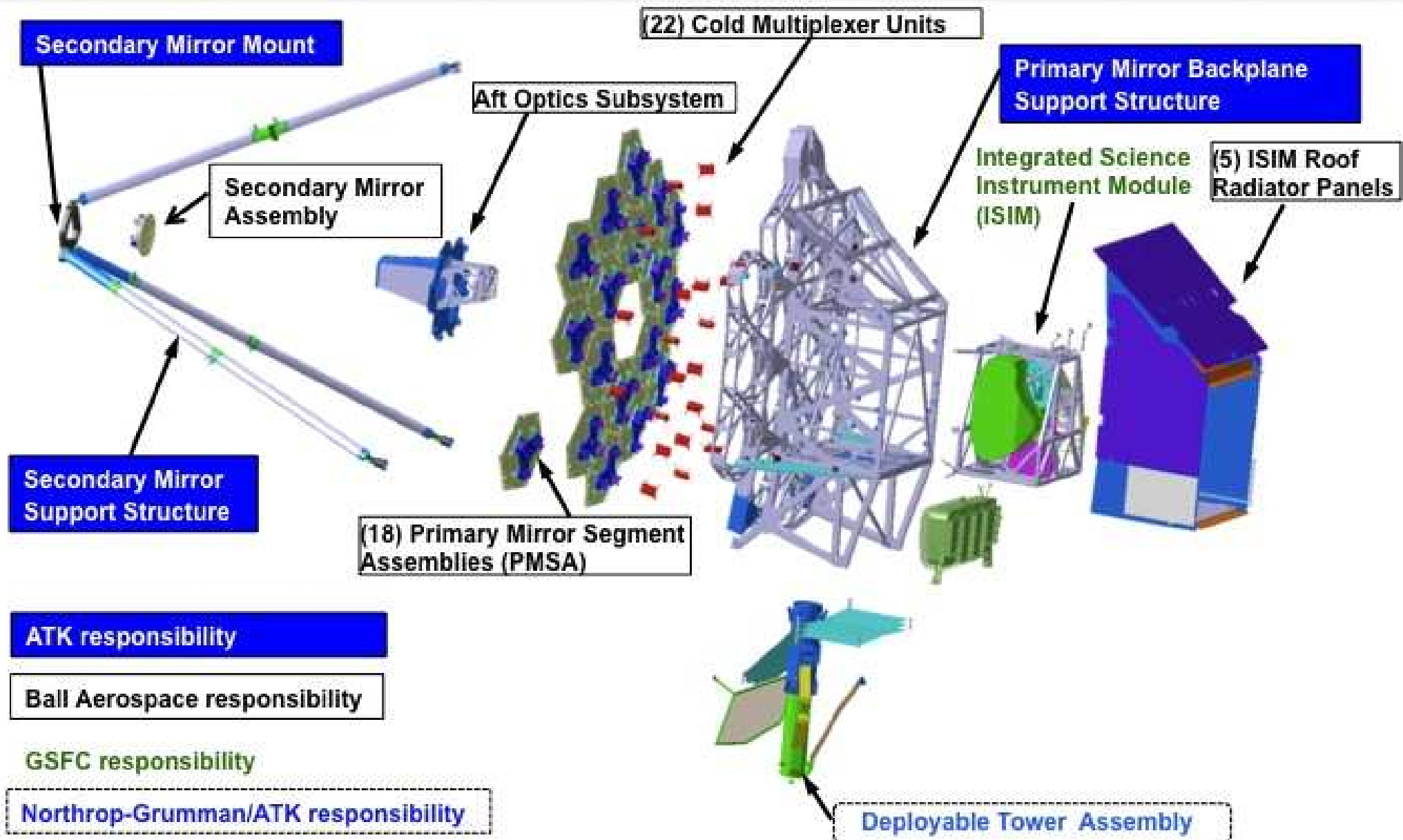
JWST's mid-infrared (5–29 μm) camera and spectrograph:

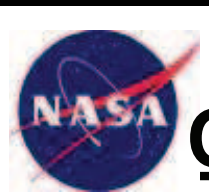
- MIRI — built by ESA consortium of 10 ESA countries & NASA JPL.
- Flight build completed and tested with First Light in July 2011.

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

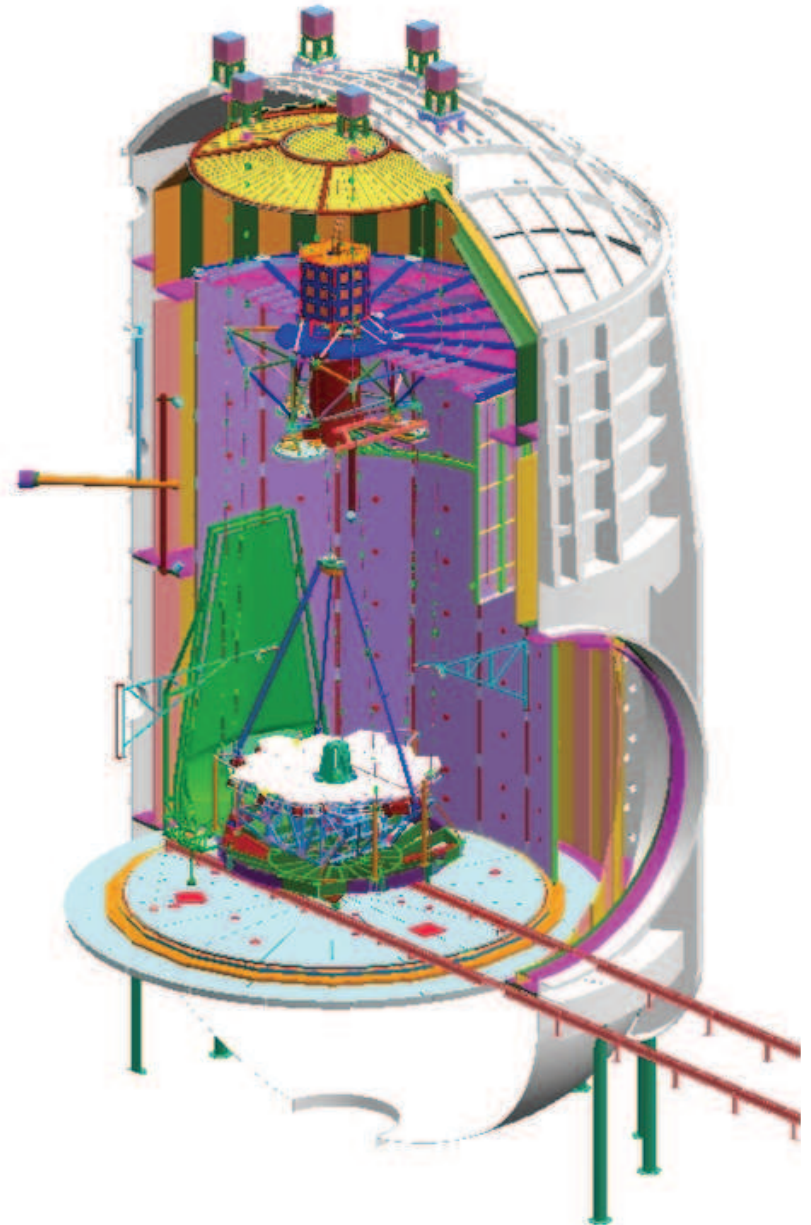
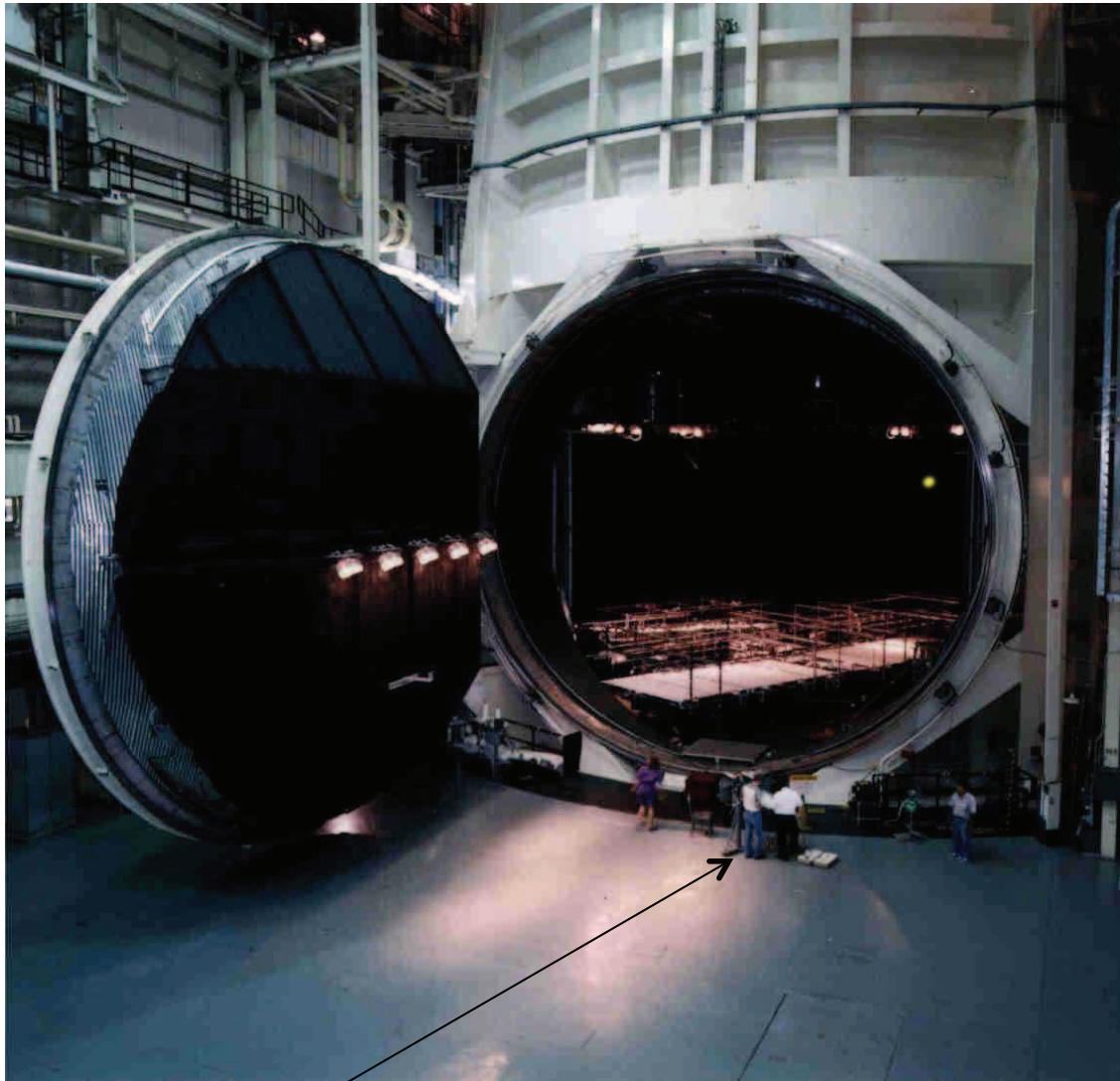


TELESCOPE ARCHITECTURE





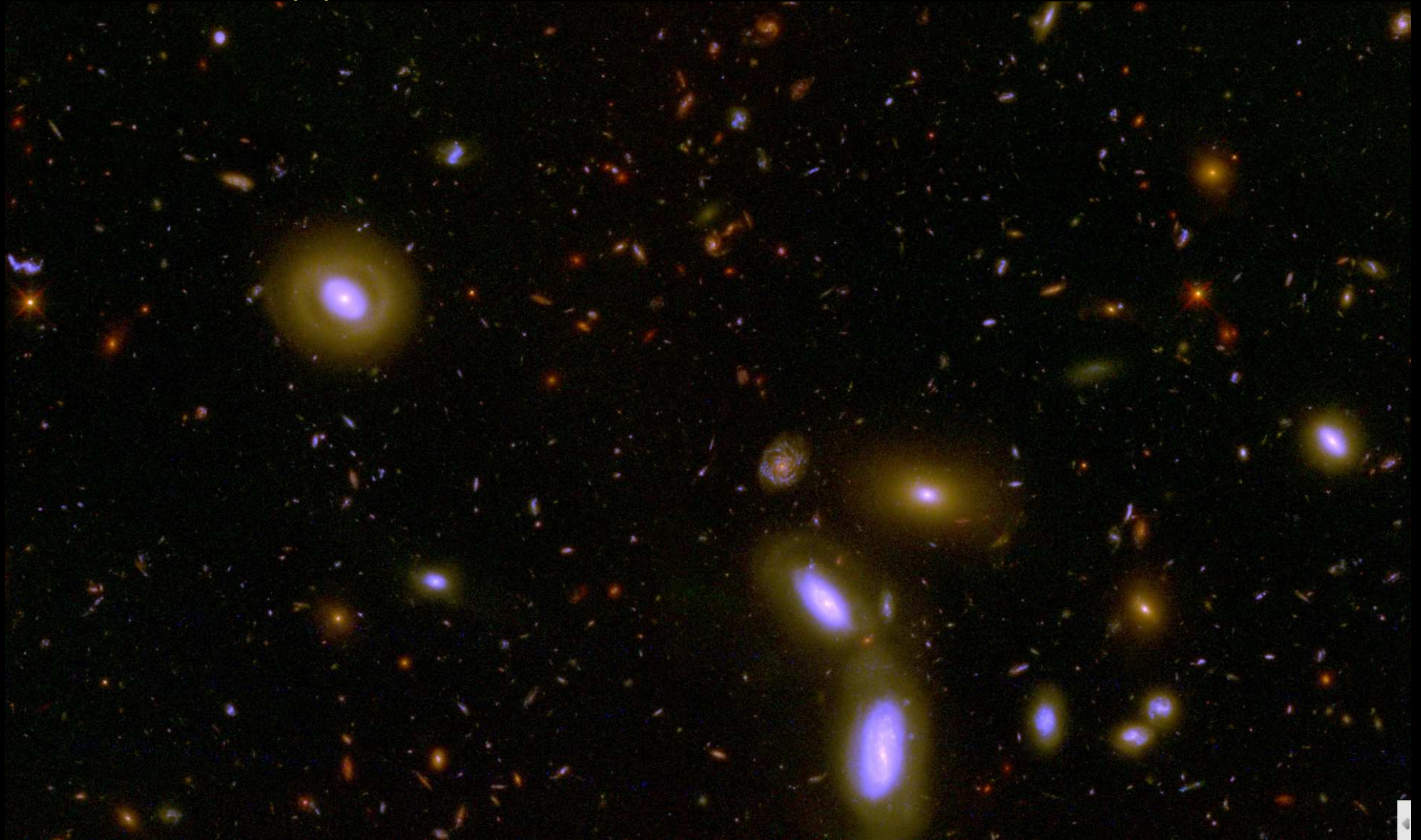
OTE Testing – Chamber A at JSC



Notice people for scale

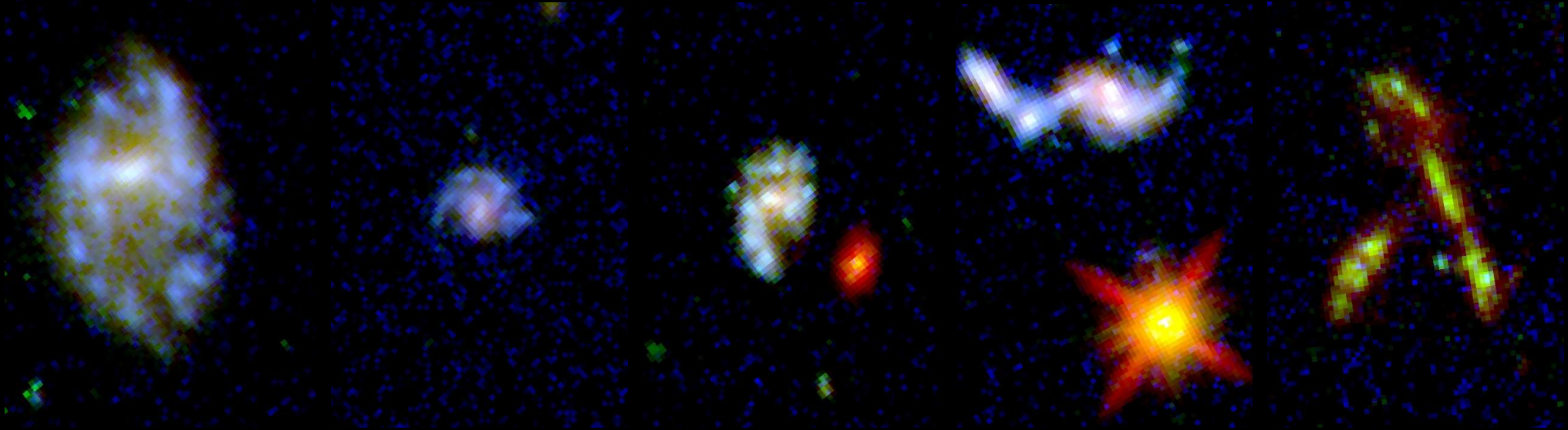
Will be the largest cryo vacuum test chamber in the world

- (4) How can JWST measure Galaxy Assembly?

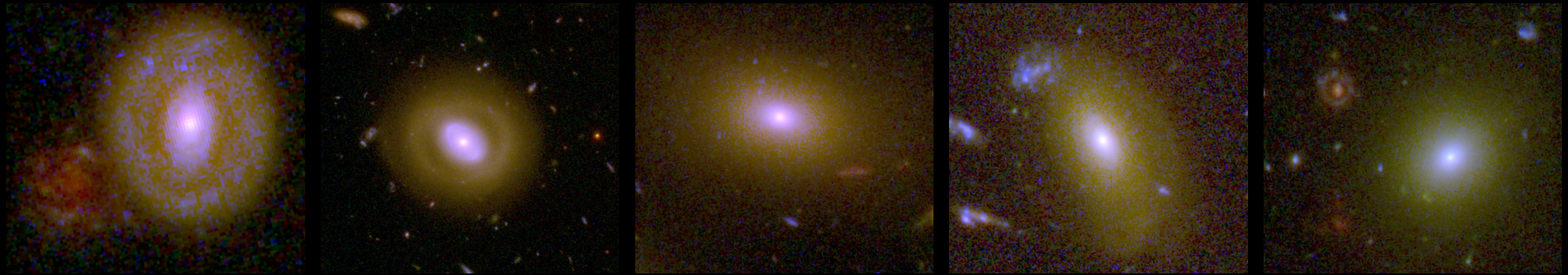


10 filters with HST/WFC3 & ACS reaching $AB=26.5-27.0$ mag ($10-\sigma$) over 40 arcmin^2 at $0.07-0.15''$ FWHM from $0.2-1.7 \mu\text{m}$ (UVUBVizYJH). JWST adds $0.05-0.2''$ FWHM imaging to $AB \simeq 31.5$ mag (1 nJy) at $1-5 \mu\text{m}$, and $0.2-1.2''$ FWHM at $5-29 \mu\text{m}$, tracing young+old SEDs & dust.

Some science results of the Wide Field Camera Early Release Science data:



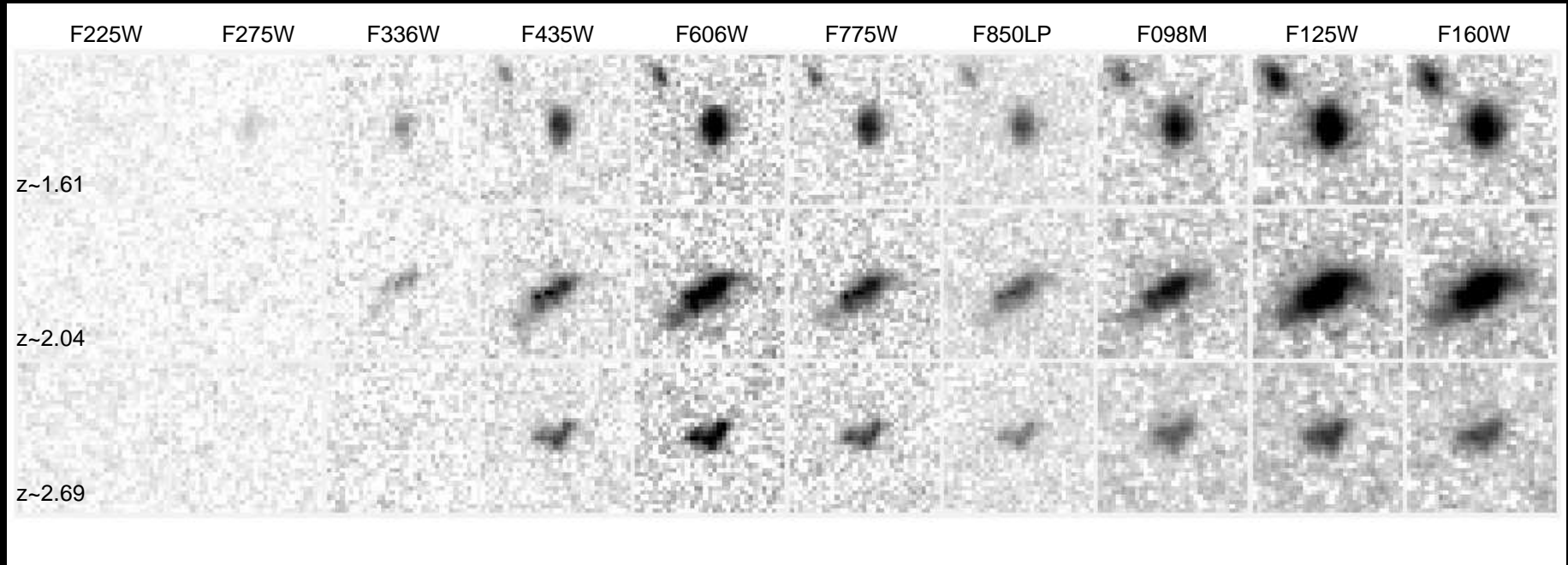
Galaxy structure at the peak of the merging epoch ($z \simeq 1-2$) is very rich: some resemble the cosmological parameters H_0 , Ω , ρ_o , w , and Λ , resp.



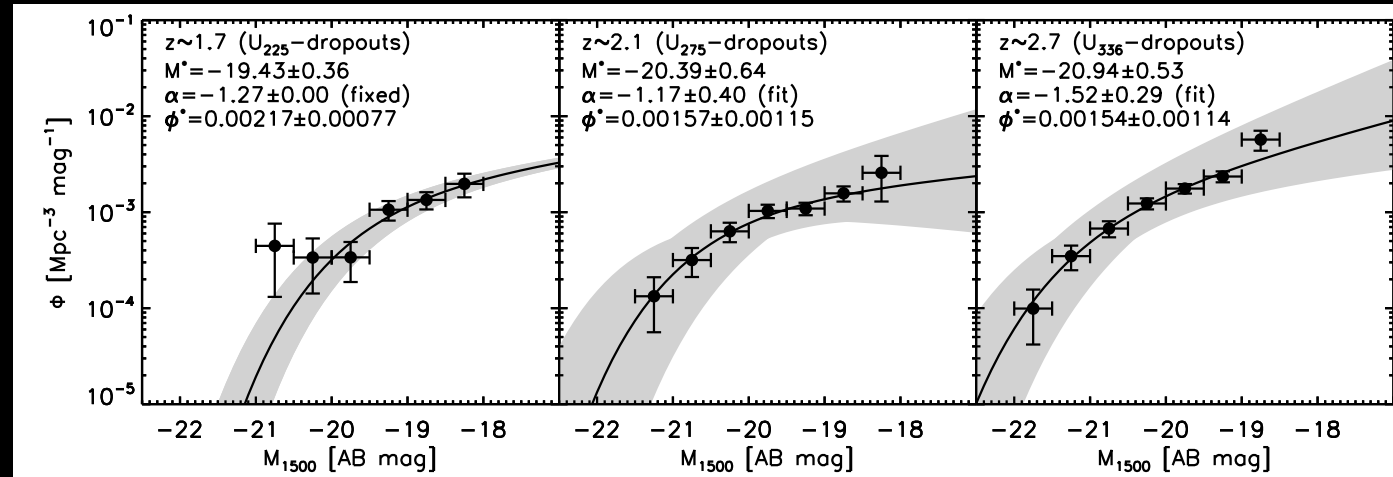
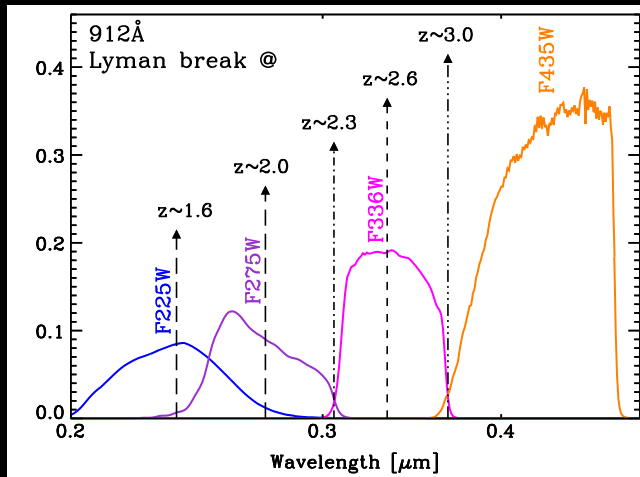
Panchromatic WFC3 ERS images of early-type galaxies with nuclear star-forming rings, bars, weak AGN, or other interesting nuclear structure.

(Rutkowski et al. 2012 ApJS 199, 4) \implies “Red & dead” galaxies aren’t dead!

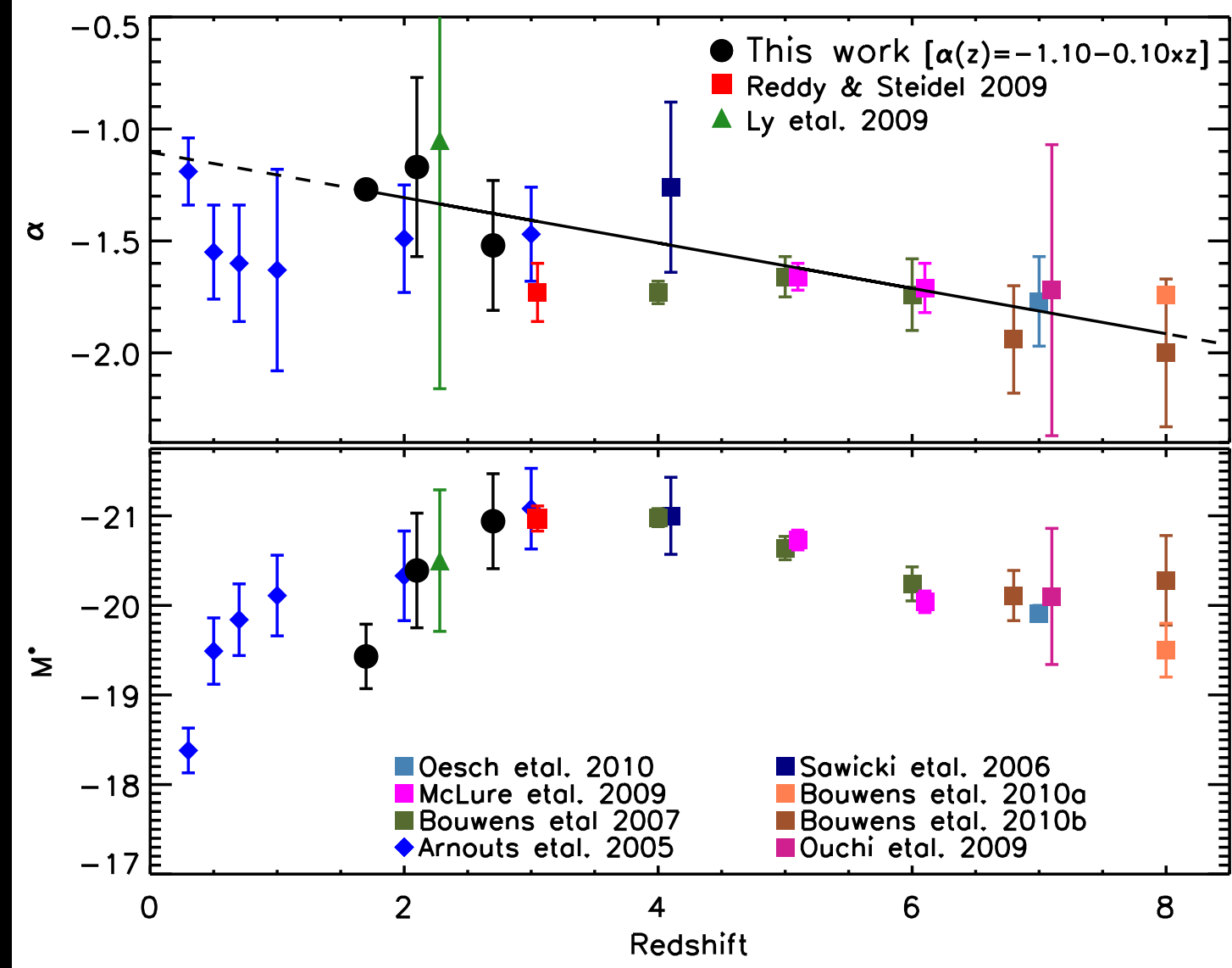
- JWST will observe any such objects from 0.7–29 μm wavelength.



Lyman break galaxies at the peak of cosmic SF ($z \simeq 1-3$; Hathi et al. 2010)

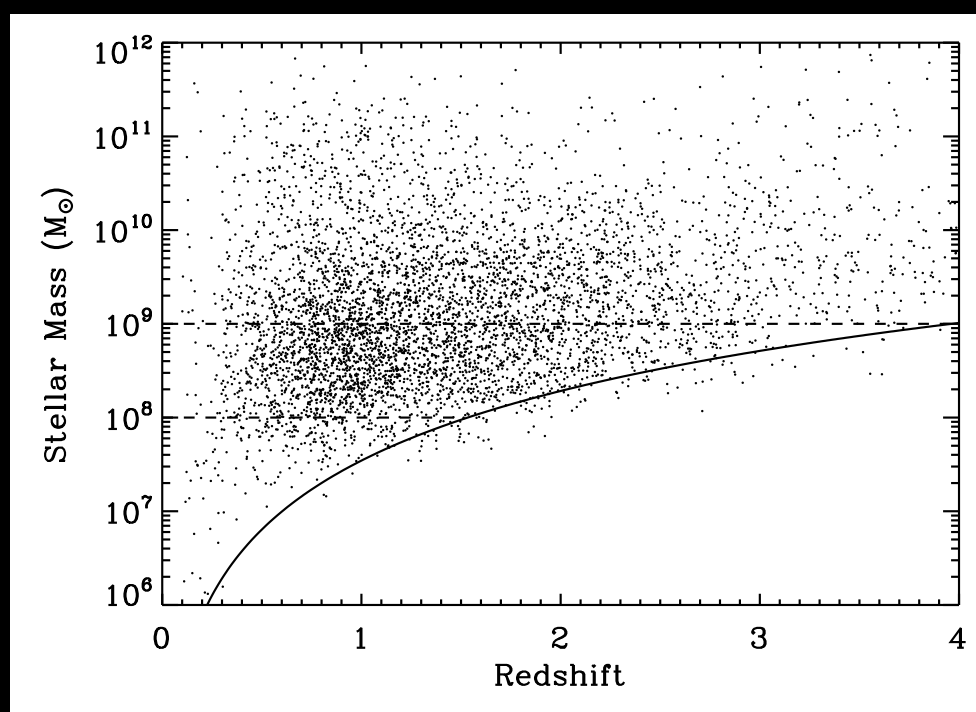
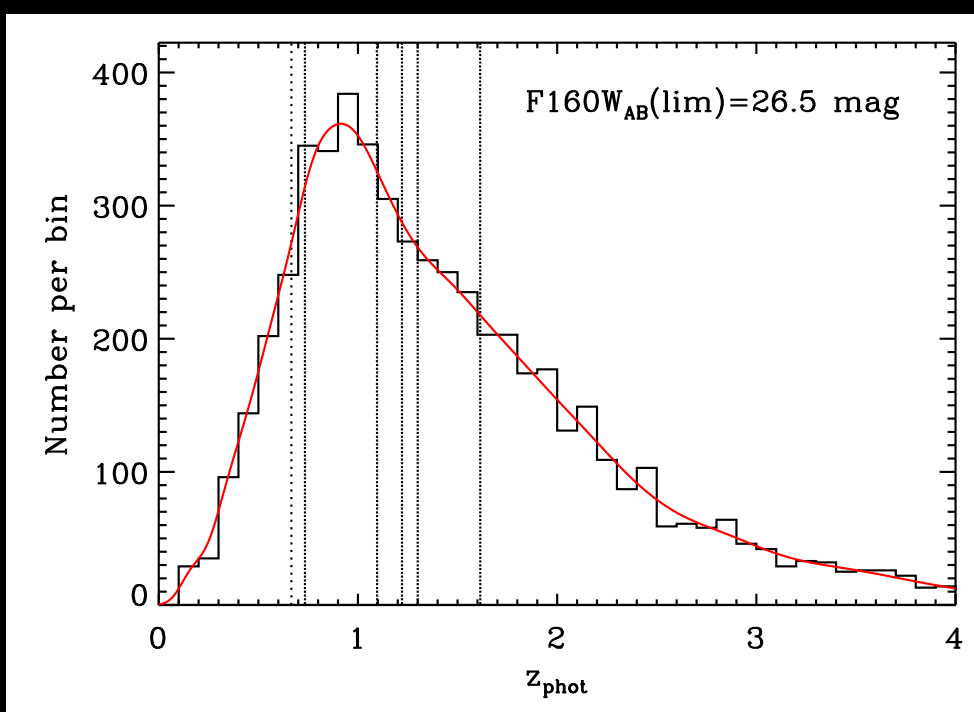


- JWST will similarly measure faint-end LF-slope evolution for $1 \lesssim z \lesssim 12$.
(e.g., Bouwens et al. 2010; Hathi et al. 2012, 2012; Oesch et al. 2010).



Measured faint-end LF slope evolution (top) and characteristic luminosity evolution (bottom) from Hathi et al. 2010 (ApJ, 720, 1708).

- 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 $M^* \gtrsim -19$.
- ⇒ Could have critical consequences for gravitational lensing bias at $z \gtrsim 10$.



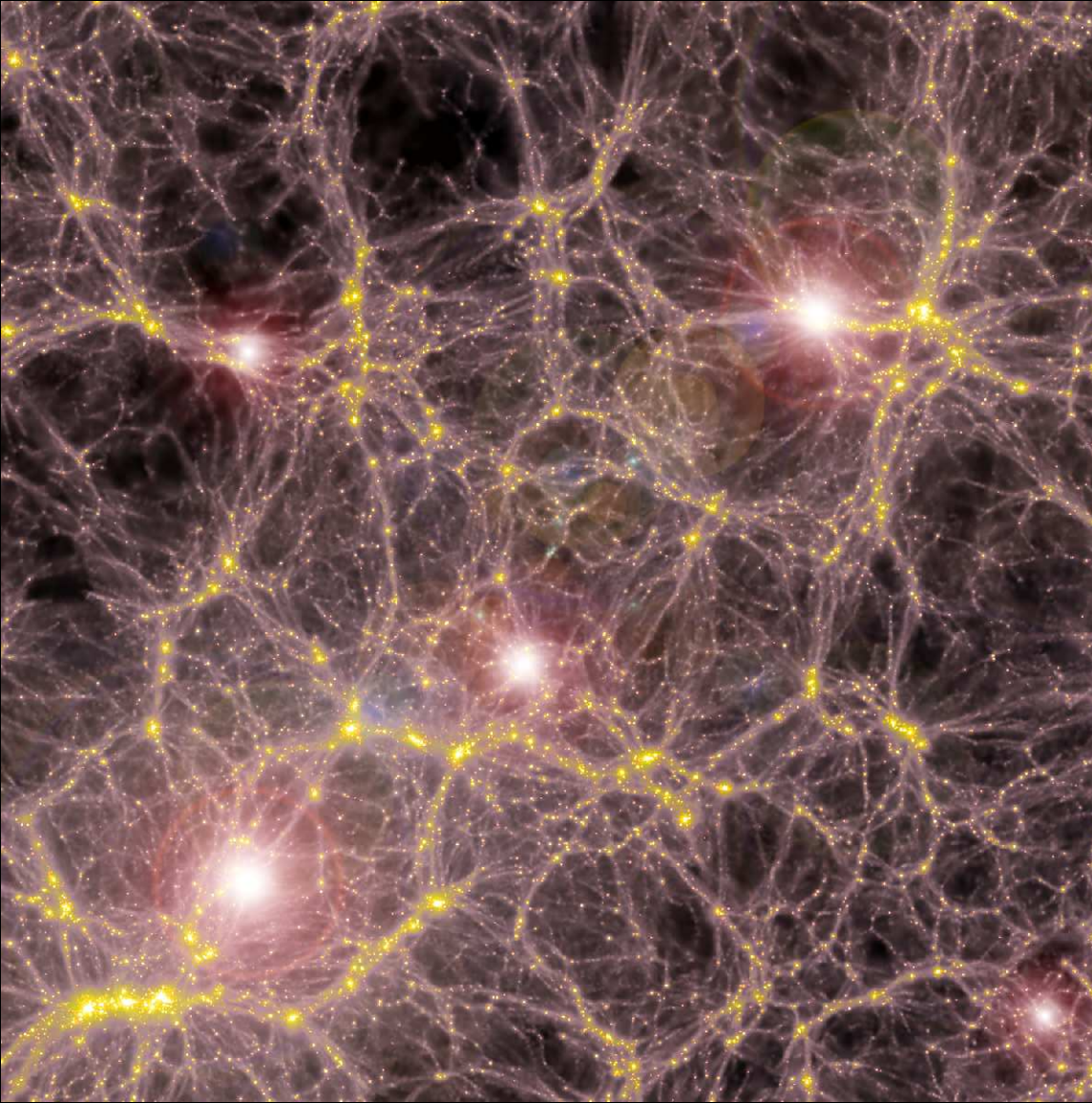
WFC3 ERS 10-band redshift estimates accurate to $\lesssim 4\%$ with small systematic errors (Hathi et al. 2010, 2012), resulting in a reliable $N(z)$.

- Measure masses of faint galaxies to $AB=26.5 \text{ mag}$, tracing the process of galaxy assembly: downsizing, merging, (& weak AGN growth?).

ERS shows WFC3's new panchromatic capabilities on galaxies at $z \simeq 0-7$.

- HUDF shows WFC3 $z \simeq 7-9$ capabilities (Bouwens⁺ 2010; Yan⁺ 2010).
- WFC3 is an essential pathfinder at $z \lesssim 8$ for JWST ($0.7-29 \mu\text{m}$) at $z \gtrsim 9$.
- JWST will trace mass assembly and dust content 3–4 mags deeper from $z \simeq 1-12$, with nanoJy sensitivity from $0.7-5 \mu\text{m}$.

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



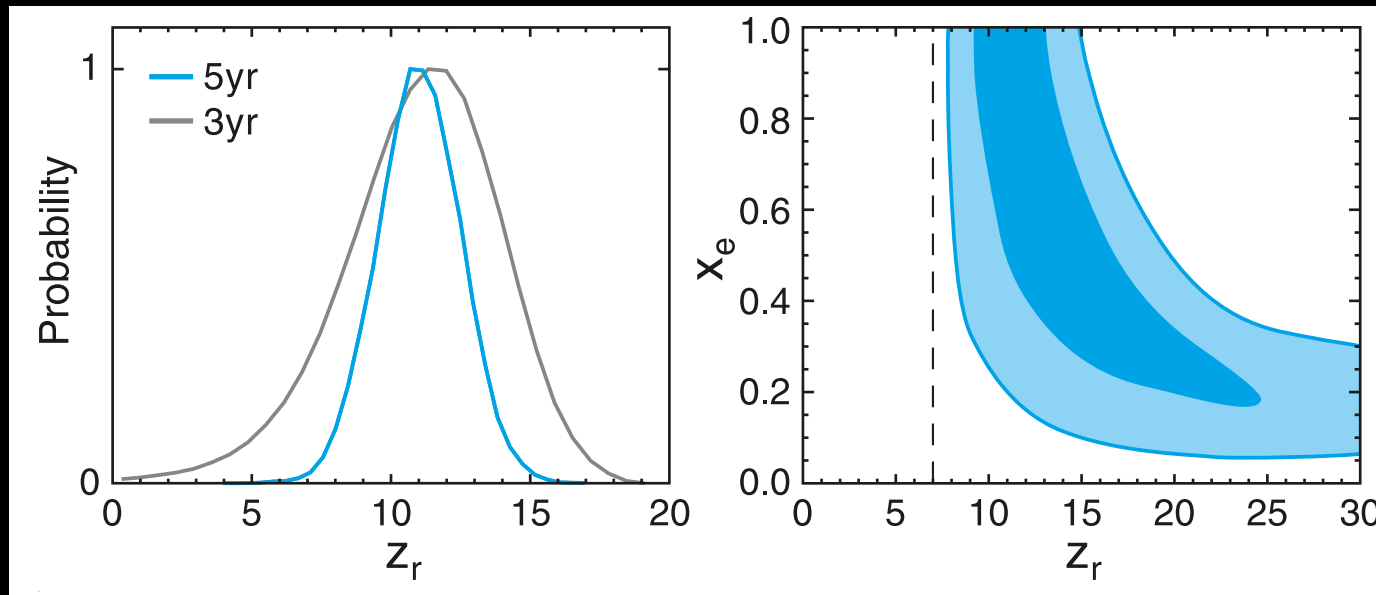
- Detailed Hydrodynamical models (e.g., V. Bromm) suggest that massive Pop III stars may have reionized universe at redshifts $z \lesssim 10-30$ (First Light).
- A this should be visible to JWST as the first Pop III stars and surrounding (Pop II.5) star clusters, and perhaps their extremely luminous supernovae at $z \simeq 10 \rightarrow 30$.

We must make sure we theoretically understand the likely Pop III mass-range, their IMF, their duplicity and clustering properties, their SN-rates, etc.

Implications of the (2011) 7-year WMAP results for JWST science:

HST/WFC3 $z \lesssim 7-9$ ←

→ JWST $z \simeq 8-25$



The year-7 WMAP data provided much better foreground removal (Dunkley et al. 2009; Komatsu et al. 2011; see also Planck 2013):

⇒ First Light & Reionization occurred between these extremes:

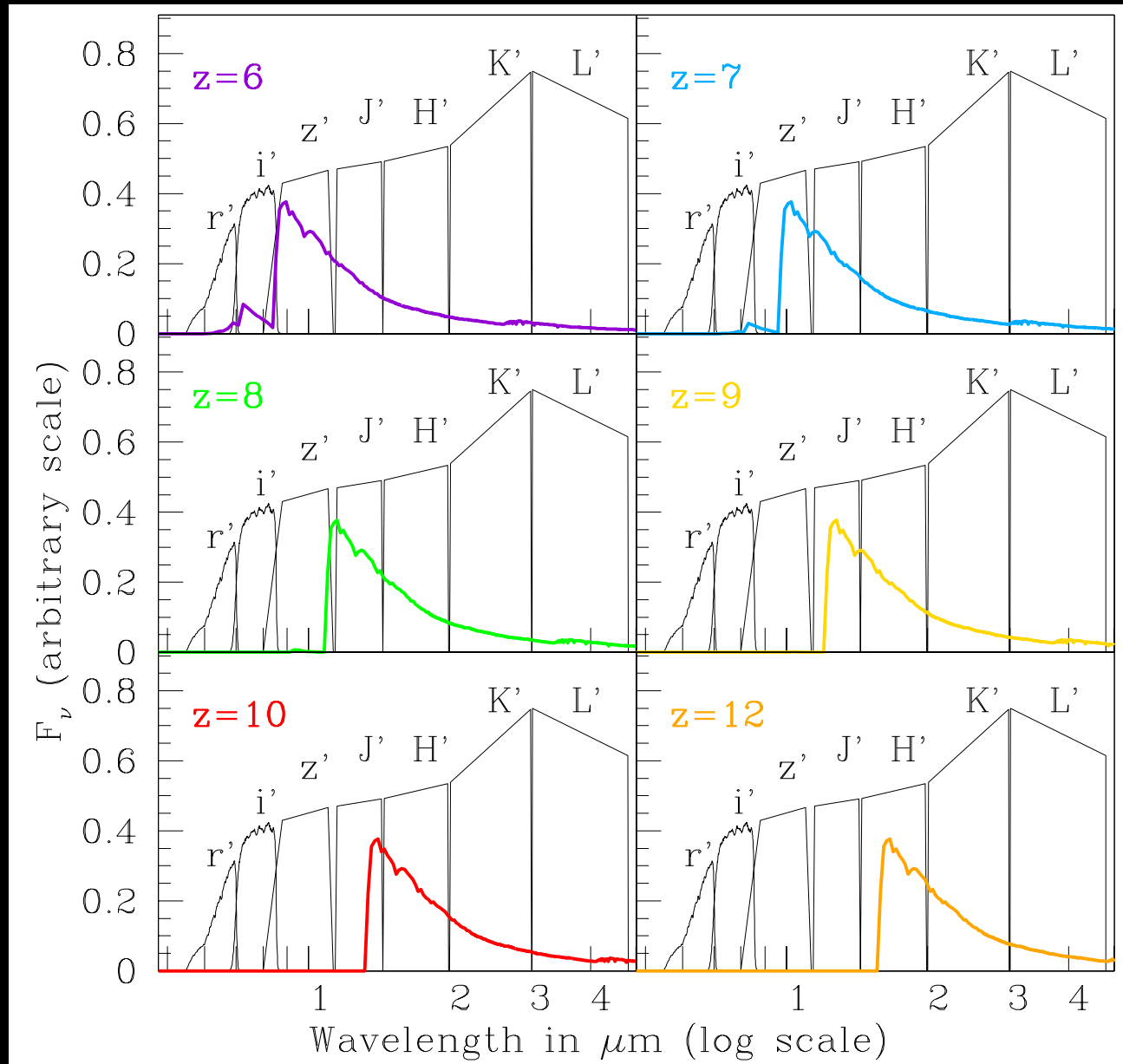
- (1) Instantaneous at $z \simeq 10.4 \pm 1.2$ ($\tau = 0.087 \pm 0.014$), or, more likely:
- (2) Inhomogeneous & drawn out: starting at $z \gtrsim 20$, peaking at $z \simeq 11$, ending at $z \simeq 7$. The implications for HST and JWST are:

- HST/ACS has covered $z \lesssim 6$, and WFC3 is now covering $z \lesssim 7-9$.

- For First Light & Reionization, JWST must sample $z \simeq 8$ to $z \simeq 15-20$.

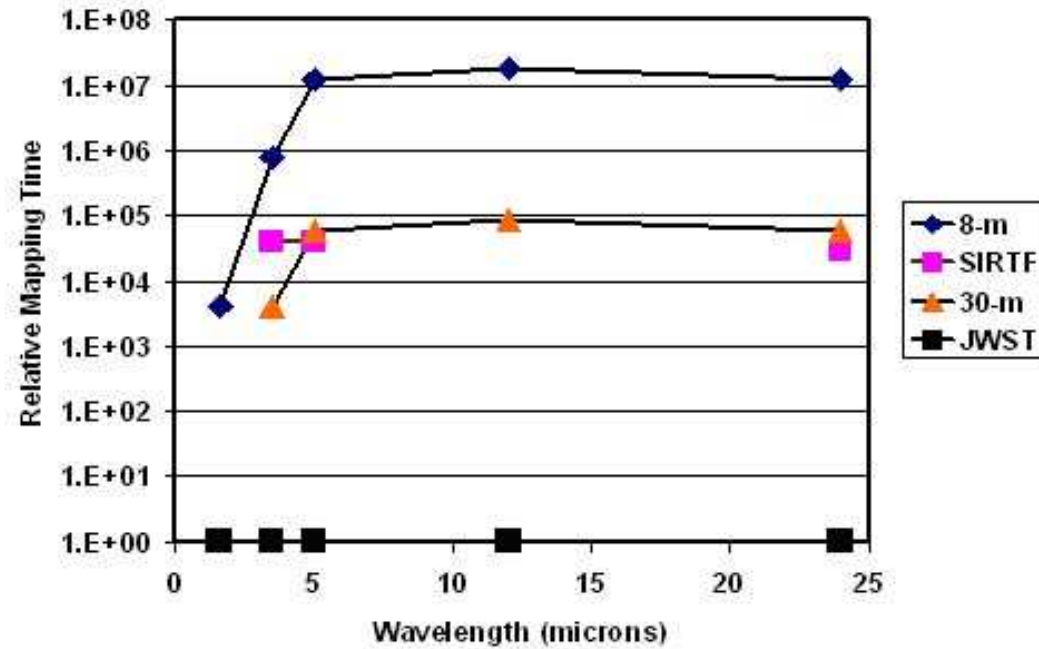
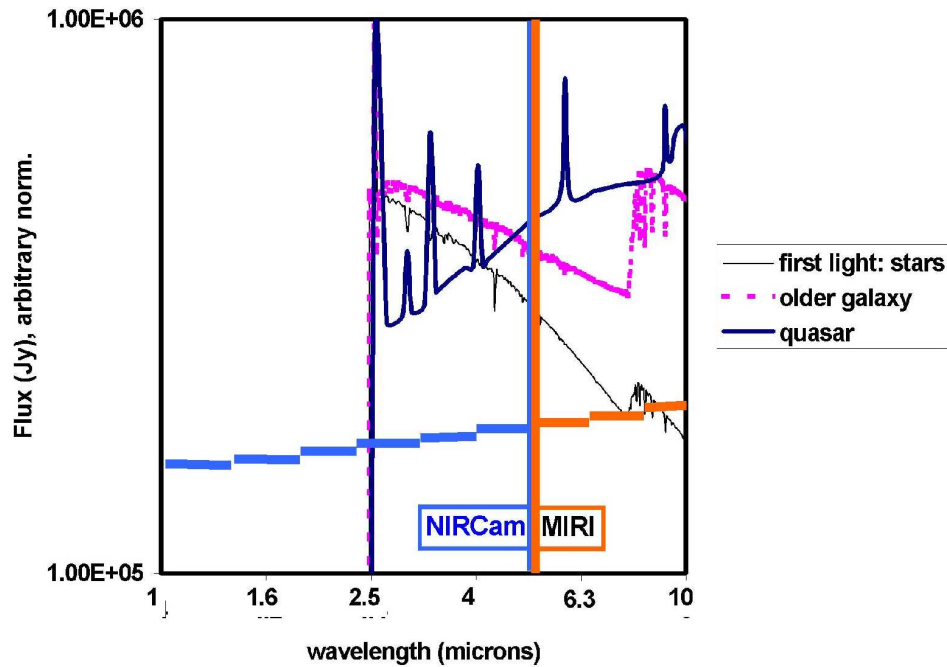
⇒ JWST must cover $\lambda = 0.7-29 \mu\text{m}$, with its diffraction limit at $2.0 \mu\text{m}$.

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



- Can't beat redshift: to see First Light, must observe near-mid IR.
- ⇒ This is why JWST needs NIRCам at 0.8–5 μm and MIRI at 5–28 μm .

- (4) What sensitivity will JWST have?

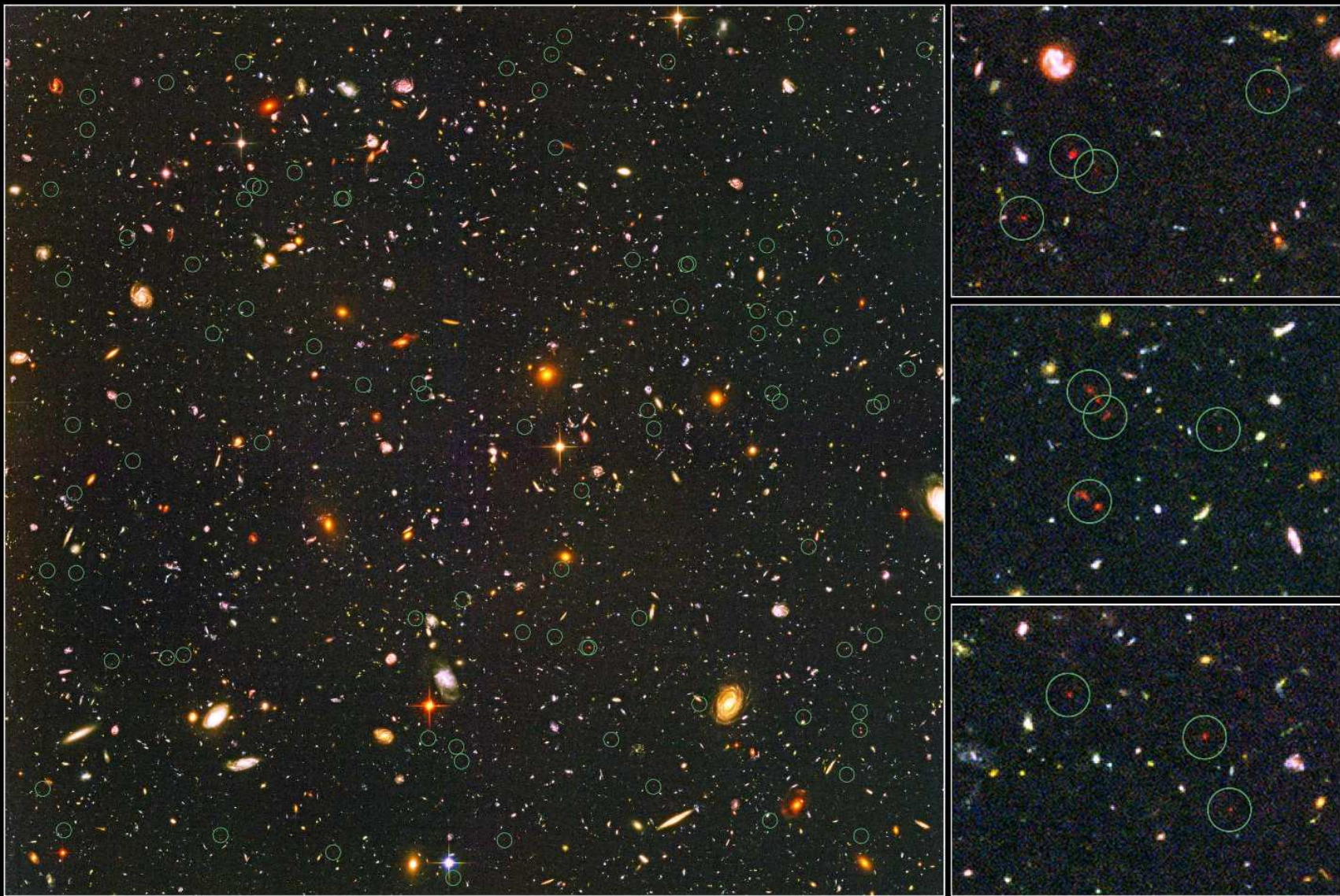


NIRCam and MIRI sensitivity complement each other, straddling $\lambda \simeq 5 \mu\text{m}$.

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.

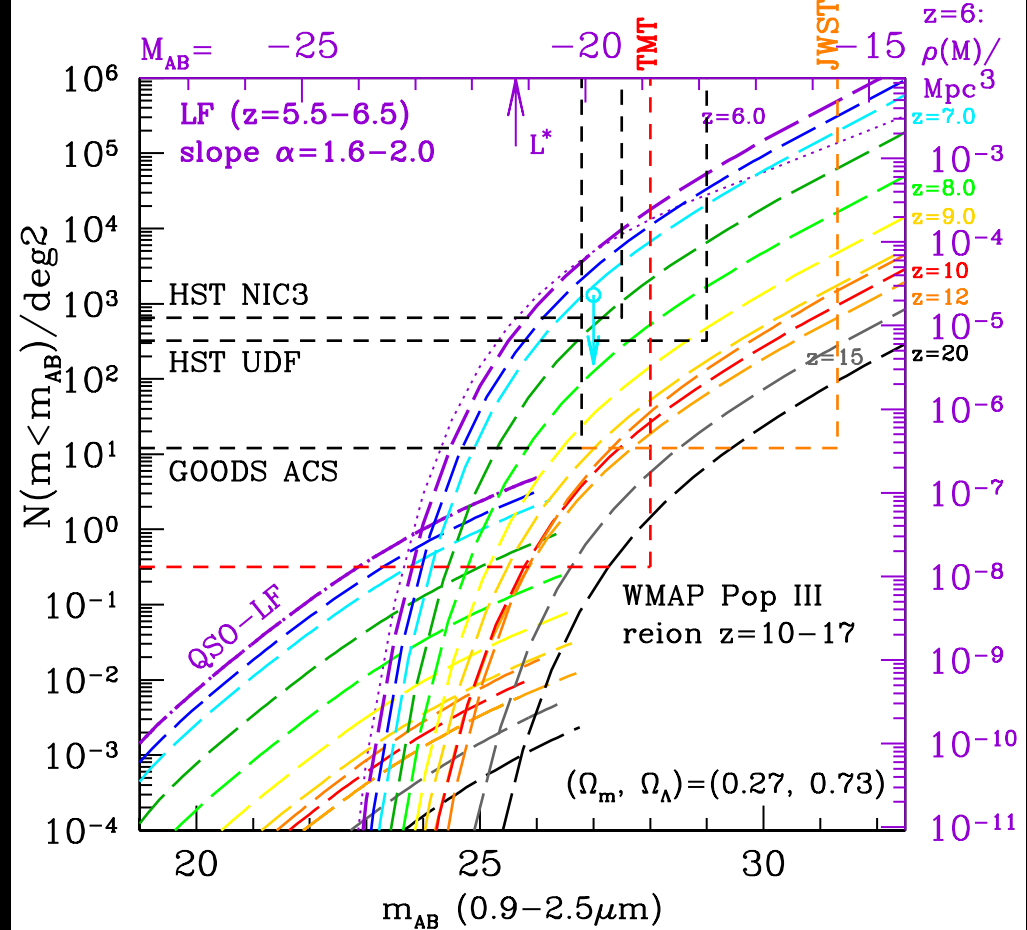
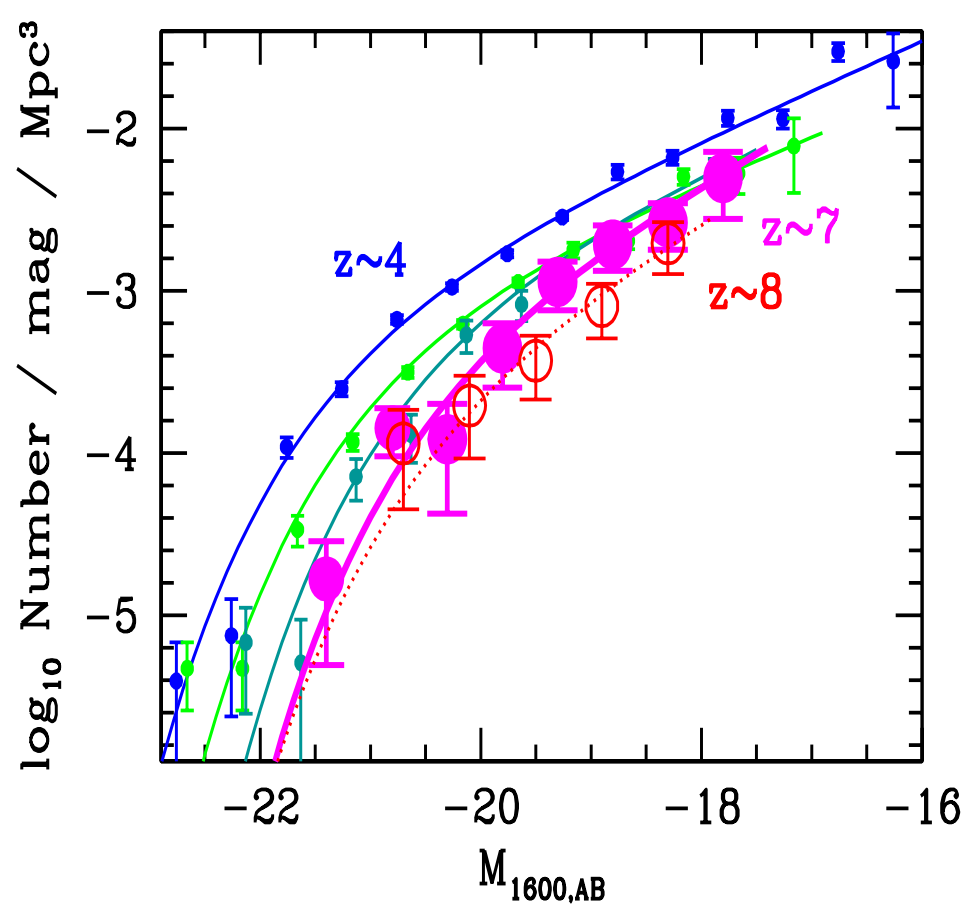


Distant Galaxies in the Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

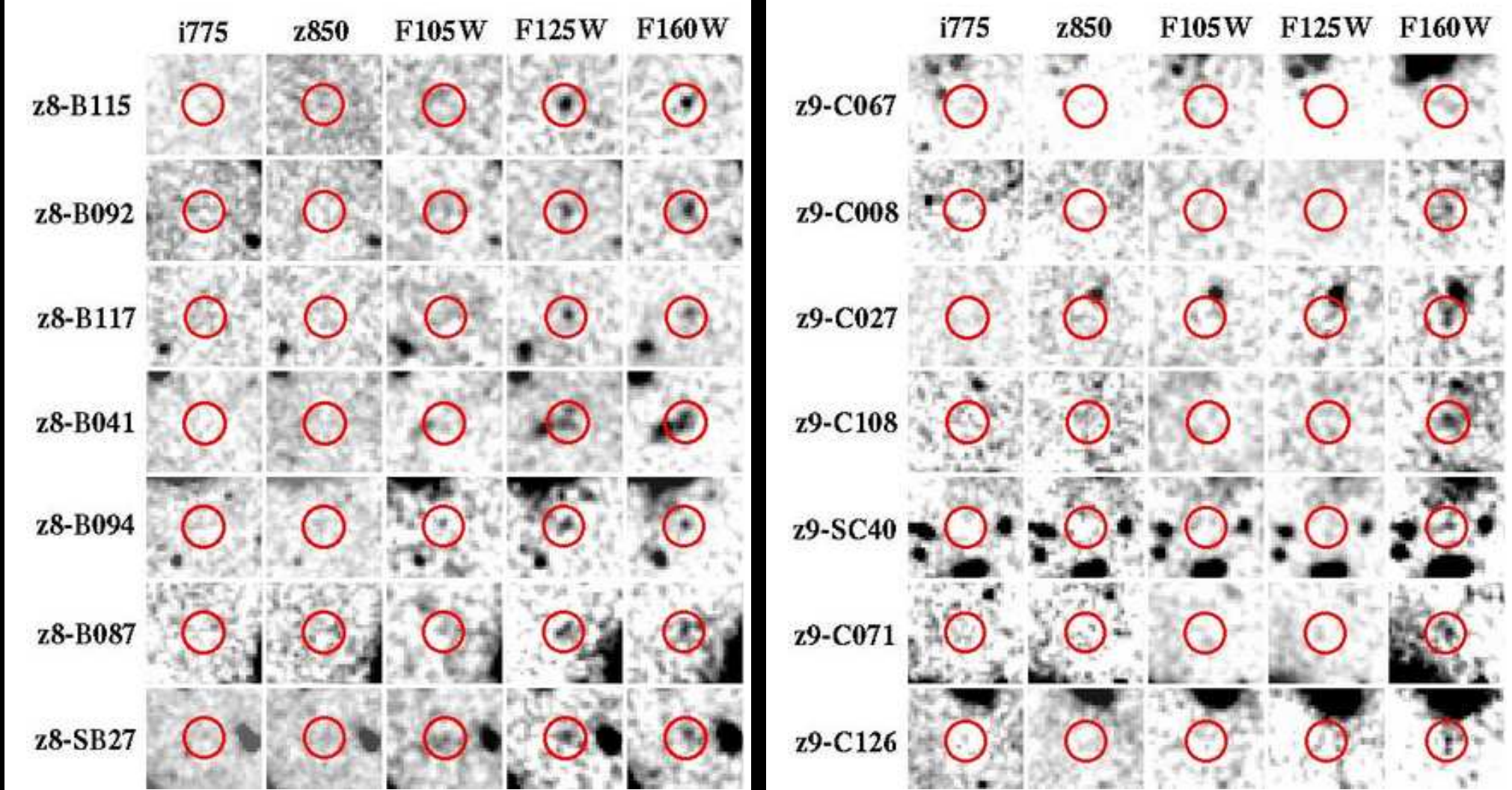
NASA, ESA, R. Windhorst (Arizona State University) and H. Yan (Spitzer Science Center, Caltech)

STScI-PRC04-28

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

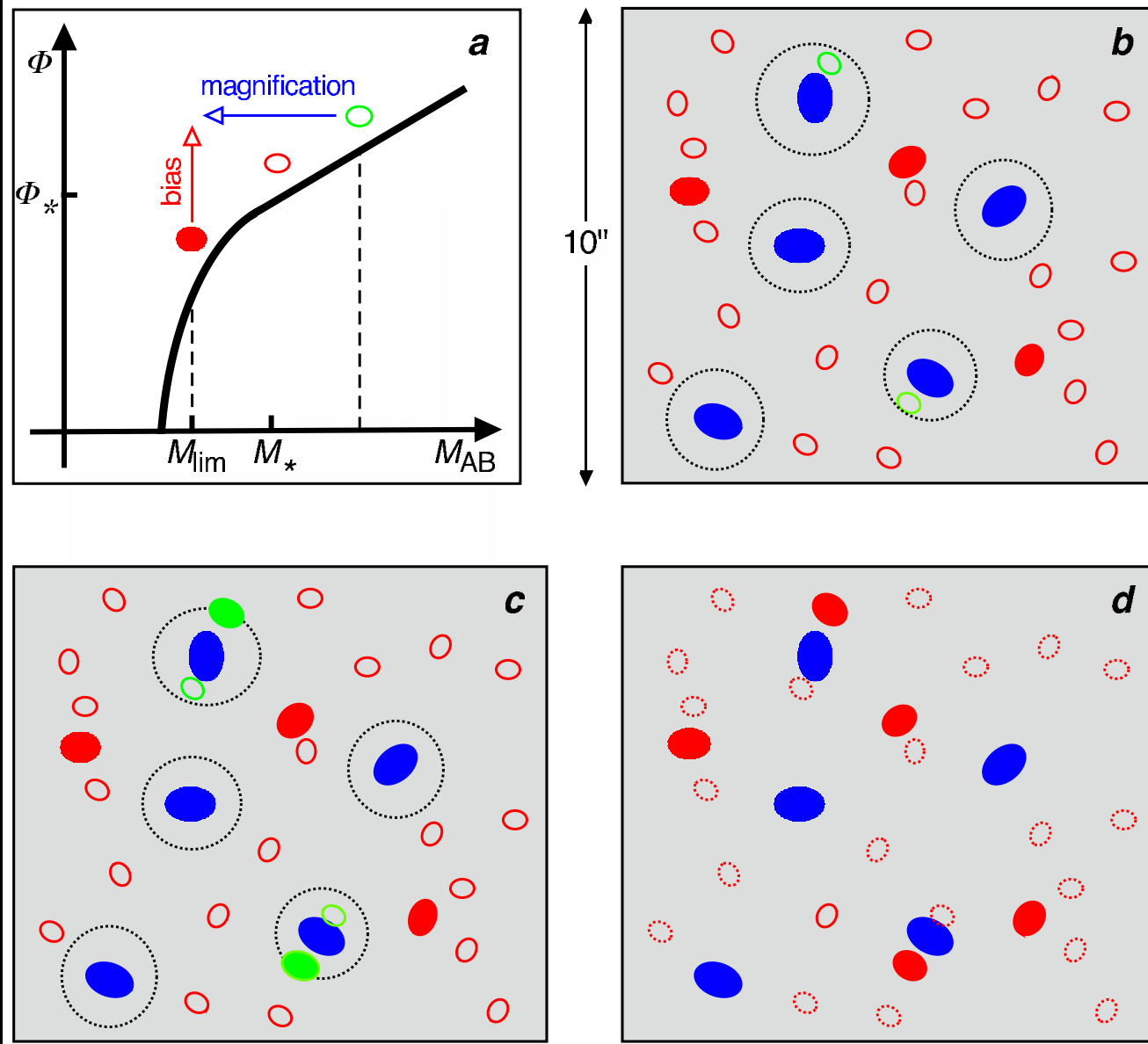


- Objects at $z \gtrsim 9$ are rare (Bouwens⁺ 10; Trenti,⁺ 10; Yan⁺ 10), since volume elt is small, and JWST samples brighter part of LF. JWST needs its sensitivity/aperture (A), field-of-view (Ω), and λ -range ($0.7-29 \mu\text{m}$).
- With proper survey strategy (area AND depth), JWST can trace the 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 $2.0 \mu\text{m}$ diffraction limit for this.



- $\sim 10\text{--}40\%$ of the HUDF Y-drops and J-drops appear close to bright galaxies (Yan et al. 2010, Res. Astr. & Ap., 10, 867).
- This is expected from gravitational lensing bias by galaxy dark matter halo distribution at $z \simeq 1\text{--}2$ (Wyithe et al. 2011, Nature, 469, 181).
- Need JWST to measure $z \simeq 9\text{--}15$ LFs, and see if fundamentally different from $z \lesssim 8$. Does gravitational lensing bias boost LF bright-end?





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

- Foreground galaxies ($z \simeq 1-2$ or $\text{age} \simeq 3-6$ 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.

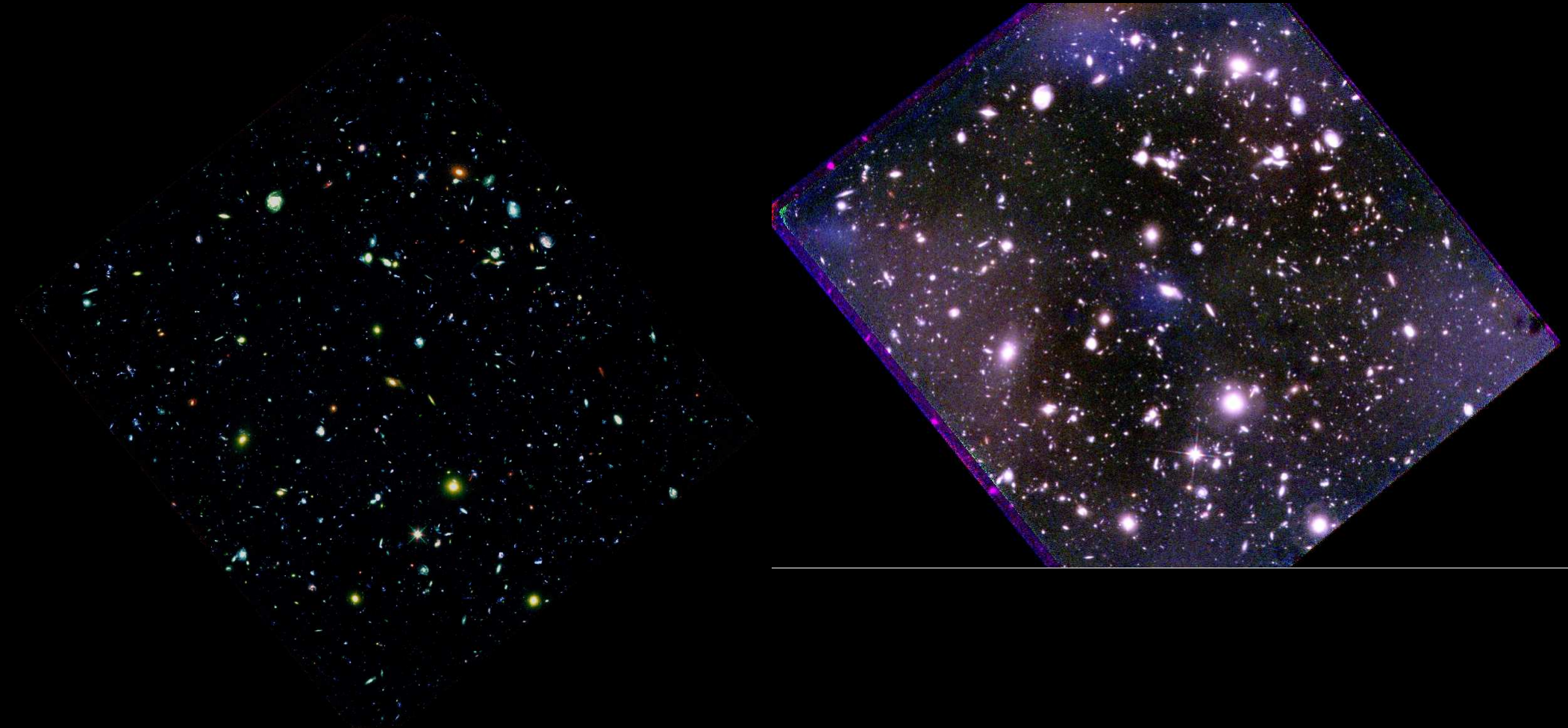


Two fundamental limitations determine ultimate JWST image depth:

(1) Cannot-see-the-forest-for-the-trees effect: Background objects blend into foreground neighbors \Rightarrow Need multi- λ 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 $2.0\mu\text{m}$ PSF and straylight specs essential to handle this.



(Left) 128-hr HST/WFC3 IR-mosaic in HUDF at $1\text{--}1.6\mu\text{m}$ (YJH filters; Bouwens et al 2010, Yan et al. 2010; +85-hr by R. Ellis in 09/2012).

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

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

⇒ 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.

Management replan in 2010-2011. No technical showstoppers thus far:

- 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 CO₂ 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

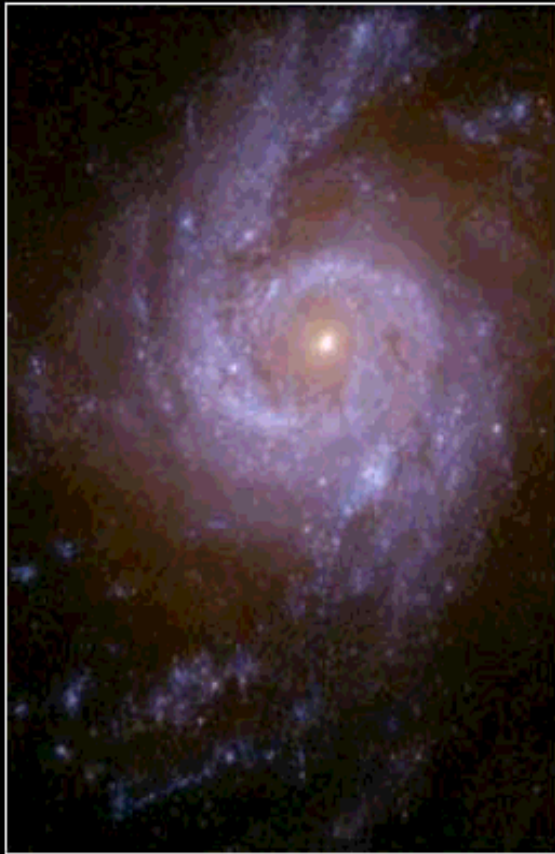
Windhorst, R., et al., 2011, ApJS, 193, 27 (astro-ph/1005.2776).

(4b) Predicted Galaxy Appearance for JWST at redshifts $z \simeq 1-15$

NGC 3310

ESO0418-008

UGC06471-2



Ultraviolet Galaxies

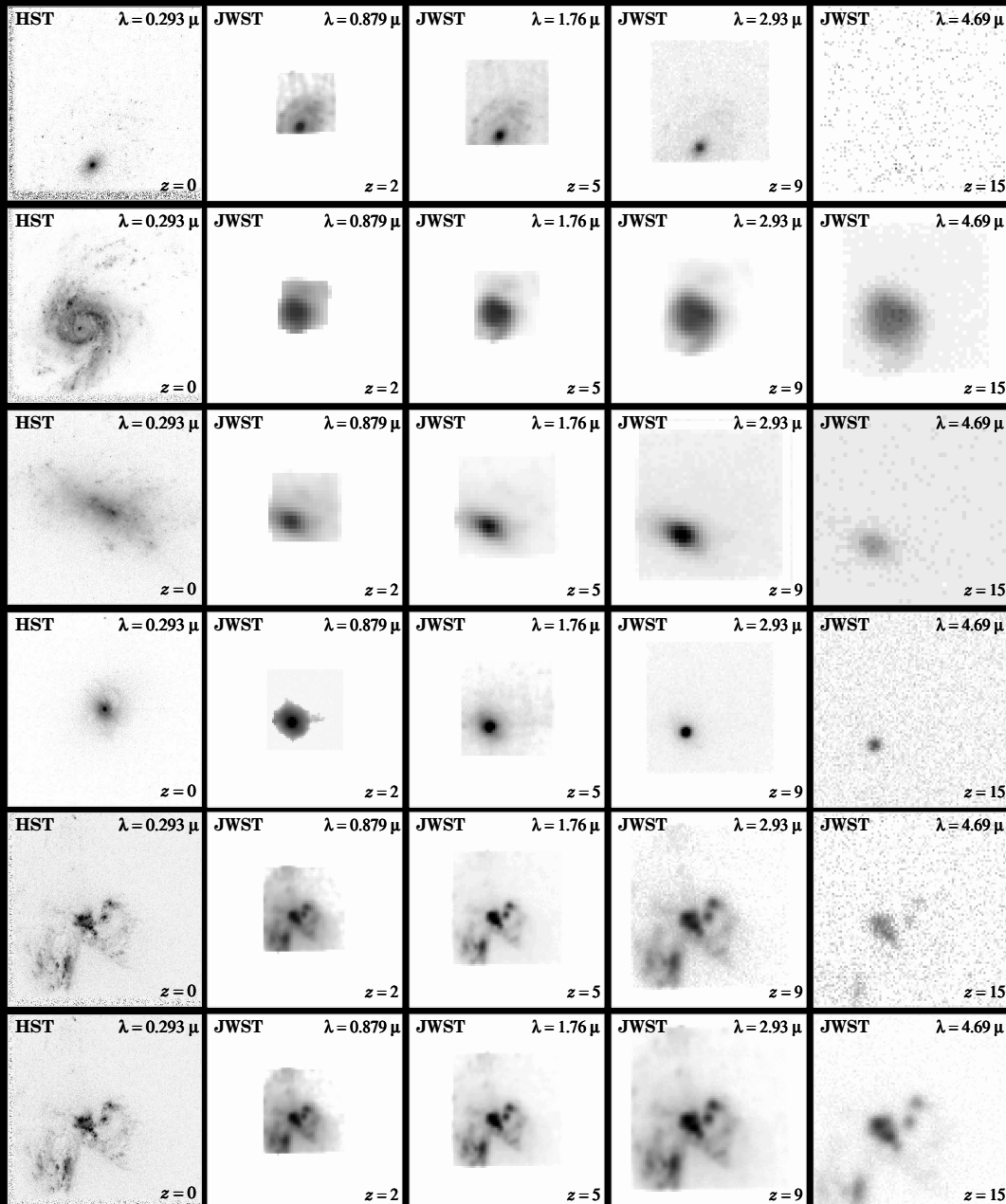
HST • WFPC2

NASA and R. Windhorst (Arizona State University) • STScI-PRC01-04

- 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 $z \simeq 1-15$

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

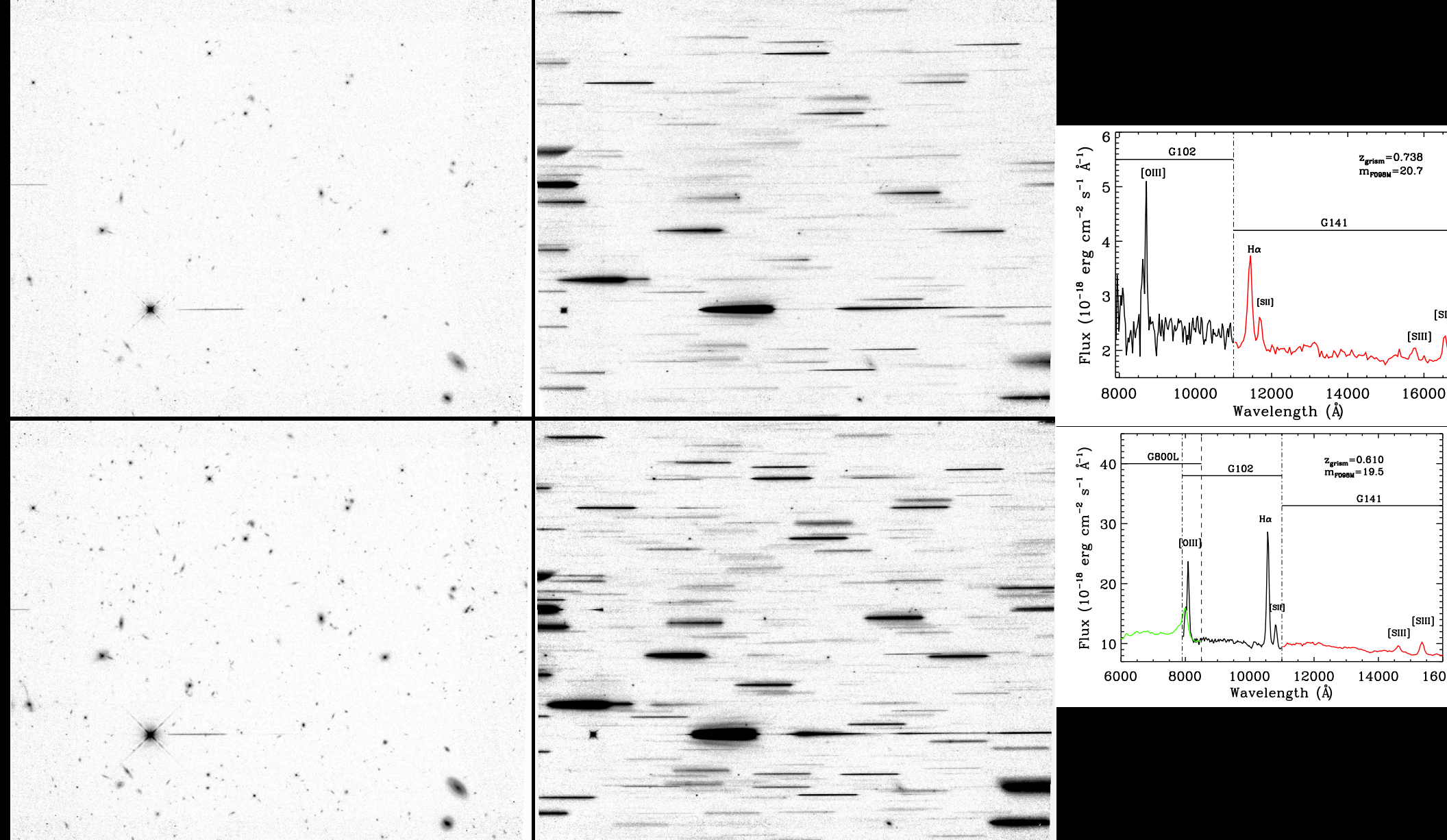


With Hubble UV-optical images as benchmarks, JWST can measure the evolution of galaxy structure & physical properties over a wide range of cosmic time:

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

Visible to JWST at very high z are:

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

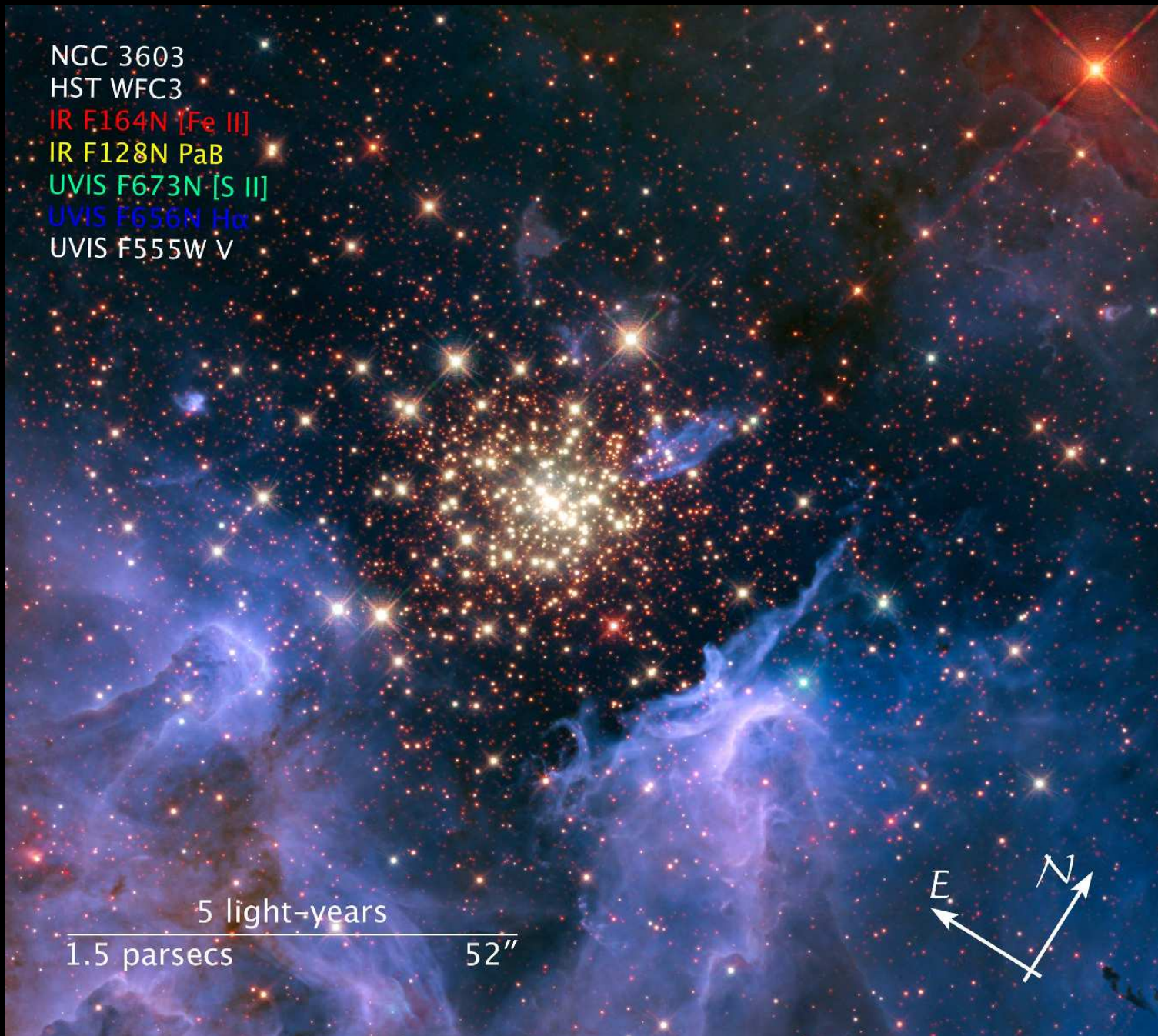


HST/WFC3 G102 & G141 grism spectra in GOODS-S ERS (Straughn⁺ 2010)

IR grism spectra from space: unprecedented new opportunities in astrophysics.

- JWST will provide near-IR grism spectra to $AB \lesssim 29$ mag from 2–5.0 μm .

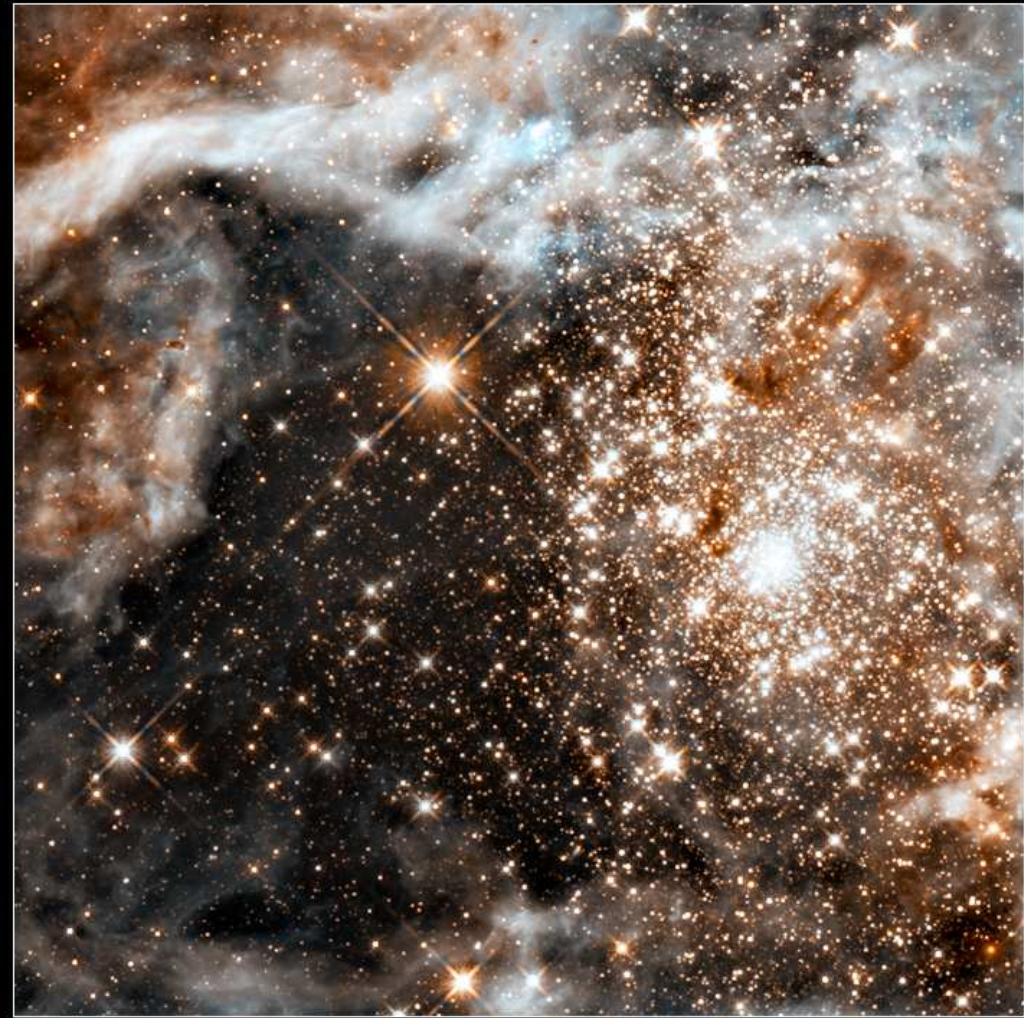
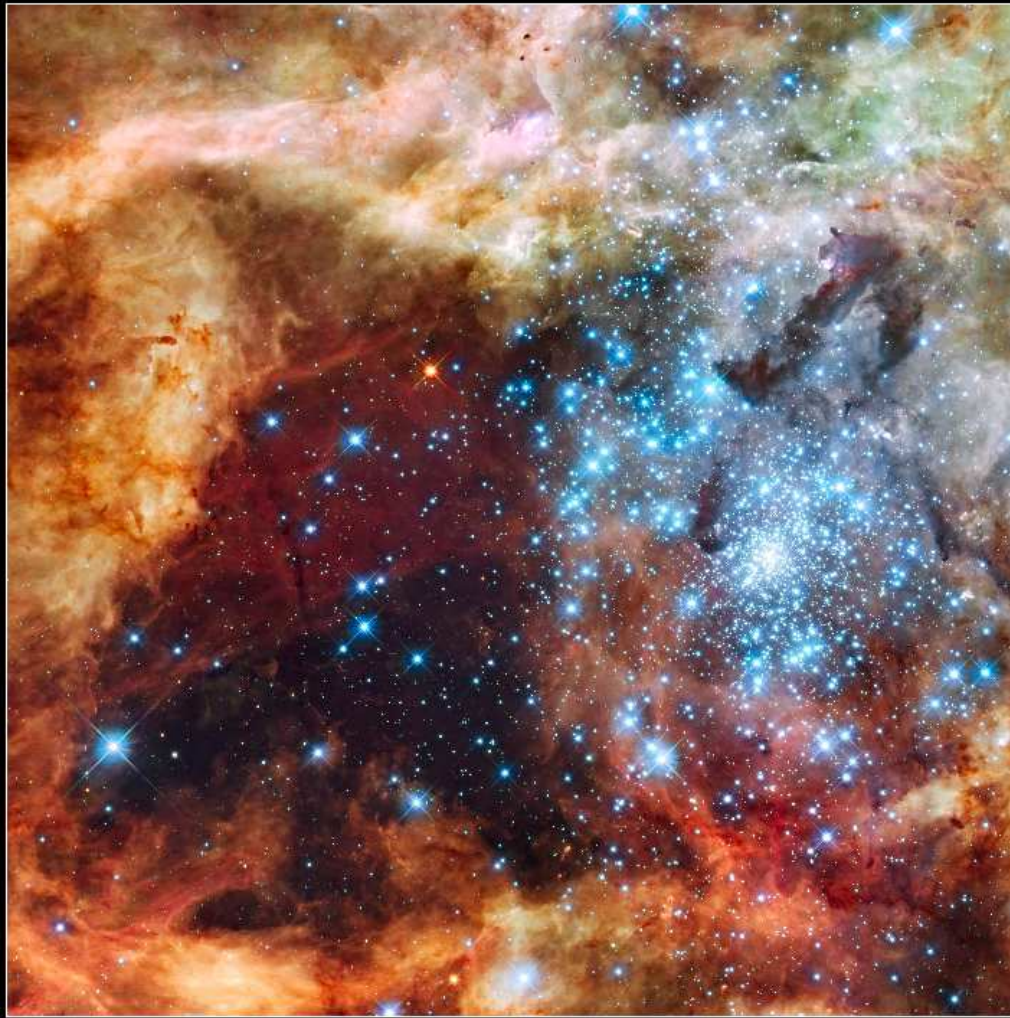
(6) How can JWST measure Earth-like exoplanets?



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

Visible

Infrared



30 Doradus Nebula and Star Cluster
Hubble Space Telescope ■ WFC3/UVIS/IR

NASA, ESA, F. Paresce (INAF-IASF, Italy), and the WFC3 Science Oversight Committee

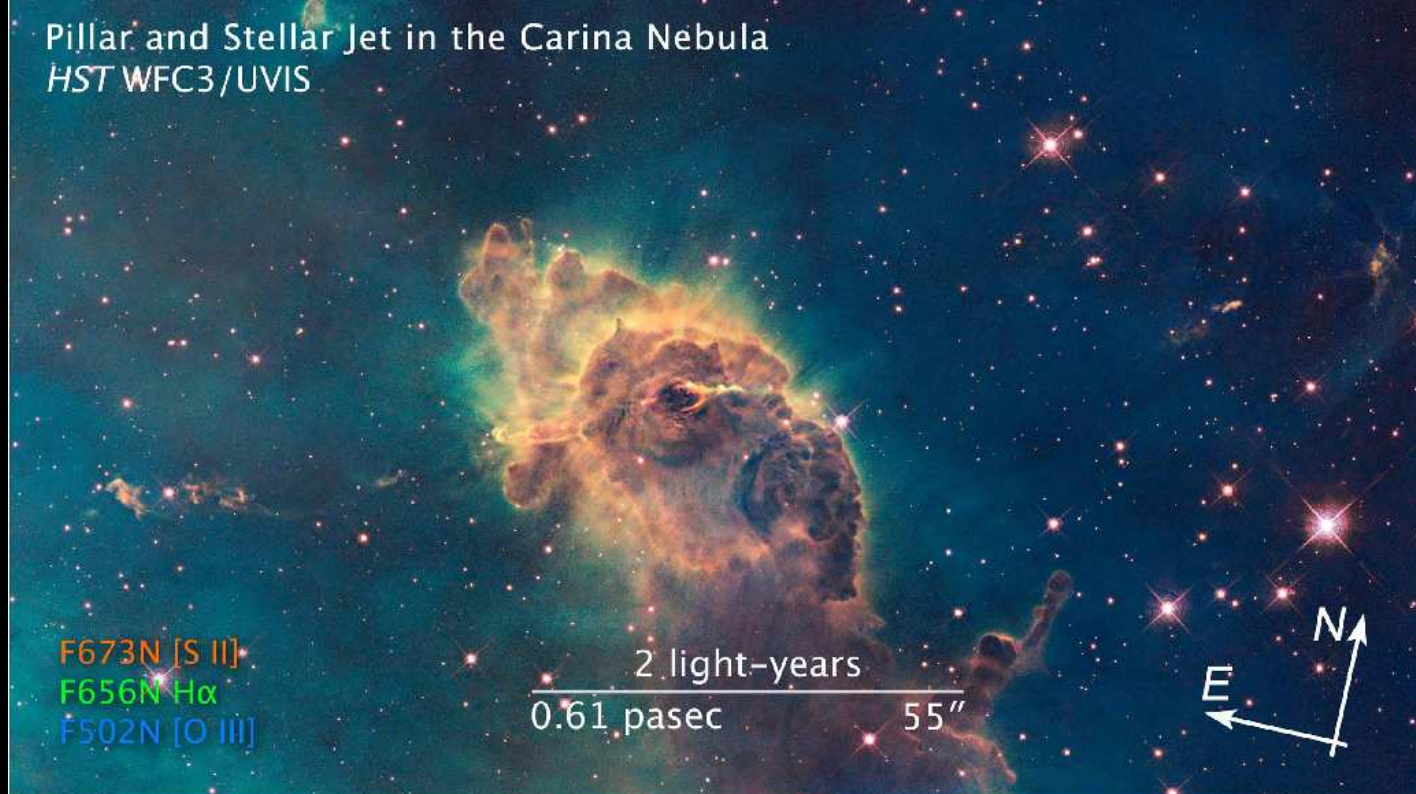
STScI-PRC09-32b

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





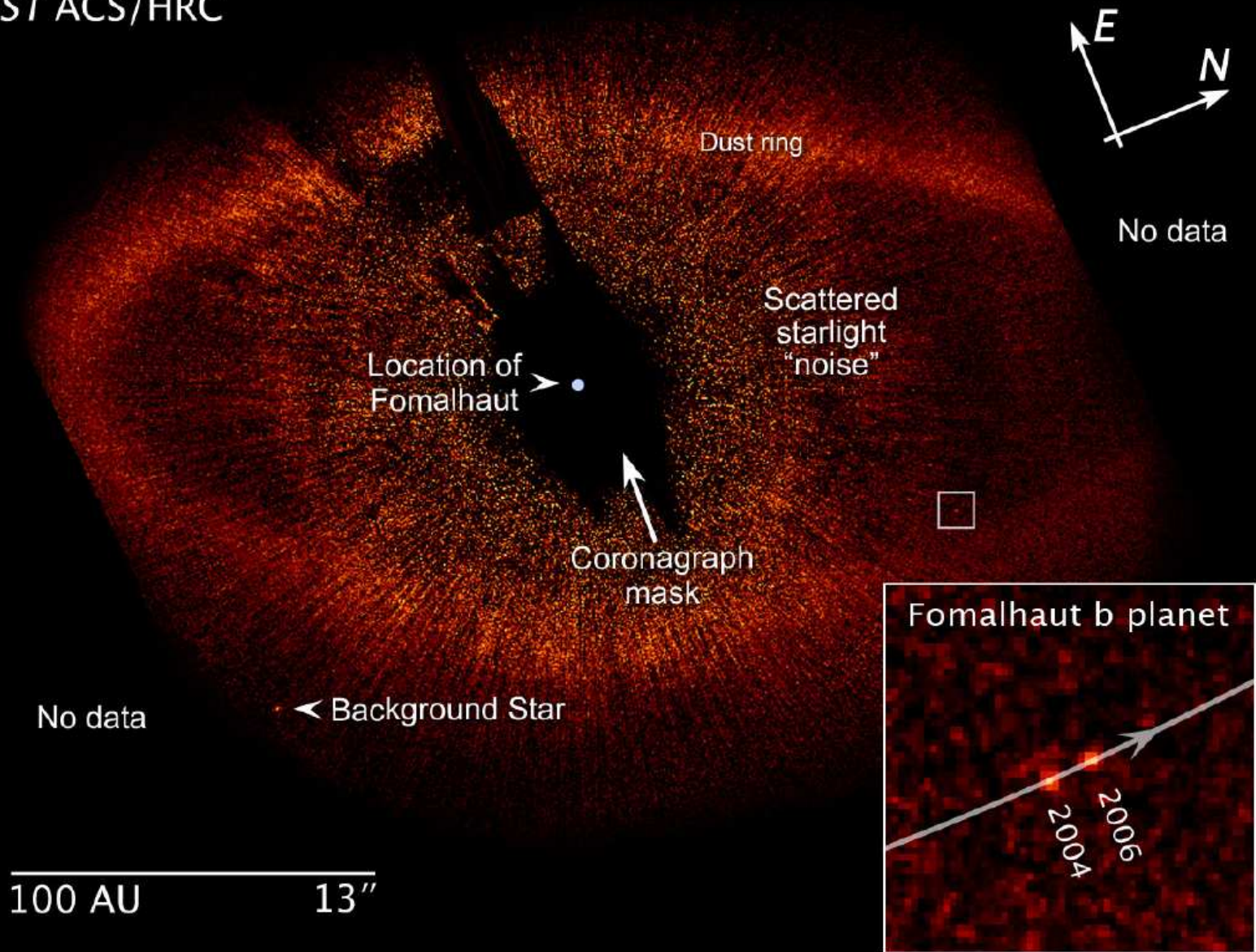
Pillar and Stellar Jet in the Carina Nebula
HST WFC3/UVIS



HST WFC3/IR



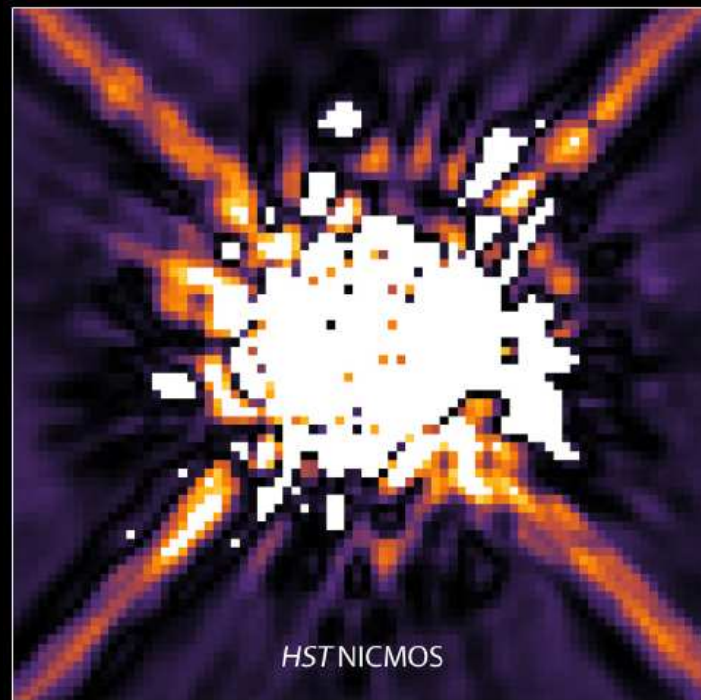
Fomalhaut
HST ACS/HRC



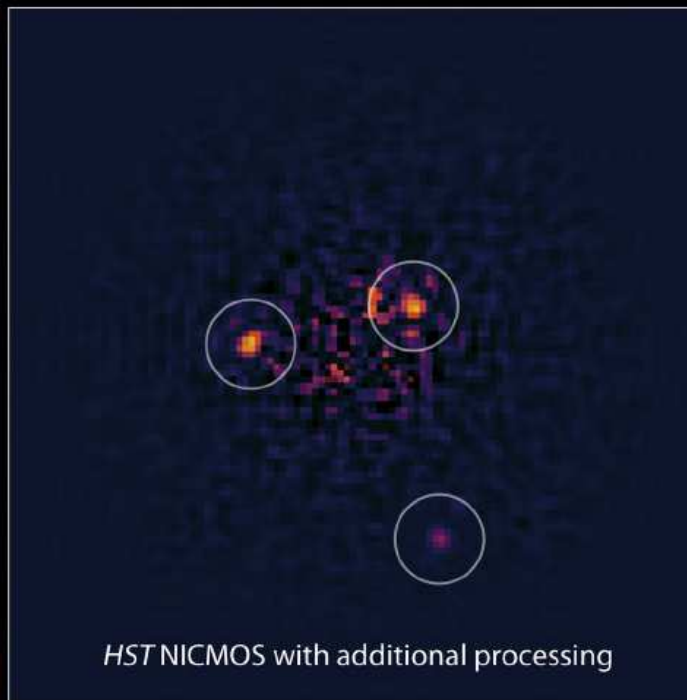
HST/ACS Coronagraph imaging of planetary debris disk around Fomalhaut:
First direct imaging of a moving planet forming around a nearby star!

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

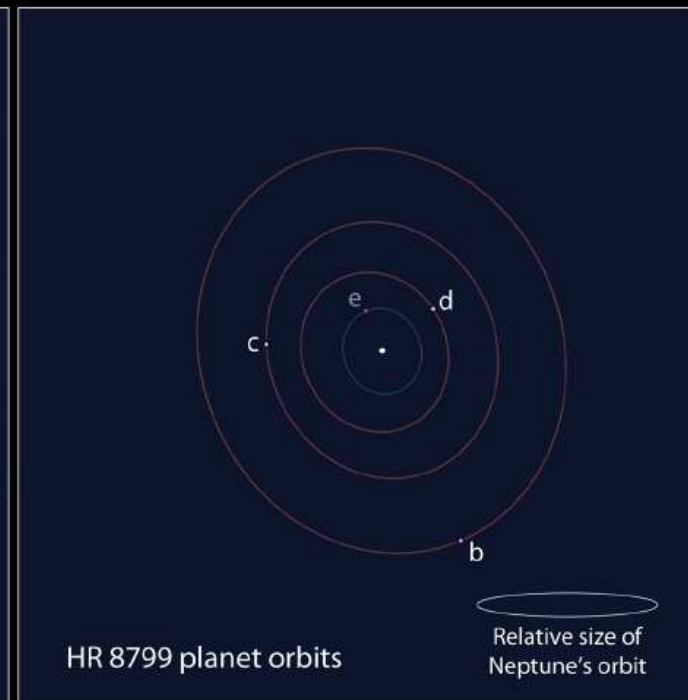
Exoplanet HR 8799 System



HST/NICMOS



HST/NICMOS with additional processing



HR 8799 planet orbits

Relative size of
Neptune's orbit

NASA, ESA, and R. Soummer (STScI)

STScI-PRC11-29

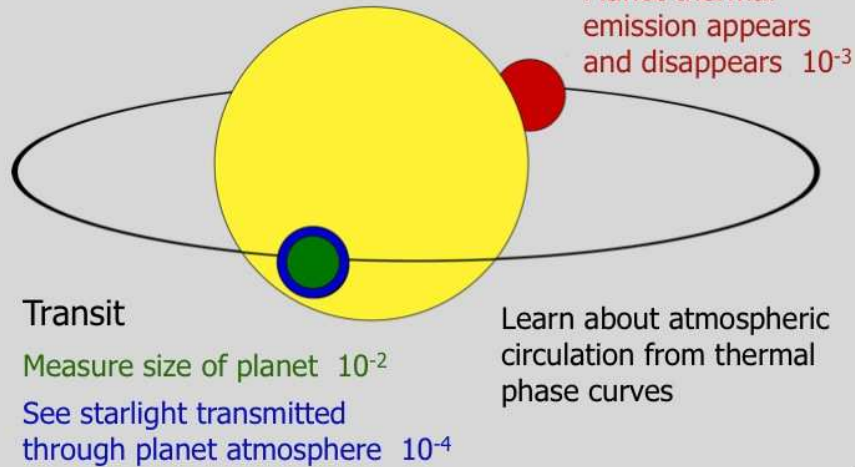
HST/NICMOS imaging of planetary system around the (carefully subtracted) star HR 8799: Direct imaging of planets around a nearby star.

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

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

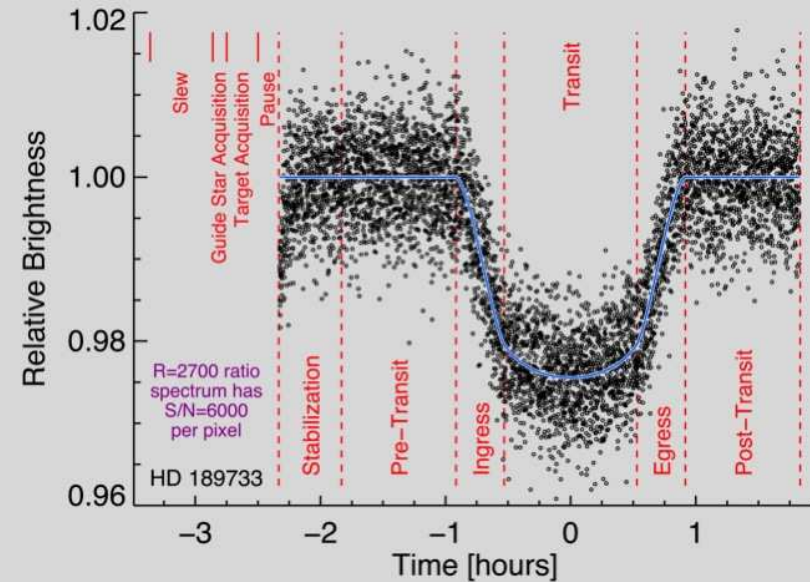
Schematic of Transit and Eclipse Science

Seager & Deming (2010, ARAA, 48, 631)



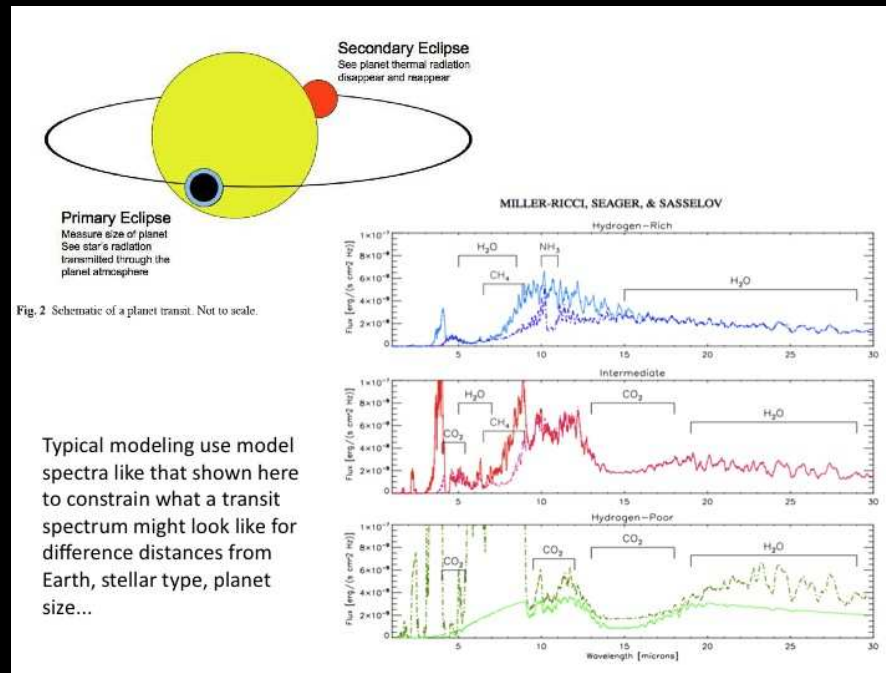
6

Timeline of a Transit Observation



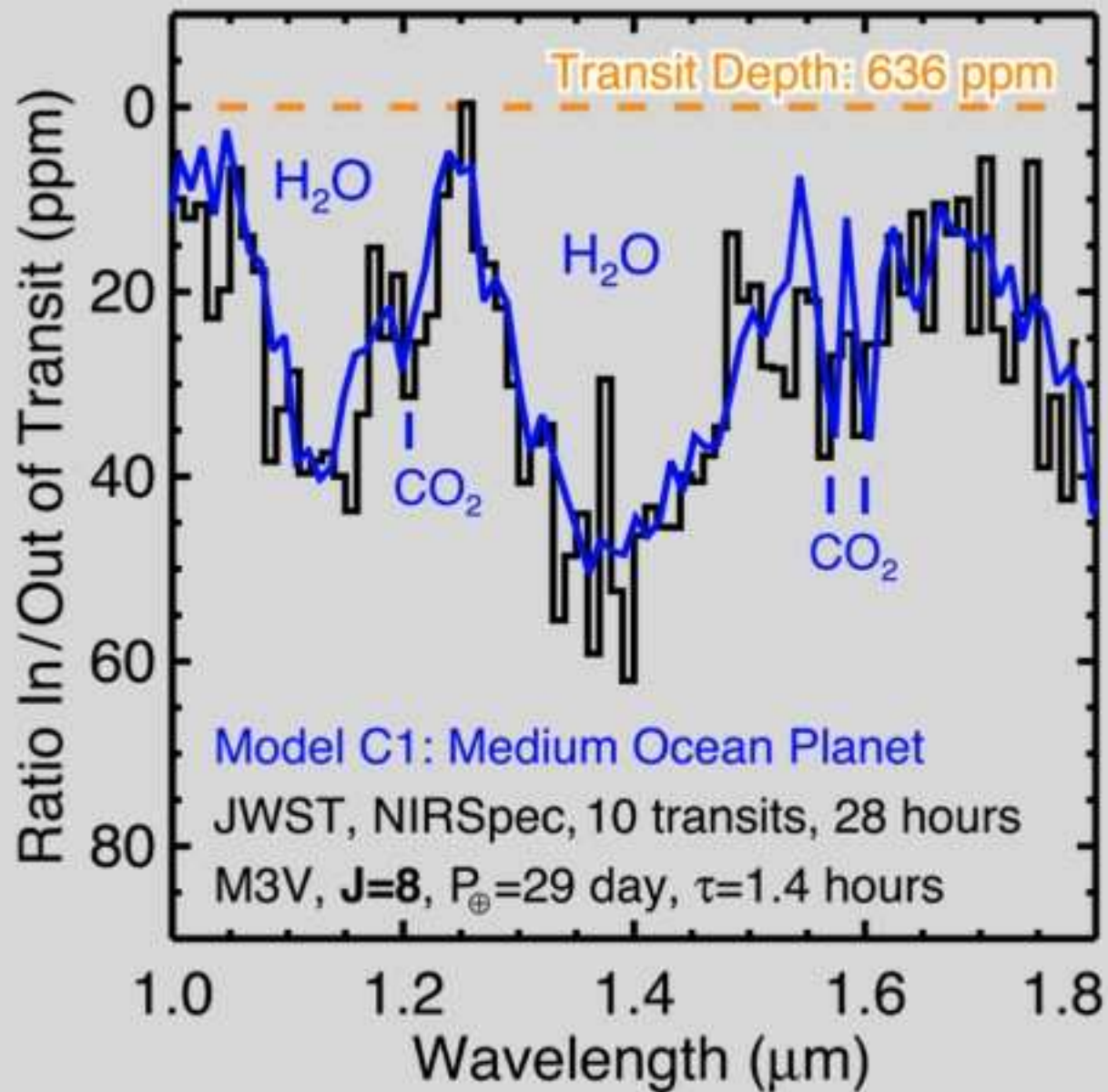
13

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.

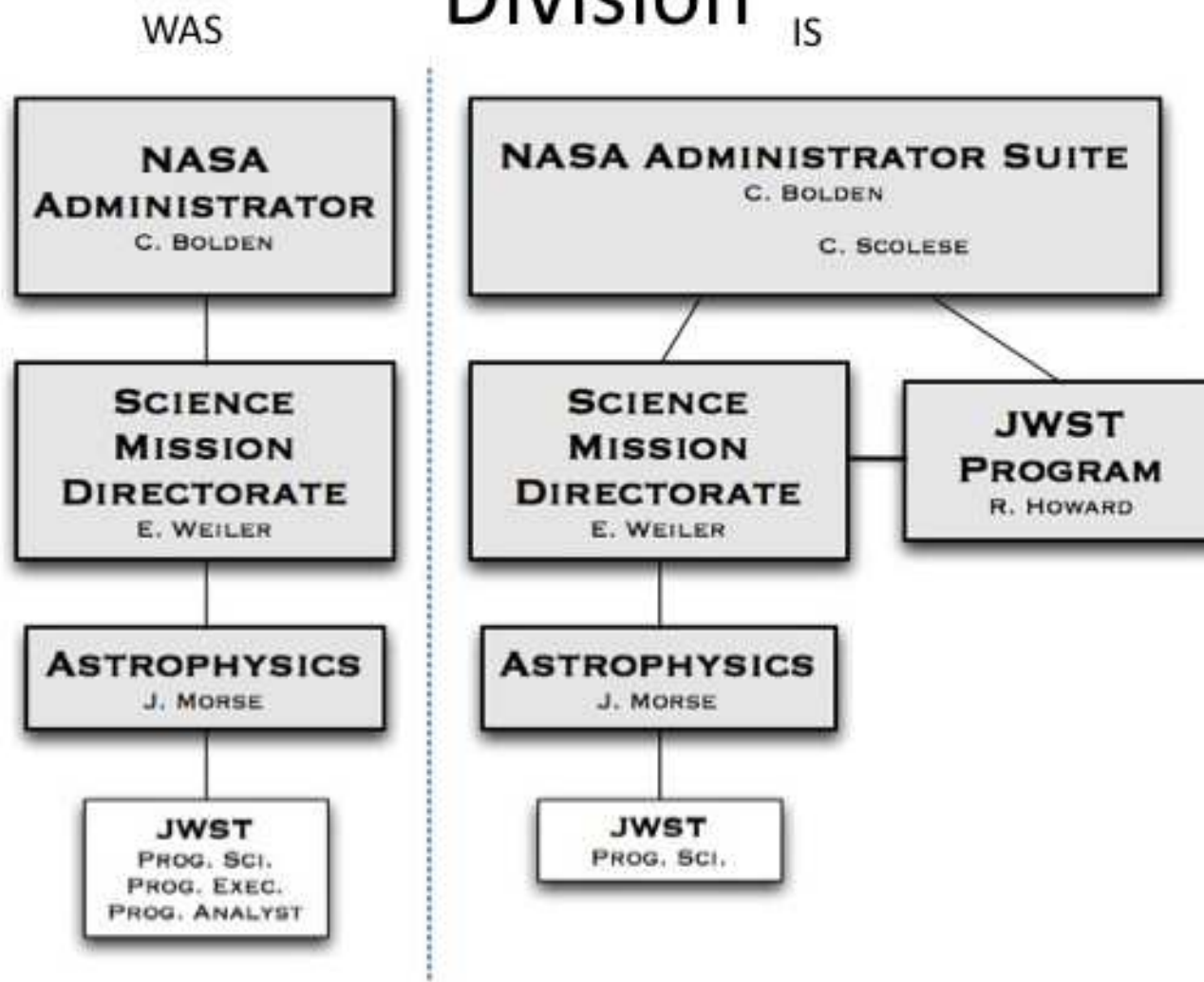
Transit Spectrum of Habitable “Ocean Planet”



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

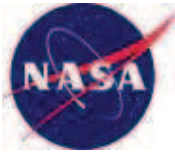
(7) Update of JWST programmatics as of 2011/2012:

JWST moved out of Astrophysics Division

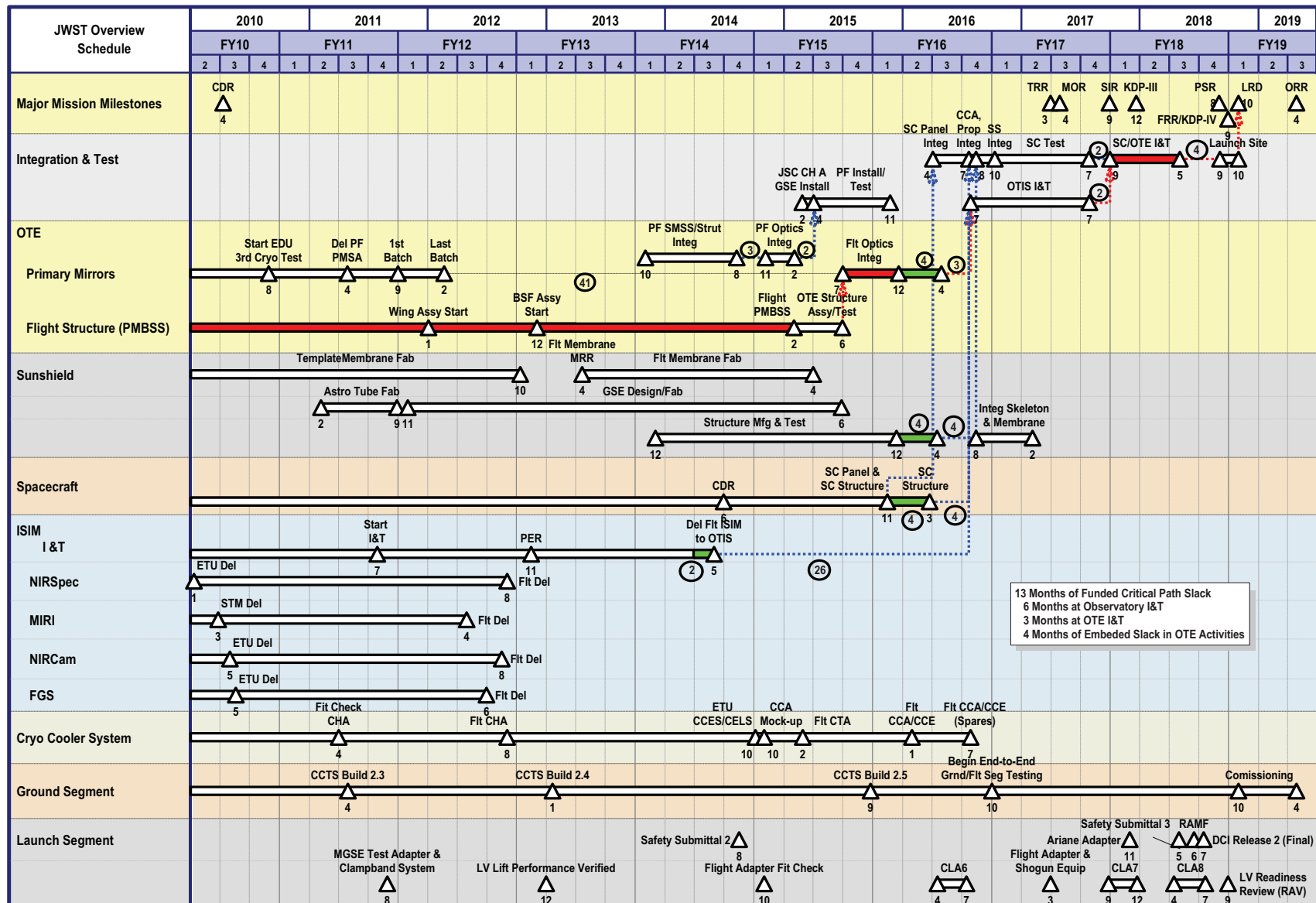


NASA HQ Reorg: JWST budget no longer comes directly from SMD/Ap.

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

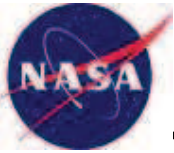


JWST Master Schedule

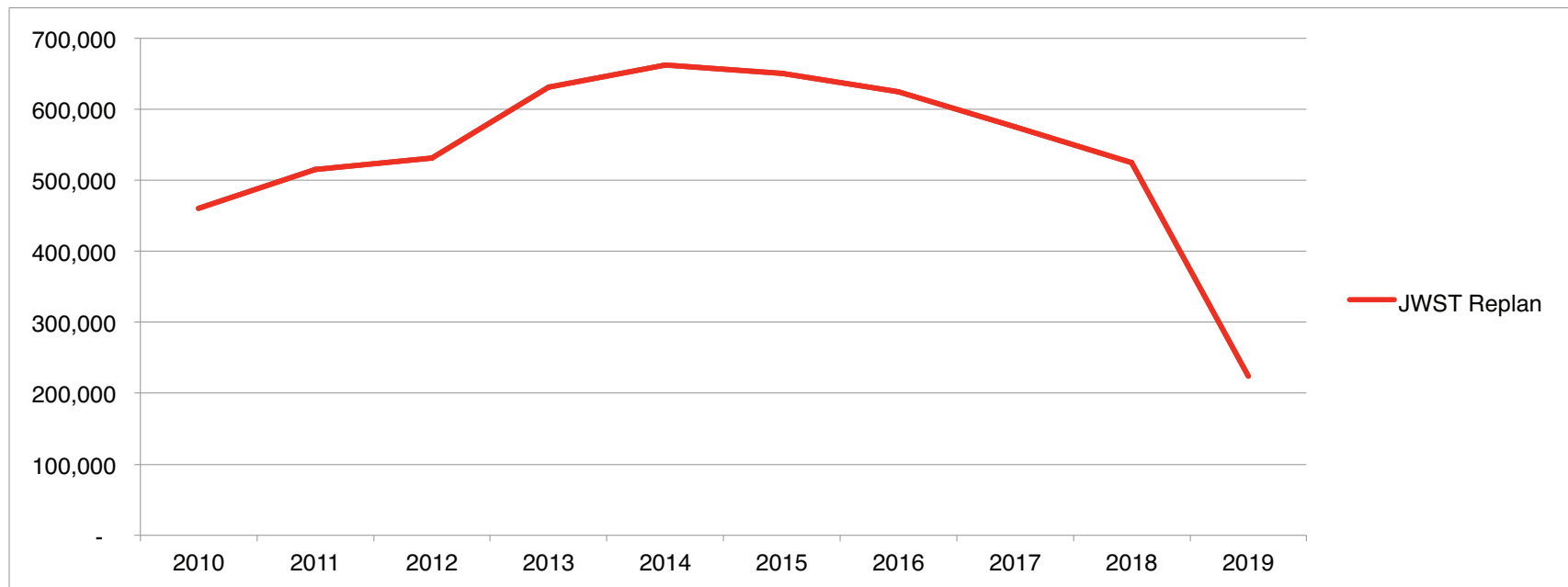


JWST schedule replan for FY12–18 as of 2011 (W. Ochs; NASA GSFC).

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

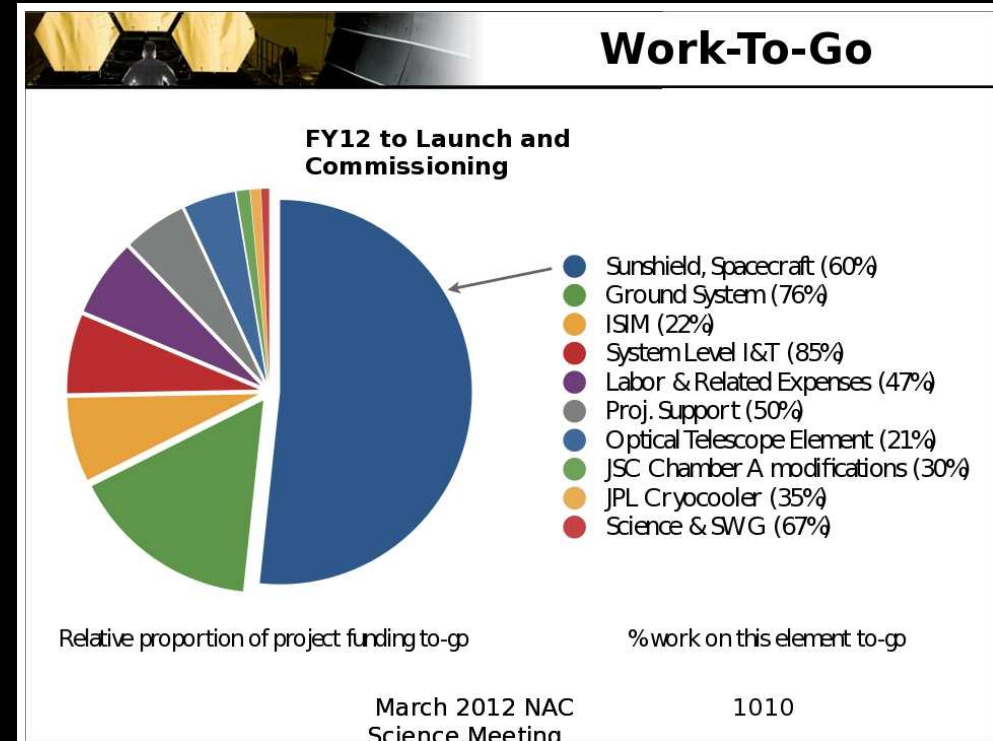
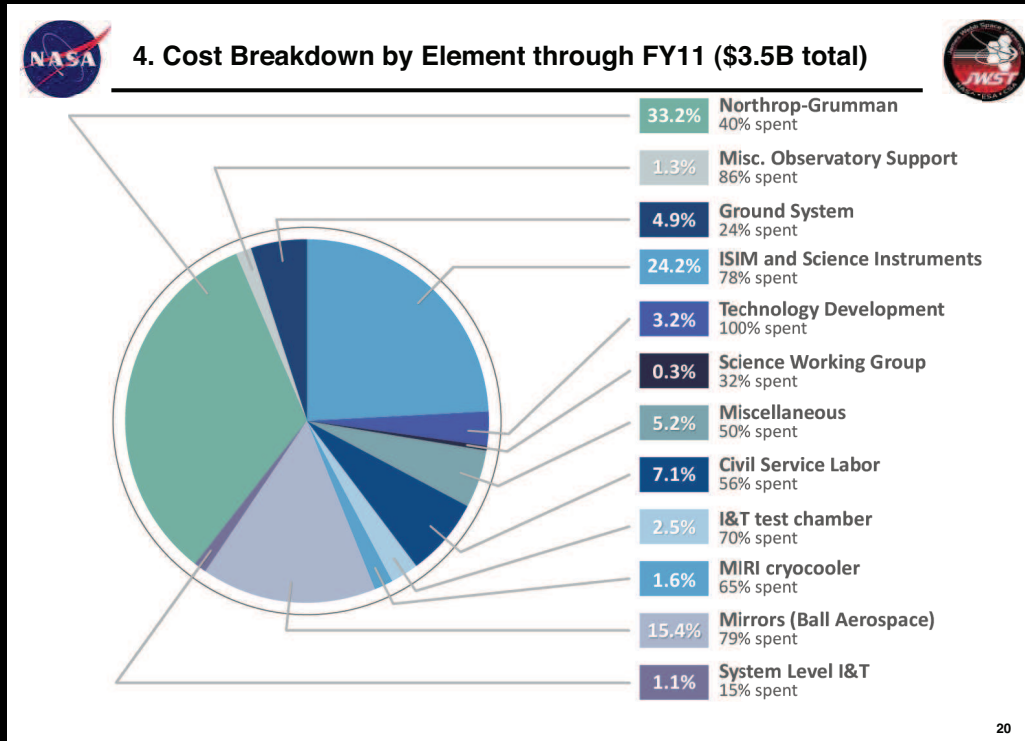


JWST Budget Profile (July 2011)



- **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

(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





Baseline "Cup Down" Tower Configuration at JSC (Before)



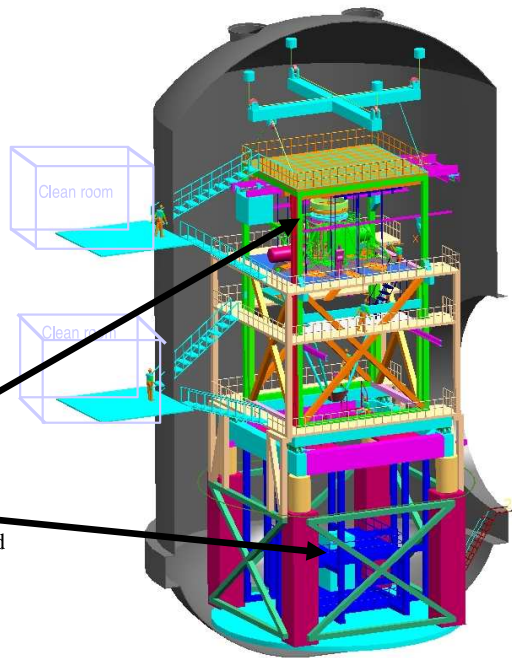
Most recent Tower Design shows an Inner Optical Tower supported by a Outer structure with Vibration Isolation at the midplane. Everything shown is in the 20K region (helium connections, etc. not shown) except clean room and lift fixture.

Current plan calls for 33KW cooldown capability, 12 KW steady state, 300-500mW N2 cooling

JSC currently has 7 KW He capability

Current plan includes 10 trucks of LN2/day during cooldown

Interferometers, Sources, Null Lens and Alignment Equipment Are in Upper and Lower Pressure Tight Enclosure Inside of Shroud



JSC "Cup Up" Test Configuration (New Proposal)

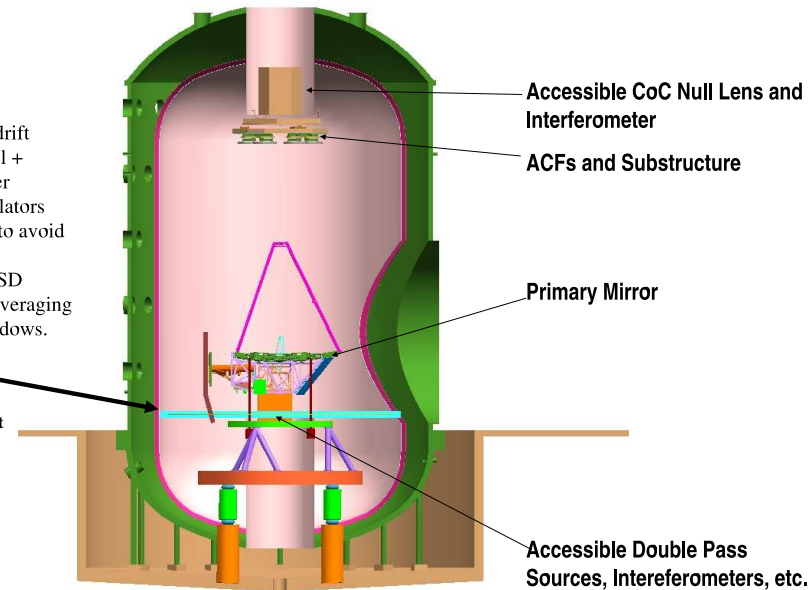


No Metrology Tower and Associated Cooling H/W.
External Metrology

Two basic test options:

1. Use isolators, remove drift through fast active control + freeze test equipment jitter
 2. Eliminate vibration isolators (but use soft dampeners) to avoid drift, freeze out jitter
- Builds on successful AMSD heritage of freezing and averaging jitter, testing through windows.

Possible payload "floor" to separate ambient pressure and temperature.



Drawing care of ITT

Page 6

JWST underwent several significant replans and risk-reduction schemes:

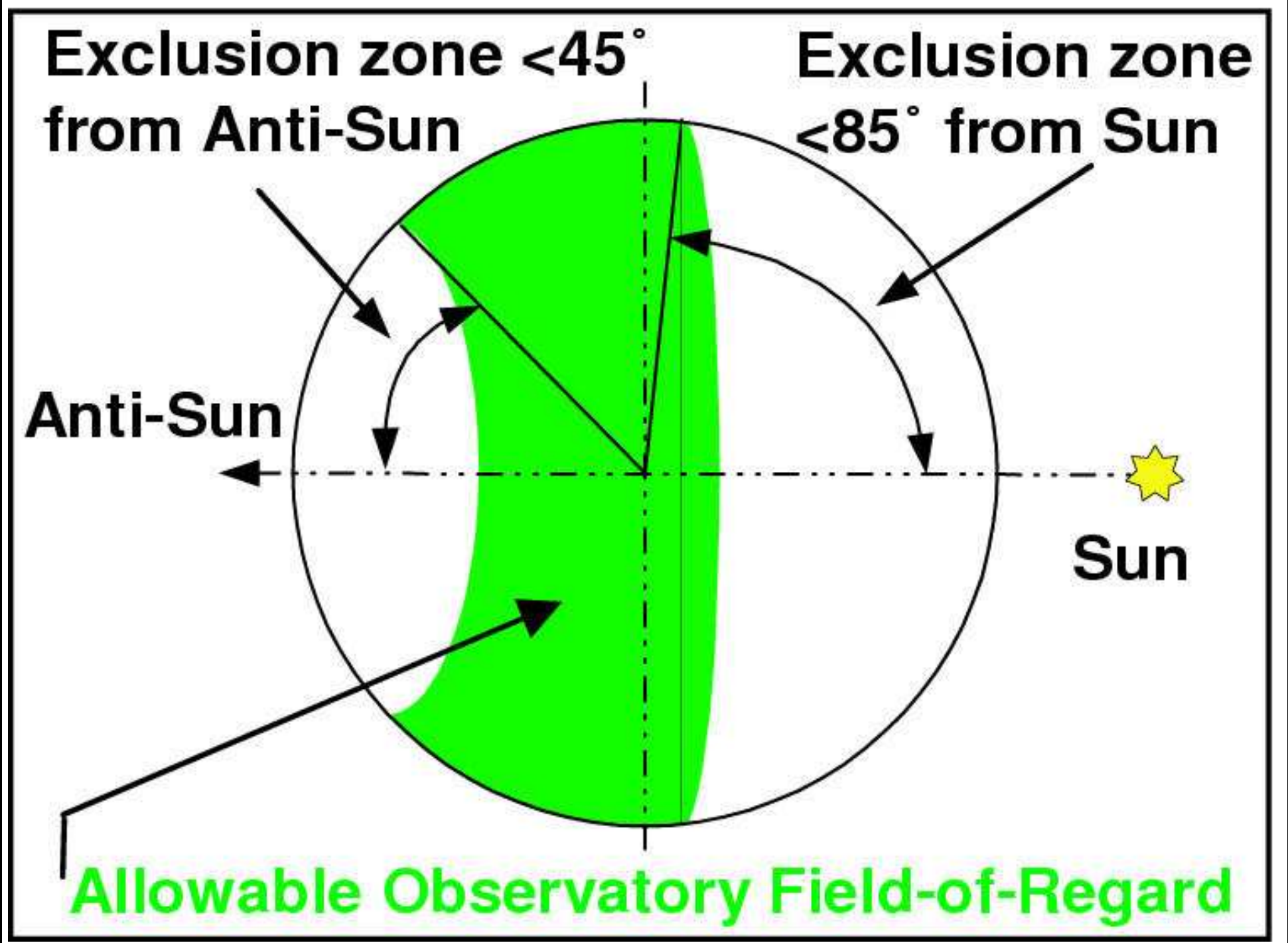
- $\lesssim 2003$: Reduction from 8.0 to 7.0 to 6.5 meter. Ariane-V launch vehicle.
- 2005: Eliminate costly 0.7-1.0 μm performance specs (kept 2.0 μm).
- 2005: Simplification of thermal vacuum tests: cup-up, not cup-down.
- 2006: All critical technology at Technical Readiness Level 6 (TRL-6).
- 2007: 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.



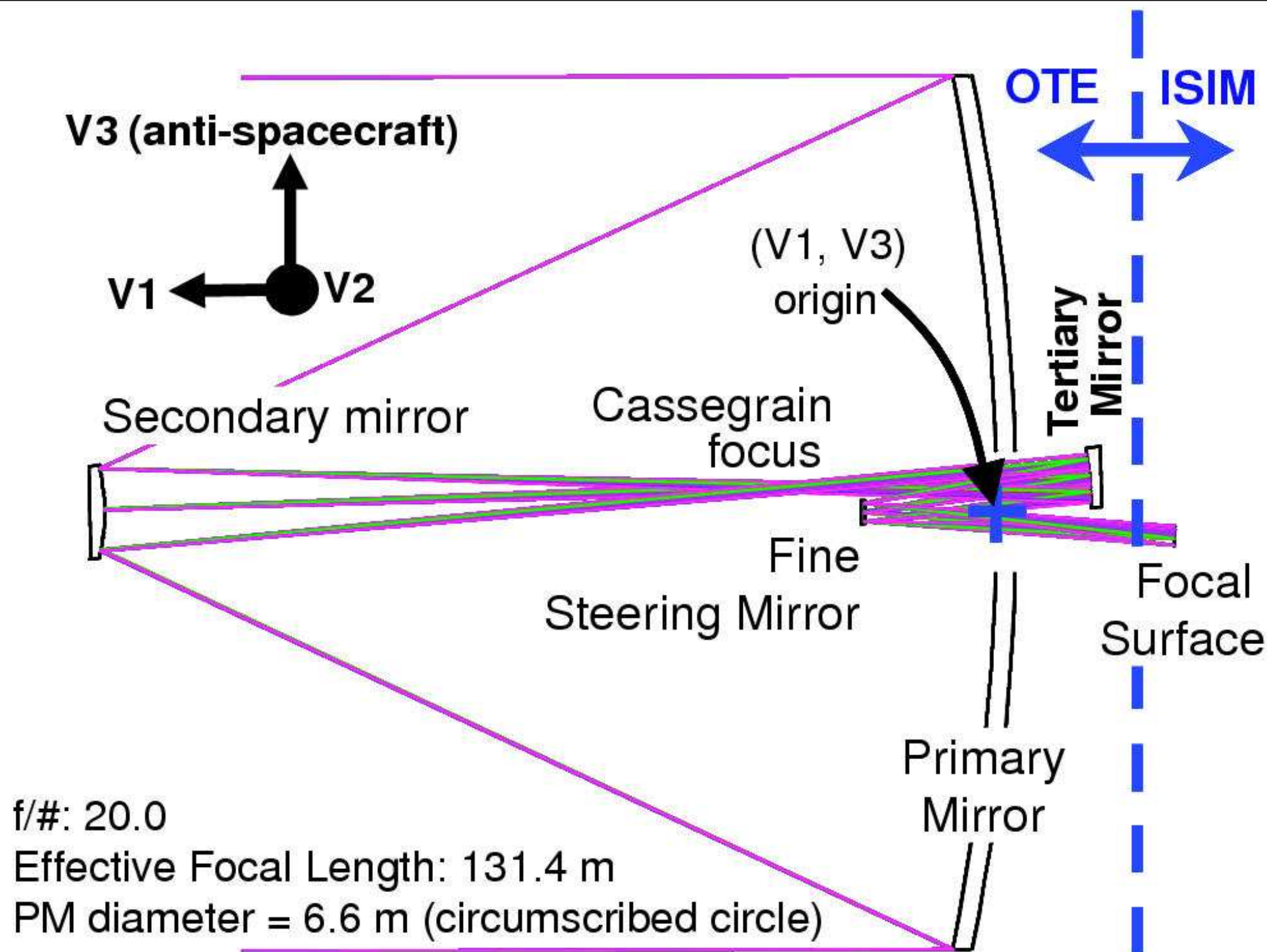
Life-sized JWST model, at NASA/GSFC with the whole JWST Project ...



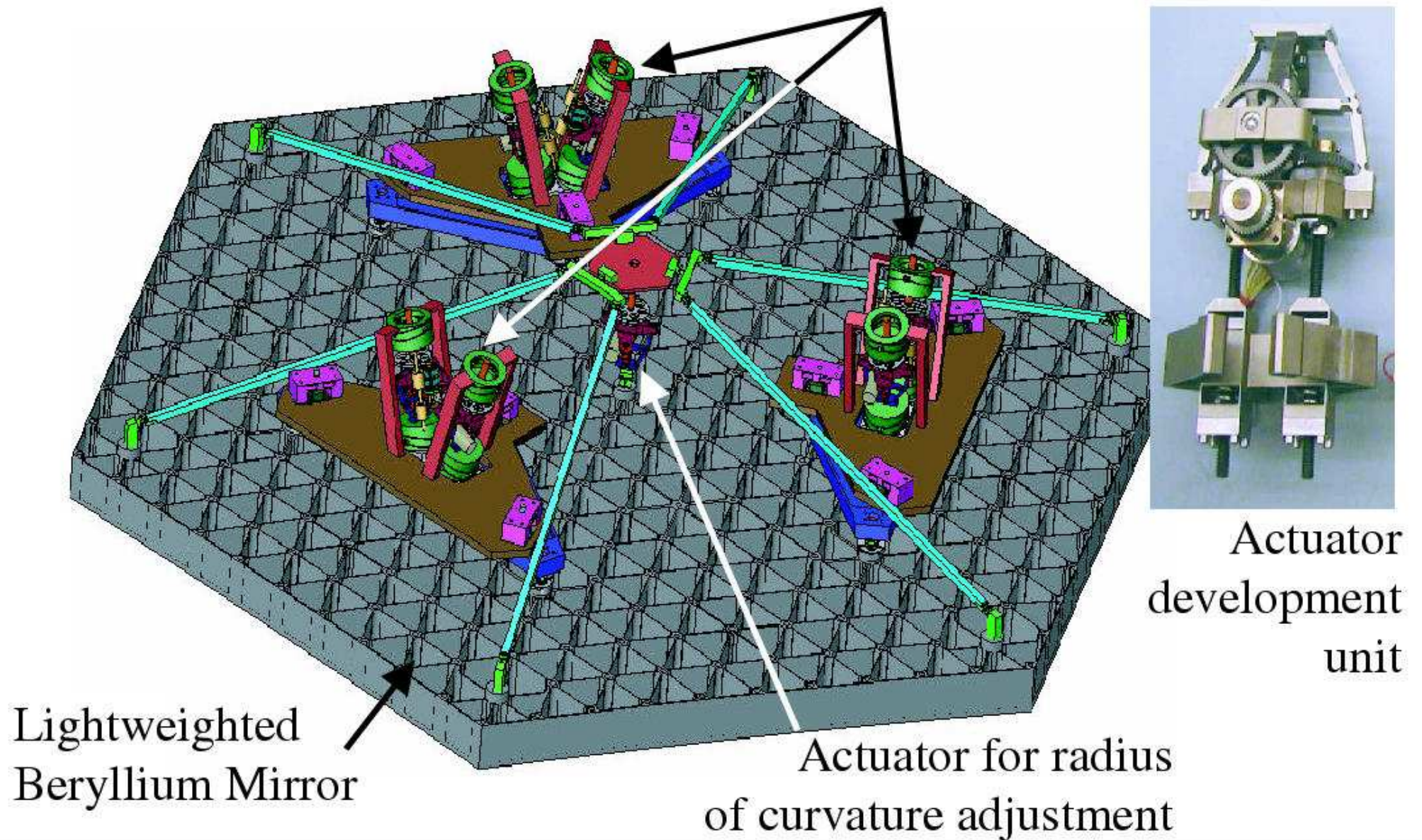
Life-sized JWST model, at NASA/GSFC Friday afternoon after 5 pm ...



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

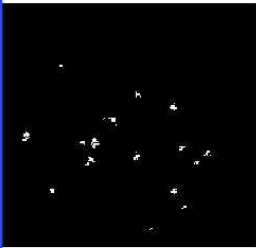


Actuators for 6 degrees of freedom rigid body motion



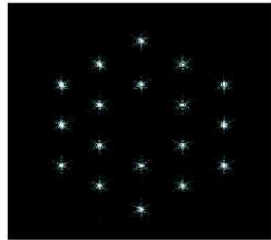
Active mirror segment support through “hexapods”, similar to Keck.
Redundant & doubly-redundant mechanisms, quite forgiving against failures.

**First light
NIRCam**



1.
Segment
Image
Capture

After Step 1



Initial Capture

18 individual 1.6-m diameter aberrated
sub-telescope images
PM segments: < 1 mm, < 2 arcmin tilt
SM: < 3 mm, < 5 arcmin tilt

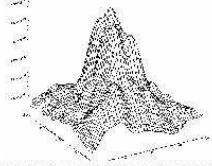
Final Condition

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

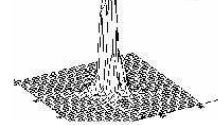


Primary Mirror segments:
< 1 mm, < 10 arcsec tilt
Secondary Mirror :
< 3 mm, < 5 arcmin tilt

WFE < 200 μm (rms)

3. Coarse Phasing - Fine Guiding (PMSA piston)

After Step 3

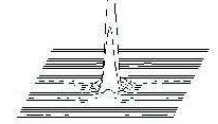


WFE: < 250 μm rms

WFE < 1 μm (rms)

4. Fine Phasing

After Step 4

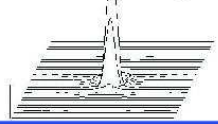


WFE: < 5 μm (rms)

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

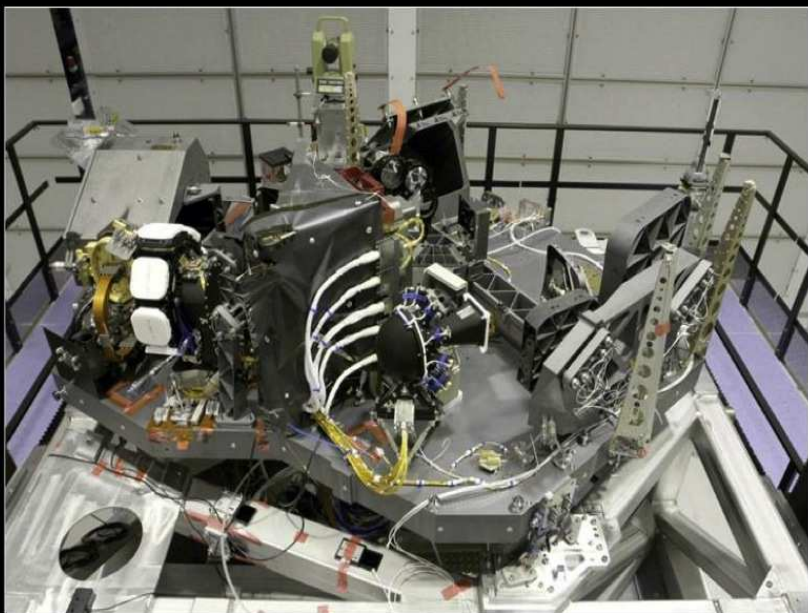


JWST's short-wavelength ($0.6\text{--}5.0\mu\text{m}$) imagers:

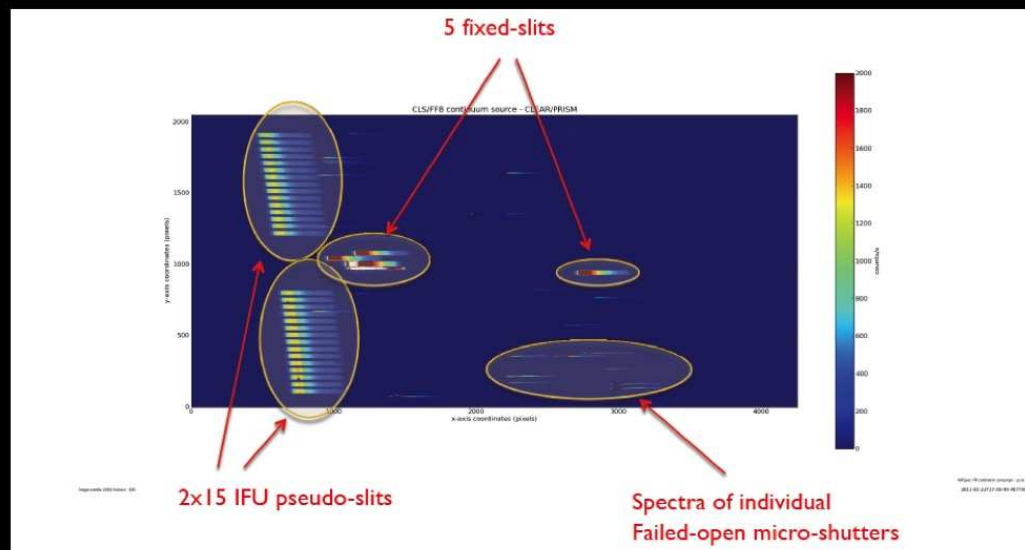
- NIRCam — built by UofA (AZ) and Lockheed (CA).
- Fine Guidance Sensor (& $1\text{--}5\mu\text{m}$ grisms) — built by CSA (Montreal).
- NIRCam scheduled for delivery to GSFC Fall 2011, FGS early 2013.



FLIGHT NIRSpec



Flight NIRSpec First Light

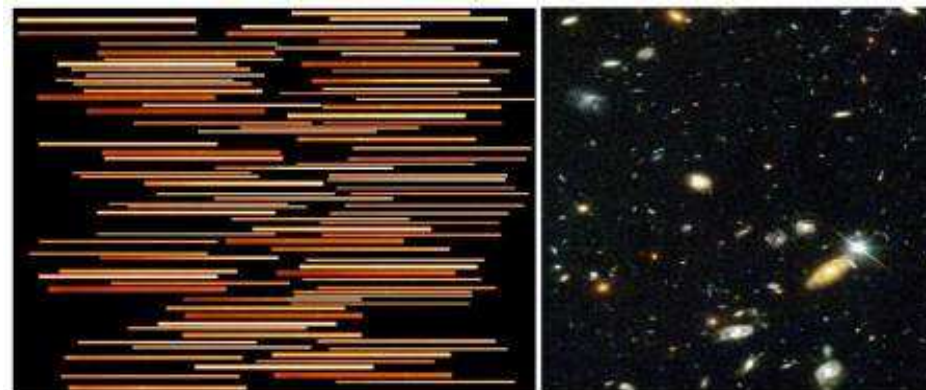
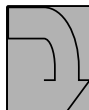
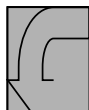


JWST's short-wavelength ($0.6\text{--}5.0\mu\text{m}$) spectrograph:

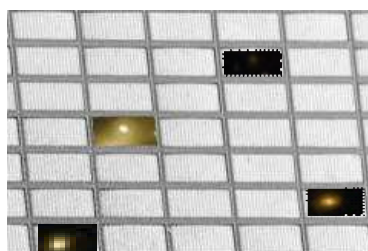
- NIRSpec — built by ESA/ESTEC and Astrium (Munich).
- Flight build completed and tested with First Light in Spring 2011.

Final NIRSpec delivery to NASA/GSFC in early 2013.

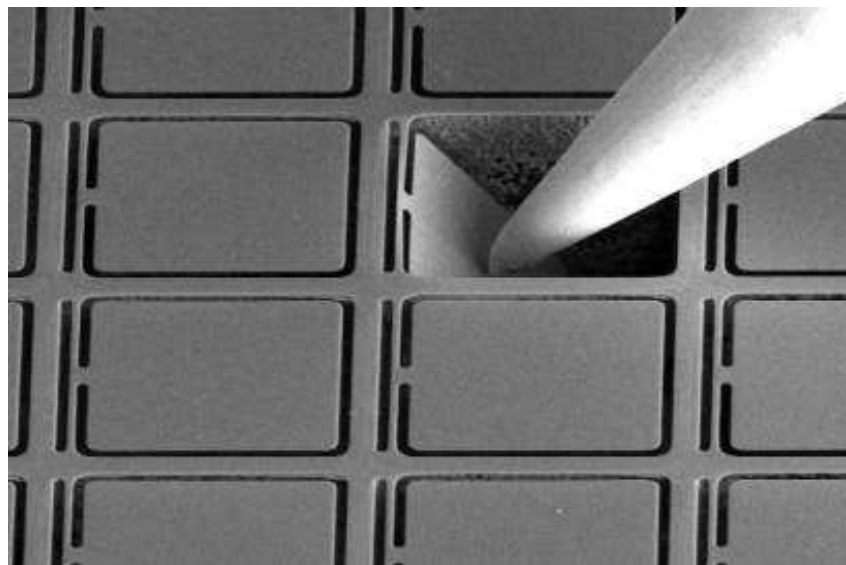
Astronomy Scene



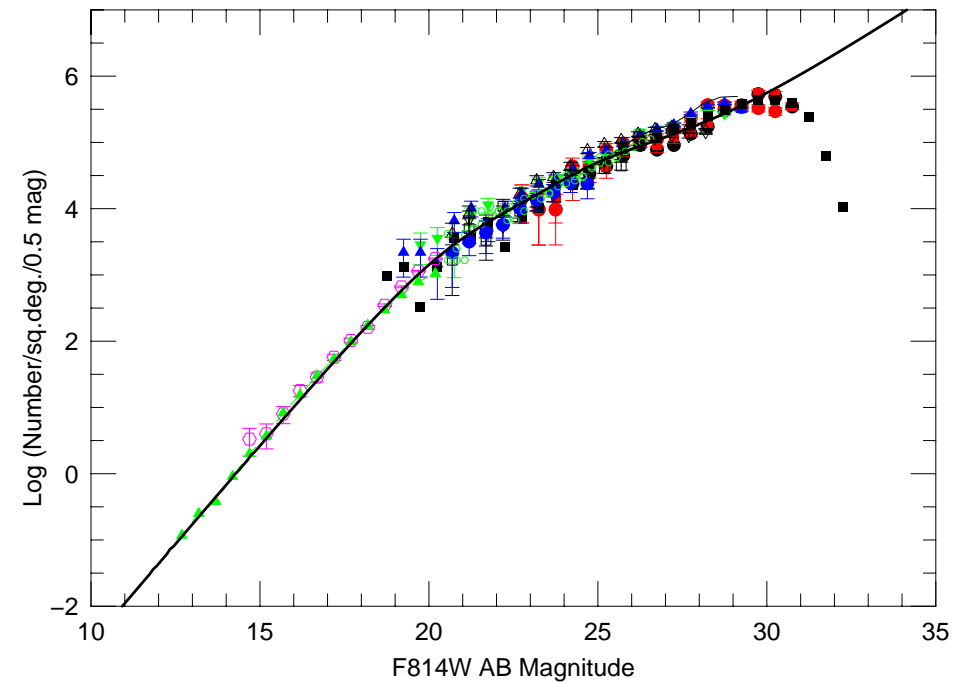
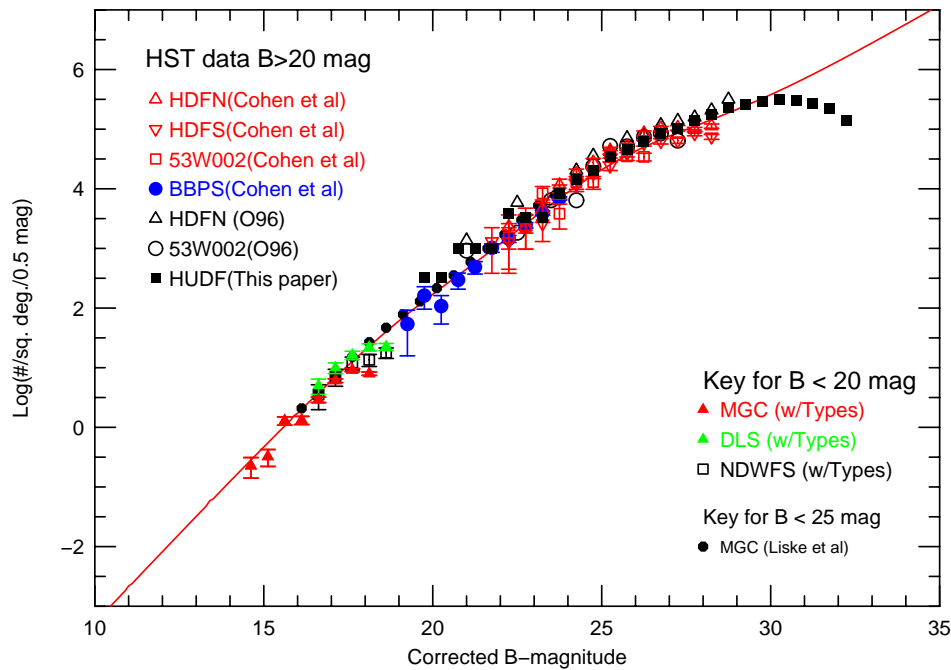
Metal Mask/Fixed Slit



Shutter Mask

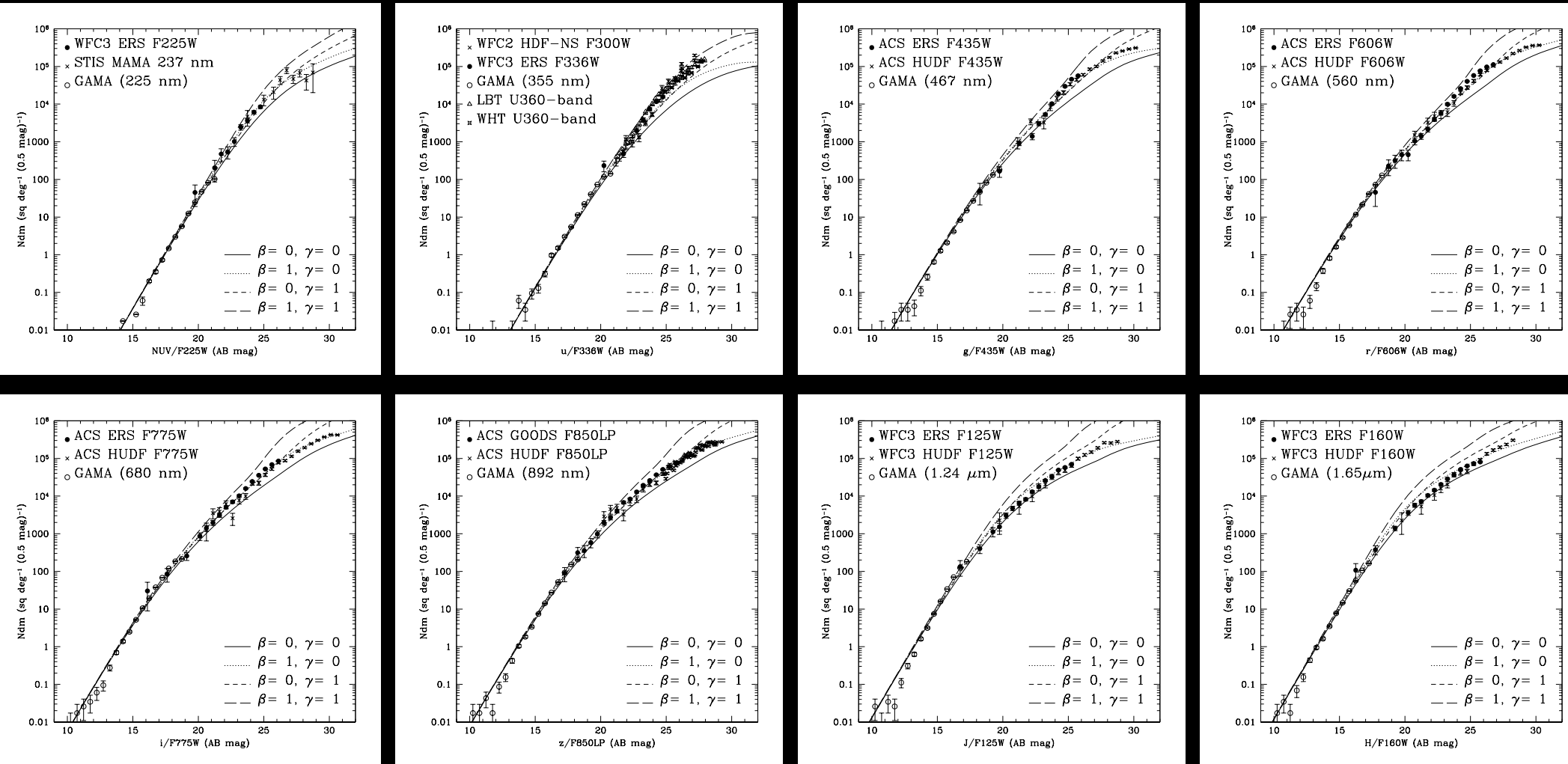


Appendix 1: will JWST (& SKA) reach the Natural Confusion Limit?



- HUDF galaxy counts (Cohen et al. 2006): expect an integral of $\gtrsim 2 \times 10^6$ galaxies/deg² to AB=31.5 mag ($\simeq 1$ nJy at optical wavelengths). JWST and SKA will see similar surface densities to $\simeq 1$ and 10 nJy, resp.
- \Rightarrow Must carry out JWST and SKA nJy-surveys with sufficient spatial resolution to avoid object confusion (from HST: this means FWHM $\lesssim 0''.08$).
- \Rightarrow Observe with JWST/NIRSpec/MSA and SKA HI line channels, to disentangle overlapping continuum sources in redshifts space.

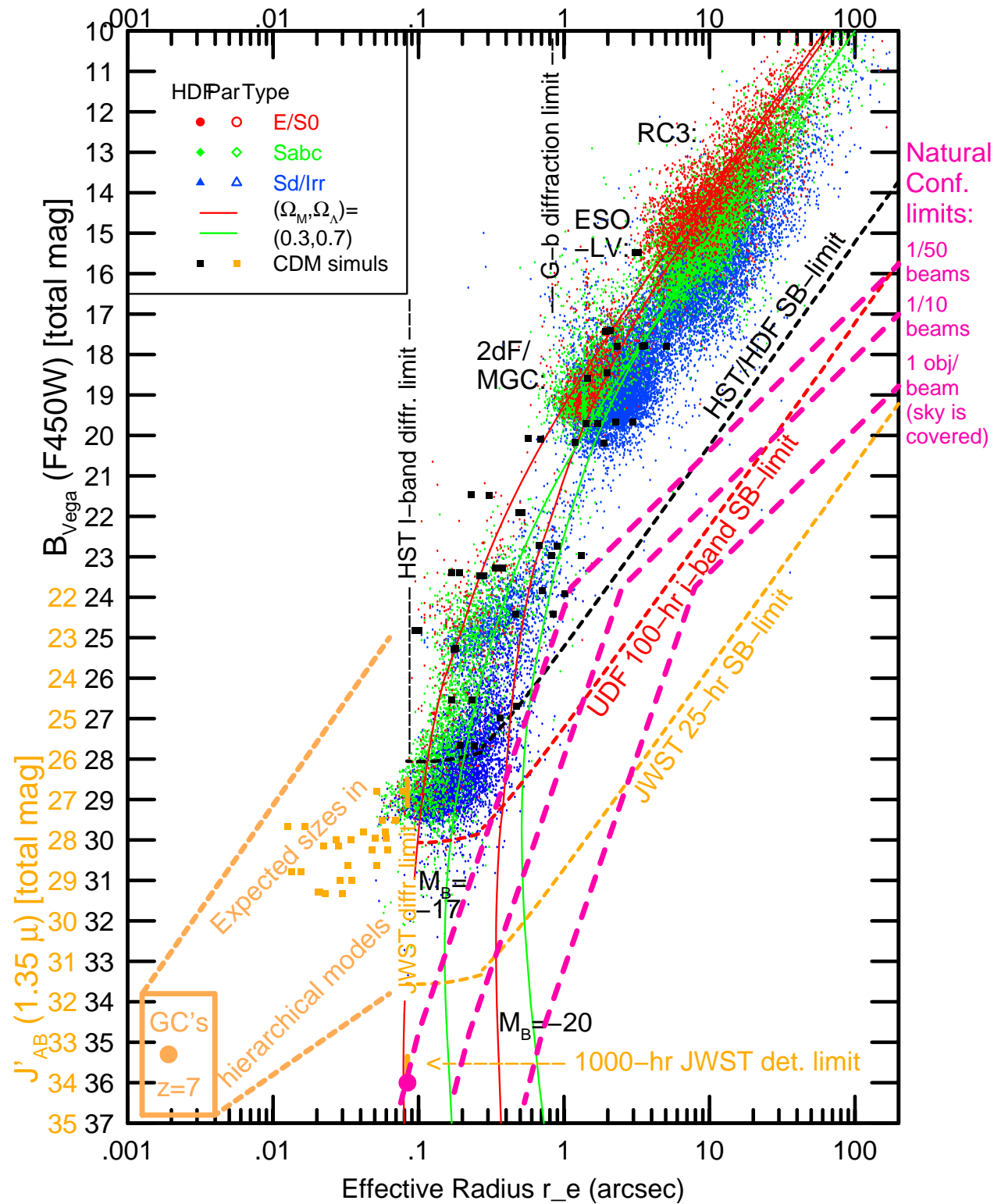
Panchromatic Galaxy Counts from $\lambda \simeq 0.2\text{--}2\mu\text{m}$ for $AB \simeq 10\text{--}30$ mag



Data: GALEX, ground-based GAMA, HST ERS ACS+WFC3 + HUDF ACS+WFC3 (*e.g.*, Windhorst et al. 2011, ApJS 193, 27):

Filters: F225W, F275W, F336W, F435W, F606W, F775W, F850LP, F098M/F105W, F125W, F160W.

● No single Lum.+Dens evol model fits over 1 dex in λ and 8 dex in flux.



Combination of ground-based and space-based HST surveys show:

- (1) Apparent galaxy sizes decline from the RC3 to the HUDF limits:
- (2) At the HDF/HUDF limits, this is *not* only due to SB-selection effects (cosmological $(1+z)^4$ -dimming), but also due to:
 - (2a) hierarchical formation causing size evolution:
$$r_{hl}(z) \propto r_{hl}(0) (1+z)^{-1}$$
 - (2b) increasing inability of object detection algorithms to deblend galaxies at faint mags (“natural” confusion \neq “instrumental” confusion).
- (3) At $AB \gtrsim 30$ mag, JWST and at $\gtrsim 10$ nJy, SKA will see more than 2×10^6 galaxies/deg². Most of these will be unresolved ($r_{hl} \lesssim 0''.1$ FWHM (Kawata et al. 2006). Since $z_{med} \simeq 1.5$, this influences the balance of how $(1+z)^4$ -dimming & object overlap affects the catalog completeness.
- For details, see Windhorst, R. A., et al. 2008, Advances in Space Research, Vol. 41, 1965, (astro-ph/0703171) “High Resolution Science with High Redshift Galaxies”