How will the Webb Space Telescope measure First Light Reionization, & Galaxy Assembly in the post WFC3 era?

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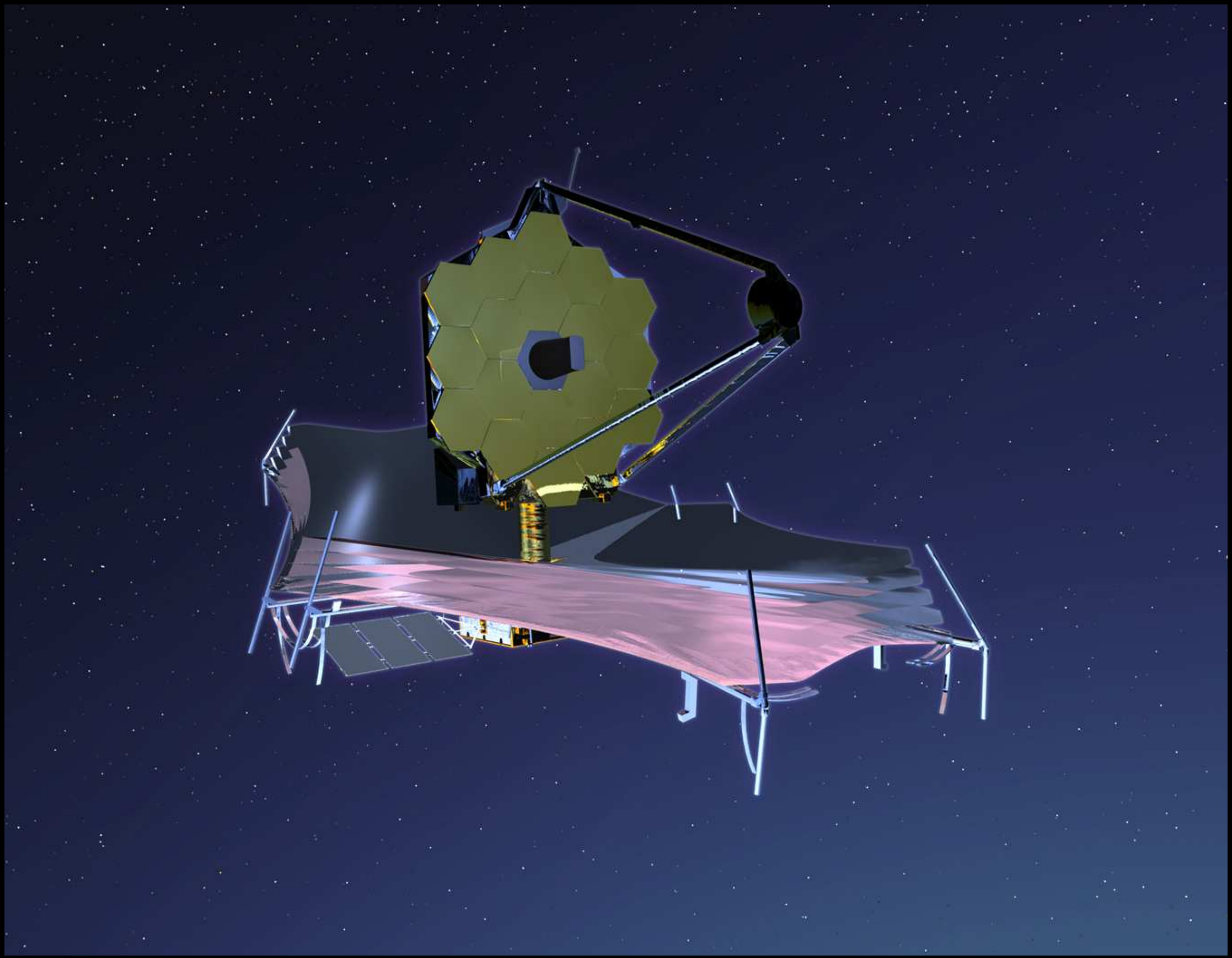


Review at the Ringberg First Galaxies Workshop, Bavaria, Mo. June 27, 2011

Outline

James Webb Space Telescope: NASA's next Flagship mission after Hubble.

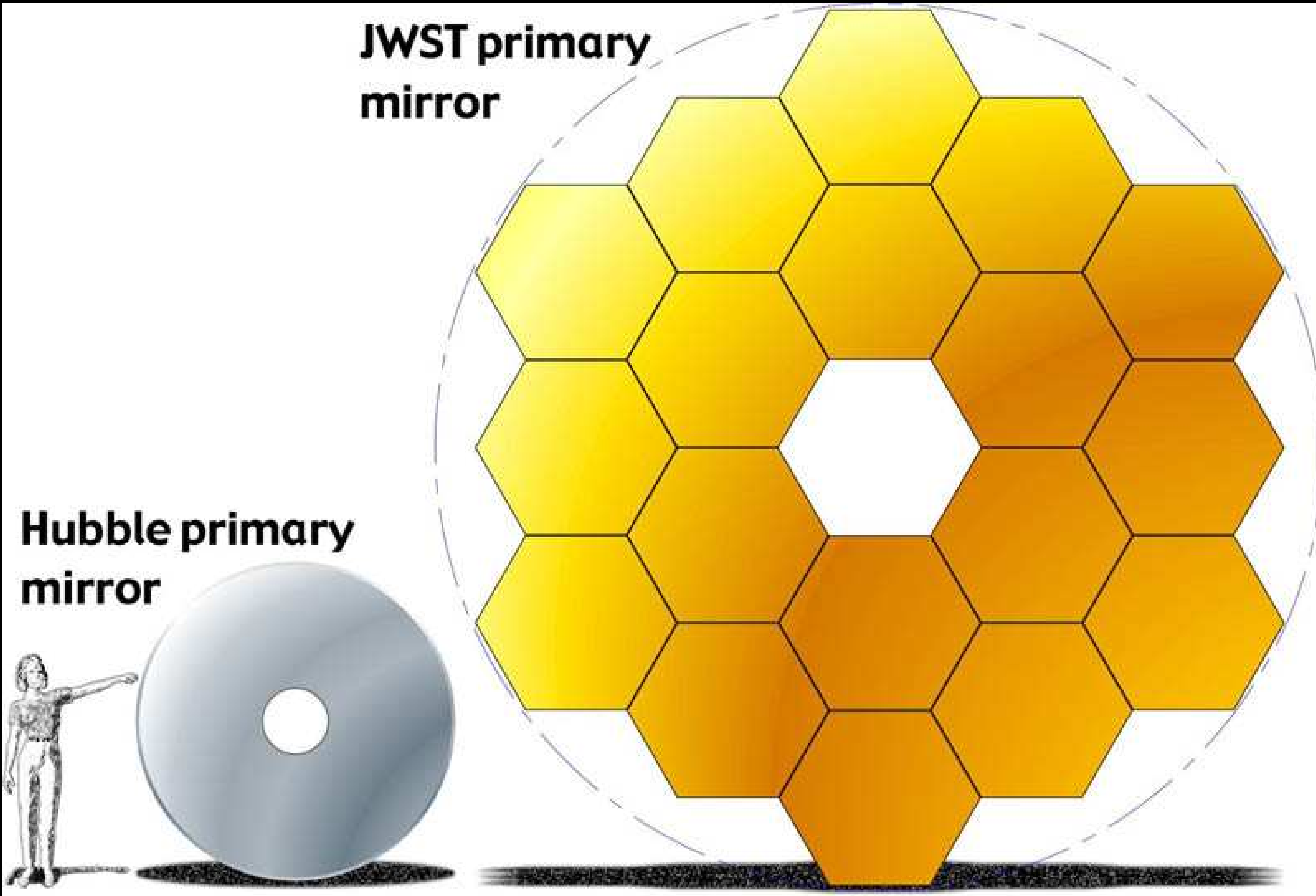
Astro 2010 Decadal Survey assumed: JWST science is done after 2015.

- (1) What is JWST and how will it be deployed?
- (2) What instruments and sensitivity will JWST have?
- (3) How can JWST can measure First Light & Reionization?
- (4) How can JWST measure Galaxy Assembly?

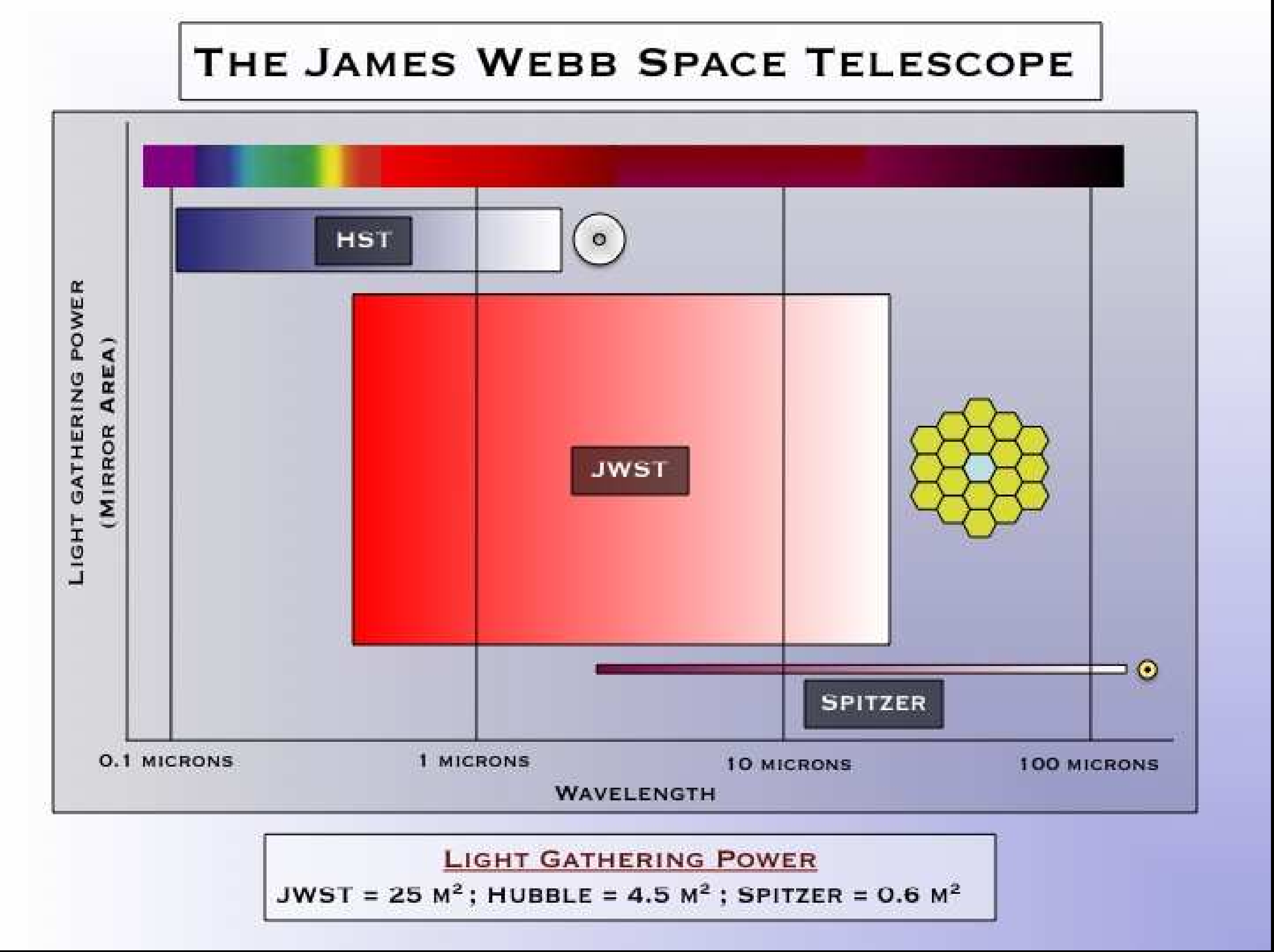
  [With some recent Hubble WFC3 results to support (3) & (4)].
- (5) Predicted Galaxy Appearance for JWST at redshifts $z\simeq1$–15.
- (6) Summary and Conclusions.
- Appendix 1: Will JWST reach the Natural Confusion Limit?

Sponsored by NASA/JWST & HST

ASU Arizona State University

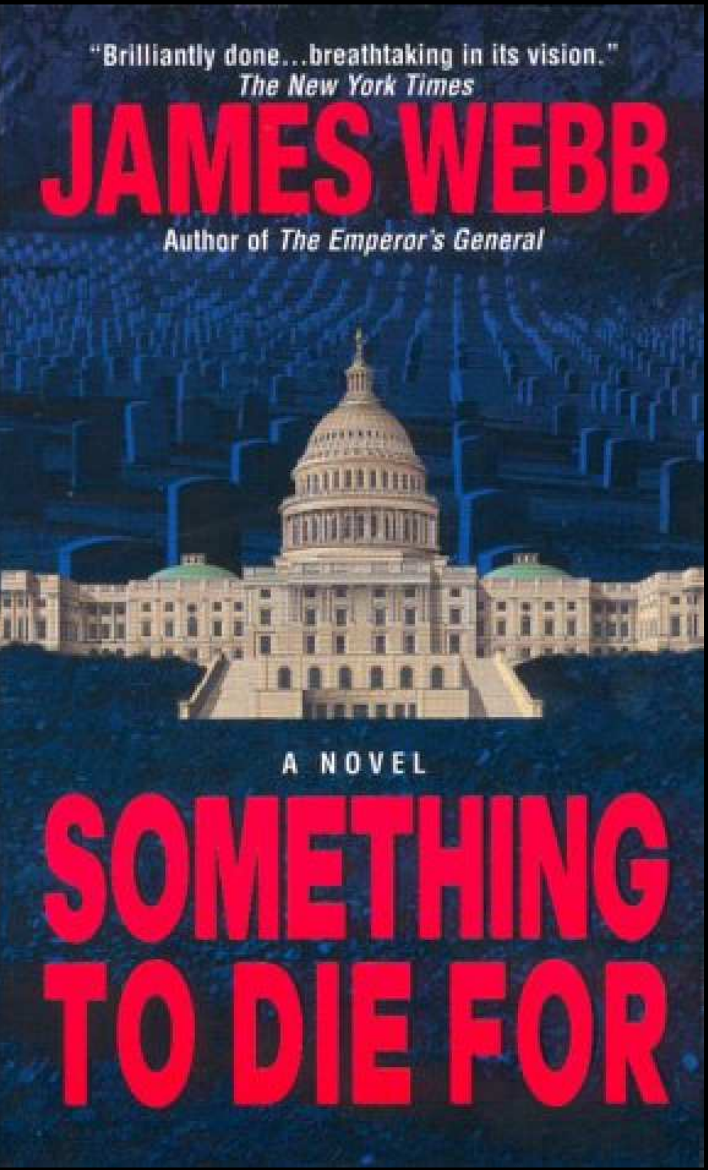


JWST ∼2.5× larger than Hubble, so at ∼2.5× larger wavelengths:
JWST has the same resolution in the near-IR as HST in the optical.



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.



Need hard-working grad students & postdocs in $\gtrsim$2015 ... It'll be worth it!

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

• (1) What is the James Webb Space Telescope (JWST)?

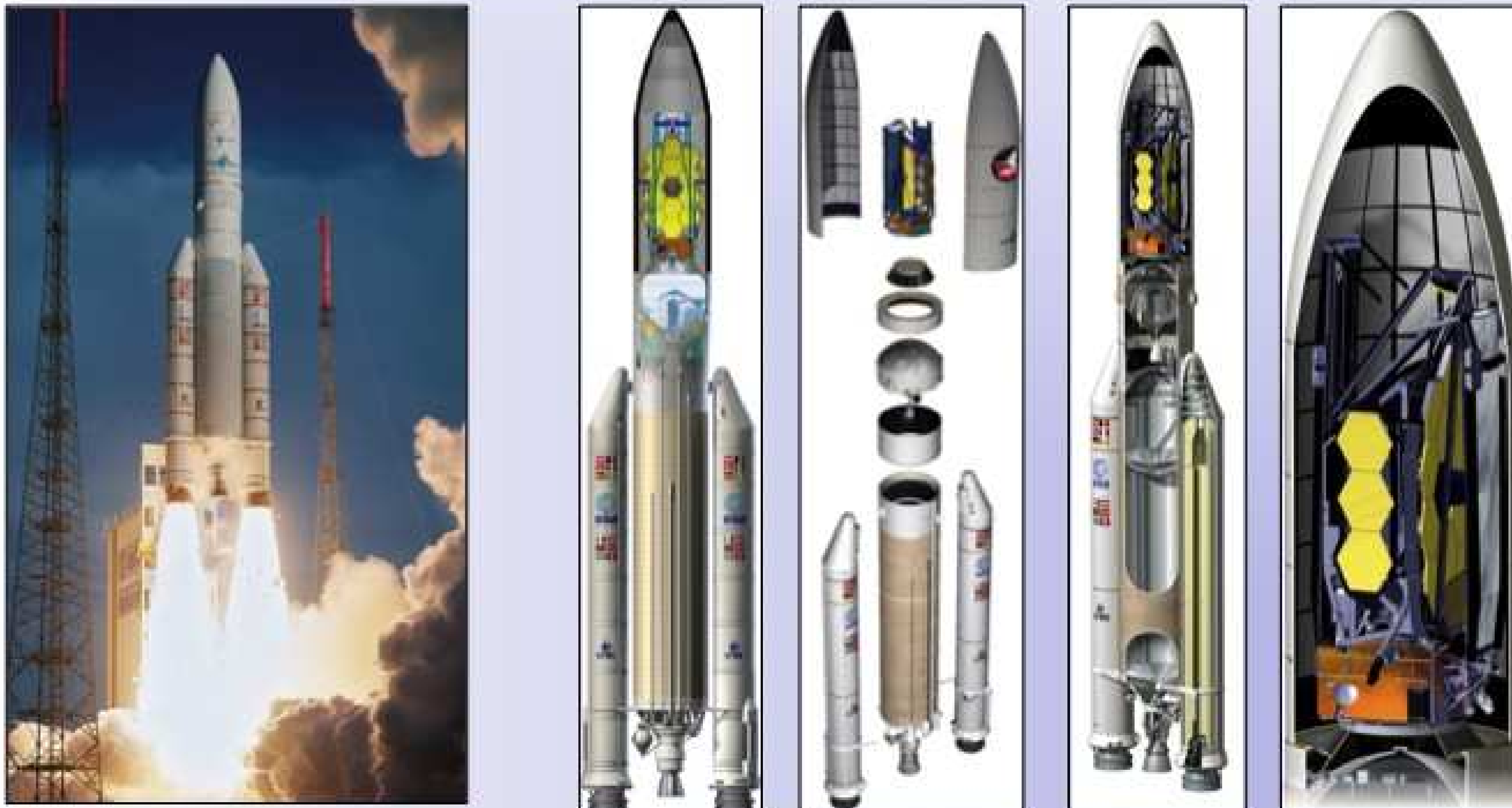
• A fully deployable 6.5 meter (25 m^2) segmented IR telescope for imaging and spectroscopy from 0.7 to 29 μm, to be launched in June $\gtrsim$2015.

• Nested array of sun-shields to keep its ambient temperature at 35-45 K, allowing faint imaging (AB$\lesssim$31.5) and spectroscopy (AB$\lesssim$29 mag).

THE JAMES WEBB SPACE TELESCOPE

JWST LAUNCH

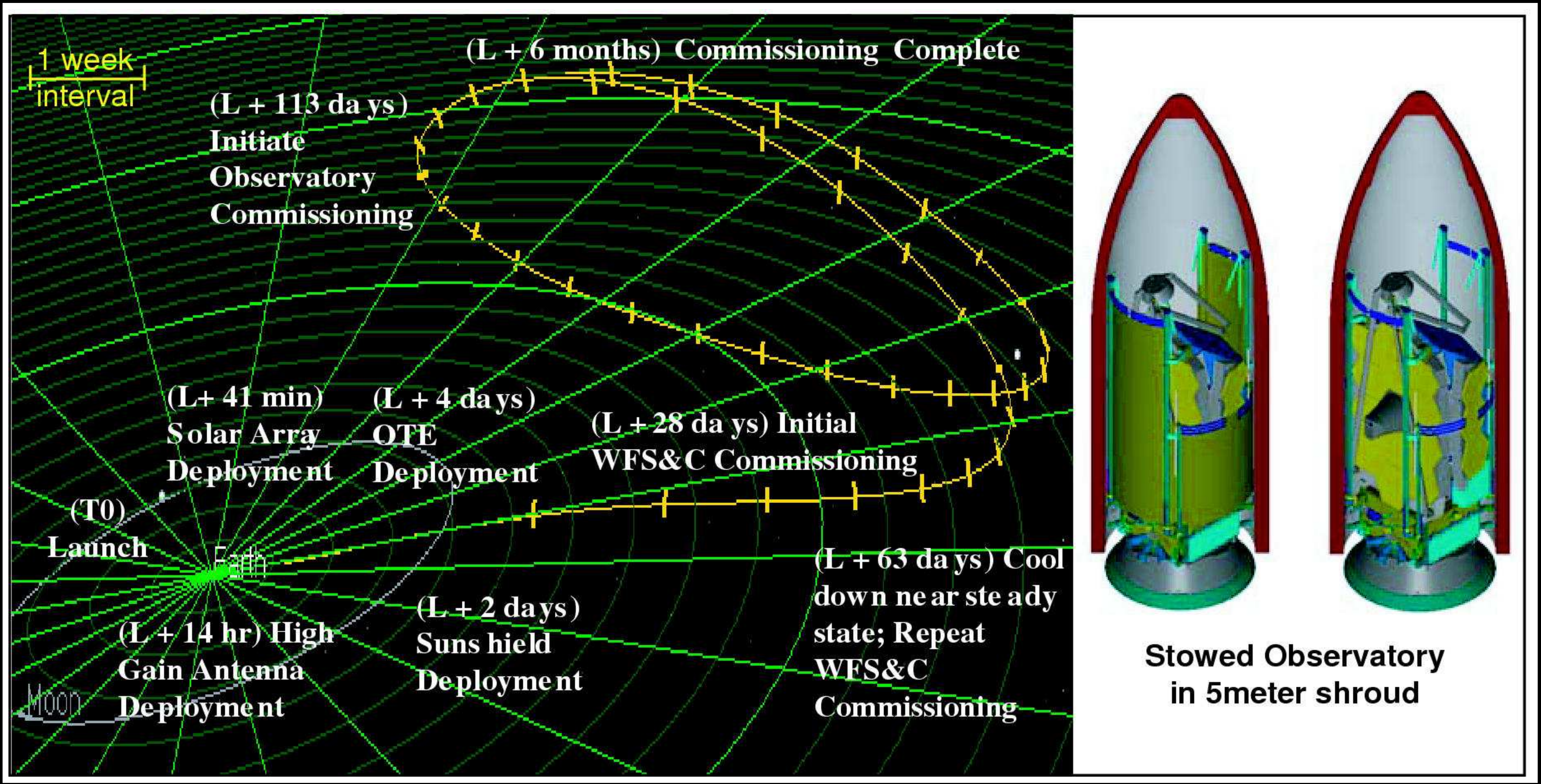
- LAUNCH VEHICLE IS AN ARIANE 5 ROCKET, SUPPLIED BY ESA
- SITE WILL BE THE ARIANESPACE'S ELA-3 LAUNCH COMPLEX NEAR KOUROU, FRENCH GUIANA



ARIANESPACE – ESA - NASA

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

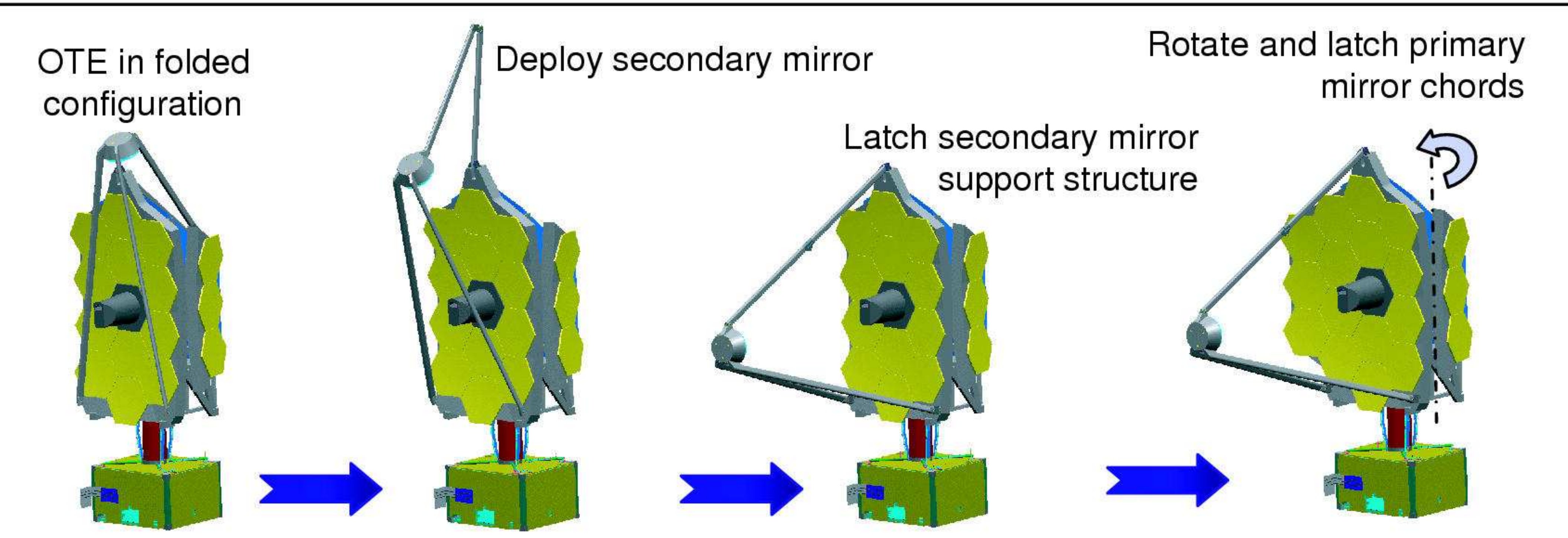
• (1) How will JWST travel to its L2 orbit?



• After launch in June 201? with the Ariane-V, JWST will orbit around the 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.

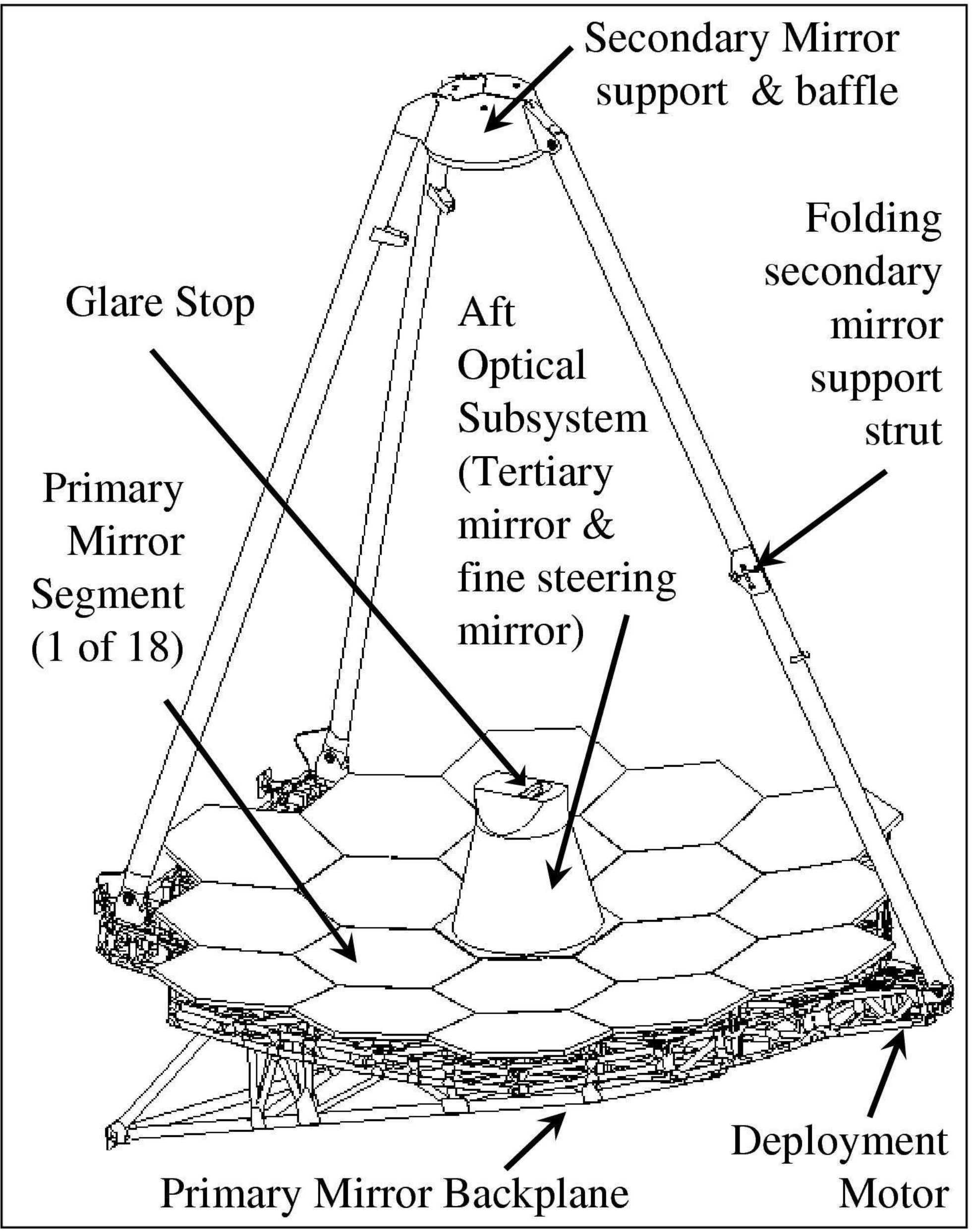
• (1) How will JWST be automatically deployed?



• During its several month journey to L2, JWST will be automatically deployed in phases, its instruments will be tested and calibrated, and it will then be inserted into an L2 halo orbit, 1.5 million km from Earth.

• The entire JWST deployment sequence will be tested several times on the ground — but only in 1-G: component and system tests at JSC.

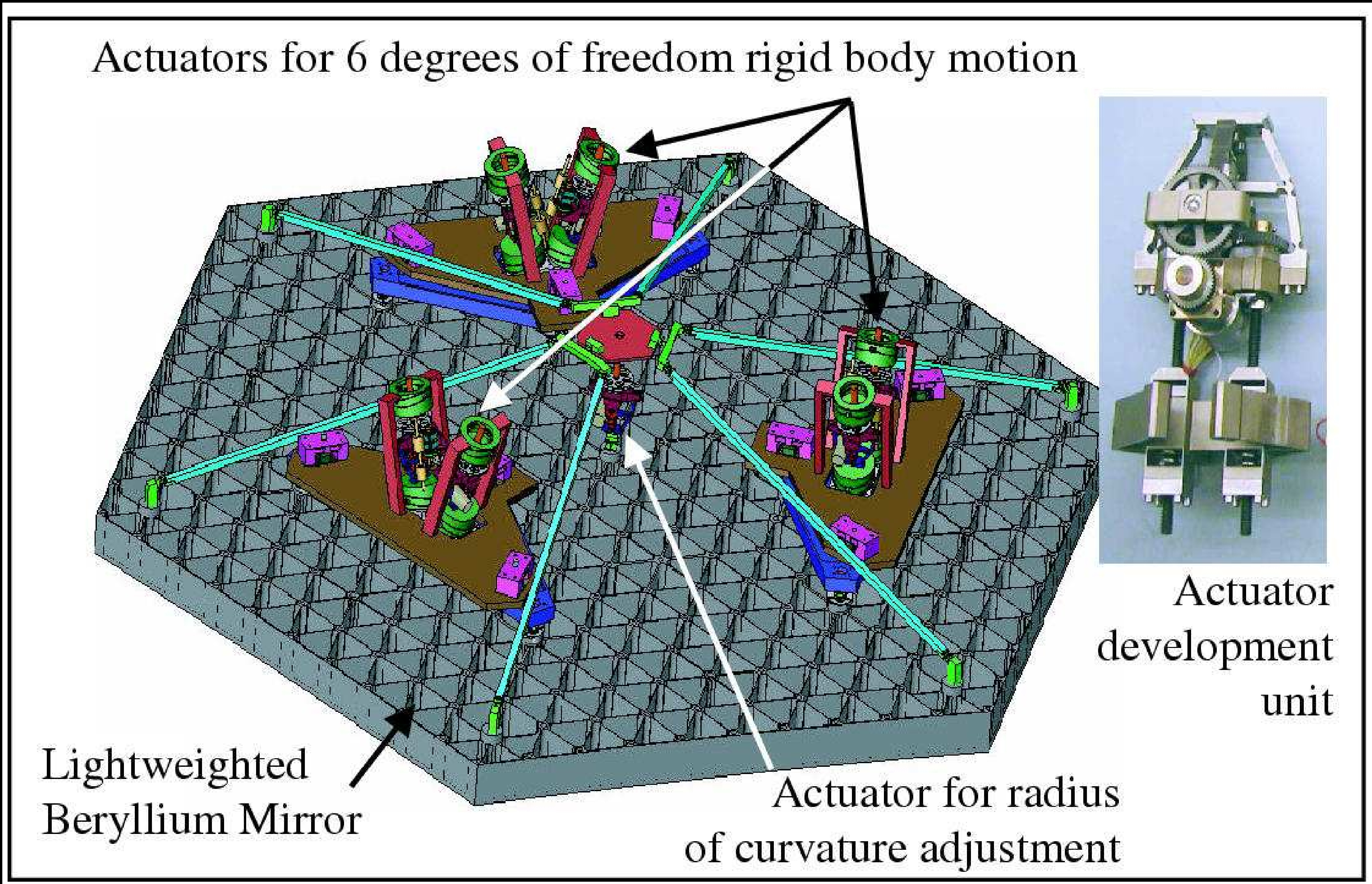
• Component fabrication, testing, & integration is on schedule: 3 out of 18 flight mirrors completely done, and at the 45K 2.0μm diffraction limit!



Ball 1/6-model for WFS: diffraction-limited 2.0 μm images (Strehl$\gtrsim$0.85).

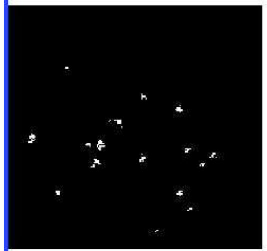
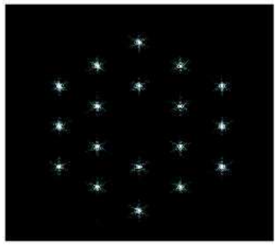
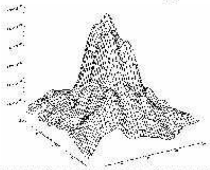
Wave-Front Sensing tested hands-off at 45 K in 1-G at JSC in 2012–2014.

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



Active mirror segment support through hexapods (7 d.o.f.), similar to Keck.

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

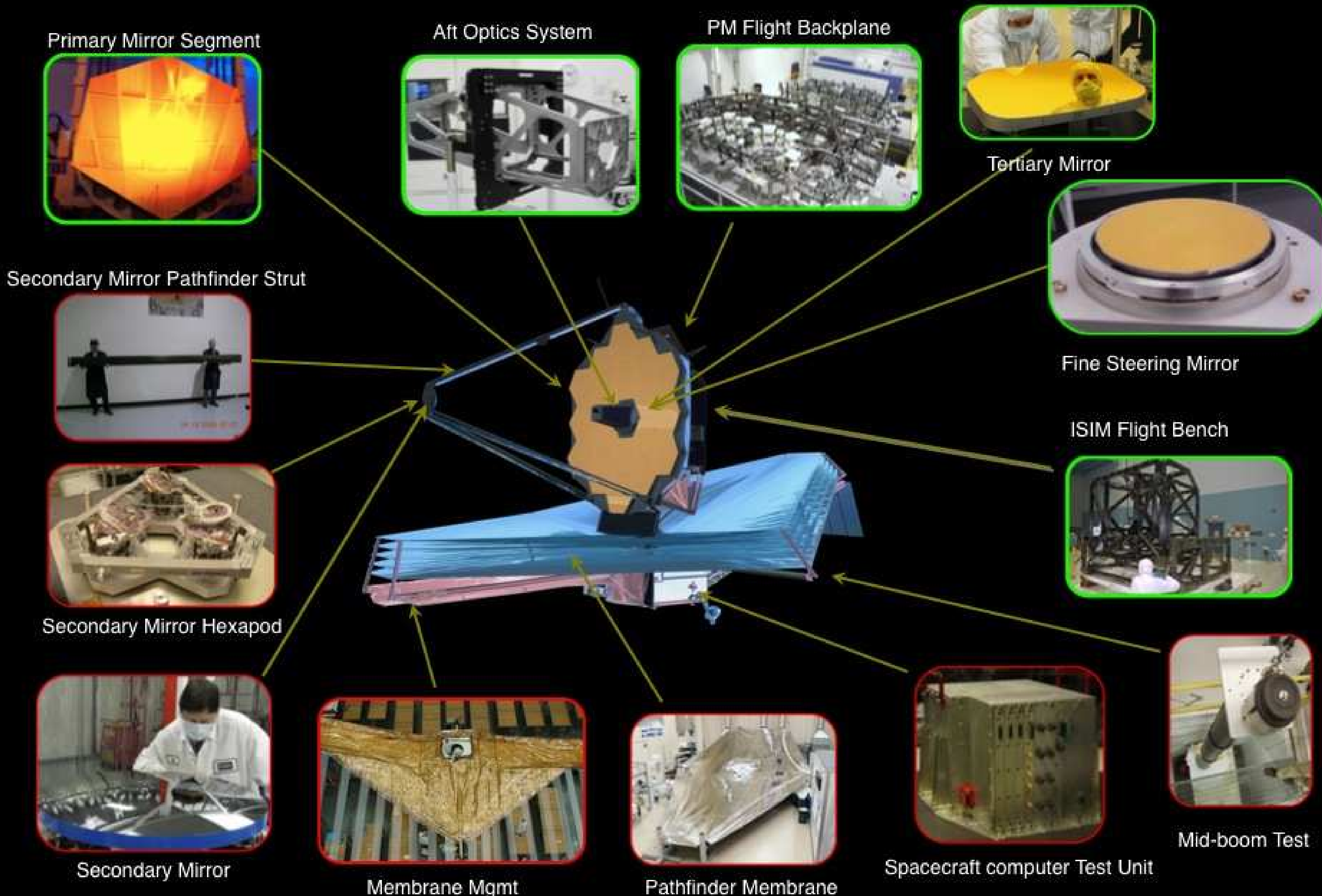
Step		Initial Capture	Final Condition
First light NIRCam  1. Segment Image Capture	**After Step 1** 	18 individual 1.6-m diameter aberrated sub-telescope images PM segments: < 1 mm, < 2 arcmin tilt SM: < 3 mm, < 5 arcmin tilt	PM segments: < 100 μm, < 2 arcsec tilt SM: < 3 mm, < 5 arcmin tilt
2. Coarse 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 that at Keck and HET.

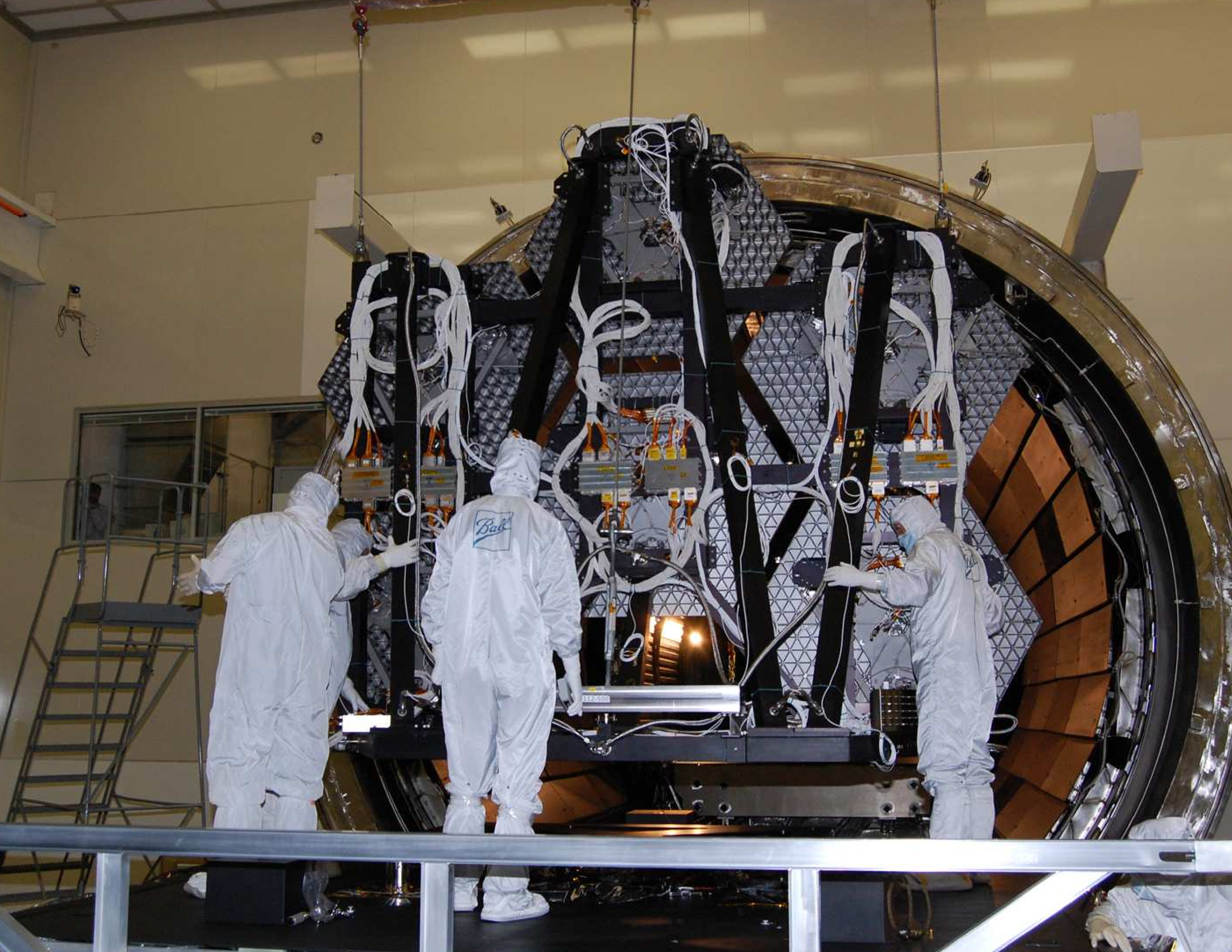
Successful WFS demo of H/W, S/W on 1/6 scale model (2 μm-Strehl$\gtrsim$0.85).

Need WFS-updates every $\sim$14 days, depending on scheduling/SC-illumination.

JWST Hardware Status



Mirror Acceptance Testing

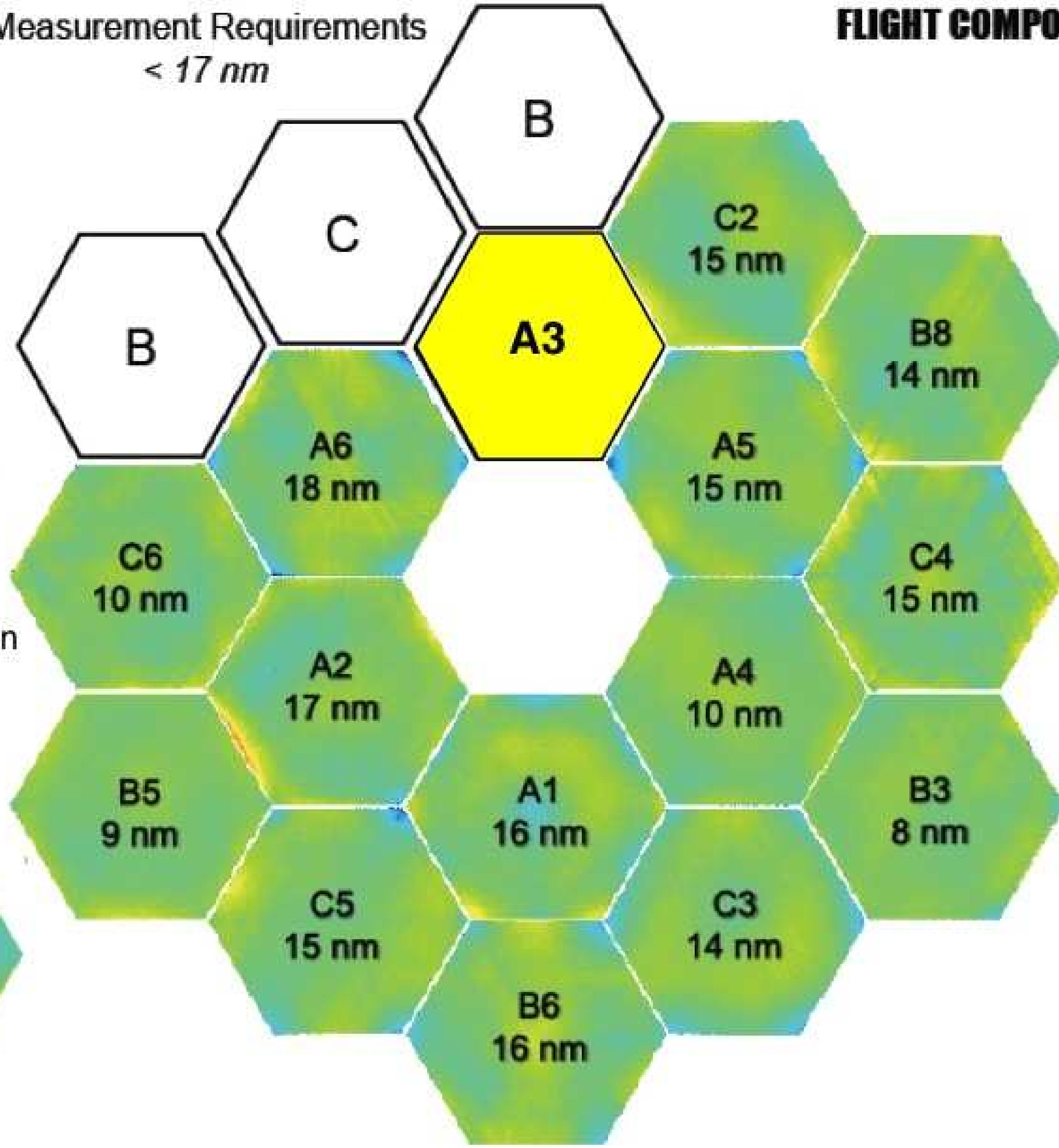


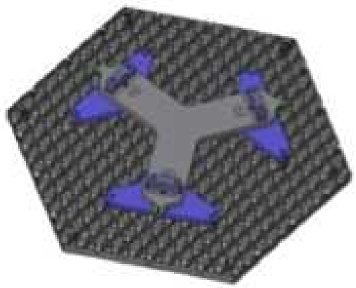
15 Flight Mirrors Completed Polishing

Tinsley Final Measurement Requirements
Total Figure *< 17 nm*

FLIGHT COMPOSITE RMS: **13.9 nm**

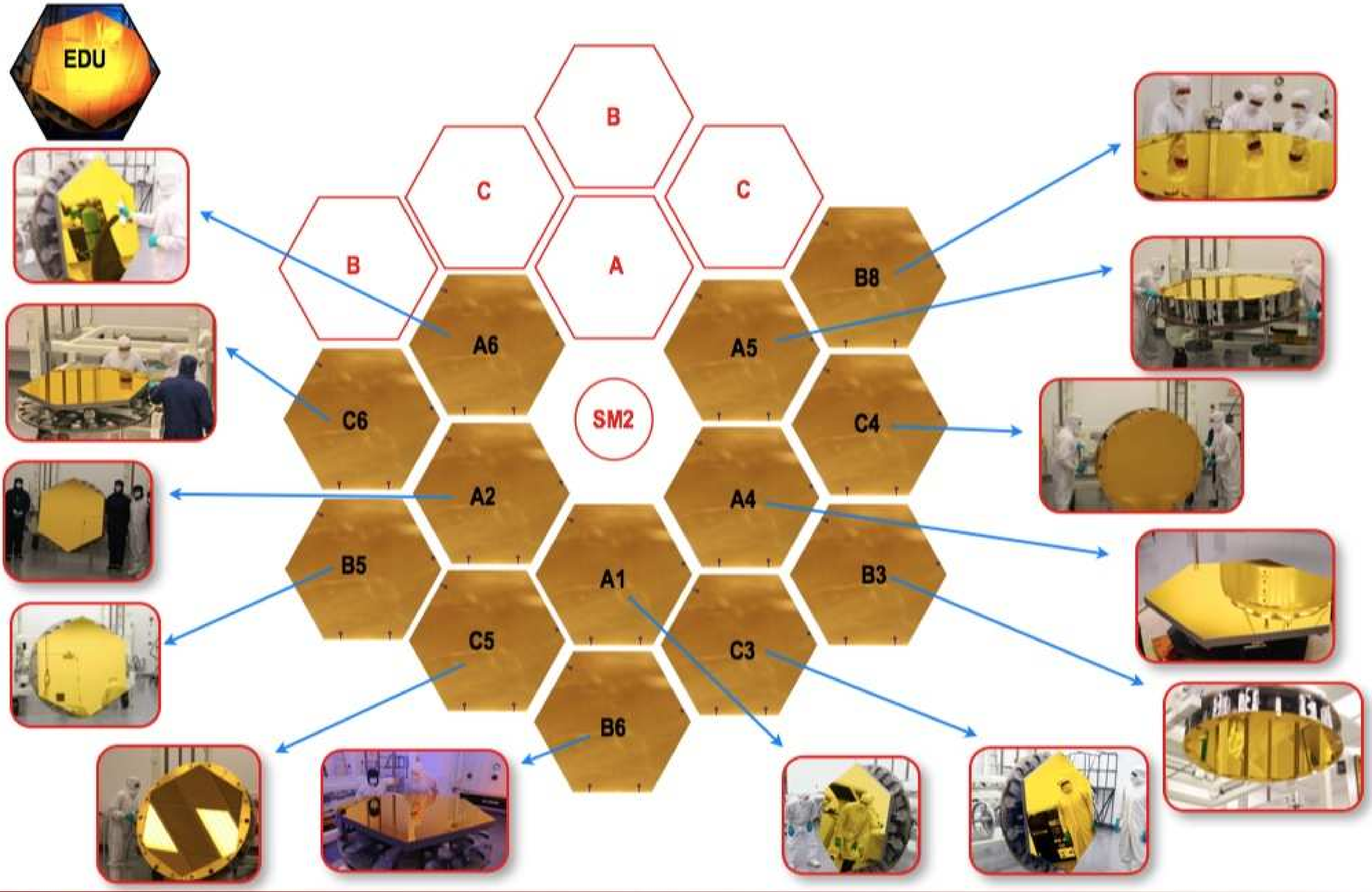
PV: **976.4 nm**

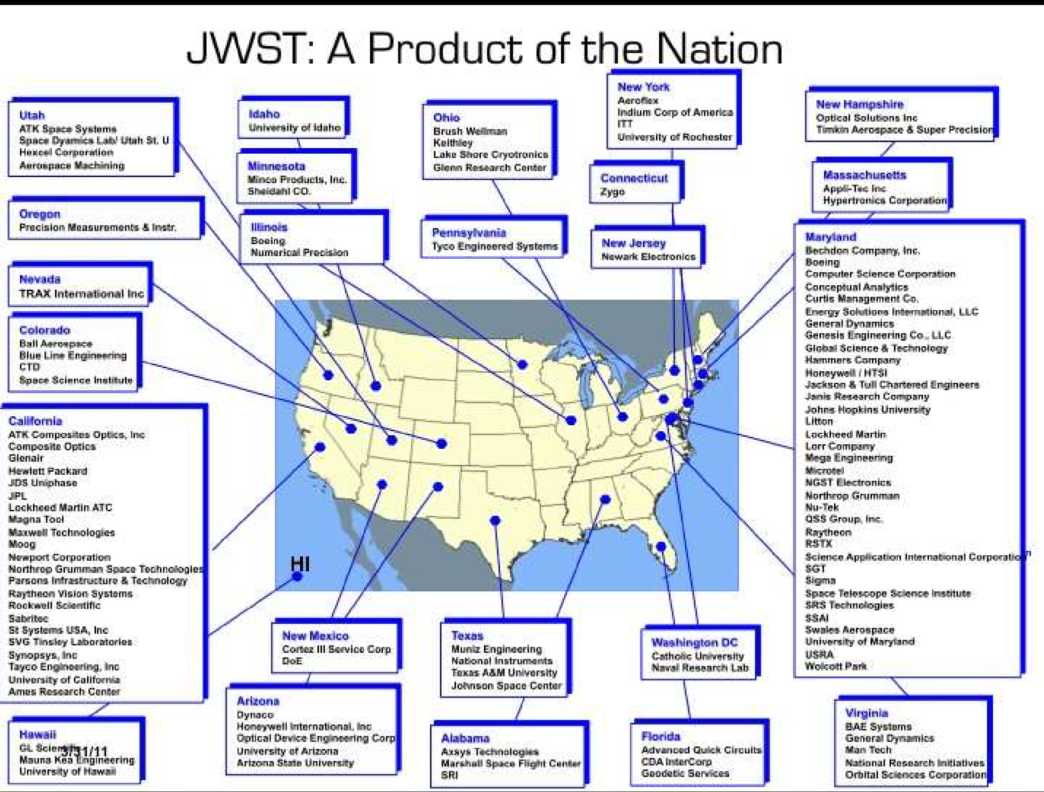


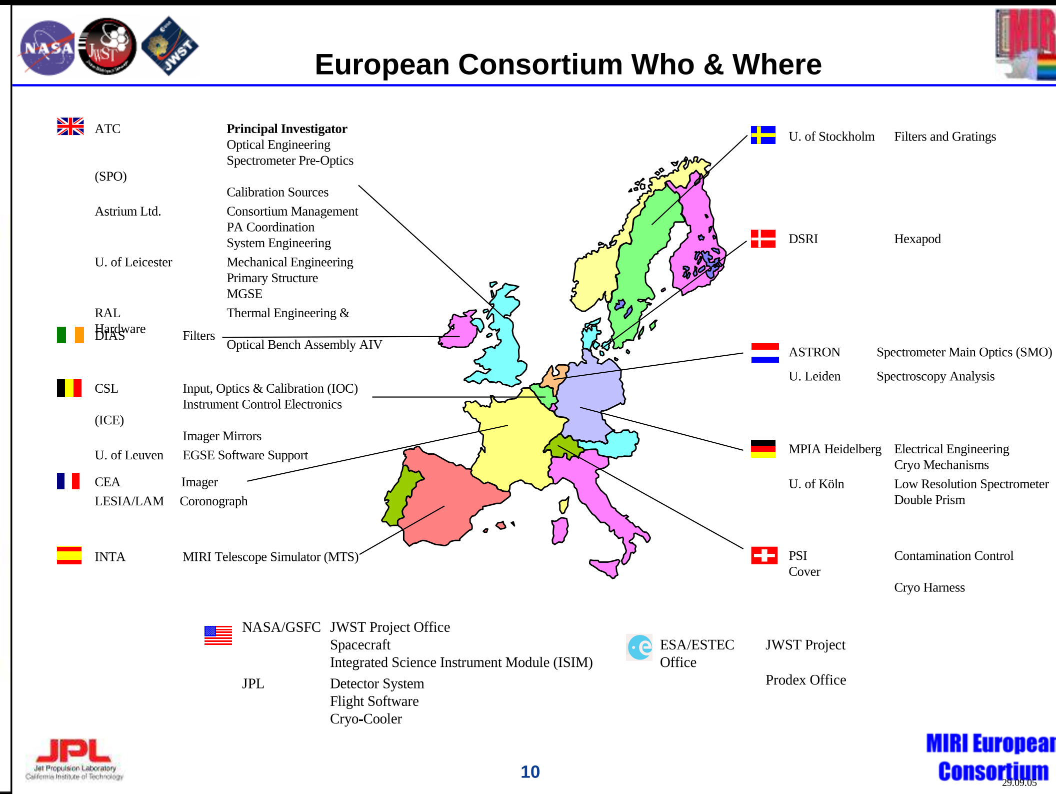


Mirror test configuration

13 Gold-Coated Flight PMSAs







- JWST hardware made in 23 US States: $\gtrsim$70% of launch-mass finished.

- Launch Vehicle (Ariane V), NIRSpec, & MIRI provided by EU/ESA.

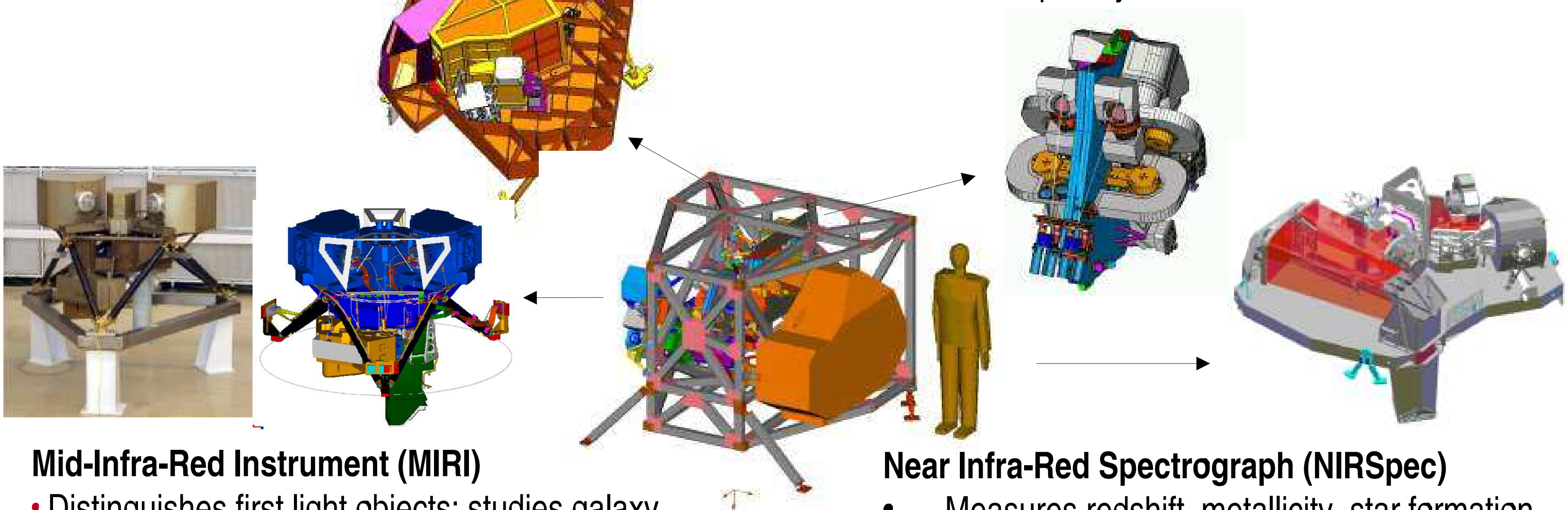
- JWST Fine Guider Sensor + nTFI provided by Canadian Space Agency.

• (2) What instruments will JWST have? US (UofA, JPL), ESA, and 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

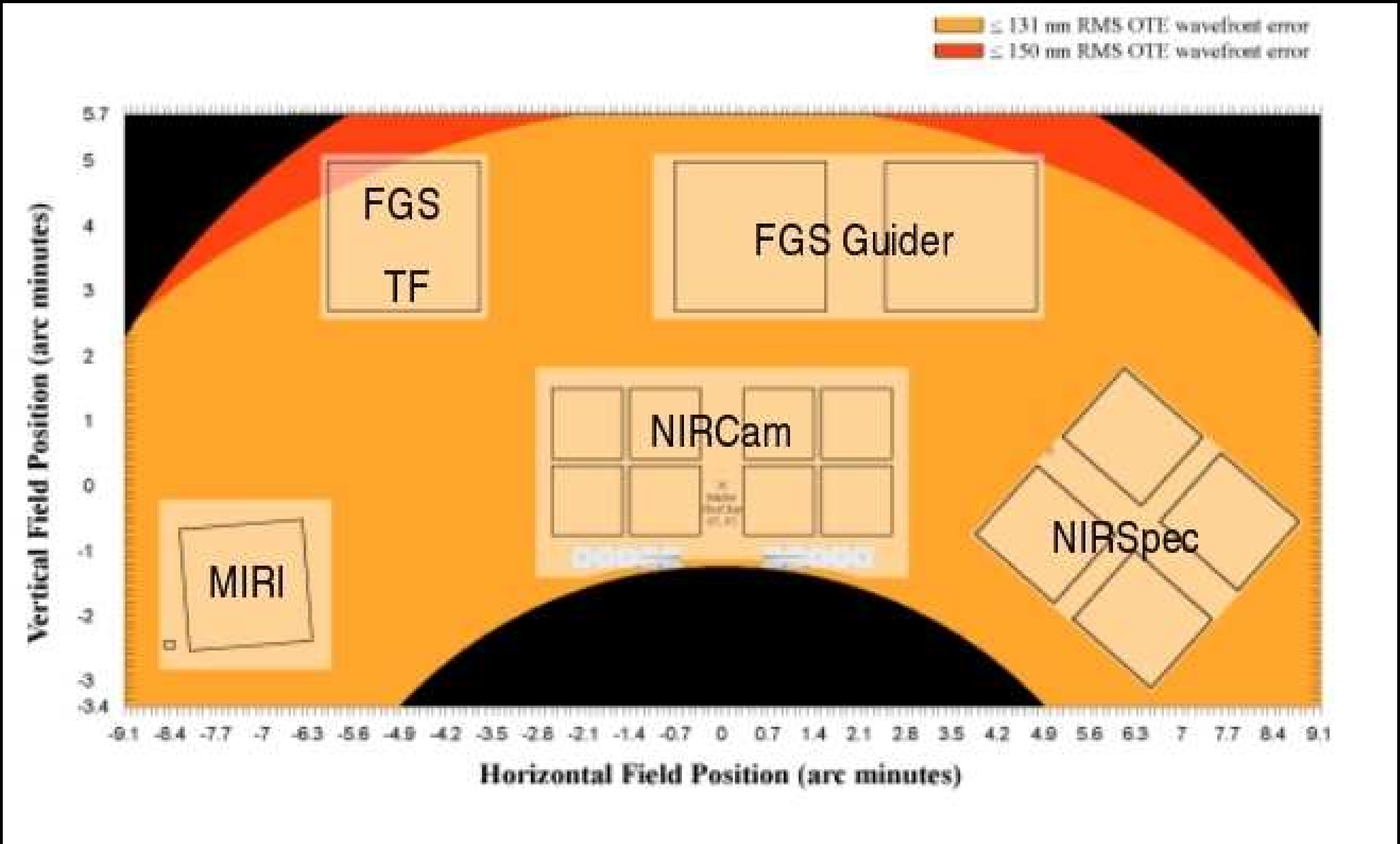
Near Infra-Red Camera (NIRCam)
- Detects first light galaxies and observes galaxy assembly sequence
- 0.6 to 5 microns
- Supports Wavefront Sensing & Control
- Developed by Univ. of AZ & LMATC

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

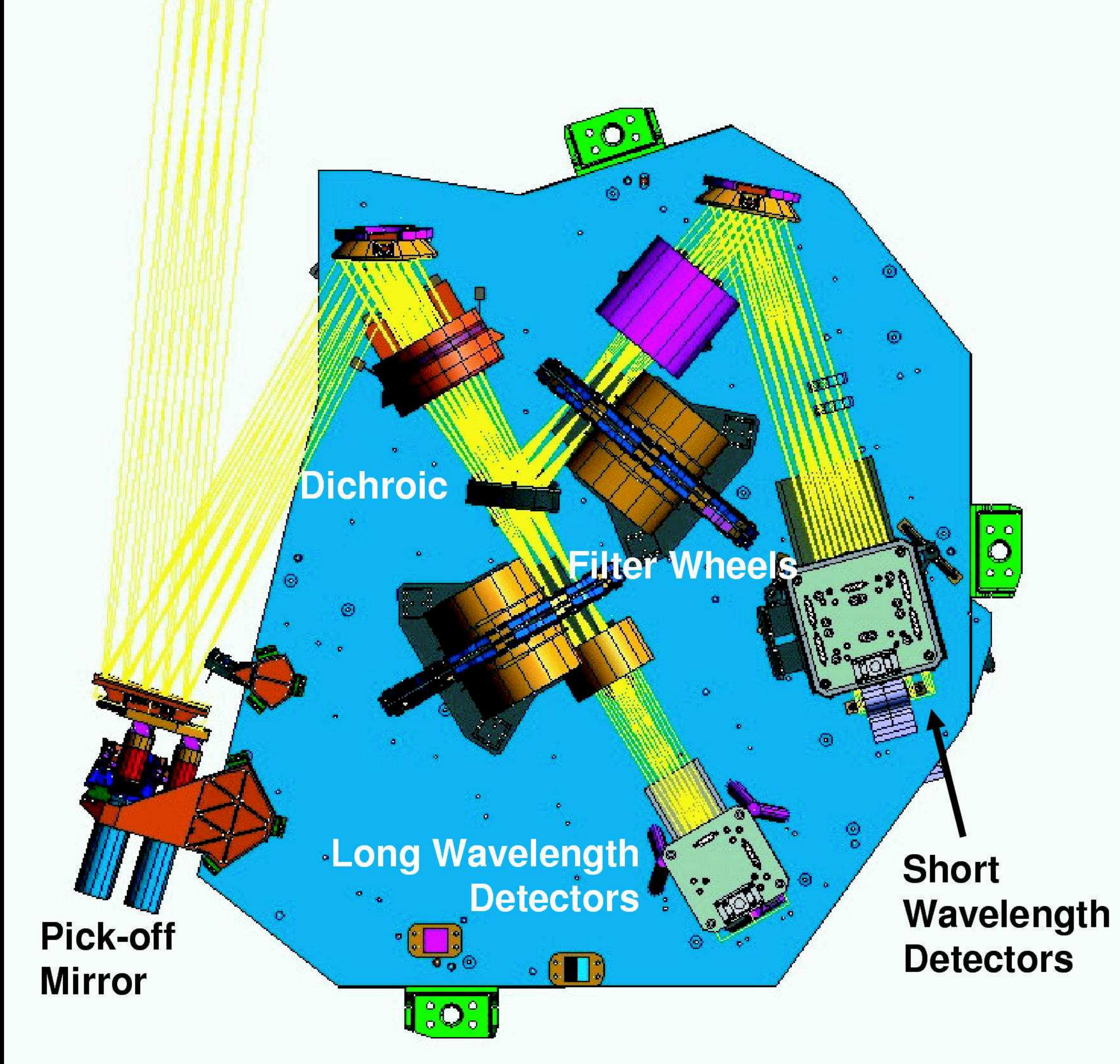
Near Infra-Red Spectrograph (NIRSpec)
- Measures redshift, metallicity, star formation rate in first light galaxies
- 0.6 to 5 microns
- Simultaneous spectra of >100 objects
- Developed by ESA & EADS with NASA/ GSFC Detector & Microshutter Subsystems

• (2) What instruments will JWST have?



All JWST instruments can in principle be used in parallel observing mode:

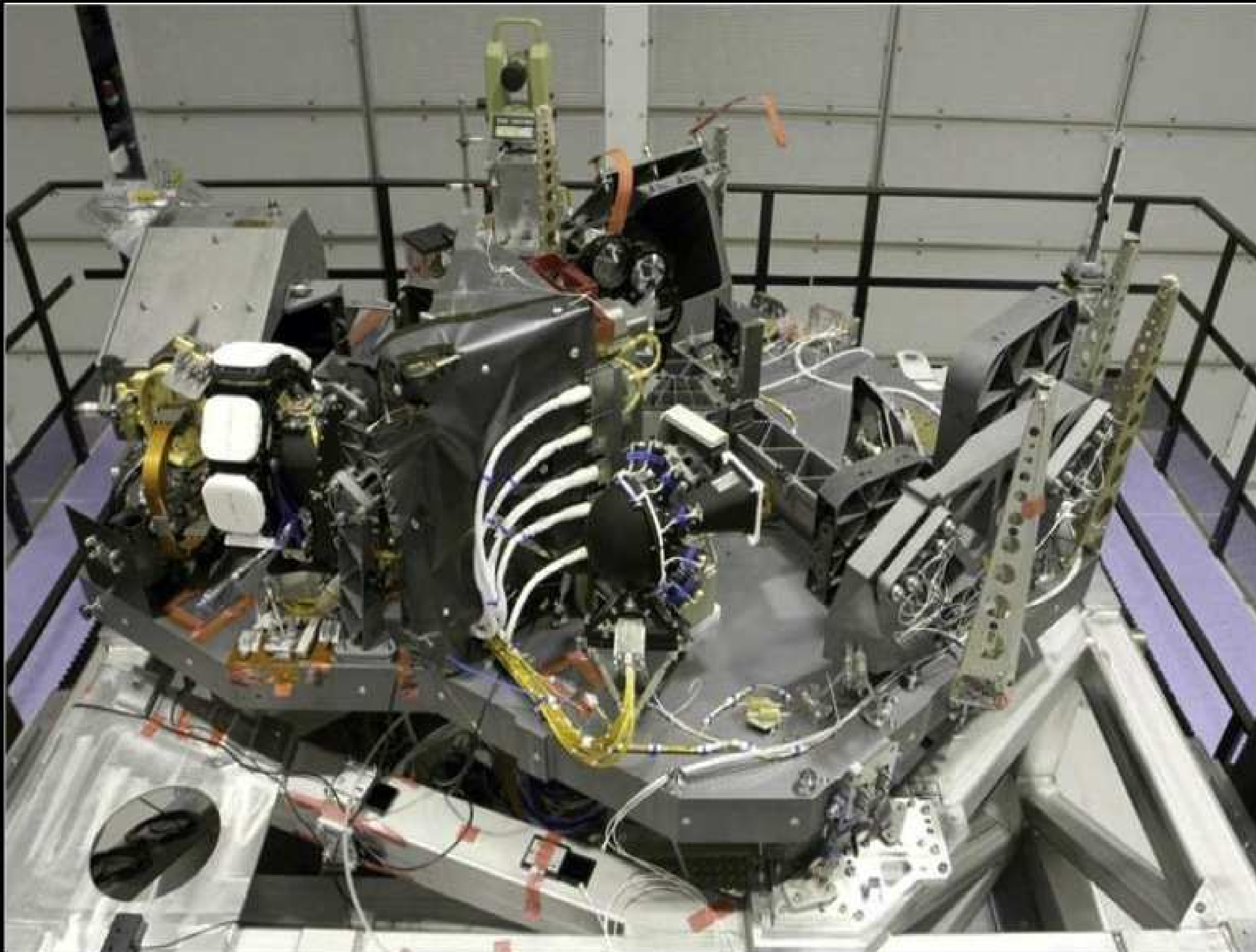
• Currently only being implemented for parallel *calibrations*.

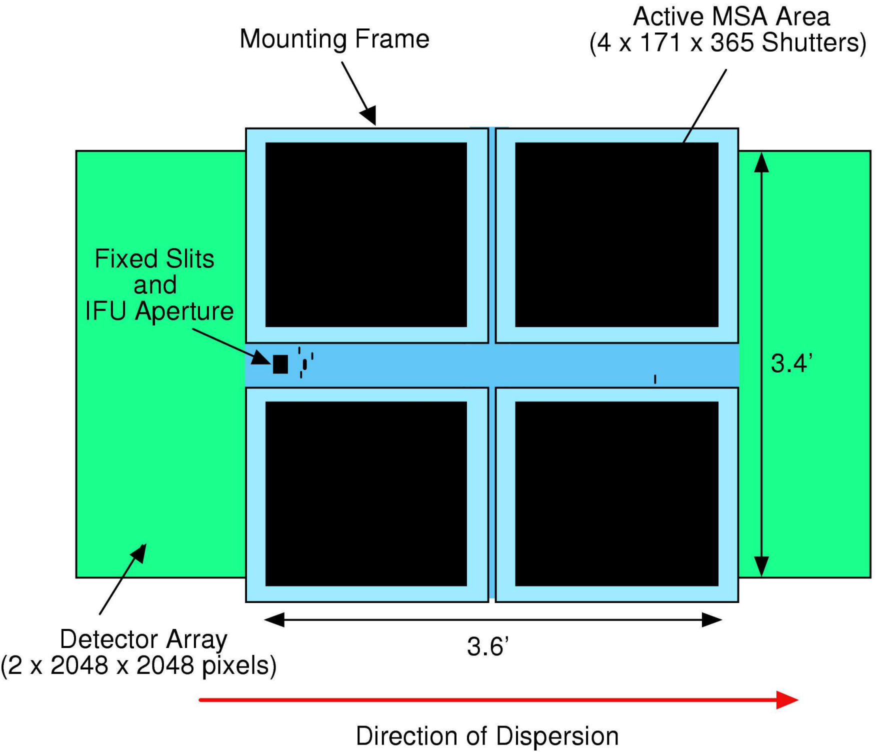


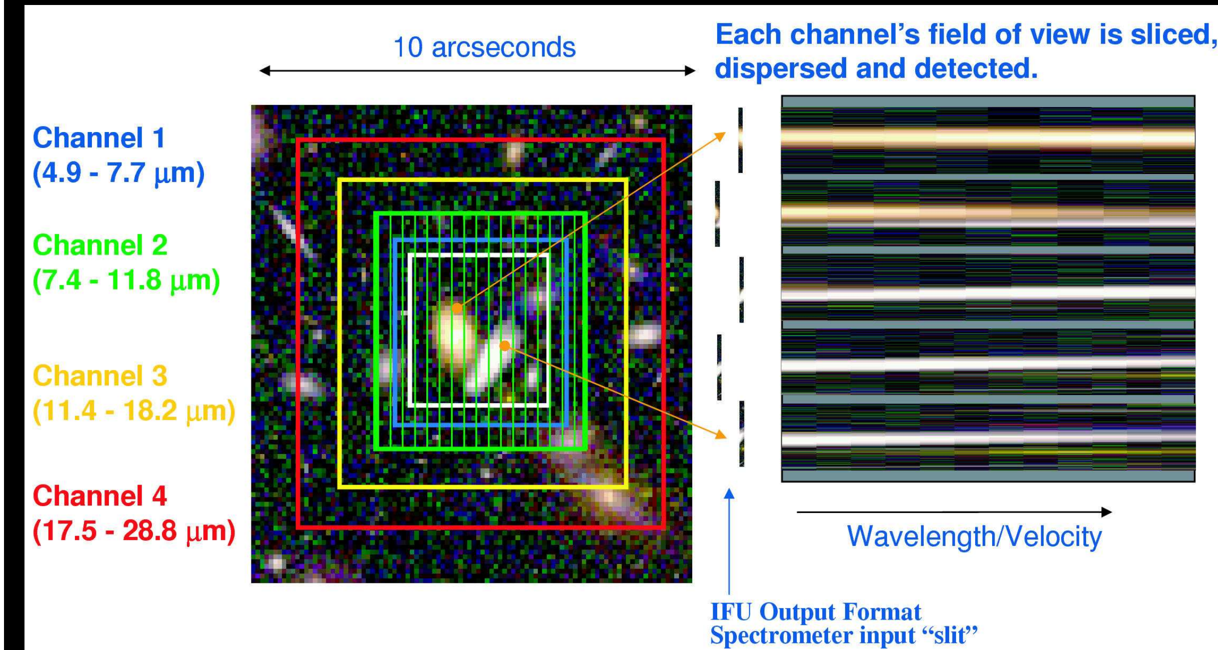
Layout of JWST NIRCam — the UofA–Lockheed NIR-Camera

ETU NIRCam

FLIGHT NIRSpec







JWST offers significant multiplexing for faint object spectroscopy:

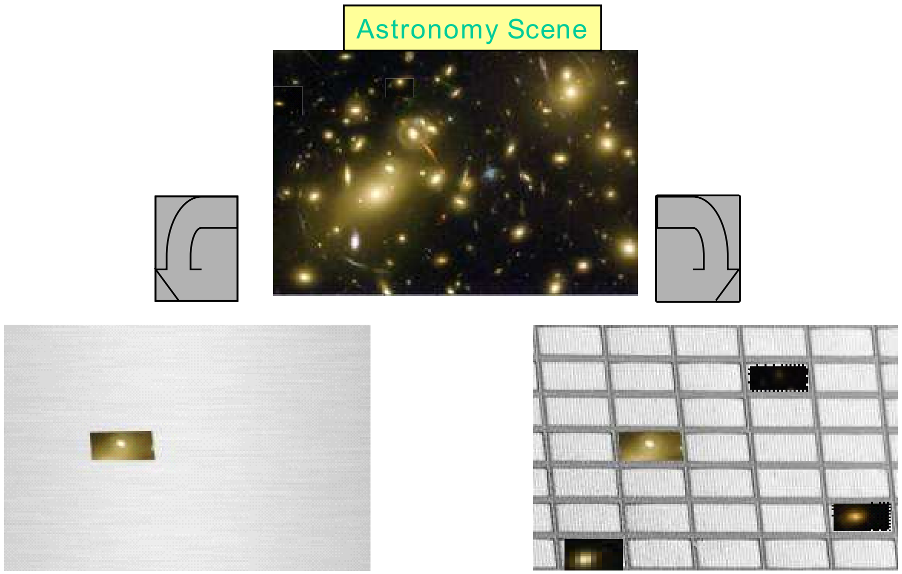
- NIRSpec/MSA with $4\times 62{,}415$ independently operable micro-shutters (MEMS) that cover $\lambda \simeq 1$–5 μm at R$\simeq$100–1000.

- MIRI/IFU with 400 spatial pixels covering 5–29 μm at R$\sim$2000–4000.

- FGS/TFI that covers a $2\farcm2 \times 2\farcm2$ FOV at $\lambda \simeq 1.6$–4.9 μm at R$\simeq$100.

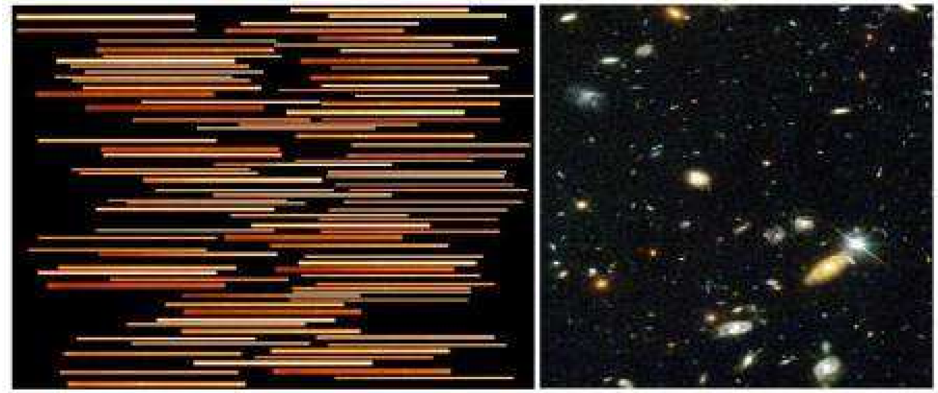
[• NIRCam offers R$\simeq$5 imaging from 0.7–5μm over two $2\farcm3 \times 4\farcm6$ FOV's.]

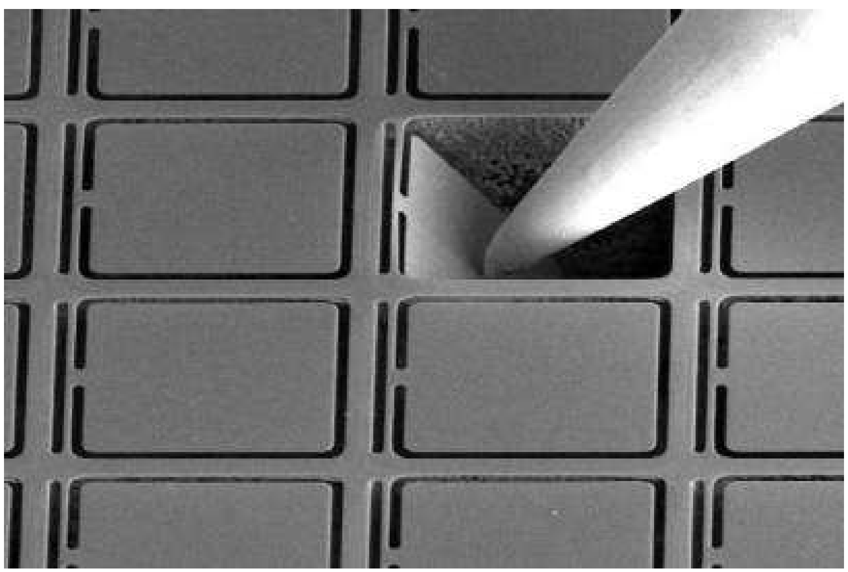
Micro Shutters



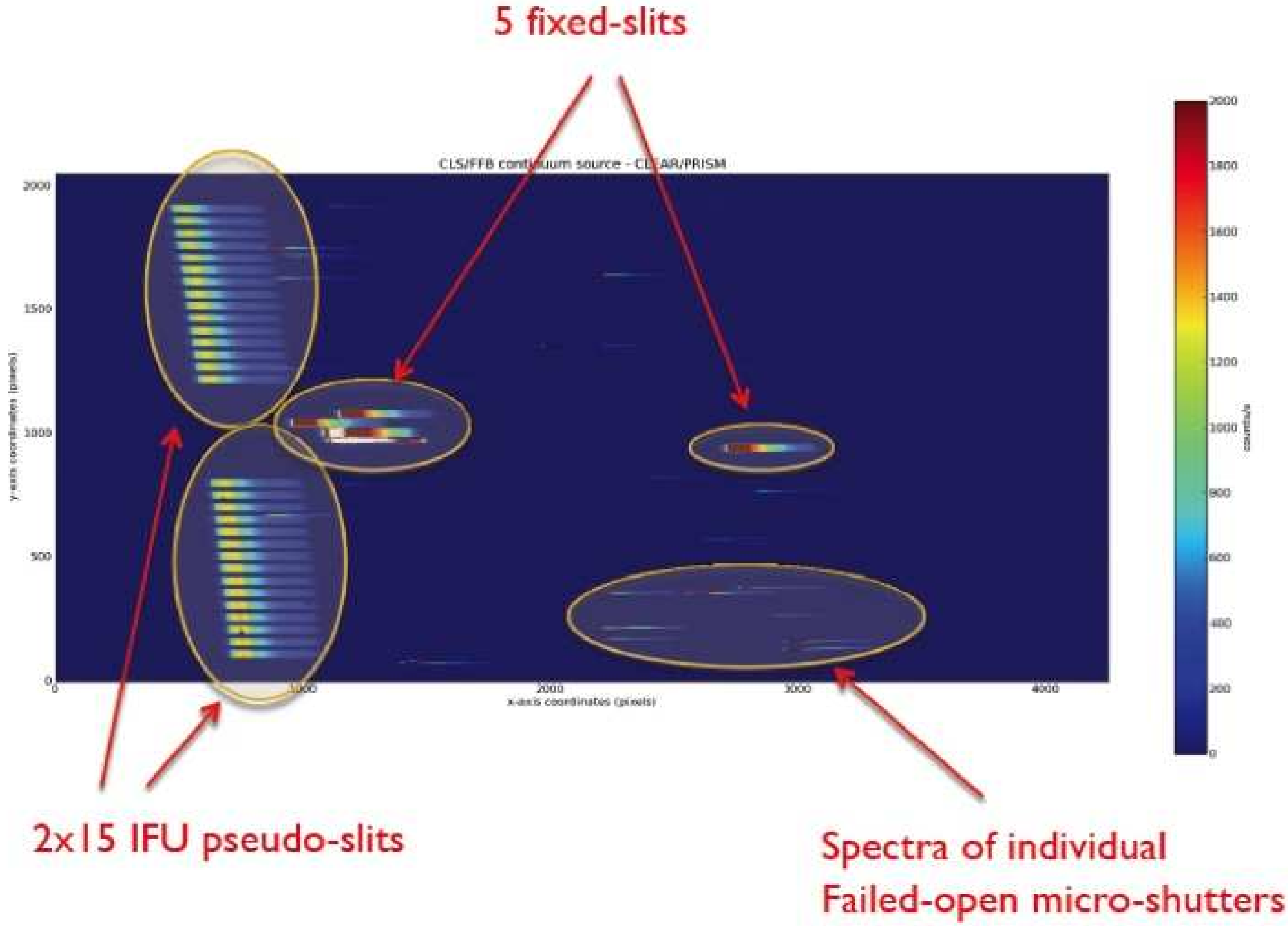
Metal Mask/Fixed Slit

Shutter Mask





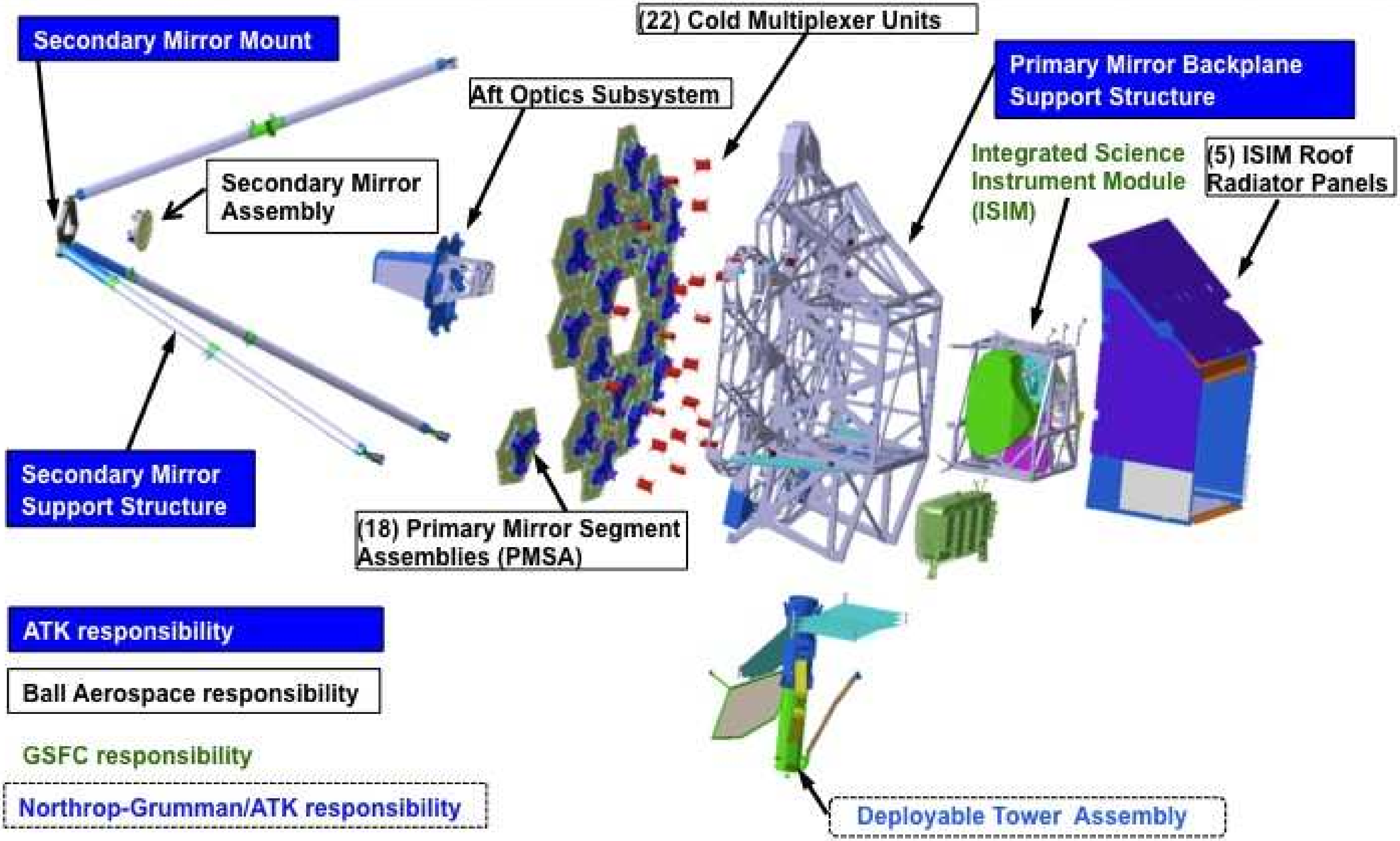
Flight NIRSpec First Light



Flight MIRI

Flight Fine Guidance Sensor

TELESCOPE ARCHITECTURE



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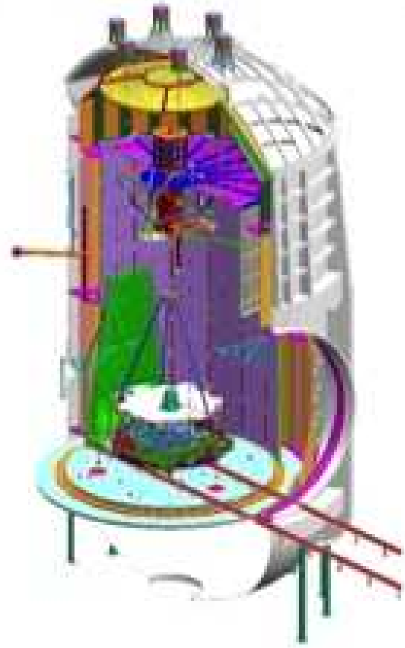
Despite NASA's CAN-do approach: Must find all the cans-of-worms ...

TELESCOPE TESTING CHAMBER AT JOHNSON SPACE CENTER

Notice people for scale

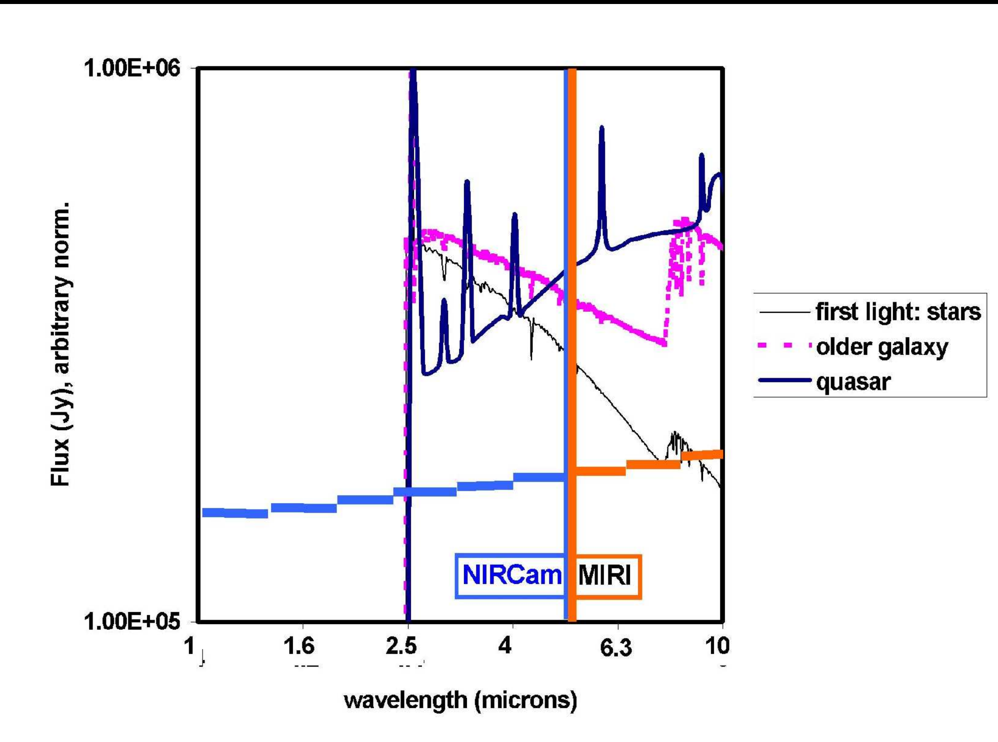
Largest simulation of deep space ever attempted will be done here

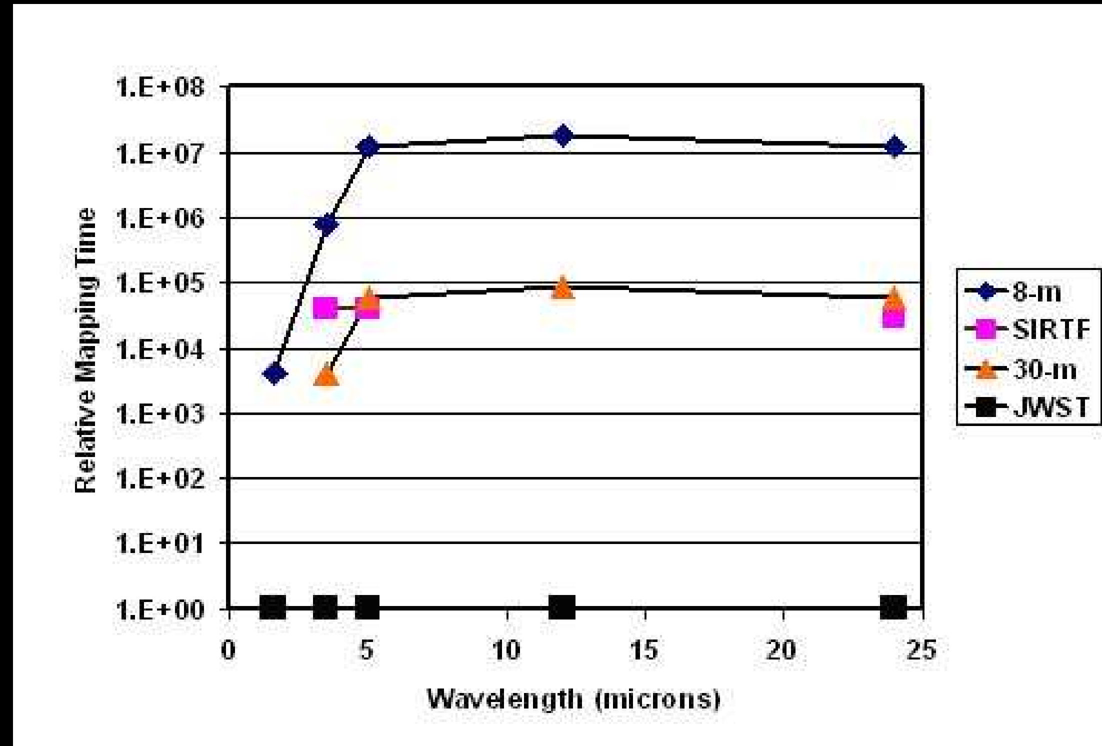


Telescope and science instruments installed in the test chamber

Element Progress

• (2) What sensitivity will JWST have?





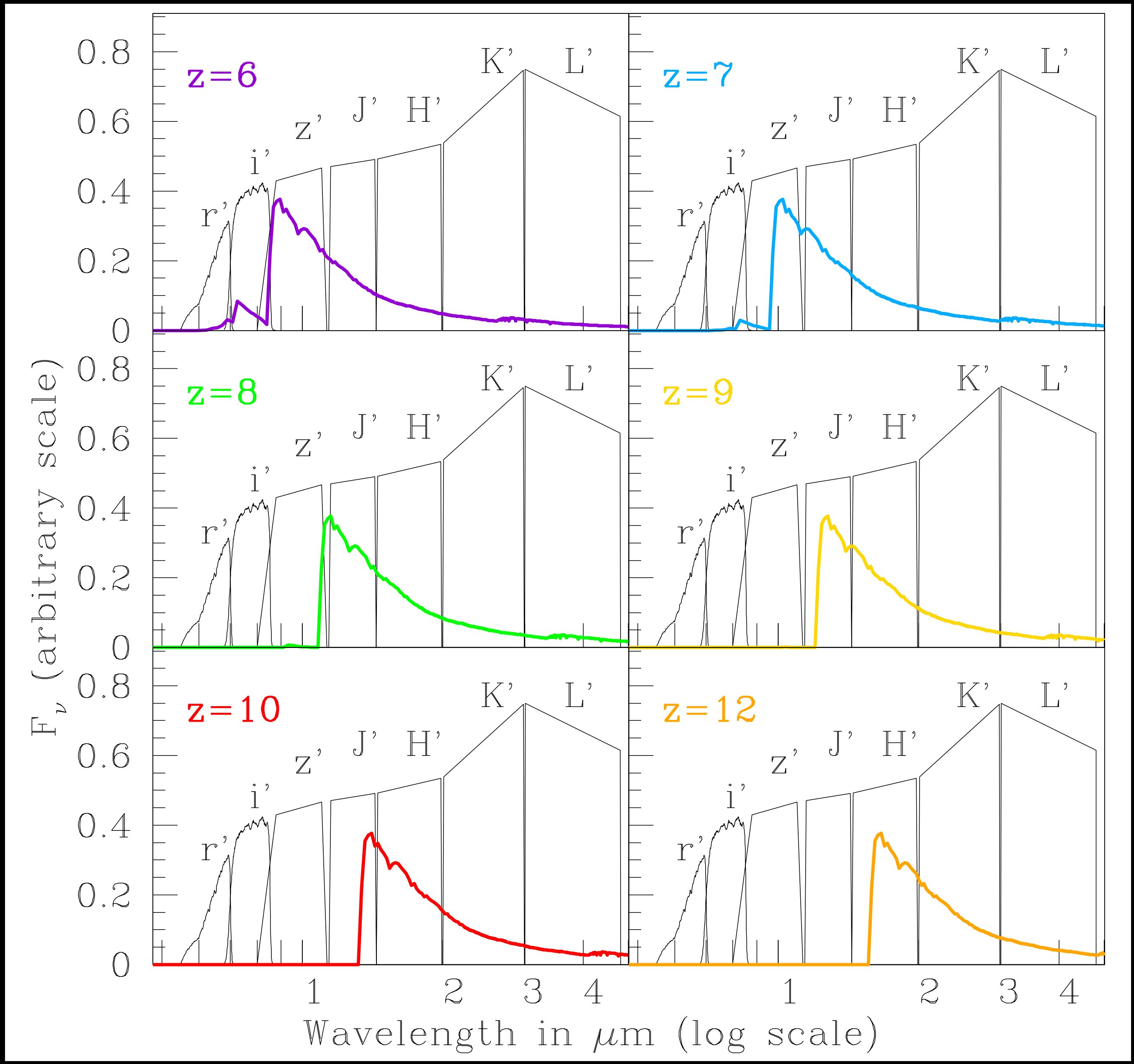
NIRCam and MIRI sensitivity complement each other, straddling $\lambda \simeq 5\ \mu$m.

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.

• (3) How can JWST measure First Light and Reionization?

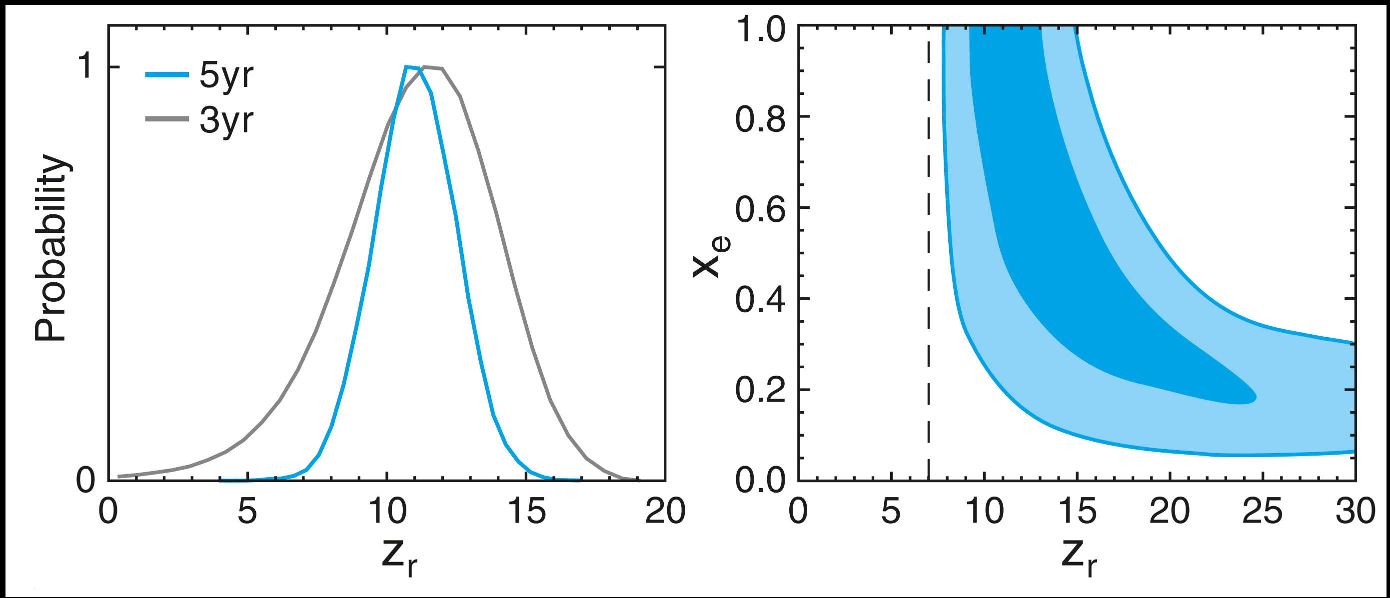


• Can't beat redshift: to see First Light, must observe near–mid IR.

$\Rightarrow$ This is why JWST needs NIRCam at 0.8–5 μm *and* MIRI at 5–29 μm.

Implications of the (2010) 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. 2009, 2011):

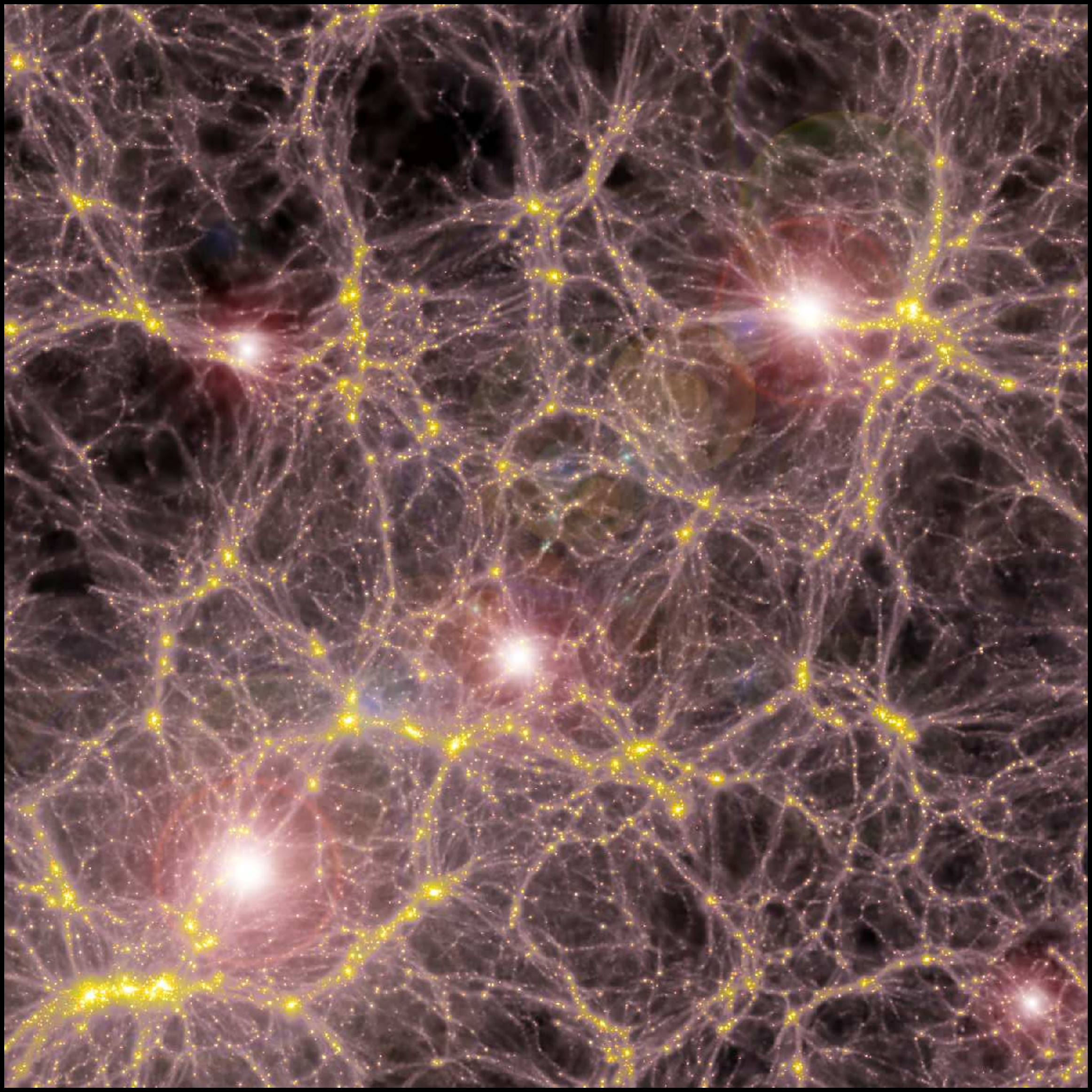
$\Longrightarrow$ First Light & Reionization occurred between these extremes:

- (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.

$\Rightarrow$ JWST must cover $\lambda = 0.7$–29 μm, with its diffraction limit at 2.0 μm.

• (3) How will JWST Observe First Light and Reionization?

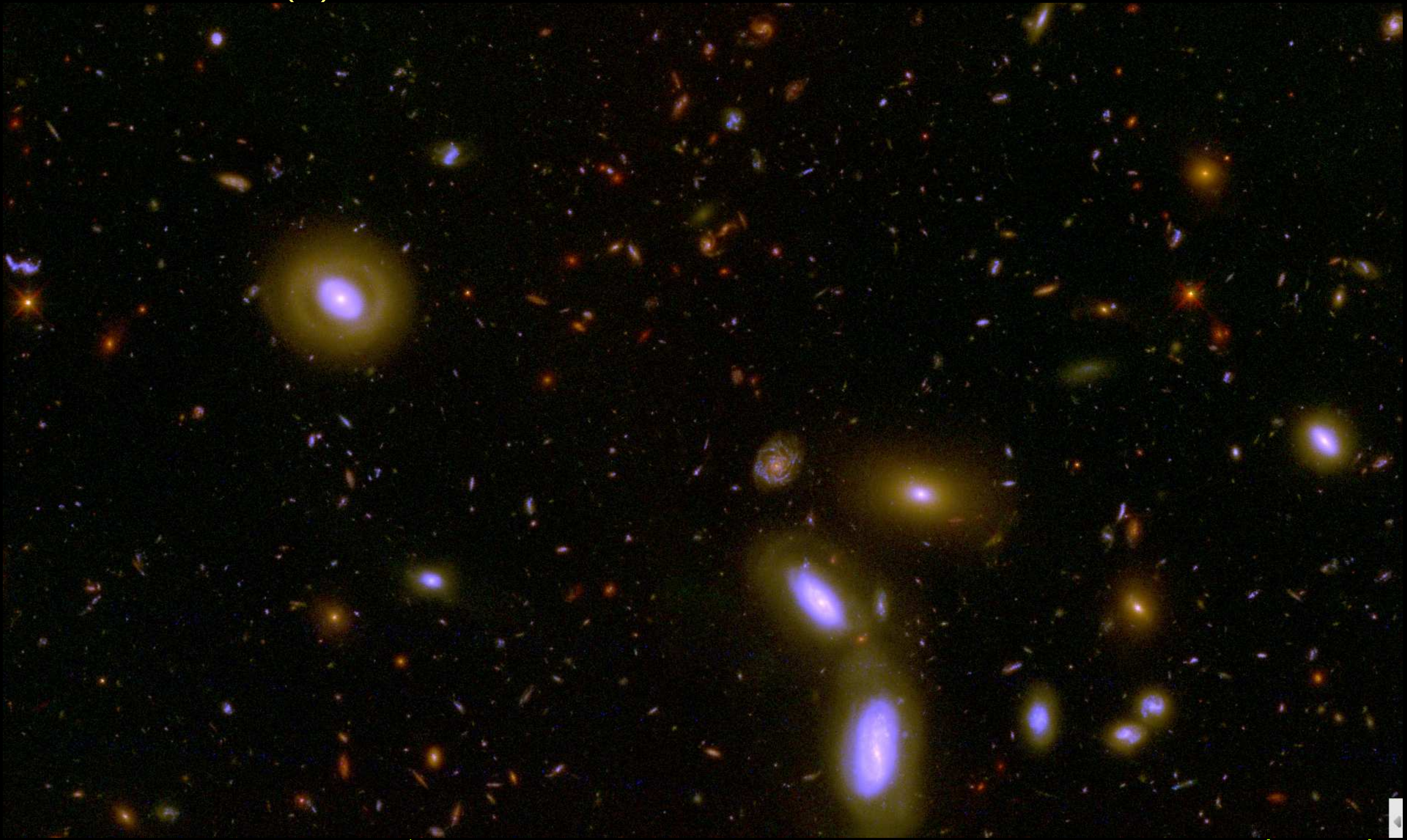


• Detailed Hydrodynamical models (V. Bromm; many others this Conf) suggest that massive Pop III stars may have reionized universe at redshifts $z \lesssim 10$–30 (First Light).

• 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 $z \simeq 10 \longrightarrow 30$.

See many talks this Conference: We must make sure we theoretically understand the likely Pop III mass-range, their IMF and SN-rates, etc.

• (4) How can JWST measure Galaxy Assembly?

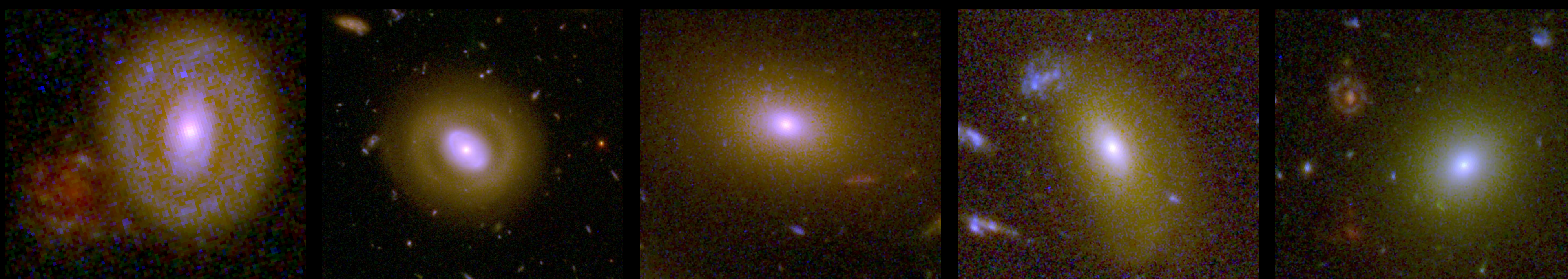


10 filters with HST/WFC3 & ACS reaching AB=26.5-27.0 mag (10-σ) over 40 arcmin^2 at 0.07–0.15" FWHM from 0.2–1.7μm (UVUBVizYJH).

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

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

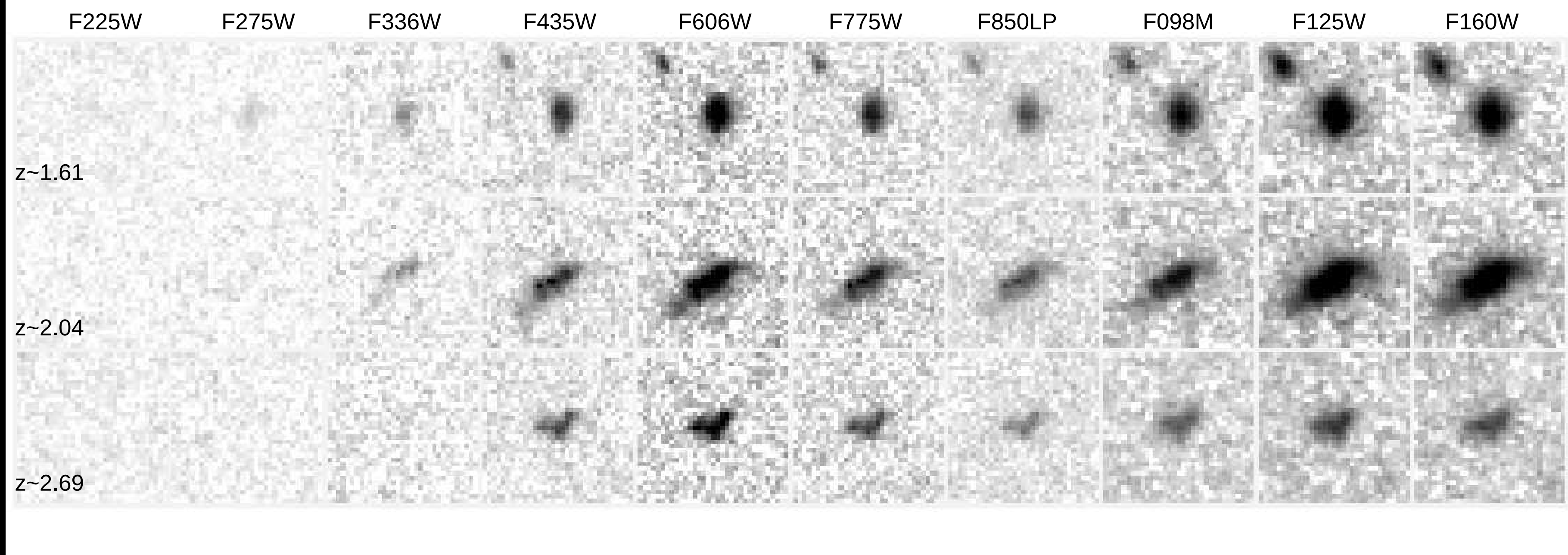
Galaxy structure at the peak of the merging epoch (z$\simeq$1–2) is very rich: some resemble the cosmological parameters $\boldsymbol{H_0}$, $\boldsymbol{\Omega}$, $\boldsymbol{\rho_o}$, $\boldsymbol{w}$, and $\boldsymbol{\Lambda}$, resp.



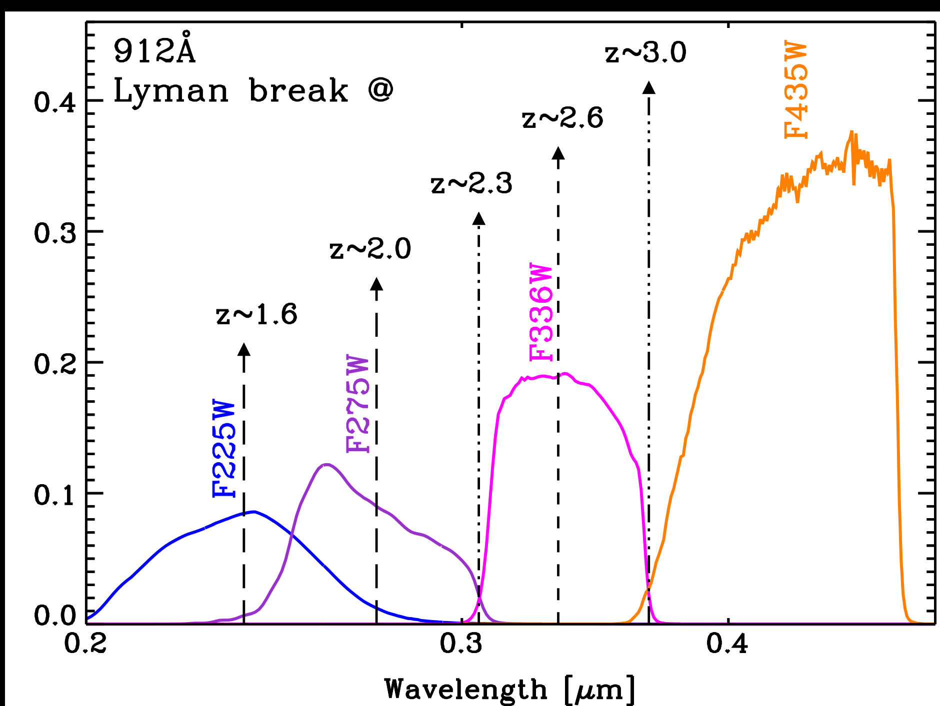
Panchromatic WFC3 ERS images of early-type galaxies with nuclear star-forming rings, bars, weak AGN, or other interesting nuclear structure.

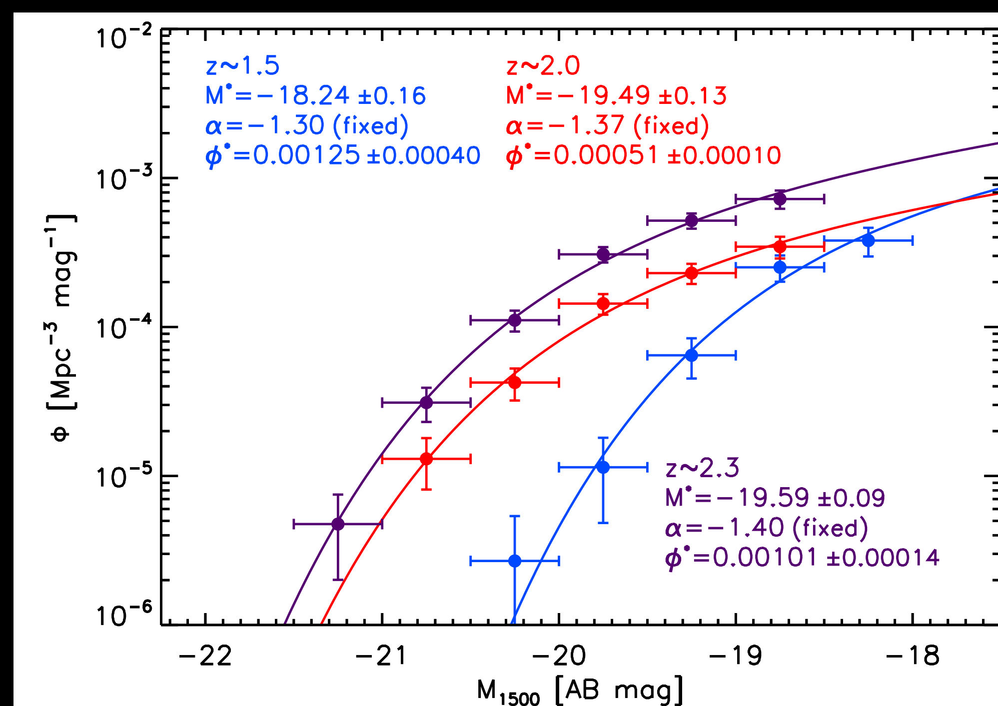
(Rutkowski et al. 2010) $\Longrightarrow$ "Red and dead" galaxies aren't dead!

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

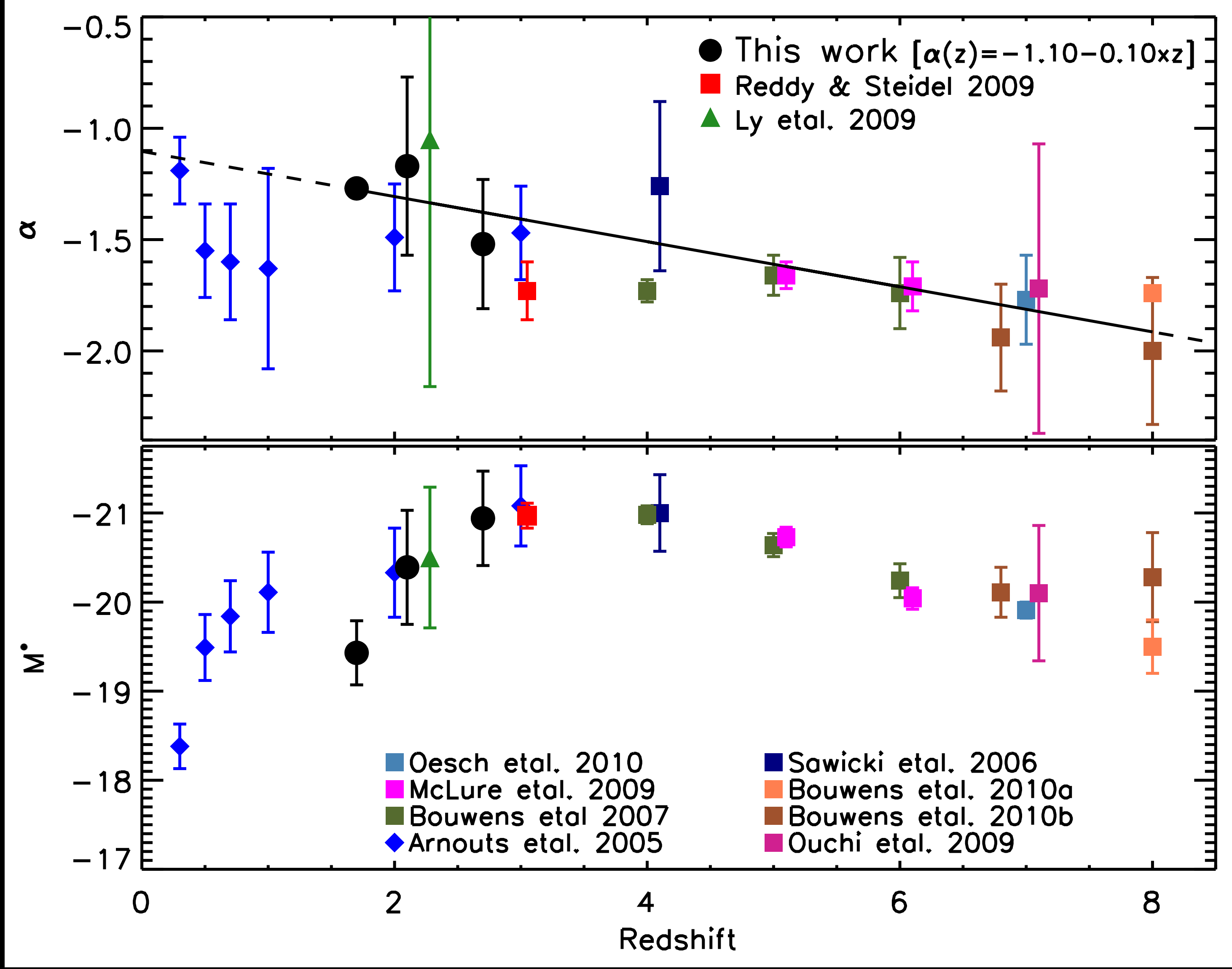


Lyman break galaxies at the peak of cosmic SF (z≃1-3; Hathi ea. 2010)





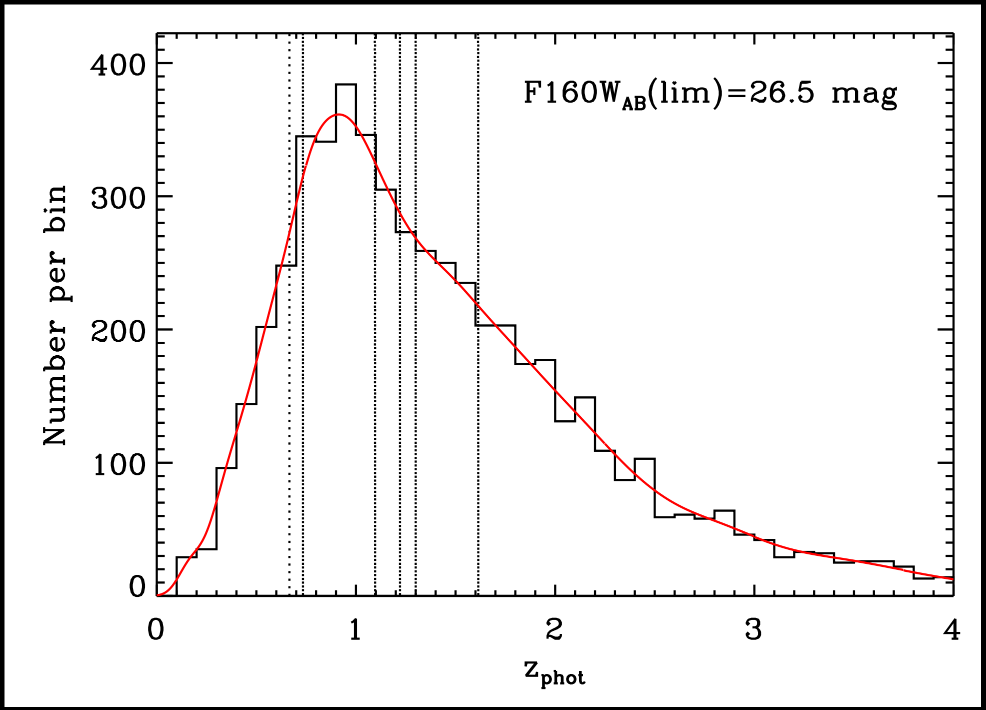
- JWST will similarly measure faint-end LF-slope evolution for 1≲z≲12.

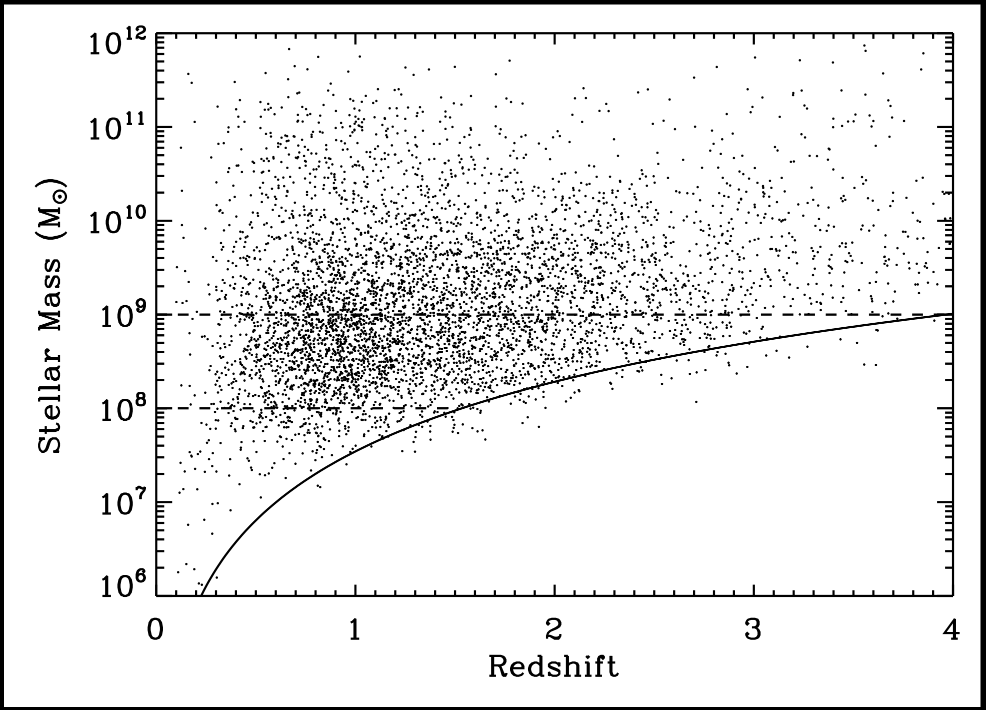


Measured faint-end LF slope evolution (top) and characteristic luminosity evolution (bottom) from Hathi et al. 2010, ApJ, 720, 1708 (arXiv:1004.5141v2).

- 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!

$\Rightarrow$ Could have critical consequences for gravitational lensing bias at z$\gtrsim$10!





WFC3 ERS 10-band redshift estimates accurate to ∼4% with small systematic errors (Cohen et al. 2010), resulting in a reliable redshift distribution.

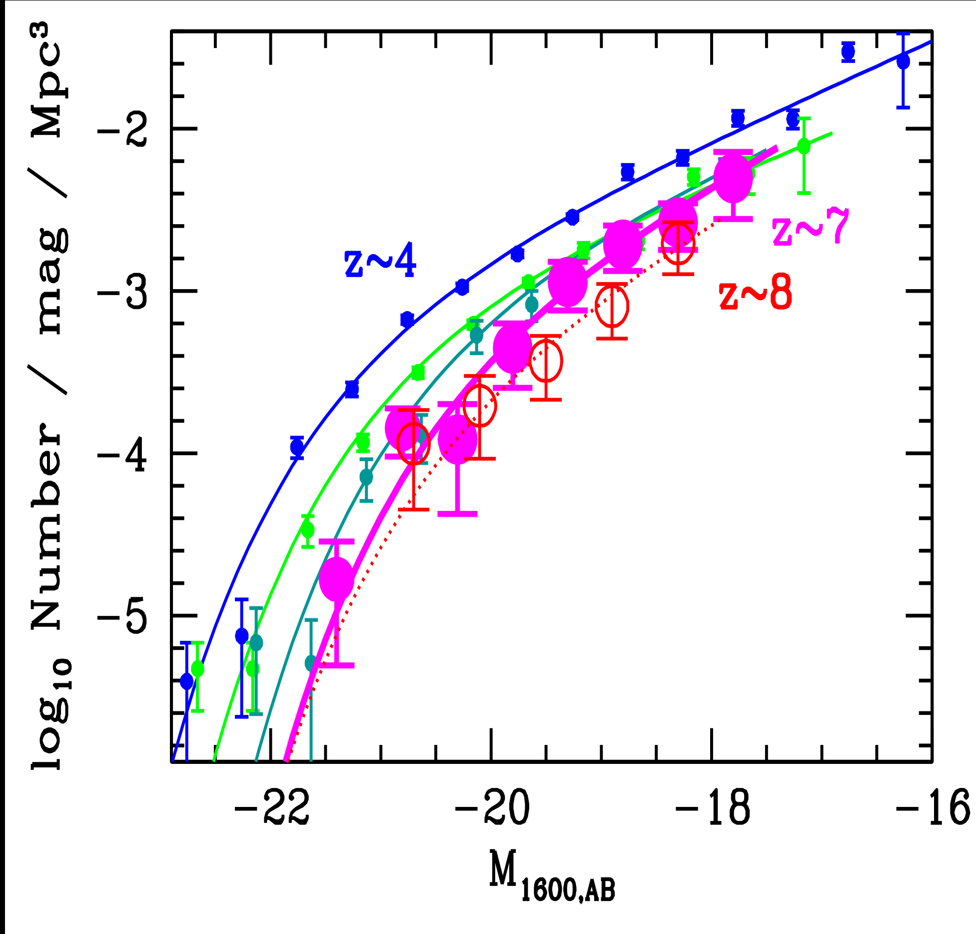
● Reliable masses of faint galaxies to AB=26.5 mag, accurately tracing the process of galaxy assembly: downsizing, merging, (& weak AGN growth?)

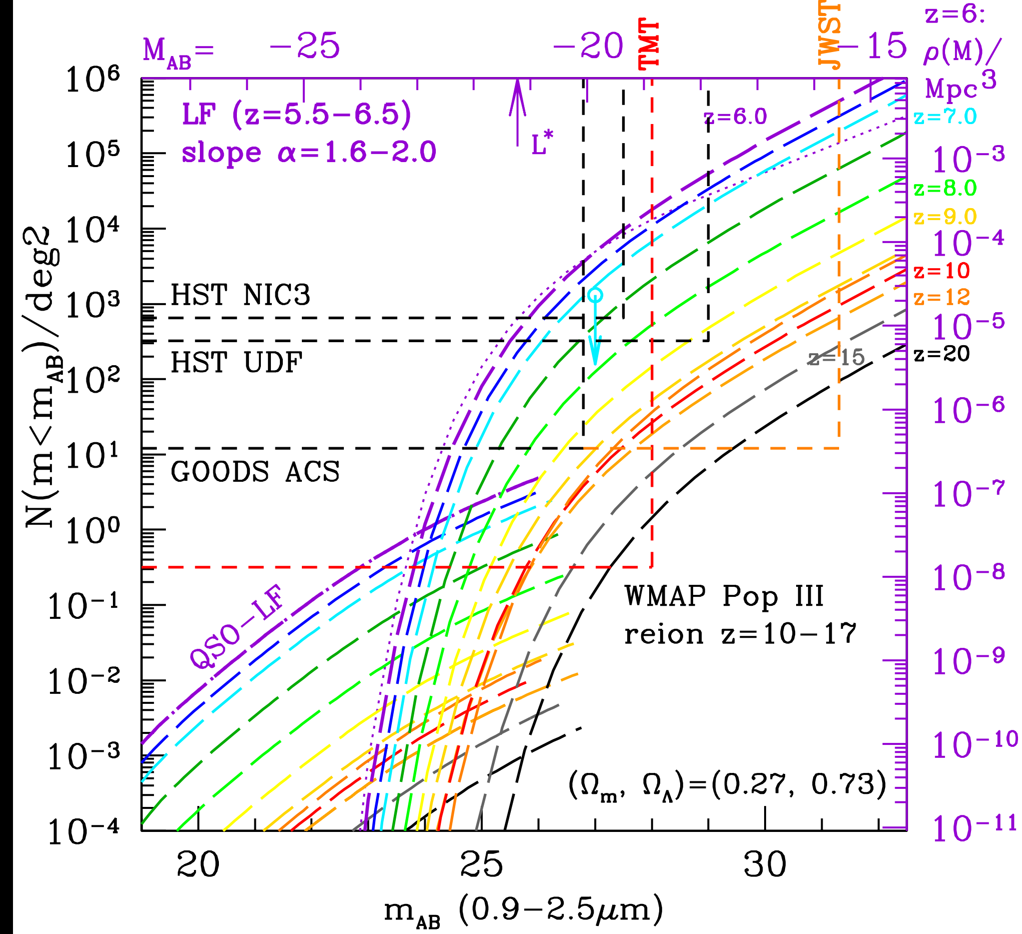
ERS shows WFC3's new panchromatic capabilities on galaxies at $z \simeq 0$–7.

● HUDF shows WFC3 $z \simeq 7$–9 capabilities (Bouwens$^+$ 2010; Yan$^+$ 2010).

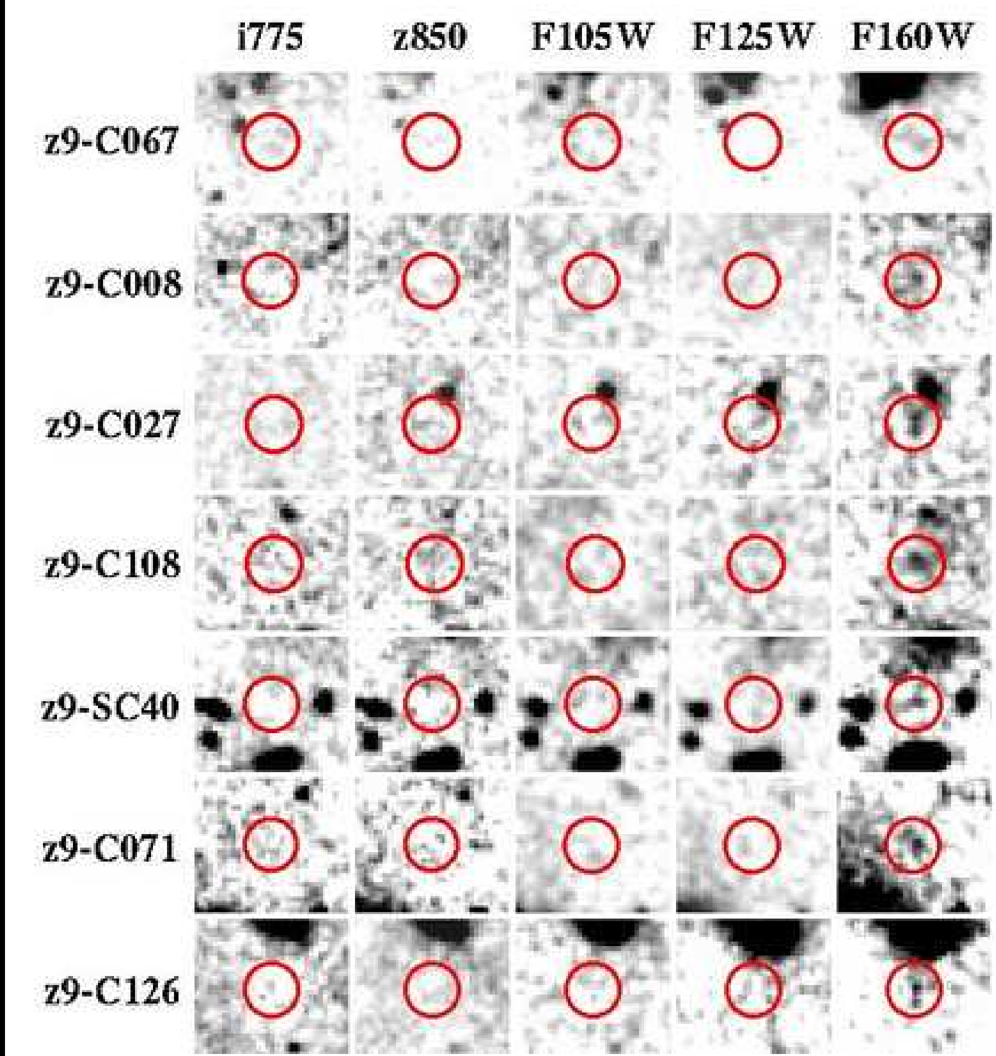
⇒ WFC3 is an essential pathfinder at $z \lesssim 8$ for JWST (0.7–29 μm) at $z \gtrsim 9$.

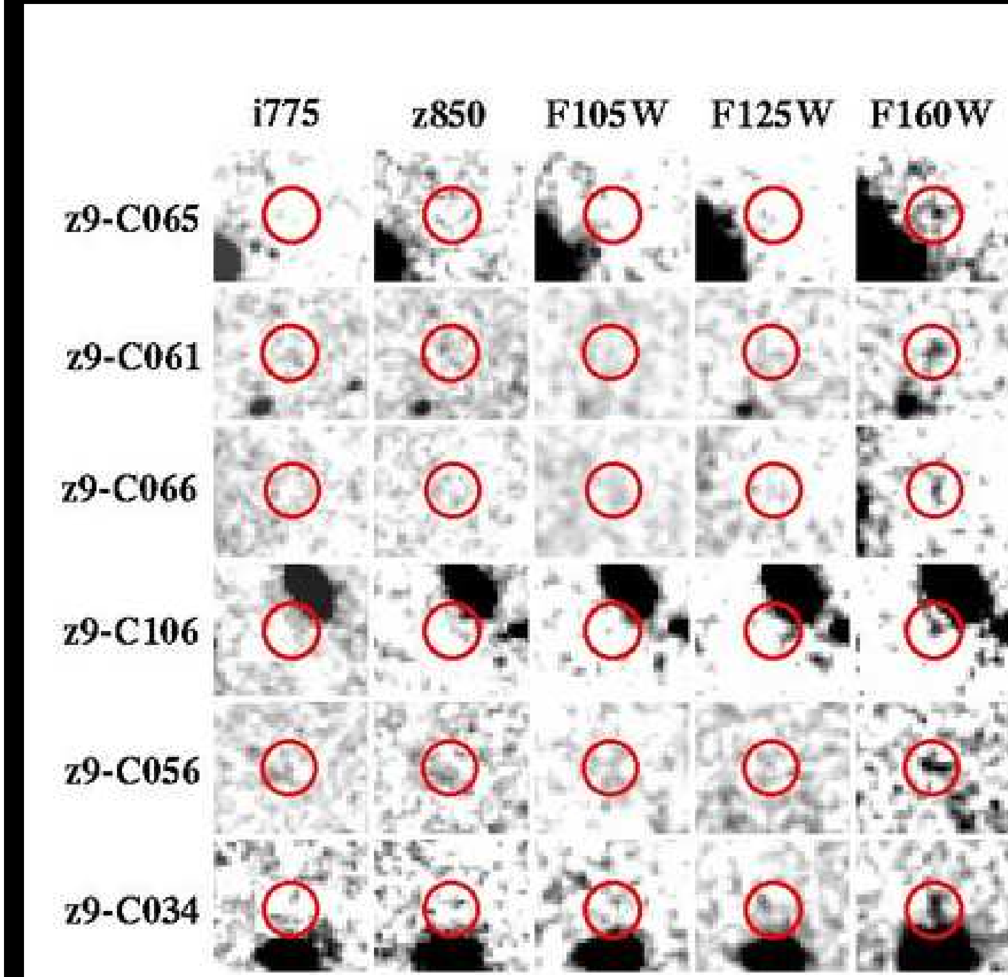
● JWST will trace mass assembly and dust content 3–4 mags deeper from $z \simeq 1$–12, with nanoJy sensitivity from 0.7–5μm.



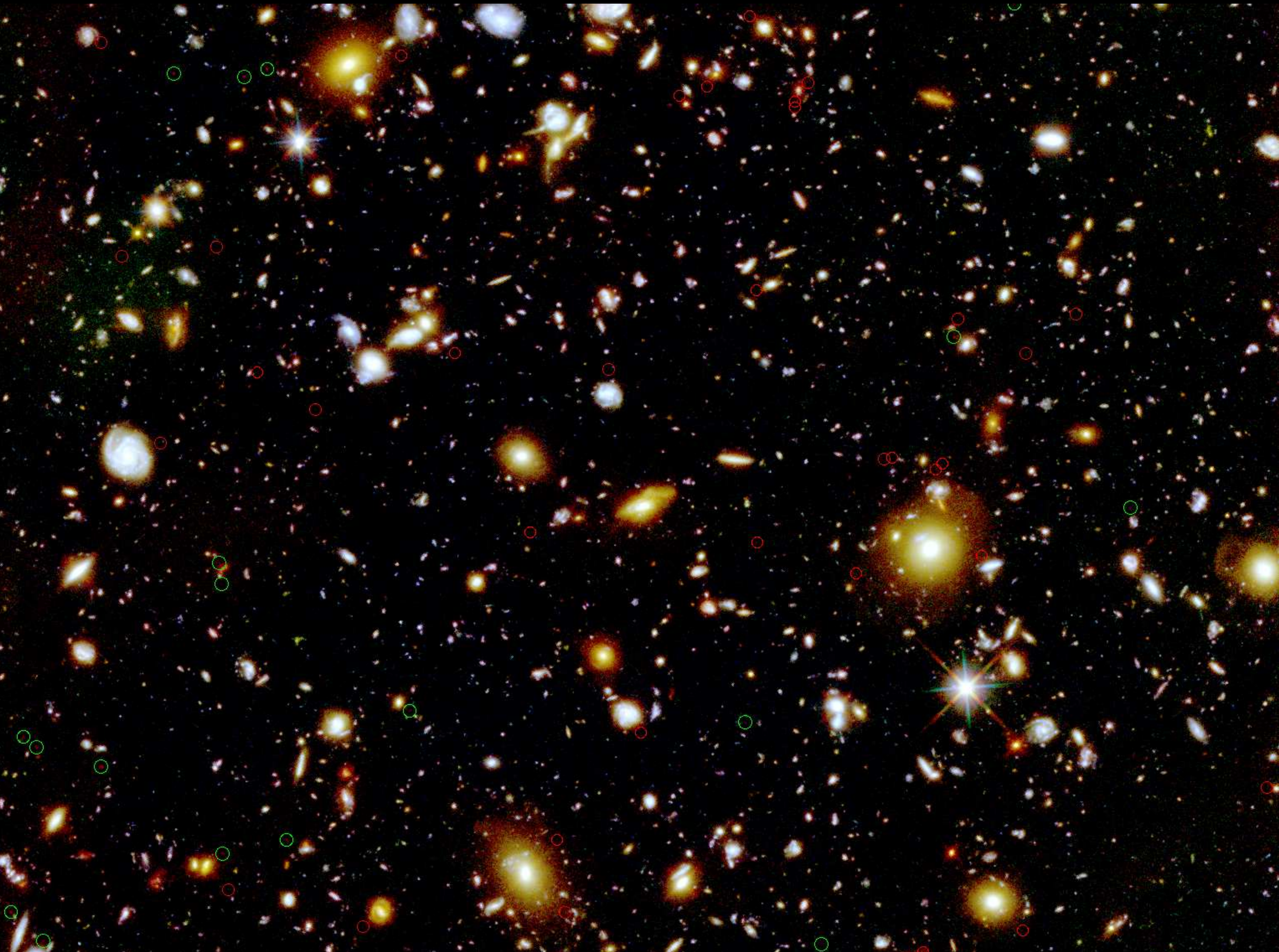


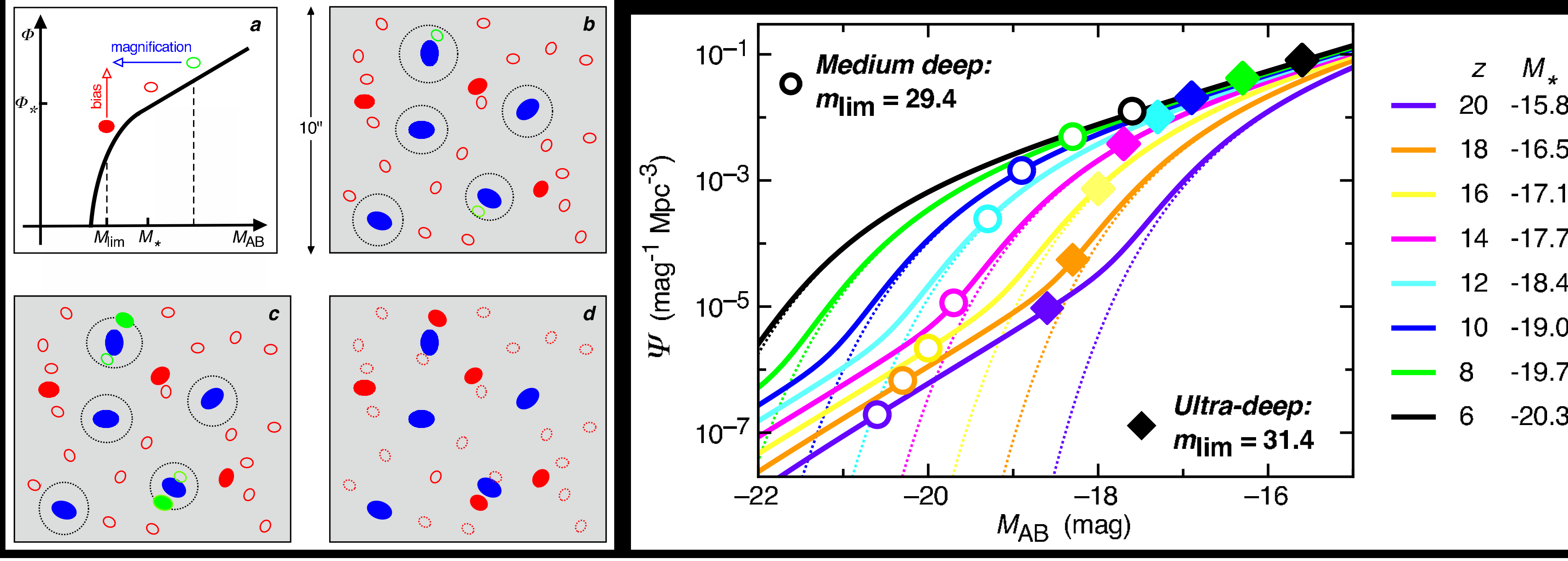
- Objects at z$\gtrsim$9 are rare (Bouwens^{+} 10; Trenti,$^{+}$ 10; Yan^{+} 10), since volume elt is small, and JWST samples brighter part of LF. JWST needs its sensitivity/aperture (A), field-of-view ($\mathbf{\Omega}$), and $\boldsymbol{\lambda}$-range (0.7-29 $\boldsymbol{\mu}$m).
- With proper survey strategy (area AND depth), JWST can trace the entire reionization epoch and detect the first star-forming objects.
- To study co-evolution of SMBH-growth and proto-bulge assembly for z$\lesssim$10–15 requires new AGN finding techniques for JWST.

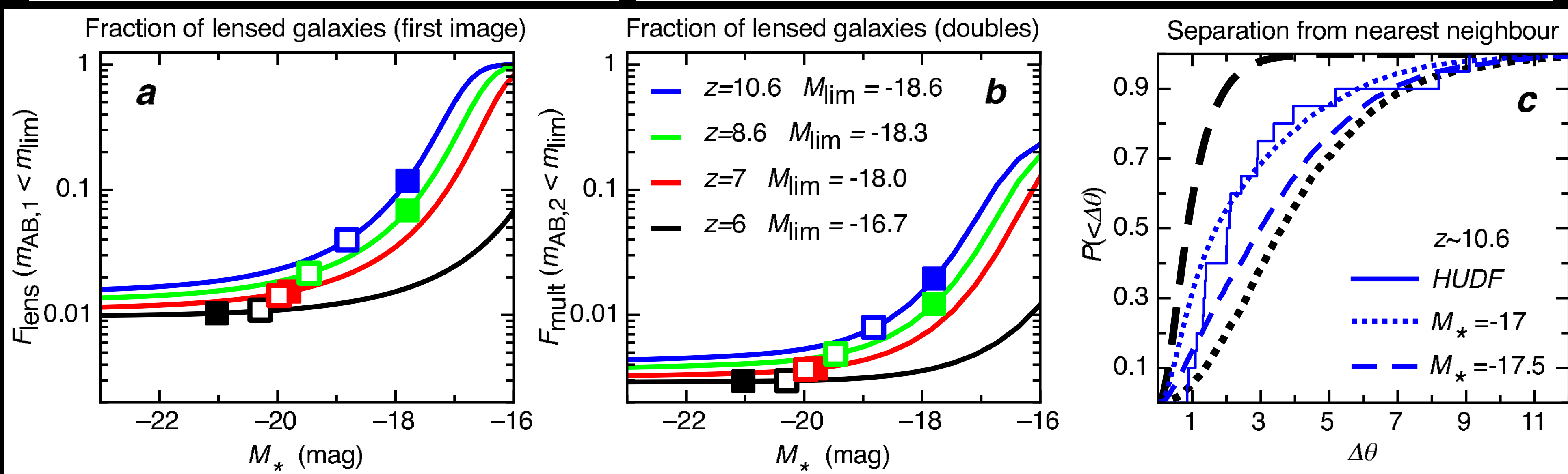




- ∼10–40% of the Y-drops and J-drops appear close to bright galaxies (Yan et al. 2010, Res. Astr. & Ap., 10, 867; astro.0910.0077).
- This is expected from gravitational lensing bias by galaxy dark matter halo distribution at z≃1–2 (Wyithe et al. 2011, Nature, 469, 181).
- Need JWST to measure z≳9 LF, and see if it's fundamentally different from the z≲8 LFs. Does a gravitational lensing bias cause power-law LF?

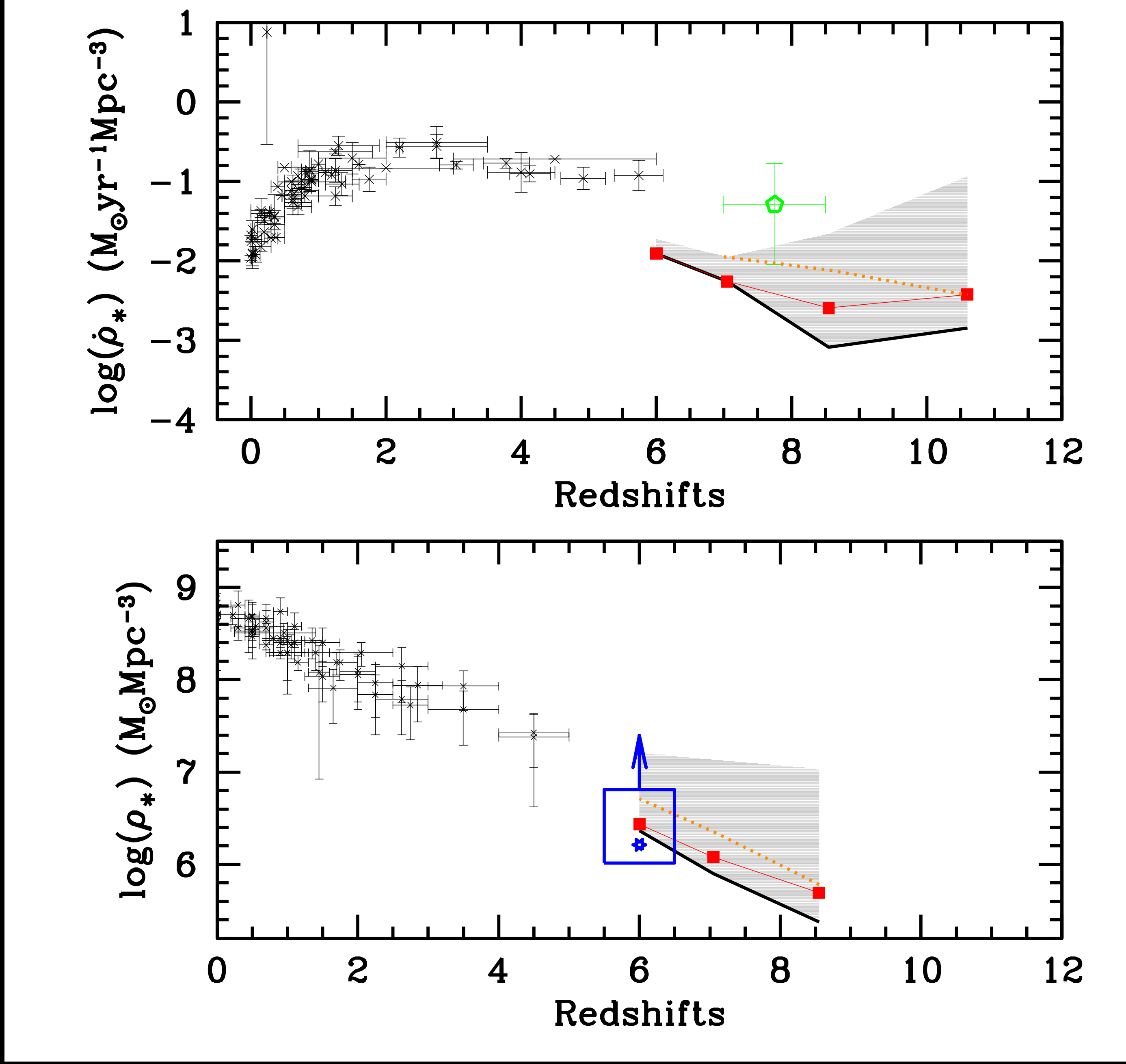






Wyithe et al. (2011, Nature, 469, 181): With a steep faint-end LF-slope $\alpha \gtrsim 2$, and a characteristic faint $M^* \gtrsim$–19 mag, foreground galaxies (at z≃1–2) may cause significant boosting by gravitational lensing at z≳8–10.

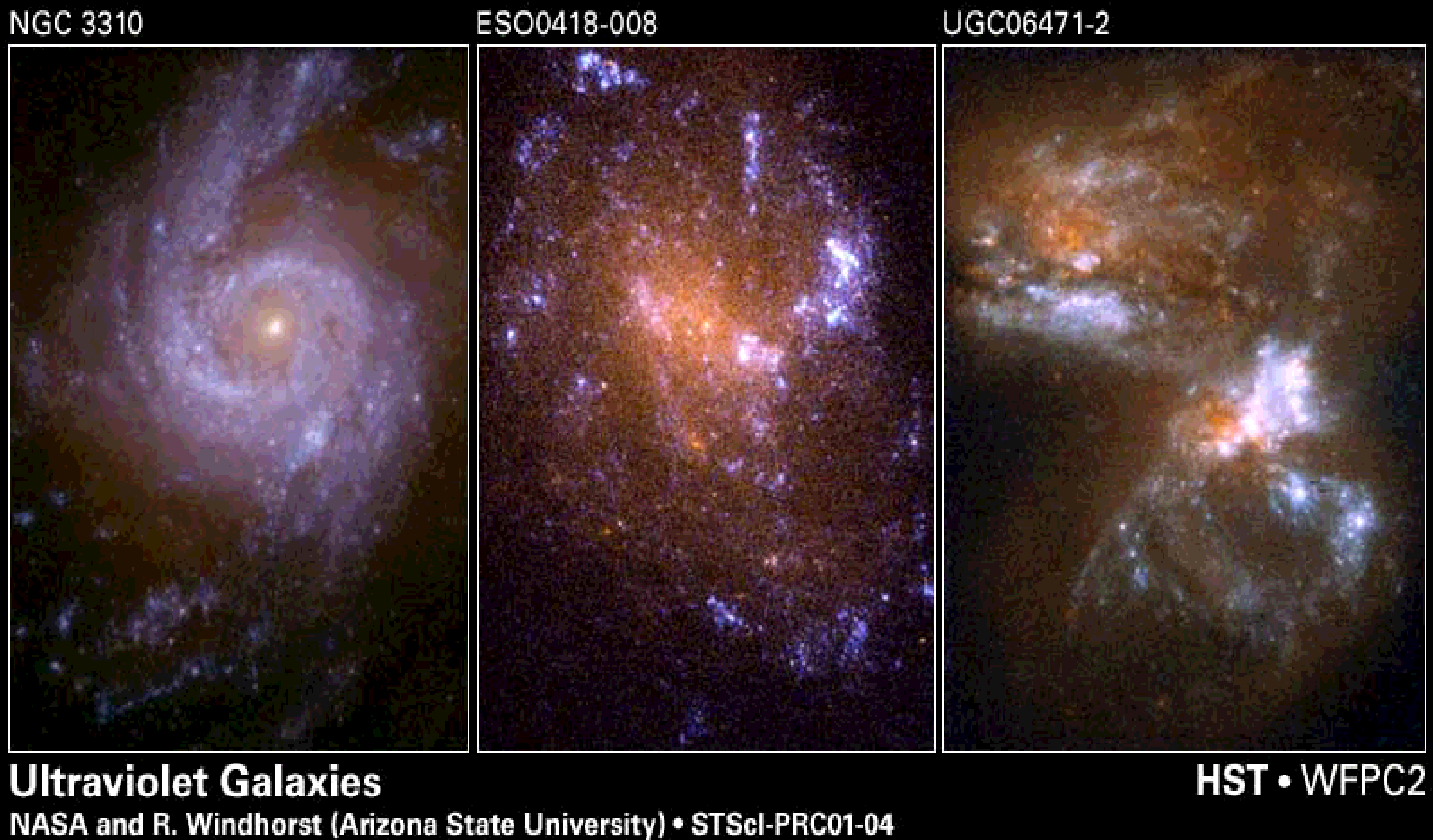
- This could change the landscape for JWST observing strategies.



Current WFC3 uncertainties on Y, J-drops large enough that at z≳8-10, a range of possibilities is allowed (Bouwens+ 2010, Yan+ 2010).

- Need JWST to fully measure the LF and SFR for 8≲z≲15.

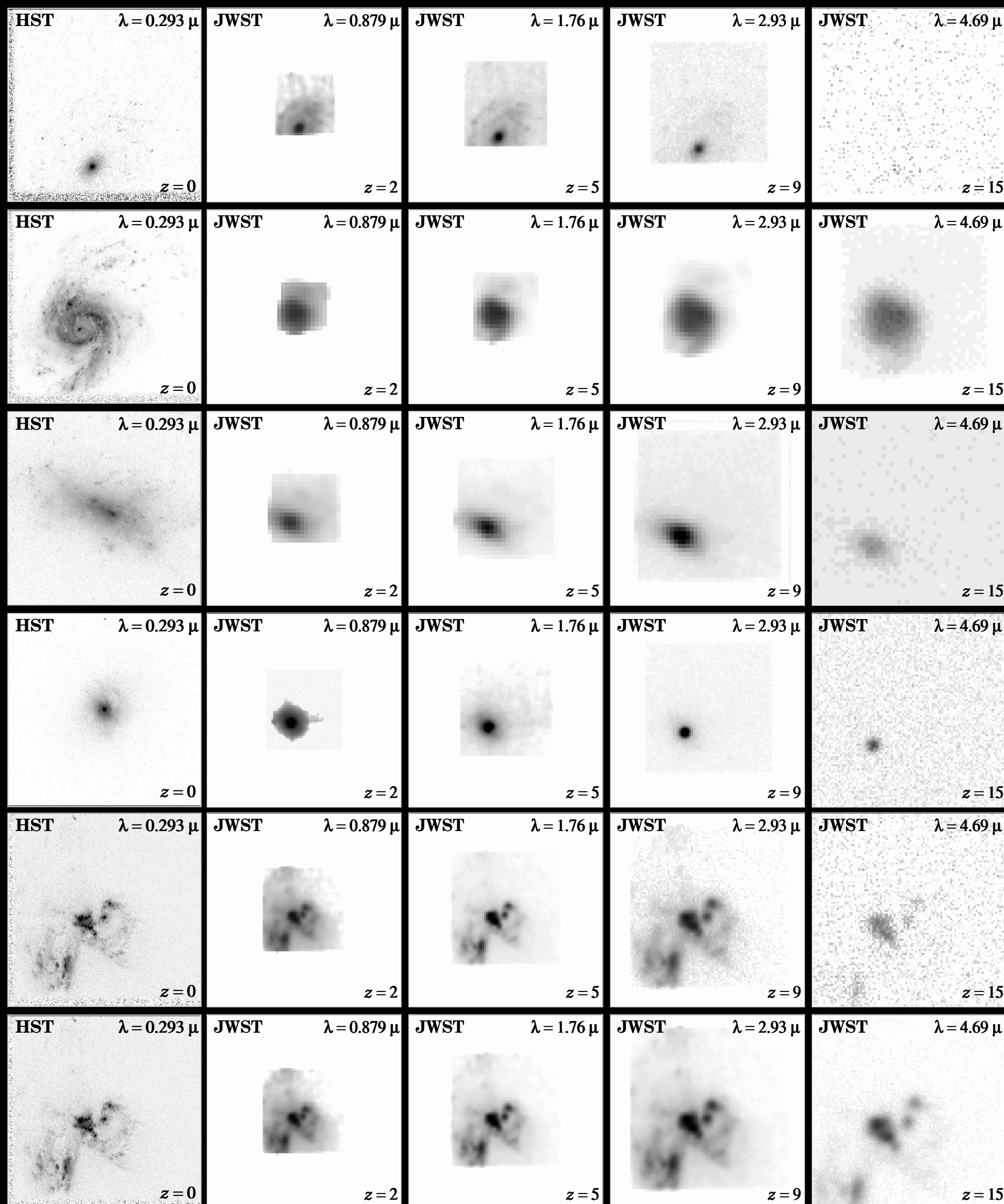
(5) Predicted Galaxy Appearance for JWST at z≃1–15



- 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 UV images are benchmarks for comparison with very high redshift galaxies seen by JWST, enabling quantitative analysis of the restframe-λ dependent structure, B/T, CAS, SFR, mass, dust, etc.

(5) Predicted Galaxy Appearance for JWST at z≃1–15 (w/ C. Conselice)

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



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

- (1) Most disks will SB-dim away at high z, but most formed at z$\lesssim$1–2.
- (2) High SB structures are visible to very high z.
- (3) Point sources (AGN) are visible to very high z.
- (4) High SB-parts of mergers/train-wrecks, etc., are visible to very high z.

(6) Conclusions

(1) JWST Project is technologically front-loaded and well on track:

- Passed Non-Advocate Review (T-NAR) in 2007, and Mission Preliminary Design Review (PDR) in 2008. Mission CDR in 2010. Replan in 2011.
- More than 70% of JWST H/W built, & meets/exceeds specs as of 06/11.

(2) JWST is designed to map the epochs of First Light, Reionization, and Galaxy Assembly in detail. JWST will determine:

- The formation and evolution of the first (reionizing) Pop III star-clusters.
- Faint-end LF-slope evol: (how) did dwarf galaxies finish reionization?
- The origin of the Hubble sequence in hierarchical formation scenarios.

(3) JWST will have a major impact on astrophysics after 2015:

- Current generation students, postdocs will use JWST during their career
- JWST will define the next frontier to explore: the Dark Ages at $z \gtrsim 20$.

SPARE CHARTS

Observers Wish-list of Theoretical Predictions for the JWST era:

- (1a) Halo/Stellar M_h/M_* (M, z, r/r_e, $\Delta\rho/\rho$, ...).

- (1b) Galaxy Mass & Luminosity Fns: $M^*(z)$, $L^*(z)$, $\alpha(z)$, $\phi^*(z)$.

- (2a) SNe (IMF, r/r_e, z), SN-feedback (M_*, z, ...).

- (2b) Pop III/II.5 SNe (IMF, Fe/H(z), t, z).

- (2c) Fe/H (M_*, r/r_e, z) & A_V (M_*, r/r_e, z).

- (3a) SMBH (M_b, z, $\Delta\rho/\rho$, ...).

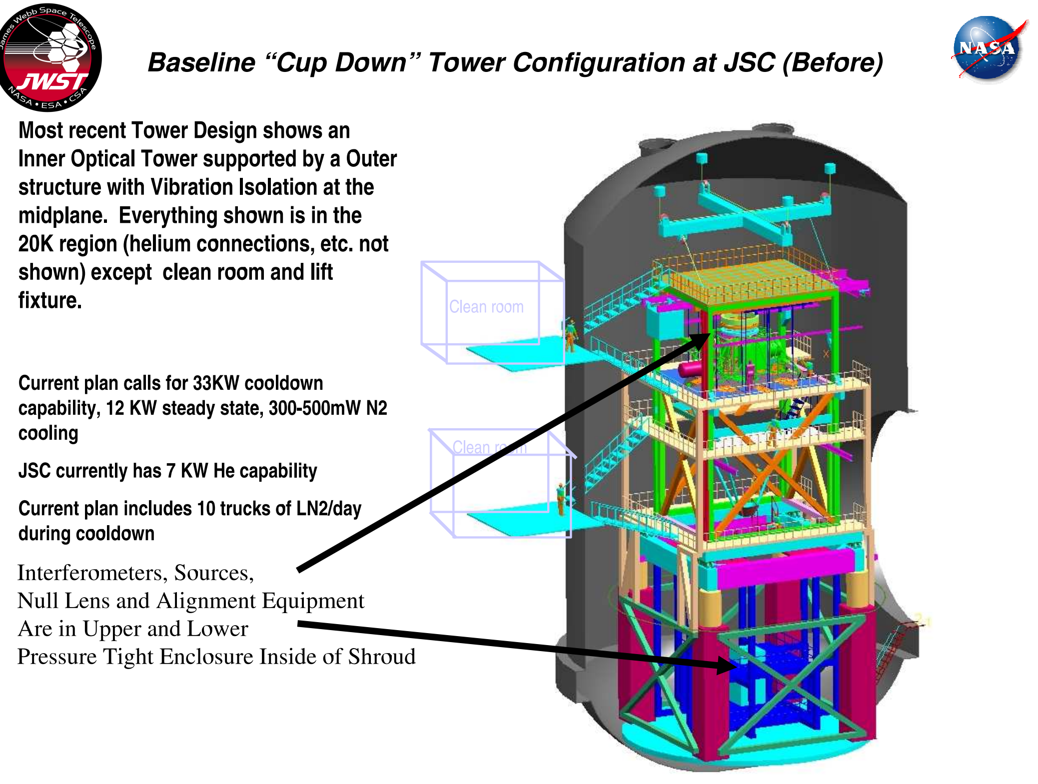
- (3b) [Weak] AGN LF(z), AGN-feedback (M_b, z) .

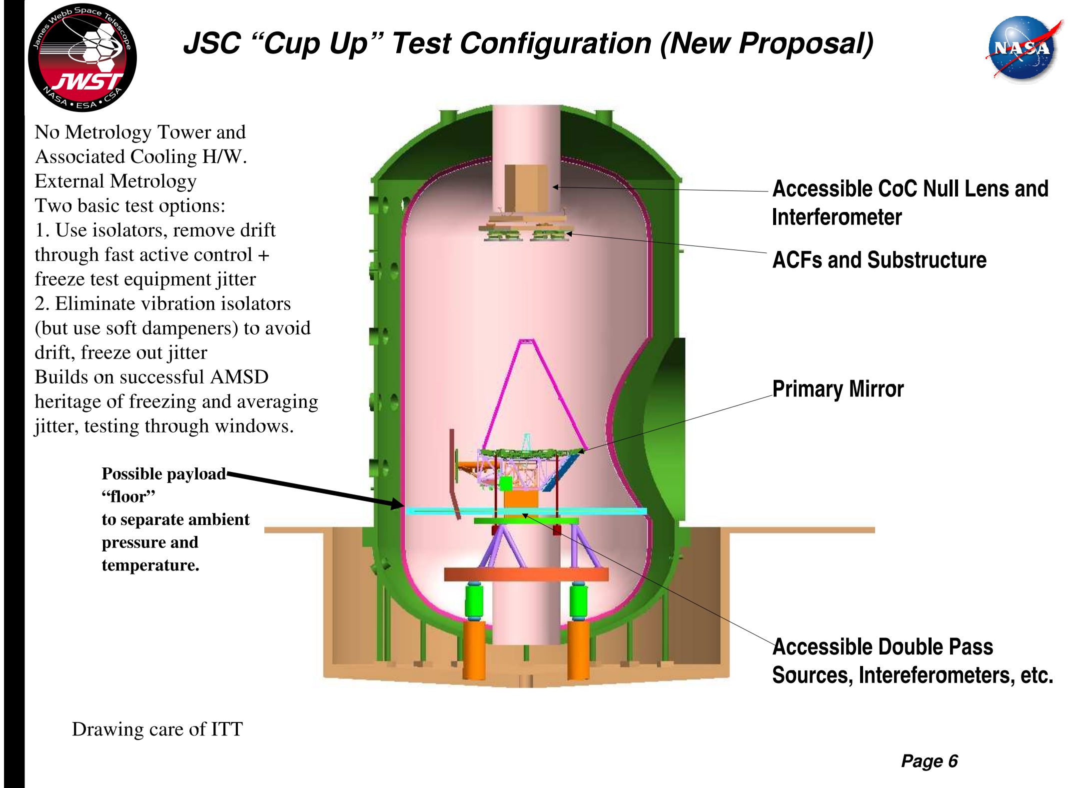
- (4) Gravitational Lensing Bias ($\Delta\rho/\rho$(z), z).

- (5) What else? — See many speakers this Conference.

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 — Reviewing Testing.

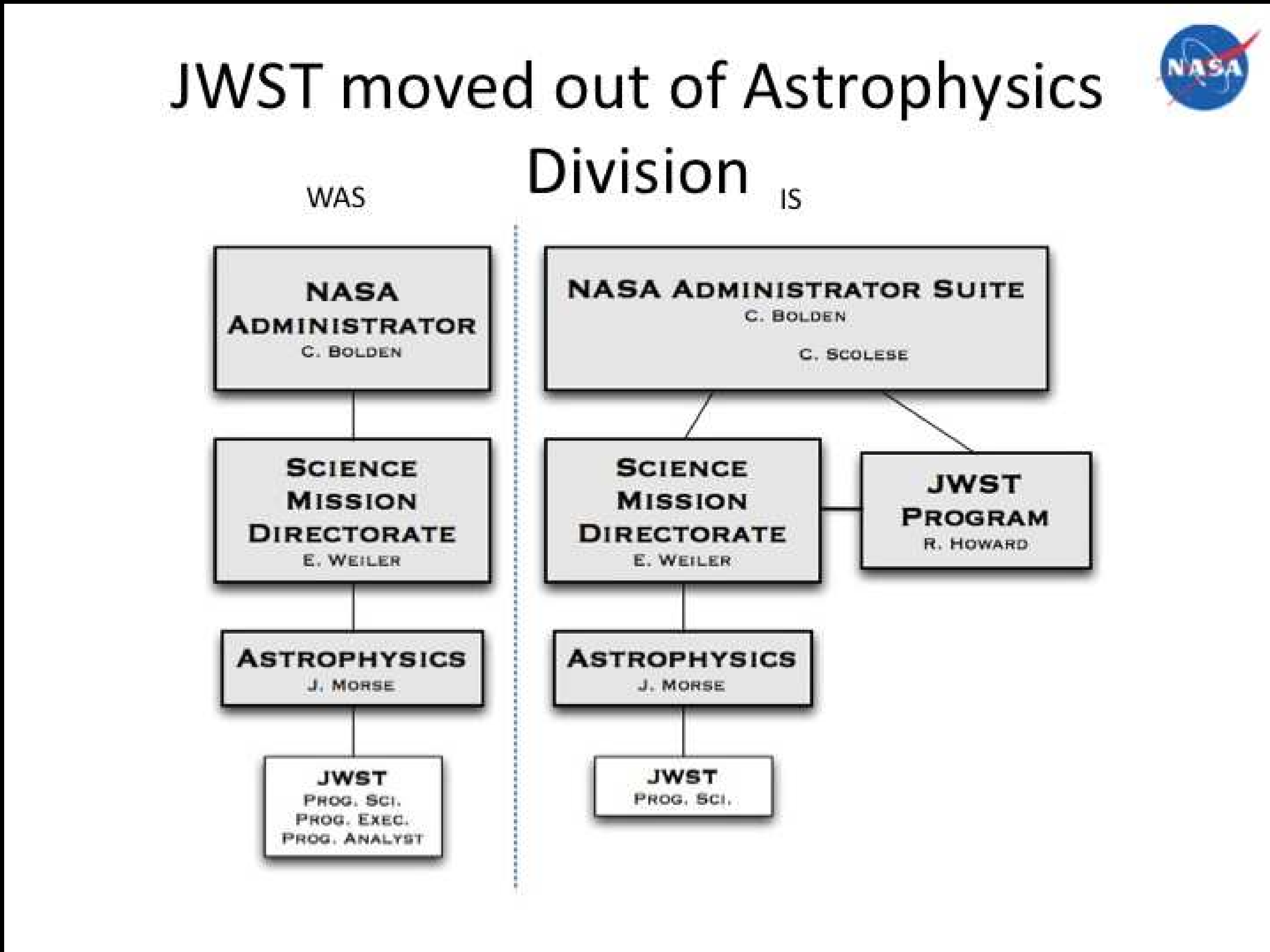
THE JAMES WEBB SPACE TELESCOPE

THE JWST SUNSHIELD

The James Webb Space Telescope

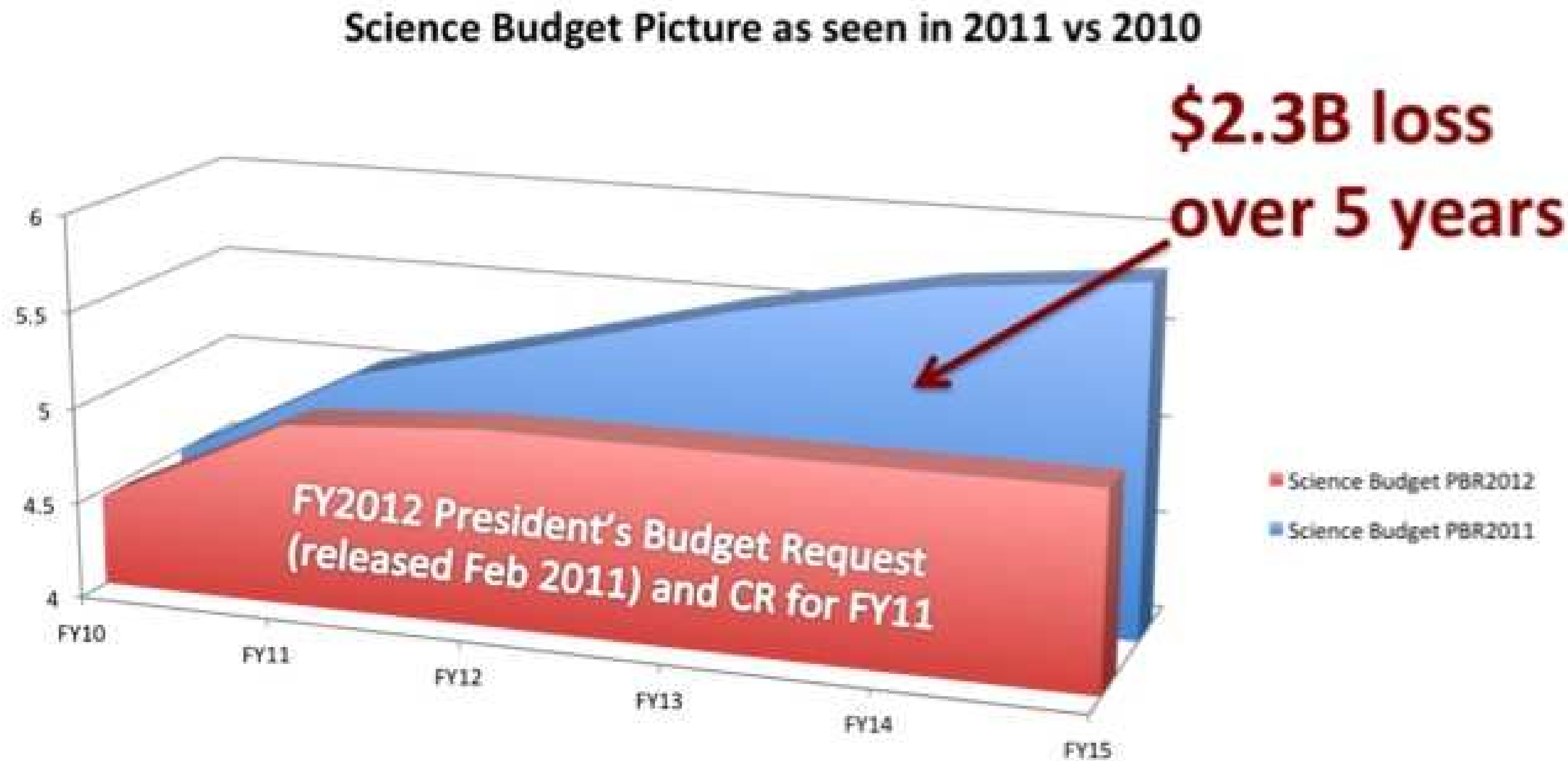
JWST Sunshield

(7) How to launch JWST while minimizing impact on NASA Space Science?



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

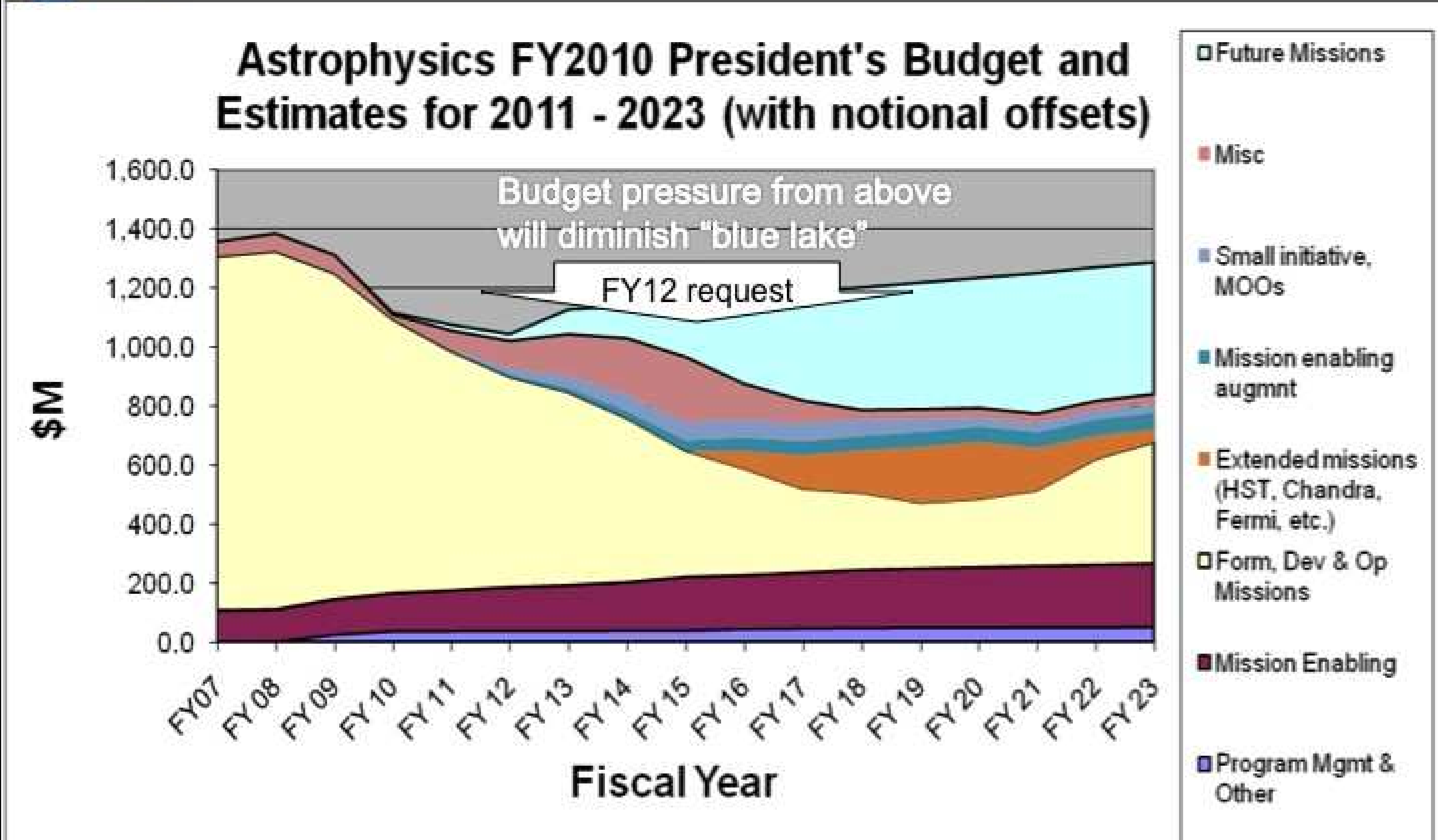
NASA Science shrinks 8% relative to 2011 President's Budget Request



NASA science Budget flat beginning 2012

NASA Space Science has external budget pressures independent of JWST.

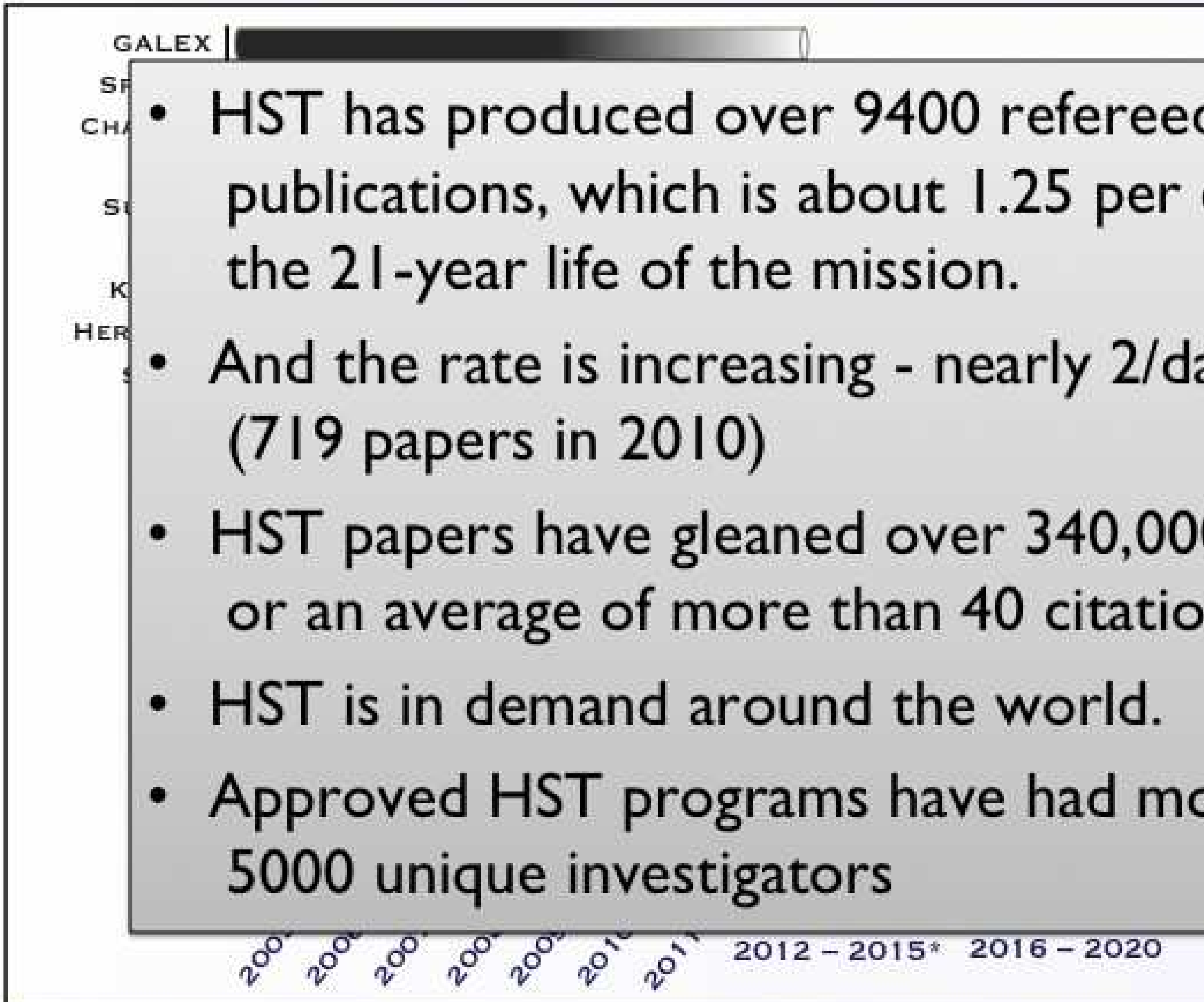
Astrophysics Division



Launching JWST as early as possible helps keep "blue lake" bottom intact.

NASA's Great Observatories Impact

The Impact of GO Funding on US Astronomy

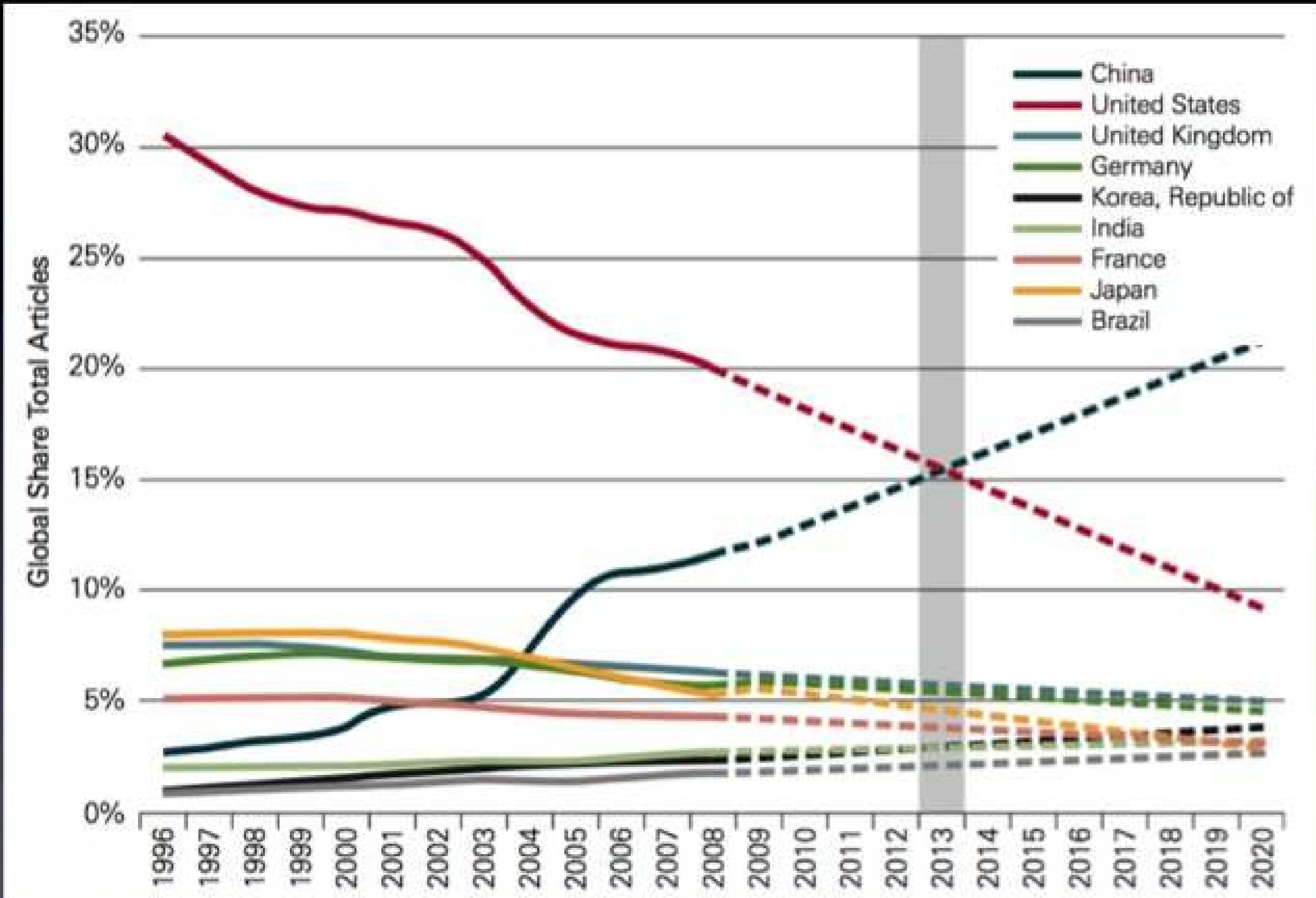


- HST has produced over 9400 refereed publications, which is about 1.25 per day over the 21-year life of the mission.
- And the rate is increasing - nearly 2/day last year. (719 papers in 2010)
- HST papers have gleaned over 340,000 citations, or an average of more than 40 citations per day.
- HST is in demand around the world.
- Approved HST programs have had more than 5000 unique investigators

*Minimum Projection: Assumes flat HST funding at $30M / year

NASA Great Observatories had enormous impacts last two decades: NASA must keep a healthy mix of big, medium and small space missions.

Projected growth in scientific literature



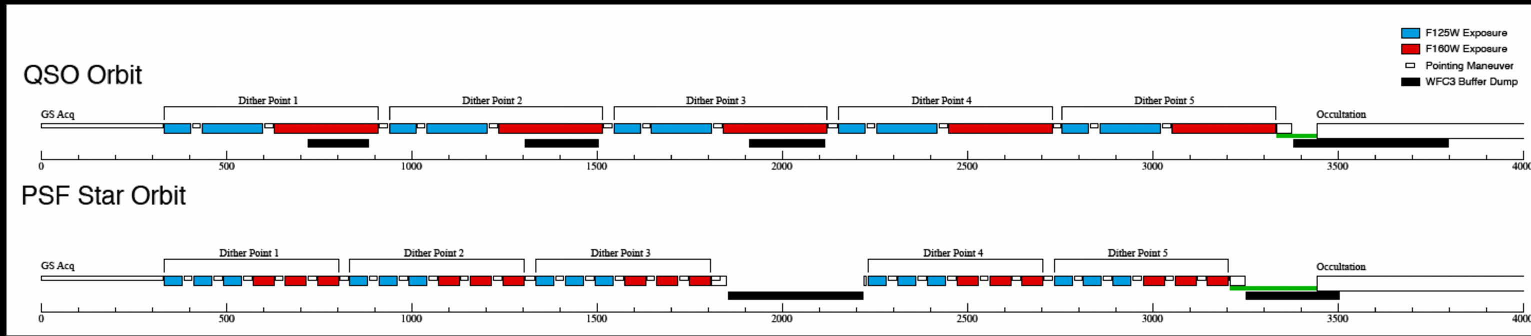
Royal Society

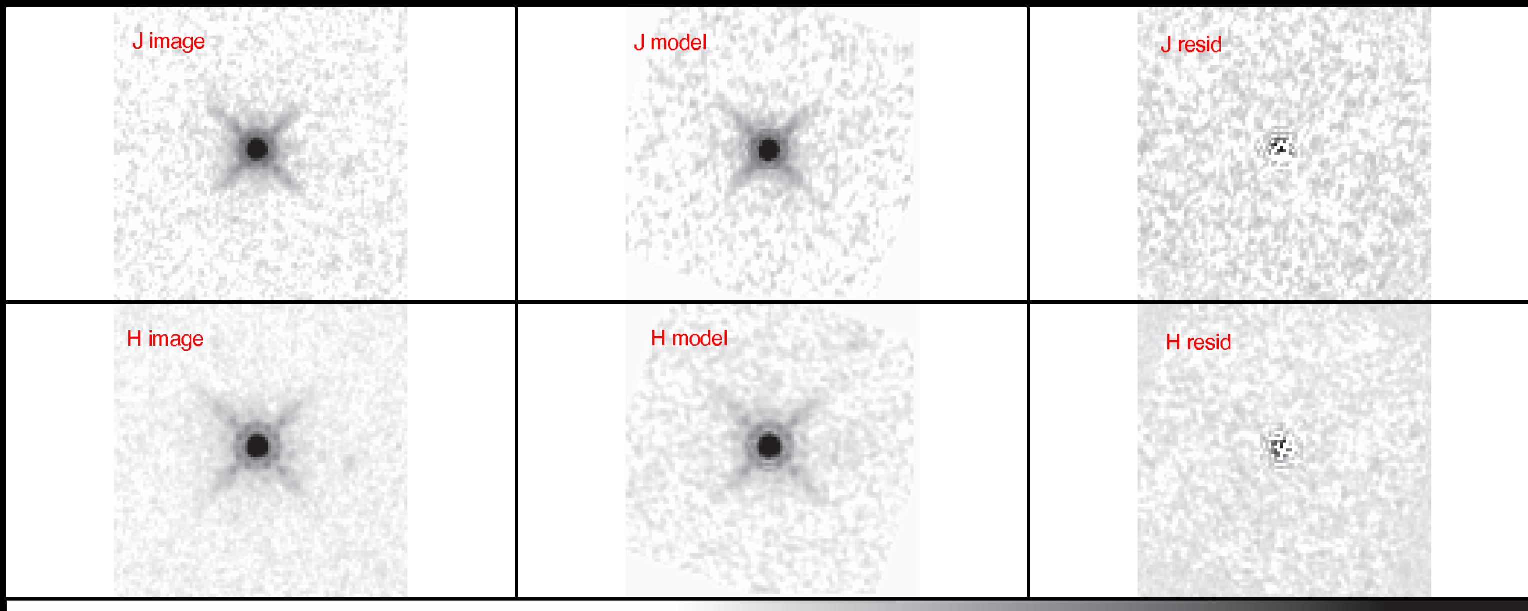
US and NASA must have major future facilities to remain competitive ...

we do not want this to happen to U.S. astrophysics

or risk ending up like SSC (left). Canceled project funds never returns!

HST WFC3 observations of SDSS Quasar Host Galaxies at z$\simeq$6

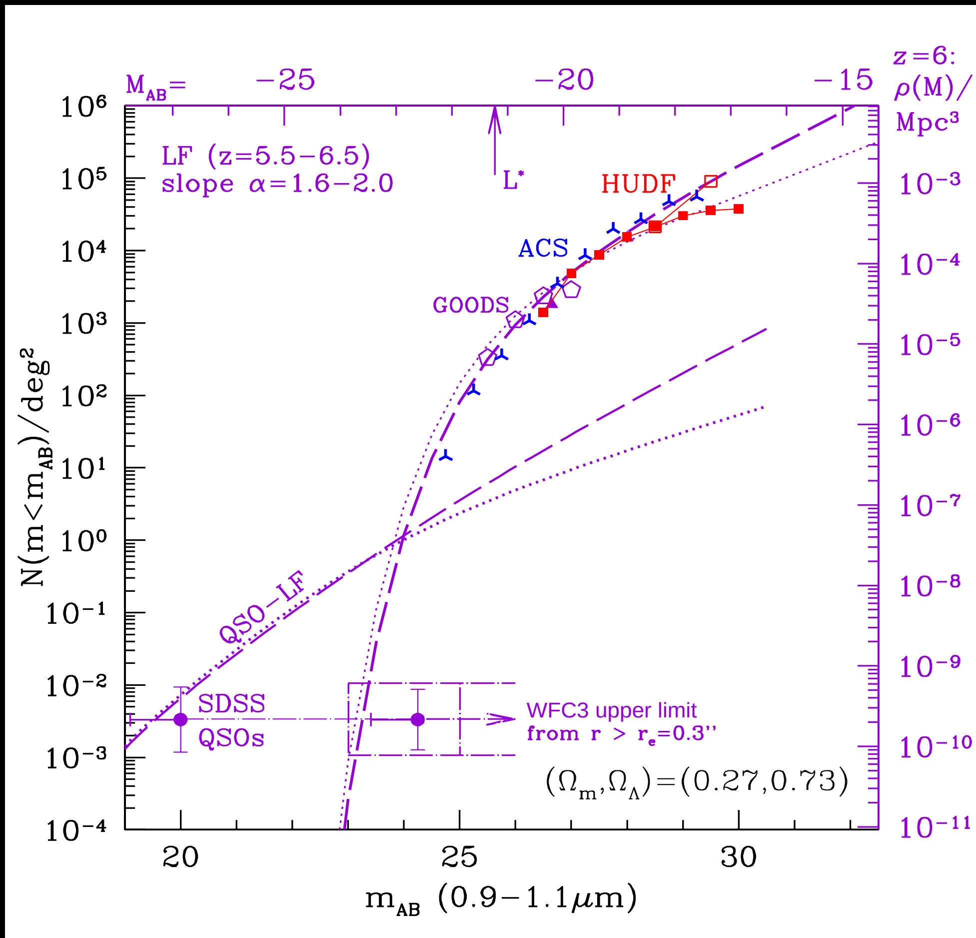


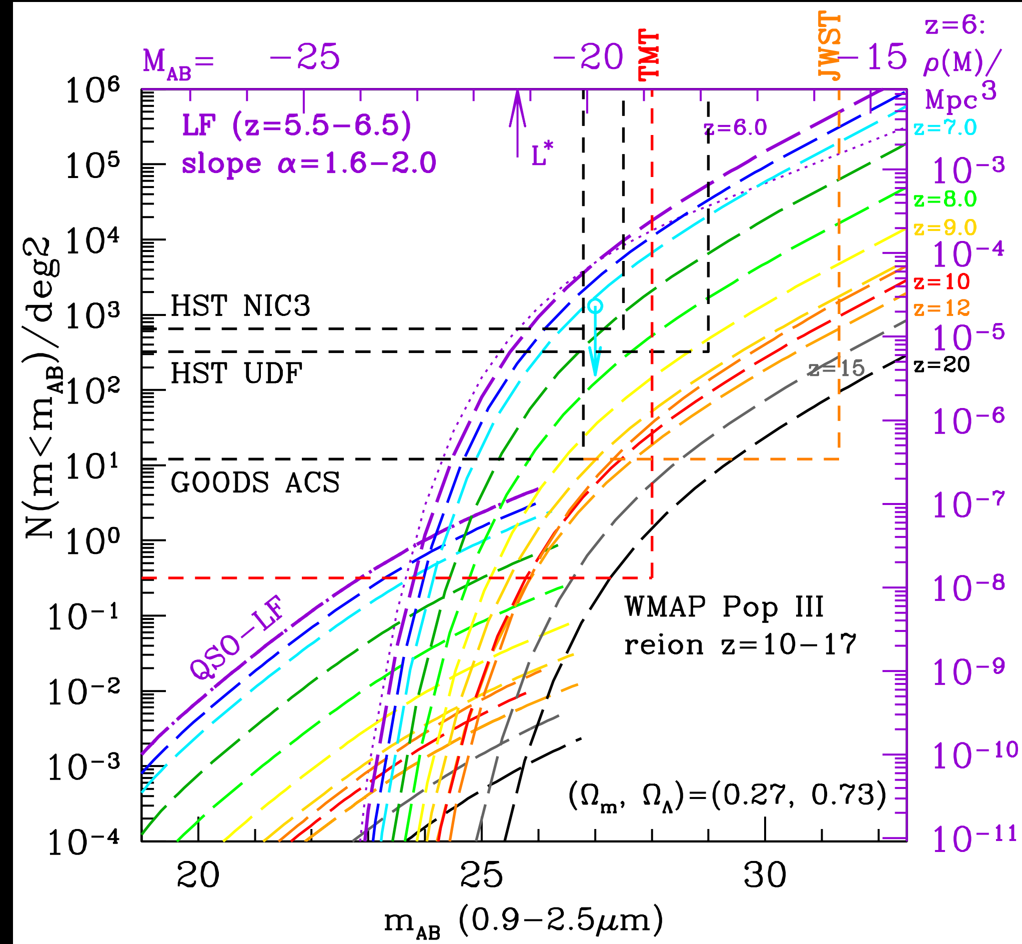


Careful contemporaneous orbital WFC3 PSF-subtraction: removes most of HST "OTA spacecraft breathing" effects (Mechtley et al. 2011).

Using BA=15 mag PSF subtracts 18.5 mag QSO nearly to the noise limit: NO underlying host galaxy detected to AB$\gtrsim$25 mag (r$\gtrsim$0.″3).

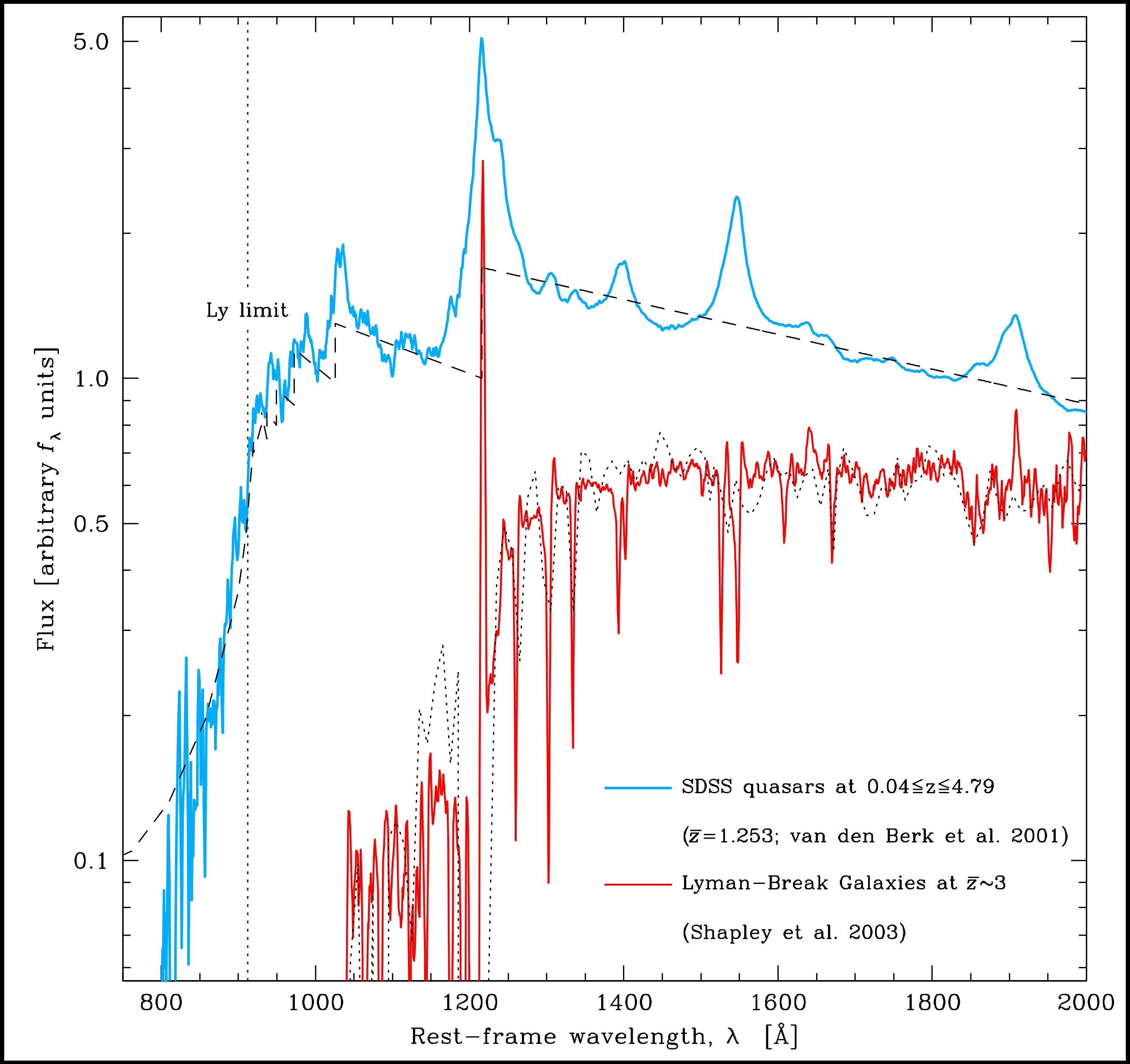
THE most luminous objects in the Universe: Do all host galaxies have M$<<M^*$? $\Longrightarrow$ Major implications for Galaxy Assembly–SMBH Growth!



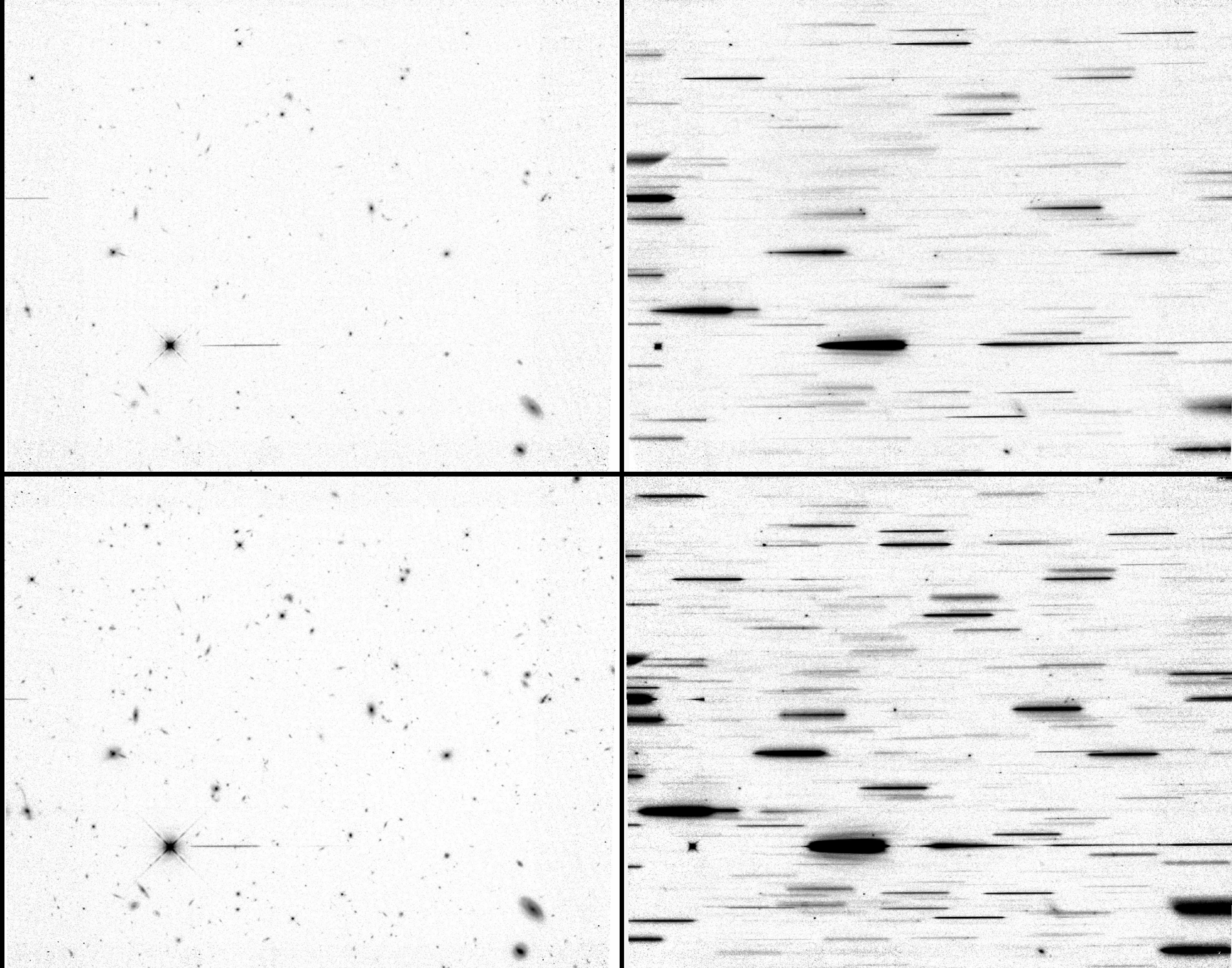


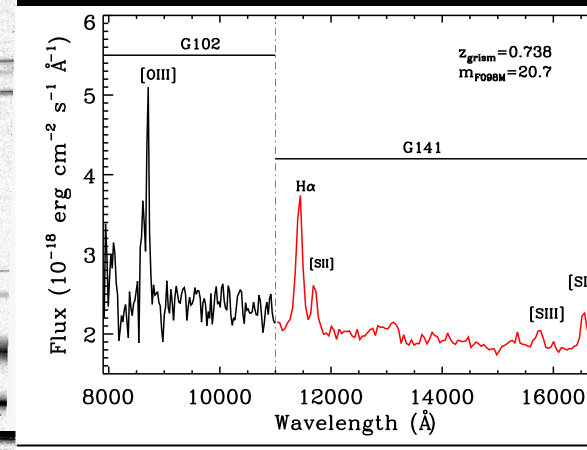
- Objects at z$\gtrsim$9 are rare (Bouwens+ 2010, Yan+ 2010), since volume element is small, and JWST samples brighter part of LF. JWST needs its sensitivity/aperture (A), field-of-view (Ω), and λ-range (0.7-29 μm).
- With proper survey strategy (area AND depth), JWST can trace the entire reionization epoch and detect the first star-forming objects.
- To study co-evolution of SMBH-growth and proto-bulge assembly for z$\lesssim$10–15 requires new AGN finding techniques for JWST.

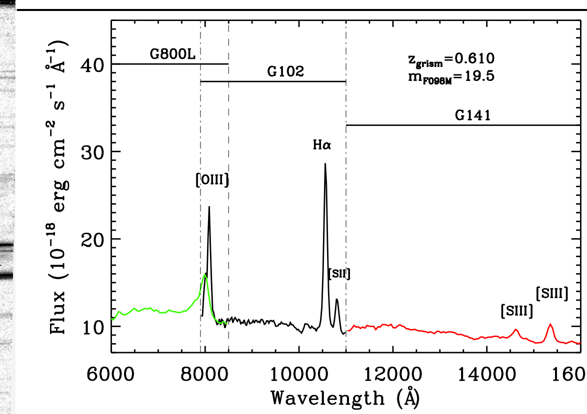
Caveat: Can the Hard-UV of weak AGN outshine Dwarf Galaxies?



• In principle, the hard-UV of QSO's and weak AGN can outdo the young SED's of LBG's or dwarf galaxies, but likely by no more than $\gtrsim$1 dex.





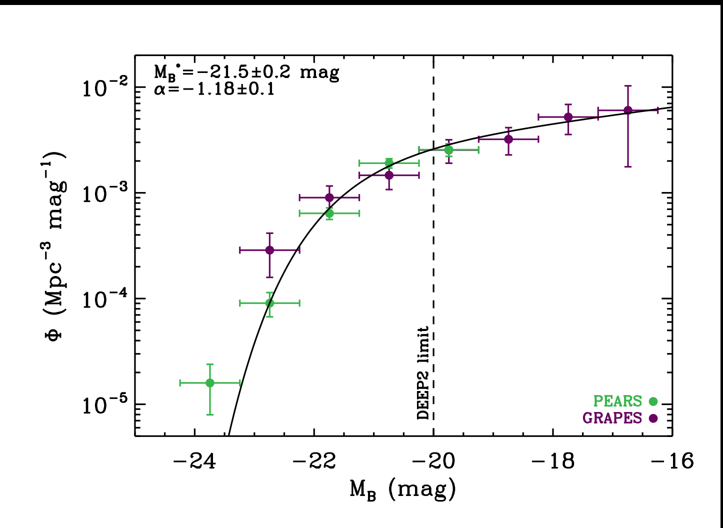


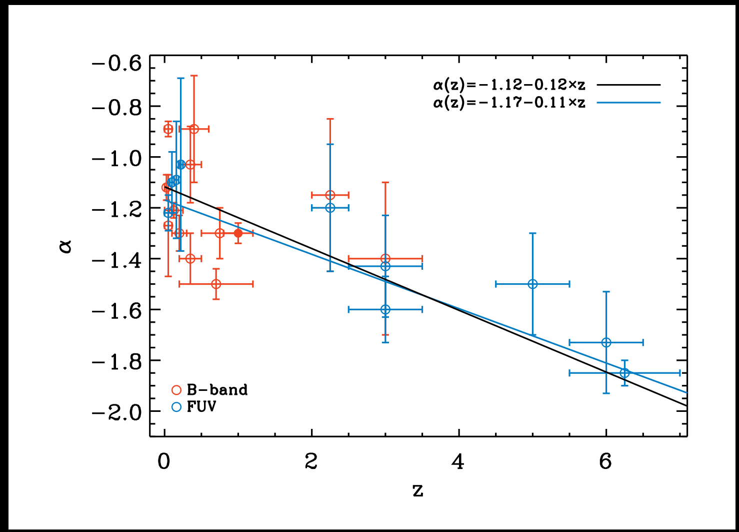
HST/WFC3 G102 & G141 grism spectra in GOODS-S ERS (Straughn+ 2010)

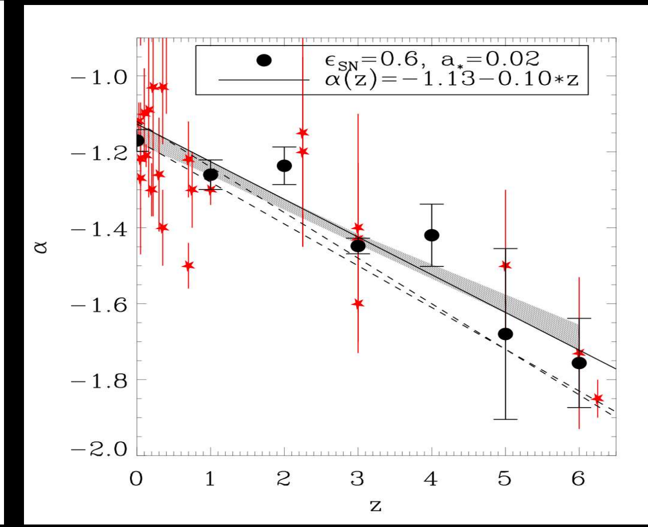
IR grism spectra from space: unprecedented new opportunities in astrophysics.

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

Faint-end LF-Slope Evolution (fundamental, like local IMF)







Faint-end LF-slope at z$\gtrsim$1 with accurate ACS grism z's to AB$\lesssim$27 (Cohen et al.; Ryan et al. 2007, ApJ, 668, 839) constrains hierarchical formation:

- Star-formation and SN feedback produce different faint-end slope-evolution: new physical constraints (Khochfar ea. 2007, ApJL, 668, L115).
- JWST will provide fainter spectra (AB$\lesssim$29) and spectro-photometric redshifts to much higher z ($\lesssim$20). JWST will trace α-evolution for z$\lesssim$12.
- Can measure environmental impact on faint-end LF-slope α directly.
- Expect convergence to slope $|\alpha|\equiv$2 at z>6 before feedback starts?
- Constrain onset of Pop III SNe epoch, Type II & Type Ia SN-epochs.

• (4) How can JWST measure Galaxy Assembly?

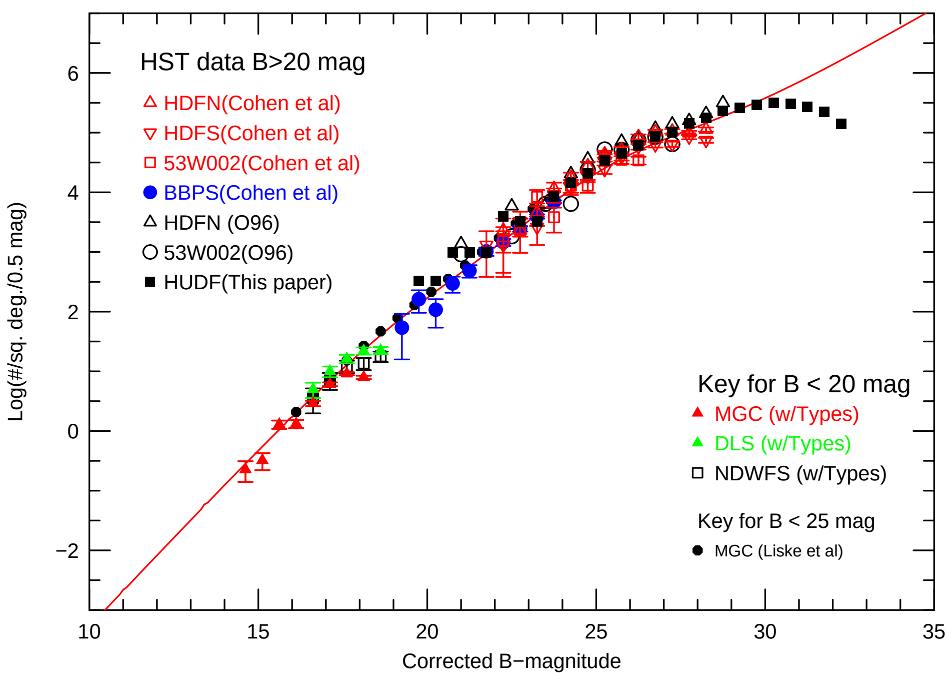
HST helped show how galaxies formed and evolved in the last 12–13 Gyrs:

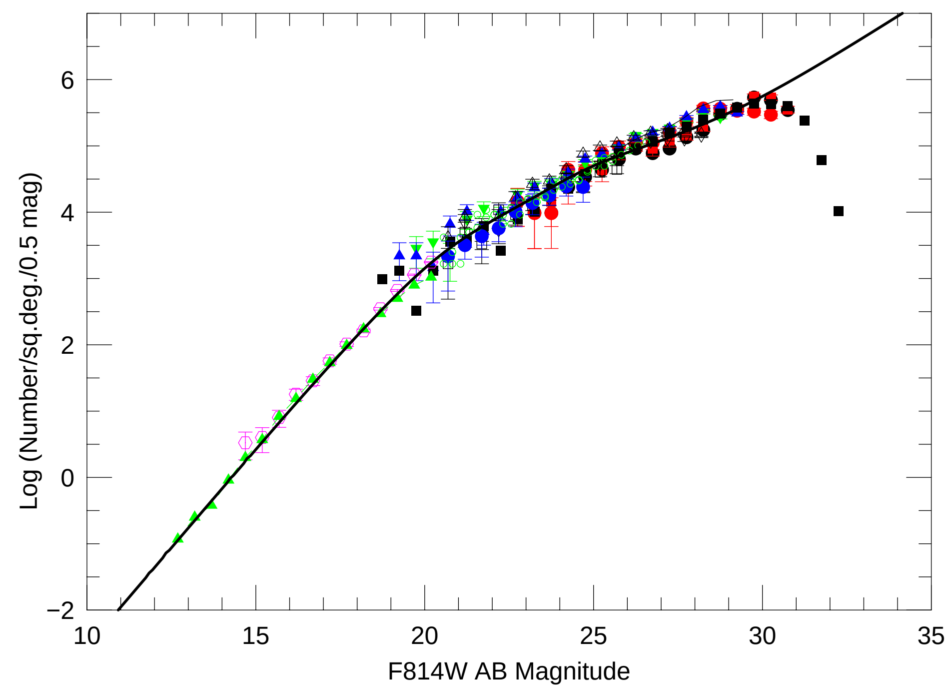
- Galaxies of all types formed over a wide range of time, but with a notable transition around z$\sim$1–1.5, when Hubble sequence appears:
- Subgalactic units rapidly merge from z$\simeq$7$\longrightarrow$1 to grow bigger units.
- Merger products settle as galaxies with large bulges or disks at z$\lesssim$1. These evolved mostly passively since then, resulting in the giant galaxies that we see today.

JWST is designed to observe the following re. Galaxy Assembly:

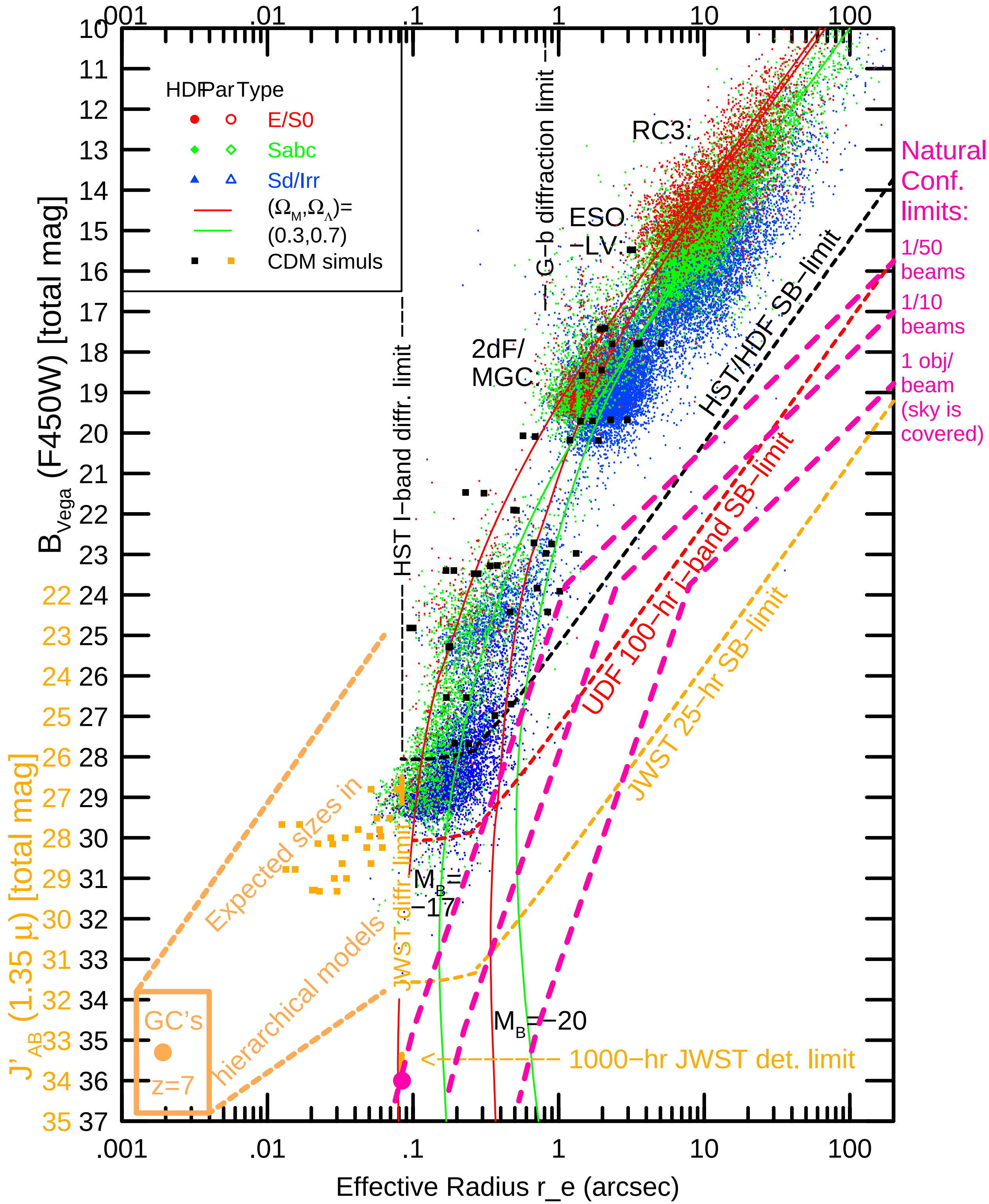
- Formation and evolution of Pop III star-clusters in the first 0.5 Gyr.
- Faint-end LF-slope evolution: (how) did dwarf galaxies finish reionization after 0.5–1 Gyr? Was there a transition to Pop-III objects?
- Measure how galaxies of all types formed over a wide range of cosmic time, by accurately measuring their SF, mass, Fe/H, and dust distributions, rest-frame structure and type, etc., as function of redshift for z$\lesssim$15.

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/deg^2 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.



HDF Par Type
E/S0
Sabc
Sd/Irr
(Ω_M,Ω_Λ)=
(0.3,0.7)
CDM simuls
RC3:
ESO
–LV:
2dF/
MGC:
G–b diffraction limit
HST I–band diffr. limit
HST/HDF SB–limit
UDF 100–hr I–band SB–limit
JWST 25–hr SB–limit
JWST diffr. limit
Expected sizes in
hierarchical models
GC's
z=7
M_B=
–17
M_B=–20
1000–hr JWST det. limit
Natural
Conf.
limits:
1/50
beams
1/10
beams
1 obj/
beam
(sky is
covered)
B_Vega (F450W) [total mag]
J'_AB (1.35 μ) [total mag]
Effective Radius r_e (arcsec)
.001
.01
.1
1
10
100

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 causes 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$10 nJy, SKA will see more than 2×10^6 galaxies/deg^2. Most of these will be unresolved ($r_{hl} \lesssim 0\farcs1$ 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"

- References and other sources of material shown:

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

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

http://wwwgrapes.dyndns.org/udf_map/index.html [Clickable HUDF map]

http://www.jwst.nasa.gov/ and 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/guider/

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, p. 1965 (astro-ph/0703171) "High Resolution Science with High Redshift Galaxies"