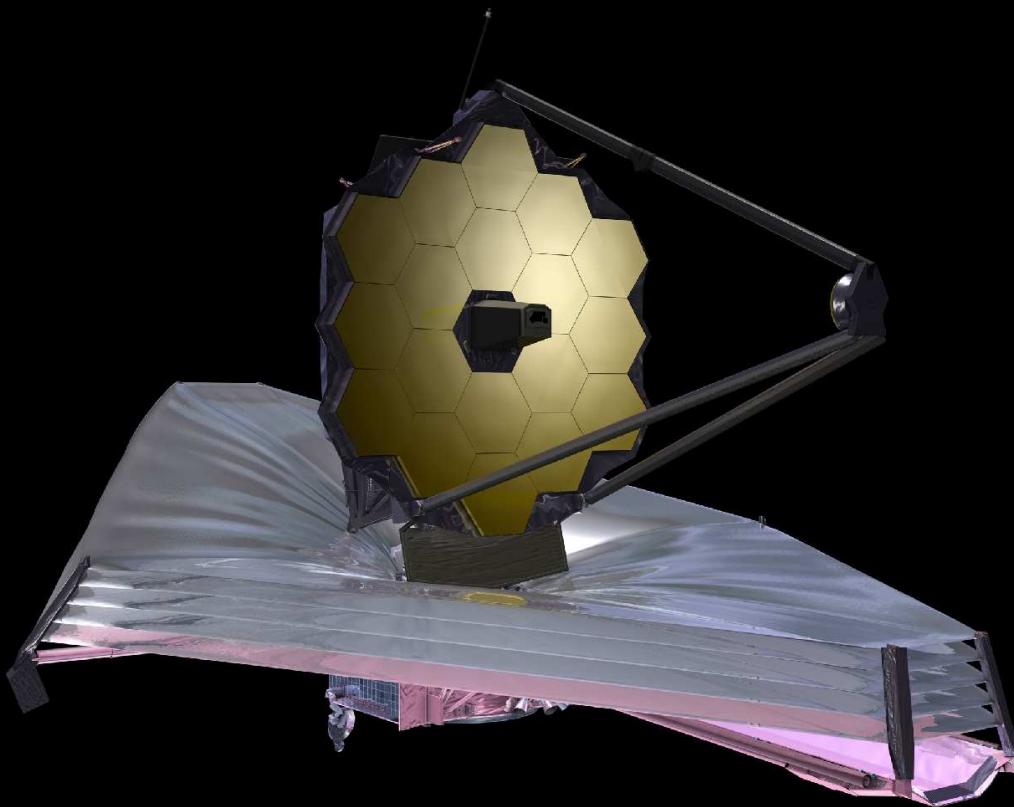


# How will the Webb Space Telescope measure First Light Reionization, & Galaxy Assembly in the post WFC3 era?

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Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

*Collaborators: S. Cohen, R. Jansen (ASU), C. Conselice, S. Driver (UK), & H. Yan (OSU) & (Ex) ASU Grads: N. Hathi, H. Kim, M. Mechtley, R. Ryan, M. Rutkowski, A. Straughn, & K. Tamura*



*Colloquium at the Universidad Complutense de Madrid; Madrid, Thursday November 10, 2011*

*All presented materials are ITAR-cleared.*

# Outline

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

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

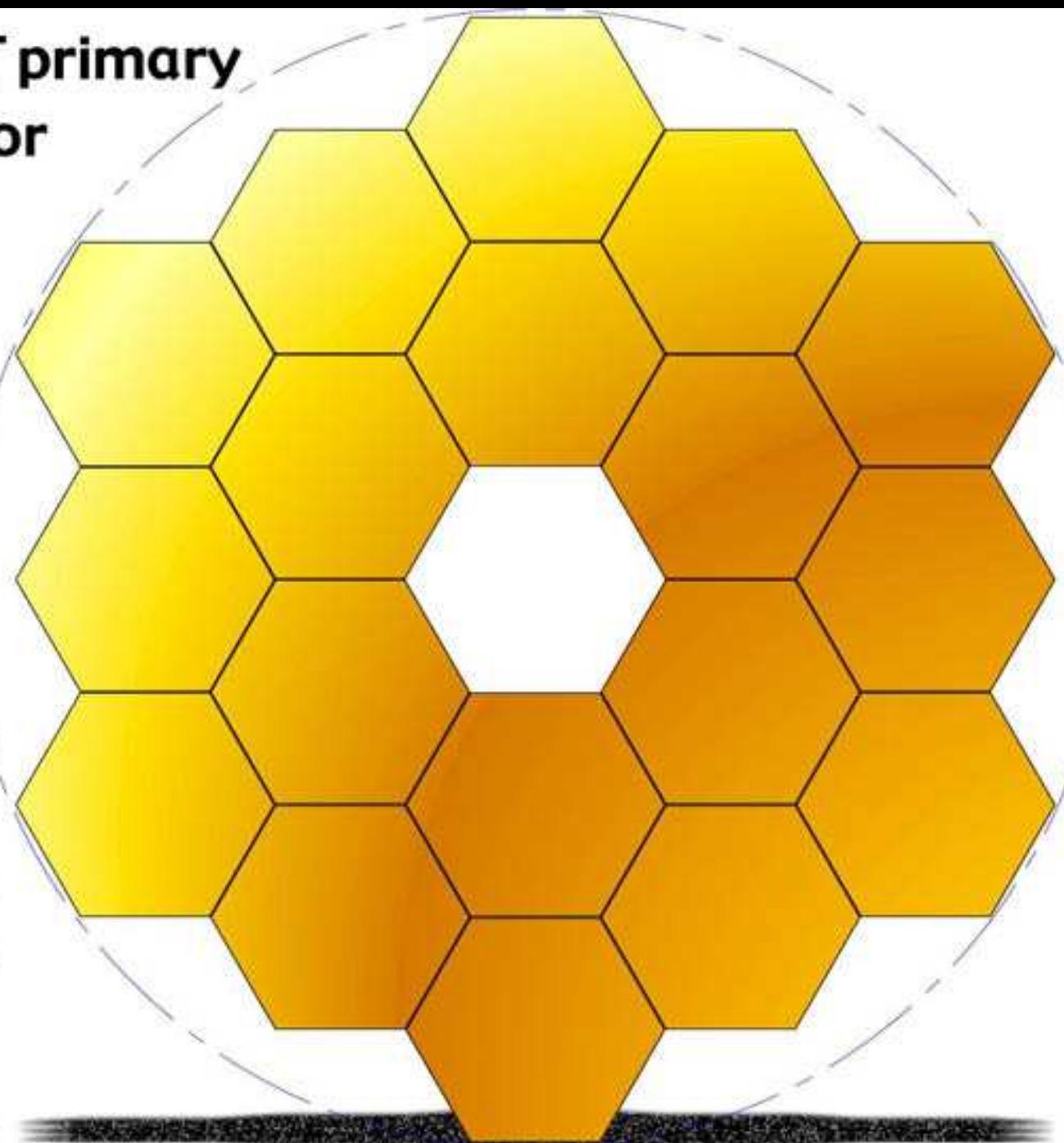
- (1) What is JWST and how will it be deployed?
- (2) What instruments and sensitivity will JWST have?
- (3) How can JWST measure First Light & Reionization?
- (4) How can JWST measure Galaxy Assembly?

[Recent Hubble WFC3 results on (3) & (4): see many talks this Conf.]

- (5) Predicted Galaxy Appearance for JWST at redshifts  $z \simeq 1-15$ .
- (6) Summary and Conclusions.
- Appendix 1: Will JWST reach the Natural Confusion Limit?

Sponsored by NASA/JWST & HST

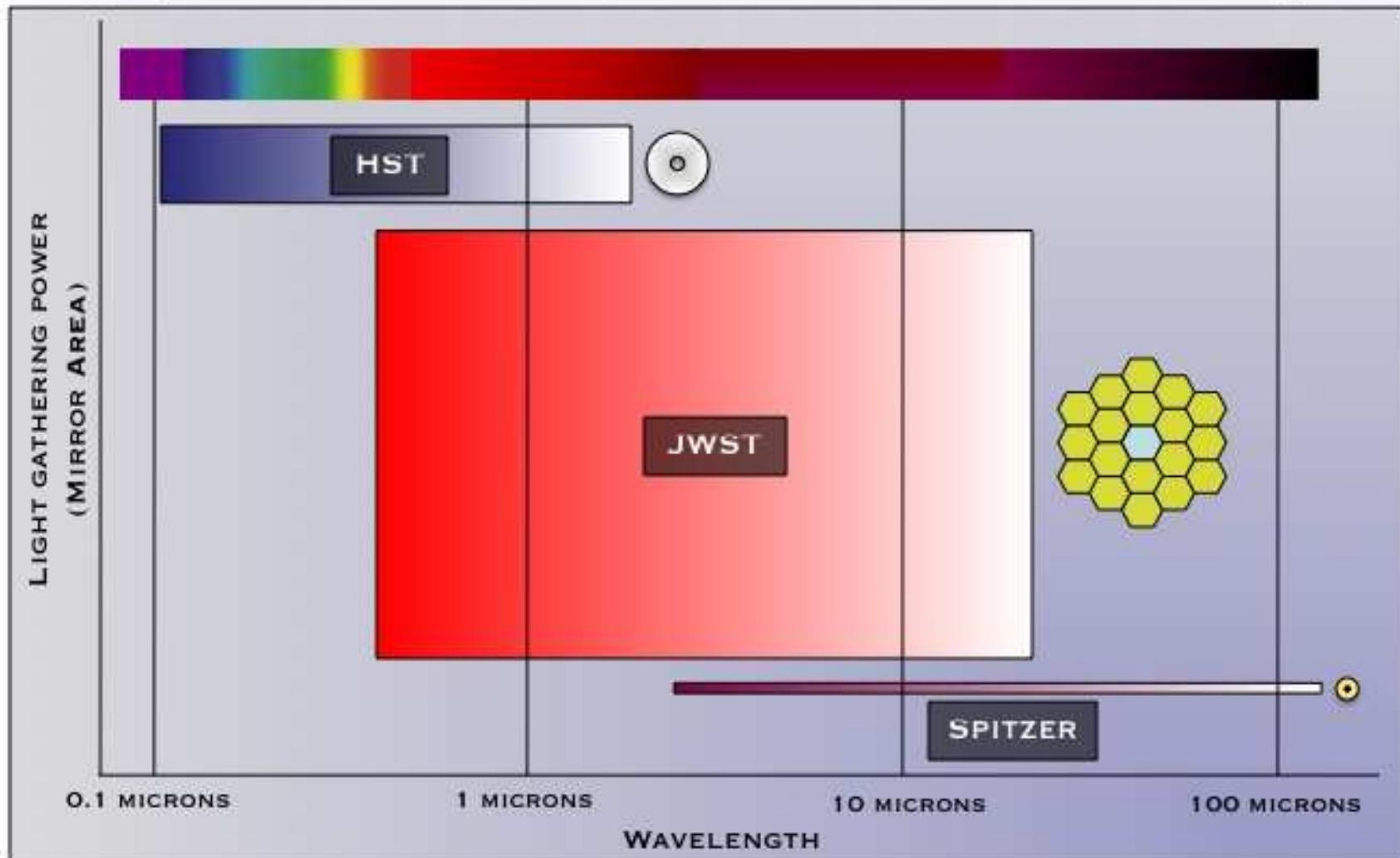
**JWST primary  
mirror**



**Hubble primary  
mirror**

JWST  $\sim 2.5 \times$  larger than Hubble, so at  $\sim 2.5 \times$  larger wavelengths:  
JWST has the same resolution in the near-IR as HST in the optical.

# THE JAMES WEBB SPACE TELESCOPE



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.

"Brilliantly done...breathtaking in its vision."

*The New York Times*

# JAMES WEBB

Author of *The Emperor's General*



A NOVEL

# SOMETHING TO DIE FOR



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 ( $25 \text{ m}^2$ ) segmented IR telescope for imaging and spectroscopy from 0.7 to  $29 \mu\text{m}$ , to be launched in June  $\gtrsim 2017$ .
- Nested array of sun-shields to keep its ambient temperature at 35-45 K, allowing faint imaging ( $\text{AB} \lesssim 31.5$ ) and spectroscopy ( $\text{AB} \lesssim 29$  mag).

# THE JAMES WEBB SPACE TELESCOPE

## JWST LAUNCH

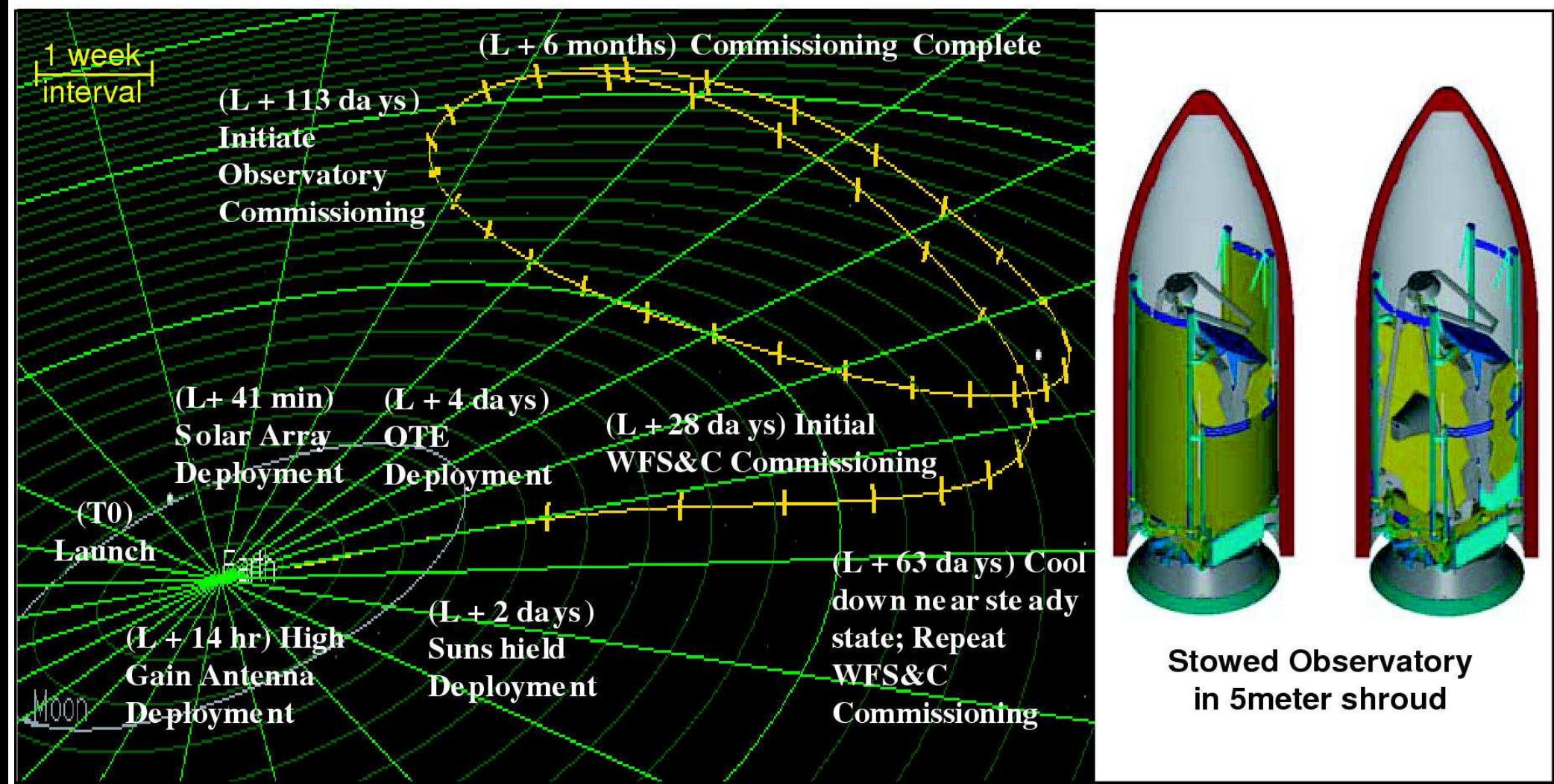
- LAUNCH VEHICLE IS AN ARIANE 5 ROCKET, SUPPLIED BY ESA
- SITE WILL BE THE ARIANESPACE'S ELA-3 LAUNCH COMPLEX NEAR KOUROU, FRENCH GUIANA



ARIANESPACE - ESA - NASA

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

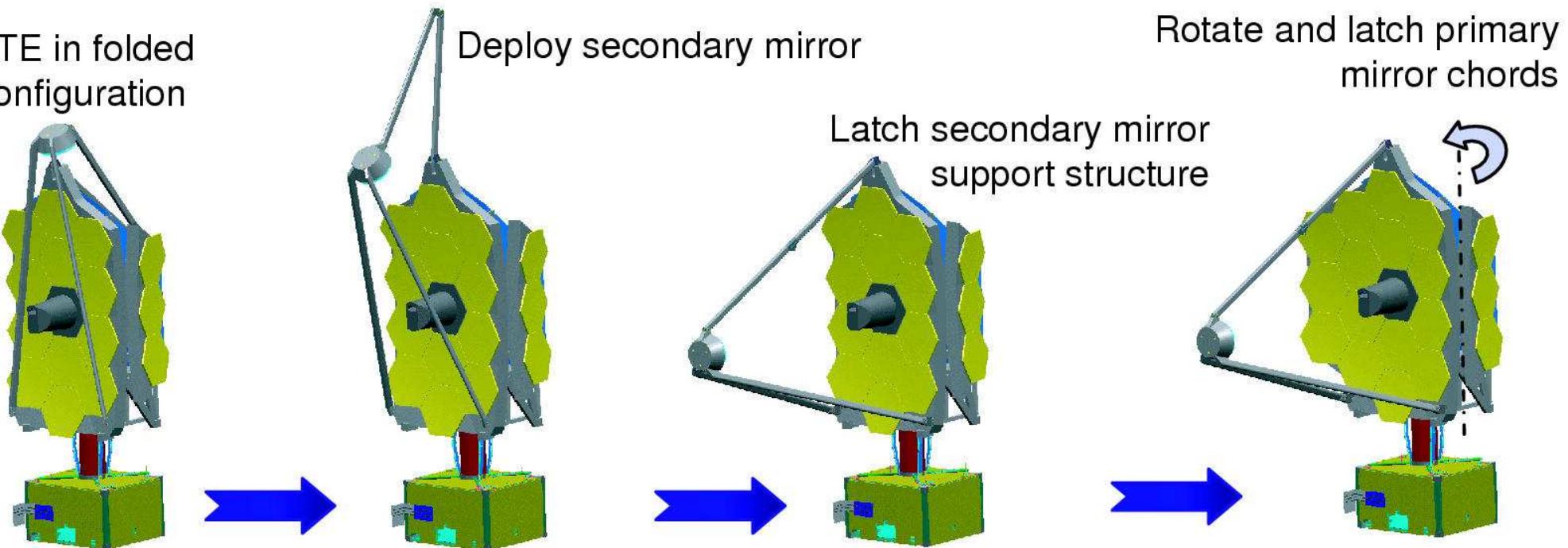
- (1) How will JWST travel to its L2 orbit?



- After launch in June 2017 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?

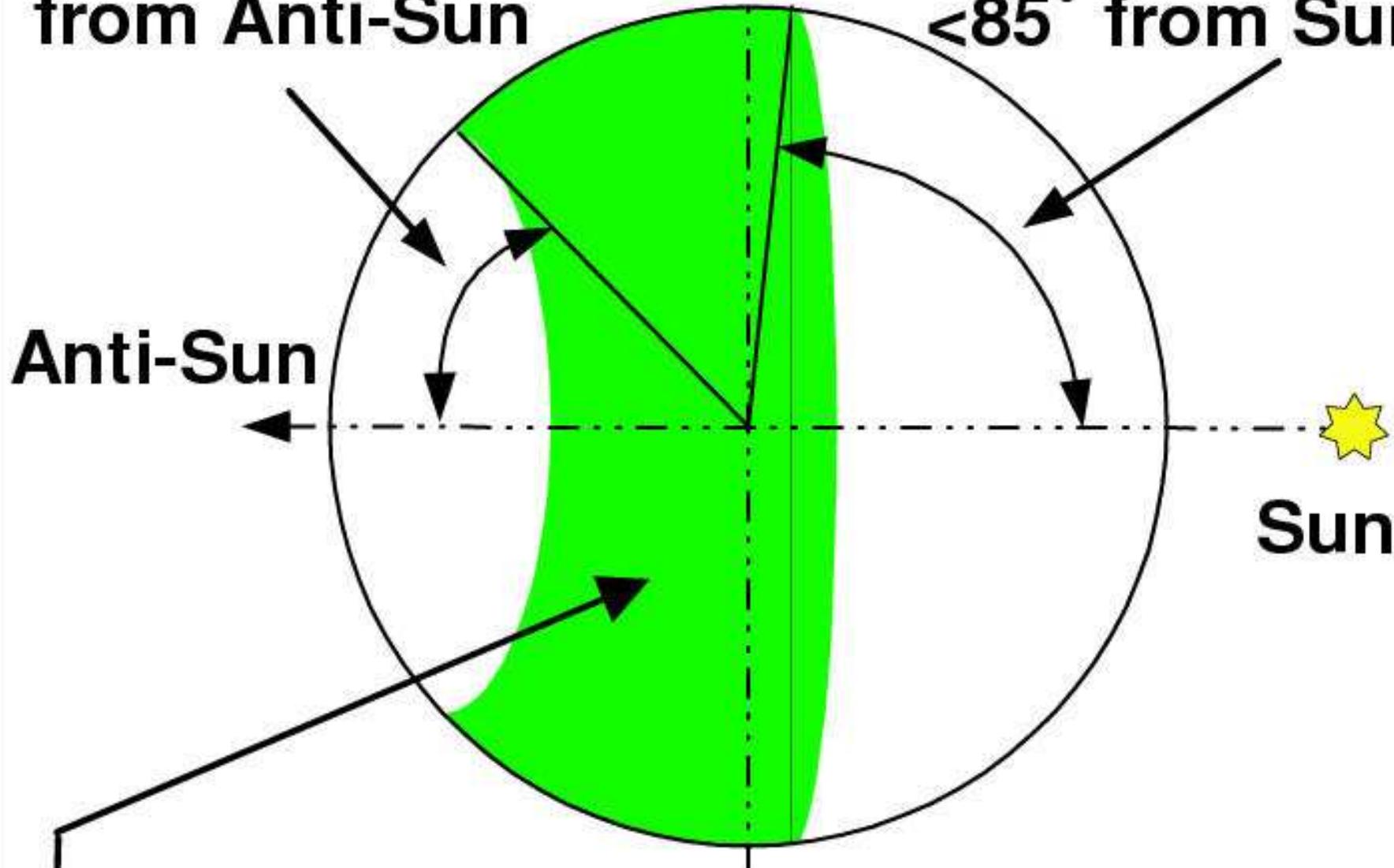
OTE in folded configuration



- 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: 18 out of 18 flight mirrors completely done, and at the 45K 2.0 $\mu$ m diffraction limit!

**Exclusion zone <45° from Anti-Sun**

**Exclusion zone <85° from Sun**



**Allowable Observatory Field-of-Regard**

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

V3 (anti-spacecraft)

V1  
V2

Secondary mirror

Cassegrain focus

Fine Steering Mirror

f/#: 20.0

Effective Focal Length: 131.4 m

PM diameter = 6.6 m (circumscribed circle)

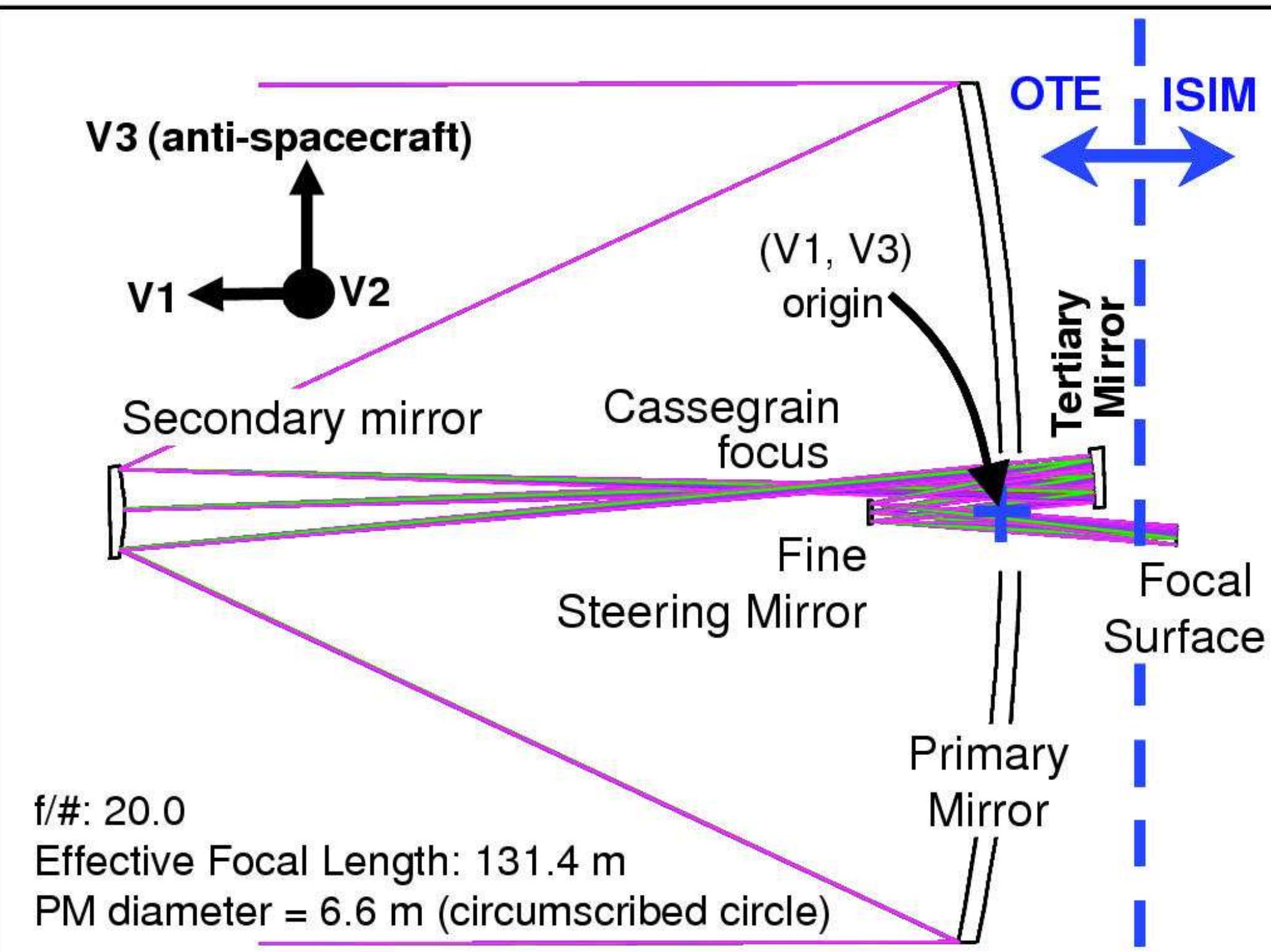
(V1, V3)  
origin

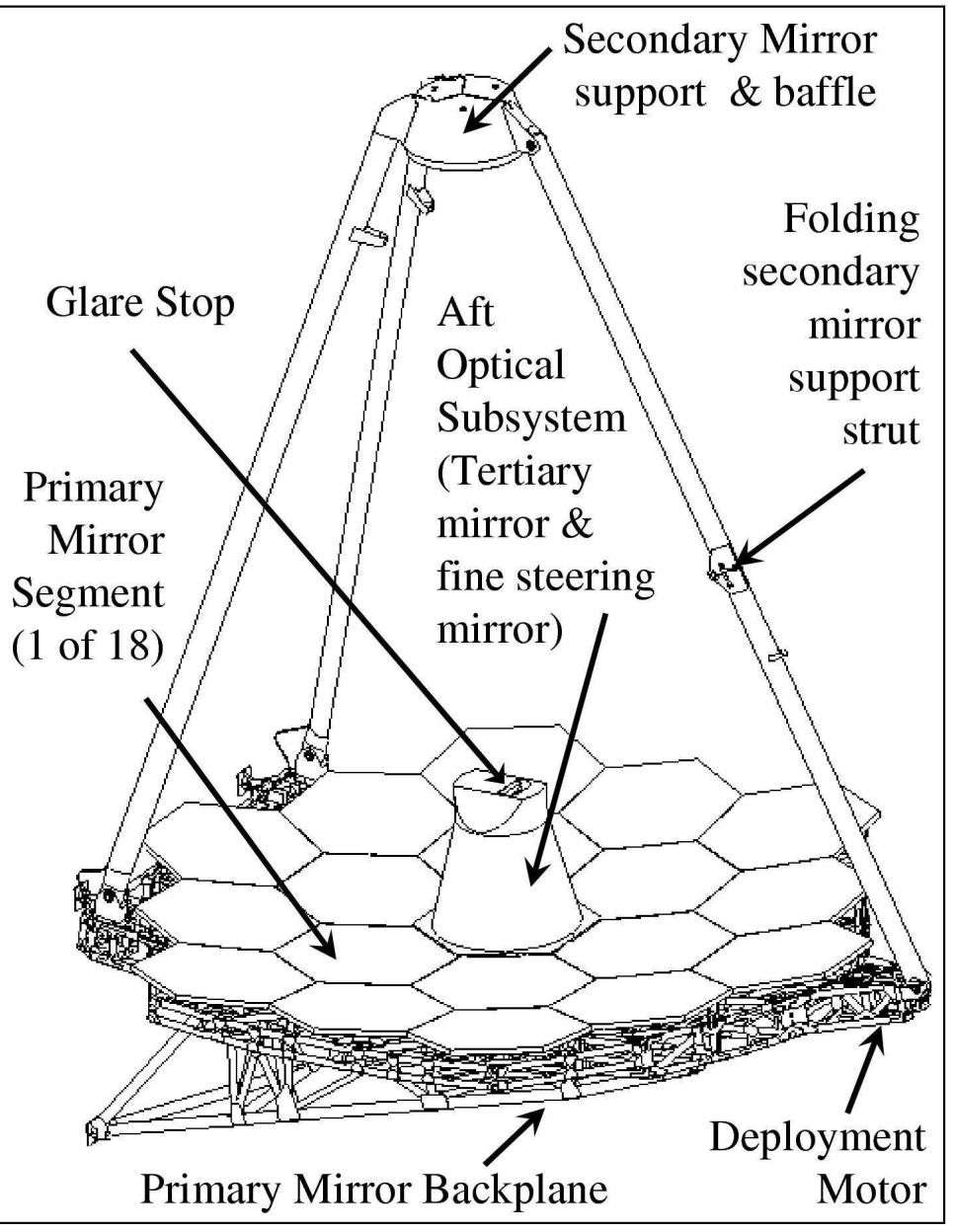
OTE  
ISIM

Tertiary  
Mirror

Focal  
Surface

Primary  
Mirror



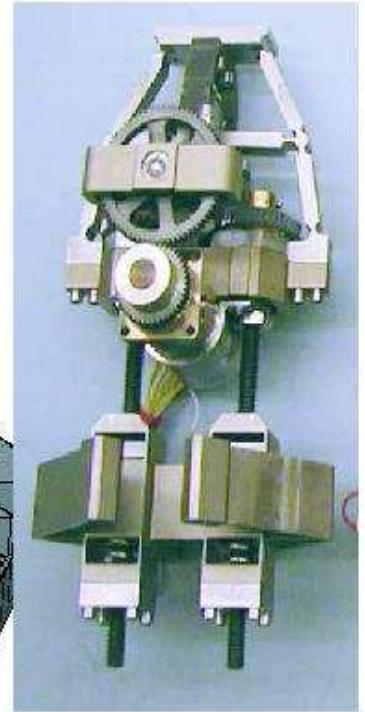
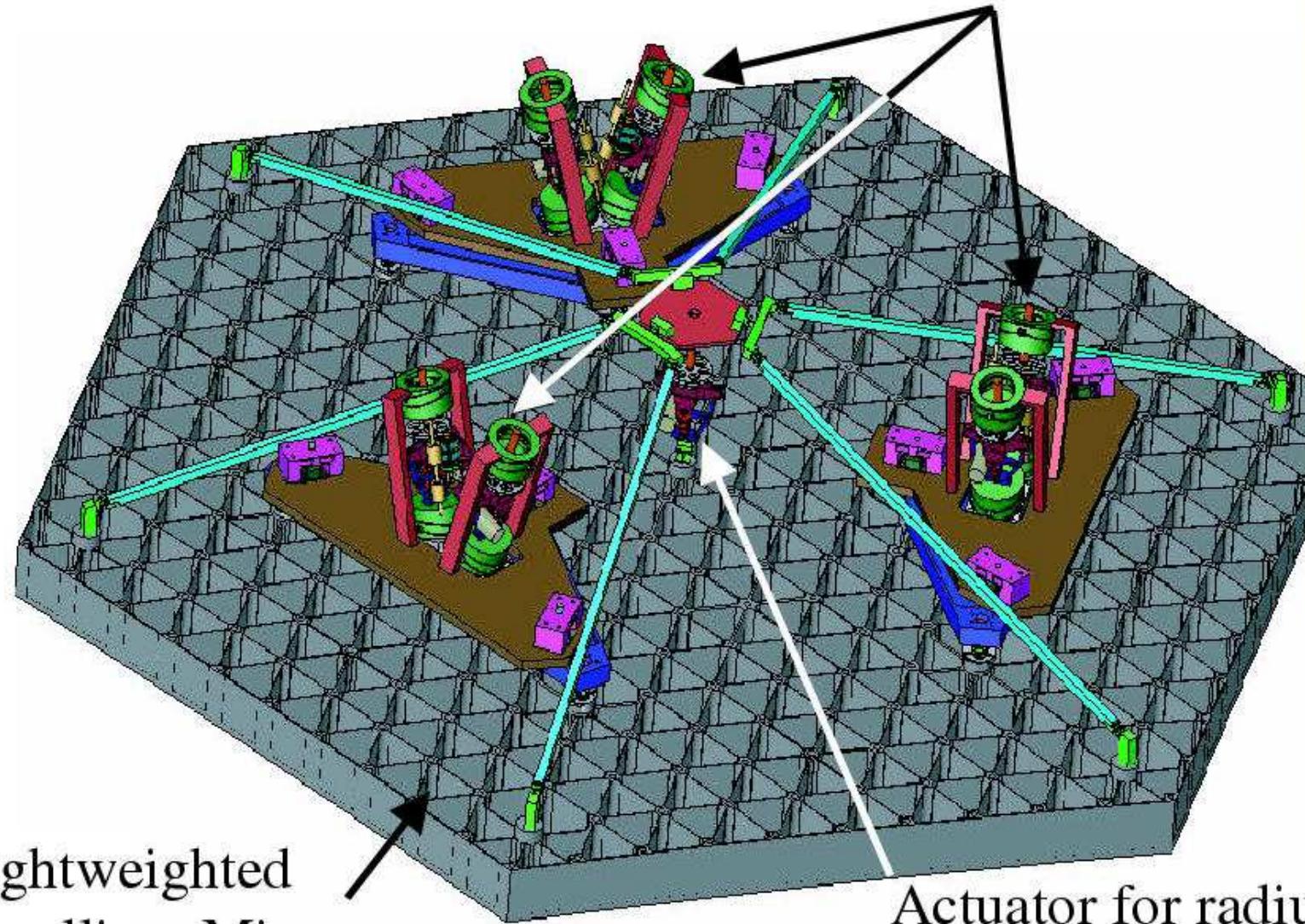


Ball 1/6-model for WFS: diffraction-limited  $2.0 \mu\text{m}$  images (Strehl  $\gtrsim 0.85$ ).

Wave-Front Sensing tested hands-off at 45 K in 1-G at JSC in 2012–2015.

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

## Actuators for 6 degrees of freedom rigid body motion



Actuator  
development  
unit

Lightweighted  
Beryllium Mirror

Actuator for radius  
of curvature adjustment

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

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

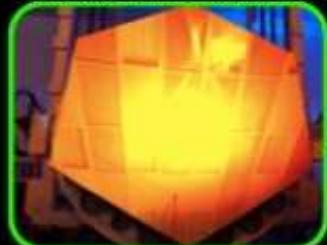
First light NIRCam	After Step 1	Initial Capture	Final Condition
1. Segment Image Capture		18 individual 1.6-m diameter aberrated sub-telescope images  PM segments: < 1 mm, < 2 arcmin tilt  SM: < 3 mm, < 5 arcmin tilt	PM segments: < 100 μm, < 2 arcsec tilt  SM: < 3 mm, < 5 arcmin tilt
<b>2. Coarse Alignment</b> Secondary mirror aligned Primary RoC adjusted		Primary Mirror segments: < 1 mm, < 10 arcsec tilt  Secondary Mirror : < 3 mm, < 5 arcmin tilt	WFE < 200 μm (rms)
<b>3. Coarse Phasing - Fine Guiding (PMSA piston)</b>		WFE: < 250 μm rms	WFE < 1 μm (rms)
<b>4. Fine Phasing</b>		WFE: < 5 μm (rms)	WFE < 110 nm (rms)
<b>5. Image-Based Wavefront Monitoring</b>		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 ( $2 \mu\text{m}$ -Strehl  $\gtrsim 0.85$ ). Need WFS-updates every  $\sim 10$  days, depending on scheduling/SC-illumination.

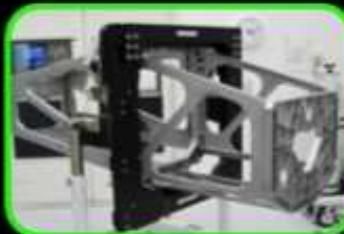


# JWST Hardware Status

Primary Mirror Segment



Aft Optics System



PM Flight Backplane



Tertiary Mirror

Secondary Mirror Pathfinder Strut



Fine Steering Mirror



ISIM Flight Bench



Secondary Mirror Hexapod



Secondary Mirror



Membrane Mgmt



Pathfinder Membrane

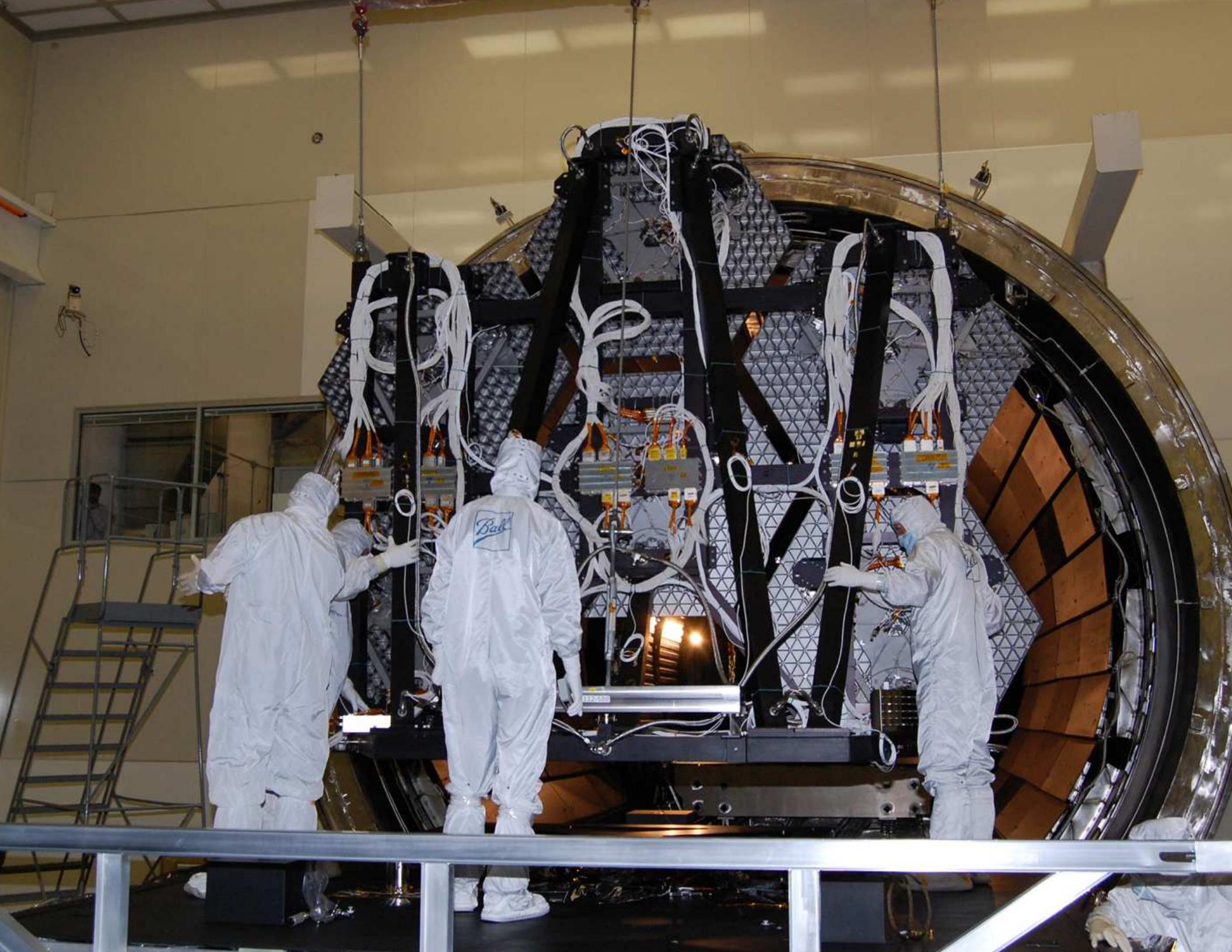


Mid-boom Test

Spacecraft computer Test Unit

# Mirror Acceptance Testing



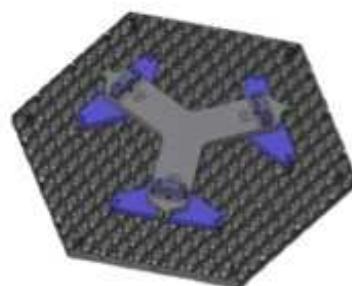




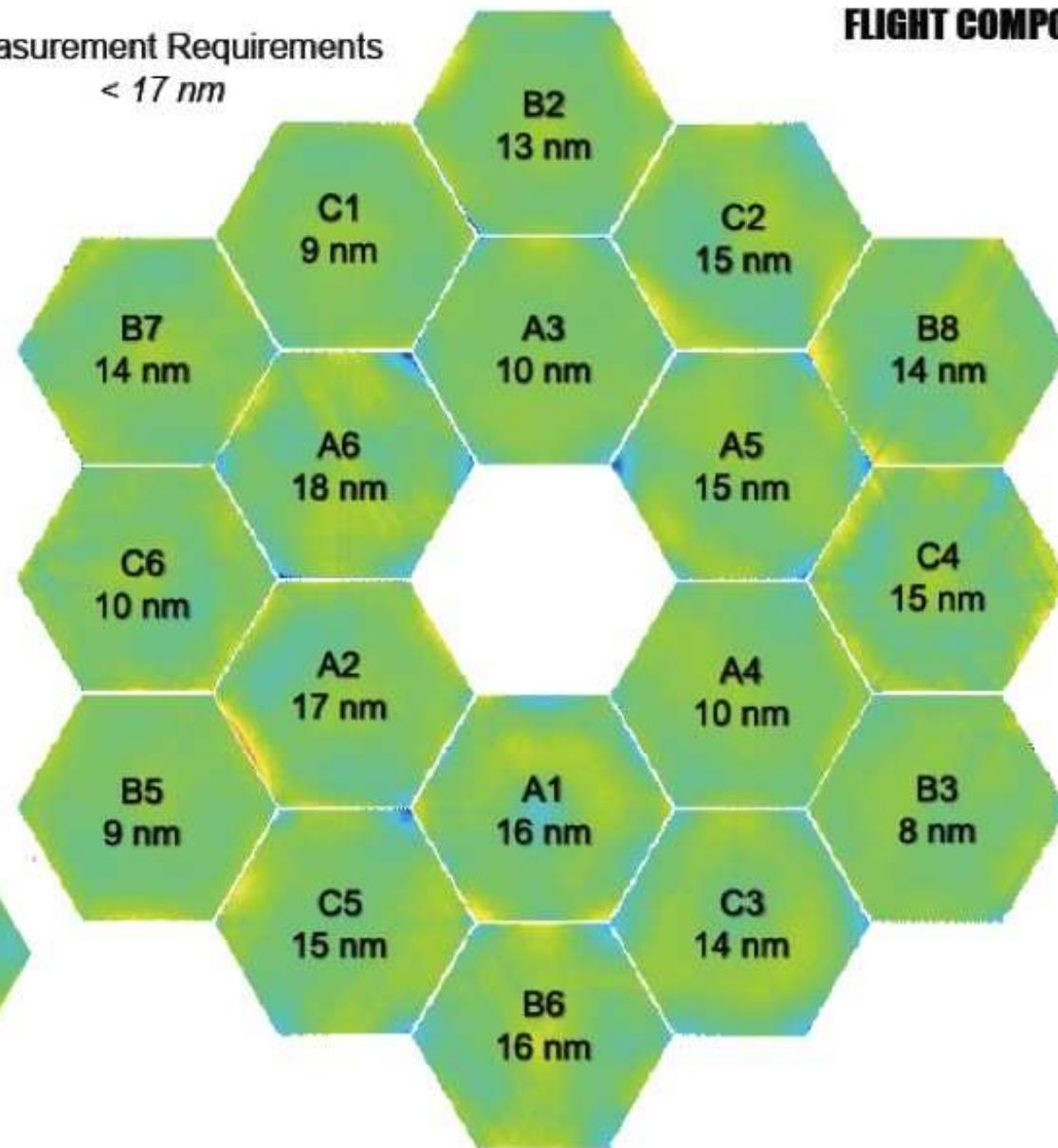
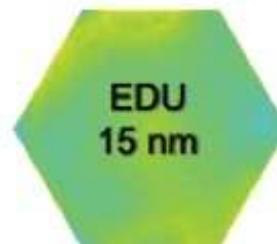
# JWST Flight Mirrors Have Completed Polishing



Tinsley Final Measurement Requirements  
*Total Figure* < 17 nm



Mirror test configuration



FLIGHT COMPOSITERMS:

13.3 nm

PV:

976.4 nm

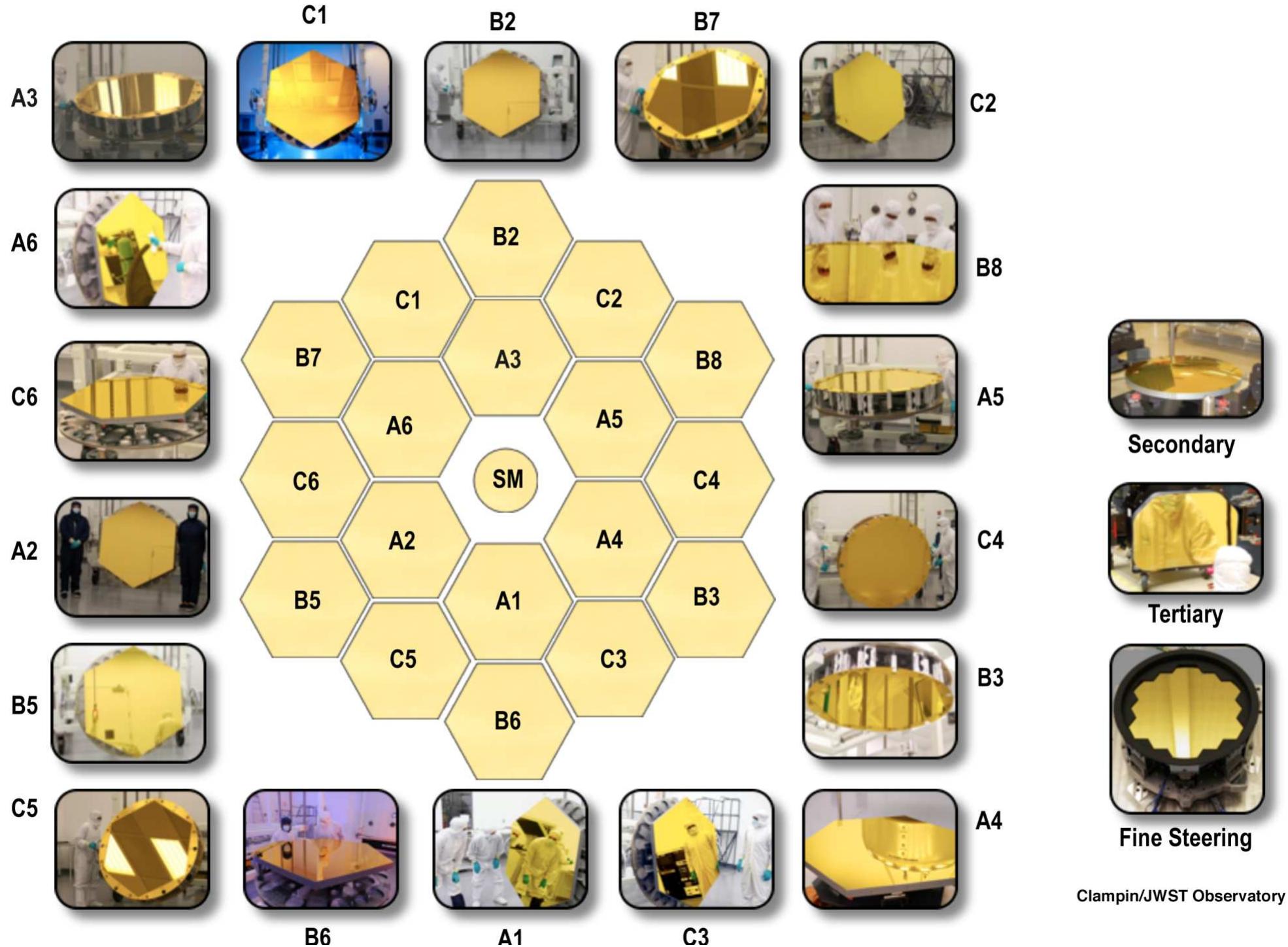


200.0

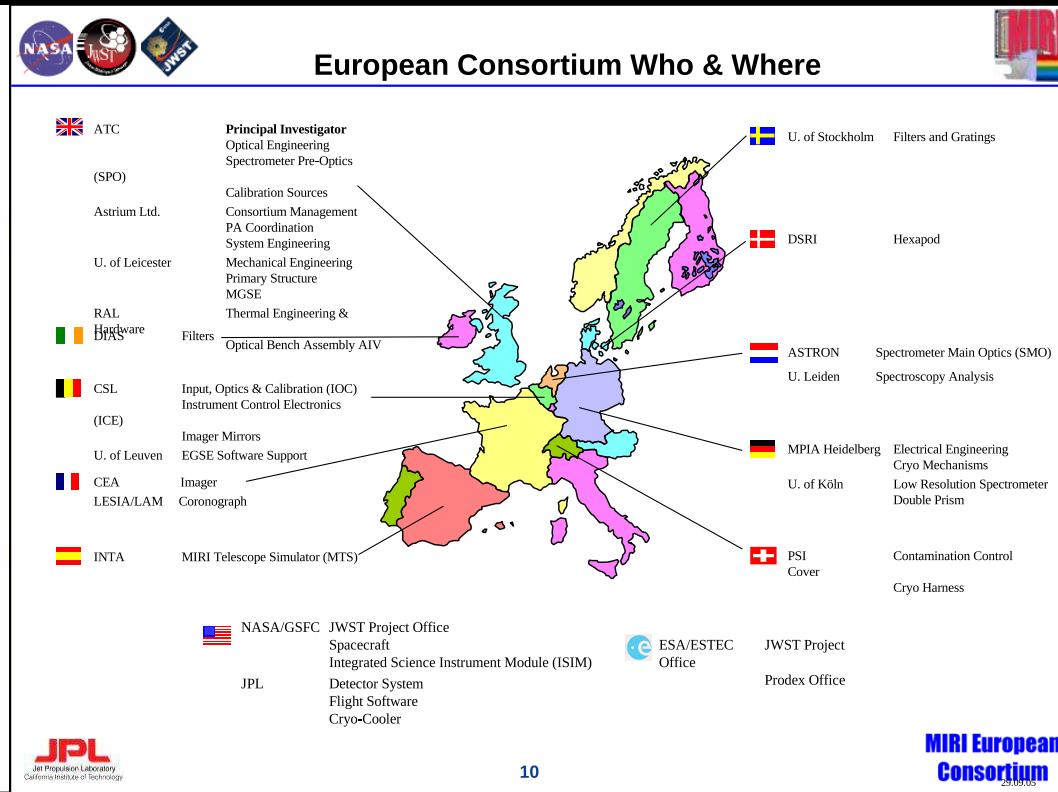
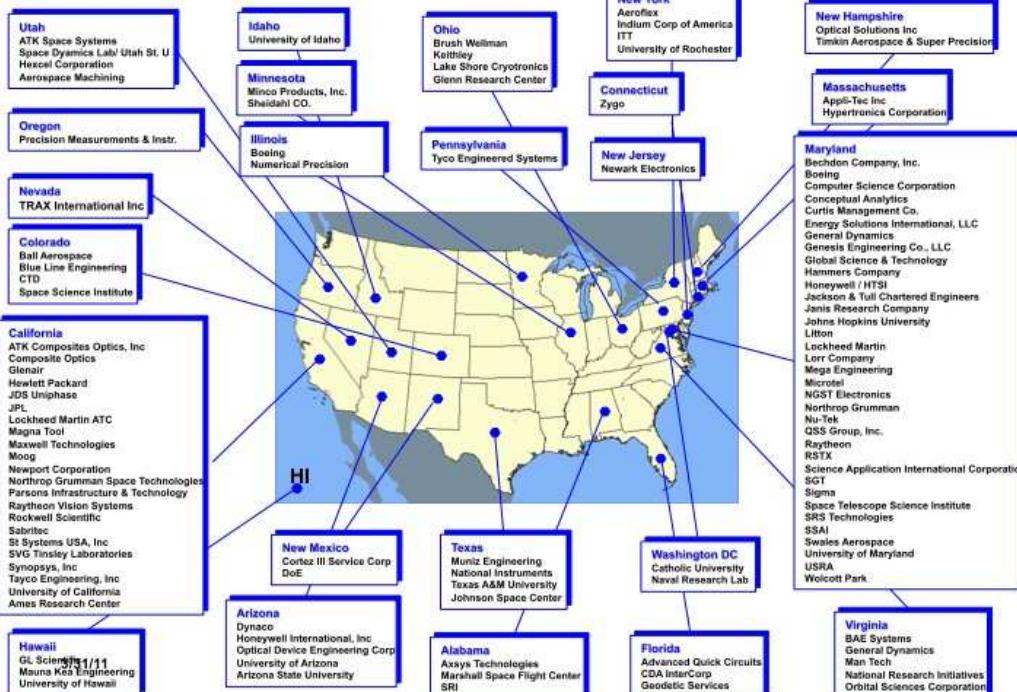
nm

-200.0

# All mirrors are gold-coated



## JWST: A Product of the Nation



- JWST hardware made in 27 US States:  $\gtrsim 75\%$  of launch-mass finished.
- Launch Vehicle (Ariane V), NIRSpec, & MIRI provided by ESA.
- JWST Fine Guider Sensor + NIRISS provided by Canadian Space Agency.

## ● (2) What instruments will JWST have? US (UofA, JPL), ESA, and CSA.

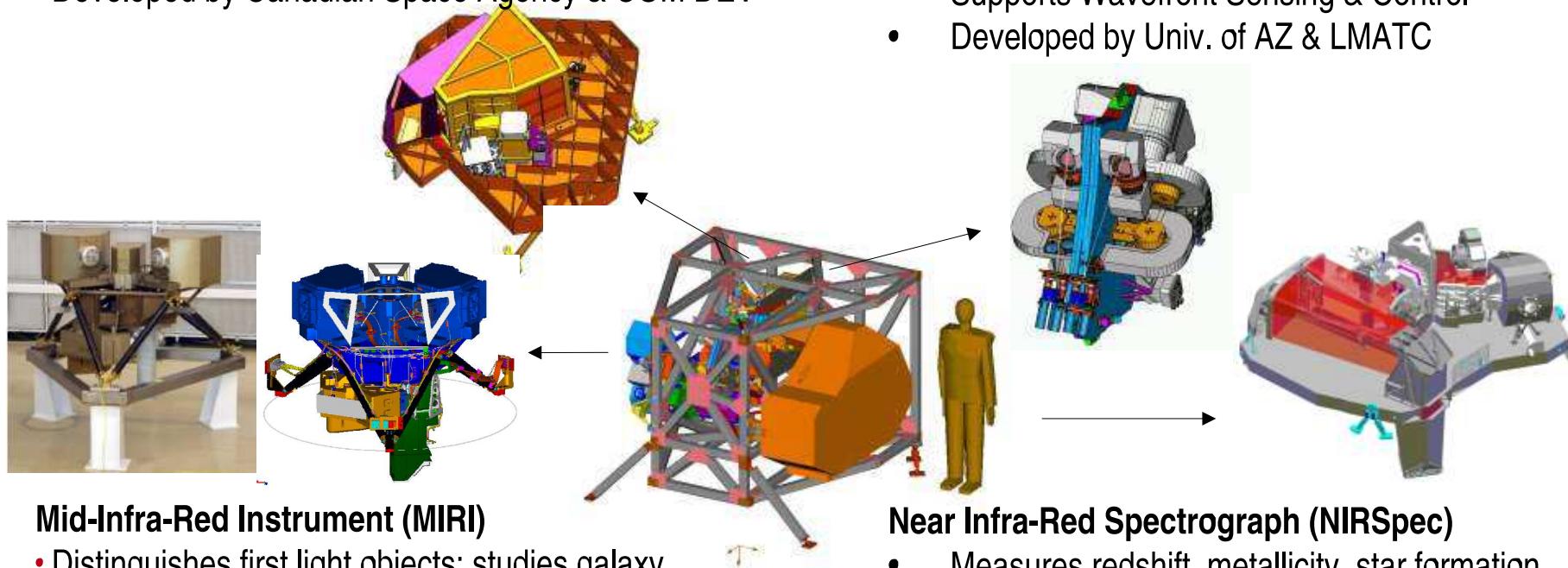


# Instrument Overview



### 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

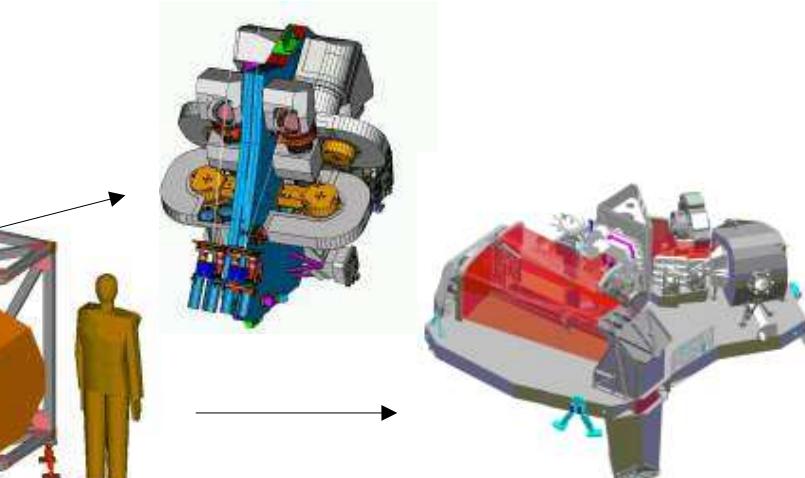


### Mid-Infra-Red Instrument (MIRI)

- 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 Camera (NIRCam)

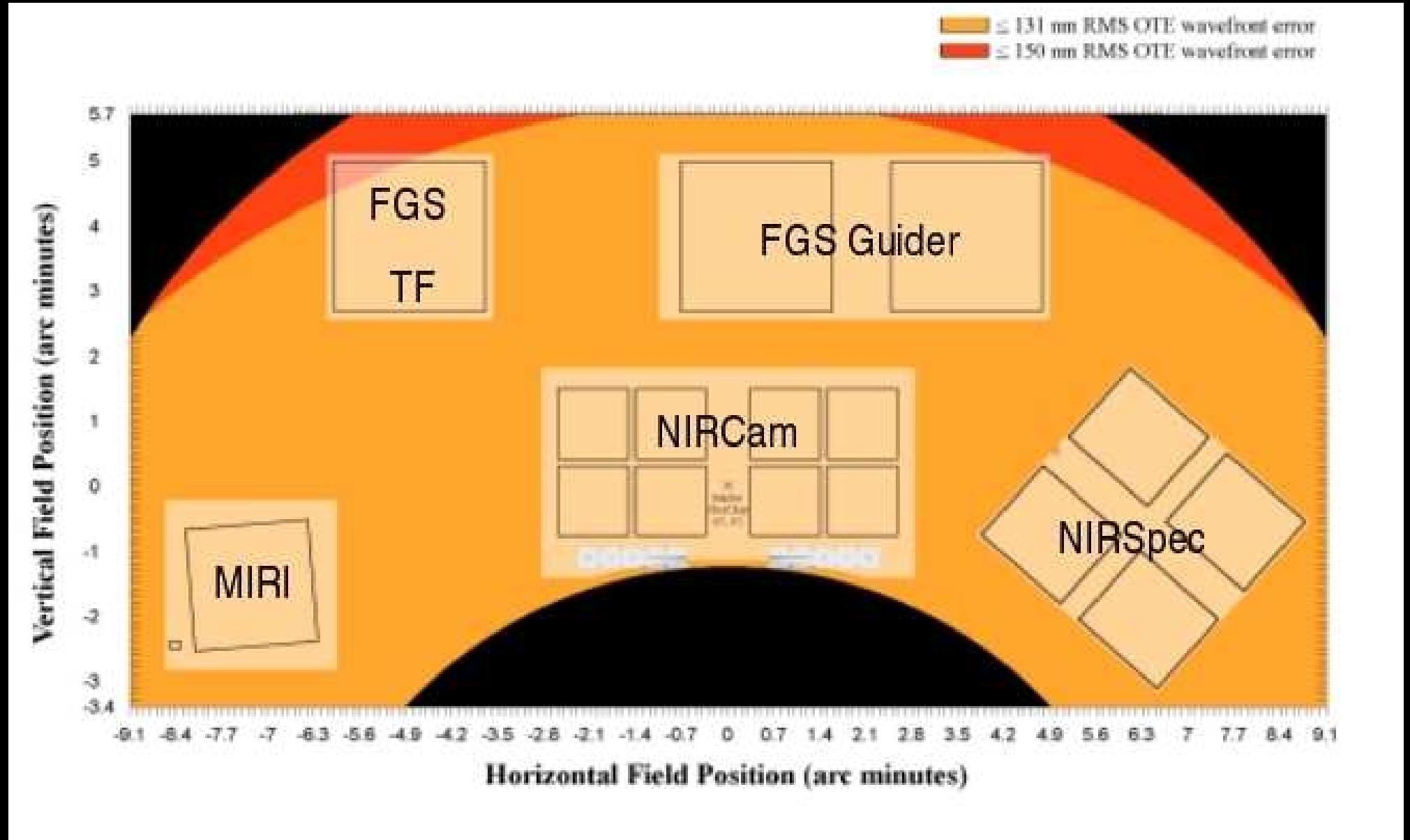
- Detects first light galaxies and observes galaxy assembly sequence
- 0.6 to 5 microns
- Supports Wavefront Sensing & Control
- Developed by Univ. of AZ & LMATC



### 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*.



## ETU NIRCam



## Flight Fine Guidance Sensor

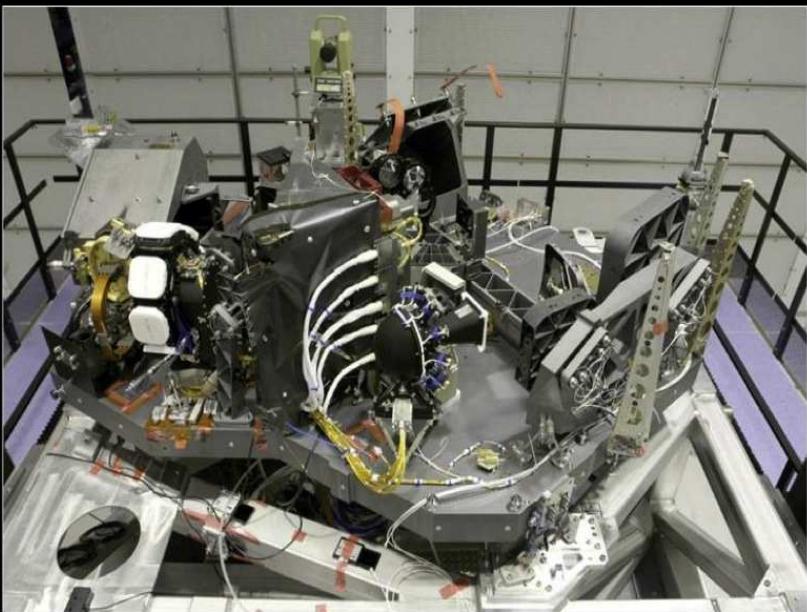


JWST's short-wavelength ( $0.6\text{--}5.0\mu\text{m}$ ) imagers:

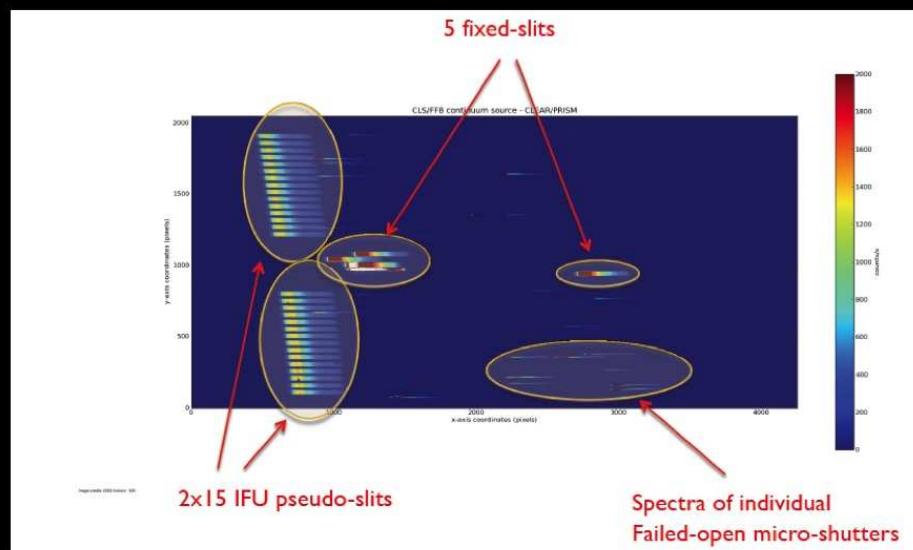
- NIRCam — built by UofA (AZ) and Lockheed (CA).
- Fine Guidance Sensor (&  $1\text{--}5\mu\text{m}$  grisms) — built by CSA (Montreal).
- Both to be delivered to GSFC late Fall 2011.



## FLIGHT NIRSpec



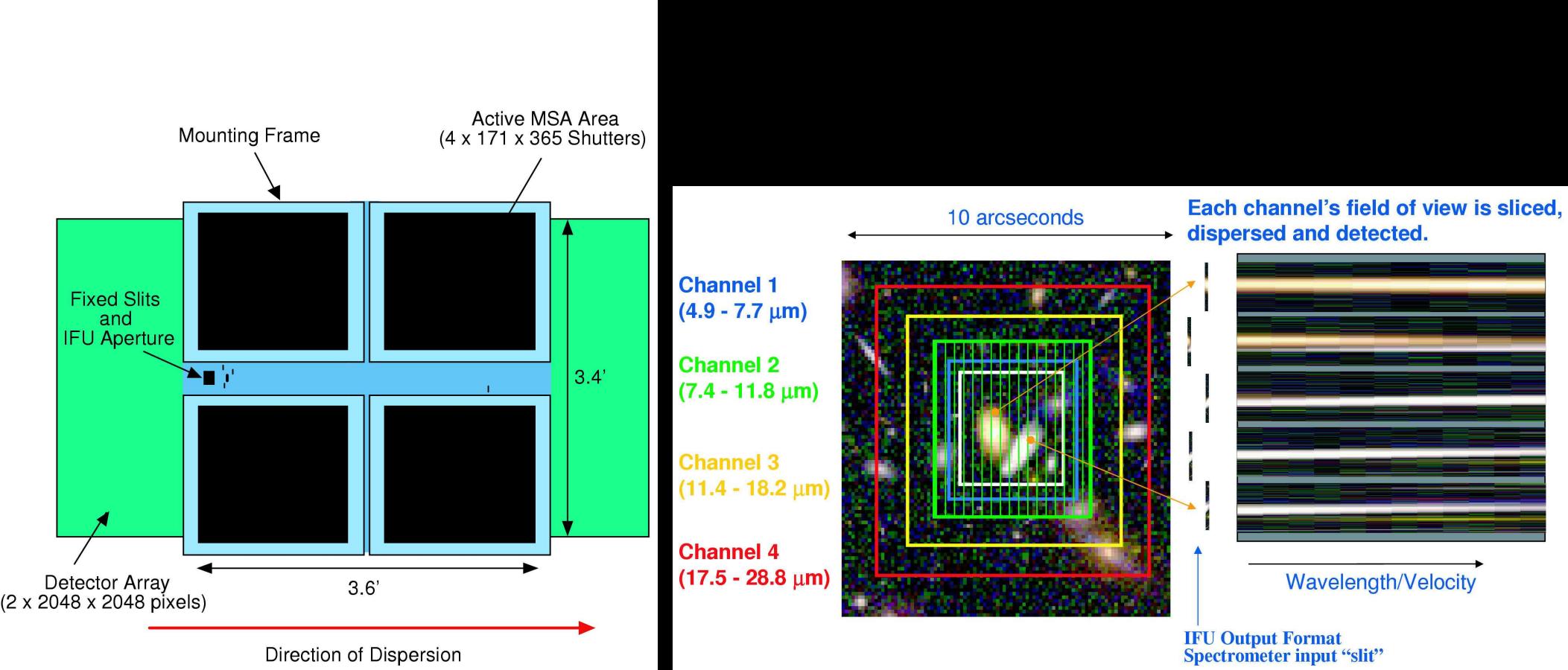
## Flight NIRSpec First Light



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.

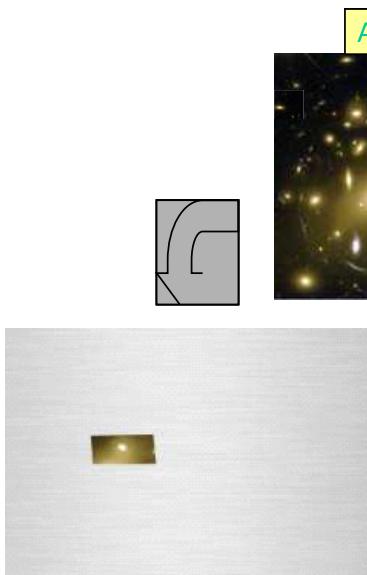
Final delivery to NASA/GSFC in early Fall 2011.



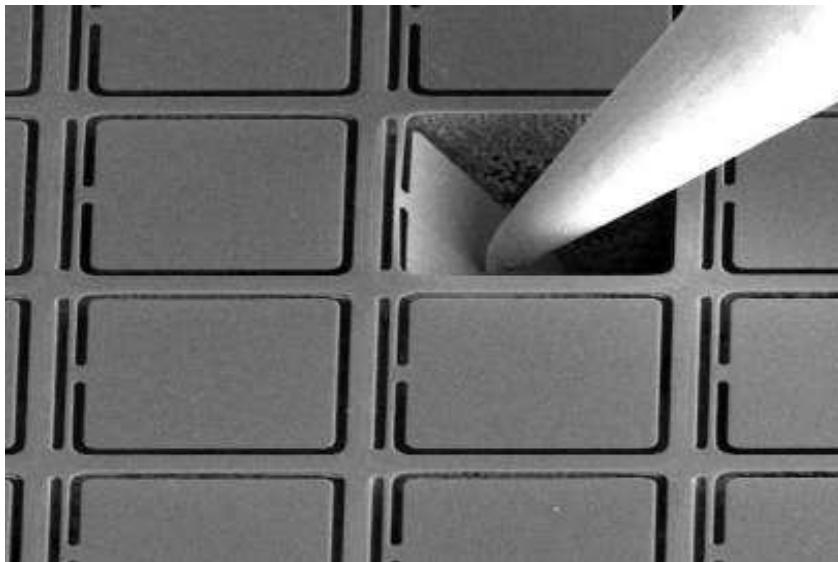
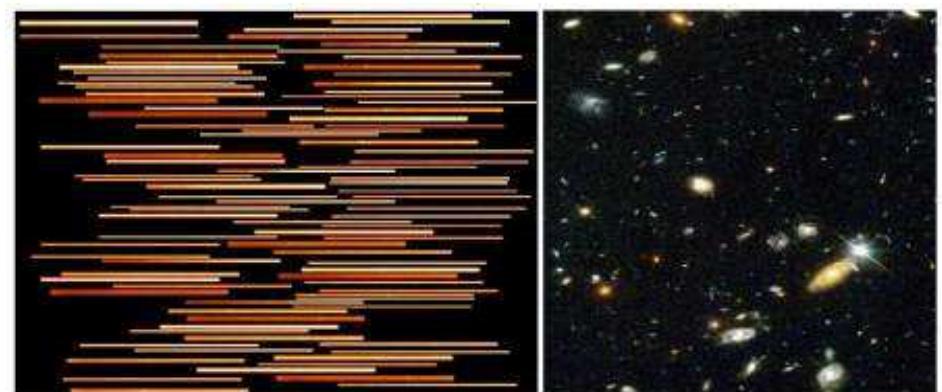
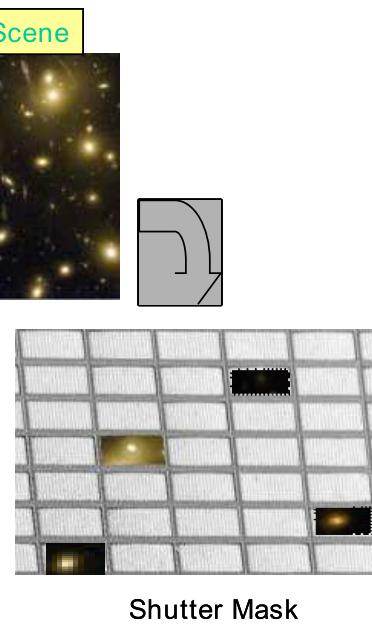
JWST offers significant multiplexing for faint object spectroscopy:

- NIRSpec/MSA with  $4 \times 62,415$  independently operable micro-shutters (MEMS) that cover  $\lambda \simeq 1\text{--}5 \mu\text{m}$  at  $R \simeq 100\text{--}1000$ .
- MIRI/IFU with 400 spatial pixels covering 5–29  $\mu\text{m}$  at  $R \sim 2000\text{--}4000$ .
- FGS/NIRISS covers a  $2!2 \times 2!2$  FOV at  $\lambda \simeq 1.6\text{--}4.9 \mu\text{m}$  at  $R \simeq 100$ .
- NIRCam offers  $R \simeq 5$  imaging from  $0.7\text{--}5 \mu\text{m}$  over two  $2!3 \times 4!6$  FOV's.]

# Micro Shutters

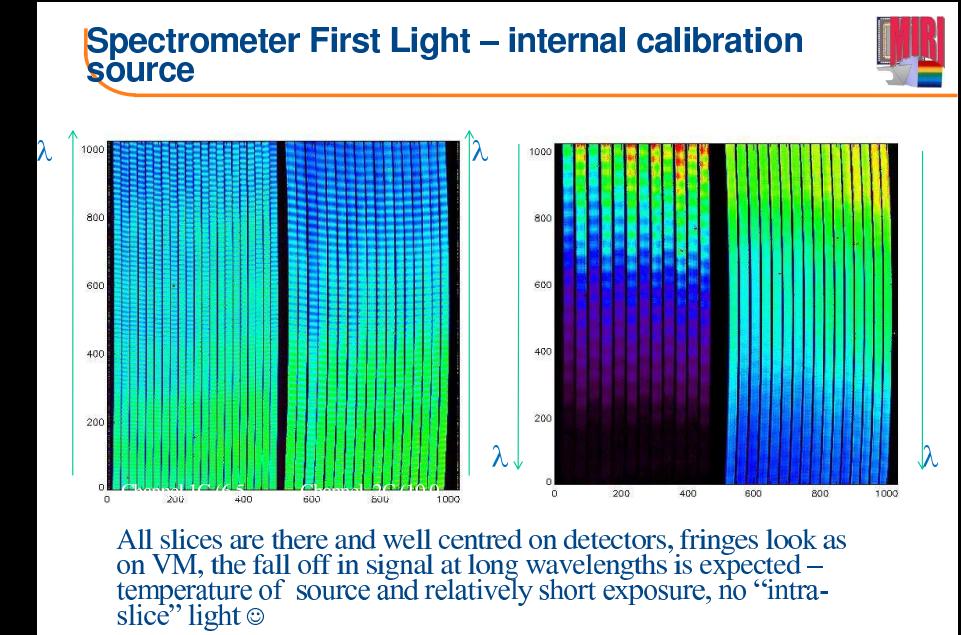


Metal Mask/Fixed Slit





## Flight MIRI



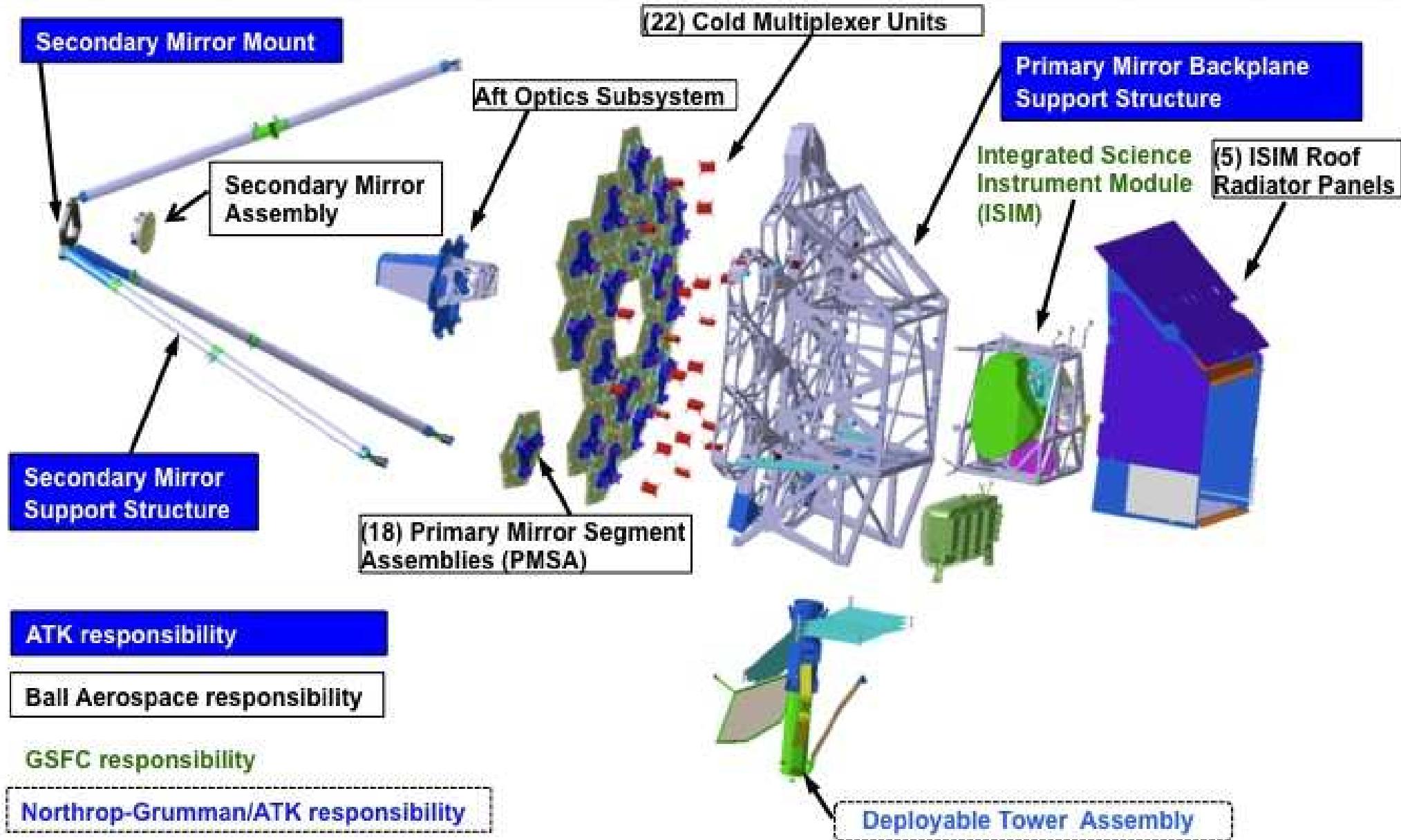
JWST's mid-infrared ( $5\text{--}29\mu\text{m}$ ) camera and spectrograph:

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

Final delivery to NASA/GSFC in early Fall 2011.



# TELESCOPE ARCHITECTURE





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

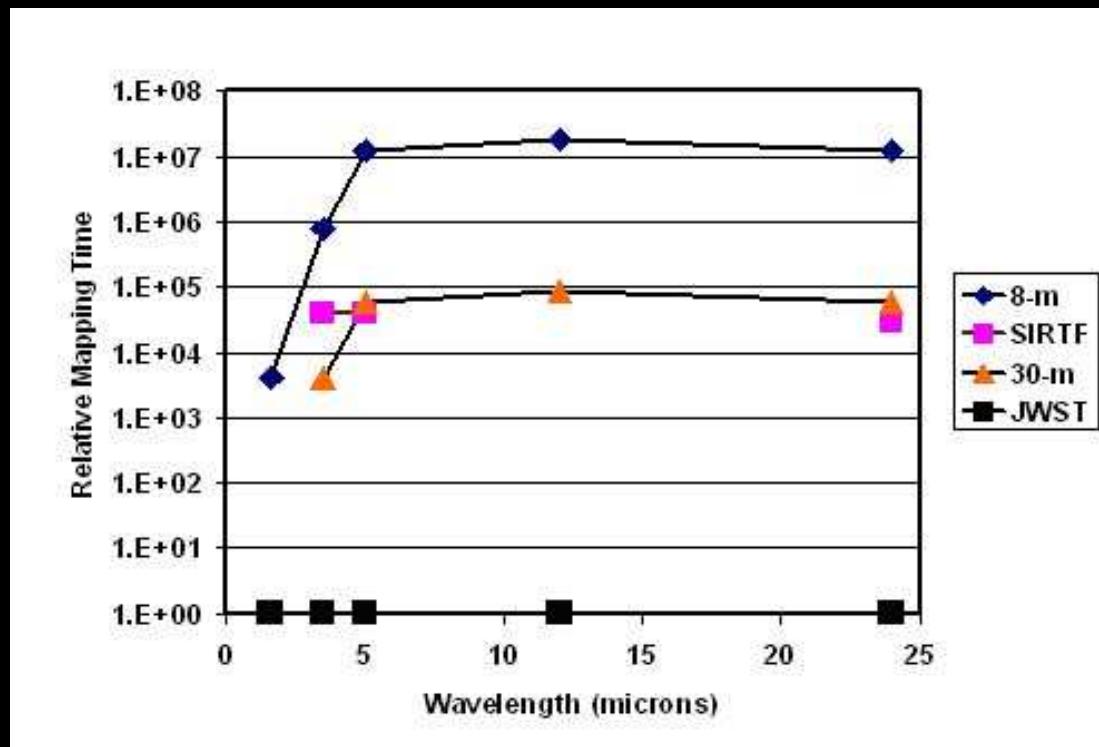
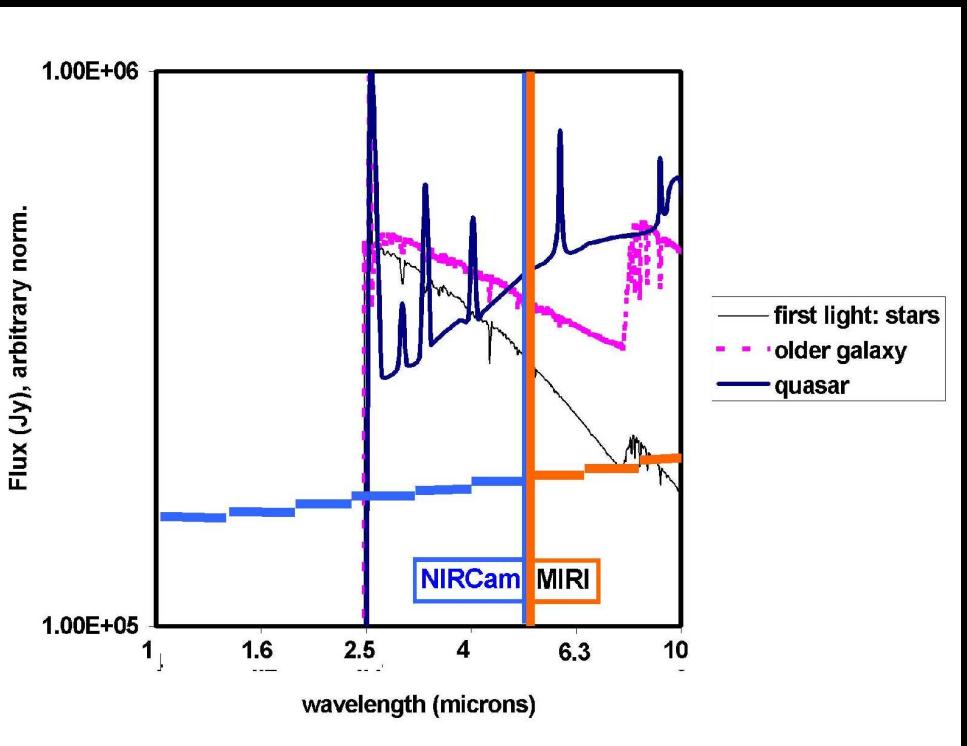


Telescope and science instruments installed in the test chamber

Element Progress



## • (2) What sensitivity will JWST have?



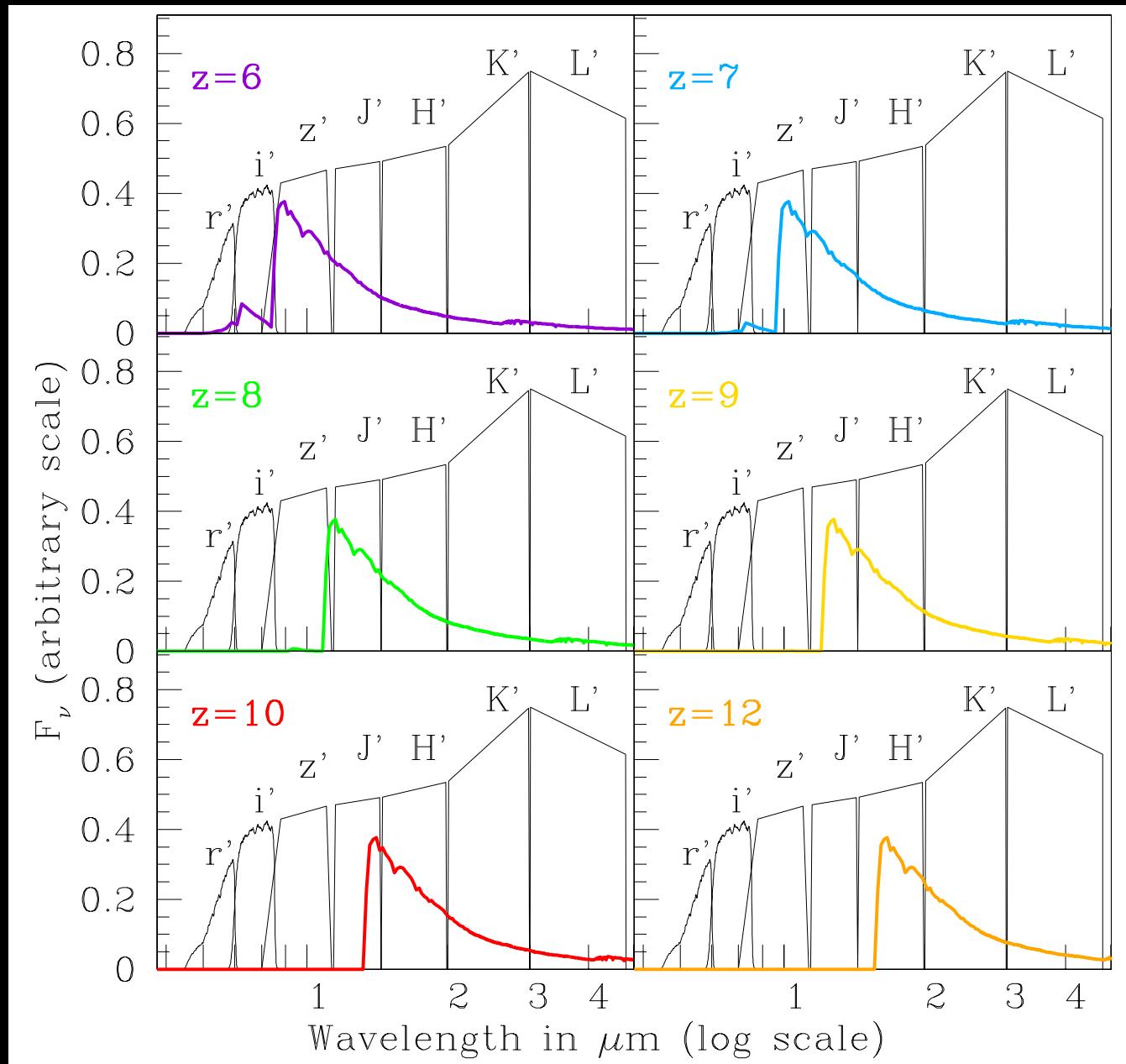
NIRCam and MIRI sensitivity complement each other, straddling  $\lambda \simeq 5 \mu\text{m}$ .

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.  $\lambda$  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?

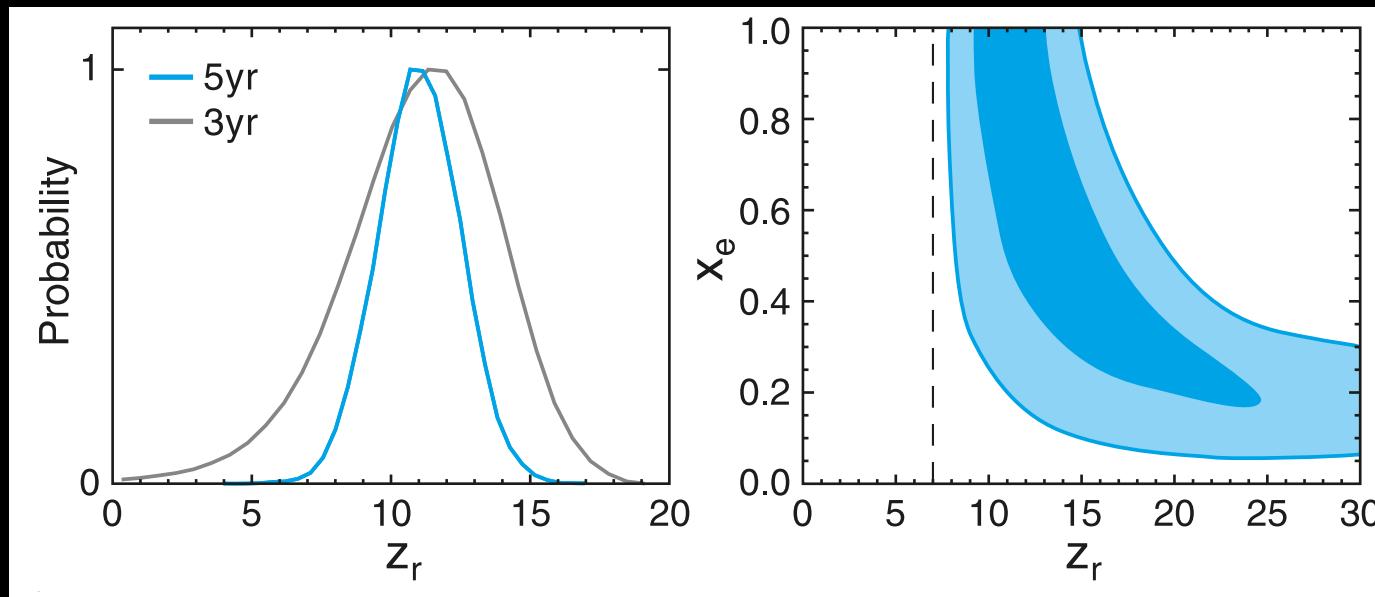


- Can't beat redshift: to see First Light, must observe near-mid IR.  
⇒ This is why JWST needs NIRCam at 0.8–5  $\mu\text{m}$  and MIRI at 5–29  $\mu\text{m}$ .

# Implications of the (2010) 7-year WMAP results for JWST science:

HST/WFC3  $z \lesssim 7\text{--}9 \leftarrow$

$\longrightarrow$  JWST  $z \simeq 8\text{--}25$

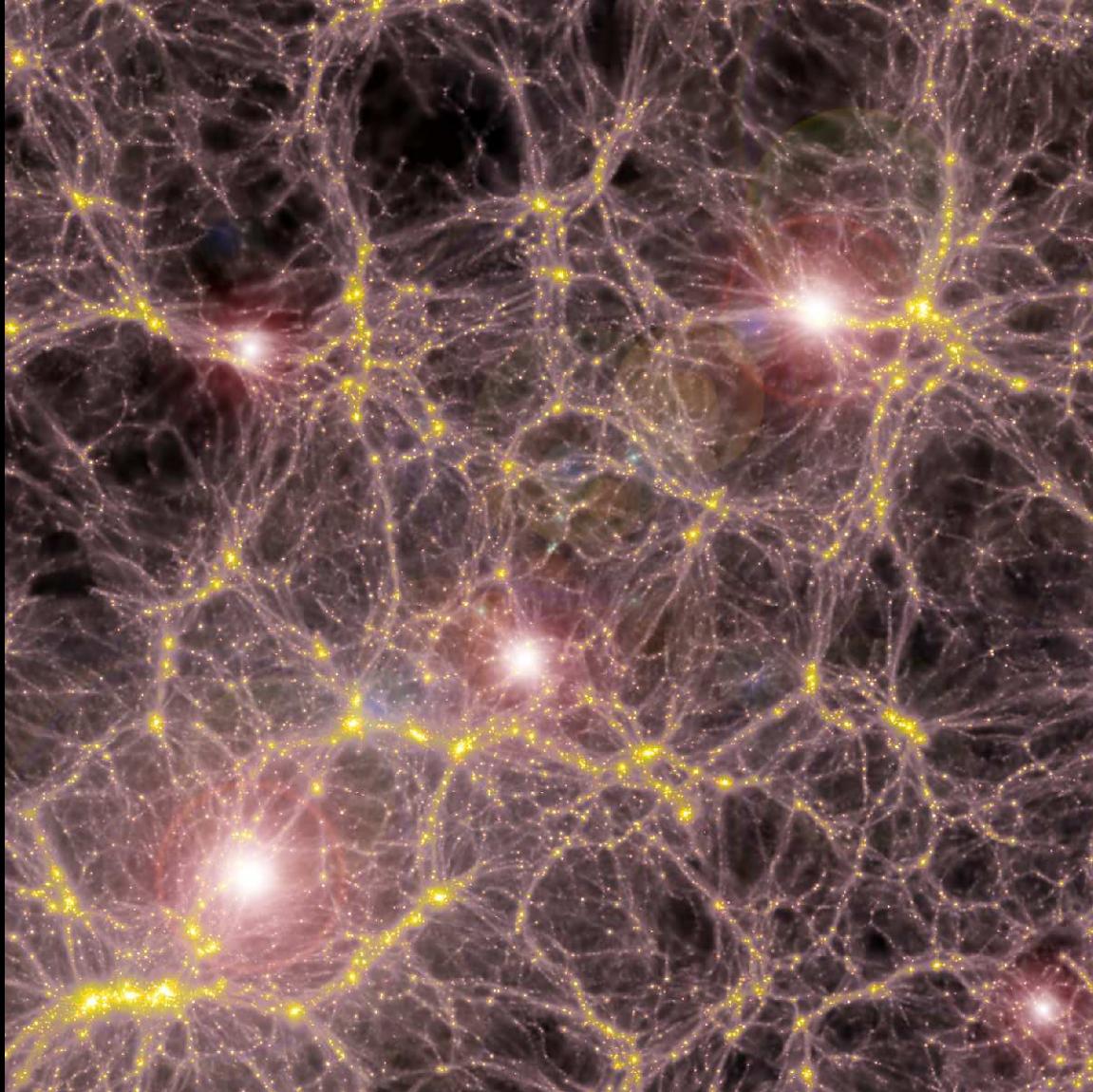


The year-7 WMAP data provided much better foreground removal  
(Dunkley et al. 2009; Komatsu et al. 2009, 2011):

$\implies$  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  $z \lesssim 7\text{--}9$ .
  - For First Light & Reionization, JWST must sample  $z \simeq 8$  to  $z \simeq 15\text{--}20$ .
- $\Rightarrow$  JWST must cover  $\lambda = 0.7\text{--}29 \mu\text{m}$ , with its diffraction limit at  $2.0 \mu\text{m}$ .

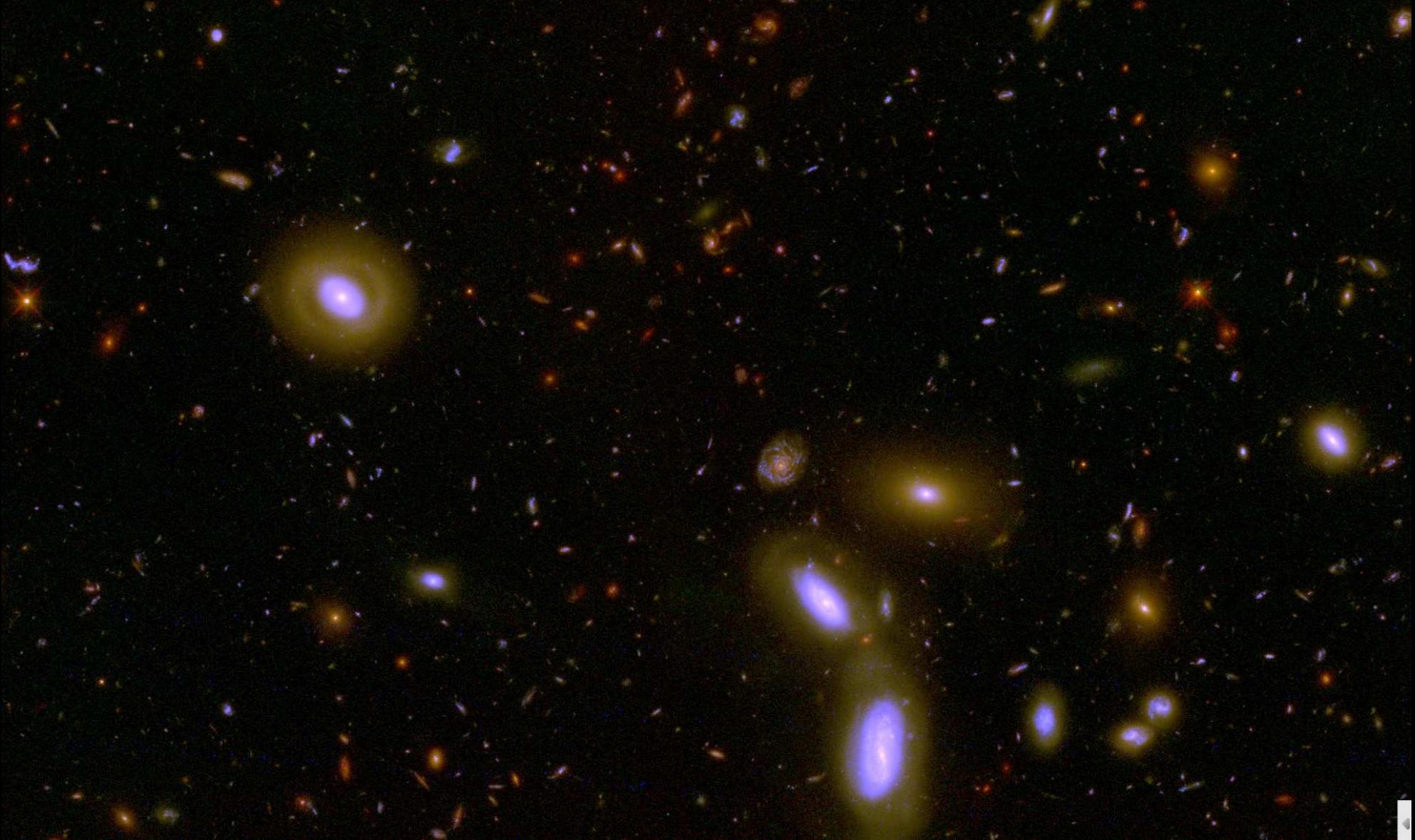
- (3) How will JWST Observe First Light and Reionization?



- 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  $z \simeq 10 \rightarrow 30$ .

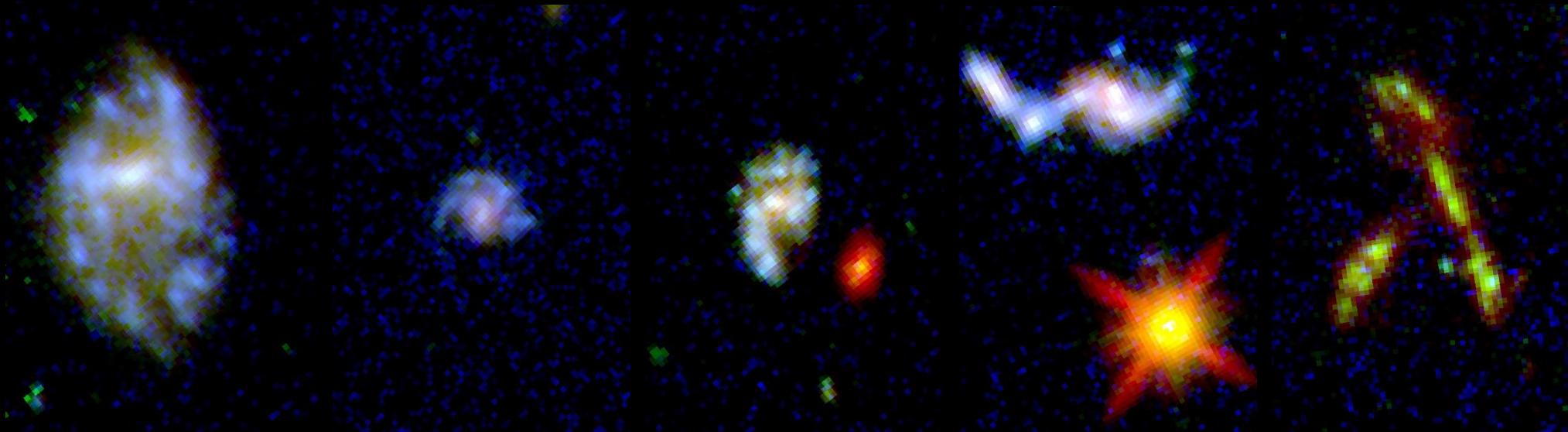
We must make sure we theoretically understand the likely Pop III mass-range, their IMF, their duplicity and clustering properties, their SN-rates, etc. [See many talks this Conference.]

- (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<sup>2</sup> at 0.07–0.15" FWHM from 0.2–1.7 $\mu$ m (UVUBVizYJH). JWST adds 0.05–0.2" FWHM imaging to AB $\simeq$ 31.5 mag (1 nJy) at 1–5 $\mu$ m, and 0.2–1.2" FWHM at 5–29 $\mu$ m, tracing young+old SEDs & dust.

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



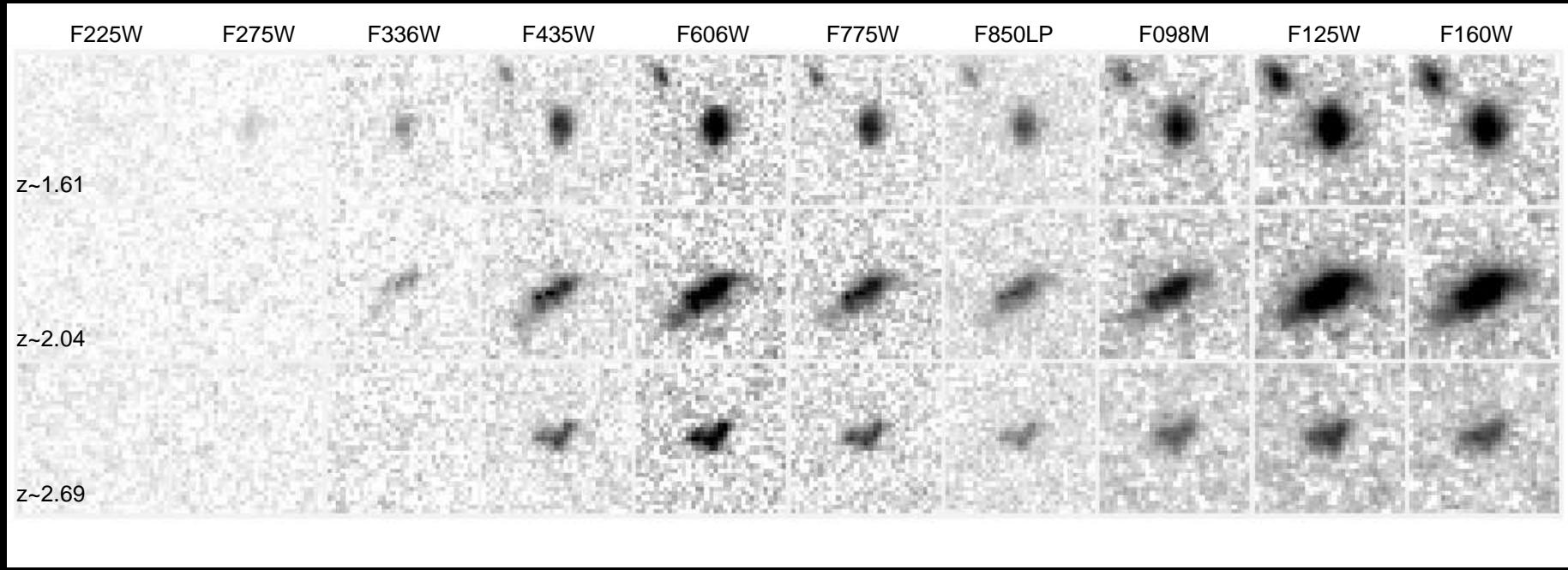
Galaxy structure at the peak of the merging epoch ( $z \approx 1-2$ ) is very rich: some resemble the cosmological parameters  $H_0$ ,  $\Omega$ ,  $\rho_O$ ,  $w$ , and  $\Lambda$ , resp.



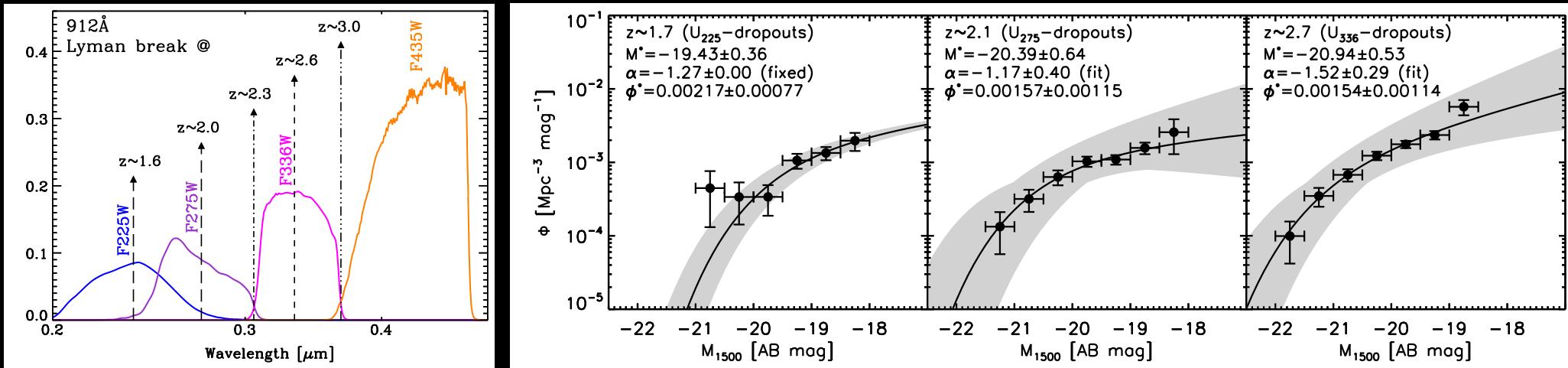
Panchromatic WFC3 ERS images of early-type galaxies with nuclear star-forming rings, bars, weak AGN, or other interesting nuclear structure.

(Rutkowski et al. 2011)  $\Longrightarrow$  “Red and dead” galaxies aren’t dead!

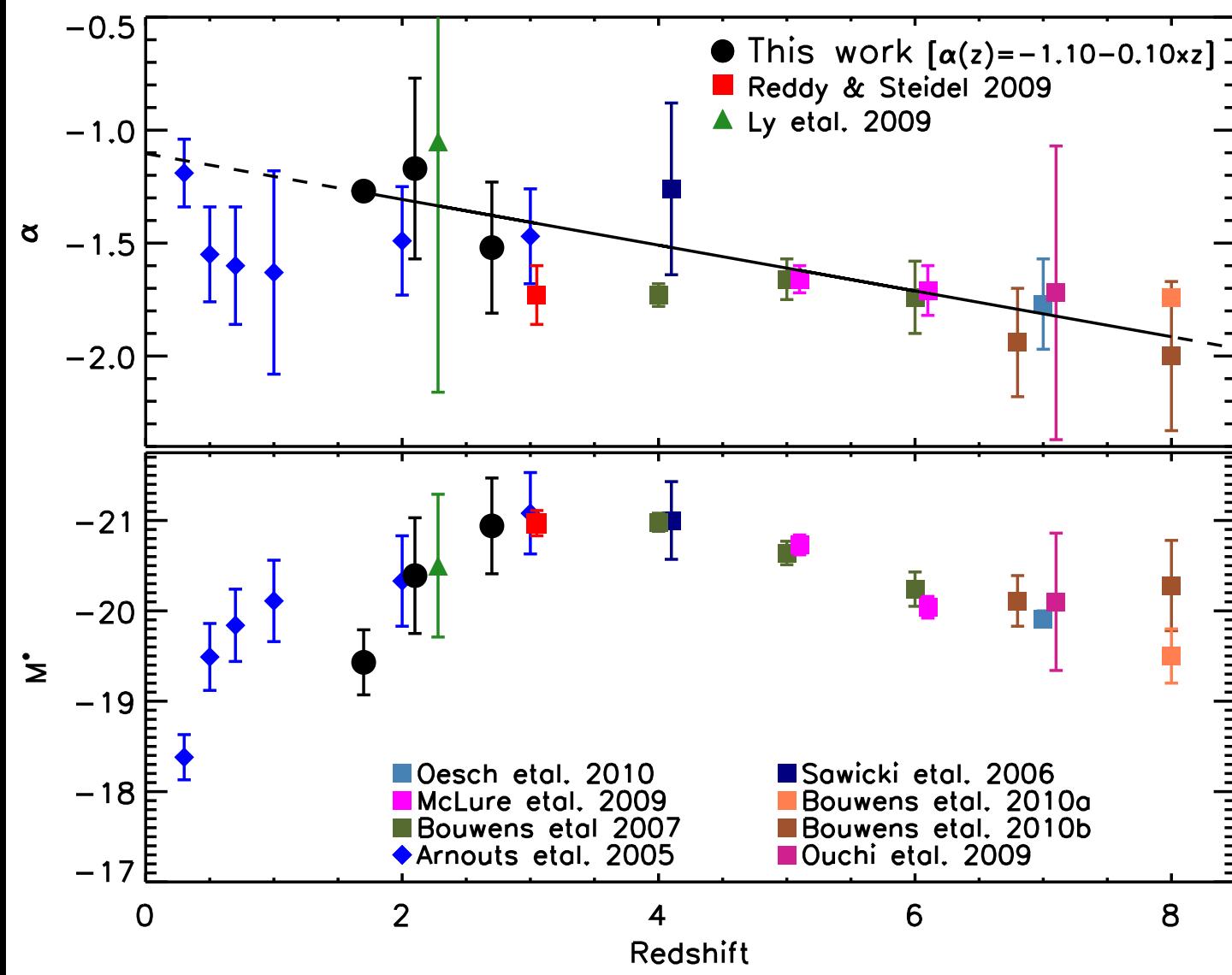
- JWST will observe all such objects from 0.7–29  $\mu\text{m}$  wavelength.



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

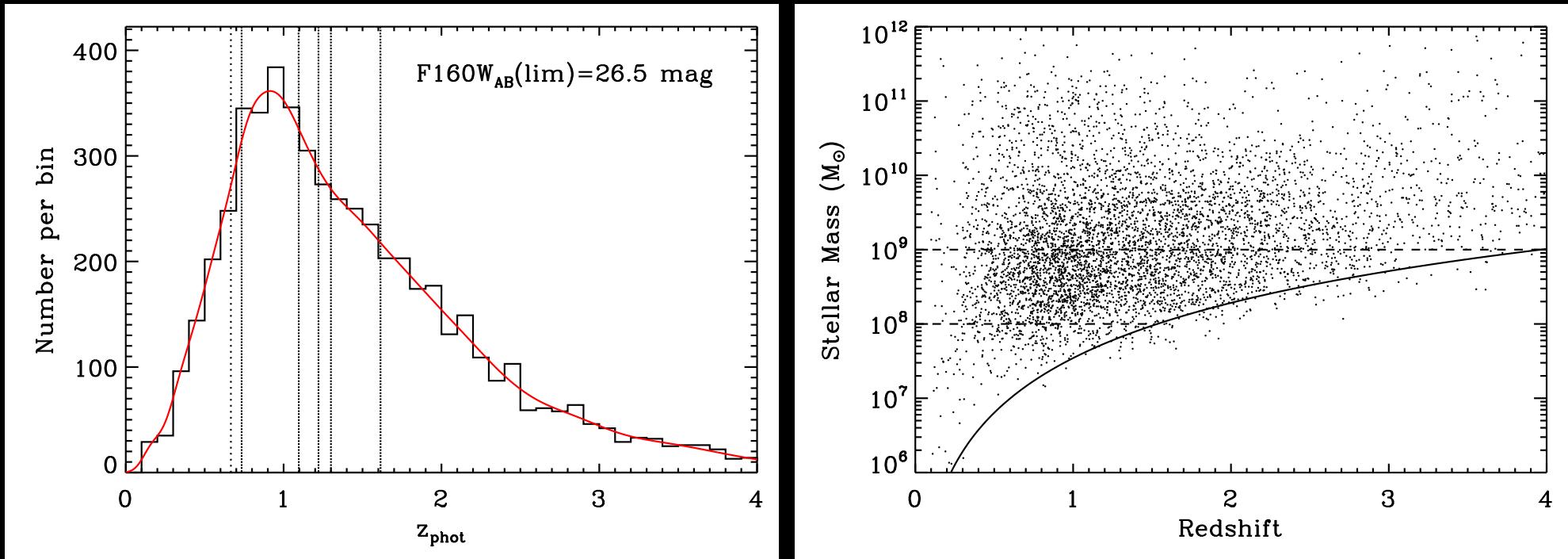


- JWST will similarly measure faint-end LF-slope evolution for  $1 \lesssim z \lesssim 12$ .  
[See talks by, e.g., Bouwens, Dunlop, Hathi, Oesch, Vanzella, Wilkins, Yan].



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

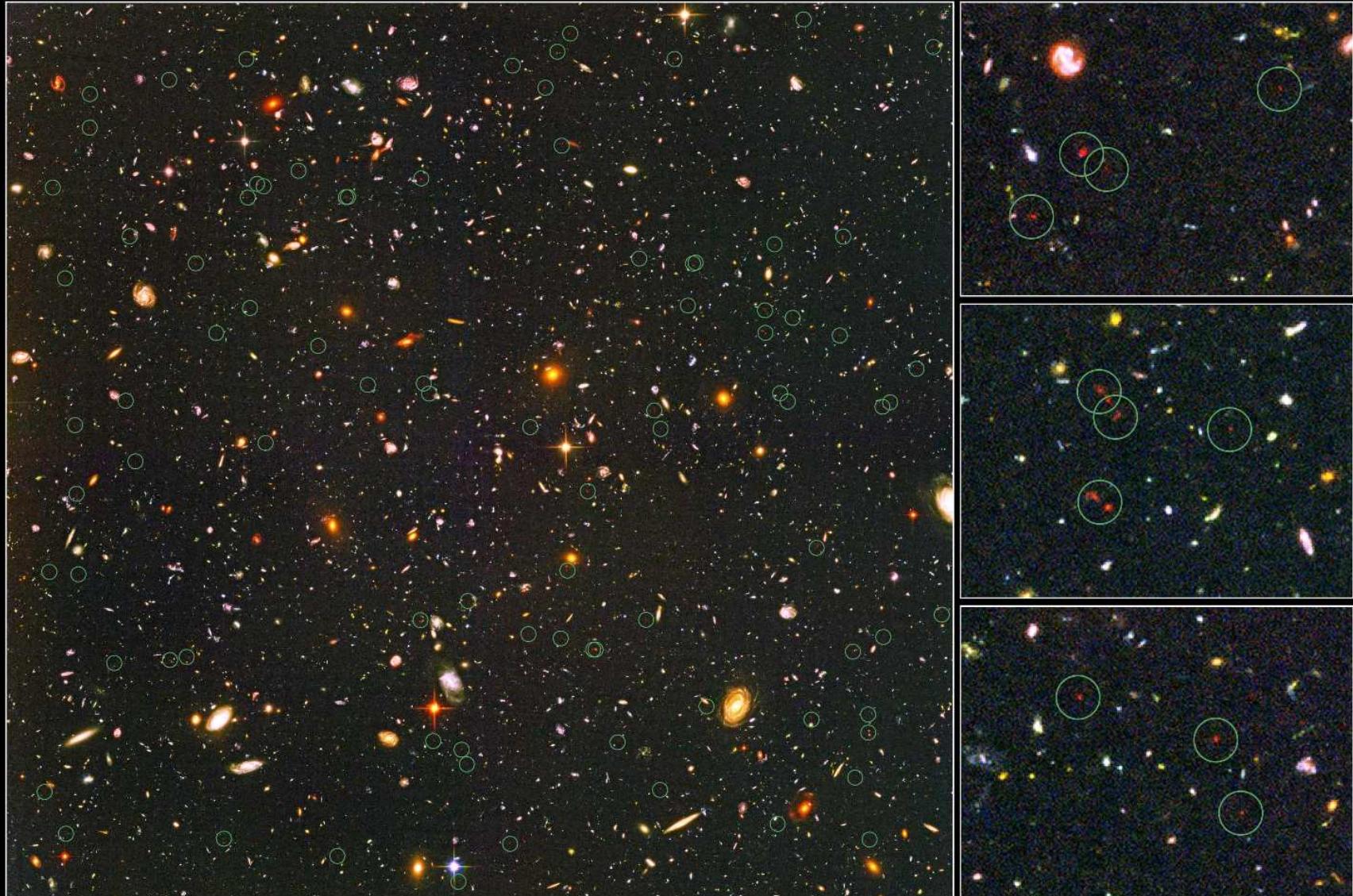


WFC3 ERS 10-band redshift estimates accurate to  $\sim 4\%$  with small systematic errors (Cohen et al. 2010), resulting in a reliable redshift distribution.

- 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 (see Wednesday talks).
- ⇒ 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  $\mu\text{m}$ .

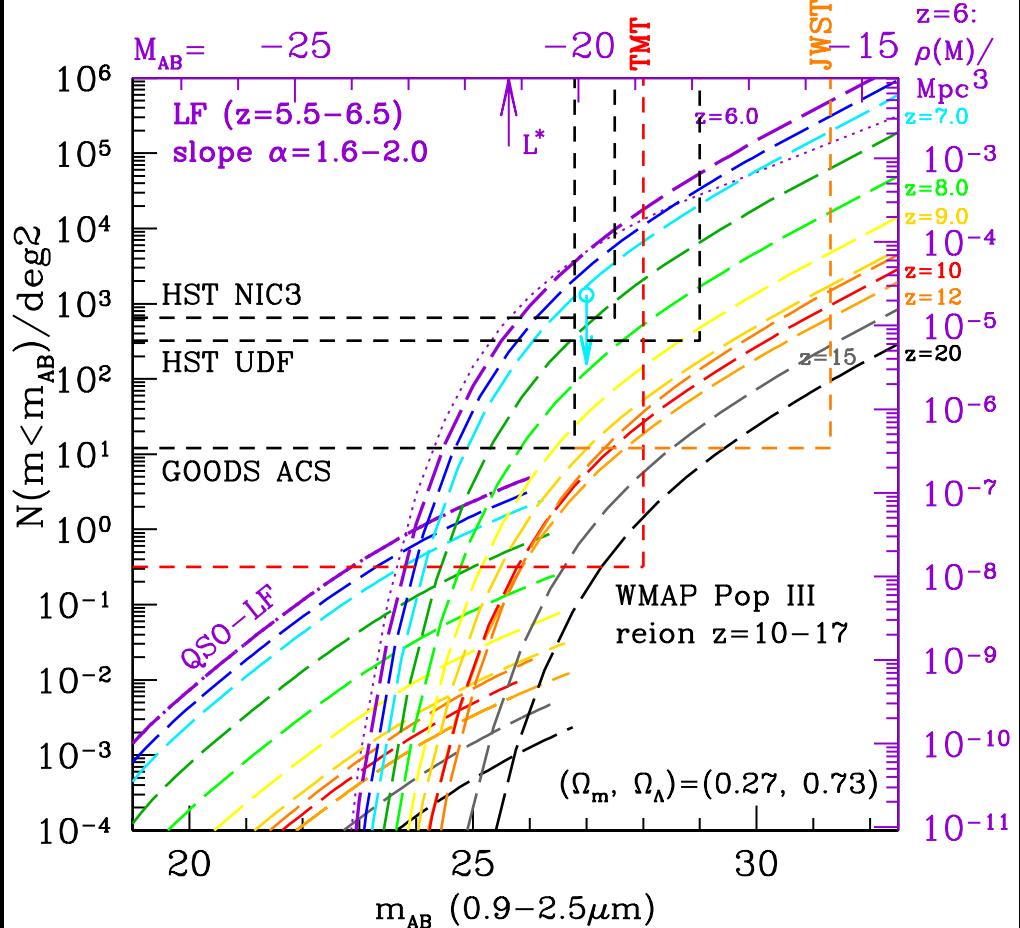
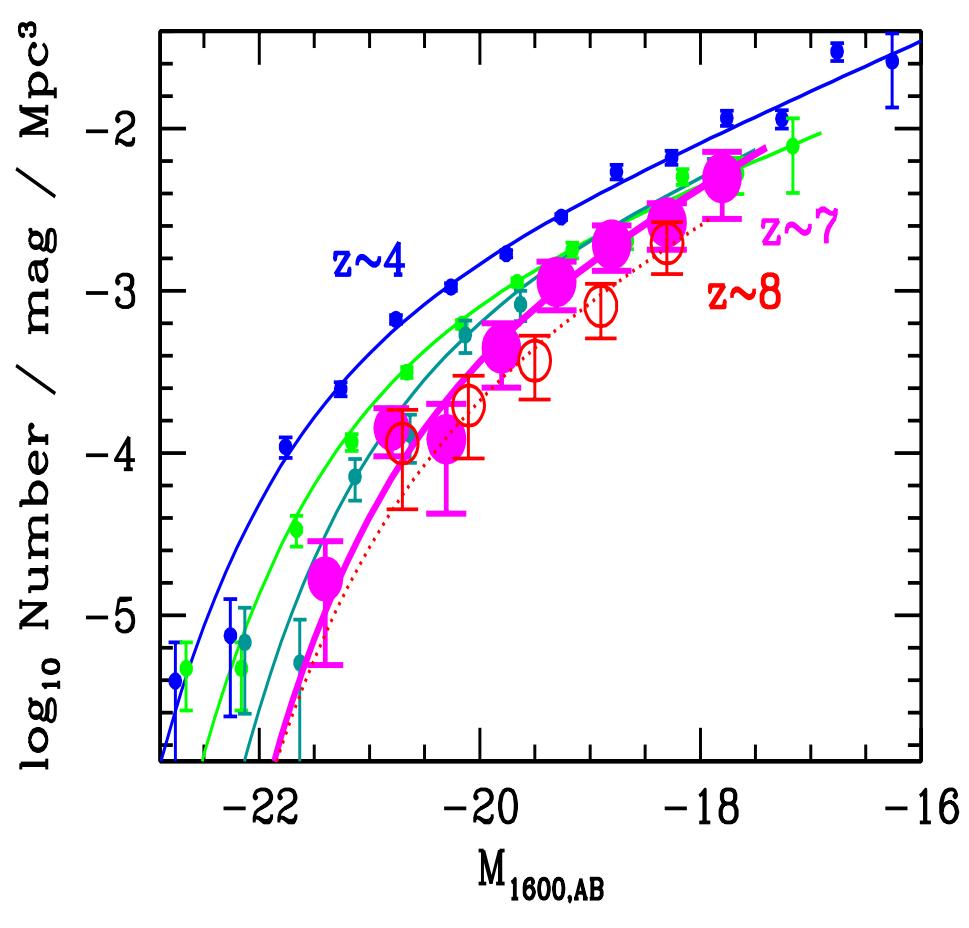


**Distant Galaxies in the Hubble Ultra Deep Field**  
Hubble Space Telescope • Advanced Camera for Surveys

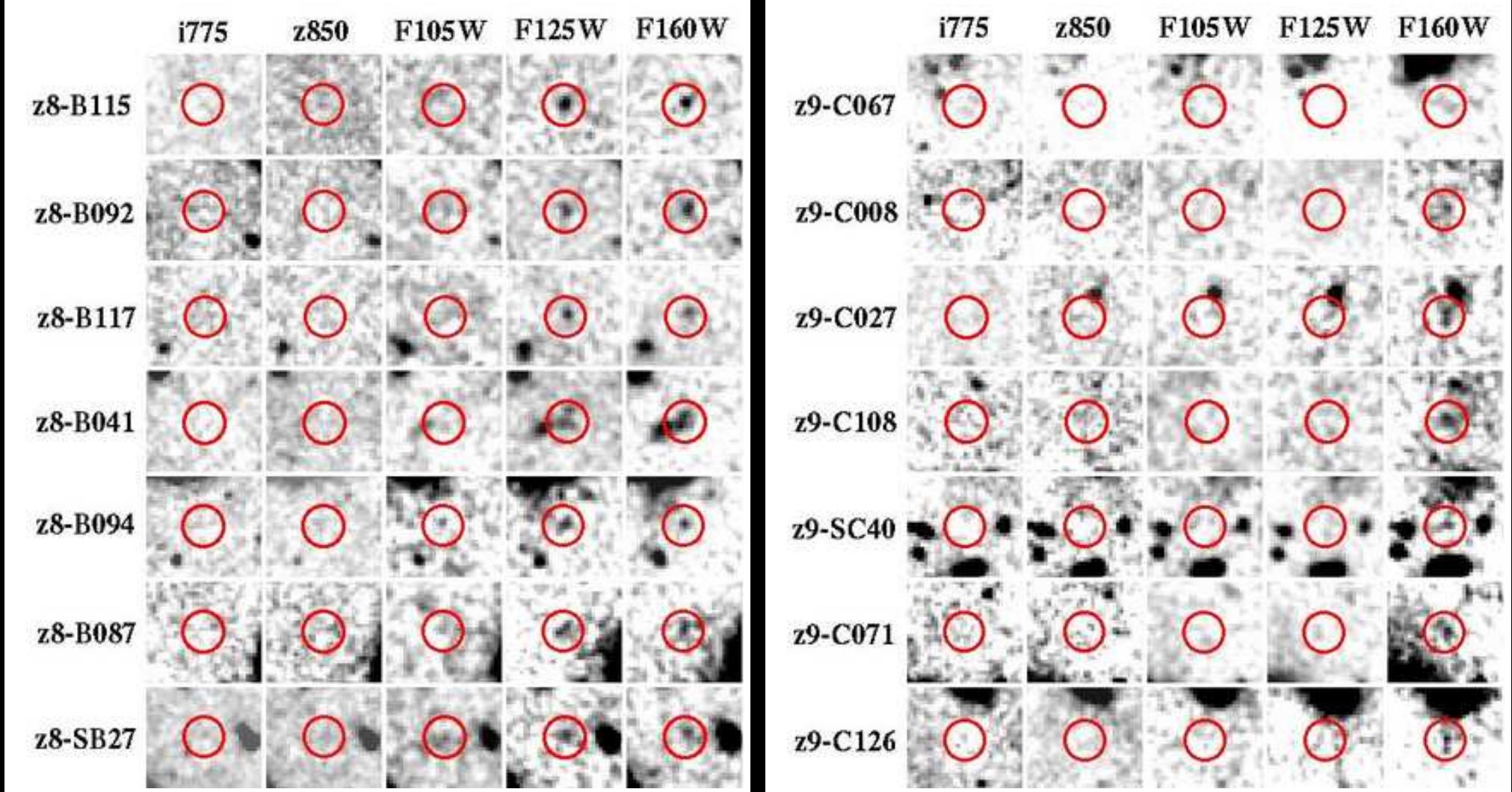
NASA, ESA, R. Windhorst (Arizona State University) and H. Yan (Spitzer Science Center, Caltech)

STScI-PRC04-28

HUDF i-drops: faint galaxies at  $z \approx 6$  (Yan & Windhorst 2004), most spectroscopically confirmed at  $z \approx 6$  to  $AB \lesssim 27.0$  mag (Malhotra et al. 2005).

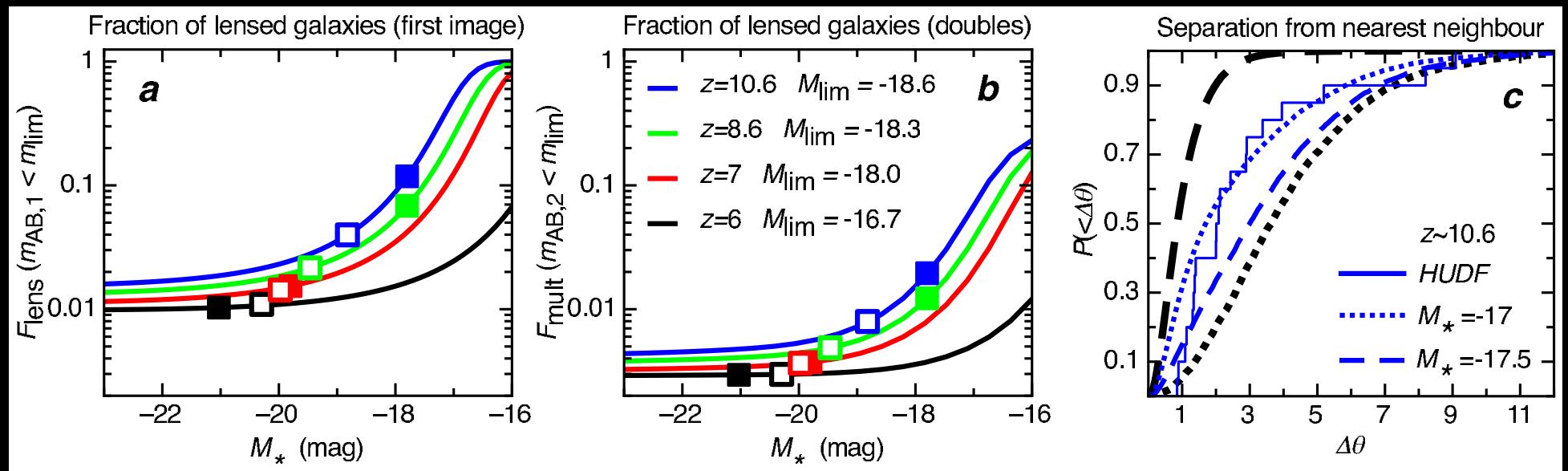
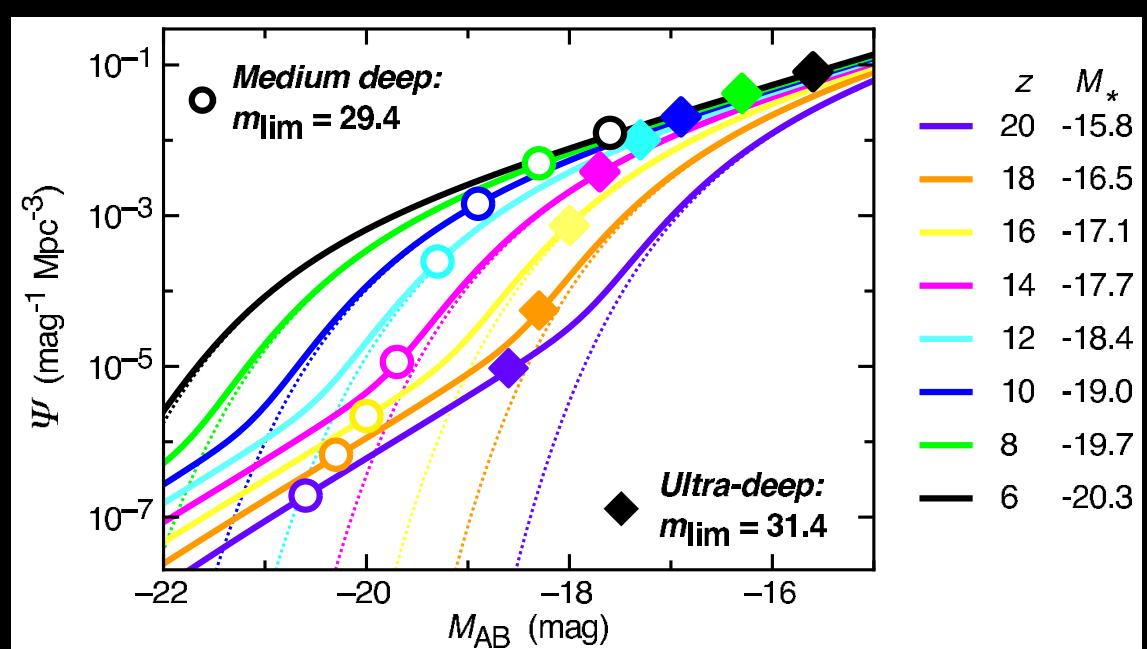
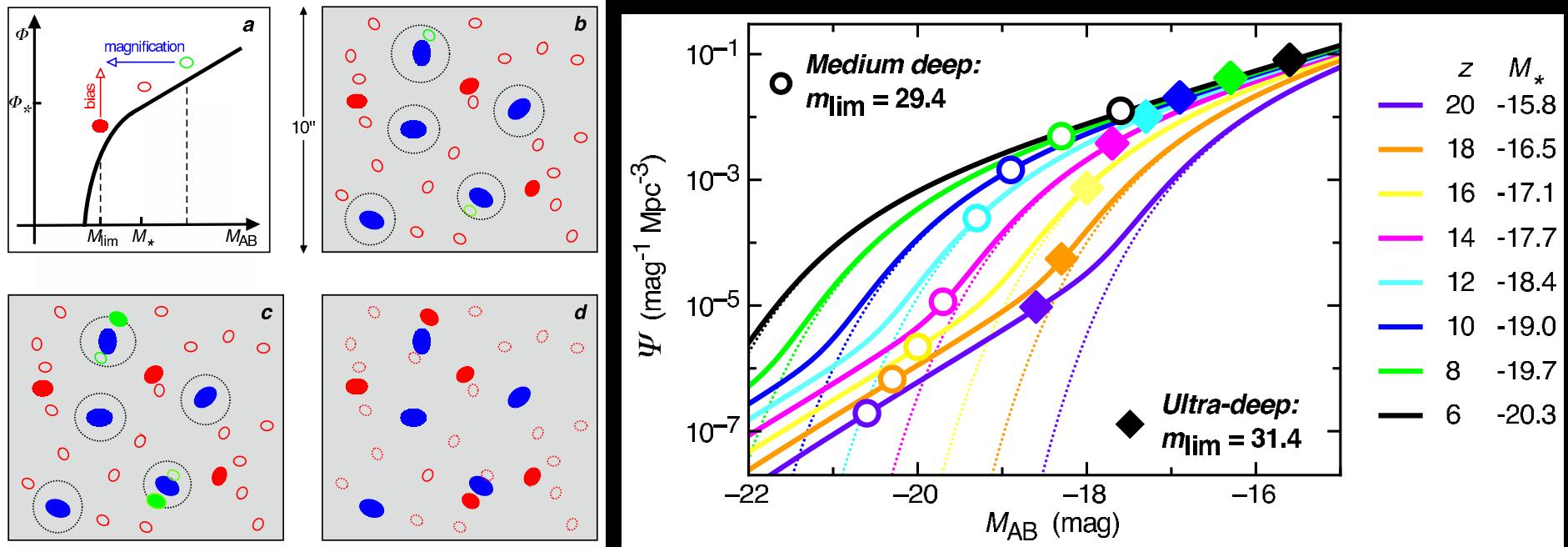


- Objects at  $z \gtrsim 9$  are rare (Bouwens<sup>+</sup> 10; Trenti,<sup>+</sup> 10; Yan<sup>+</sup> 10), since volume elt is small, and JWST samples brighter part of LF. JWST needs its sensitivity/aperture ( $A$ ), field-of-view ( $\Omega$ ), and  $\lambda$ -range (0.7-29  $\mu\text{m}$ ).
- With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



- $\sim$ 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  $z \simeq 1$ –2 (Wyithe et al. 2011, Nature, 469, 181).
- Need JWST to measure  $z \gtrsim 9$  LF, and see if it's fundamentally different from the  $z \lesssim 8$  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  $z \simeq 1-2$ ) may cause significant boosting by gravitational lensing at  $z \gtrsim 8-10$ .

- This could change the landscape for JWST observing strategies.

## (5) Predicted Galaxy Appearance for JWST at $z \simeq 1-15$

NGC 3310



ESO0418-008



UGC06471-2



### Ultraviolet Galaxies

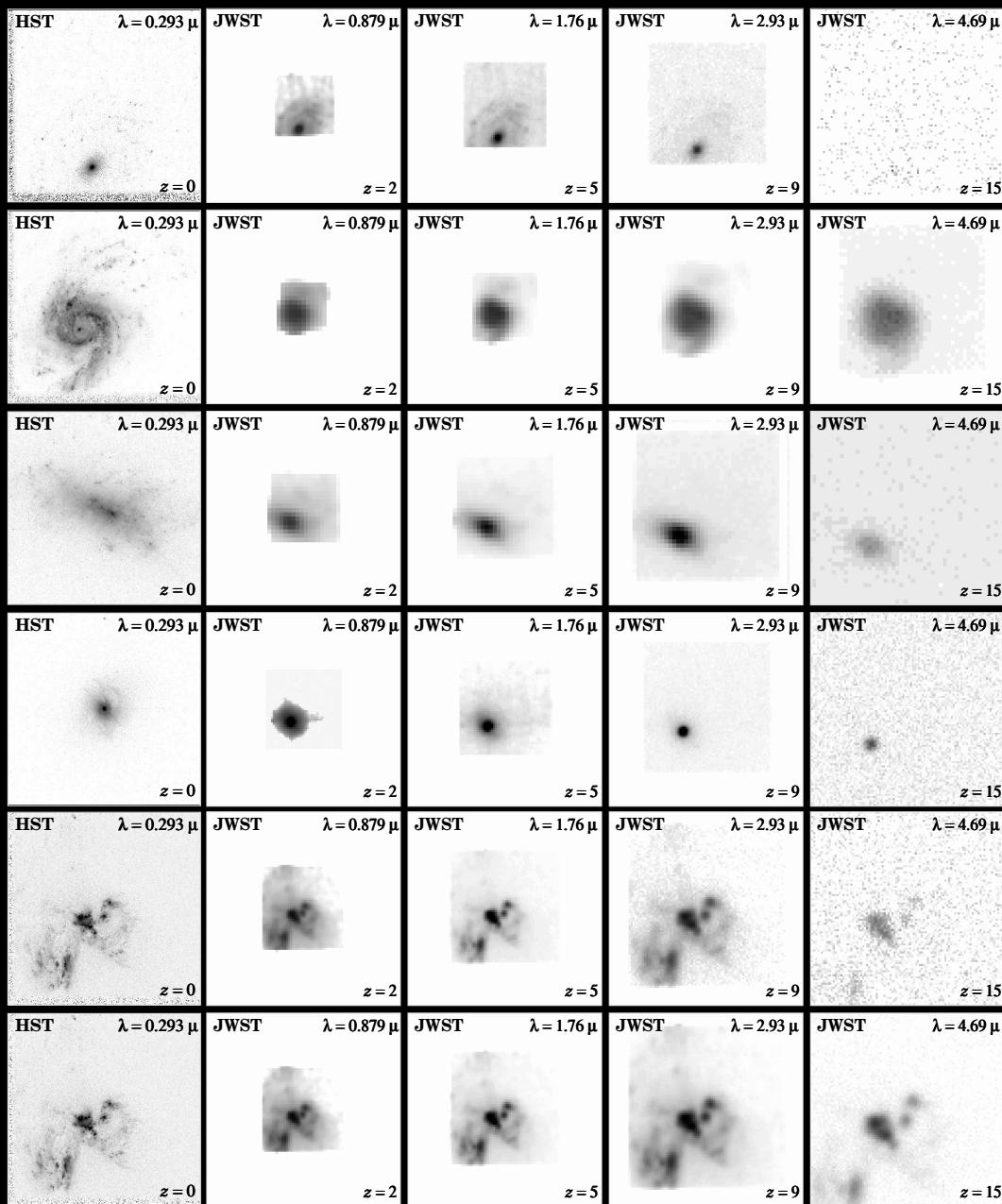
HST • WFPC2

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

## (5) Predicted Galaxy Appearance for JWST at $z \simeq 1-15$ (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

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

- Passed Mission Preliminary Design Review (PDR) in 2008, & Mission CDR in 2010. No technical showstoppers. Management replan in 2011.
- More than 75% of JWST H/W built, & meets/exceeds specs as of 11/11.

(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 this decade:

- 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

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What you can do to help save JWST — Web-links:

Thanks to Spain for your JWST support letters!

<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/>

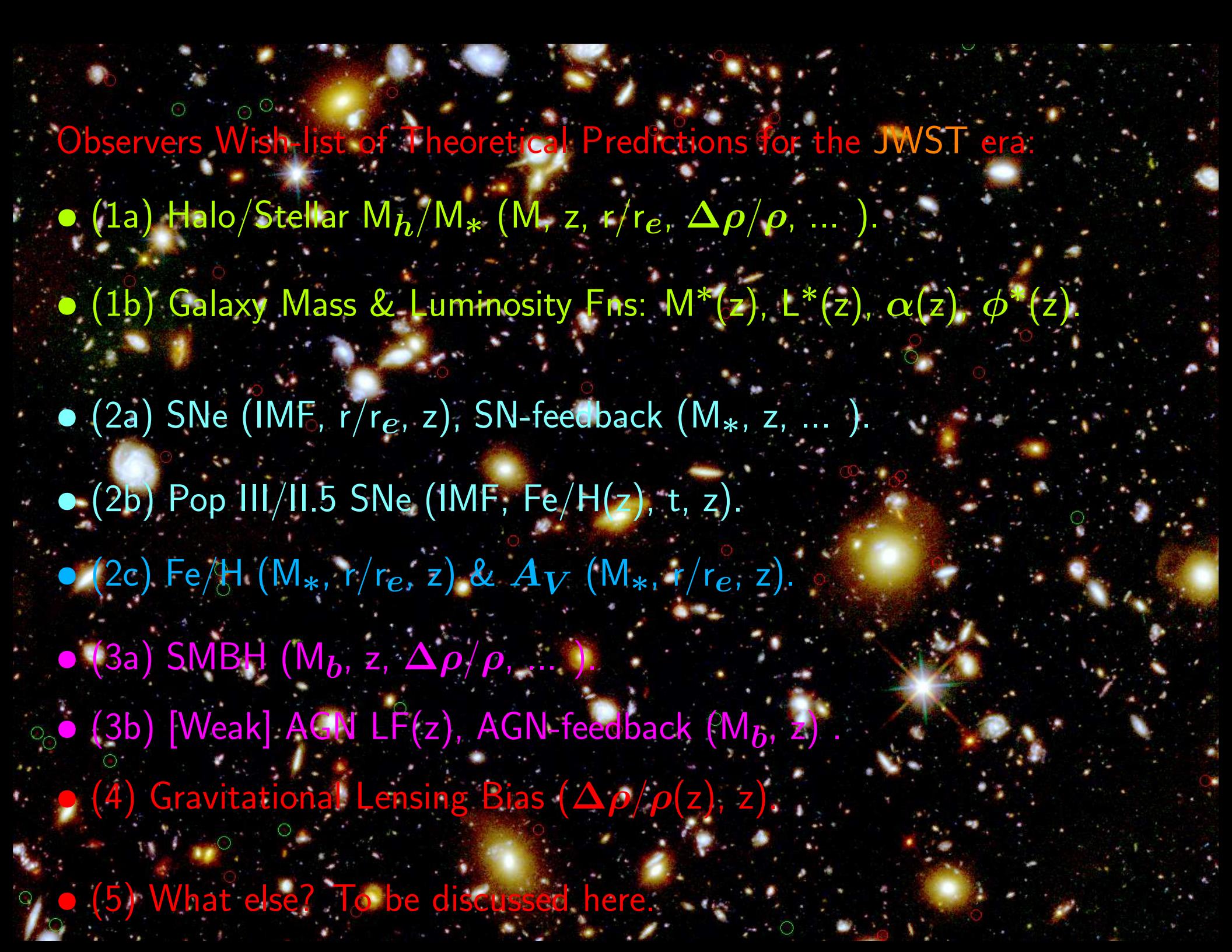
<http://www.change.org/petitions/do-not-cancel-funding-for-the-james-webb-space-telescope>

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]



## 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? To be discussed here.

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



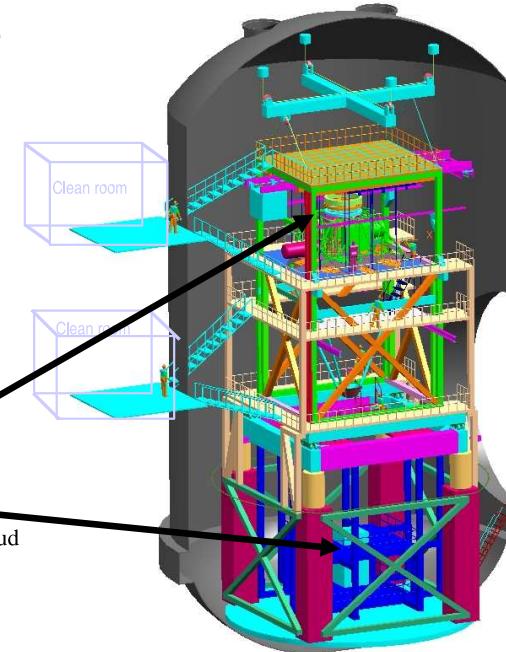
Most recent Tower Design shows an Inner Optical Tower supported by a Outer structure with Vibration Isolation at the midplane. Everything shown is in the 20K region (helium connections, etc. not shown) except clean room and lift fixture.

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)

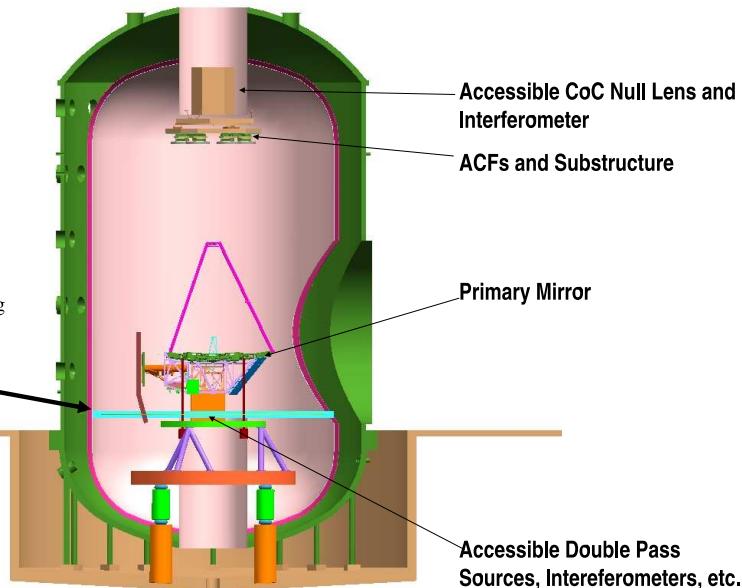


No Metrology Tower and Associated Cooling H/W. External Metrology

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:

- ≈2003: Reduction from 8.0 to 7.0 to 6.5 meter. Ariane-V launch vehicle.
- 2005: Eliminate costly 0.7-1.0  $\mu\text{m}$  performance specs (kept 2.0  $\mu\text{m}$ ).
- 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.

# 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



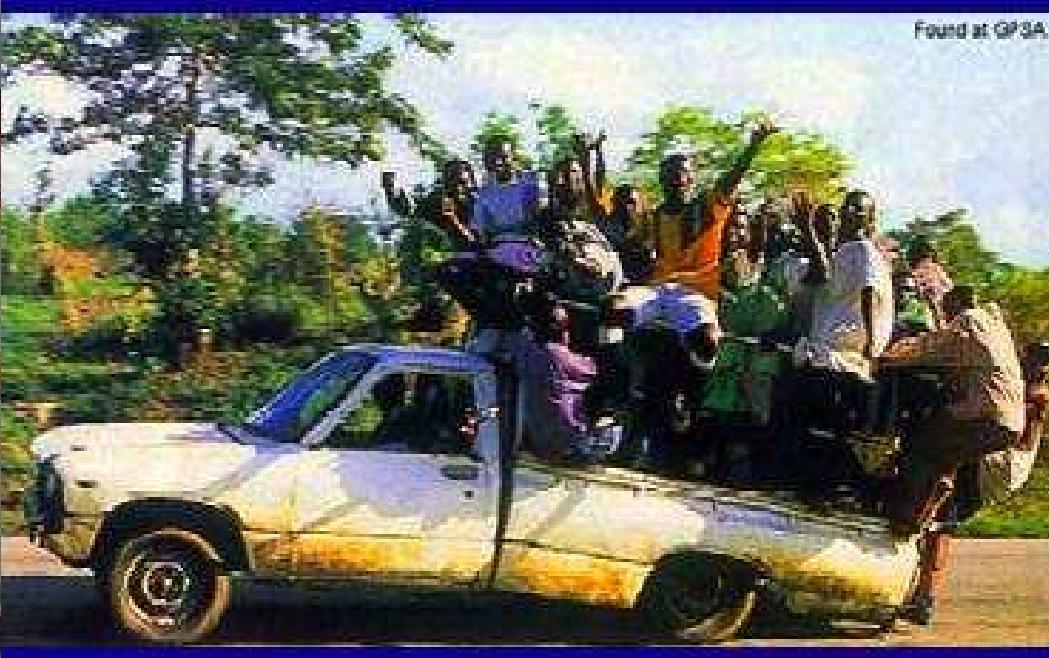
What the Scientists See:



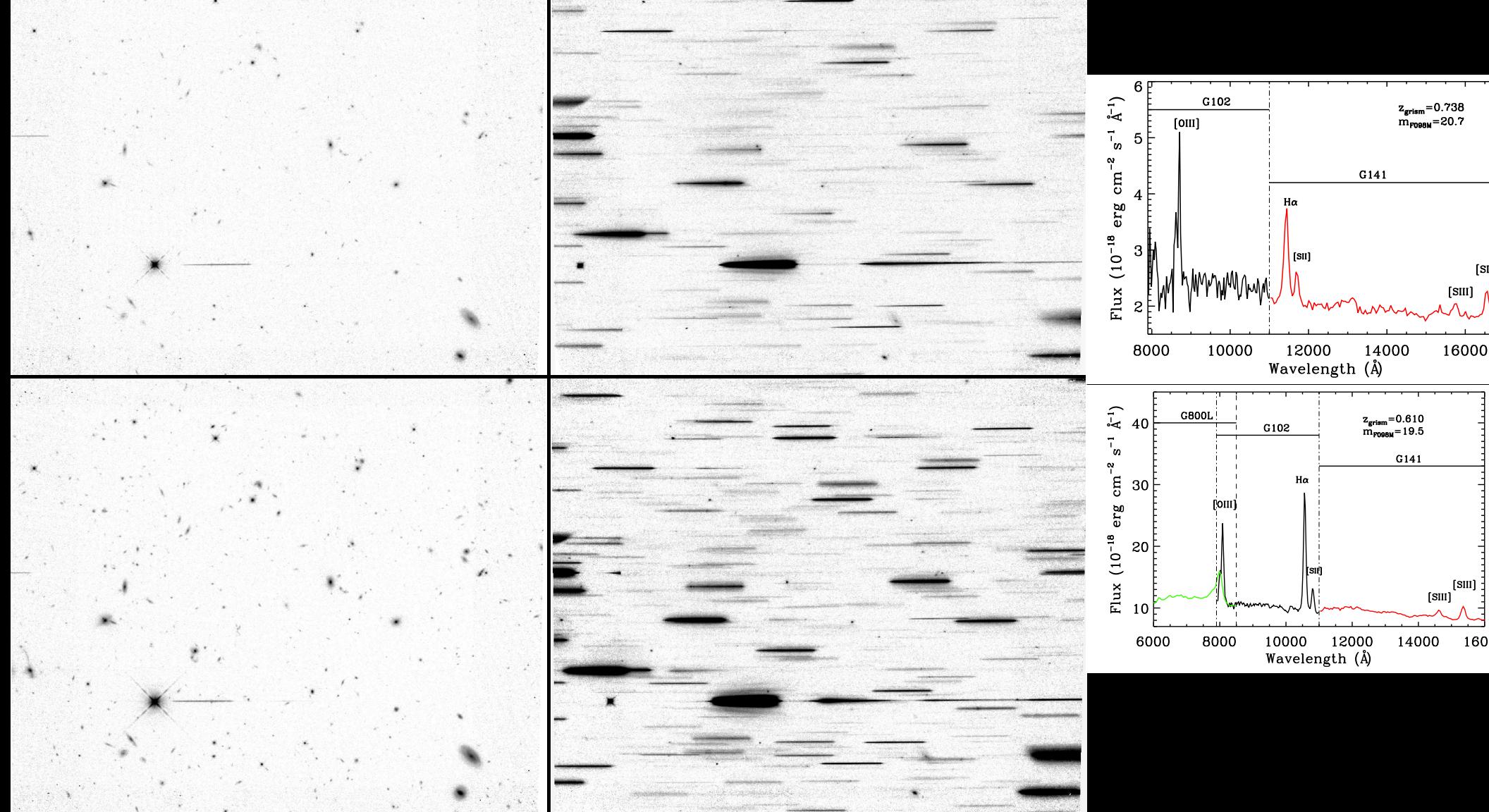
What the Project Manager Sees:



The Happy Balance



Found at OP3A.



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

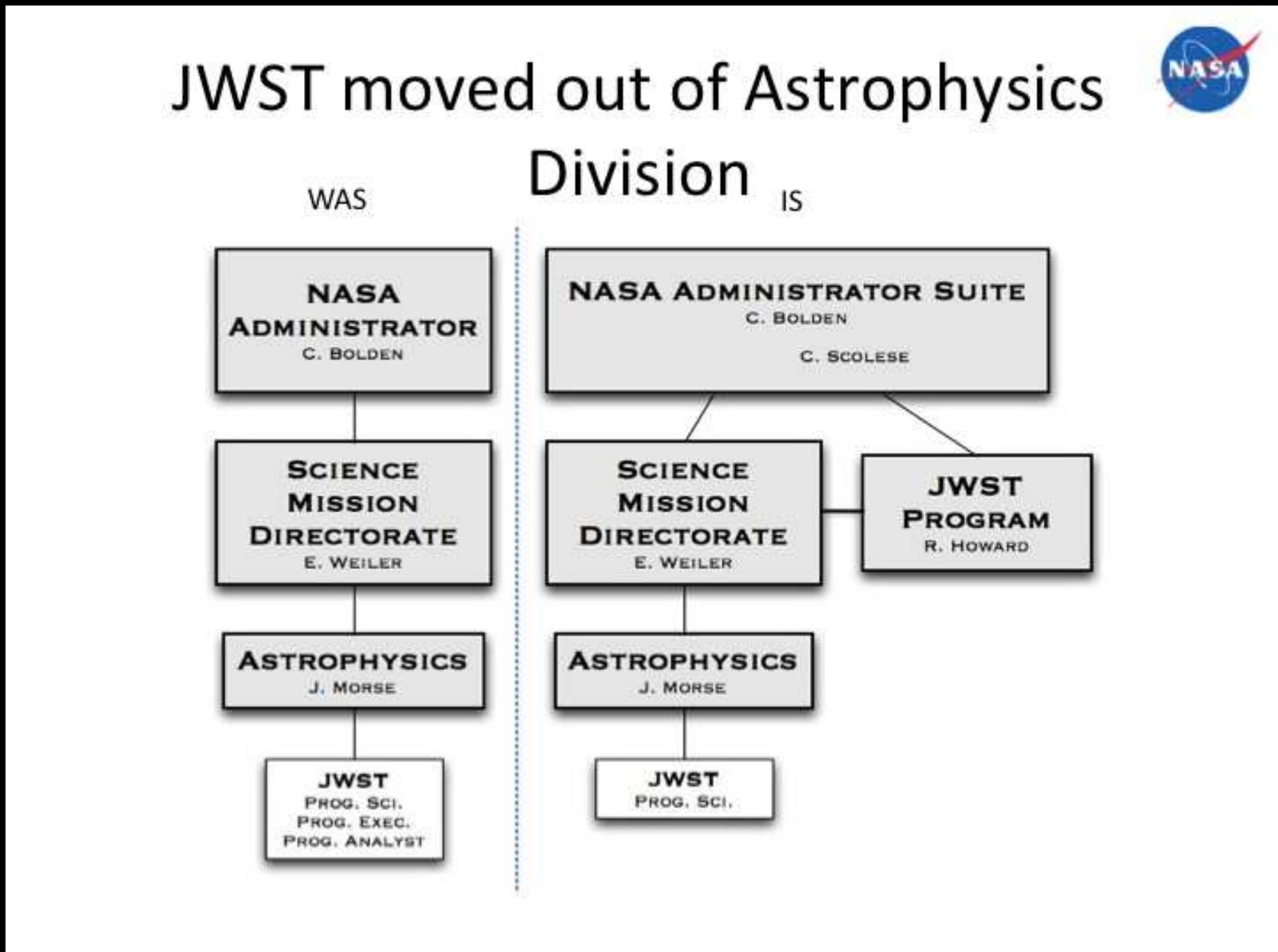
IR grism spectra from space: unprecedented new opportunities in astrophysics.

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

# THE JAMES WEBB SPACE TELESCOPE

## THE JWST SUNSHIELD

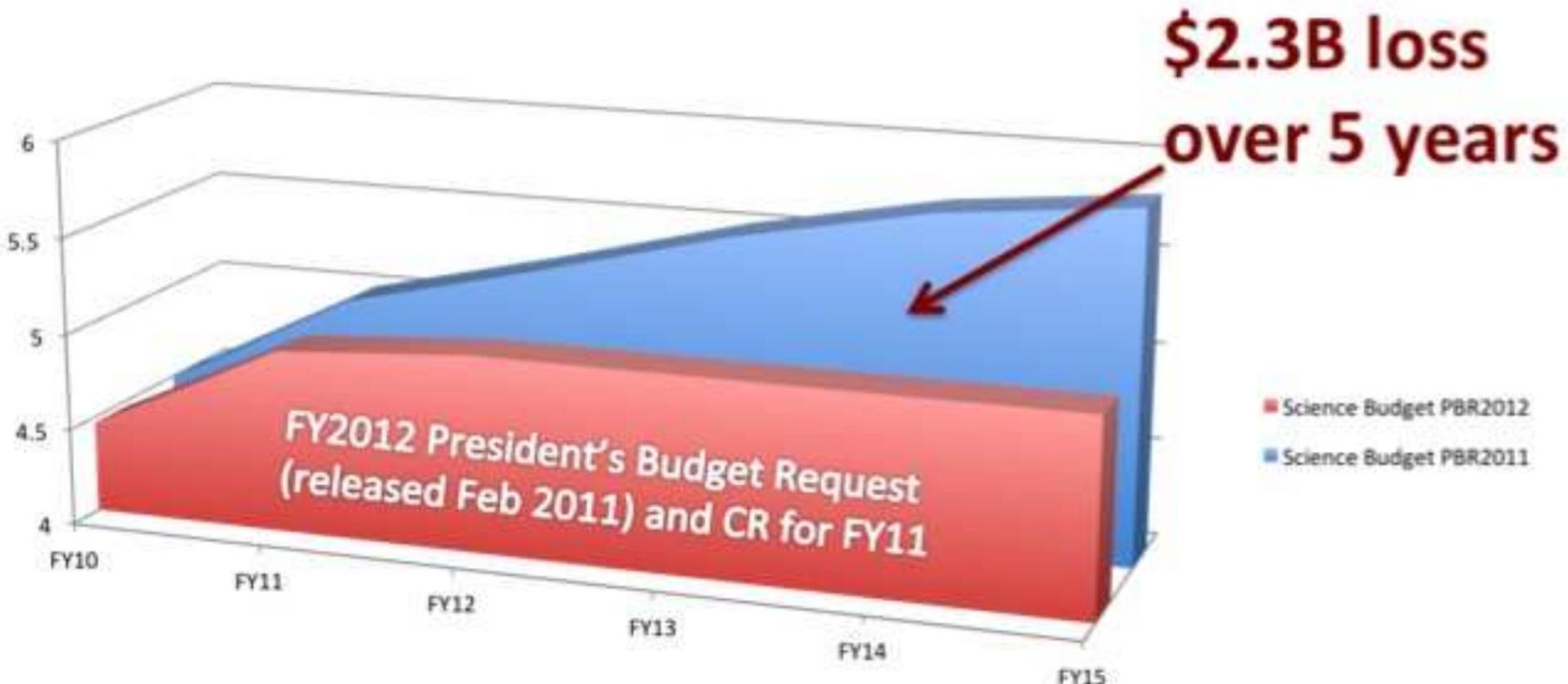




NASA HQ Reorg: JWST budget no longer comes directly from SMD/Ap.

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

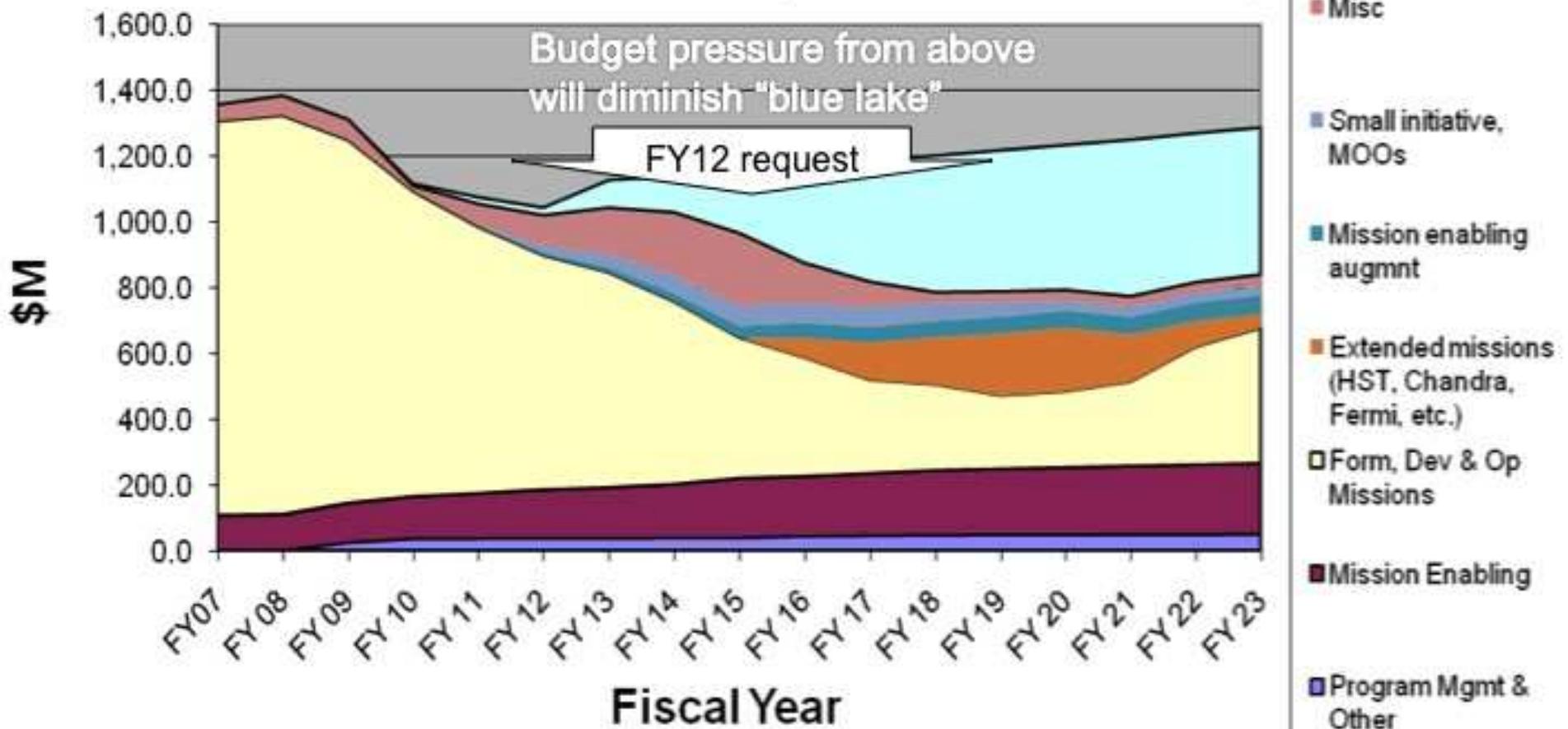
Science Budget Picture as seen in 2011 vs 2010



NASA science Budget flat beginning 2012

NASA Space Science has external budget pressures independent of JWST.

## Astrophysics FY2010 President's Budget and Estimates for 2011 - 2023 (with notional offsets)



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

GALEX |

SPIRE

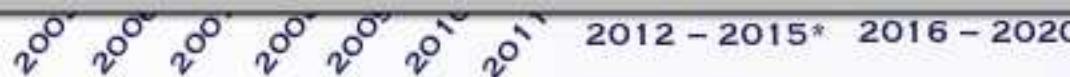
CHARISMA

SWEET

K2

HERA

- 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

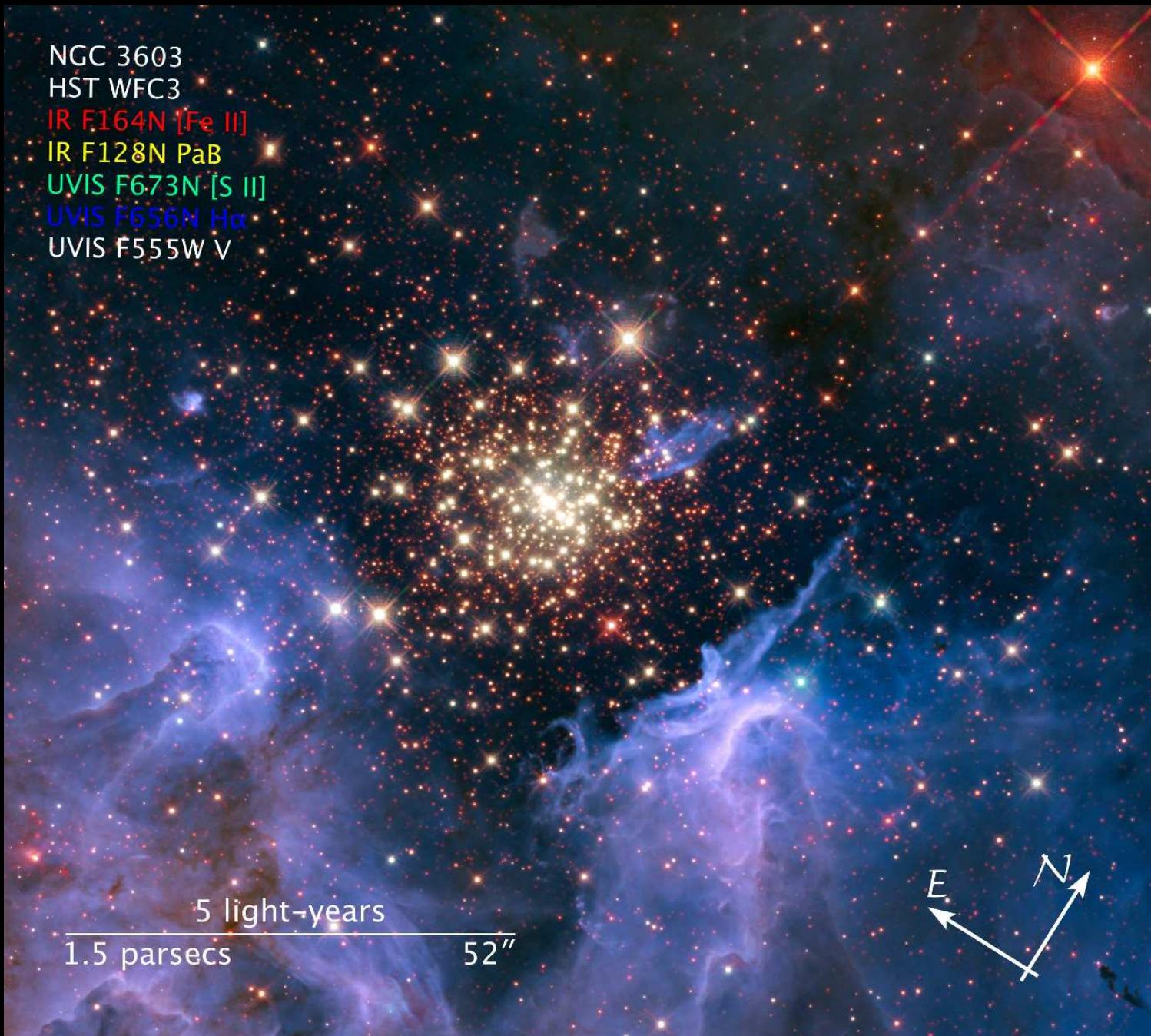
NASA Great Observatories had enormous impacts last two decades:  
NASA must keep a healthy mix of big, medium and small space missions.

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



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

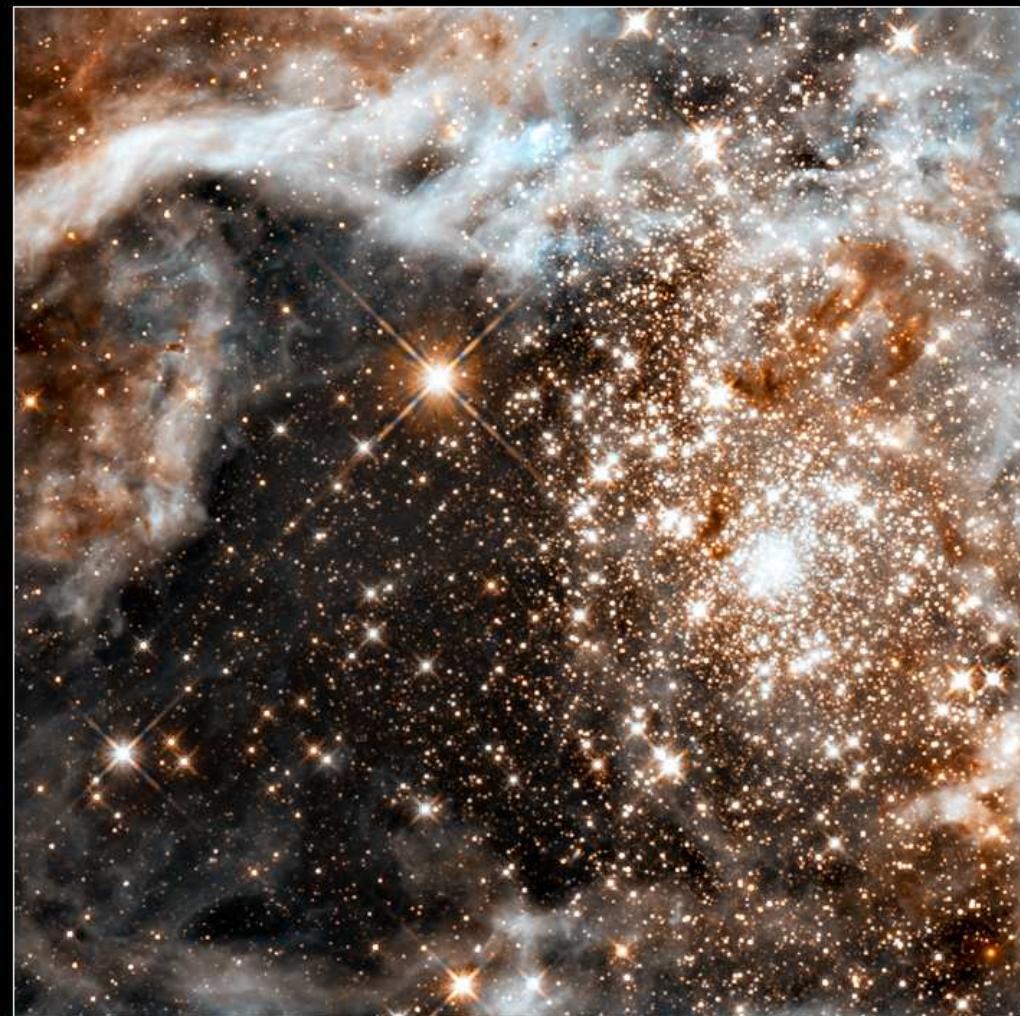
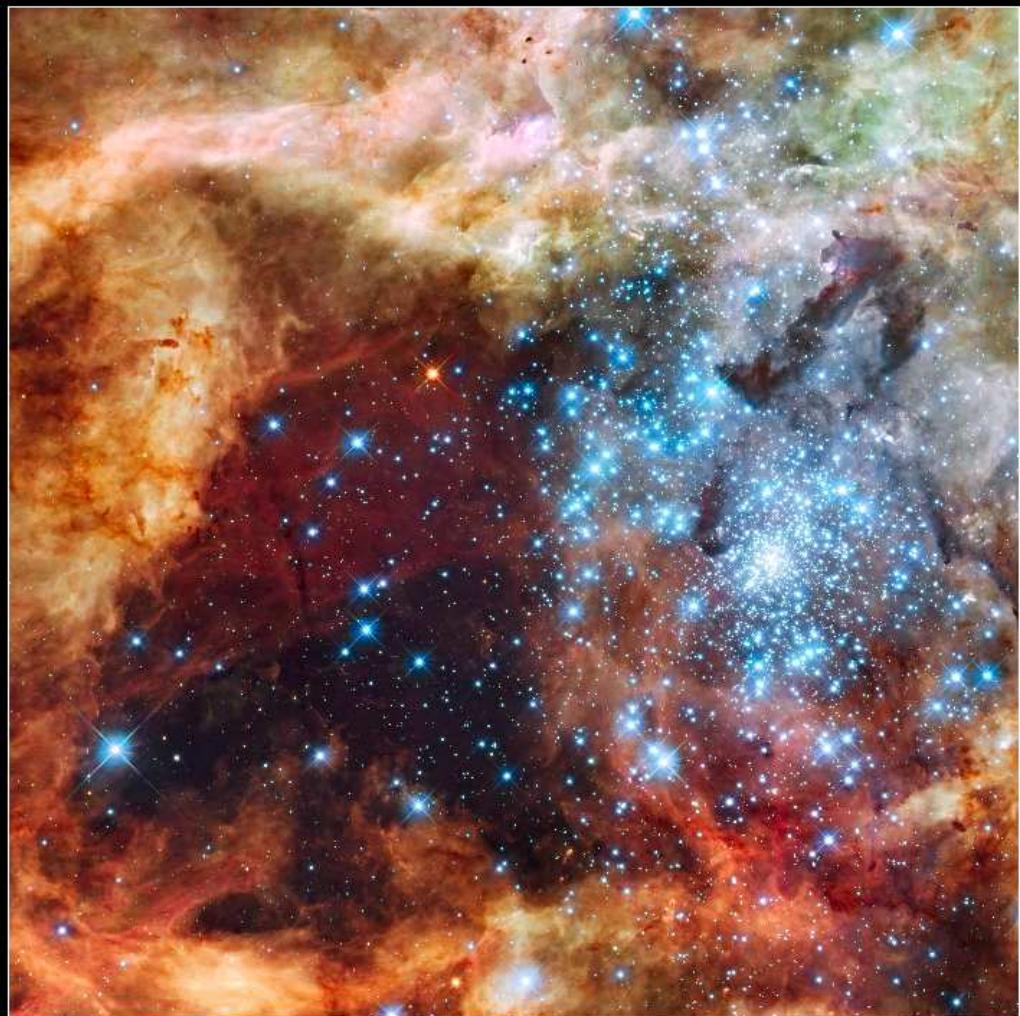
## (7) How can JWST measure Earth-like exoplanets?



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

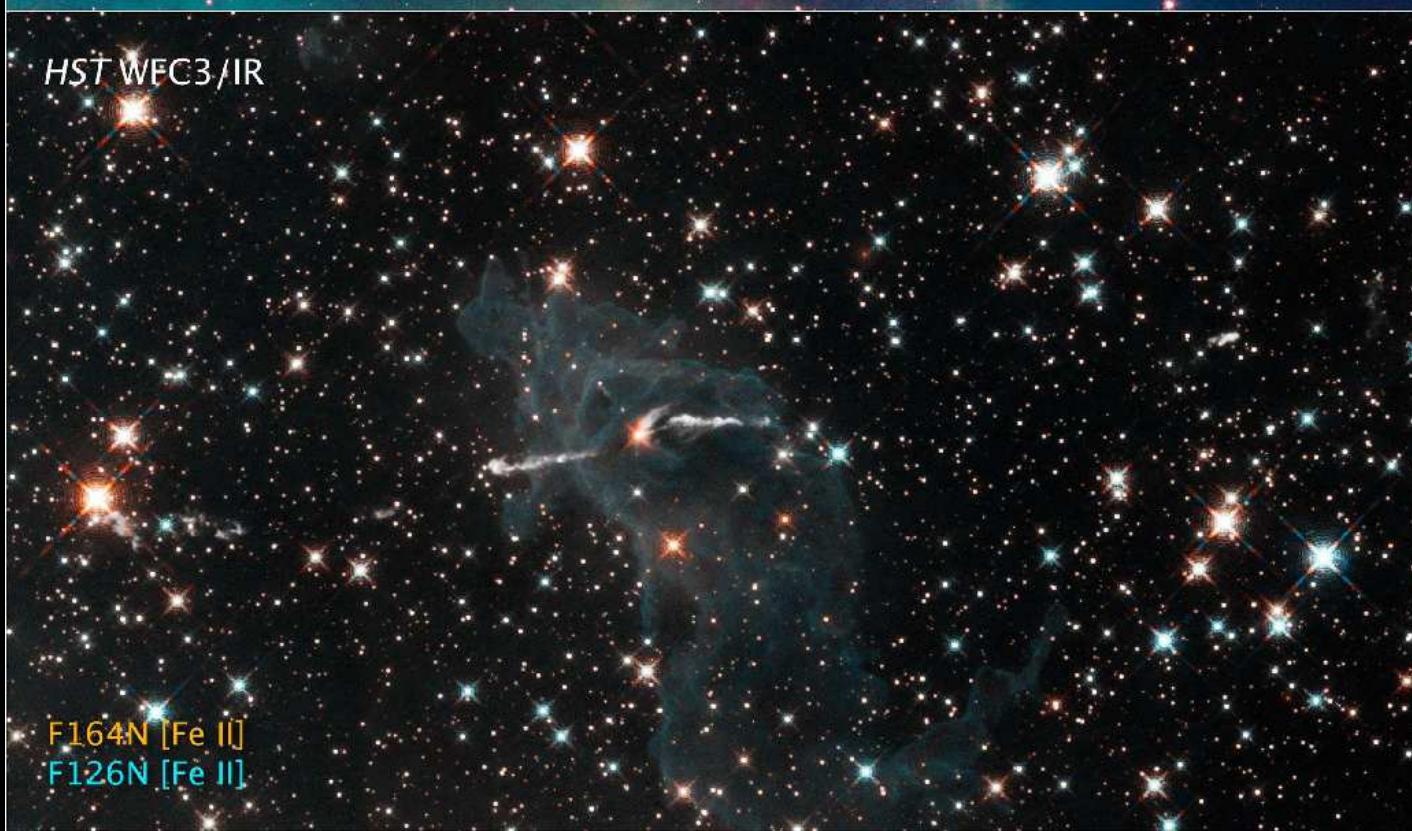
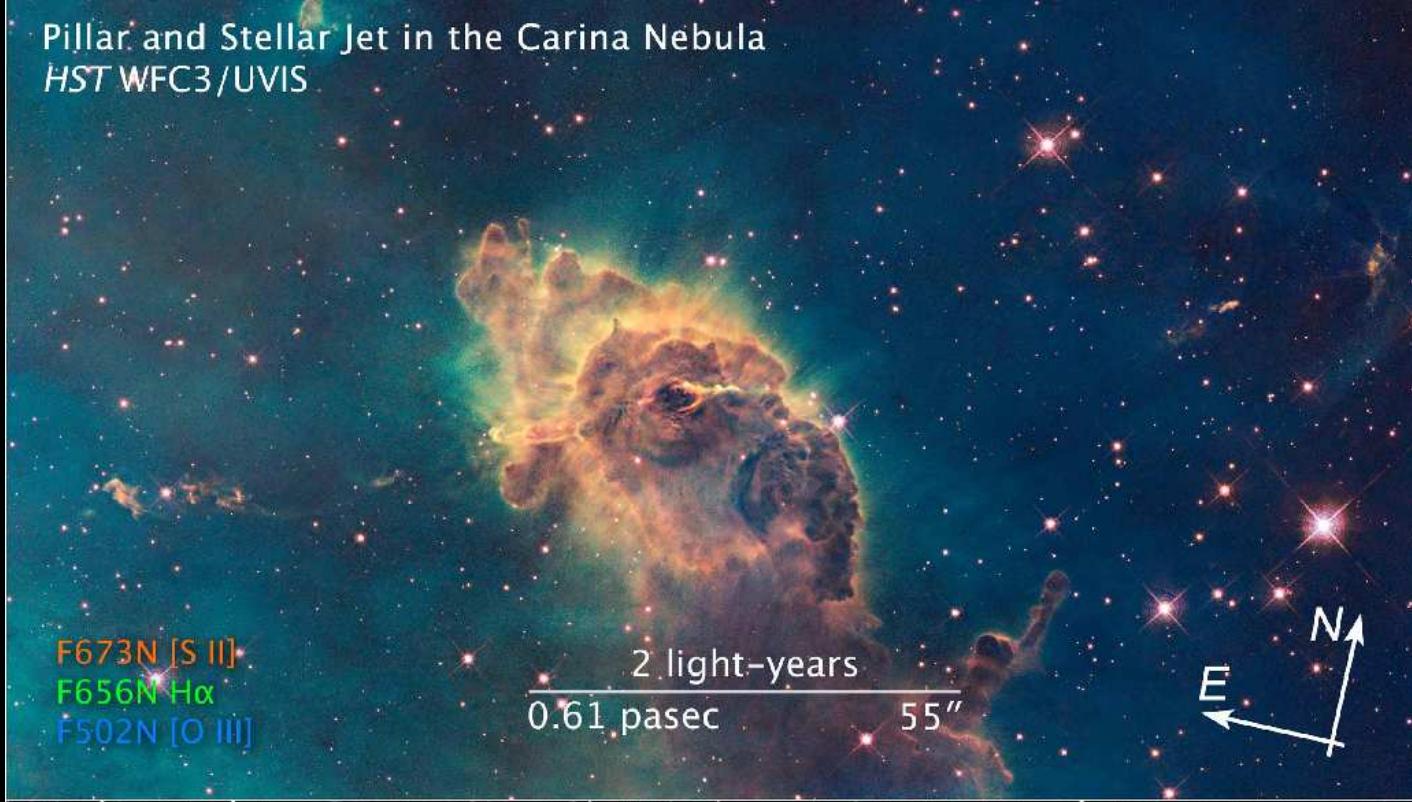
STScI-PRC09-32b

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

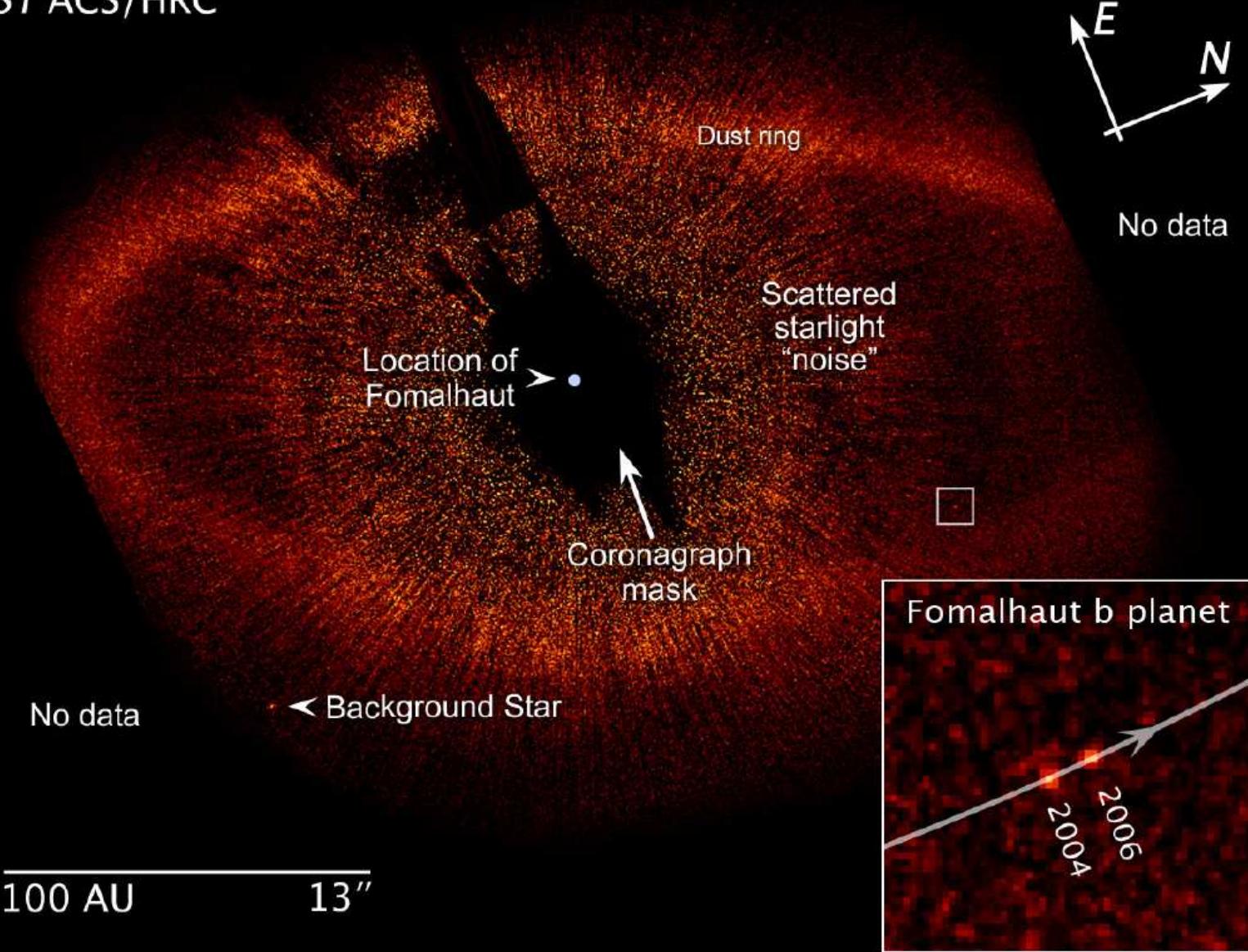




Pillar and Stellar Jet in the Carina Nebula  
HST WFC3/UVIS

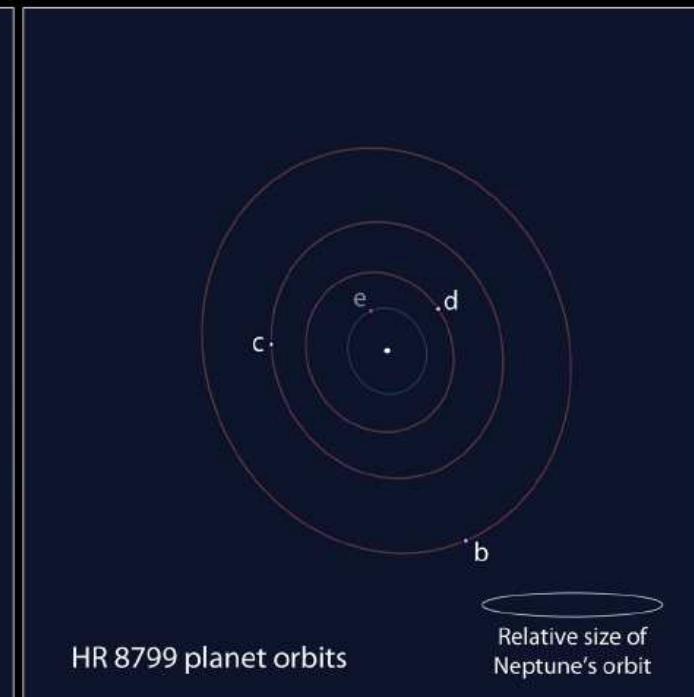
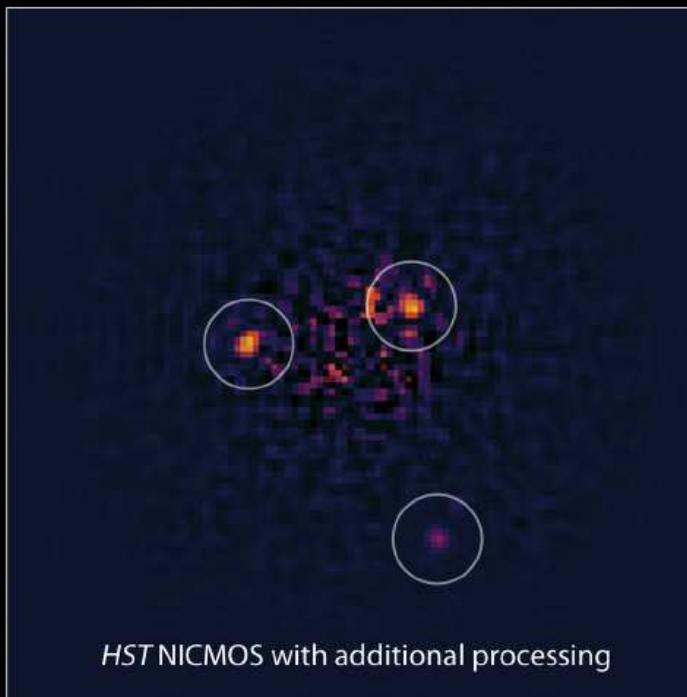
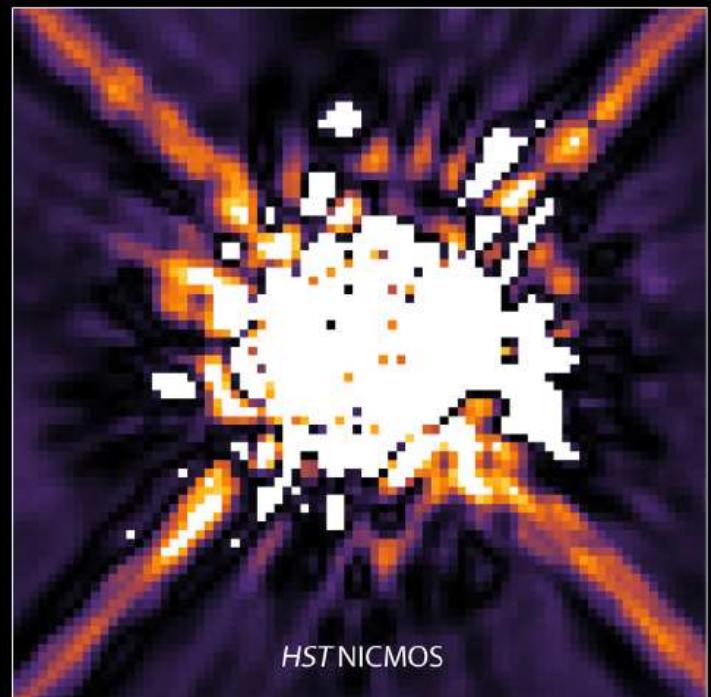


Fomalhaut  
HST ACS/HRC



HST/ACS Coronograph 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



NASA, ESA, and R. Soummer (STScI)

STScI-PRC11-29

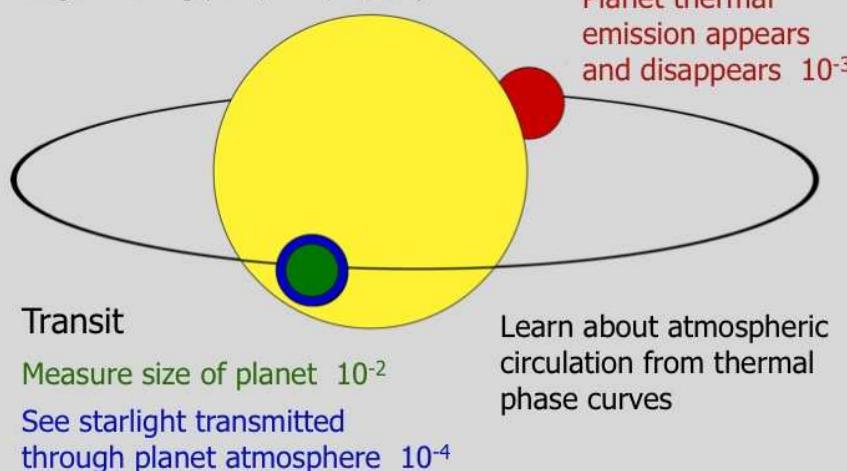
HST/NICMOS imaging of planetary system around the (carefully subtracted) star HR 8799: Direct imaging of planets around a nearby star!

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

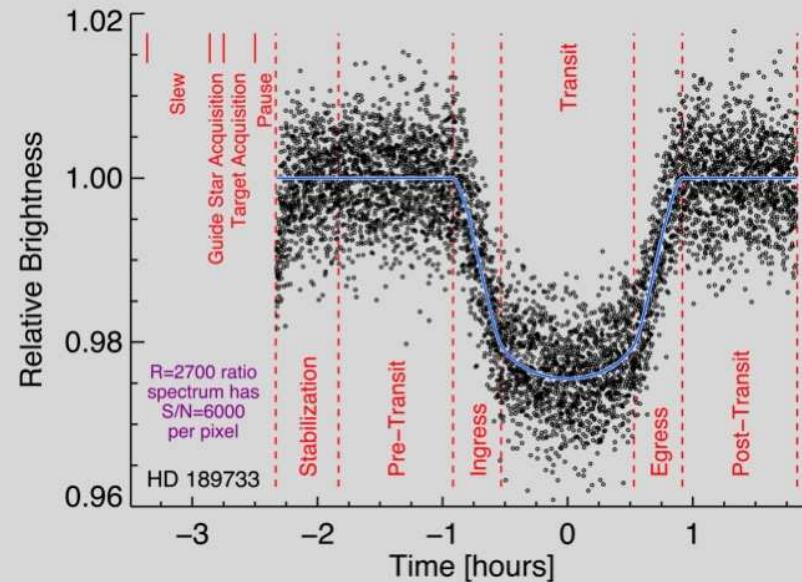
JWST can find such planets much closer in for much farther-away stars!

## Schematic of Transit and Eclipse Science

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

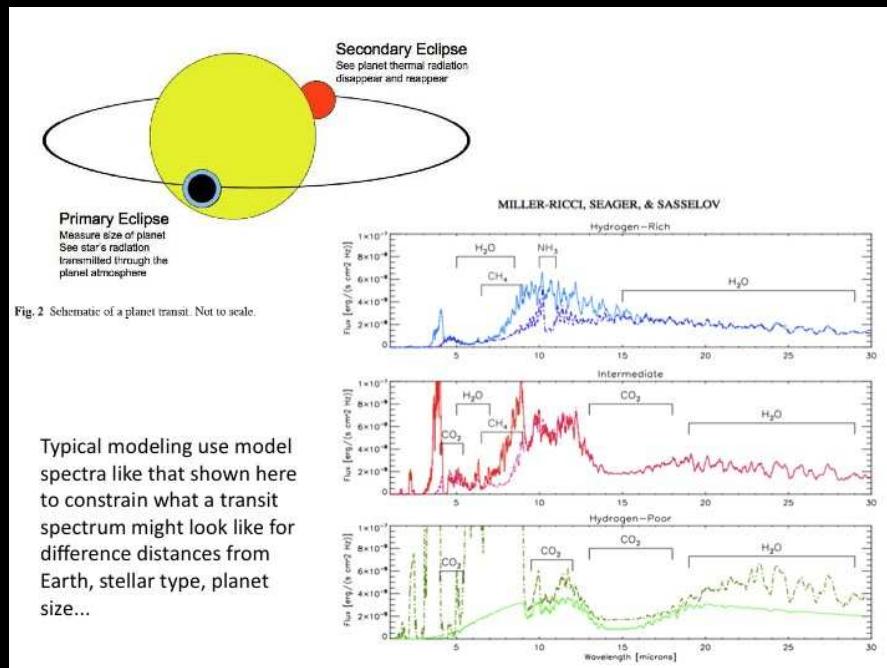


## Timeline of a Transit Observation



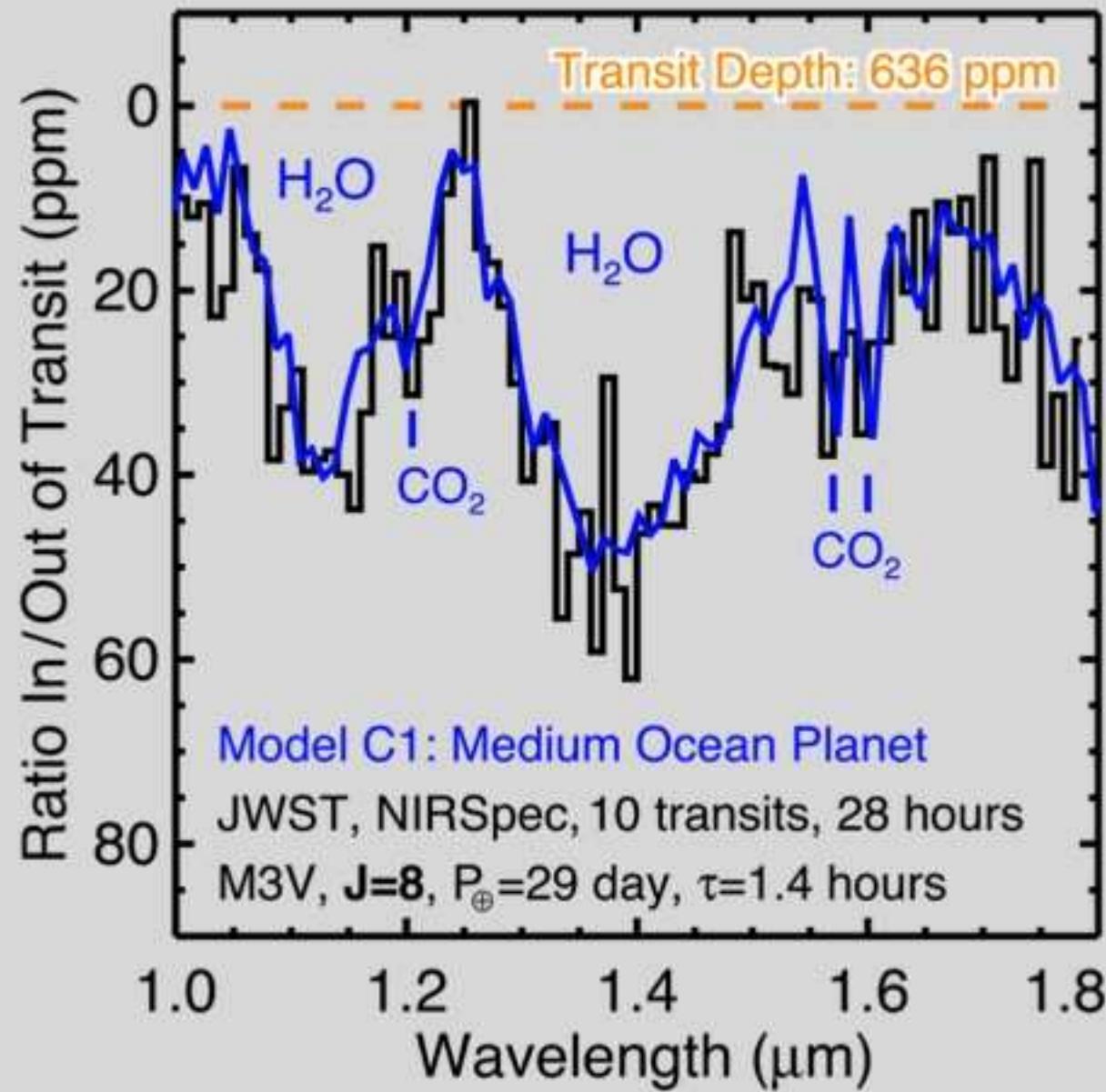
13

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



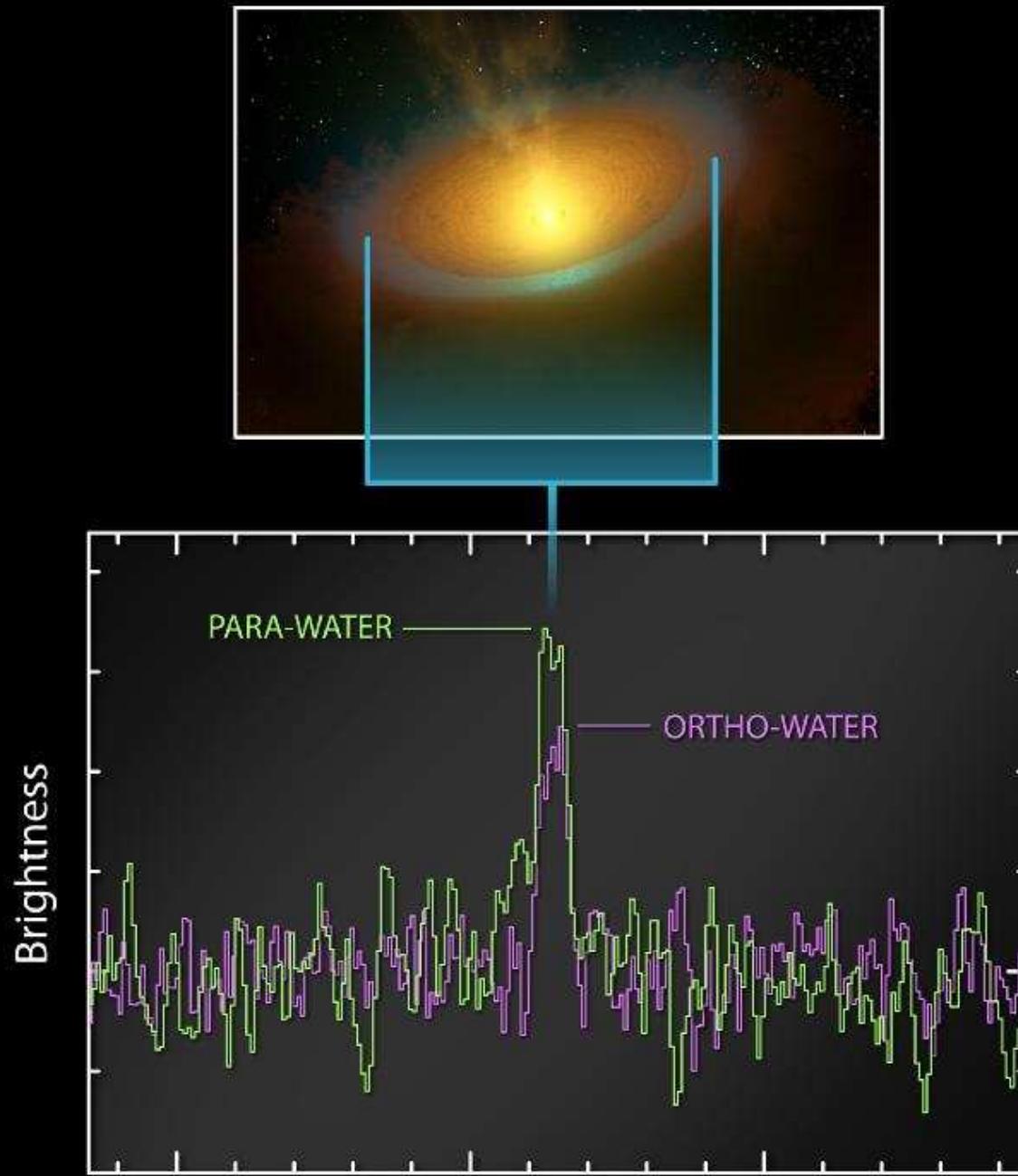
JWST IR spectra can find water and  $\text{CO}_2$  in Earth-like exoplanets.

# Transit Spectrum of Habitable “Ocean Planet”



17

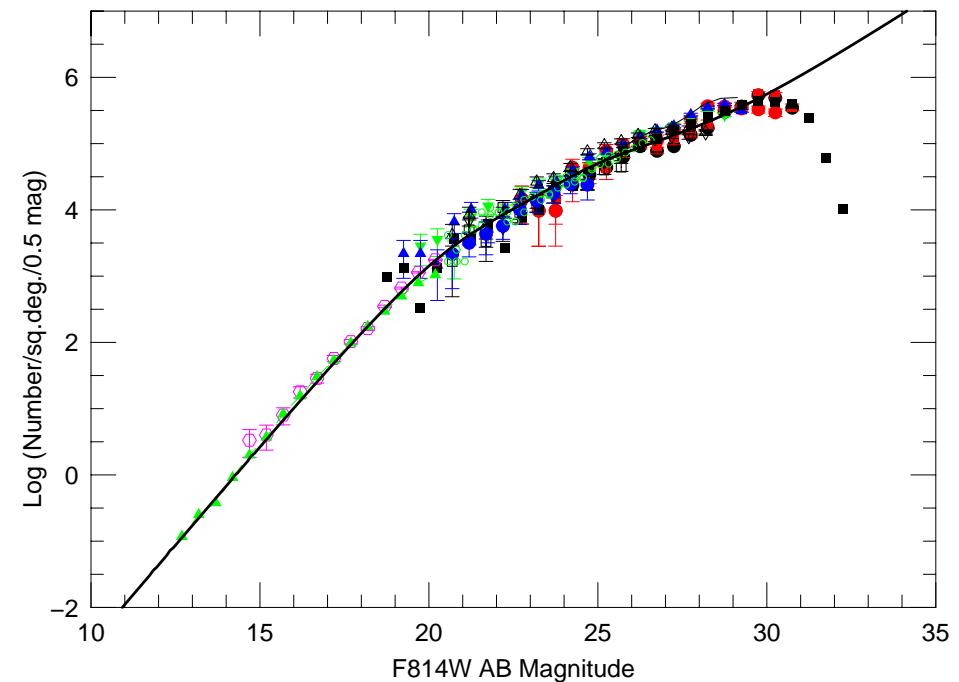
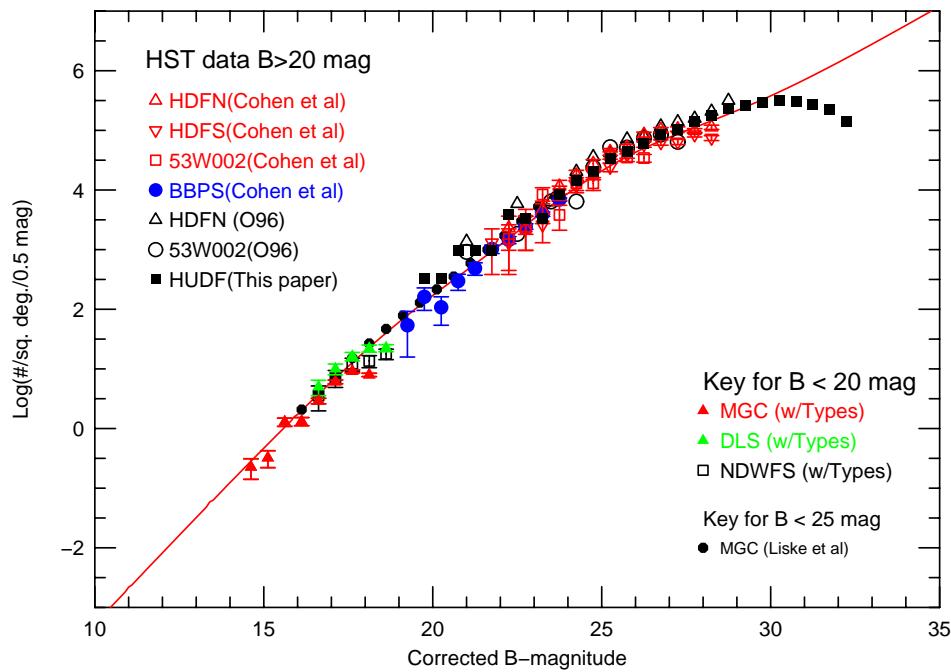
JWST IR spectra can find water and  $\text{CO}_2$  in transiting Earth-like exoplanets.



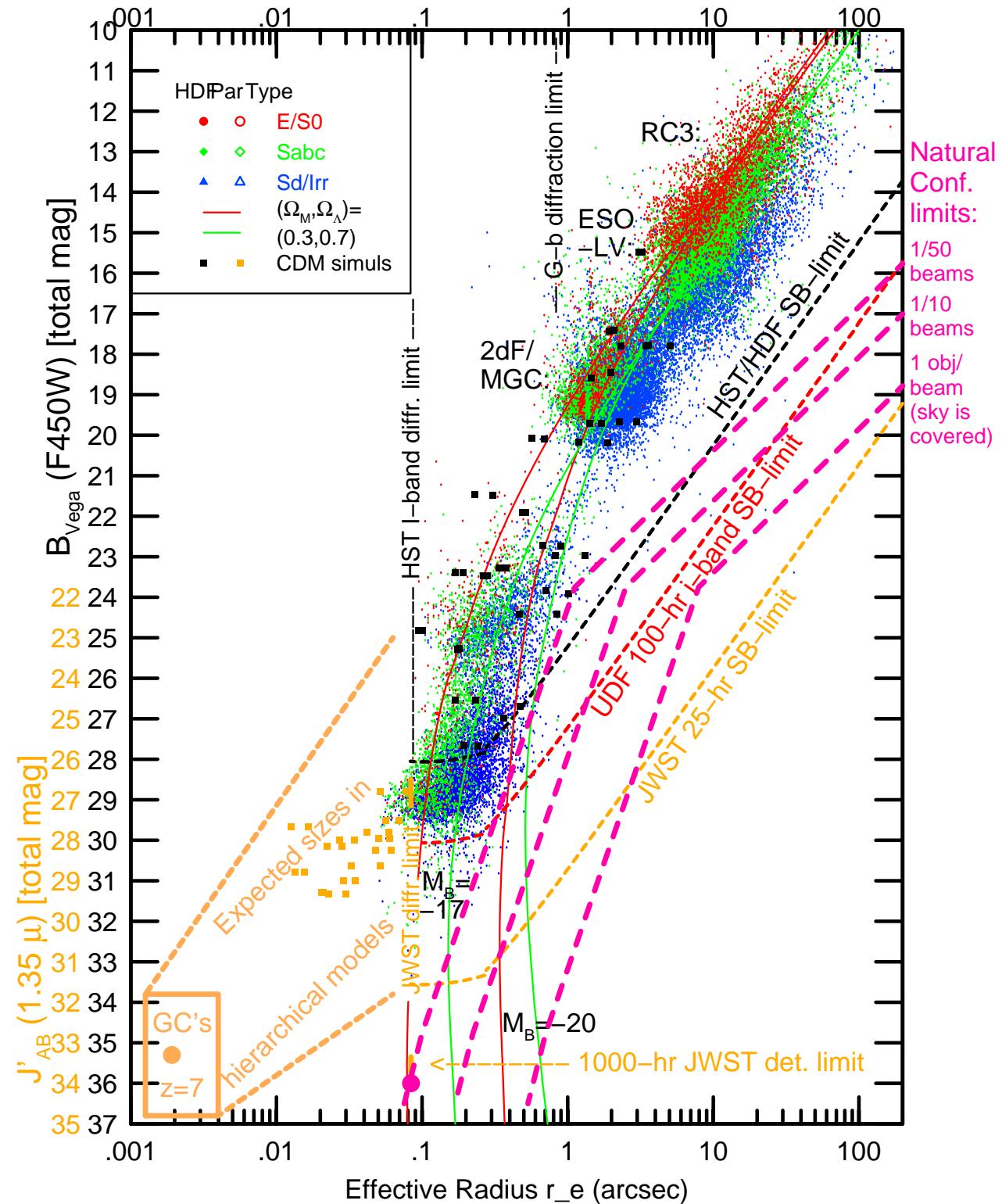
Herschel Finds Oceans of Water in Disk of Nearby Star: <http://www.nasa.gov/herschel>

JWST IR spectra can map water directly in exoplanet debris disks.

# 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/ $\text{deg}^2$  to AB=31.5 mag ( $\simeq 1 \text{ nJy}$  at optical wavelengths). JWST and SKA will see similar surface densities to  $\simeq 1$  and  $10 \text{ nJy}$ , resp.
- ⇒ Must carry out JWST and SKA nJy-surveys with sufficient spatial resolution to avoid object confusion (from HST: this means FWHM  $\lesssim 0\farcs08$ ).
- ⇒ Observe with JWST/NIRSpec/MSA and SKA HI line channels, to disentangle overlapping continuum sources in redshifts space.



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  $2 \times 10^6$  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]

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