Koo-l Panchromatic Astronomy: Past, Present, and Future

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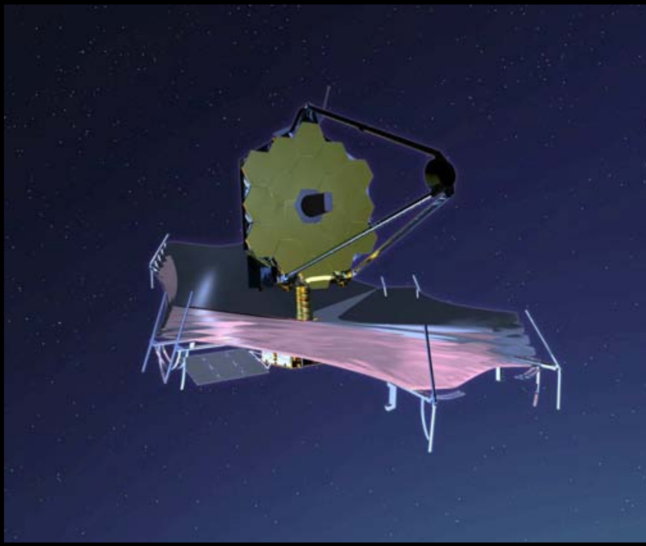
KPNO 1970's-1980's

HST $\gtrsim$2002–2009



JWST $\gtrsim$201?

Review at the UC Galaxy Workshop "Koo-fest 2011", UC Santa Cruz, Monday Aug. 8, 2011

Outline: Koo-l Panchromatic Astronomy: Past, Present, & Future

PAST: David Koo's multi-band KPNO 4m work in the 1980's.

PRESENT: Recent panchromatic imaging with the HST WFC3.

New tools to measure Galaxy Assembly from $z \simeq 8$–10 to $z \simeq 0$.
[See also talks by S. Faber, G. Illingworth, and many others here.]

FUTURE: Panchromatic near–mid-IR imaging with JWST:

- (1) JWST update: $\gtrsim$75% of hardware procured or completed.
- (2) How JWST can measure First Light (z=10–20) & Reionization.
- (3) Conclusions
- Appendix 1: Predicted Galaxy Appearance for JWST at $z \simeq 1$–15.

Sponsored by NASA/JWST & HST

ASU ARIZONA STATE UNIVERSITY

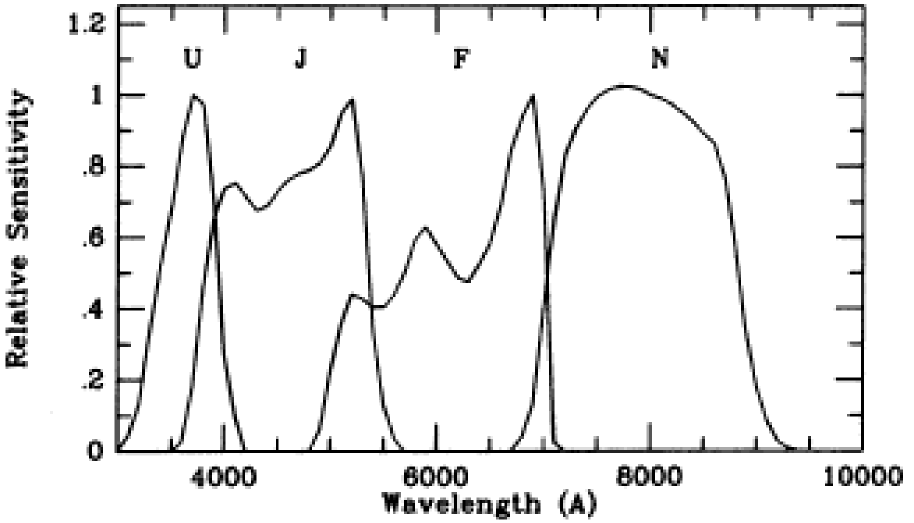
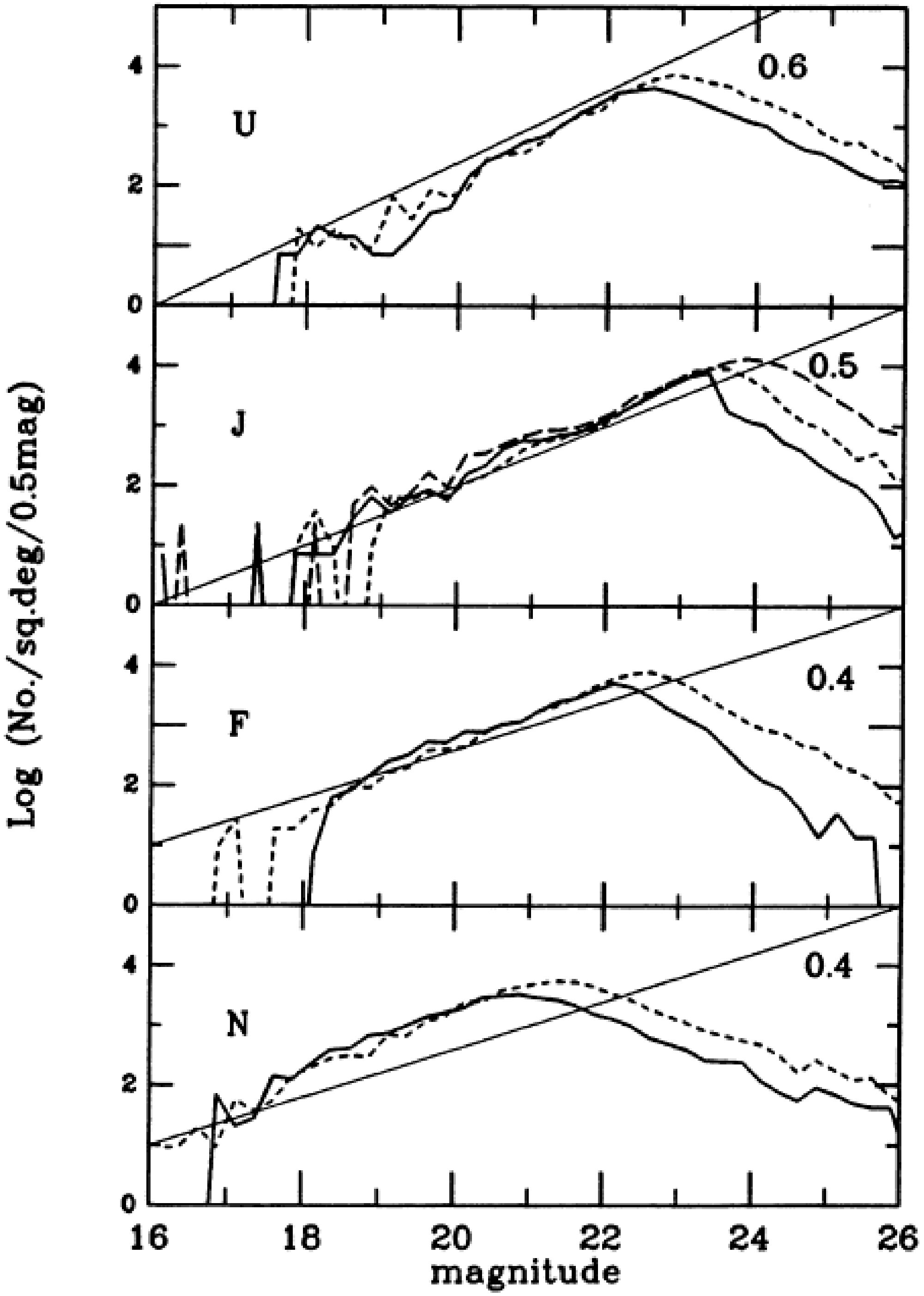


FIG. 1.—Response functions for bandpasses *U*, *J*, *F*, and *N*. See § III for a description of the derivation of the *U* and *N* bands. See Kron (1980*a*) for the *J* and *F* bands.

MULTICOLOR PHOTOMETRY OF FIELD GALAXIES



Koo 1985, AJ, 90, 418 &
Koo 1986, ApJ, 311, 651

4m Mayall plates with
with four filters: UJ^+FN,
reaching UJ^+~24 mag,
and FN~23–22 mag.

Panchromatic galaxy counts understood as changing type mix vs. epoch.

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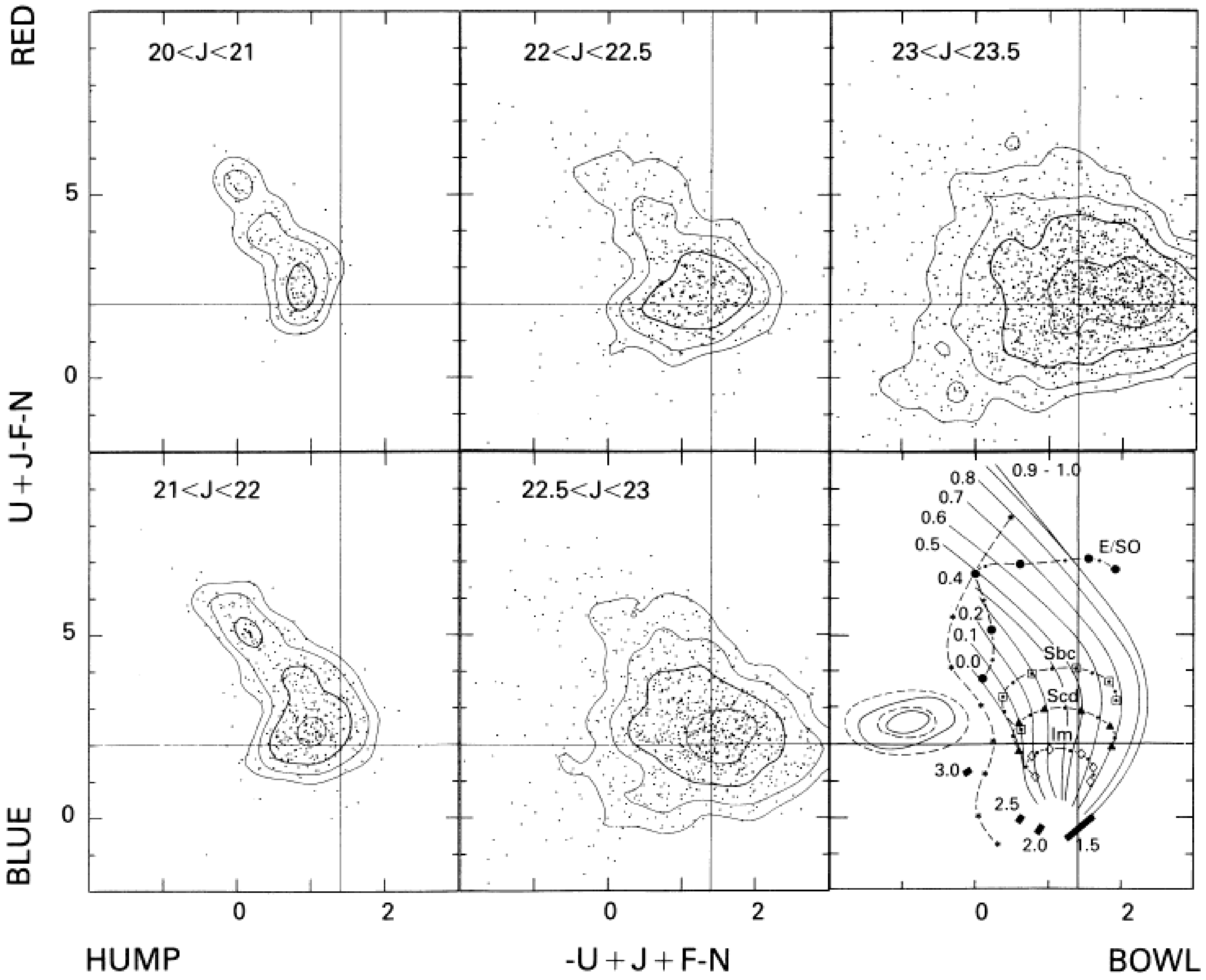


FIG. 9c

Koo (1985, 1986): UJ$^+$FN can disentangle SED-type and redshift for z≃0–1.

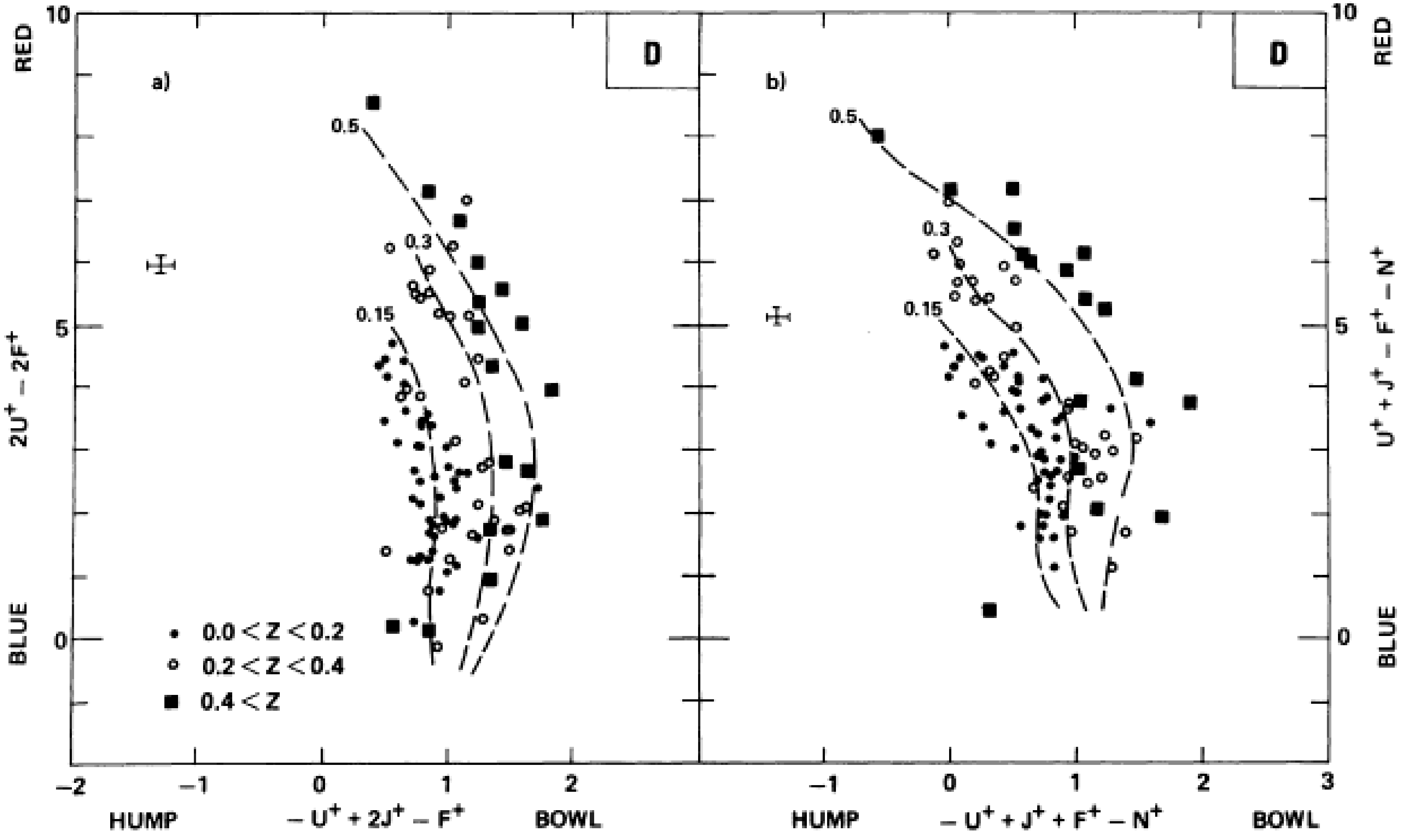


FIG. 5. Color-shape plots [*UF* for (a) and *UJFN* for (b)] showing positions of all galaxies in Table IV with redshifts measured from low-resolution spectra. The data are divided into three redshift intervals, dark dots for redshifts *z* less than 0.20, light circles for redshifts *z* between 0.2 and 0.4, and dark squares for larger redshifts, to demonstrate the segregation of galaxies of different redshifts in these color-color plots. Dashed lines marked with the redshift are the predictions from the no-evolution model D. Error bars show typical errors of the data of 0.1 mag in each of the axes.

Koo (1985, 1986): UJ^+FN actually disentangles SED-type and z for $z \lesssim 0.5$.

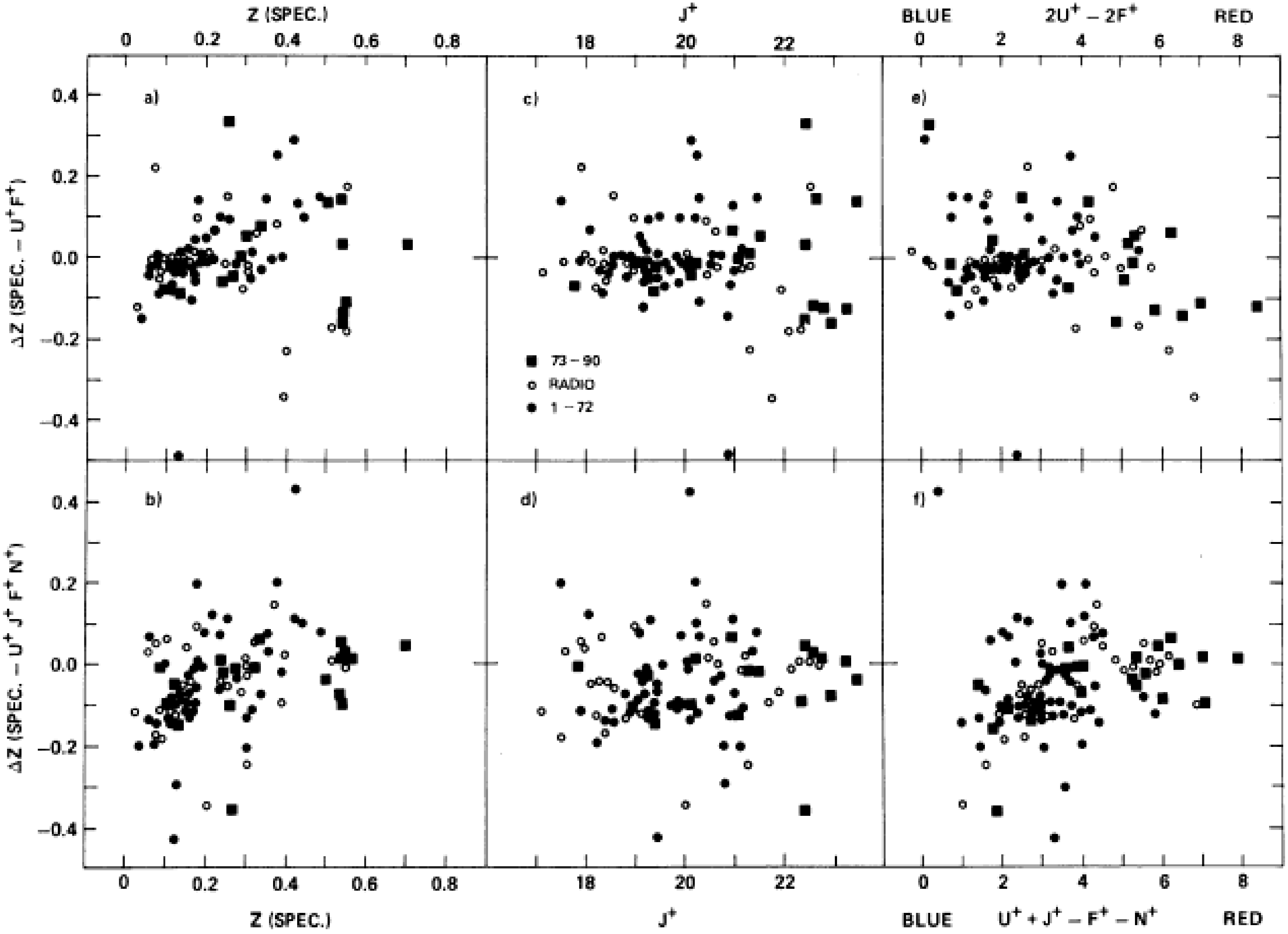
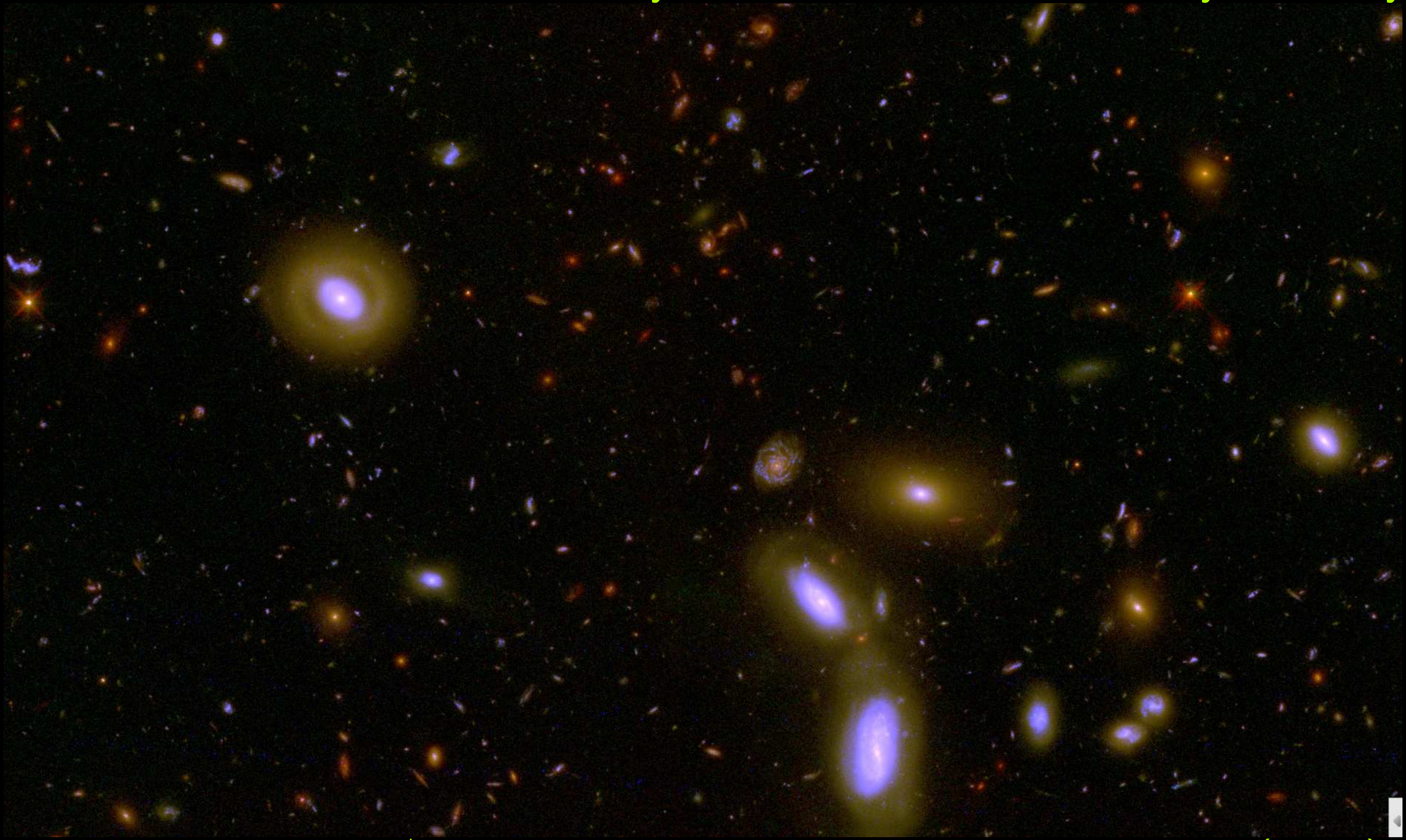


FIG. 7. Differences between spectroscopic redshifts and those estimated from broadband colors (as determined from either the *UF* or the *UJFN* color-shape diagrams) are plotted against the spectroscopic redshifts (a,b), apparent blue magnitudes J^+ (c,d), and colors (e,f). Dark dots are for galaxies with spectroscopic redshifts from Turner, Gunn, and Sargent (1981); light circles are for radio galaxies from Kron, Koo, and Windhorst (1984) or Windhorst *et al.* (1985); dark squares are for galaxies with redshifts measured by H. Spinrad, R. Kron, and the author.

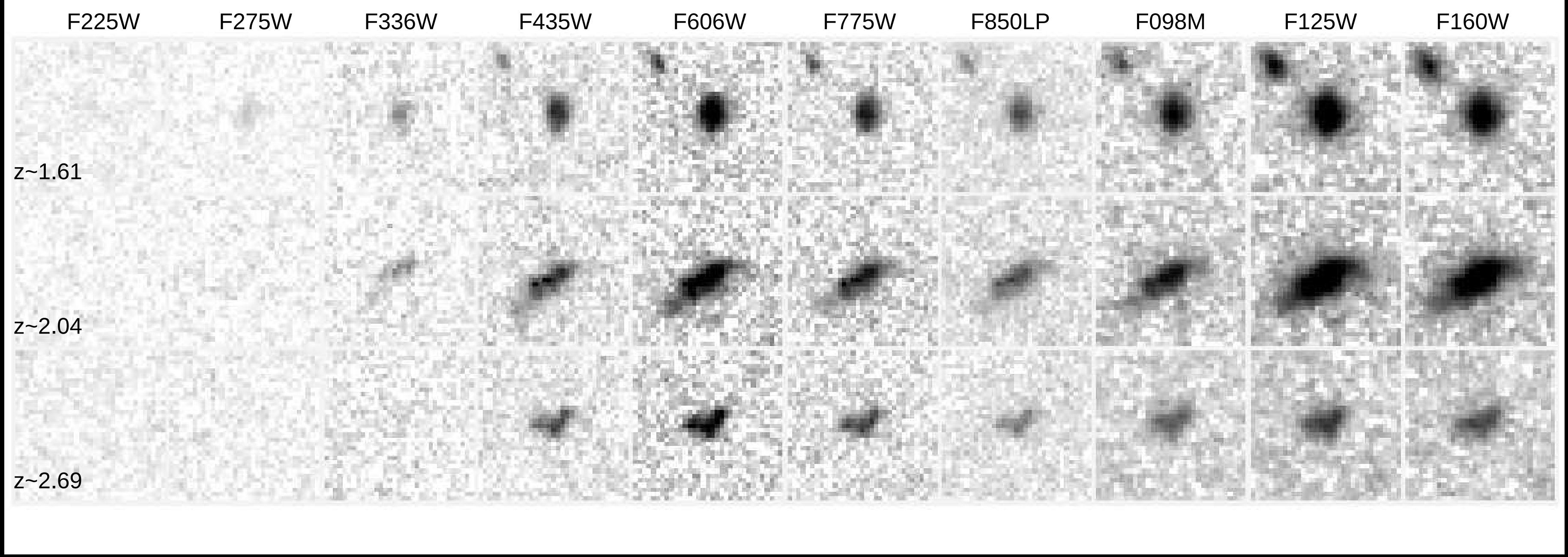
Koo (1985, 1986): first believable photoz's with $\sigma(\Delta z)/(1+z) \lesssim 0.05$.

PRESENT: Panchromatic Astronomy with the HST WFC3: Galaxy Assembly

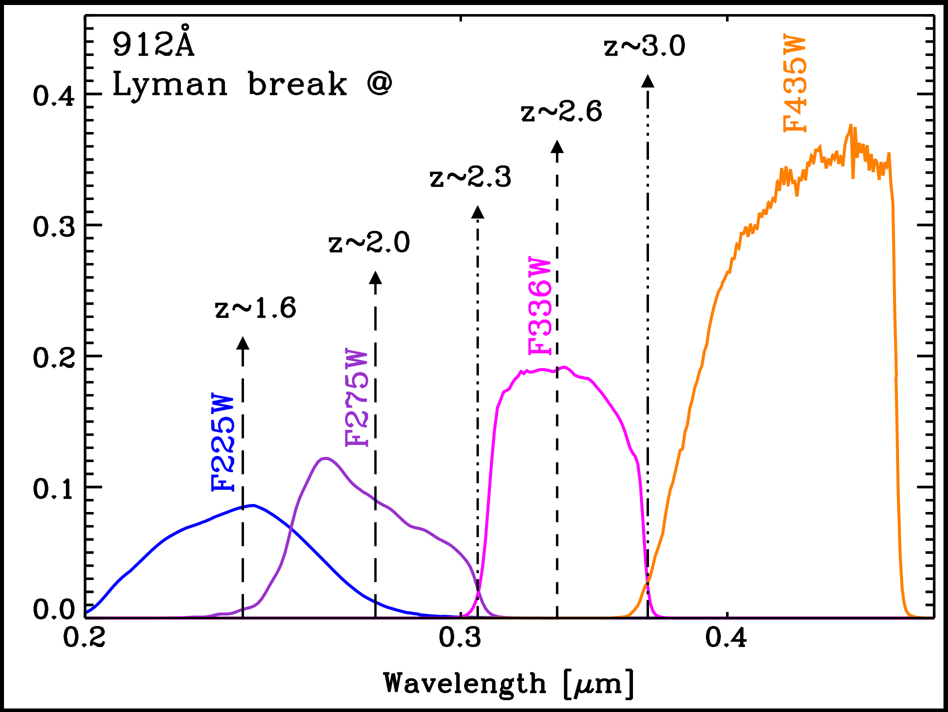


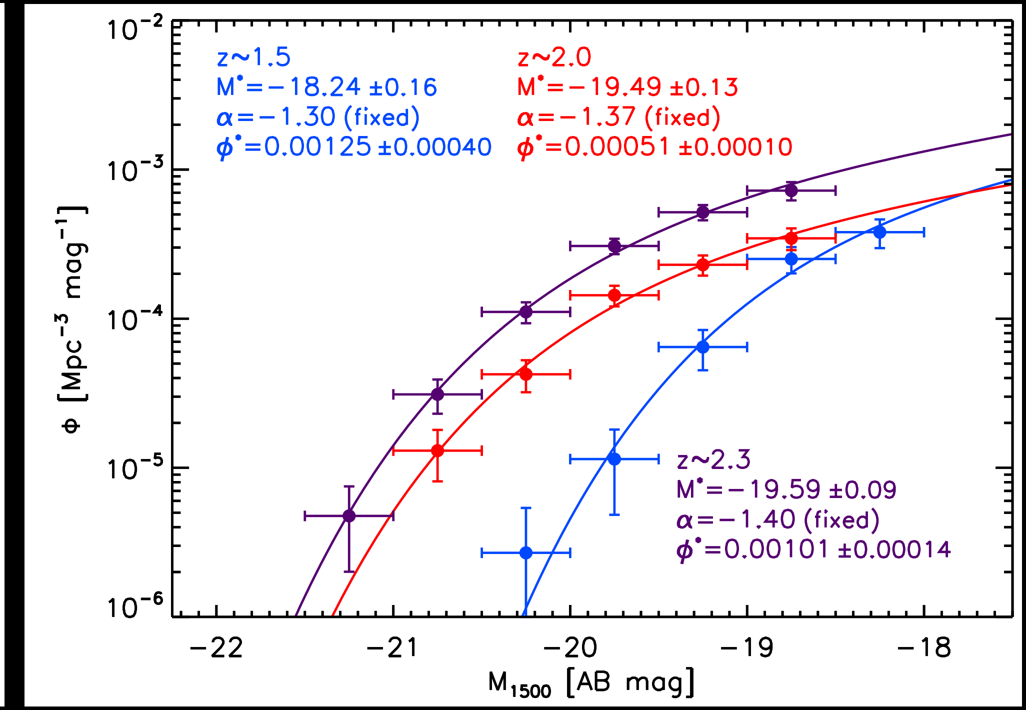
10 filters with HST/WFC3 & ACS reaching AB=26.5-27.0 mag (10-σ) over 40 arcmin^2 at 0.07–0.15" FWHM from 0.2–1.7μm (UVUBVizYJH).

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.

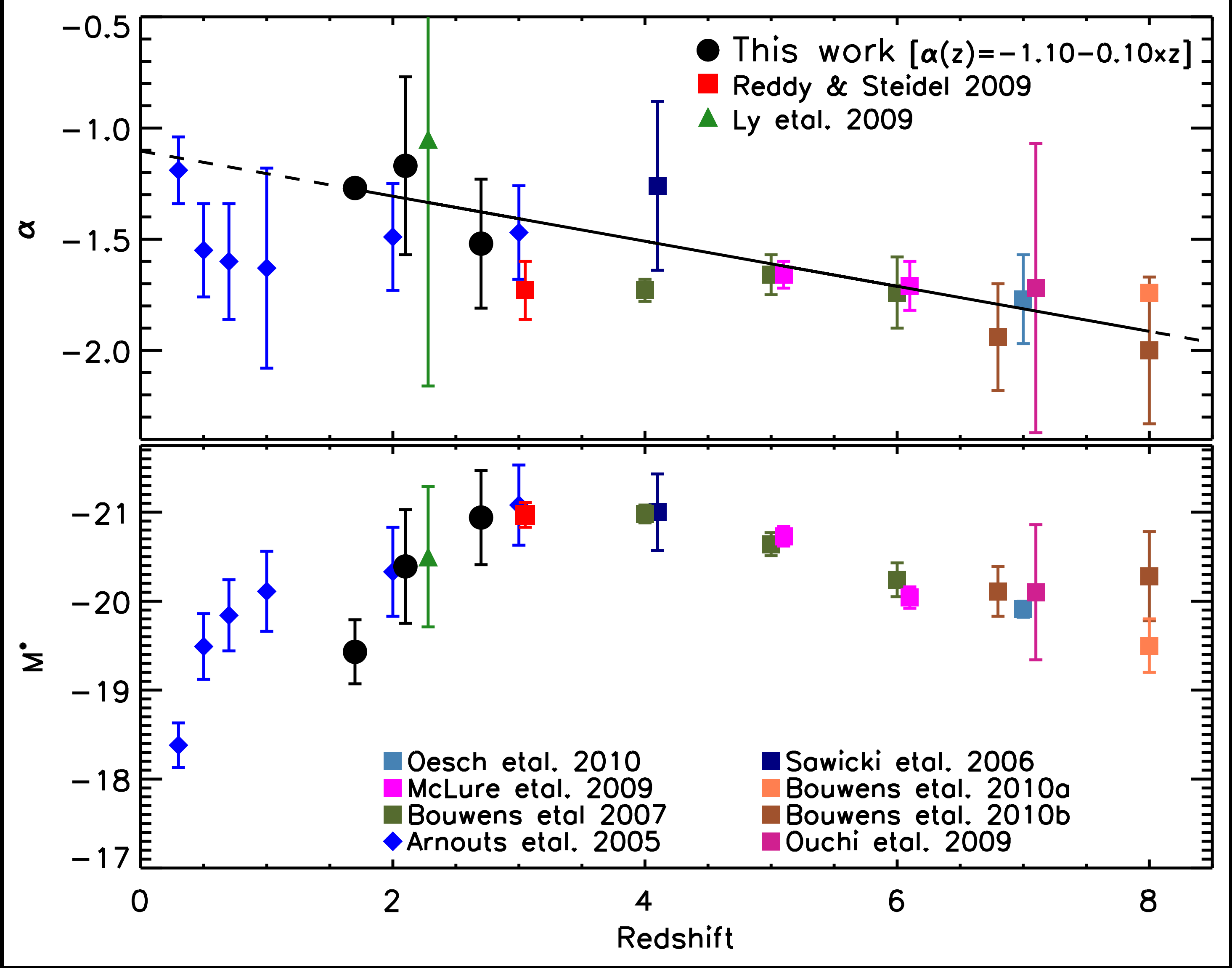


Lyman break galaxies at the peak of cosmic SF ($z \simeq 1$-3; Hathi ea. 2010)





- JWST will similarly measure faint-end LF-slope evolution for $1 \lesssim z \lesssim 12$.

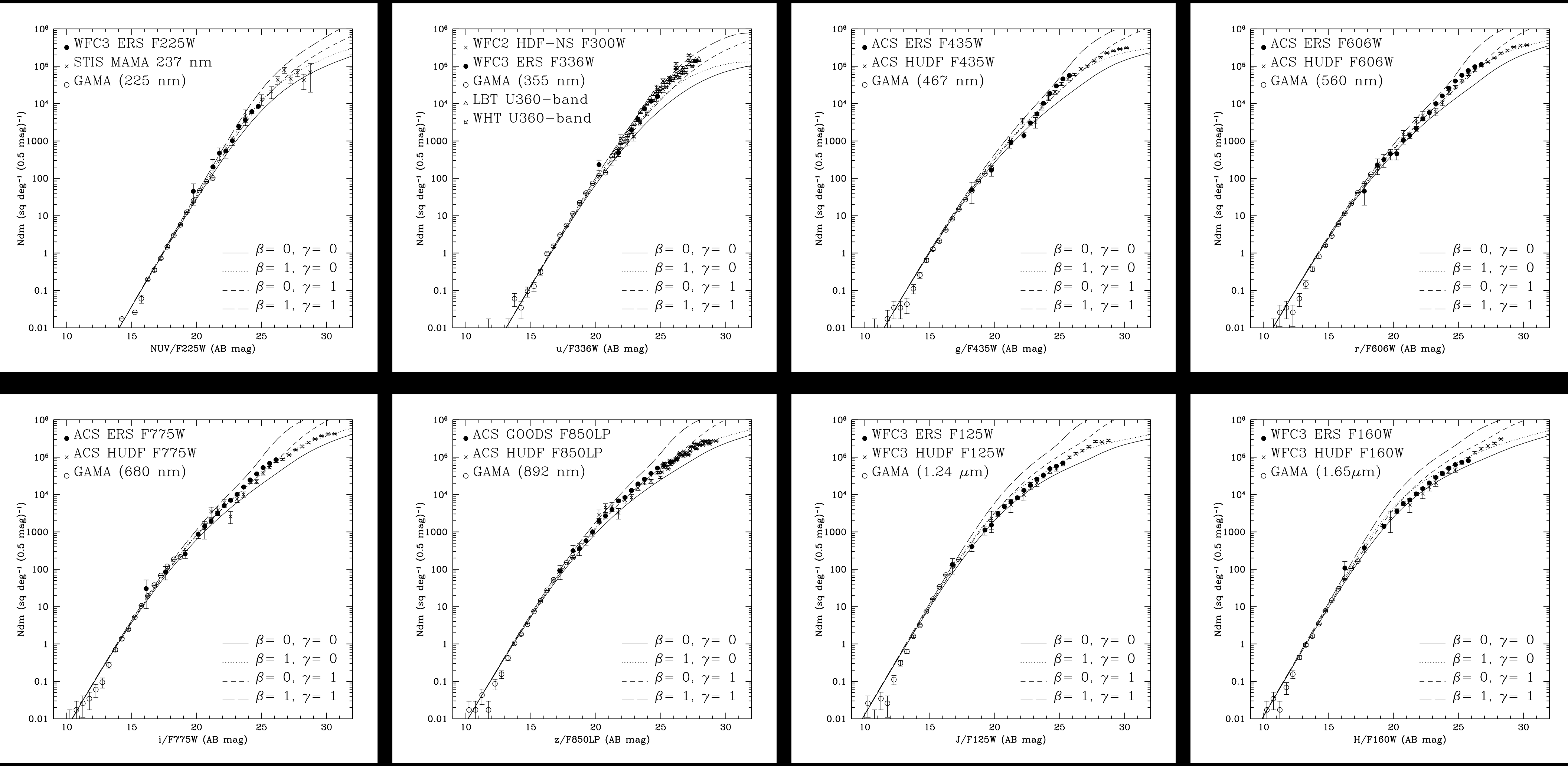


Measured faint-end LF slope evolution (top) and characteristic luminosity evolution (bottom) from Hathi et al. (2010, ApJ, 720, 1708).

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

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

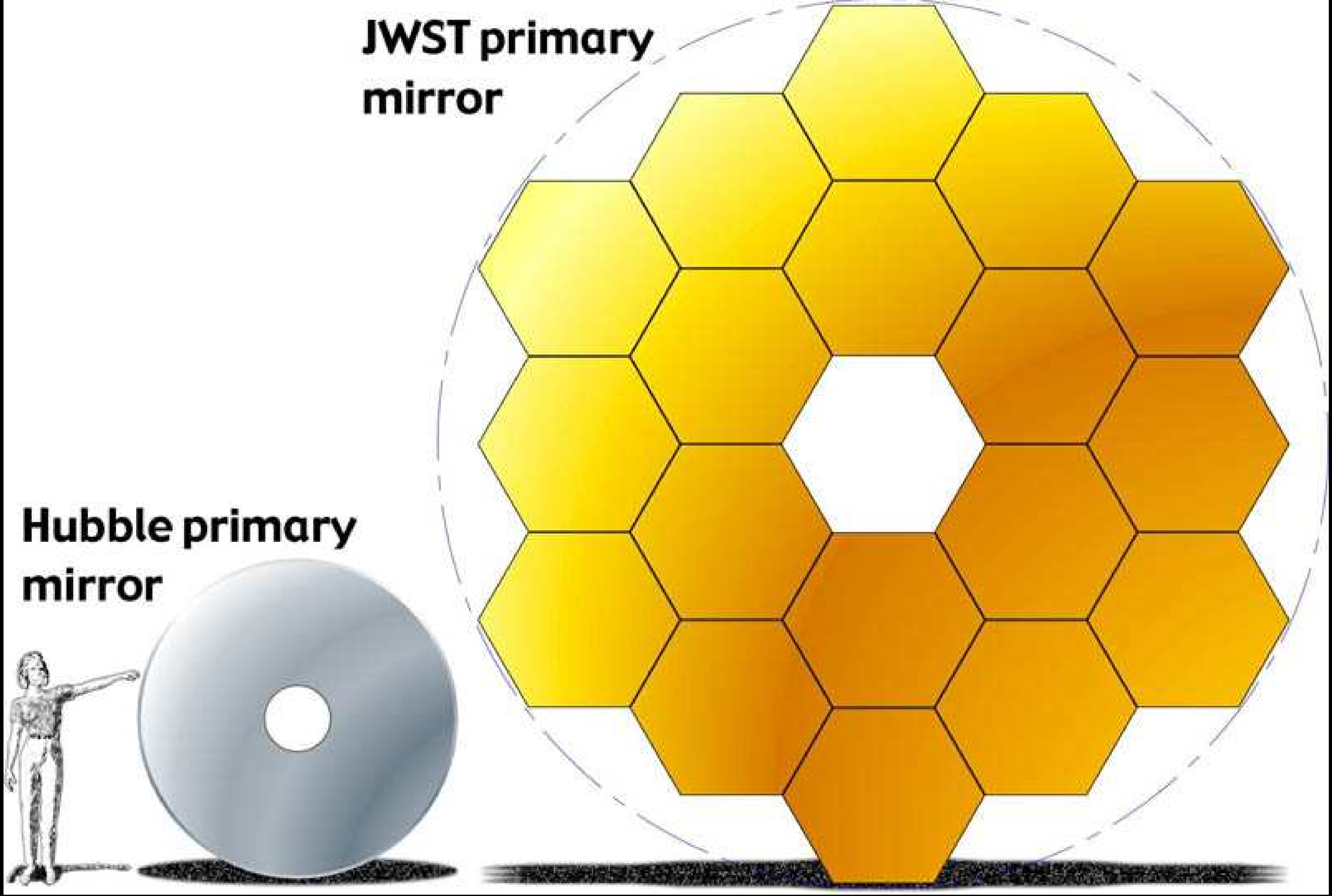
Panchromatic Galaxy Counts from $\lambda \simeq 0.2$–2μm for AB$\simeq$10–30 mag



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

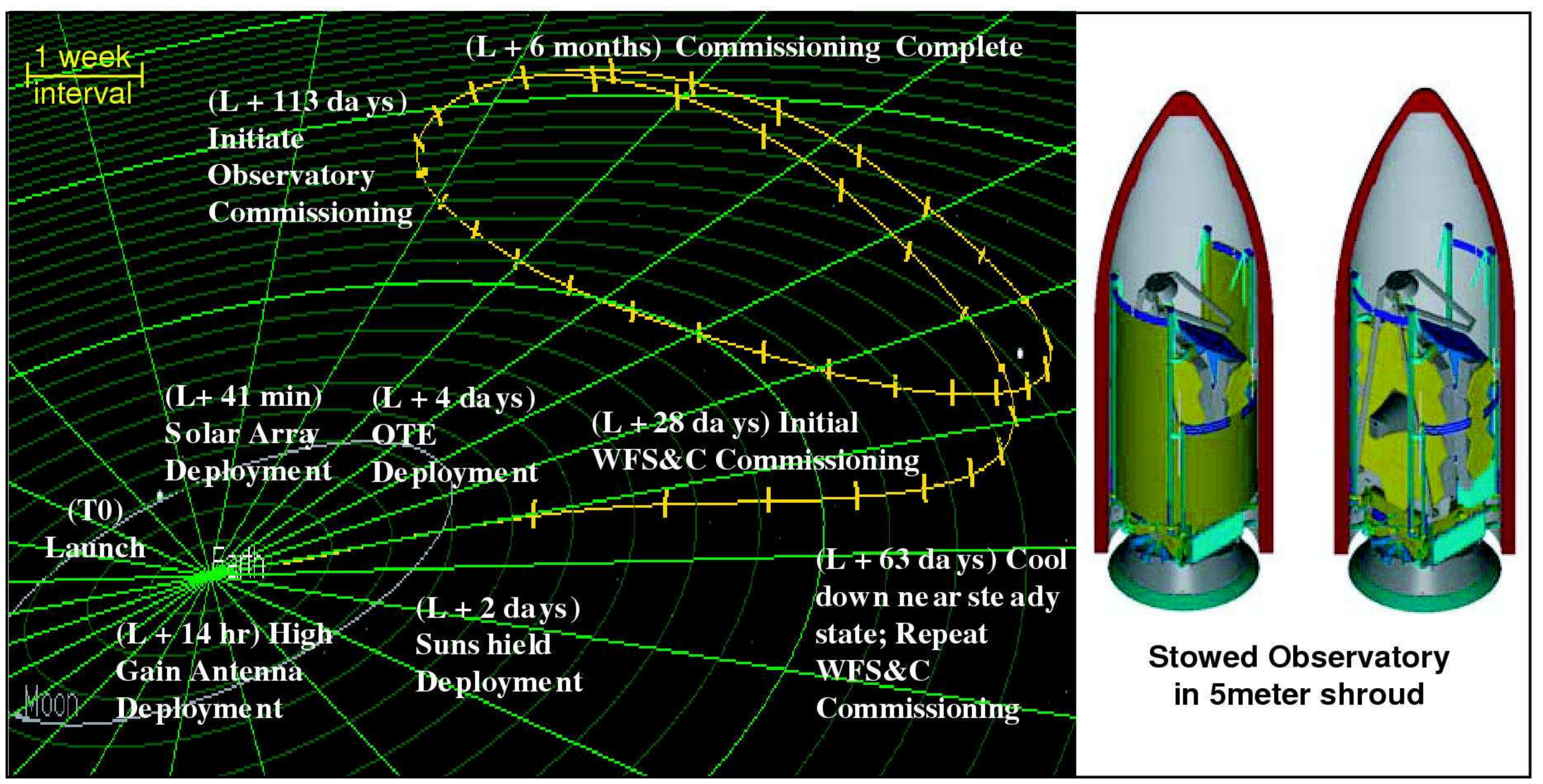
Filters: F225W, F275W, F336W, F435W, F606W, F775W, F850LP, F098M/F105W, F125W, F160W.

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

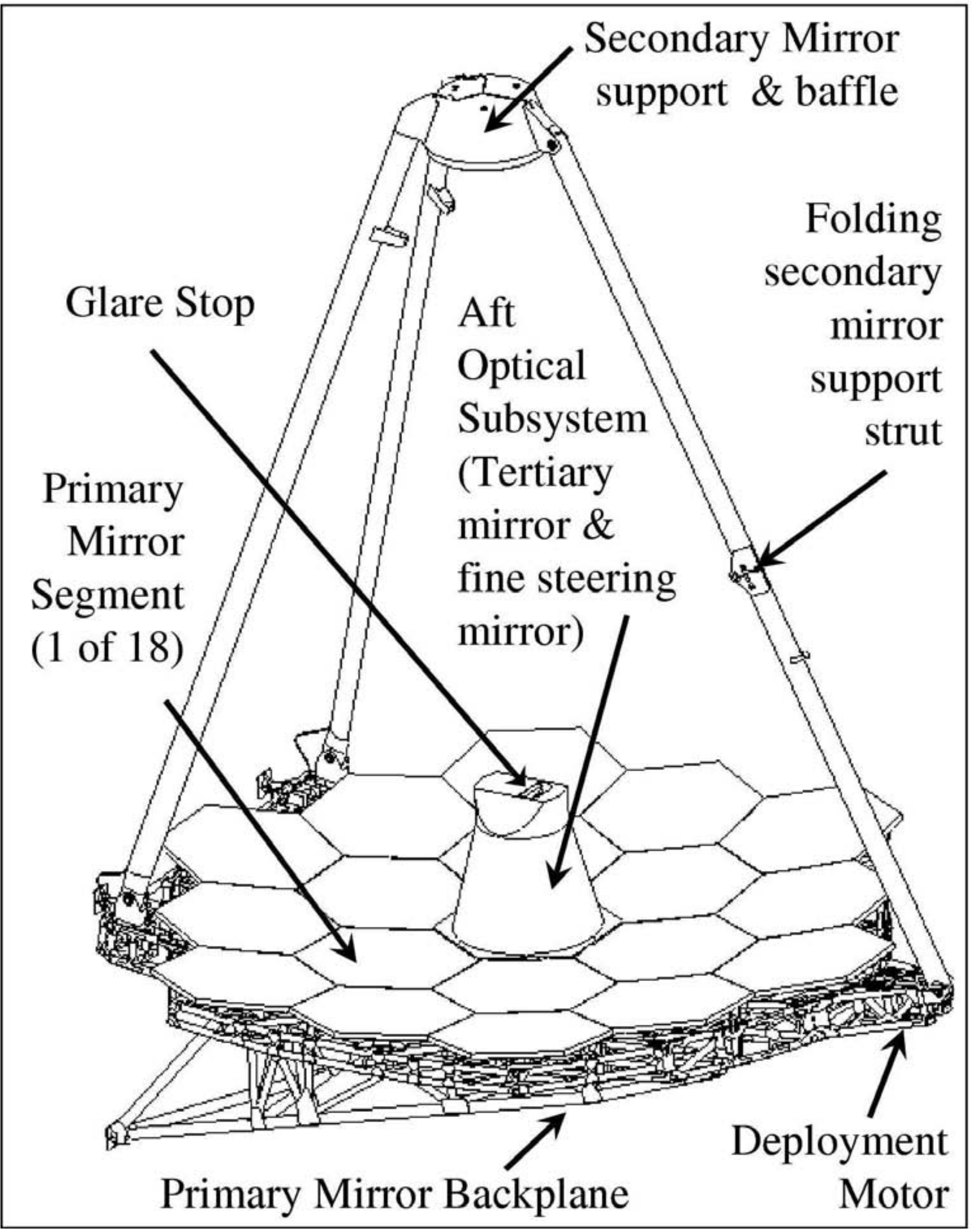


JWST ~2.5× larger than Hubble, so at ~2.5× larger wavelengths:
JWST has the same resolution in the near-IR as HST in the optical.

(1) JWST update: $\gtrsim$75% of hardware procured or completed as of 8/11.



- 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.

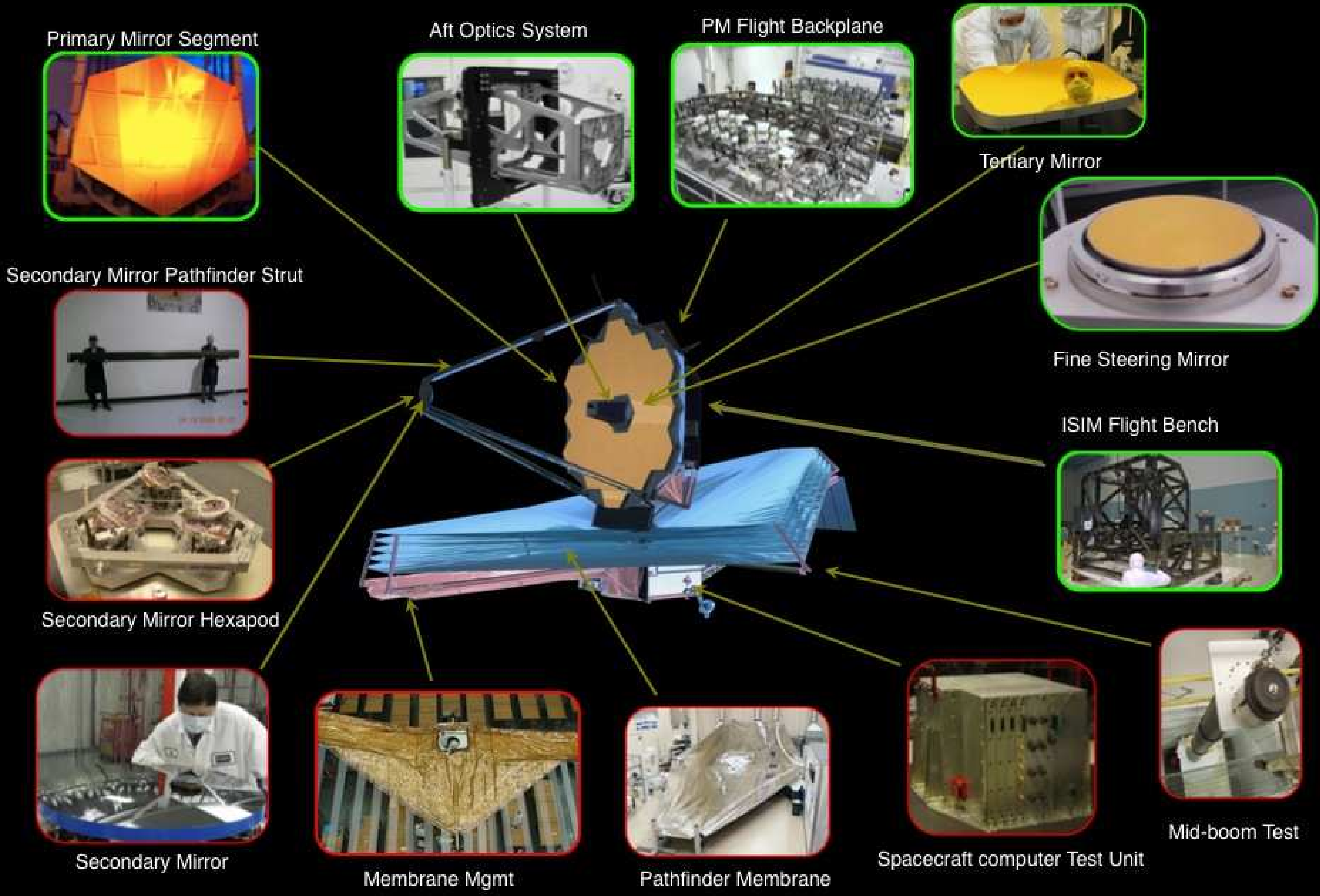


Ball 1/6-model for WFS: diffraction-limited 2.0 μm images (Strehl$\gtrsim$0.85).

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.

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

Mid-boom Test

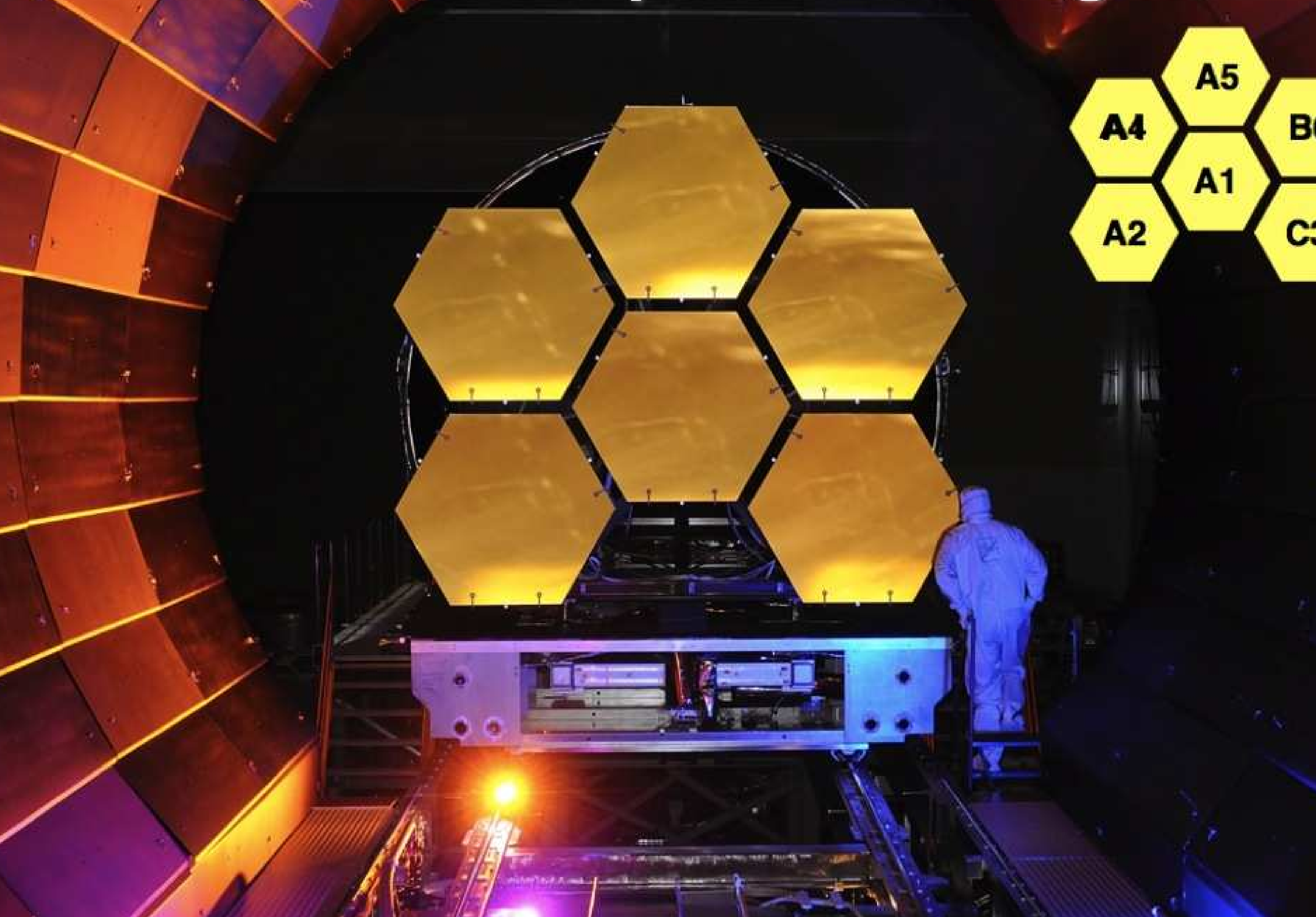
Secondary Mirror

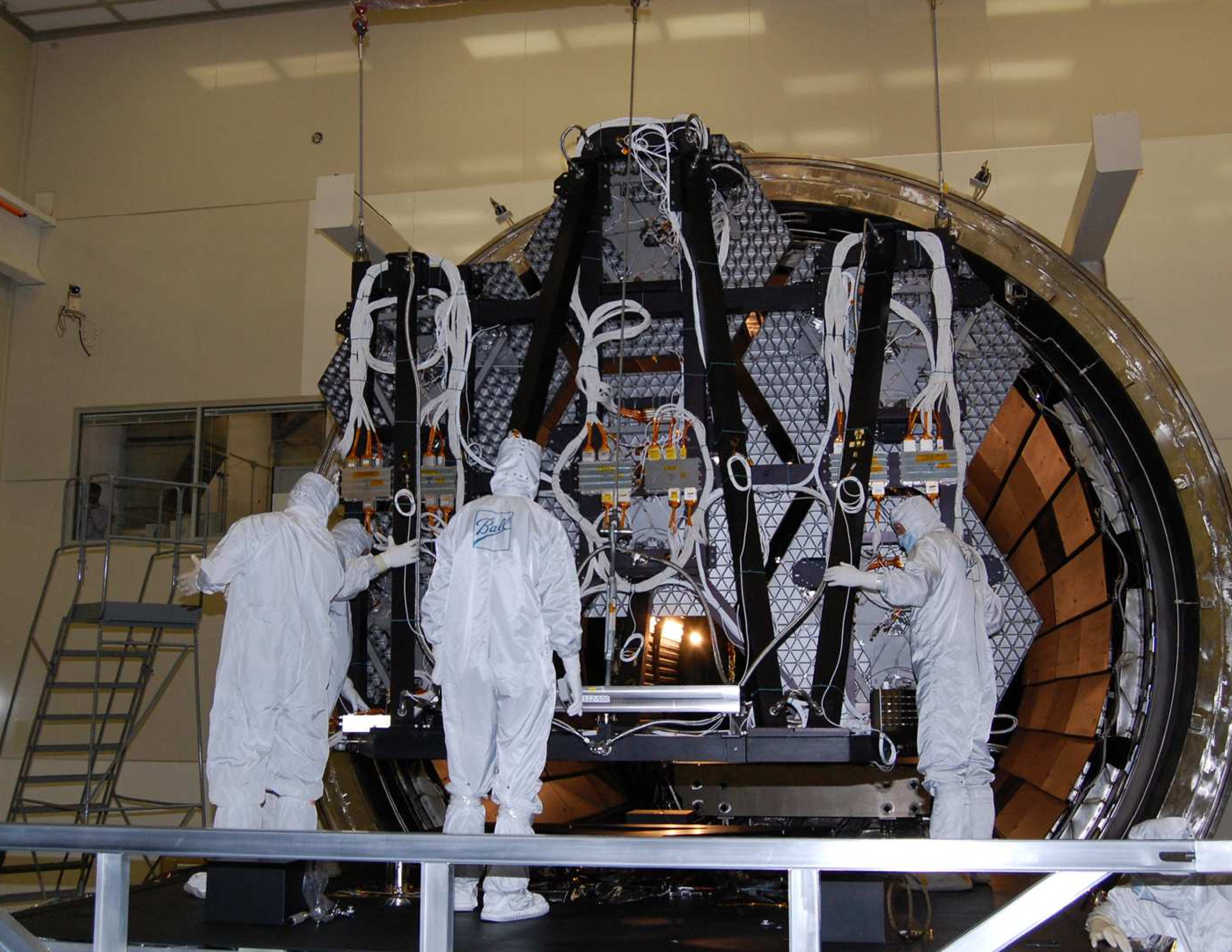
Membrane Mgmt

Pathfinder Membrane

Spacecraft computer Test Unit

Mirror Acceptance Testing



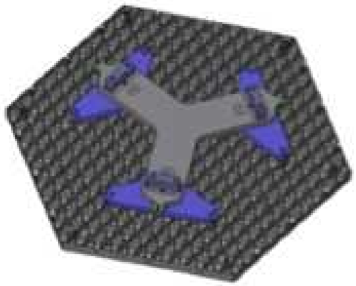

Ball

JWST Flight Mirrors Have Completed Polishing

Tinsley Final Measurement Requirements
Total Figure *< 17 nm*

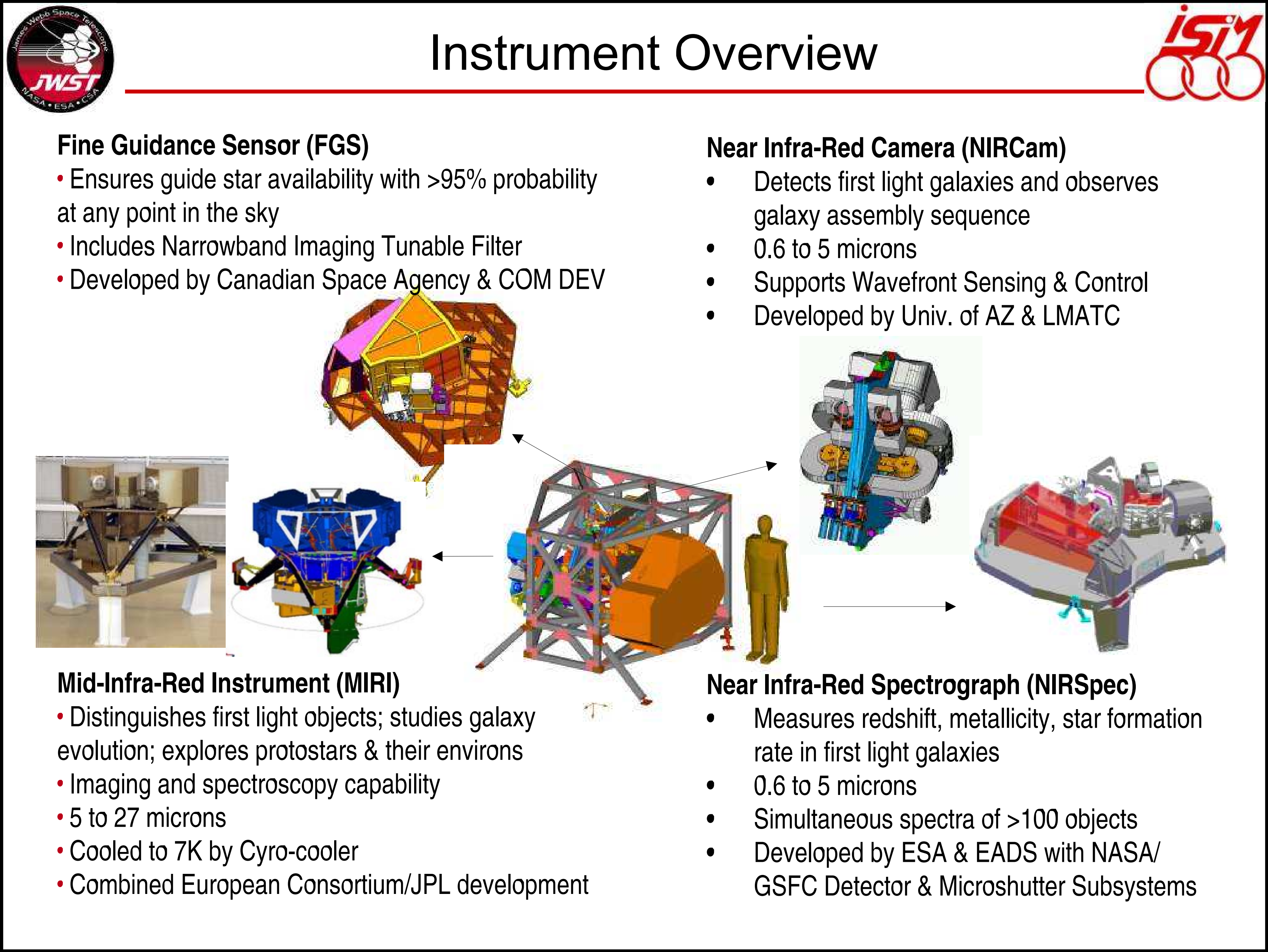
FLIGHT COMPOSITE RMS: **13.3 nm**

PV: **976.4 nm**



Mirror test configuration

(1b) 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 & NIRSpec completed 8/11; NIRCam & FGS delivery to GSFC 12/11.

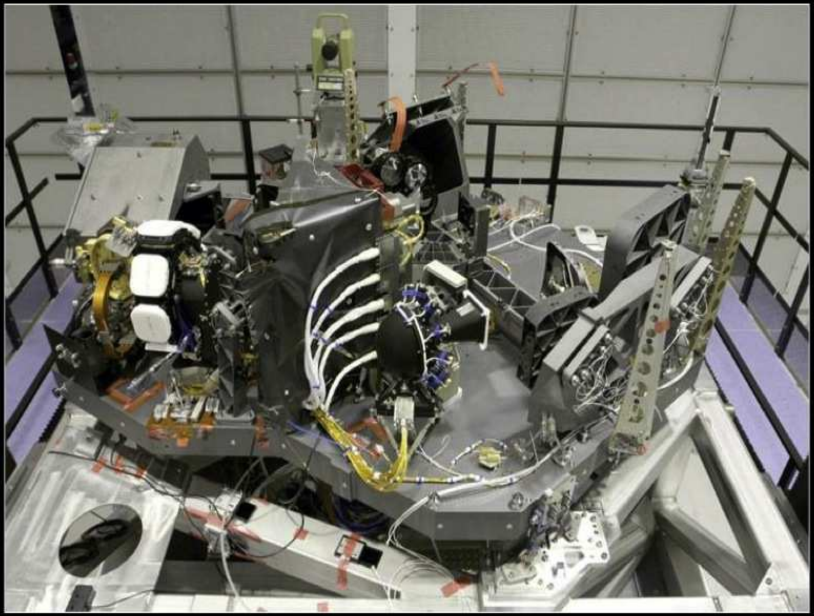
ETU NIRCam

Flight Fine Guidance Sensor

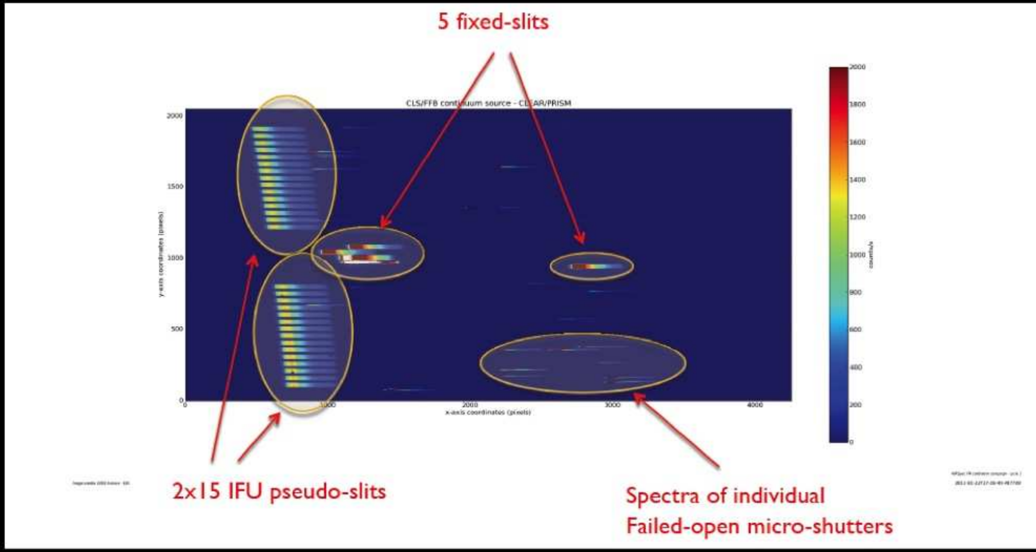
JWST's short-wavelength (0.6–5.0μm) imagers:

- NIRCam — built by UofA (AZ) and Lockheed (CA).
- Fine Guidance Sensor (& 1–5 μm grisms) — built by CSA (Montreal).
- Both to be delivered to GSFC late Fall 2011.

FLIGHT NIRSpec



Flight NIRSpec First Light

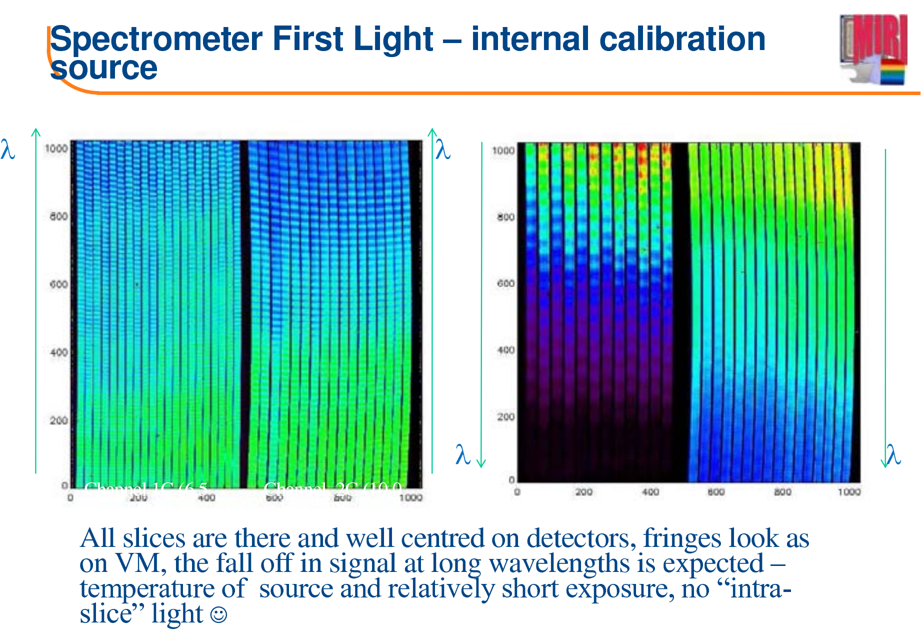


JWST's short-wavelength (0.6–5.0μm) spectrograph:

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

Final delivery to NASA/GSFC in early Fall 2011.

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 (5–29μm) camera and spectrograph:

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

Final delivery to NASA/GSFC in early Fall 2011.

TELESCOPE TESTING CHAMBER AT JOHNSON SPACE CENTER

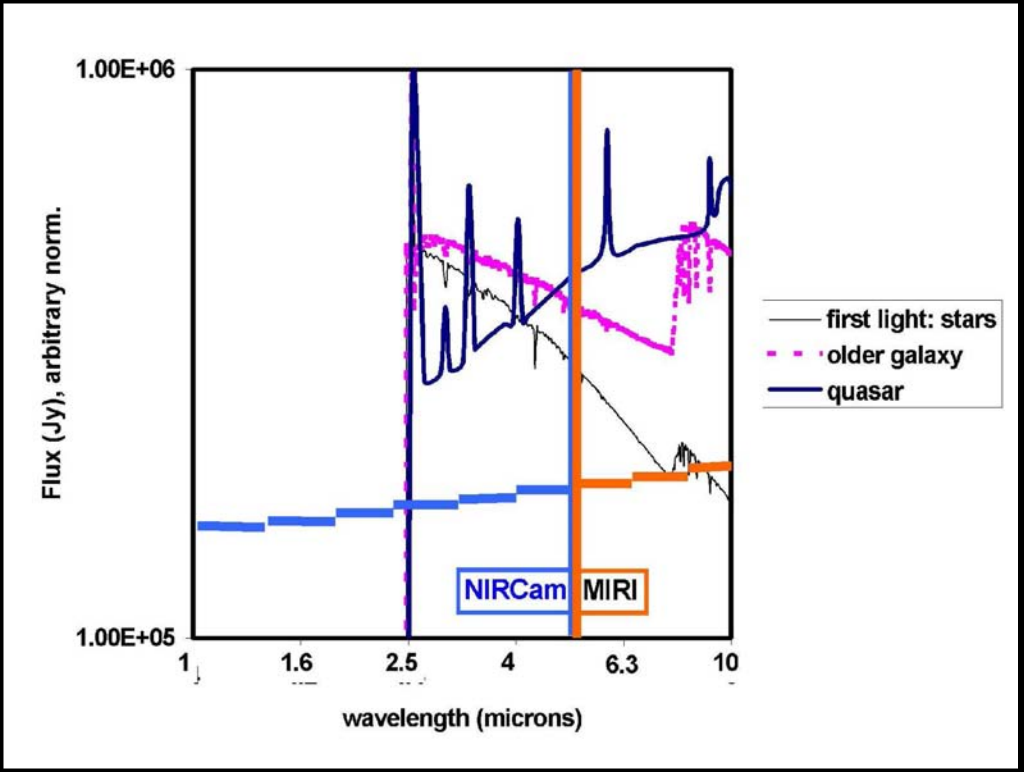
Notice people for scale

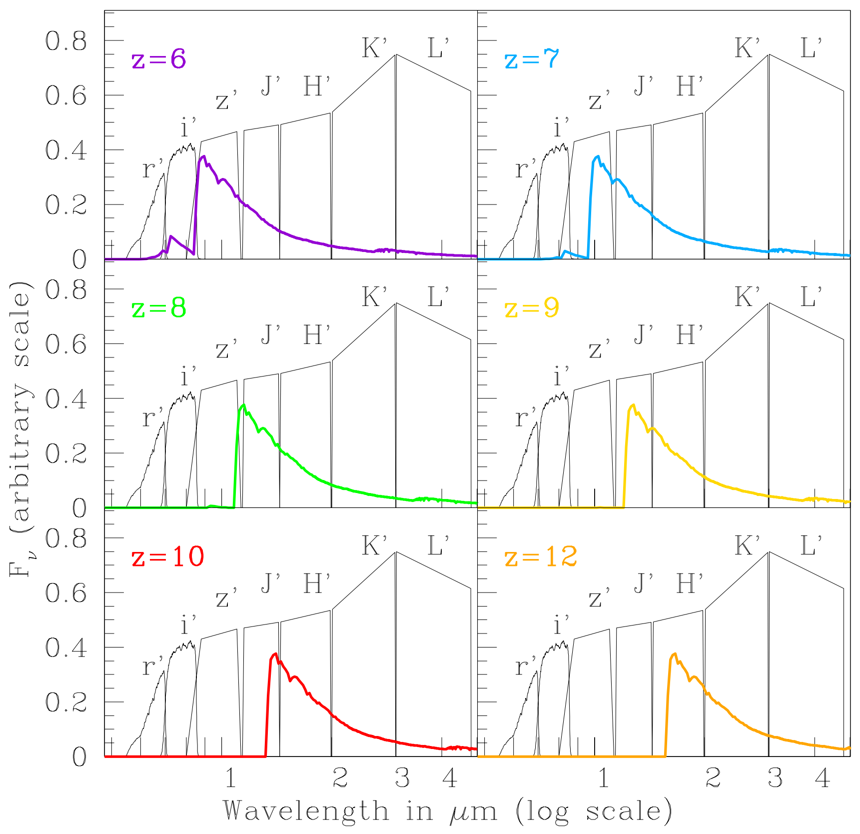
Largest simulation of deep space ever attempted will be done here

Telescope and science instruments installed in the test chamber

Element Progress

(2) How can JWST measure First Light and Reionization?





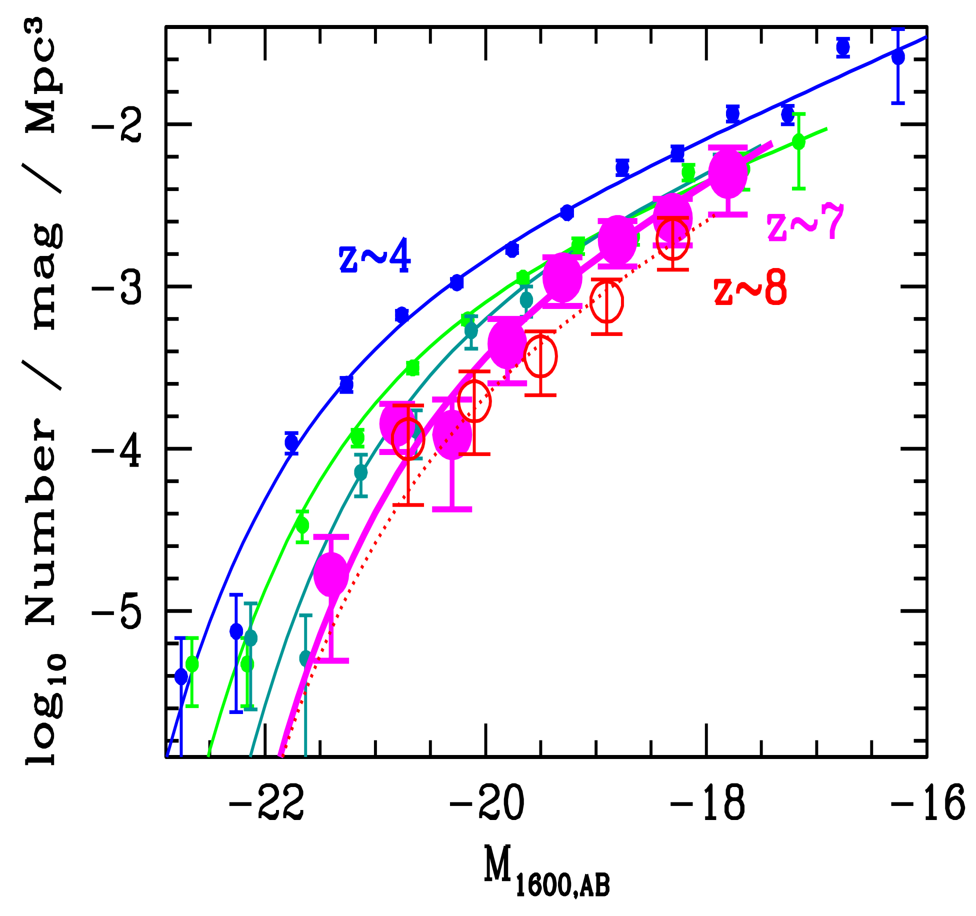
NIRCam and MIRI sensitivity complement each other, straddling $\lambda \simeq 5\ \mu$m.

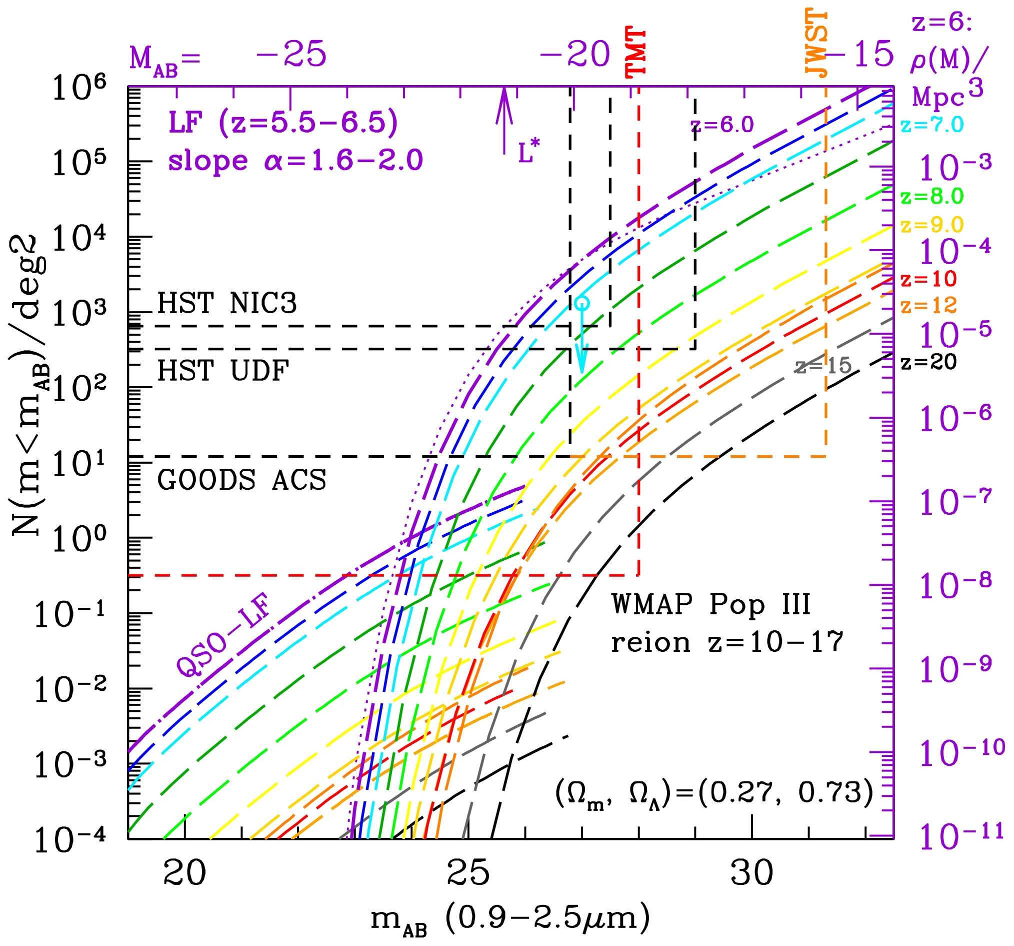
Together, they allow objects to be found to z=15–20 in $\sim 10^5$ sec (28 hrs).

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

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

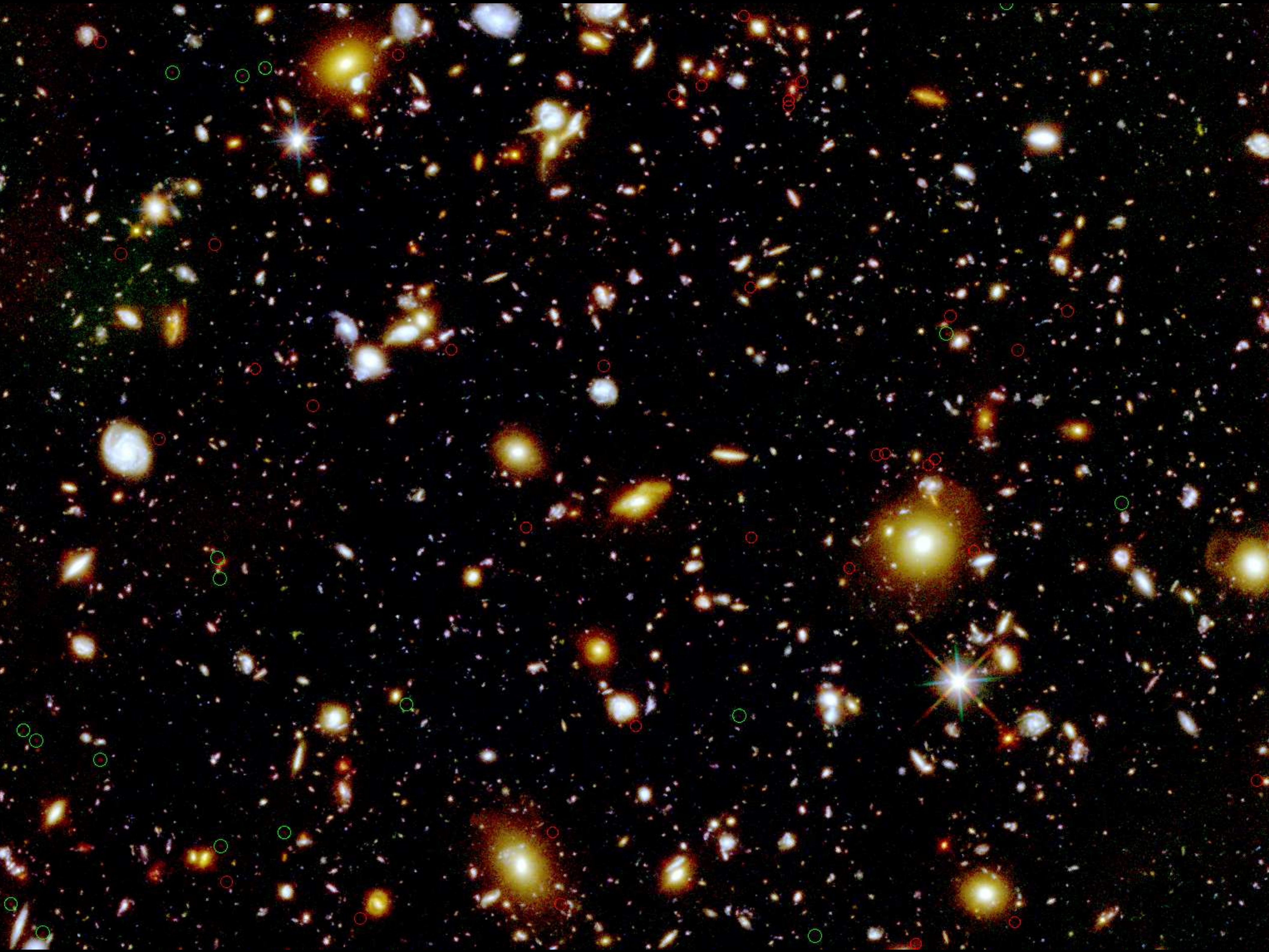


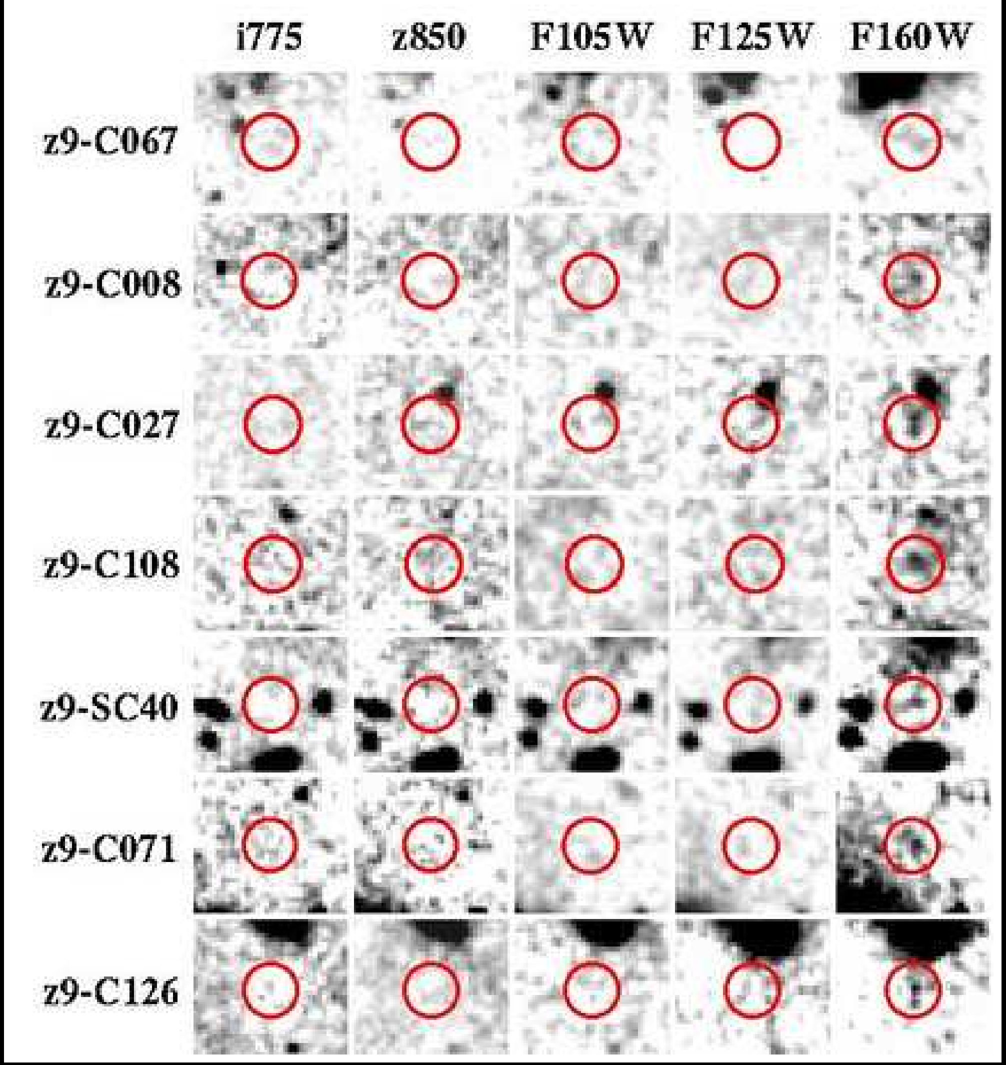


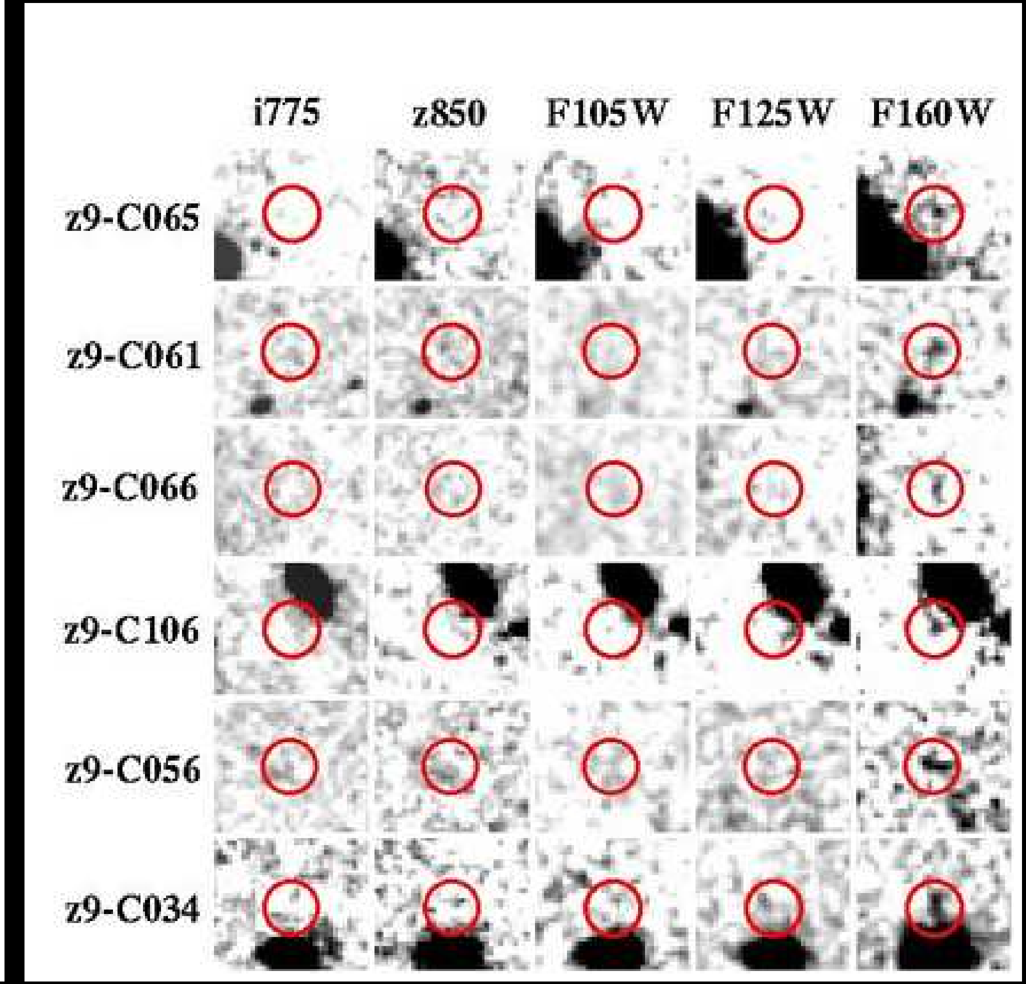
- Objects at z$\gtrsim$9 are rare (Bouwens$^+$ 10; Trenti,$^+$ 10; Yan$^+$ 10), since volume elt is small, and JWST samples brighter part of LF.

⇒ JWST needs its sensitivity/aperture (A), field-of-view (**Ω**), and **λ**-range (0.7-29 μm). [See Garth's talk, this conf.]

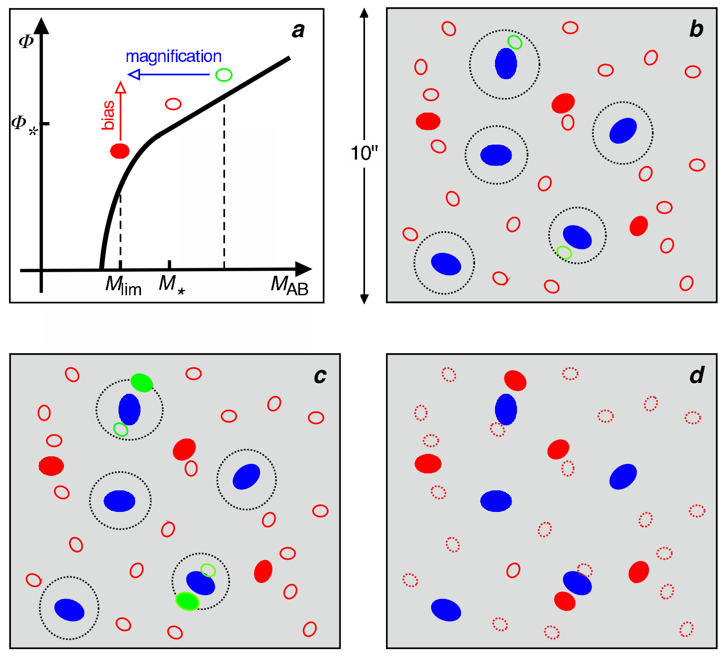
- With proper survey strategy (area AND depth), JWST can trace the entire reionization epoch and detect the first star-forming objects.

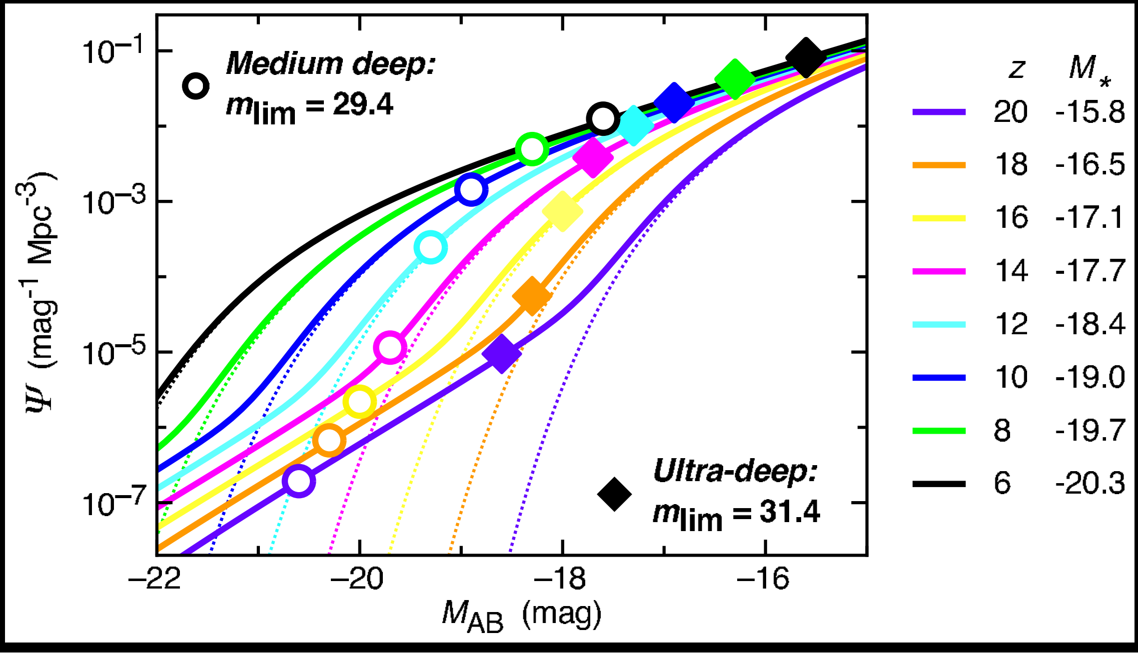


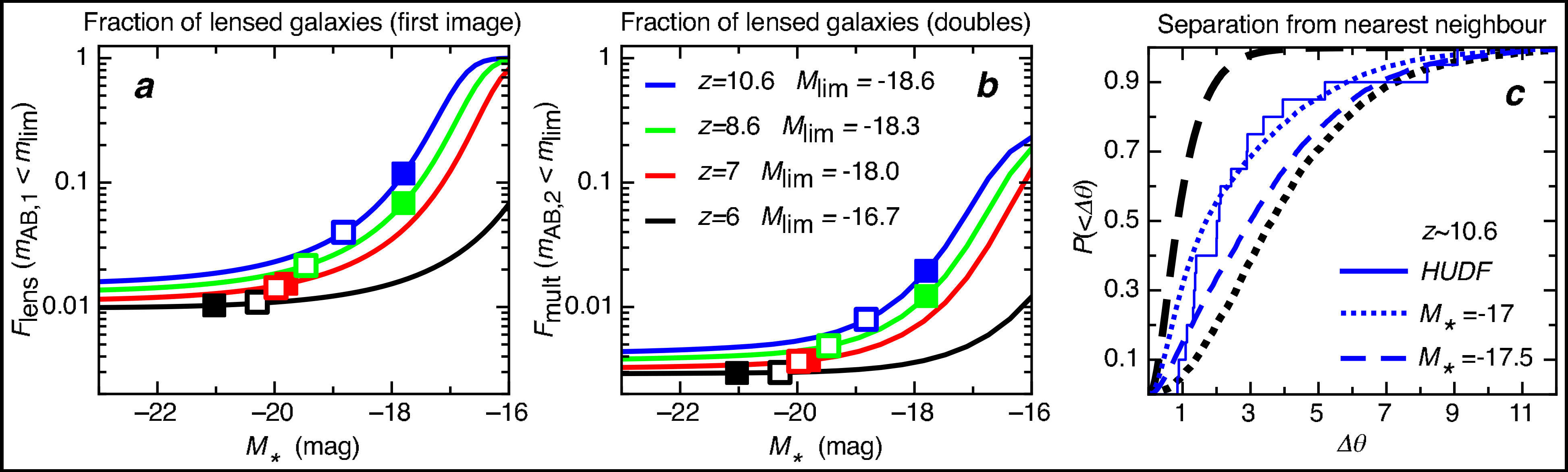




- ∼10–40% of Y-drops and J-drops appear close to bright galaxies (Yan et al. 2010, Res. Astr. & Ap., 10, 867).
- Expected from gravitational lensing bias by galaxy dark matter halo distribution at z≃1–2 (Wyithe et al. 2011, Nature, 469, 181).
- Need JWST to measure z$\gtrsim$9 LF, and see if it's fundamentally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







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

- This could change the landscape for JWST observing strategies.

Conclusions

(1) David Koo's work in the 1980's: First real panchromatic astronomy.

(2) HST ACS+WFC3: panchromatic work at $\lambda \simeq 0.2$-2μm to AB$\lesssim$30.

(3) 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 08/11.
- JWST is designed to map the epochs of First Light, Reionization, and Galaxy Assembly in detail.

(4) JWST will have a major impact on astrophysics later 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.

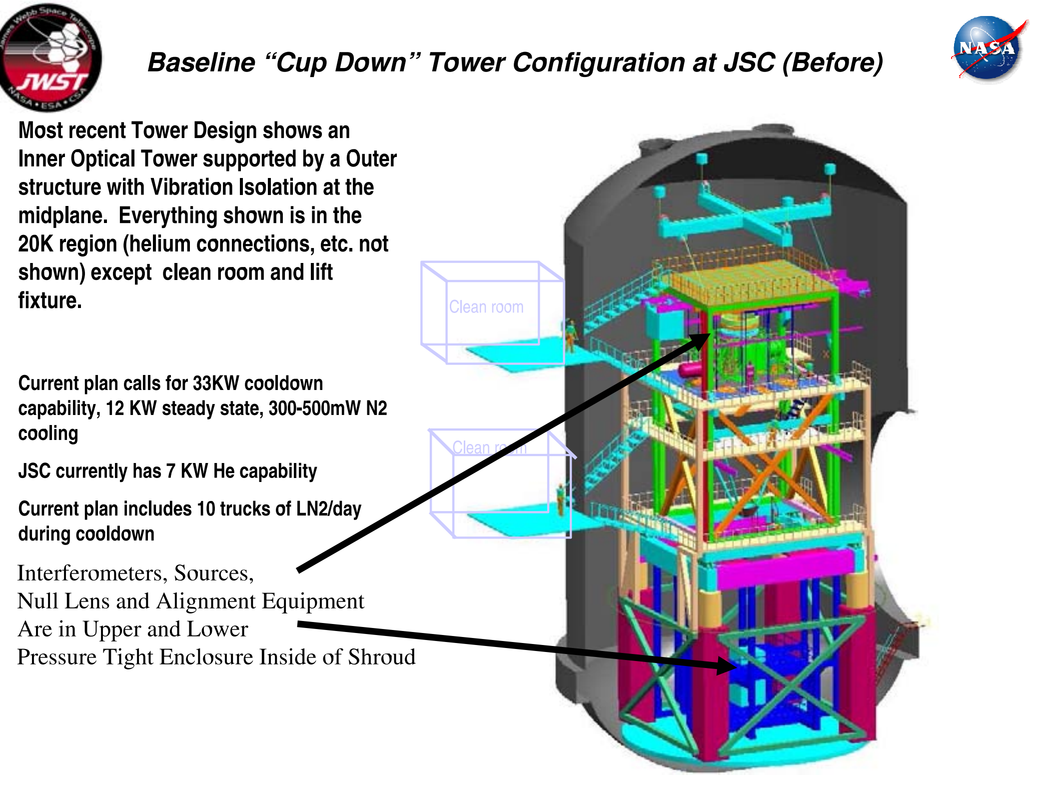
SPARE CHARTS

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

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

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)

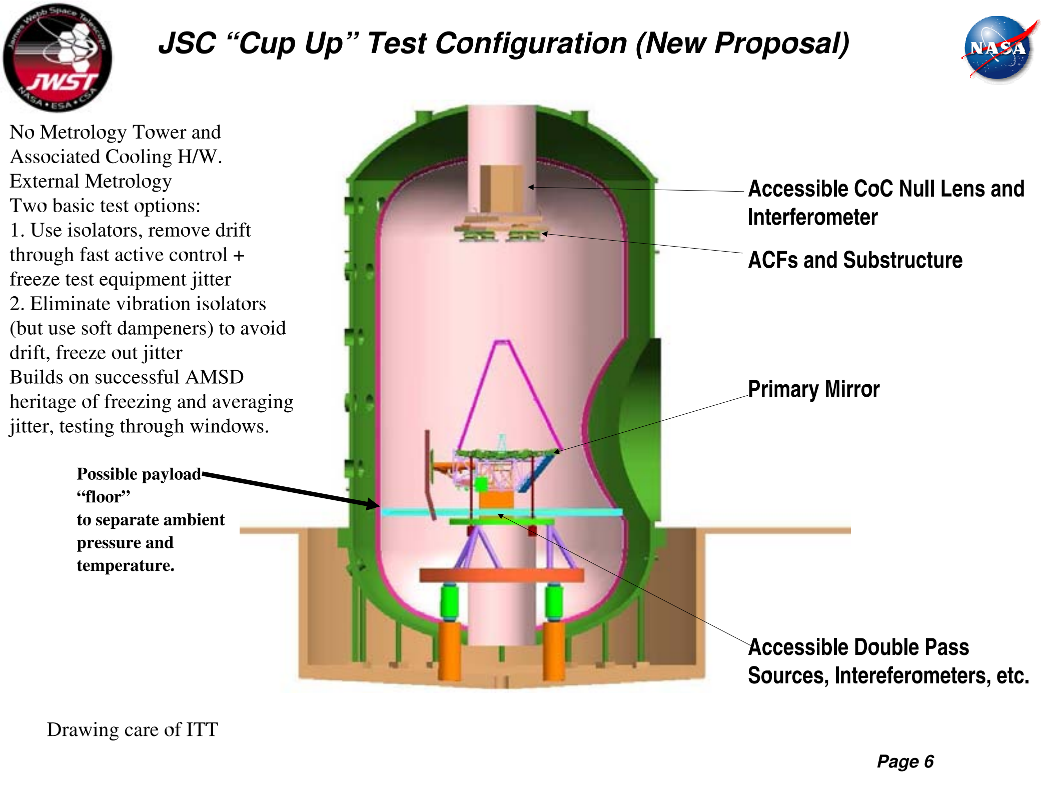
Most recent Tower Design shows an Inner Optical Tower supported by a Outer structure with Vibration Isolation at the midplane. Everything shown is in the 20K region (helium connections, etc. not shown) except clean room and lift fixture.

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.

Accessible CoC Null Lens and Interferometer

ACFs and Substructure

Primary Mirror

Accessible Double Pass Sources, Intereferometers, etc.

Drawing care of ITT

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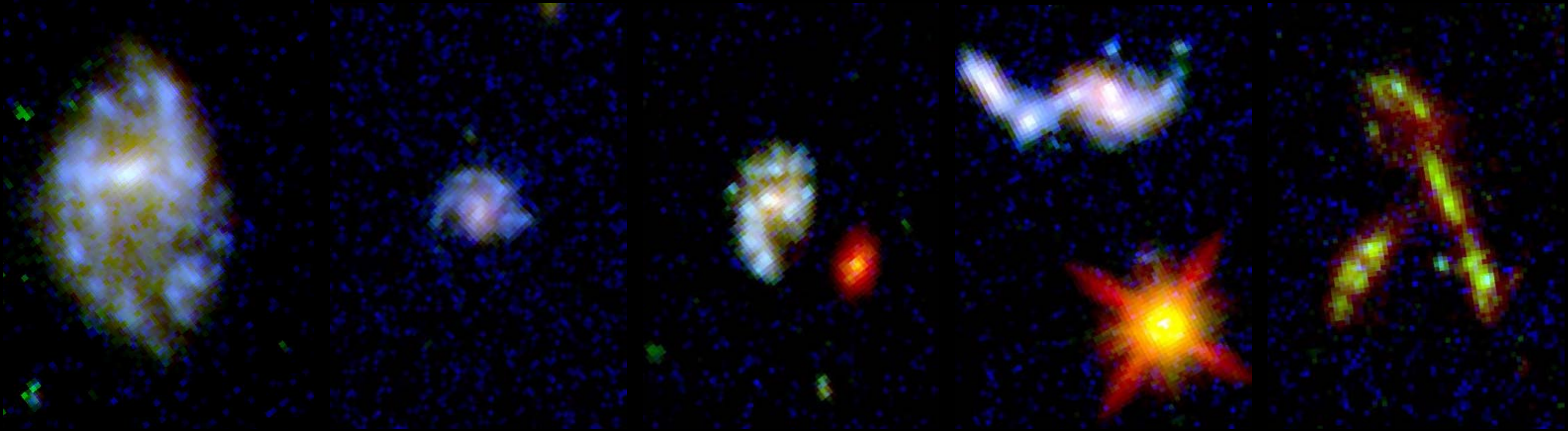
JWST underwent several significant replans and risk-reduction schemes:

- $\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.

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

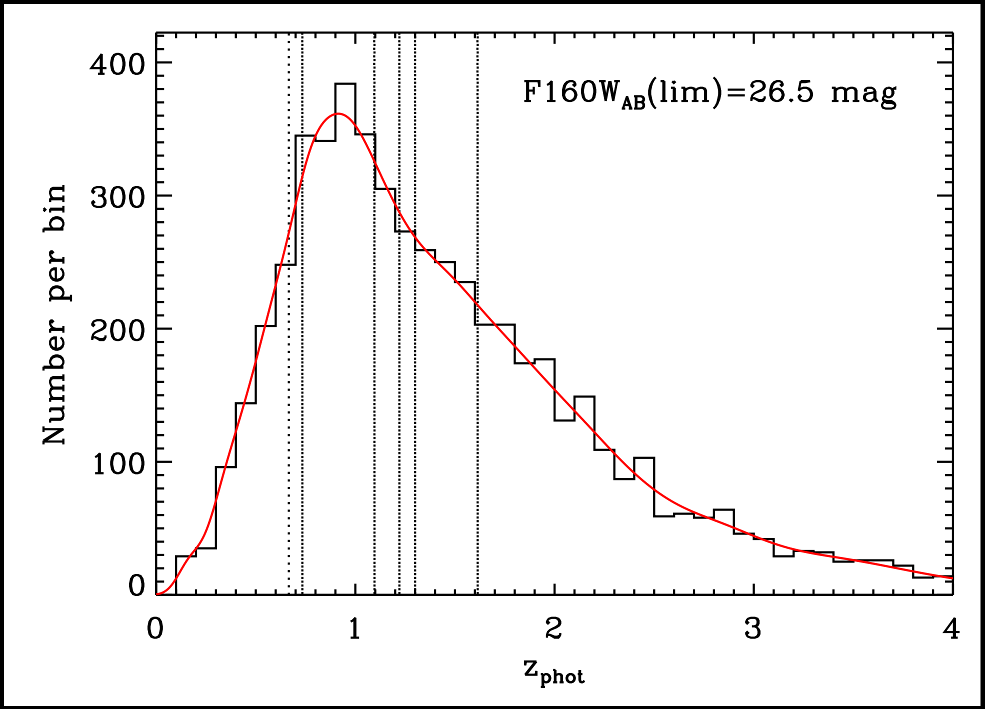


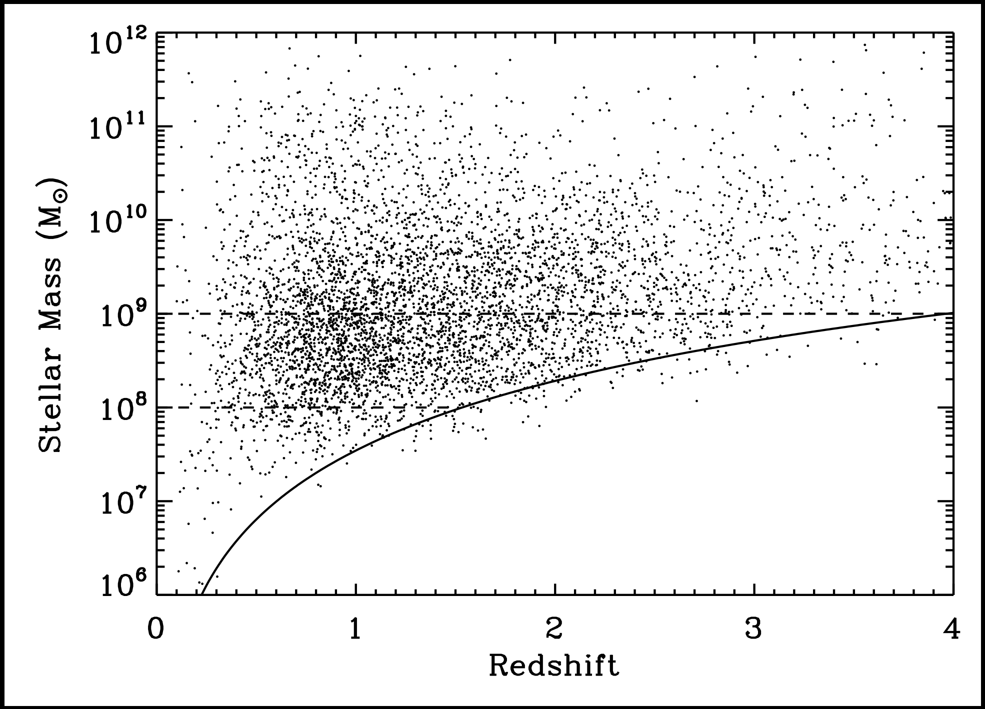
Galaxy structure at the peak of the merging epoch ($z \simeq 1$–2) is very rich: some resemble the cosmological parameters H_0 , Ω, ρ_o, w, and Λ, resp.

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

(Rutkowski et al. 2011) $\Longrightarrow$ "Red and dead" galaxies aren't dead!

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





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?)

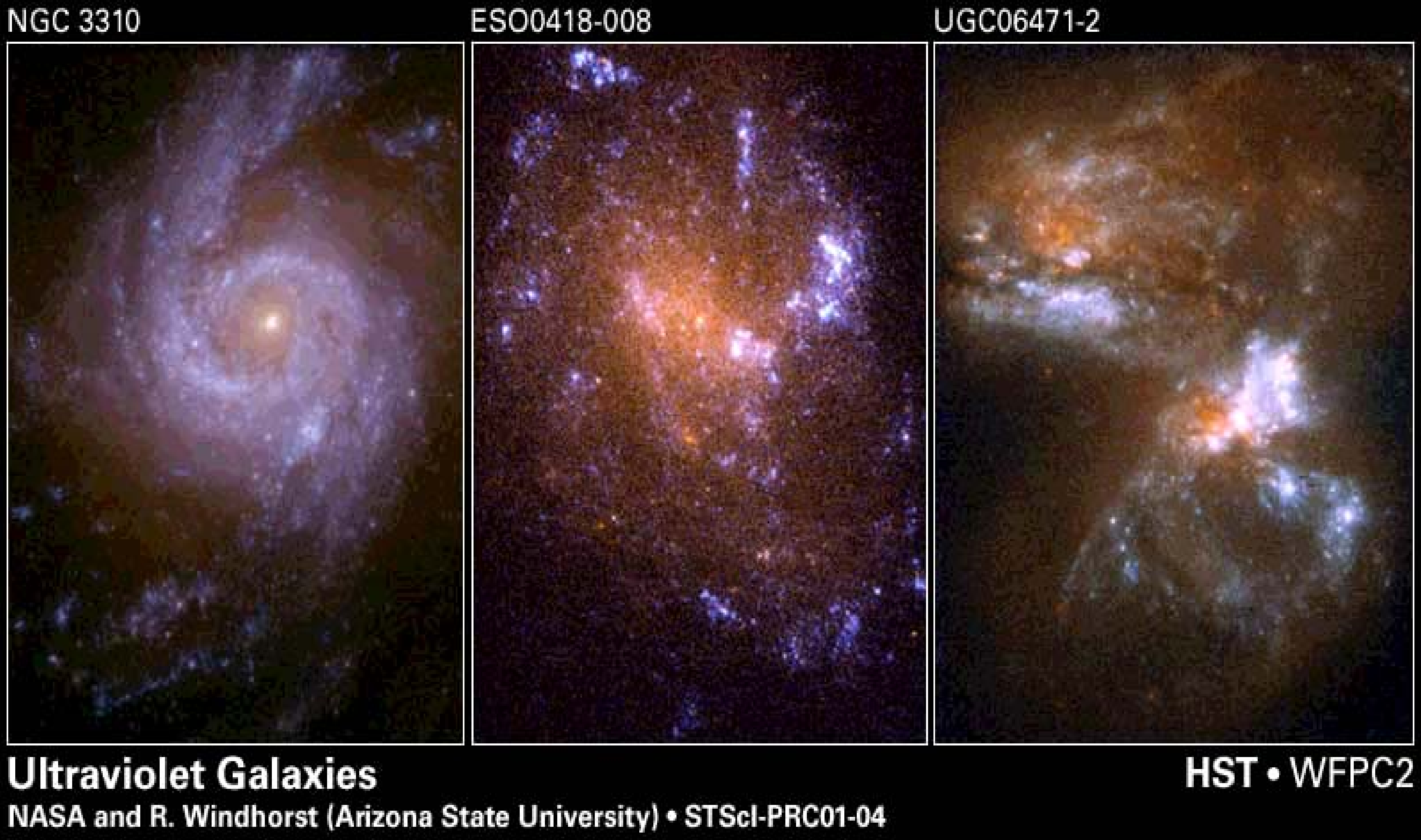
ERS shows WFC3's new panchromatic capabilities on galaxies at z$\simeq$0–8.

- 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.

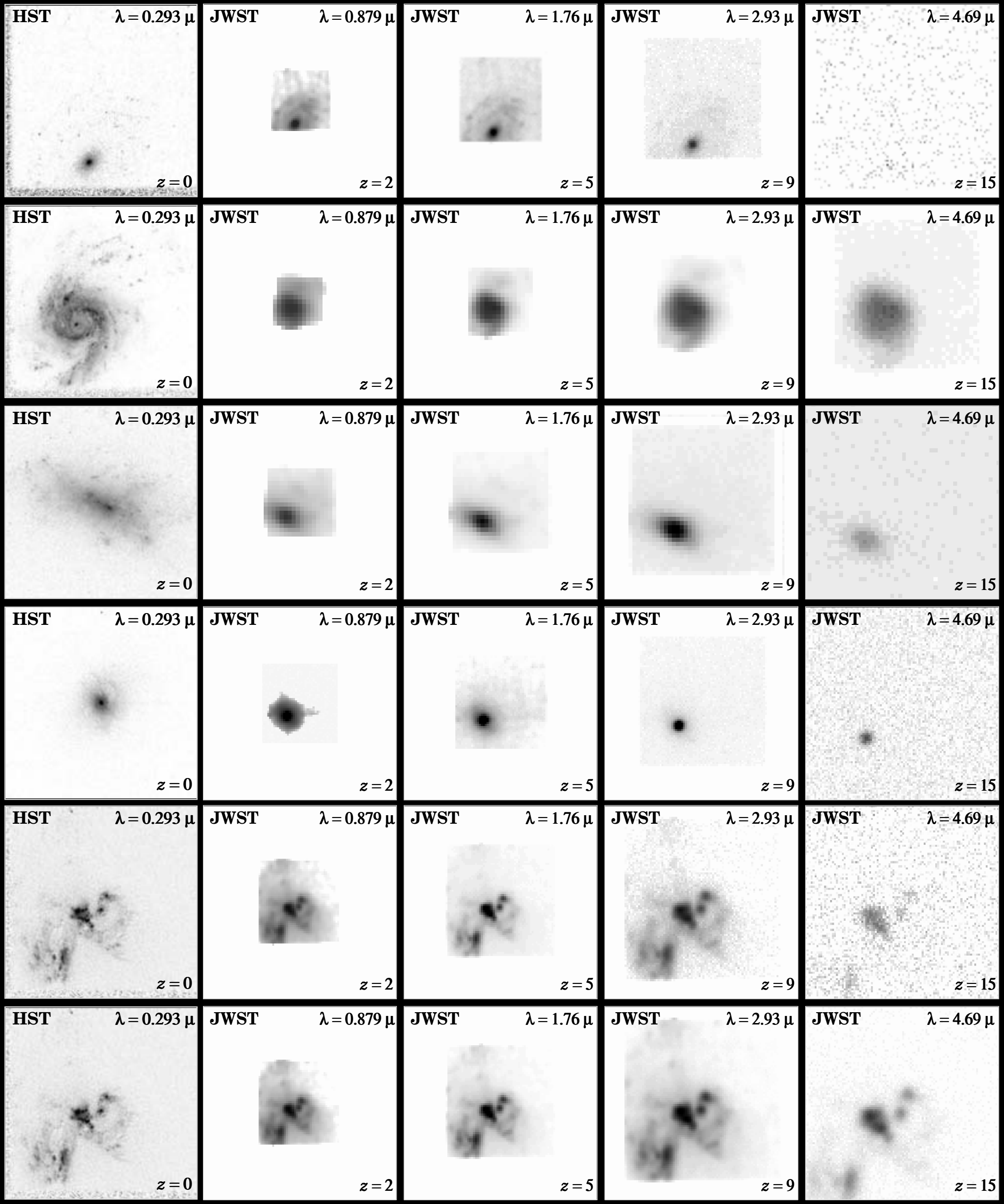
Appendix 1: Predicted Galaxy Appearance for JWST at $z \simeq 1$–15



- 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.

App. 1. Predicted Galaxy Appearance for JWST at $z\simeq1$–15 (w/ Conselice)

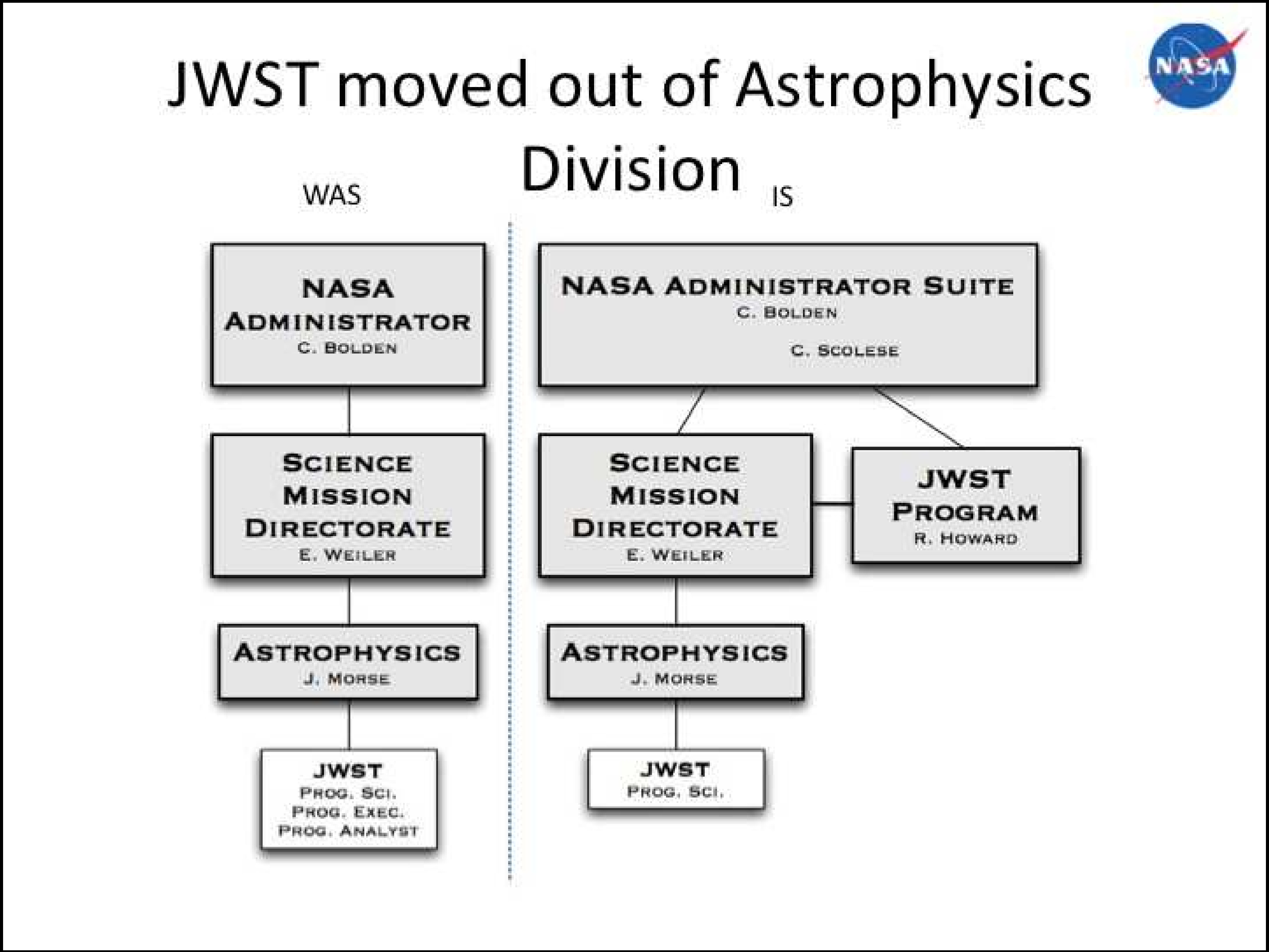
HST z=0 JWST z=2 z=5 z=9 z=15



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 $z\lesssim1$–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.

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



JWST moved out of Astrophysics Division

WAS

NASA Administrator
C. Bolden

Science Mission Directorate
E. Weiler

Astrophysics
J. Morse

JWST
Prog. Sci.
Prog. Exec.
Prog. Analyst

IS

NASA Administrator Suite
C. Bolden
C. Scolese

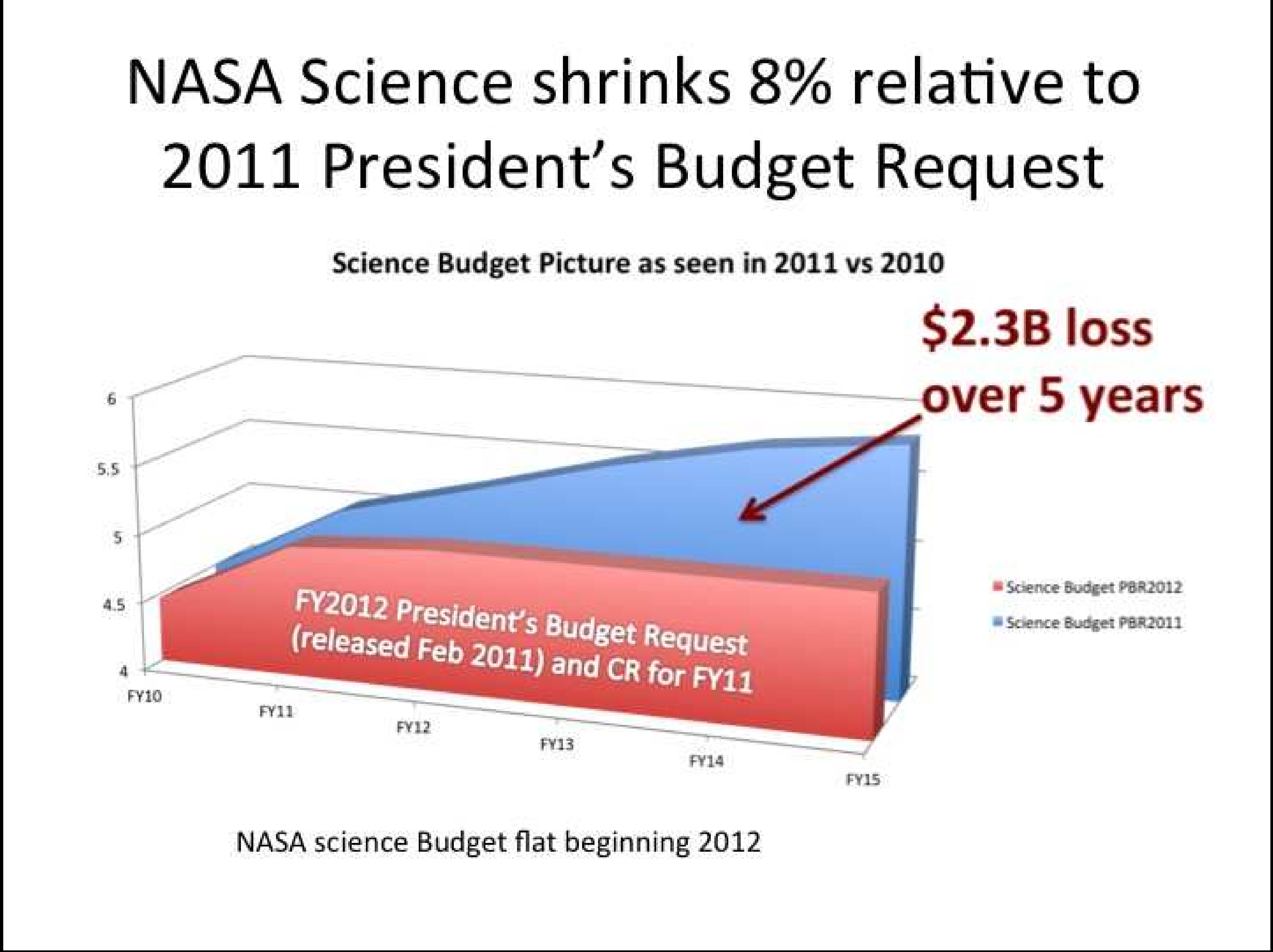
Science Mission Directorate
E. Weiler

JWST Program
R. Howard

Astrophysics
J. Morse

JWST
Prog. Sci.

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



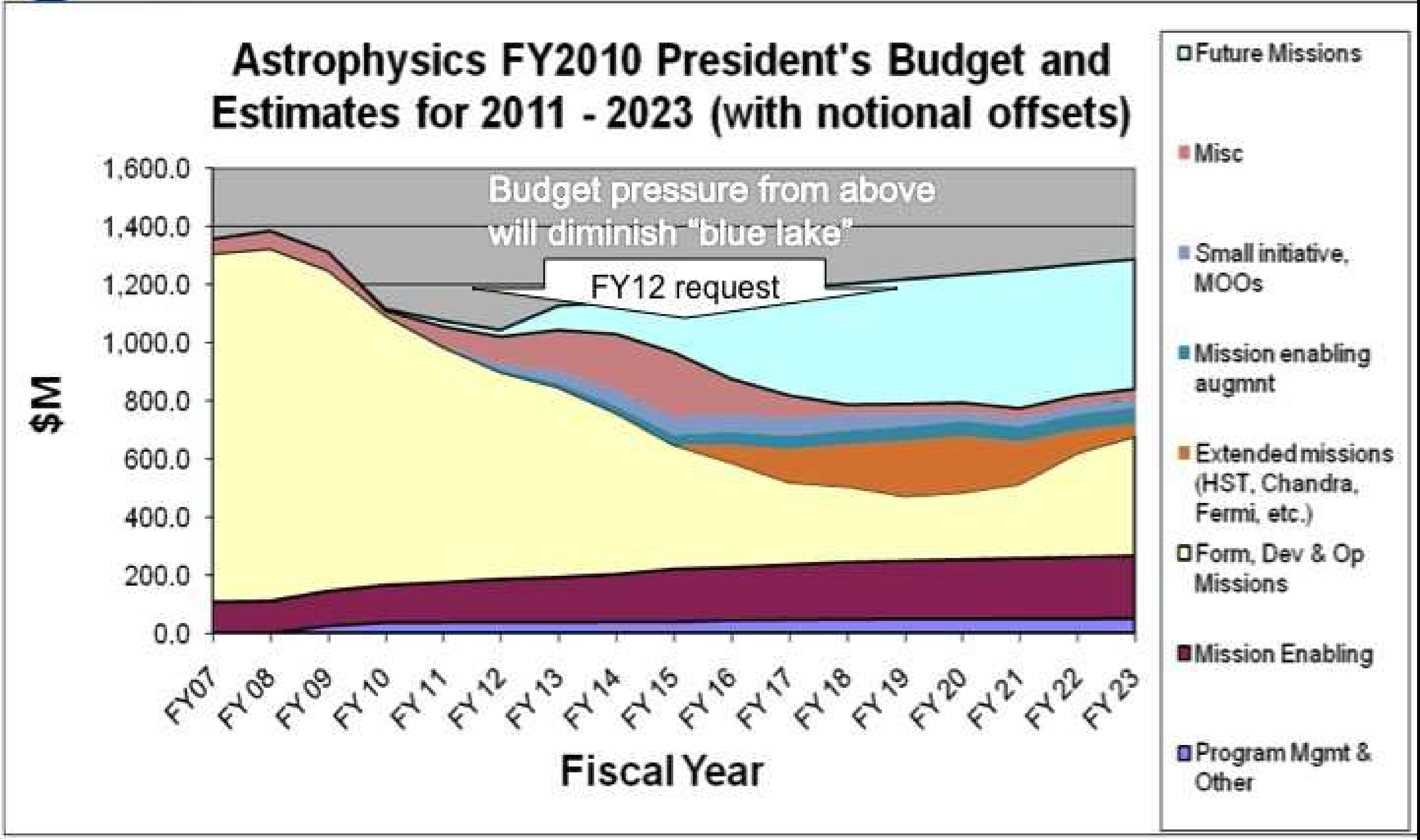
NASA Science shrinks 8% relative to 2011 President's Budget Request

Science Budget Picture as seen in 2011 vs 2010

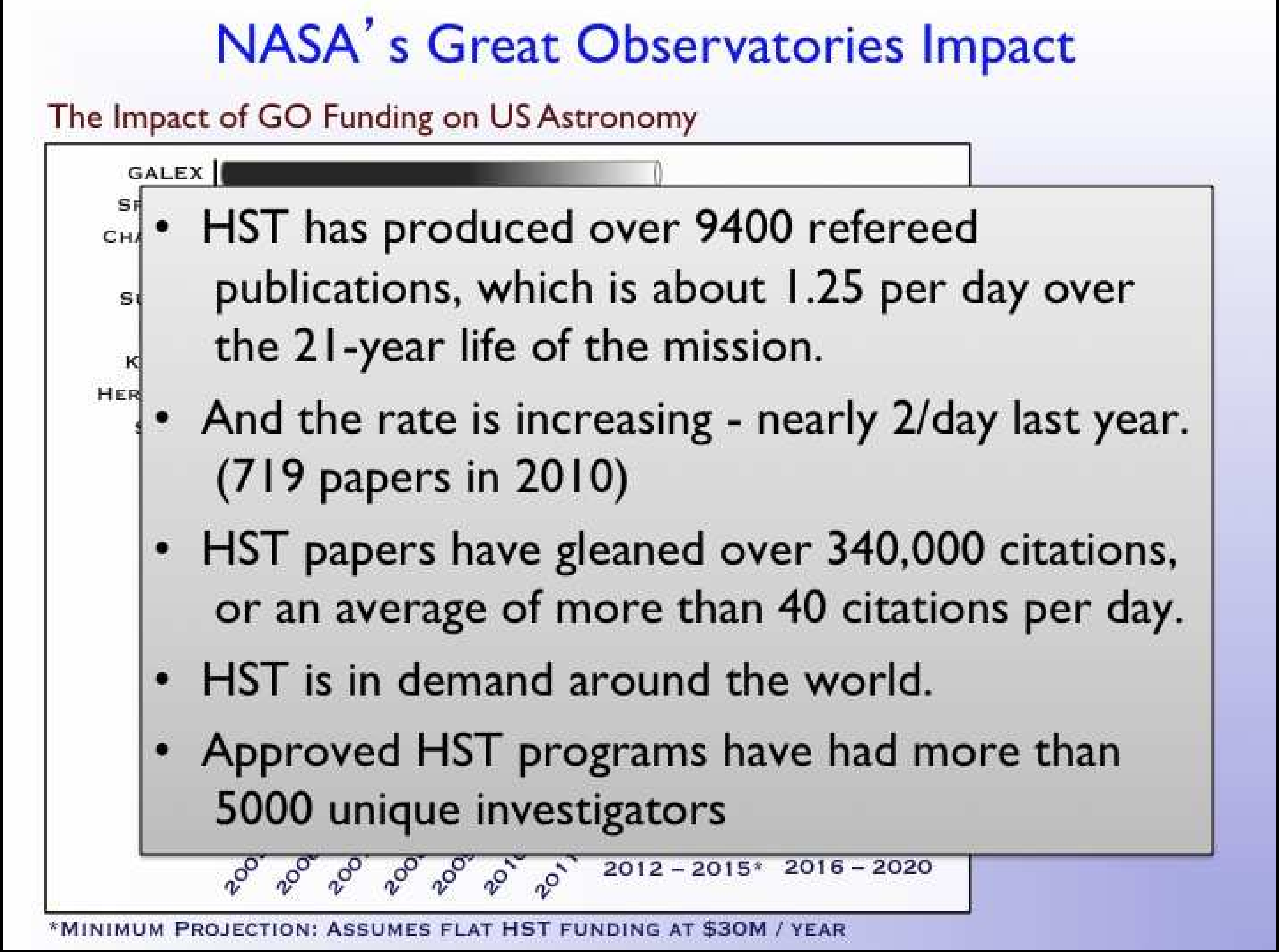
NASA science Budget flat beginning 2012

NASA Space Science has external budget pressures independent of JWST.

Astrophysics Division



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



NASA’s Great Observatories Impact

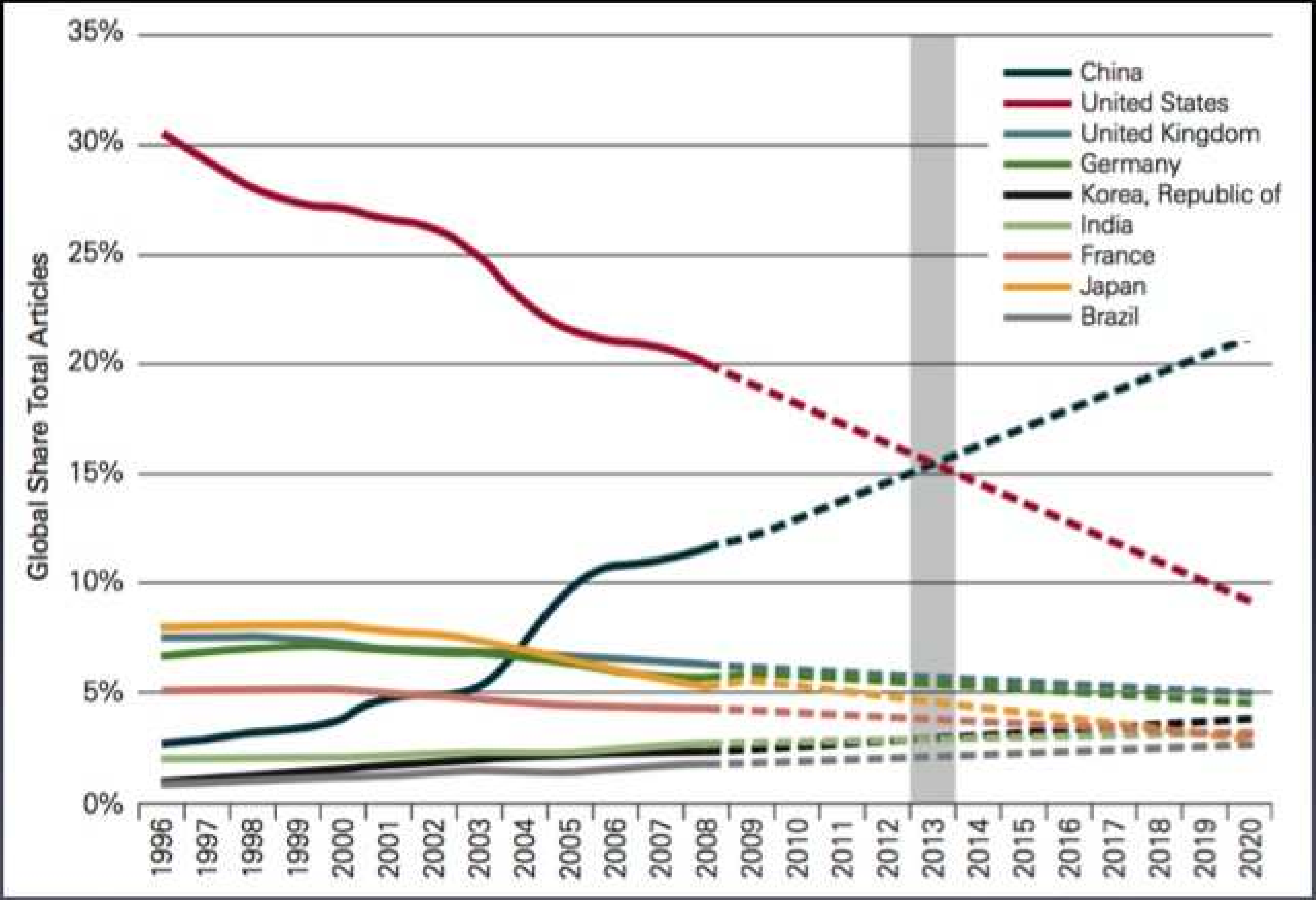
The Impact of GO Funding on US Astronomy

- 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.

- 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/

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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"