# How can JWST measure First Light, Galaxy Assembly & Supermassive Blackhole Growth: Science and Project update

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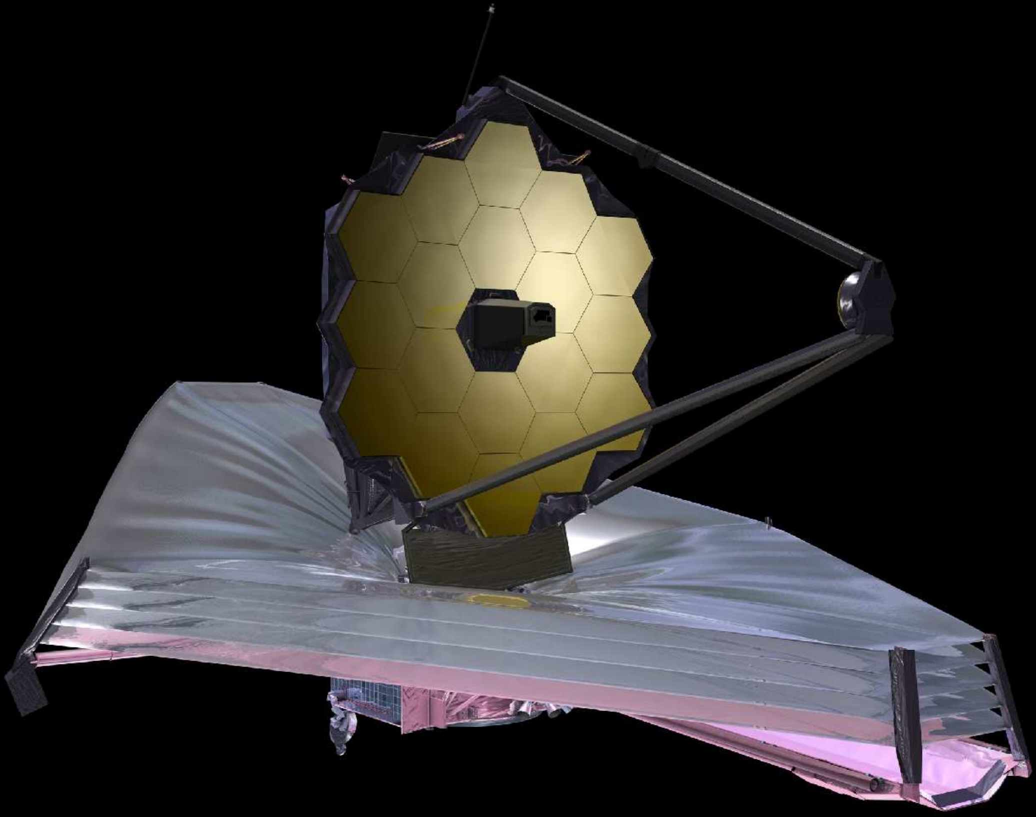
**Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist**

*Collaborators: S. Cohen, R. Jansen (ASU), C. Conselice (UK), S. Driver, A. Hopkins (OZ), & H. Yan (U-MO)*

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



*Talk at the Astronomical Society of Australia Annual Scientific Meeting, Monash University, VIC, Australia*

*Friday, July 12, 2013. All presented materials are ITAR-cleared.*

# Outline

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- (1) Brief Update of the James Webb Space Telescope (JWST)

- (2) How can JWST measure the Epochs of First Light & Galaxy Assembly, and Supermassive Black-Hole Growth?

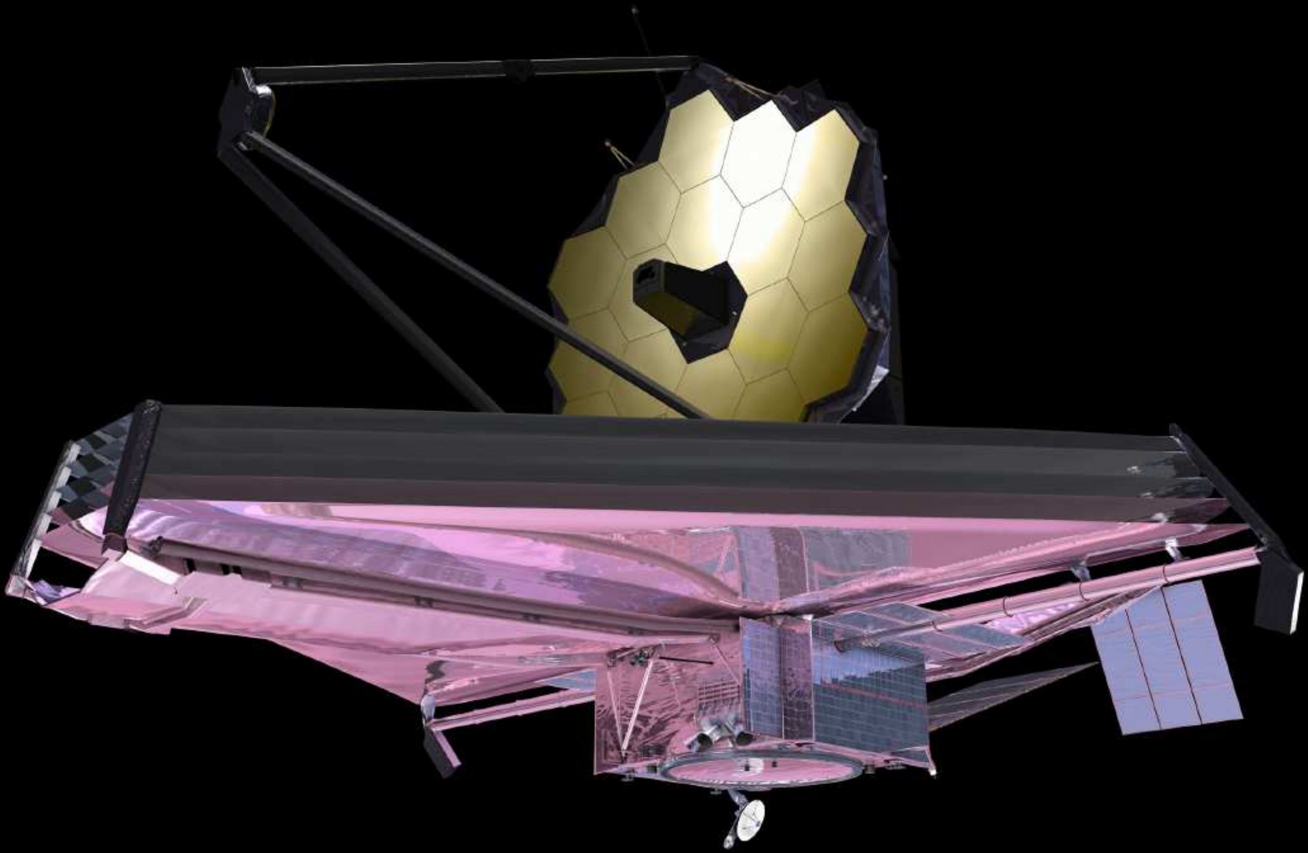
— in the context of what Hubble Wide Field Camera 3 (WFC3) has done: including the first z$\simeq$6 QSO host galaxy detections this month ...

- (3) Summary and Conclusions.

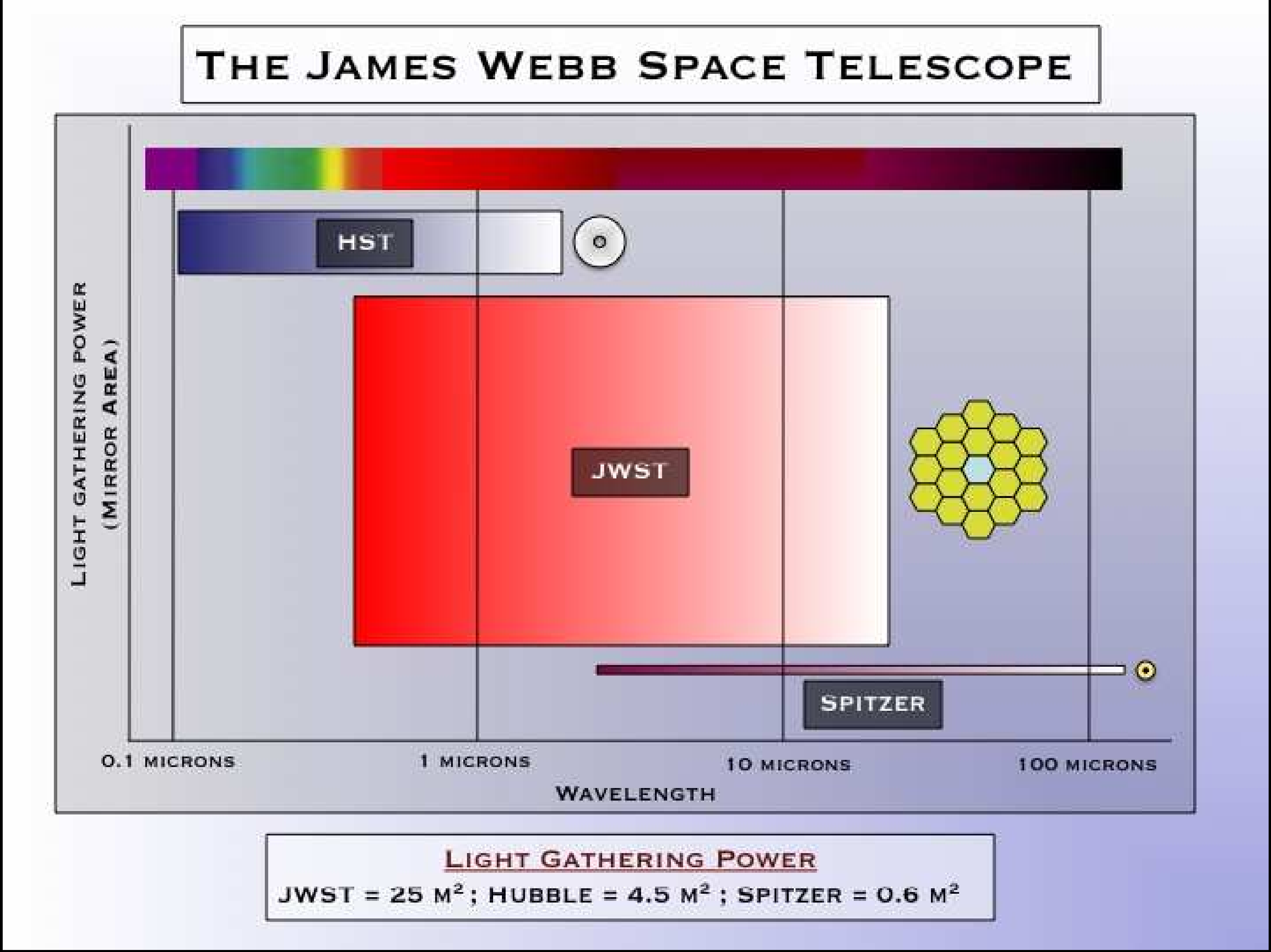
Sponsored by NASA/HST & JWST

Full 1-hr talks this trip: Canberra (June 27), Macquarie (July 4), Uluru (July 18), U. Melbourne (July 22), Perth (July 25), and Sydney (Uni July 30; AAO July 30; CSIRO July 31) — see the URL's in the Spare Charts/References).

# (1) Brief Update of the James Webb Space Telescope



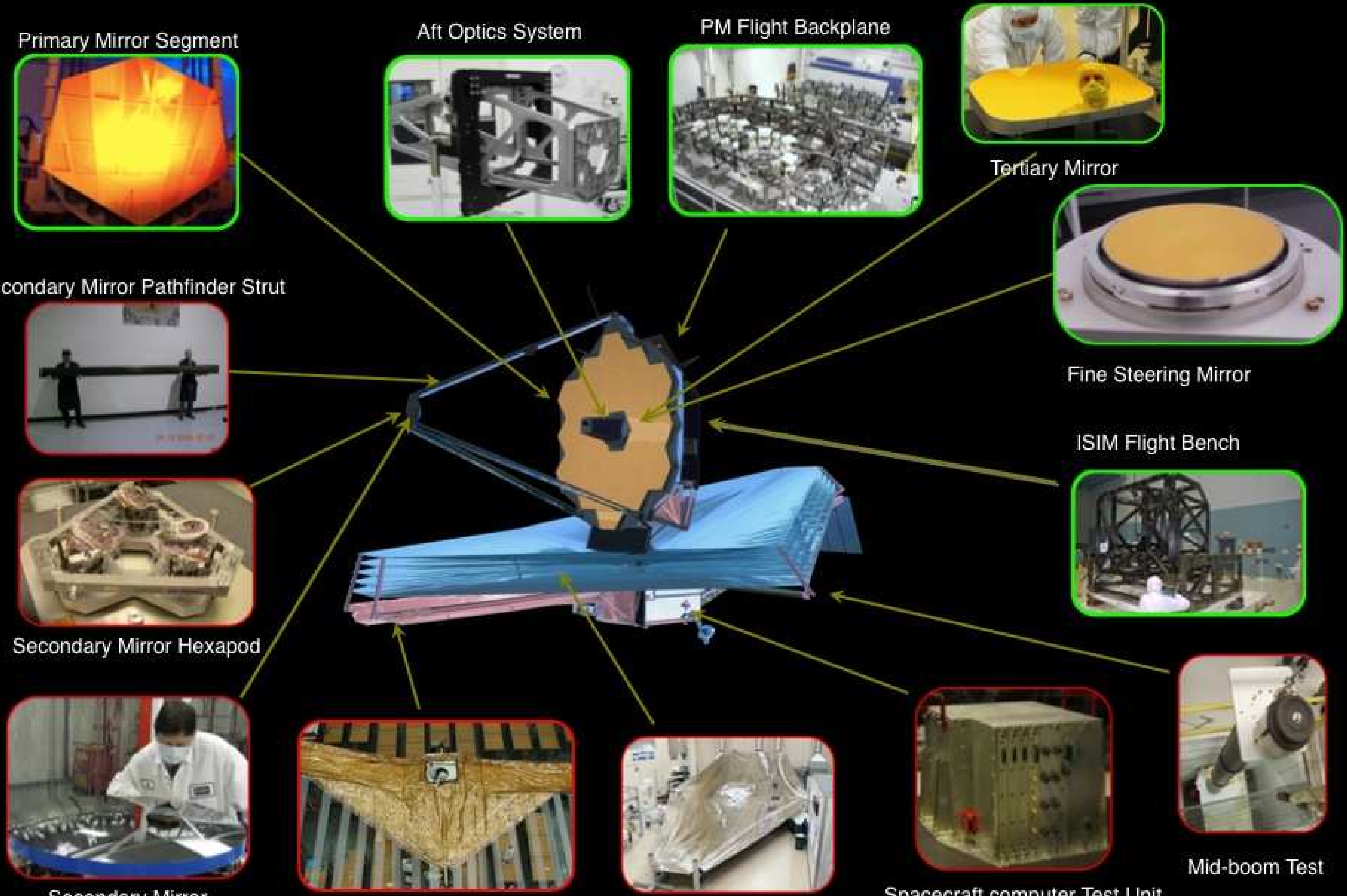
- A fully deployable 6.5 meter (25 $m^2$) segmented IR telescope for imaging and spectroscopy at 0.6–28 $\mu$m wavelength, to be launched in Fall 2018.
- Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging (AB=31.5 mag) and spectroscopy.



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.

# JWST Hardware Status



Primary Mirror Segment

Aft Optics System

PM Flight Backplane

Tertiary Mirror

Fine Steering Mirror

Secondary Mirror Pathfinder Strut

ISIM Flight Bench

Secondary Mirror Hexapod

Secondary Mirror

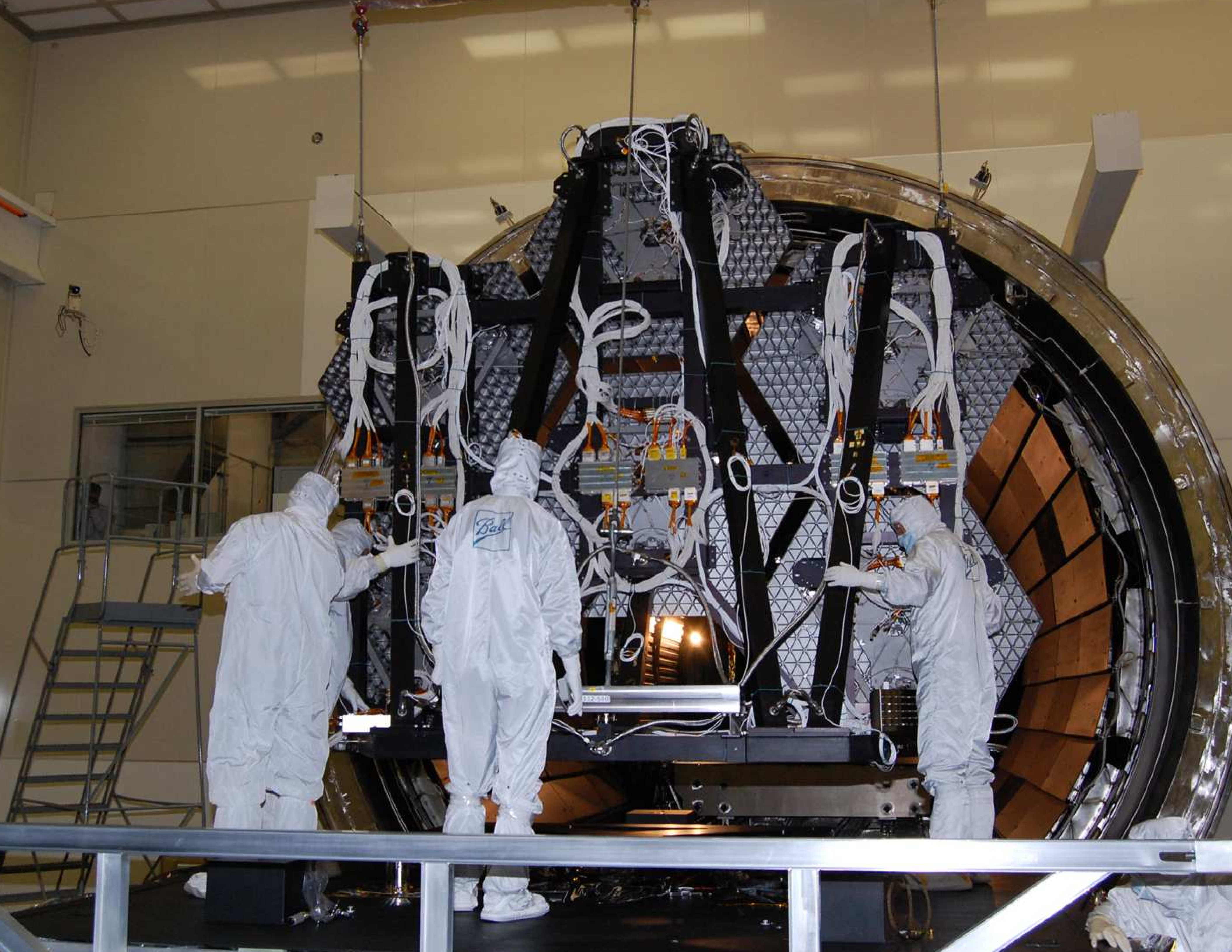
Membrane Mgmt

Pathfinder Membrane

Spacecraft computer Test Unit

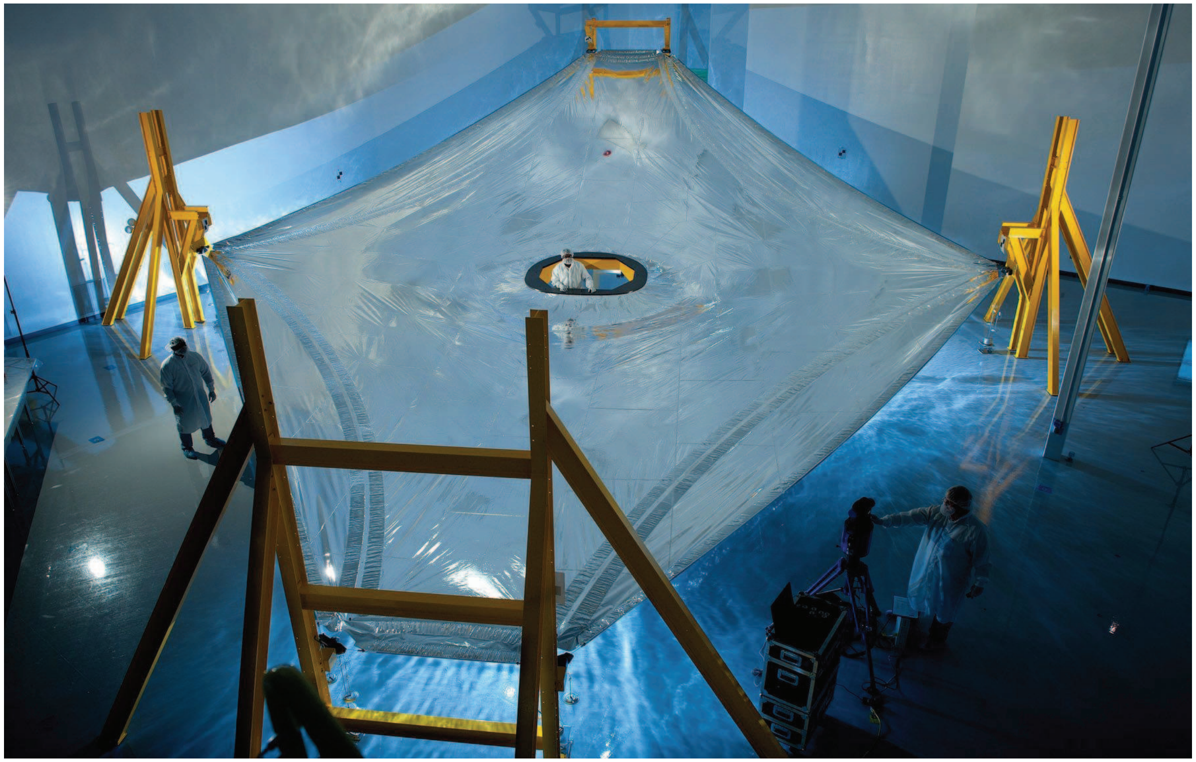
Mid-boom Test

# Mirror Acceptance Testing


Ball

# Sunshield

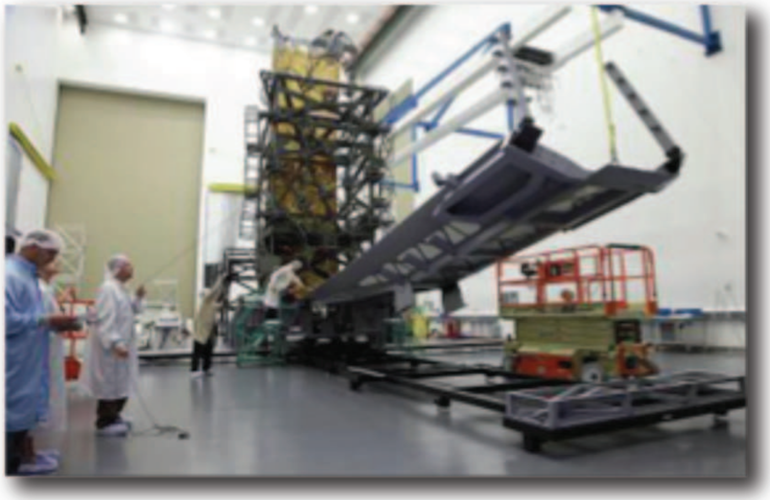
- **Template membrane build to flight-like requirements for verification of:**
  - Shape under tension to verify gradients and light line locations
  - Hole punching & hole alignment for membrane restraint devices (MRD)
  - Verification of folding/packing concept on full scale mockup
  - Layer 3 shape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



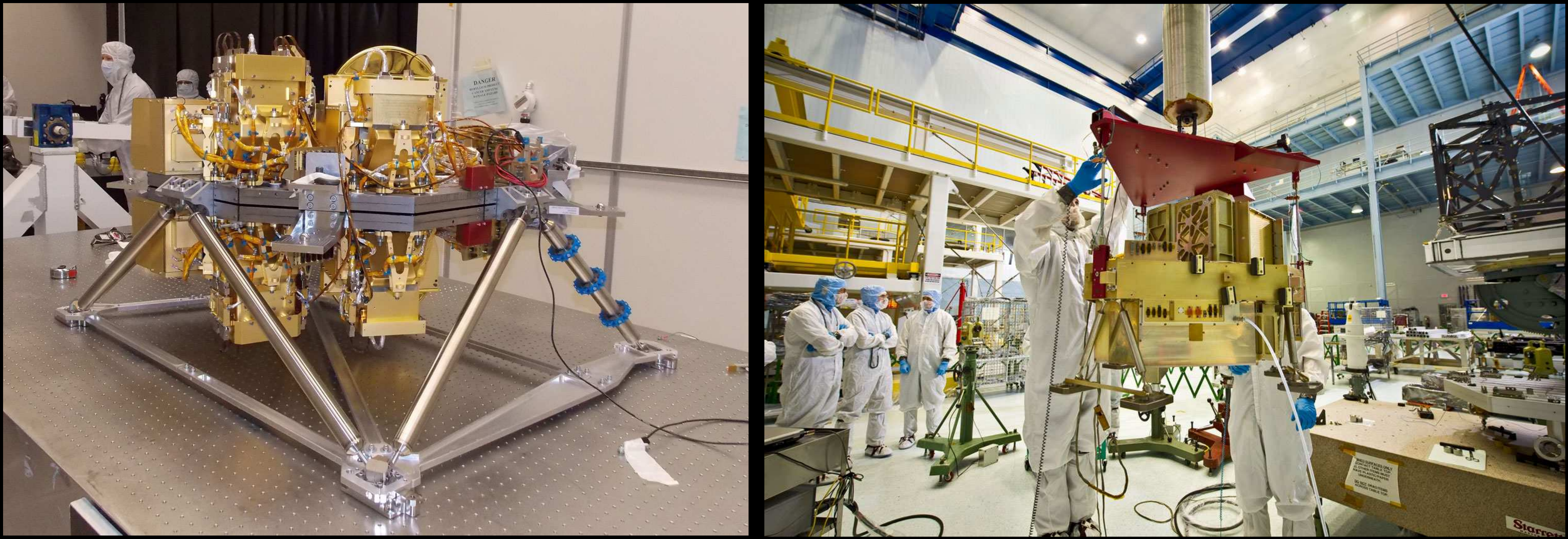
**🡐Layer-3 template membrane under tension for 3-D shape measurements at Mantech**

**Full-scale JWST mockup with sunshield pallette**

**🡓**

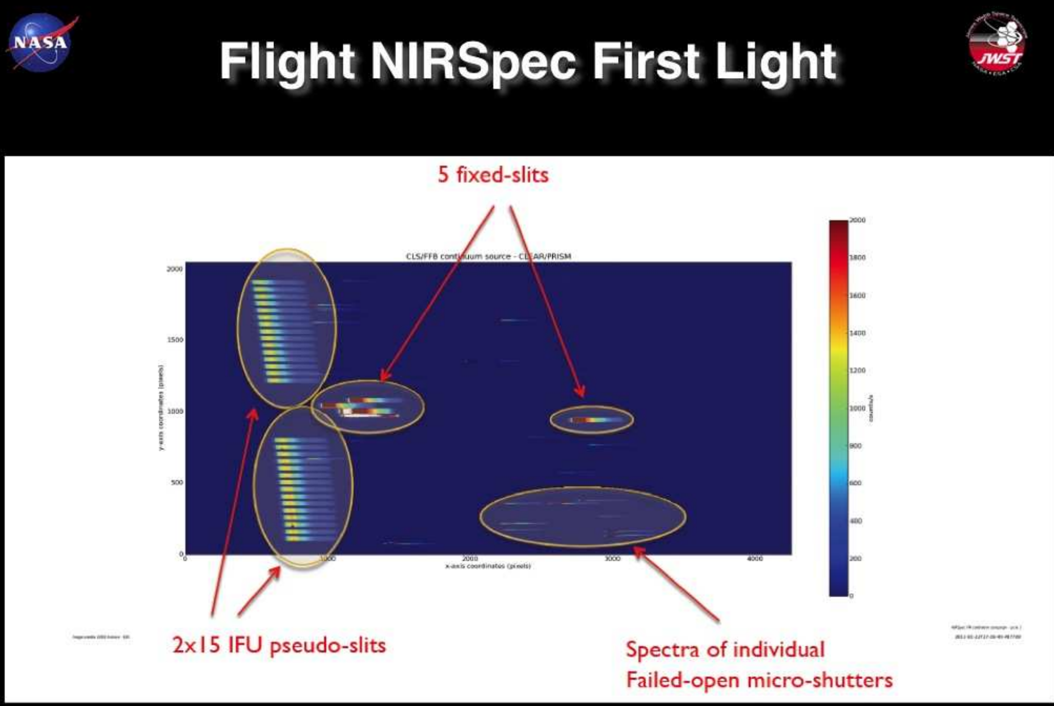


# (1b) JWST instruments update: US (UofA, JPL), ESA, & CSA.



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

- NIRCam — built by UofA (AZ) and Lockheed (CA).
- Fine Guidance Sensor (& 1–5 $\mu$m grisms) — built by CSA (Montreal).
- FGS includes very powerful low-res Near-IR grism spectrograph (NIRISS).
- FGS delivered to GSFC 07/12; NIRCam scheduled for Fall 2013.



Flight NIRSpec First Light

5 fixed-slits

2x15 IFU pseudo-slits

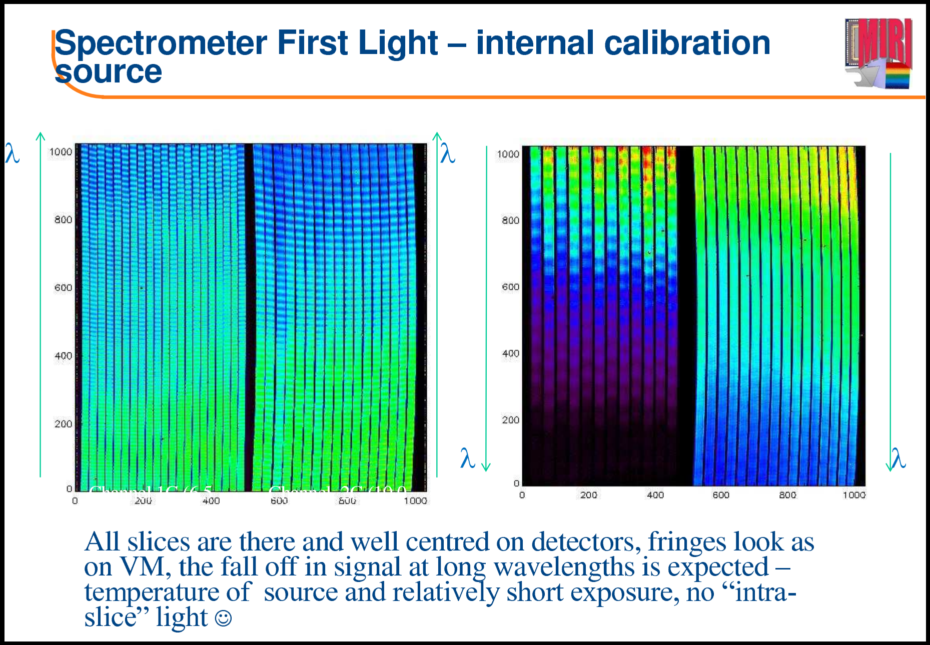
Spectra of individual
Failed-open micro-shutters

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

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

NIRSpec delivery to NASA/GSFC scheduled for Fall 2013.

# Flight MIRI



## Spectrometer First Light – internal calibration source

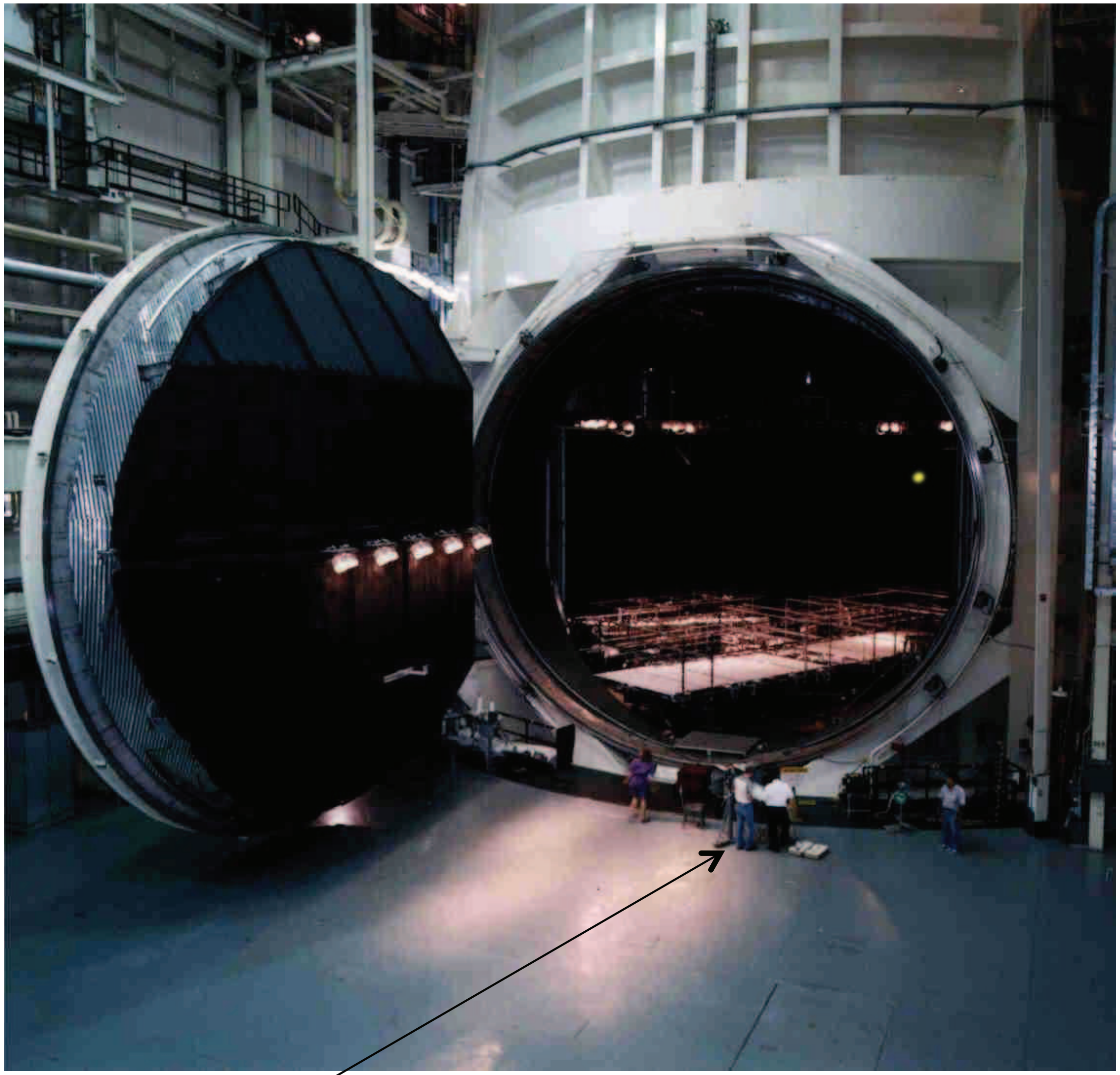
All slices are there and well centred on detectors, fringes look as on VM, the fall off in signal at long wavelengths is expected – temperature of source and relatively short exposure, no "intra-slice" light ☺

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

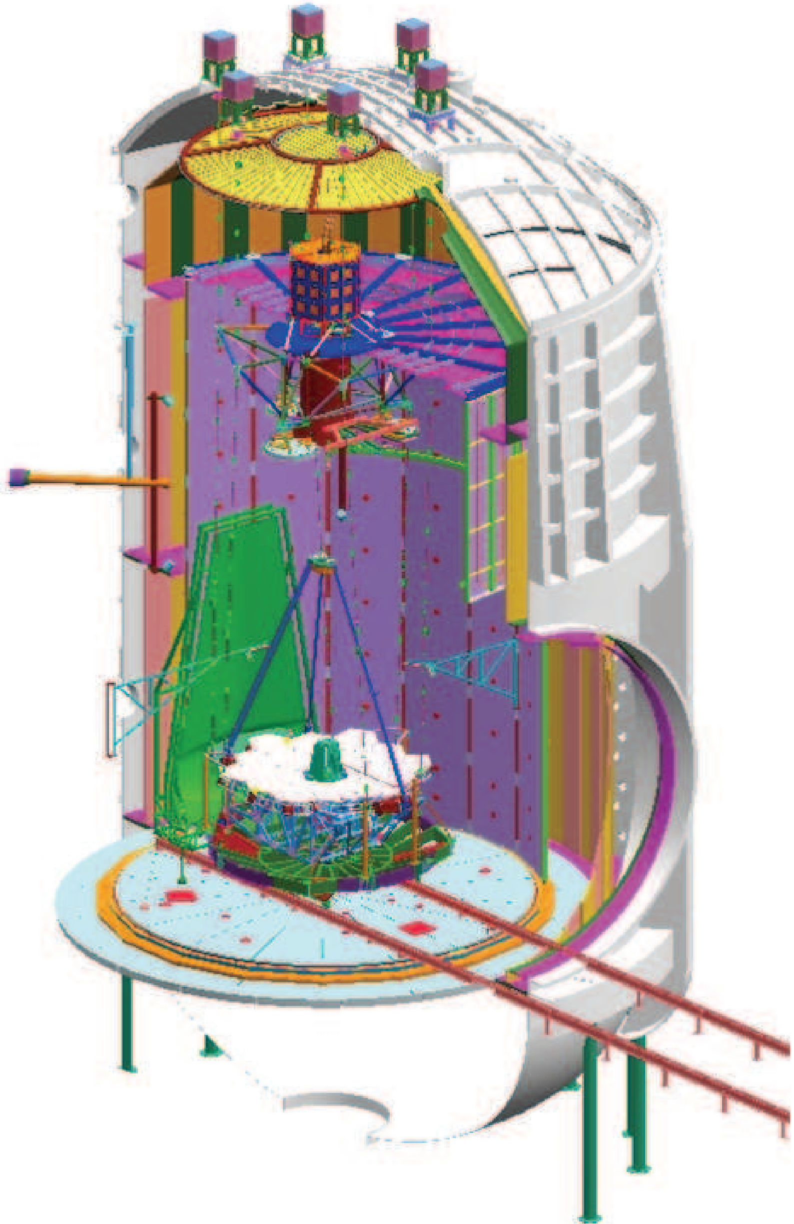
- MIRI — built by ESA consortium of 10 ESA countries & NASA JPL.
- Flight build completed and tested with First Light in July 2011.

MIRI delivered to NASA/GSFC in May 2012!

# OTE Testing – Chamber A at JSC



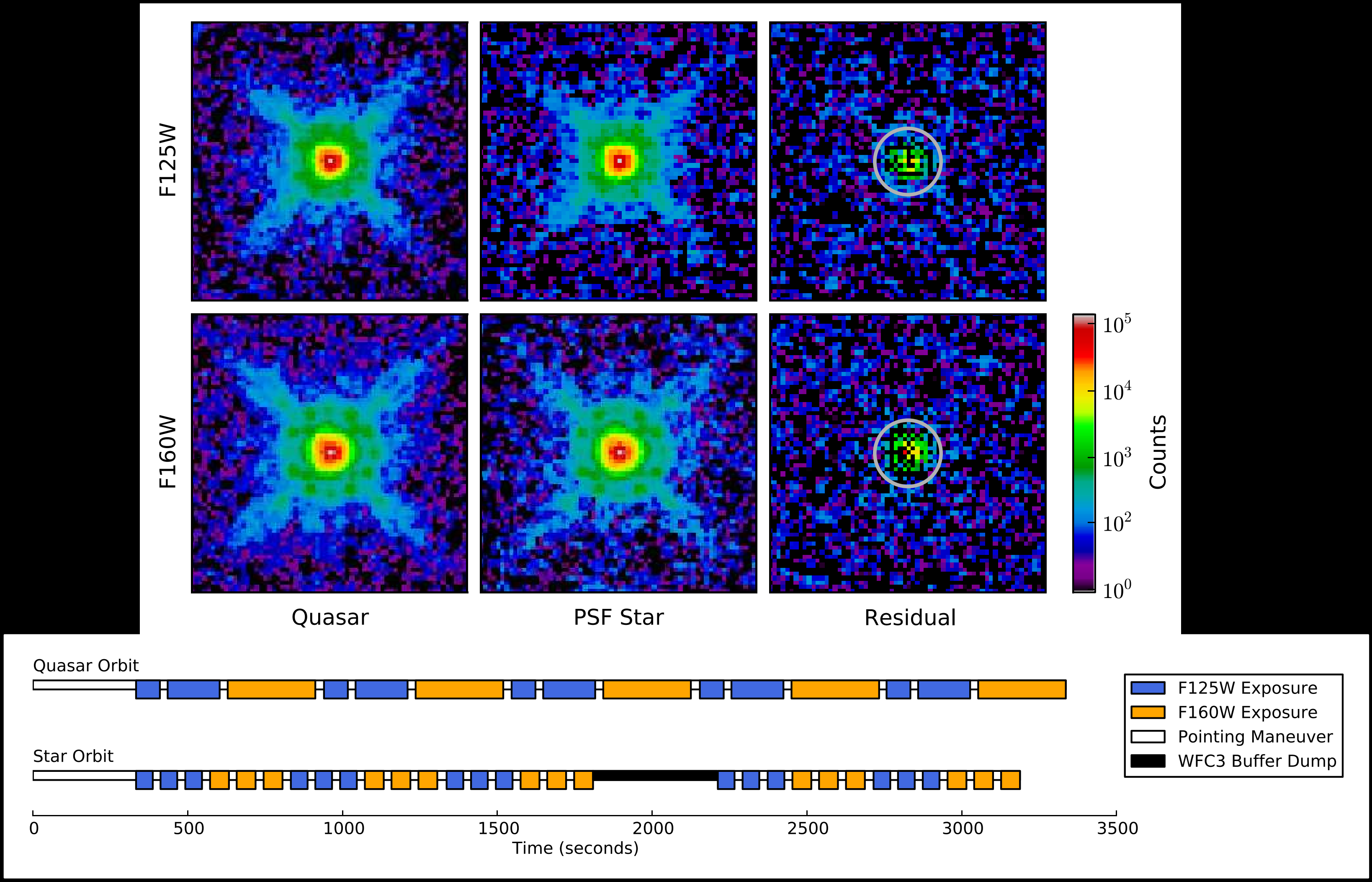
Notice people for scale



Will be the largest cryo vacuum test chamber in the world

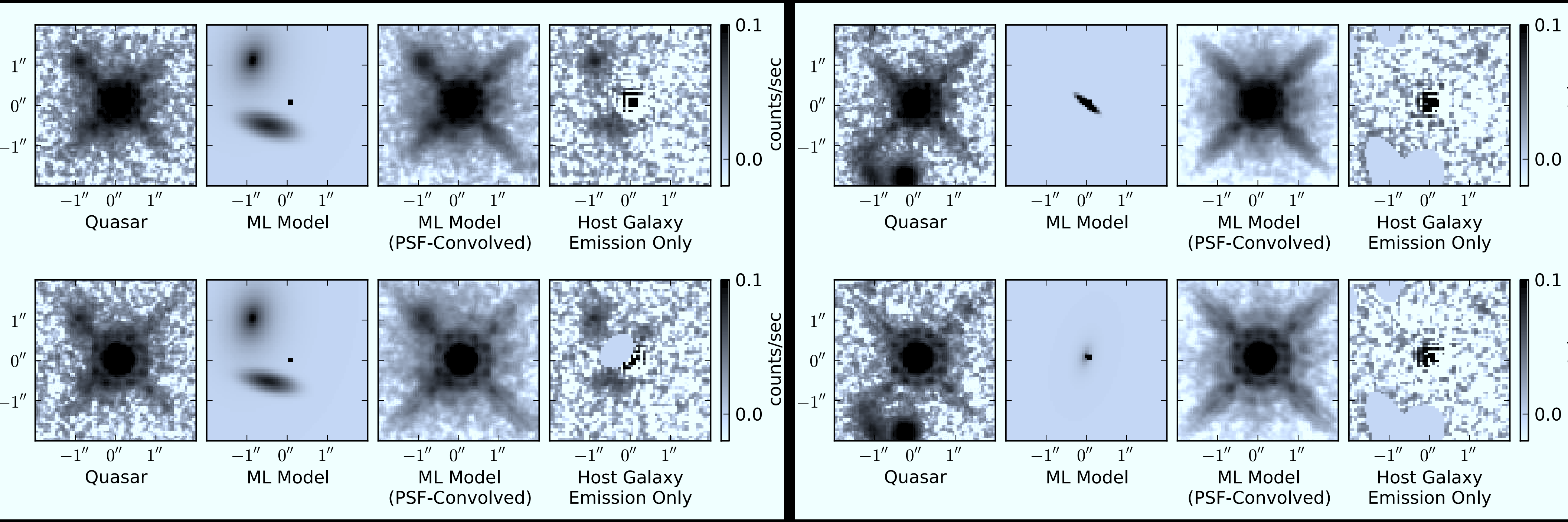
OTIS: Largest TV chamber in world: Will test whole JWST in 2015–2016.

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



- Careful contemporaneous orbital PSF-star subtraction: Removes most of “OTA spacecraft breathing” effects (Mechtley ea 2012, ApJL, 756, L38)
- PSF-star (AB=15 mag) subtracts $z$=6.42 QSO (AB=19) nearly to the noise limit: NO host galaxy detected 100× fainter (AB$\gtrsim$23.5 mag at $r \gtrsim 0''.3$).

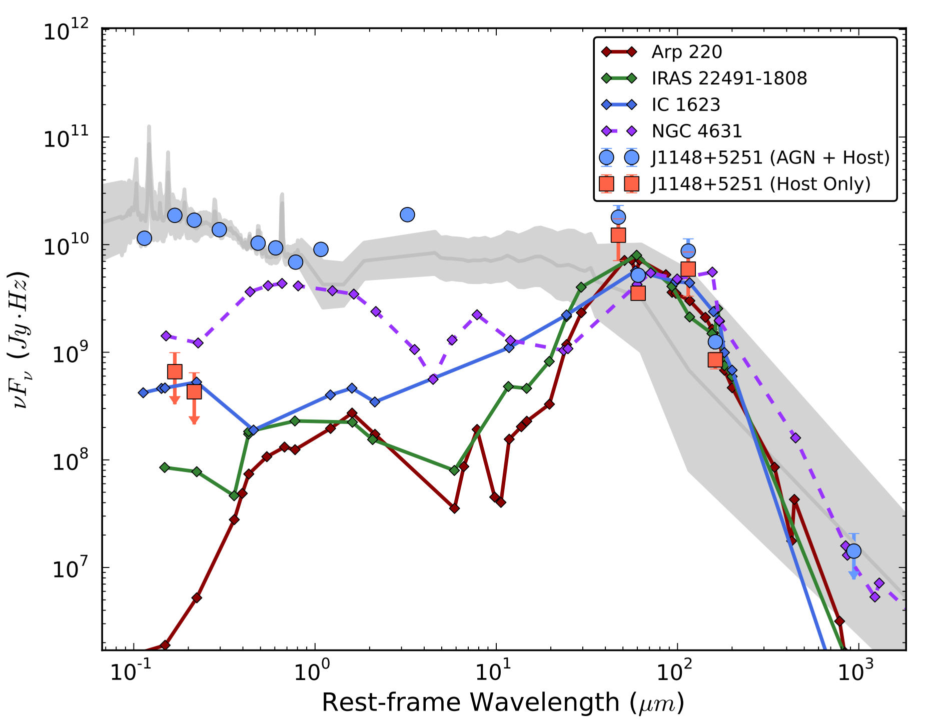
# (2) WFC3: First detection of one Quasar Host Galaxy at z$\simeq$6 (Giant merger?)

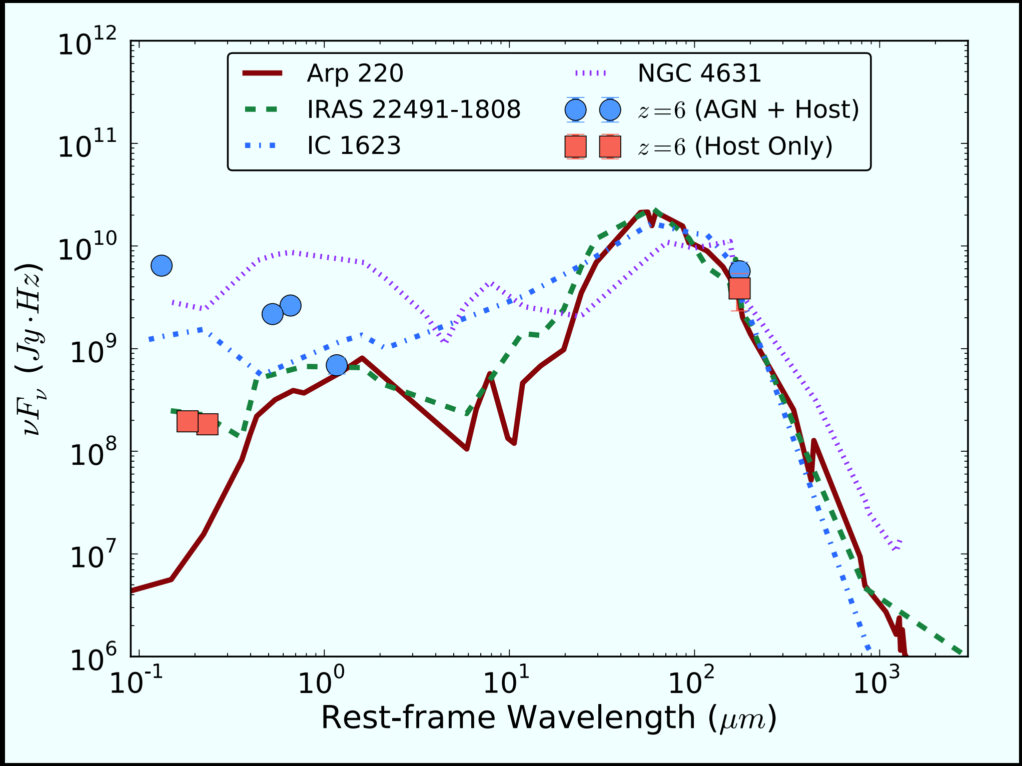


- Monte Carlo Markov-Chain of observed PSF-star + Sersic ML light-profile. Gemini AO data critical for PSF stars (Mechtley$^+$ 2013).
- First solid host galaxy detection out of four z$\simeq$6 QSOs [3 more to come].
- One z$\simeq$6 QSO host galaxy: Giant merger morphology + tidal structure?
- Same J+H structure! Blue UV-SED colors: (J–H)$\simeq$0.19, constrains dust.
- IRAS starburst galaxy-like SED from rest-frame UV–far-IR, $A_V \gtrsim 1$ mag.
- $M_{AB}^{host}$(z$\simeq$6)$\lesssim$–23.0 mag, i.e., $\gtrsim$2–3 mag brighter than L*(z$\simeq$6)!

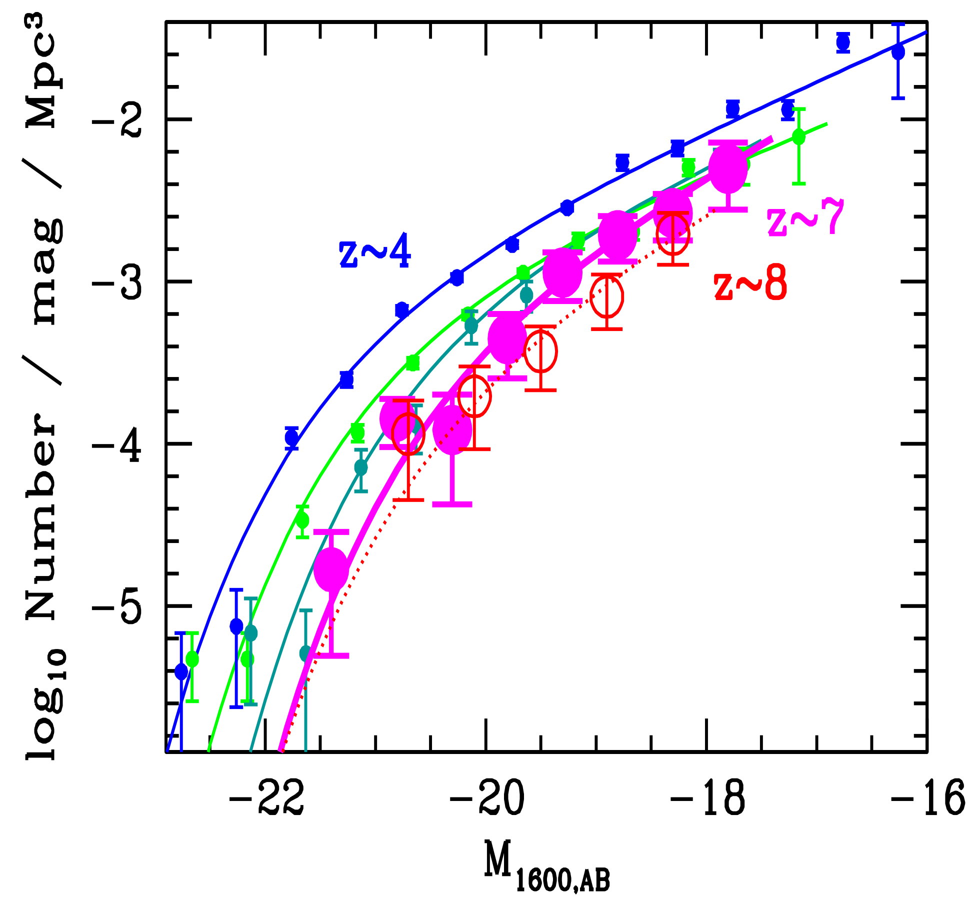
$\Rightarrow$ z$\simeq$6 QSO duty cycle $\lesssim 10^{-2}$ ($\lesssim$10 Myrs); 1/4 QSO's close to Magorrian.

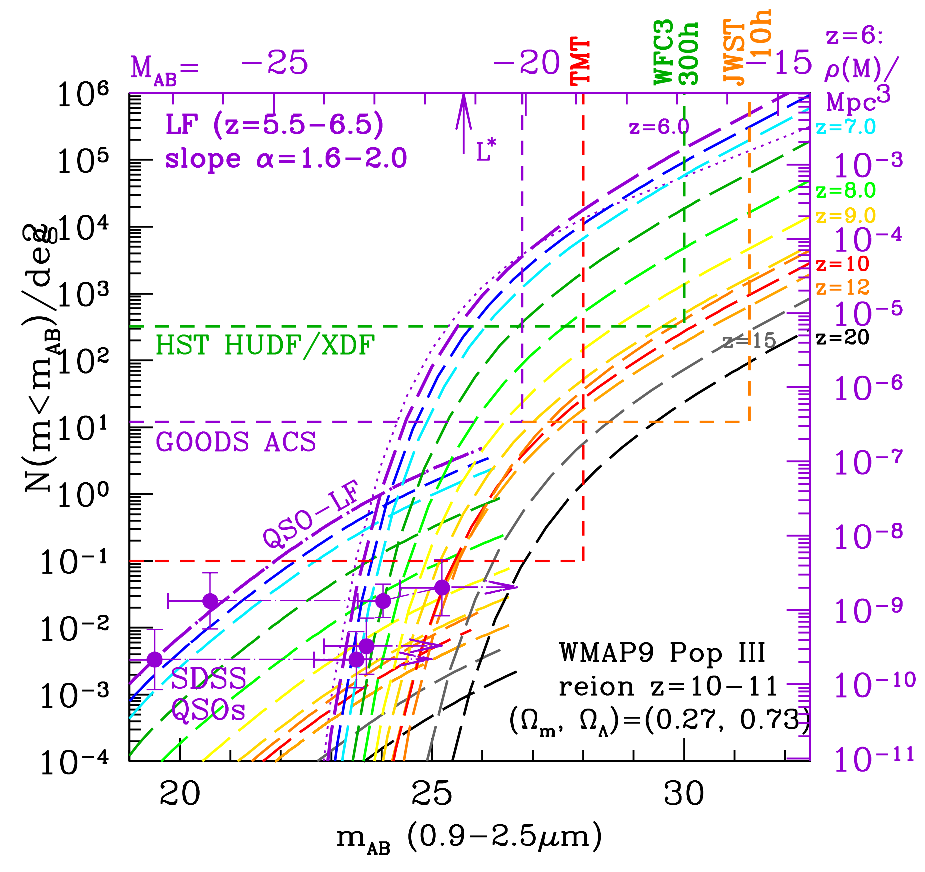
# (1) HST WFC3 observations of dusty QSO host galaxies at z$\simeq$6





- Blue dots: z$\simeq$6 QSO SED, Grey: Average radio-quiet QSO spectrum at z$\lesssim$1 (normalized at 0.5$\mu$). Red: z$\simeq$6 host galaxy (WFC3+submm).
- Nearby fiducial galaxies (starburst ages$\lesssim$1 Gyr) normalized at 100$\mu$m: Rules out z=6.42 spiral or bluer host galaxy SEDs for 1148+5251. (U)LIRGs permitted (Mechtley et al. 2012, ApJL, 756, L38).
- Detected QSO host has IRAS starburst-like SED from rest-frame UV–far-IR, $A_V$ $\gtrsim$1 mag (Mechtley et al. 2013).
- JWST Coronagraphs can do this 10–100× fainter (& for z$\lesssim$20, $\lambda\lesssim$28$\mu$m).





- Objects at z$\gtrsim$9 are rare (Bouwens$^+$ 12; 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 ($\Omega$), and $\lambda$-range (0.7-29 $\mu$m).

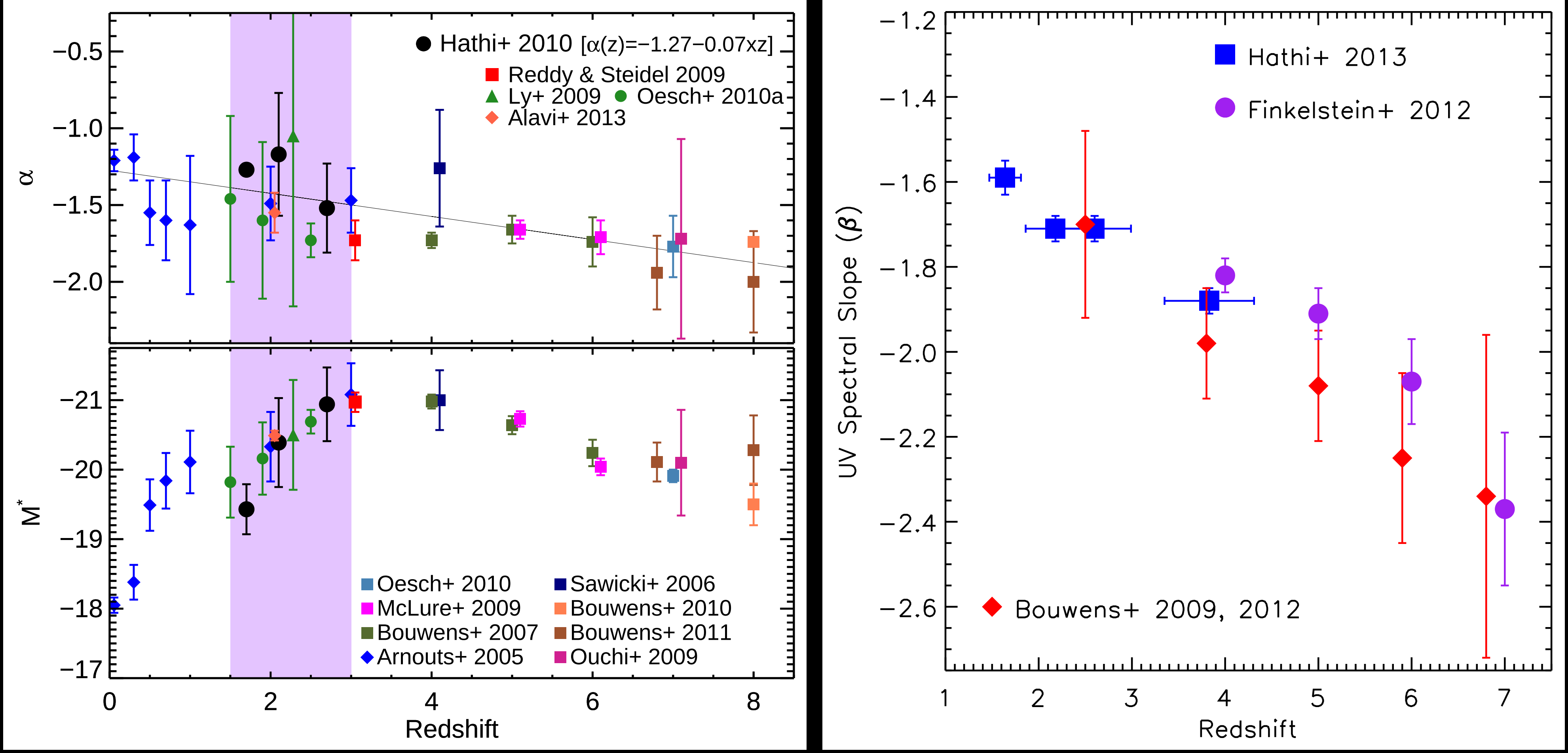
- With proper survey strategy (area AND depth), JWST can trace the entire reionization epoch and detect the first star-forming objects.

- JWST Coronagraphs can also trace super-massive black-holes as faint quasars in young galaxies: JWST needs 2.0$\mu$m diffraction limit for this.

# (2) How can JWST measure First Light, Reionization, & Galaxy Assembly?

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



Measured evolution of faint-end LF slope $\alpha$ (top), characteristic luminosity $M^*$ (bottom), and UV SED-slope $\beta$ (right; Hathi et al. 2010, 2013).

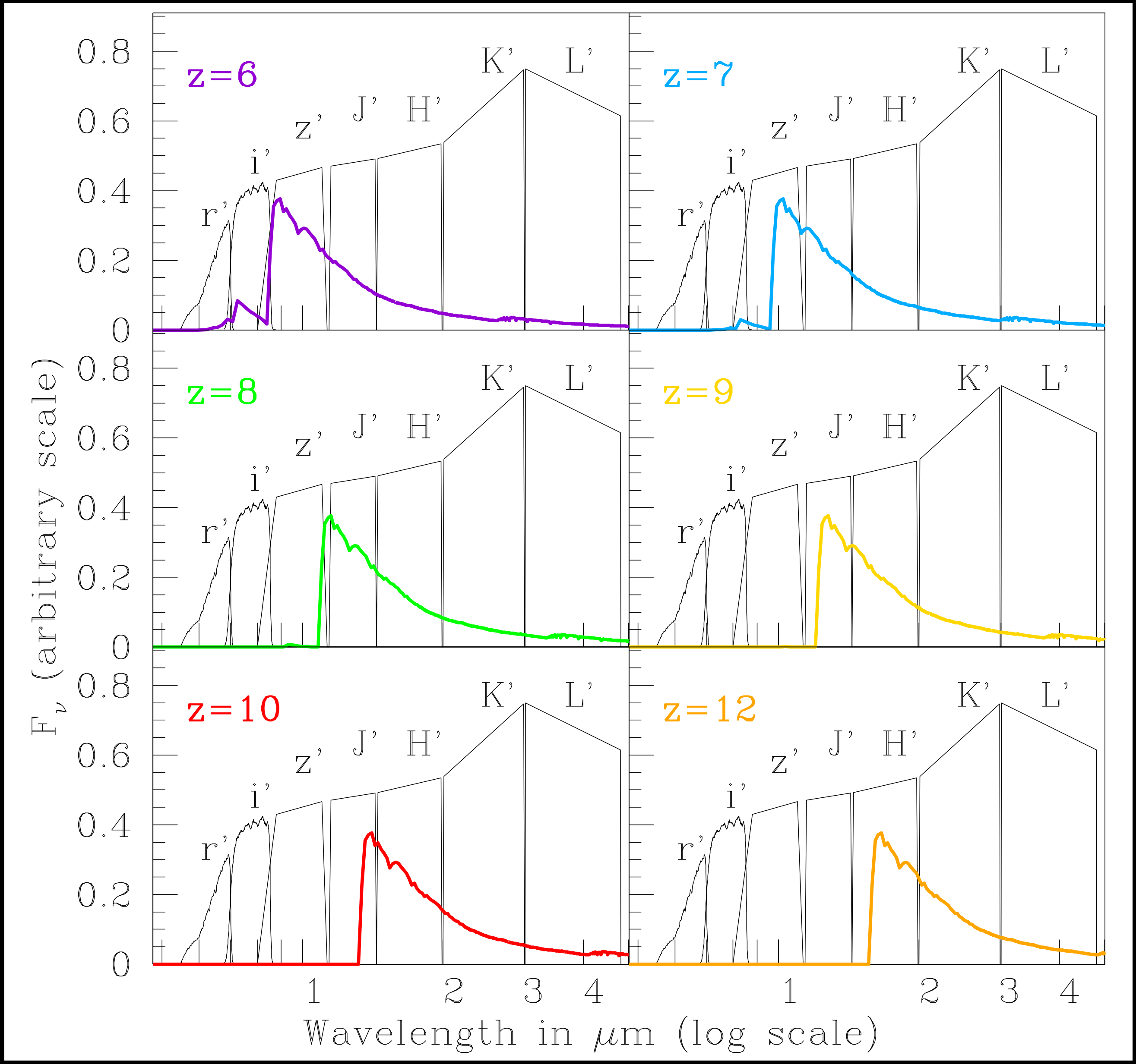
- In the JWST regime at $z \gtrsim 8$, expect faint-end LF slope $\alpha \simeq 2.0$.
- In the JWST regime at $z \gtrsim 8$, expect UV SED-slope $\beta \lesssim -2.5$.

$\Rightarrow$ Significant consequences for cosmic reionization at $z \gtrsim 6$ by dwarf galaxies.

- In the JWST regime at $z \gtrsim 8$, expect characteristic luminosity $M^* \gtrsim -19$.

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

# (2c) How will JWST measure First Light & Reionization?



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

⇒ This is why JWST needs NIRCam at 0.8–5 $\mu$m and MIRI at 5–28 $\mu$m.

Two fundamental limitations determine ultimate JWST image depth:

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

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

- Proper JWST 2.0$\mu$m PSF and straylight specs essential to handle this.

# (5) Conclusions

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

- Most $z \simeq 6$ QSO host galaxies faint (dusty?), with 1 exception: $L >> L^*$.

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

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

- More than 80% of JWST H/W built or in fab, & meets/exceeds specs.

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

- Formation and evolution of the first star-clusters after 0.2 Gyr.
- How dwarf galaxies formed and reionized the Universe after 1 Gyr.

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

- IR sequel to HST after 2018: Training the next generation researchers.
- JWST will define the next frontier to explore: the Dark Ages at $z \gtrsim 20$.

# SPARE CHARTS

- References and other sources of material shown:

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

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

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

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

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

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

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

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

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

Mather, J., & Stockman, H. 2000, Proc. SPIE Vol. 4013, 2

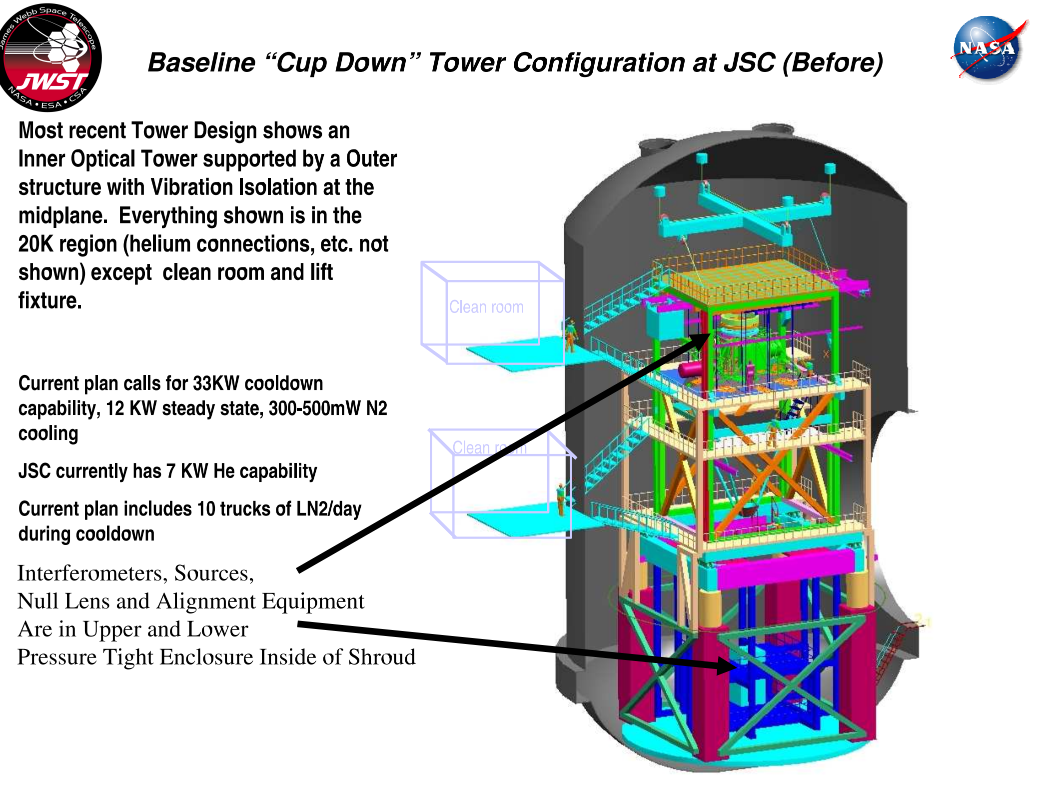
Windhorst, R., et al. 2008, Advances in Space Research, 41, 1965

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

# Northrop Grumman Expertise in Space Deployable Systems

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





**Baseline “Cup Down” Tower Configuration at JSC (Before)**

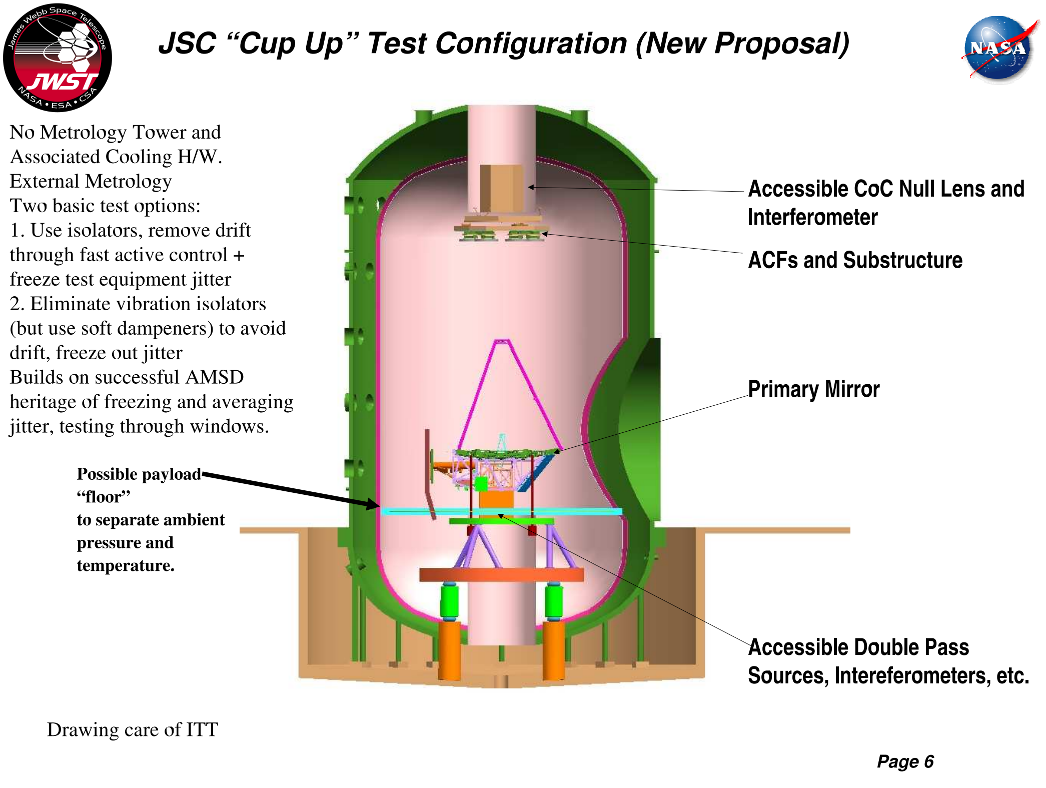
Most recent Tower Design shows an Inner Optical Tower supported by a Outer structure with Vibration Isolation at the midplane. Everything shown is in the 20K region (helium connections, etc. not shown) except clean room and lift fixture.

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

JSC currently has 7 KW He capability

Current plan includes 10 trucks of LN2/day during cooldown

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



**JSC “Cup Up” Test Configuration (New Proposal)**

No Metrology Tower and Associated Cooling H/W.
External Metrology
Two basic test options:
1. Use isolators, remove drift through fast active control + freeze test equipment jitter
2. Eliminate vibration isolators (but use soft dampeners) to avoid drift, freeze out jitter
Builds on successful AMSD heritage of freezing and averaging jitter, testing through windows.

**Possible payload “floor” to separate ambient pressure and temperature.**

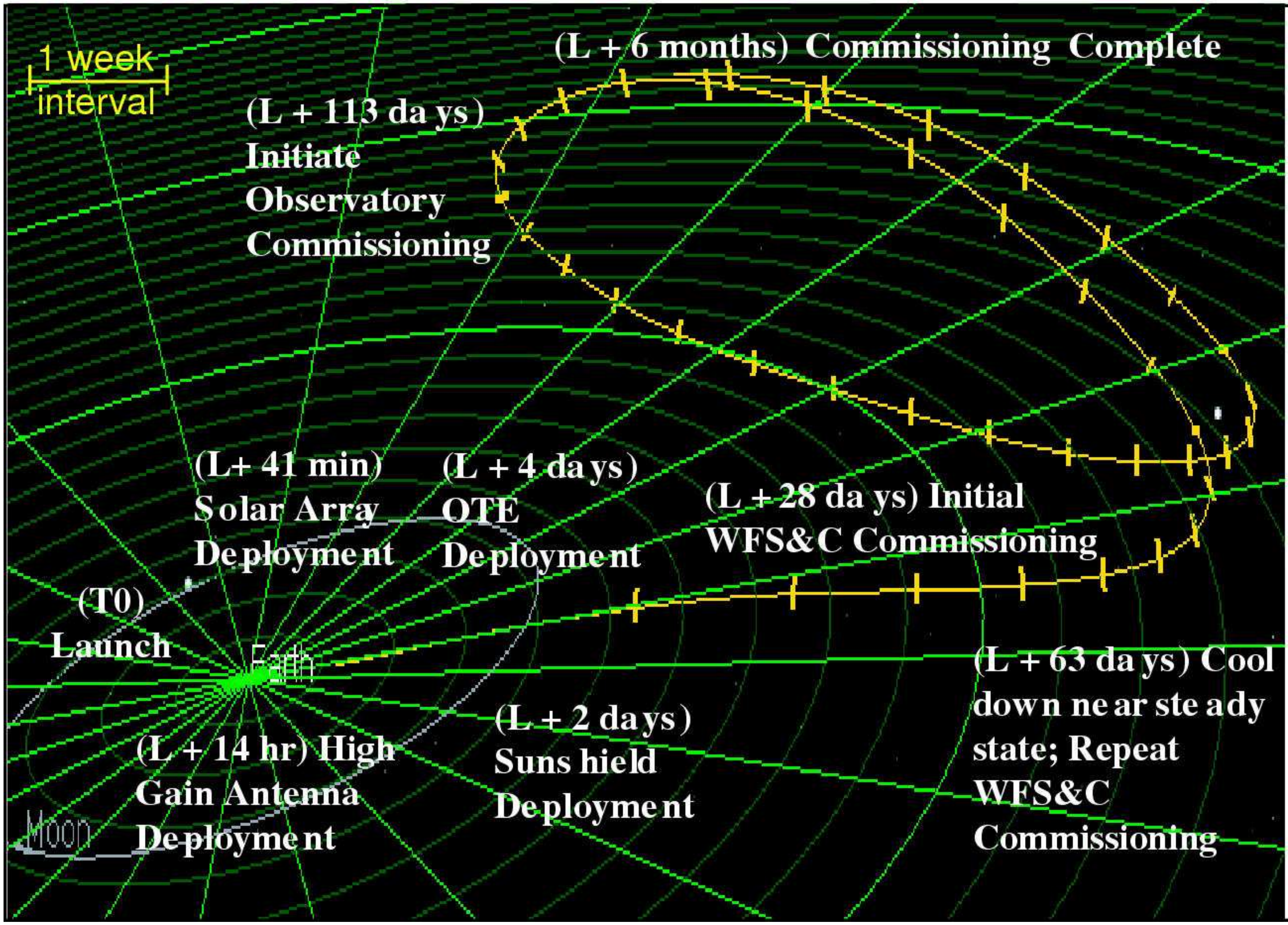
Drawing care of ITT

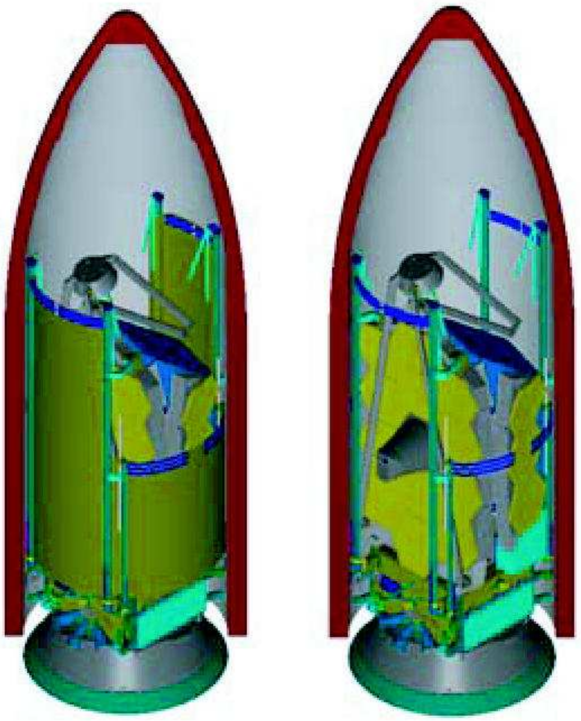
Page 6

JWST underwent several significant replans and risk-reduction schemes:

- $\lesssim$2003: Reduction from 8.0 to 7.0 to 6.5 meter. Ariane-V launch vehicle.
- 2005: Eliminate costly 0.7-1.0 $\mu$m performance specs (kept 2.0 $\mu$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, 2011: Passes Mission Critical Design Review: Replan Int. & Testing.

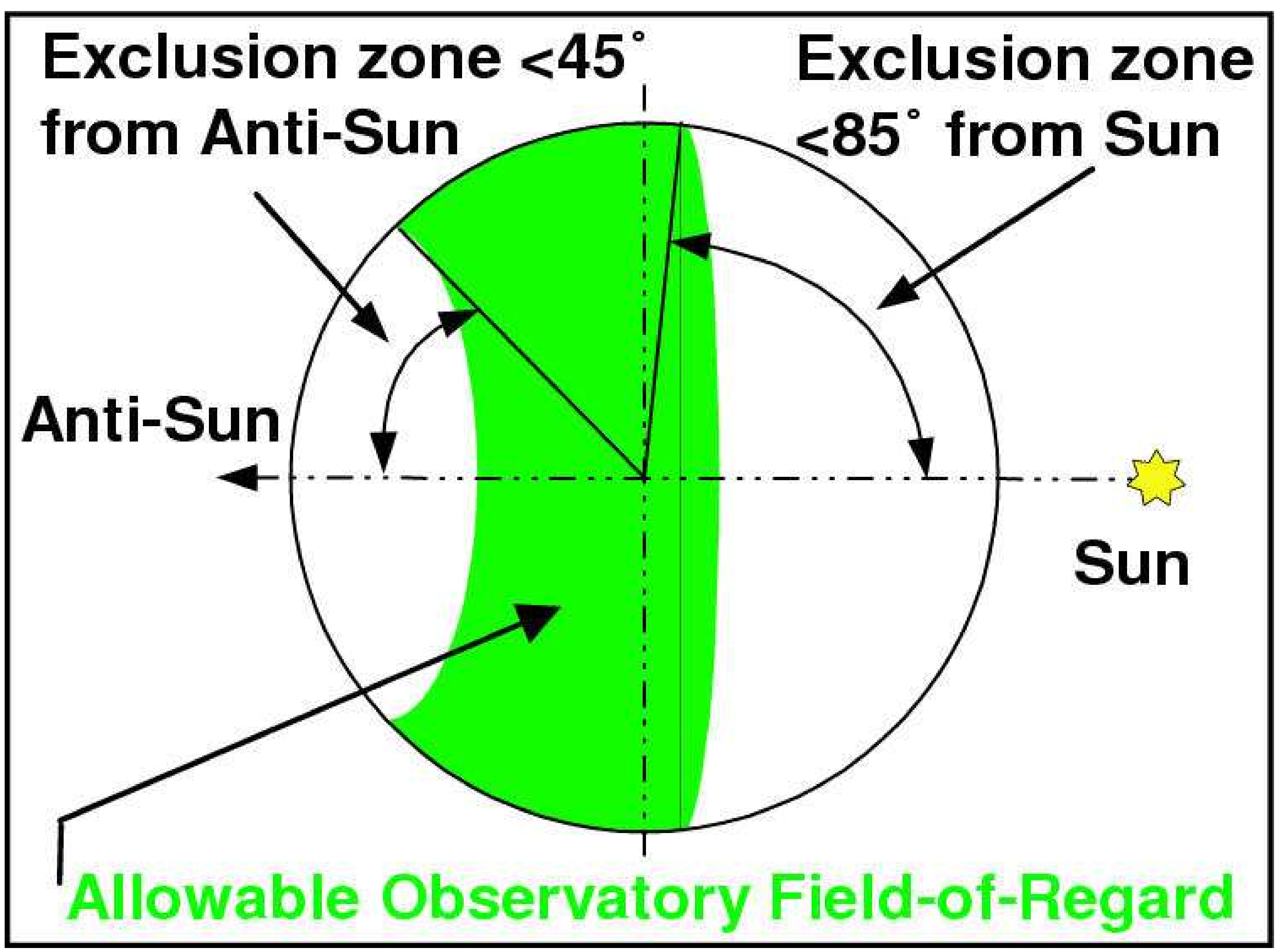
# (1a) How will JWST travel to its L2 orbit?



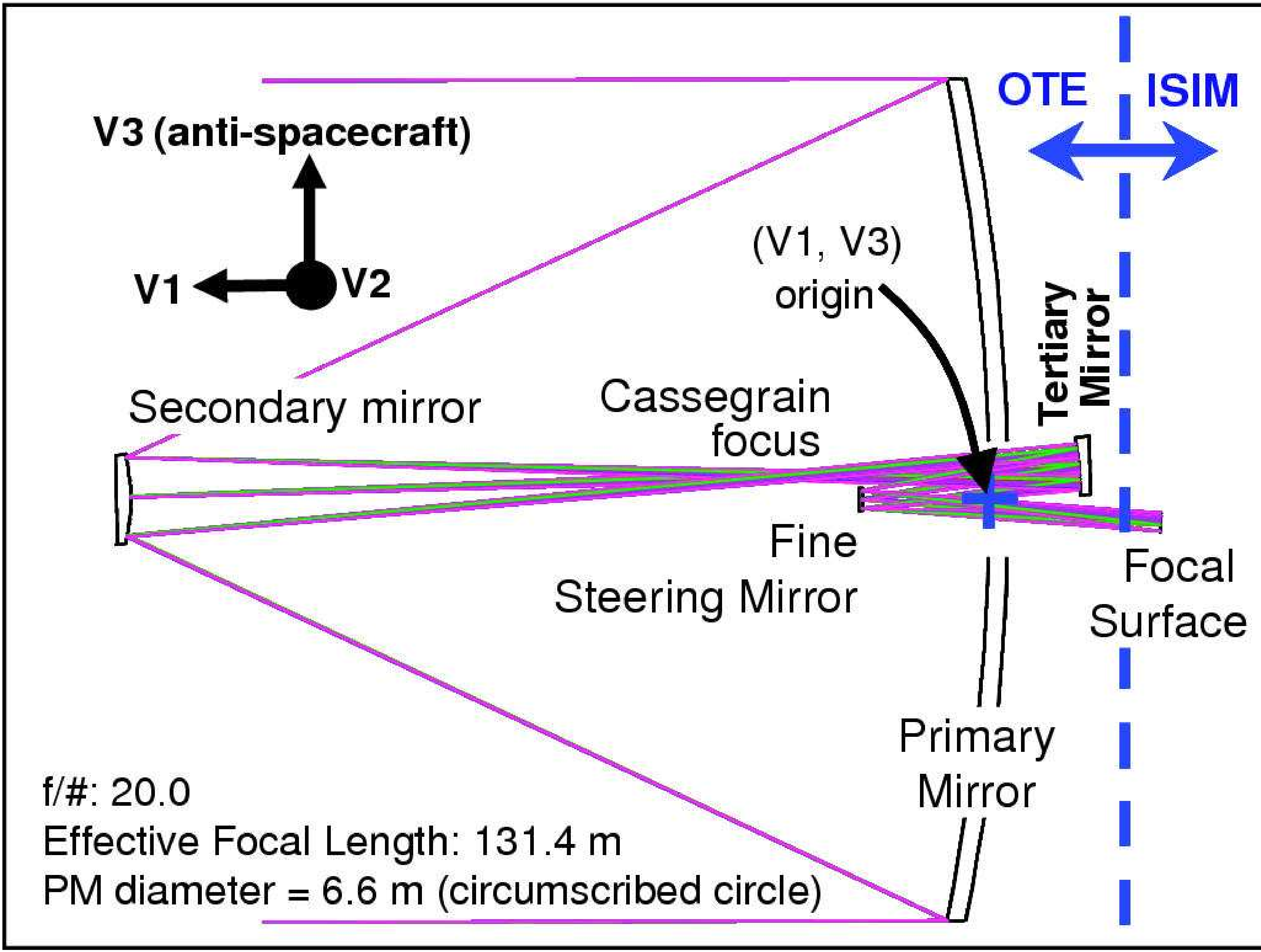


Stowed Observatory in 5meter shroud

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

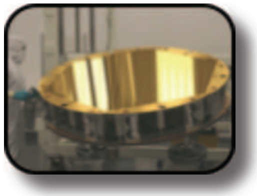


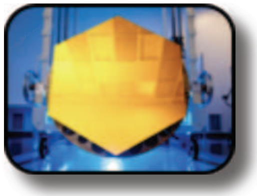
JWST can observe segments of sky that move around as it orbits the Sun.

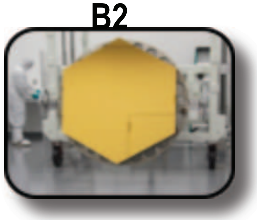


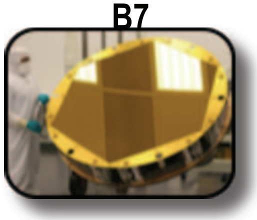
f/#: 20.0
Effective Focal Length: 131.4 m
PM diameter = 6.6 m (circumscribed circle)

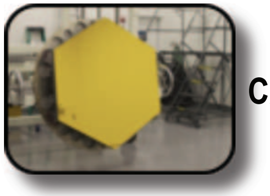
# Family Portrait

A3


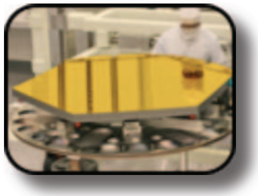
C1


B2


B7


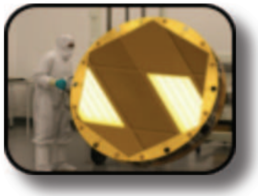

C2

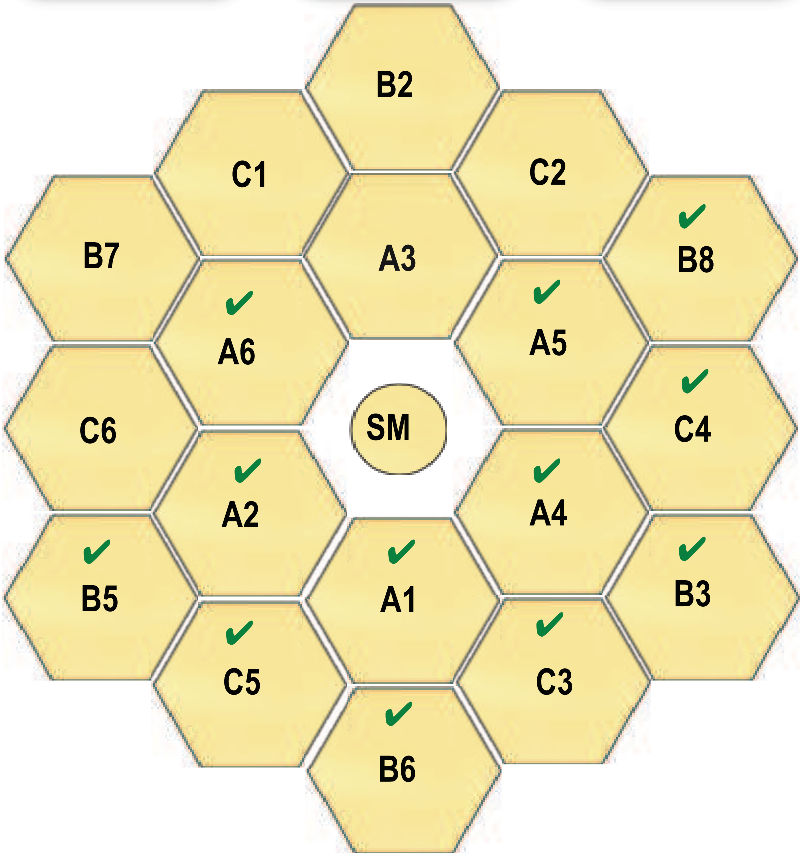
A6


C6


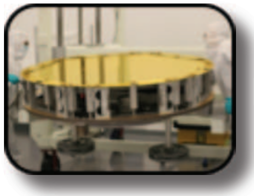
A2

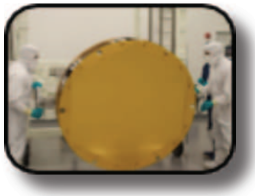

B5


C5


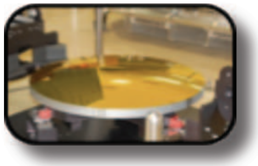



B8


A5

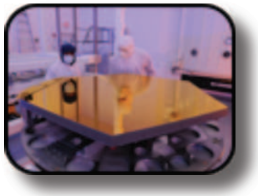

C4


B3


Secondary

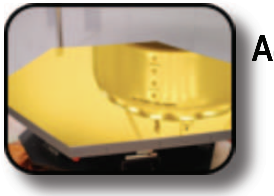

✓
Tertiary


✓
Fine Steering

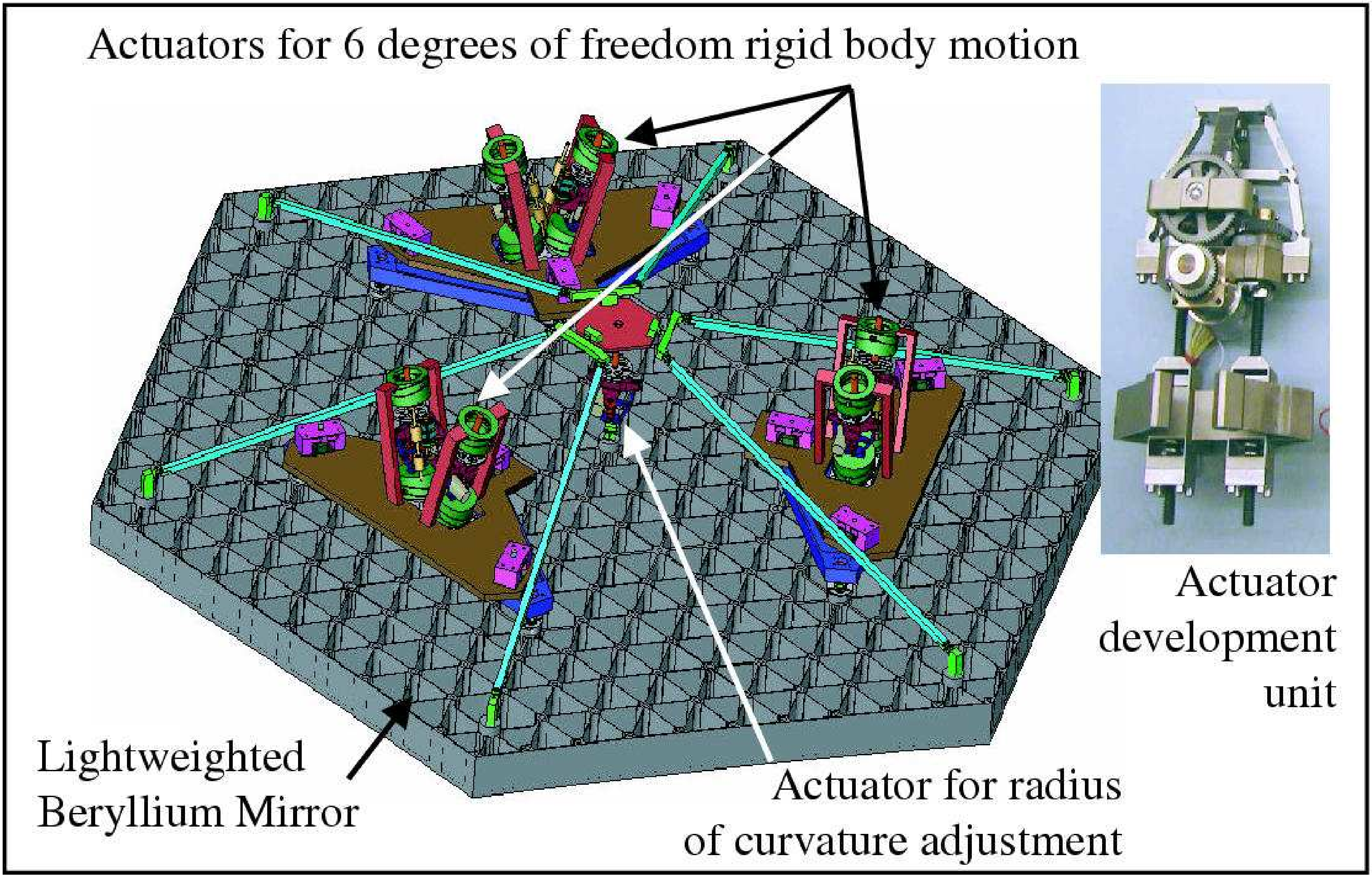

B6


A1


C3

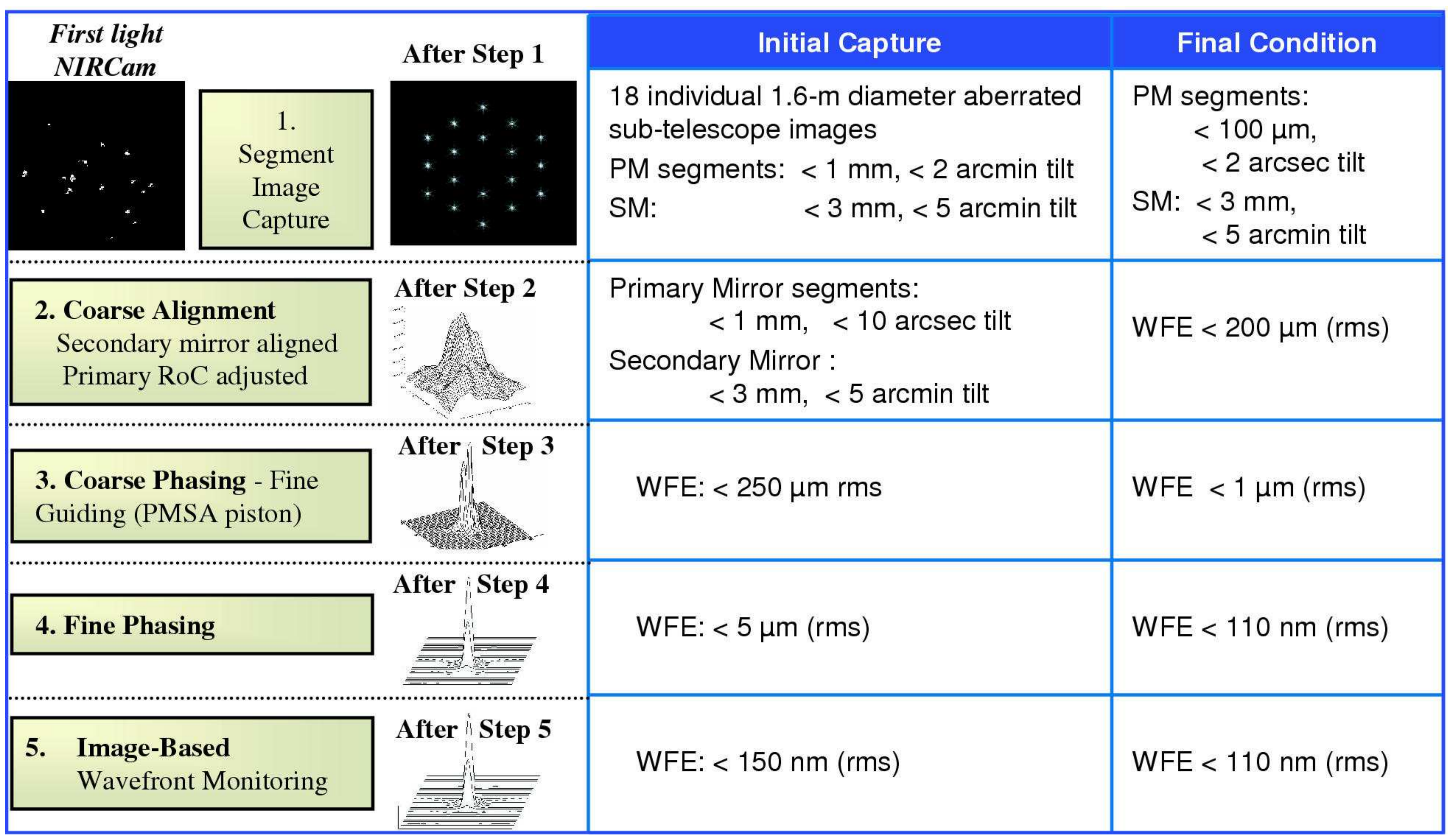

A4

✓ Mirror segment has completed all thermal testing



Active mirror segment support through "hexapods", similar to Keck.

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

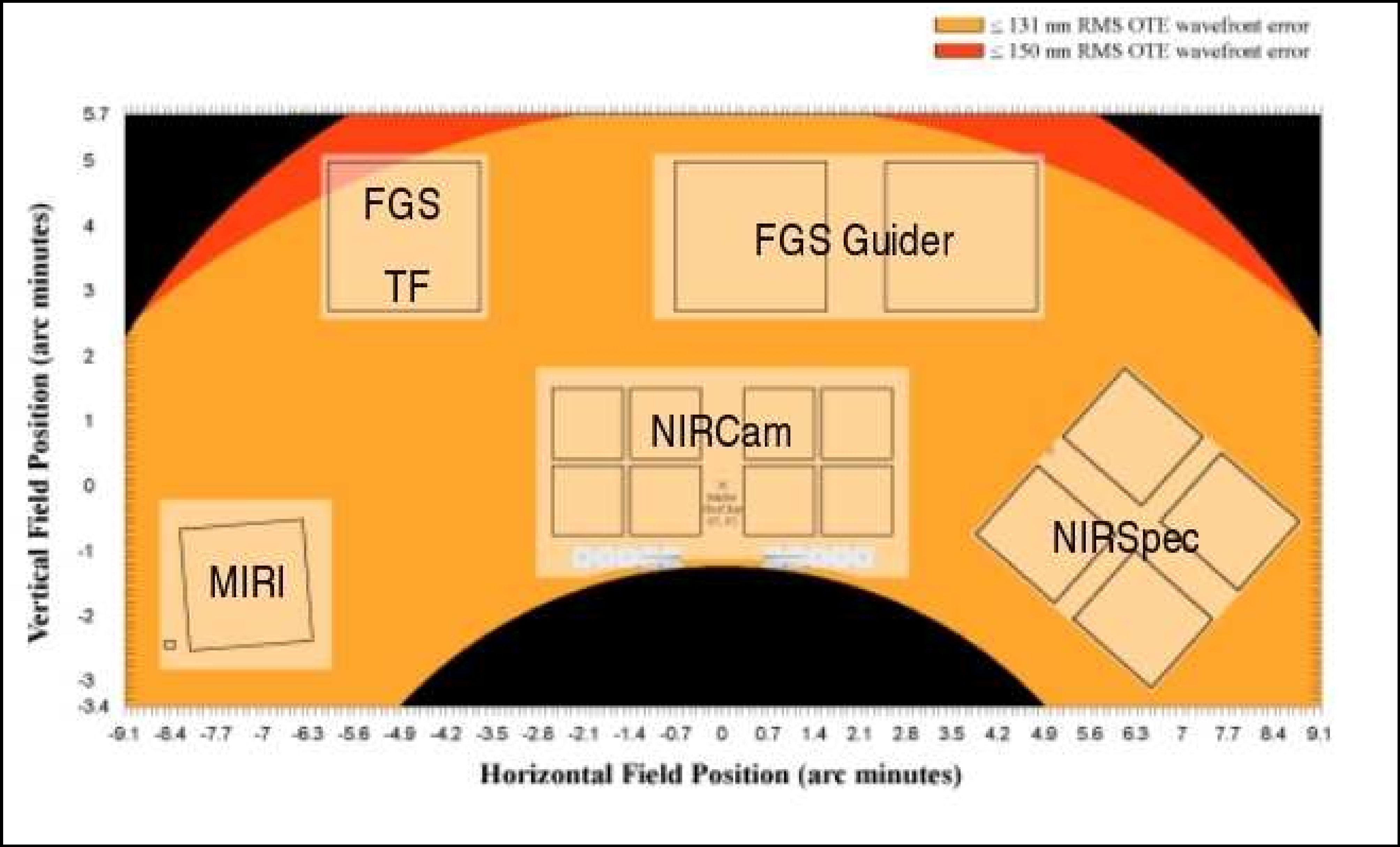


| | | Initial Capture | Final Condition |
|---|---|---|---|
| *First light NIRCam*<br>1. Segment Image Capture | After Step 1 | 18 individual 1.6-m diameter aberrated sub-telescope images<br>PM segments: < 1 mm, < 2 arcmin tilt<br>SM: < 3 mm, < 5 arcmin tilt | PM segments: < 100 μm, < 2 arcsec tilt<br>SM: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

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

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

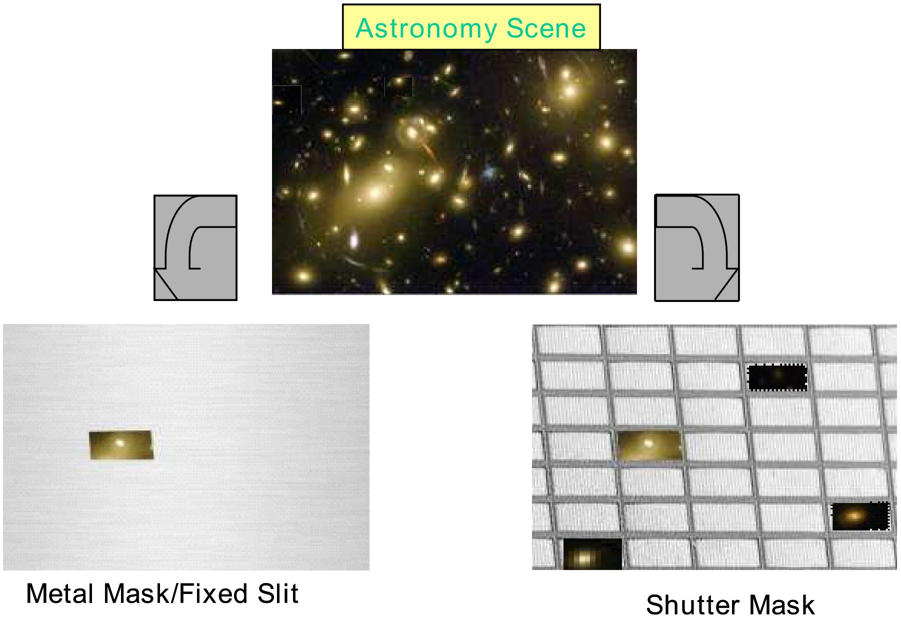
# • (1c) What instruments will JWST have?

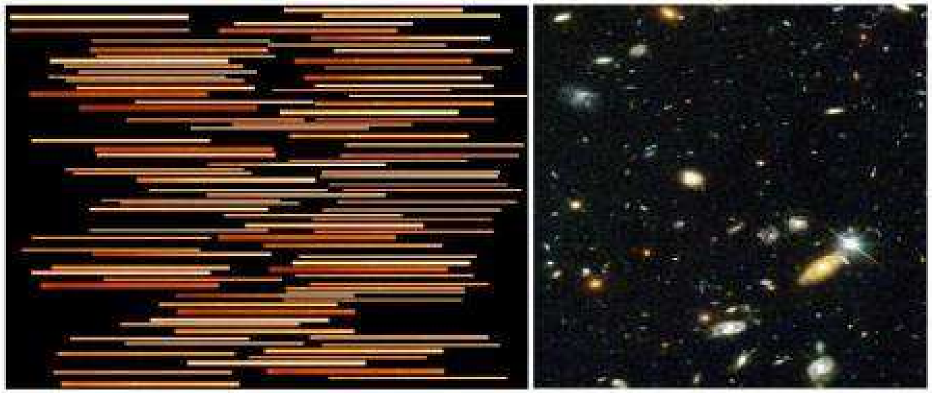


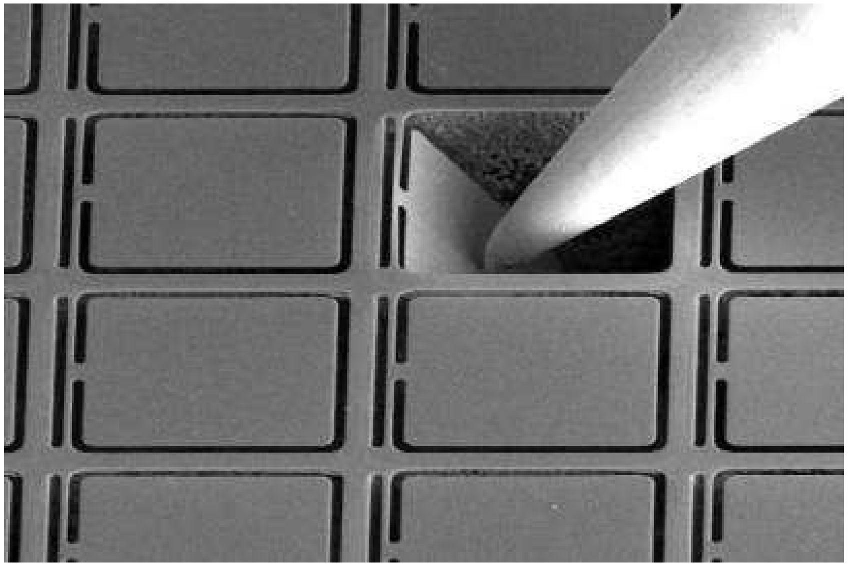
All JWST instruments can in principle be used in parallel observing mode:

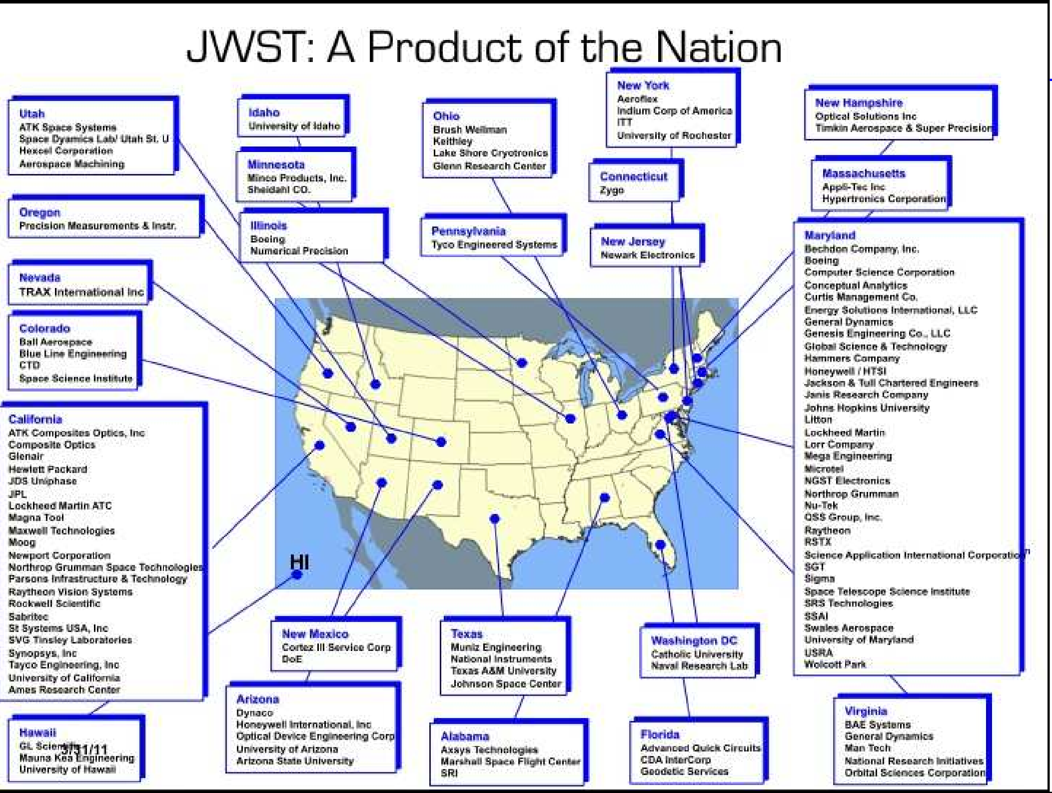
- Currently only being implemented for parallel *calibrations.*

# Micro Shutters









## JWST: A Product of the Nation

**Utah**
ATK Space Systems
Space Dyamics Lab/ Utah St. U
Hexcel Corporation
Aerospace Machining

**Idaho**
University of Idaho

**Minnesota**
Minco Products, Inc.
Sheldahl CO.

**Ohio**
Brush Wellman
Keithley
Lake Shore Cryotronics
Glenn Research Center

**New York**
Aeroflex
Indium Corp of America
ITT
University of Rochester

**Connecticut**
Zygo

**New Hampshire**
Optical Solutions Inc
Timkin Aerospace & Super Precision

**Massachusetts**
Appli-Tec Inc
Hypertronics Corporation

**Oregon**
Precision Measurements & Instr.

**Illinois**
Boeing
Numerical Precision

**Pennsylvania**
Tyco Engineered Systems

**New Jersey**
Newark Electronics

**Nevada**
TRAX International Inc

**Colorado**
Ball Aerospace
Blue Line Engineering
CTD
Space Science Institute

**California**
ATK Composites Optics, Inc
Composite Optics
Glenair
Hewlett Packard
JDS Uniphase
JPL
Lockheed Martin ATC
Magna Tool
Maxwell Technologies
Moog
Newport Corporation
Northrop Grumman Space Technologies
Parsons Infrastructure & Technology
Raytheon Vision Systems
Rockwell Scientific
Sabritec
St Systems USA, Inc
SVG Tinsley Laboratories
Synopsys, Inc
Tayco Engineering, Inc
University of California
Ames Research Center

**Maryland**
Bechdon Company, Inc.
Boeing
Computer Science Corporation
Conceptual Analytics
Curtis Management Co.
Energy Solutions International, LLC
General Dynamics
Genesis Engineering Co., LLC
Global Science & Technology
Hammers Company
Honeywell / HTSI
Jackson & Tull Chartered Engineers
Janis Research Company
Johns Hopkins University
Litton
Lockheed Martin
Lorr Company
Mega Engineering
Microtel
NGST Electronics
Northrop Grumman
Nu-Tek
QSS Group, Inc.
Raytheon
RSTX
Science Application International Corporation
SGT
Sigma
Space Telescope Science Institute
SRS Technologies
SSAI
Swales Aerospace
University of Maryland
USRA
Wolcott Park

**New Mexico**
Cortez III Service Corp
DoE

**Texas**
Muniz Engineering
National Instruments
Texas A&M University
Johnson Space Center

**Washington DC**
Catholic University
Naval Research Lab

**Hawaii**
GL Scientific
Mauna Kea Engineering
University of Hawaii

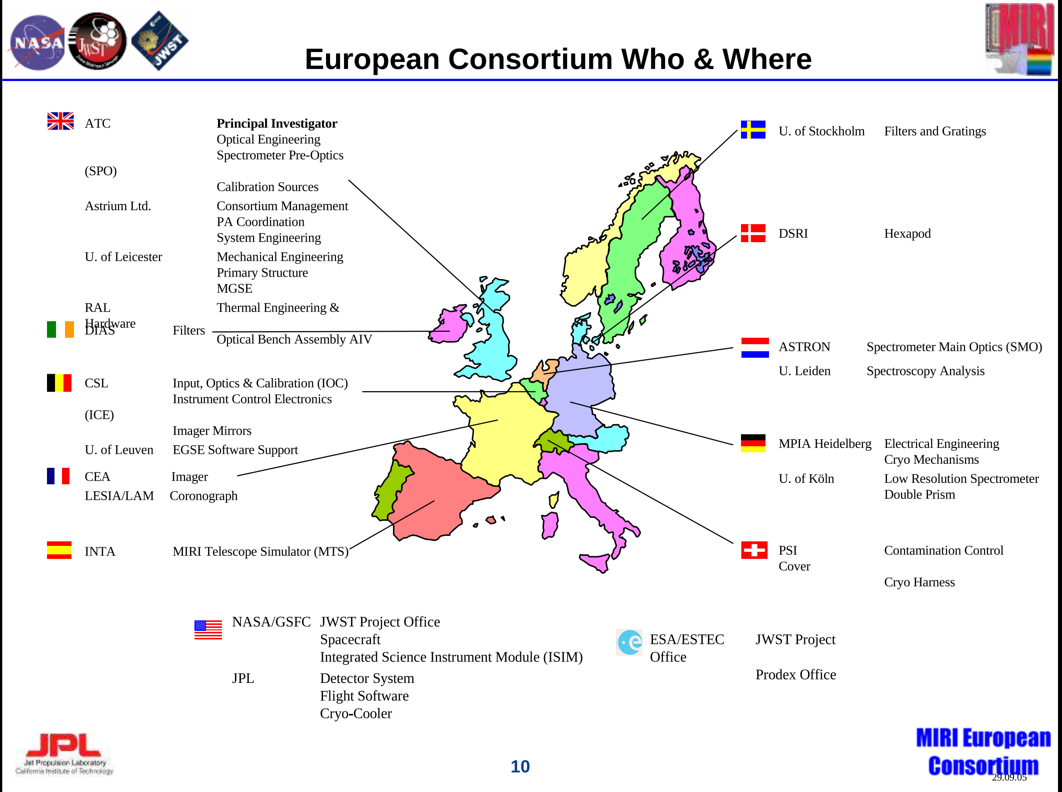
3/31/11

**Arizona**
Dynaco
Honeywell International, Inc
Optical Device Engineering Corp
University of Arizona
Arizona State University

**Alabama**
Axsys Technologies
Marshall Space Flight Center
SRI

**Florida**
Advanced Quick Circuits
CDA InterCorp
Geodetic Services

**Virginia**
BAE Systems
General Dynamics
Man Tech
National Research Initiatives
Orbital Sciences Corporation



## European Consortium Who & Where

ATC — **Principal Investigator**
Optical Engineering
Spectrometer Pre-Optics
(SPO)
Calibration Sources

Astrium Ltd. — Consortium Management
PA Coordination
System Engineering

U. of Leicester — Mechanical Engineering
Primary Structure
MGSE

RAL — Thermal Engineering &
Hardware
Optical Bench Assembly AIV

DIAS — Filters

CSL — Input, Optics & Calibration (IOC)
Instrument Control Electronics
(ICE)
Imager Mirrors

U. of Leuven — EGSE Software Support

CEA — Imager

LESIA/LAM — Coronograph

INTA — MIRI Telescope Simulator (MTS)

U. of Stockholm — Filters and Gratings

DSRI — Hexapod

ASTRON — Spectrometer Main Optics (SMO)

U. Leiden — Spectroscopy Analysis

MPIA Heidelberg — Electrical Engineering
Cryo Mechanisms

U. of Köln — Low Resolution Spectrometer
Double Prism

PSI — Contamination Control
Cover
Cryo Harness

NASA/GSFC — JWST Project Office
Spacecraft
Integrated Science Instrument Module (ISIM)

JPL — Detector System
Flight Software
Cryo-Cooler

ESA/ESTEC — JWST Project
Office
Prodex Office

Jet Propulsion Laboratory
California Institute of Technology

10

MIRI European Consortium

29.09.05

- JWST hardware made in 27 US States: $\gtrsim$75% of launch-mass finished.

- Ariane V Launch & NIRSpec provided by ESA; & MIRI by ESA & JPL.

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

- JWST NIRCam made by UofA and Lockheed.

OSIM: Here is where JWST Instruments inside ISIM are being tested.

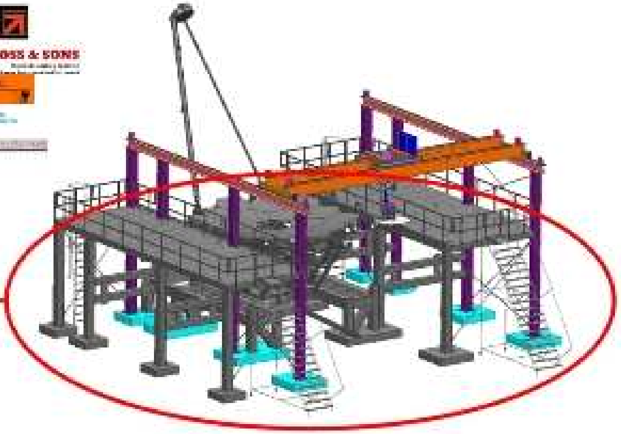
# Telescope Assembly Ground Support Equipment

Ambient Optical Alignment Stand Complete

PMD

HM CROSS & SONS

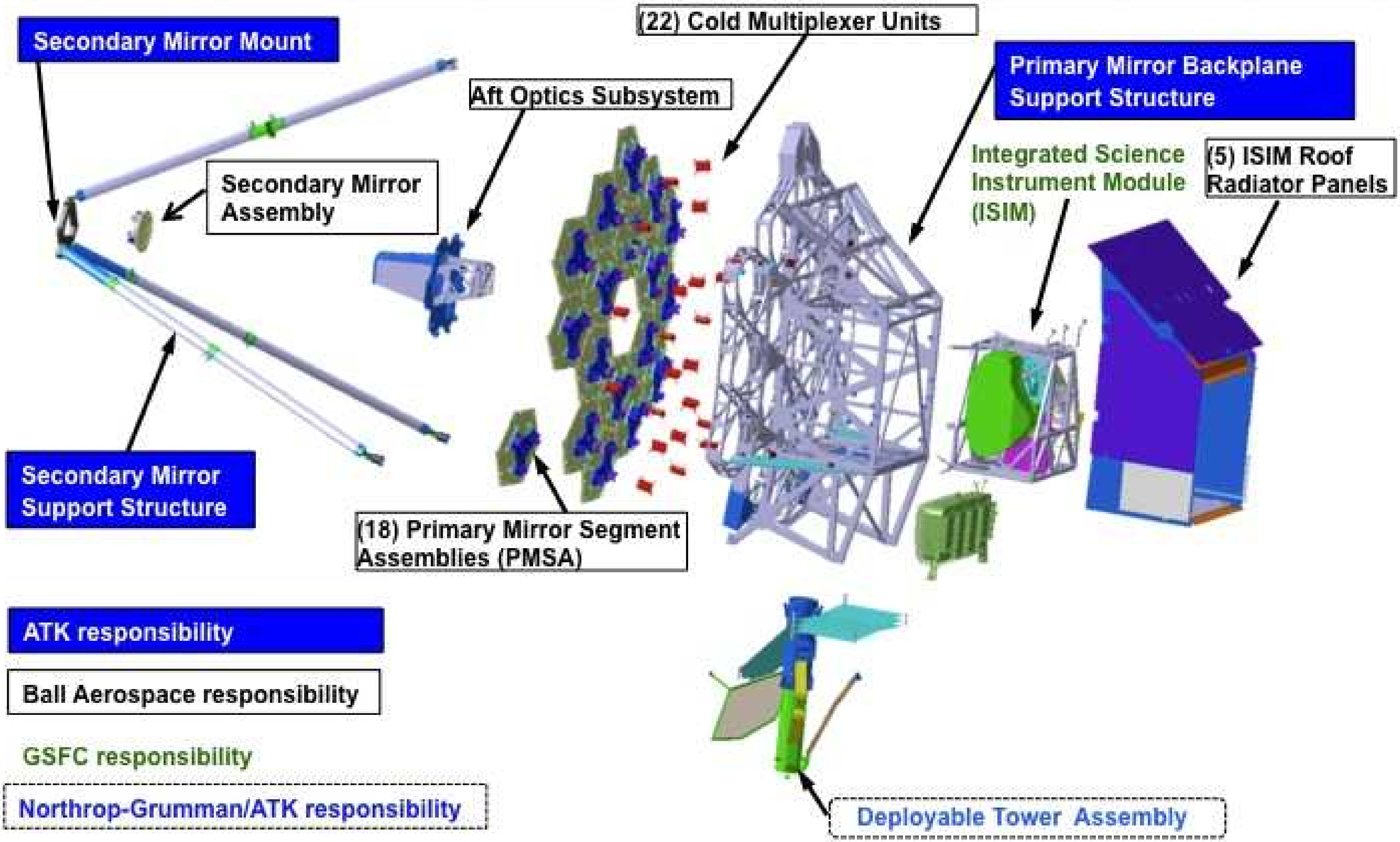
JPW



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

Landing a mirror onto backplane simulator

# TELESCOPE ARCHITECTURE



**Secondary Mirror Mount**

(22) Cold Multiplexer Units

Aft Optics Subsystem

**Primary Mirror Backplane Support Structure**

Secondary Mirror Assembly

Integrated Science Instrument Module (ISIM)

(5) ISIM Roof Radiator Panels

**Secondary Mirror Support Structure**

(18) Primary Mirror Segment Assemblies (PMSA)

Deployable Tower Assembly

**ATK responsibility**

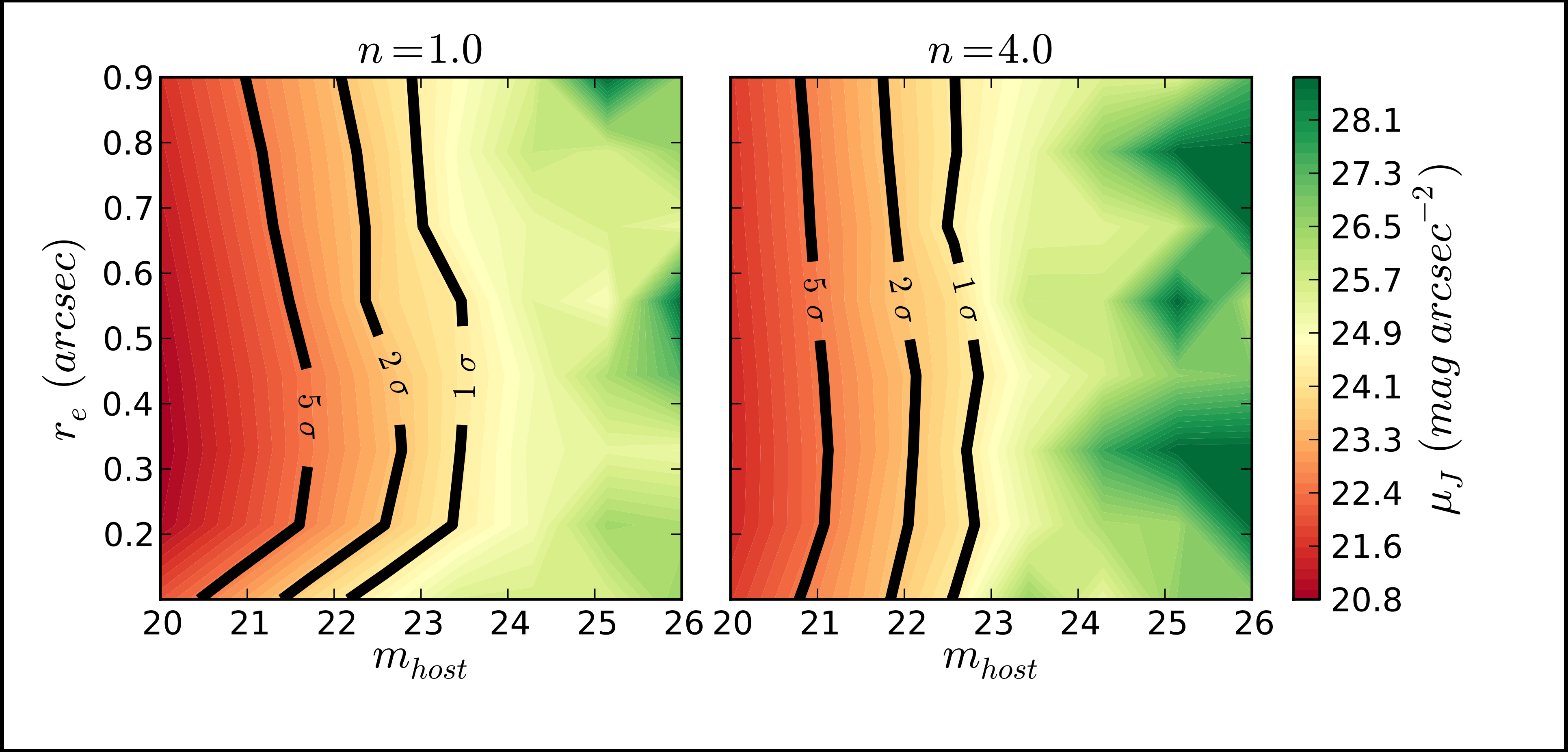
Ball Aerospace responsibility

GSFC responsibility

Northrop-Grumman/ATK responsibility

3/31/11

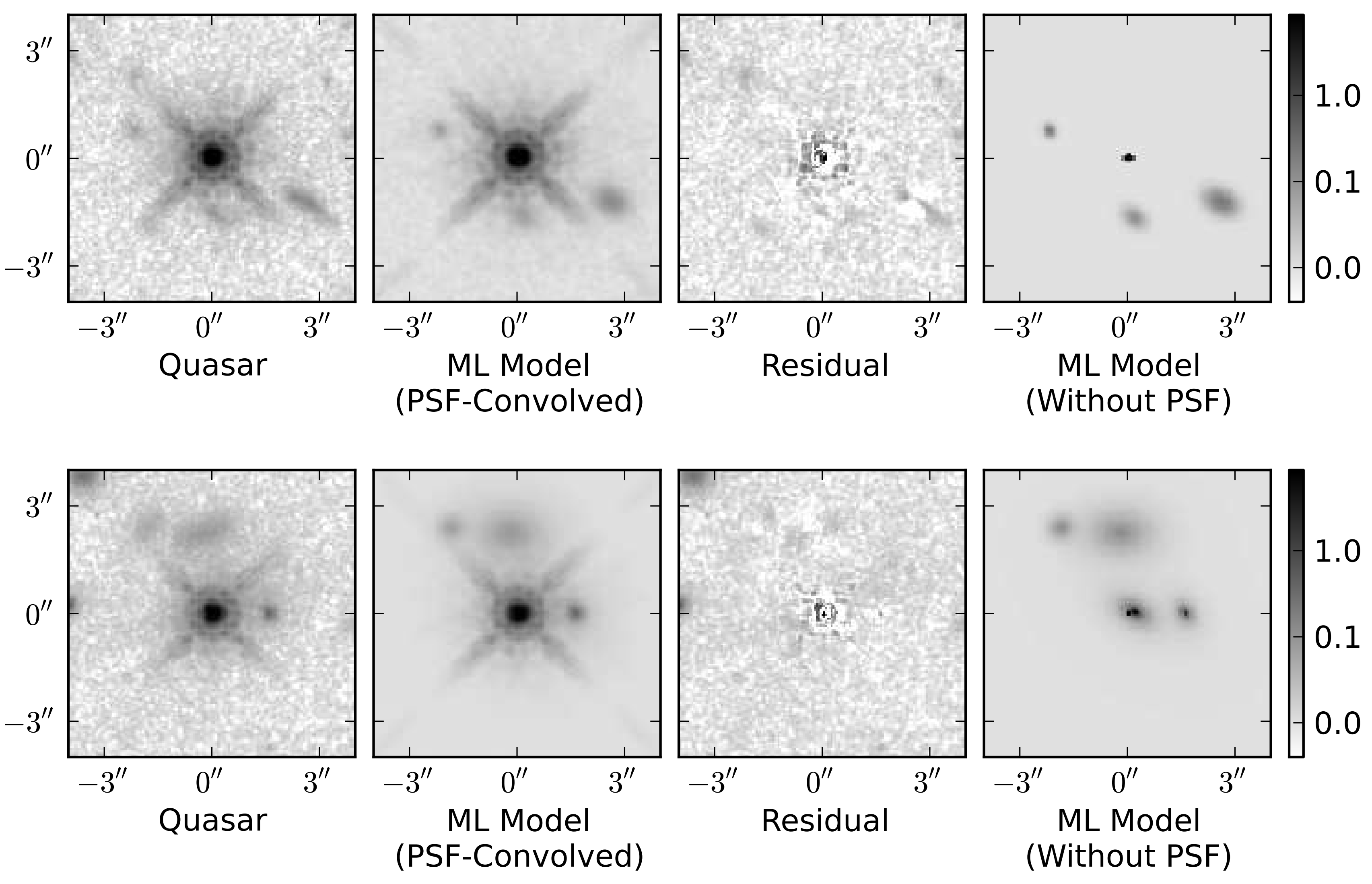
# (2) HST WFC3 observations of Quasar Host Galaxies at z$\simeq$6 (age$\lesssim$1 Gyr)



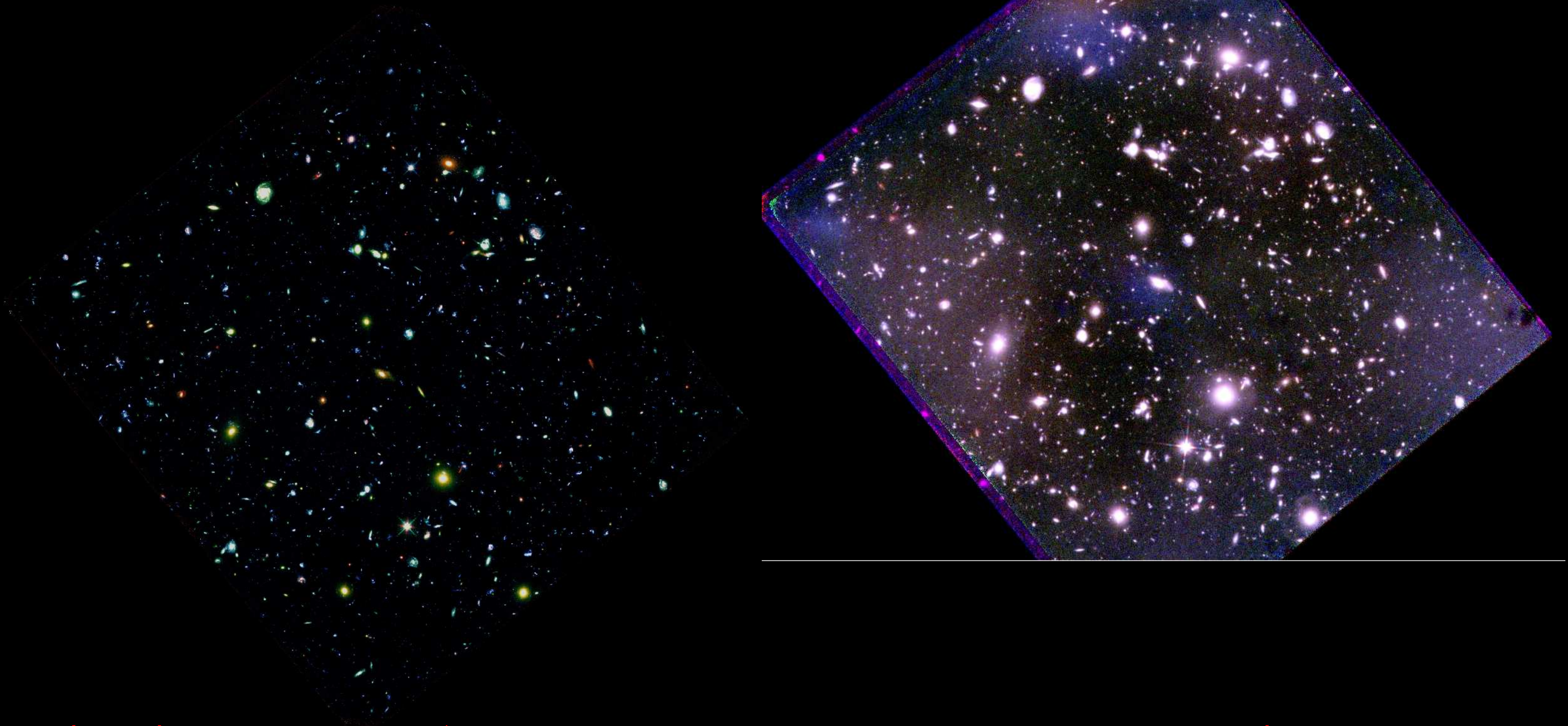
- TinyTim fit of PSF-star + Sersic models of galaxy light-profile, nearly to the noise limit: NO host galaxy at AB$\gtrsim$23.0 mag with $r_e \simeq 0\farcs5$ (Mechtley et al. 2012, ApJL, 756, L23; astro-ph/1207.3283)

- JWST Coronagraphs can do this 10–100× fainter (and for z$\lesssim$20, $\lambda \lesssim 28\mu$m) — but need JWST diffraction limit at 2.0$\mu$m and clean PSF to do this.

# (2) WFC3 observations of Quasar Host Galaxies at z≃2 (evidence for mergers?)



- Monte Carlo Markov-Chain runs of observed PSF-star + Sersic ML light-profile models: merging neighbors (some with tidal tails?; Mechtley, Jahnke, Koekemoer, Windhorst et al. 2013).
- JWST Coronagraphs can do this 10–100× fainter (& for $z \lesssim 20$, $\lambda \lesssim 28 \mu m$).

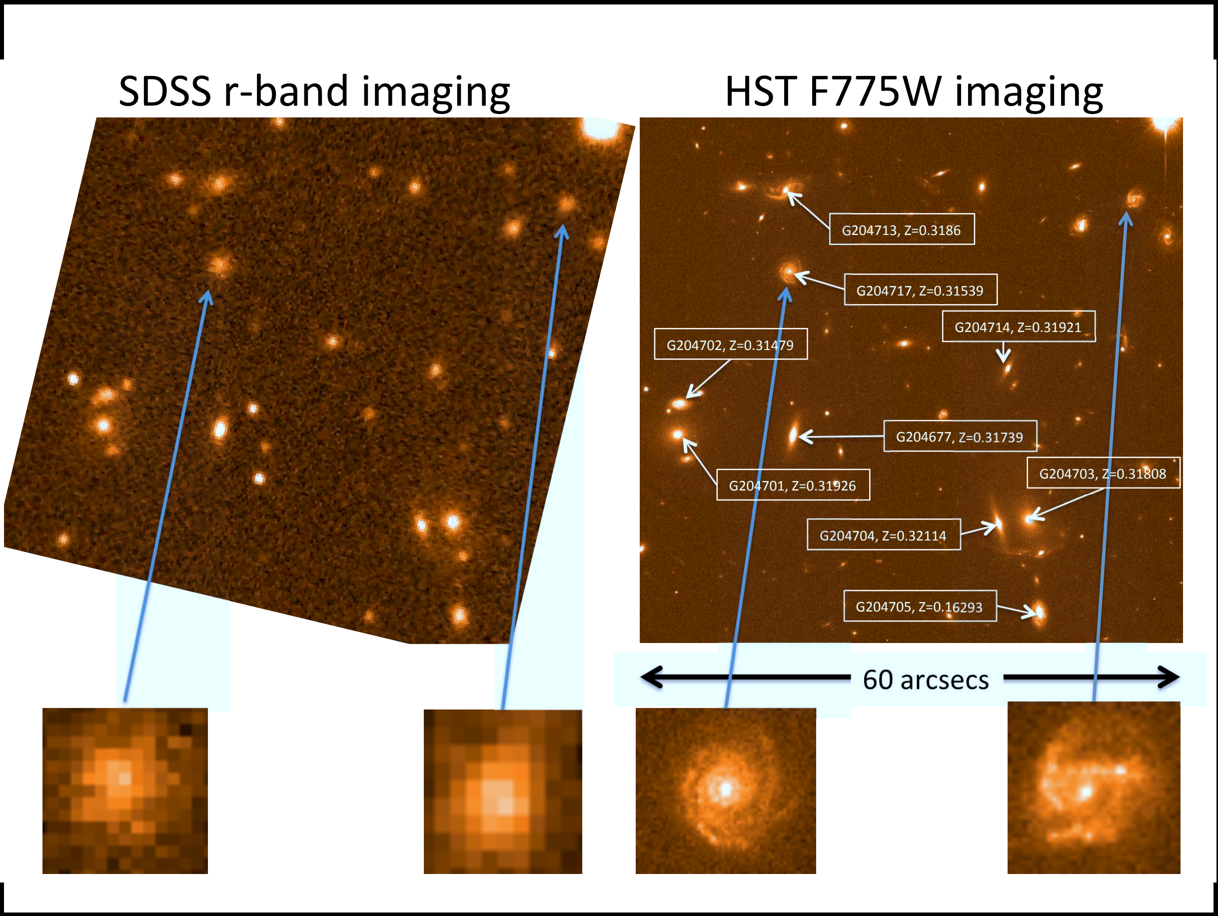


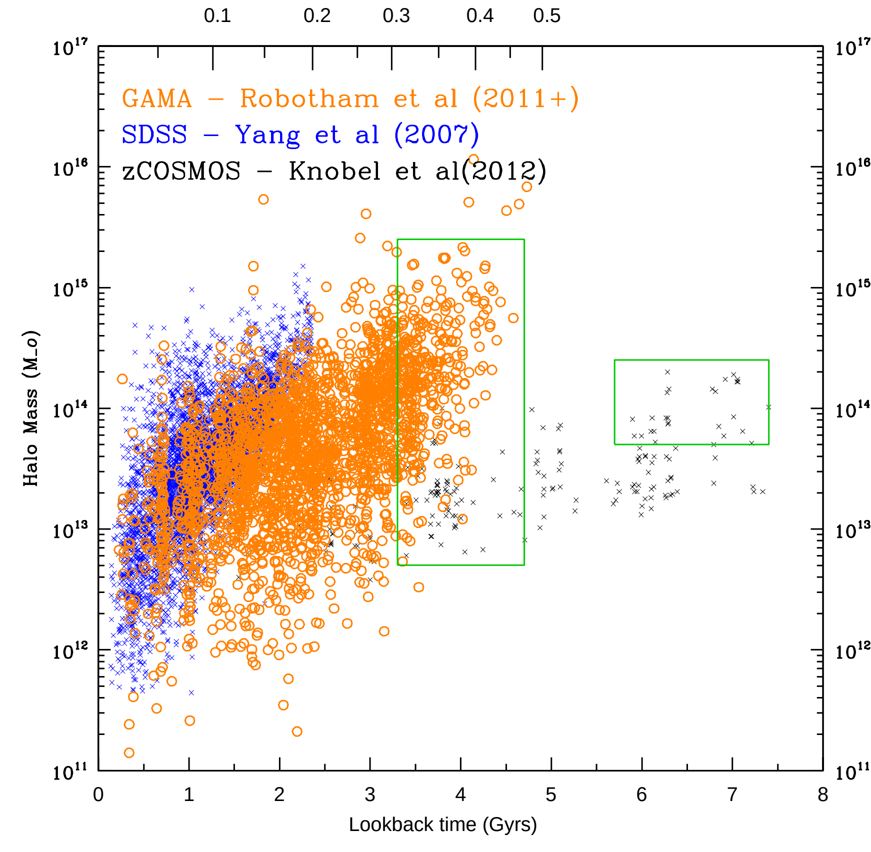
(Left) 128-hr HST/WFC3 IR-mosaic in HUDF at 1–1.6$\mu$m (YJH filters; Bouwens et al 2010, Yan et al. 2010; +85-hr by R. Ellis in 09/2012).

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

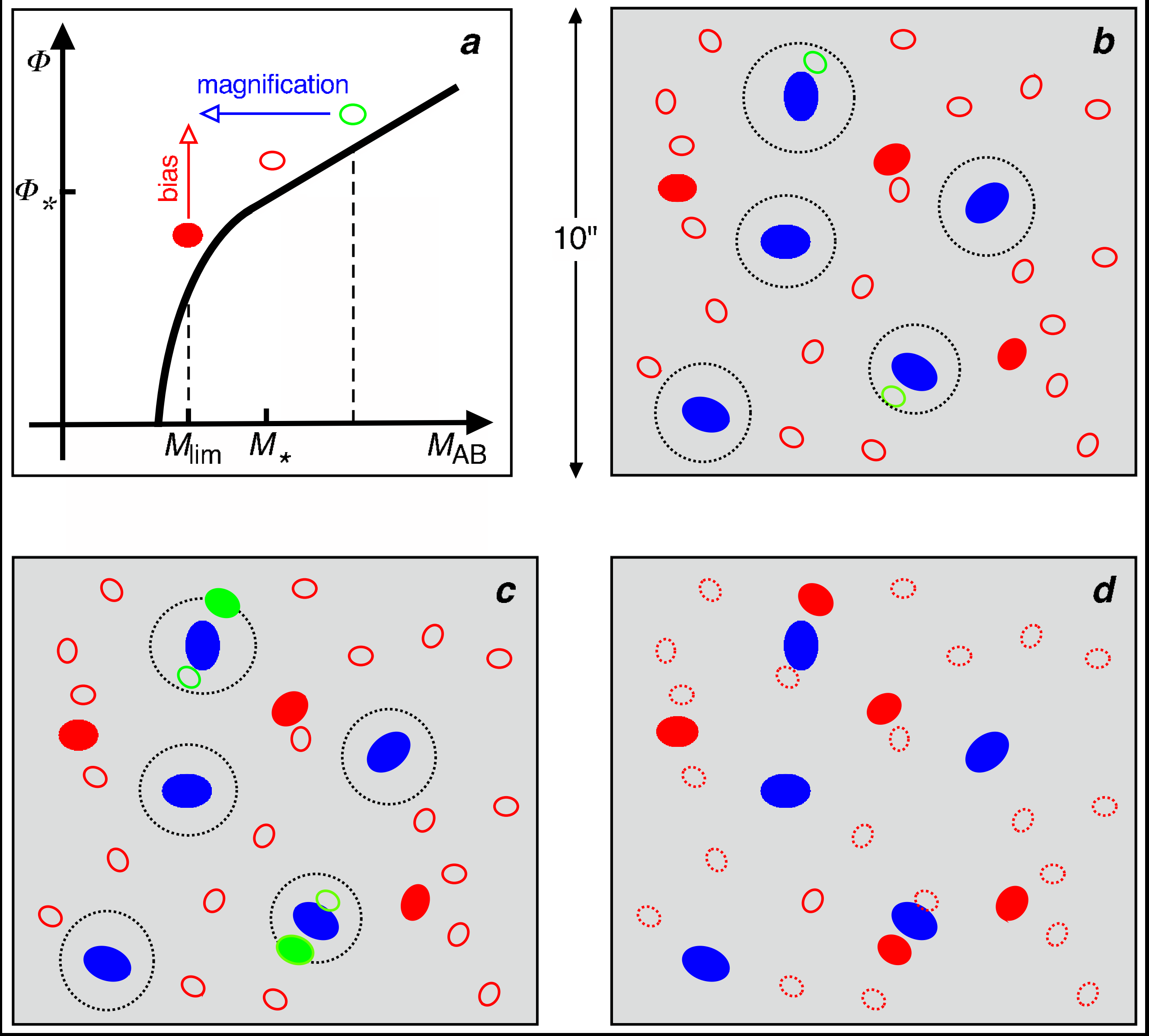
- The CLOSED-TUBE HST has residual low-level systematics: Imperfect removal of detector artifacts, flat-fielding errors, and/or faint straylight.

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



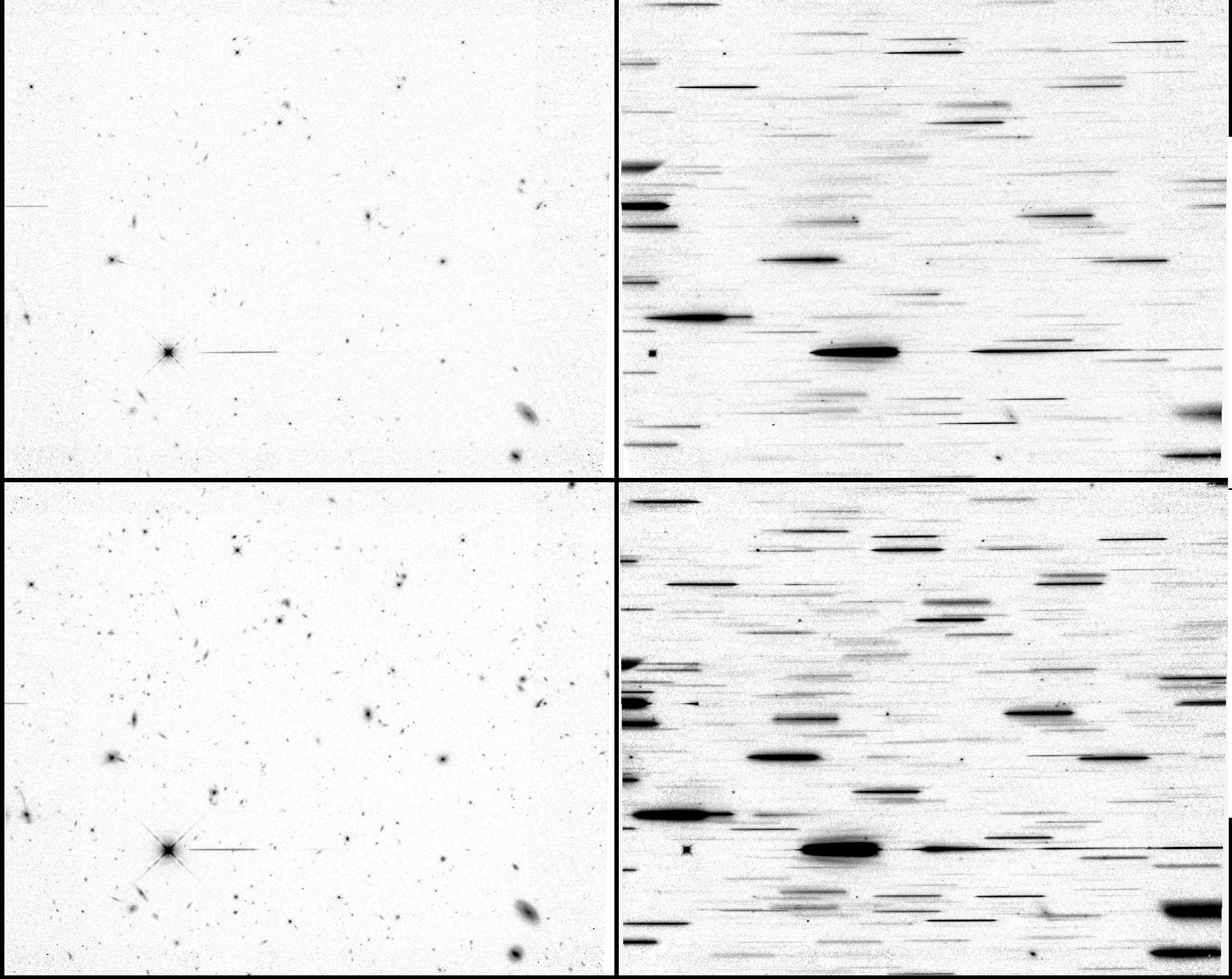


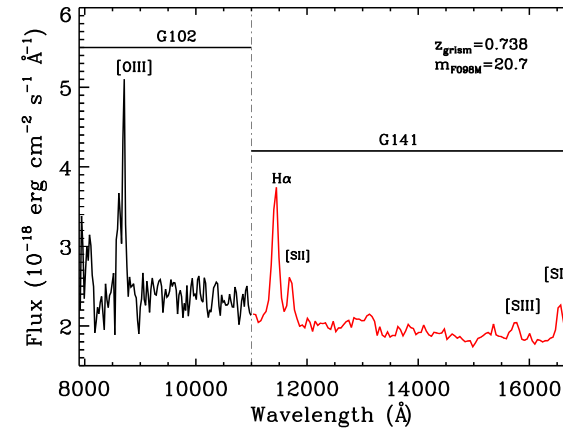
- Select the most massive galaxy groups at z$\gtrsim$0.3 as gravitational lensing-bias targets for JWST studies at z$\gtrsim$2-15.
- In rich clusters, it will be harder to separate intra-cluster straylight from out-of-field or rogue path straylight in ultradeep JWST images.

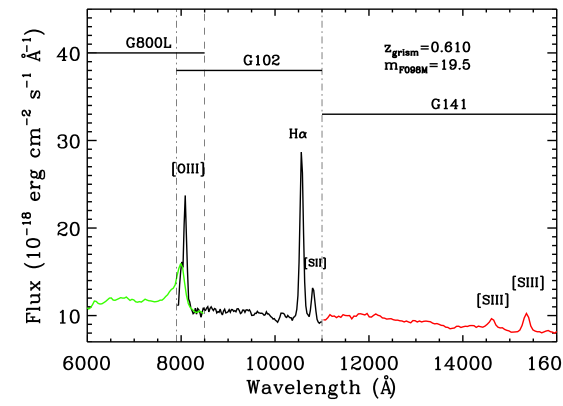


Hard to see the forest for the trees in the first 0.5 Gyrs?:

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





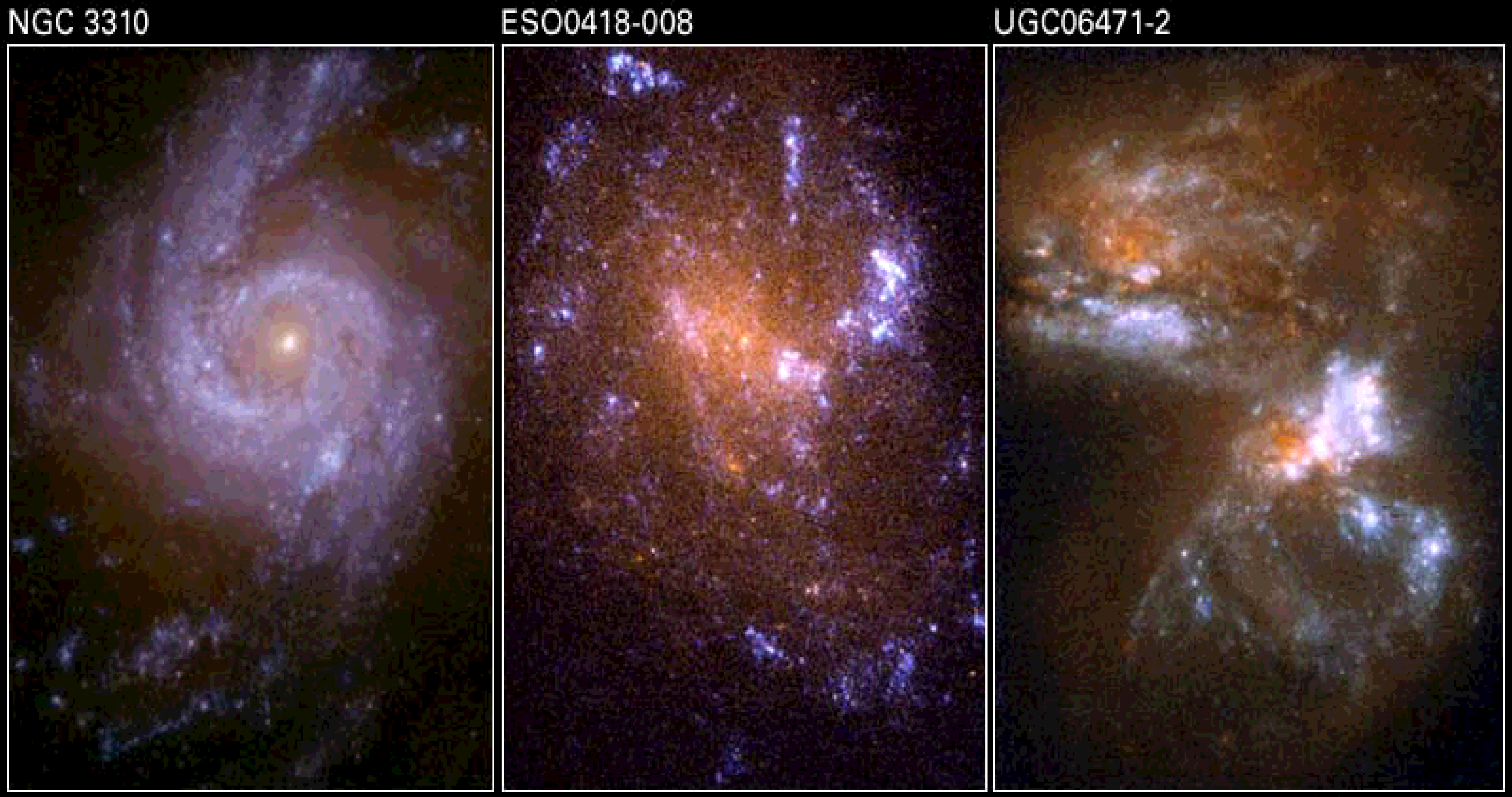


HST/WFC3 G102 & G141 grism spectra in GOODS-S ERS (Straughn$^{+}$ 2010)

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 $\mu$m.

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



**Ultraviolet Galaxies**

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

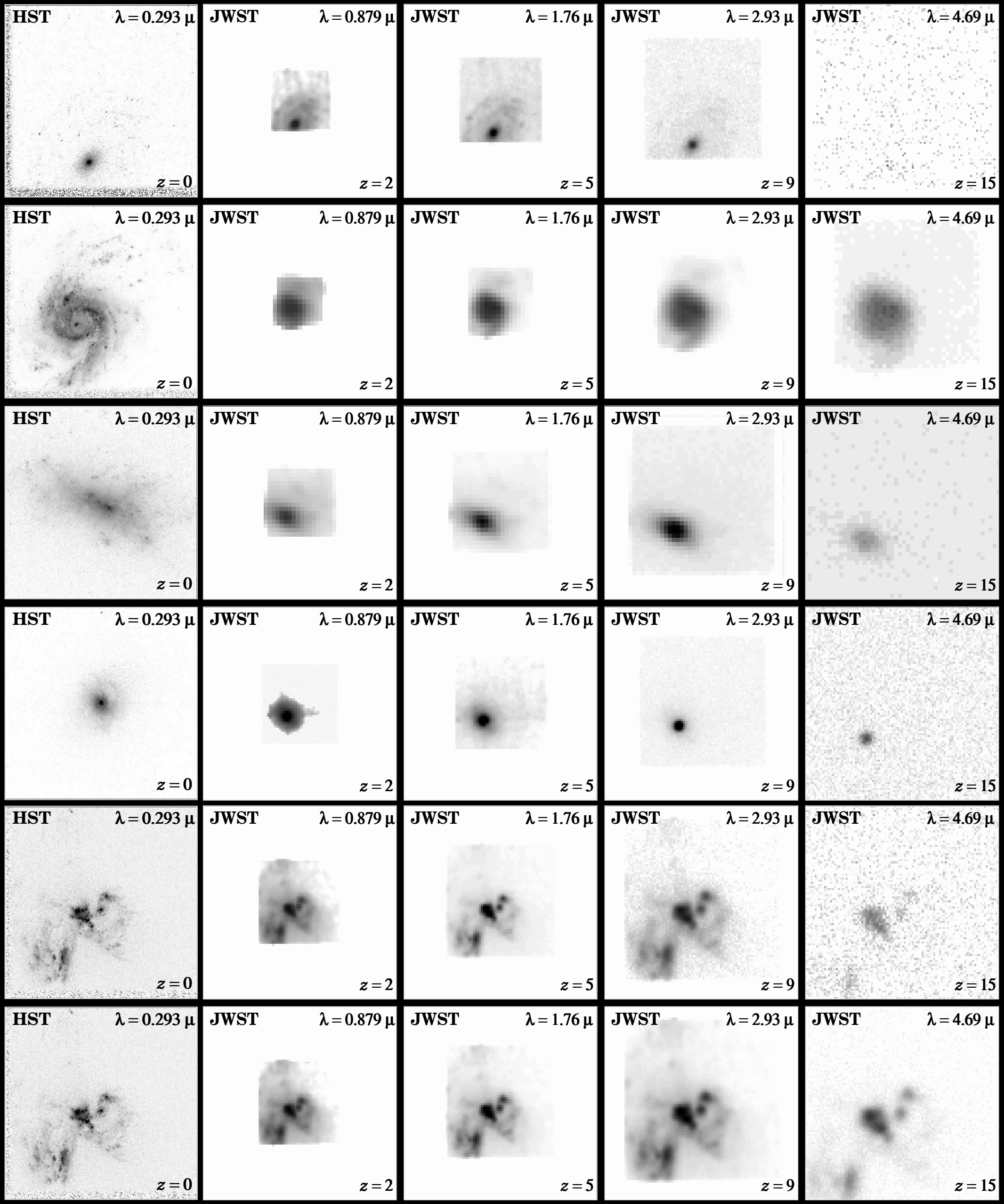
**HST** • WFPC2

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

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

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

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



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

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

Visible to JWST at very high z are:

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