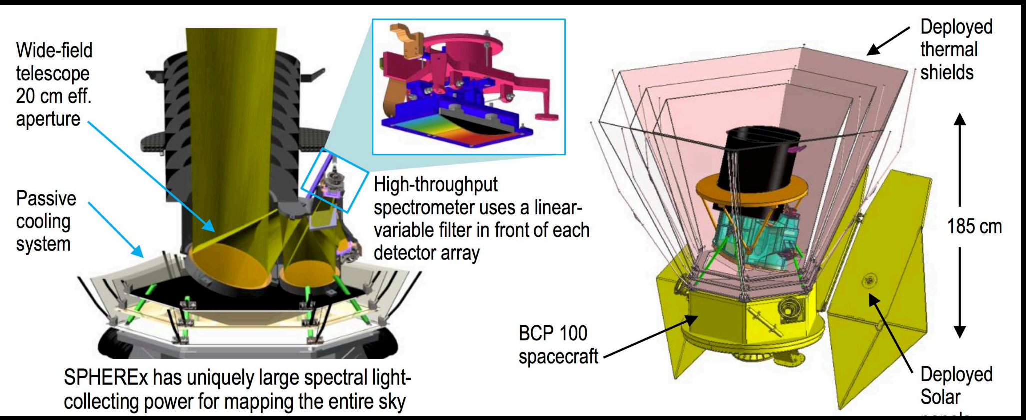
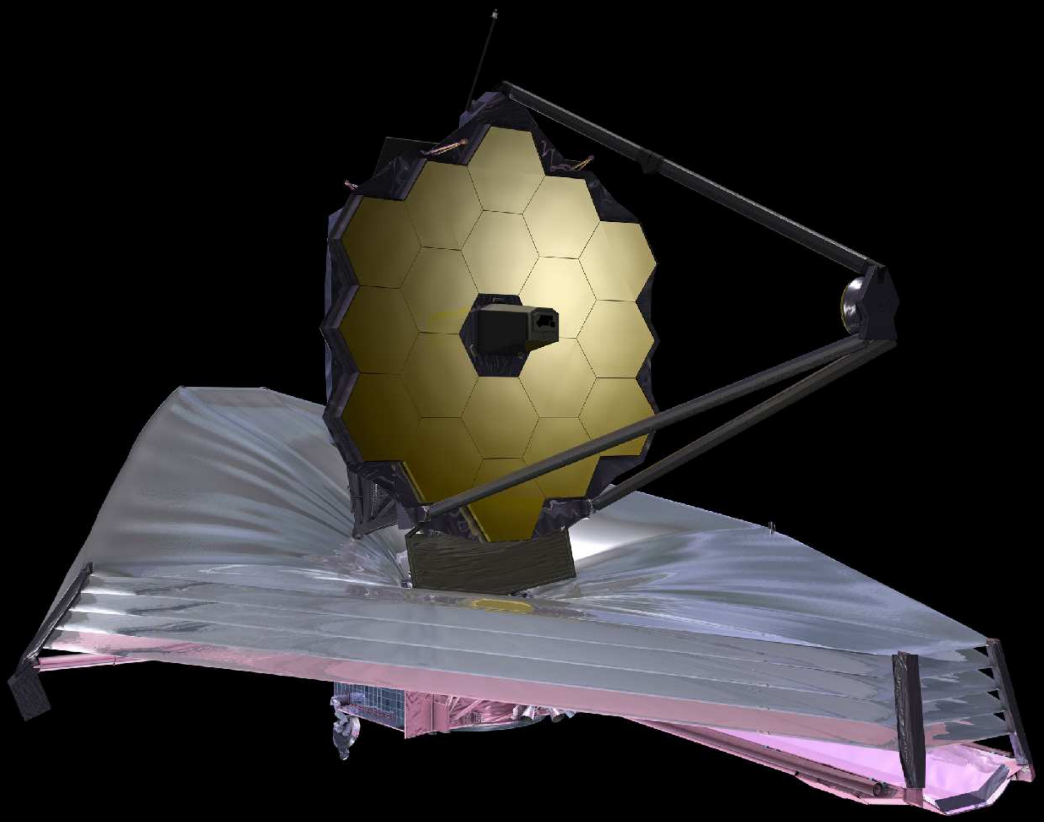
JWST Synergies with SPHEREx, and How to Exploit them.

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

S. Cohen, R. Jansen (ASU), B. Frye (UofA), C. Conselice (UK), S. Driver (OZ), S. Wyithe (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 SPHEREx Community Workshop, Thursday Feb. 25, 2016 Caltech (Pasadena, CA)

All presented materials are ITAR-cleared.

Outline

- (1) Update on the James Webb Space Telescope (JWST), 2015.
- (2) JWST–SPHEREx Synergy: Ground-Truth Calibration
- (3) JWST–SPHEREx Synergy: Rare & Red (Dusty) Objects for JWST

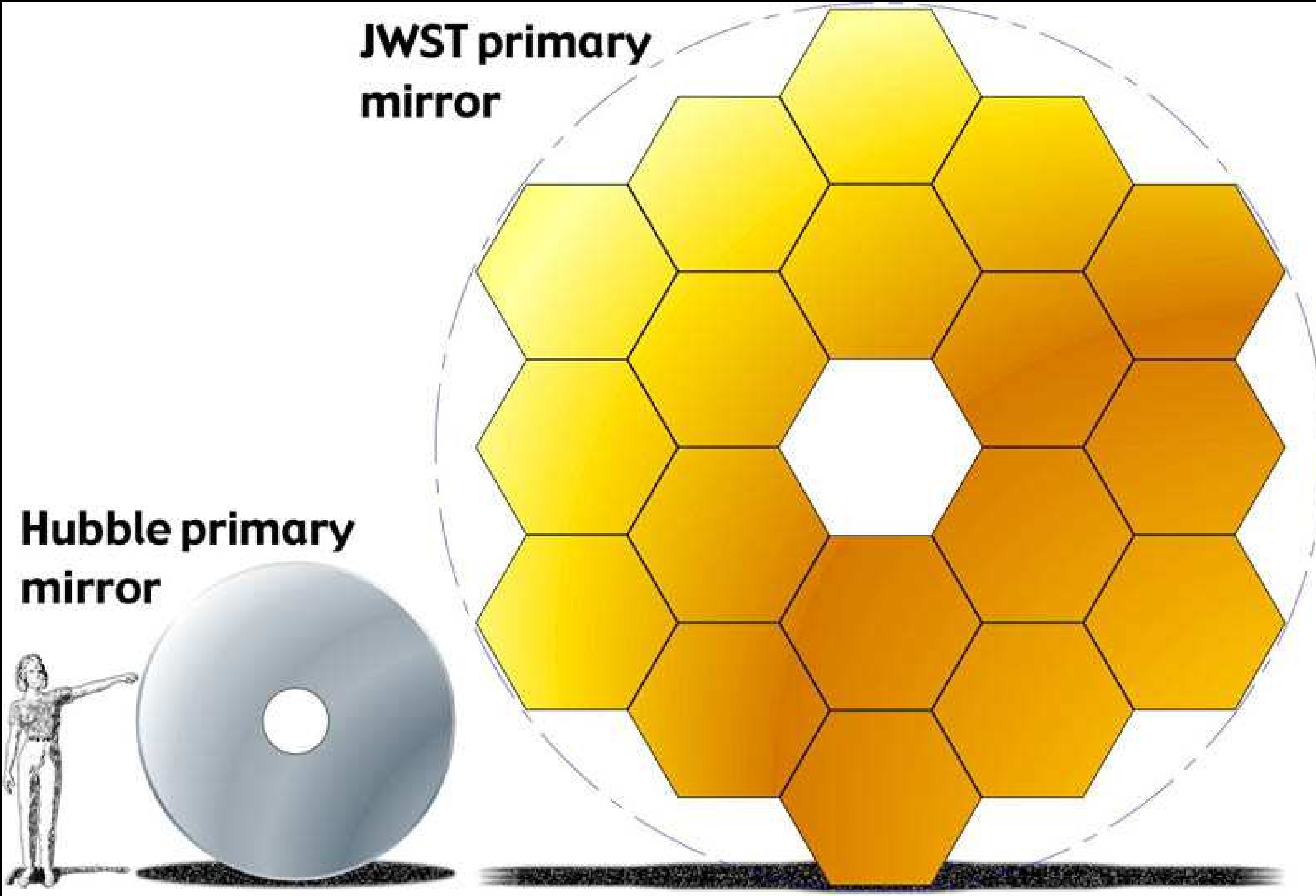
Rare and Red: (Dusty) z$\simeq$2–7 QSOs.

Rare, Red, and Dead: z$\sim$0.5–2 Early Type Galaxies (M. Kriek's talk).

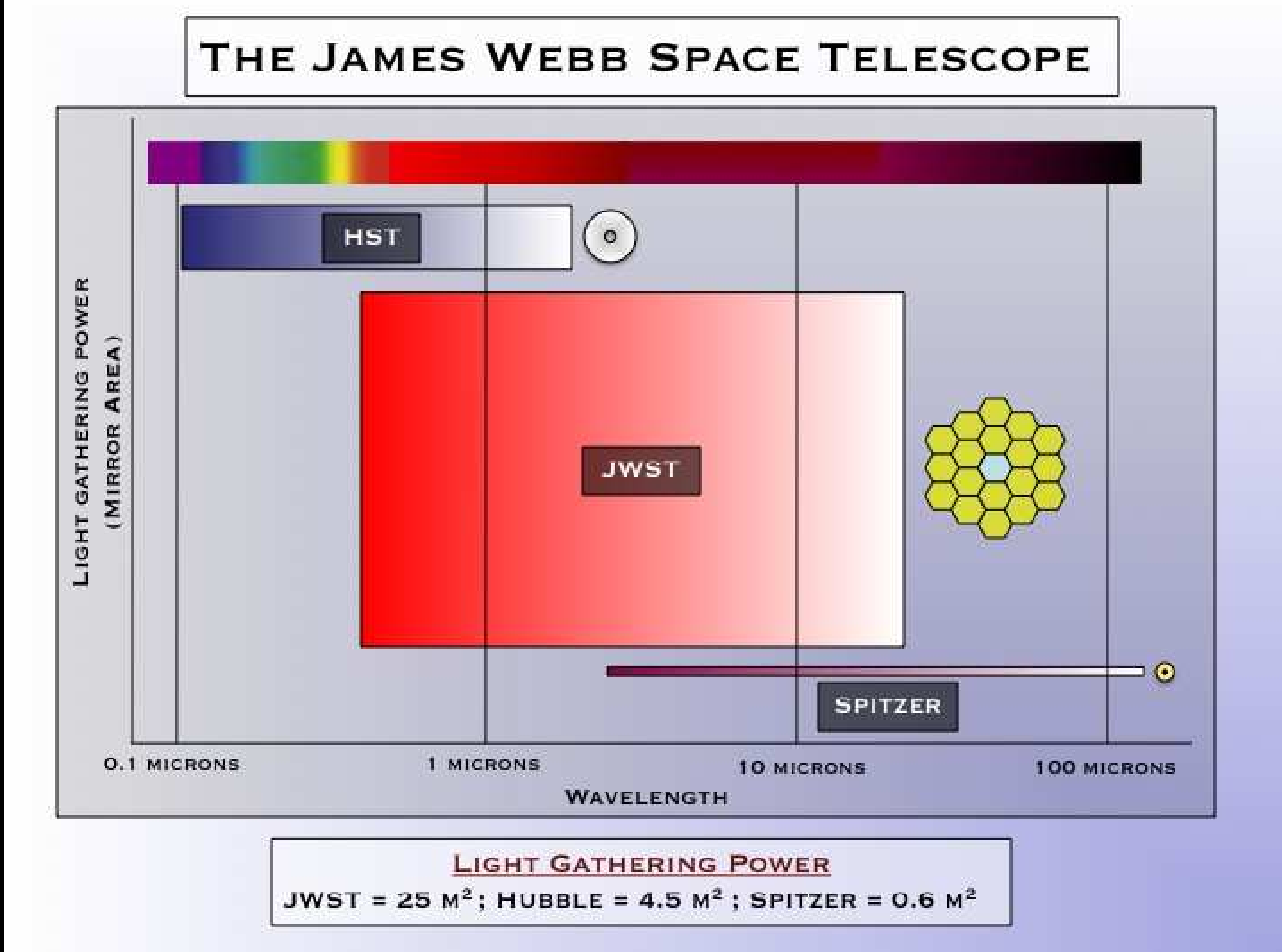
- (4) Summary and Conclusions
- (5) First Light with JWST on lensing z$\lesssim$0.5 clusters: SPHEREx Synergy

Sponsored by NASA/HST & JWST

Talk is on: http://www.asu.edu/clas/hst/www/jwst/jwsttalks/spherex16_jwstsynergies.pdf



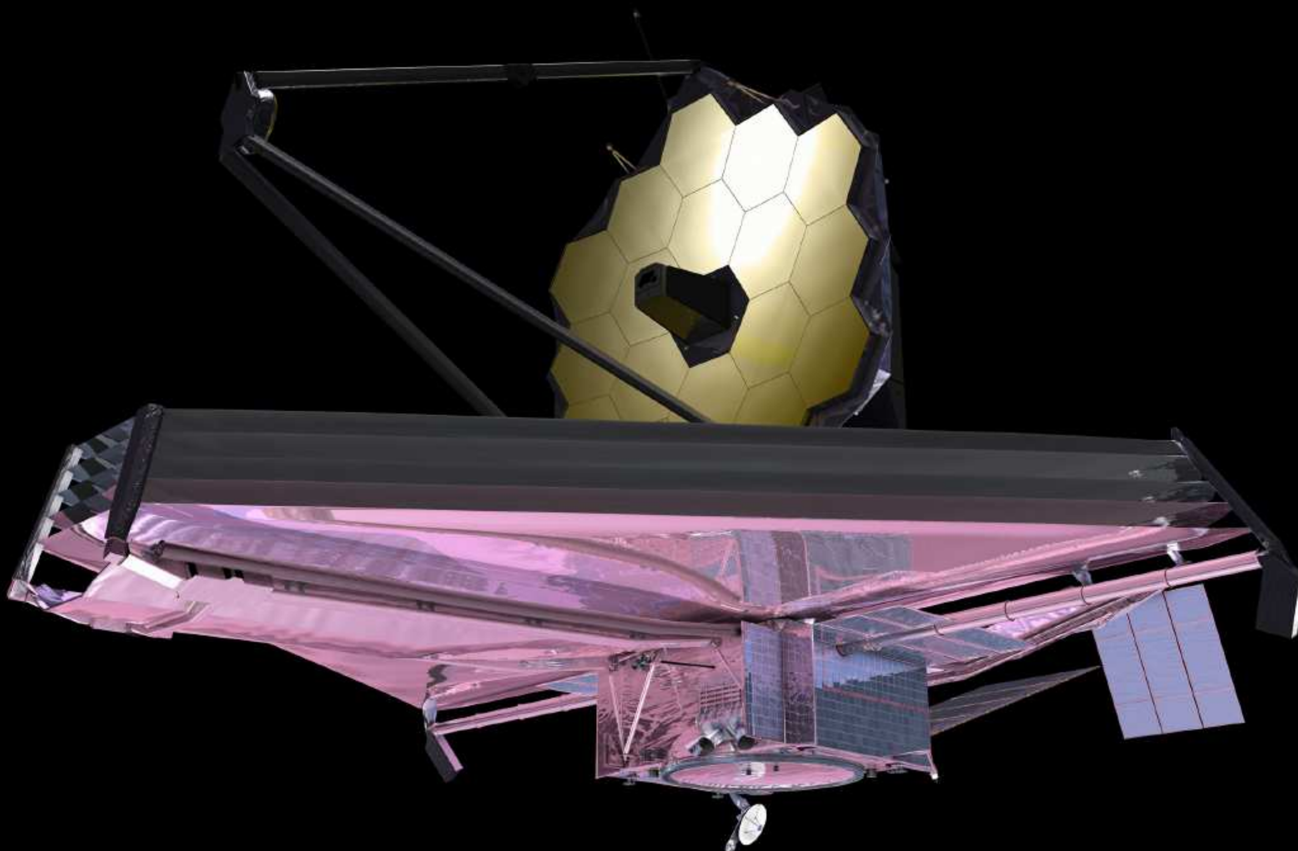
JWST $\simeq$2.5$\times$ larger than Hubble, so at $\sim$2.5$\times$ larger wavelengths:
JWST has the same resolution in the near-IR as Hubble in the optical.



- JWST is the perfect near–mid-IR sequel to HST and Spitzer.
- SPHEREx will be the perfect 0.7-5μm ALL-SKY object finder for JWST.

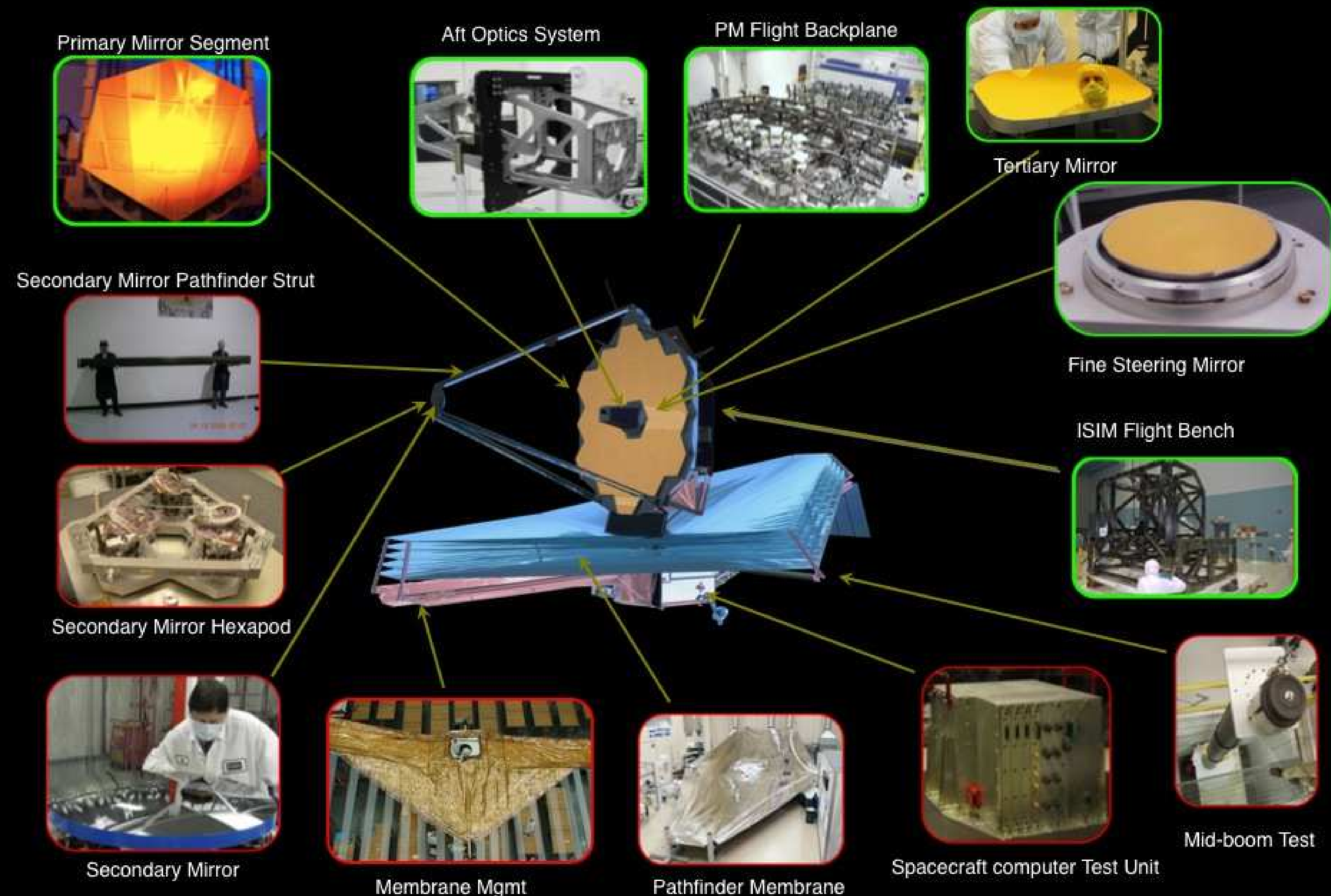
Area: SPHEREx$\simeq$JWST$/30^2$; Ω: SPH$\gtrsim$JW$\times10^4$; Cost: SPH$\simeq$JW$/48$.

(1) Update of the James Webb Space Telescope as of 2016.



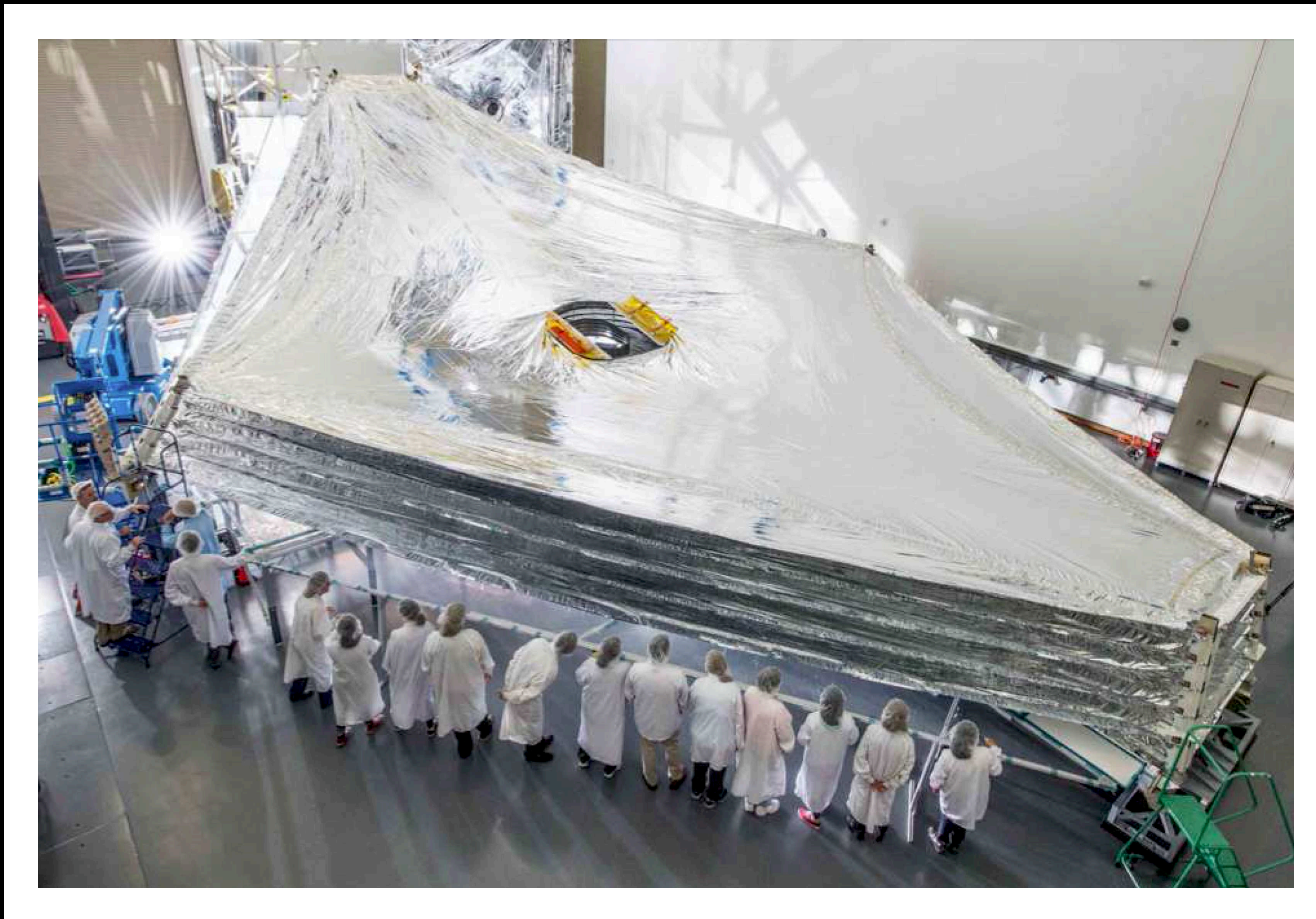
- A fully deployable 6.5 meter (25 m^2) segmented IR telescope for imaging and spectroscopy at 0.6–28 μm wavelength, to be launched in Fall 2018.
- Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging (AB=31.5 mag) and spectroscopy.

JWST Hardware Status



Feb. 2016: $\gtrsim$98% of launch mass designed and built ($\gtrsim$65% weighed).

(1) JWST hardware to date, and how to best use it for high redshift lensing.



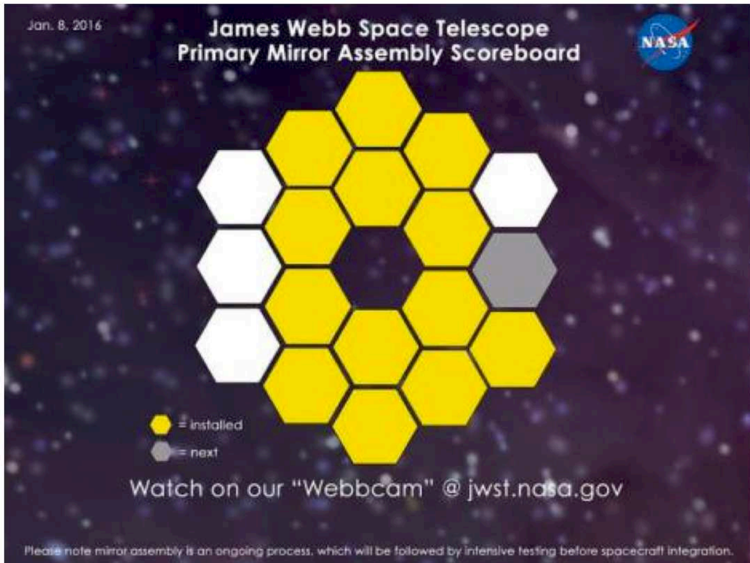
[LEFT]: Aug. 2014: Engineering Kapton Sunshield; 2015: Flight Sunshield.

[RIGHT]: Nov. 2014: First JWST mirrors mounted onto support structure, using Engineering Demos — 18 Flight mirrors mounted by Feb. 2016.

- Our Galaxy is a bright IR source at $\lambda \gtrsim 1$–5μm: In certain directions of sky, straylight will hit secondary mirror via Sunshield: $\lesssim 40\%$ [95%] of Zodi.

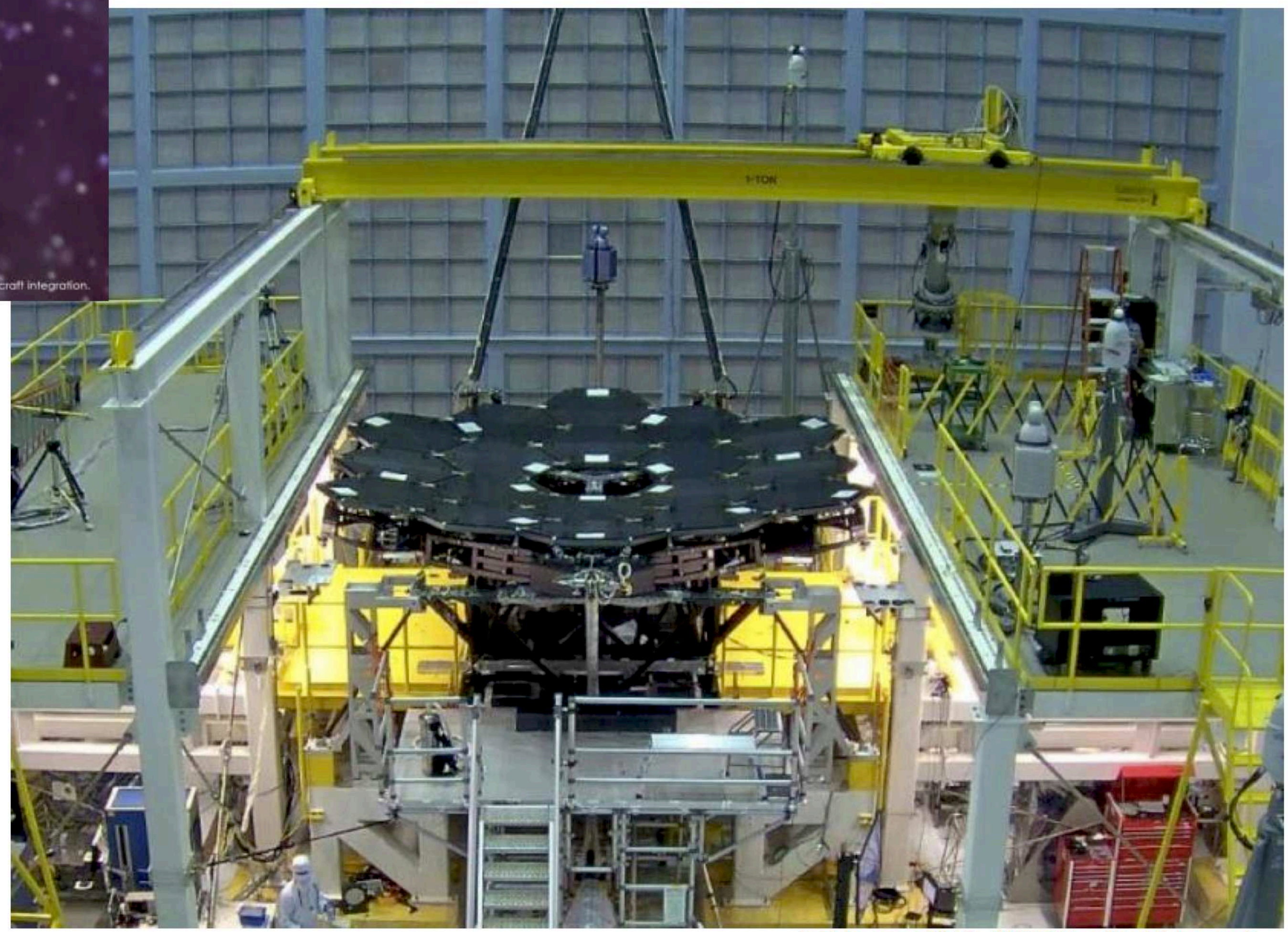
- SPHEREx can measure this for JWST lensing studies of First Light objects.

Much progress has been made in OTE integration



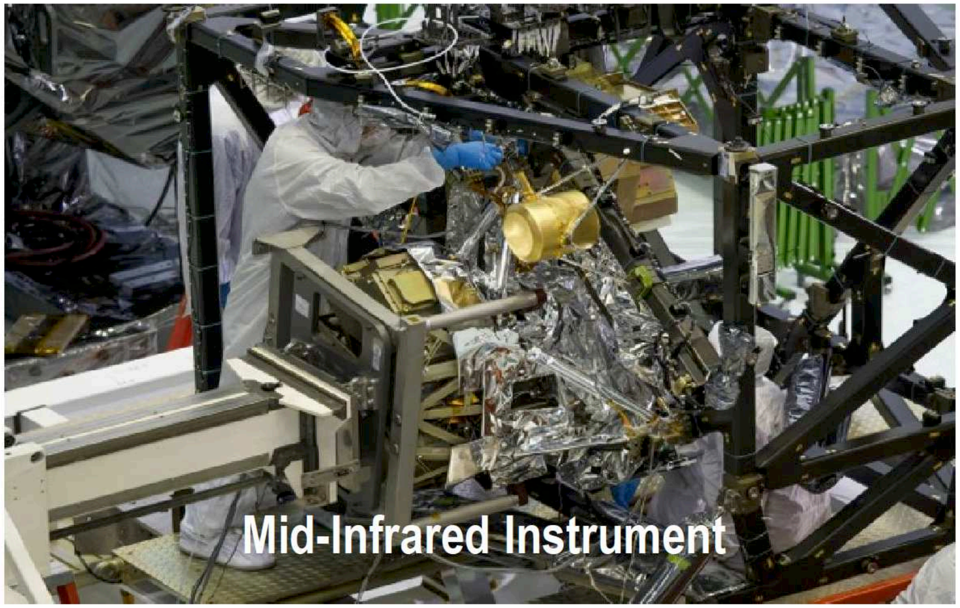
← Where we were at last month's call

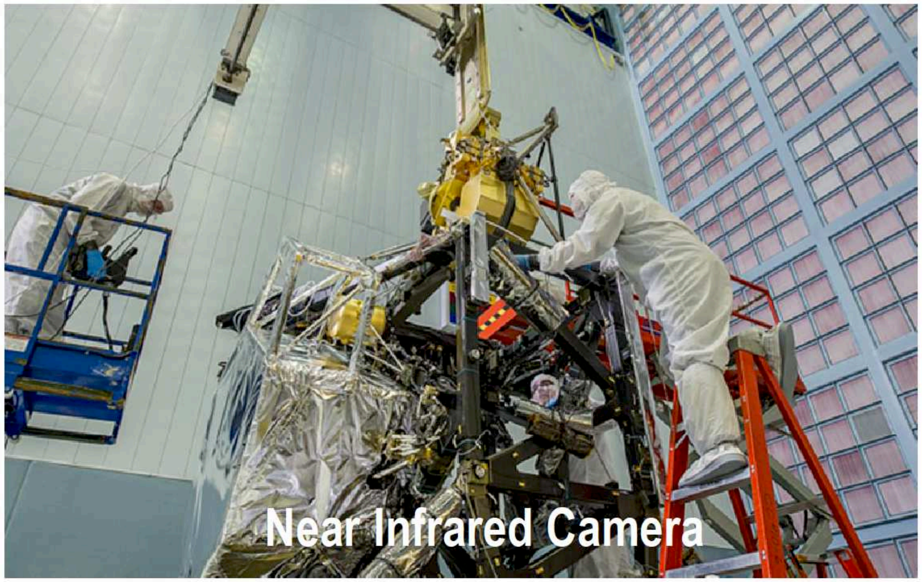
Current: all 18 PMSAs installed, liquid-shim-cured, & metrologized. Align-ments meet specifi-cations, and actuator motions verified
Big milestone! →

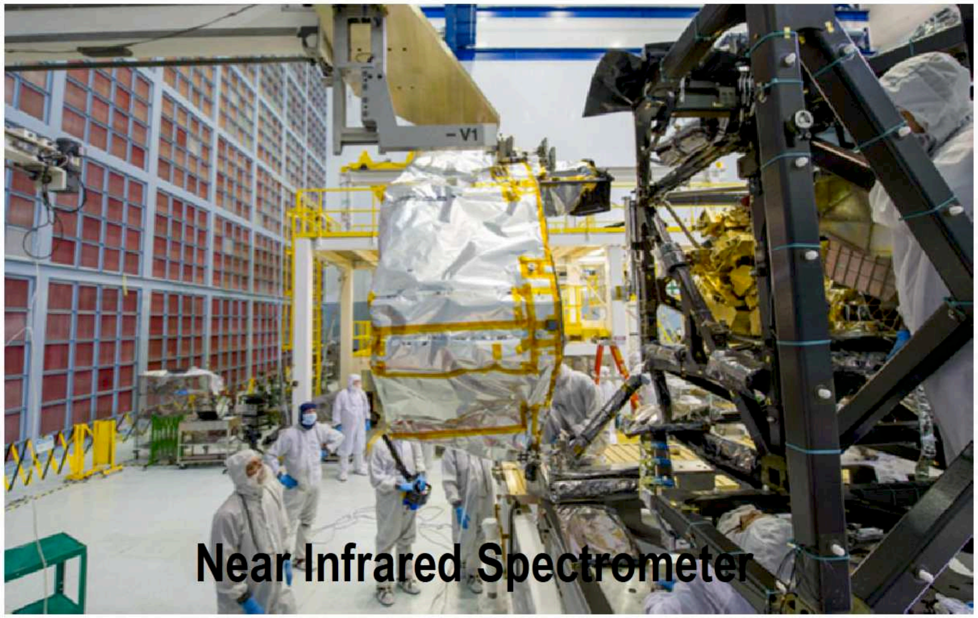


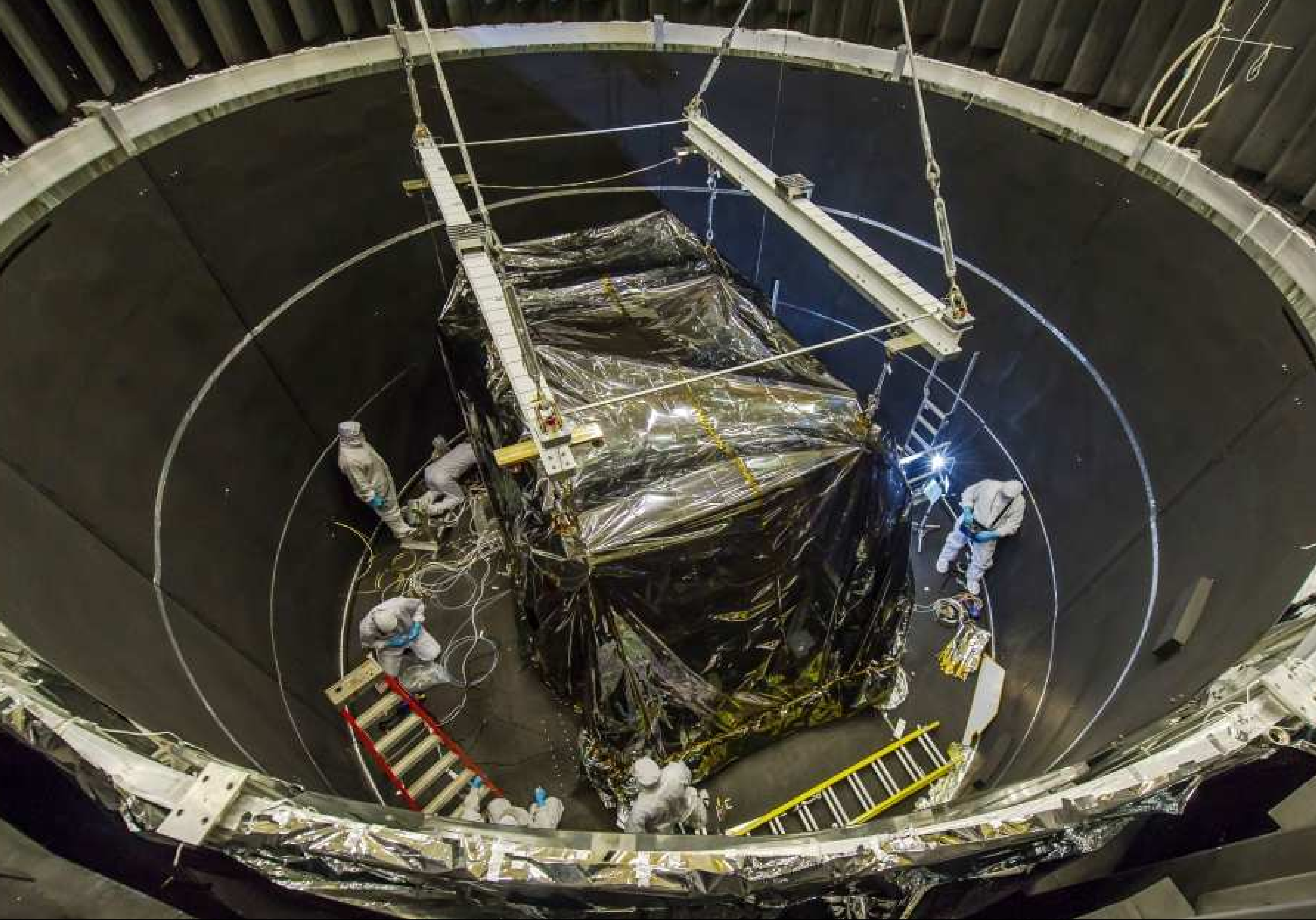
JWST lifetime: Requirement: 5 yrs; Goal: 10 yrs. SPHEREx overlaps!

All Instruments Integrated



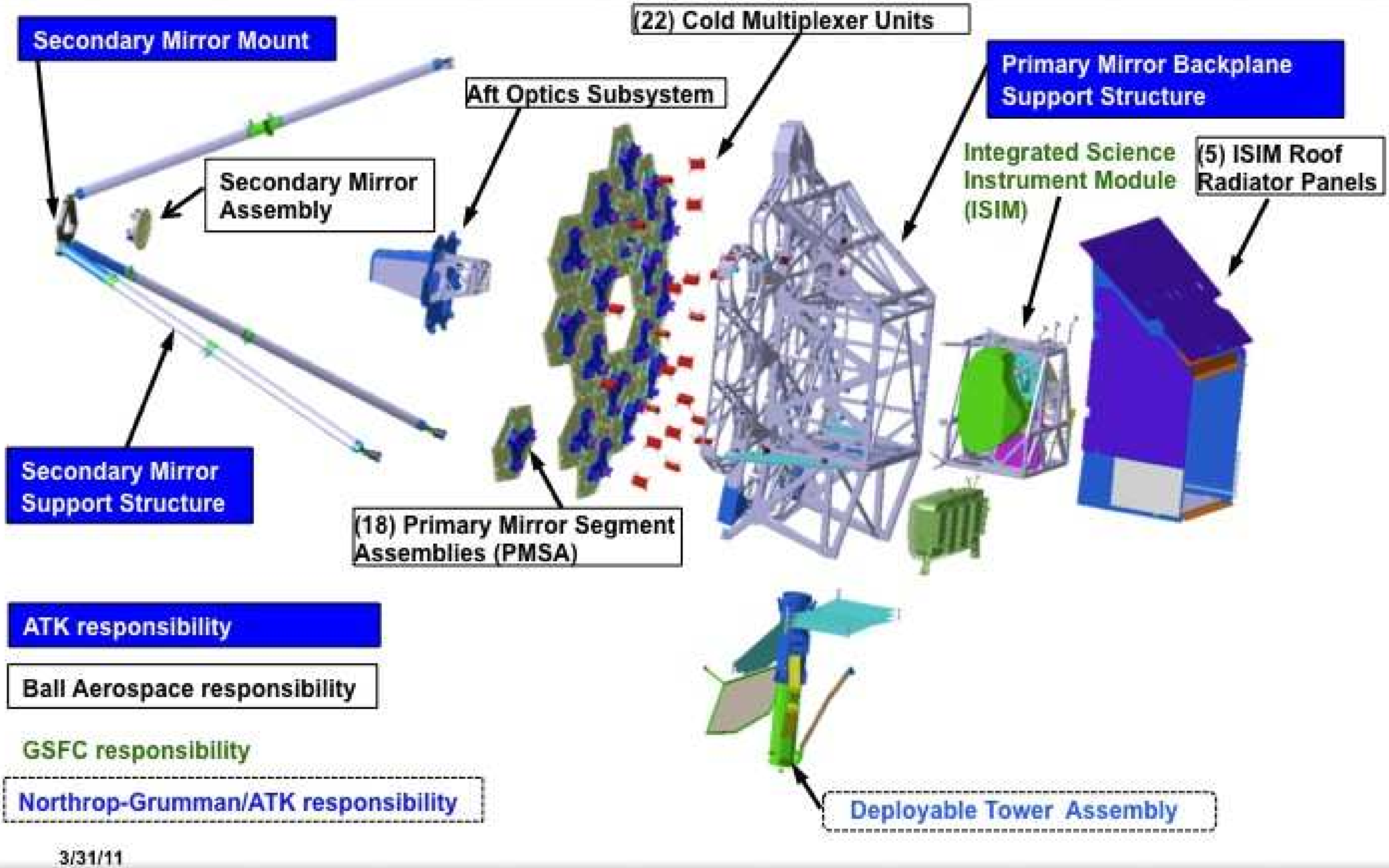






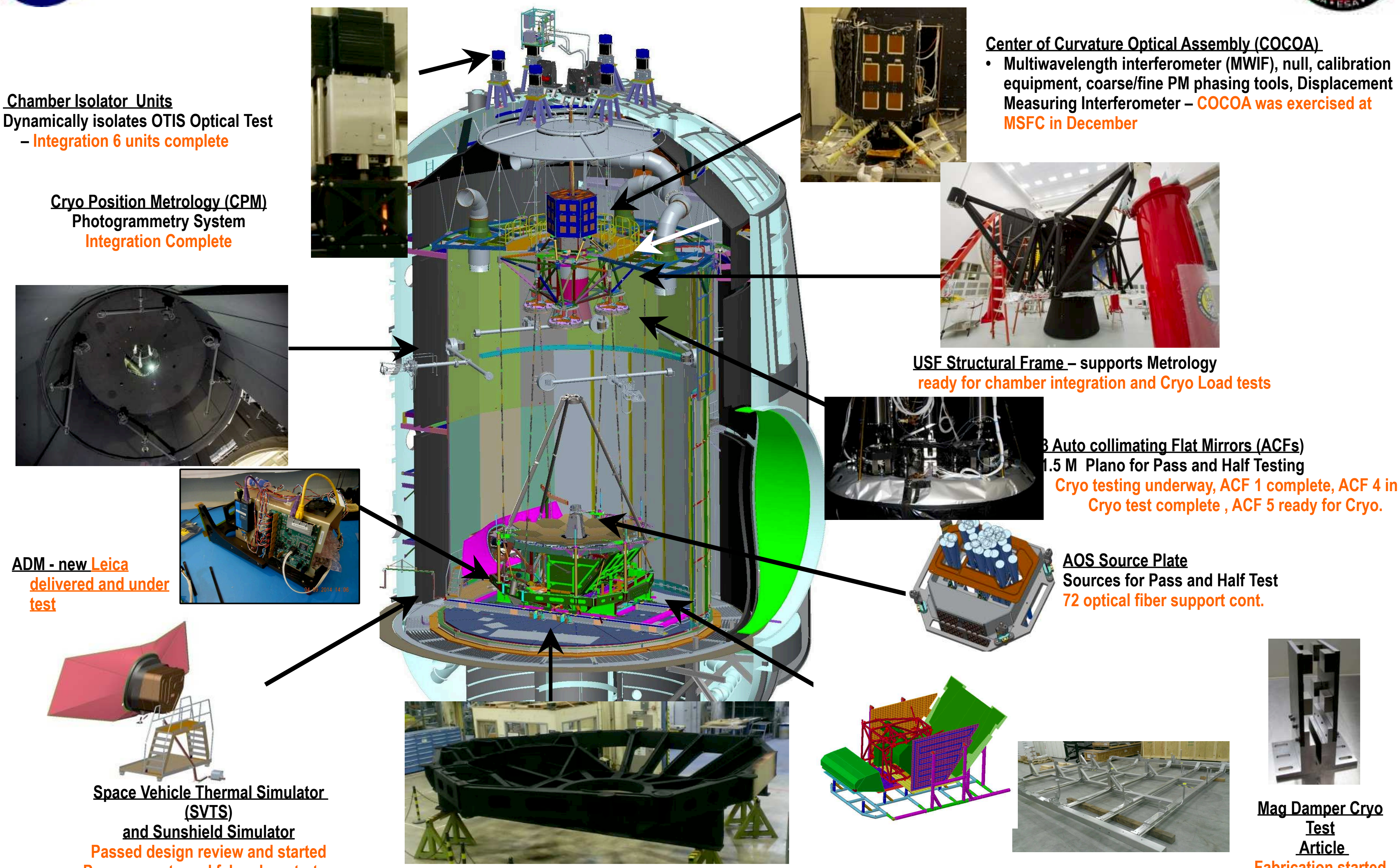
Flight ISIM with all 4 instruments: CryoVac Test 3: Oct. 2015–Feb. 2016.

TELESCOPE ARCHITECTURE



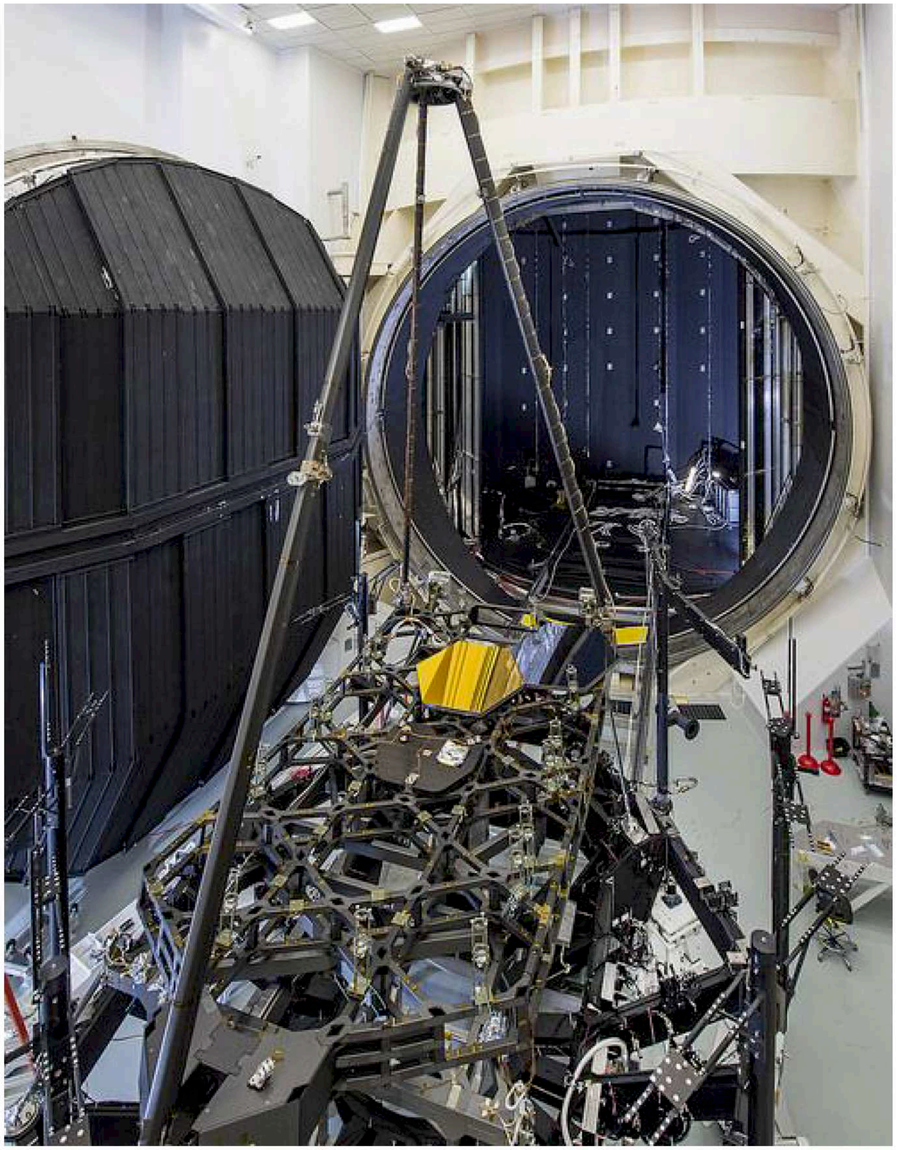
2016: Finish total system integration at GSFC and Northrop.

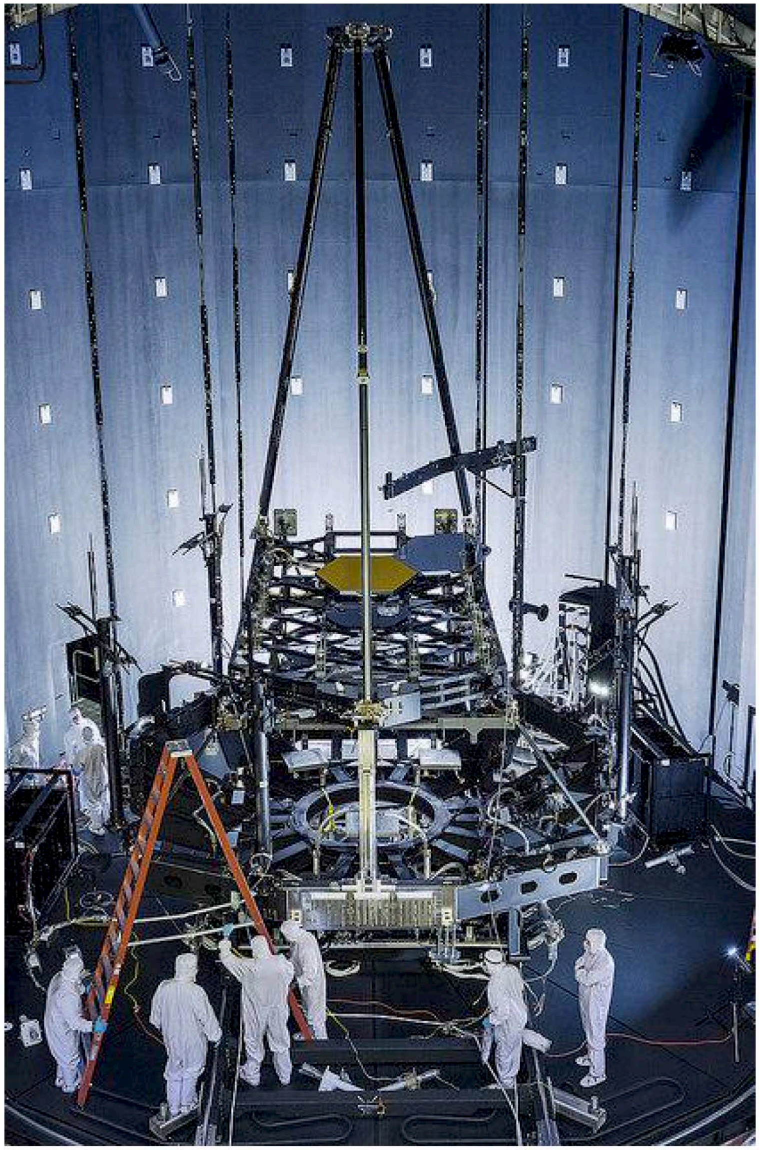
OTIS Test GSE Architecture and Subsystems



World's largest TV chamber OTIS: Will test whole JWST in 2017.

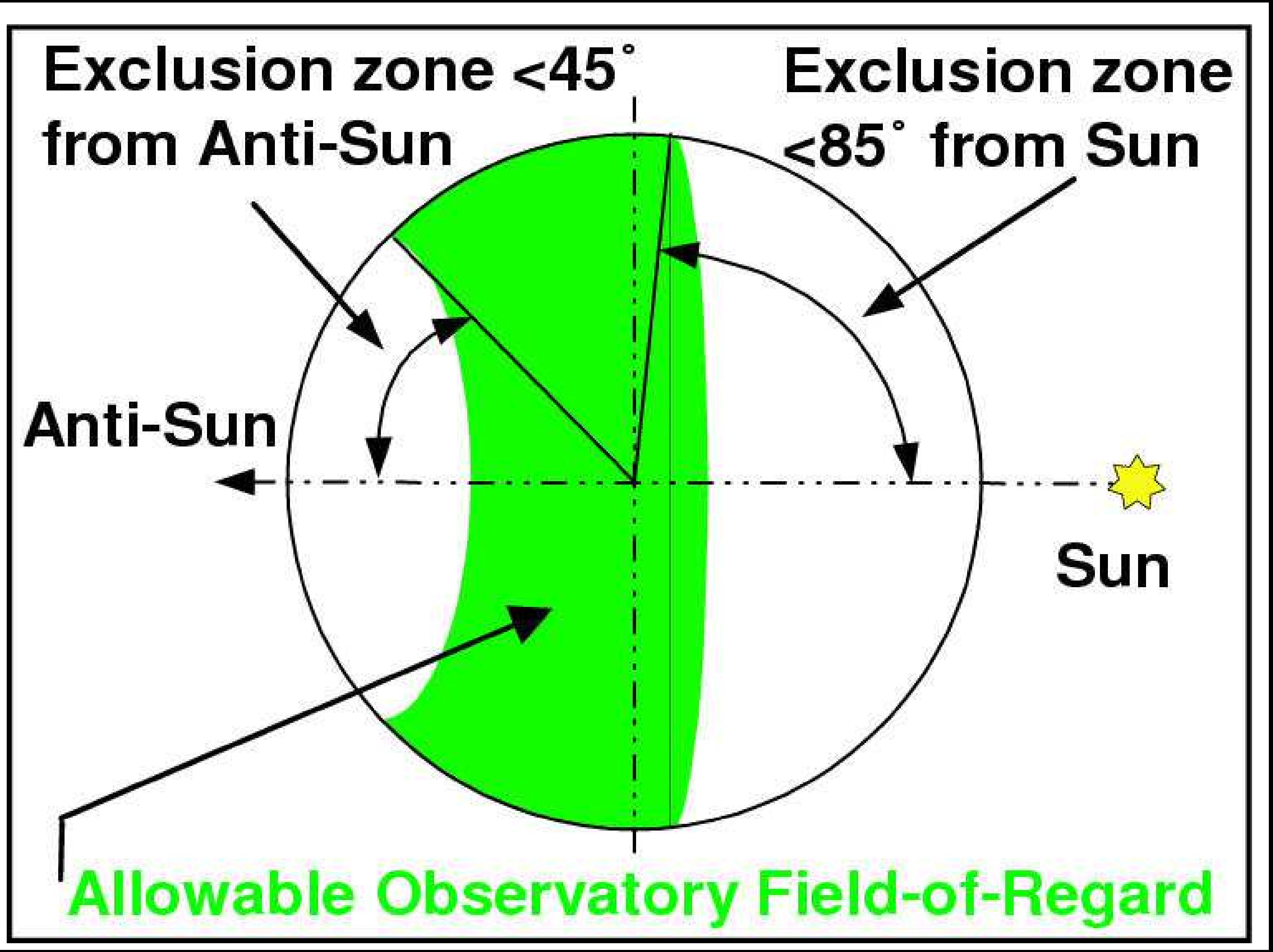
Pathfinder & JSC Chamber A: getting ready for OGSE1 (and eventually OGSE2 & Thermal Pathfinder)





Testing chamber with JWST Engineering model. 2017: Test real JWST.

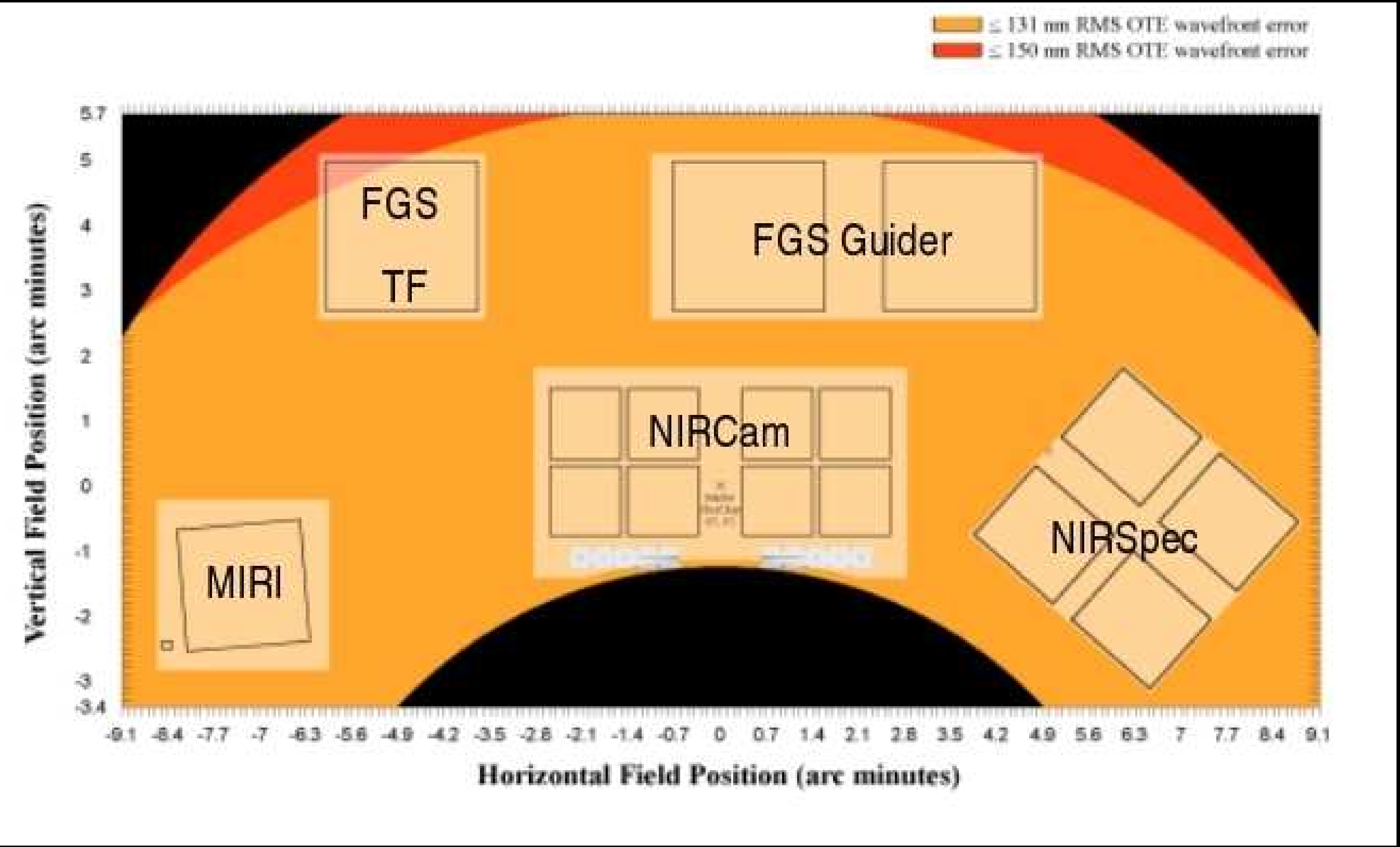
(2) JWST–SPHEREx Calibration Synergy: Ground-Truth Calibrations



JWST can observe North/South Ecliptic Pole continuously ($r \lesssim 5^\circ$ CVZs):

- LMC affects SEP CVZ. NEP has good regions (see Finkbeiner's talk).
- Great for Galactic proper motion, high redshift variability, etc.
- NEP survey provides perfect calibrations for SPHEREx (& WFIRST).

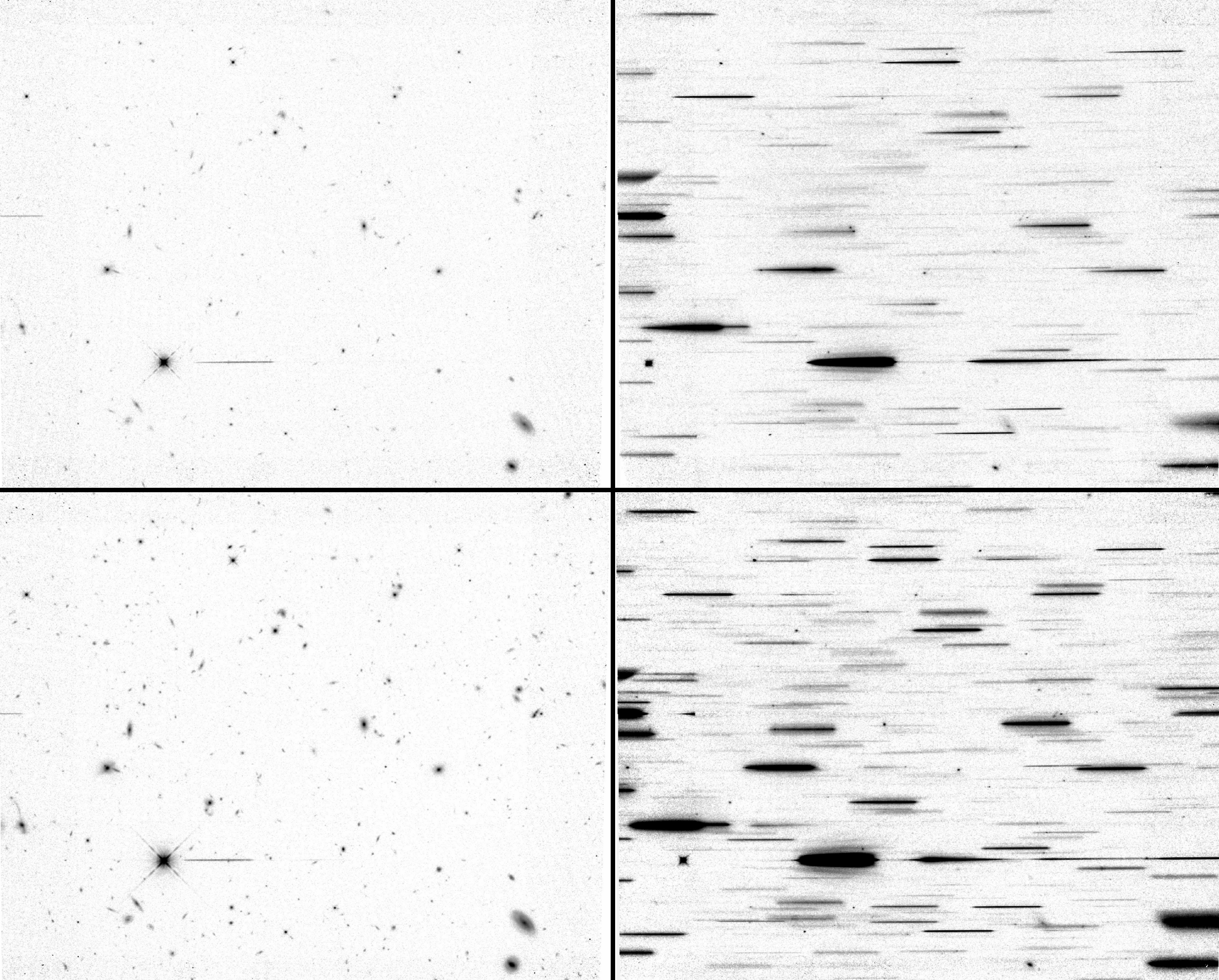
(2) JWST–SPHEREx Calibration Synergy: Ground-Truth Calibrations

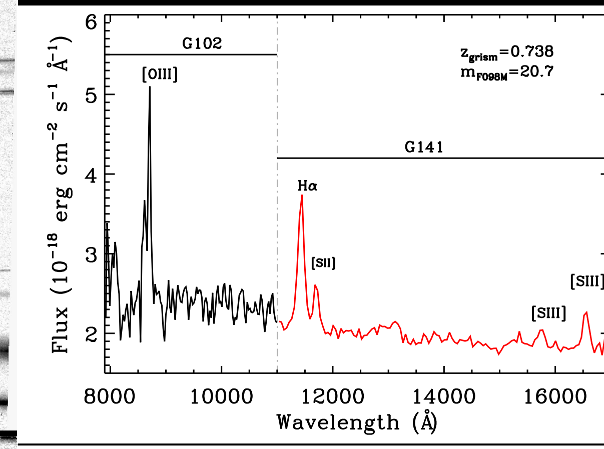


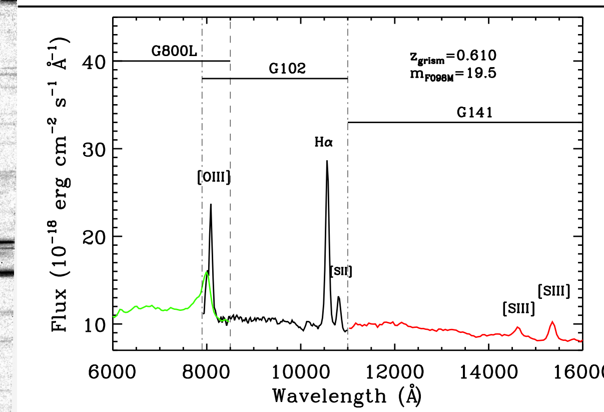
FY$\gtrsim$16: JWST instruments can NOW be used for science parallels!!

- Currently being implemented for most used instrument pairs.

Provides perfect grism+imaging calibration data for SPHEREx (& WFIRST).







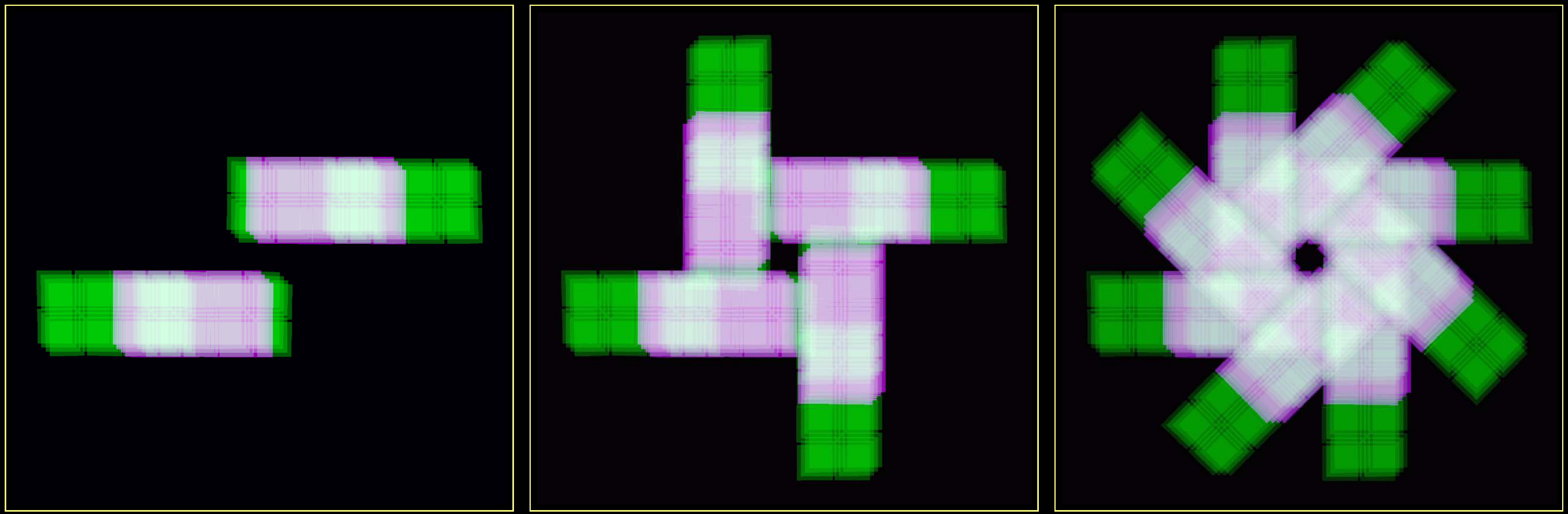
HST/WFC3 G102 & G141 grism spectra in GOODS-S ERS (Straughn^{+} 2011)

JWST parallels: R∼150 grism spectra to AB$\lesssim$27 + 1–5μm images to AB$\lesssim$29.

10×10′ NEP provides ground-truth to AB$\lesssim$27 for SPHEREx (& WFIRST).

See M. Kriek's talk on 3DHST. There are also ACS G800L GRAPES & PEARS, and WFC3 G102L FIGS surveys (Malhotra et al.).

Exposure Maps of NEP JWST-Windmill & GO-Extensions:



[LEFT]: Parallel NIRISS R150C+R150R grism spectra at ΔPA=0+180° overlayed on primary NIRCam images.

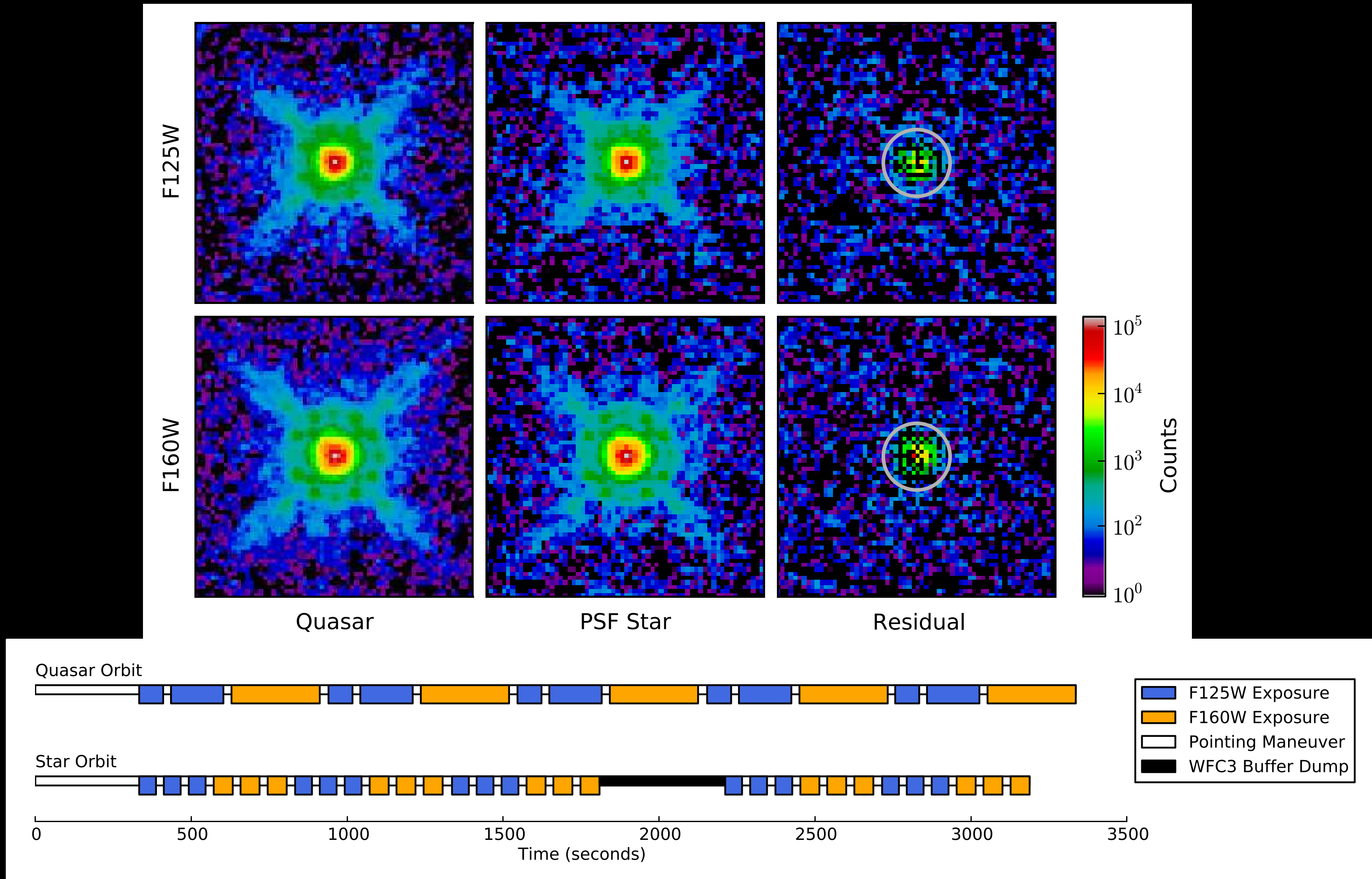
[MIDDLE]: Same with ΔPA=90+270° added.

[RIGHT]: Possible GO-Community extensions in JWST Cycle $\gtrsim$1.

White regions: NIRCam exposures overlap, reaching $\lesssim$0.75 mag deeper.

$10\times10'$ NEP provides ground-truth to AB$\lesssim$27 for SPHEREx (& WFIRST).

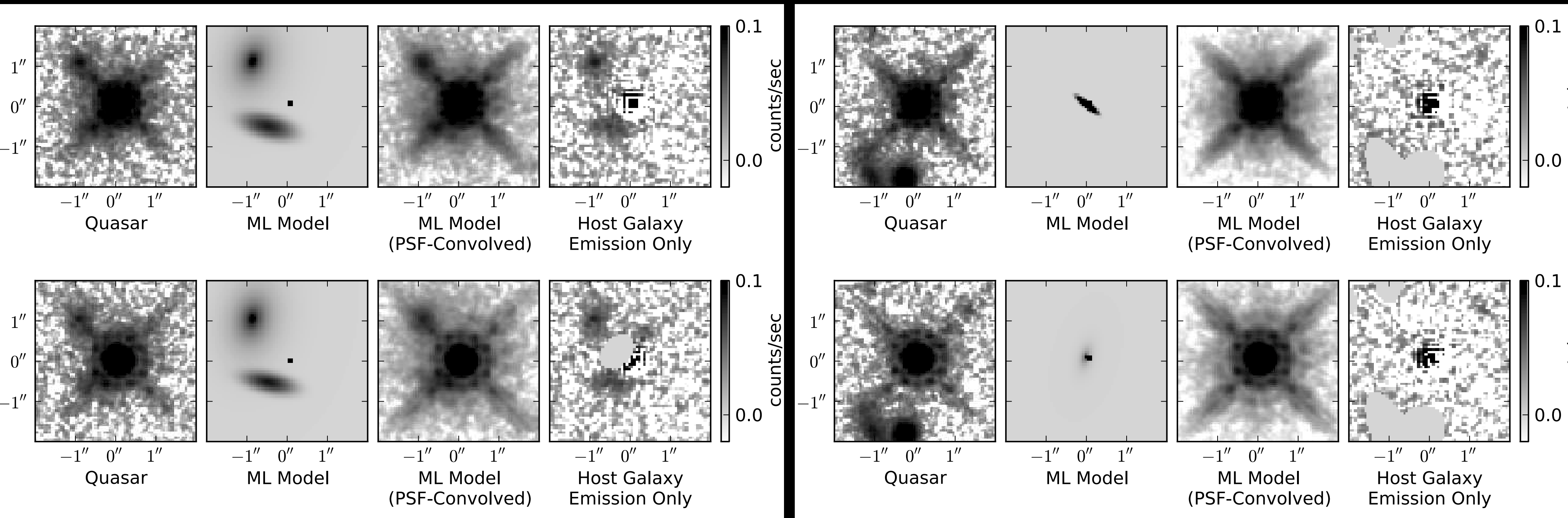
• (3) JWST–SPHEREx Synergy: Rare and Dusty Objects: z≃2–7 QSOs



• 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≃18.5) nearly to the noise limit: NO host galaxy detected 100×fainter (AB≳23.5 at r≳0.″3).

(3) WFC3 Detection of QSO Host Systems at z≃6: Dusty Merger?

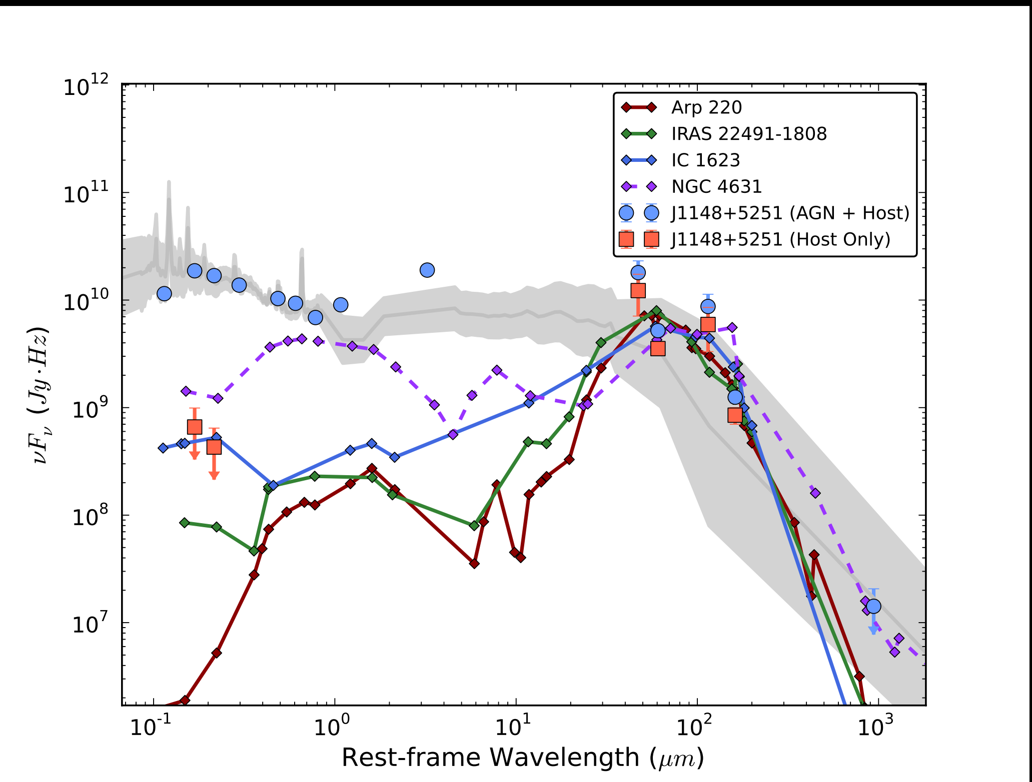


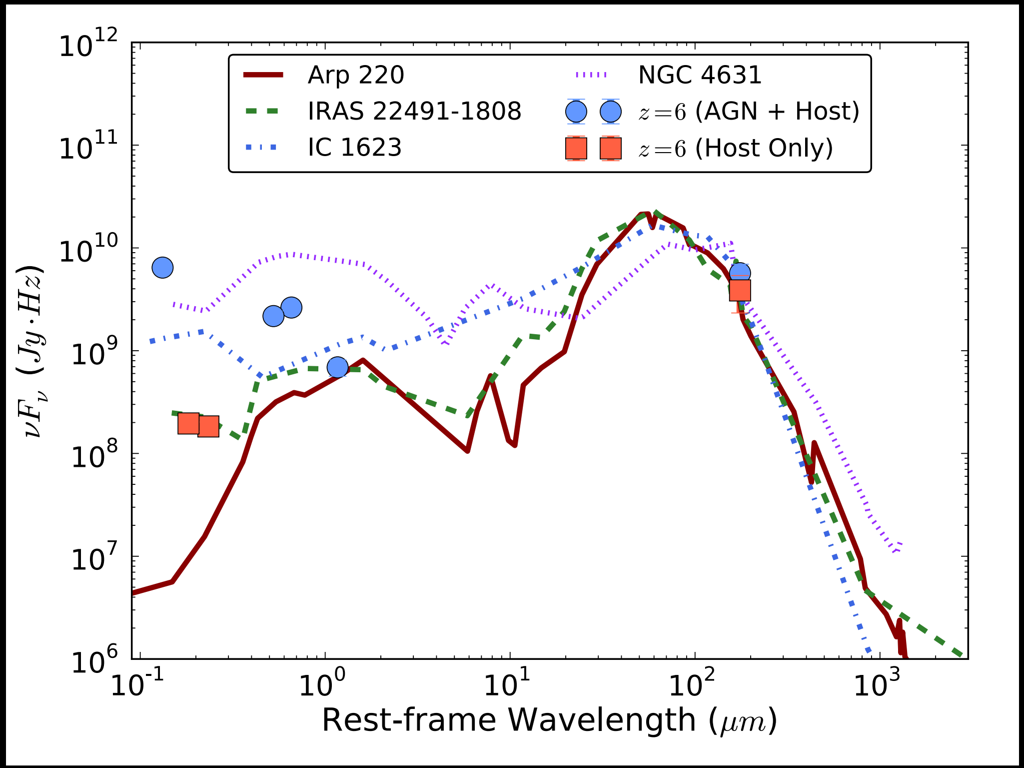
- Monte Carlo Markov-Chain of observed PSF-star + Sersic ML light-profile. Gemini AO images to pre-select PSF stars (Mechtley+ 2014).
- First detection out of five z≃6 QSOs [2/5 hosts detected].
- One z≃6 QSO host galaxy: Giant merger morphology + tidal structure??

- Same J+H structure! Blue UV-SED colors: (J–H)≃0.19, constrains dust.
  - IRAS starburst-like SED from rest-frame UV–far-IR, $A_{FUV}\sim1$ mag.
- M_{AB}^{host}(z≃6)≲–23.0 mag, i.e., ∼2 mag brighter than L*(z≃6)!

- SPHEREx provides ALL-SKY samples of (dusty!) z≃2–7 QSOs for JWST.

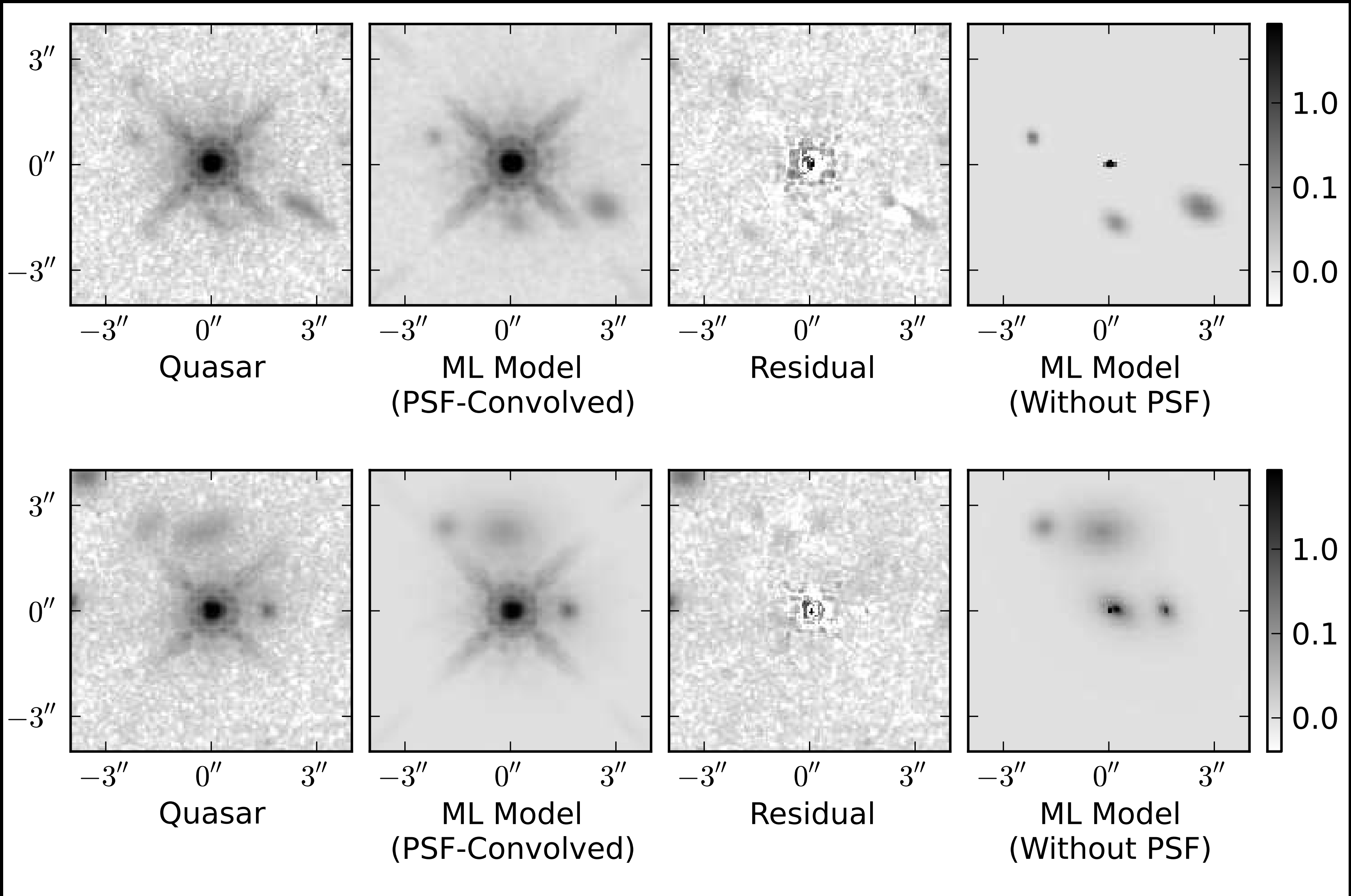
(3) Observations of QSO Host Systems at z≃6: Dusty Mergers?





- Blue dots: z≃6 QSO SED, Grey: Average radio-quiet SDSS QSO spectrum at z≳1 (normalized at 0.5μ). Red: z≃6 host galaxy (WFC3+submm).
- Nearby fiducial galaxies (starburst ages≲1 Gyr) normalized at 100μm: [LEFT] Rules out z=6.42 spiral or bluer host galaxy SEDs for 1148+5251. (U)LIRGs & Arp 220s permitted (Mechtley et al. 2012, ApJL, 756, L38). [RIGHT] Detected QSO host has IRAS starburst-like SED from rest-frame UV–far-IR, A_{FUV}(host)∼1 mag (Mechtley et al. 2012; 2014 PhD).
- SPHEREx provides ALL-SKY samples of (dusty!) z≃2–7 QSOs for JWST.

(3) Observations of QSO Host Systems at z≃2: Dusty Mergers?



• Monte Carlo Markov-Chain runs of observed PSF-star + Sersic ML light-profile models: merging neighbors (some with tidal tails?; Mechtley, Jahnke, Windhorst et al. 2016; astro-ph/1510.08461).

• SPHEREx provides ALL-SKY samples of (dusty!) z≃2–7 QSOs for JWST.

(4) Summary and Conclusions

(1) JWST in final integration & testing: On track for Oct 2018 launch.

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

- More than 98% of JWST H/W built or in fab, & meets/exceeds specs.

(2) JWST–SPHEREx Calibration Synergy: Ground-Truth Calibrations

JWST provides perfect grism+imaging calibration for SPHEREx (& WFIRST)

$10 \times 10'$ NEP provides ground-truth to AB$\lesssim$27 for SPHEREx (& WFIRST).

(3) JWST–SPHEREx Synergy: Rare, Red (Dusty) or Dead Objects:

- SPHEREx provides ALL-SKY samples of (dusty!) $z \simeq 2$–7 QSOs for JWST.
- SPHEREx provides ALL-SKY samples of Early Type Galaxies (M. Kriek's talk).

- (4) To see the most First Light, JWST must cover the best lensing clusters!
  - Need to consider brightness of — and low-level gradients in — IntraCluster Light (ICL). SPHEREx will help map & calibrate this.

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

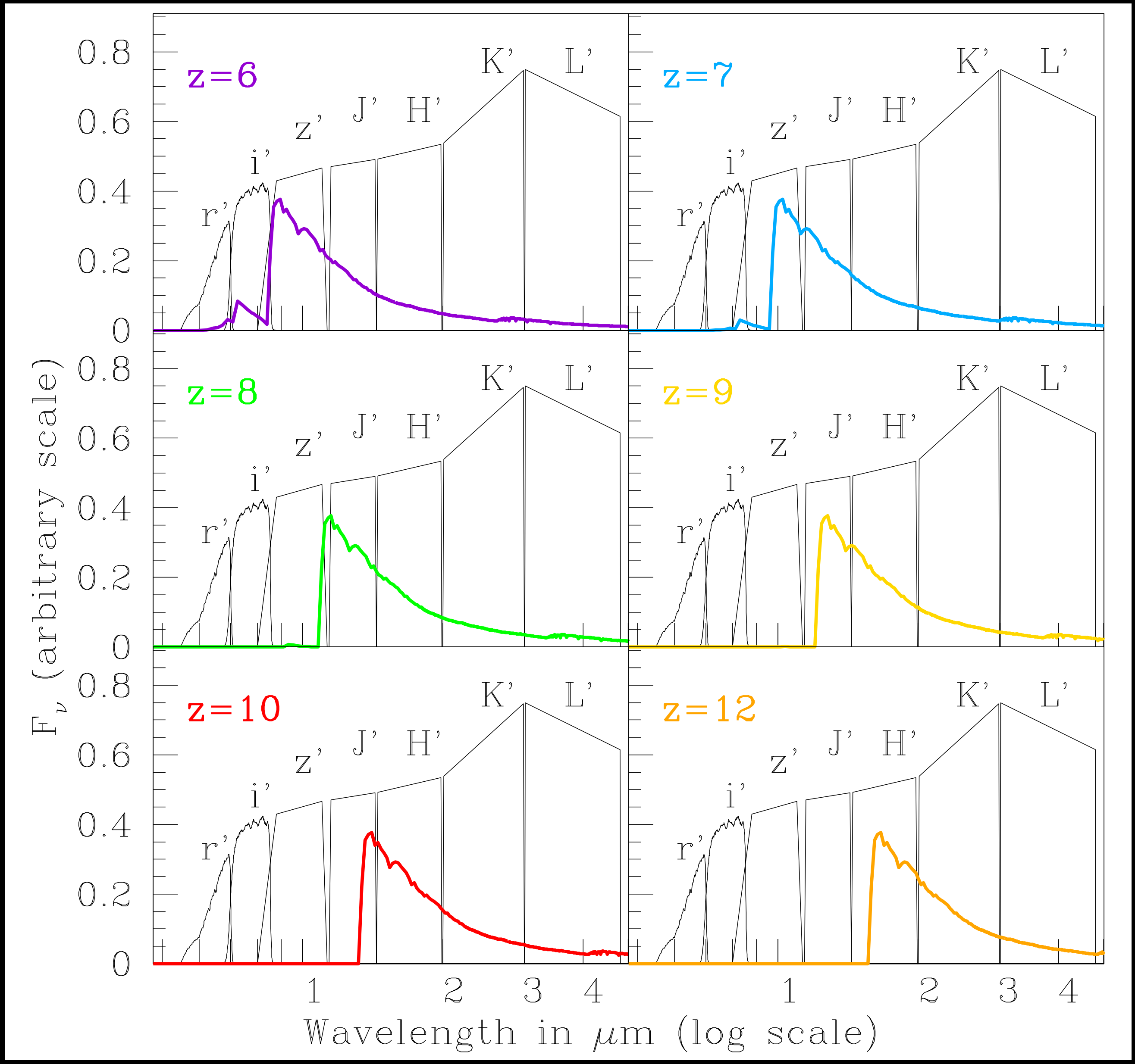
Gardner, J. P., et al. 2006, Space Science Reviews, 123, 485–606

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

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

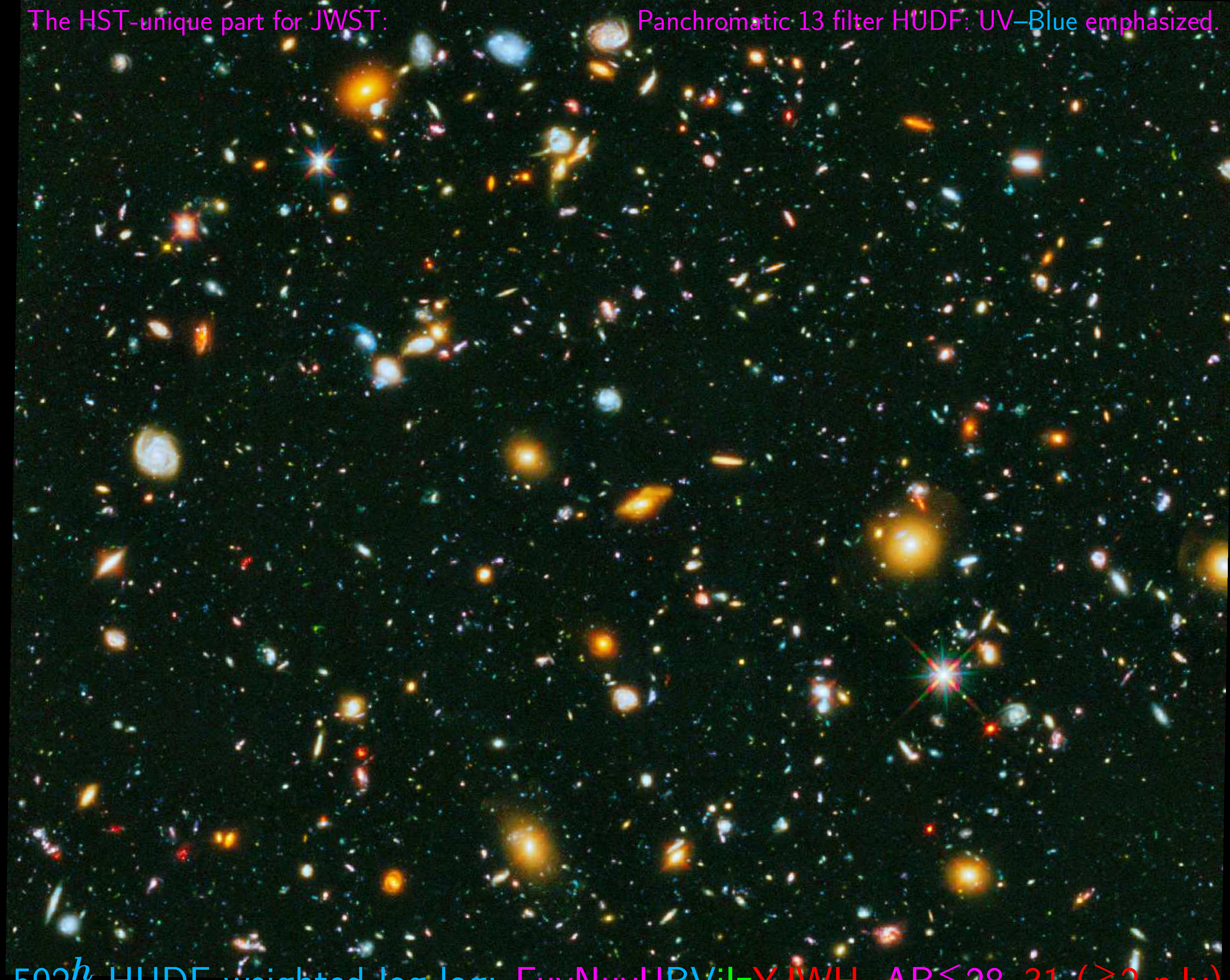
Windhorst, R., et al., 2011, ApJS, 193, 27 (astro-ph/1005.2776).

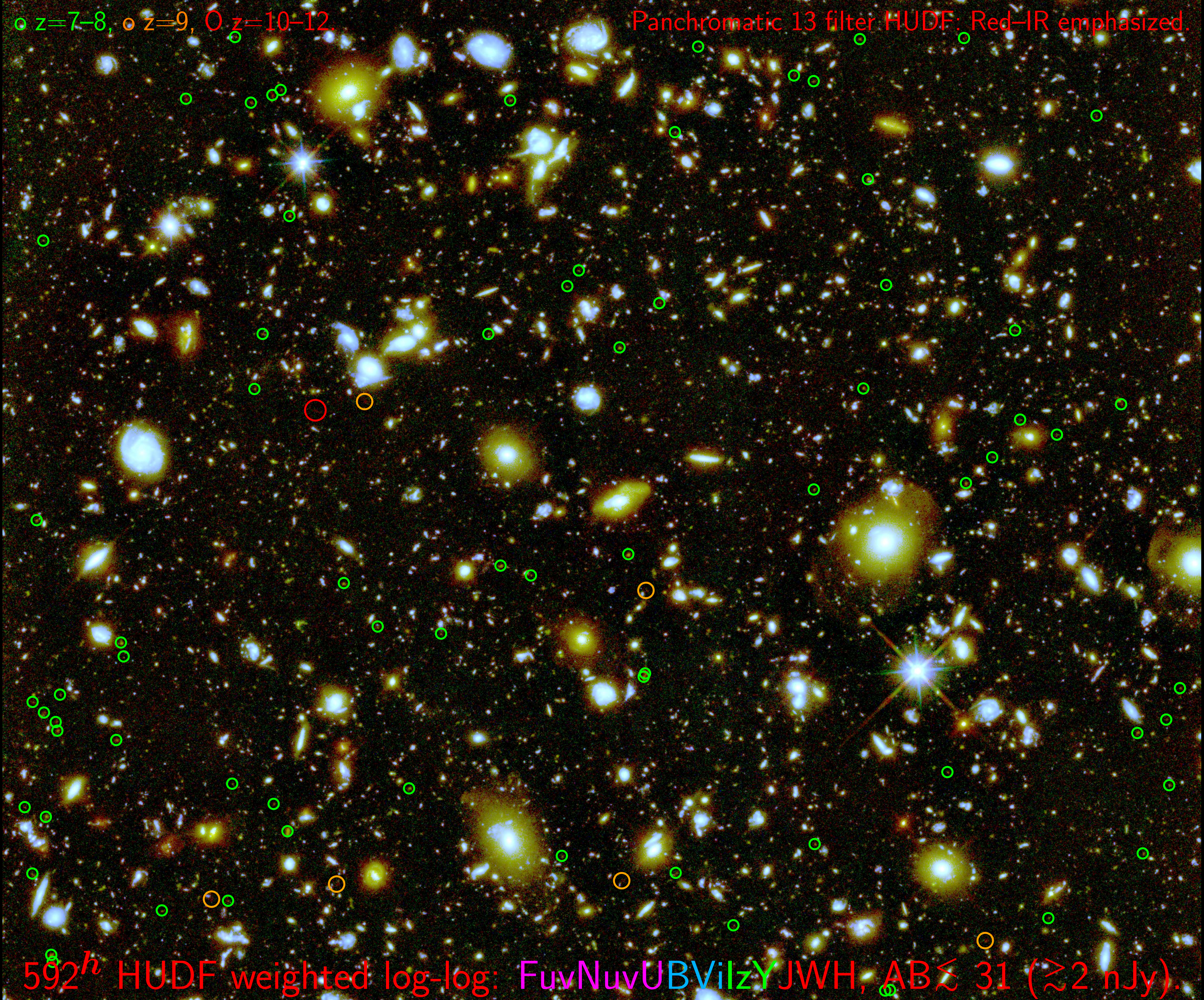
(5) How will Webb measure First Light: What to expect in (Ultra)Deep Fields?

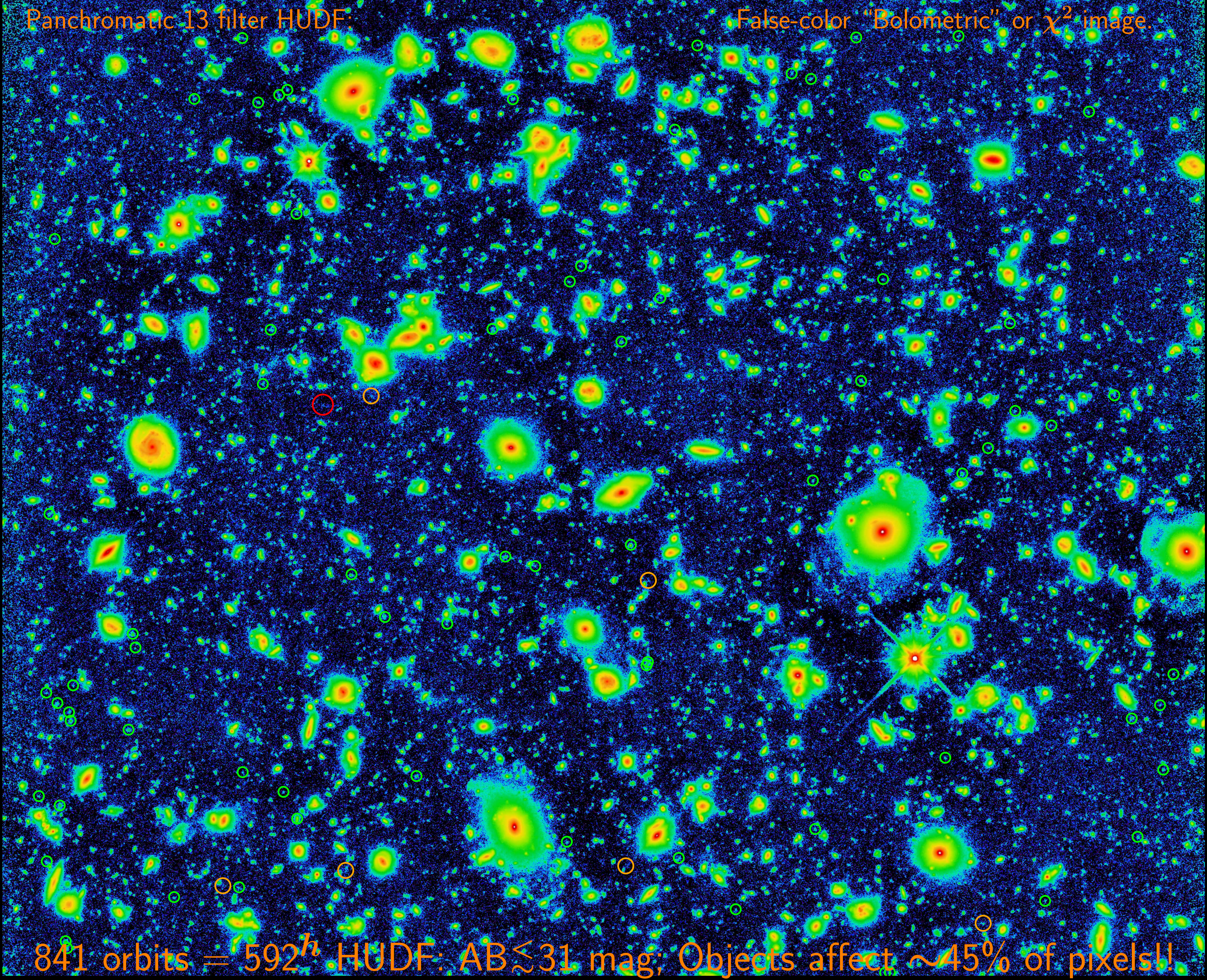


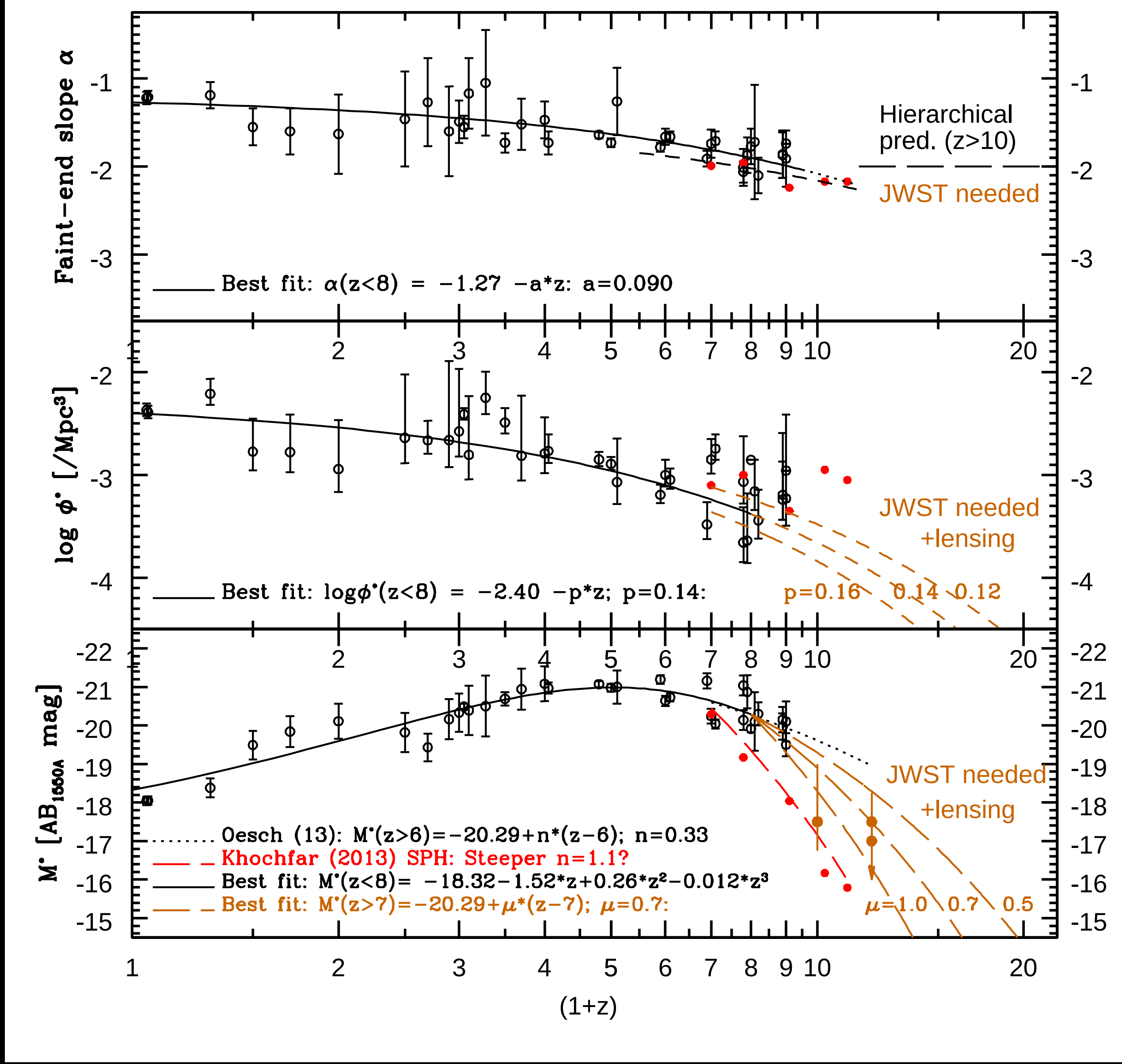
- Can't beat redshift: to see First Light, must observe near–mid IR.

⇒ This is why JWST needs NIRCam at 0.8–5 μm and MIRI at 5–28 μm.


The HST-unique part for JWST:
Panchromatic 13 filter HUDF: UV–Blue emphasized.
592^h HUDF weighted log-log: FuvNuvUBViIzYJWH, AB$\lesssim$28–31 ($\gtrsim$2 nJy).


o z=7–8, o z=9, O z=10–12.
Panchromatic 13 filter HUDF: Red–IR emphasized.
592h HUDF weighted log-log: FuvNuvUBViIzYJWH, AB ≲ 31 (≳2 nJy).

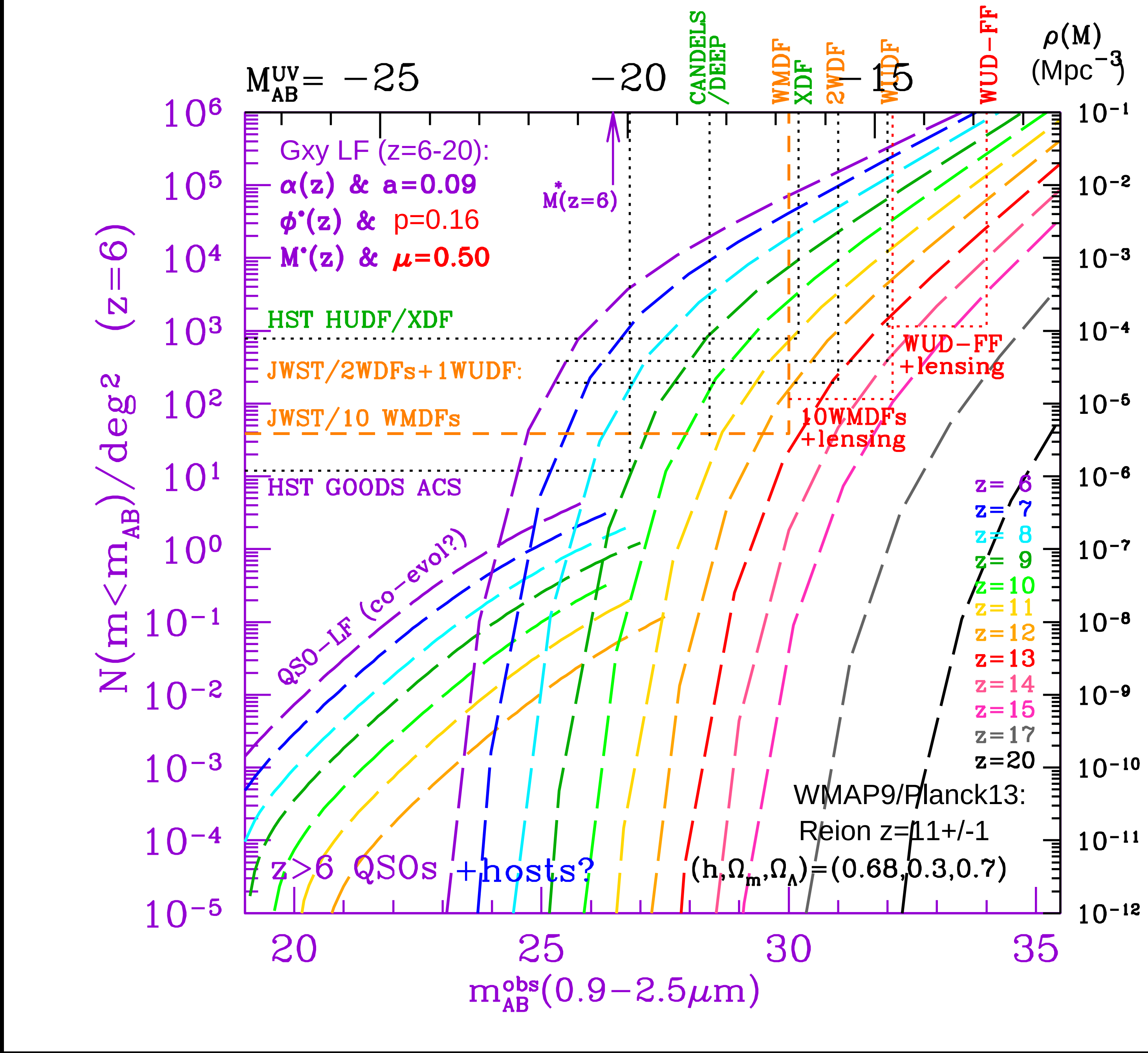

Panchromatic 13 filter HUDF:
False-color "Bolometric" or χ^2 image.
841 orbits = 592^h HUDF: AB$\lesssim$31 mag; Objects affect ~45% of pixels!!



Evolution of Schechter UV-LF: faint-end LF-slope α(z), Φ^* (z) & M^* (z):

- For JWST z$\gtrsim$8, expect $\alpha\lesssim$–2.0; $\Phi^* \lesssim 10^{-3}$ (Mpc^{-3}) (Bouwens$^+$ 14).
- HUDF: Characteristic M^* may drop below –18 or –17.5 mag at z$\gtrsim$10.

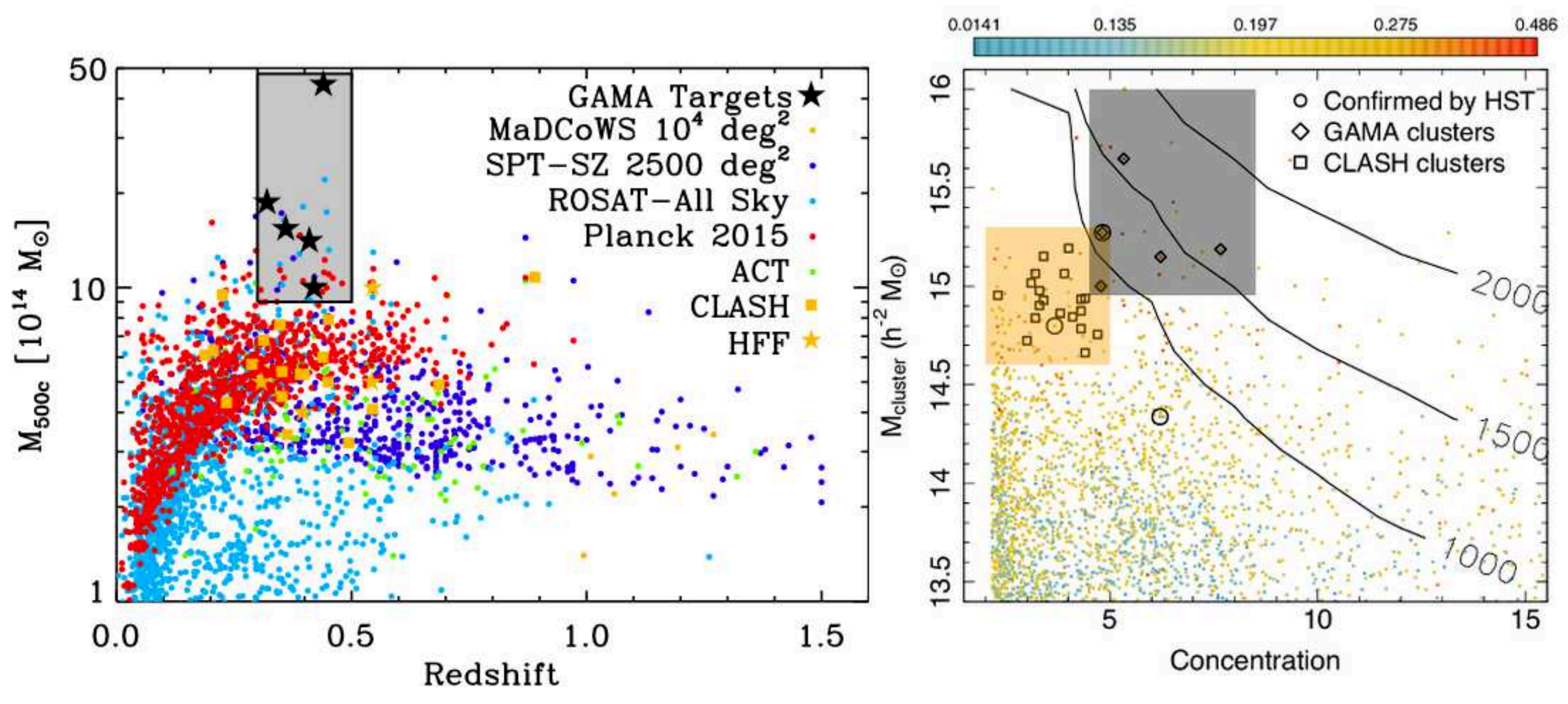
$\Rightarrow$ Will have significant consequences for JWST survey strategy.



Schechter LF (6≲z≲20) with best-fit α(z), Φ^* (z), M^* (z) & μ=0.50.

Area/Sensitivity for: HUDF/XDF, **10 WMDFs**, 2 WDFs, & 1 WUDF.

- Will need lensing targets for WMDF–WUDFF to see z≃12–15 objects.



What are the best lensing clusters for JWST to see First Light?:

[LEFT] Best lensing clusters vs. ROSAT, Planck, SPT, MaDCoWS.

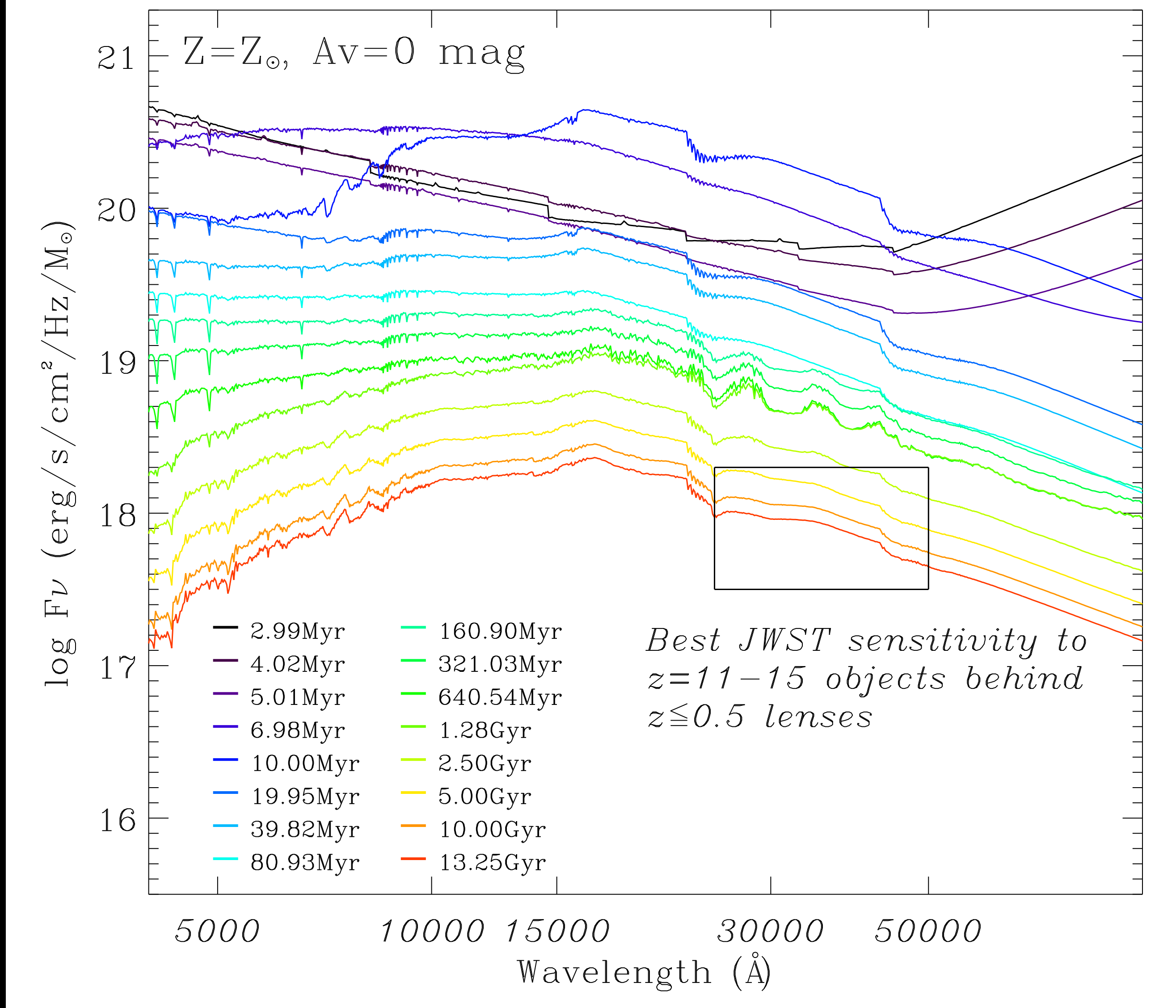
[RIGHT] Best lensing clusters vs. CLASH clusters.

(Contours: Number of lensed JWST sources at z≃1–15 to AB≲31 mag).

- Resulting sweet spot for JWST lensing of First Light Objects (z≳10):

Redshift: 0.3≲z≲0.5; Mass: $10^{15-15.6}\ M_{\odot}$; Concentration: 4.5≲C≲8.5

SPHEREx to characterize total light of best lensing z≲0.5 clusters for JWST.



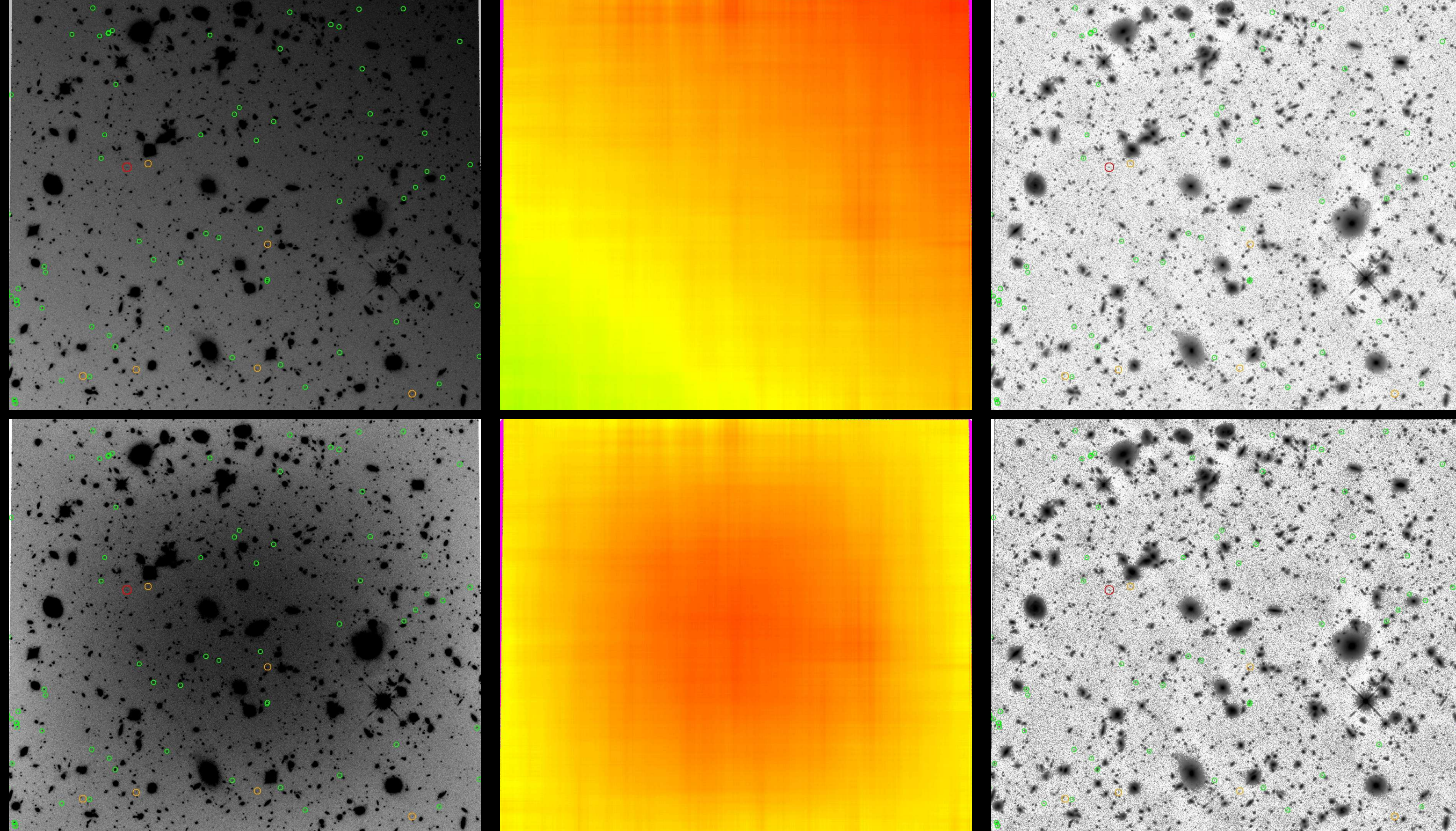
Galaxy SEDs for different ages: peak at $\lambda_{rest} \simeq 1.6\mu$m (Kim et al. 2016).

JWST-NIRCam peaks in sensitivity for λ=3–5μm, where Zodi is lowest.

Sweet spot for JWST lensing cluster is z$\lesssim$0.5: Zodi-gain beats $(1+z)^4$.

- Minimizes effects from near-IR K-correction and ambient ICL!

SPHEREx to characterize total light of best lensing z$\lesssim$0.5 clusters for JWST.



[TOP]: [Left] HUDF F160W image with *worst case* (95% of Zodi) rogue-path amplitude imposed ± a 4% *linear gradient* from corner-to-corner.

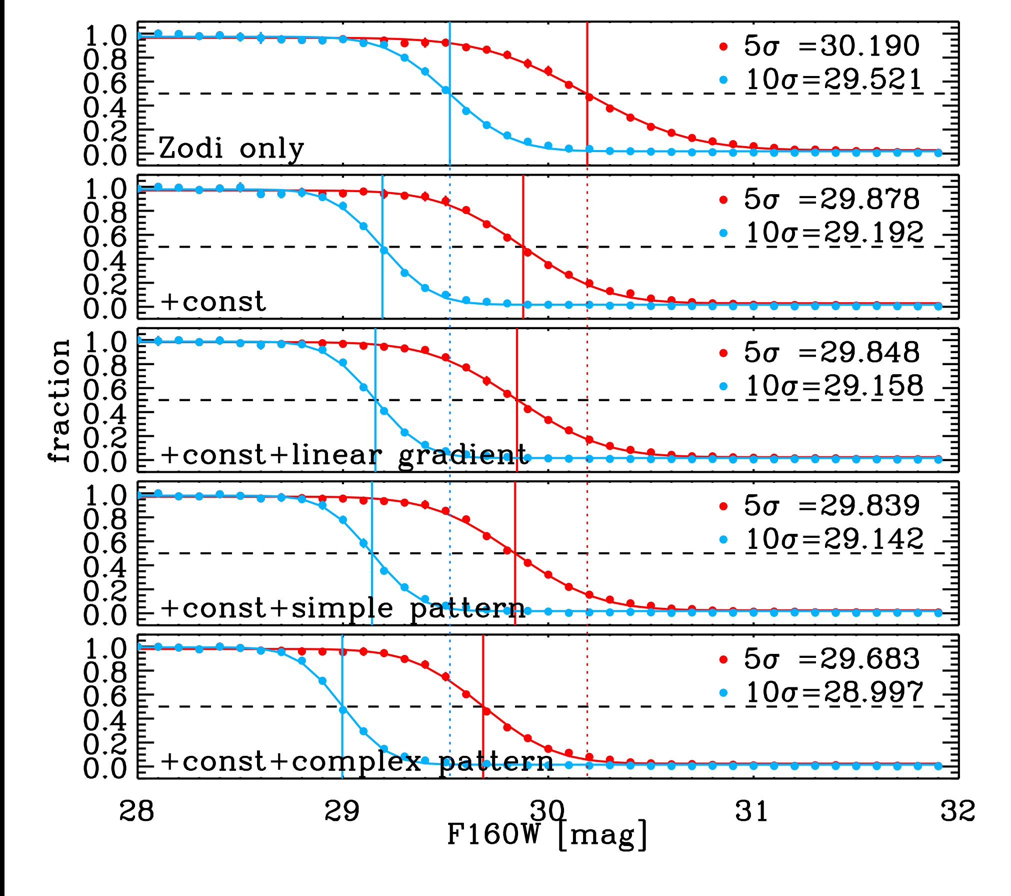
[Middle]: Best fit to sky-background with R. Jansen's "rjbgfit.pro".

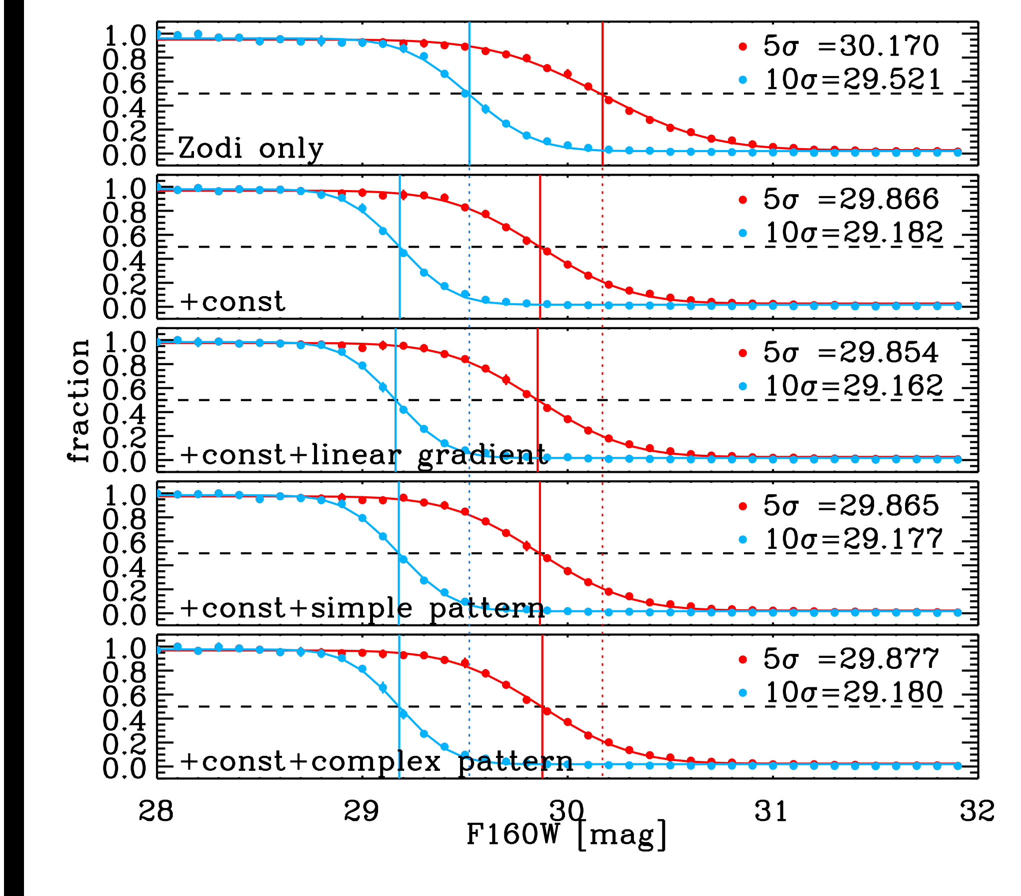
[Right]: HUDF image from left with best-fit sky-background subtracted.

[BOTTOM]: Same as top, but with *single-component 2D pattern* superimposed, modeled & removed.

- If JWST rogue-path straylight has slight or complex gradients, we must carefully plan JWST imaging of lensing clusters with strong ICL.

SPHEREx to characterize total light of best lensing z$\lesssim$0.5 clusters for JWST.





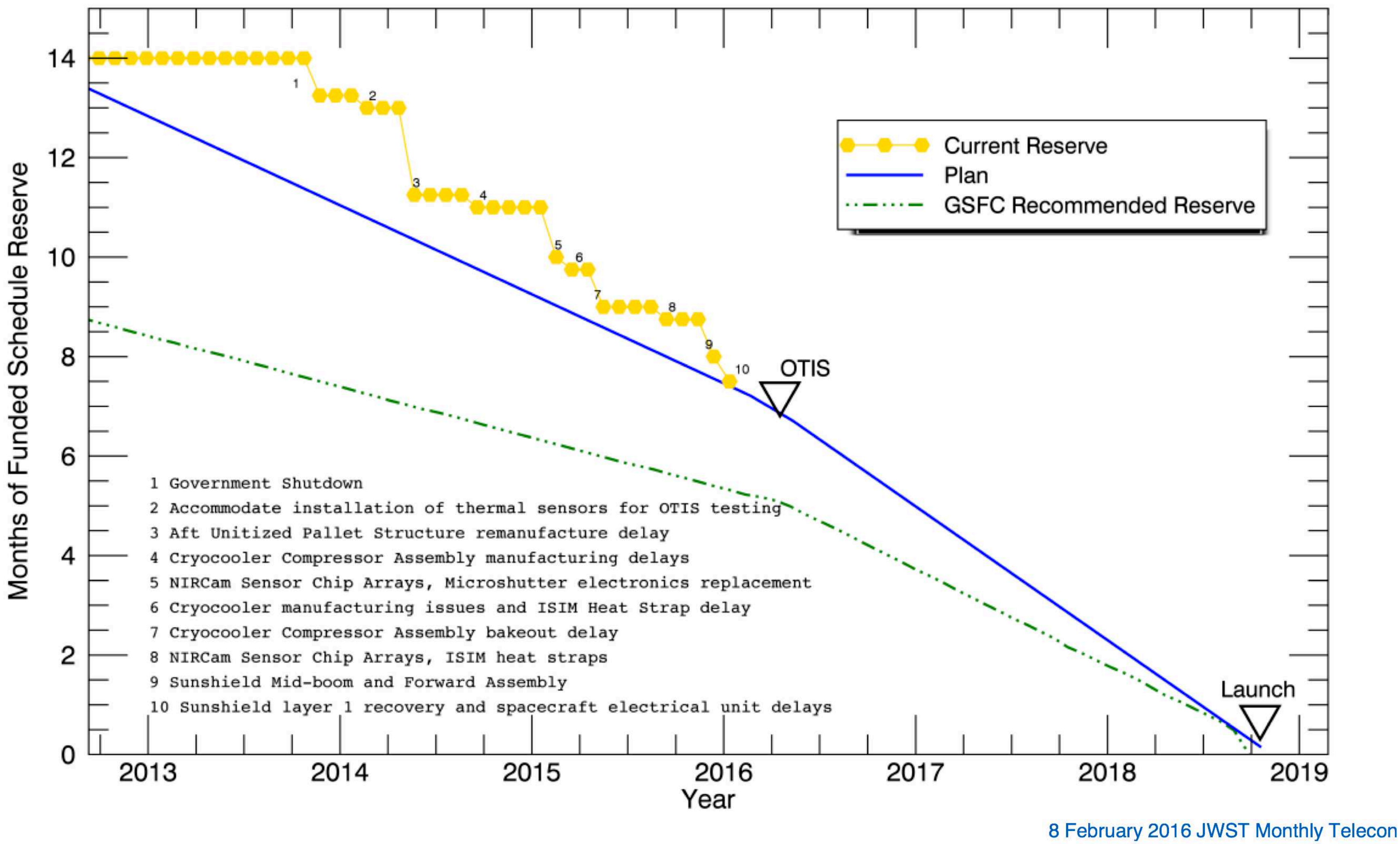
[LEFT]: Completeness tests in HUDF F160W image *before* imposing on top of Zodi (=22.70 H-mag arcsec^{-2}; Petro 2001) [2nd–5th row]: *Constant 95% of Zodi amplitude*; + *a ±4% linear gradient*; or *simple 2D pattern of ±4%*; or *a more complex pattern*.

[RIGHT]: Same as left *after* best fit to + removal of image sky-background.

Red and blue lines: 50% 5-σ and 10-σ AB-completeness limits, resp.

• Simple low-frequency rogue-path gradients can be removed from "random" deep fields, without much extra loss in sensitivity. Clusters: TBD.

Funded Schedule Reserve



Keys to stay on schedule: 1) Sufficient Project contingency ($\gtrsim$25% of total).
2) Well replanned and managed Project (starting late summer 2011).

Fiscal Year 2016 JWST HQ Milestones

Month	#	Milestone	FY2015 Deferral	Comment
Oct-15	1	Start Integrated Science Instrument Module (ISIM) cryovacuum test #3	•	Completed 10/27/15
Nov-15	2	Deliver update for launch and activation sequence of events for JWST commissioning		Completed 10/29/15
	3	Deliver the Observatory Operations Handbook Vol 1&2 updates		Completed 10/30/15
	4	Deliver new build of the proposal planning software for Telescope plus ISIM (OTIS) testing		Completed 10/30/15
Dec-15	5	Complete second test of Pathfinder Telescope equipment at the JSC Chamber A		Completed 10/31/15
	6	Complete Solar Array panel #2 cell installation		Completed 12/24/15
	7	Complete Sunshield Mid-Boom Assembly #1 functional test		Delayed to April for reassembly of mid-boom #1
	8	Complete Delivery of Reaction Wheel Assemblies to Observatory Integration and Test (I&T)	•	Two of 3 wheels delivered in December, 1 in May, being rebuilt, no schedule impact
	9	Deliver Data Management Subsystem build for basic data search and distribution functionality		Completed 11/30/15
Jan-16	10	Deliver flight Aft Optics System to Telescope I&T		Completed 12/14/15
	11	Complete final checkout of new GSFC vibration shaker table		Delayed till March, vertical shaker issues
	12	Sunshield Flight Layer #4 shipped to Northrop-Grumman		Completed 12/3/15
	13	Sunshield Forward Cover Assembly shipped to Northrop-Grumman	•	Delayed till June. Nexolve revised schedule to implement NGAS design changes. No anticipated schedule impact
	14	Complete Flight Operations Subsystem System Design Review #2		Completed 12/17/15
	15	Complete Mission Operations Center construction at STScI		Completed 12/29/15
Feb-16	16	Deliver Aft Deployable Instrument Radiator to Observatory I&T		
	17	Deliver Command & Telemetry computer to Observatory I&T		Delayed till March to re-run testing
	18	Deliver Secondary Mirror Support Structure verification report to GSFC		Completed 1/28/16
	19	Complete deliveries of Spacecraft wire harnesses		Completed 1/22/16
	20	Deliver spare Cryocooler Compressor Assembly to JPL	•	
Mar-16	21	Start Spacecraft Panel Integration		Completed 10/26/15
	22	Complete Sunshield Mid-Boom Assembly #2 functional test		Forecasting June completion date due to latch and detent pin redesign and tubessegment rebuild
	23	Complete cryocooler thermal performance acceptance testing		

Milestones: How the Project reports its progress monthly to Congress.

Milestone Performance

- Since the September 2011 replan JWST reports high-level milestones monthly to numerous stakeholders

	Total Milestones	Total Milestones Completed	Number Completed Early	Number Completed Late	Deferred to Next Year	Deferred more than one quarter
FY2011	21	21	6	3	0	0
FY2012	37	34	16	2	3	3
FY2013	41	38	20	5	3	2
FY2014❖	36	23	10	8	11	10
FY2015	48	44	22	12	4	3
FY2016	46	15	13	7*	0	0

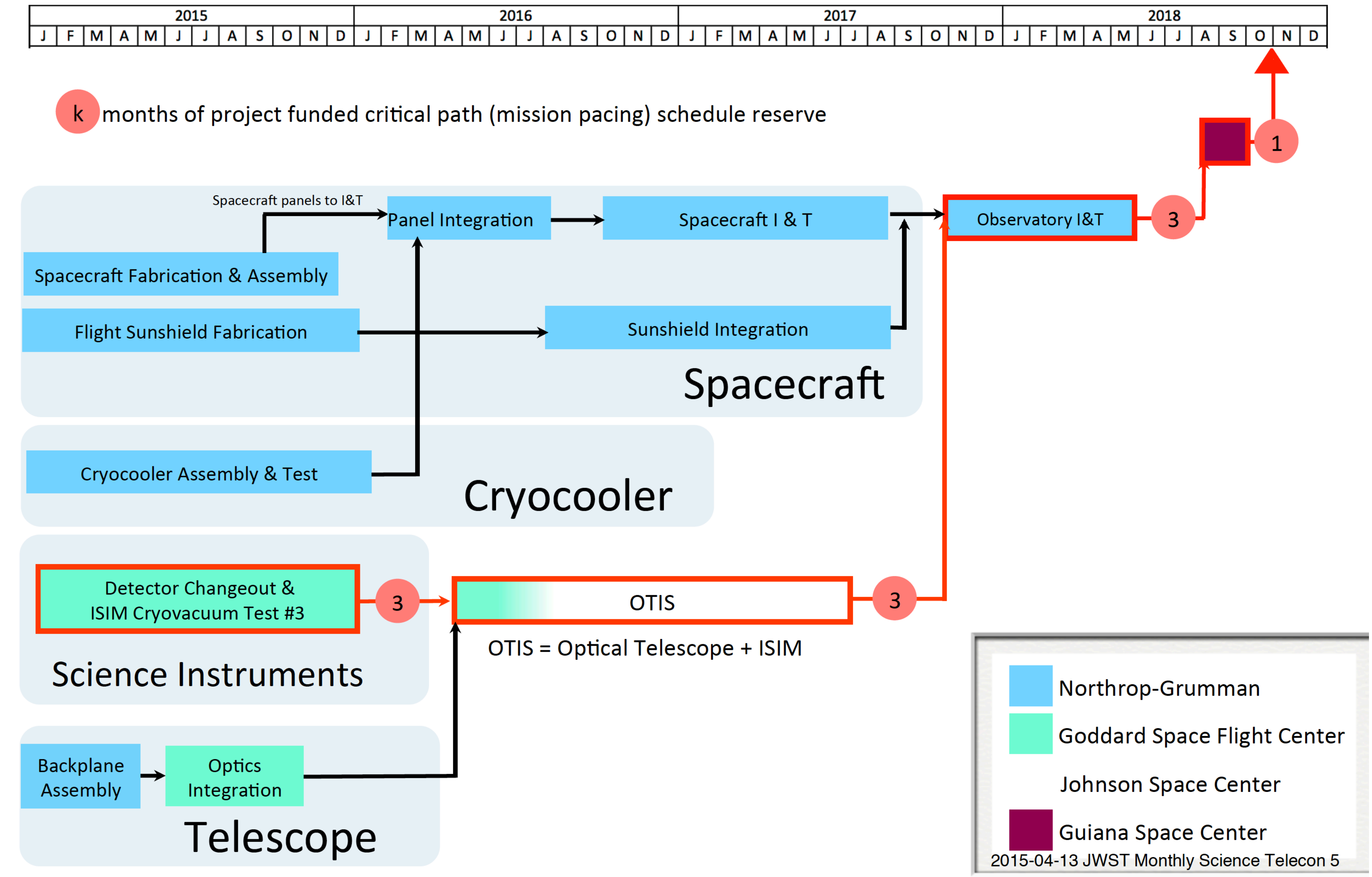
*Late milestones have been or are forecast to complete within the year. Deferred milestones are not included in the number-completed-late tally.

❖ Milestone accounting in FY2014 was complicated by the government shutdown and multicomponent milestones

FY14: 8 milestones late by 1 month due to Oct 13 Government shutdown.

FY15: Most the "Lates" not on critical path, causing no launch delay.

Simplified Schedule



Path forward to Launch (in Oct. 2018): 10 months schedule reserve.

Instruments+detectors & Optical Telescope Element remain on critical path.