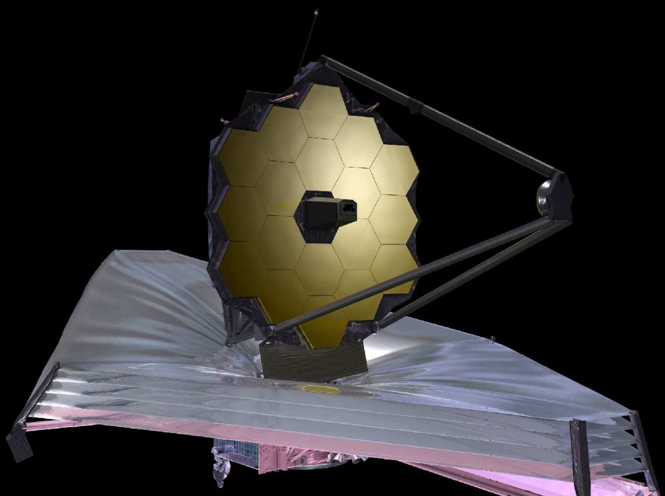
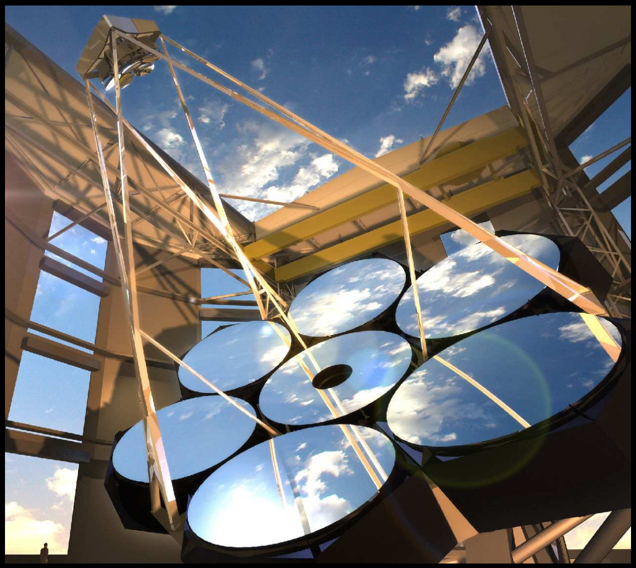
The James Webb Space Telescope and First Light: Project Update, What to Expect & How to Prepare.

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

Collaborators: S. Cohen, L. Jiang, R. Jansen (ASU), S. Driver, A. Hopkins & S. Wyithe (OZ)

(+Ex-students): N. Hathi, H. Kim, M. Mechtley, R. Ryan, M. Rutkowski, A. Straughn, & H. Yan





Talk at the ASU Origins Workshop: "Is Our Universe Necessary?", ASU, Tempe, AZ, Sat Feb 1, 2014

Outline

- (1) Brief Update on the James Webb Space Telescope (JWST) Project
- (2) JWST and First Light: What Will it See & How to Prepare?
- (3) Charts to Answer what You Always Wanted to Ask but didn't.

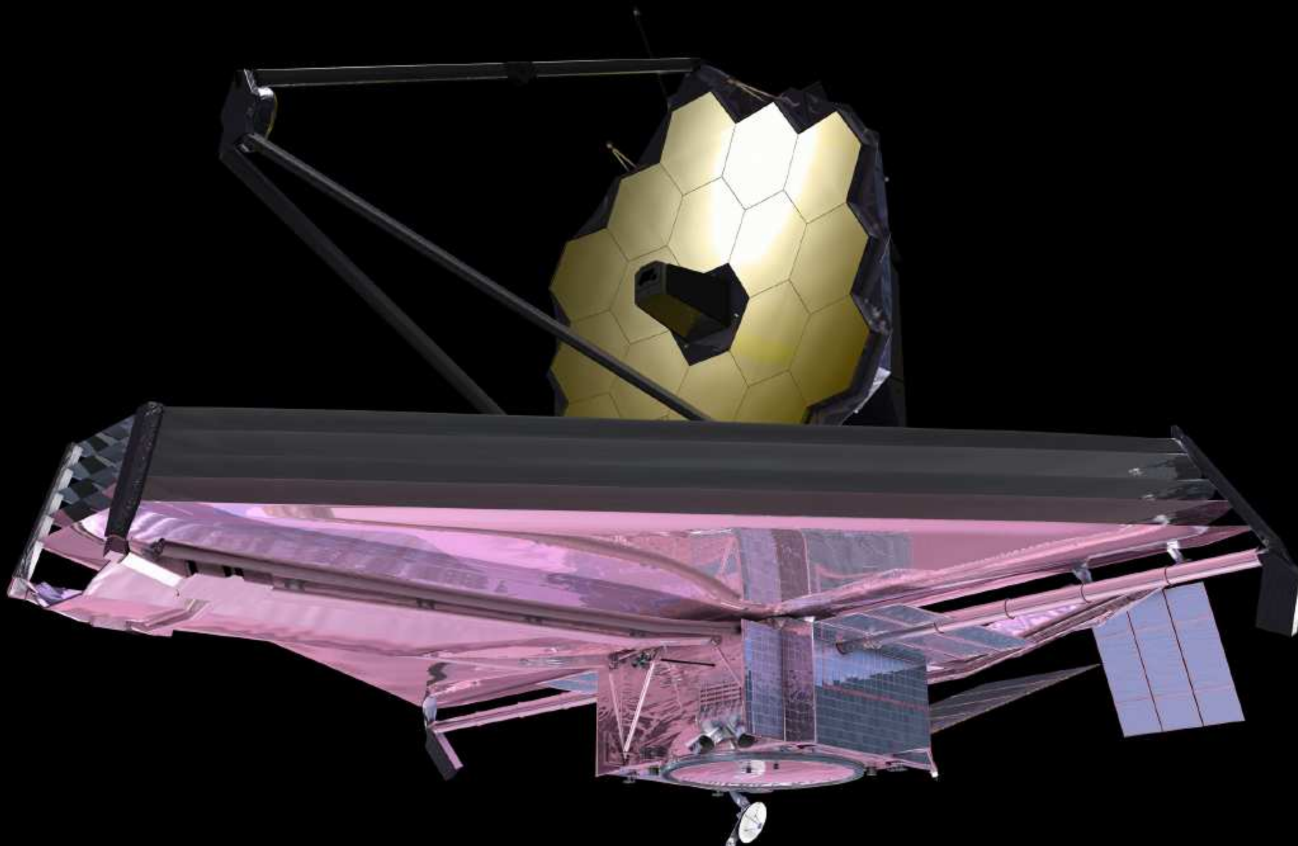
Workshop Question: Is Our Universe (incl. First Light!) necessary?

My Answer: To answer Q, need JWST + scientists, engineers, machinists, managers, politicians, lobbyists & lawyers $\Longrightarrow$ Need Universe!

Sponsored by NASA/HST & JWST

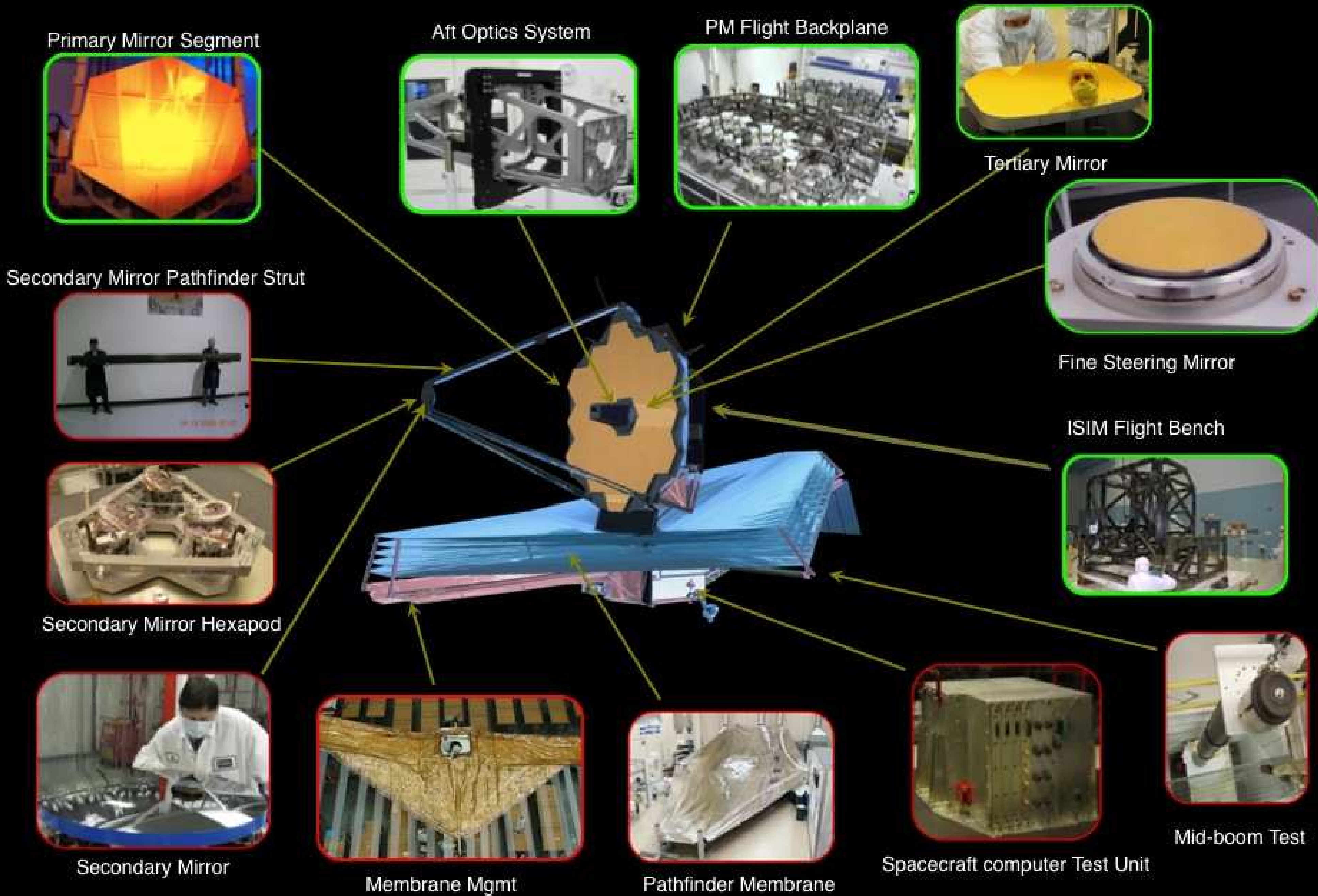
Arizona State University

(1) Brief Update on the JWST Project



- 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 Oct. 2018.
- Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging (AB=31.5 mag = 1 nJy) and spectroscopy.

JWST Hardware Status



80% of launch mass designed and built as of Jan. 2014.

JWST instrument update: US (UofA, JPL), ESA, & CSA.

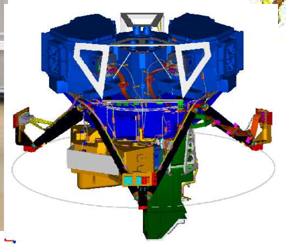
Instrument Overview

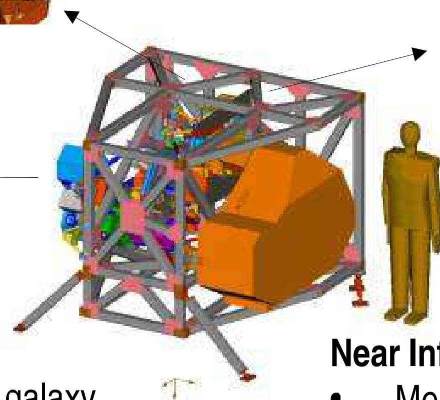
Fine Guidance Sensor (FGS)

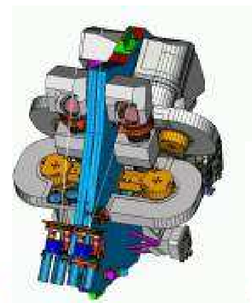
- Ensures guide star availability with >95% probability at any point in the sky
- Includes Narrowband Imaging Tunable Filter
- Developed by Canadian Space Agency & COM DEV

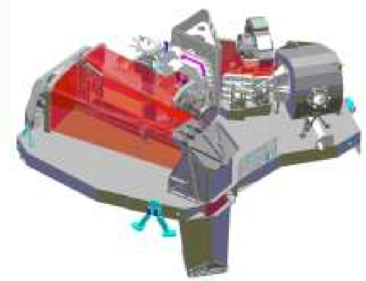
Near Infra-Red Camera (NIRCam)

- 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

All delivered: MIRI 05/12; FGS 07/12; NIRCam 07/13, NIRSpec 9/13!

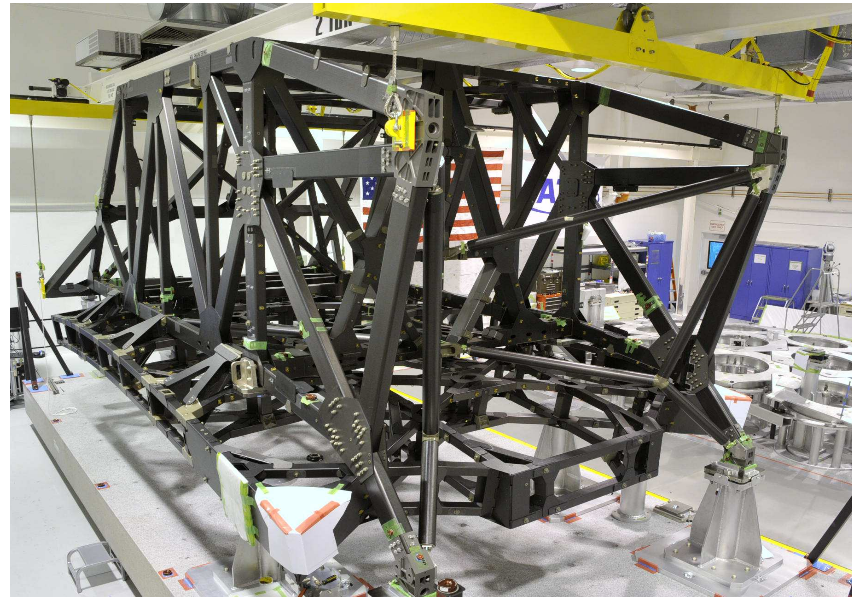
Mirror Status

- **15 flight primary mirrors and the flight secondary mirror are at GSFC in storage**
  - All spares were at GSFC in storage (SM spares, 3 PMSA spares)
    - 2 EDU mirrors sent back to Ball for gear motor rework
  - All flight gear motor refurbishment is complete
  - All flight mirrors will be at GSFC by end of year, needed in 2015

Jan 2014: All 18 flight mirrors now delivered to NASA GSFC (MD).

Backplane Support Frame, Center Section, & Wings

- Center Section is complete
- Wings and cryo cycling is complete
- BSF assembly is complete
- Integration of the BSF to Center Section Complete
  - Cryo Cycling at MSFC XRCF complete



BSF and Center Section

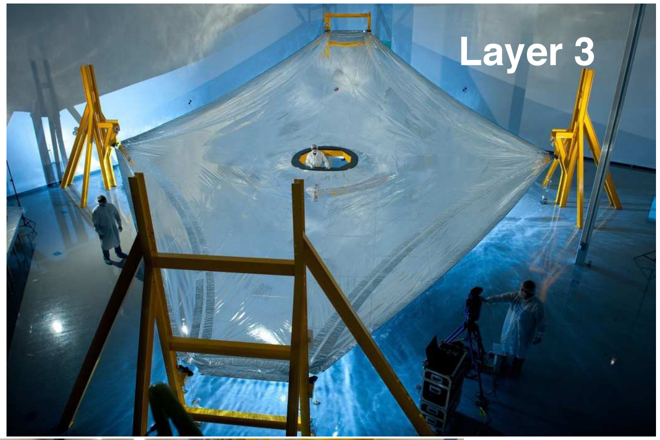
BSF/Center Section coming out of XRCF

Jan 2014: Flight back-plane ready to receive mirrors in 2014.

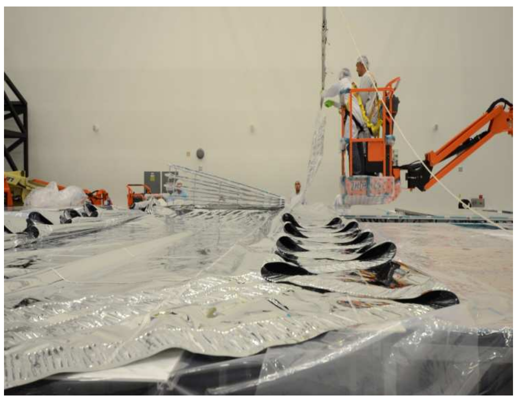
Sunshield Template Membrane Work Completed

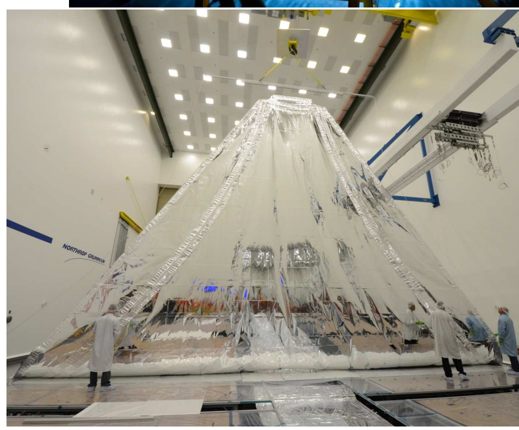
Templates Verify Design/Manufacturing Prior to Flight Build

- **All Template Layers Completed**
- **Preparing for flight article manufacturing**
- **First two Flight Manufacturing Readiness Reviews Completed**
- **Membrane pull out test complete**

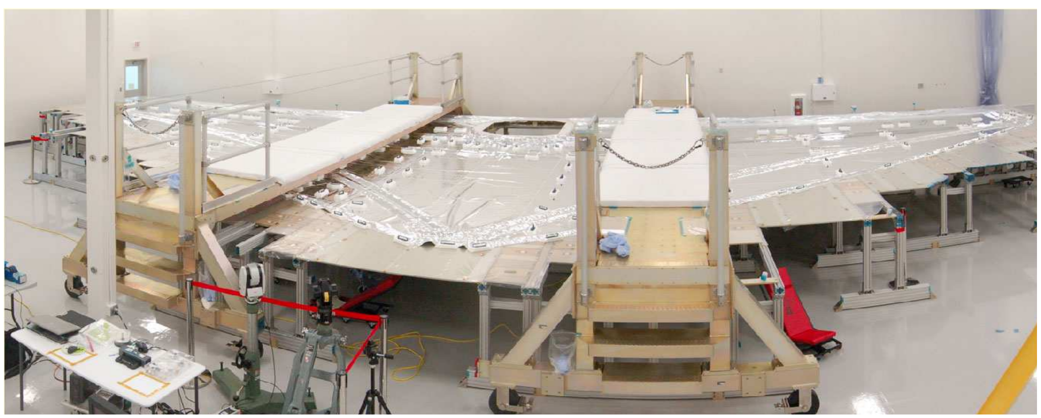


Stringing Operations



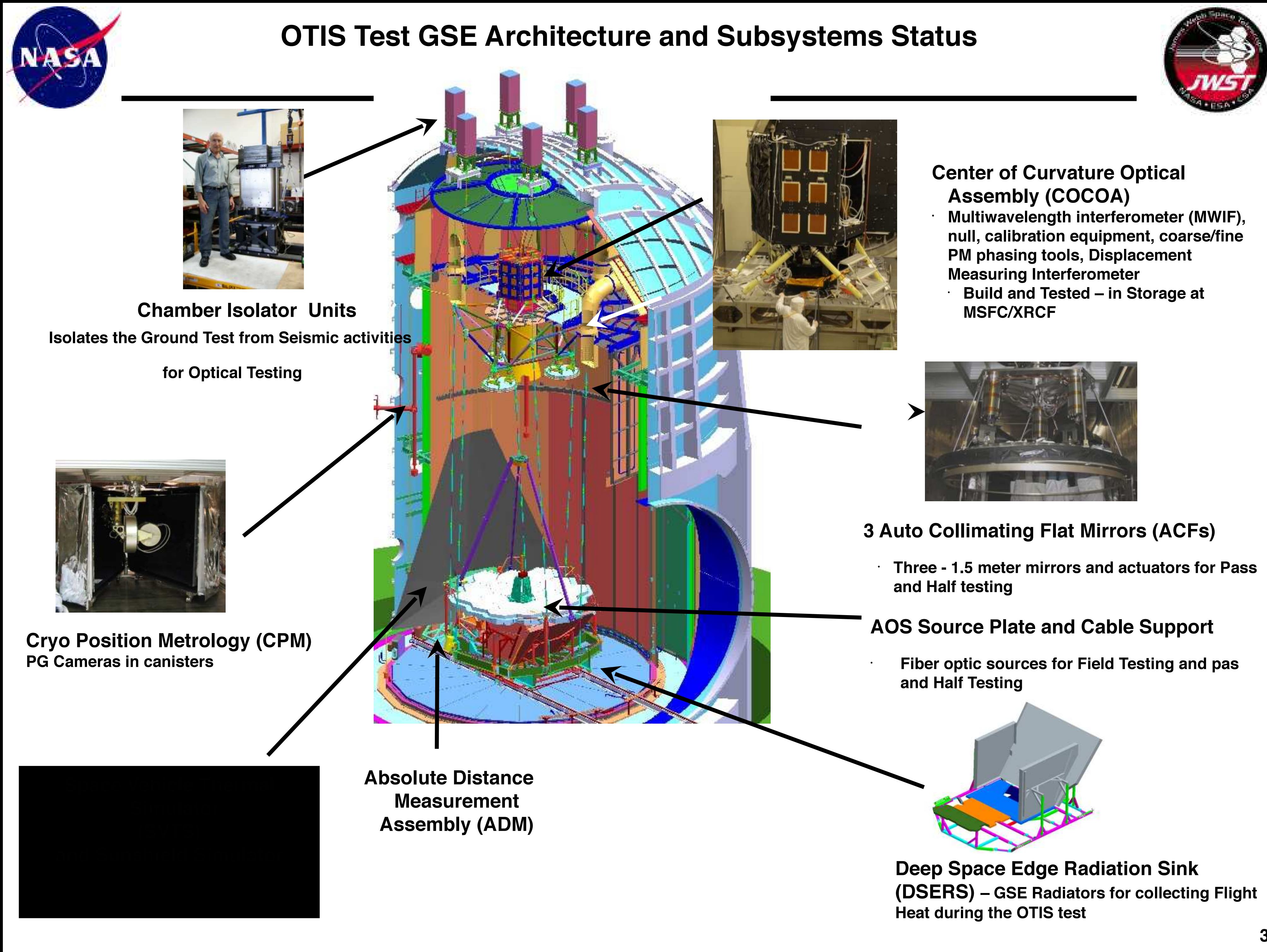


Template Layers 3-5



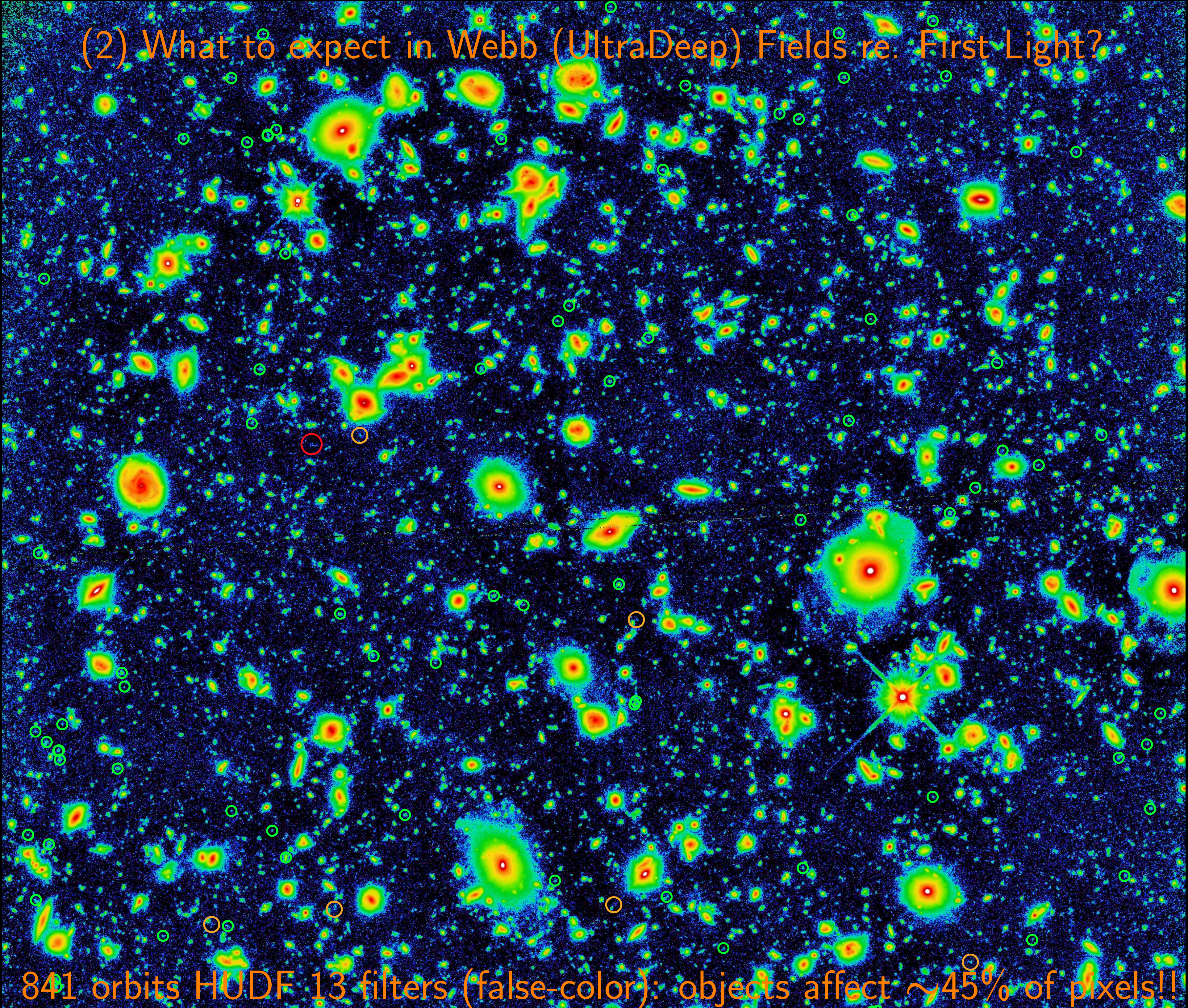
Hole Tool Operations

Flight sunshield to be completed & tested by 2015 at Northrop (CA).

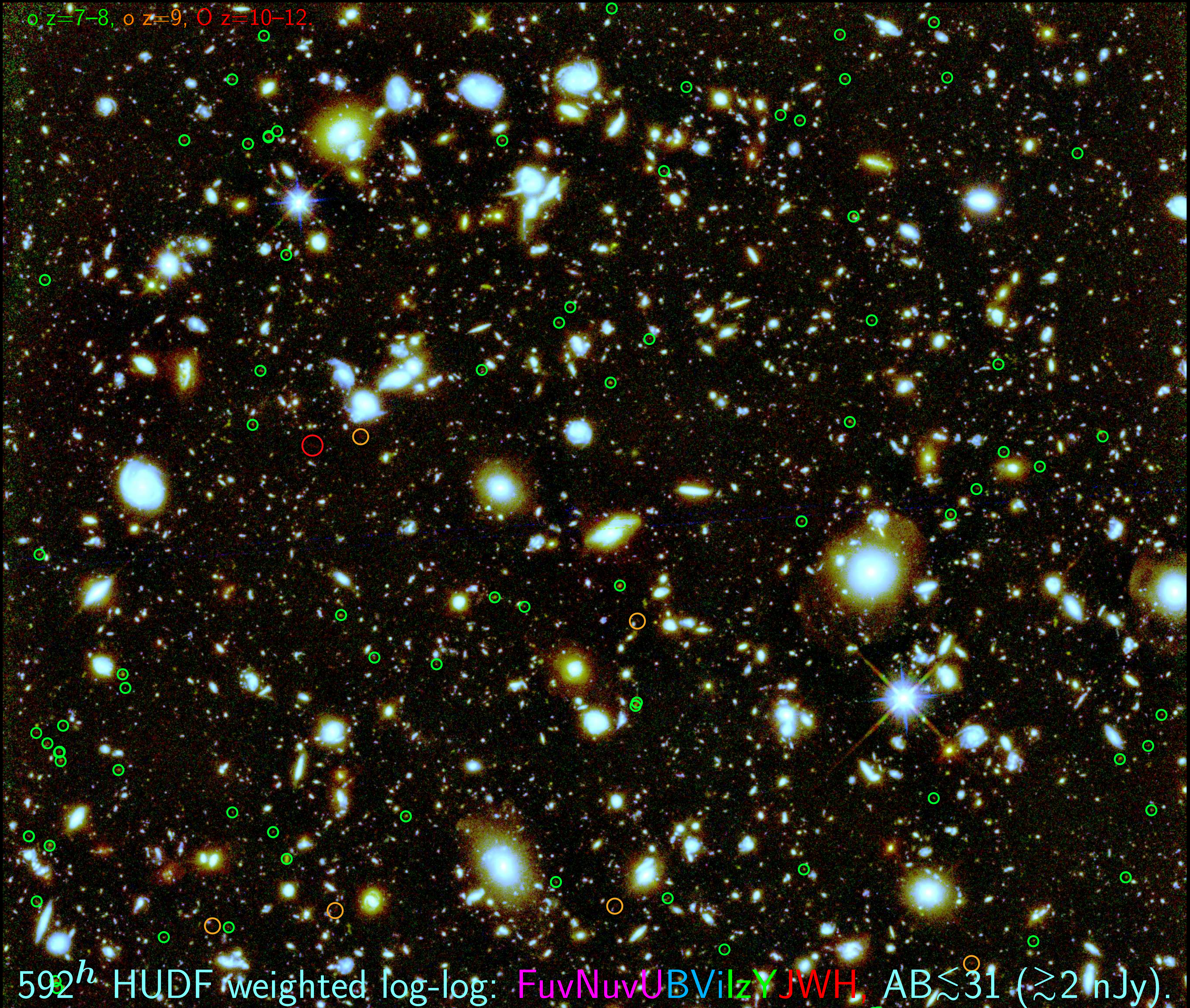


Testing of complete telescope at NASA JSC (Houston) in 2016–2017.

(2) What to expect in Webb (UltraDeep) Fields re. First Light?

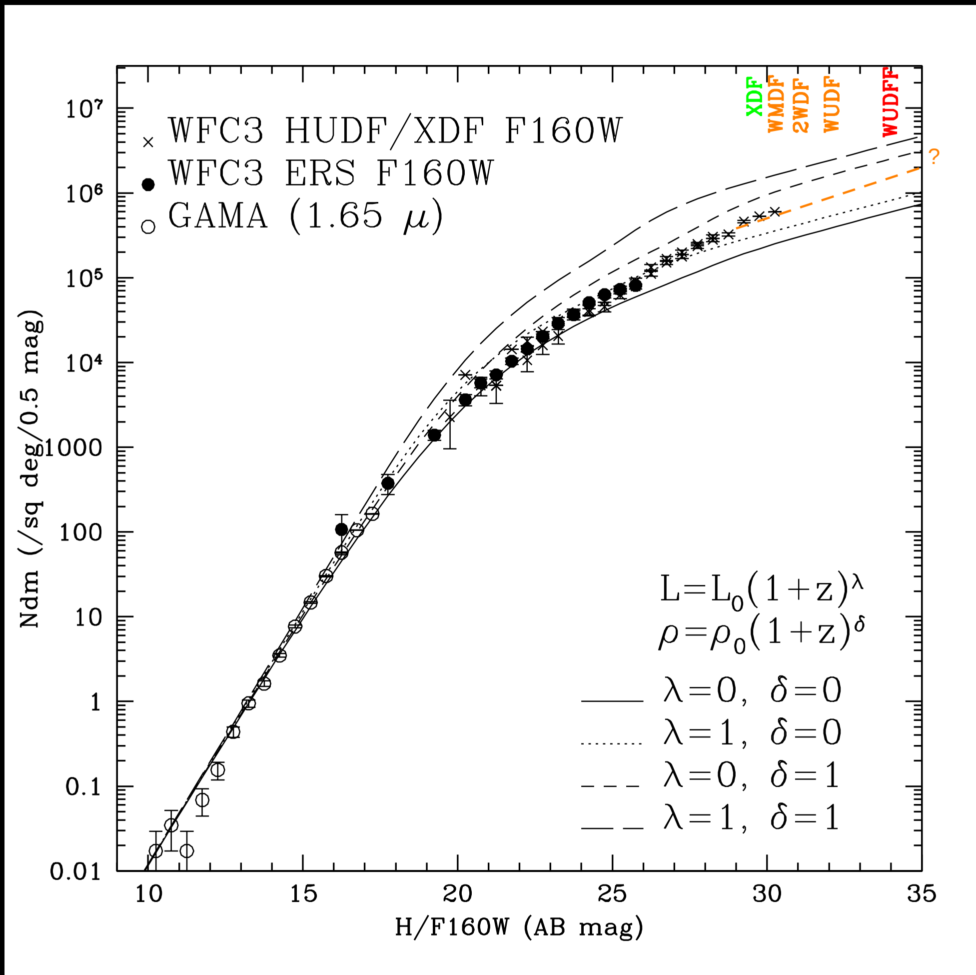


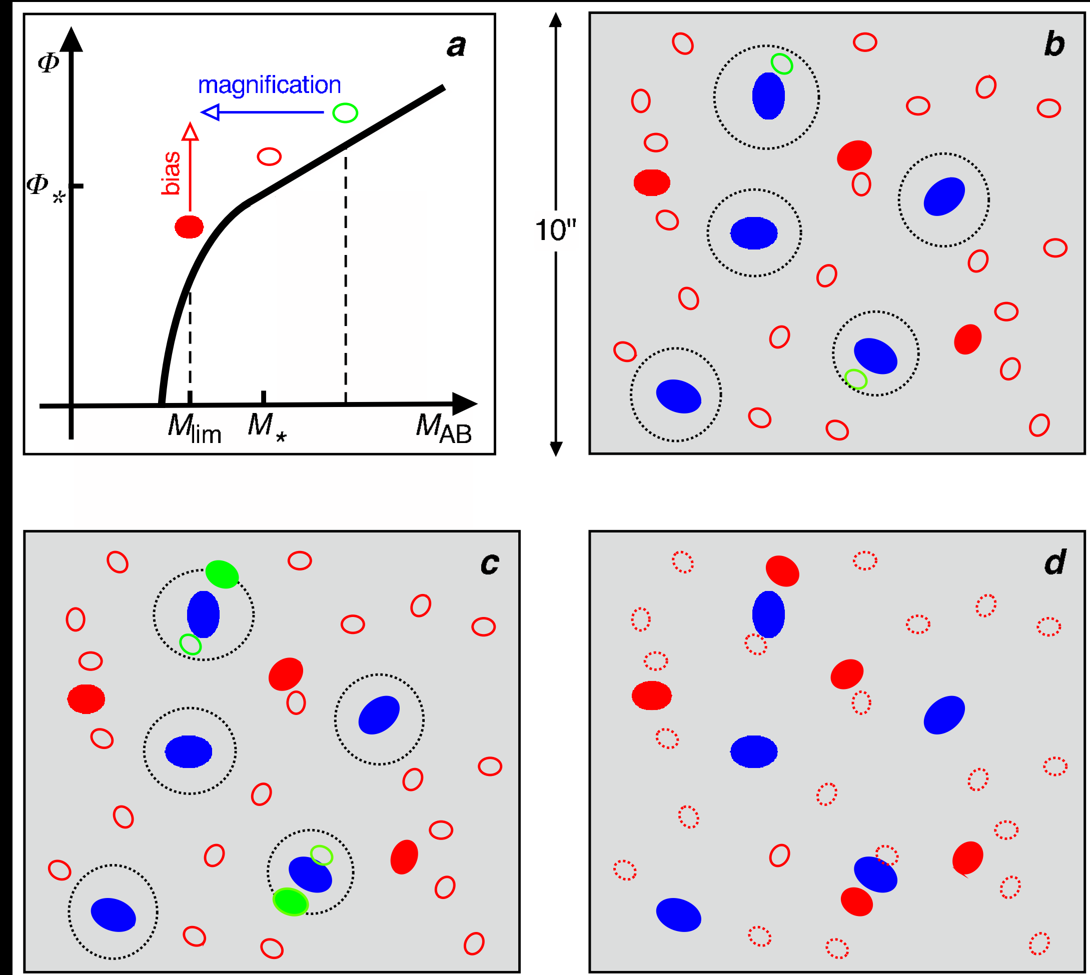
841 orbits HUDF 13 filters (false-color): objects affect ~45% of pixels!!



592^h HUDF weighted log-log: FuvNuvUBViIzYJWH, AB$\lesssim$31 ($\gtrsim$2 nJy).

HUDF WFC3 IR Galaxy Counts: What to expect in Webb (UltraDeep) Fields?



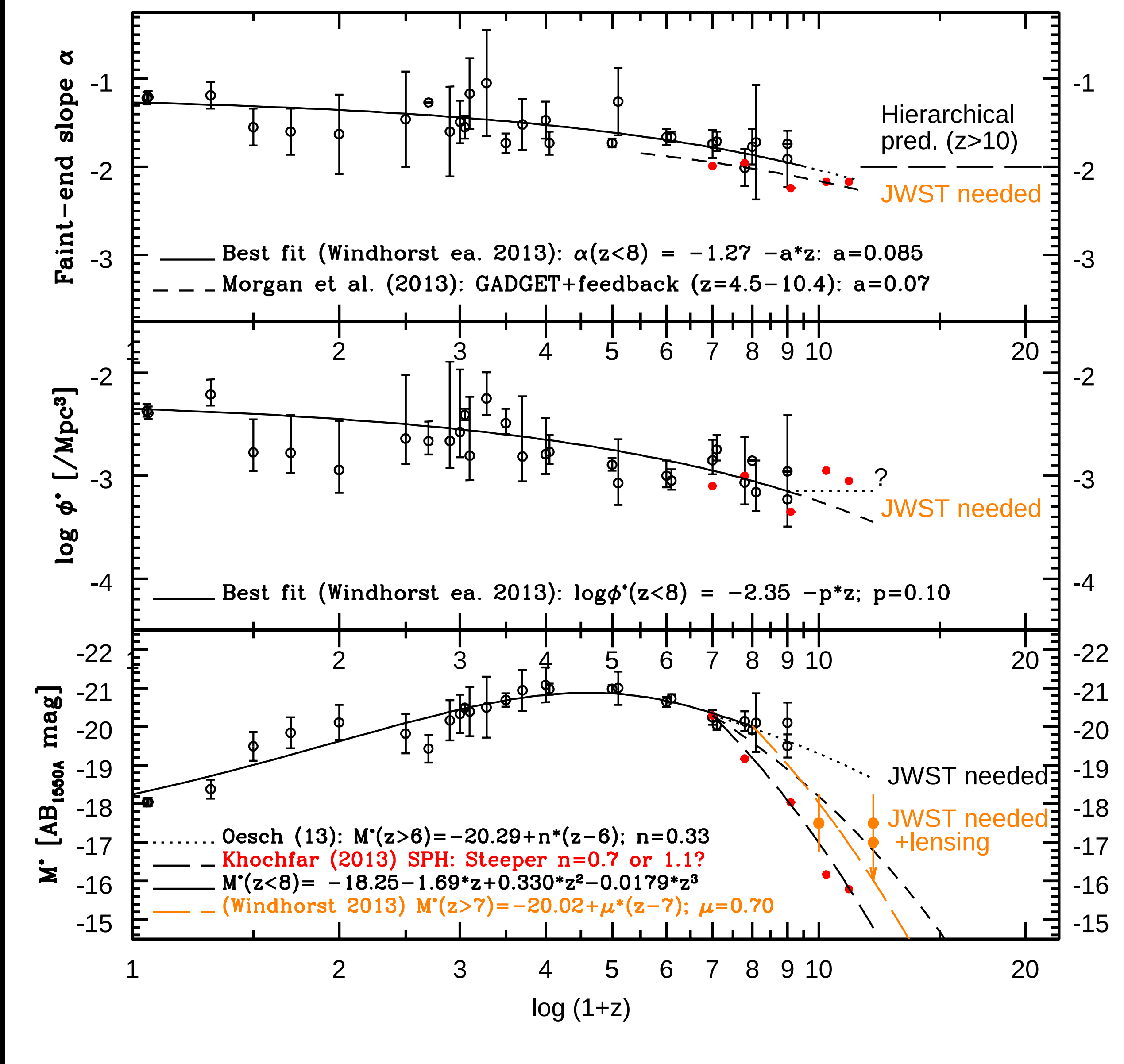


1.6μm counts (Windhorst+2011). [F150W, F225W, F275W, F336W, F435W, F606W, F775W, F850LP, F105W, F125W, F140W not shown].

- Faint-end near-IR count-slope$\simeq$0.12$\pm$0.02 dex/mag $\Longleftrightarrow$

Faint-end LF-slope(z_{med} $\simeq$1.6) $\alpha\simeq$–1.4 $\Rightarrow$ reach $M_{AB}\simeq$–14 mag.

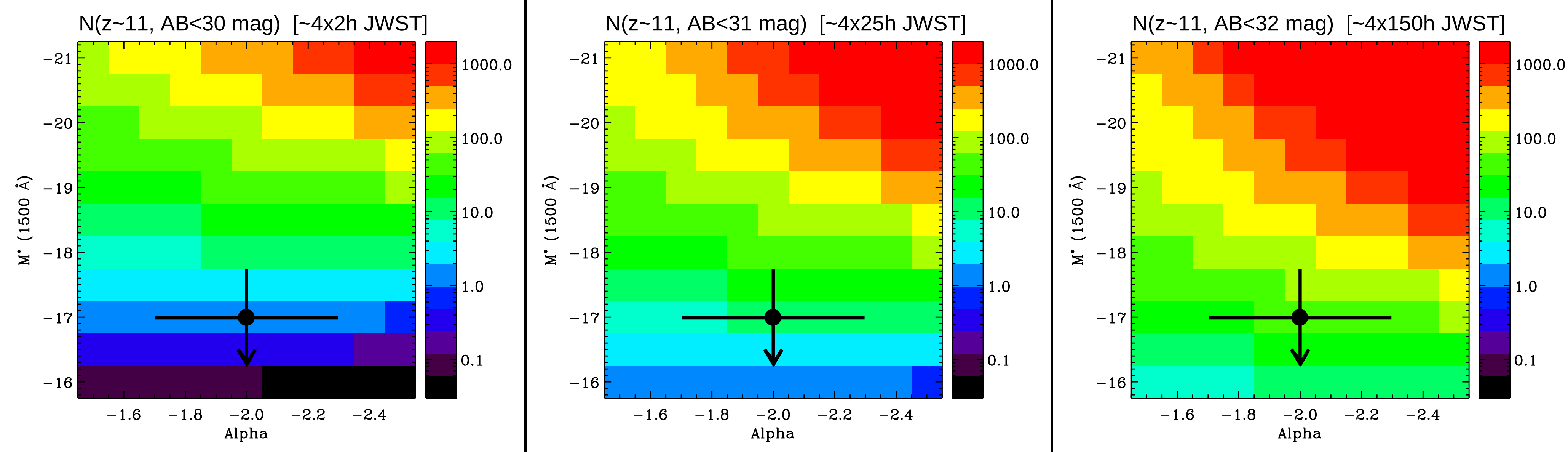
- WUDF (- - -) can see AB$\lesssim$32 objects: M_{AB} $\simeq$–15 (LMCs) at z$\simeq$11.
- Lensing will change the landscape for JWST observing strategies.



Evolution of Schechter 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}) (Oesch$^+$ 11).
- HUDF: Characteristic M^* may drop below –18 or –17.5 mag at z$\gtrsim$10.

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



What do the 6 possible z≃9 and single z≳10 HUDF candidate mean?

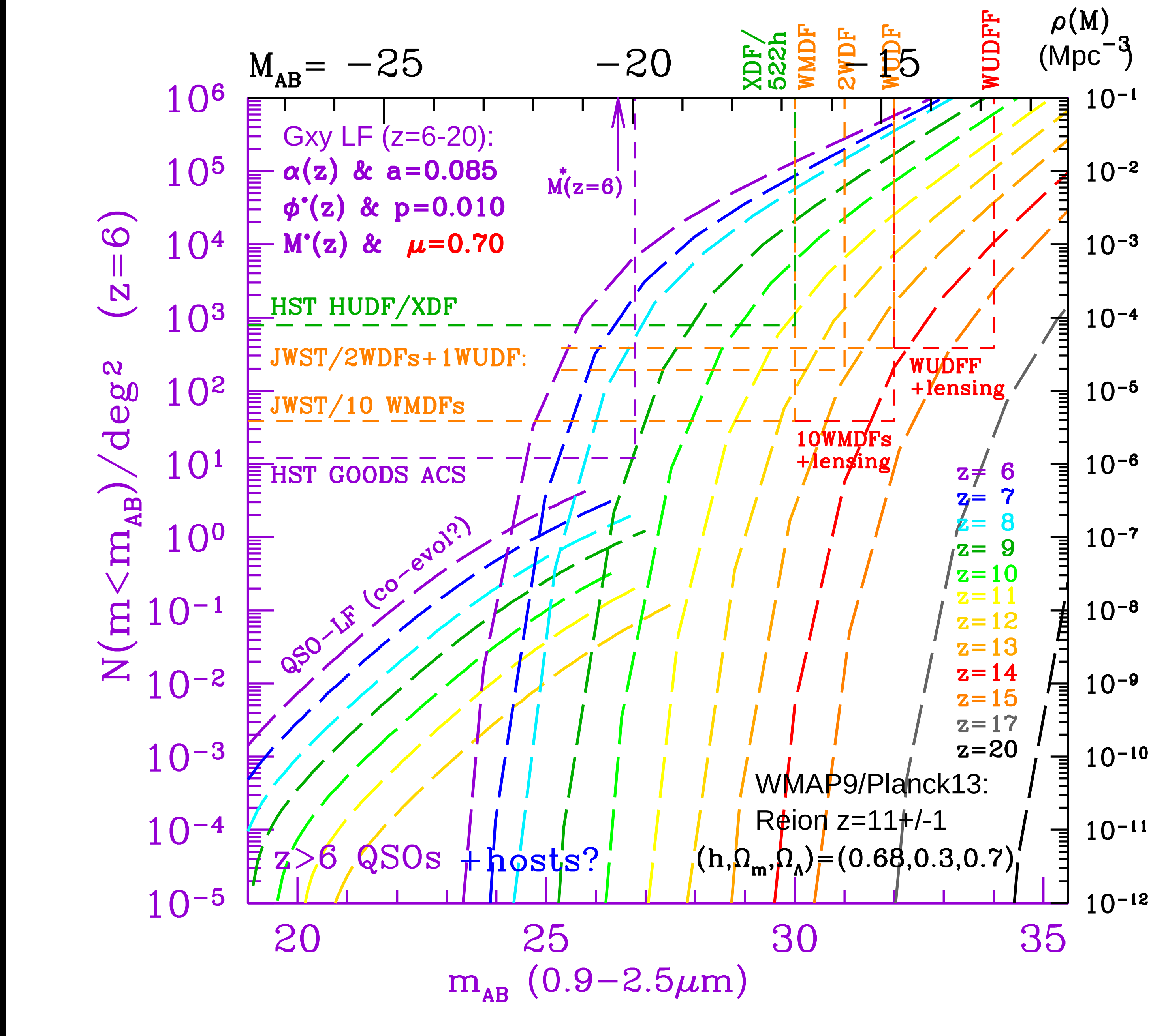
Integrate Schechter LFs with α(z), Φ^* (z) and M^* (z): ≲45% sky-coverage by AB≲30 objects (Koekemoer+13). Cosmic Variance ≳30%.

For any α(z≳9–10), implies M^* (z≳10)≳–17.5 mag (fainter!), so plan:

- (1) [Left] Webb "Medium-Deep" Fields (**WMDF**) (10×4×2h RAW): Expect few z≃10–12 objects to AB≲30 mag, so plan lensing targets.

- (2) [Middle] Webb Deep Field (**WDF**) (4×25h 7-filt NIRCam GTO): Expect 8–25 objects at z≃10–12 to AB≲31 mag.

- (3) [Right] Webb UltraDeep Field (**WUDF**) (4×150h; NIRCam DD?]: Expect 30–90 objects to AB≲32 mag, many more if lensing targets.

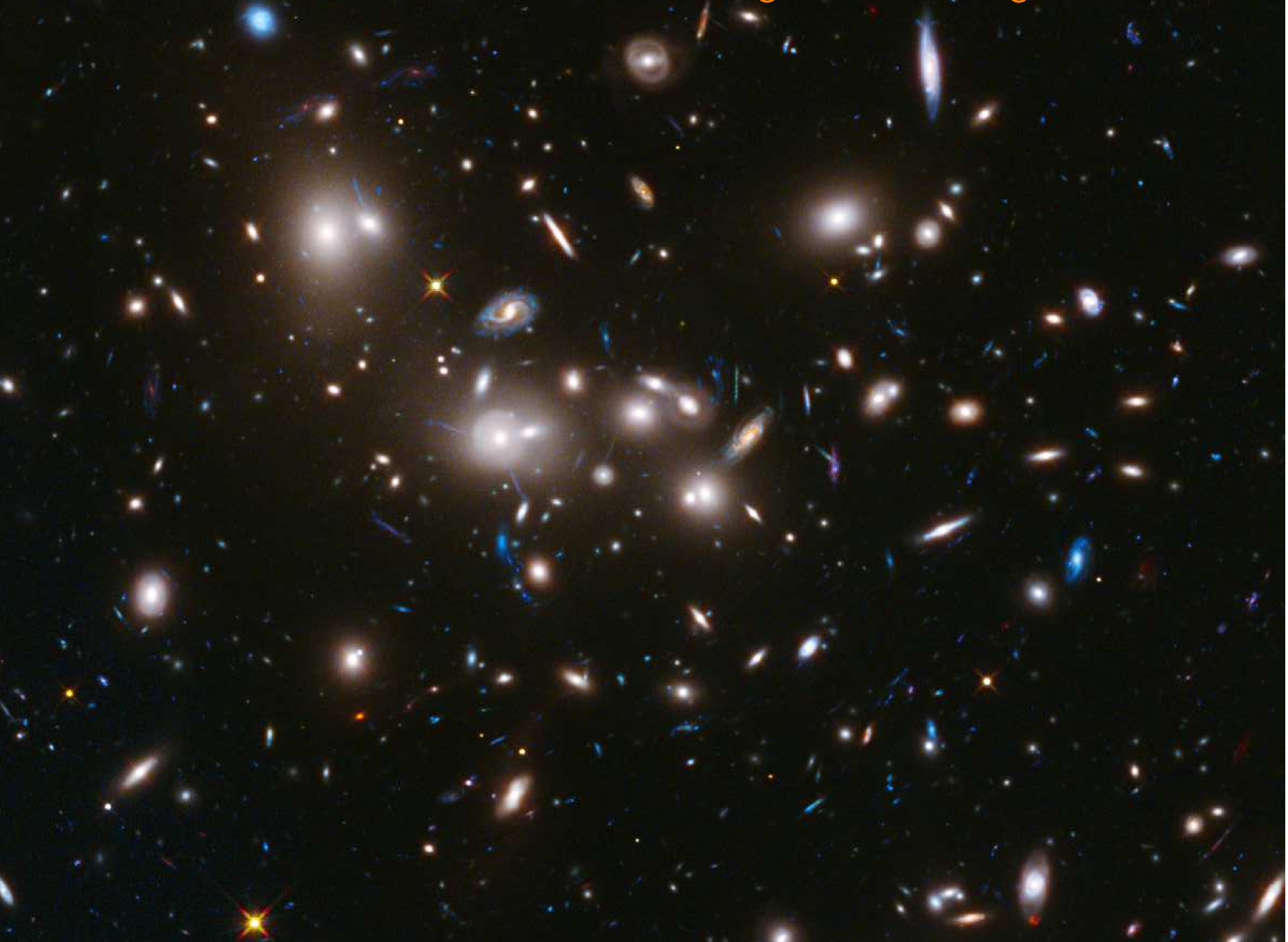


Schechter LF ($z \lesssim 6 \lesssim 20$) with $\alpha(z)$, Φ^* (z), M^* (z) above & μ=0.70.

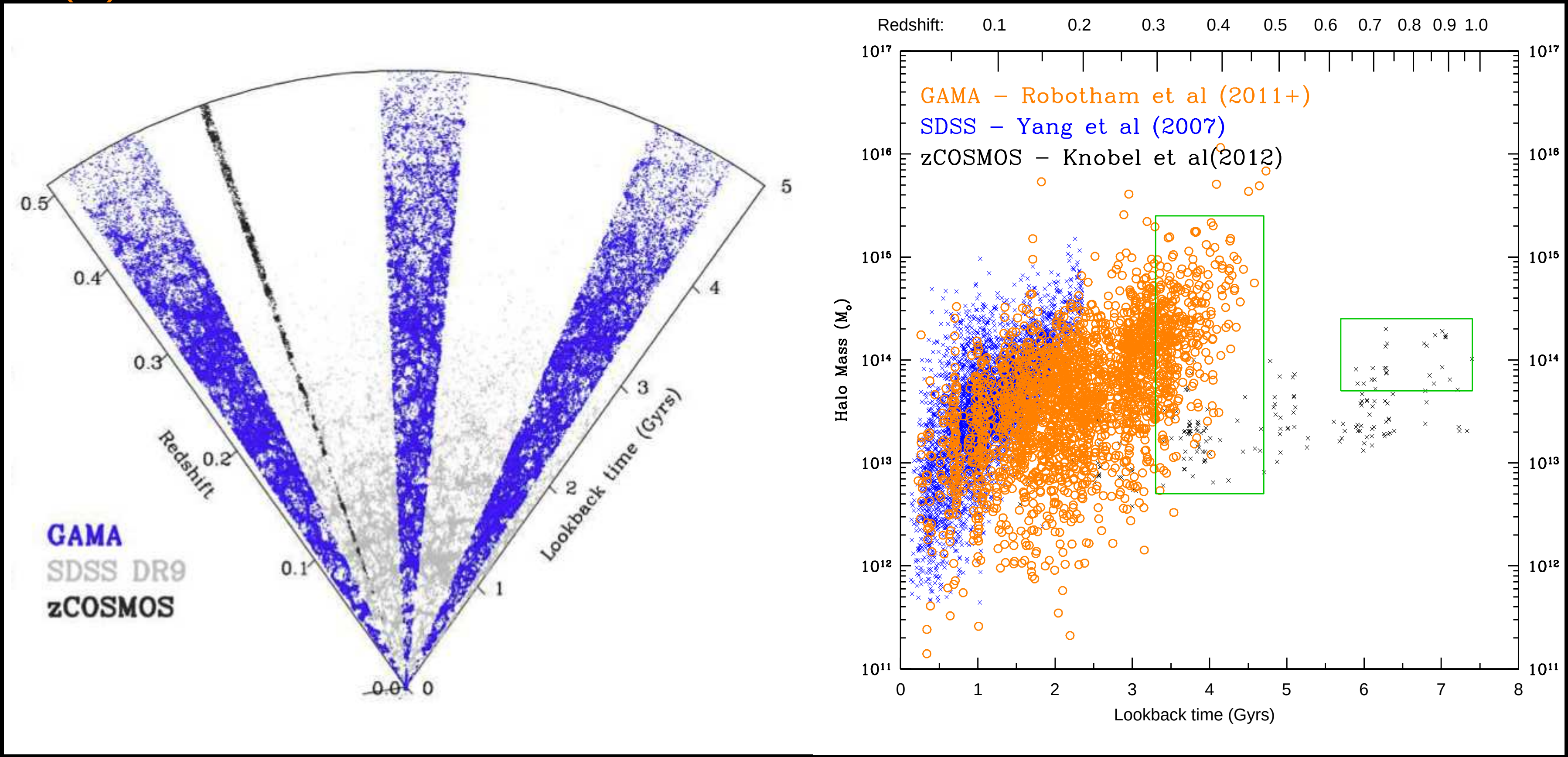
Area/Sensitivity for: HUDF/XDF, 10 WMDFs, 2 WDFs, & 1 WUDF.

- Will need lensing targets for WMDF–WUDFF to see z≃14–16 objects.

HST Frontier Field A2744: JWST needs lensing to see First Light at $z \gtrsim 10$–15!



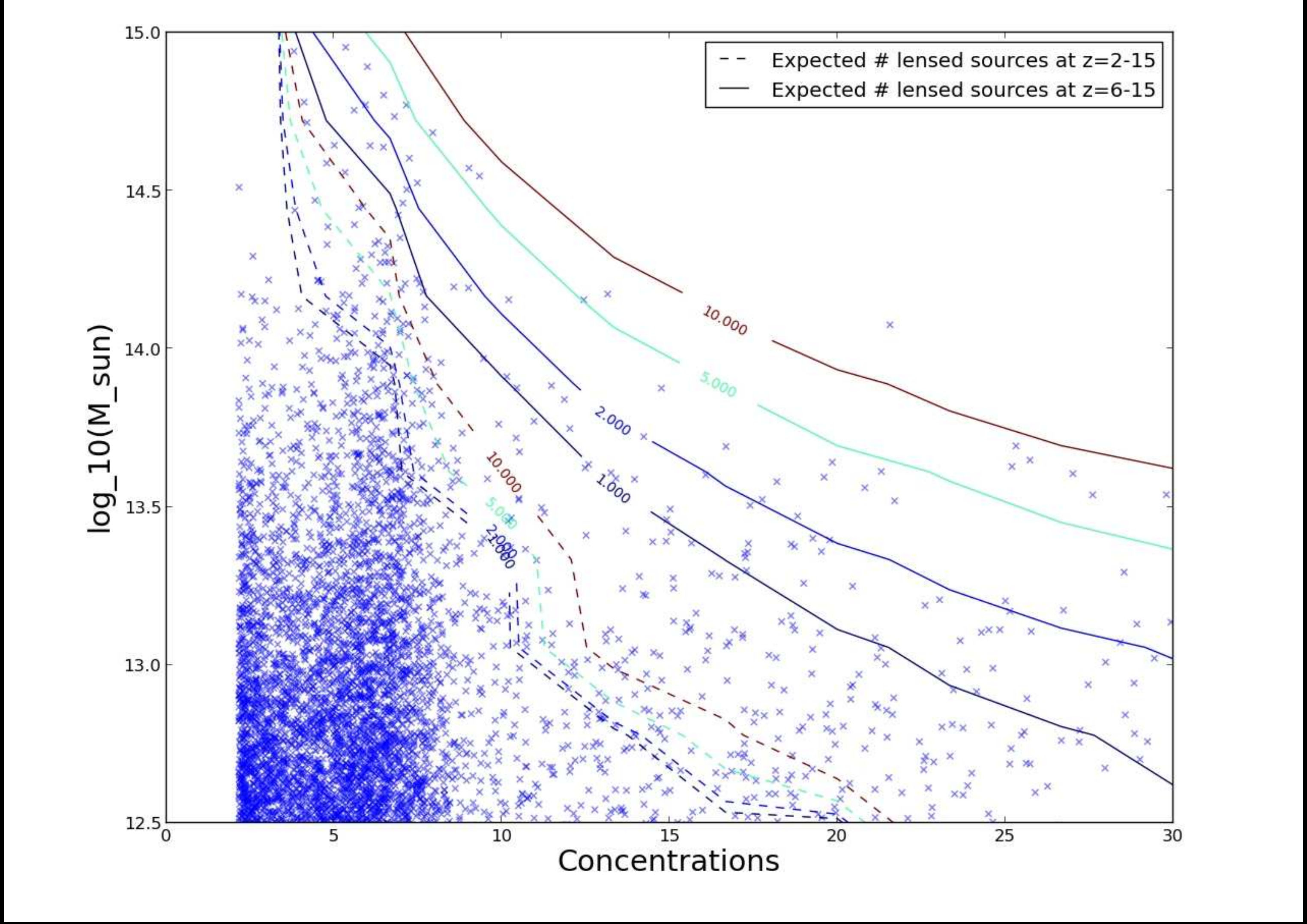
(2) Gravitational Lensing to see First Light population at z$\gtrsim$10.



What are the best lenses in 2018: Rich clusters or (compact) galaxy groups?

[Left] Redshift surveys: SDSS z$\lesssim$0.25 (Yang$^+$ 2007), GAMA z$\lesssim$0.45 (Robotham$^+$ 2011), and zCOSMOS z$\lesssim$1.0 (Knobel$^+$ 2012).

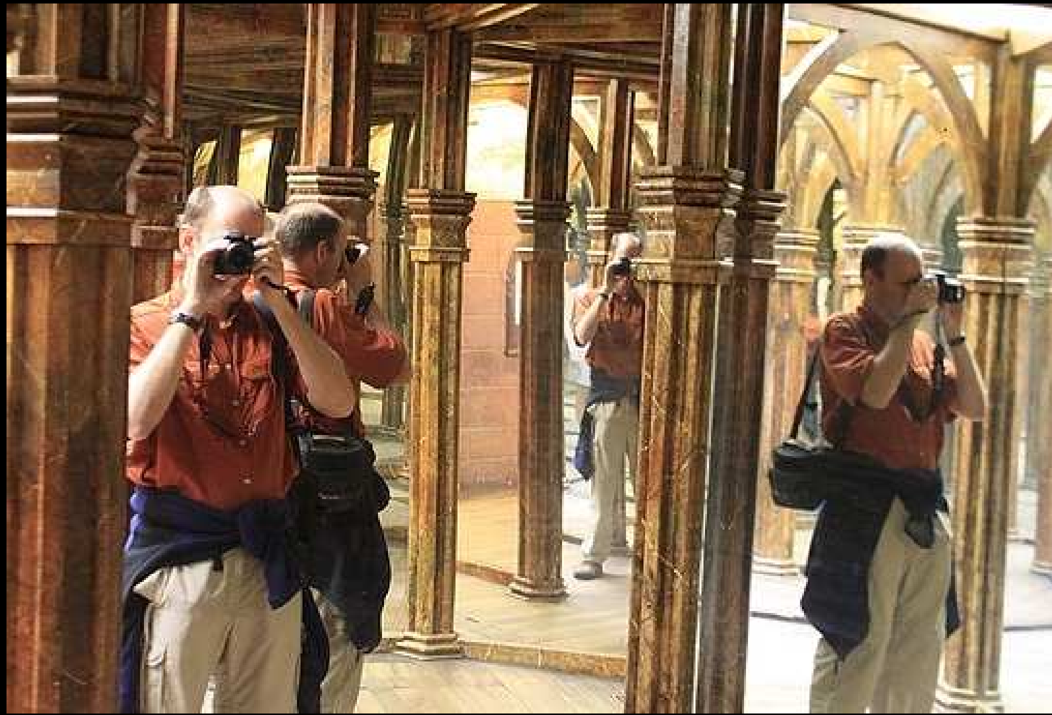
- GAMA: 22,000 groups z$\lesssim$0.45; 2400 with $N_{spec}\gtrsim5$ (Robotham$^+$ 11).
  - $\lesssim$10% of GAMA groups compact for lensing (Konstantopoulos$^+$ 13).
- Large group sample to identify optimal lens-candidates for z$\gtrsim$6 sources.



GAMA group mass versus concentration assuming NFW DM halo profiles.
Contours = Nr of expected lensed sources (Δz=1; Barone-Nugent$^+$ 13).

- 10 WMDFs on best GAMA groups add ∼50–100 z≃6–15 sources (AB≲30).
- Also get ≳10× more (≳500) lensed sources at ≃2–15.

WUDFF if pointed at clusters adds ∼6× more (≳3000) sources at 6≲z≲15.



Two fundamental limitations may determine ultimate JWST image depth:

(1) Cannot-see-the-forest-for-the-trees effect [Natural Confusion limit]:

Background objects blend into foreground because of their own diameter
$\Rightarrow$ Need multi-λ deblending algorithms.

(2) House-of-mirrors effect ["Gravitational Confusion"]: Most First Light objects at z$\gtrsim$12–14 may need to be found by cluster or group lensing.

$\Rightarrow$ Need multi-λ object finder that works on sloped backgrounds

$\Rightarrow$ If M*(z$\gtrsim$10)$\gtrsim$–18, need to use & model gravitational foreground.

Conclusions

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

- Project replan in 2010-2011. No technical showstoppers thus far.
- More than 80% of JWST H/W built or in fab, & meets/exceeds specs.

(2) 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.
- JWST will need to use lensing to see First Light objects at $z \gtrsim 12$.

(3) 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: Dark Ages at $z \gtrsim 15$–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/

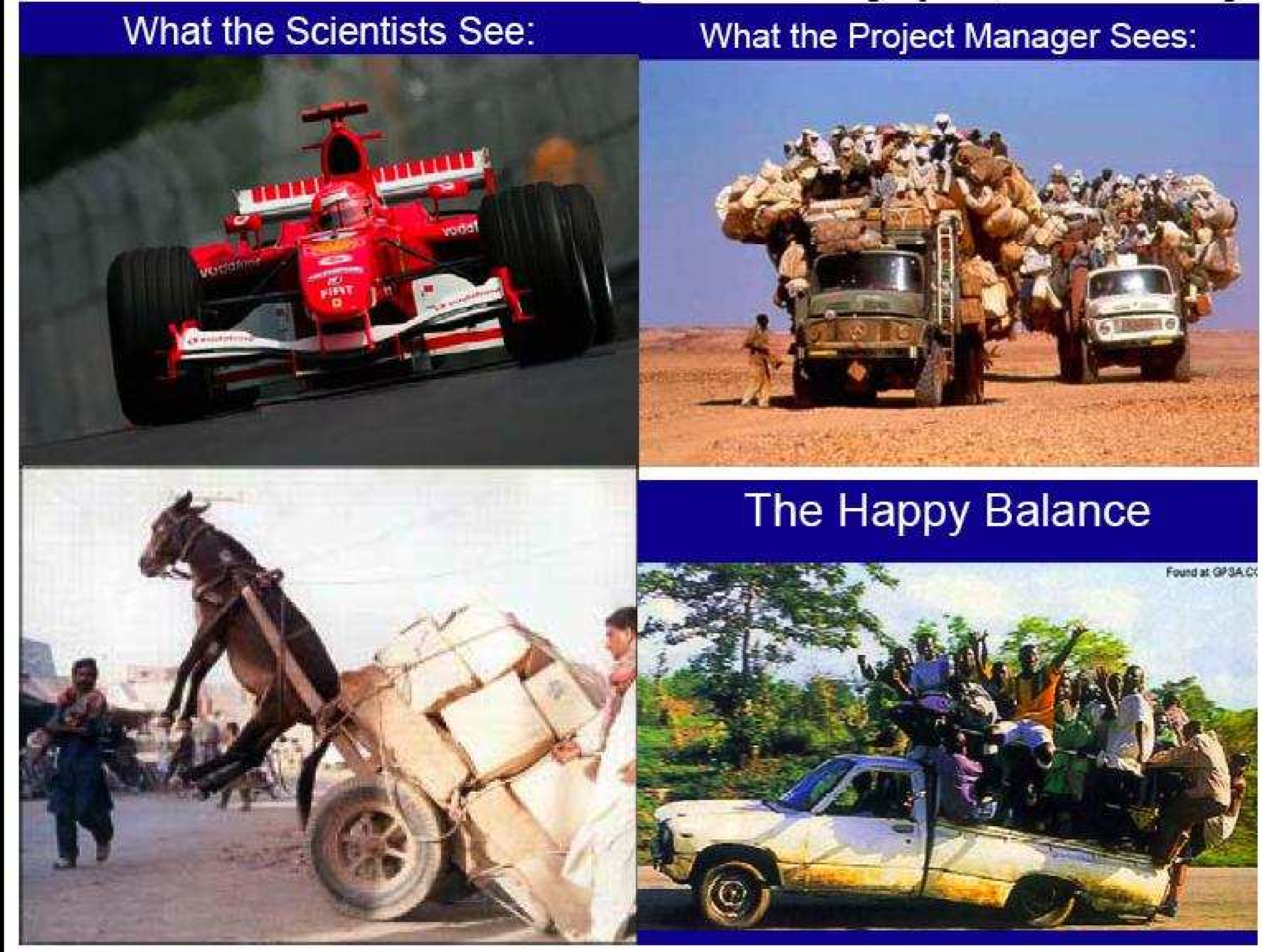
http://www.stsci.edu/jwst/instruments/fgs

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

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

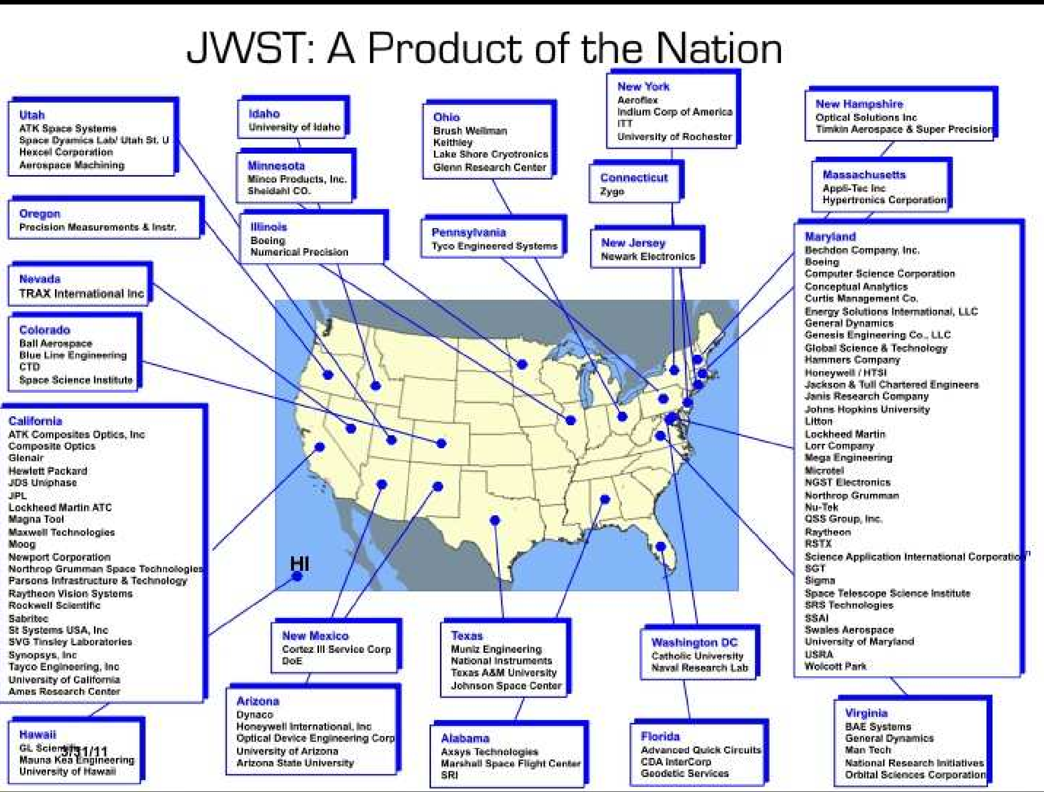
Windhorst, R., et al. 2008, Advances in Space Research, 41, 1965

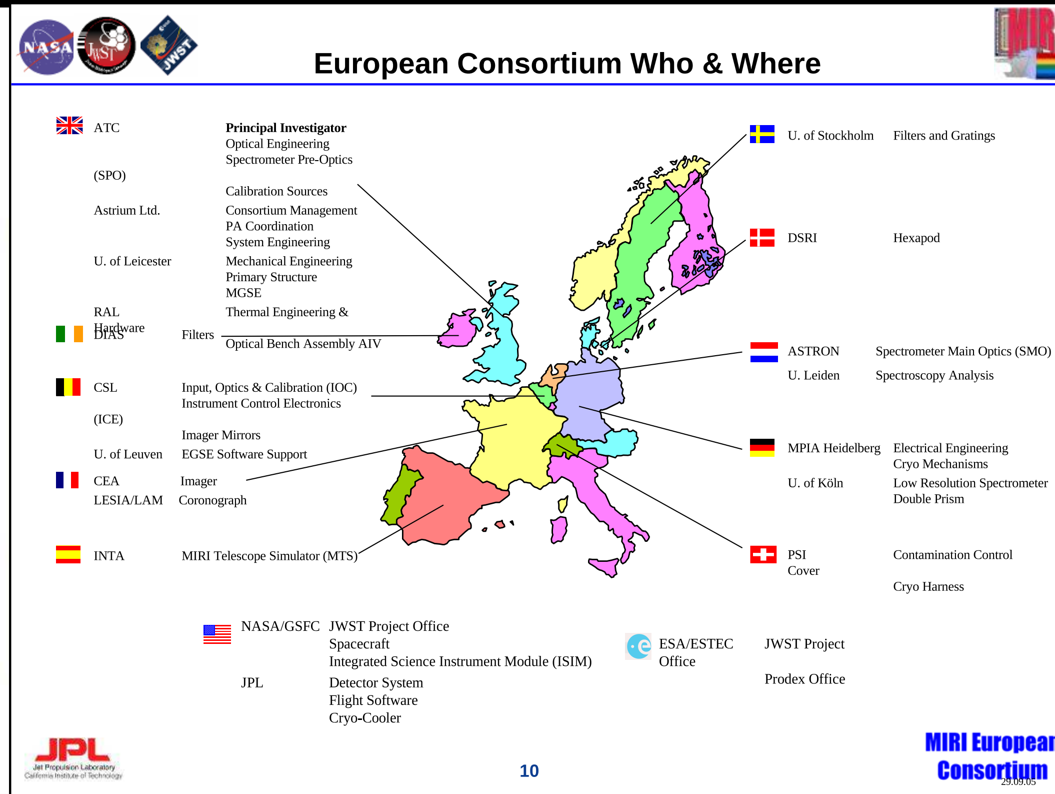
Windhorst, R., et al., 2011, ApJS, 193, 27 (astro-ph/1005.2776).



Any (space) mission is a balance between what science demands, what technology can do, and what budget & schedule allows ... (courtesy Prof. Richard Ellis).

Mega-Projects must learn how to build Coalition / fit into community ...





- JWST hardware made in 27 US States: $\gtrsim$80% 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.

Fiscal Year 2014 HQ Milestones

Assumes JWST is appropriated in FY2014 the full President's budget request of new obligation authority (NOA).

Month	Milestone		Comment
Oct-13	1	Primary Mirror Backplane Support Structure Cryogenic Testing Readiness Review	Completed 9/10
Nov-13	2	Mirror Deployment Electronics Unit Manufacturing Readiness Review	Completed 10/8
	3	Jet Propulsion Lab. (JPL) Cryogenic Test Chamber Readiness Review	Delayed: pulse tube, cooler shield issues
	4	Johnson Space Center (JSC) Telescope and ISIM support structure fabrication complete	Completed 11/4
Dec-13	5	Spacecraft Critical Design Review Complete	Delayed to 1/14 [shutdown]
	6	MIRI Cryocooler Flight Cold Head Assembly delivered to ISIM	Delayed 1/21/2014
	7	JSC Clean Room ready to receive ground support equipment	Delayed to 1/14 [shutdown]
	8	Complete ISIM cryogenic-vacuum risk reduction test	Concluded 11/13/2013, but not all tests completed because of shutdown
Jan-14	9	Delivery of last Primary Mirror Segment to GSFC	Completed 12/16
	10	Observatory Operations software scripts Build 3 Complete	
	11	New detector focal plane arrays for NIRCam ready for integration into instrument	Completed 11/20
Feb-14	12	Secondary Mirror Mount delivery	
	13	MIRI Cryocooler flight electronics delivered to JPL	
	14	Final Data Management Subsystem Design Review	Completed 11/22
	15	Flight NIRCam and NIRSpec ready for integration into ISIM	Delayed to 3/14 [shutdown]
Mar-14	16	Spacecraft Solar Array Manufacturing Readiness Review	
	17	JSC Chamber A Telescope ground support equipment test #1 design review	
Apr-14	18	Telescope actuators electronics drive unit delivery	
	19	Flight MIRI cryocooler assembly delivered to JPL	
	20	MIRI Cryocooler Flight Refrigerant Line Deployment Assembly delivered to integration and testing	
	21	Sunshield Membrane Cover Assembly Manufacturing Readiness Review	
	22	MIRI cryocooler Test Readiness Review	
May-14	23	Updated Observatory Commissionning Plan (rev C) delivery	
	24	Start acceptance testing of flight cryocooler assembly and associated electronics	
	25	Start cryo-vacuum test with fully integrated ISIM ("CV2")	Delayed to 6/14 [shutdown]
Jun-14	26	Flight spare MIRI cryocooler assembly delivered to JPL	
	27	JSC Chamber A bake-out and cryogenic proof testing complete	
	28	Hardware ready for MIRI cryo cooler test #3: checkout complete	
Jul-14	29	Spacecraft Mid-Course Correction Thruster Final Assembly complete	
	30	Proprosal Planning Subsystem build 9 complete	
Aug-14	31	Sunshield Mid-boom and Stem assembly Manufacturing Readiness Review	
	32	Spacecraft Flight Software Build 2.2 Test Readiness Review	
	33	NIRSpec and FGS/NIRISS new Focal Plane Arrays ready for integration	Delayed to 9/14 [shutdown]
Sep-14	34	JSC cryogenic test telescope and ISIM test ground support equipment integration complete	
	35	Complete cryo-vacuum test of fully integrated ISIM ("CV2")plete	Delayed to 10/14 [shutdown]
	36	NIRSpec new microshutters ready for integration	Delayed to 10/14 [shutdown]

Blue font denotes milestones accomplished ahead of schedule, orange font denotes milestones accomplished late.

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

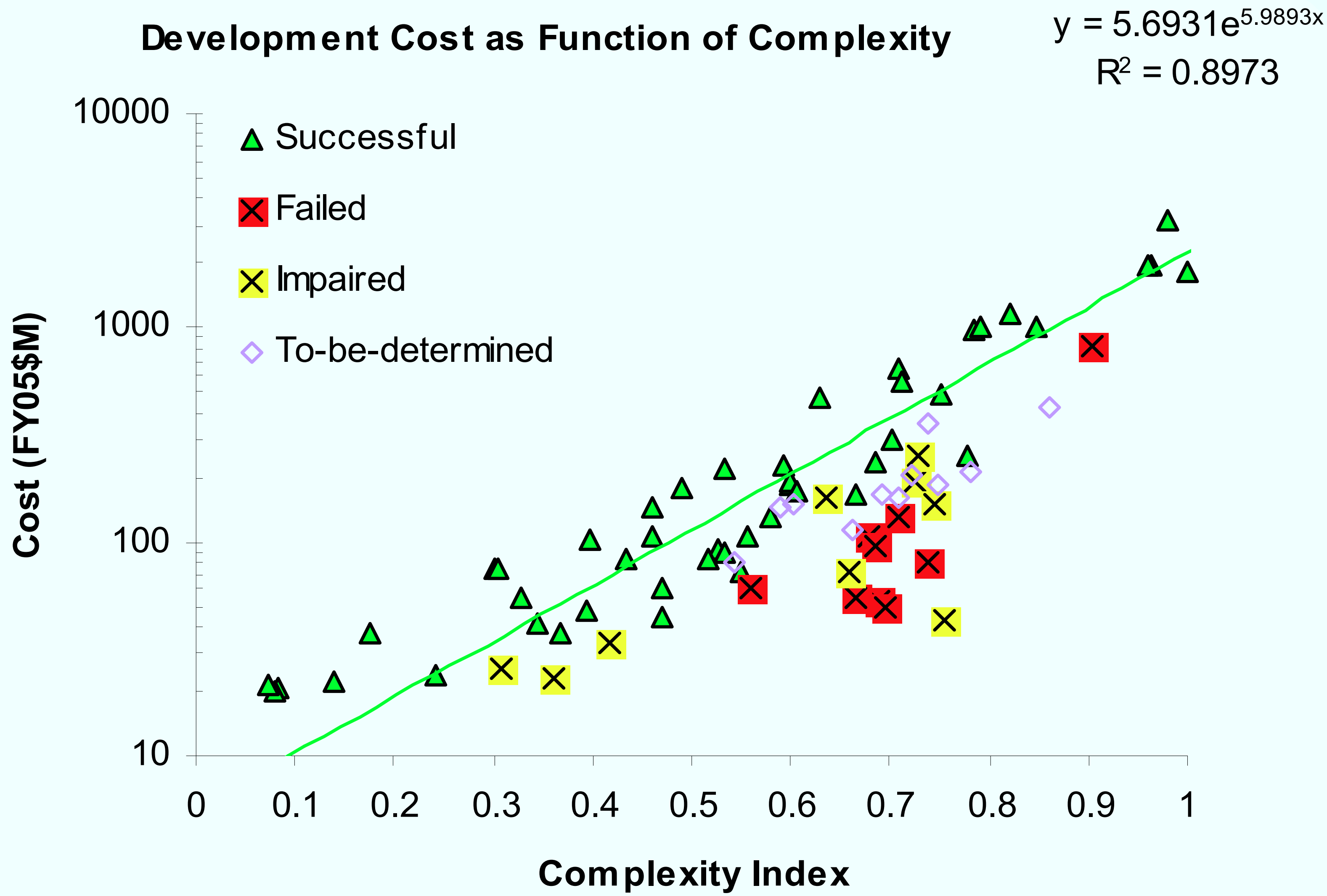
	Total Milestones	Total Milestones Completed	Number Completed Early	Number Completed Late	Deferred to Next Year
FY2011	21	21	6	3	0
FY2012	37	34	16	2	3
FY2013	41	38	20	5	3
FY2014	36	7	5	10*	0

*Late milestones have been or are forecast to complete within the year.
Shutdown related delayed milestones included in this tally

7 out of 10 FY14 milestones late by 1 month due to Government shutdown.

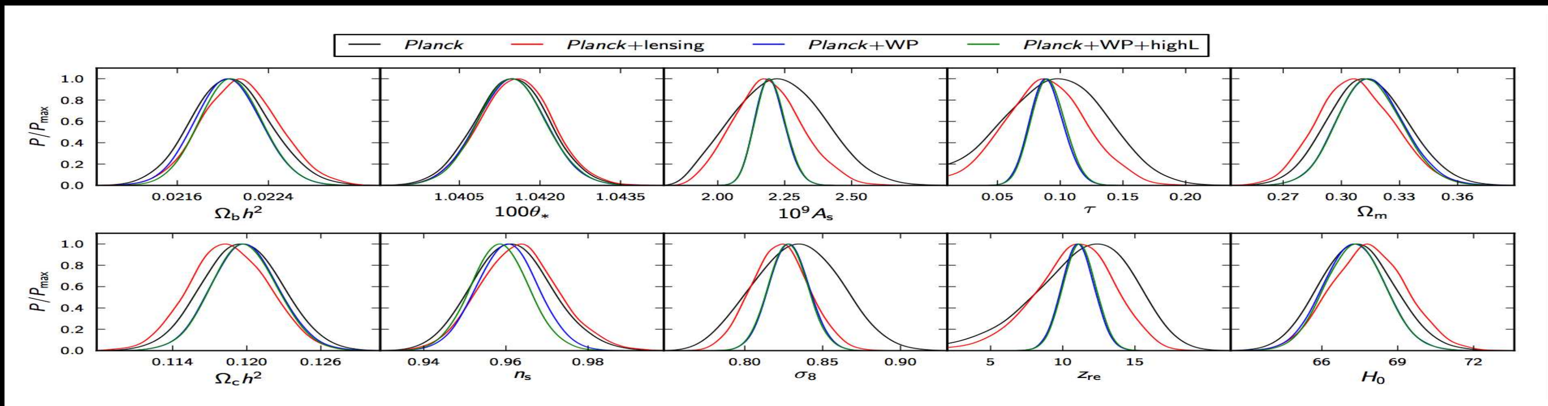
None of these are on the critical path, so caused no launch delay.

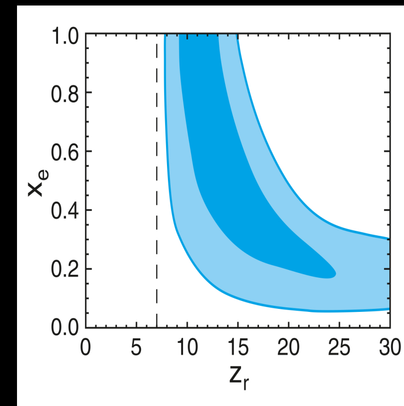
When is a Mission Too Cheap?*



* "A Complexity-based Risk Assessment of Low-Cost Planetary Missions: When is a Mission Too Fast and Too Cheap?", Bearden, D. A.

Implications of the WMAP year-9 & Planck13 results for JWST science:





HST/WFC3 z$\lesssim$7–9 $\longleftarrow$ $\longrightarrow$ JWST z$\simeq$8–25

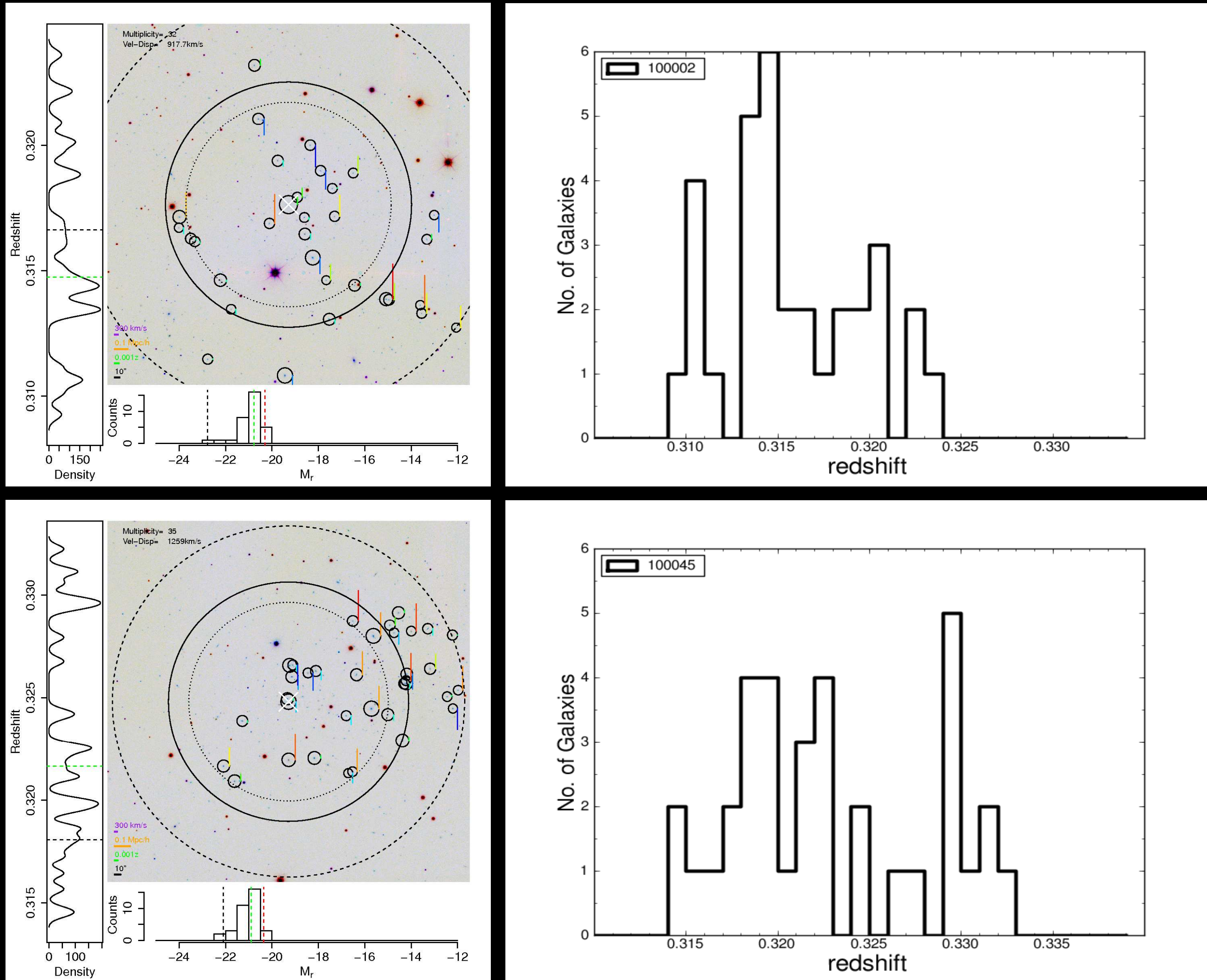
The year-9 WMAP data provided better foreground removal (Komatsu$^+$ 2011; Hinshaw$^+$ 2012; but see: Planck XVI 2013.)

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

- (1) Instantaneous at z$\simeq$11.1$\pm$1.1 (τ=0.089$\pm$0.013), or, more likely:
- (2) Inhomogeneous & drawn out: starting at z$\gtrsim$20, peaking at z$\lesssim$11, ending at z$\simeq$7. The implications for HST and JWST are:

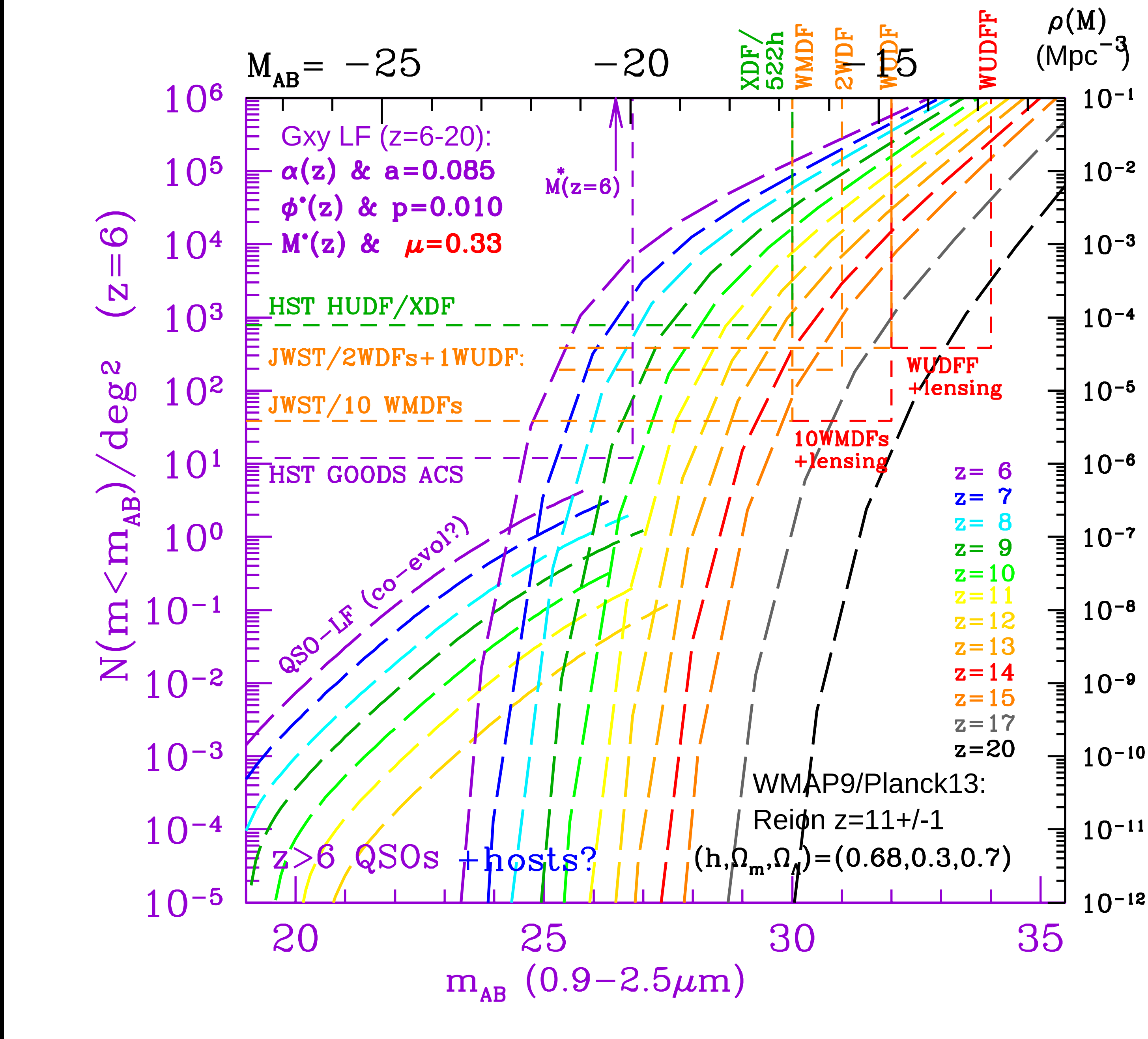
- HST/ACS has covered z$\lesssim$6, and WFC3 is covering z$\lesssim$7–9.
- For First Light & Reionization, JWST will survey z$\simeq$8 to z$\simeq$15–20.

Question: If Planck-$\tau\downarrow\lesssim$0.08 (TBD, Planck14), then how many reionizers will JWST see at z$\simeq$10–20?



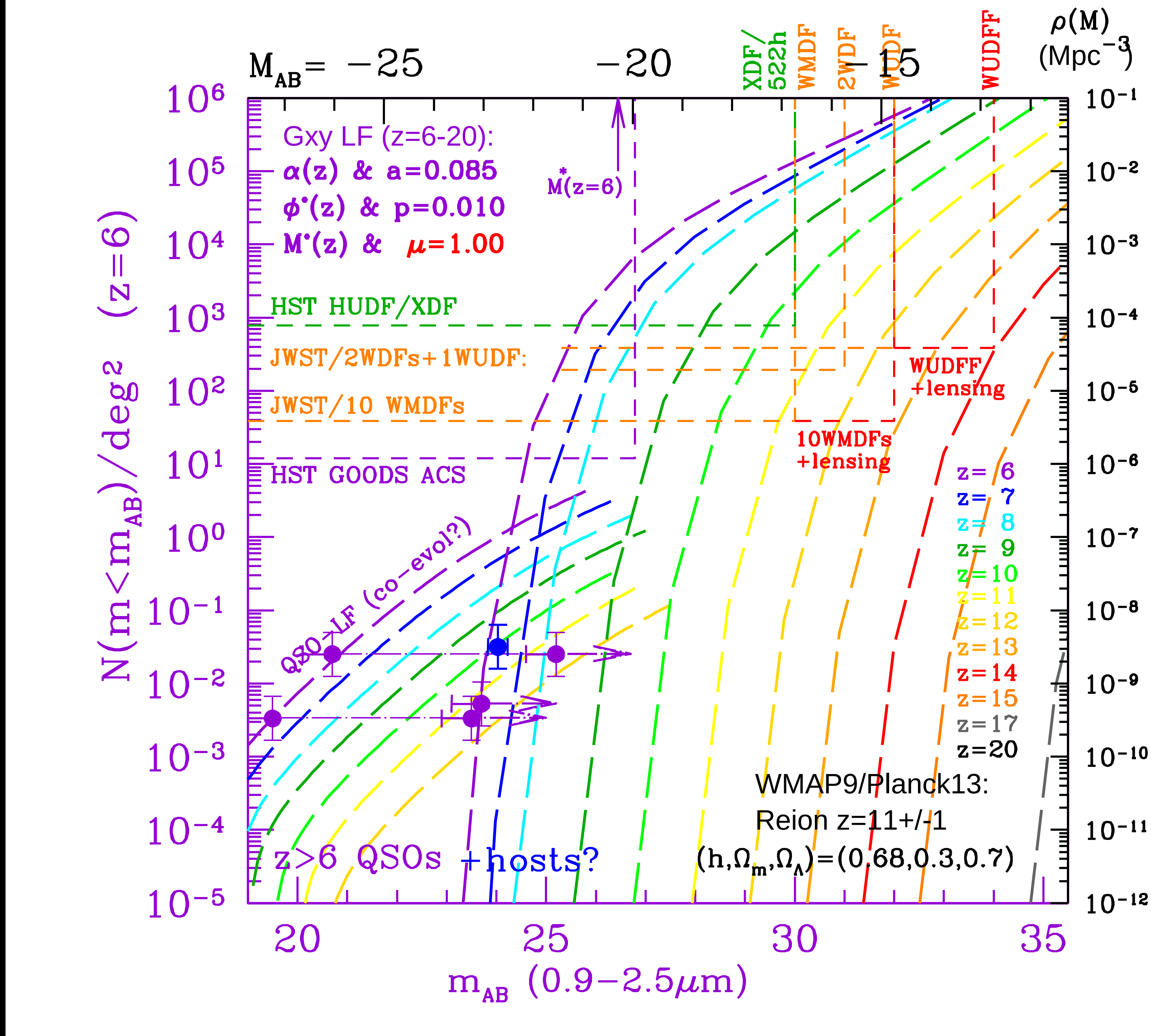
[Left] GAMA groups with secure AAT redshifts for R≲19.8 AB-mag.
Also show redshift probability and absolute magnitude (M_r) distributions.
[Right] Measured group redshift distribution for two GAMA groups.

- Will select our WMDF IDS targets on groups (+ some clusters).



Same as p. 15, but optimistic M^* (z) drop: μ=0.33 (Oesch et al. 2013).

- If so, far more 9≲z≲12 objects expected in XDF, even though N(6≲z≲8) remains the same $\Longleftrightarrow$ M^* (z≃11) fainter than −17.5±0.5 mag?



Same as pg. 15, but pessimistic M^* (z) evolution parameter: μ=1.0.

- If so, JWST surveys would need lensing to see most $\gtrsim$11 objects.
- Add z$\simeq$6 QSO host galaxy limits (or fluxes) by Mechtley$^+$ (2012, 2013).

B, I, J AB-mag vs. half-light radii r_e from RC3 to HUDF limit are shown.

All surveys limited by by SB (+5 mag dash)

Deep surveys bounded also by object density.

Violet lines are gxy counts converted to to natural conf limits.

Natural confusion sets in for faintest surveys (AB≳25). Will update for JWST.