Measuring First Light, Galaxy Assembly & Supermassive Blackhole Growth with JWST (IDS program)

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Presentation to the JWST Science Working Group, Monday Nov. 25, 2013

Science and IDS Goals (Old & New)

(1) Galaxy Assembly & Supermassive Black-Hole (SMBH) Growth.

(2) Studying the Epochs of First Light & Reionization,
and the first AGN Growth: QSO host galaxies at z$\gtrsim$6.

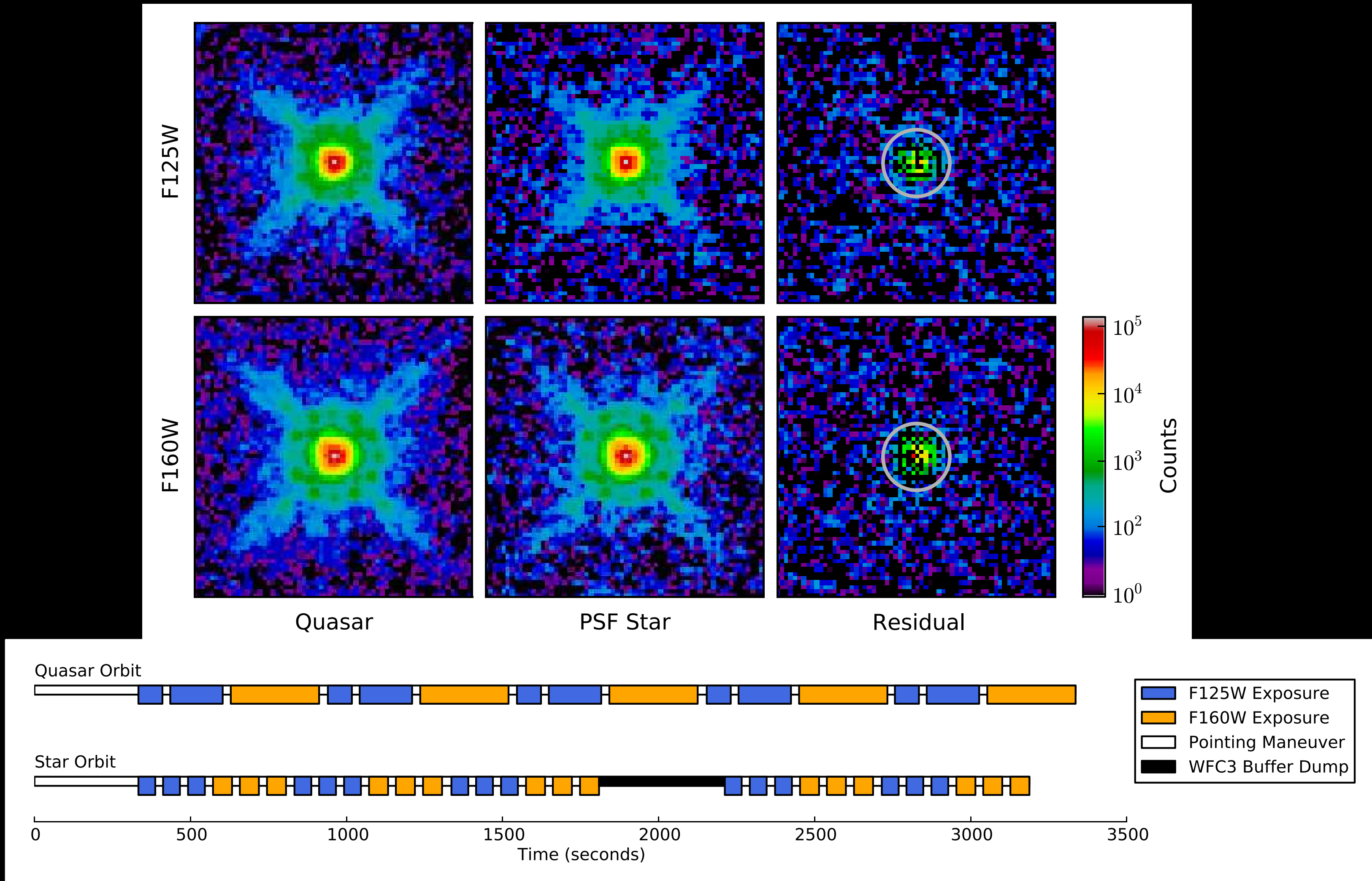
(3) How to optimize First Light studies with JWST.

(4) Studying limitations of JWST based on experience from HST:

- (4a) Potential Impact of JWST straylight *gradients* & their removal.
- (4b) The Natural Confusion Limit.

Will mostly concentrate on parts (2) and (3) today, and possibly (4a), and leave the rest for later.

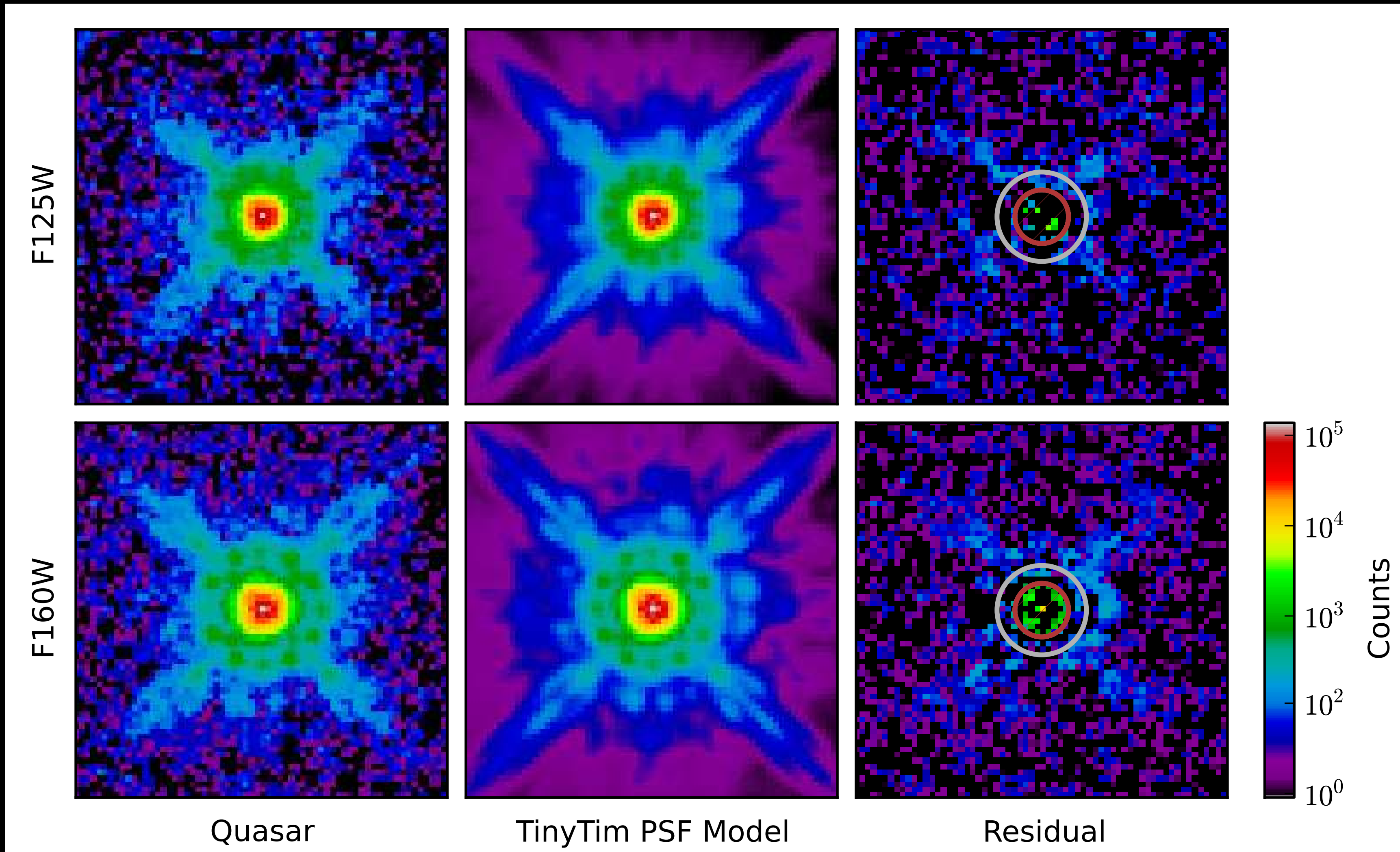
(2) Observations of QSO host galaxies at z≃6 (1st Gyr)



- 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≃18.5) nearly to the noise limit: NO host galaxy detected 100× fainter (AB$\gtrsim$23.5 at r$\gtrsim$0$''$.3)!

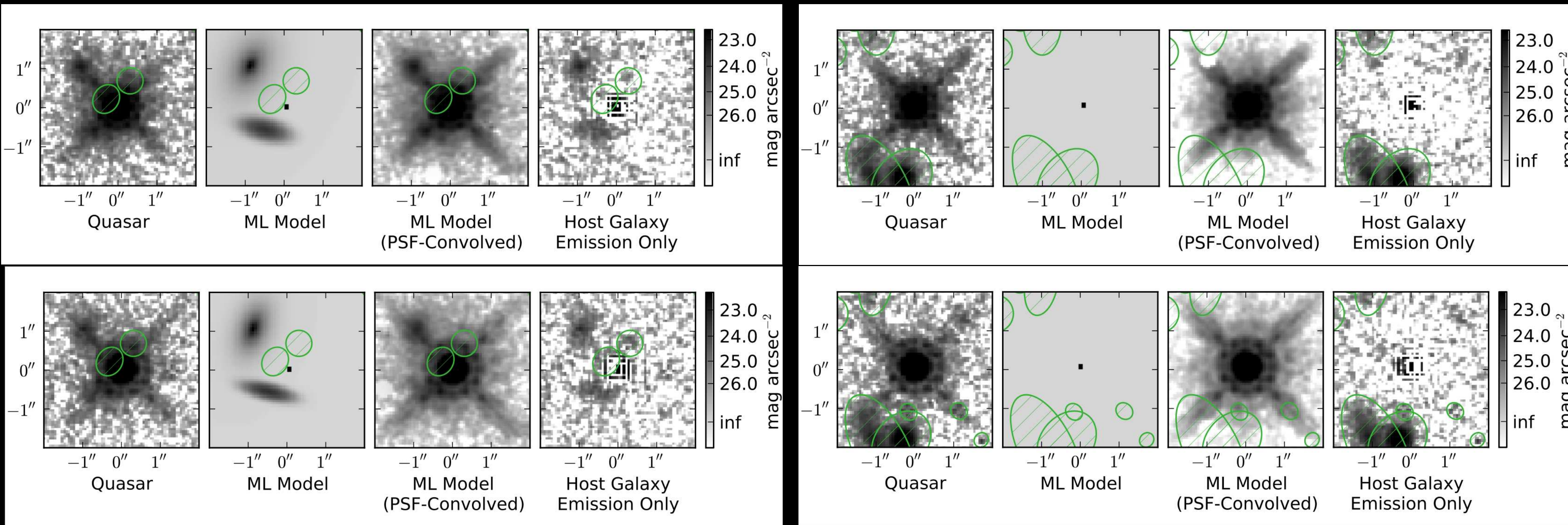
(2) Observations of dusty QSO host galaxies at z≃6.



- TinyTim fit of PSF-star + Sersic models QSO nearly to the noise limit: Again no z=6.42 host galaxy at AB$\gtrsim$23.5 mag at radius r$\simeq$0.″3–0.″5.

- Will do this with JWST Coronagraphs much fainter and at $\lambda \gtrsim 2\mu$m, since these objects may be very dusty (see also G. Rieke's earlier presentation).

(2) Detection of QSO host galaxy candidates at z≃6.



- Monte Carlo Markov-Chain of observed PSF-star + Sersic ML light-profile. Gemini AO data critical for PSF stars (Mechtley^{+} 2013).

- One host gxy detection out of four z≃6 QSOs [3 more to be observed].

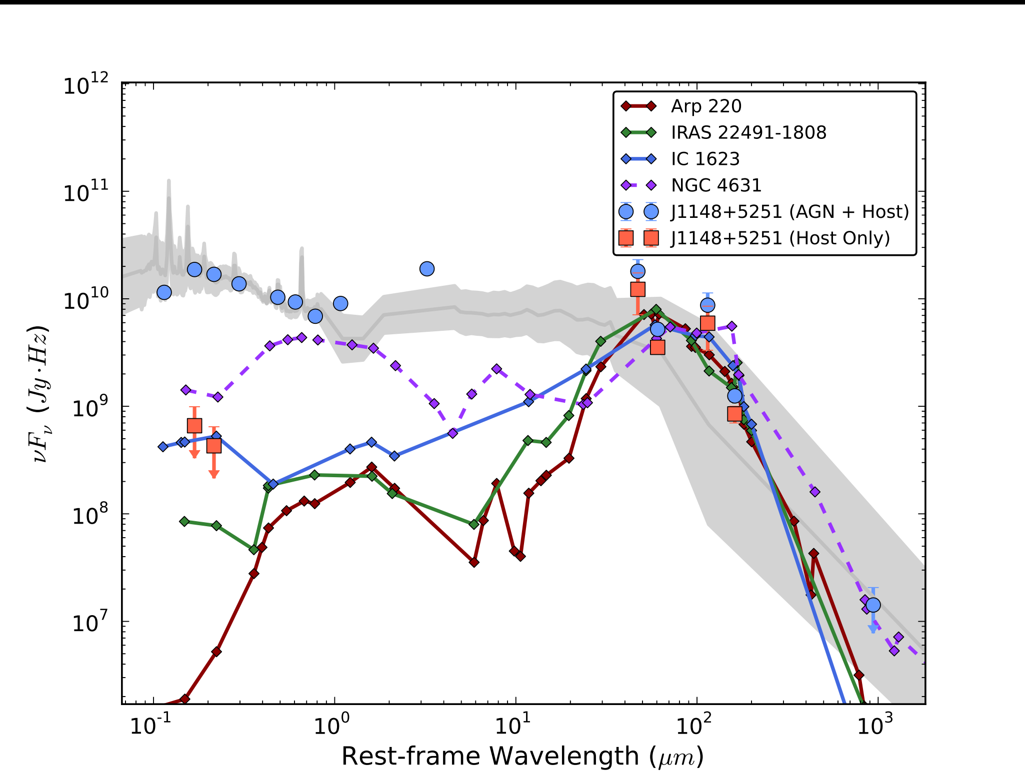
- [Left]: P(z$\lesssim$5 interloper)≃0.6–2%. Has merger morphology in J+H.

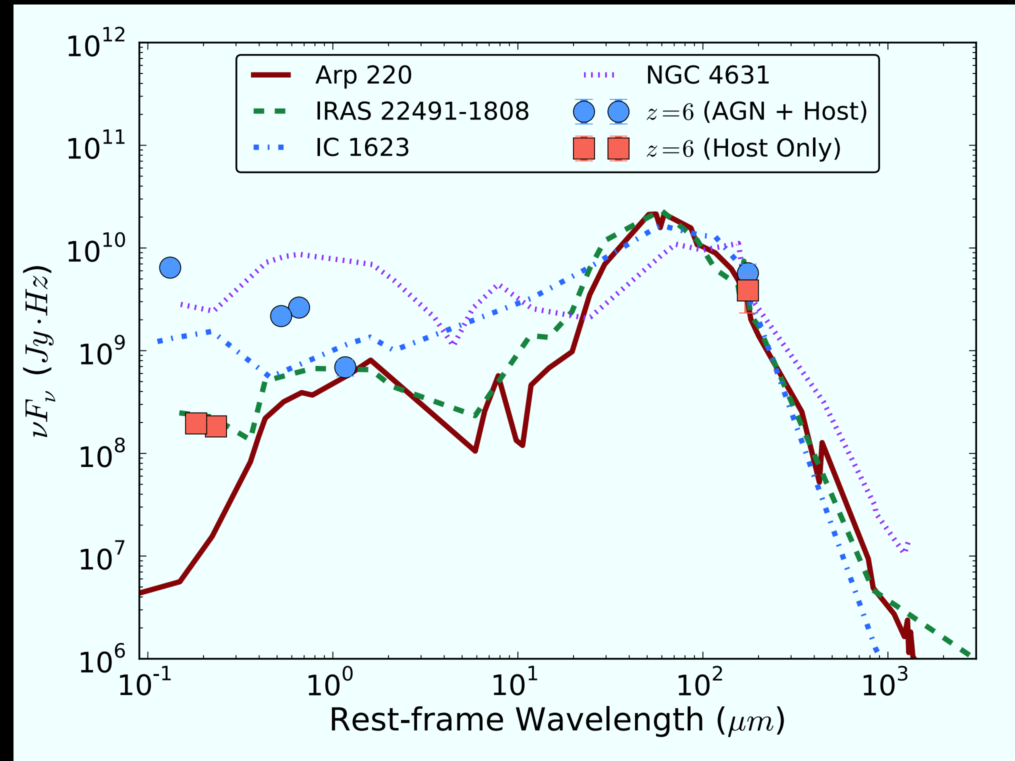
- Same J+H structure! Blue UV-SED colors: (J–H)≃0.19, constrains dust.

- IRAS starburst-like SED from rest-frame UV–far-IR, $A_{FUV} \gtrsim 1$ mag.

- M_{AB}^{host}(z≃6)$\lesssim$–23.0 mag, i.e., ∼2 mag brighter than L*(z≃6).

(2) Need JWST Coronography of dusty QSO host galaxies at z≃6:





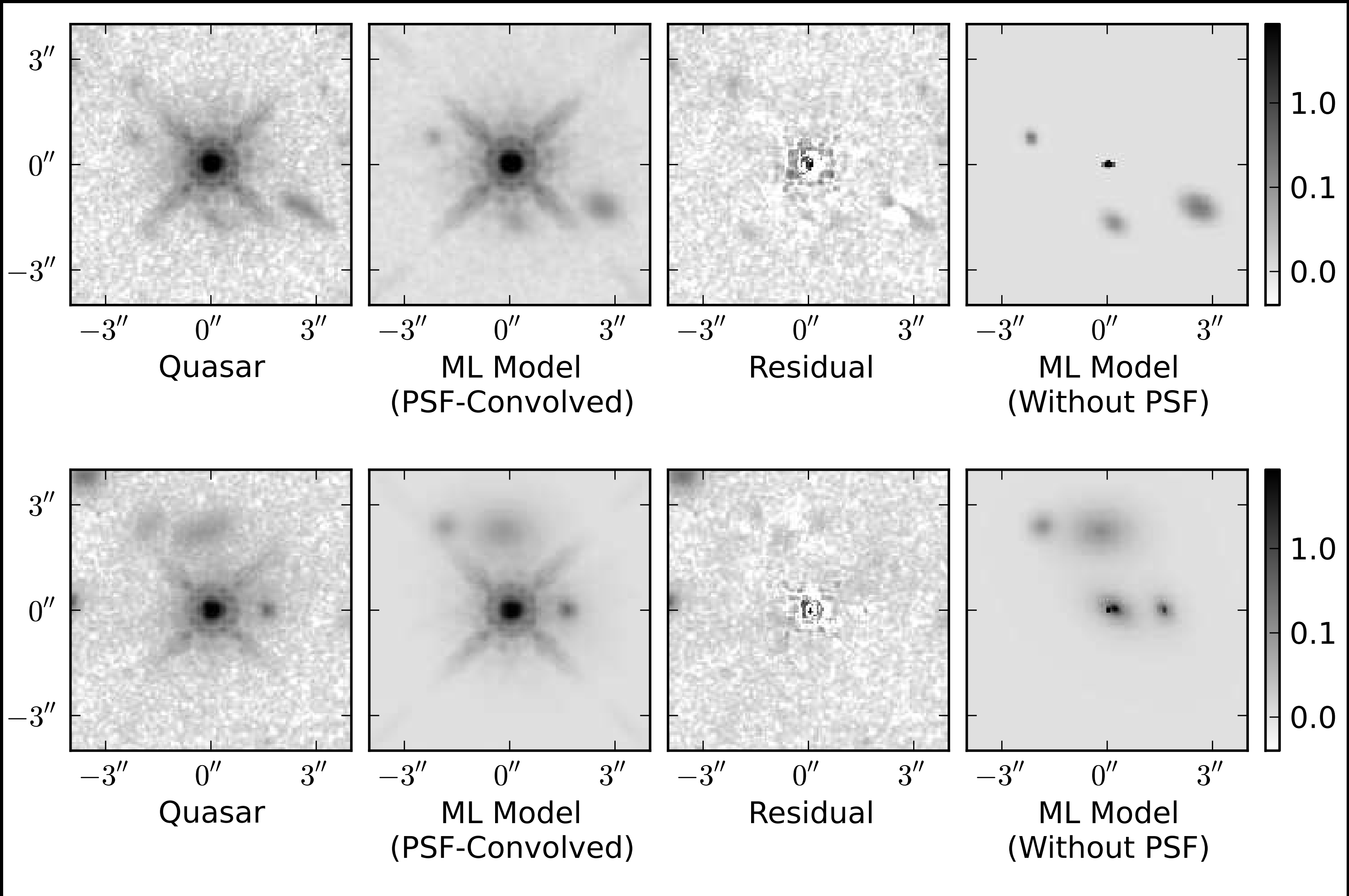
- Blue dots: z≃6 QSO SED, Grey: Average radio-quiet SDSS QSO spectrum at z≳1 (normalized at 0.5μ). Red: z≃6 host galaxy (WFC3+submm).
- Nearby fiducial galaxies (starburst ages≲1 Gyr) normalized at 100μm:

[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).

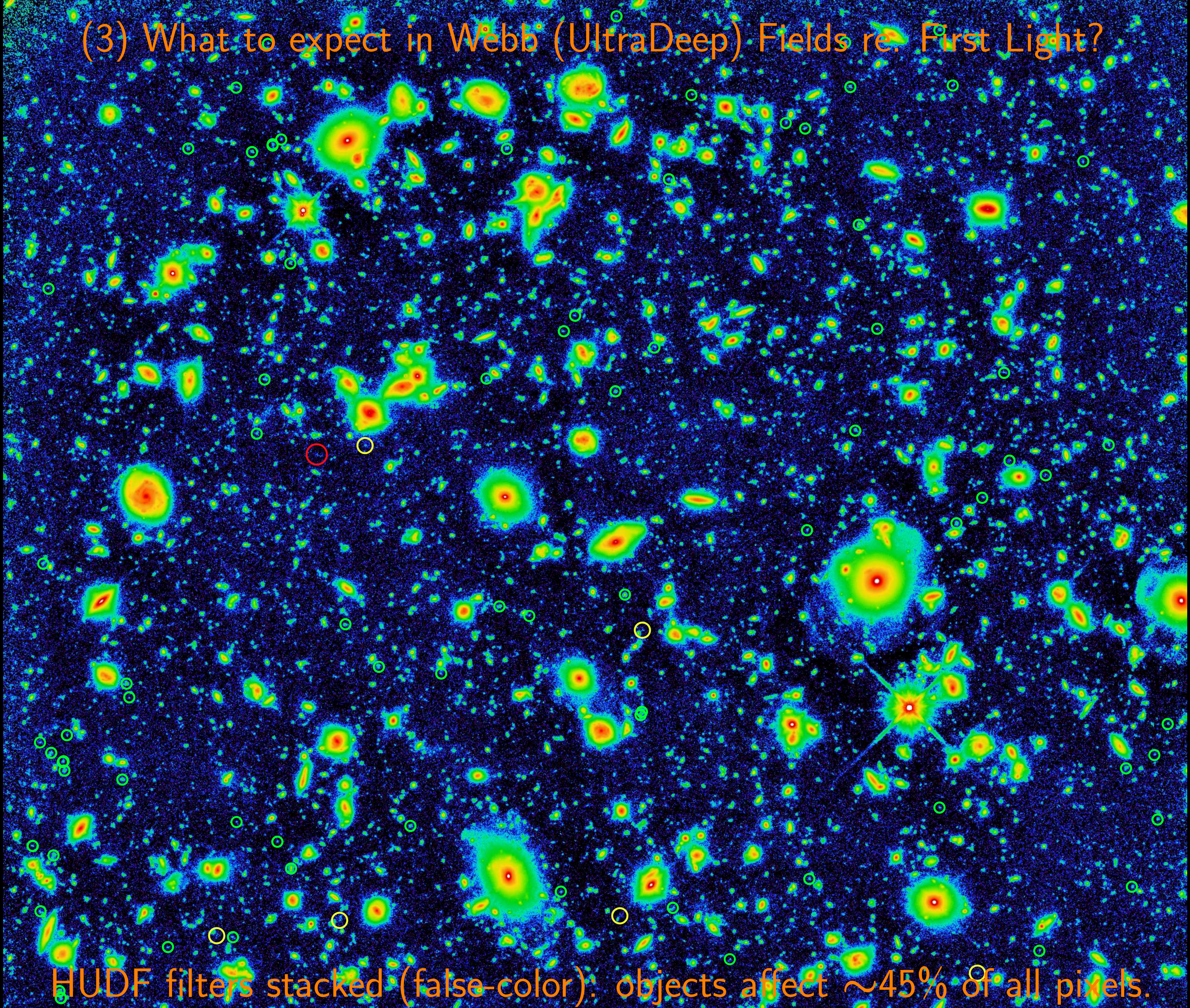
[RIGHT] Detected host has starburst-like UV–far-IR SED, A_{FUV}(host)≳1^m (Mechtley$^+$ 2013). Need JWST Coronagraphs to see hosts at λ≳2μm.

(2) WFC3 observations of QSO host galaxies at z≃2 (evidence for mergers?)



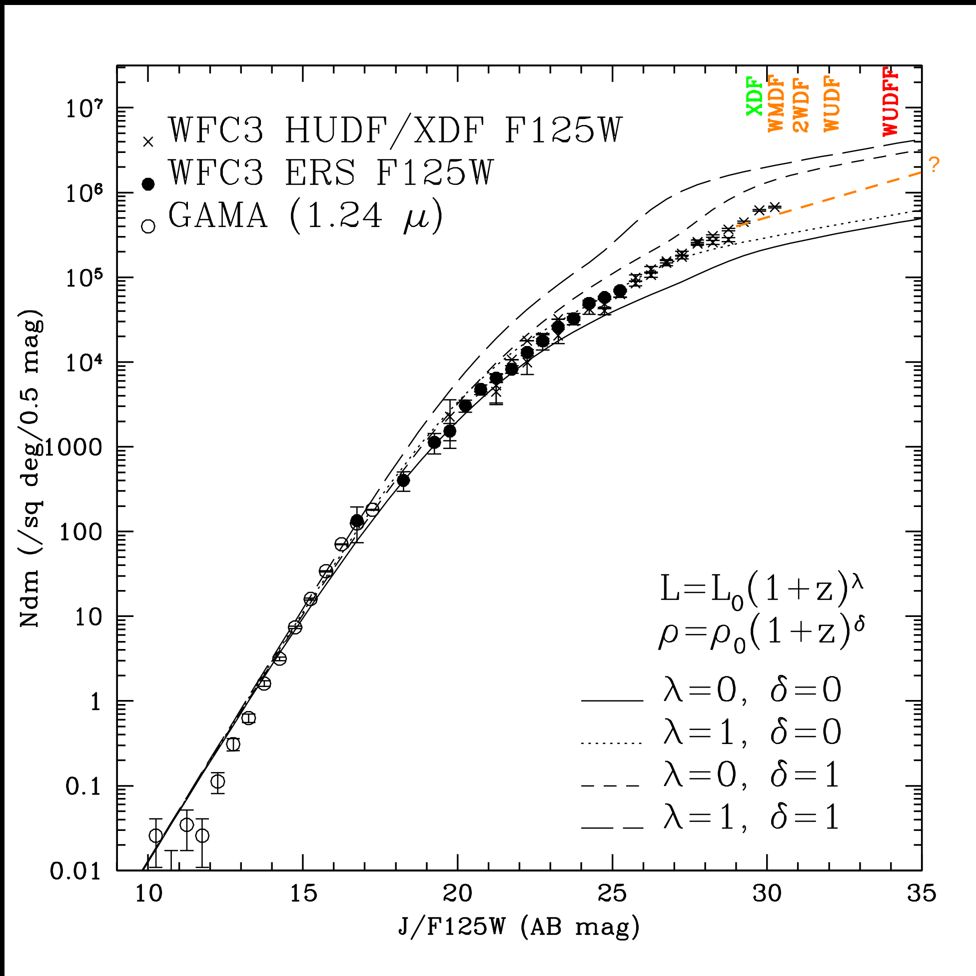
- Monte Carlo Markov-Chain runs of observed PSF-star + Sersic ML light-profile models: 50% have neighbors/mergers (Mechtley, Jahnke, Koekemoer, Windhorst et al. 2013).
- Will do this with JWST Coronagraphs much fainter and at $\lambda \gtrsim 2\mu$m.

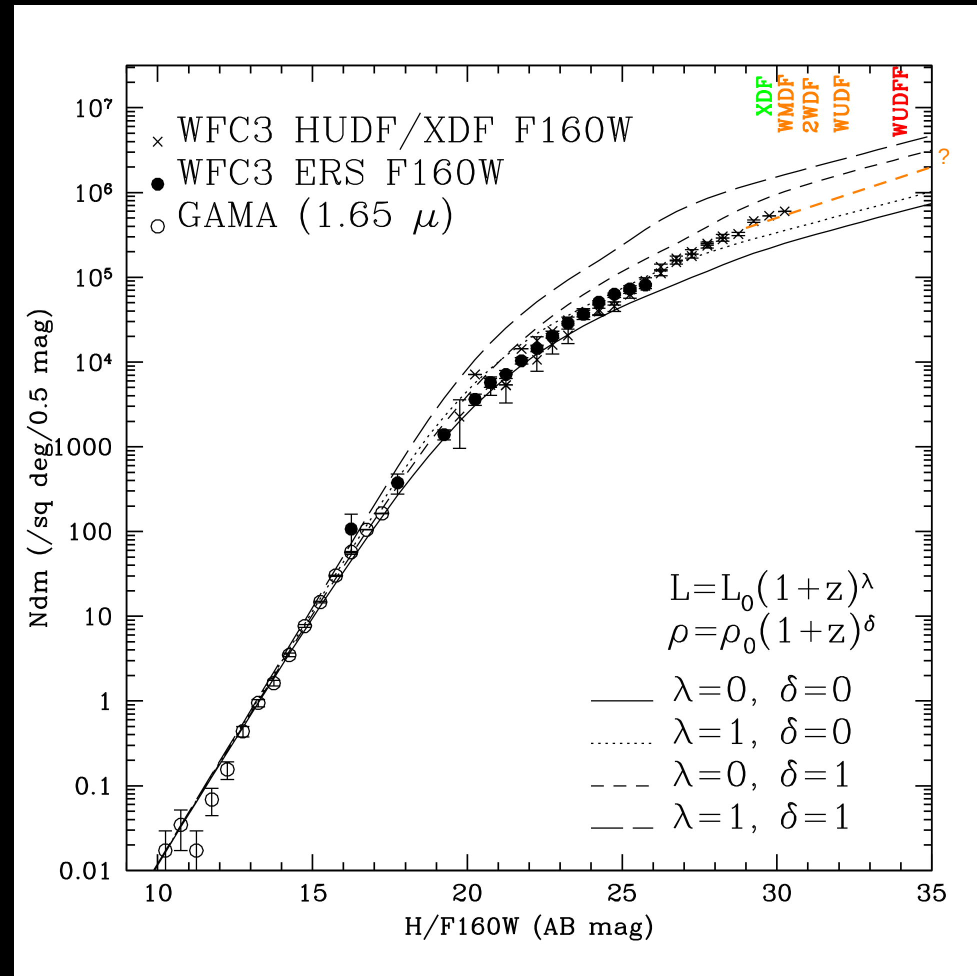
(3) What to expect in Webb (UltraDeep) Fields re. First Light?



HUDF filters stacked (false-color): objects affect ∼45% of all pixels.

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





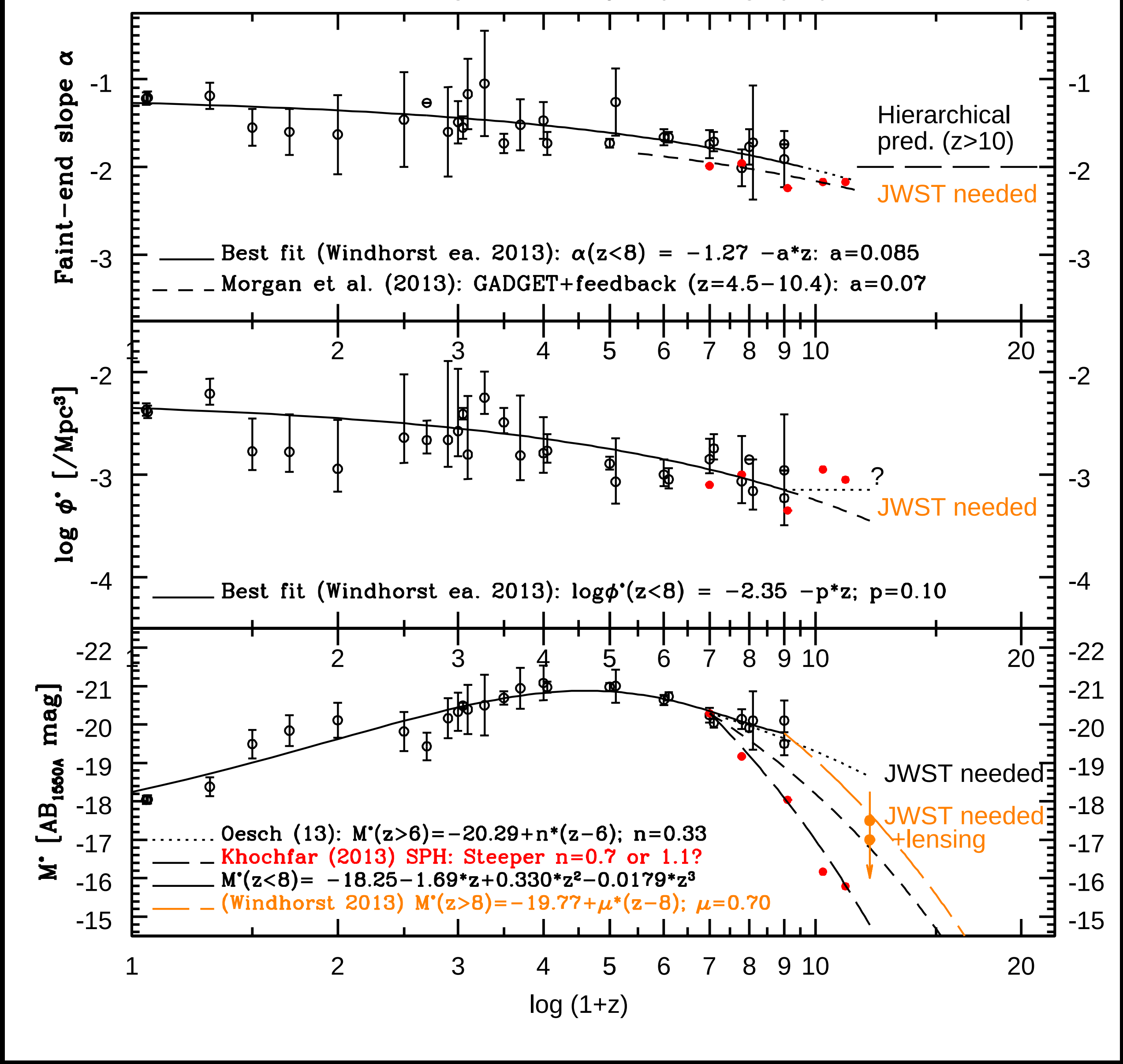
Data: GALEX, GAMA, HST ERS + HUDF/XDF ACS+WFC3 (*e.g.*, Windhorst et al. 2011; Ellis$^+$ 2012; Illingworth$^+$ 2012): F125W, F160W. [F225W, F275W, F336W, F435W, F606W, F775W, F850LP, F098M/F105W, F140W, not shown].

- HUDF: Faint-end near-IR mag-slopes ≃0.12±0.02 to AB≲30 mag ⟺

At z_{med} ≃1.6, faint-end LF-slope α≃–1.4 reaches M_{AB}≃–14 mag.

- WUDF (- - -) can see AB≲32 objects: M_{AB} ≃–15 (LMCs) at z≃11.

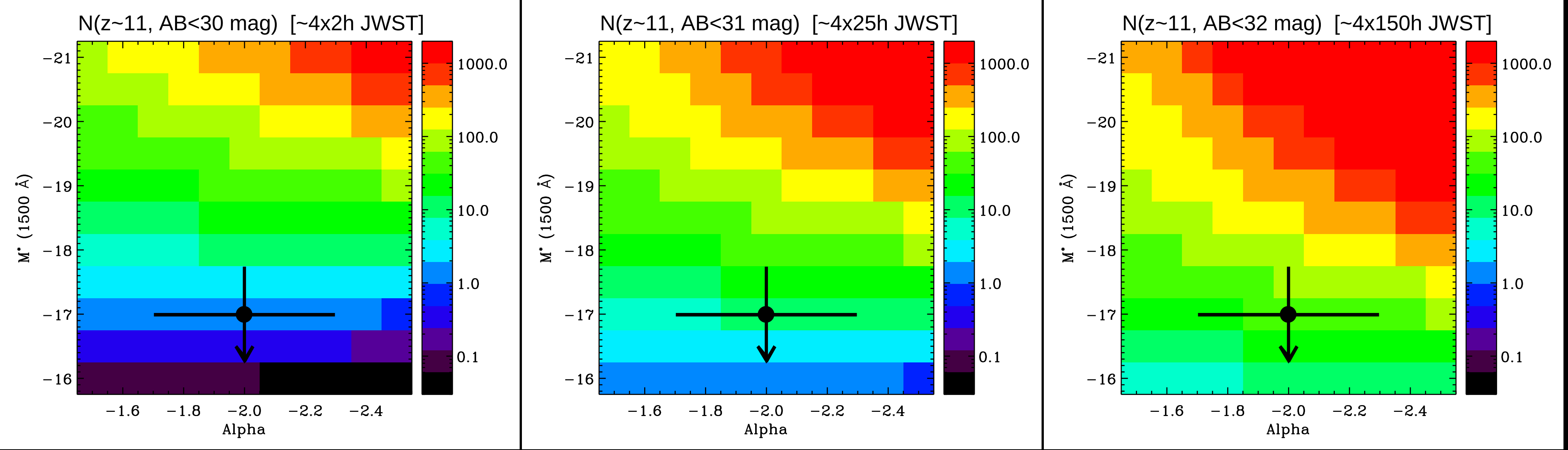

HUDF weighted log-log stretch: 522 hrs BViIzYJWH. AB ≲30 mag



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).
- XDF: Characteristic M^* may drop below –18 or –17.5 mag at z$\gtrsim$10.

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



What does the single plausible z$\gtrsim$10 detection in the HUDF mean?

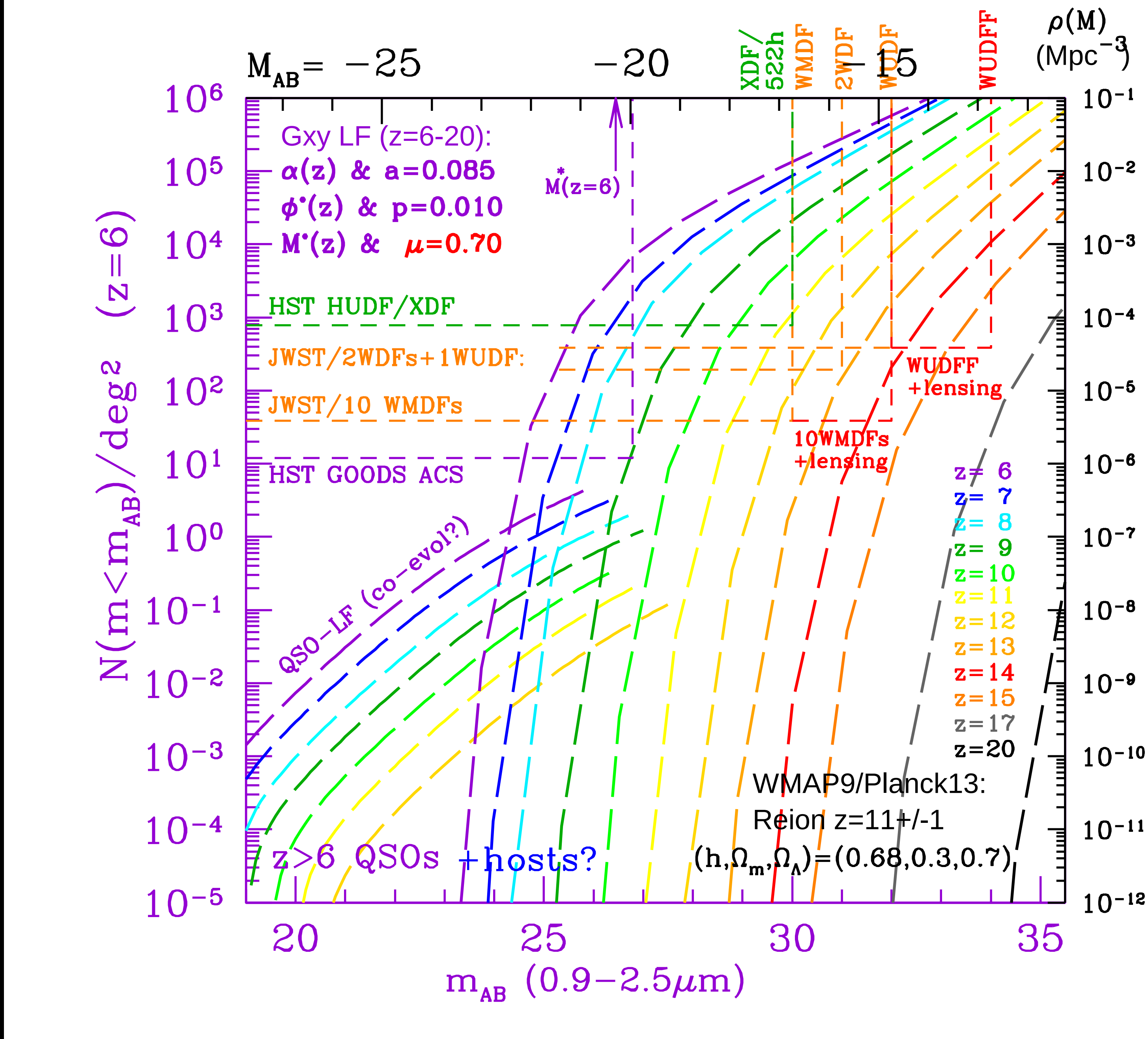
Integrate Schechter LFs with α(z), Φ^* (z) and M^* (z): $\lesssim$45% sky-coverage by AB$\lesssim$30 objects (Koekemoer+13); Cosmic variance $\gtrsim$30%.

For any α(z$\gtrsim$10), implies M^* (z$\gtrsim$10)$\gtrsim$–17.5 mag (fainter!), so assume:

- (1) [Left] Webb "Medium-Deep" Field (**WMDF**) (10×4×2h IDS): Expect few z$\simeq$10–12 objects to AB$\lesssim$30 (XDF), so plan lensing targets.

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

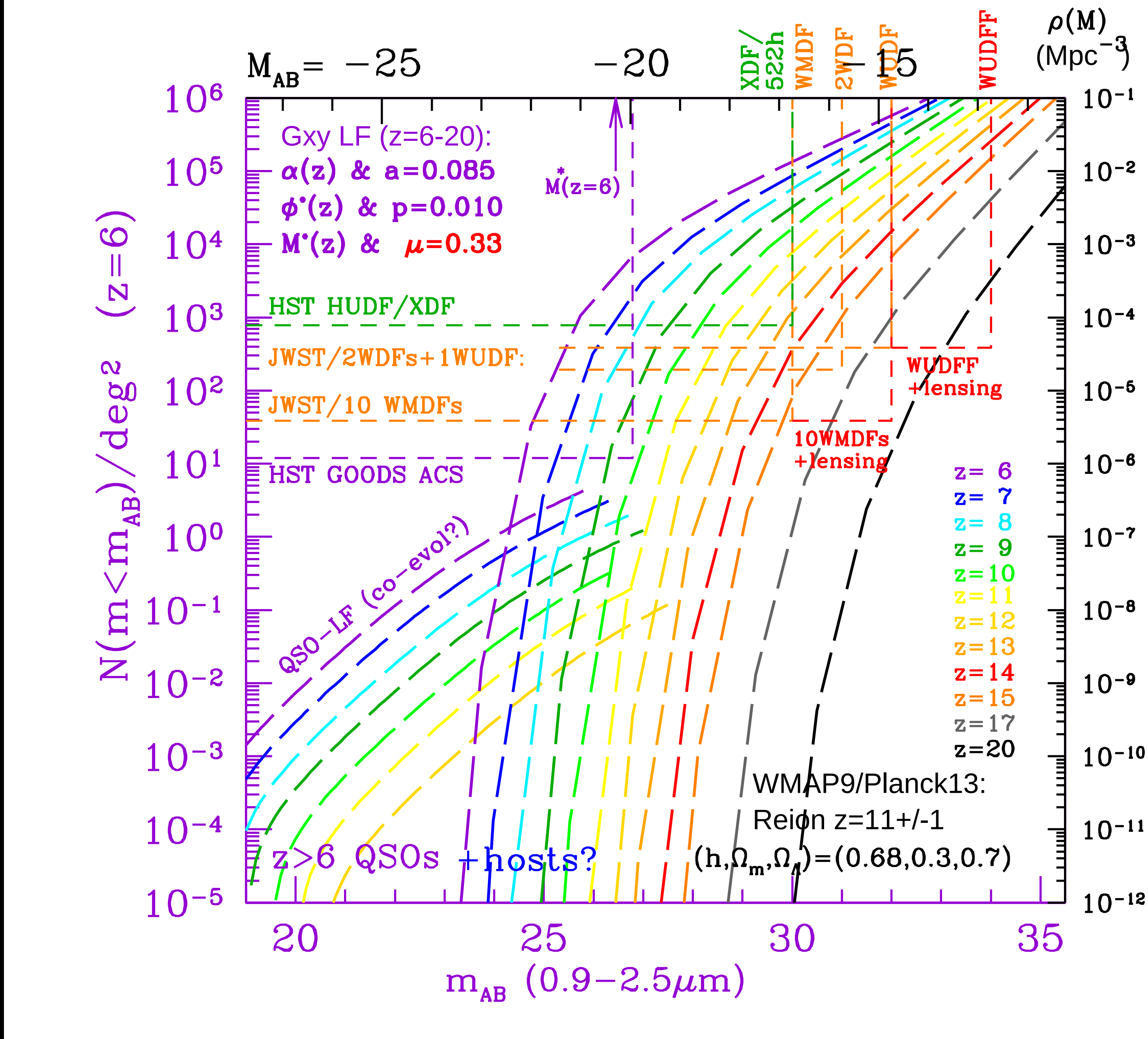
- (3) [Right] Webb UltraDeep Field (**WUDF**) (4×150h; NIRCam DD?]: Expect 30–90 objects to AB$\lesssim$32 mag, many more if lensing target.



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

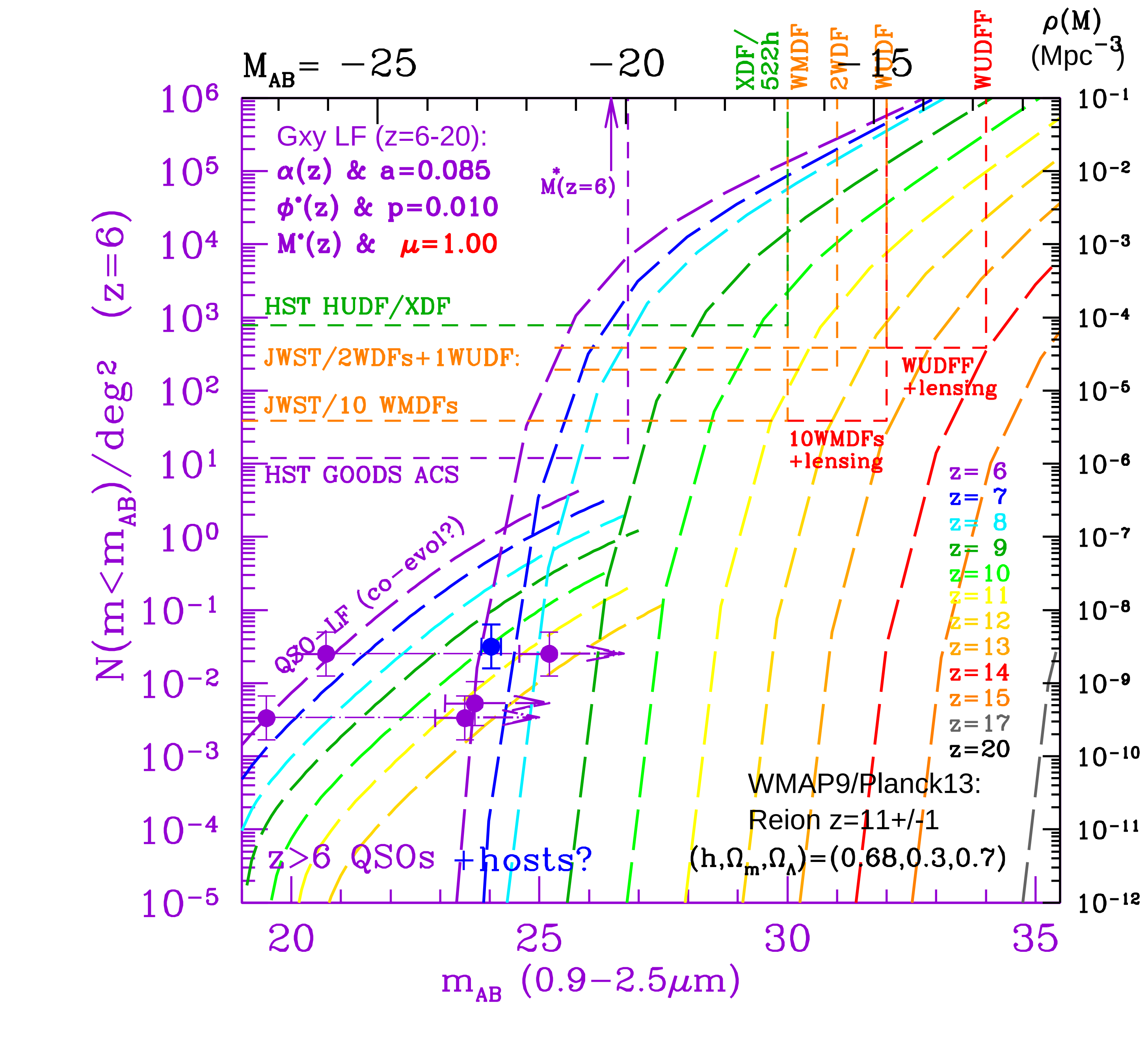
Area/Sensitivity for: HUDF/XDF, 10 WMDFs (IDS), 2 WDFs, & 1 WUDF.

- May need lensing targets for WMDF–WUDFF to see $z \simeq 14$–16 objects.



Same as p. 13, but optimistic M^* (z) drop: μ=0.33 (Oesch et al. 2013).

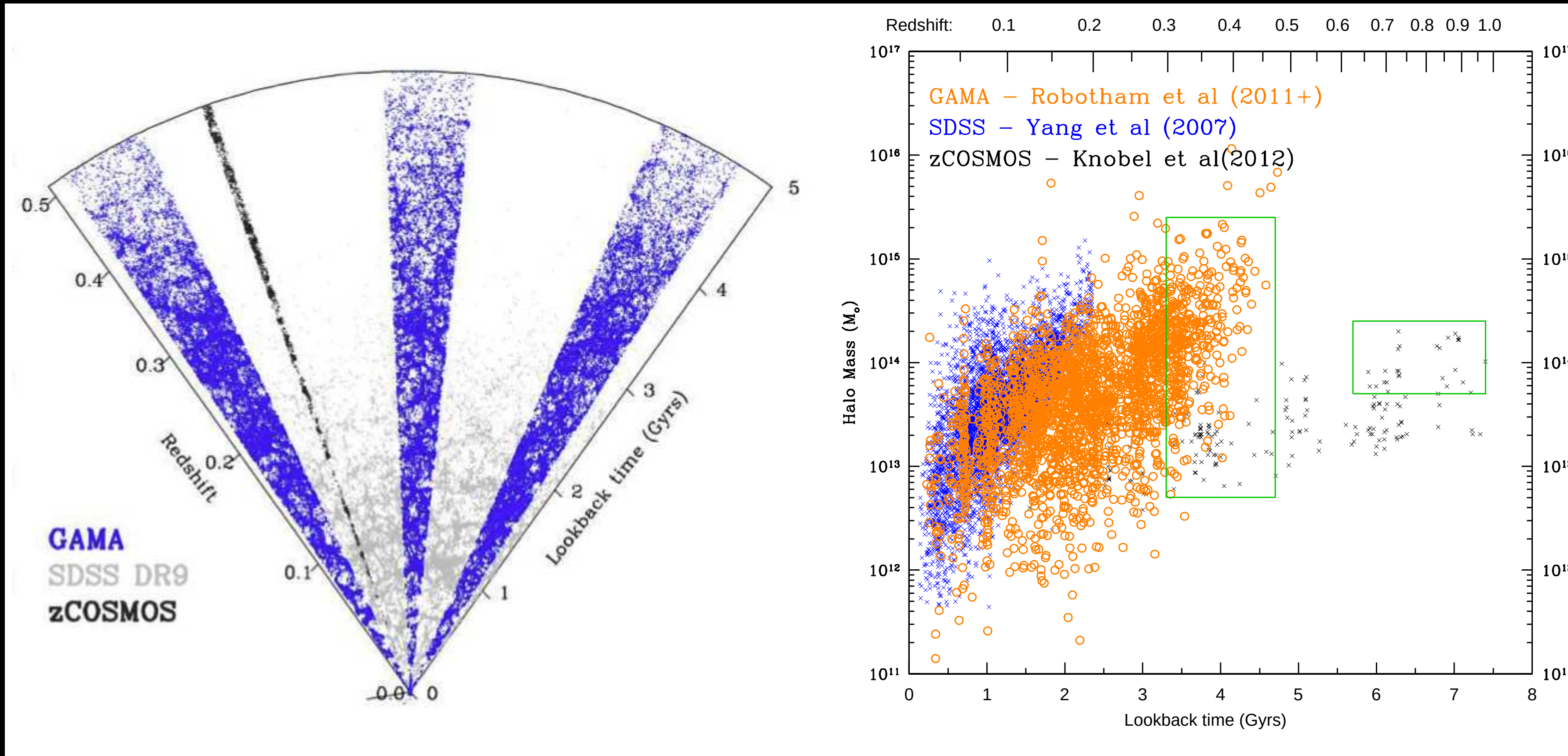
- If so, far more 9≲z≲12 objects expected in XDF, even though N(6≲z≲8) remains the same $\Longleftrightarrow$ M^* (z≃11) fainter than −17.5±0.5 mag?



Same as pg. 13, but pessimistic M^* (z) evolution parameter: μ=1.0.

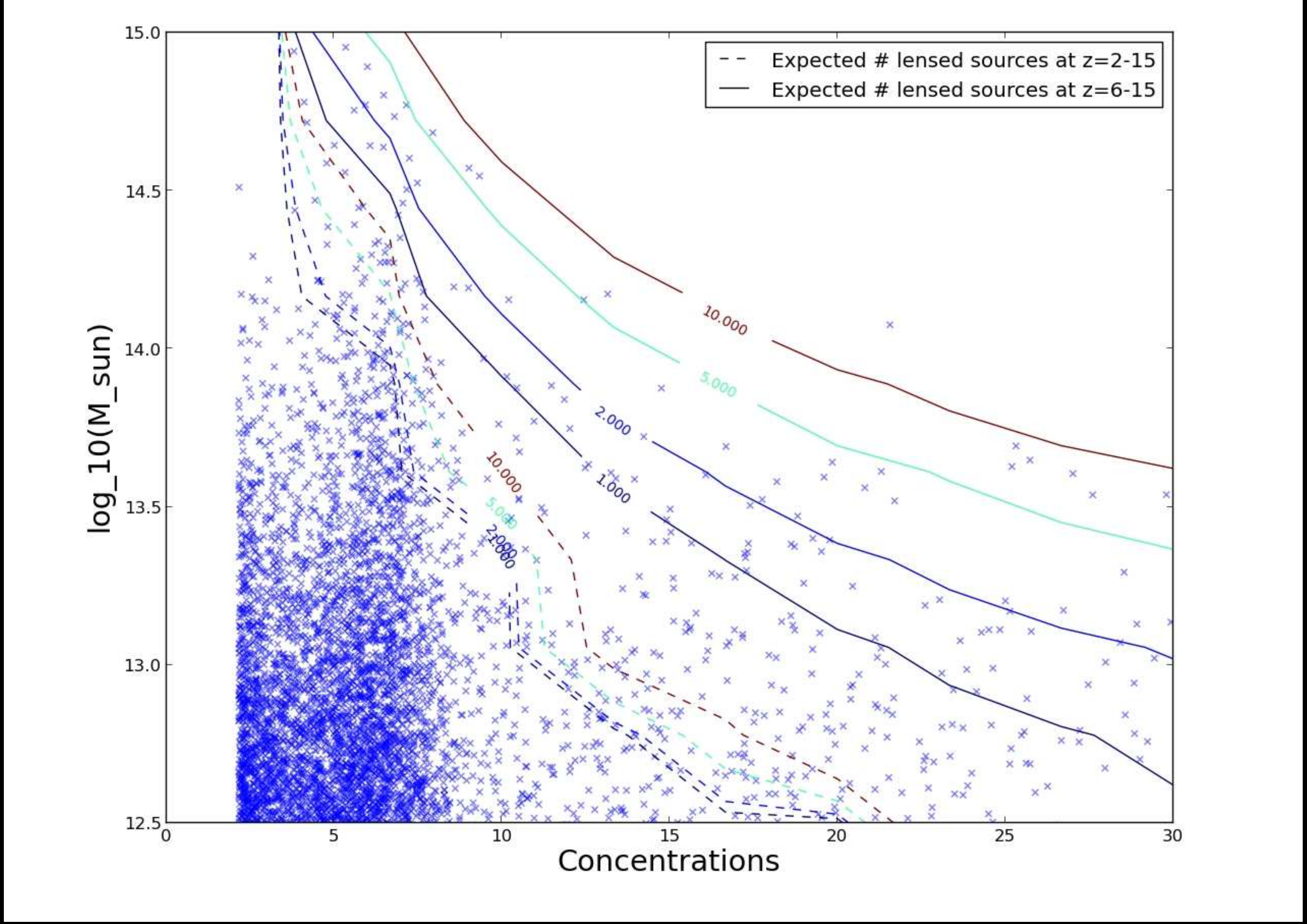
- If so, JWST surveys would need lensing to see most $\gtrsim$11 objects.
- Add z$\simeq$6 QSO host galaxy limits (or fluxes) by Mechtley$^+$ (2012, 2013).

(3b) Gravitational Lensing to see the population at z≳10.



[Left] Cone plots of redshift surveys: SDSS z≲0.25 (Yang+ 2007), GAMA z≲0.45 (Robotham+ 2011), and zCOSMOS z≲1.0 (Knobel+ 2012).

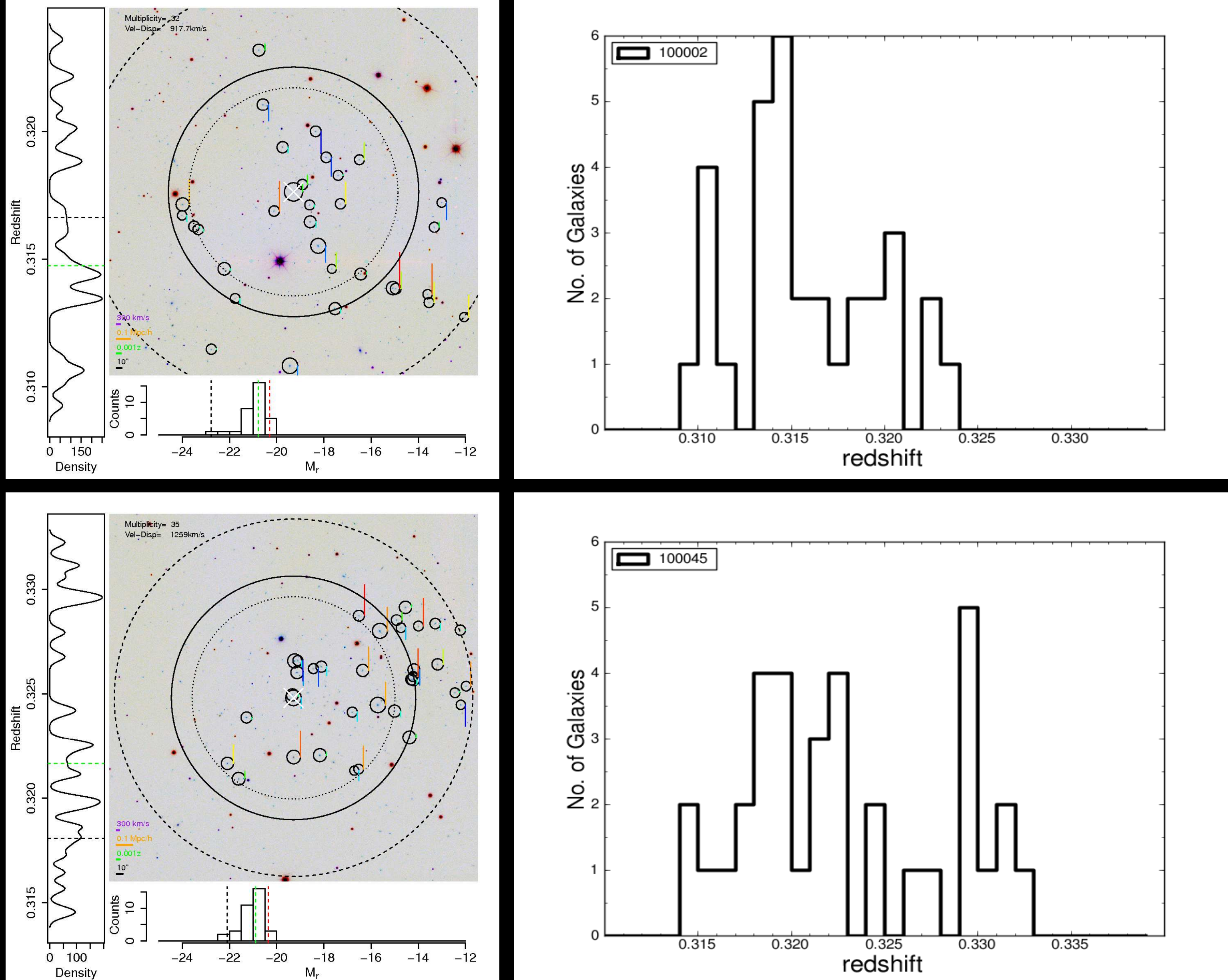
- GAMA: 22,000 groups z≲0.45, 2400 with N_{spec}≳5 (Robotham 11).
- zCOSMOS: reaches ∼2×larger z's (z≲1), covers smaller area.
  - ≲10% of high-N_{zspec} (≥5) groups compact (Konstantopoulos+ 13).
- Need large group sample to identify optimal lens-candidates for z≳6 sources.



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.



[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).

IDS Observing plan and Conclusions

Survey	Old Plan (flds×exp=tot)	New Plan	AB-limit (5-σ)	Comments
Medium	30×1=30h	—	28.6	MS will do
Medium-Deep	5×5=25h	10×7.5=75h	29.6	Use Gr/Cl lensing
Deep	1×45h	—	$\lesssim$31	MJR does 200 h
NIRSpec	10 h	—	TBD	GTOs will do
Coronagraph	—	1×2h	TBD	Consult GTOs
Total IDS	110 h incl OH	77 h excl OH		110 h incl OH

All NIRCam exposures assume equal parts in 7 filters IJHK+LMN (twice as long in N). I leave the option open to trade 1–2 Medium-Deep survey fields in for NIRSpec time for follow-up on specific imaging targets.

(1) SWG will need to very carefully consider the optimal JWST plan to observe the largest number of First Light objects at z$\gtrsim$10–12.

(2) Close coordination between IDS's, GTO's, and STScI to make complementary plans is be best: e.g., WMDF(IDS), WDF(GTO) and WUDFF(DD?).

Other ongoing and future work:

(1) Modeling of group lensing candidates to provide an large sample for JWST first light studies (with S. Wyithe's Melbourne and S. Driver's Perth groups).

(2) Obtain further ground-based data on these groups (LBT blue imaging and Gemini spectra (with A. Hopkins' group in Sydney).

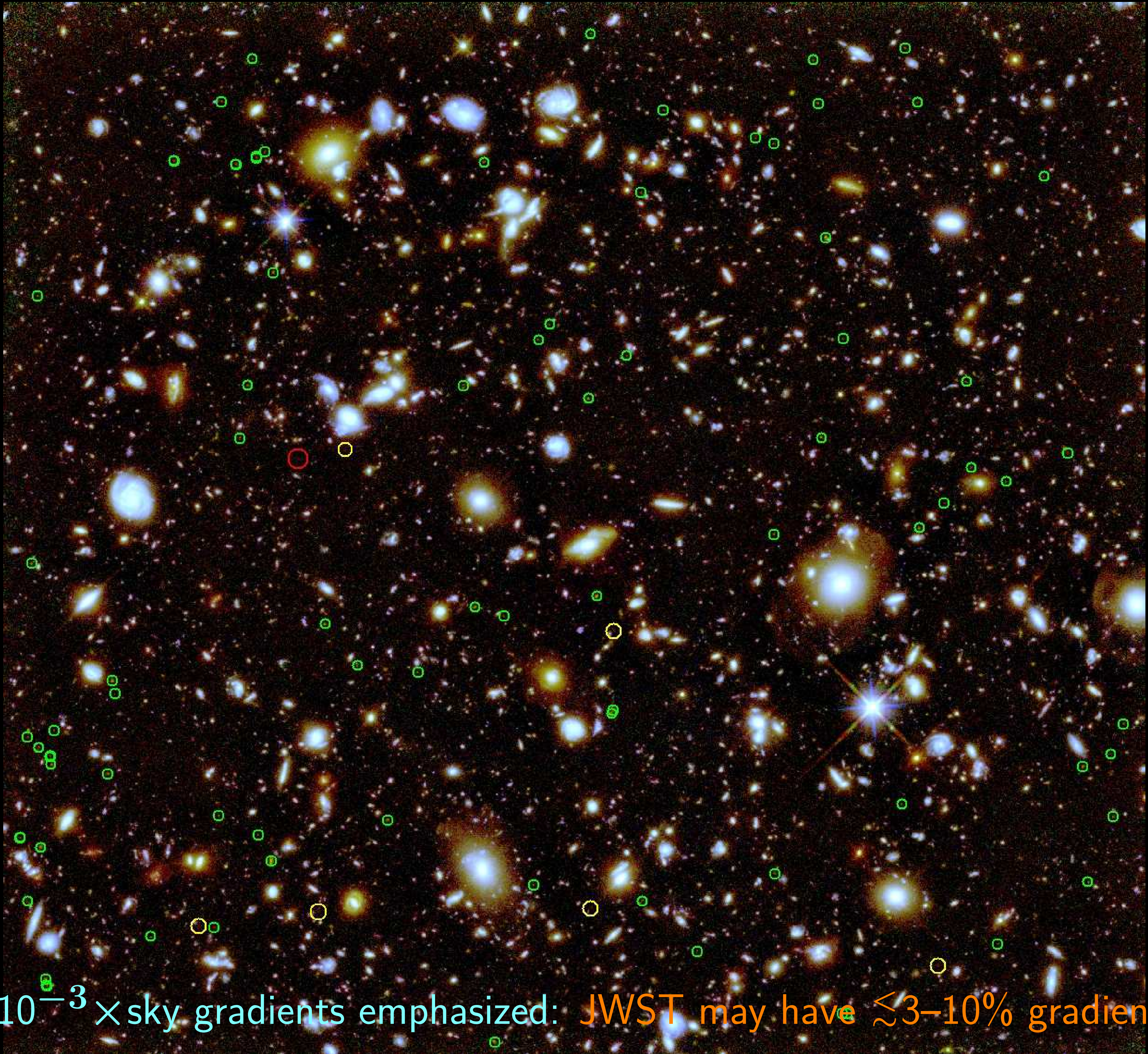
(3) Detailed hierarchical modeling of the evolution of the LF parameters (collaboration with Khochfar (UK) and Scannapieco (ASU).

(4) Develop next generation object finder that works on multiple wavelength images and work well in ultra-crowded fields (with IBM scientists and Marseille group).

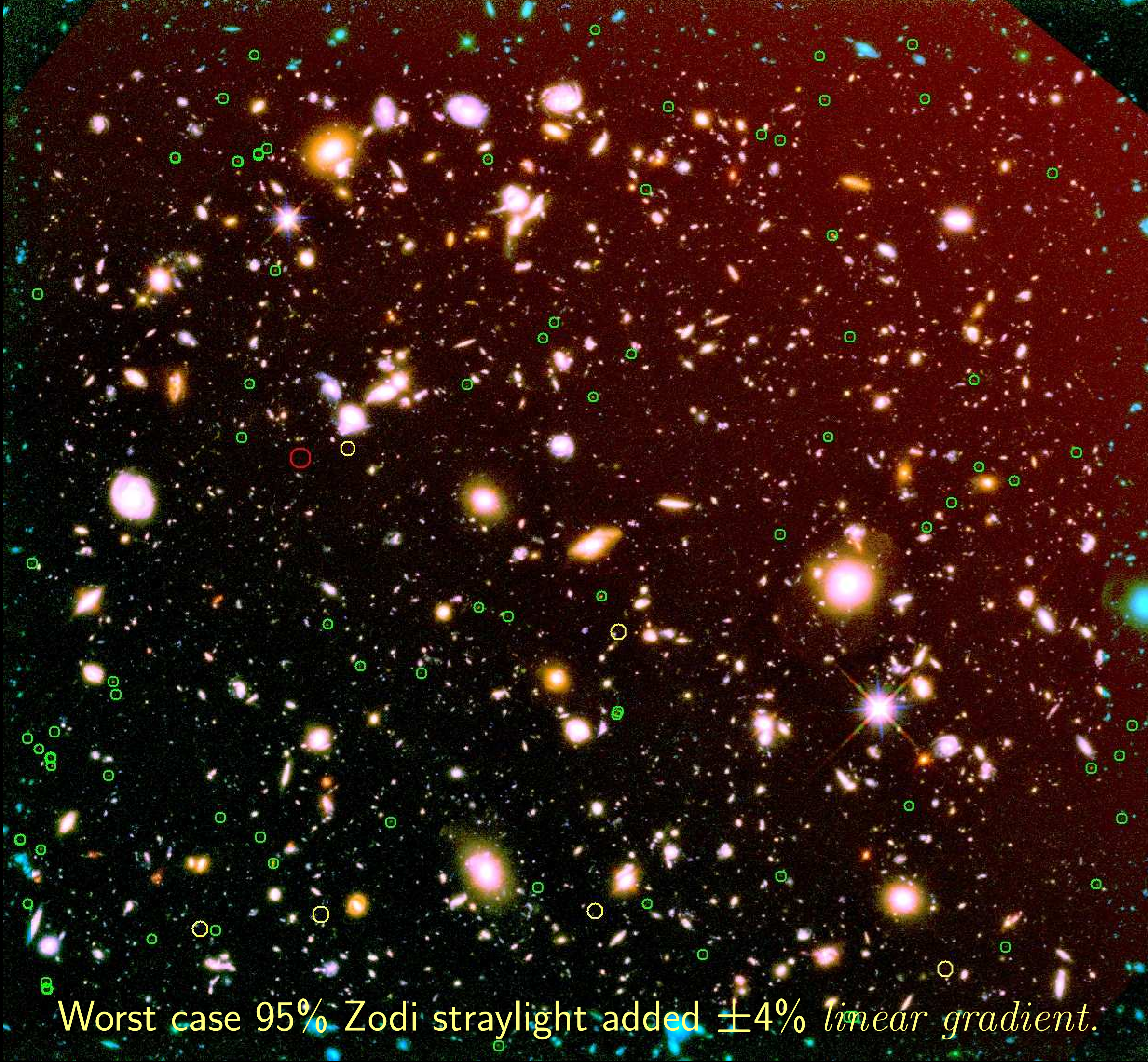
SPARE CHARTS

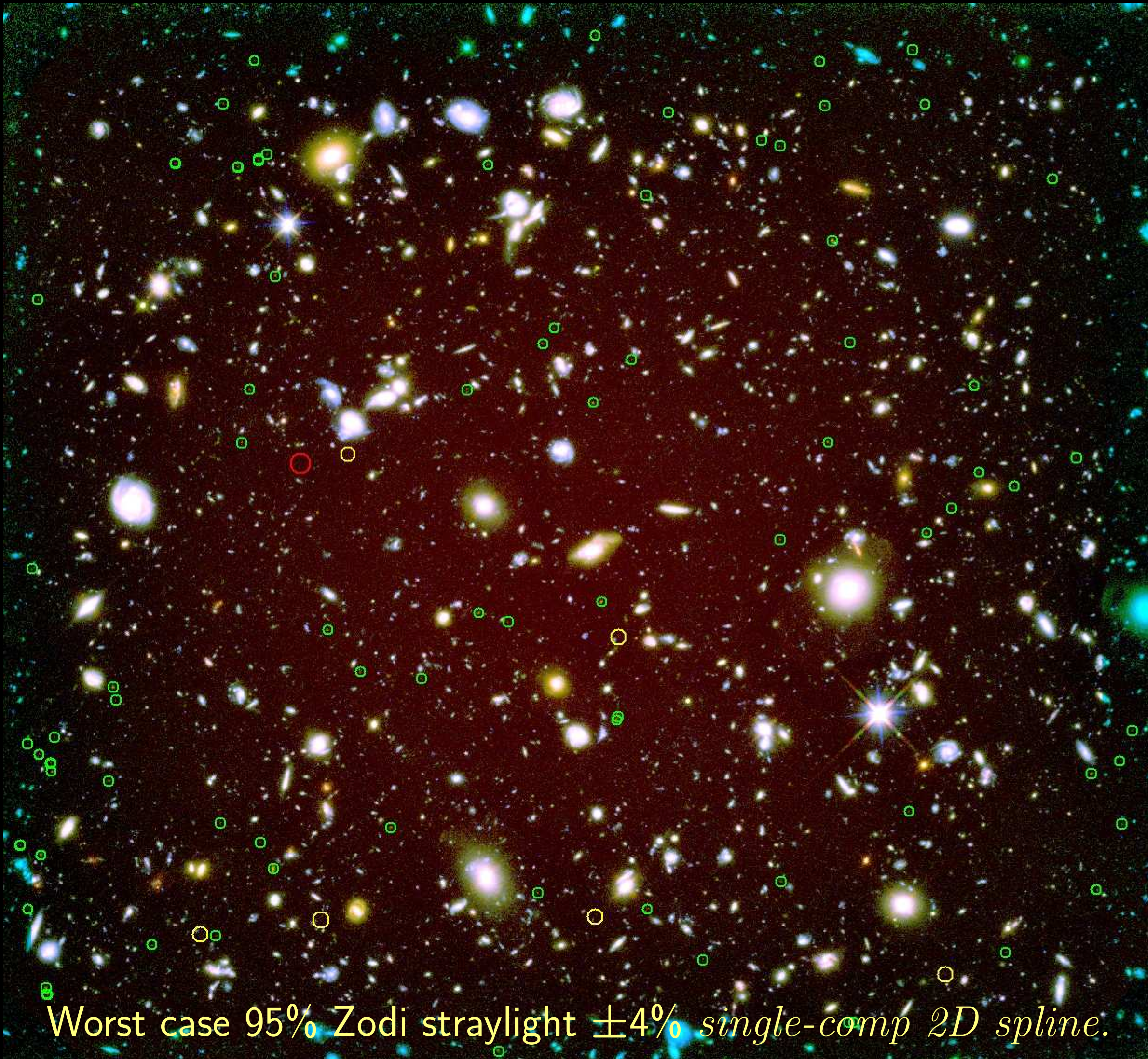
- (4a) Potential Impact of JWST straylight *gradients* & their removal.

- (4b) The Natural Confusion Limit.



$\sim 10^{-3} \times$ sky gradients emphasized: JWST may have $\lesssim$3–10% gradients.


Worst case 95% Zodi straylight added ±4% *linear gradient.*



Worst case 95% Zodi straylight ±4% *single-comp 2D spline.*

Worst case 95% Zodi straylight ±4% *2× 2-comp 2D spline.*

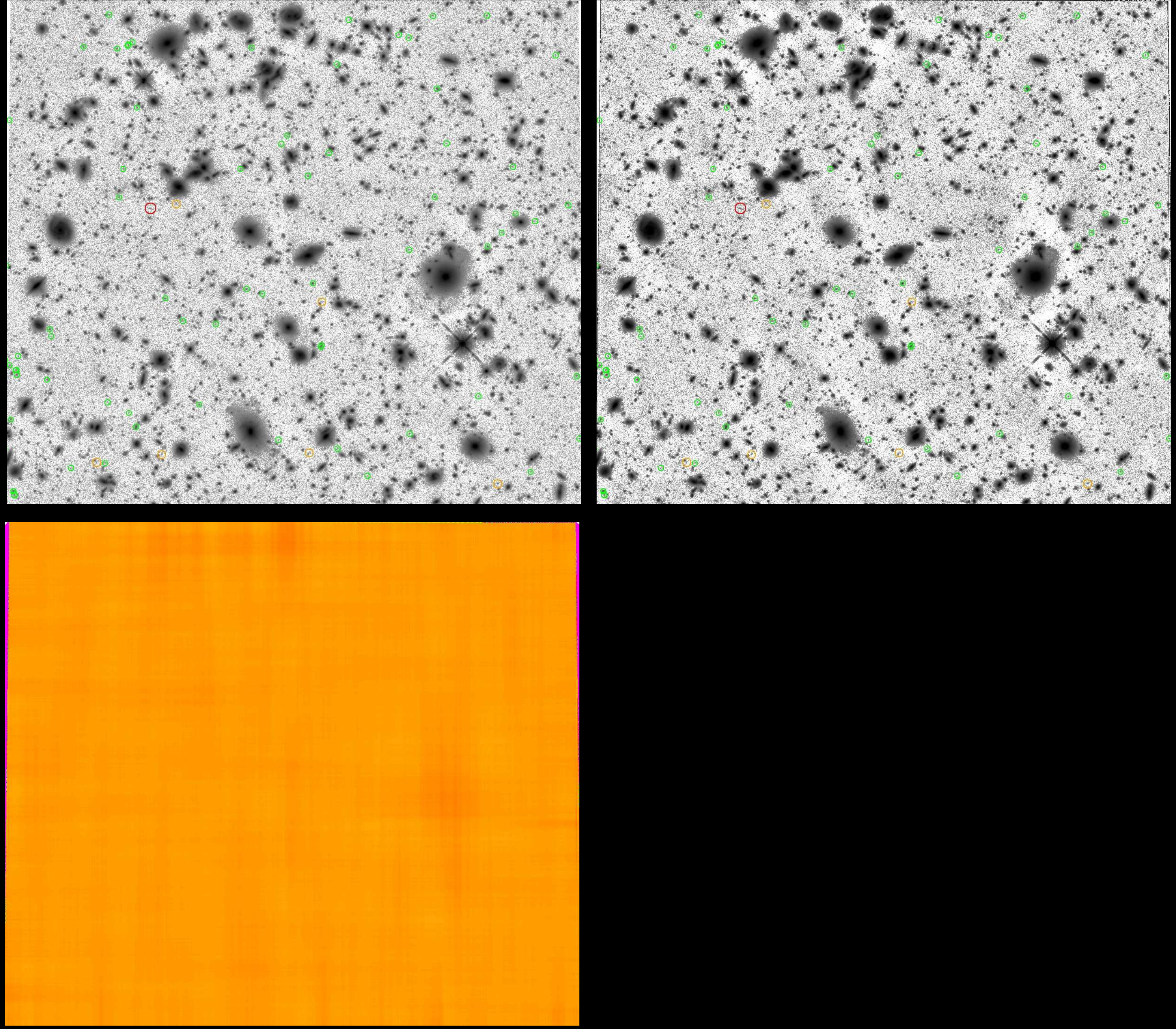
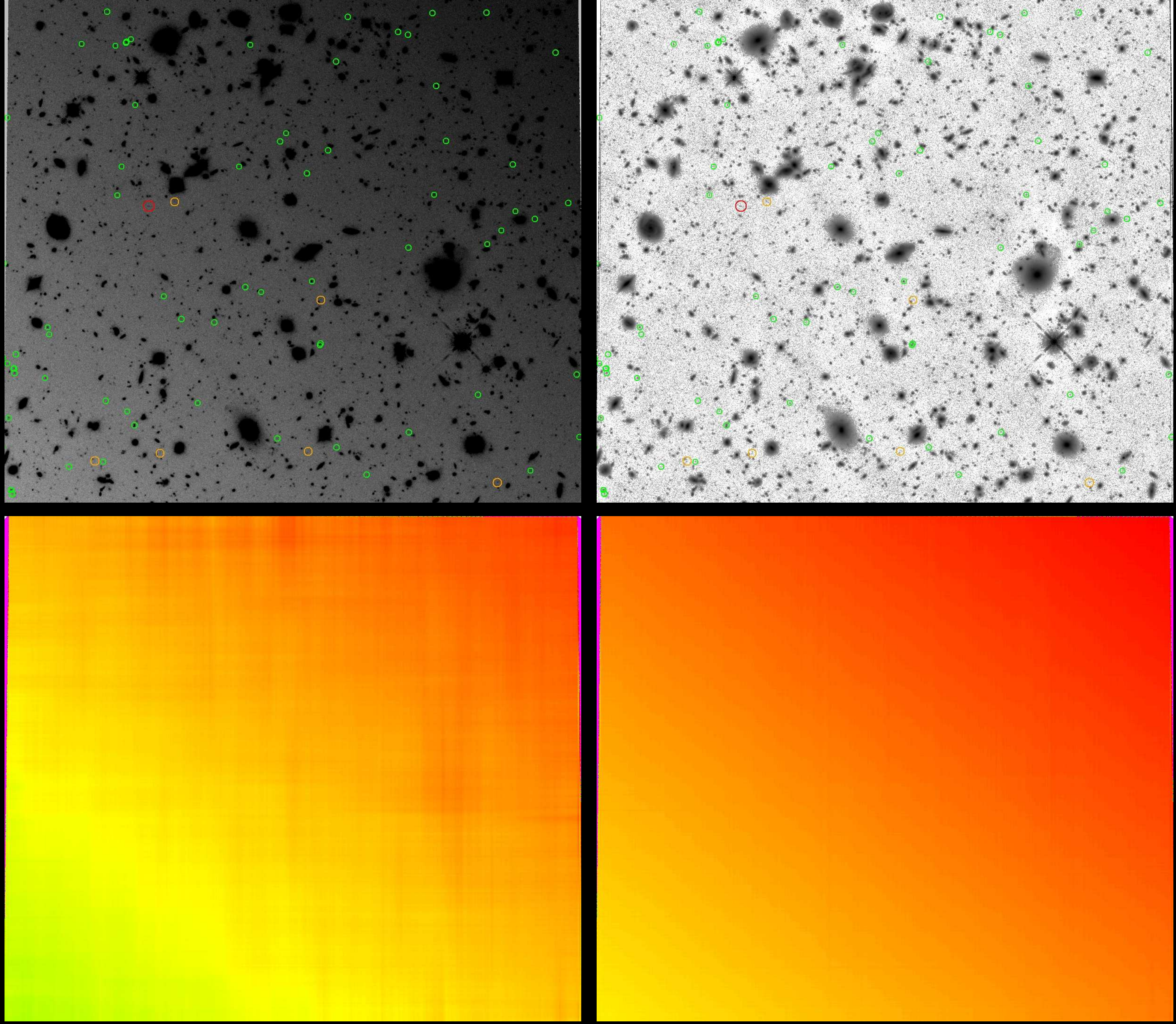
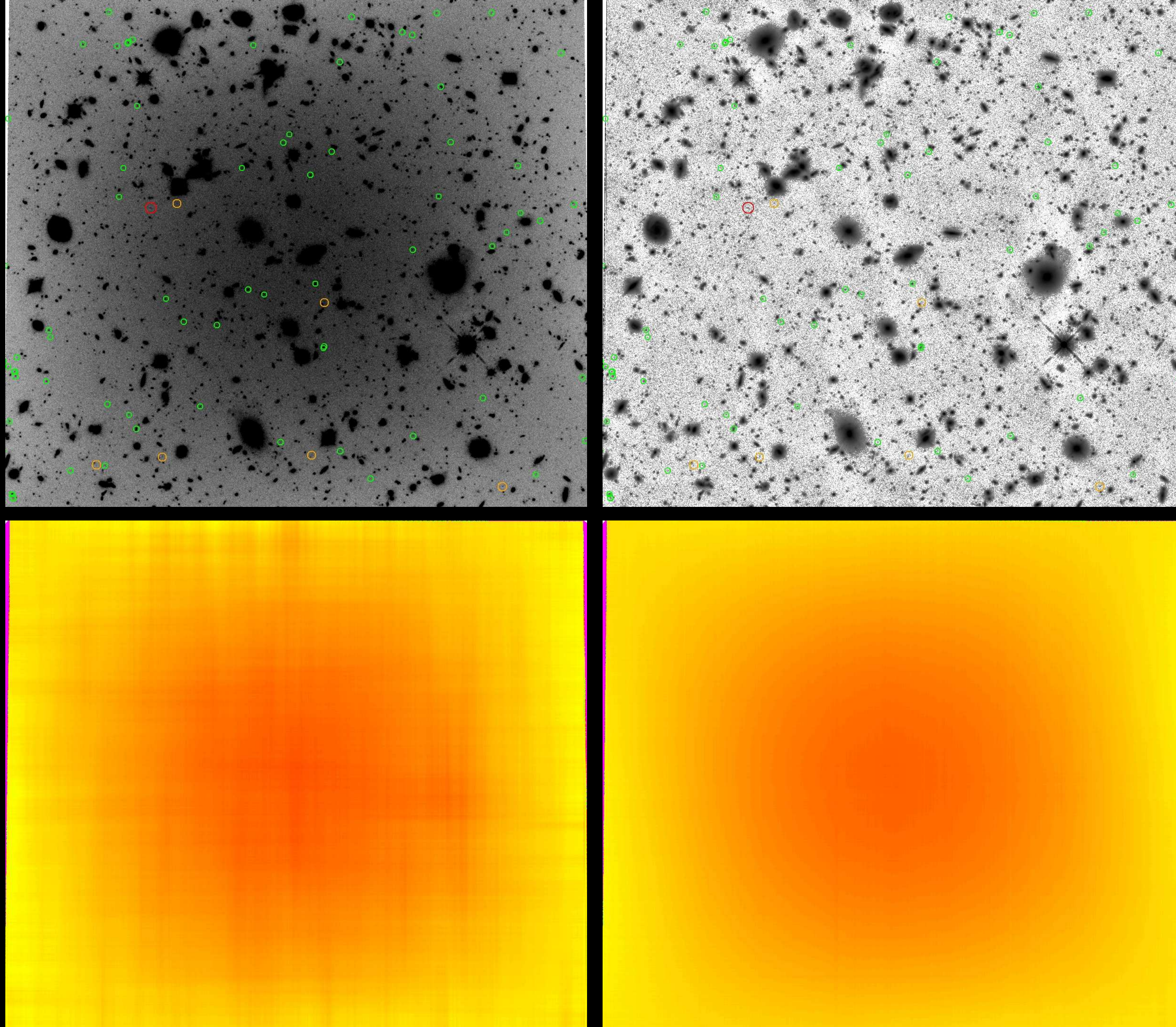


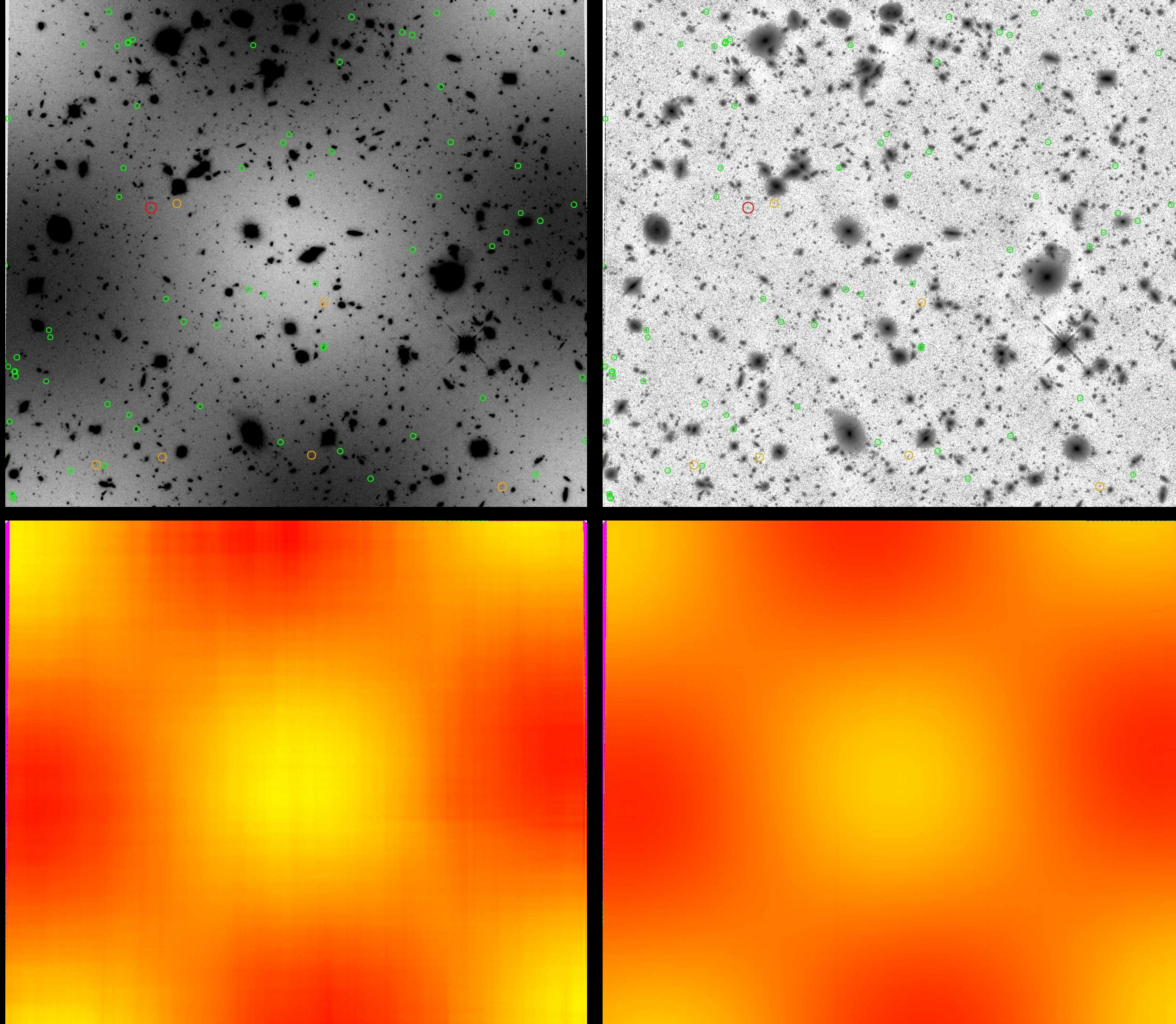
Fig. 2a: [Top Left] HUDF F160W, *no* gradient. [Top Right] with best fit. [Bottom Left] Best fit to (flat) sky-background with “rjbgfit.pro”.



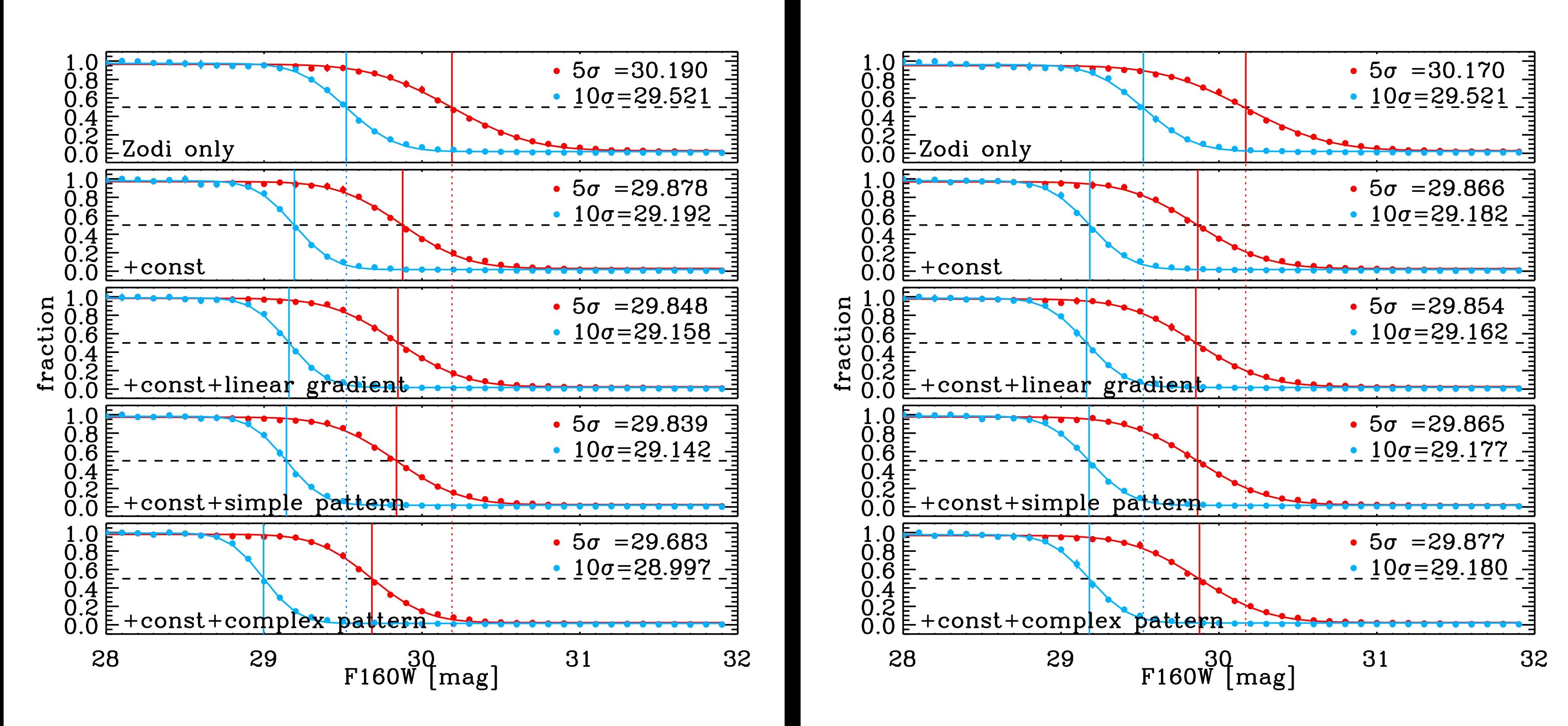
[Left] Worst case 95% of Zodi ±4% *linear gradient*. [Right] Removed.
[Bottom Left] Best fit sky-background; [Bottom Right] Smoothed best fit bg.



[Left] Worst case 95% of Zodi ±4% *single-comp spline*. [Right] Removed.
[Bottom Left] Best fit sky-background; [Bottom Right] Smoothed best fit bg.



[Left] Worst case 95% of Zodi ±4% *2×2-comp 2D spline*. [Right] Removed.
[Bottom Left] Best fit sky-background; [Bottom Right] Smoothed best fit bg.



Completeness test of HUDF F160W image *before* [left] and *after* [right] gradient removal:

Row 1–2 show constant level sky, 2nd–5th row results for linear–splines:

- Code recovers almost all object flux & catalog completeness after gradient removal. SExtractor does the same, except for complex gradients.
- Noise-penalty from constant pedestal of course always remains.
- May also need to remove ICL gradients in JWST cluster lensing images.

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$\gtrsim$25). Will update for JWST.