Observing AGN growth with HST and JWST:

When during galaxy assembly did AGN growth take place?

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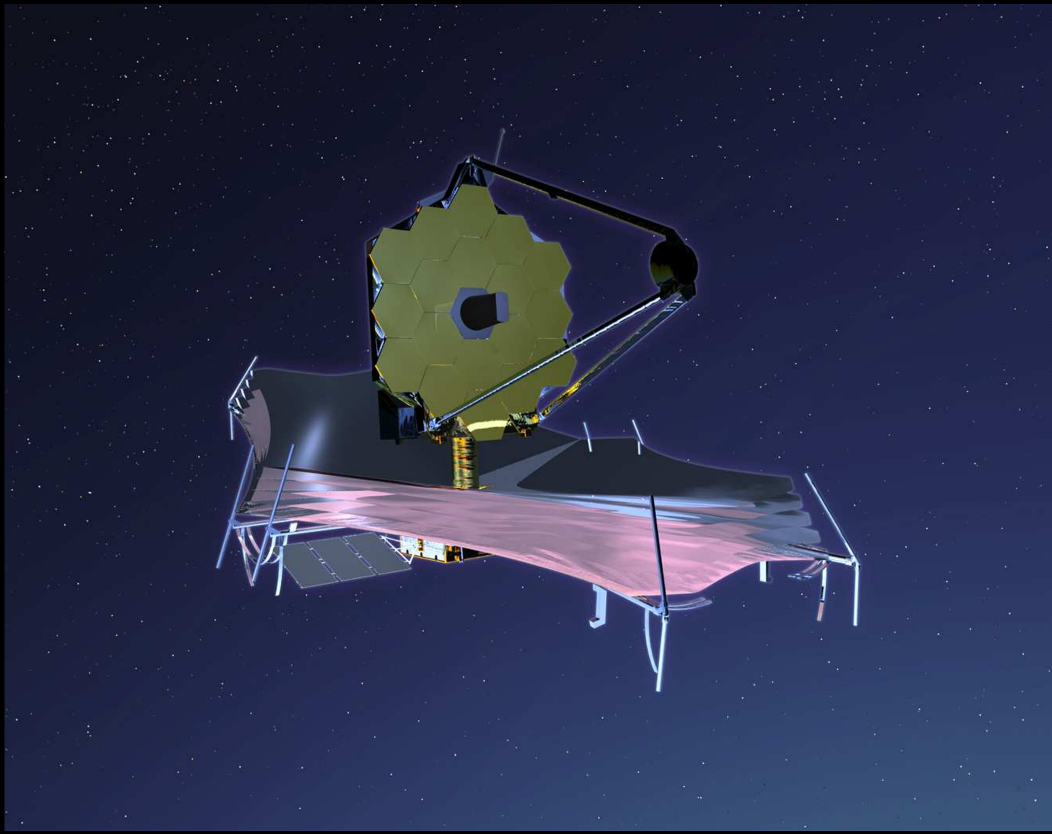


Lunchtalk at University of Kansas, Lawrence, Tuesday March 1, 2011

"For God's sake, Edwards. Put the laser pointer away."

The danger of having Quasar-like devices too close to home ...

Outline

- (0) Summary of First Light and H-Reionization at z$\gtrsim$6:
What has HST done, and what can JWST do?

- (1) HST/WFC3 & JWST: how did AGN/SMBH-growth go hand-in-hand with Galaxy Assembly?

- (2) (Major) mergers in GOODS & HUDF: Measuring Galaxy Assembly?

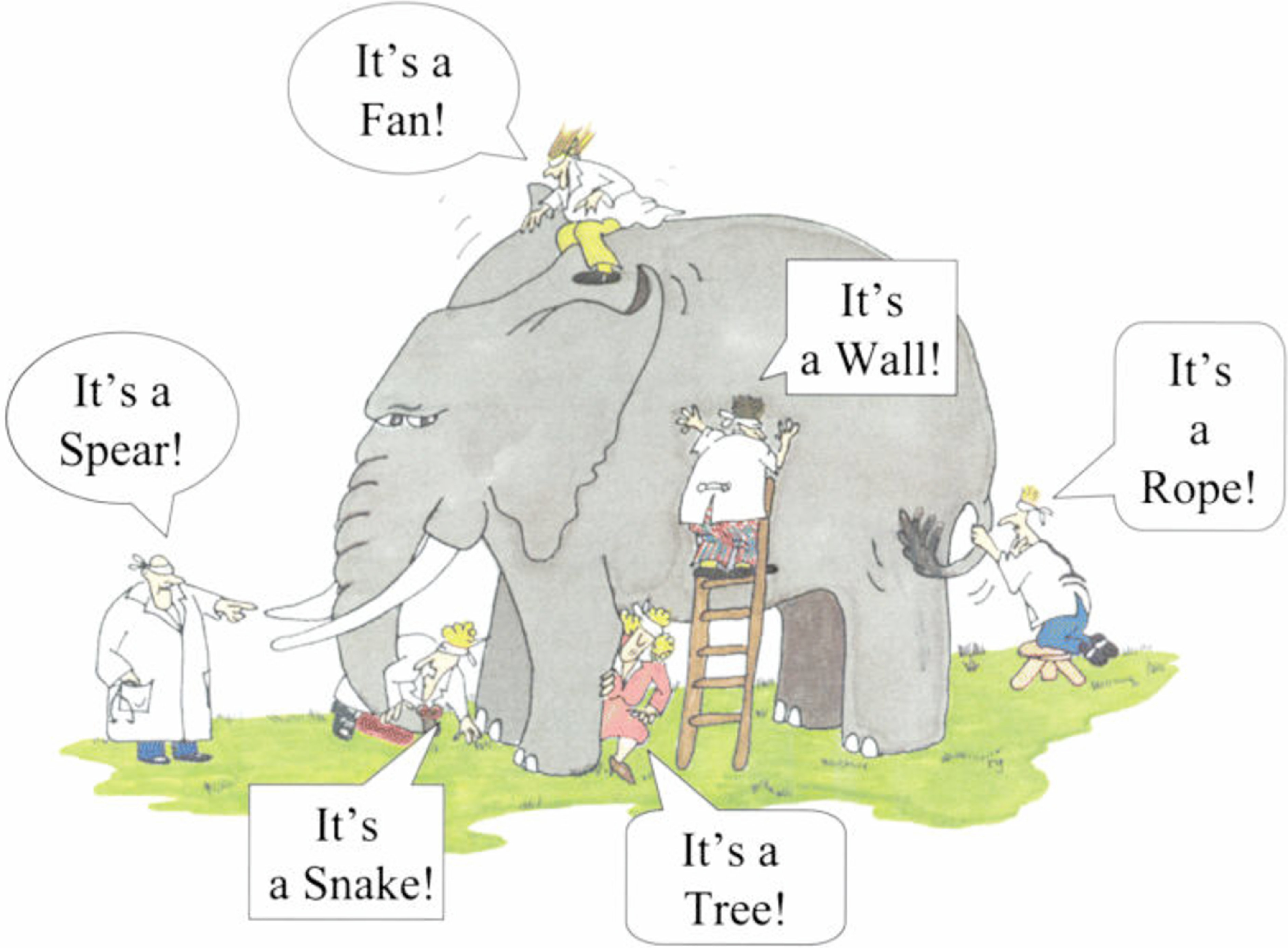
- (3) Variable Objects in the HUDF: A measure of AGN/SMBH-Growth?

- (4) Epoch dependent major merger rate to AB$\lesssim$27 and Chandra N(z).

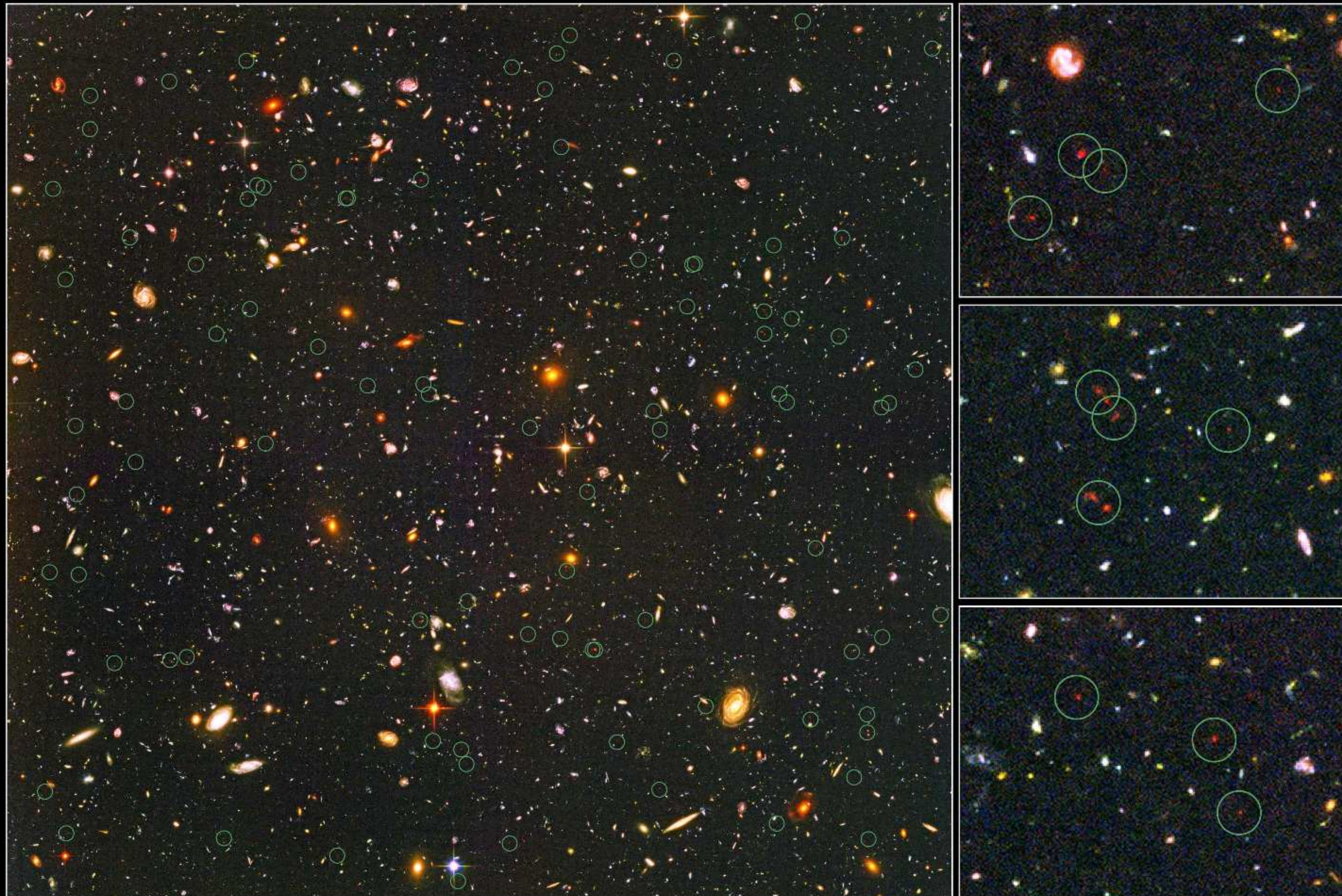
- (5) SED ages of radio and X-ray host galaxies vs. epoch:
May trace AGN-growth vs. Galaxy Assembly directly.

- (6) Summary and Conclusions: Delta t(X-ray/Radio X— field) $\lesssim$1 Gyr.

Sponsored by NASA/JWST. All charts ITAR cleared



AGN are the cosmic elephants that surprise both observers and theorists ... !



Distant Galaxies in the Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

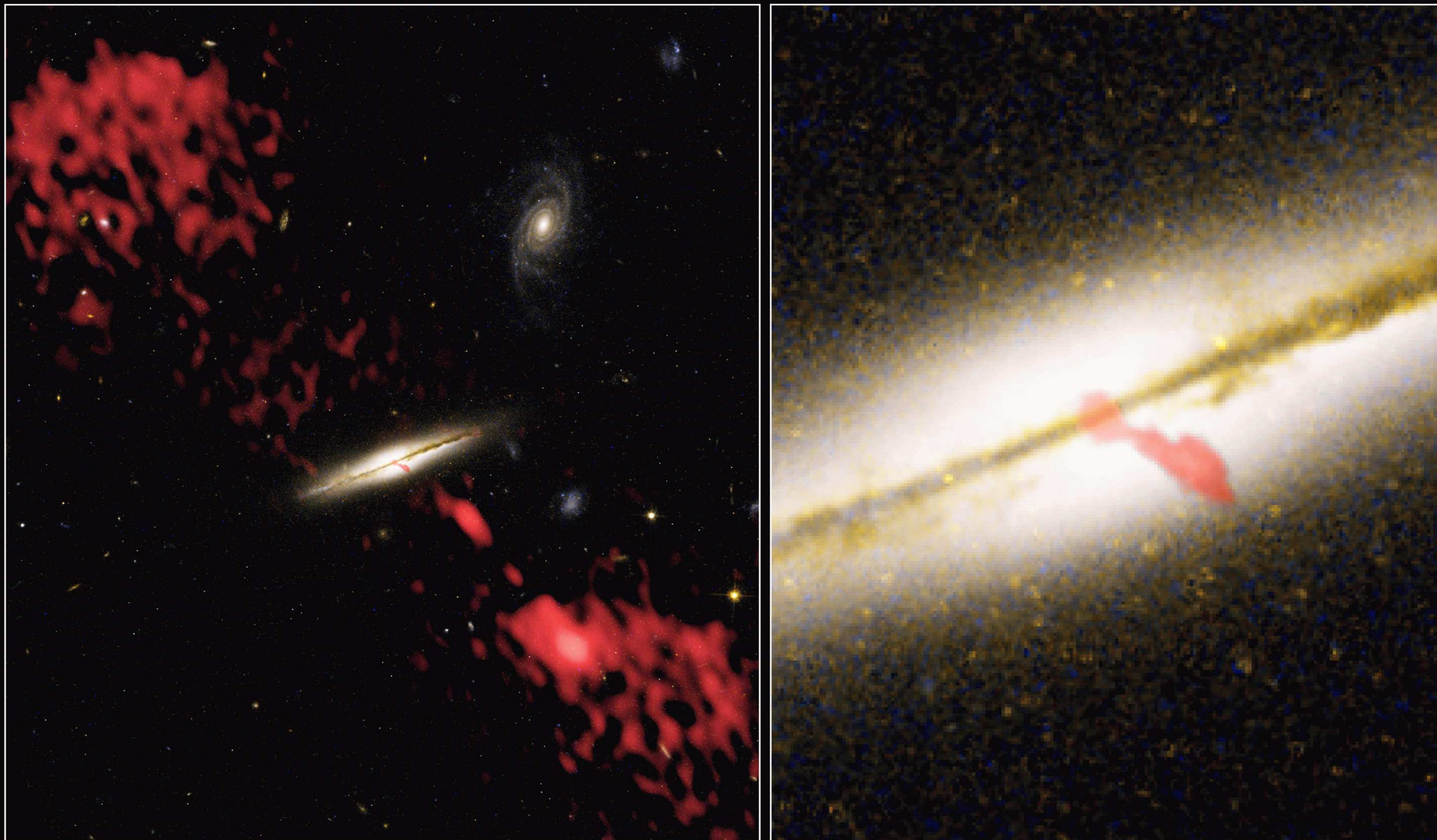
NASA, ESA, R. Windhorst (Arizona State University) and H. Yan (Spitzer Science Center, Caltech) STScI-PRC04-28

In an HUDF^3 volume at z≃2–6:

M$_{DM}$ $\sim$ 10$^{12-13}$ $M_\odot$, M$_{baryon}$ $\sim$ 2×10$^{11-12}$ $M_\odot$,

M$^*_{gxys}$ $\sim$ 2×10$^{10-11}$ $M_\odot$, M$_{SMBH}$ $\sim$ 4×10$^{7-8}$ $M_\odot$.

(0) How can HST & JWST measure Galaxy Assembly & SMBH/AGN Growth?

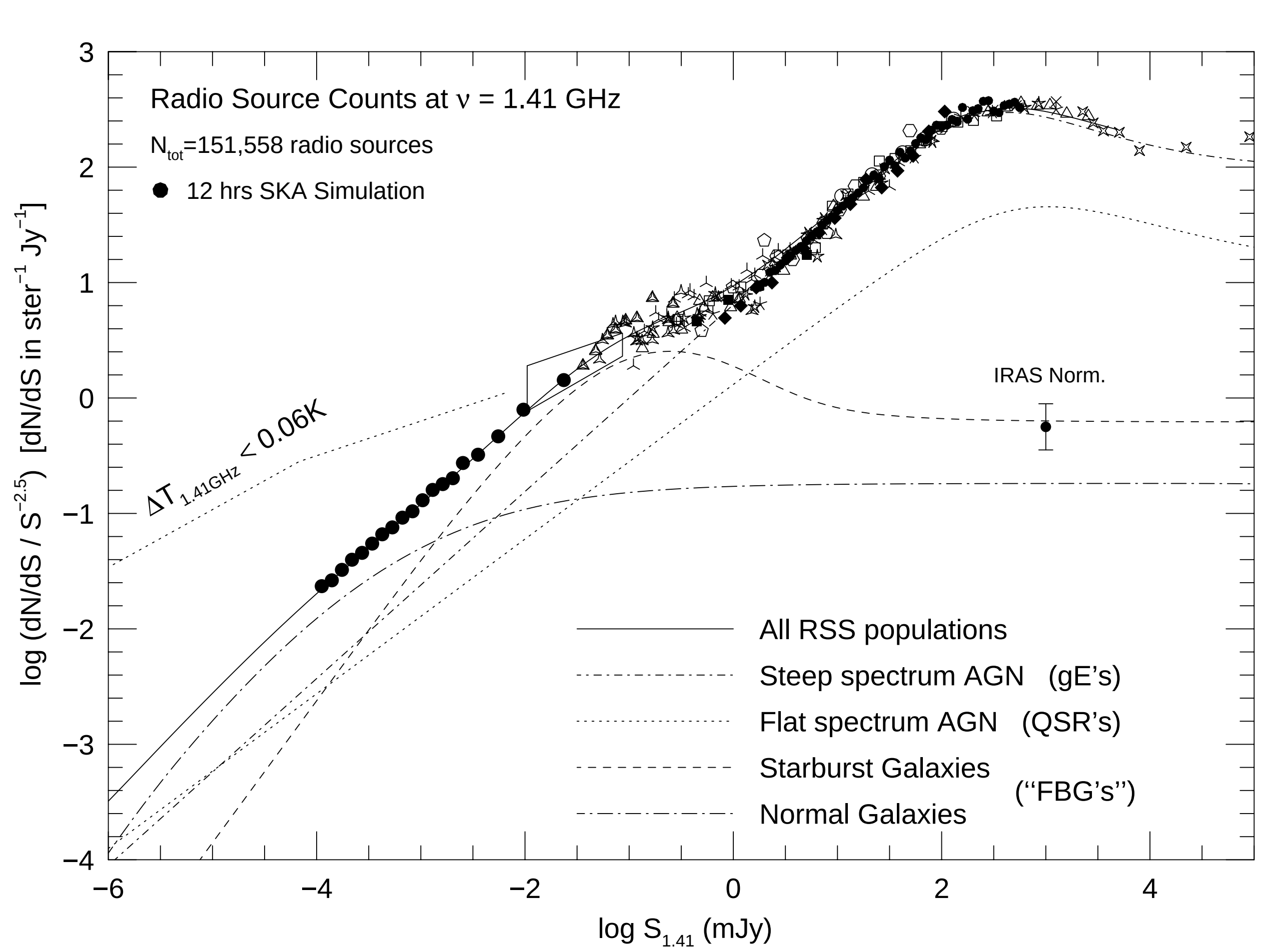


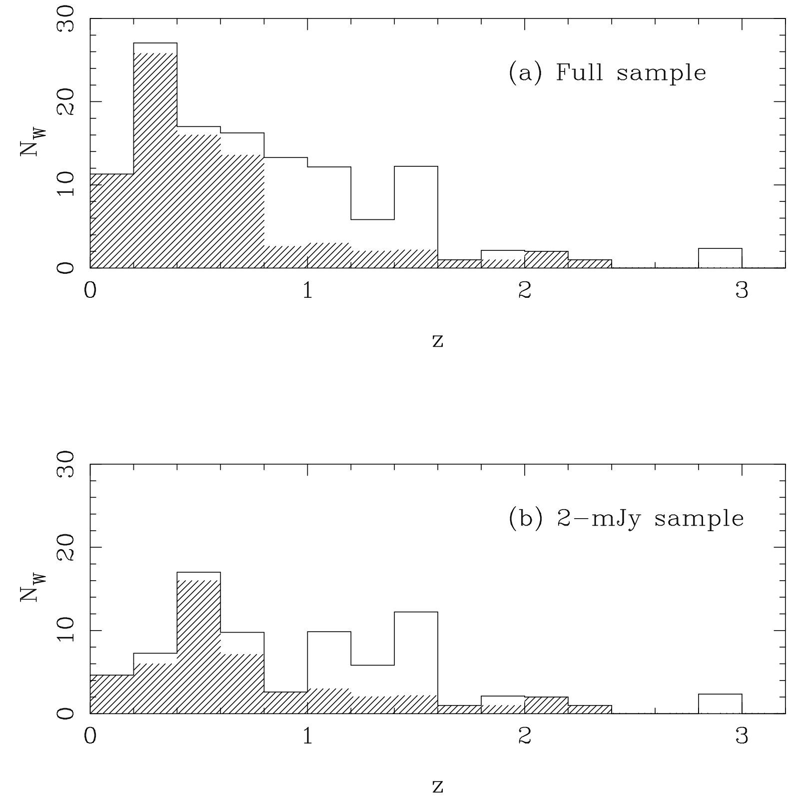
Radio Galaxy 0313-192

Hubble Space Telescope ACS WFC ▪ **Very Large Array**

NASA, NRAO/AUI/NSF and W. Keel (University of Alabama) ▪ STScI-PRC03-04

Question: How long after last (major) merger/SF does AGN activity show?



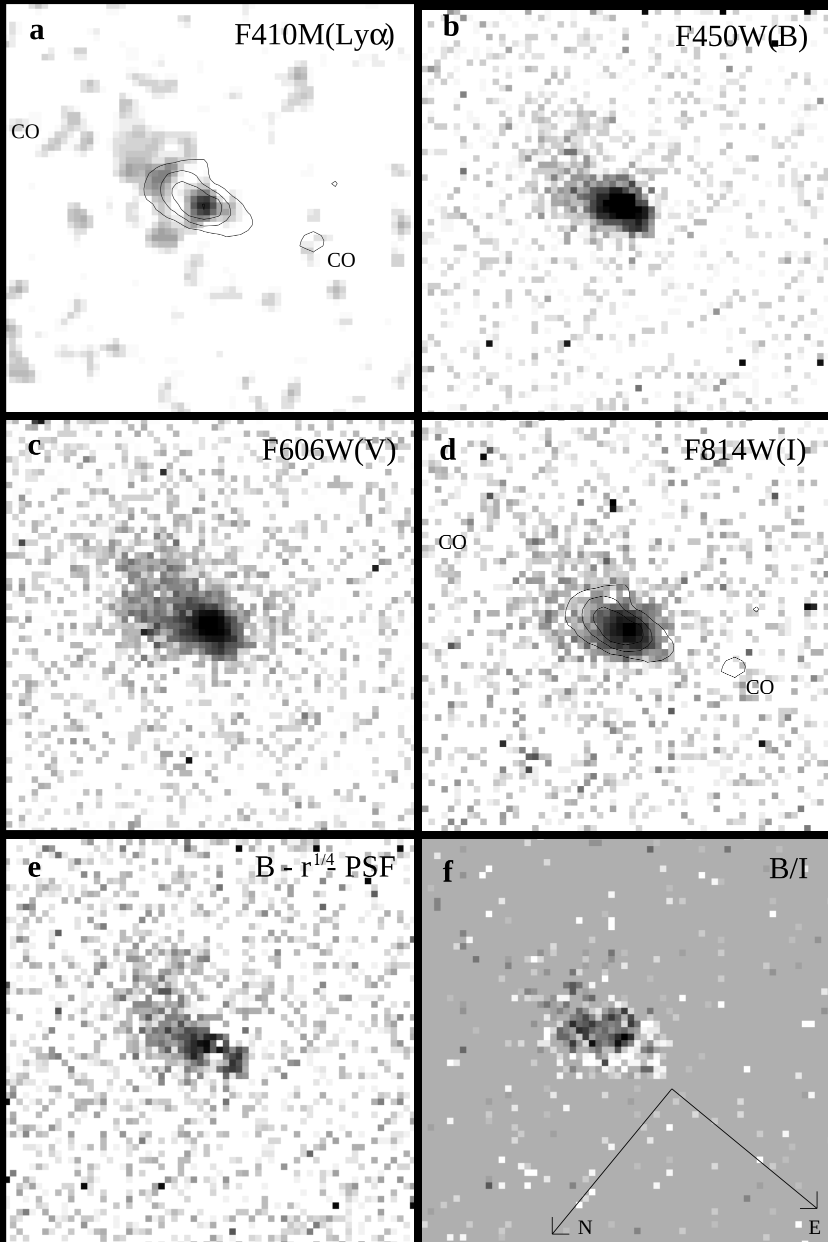


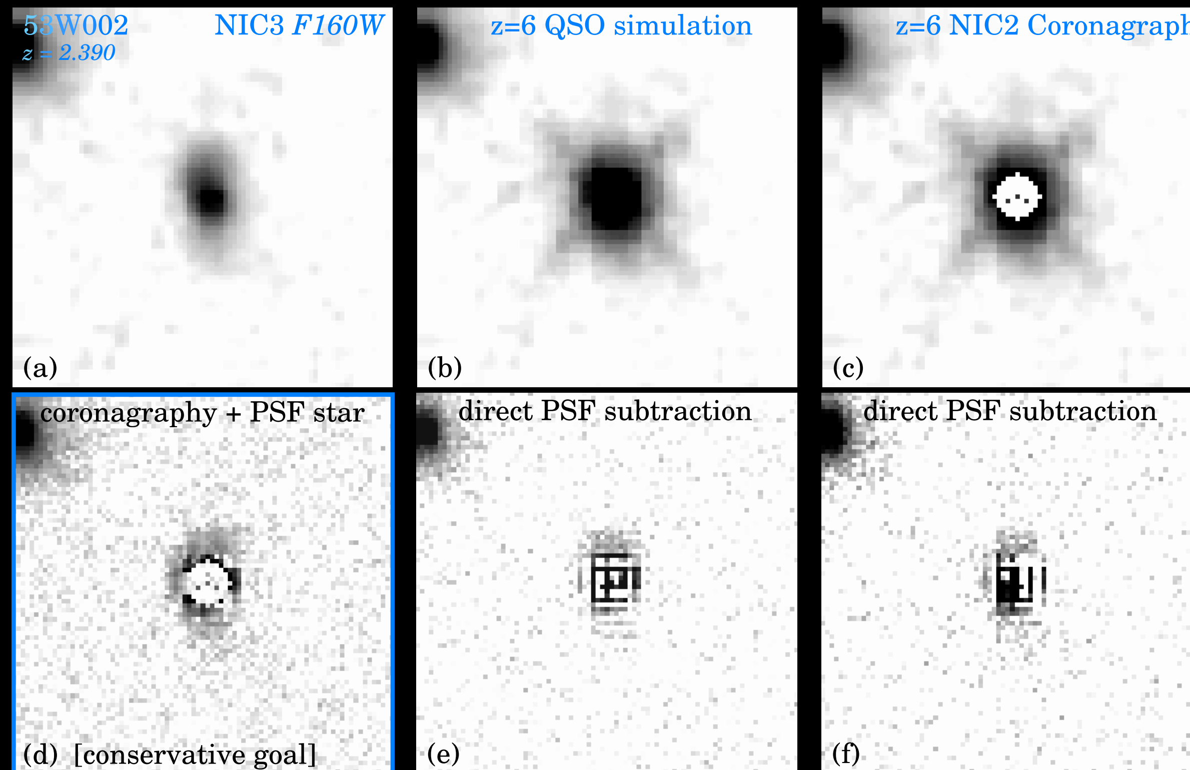
(LEFT) 1.41 GHz source counts (Windhorst et al. 1993, 2003; Hopkins et al. 2000) from 100 Jy to 100 nJy: AGN (monsters) dominate $\gtrsim$1 mJy, starbursts below 1 mJy [12-hr SKA simulation below 10 μJy].

(RIGHT) Redshift distribution of mJy radio sources (Waddington^{+} 2001):

- Median redshift z_{med} $\lesssim$1 at all flux levels, due to radio K-correction.
- Same in X-rays $\Longrightarrow$ Radio and X-ray fairly poor high-z AGN tracers!

(Left): HST/PC of radio galaxy 53W002 at z=2.39 (Windhorst et al. 1998): rest-UV $r^{1/4}$-law + Lyα & Cont AGN-cloud.

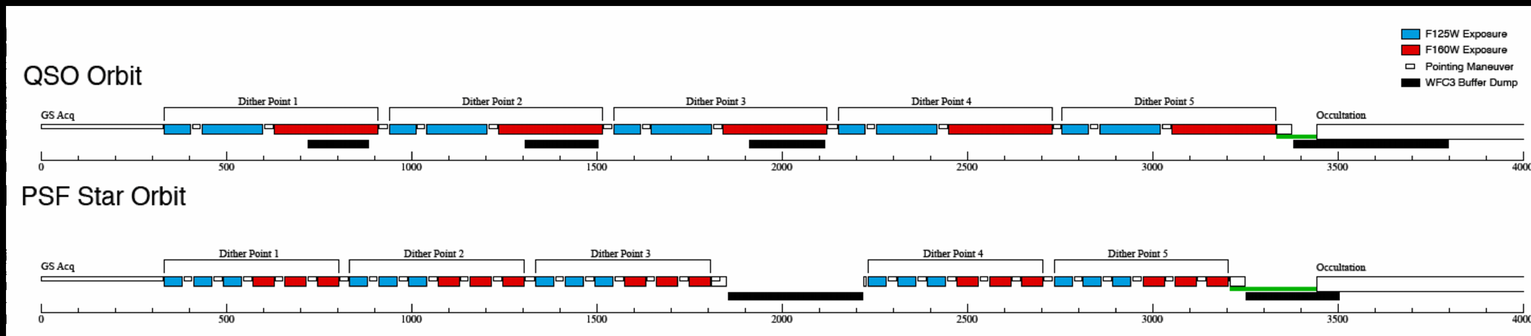


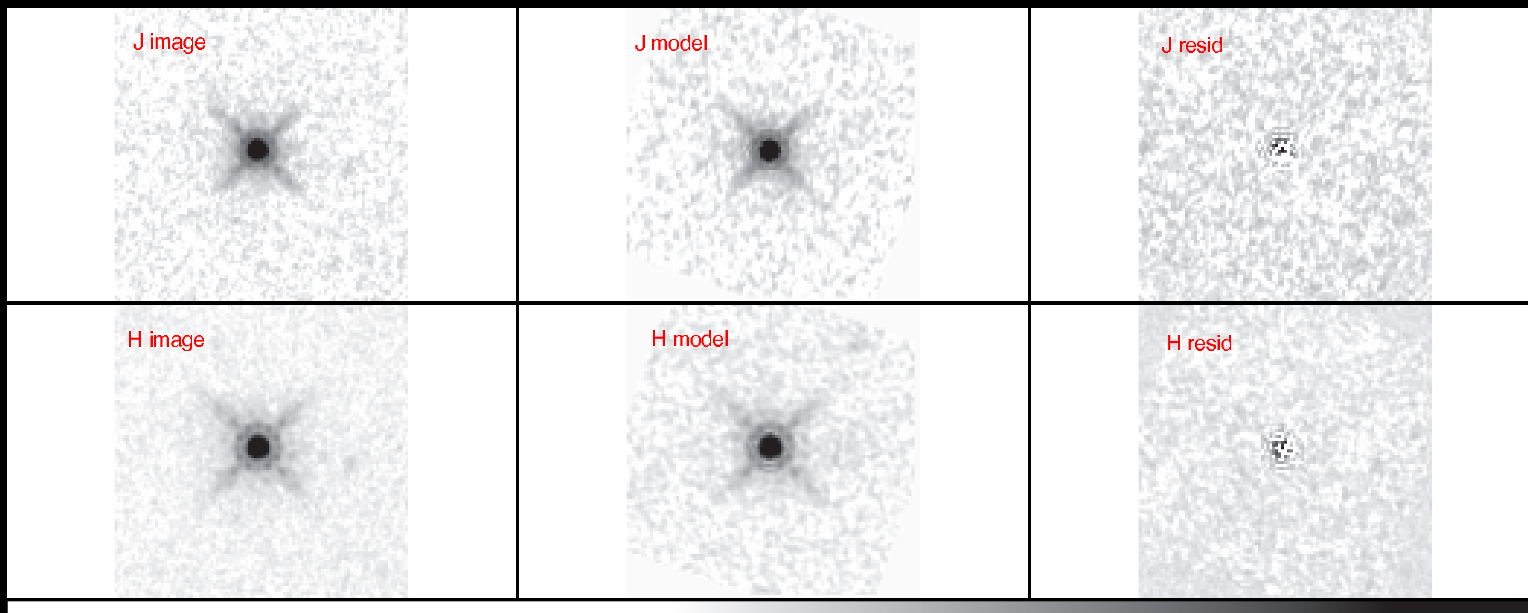


Coronagraph simulation of z=6 SDSS QSO host (using HST/NIC2+Corona). Can measure $>L^*$ AGN-host at z$\gtrsim$6.

- JWST can measure AGN hosts 3 mag fainter in restframe UV-Opt to z$\lesssim$20.
- Such AGN are very rare. JWST must use other ways to trace AGN-growth.

HST WFC3 observations of SDSS Quasar Host Galaxies at z$\simeq$6



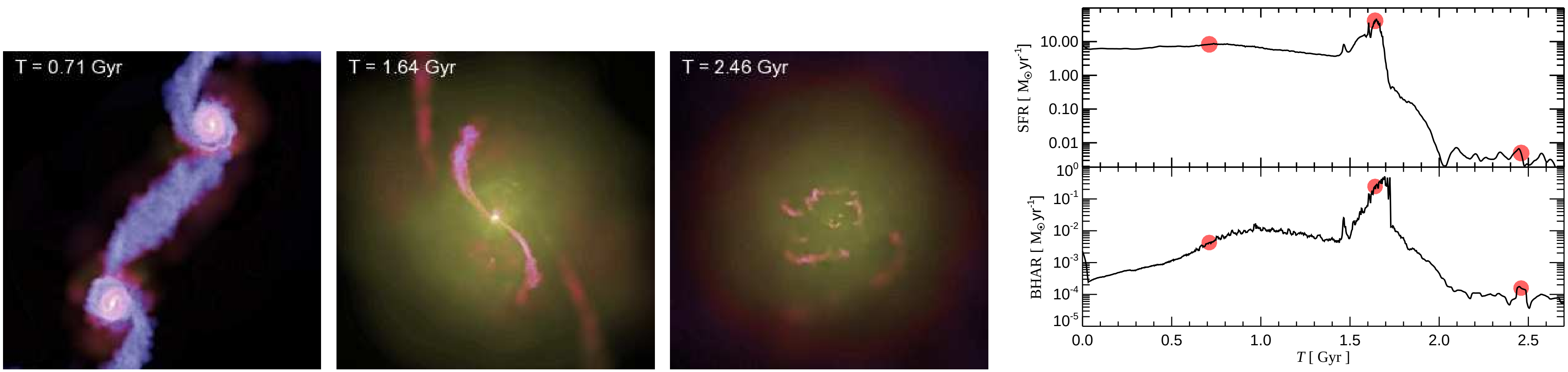


Careful contemporaneous orbital WFC3 PSF-subtraction: removes most of HST "OTA spacecraft breathing" effects (Mechtley et al. 2011).

Using BA=15 mag PSF subtracts 18.5 mag QSO nearly to the noise limit: NO underlying host galaxy detected to AB$\gtrsim$25 mag ($r \gtrsim 0''.3$).

THE most luminous objects in the Universe: Do all host galaxies have M$<<M^*$? $\Longrightarrow$ Major implications for Galaxy Assembly–SMBH Growth!

(0) How to trace SMBH/AGN-growth after Galaxy Merger &/or Starburst?

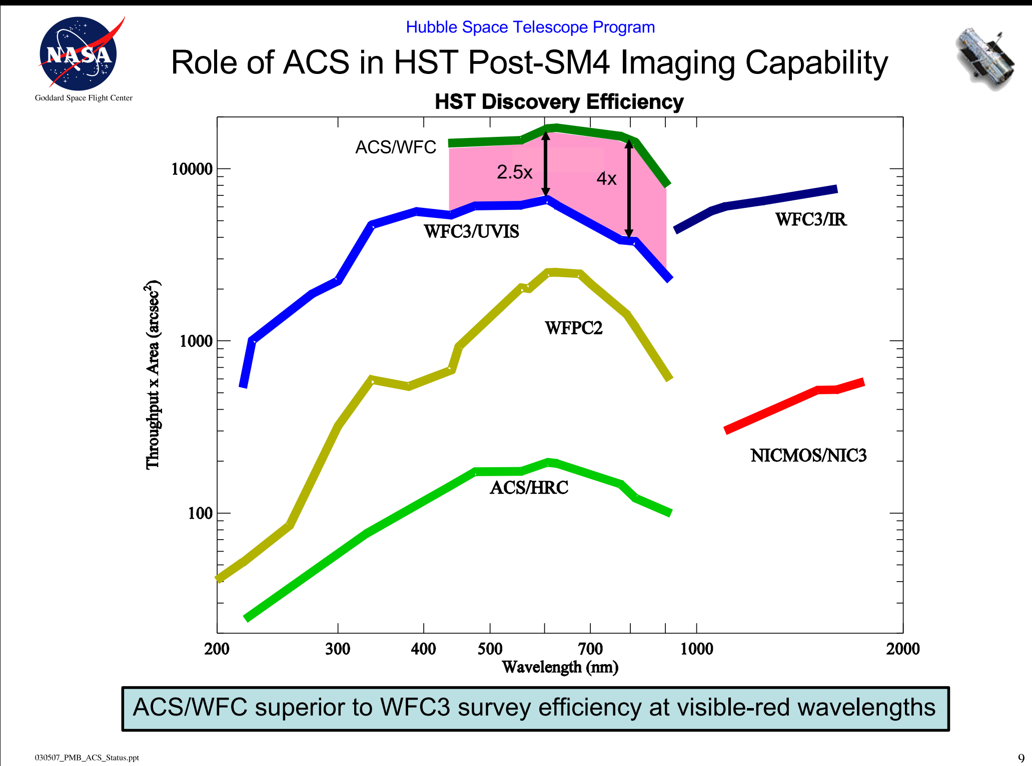


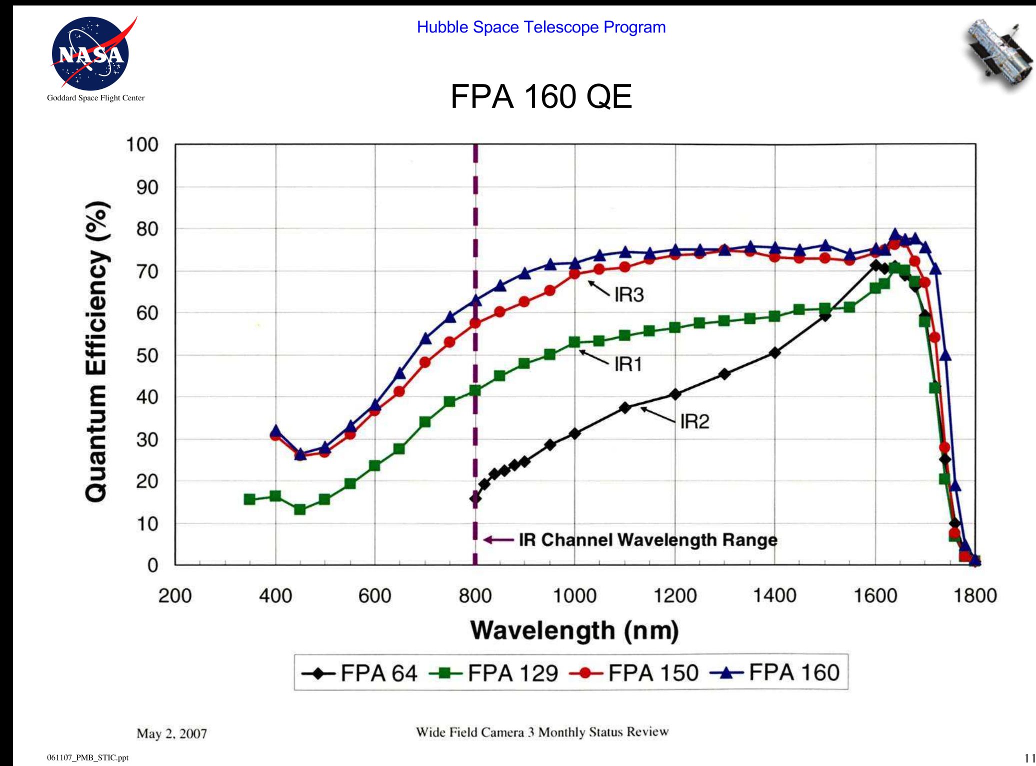
- [LEFT] Simulated merger of two disk galaxies at three different times, including the effects of SMBH growth and AGN feedback by Springel, di Matteo, Hernquist (2005, ApJ, 620, 79). Shown is the gas distribution with color indicating temperature, and brightness indicating gas density.

- [RIGHT] Evolution of the accretion rate onto the SMBH (top) and the SF-rate (bottom). Red dots mark the times of the three images.

$\Leftrightarrow$ In hydrodynamical simulations, the object resembles a tadpole galaxy $\sim$0.7 Gyr after the merger starts, the AGN is triggered and expels the dust $\gtrsim$1.6 Gyr after the merger starts, *i.e.*, $\gtrsim$1 Gyr after the starburst stage.

WFC3: Hubble's new Panchromatic High-Throughput Camera





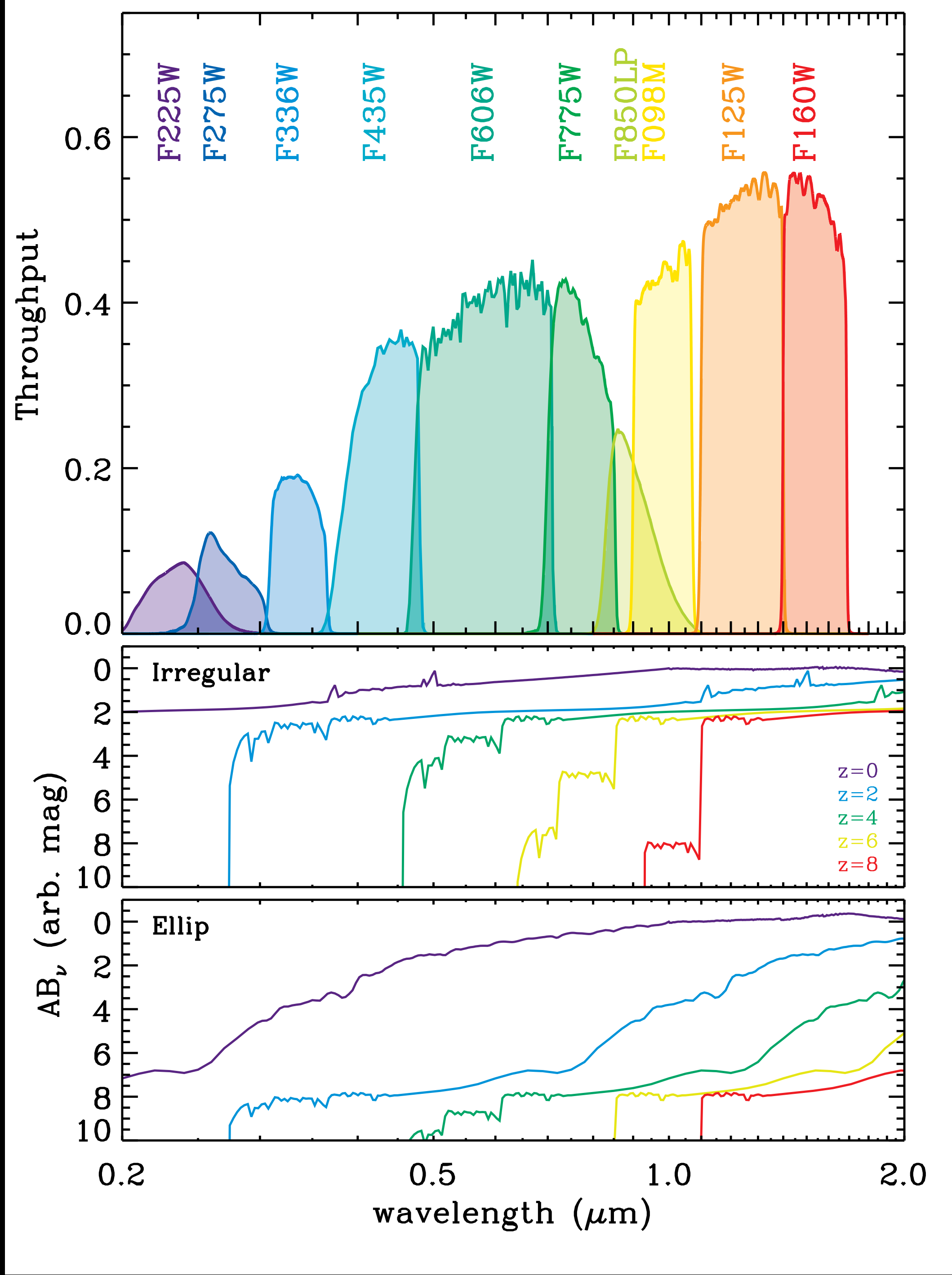
WFC3/UVIS channel has unprecedented UV–blue throughput & areal coverage:

- QE$\gtrsim$70%, 4k$\times$4k E2V array of $0\farcs04$ pixel, FOV $\simeq 2\farcm67 \times 2\farcm67$

WFC3/IR channel has unprecedented near–IR throughput & areal coverage:

- QE$\gtrsim$70%, 1k$\times$1k Hawaii array of $0\farcs13$ pixel, FOV $\simeq 2\farcm25 \times 2\farcm25$

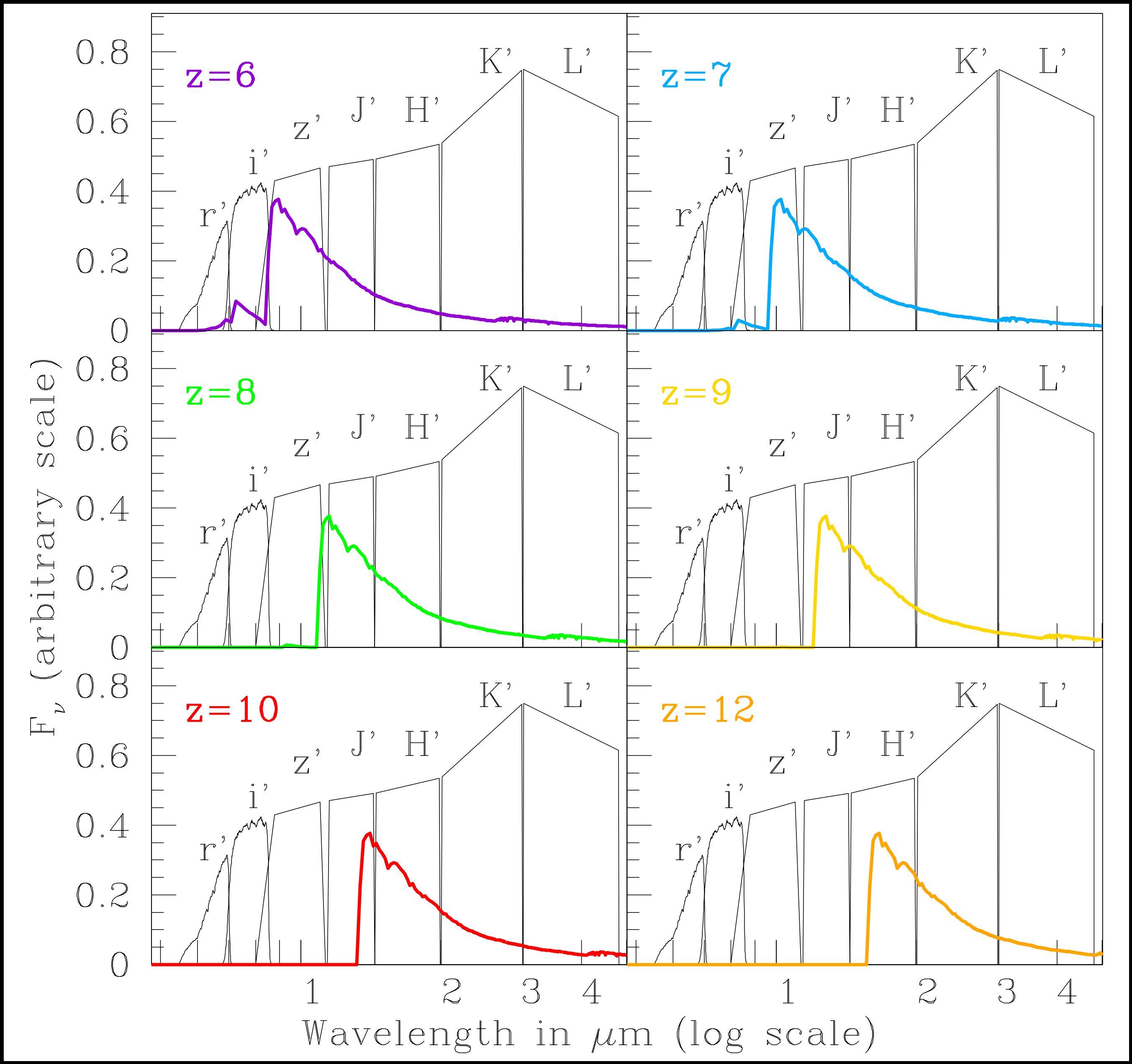
$\Longrightarrow$ WFC3 opened major new parameter space for astrophysics in 2009.



Panchromatic HST/WFC3 & ACS filters used in GOODS-South ERS.

Filters designed for Star-formation and galaxy mass assembly at z≃1–5.

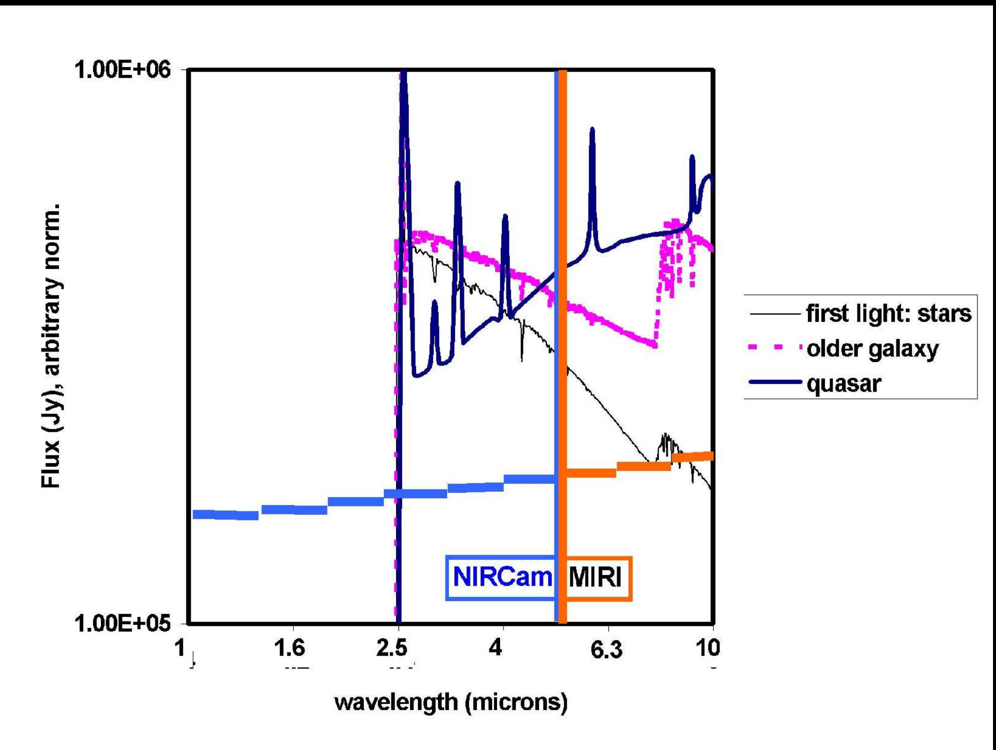
How can HST & JWST measure Galaxy Assembly & SMBH/AGN Growth?

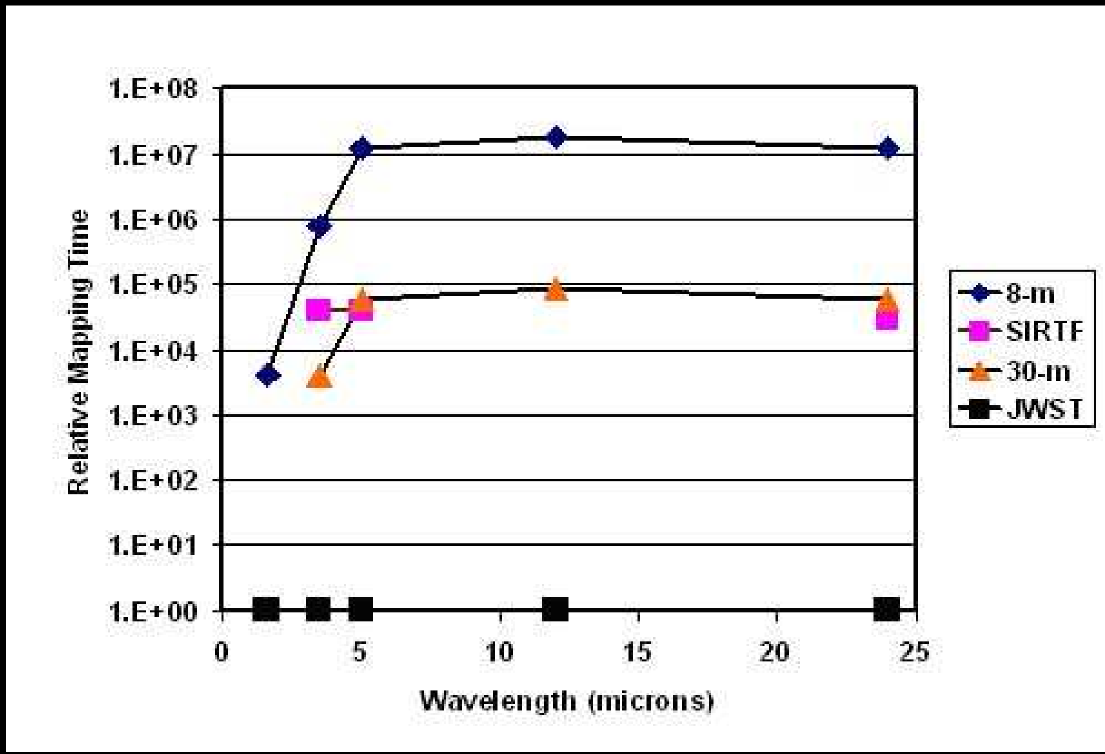


- Can't beat redshift: to see First Light, must observe near–mid IR.

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

• (1b) What sensitivity will JWST have?



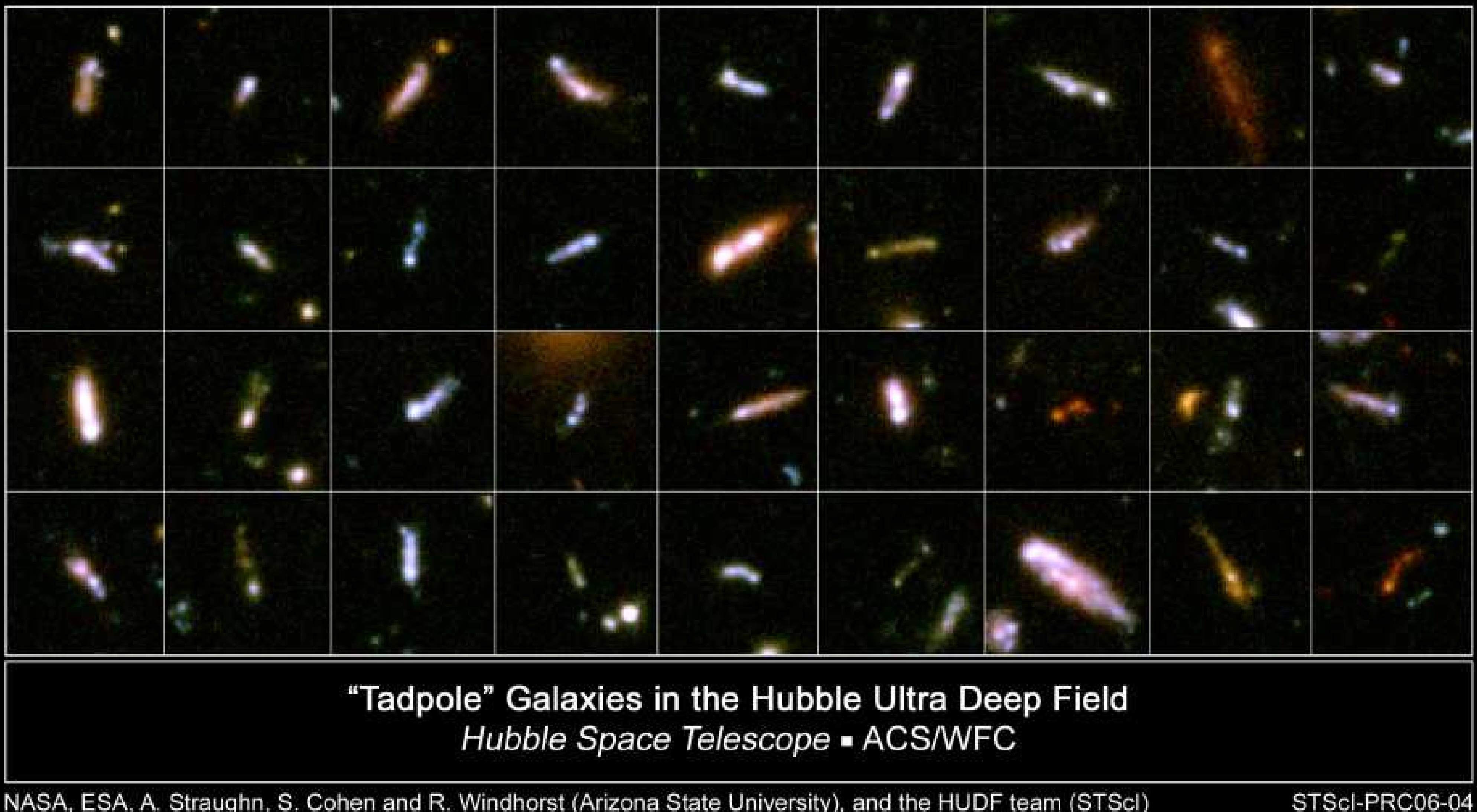


NIRCam and MIRI sensitivity complement each other, straddling $\lambda \simeq 5\ \mu$m. Together, they allow objects to be found to z=15–20 in $\sim 10^5$ sec (28 hrs).

LEFT: NIRCam and MIRI broadband sensitivity to a Quasar, a "First Light" galaxy dominated by massive stars, and a 50 Myr "old" galaxy at z=20.

RIGHT: Relative survey time vs. λ that Spitzer, a ground-based IR-optimized 8-m, and a 30-m telescope would need to match JWST.

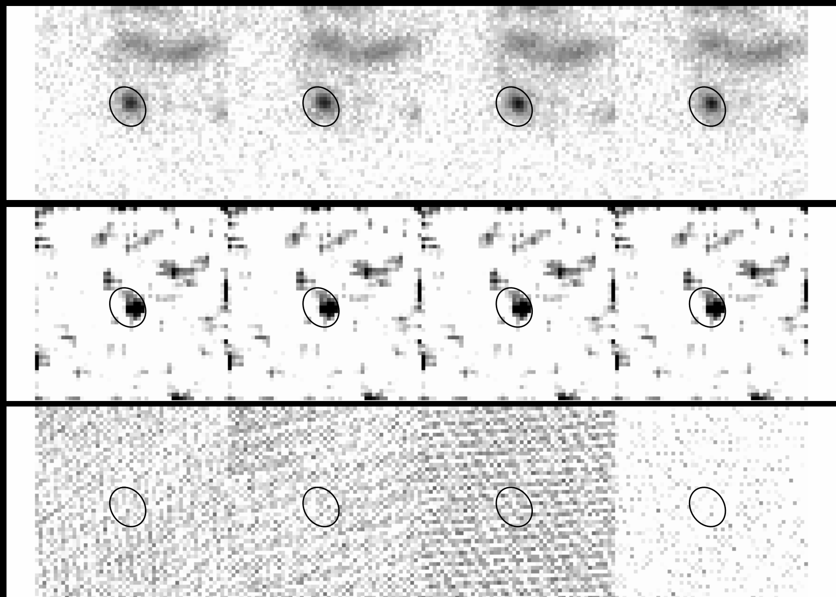
(2) A study of Early-Stage Mergers in the HUDF: Any AGN?

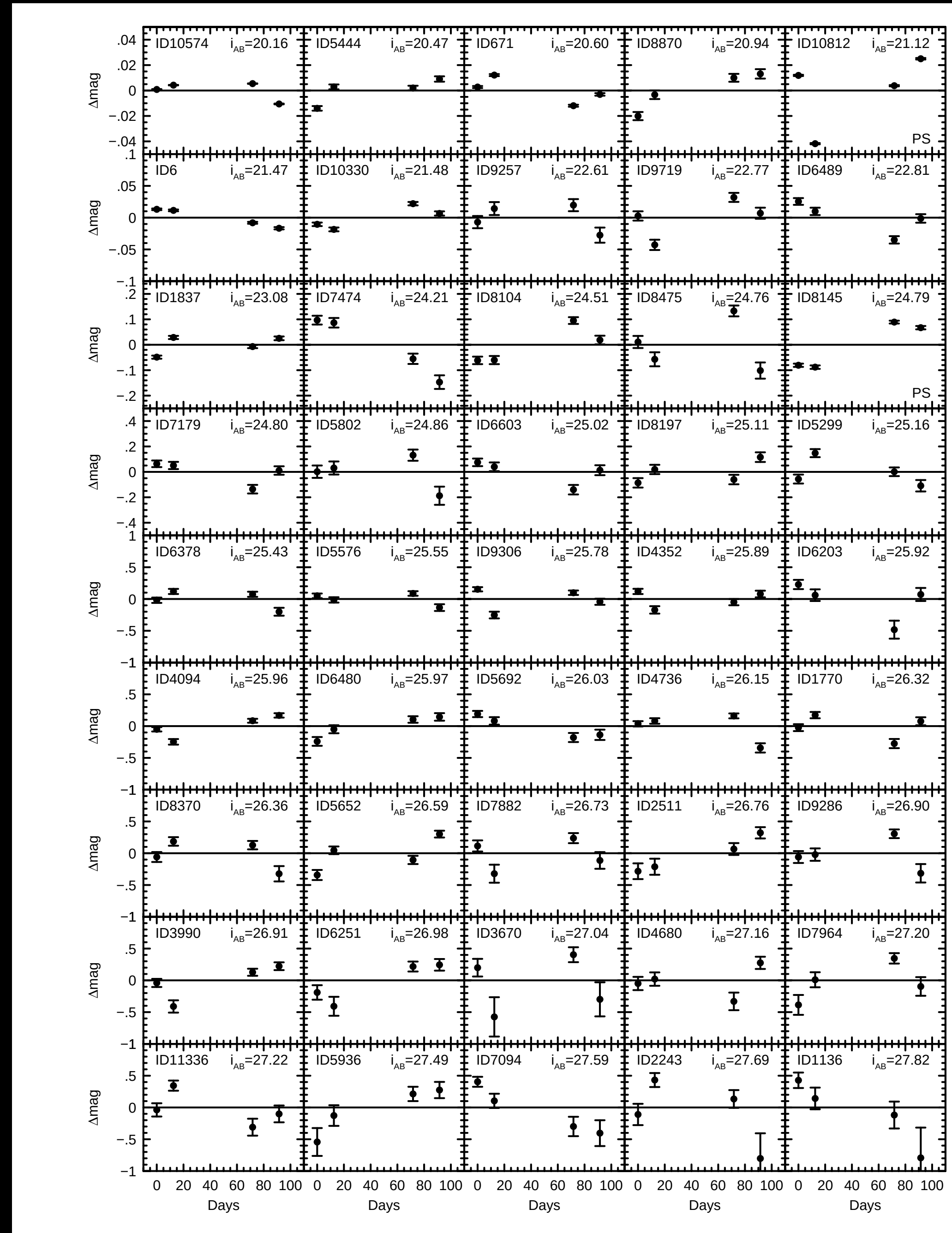


Tadpole galaxies in HUDF: www.hubblesite.org/newscenter/archive/2006/04/

Straughn, A. N., et al. 2006, ApJ, 639, 724 (astro-ph/0511423)

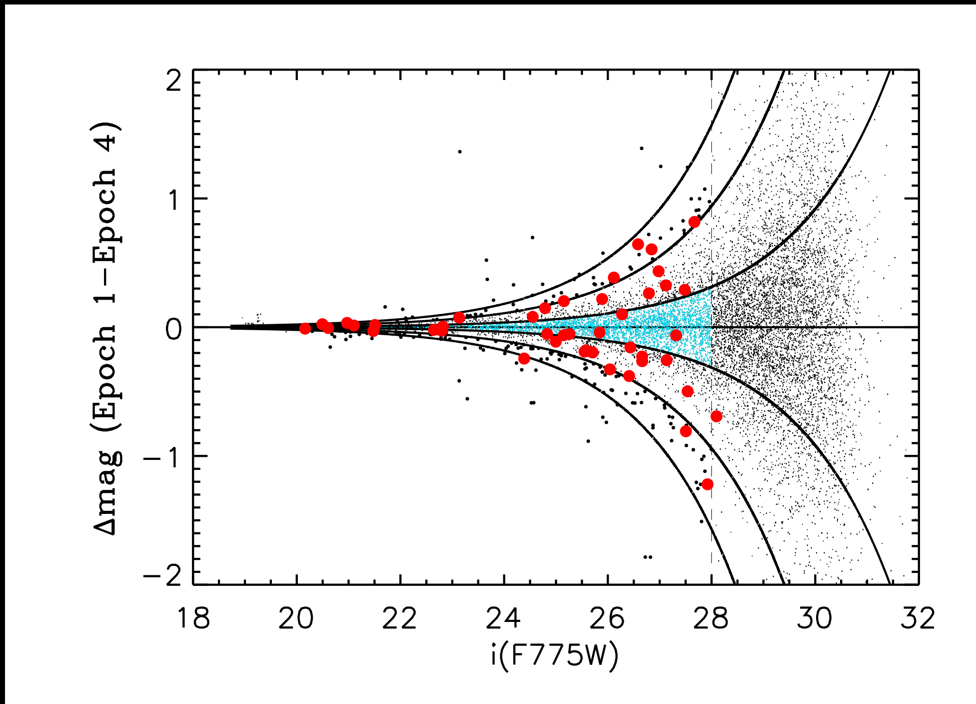
(3) Variable Objects in the HUDF

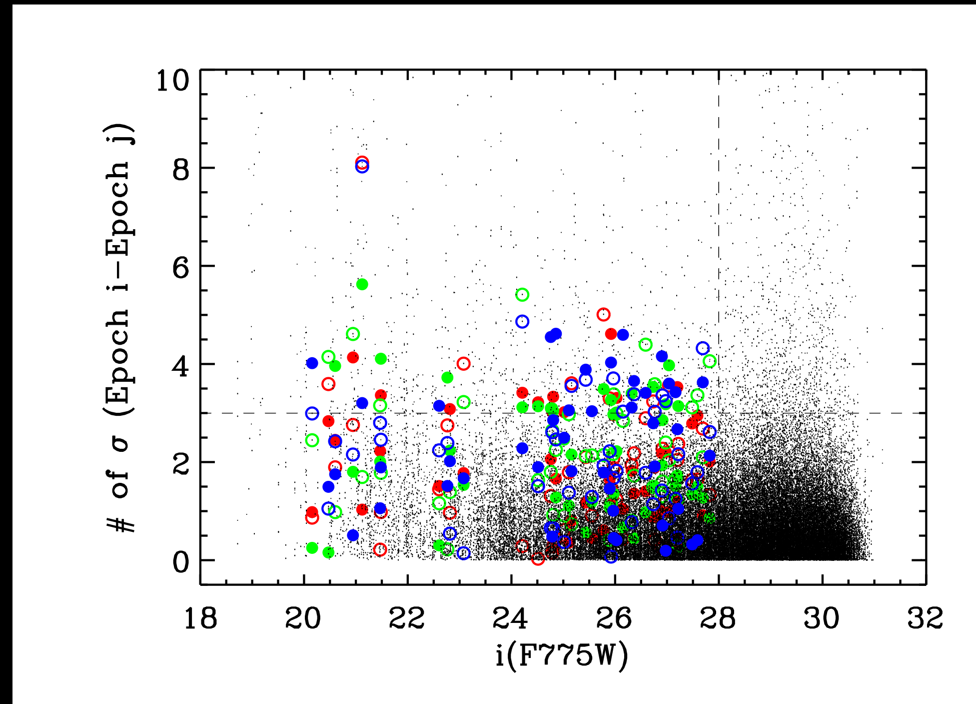




Top: 4 epochs; Middle: Variance map; Bottom: 4 Weight-maps. (Cohen, S., et al. 2006, ApJ, 639, 731; astro-ph/0511414)

Light curves: Can detect bright HUDF variable objects on timescales of days–months, even if $|\Delta \text{mag}|(t) \lesssim 1$–$2\%$!





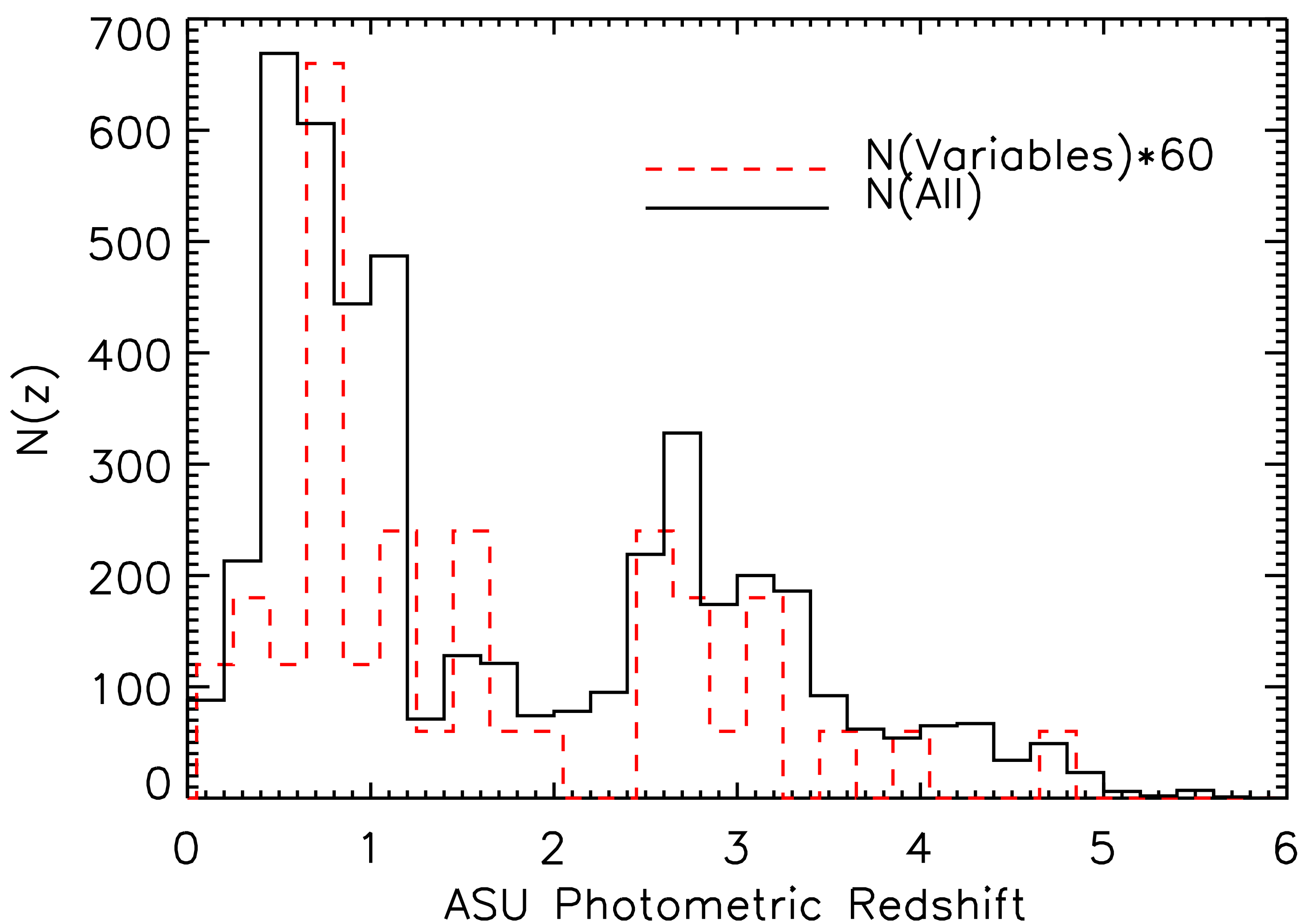
Flux ratio of all objects between two HUDF epochs (Δt$\simeq$few weeks–months) vs. total i-band flux. Lines are at $\pm 1.0\sigma$ (blue), $\pm 3.0\sigma$, $\pm 5.0\sigma$.

- Objects with |Delta mag|$\geq 3.0\sigma$ in $\geq$2 epoch-pairs are variable.
- 3 out of 16 Chandra sources are faint point-like objects variable at $\gtrsim 3.0\sigma$; other Chandra sources are brighter (early-type) galaxies.

$\Rightarrow$ Variable point sources are valid AGN candidates:

- $\sim$1% of all HUDF galaxies have weak variable AGN.

- We only sample ΔFlux $\gtrsim$10—30% on timescales of months. This AGN sample is not complete — we miss all non-variable and obscured AGN.

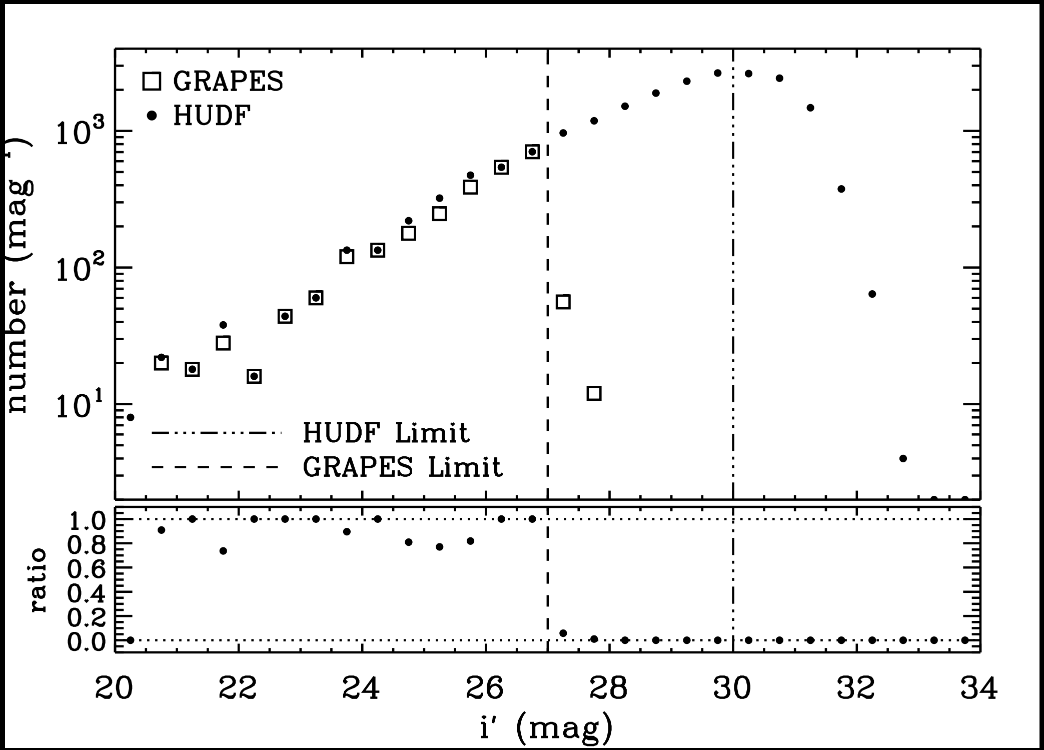


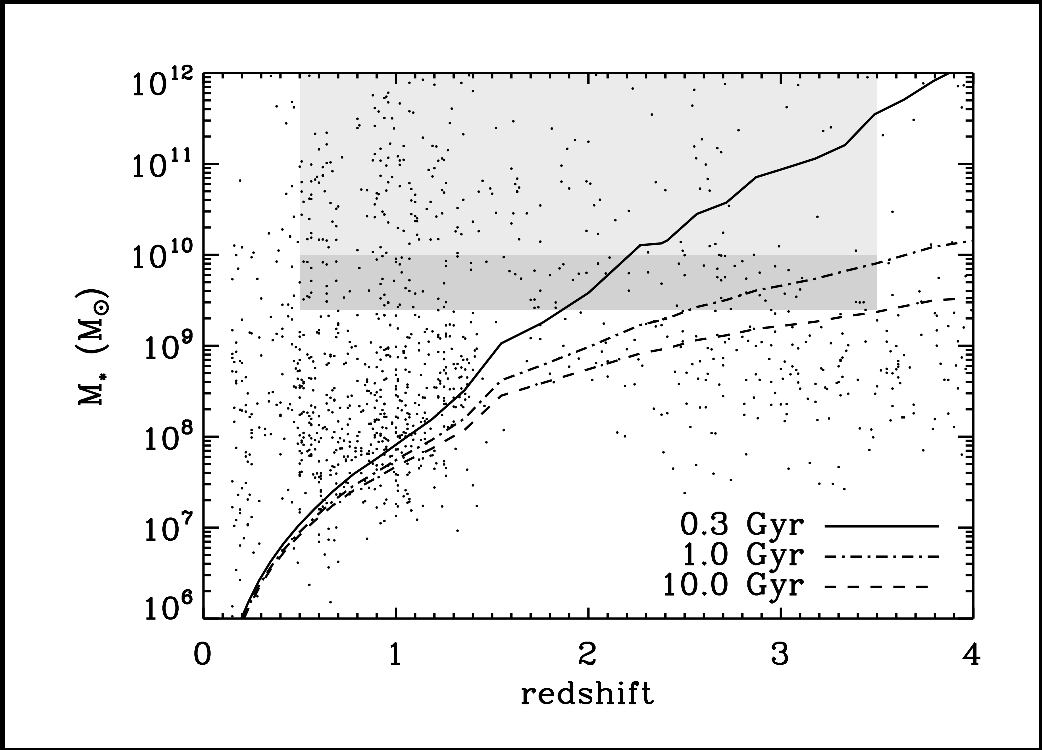
BViz(JH) Photo-z distribution of HUDF field gxys and variable objects:

- Variable objects show a similar N(z) as field galaxies. About 1% of all field galaxies have variable weak AGN at all redshifts.

$\Rightarrow$ If variable objects are representative of all weak AGN, SMBH growth keeps pace with the cosmic SFR (which peaks at $z \simeq 1$–2).

(4) Epoch dependent major merger rate to AB$\lesssim$27 mag.





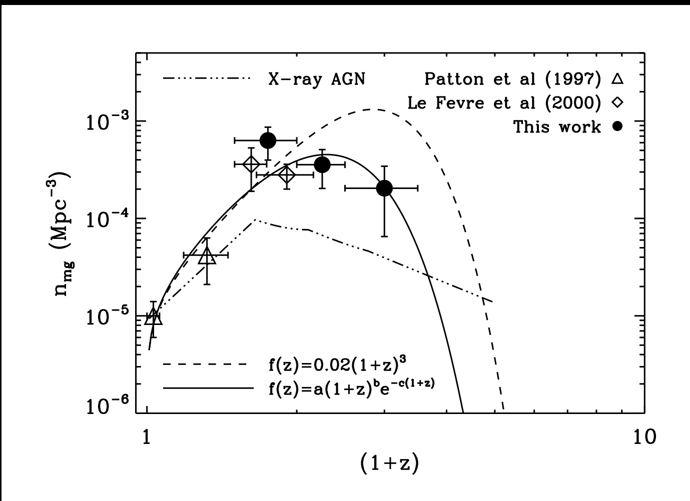
Ryan et al. (2007): HST/ACS grism pair-fraction(z) — sample selection:

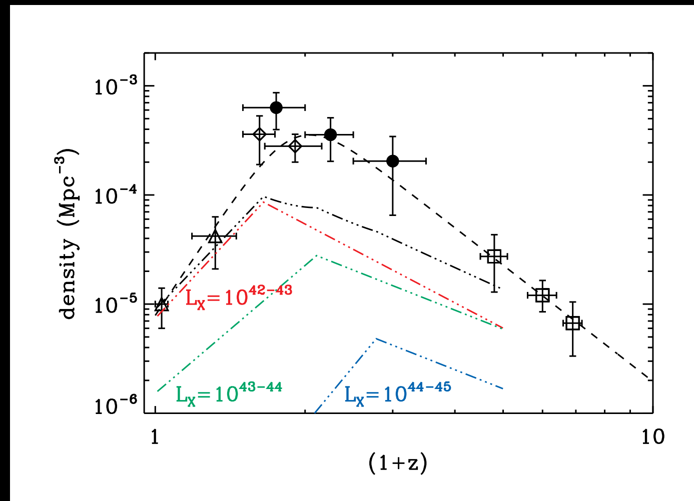
- HUDF broad-band point source completeness at $i_{AB} \lesssim$30.0 mag.
- HUDF ACS grism point source completeness at $i_{AB} \lesssim$27.0 mag.

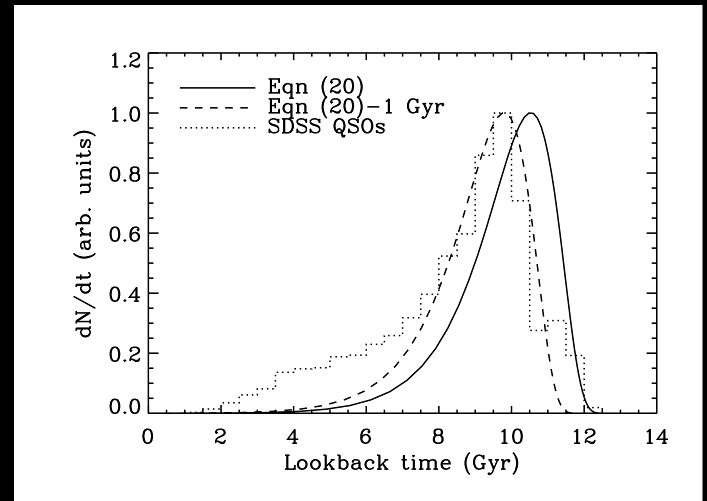
Mass completeness limit for z$\lesssim$2 from flux limits/SED fitting:

- M$\gtrsim 10^{10.0}\ M_\odot$ for primary galaxy mass in pair.
- M$\gtrsim 10^{9.4}\ M_\odot$ for secondary galaxy mass in pair ($0.25 \leq M_2/M_1 \leq 1$).

(4) Epoch dependent major merger rate to AB≲27, X-ray n(z)





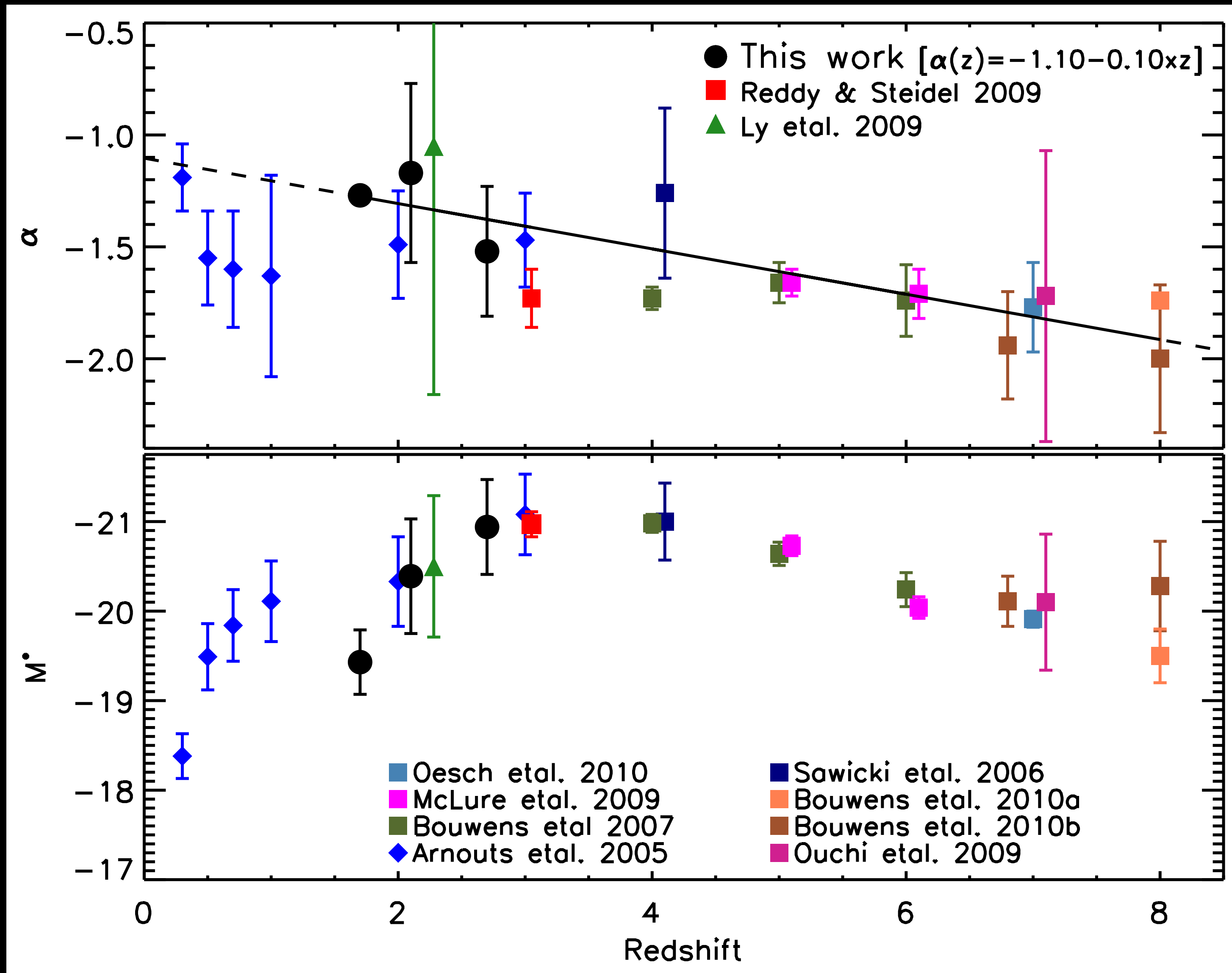


Ryan et al. (2007, 2008): HST/ACS grism epoch-dependent galaxy pair-fraction for AB≲27, z≲6: spectro-photo-z's for both objects in pair. Merger samples are very complex to select (Lotz et al. 2009).

Galaxy major ($0.25 \leq M_2/M_1 \leq 1$) merger density compared to Chandra SDSS QSO density vs. z: Similar curves, but with a ∼1 Gyr offset??

⇒ Circumstantial support for hierarchical models: a ∼1 Gyr delay between major mergers & visible SMBH feeding — weak AGN?

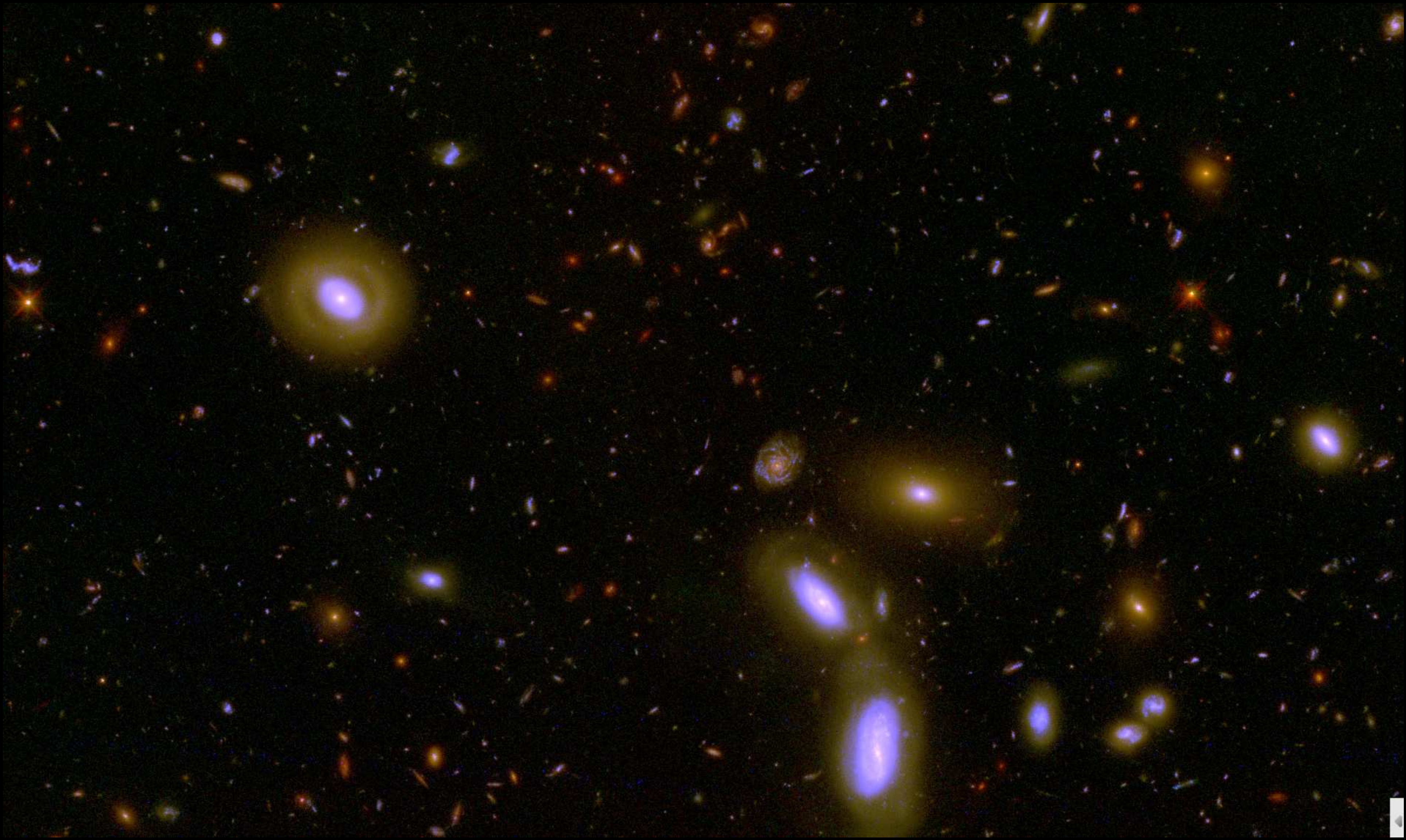
- JWST will be able to do this 3 mag fainter, from 0.7–5.0 μm, sampling rest-frame UV-optical for z≃0–20.



Measured faint-end LF slope evolution (top) and characteristic luminosity evolution (bottom) from Hathi et al. 2010, ApJ, 720, 1708 (arXiv:1004.5141v2).

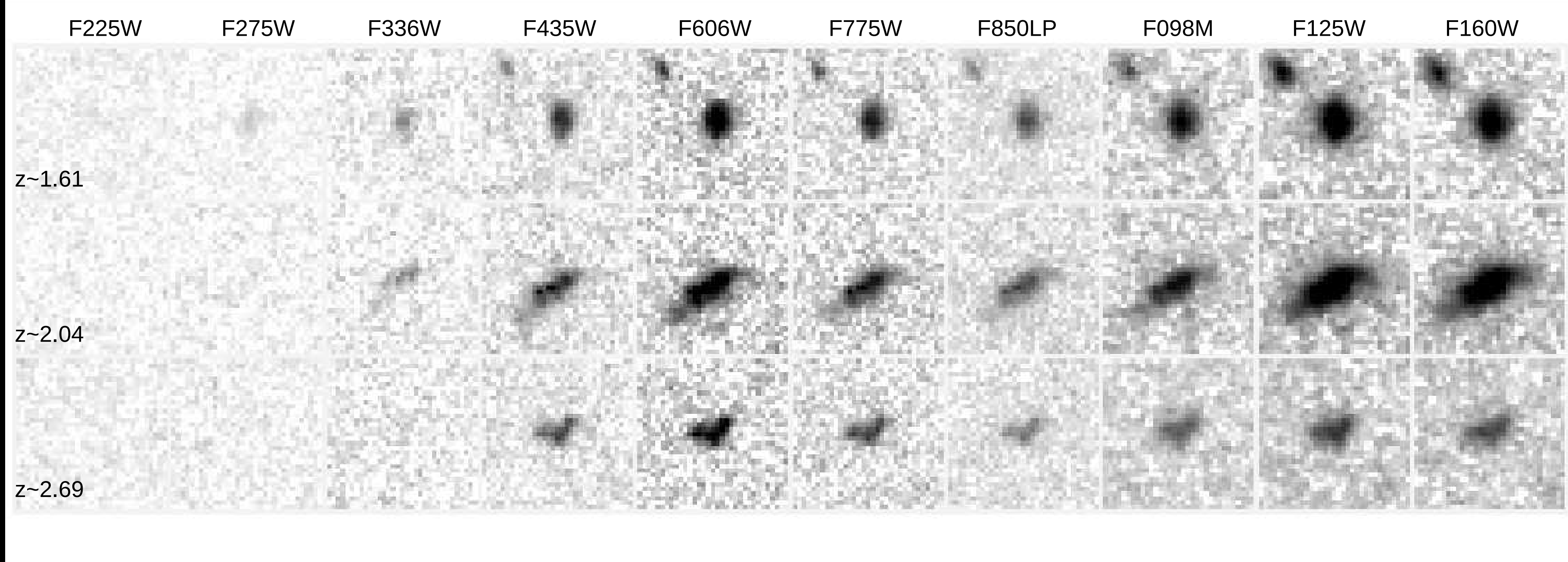
- In the JWST regime at z$\gtrsim$8, expect faint-end LF slope $\alpha \simeq$2.0!
- In the JWST regime at z$\gtrsim$8, expect characteristic luminosity $M^* \gtrsim$–19!

- (5) Can we DIRECTLY trace weak AGN growth with WFC3 and JWST?

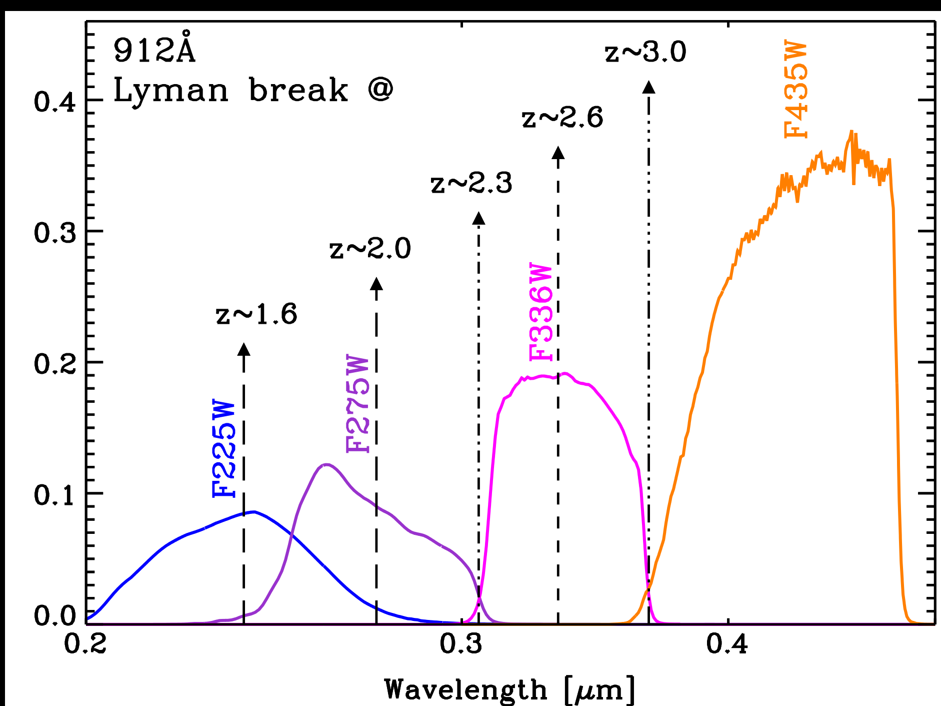


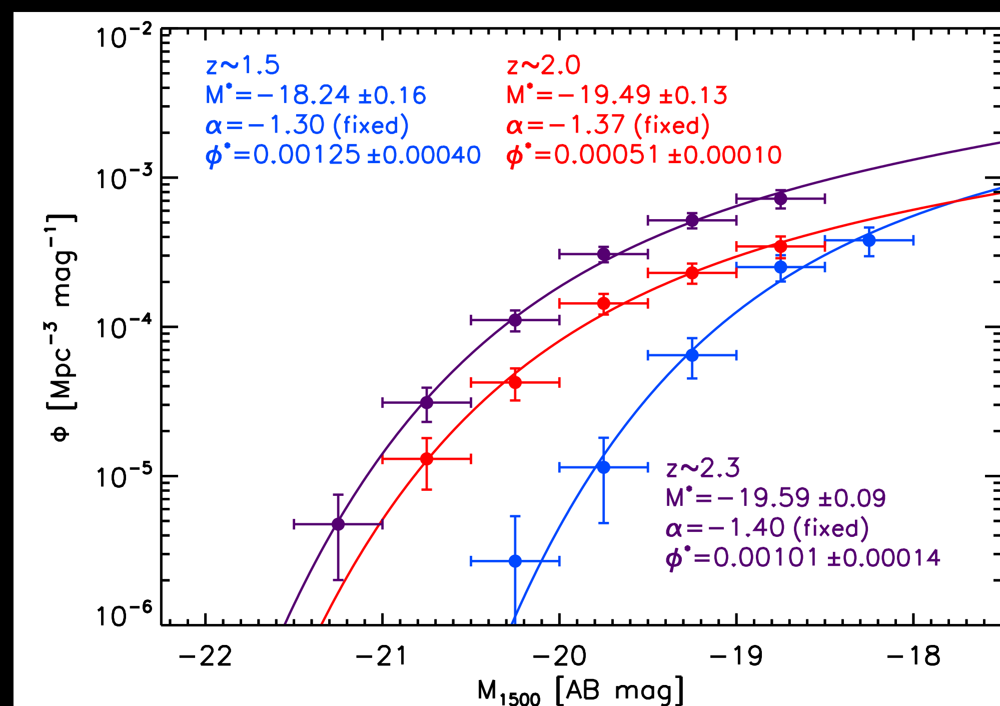
10 filters with HST/WFC3 & ACS reaching AB=26.5-27.0 mag (10-σ) over 40 arcmin^2 at 0.07–0.15" FWHM from 0.2–1.7μm (UVUBVizYJH).

JWST adds 0.05–0.2" FWHM imaging to AB$\simeq$31.5 mag (1 nJy) at 1–5μm, and 0.2–1.2" FWHM at 5–29μm, tracing young+old SEDs & dust.



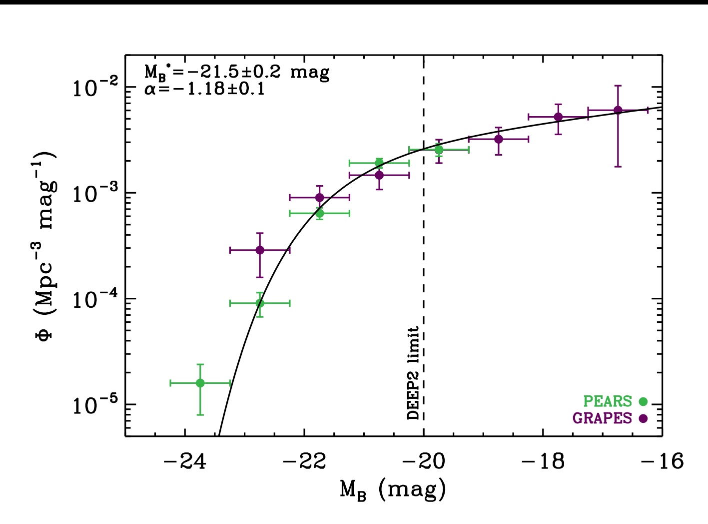
WFC3 Lyman break galaxies at the peak of cosmic SF (z≃1-3; Hathi[+] 2010)

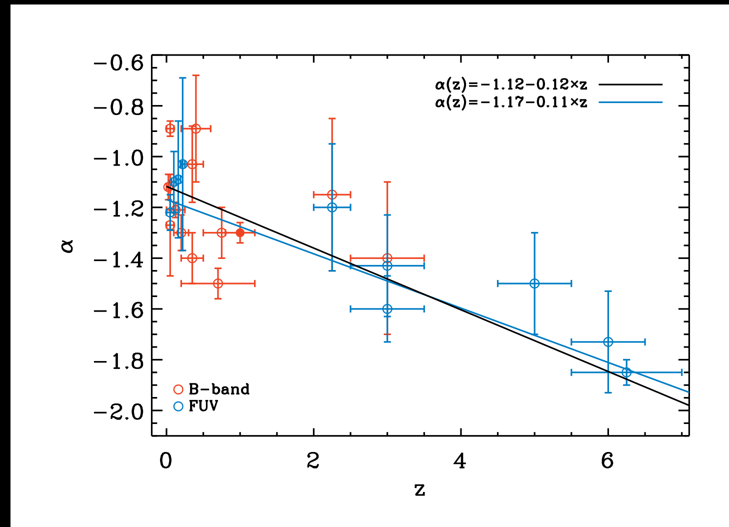


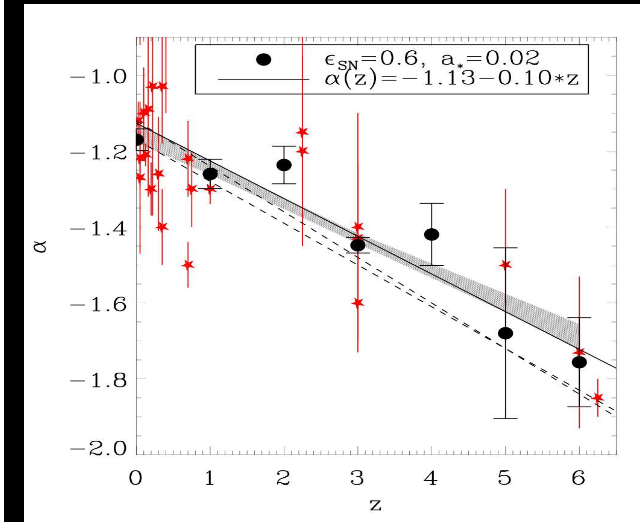


- JWST will similarly measure faint-end LF-slope evolution for $1 \lesssim z \lesssim 12$.

Faint-end LF-Slope Evolution (fundamental, like local IMF)





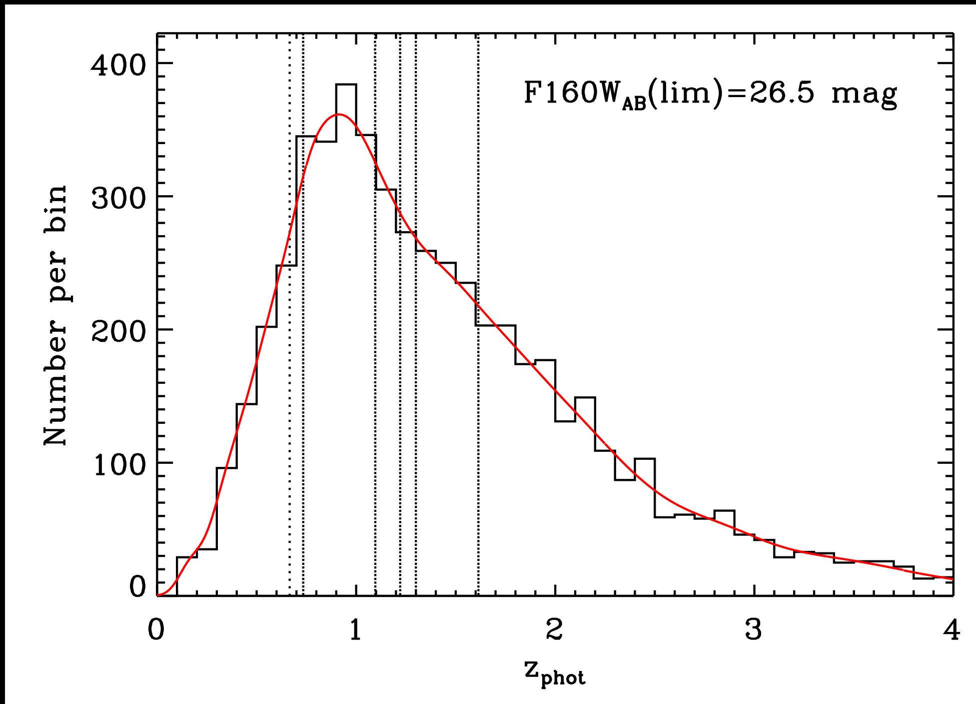


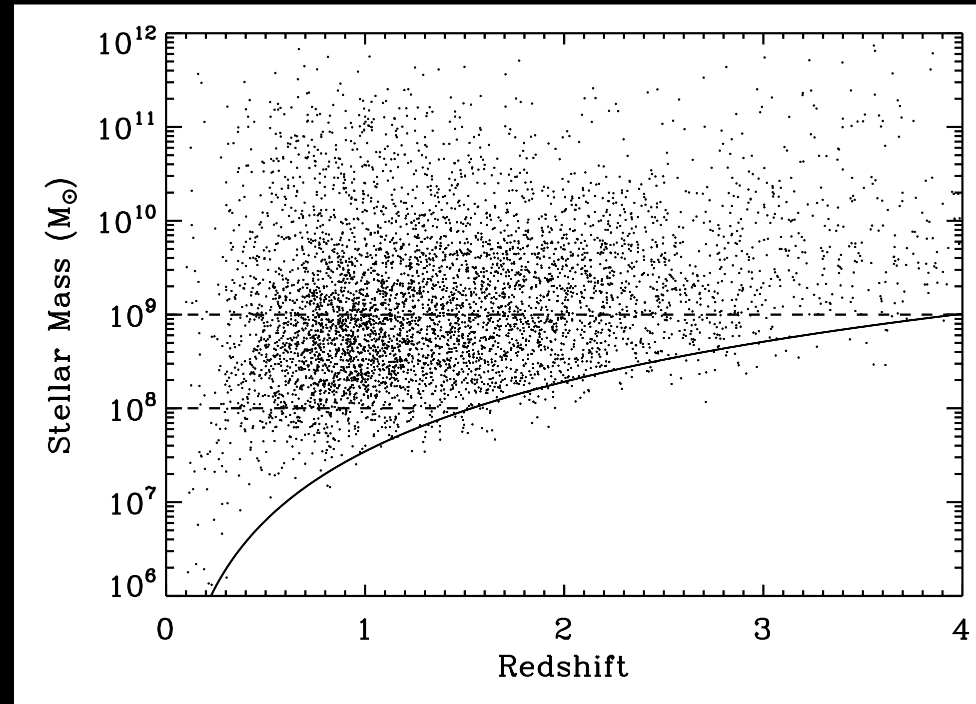
Faint-end LF-slope at z$\gtrsim$1 with accurate ACS grism z's to AB$\lesssim$27 (Cohen et al.; Ryan et al. 2007, ApJ, 668, 839) constrains hierarchical formation:

- Star-formation and SN feedback produce different faint-end slope-evolution: new physical constraints (Khochfar ea. 2007, ApJL, 668, L115).

- JWST will provide fainter spectra (AB$\lesssim$29) and spectro-photometric redshifts to much higher z ($\lesssim$20). JWST will trace α-evolution for z$\lesssim$12.

- Can measure environmental impact on faint-end LF-slope α directly.





WFC3 ERS 10-band redshift estimates accurate to ∼4% with small systematic errors (Cohen et al. 2010), resulting in a reliable redshift distribution.

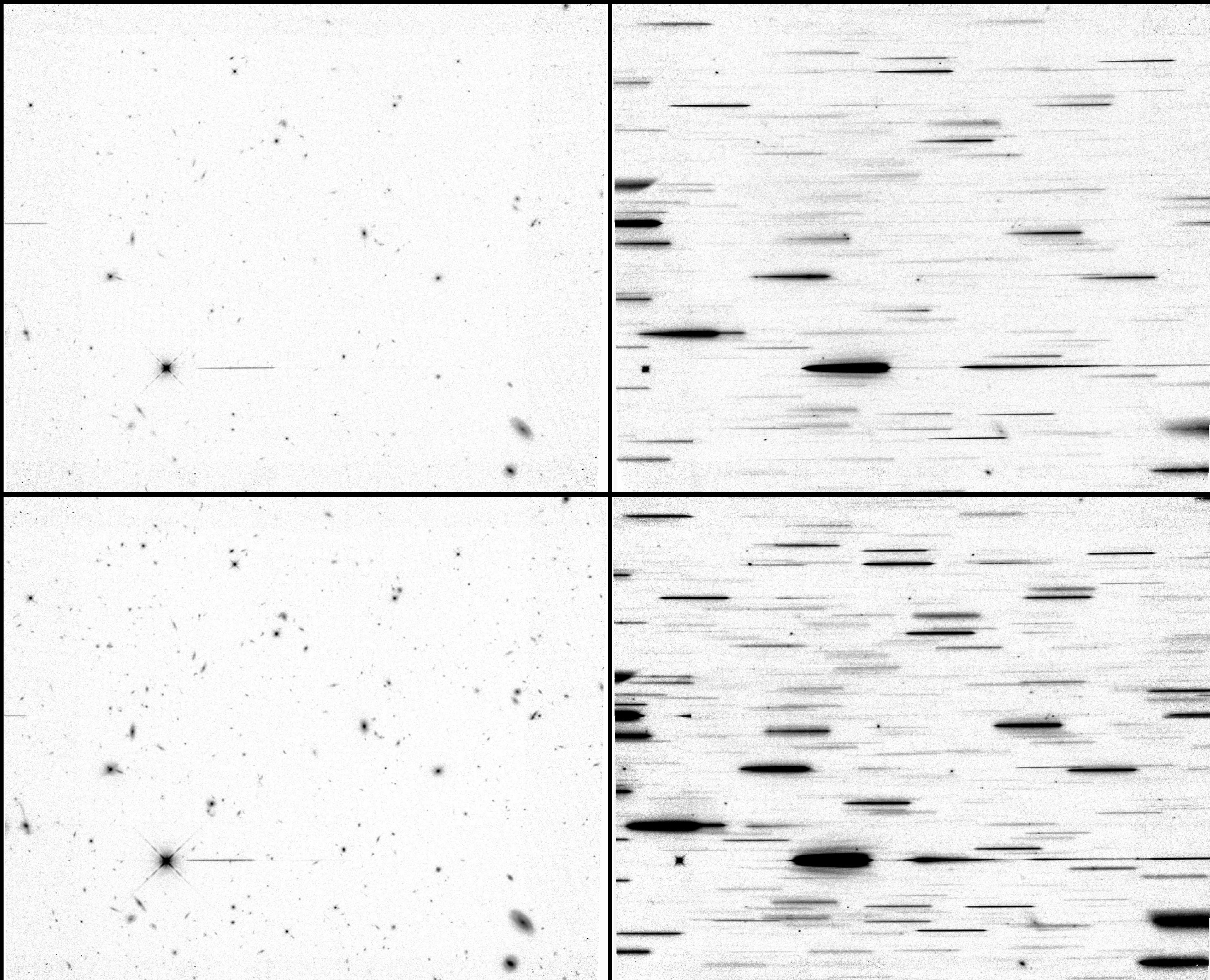
• Reliable masses of faint galaxies to AB=26.5 mag, accurately tracing the process of galaxy assembly: downsizing, merging, (& weak AGN growth?)

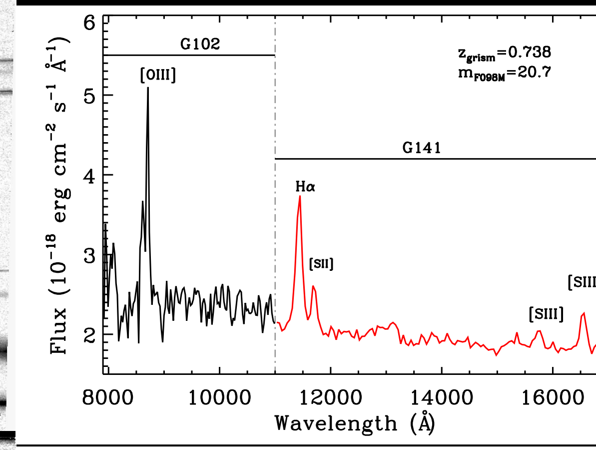
ERS shows WFC3's new panchromatic capabilities on galaxies at z≃0–7.

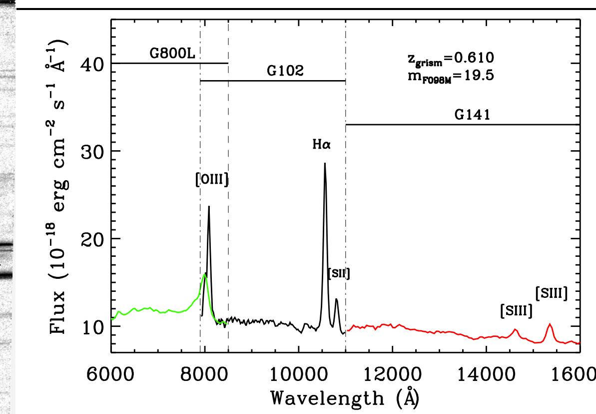
• HUDF shows WFC3 z≃7–9 capabilities (Bouwens+ 2010; Yan+ 2010).

⇒ WFC3 is an essential pathfinder at z≲8 for JWST (0.7–29 μm) at z≳9.

• JWST will trace mass assembly and dust content 3–4 mags deeper from z≃1–12, with nanoJy sensitivity from 0.7–5μm.







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 μm.

(5) Radio & X-ray host SED-ages: trace AGN growth directly?

[1] DATA: HST GOODS BVizJHK photometry and VLT JHK + redshifts.

[2] METHOD: SED fitting for 0.12$\lesssim\lambda_{rest}\lesssim$1.6 μm, using:

- (a) Bruzual-Charlot (2007) stellar population models.
- (b) + AGN power law $S_\nu \propto \nu^\alpha$ bluewards of the IR dust emission.
- VLT redshifts for all objects AB$\lesssim$24–25 (Le Fèvre et al. 2004; Szokoly et al. 2004; Vanzella et al. 2005, 2008; see www.eso.org/science/goods/)

For typical z$\simeq$0.5-1.5, BVizJHK bracket the Balmer+4000Å breaks.

[3] SED fitting:

- Use solar metallicity and Salpeter IMF (most objects at z$\lesssim$2).
- E-folding times τ in log spaced n=16 grid from 0.01-100 Gyr.
- n=244 ages $\lesssim$ age of Universe at each redshift in WMAP-cosmology.
- Calzetti et al. dust extinction: A_V = [0, 4.0] in 0.2 mag steps (n=21).
- α=[0, 1.5] in steps of 0.1 (n=16 values).

[4] Yields $\sim 10^6$ models for 1549 GOODS galaxies with VLT redshifts.

Best χ^2 fit stellar mass + possible AGN UV–optical power-law component.

Method follows Windhorst et al. (1991, 1994, 1998), where HST + ground-based UBgriJHK images showed non-negligible AGN components in mJy radio galaxies.

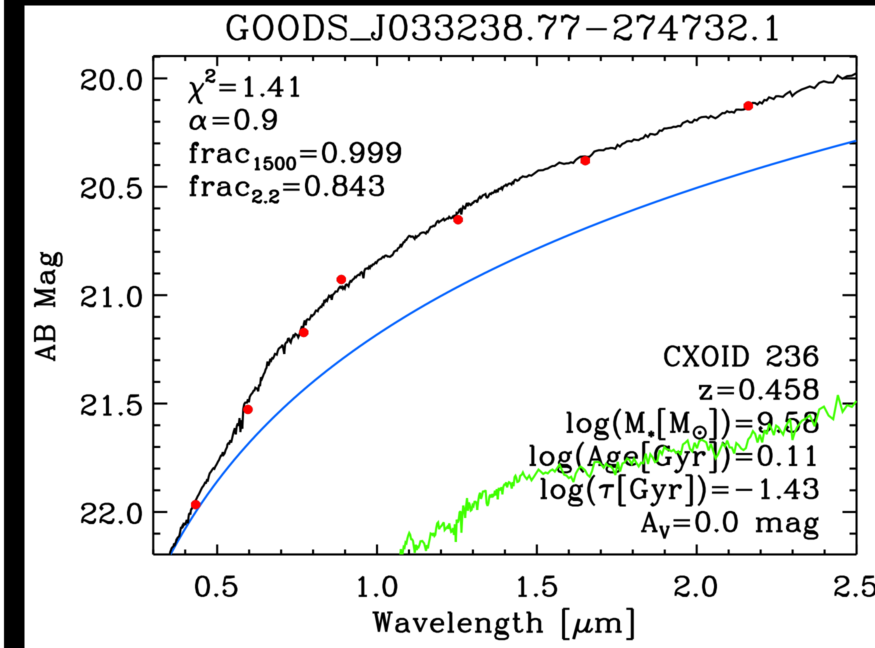
[5] Work in progress on other potential caveats:

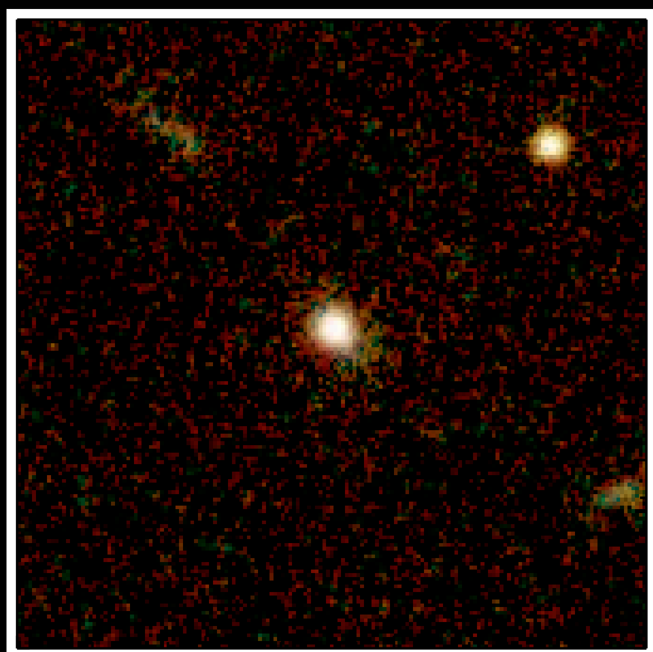
• Young stellar populations have power-law UV spectra (Hathi et al. 2008), and may overestimate UV AGN power-law.

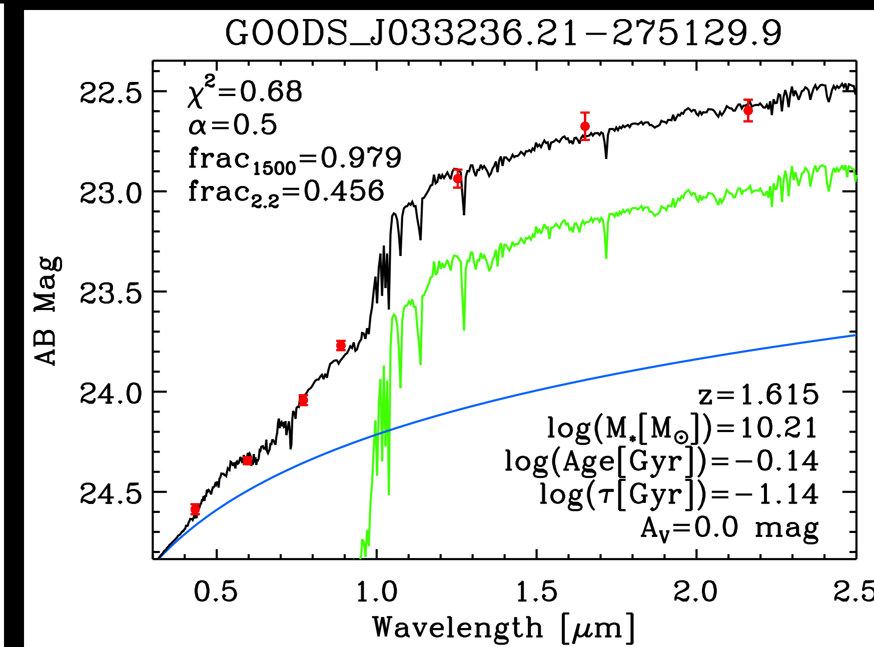
• Include IRAC data and incorporate 1–2 Gyr red AGB population.

[6] Repeat [1]–[5] for 7000 ERS objects with 10-band spz's to AB=27 mag.

• Fit the BC03 stellar SED only to objects where χ^2 doesn't require both.

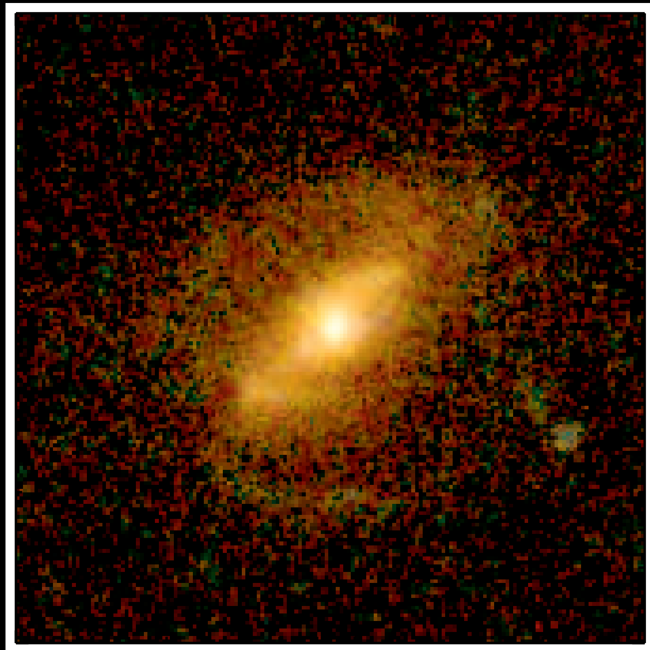


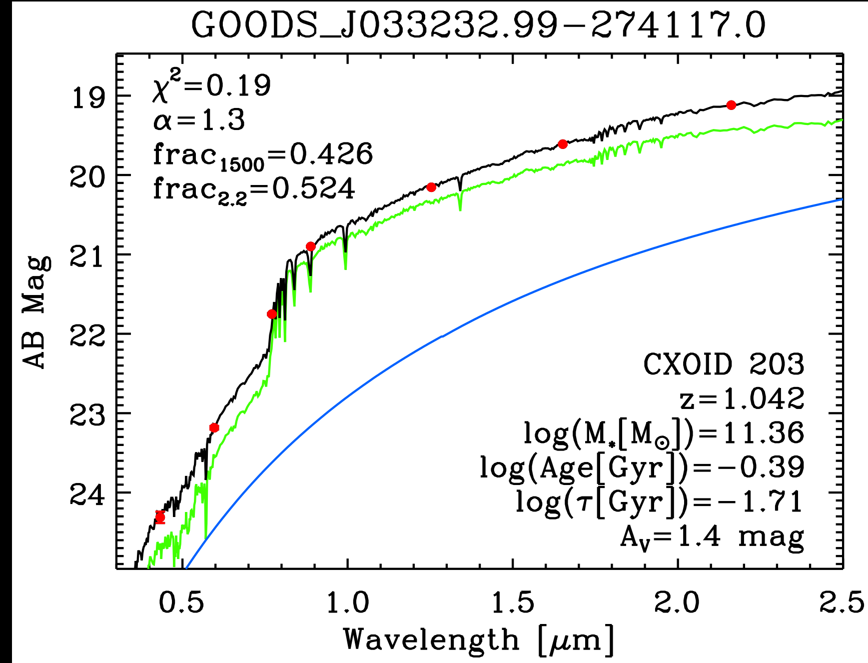


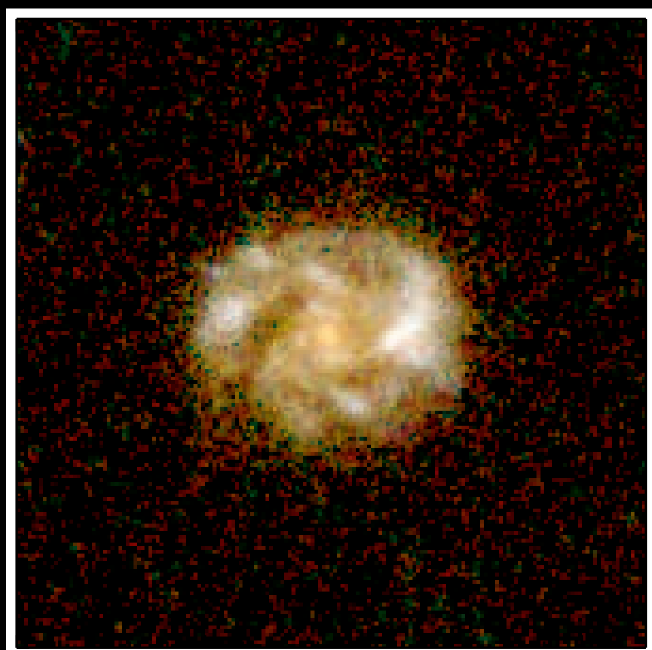


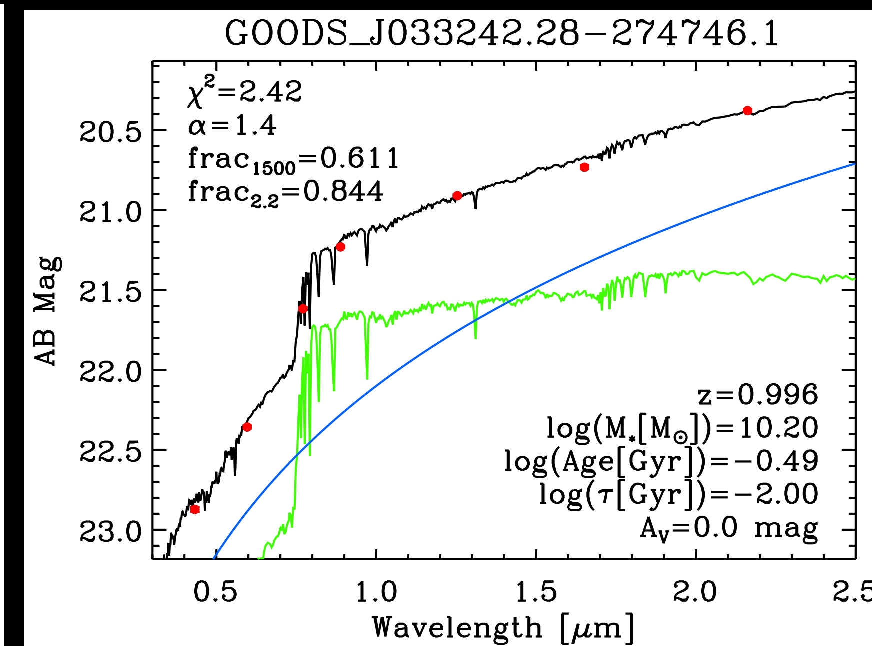
Cohen et al. (2010): GOODS/VLT BVizJHK images

Best fit Bruzual-Charlot (2003) SED + power law AGN.









Cohen et al. (2010): GOODS/VLT BVizJHK images

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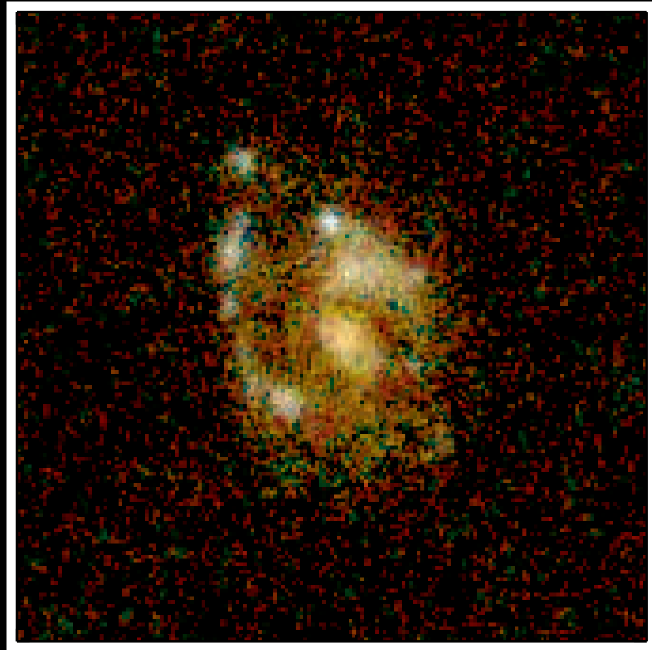
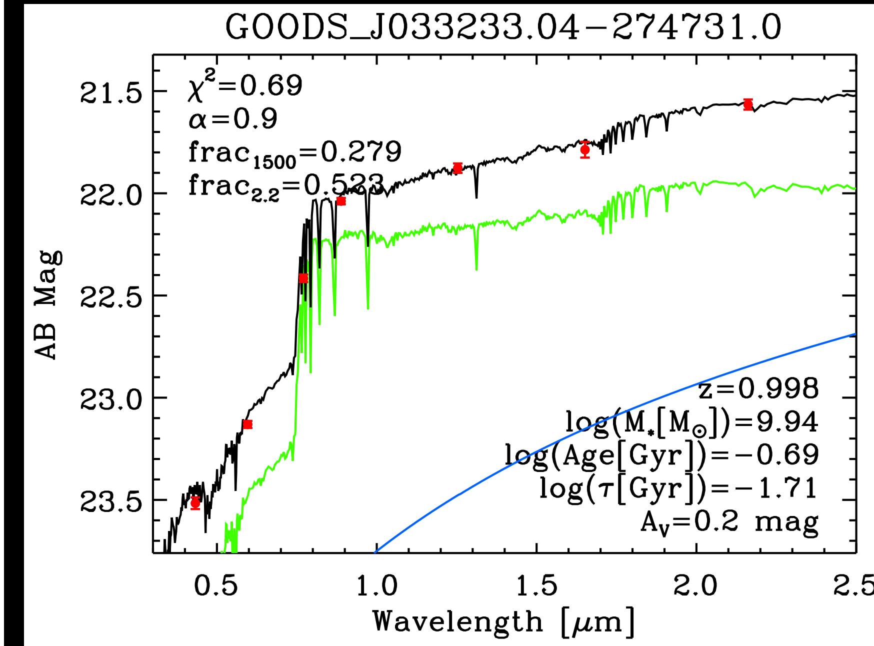
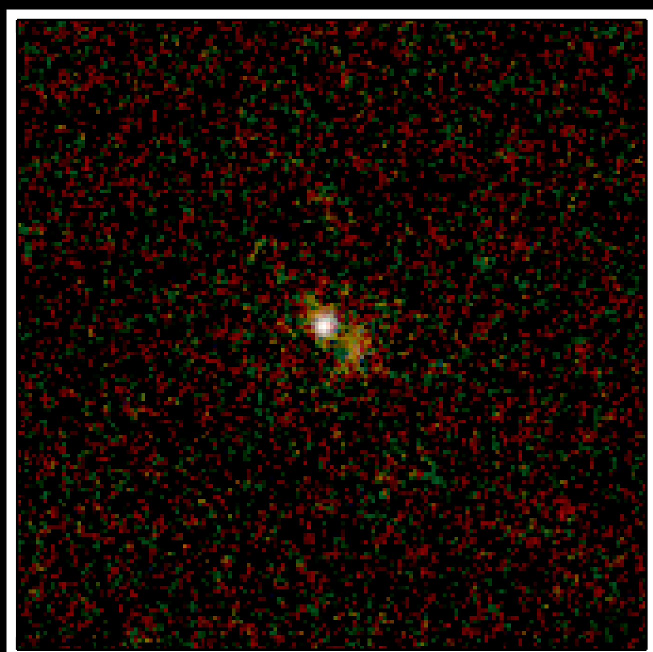
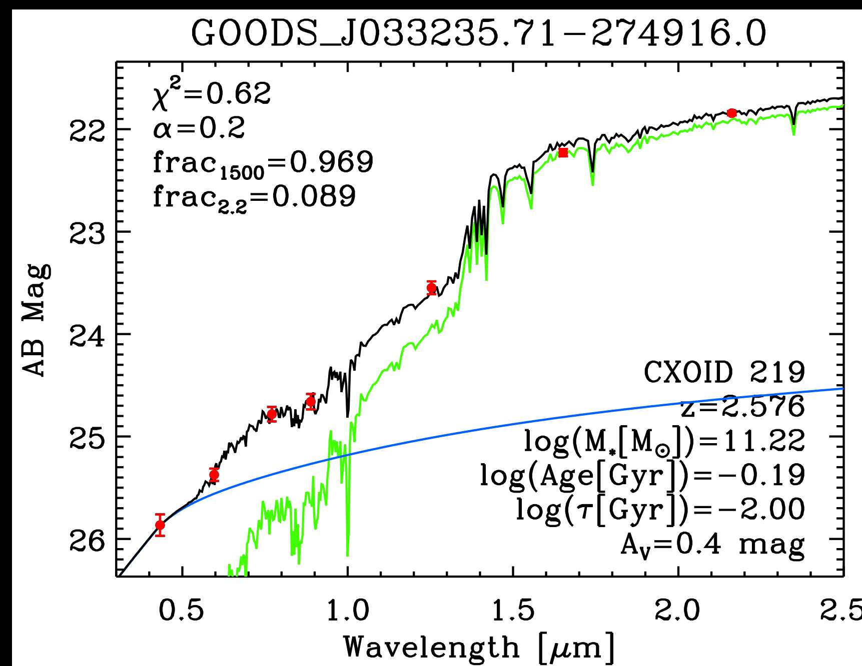


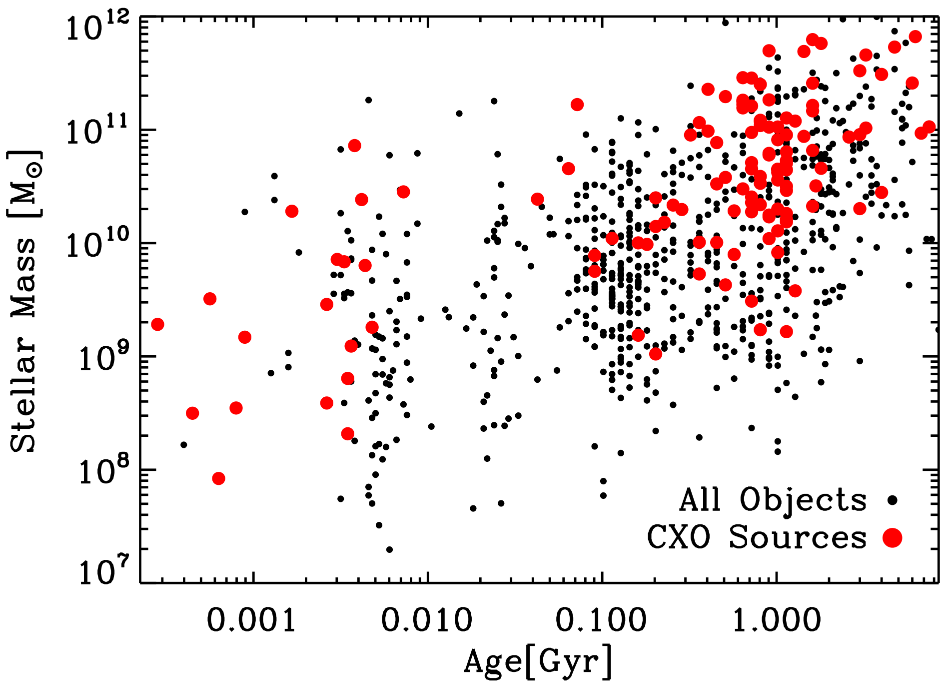


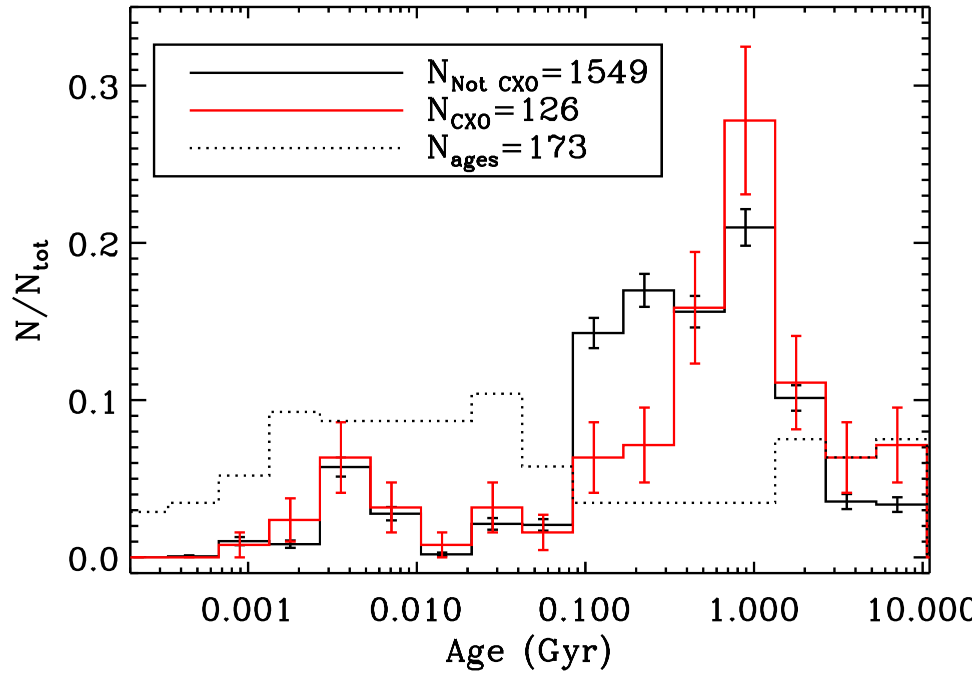




Cohen et al. (2010): GOODS/VLT BVizJHK images

Best fit Bruzual-Charlot (2003) SED + power law AGN.

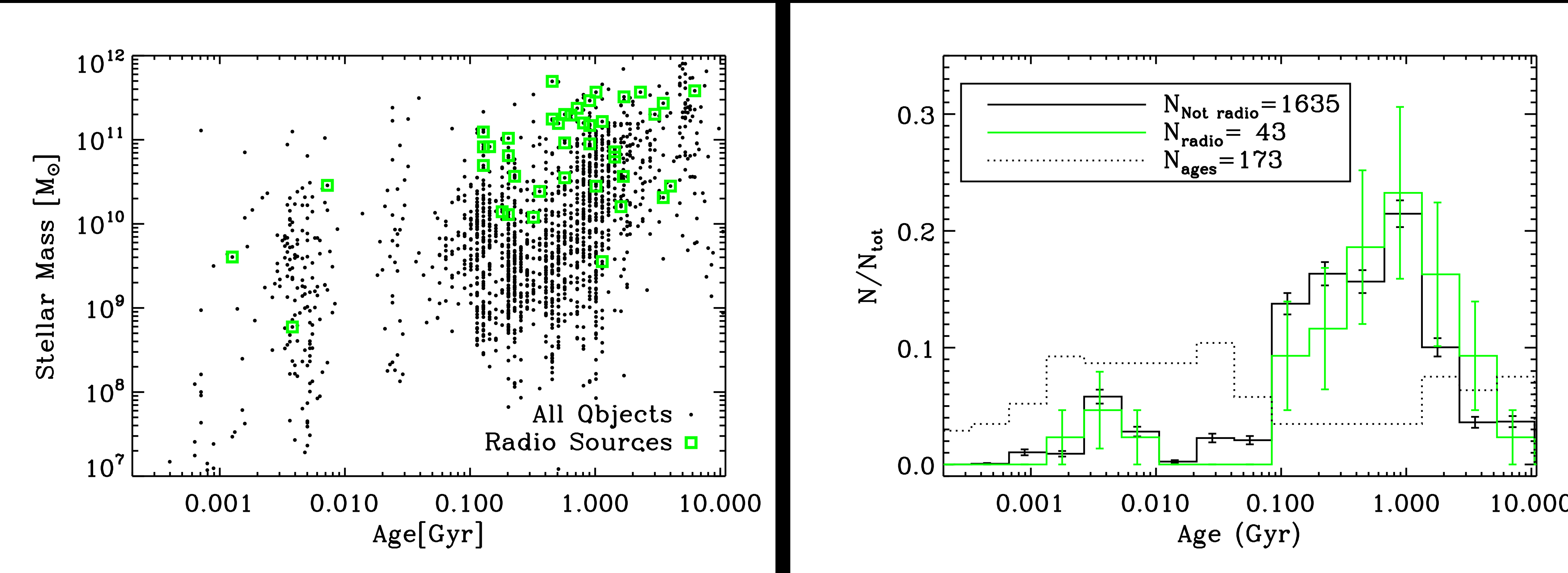




Cohen et al. (2010): Best fit Stellar Mass vs. Age: X-ray and field galaxies.

Field galaxies have: Blue cloud of ∼100-200 Myr, Red cloud of $\gtrsim$1–2 Gyr.

- X-ray sources reside in galaxies that are a bit older than the general field population, but by no more than $\lesssim$0.5–1 Gyr on average.
- JWST+WFC3 can disentangle multiple SED + AGN power-law from 15-band photometry to AB=30 mag for z$\lesssim$10.
- JWST can trace AGN-growth, host galaxy masses and ages since z∼10.



Cohen et al. (2010): Best fit Stellar Mass vs. Age: Radio and field galaxies.

Field galaxies have: Blue cloud of ∼100-200 Myr, Red cloud of ≳1–2 Gyr.

- Radio galaxies are a bit older than the general field population, but by no more than ≲0.5–1 Gyr on average.
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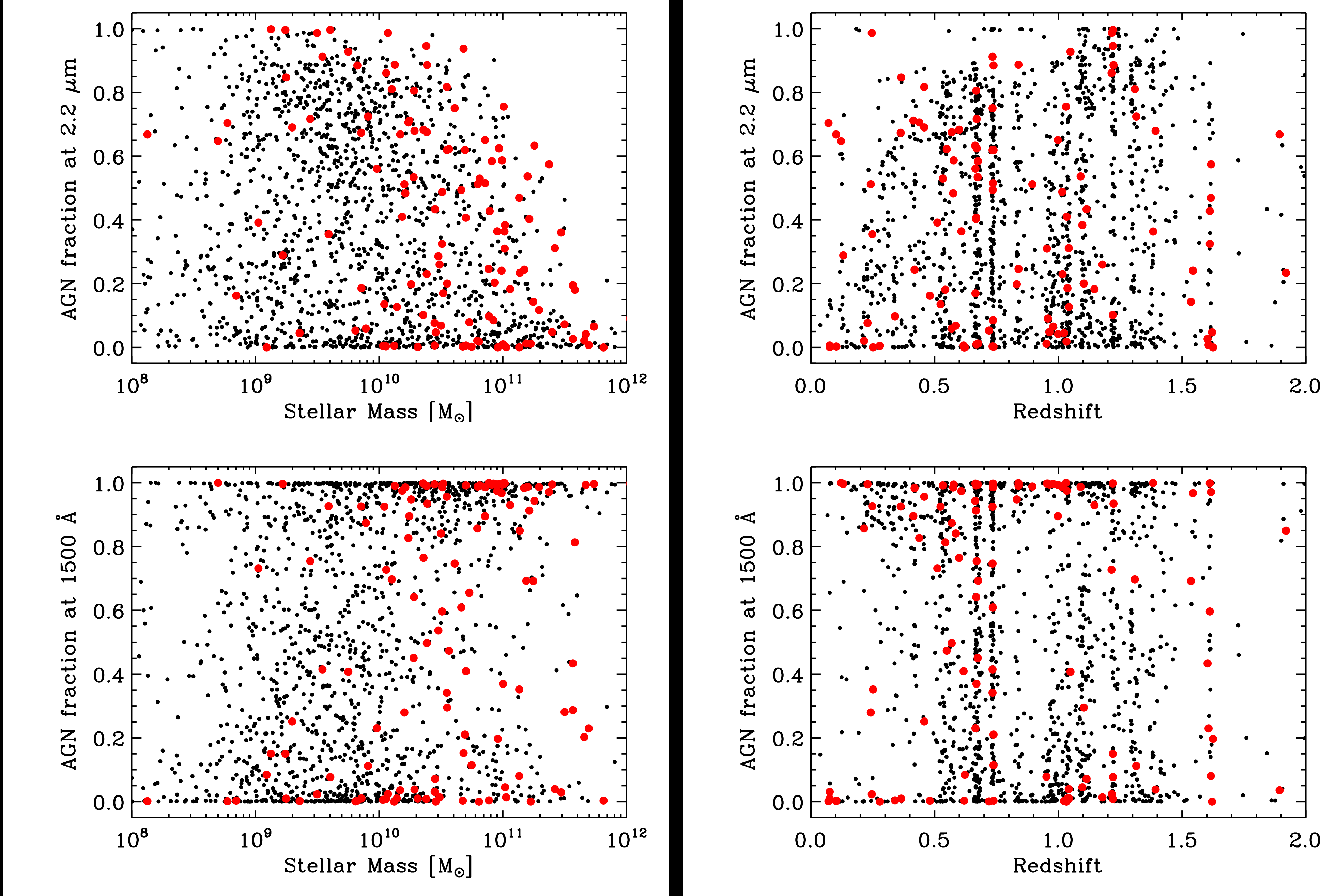
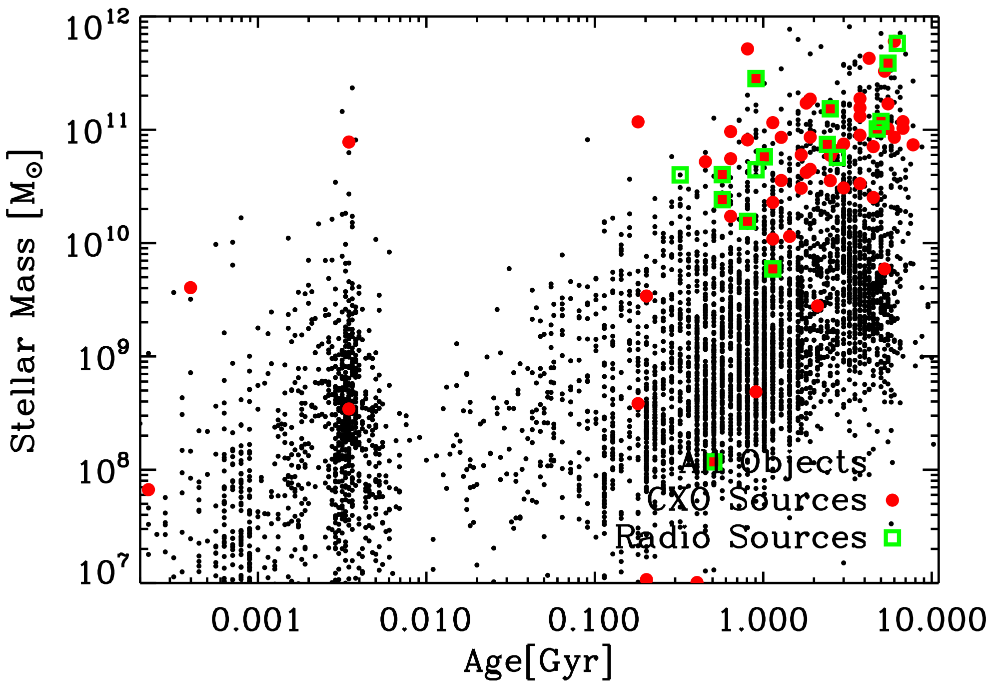
- JWST can trace AGN-growth, host galaxy masses and ages since z∼10.

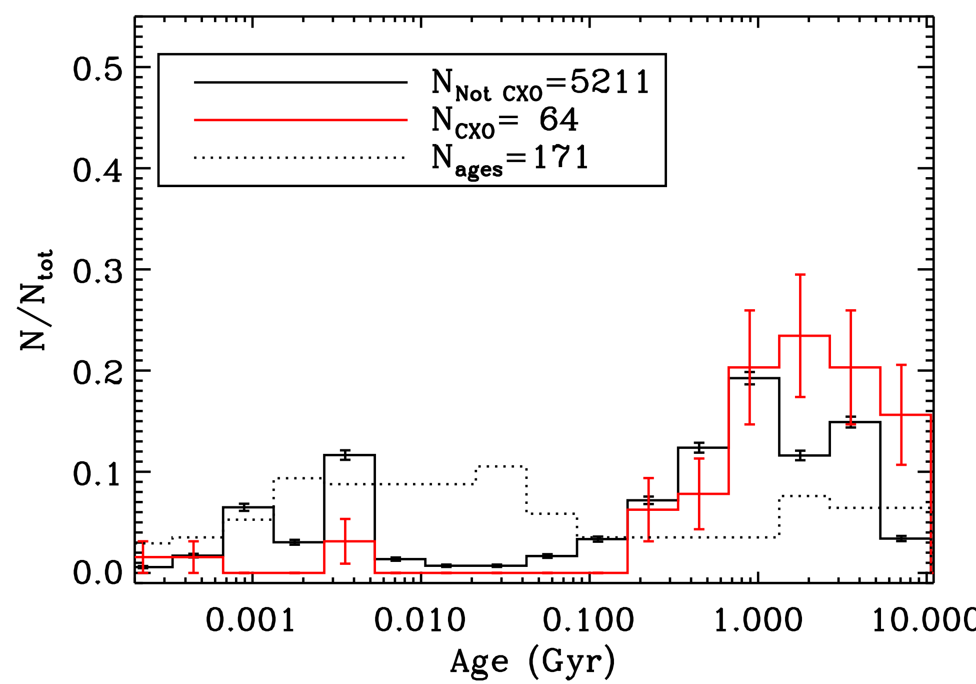


Cohen$^+$ (2010): AGN fraction vs. Stellar Mass & z: X-ray and field gxys.

⇒ Many more with best-fit f(AGN)$\gtrsim$50% to be detected by IXO or SKA!

- JWST can trace power-law SED-fraction for M$\gtrsim 10^8$ $M_\odot$ and z$\lesssim$10.

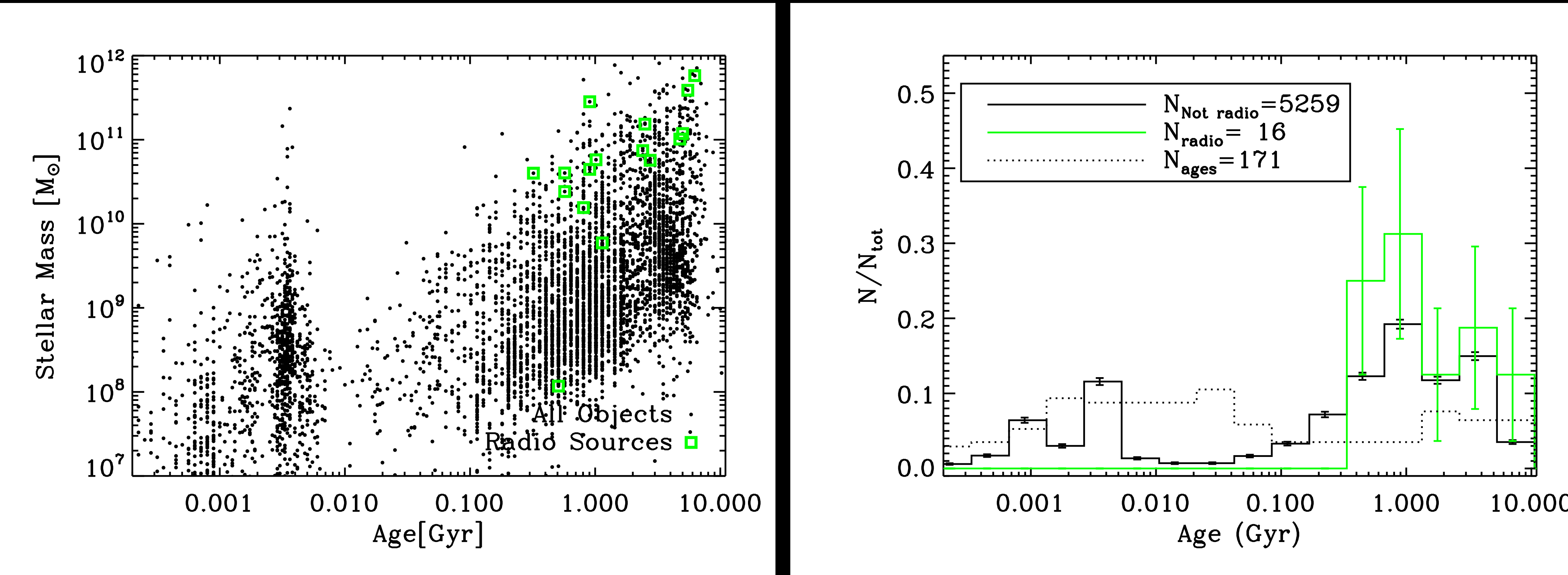




Cohen et al. (2010): Best fit Stellar Mass vs. Age: X-ray and field galaxies.

Field galaxies have: Blue cloud of ∼100-200 Myr, Red cloud of $\gtrsim$1–2 Gyr.

- X-ray sources reside in galaxies with M$\gtrsim 10^{10}$ $M_\odot$, and are older than the field population by $\lesssim$0.5–1 Gyr on average.
- JWST+WFC3 can disentangle multiple SED + AGN power-law from 15-band photometry to AB=30 mag for z$\lesssim$10.
- JWST can trace AGN-growth, host galaxy masses and ages since z∼10.



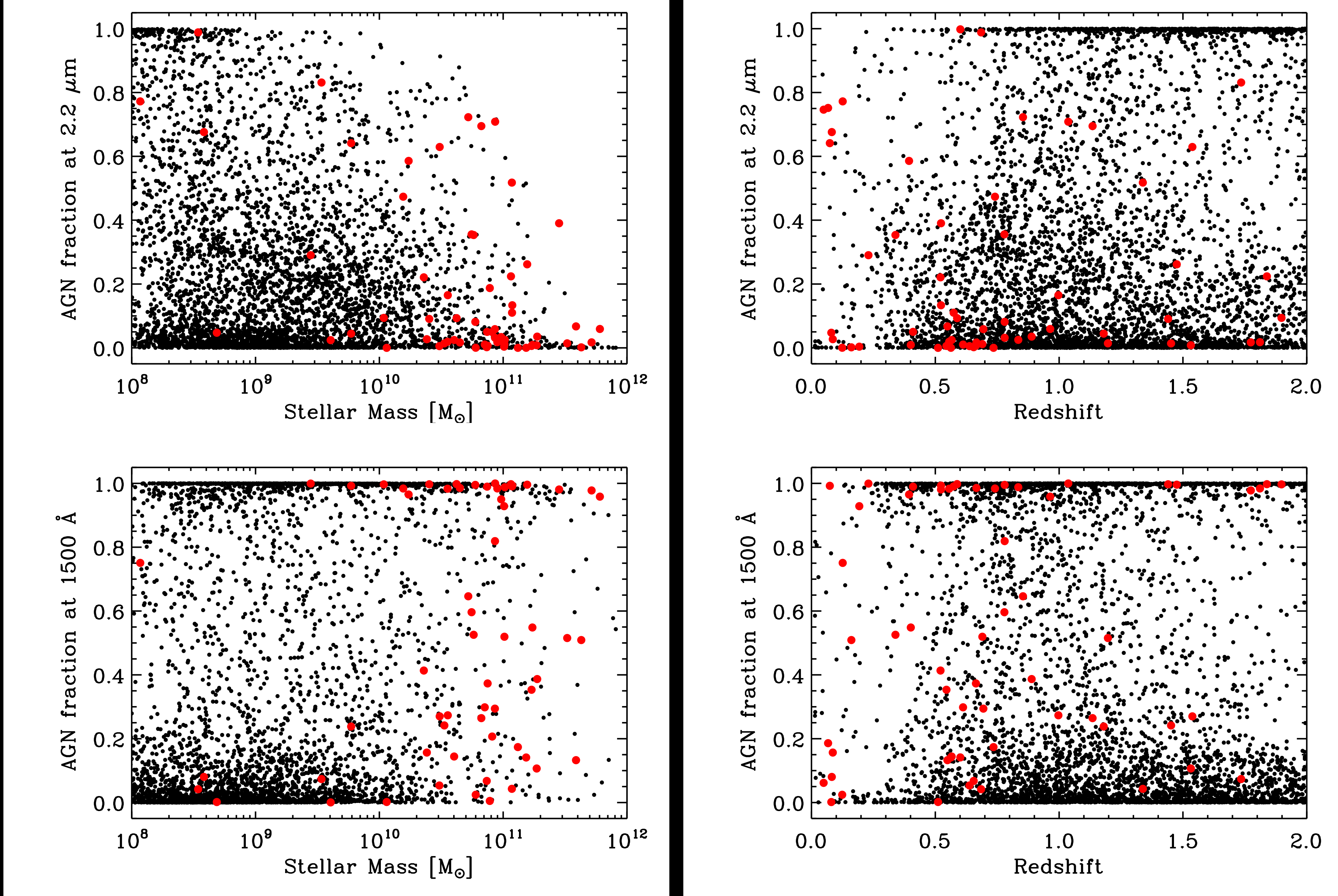
Cohen et al. (2010): Best fit Stellar Mass vs. Age: Radio and field galaxies.

Field galaxies have: Blue cloud of ∼100-200 Myr, Red cloud of ≳1–2 Gyr.

- Radio sources reside in galaxies with M$\gtrsim 10^{10}\ M_{\odot}$. Not enough statistics yet to say if radio hosts in ERS older than field galaxies.

- JWST+WFC3 can disentangle multiple SED + AGN power-law from 15-band photometry to AB=30 mag for z$\lesssim$10.

- JWST can trace AGN-growth, host galaxy masses and ages since z∼10.



Cohen^{+} (2010): AGN frac vs. Stellar Mass & ***spz***: X-ray & field gxys.

⇒ Many more with best-fit f(AGN)$\gtrsim$50% to be detected by IXO or SKA!

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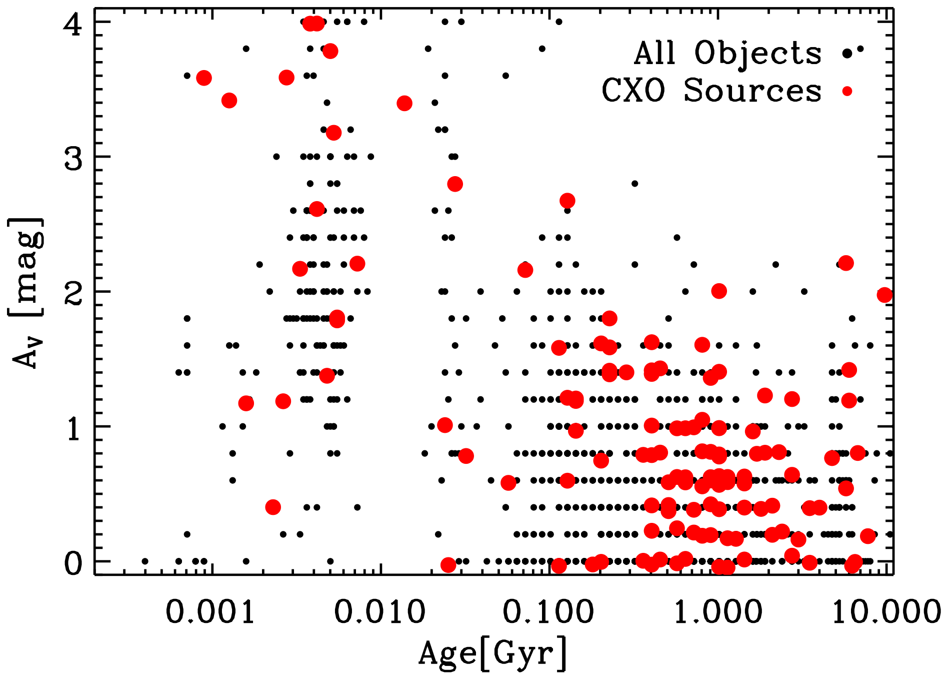
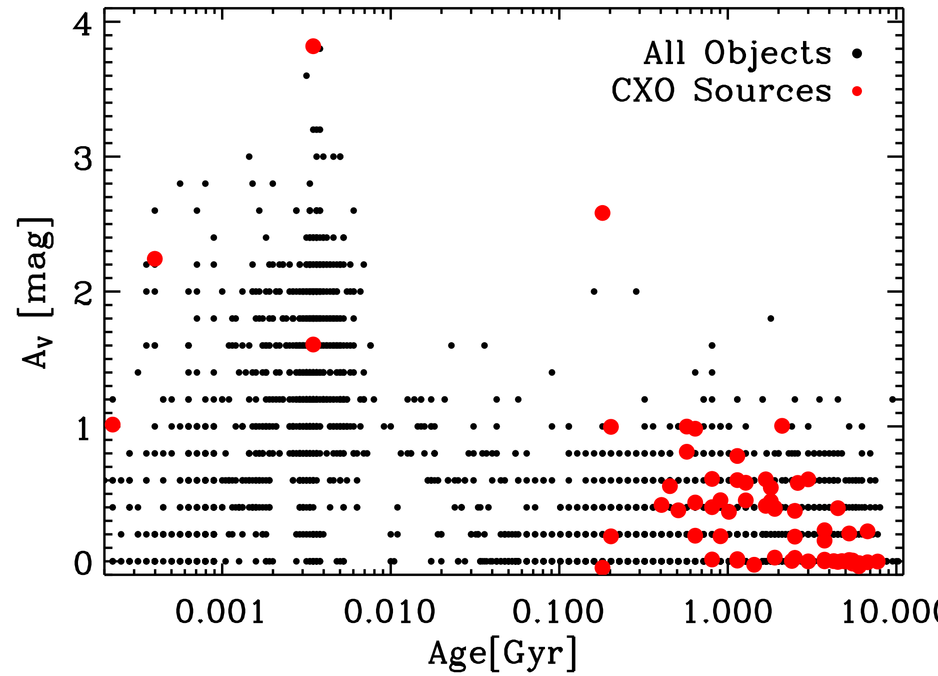




LEFT: 1549 CDF-S objects with z's. RIGHT: 7000 CDF-S ERS with spz's.

Cohen et al. (2010): Best fit extinction A_V distribution: X-ray and field.

- In Hopkins et al. (2006, ApJS, 163, 1) scenario, dust and gas are expelled *after* the starburst peaks and *before* before the AGN becomes visible.
- Older galaxies have less dust after merger/starburst/outflow.
- But the age-metallicity relation may complicate this.

(6) Summary and Conclusions

(1) (Major) Mergers have a redshift distribution similar to that of HUDF field galaxies, but no AGN seen amongst them.

(2) Variable objects have a redshift distribution similar to that of HUDF field galaxies, and likely trace brief(!) episodes of SMBH growth.

• There is very little overlap between (1) and (2): HUDF mergers likely preceded visible weak-AGN variability.

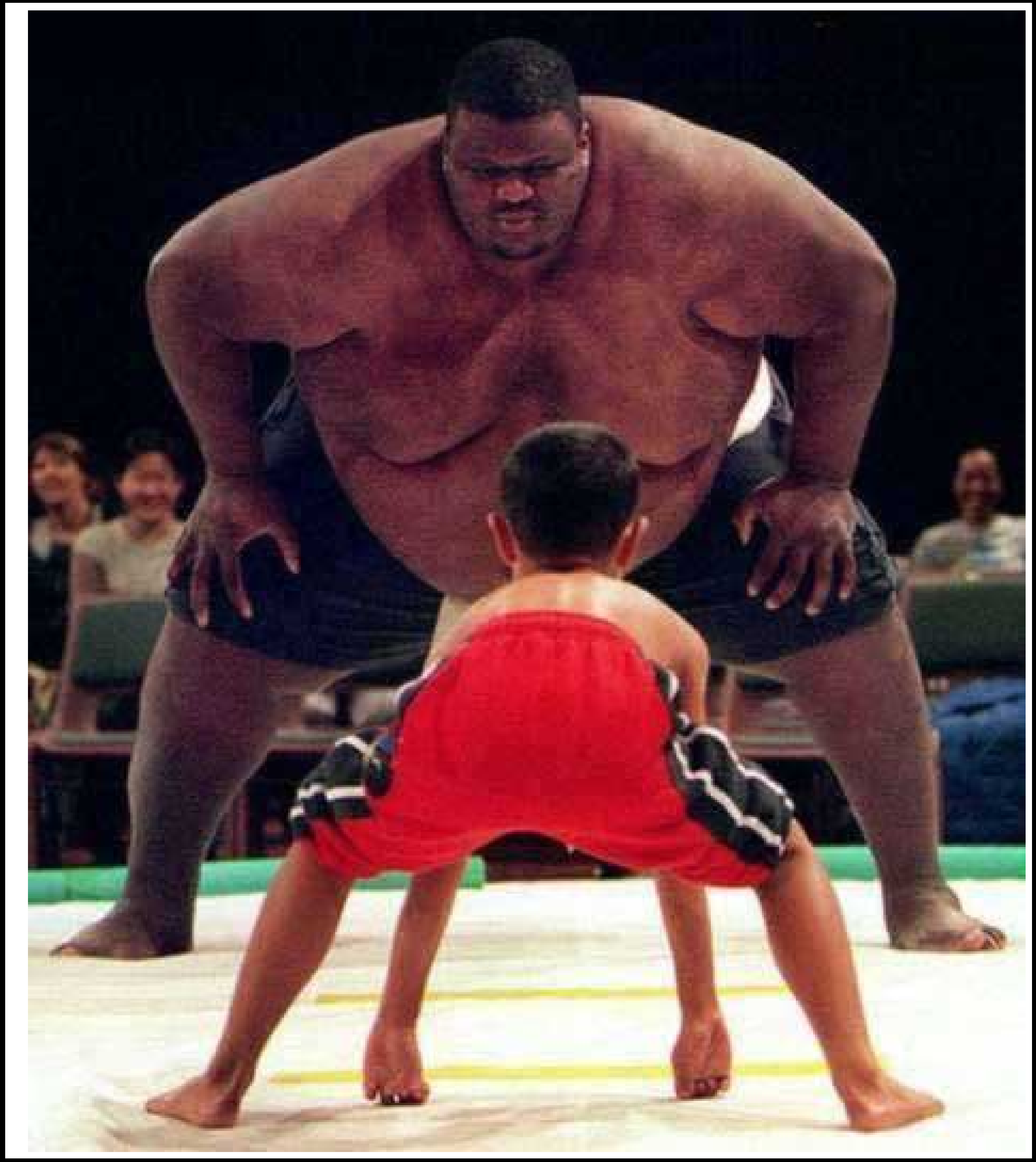
(3) Epoch dependent density of major mergers may precede peak in X-ray selected AGN $\rho(z)$, but by no more than 1–2 Gyr (circumstantial).

(4) Radio and X-ray selected galaxies are — at $z \simeq 0.5$–2 — on average 0.5–1 Gyr older than the typical FBG or LBG age of 0.1–0.2 Gyr.

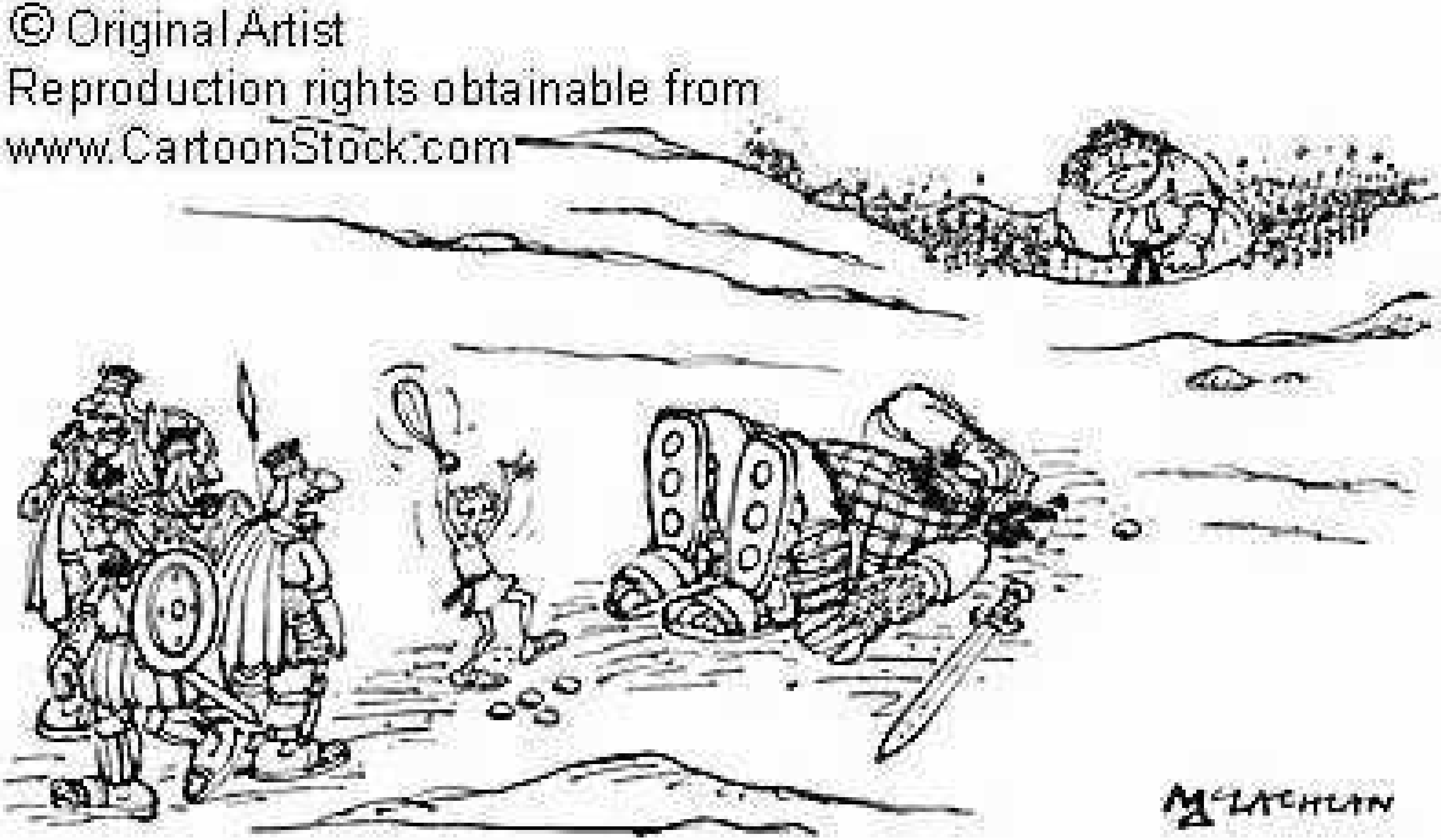
(5) AGN growth likely stays in pace with Galaxy Assembly, but Radio &/or X-ray source appear $\lesssim$1 Gyr after merger/starburst.

• JWST can measure this in great detail to AB$\lesssim$31 mag from 0.7–5.0 μm, tracing galaxy assembly and AGN/SMBH-growth since $z \lesssim 10$–15.

SPARE CHARTS

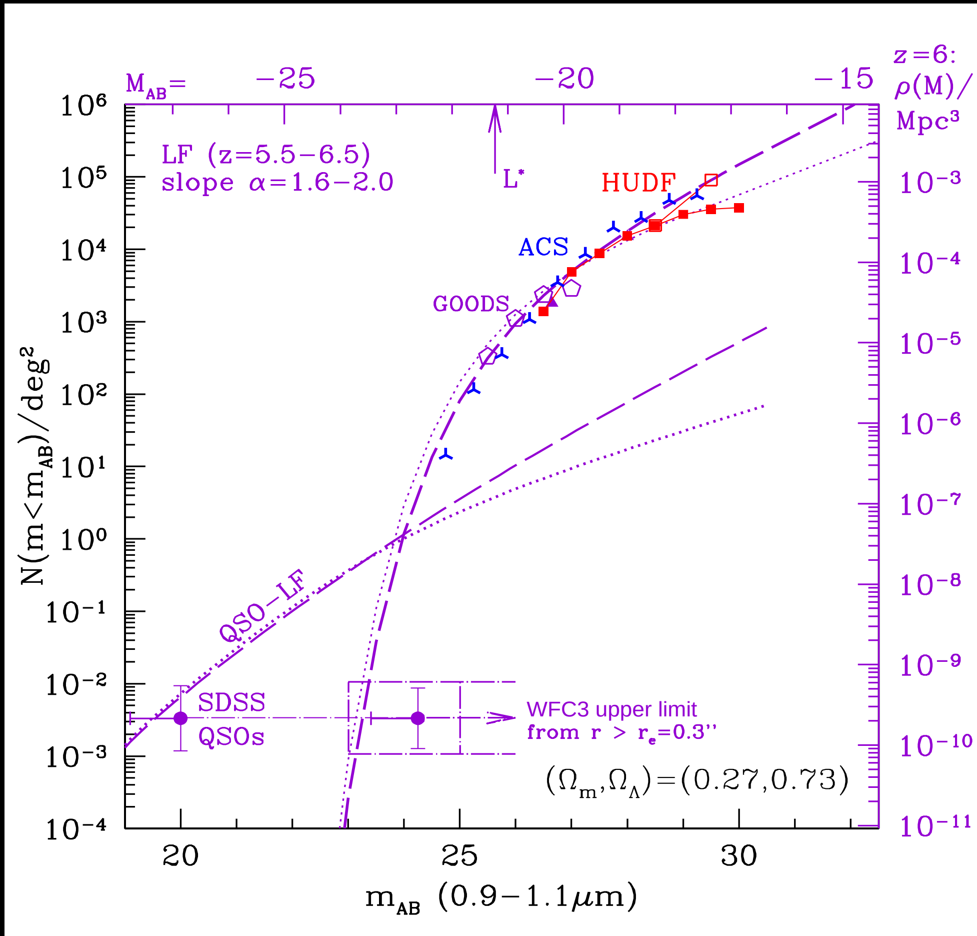


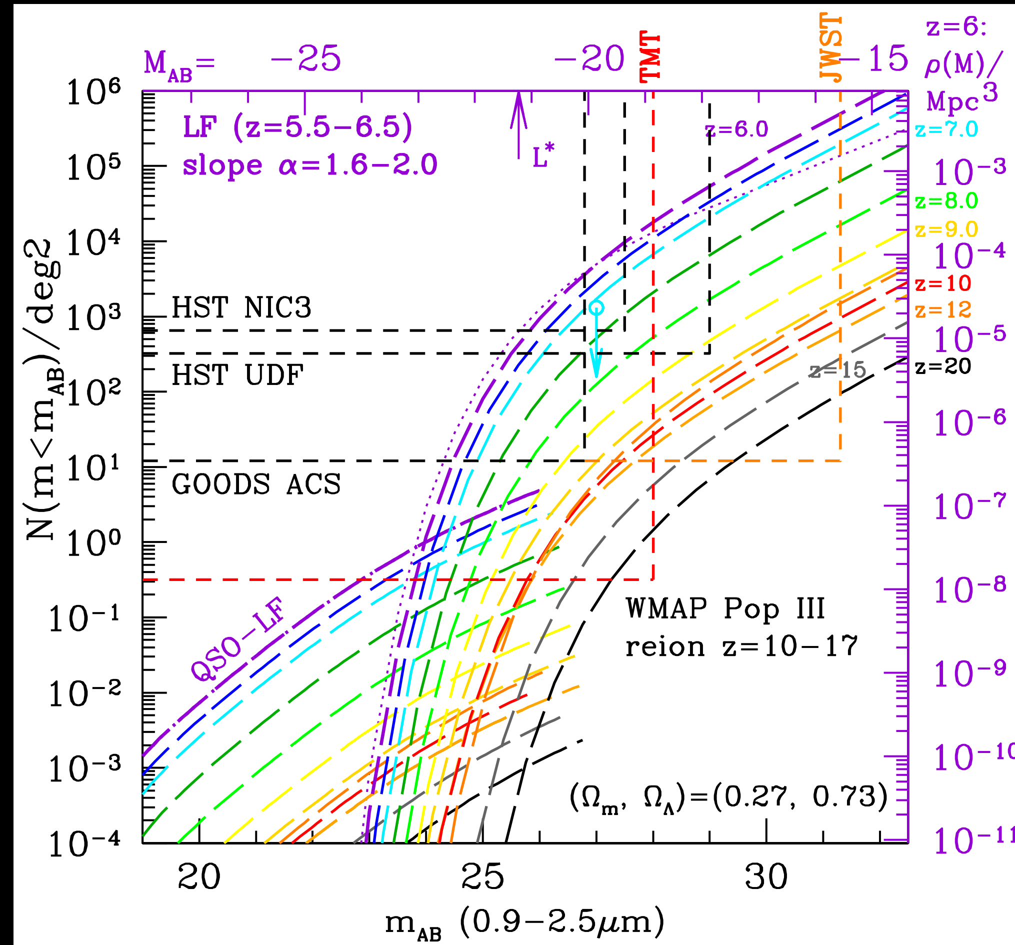
At the end of H-reionization, dwarfs had beaten the Giants, but ...



"You've done it now, David - Here comes his mother."

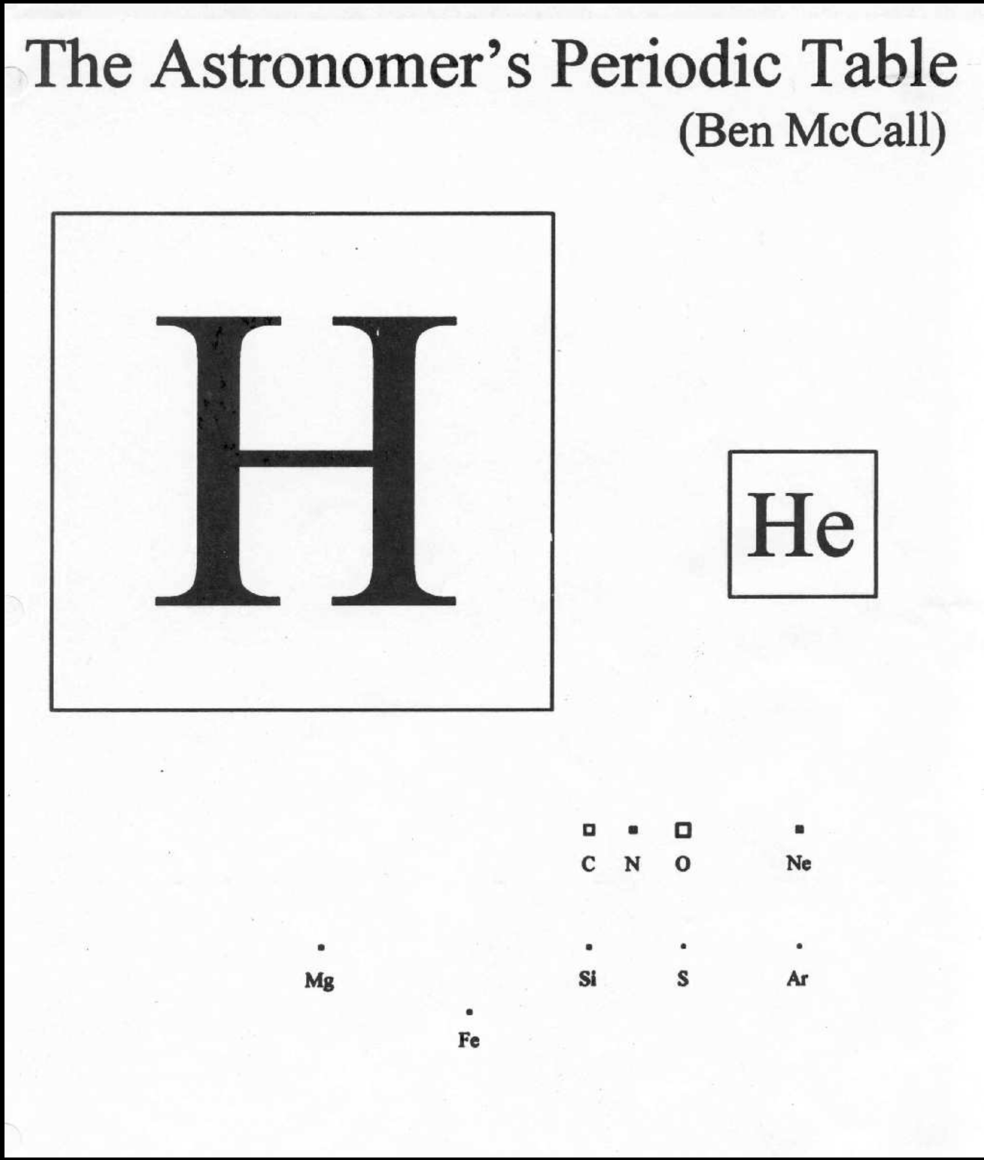
What comes around, goes around ...





- Objects at z≳9 are rare (Bouwens$^+$ 2010, Yan$^+$ 2010), since volume element is small and JWST samples brighter part of LF. JWST needs its sensitivity/aperture (A), field-of-view (**Ω**), and **λ**-range (0.7-29 **μ**m).
- With proper survey strategy (area AND depth), JWST can trace the entire reionization epoch and detect the first star-forming objects.
- To study co-evolution of SMBH-growth and proto-bulge assembly for z≲10–15 requires new AGN finding techniques for JWST.

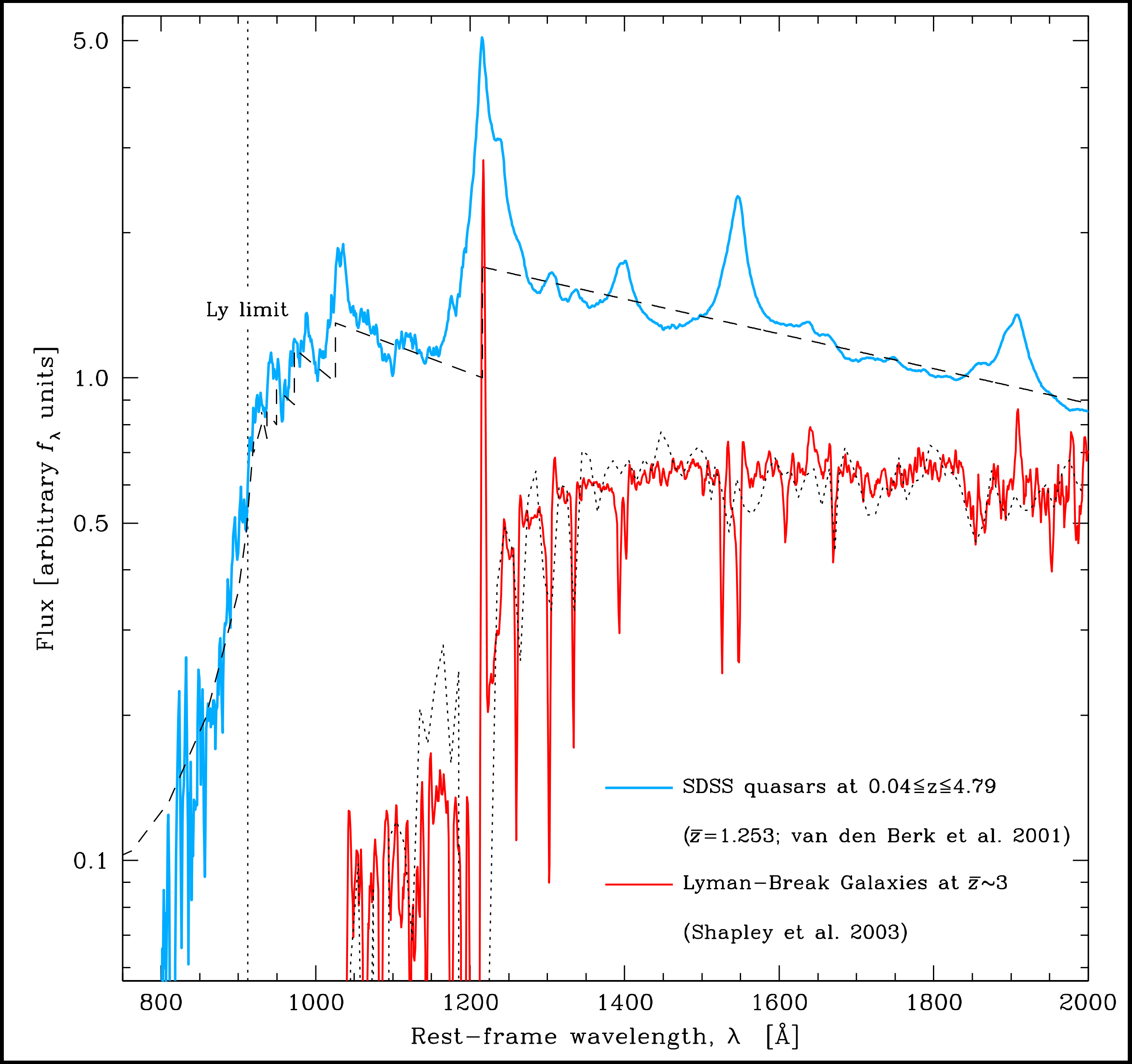
The Universe was reionized (at least) twice:



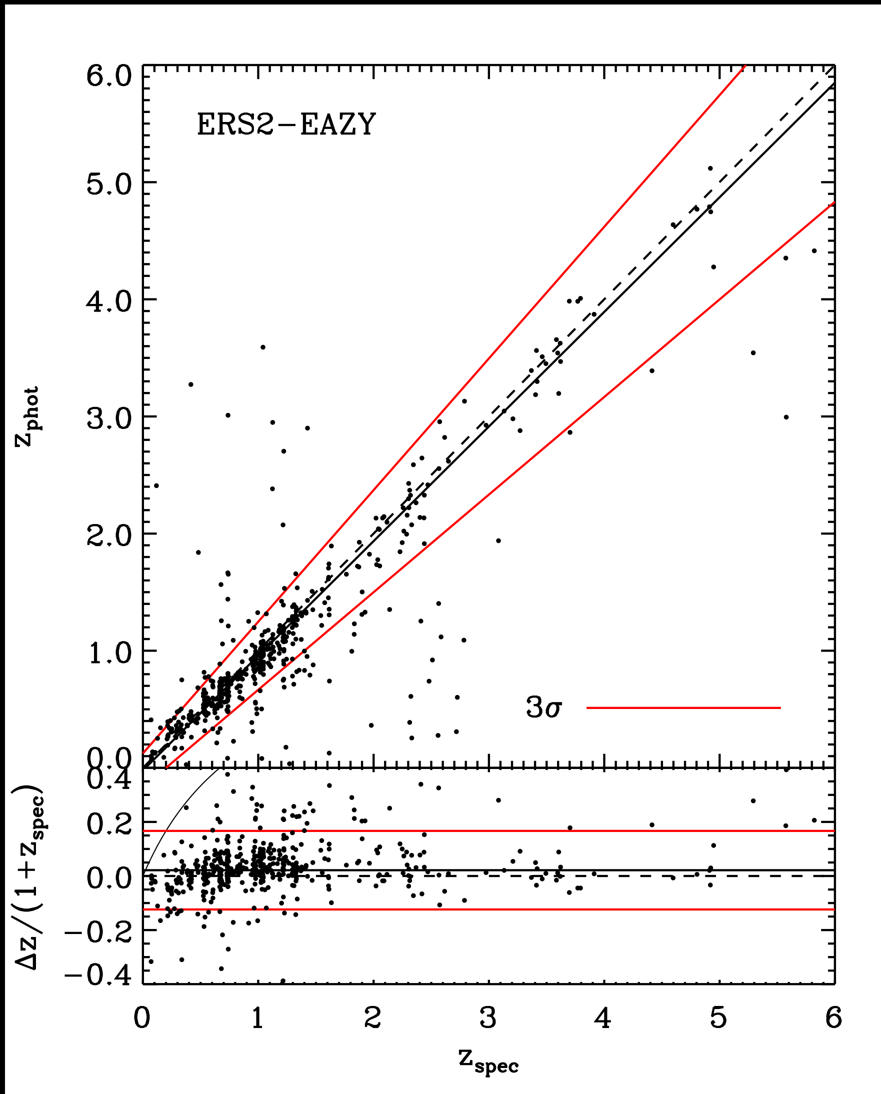
[Astronomers periodic table — with cosmic abundances included:]

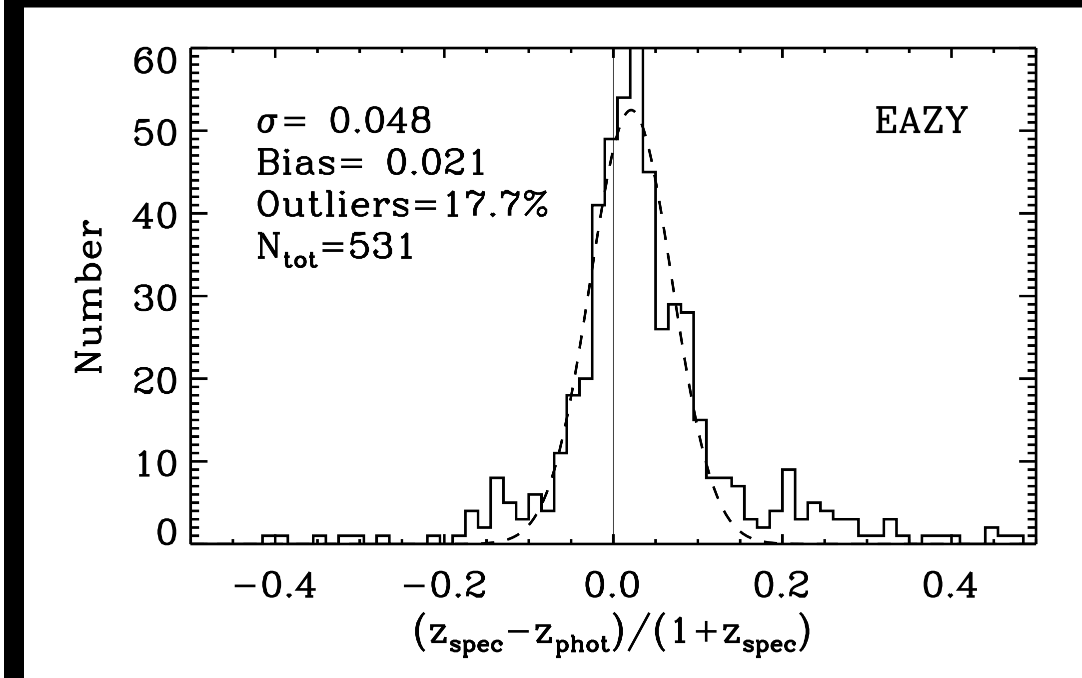
- SF in dwarfs galaxies likely caused H-reionization at $z \simeq 12 \longrightarrow z \simeq 7$.
- Hard-UV of QSO's and weak AGN likely caused He-reionization at $z \simeq 3$.

Caveat: Can the Hard-UV of weak AGN outshine Dwarf Galaxies?



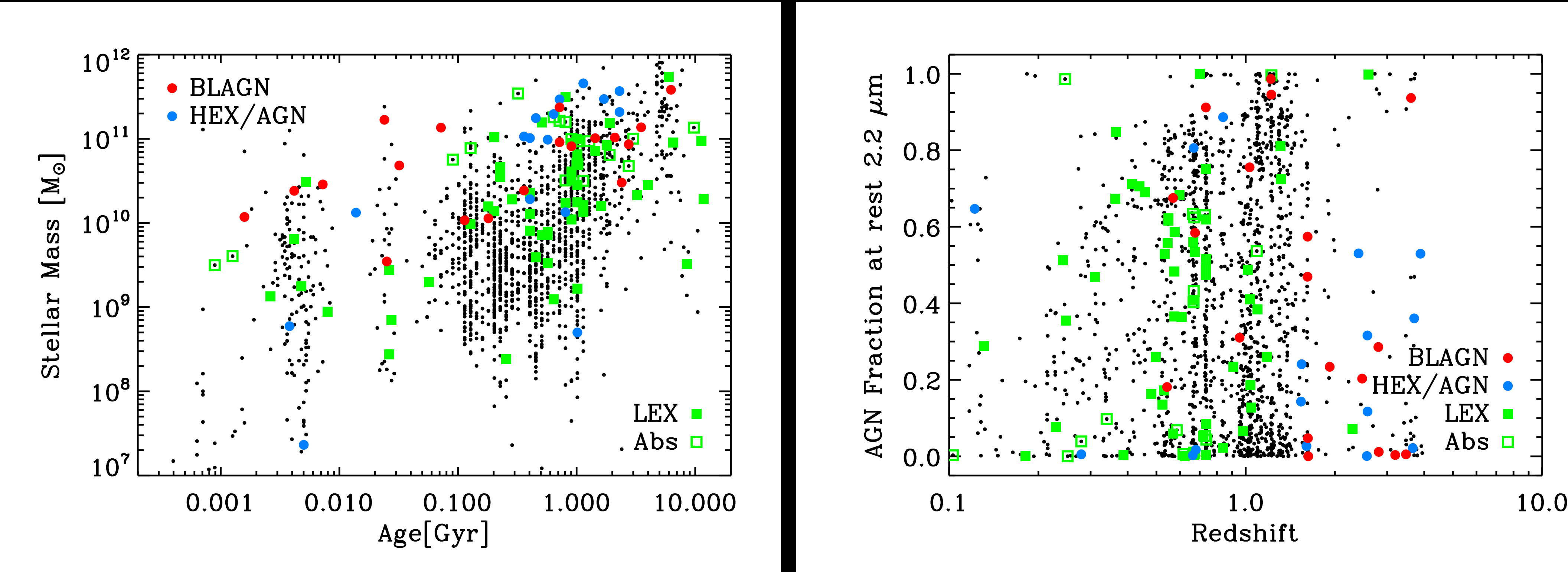
• In principle, the hard-UV of QSO's and weak AGN can outdo the young SED's of LBG's or dwarf galaxies, but likely by no more than $\gtrsim$1 dex.





WFC3 ERS 10-band redshift estimates accurate for AB$\lesssim$27 mag to ∼4%, especially at 1$\lesssim$z$\lesssim$2, with small systematics (Cohen et al. 2010).

- JWST can get accurate photo-z's to AB$\lesssim$31 mag for at z$\simeq$0.5–15.



Cohen et al. (2010): At all ages, the most massive hosts are QSO-1/2's (based on AGN lines in *optical spectra* by Szokoly et al. 2004):

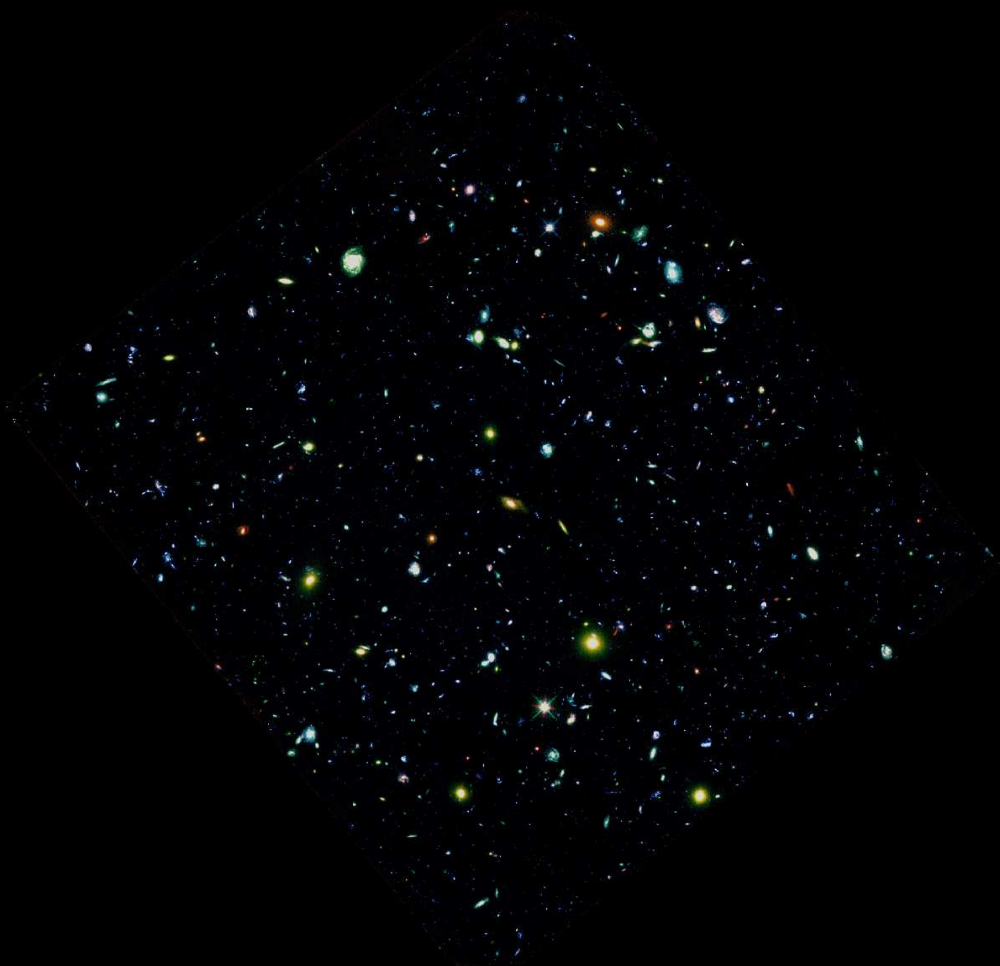
- This is illustrates the well known L_X-L_{opt} correlation.

All optical AGN types: emission lines and absorption features.

Most $\gtrsim$0.5–1 Gyr SEDs do not show AGN signatures in optical spectra.

- For majority of AGN-1's: $\lesssim$50% of 2 μm-flux comes from the AGN !?

Many more with best-fit f(AGN)$\gtrsim$50% to be detected by IXO or SKA!

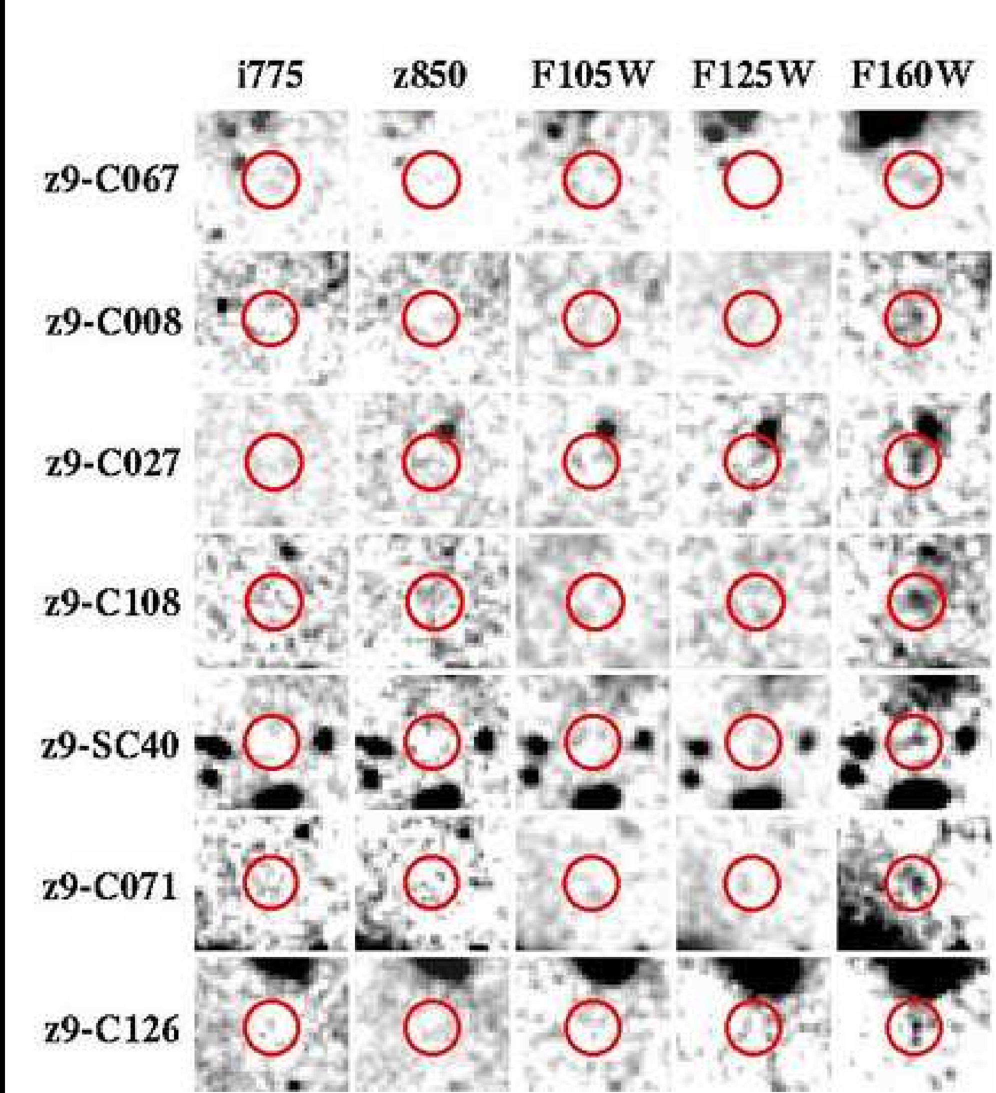
 

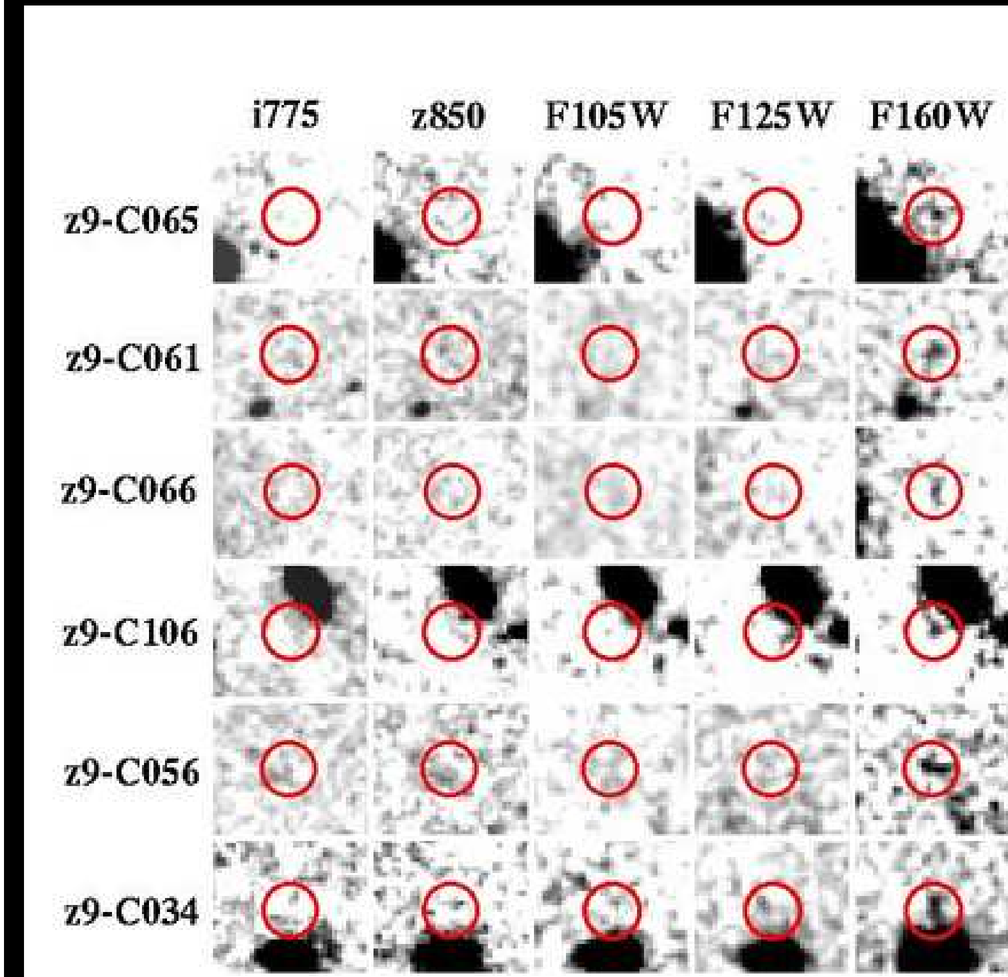
(Left) HST/WFC3 IR-mosaic in YJH in the HUDF: Bouwens et al (2010), Yan et al. (2010; astro-ph/0910.0077).

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

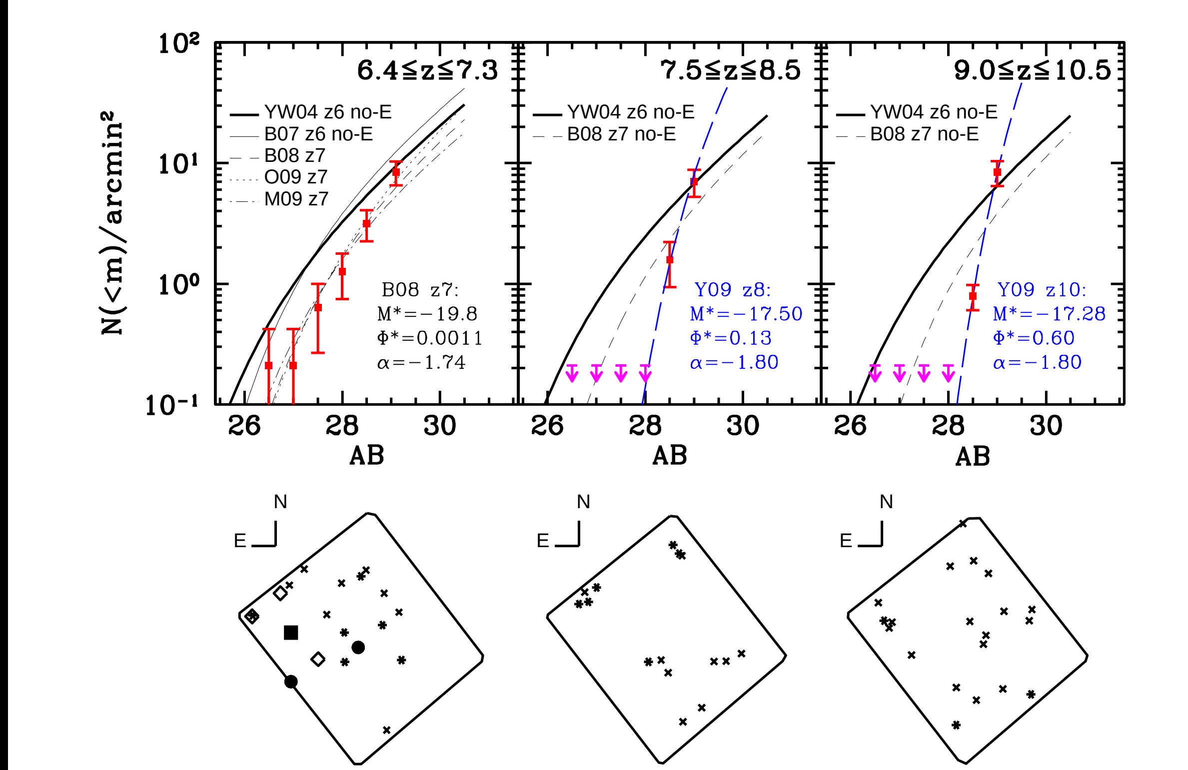
- The CLOSED-TUBE HST has residual low-level systematics: imperfect removal of detector artifacts, flat-fielding errors, and/or faint straylight.

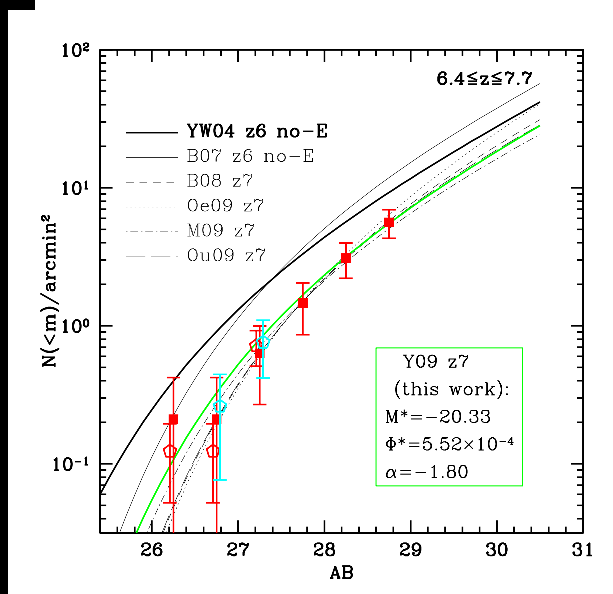
- The open JWST architecture needs perfect baffling and rogue path mitigation to do ultradeep JWST fields (JUDF's) to 10^{-4} of sky.

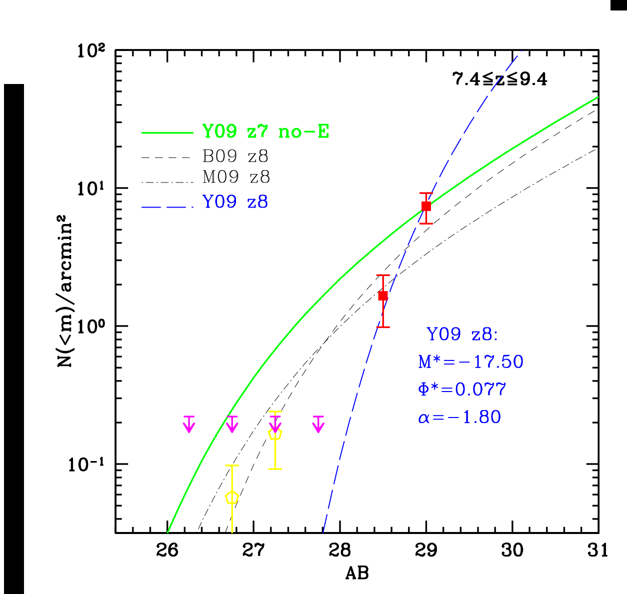




- ∼30–50% of the Y-drops and J-drops close to bright galaxies (Yan et al. 2010, Res. Astr. & Ap., 10, 867; astro.0910.0077).
- This is expected from gravitational lensing bias by galaxy dark matter halo distribution at z≃1–2 (Wyithe et al. 2011, Nature, 469, 181.
- Need JWST to measure z≳9 LF, and see if it's fundamentally different from the z≲8 LFs. Does a gravitational lensing bias cause power-law LF?

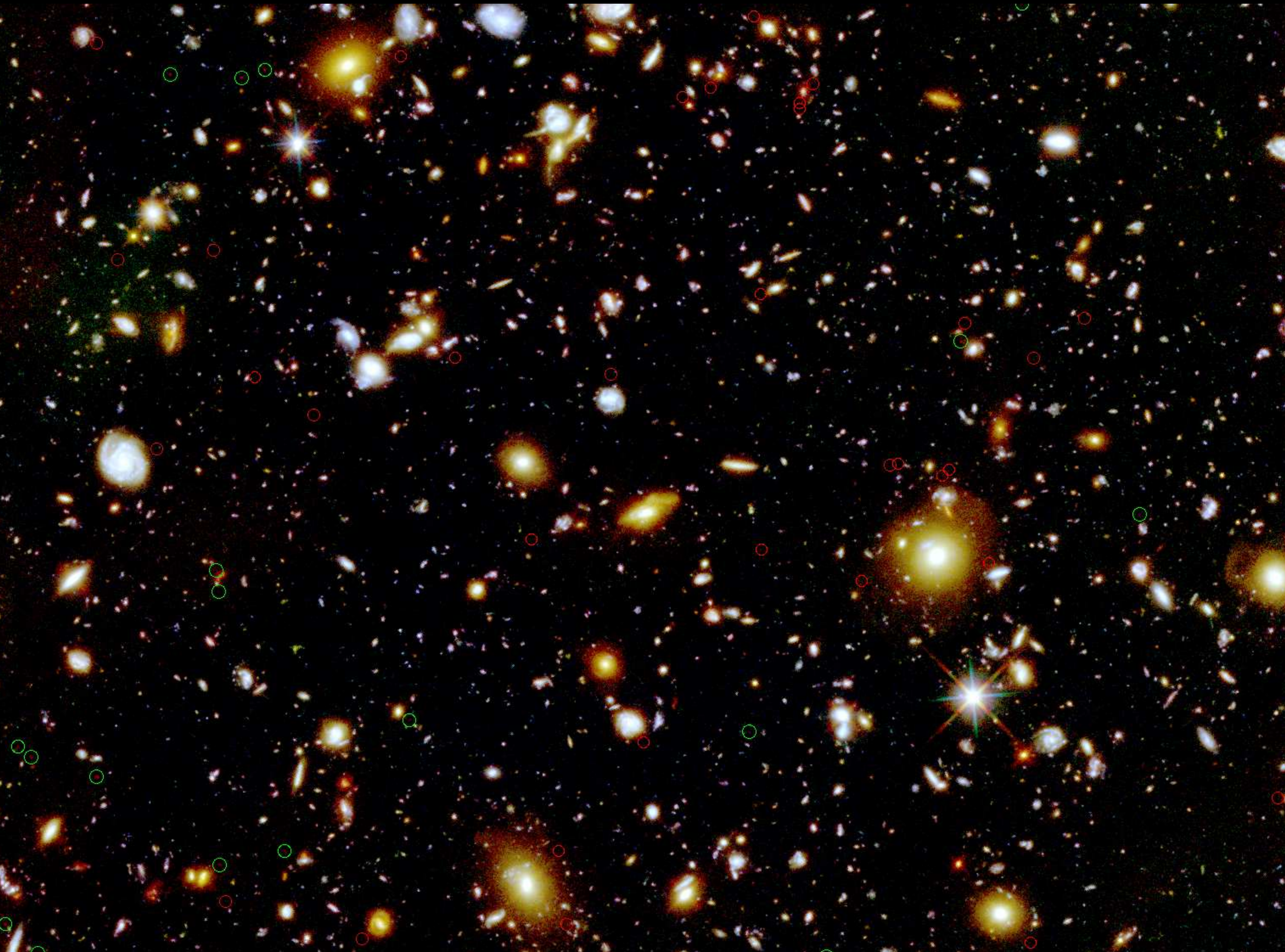


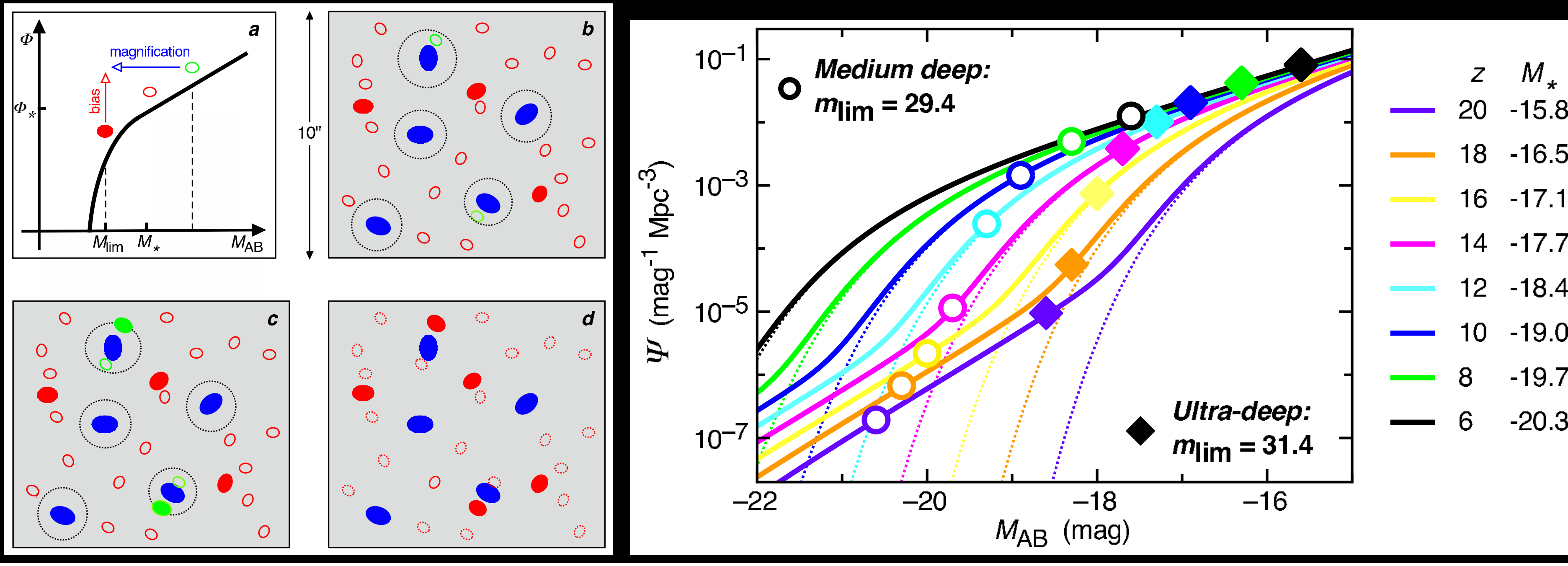


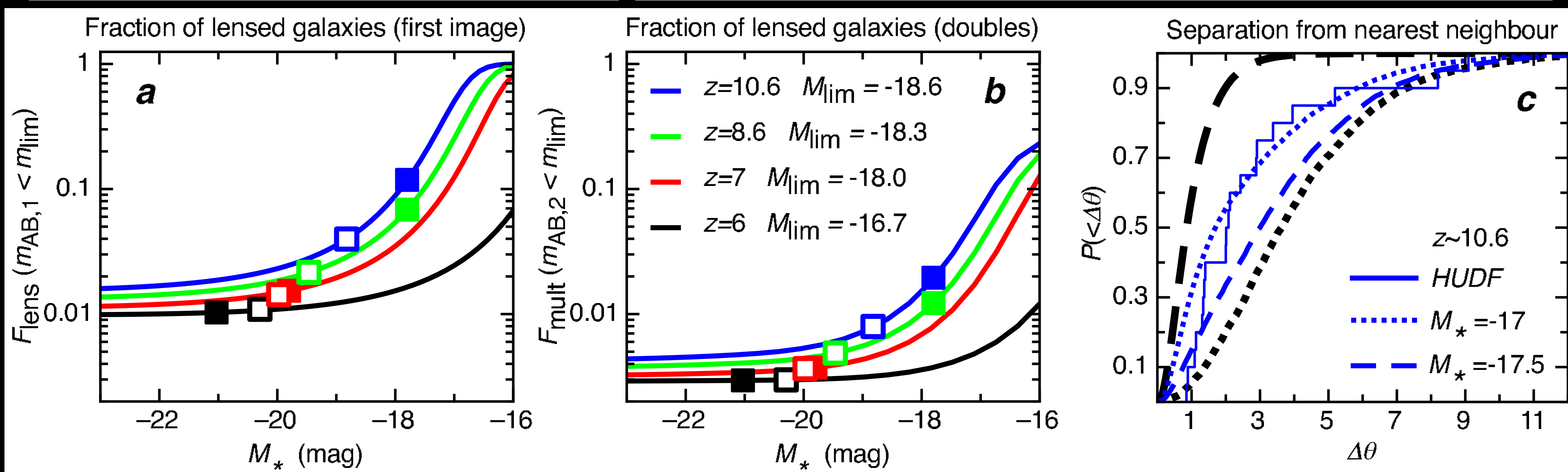


Update of Yan et al. 2009 (astro.0910.0077) HUDF with WFC3 ERS data:

- z=7 LF more firm (see Bouwens), z=8 LF refined, z=9.5 UL's still stand.

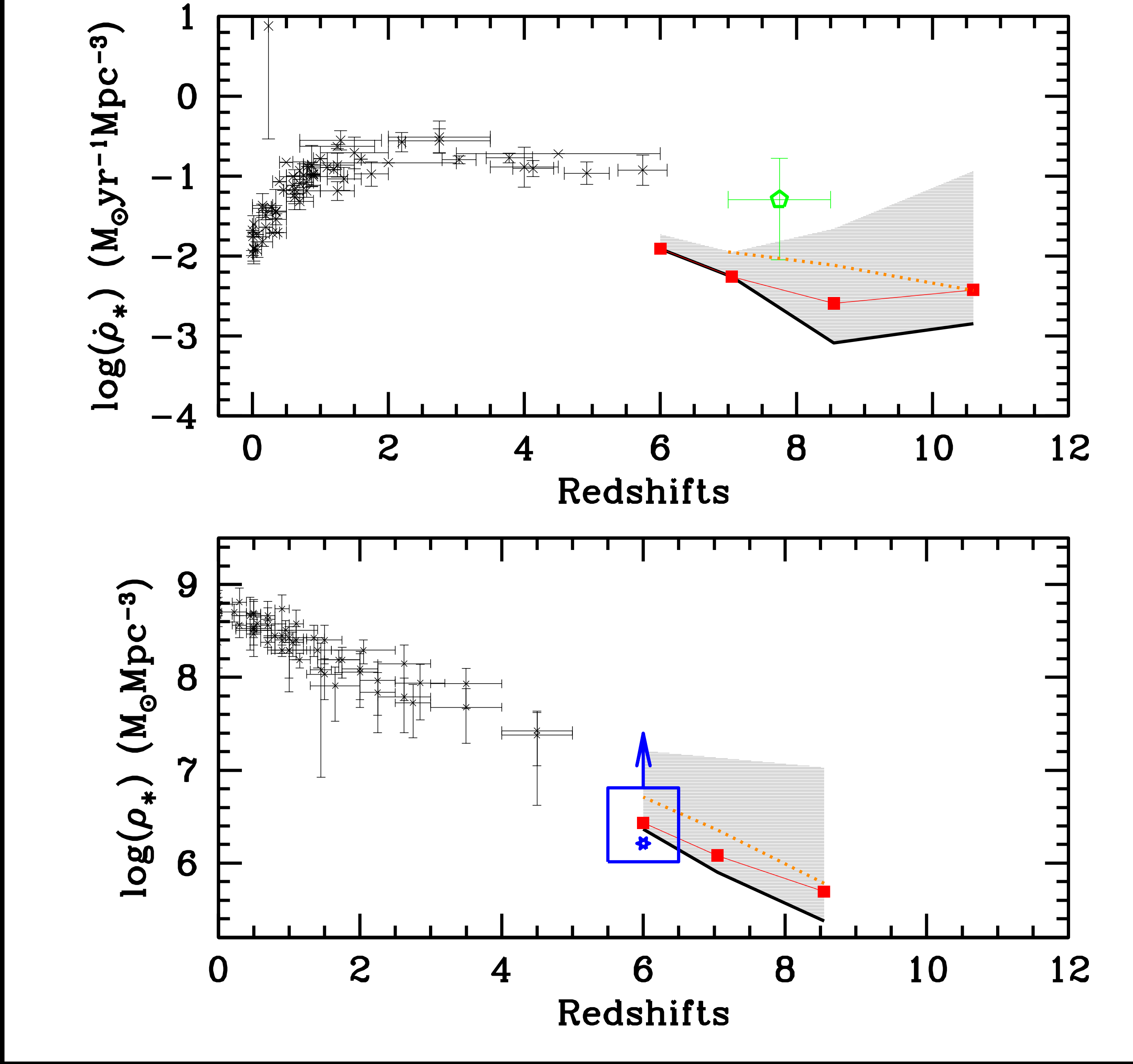






Wyithe et al. (2011, Nature, 469, 181): With a steep faint-end LF-slope $\alpha \gtrsim 2$, and a characteristic faint $M^* \gtrsim$–19 mag, foreground galaxies (at z$\simeq$1–2) may cause significant boosting by gravitational lensing at z$\gtrsim$8–10.

- This could change the landscape for JWST observing strategies.



The current WFC3 uncertainties on J-drops are large enough that at $z \gtrsim 8$, a wide range of possibilities is allowed (Yan et al. 2010; astro.0910.0077).

- Need JWST to fully measure the LF and SFR for $8 \lesssim z \lesssim 15$.

- References and other sources of material shown:

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

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

http://wwwgrapes.dyndns.org/udf_map/index.html [Clickable HUDF map]

http://www.jwst.nasa.gov/ and http://www.stsci.edu/jwst/

http://jwst.gsfc.nasa.gov/faq_scientists.html

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/guider/

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. 2007, Advances in Space Research, 42, p. 1965 (astro-ph/0703171) "High Resolution Science with High Redshift Galaxies"