A candidate redshift z~10 galaxy and rapid changes in that population at an age of 500 Myr, or: How I learned to stop worrying and love the tiny specks that look like nothing

Bouwens et al., 2011, Nature, 469

Context

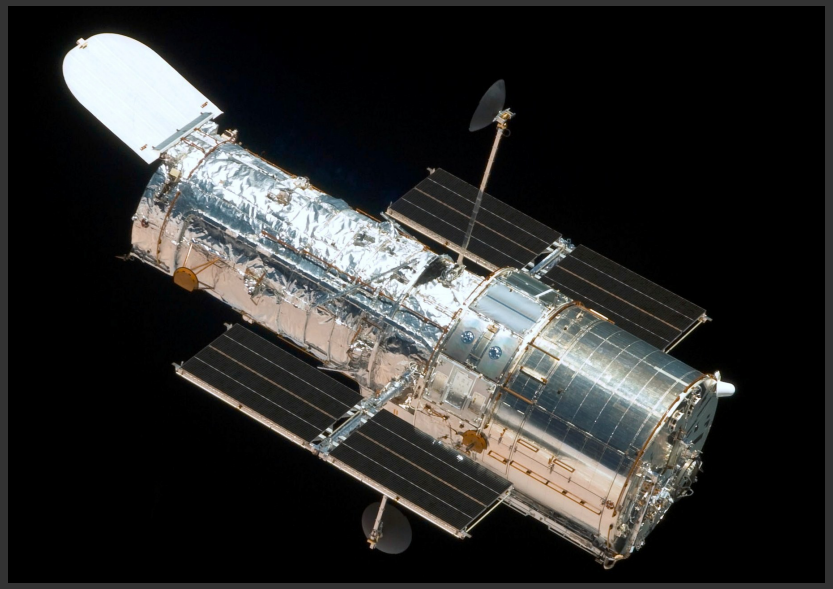
- z=10 is roughly 480 Myr after BB, z=8 is 200 Myr after that
- State of high-z catalog of objects:
  - 3<z<6: over 6000 galaxies, handful of GRBs
  - z~7: ~70 galaxies (many are “candidates”)
  - z~8: ~60 galaxies (many are “candidates”), one z~8.2 GRB
  - This work: one z~10 candidate and three z>8 candidates

Context

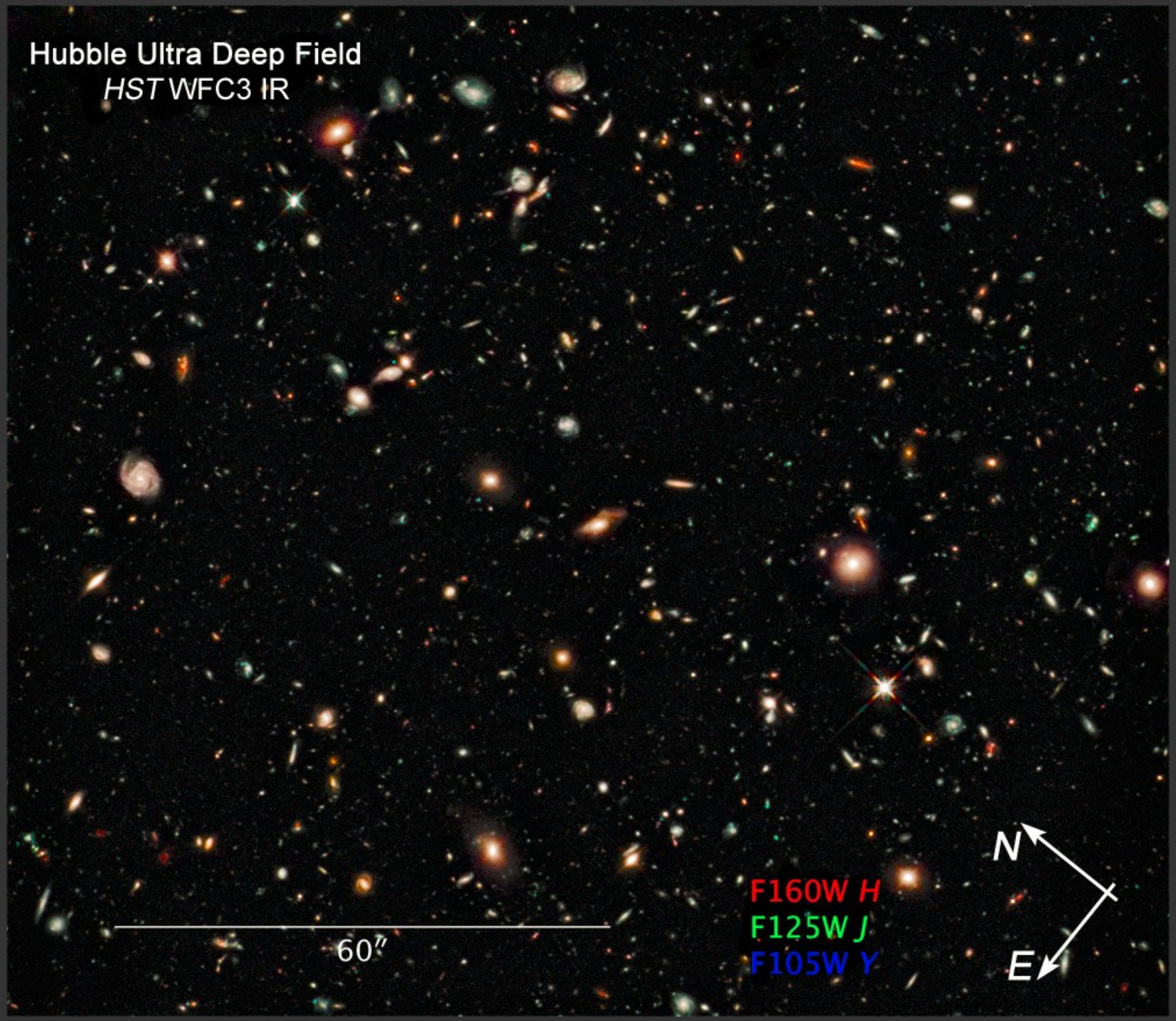
- Why do we care?
  - How galaxies are built: accretion rate of gas onto galaxies, feedback effects, DM power spectrum
  - How reionization happened
  - Evolution of the IGM, metal enrichment

How do you find these things?

- Deep photometry in UDFs from HST/WFC3, supplemented by HST/ACS and Spitzer IRAC 3.6, 4.5 um
  - 4.6 sq arcmin HUD09 + 39.2 sq arcmin ERS GOODS field
  - Sextractor for fixed aperture photometry
- But what do you look for?



The Field


Hubble Ultra Deep Field
HST WFC3 IR
60″
F160W *H*
F125W *J*
F105W *Y*
N
E

Lyman Break technique

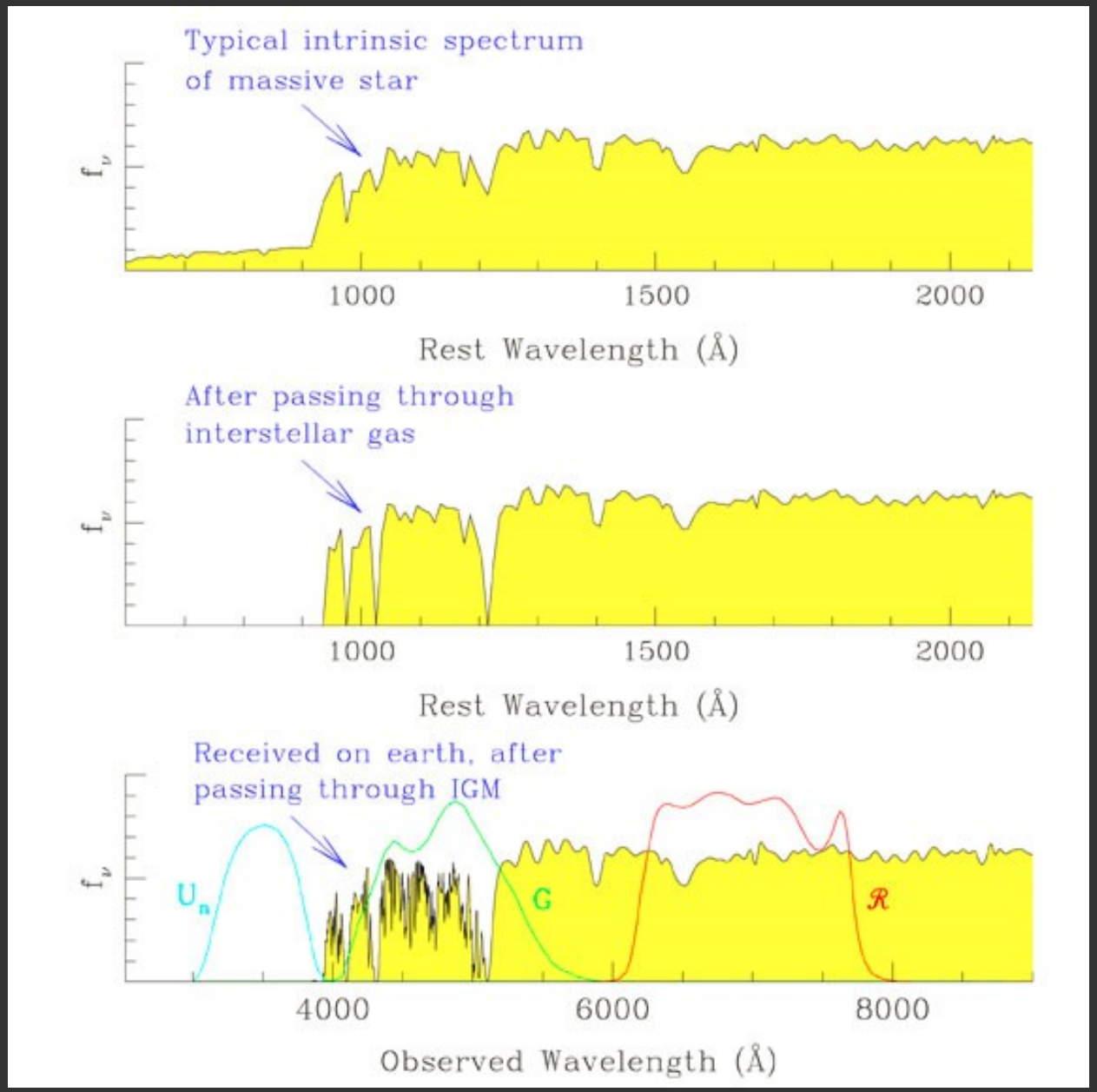


Figure by Kurt Adelberger

But what are the drawbacks?

- Contamination:
  - Spurious noise fluctuations. Especially problematic at z~10 with only one band.
  - Reddened low-z galaxies. Typically old and dusty.
  - Transient sources, esp. SNe
  - Low mass stars
  - Photometric scatter of low redshift galaxies

But what are the drawbacks?

- Contamination:

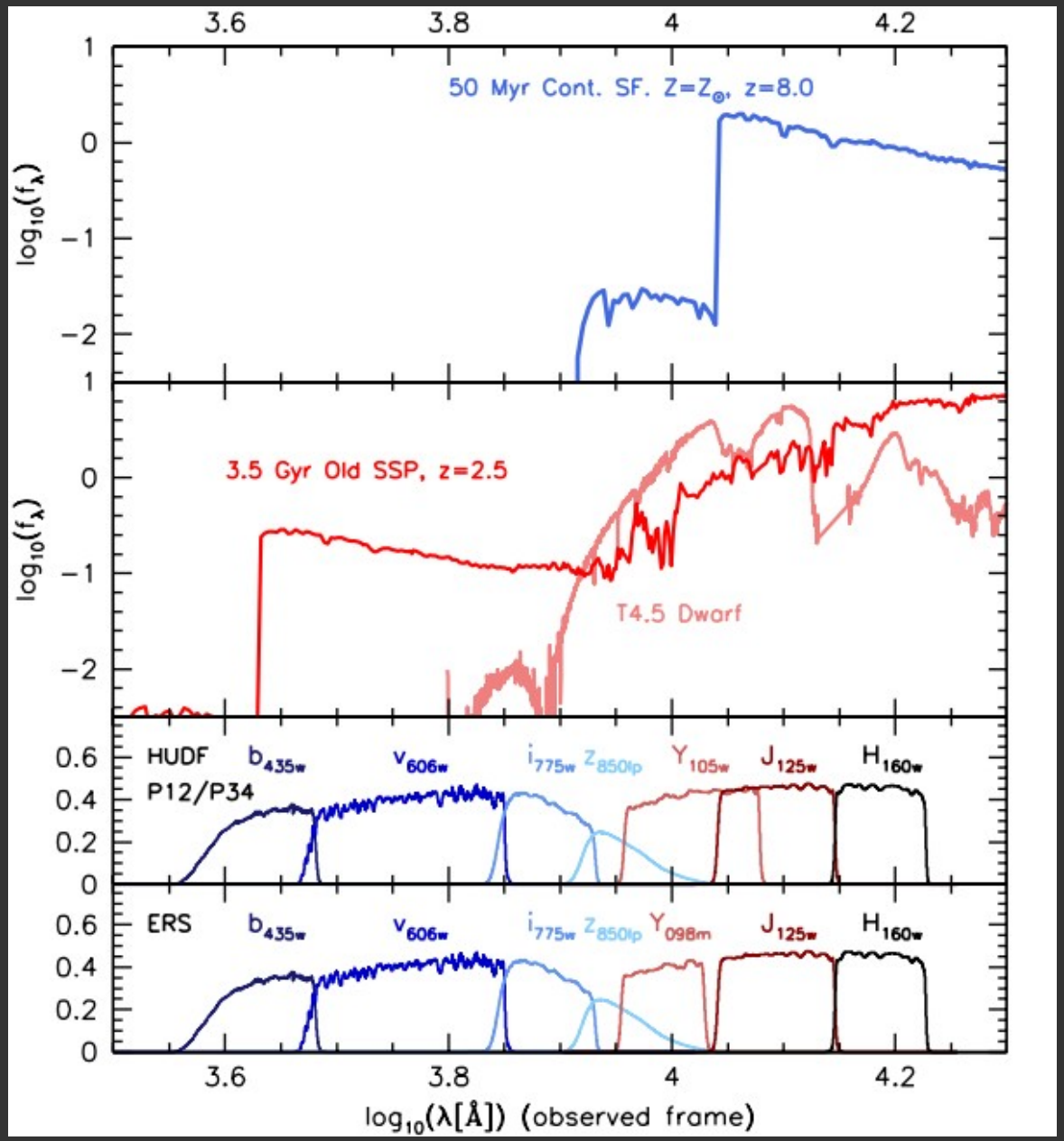


Figure 1. Top panel - Model (from the Starburst99, Leitherer et al. 1999) spectral energy distribution (SED) of a redshifted $z = 8$ star forming galaxy. Middle panel - Potential contaminants: Observed SED of a low-mass dwarf star (class: $T4.5$, Knapp et al. 2004) together with the model (Starburst99) SED of a 3.5Gyr Single-aged Stellar Population (SSP) at $z = 2.5$. The bottom two panels show the transmission functions of the combination of filters available to each field.

Lorenzoni, et al., 2011, MNRAS, 414

Selection Criteria

- J_{125} dropouts
  - J_{125}-H_{160} redder than 1.2 AB mag
  - Undetected (<2σ) blueward of J_{125}
  - >5σ in H_{160} band
  - Not detected at >1.5sigma in more than one band blueward of J_{125}
  - X^2<2.5 in BvizY-band X^2 image:
    - $\Sigma_k SGN(I_k)(I_k(x,y)/N_k)^2$

Selection Criteria

- Y_{105} dropouts
  - Y_{105}-J_{125} redder than 1.5 AB mag
  - Undetected (<2σ) in BViz
  - >5.5σ in J_{125} band

And they found stuff!

Object ID	R.A.	Dec	H_{160}[a]	$Y_{105} - J_{125}$[b]	$J_{125} - H_{160}$	r_{hl}[c]	z_{est}[d]
UDFj-39546284	03:32:39.54	−27:46:28.4	28.92±0.18	—	>2.0	0.13″	10.3
UDFy-38135539	03:32:38.13	−27:45:53.9	27.80±0.08	1.8±0.7	0.2±0.1	0.18″	8.7
UDFy-37796000	03:32:37.79	−27:46:00.0	28.01±0.11	>2.3	-0.1±0.1	0.19″	8.5
UDFy-33436598	03:32:33.43	−27:46:59.8	28.93±0.18	>1.7	0.0±0.2	0.16″	8.6

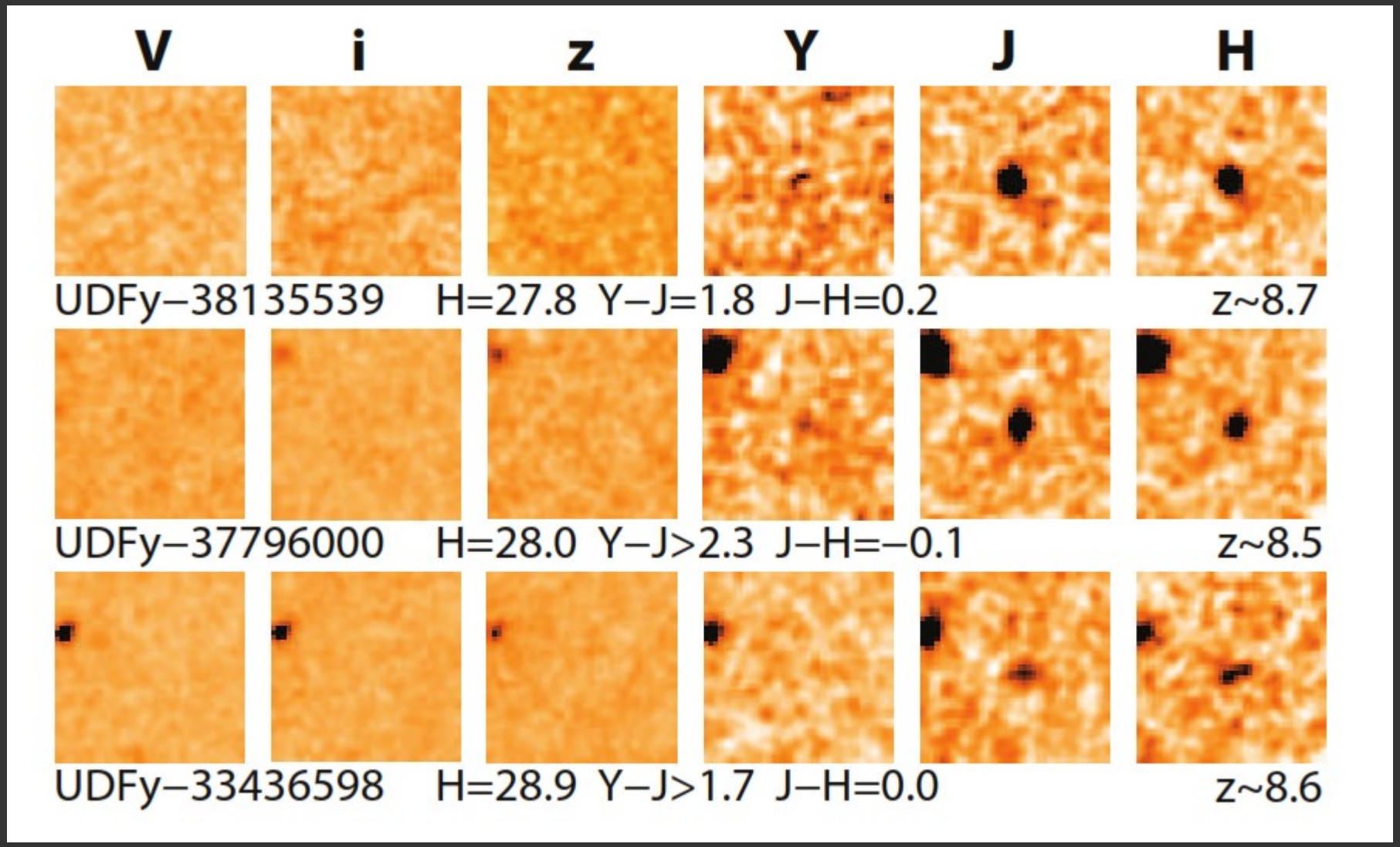
[a]The magnitudes quoted here are based upon the light inside our large scalable apertures (and also include ∼0.2-0.3 mag corrections for light on the wings of the PSF). As such, they are significantly brighter than those quoted for our candidates in smaller apertures (e.g., in Figure S1).

[b]Lower limits on the measured colors are the 1σ limits.

[c]The quoted half-light radii are as observed and are not corrected for the PSF. The half-light radius r_{hl} for the PSF is 0.09″.

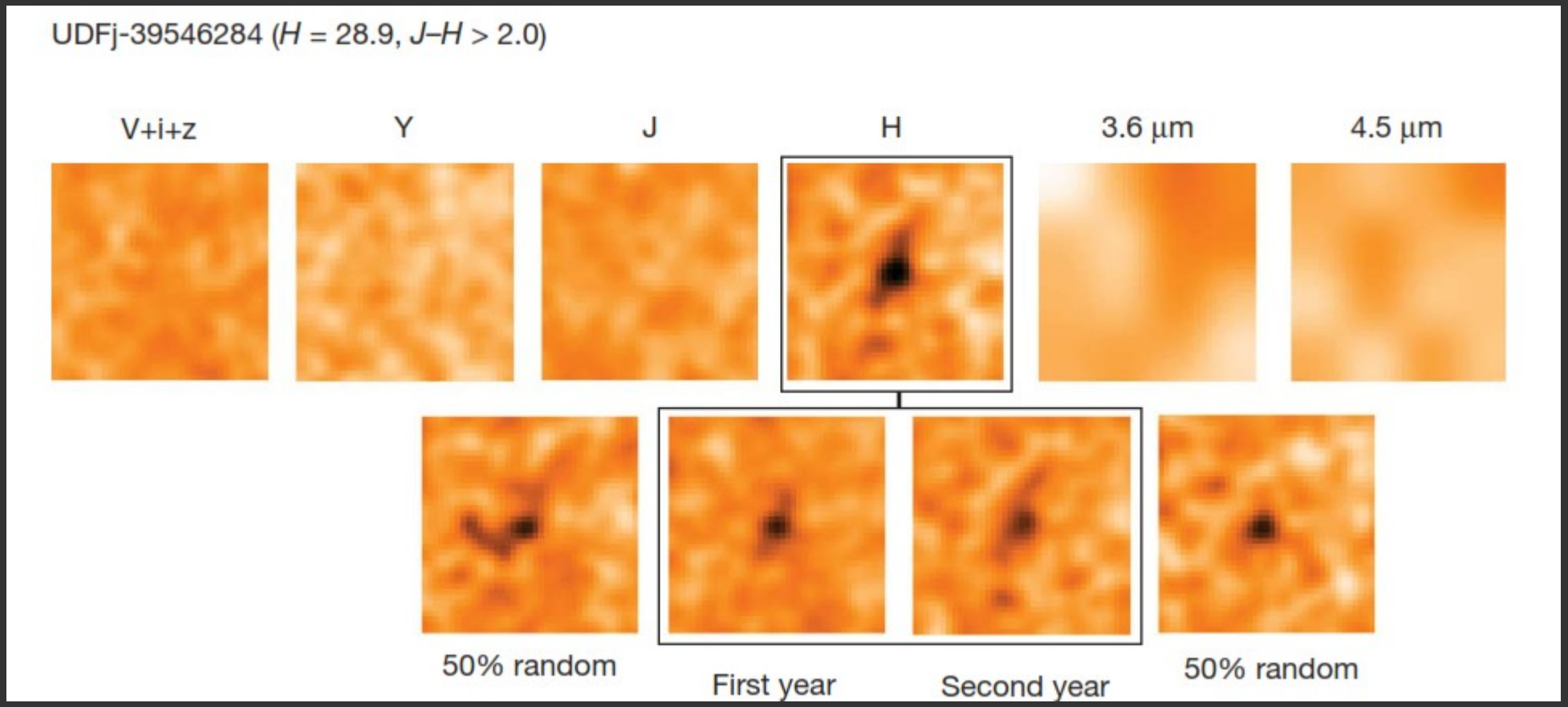
[d]Estimated redshift. See Figure 2 of the main paper for the redshift distributions

z>8 candidates



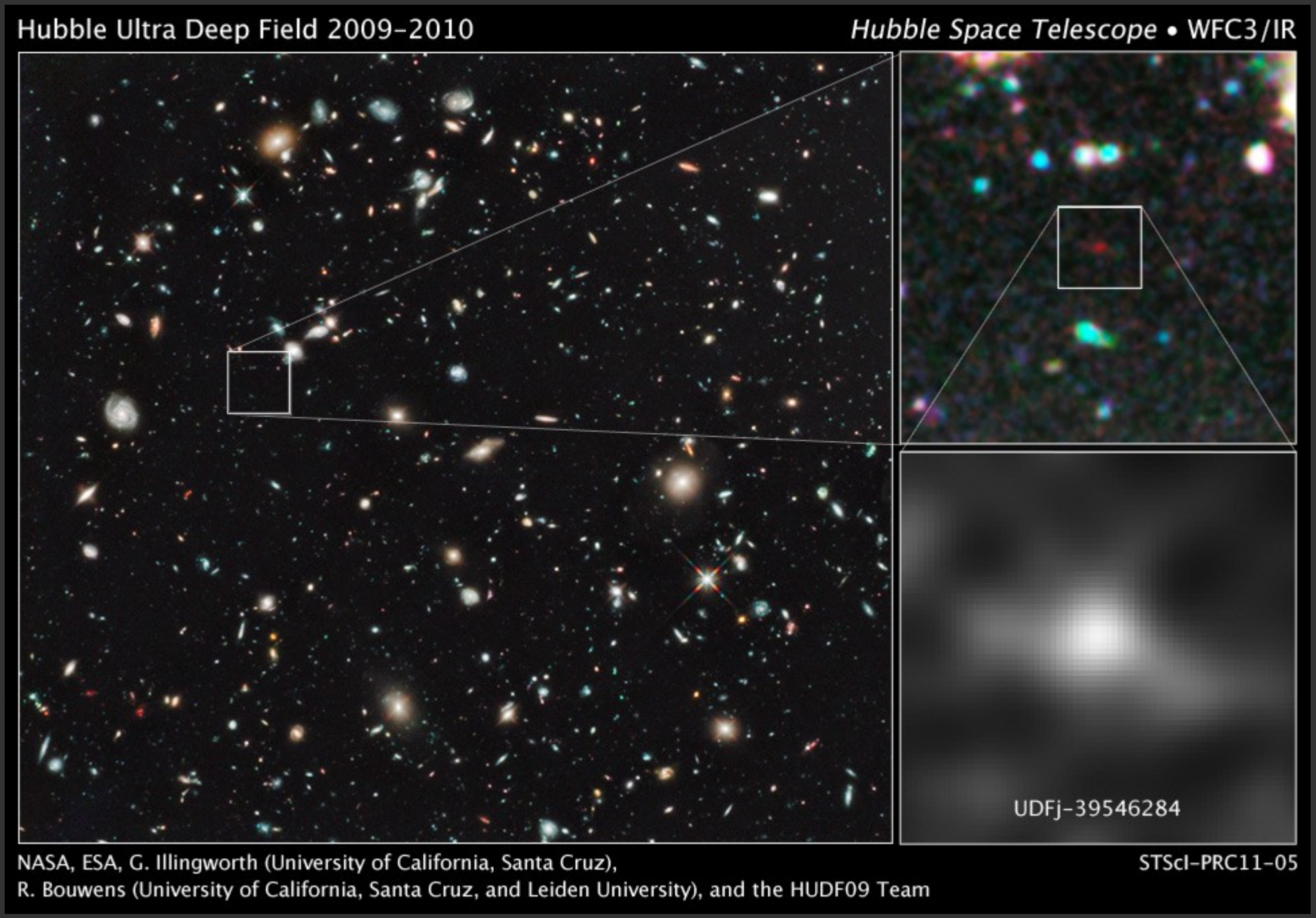
2.4” on a side, North is up

z~10 candidate

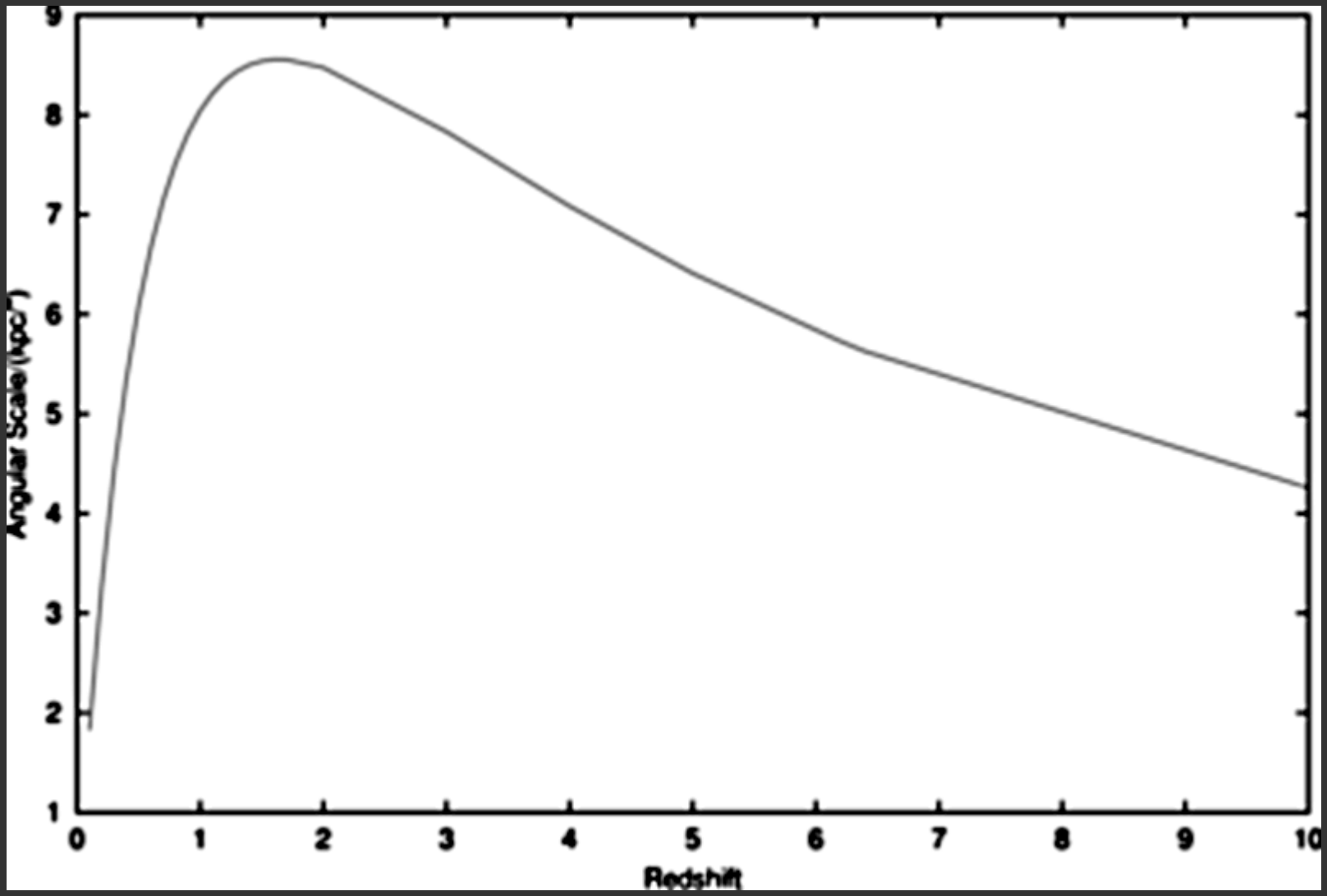


- 2.4” on a side, North is up

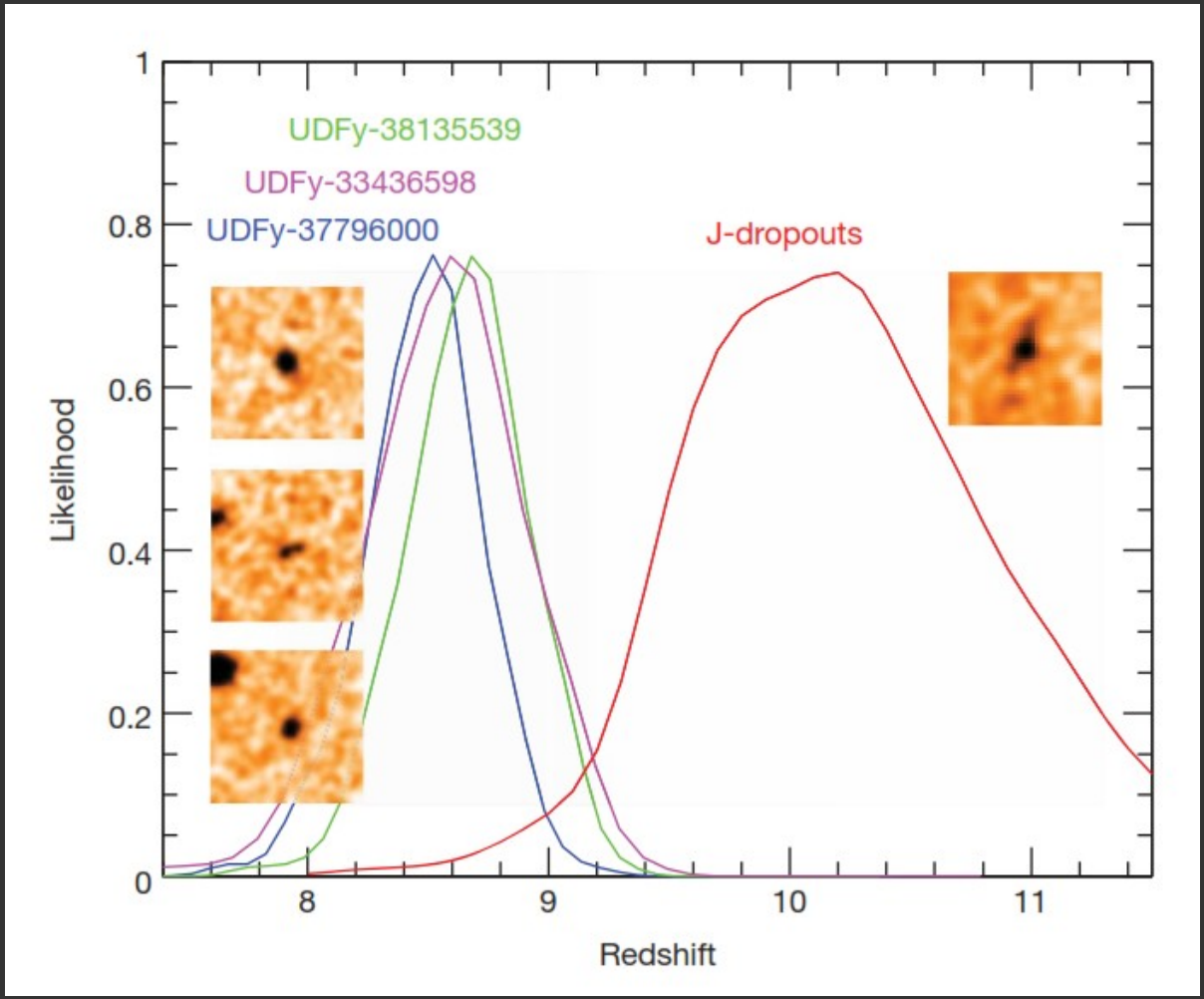
z~10 candidate



Angular size vs redshift



Redshift distributions



- Derived by adding artificial sources, reselecting

Evaluating the contamination risk

- Spurious noise fluctuations?
  - Characterized noise by smoothing and testing Gaussianity
  - Split data into subsets (random, epochs, etc)
  - Negative image test (no candidates found)
  - Y+J single epoch test

Evaluating the contamination risk

- Reddened low-z galaxies?
  - Not in Spitzer
  - Y-dropouts in absence of H test

Evaluating the contamination risk

- Sne?
  - timing makes risk negligible

Evaluating the contamination risk

- Low mass stars?
  - Extended
  - Luminosity inconsistent with reasonable distance

Evaluating the contamination risk

- Photometric scatter of low redshift galaxies?
  - 0.1 contaminants per field from Monte Carlo simulations

Evaluating the contamination risk

- Overall:
  - Per field:
    - 0.1 contaminants from photometric scatter
    - 0.1 contaminants from spurious sources
    - 0.8 real galaxies

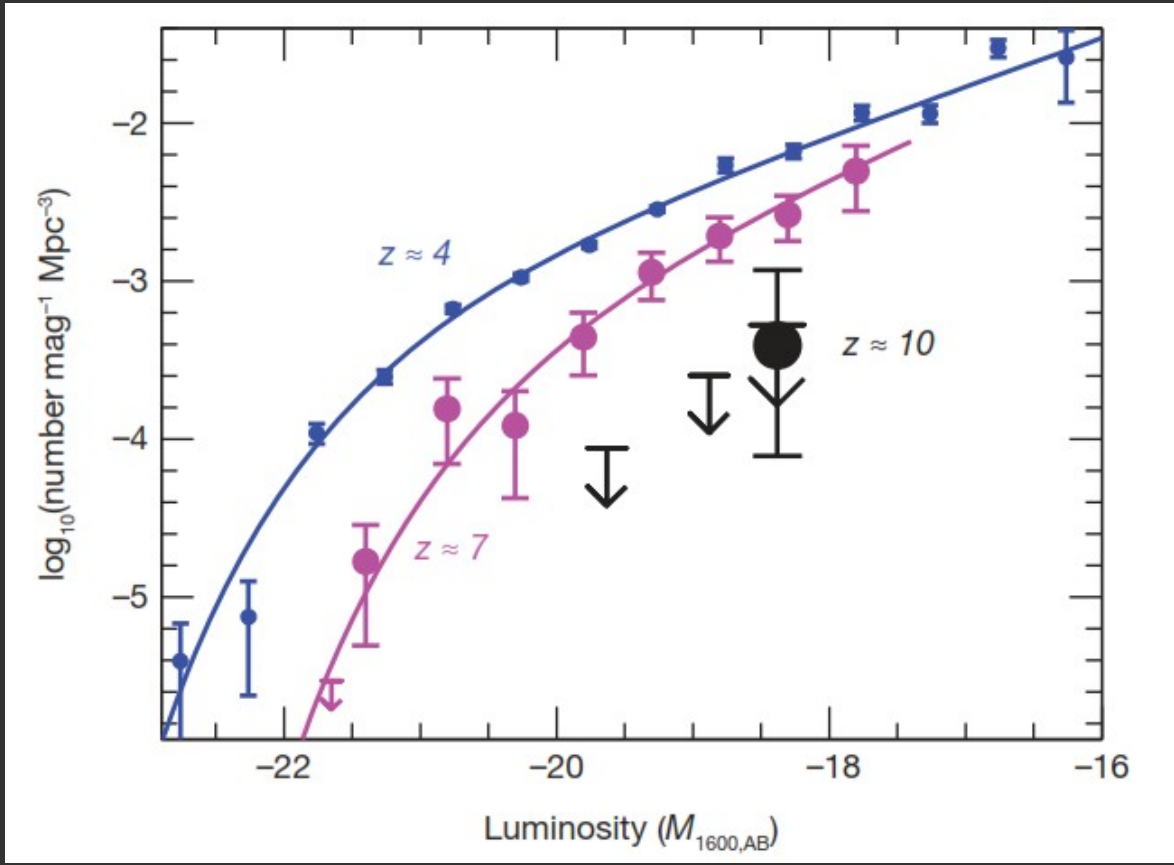
What did we learn?

- Regardless of the reality of the detection, the study constrains the galaxy population at z~10
- Is the galaxy population different at z~10?
  - 'No-evolution': Artificially redshift z~6,7 populations, add into data, reselect
    - 23+-5, 12+-4 galaxies respectively
    - Inconsistent with no evolution at 5,6 sigma
    - No upturn in star formation
  - 'Extrapolation of trends': Expect 3+-2 galaxies

Luminosity function

- The luminosity function answers our initial questions about reionization because it tells us about ionizing flux
- Faint end slope:
  - Assume -1.7
  - At best, 12^{+26}_{-10}%

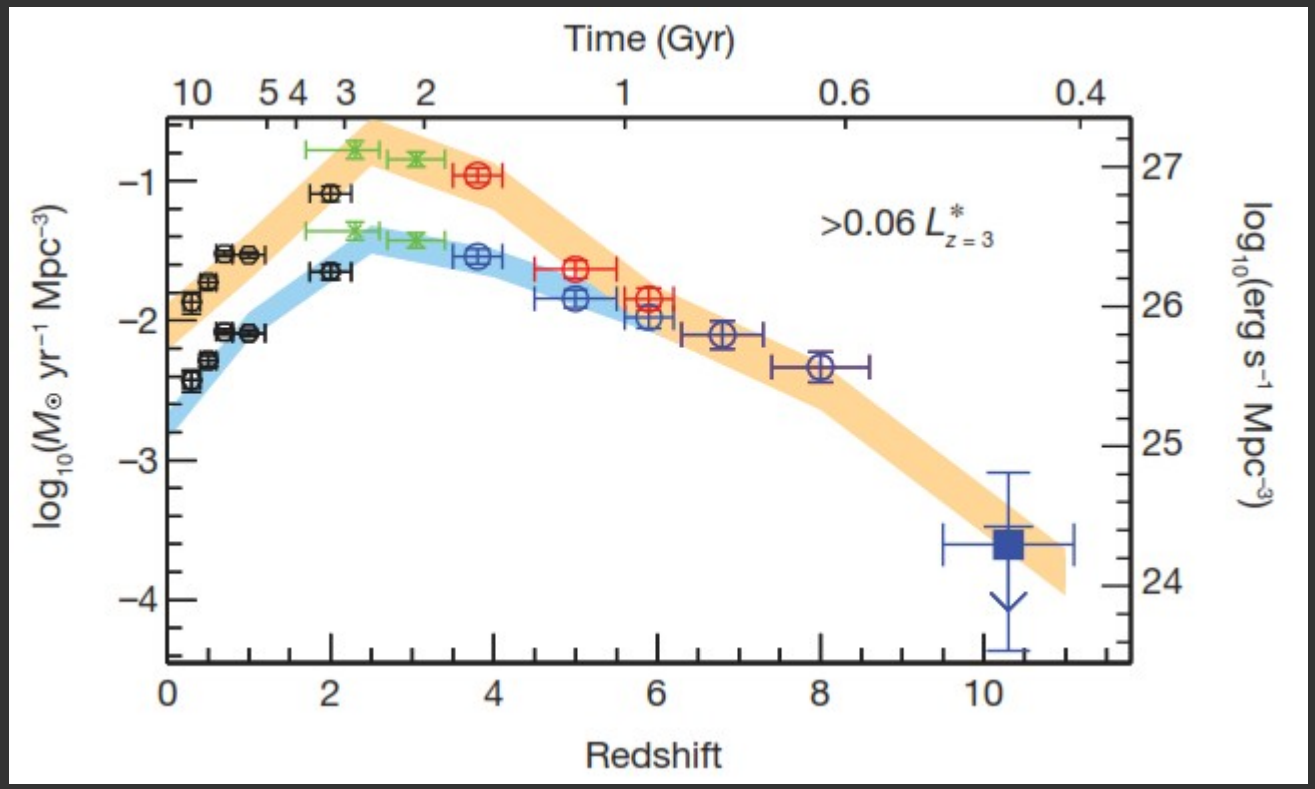
    of reionizing flux



Star Formation Rate, Luminosity density

Blue, right axis: restframe UV luminosity density

Orange, left axis: Star formation rate density, assumes Salpeter IMF



- Madau et al. Conversion may be invalid because it assumes SF over >100 Myr

Take aways

- Possible detection of z~10 galaxy
- Rapid galaxy evolution in this era
- These galaxies cannot reionize the universe alone
- Better samples and initial galaxy formation need JWST, which can possibly probe z~10 to z~15, and 21cm measurements that indirectly probe the galaxy population at higher z