Reionization: Star Forming Galaxies at z~6?

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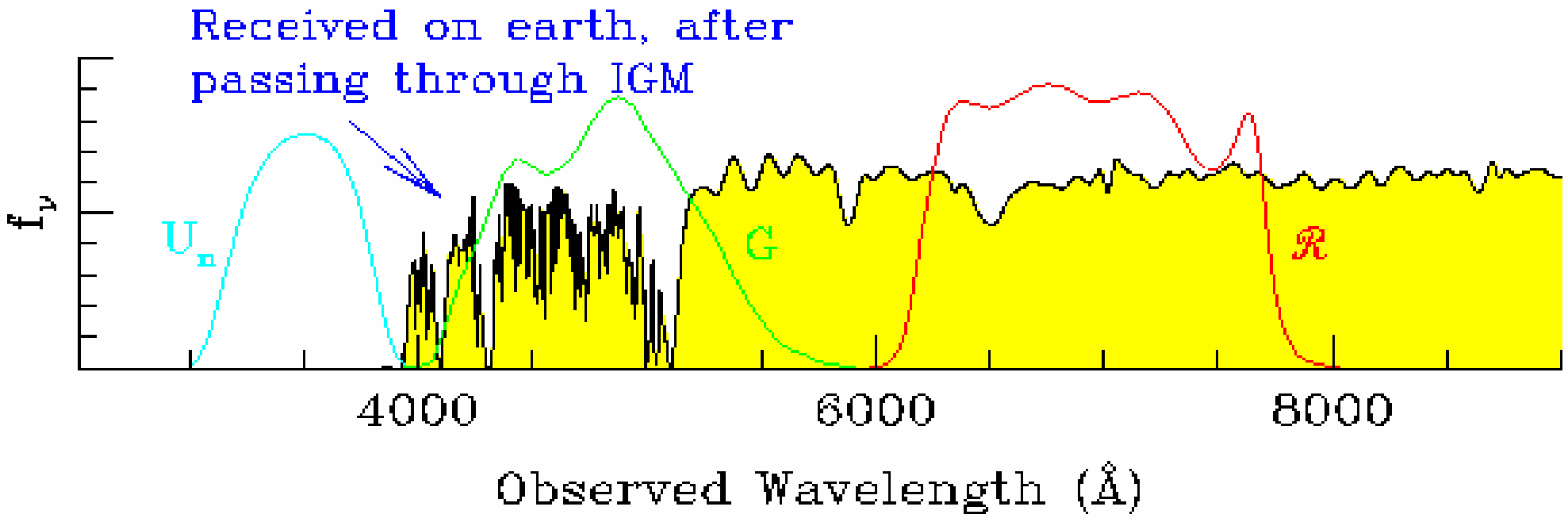
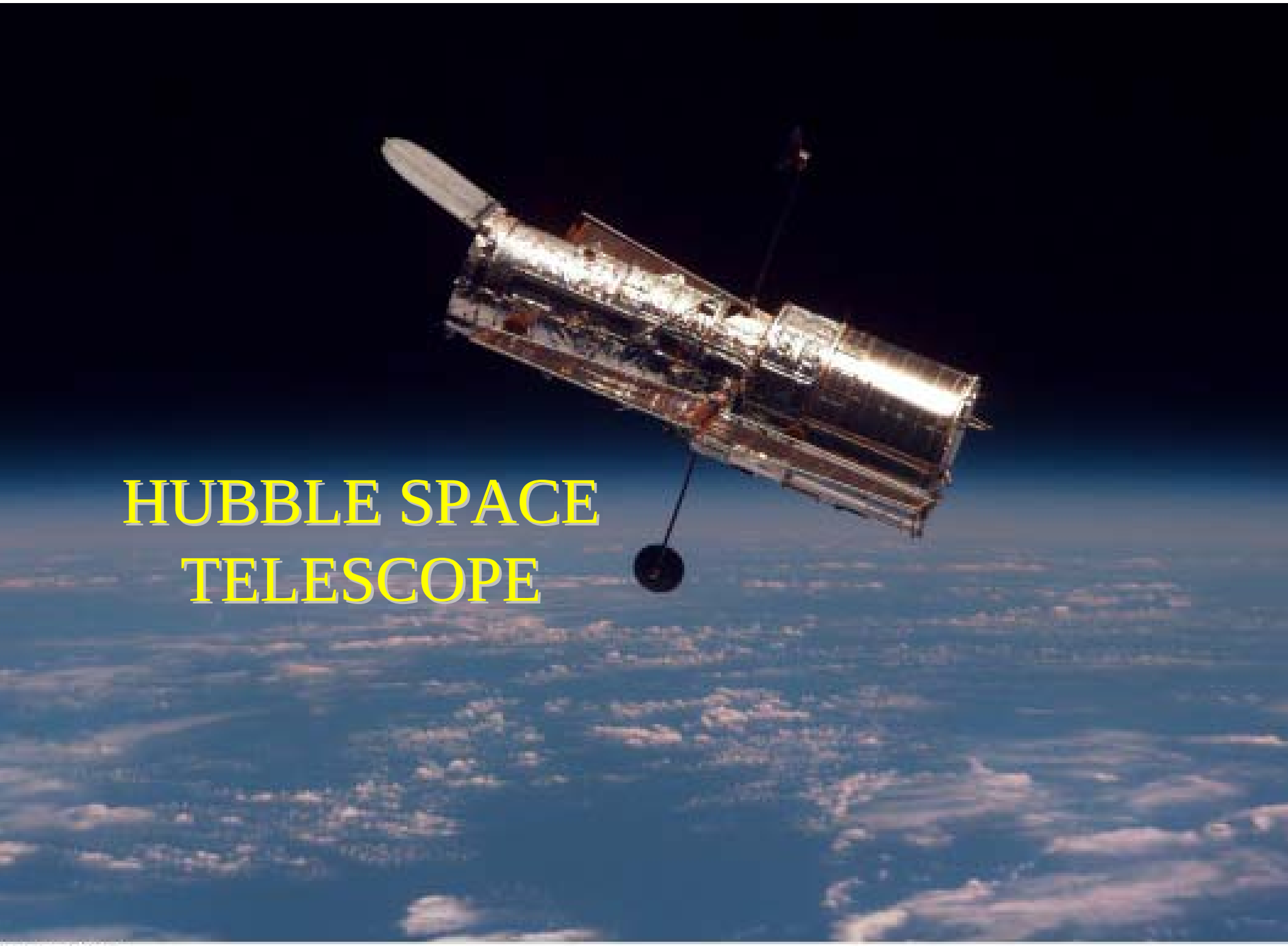
With: Elizabeth Stanway, Richard Ellis, Richard McMahon, Pat McCarthy, Tommaso Treu (Keck spec), Bob Abraham, Karl Glazebrook etc. (GLARE), Laurence Eyles, Mark Lacy (Spitzer)

Groningen, 28 June 2005



"Lyman break technique" - sharp drop in flux at λ below Ly-α. Steidel et al. have >1000 z~3 objects, "drop" in U-band.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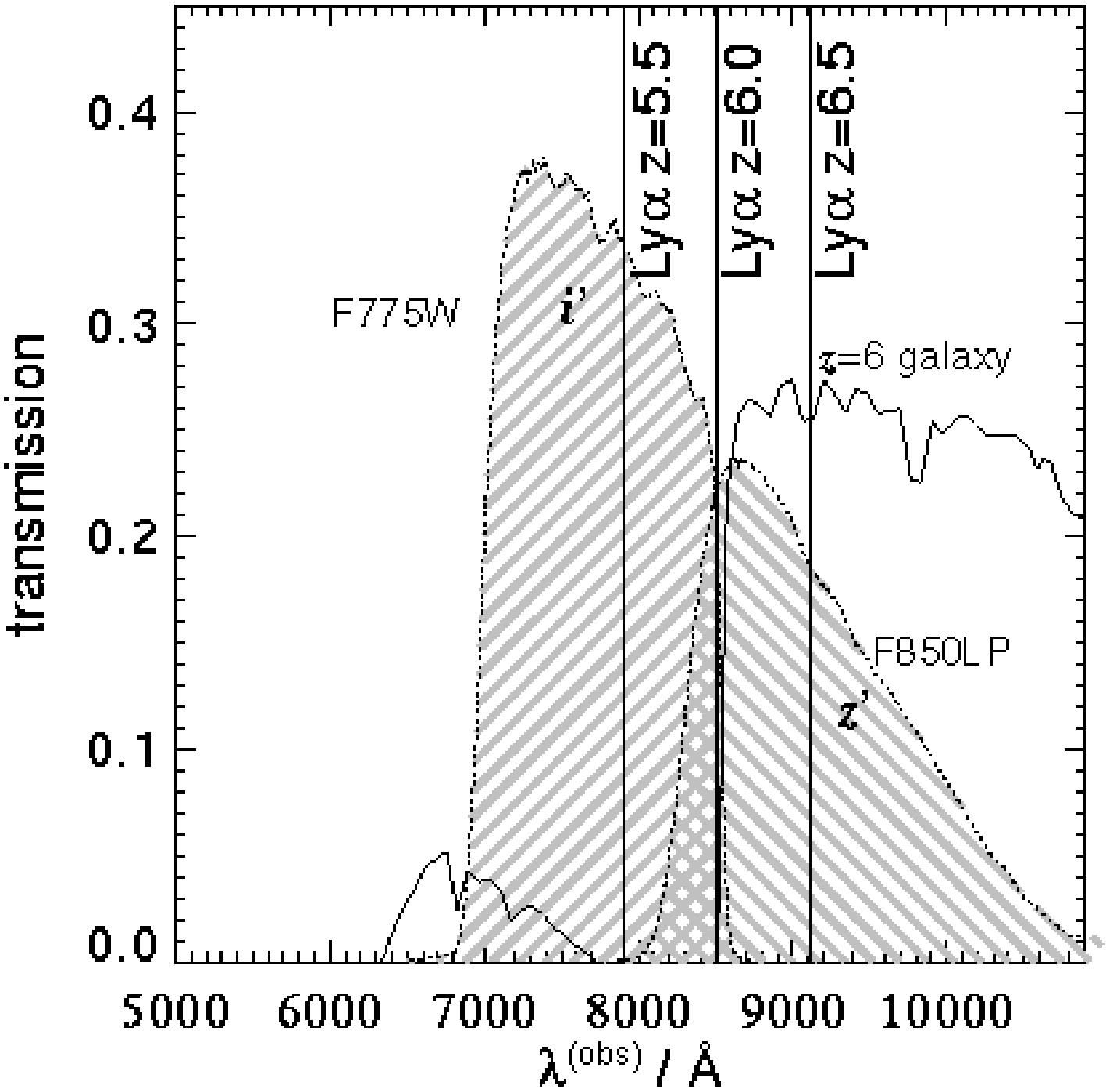
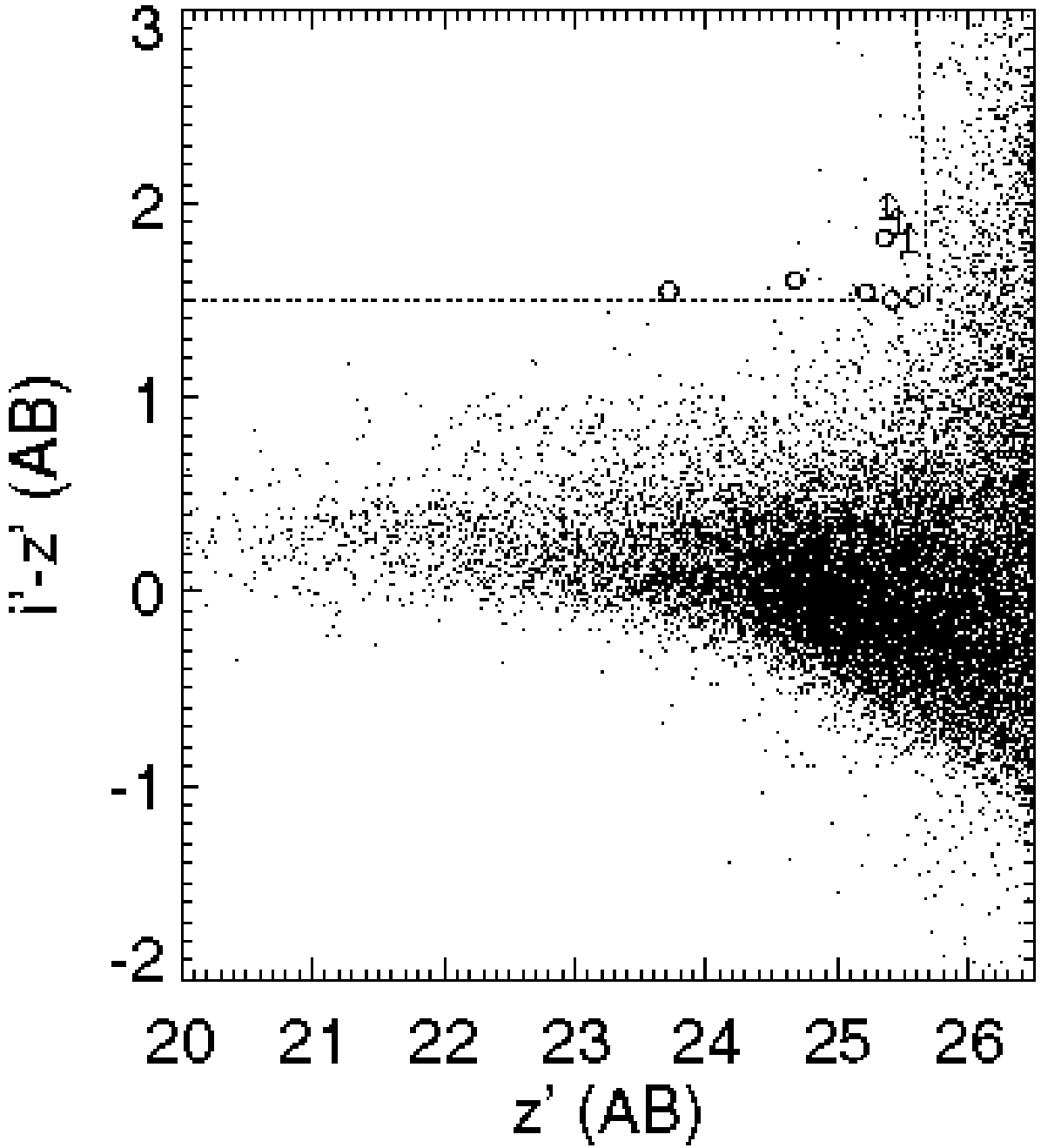
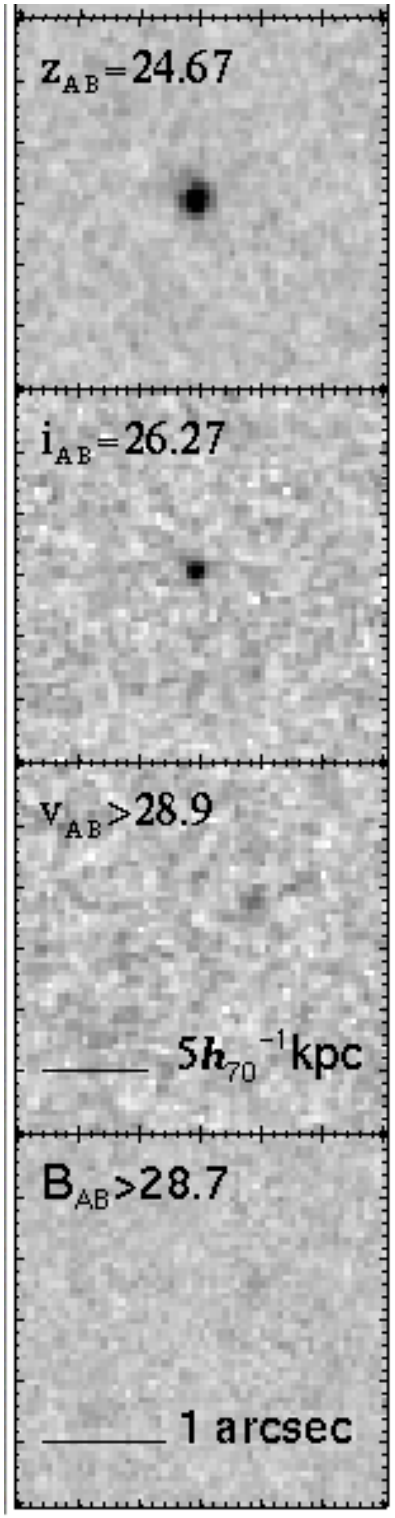
"Lyman break technique" - sharp drop in flux at λ below Ly-α. Steidel et al. have >1000 z~3 objects, "drop" in U-band.

Pushing to higher redshift- Finding Lyman break galaxies at z~6 : Elizabeth Stanway's PhD, using *i*-drops.



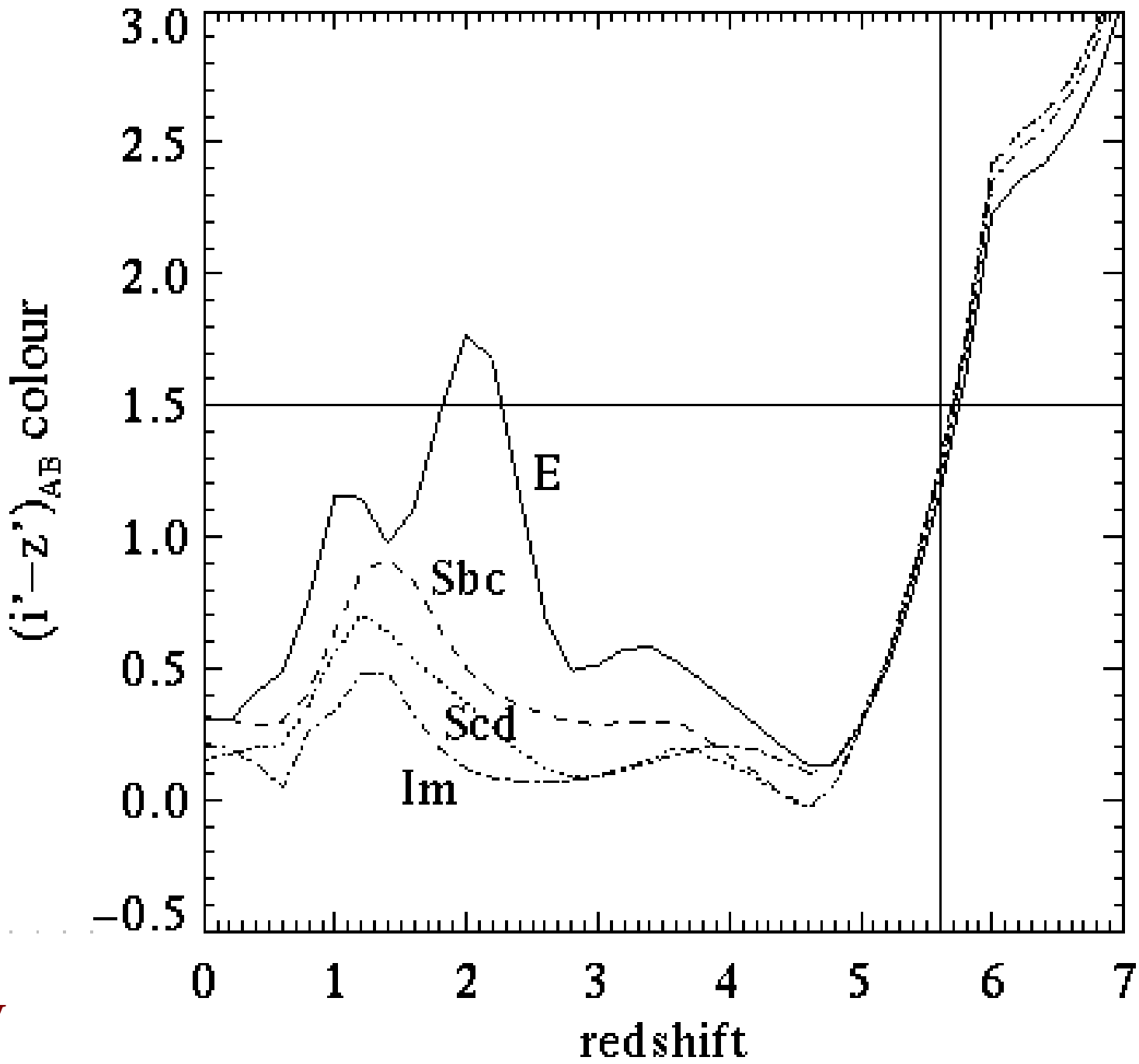


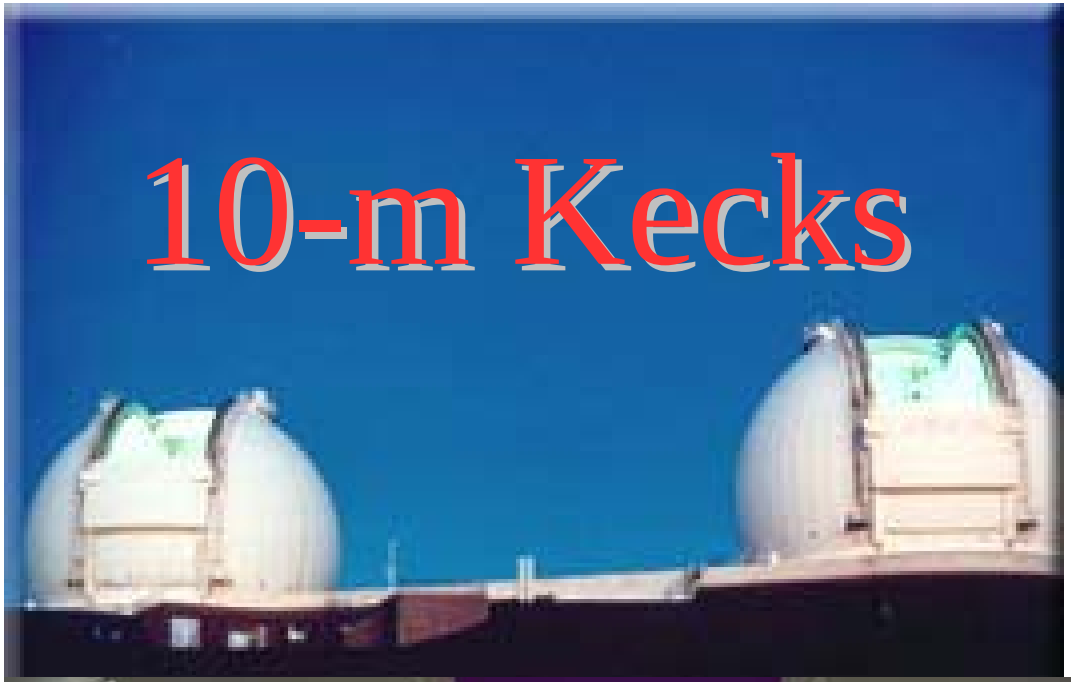


Using HST/ACS GOODS data - CDFS & HDFN, 5 epochs B,v,i',z'

By selecting on rest-frame UV, get inventory of ionizing photons from star formation.

Stanway, Bunker & McMahon (2003 MNRAS) selected z-drops 5.6<z<7 - but large luminosity bias to lower z. Contamination by stars and low-z ellipticals



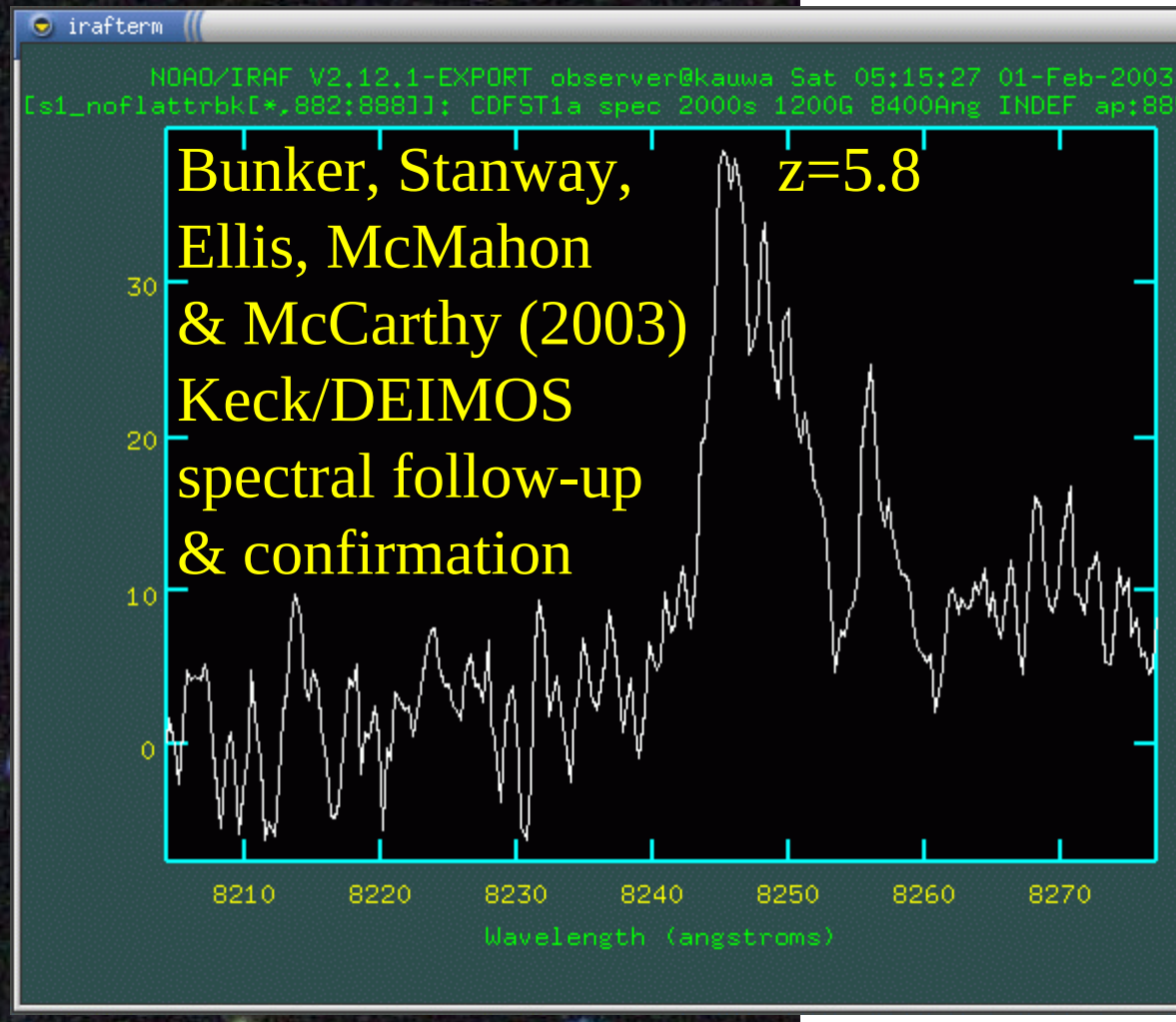

10-m Kecks

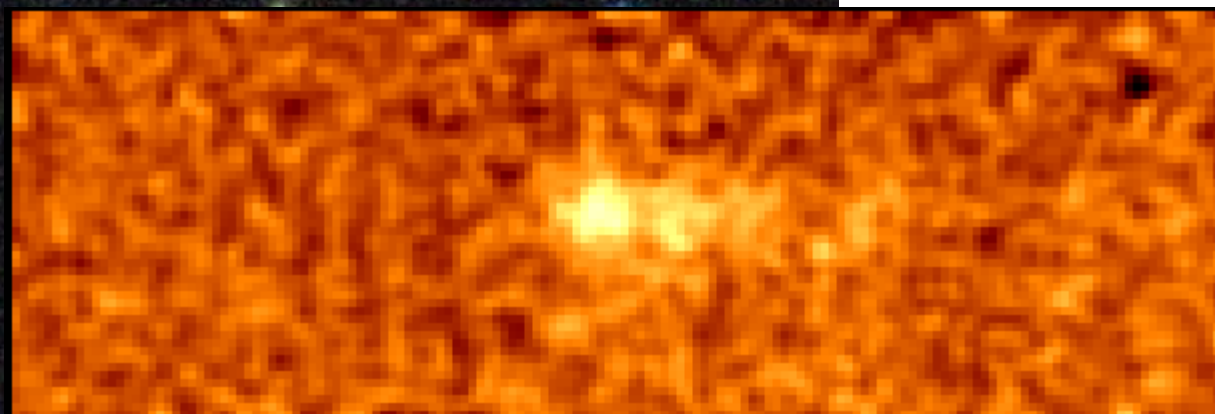

ESO VLTs


Photo©Neelon Crawford/Polar Fine Arts


8-m Gemini

The Star Formation History of the Univese





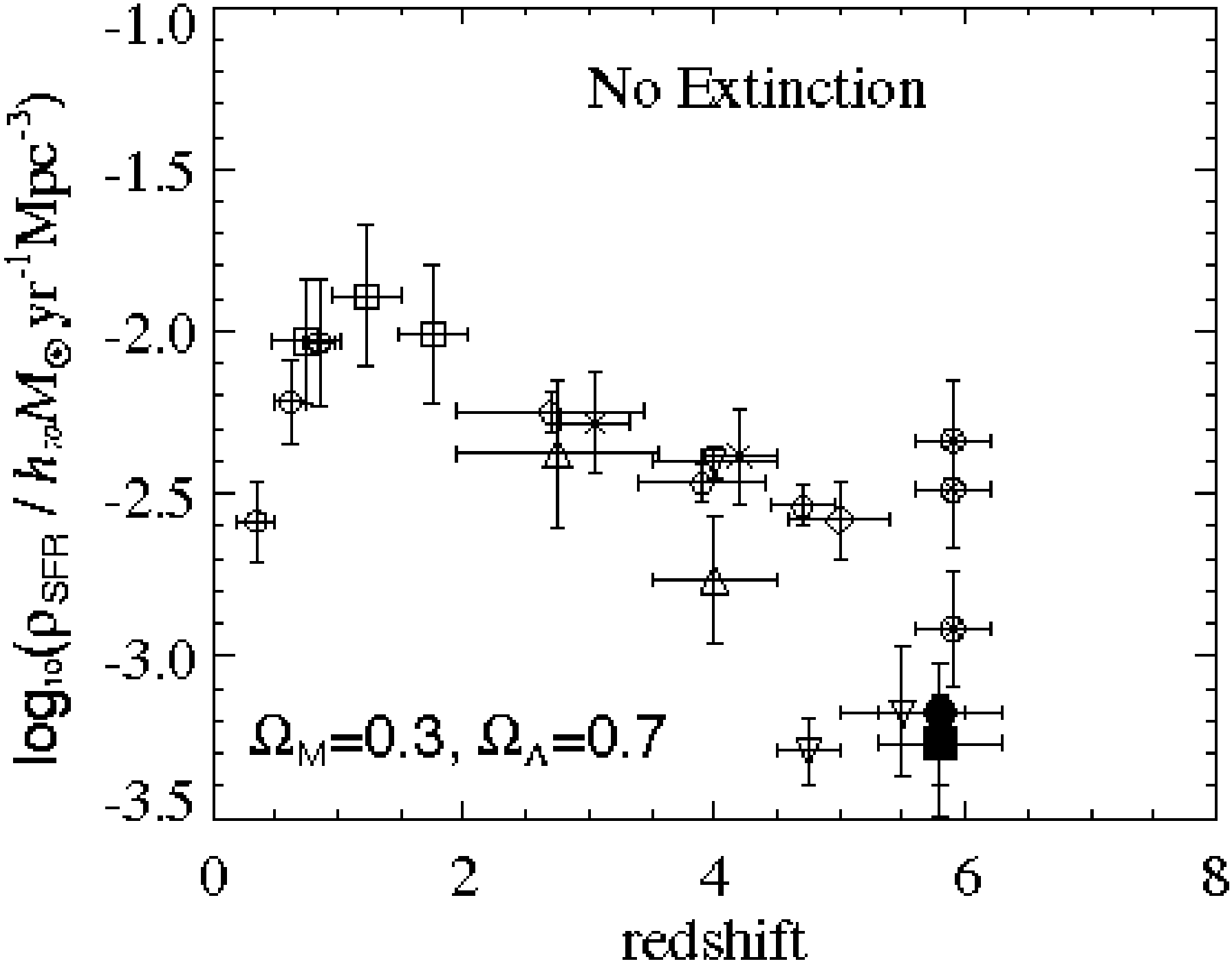
I-drops in the Chandra Deep Field South with HST/ACS

Elizabeth Stanway, Andrew Bunker, Richard McMahon 2003 (MNRAS)

The Star Formation @z~6 with HST imaging and Keck & Gemini spectra

- Select i'-z'>1.5 and z'>25.6 (AB mags) with GOODS
- Corresponds to 15M_sun/yr at z=5.9 (luminosity-weighted centre of selection window) - *prone to dust*
- this is ~1L* of the star-forming Lyman break population at z~3-4 (Steidel et al.)
- Survey about 200sq. arcmin (200,000 Mpc^3) each in 2 different GOODS fields, HDFN-N & CDFS-S
- Numbers consistent: about 6 in each (after removing M/L/T dwarf low-mass stars, major contaminant)
- Spectroscopic confirmation of 4 of these: see Lyman-α in emission in some (but not all). Using Keck/Deimos (with Richard Ellis) and Gemini/GMOS (CLAPF project, with Karl Glazebrook, Bob Abraham

Stanway, Bunker, McMahon, Ellis, Treu & McCarthy (2004)



Is the Universe at z~6 really forming fewer stars than at z~3?

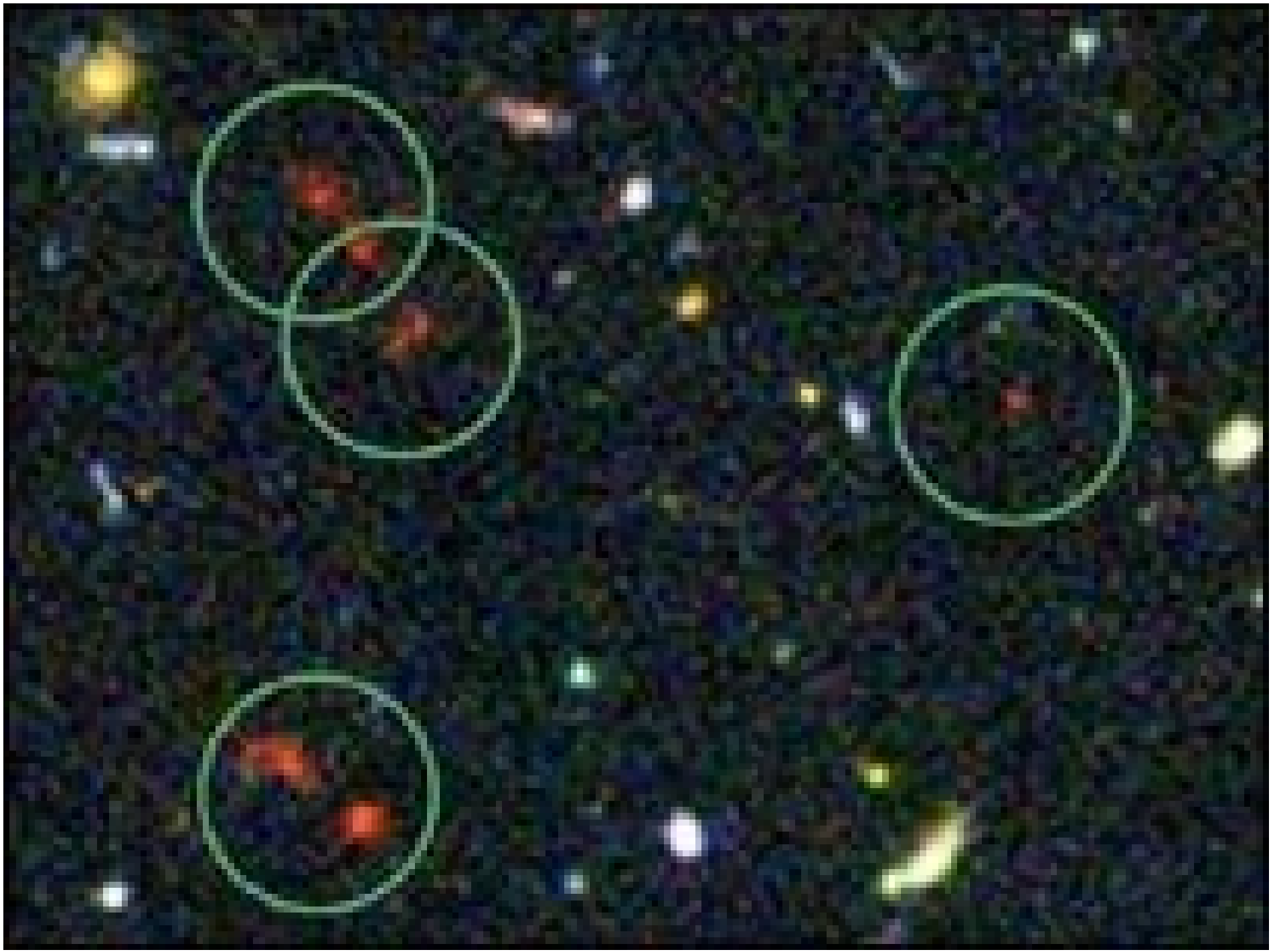
-We only probe bright end of luminosity function: ~1L*(UV) at z~3, equivalent to 15M_sun/yr

- We try to make a fair comparison: impose exactly same selection at lower redshifts

- It seems clear that the Universe at z~6 was very different from z~3: if no evolution, would ***predict 6x as many bright star forming galaxies at z~6 than we see!***

- Other groups make a correction for the faint galaxies they don't see. Depends crucially on the faint end slope
of the luminosity function (α~-1.1 locally, α=-1.6@z~3)

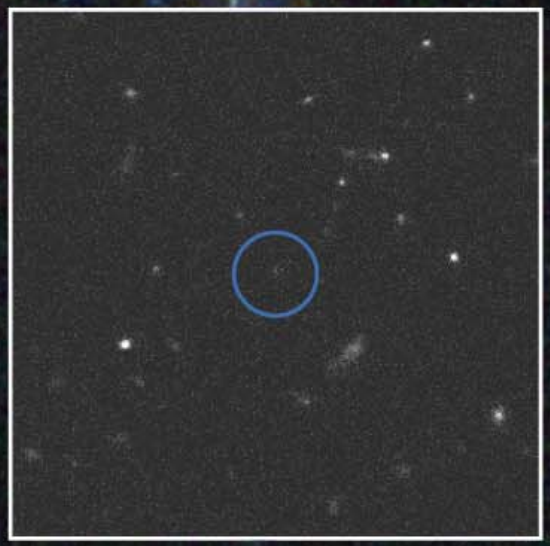
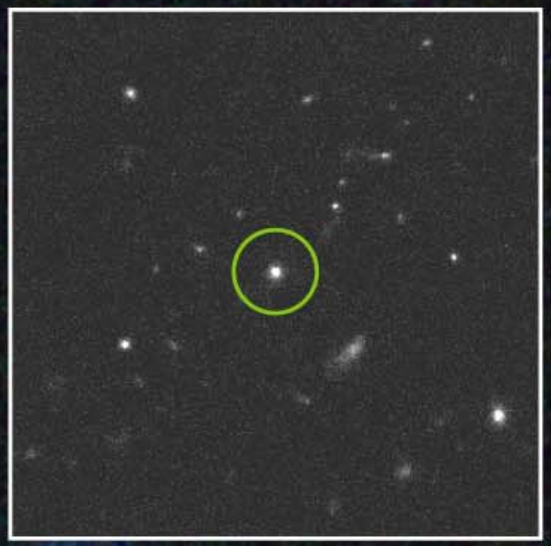
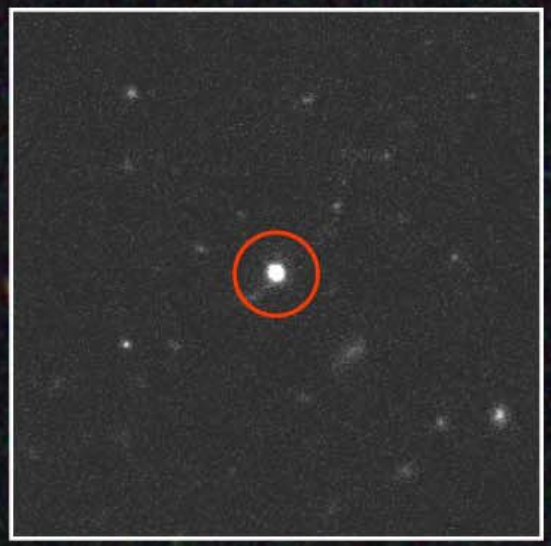
- Need recent Ultra Deep Field to address total star



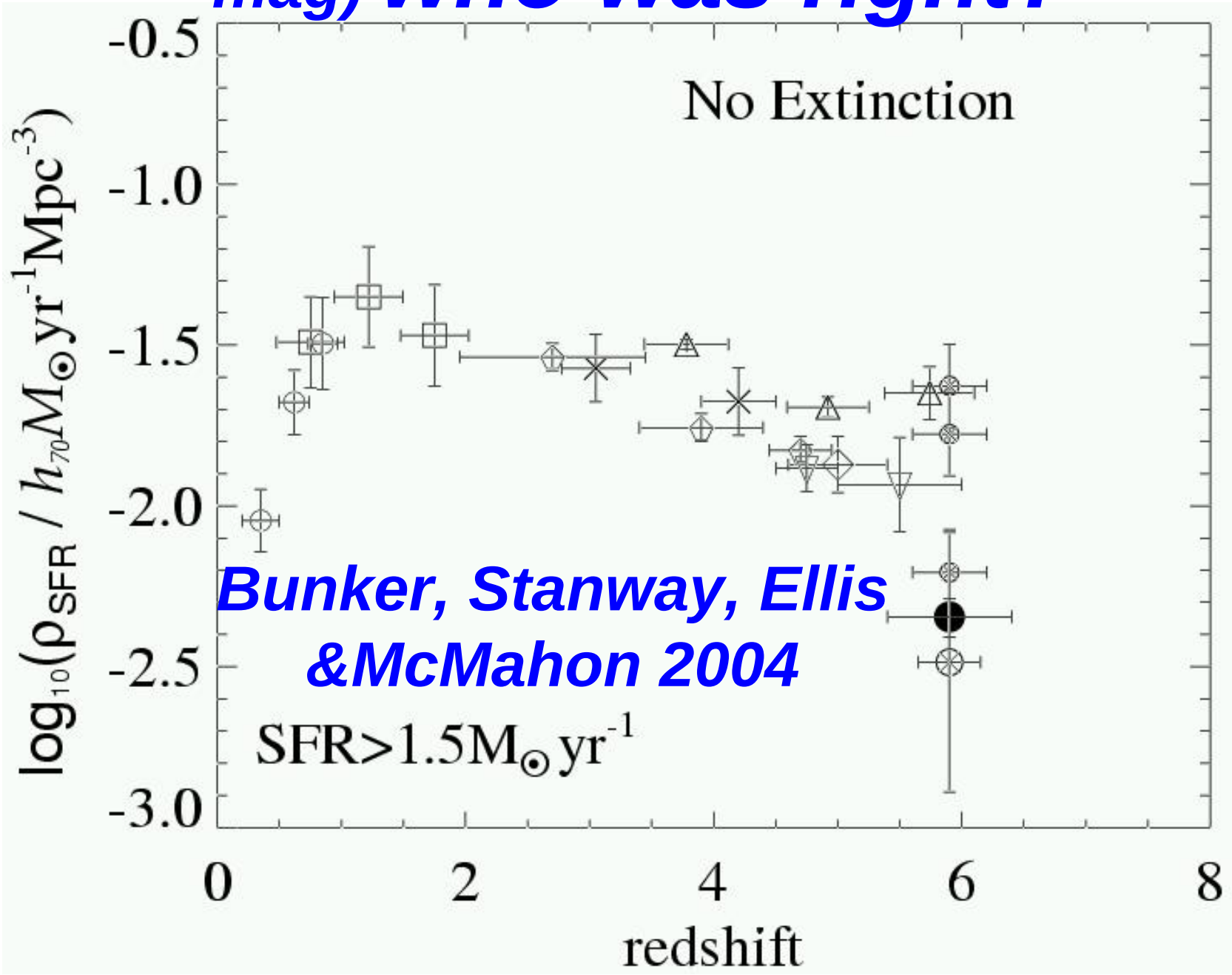
- ***Distant galaxies are very red***
- ***We showed that ACS/HST could find them****

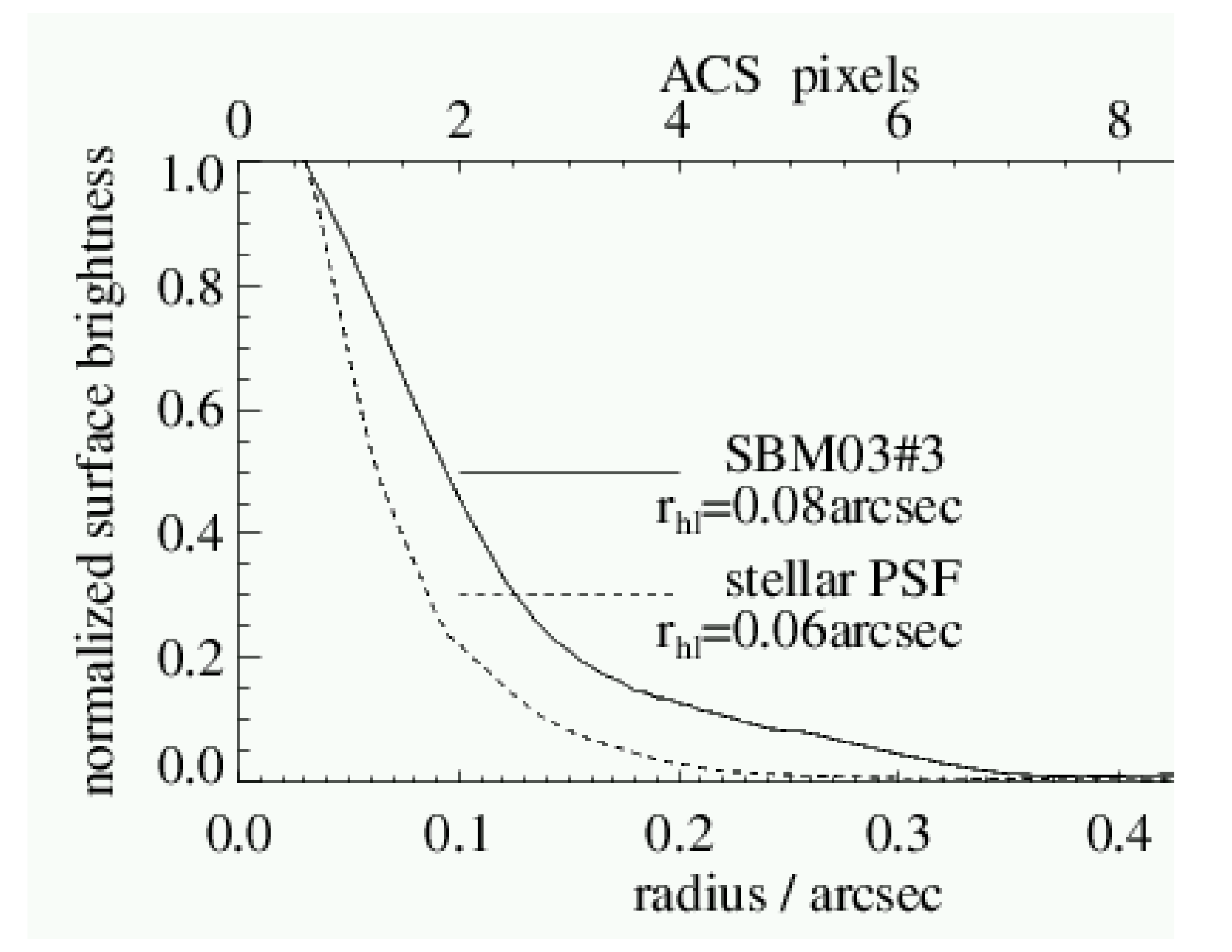
**(Stanway, Bunker and McMahon 2003 using GOODS)*

- ***We build on our technique with UDF: going fainter***

Looking at the UDF (going 10x deeper, z'=26 →28.5 mag) who was right?




ACS pixels
0
2
4
6
8
normalized surface brightness
1.0
0.8
0.6
0.4
0.2
0.0
SBM03#3
r_{hl}=0.08arcsec
stellar PSF
r_{hl}=0.06arcsec
0.0
0.1
0.2
0.3
0.4
radius / arcsec

Implications for Reionization

$$\dot{\rho}_{\rm SFR} \approx 0.013\, f_{\rm esc}^{-1} \left(\frac{1+z}{7}\right)^3 \left(\frac{\Omega_b\, h_{50}^2}{0.043}\right)^2 C_{30}\, M_\odot\, {\rm yr}^{-1}\, {\rm Mpc}^{-3}$$

From Madau, Haardt & Rees (1999) -amount of star formation required to ionize Universe (C_{30} is a clumping factor).

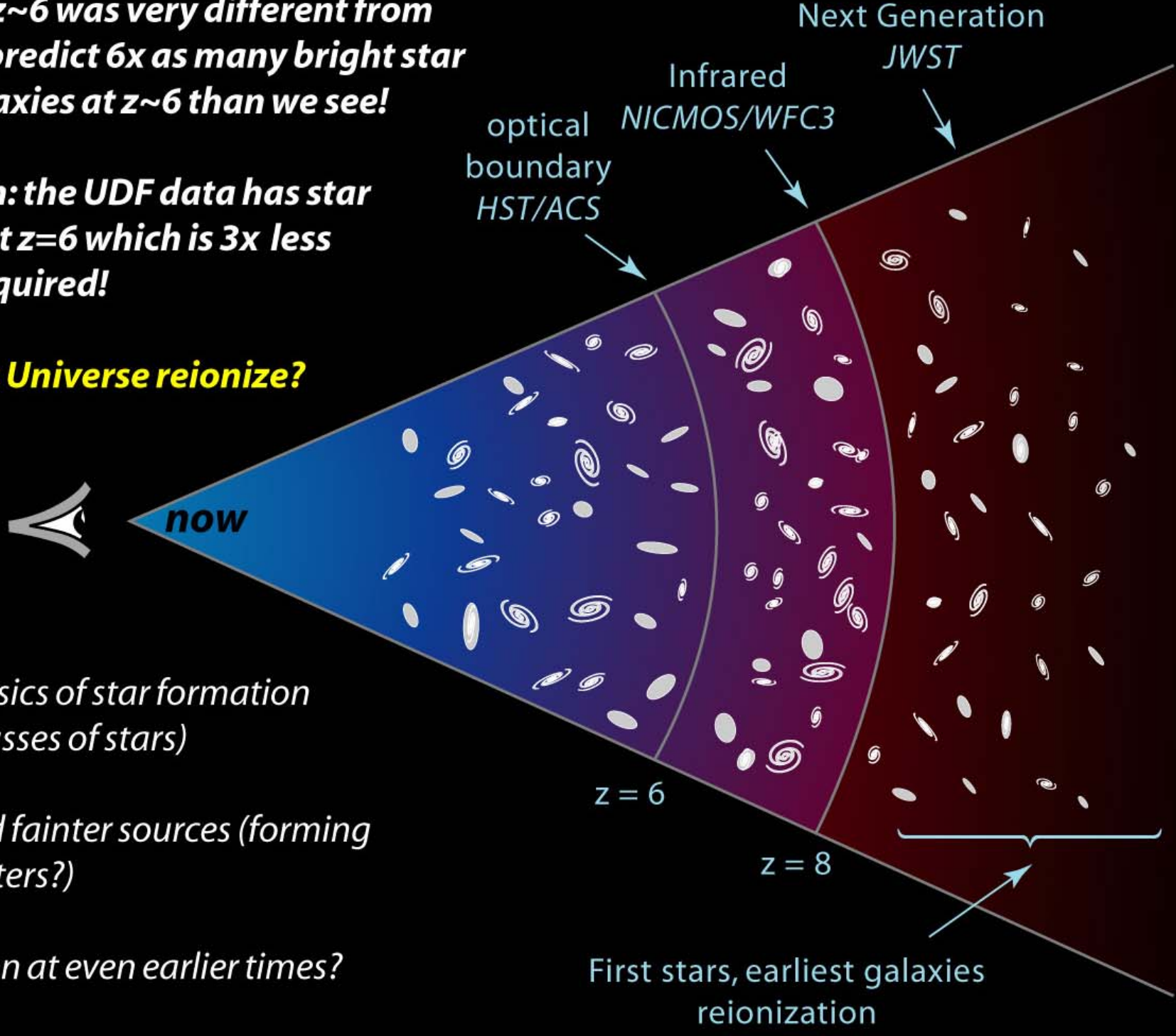
This assumes escape fraction=1 (i.e. all ionzing photons make it out of the galaxies)

Our UDF data has star formation at z=6 which is 3x *less* than that required! AGN cannot do the job.

We go down to 1M_sun/yr - but might be steep α (lots of low luminosity sources - forming

- ***Universe at z~6 was very different from z~3: would predict 6x as many bright star forming galaxies at z~6 than we see!***
- ***Reionization: the UDF data has star formation at z=6 which is 3x less than that required!***

So how does Universe reionize?



- *Different physics of star formation early on? (masses of stars)*
- *Undiscovered fainter sources (forming globular clusters?)*
- *Star formation at even earlier times?*

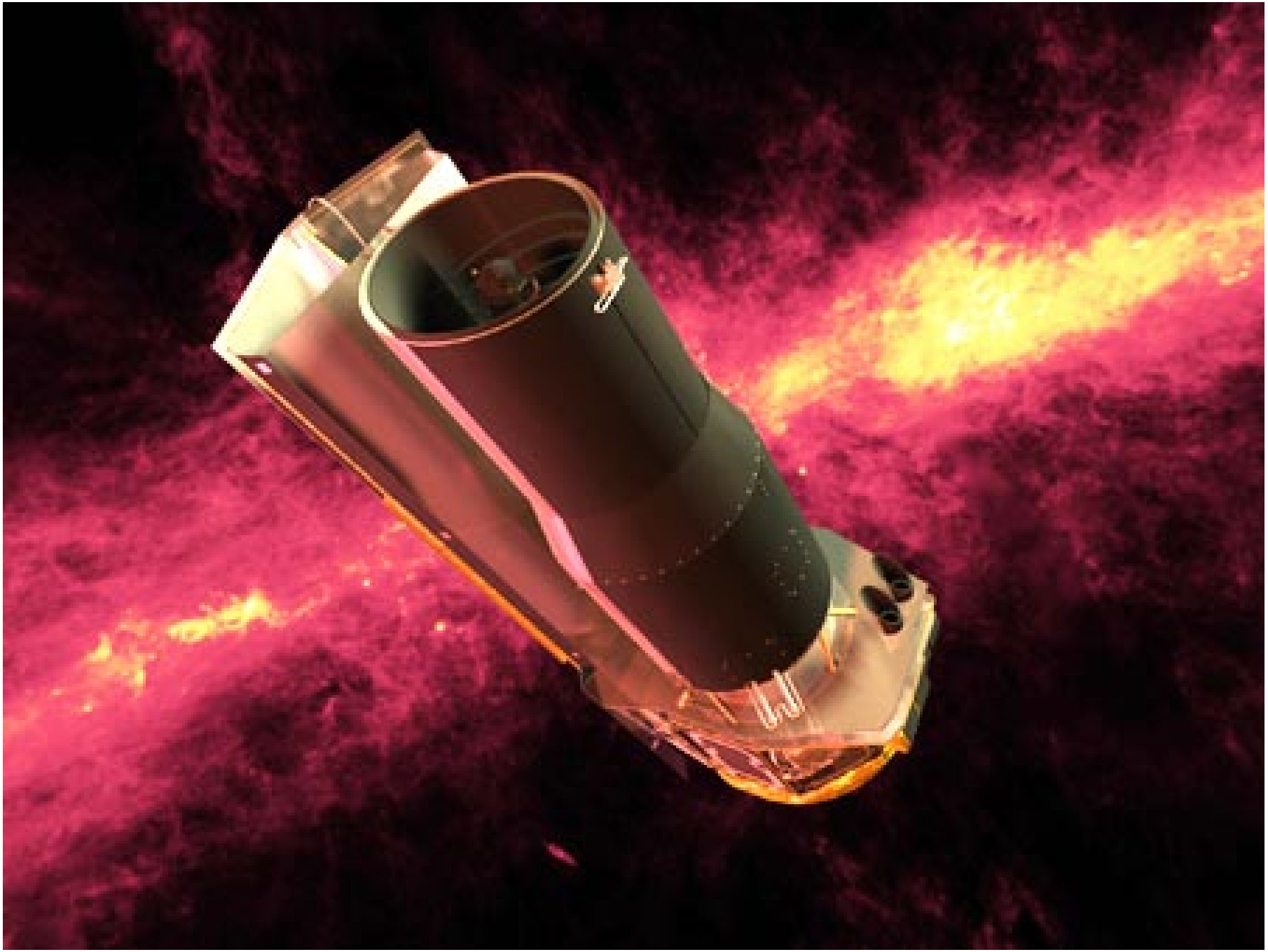
Ways out of the Puzzle

- Cosmic variance

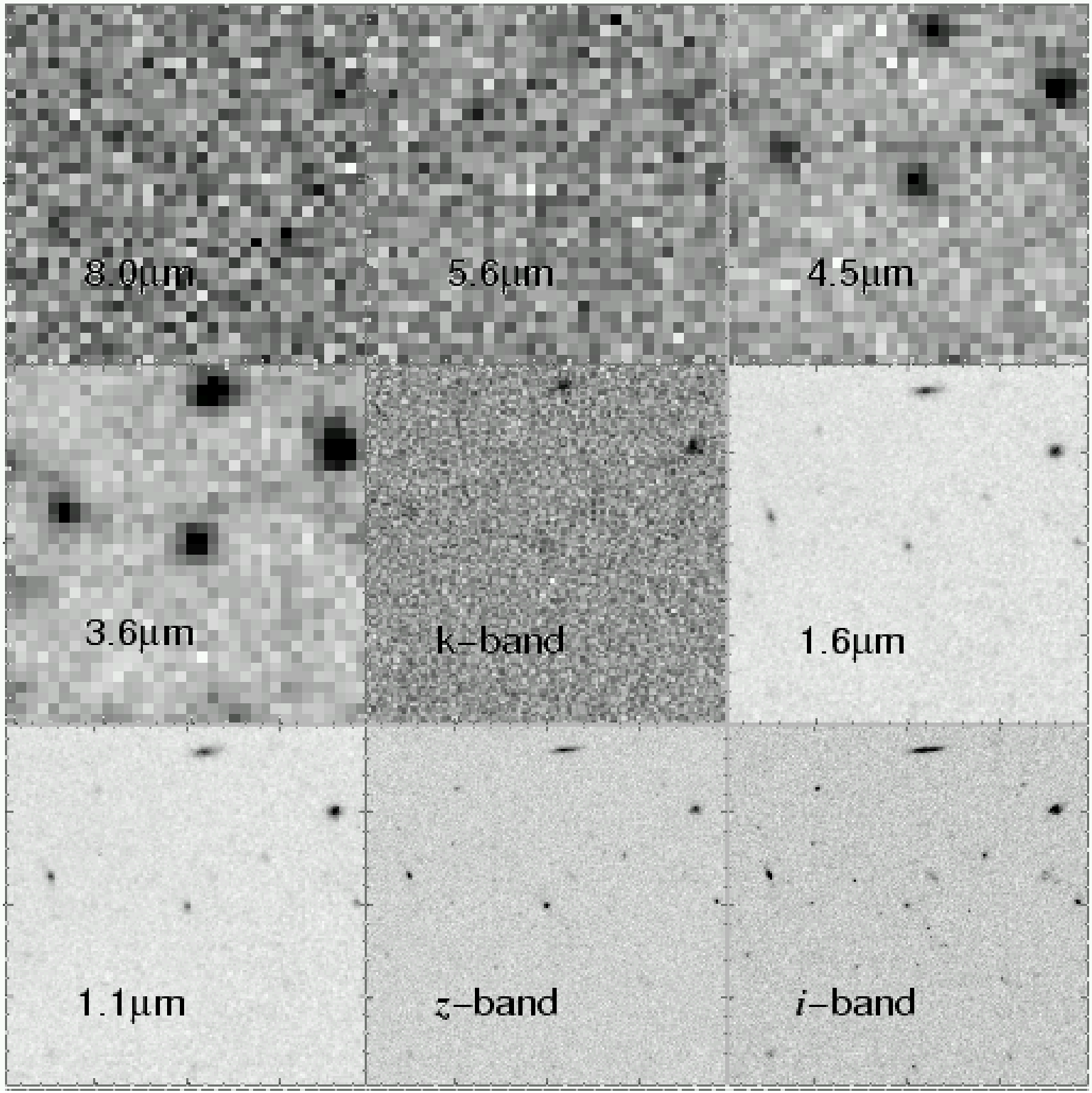
- Star formation at even earlier epochs to reionize Universe (*z*>>6)?

- Change the physics: different recipe for star formation (Initila mass function)?

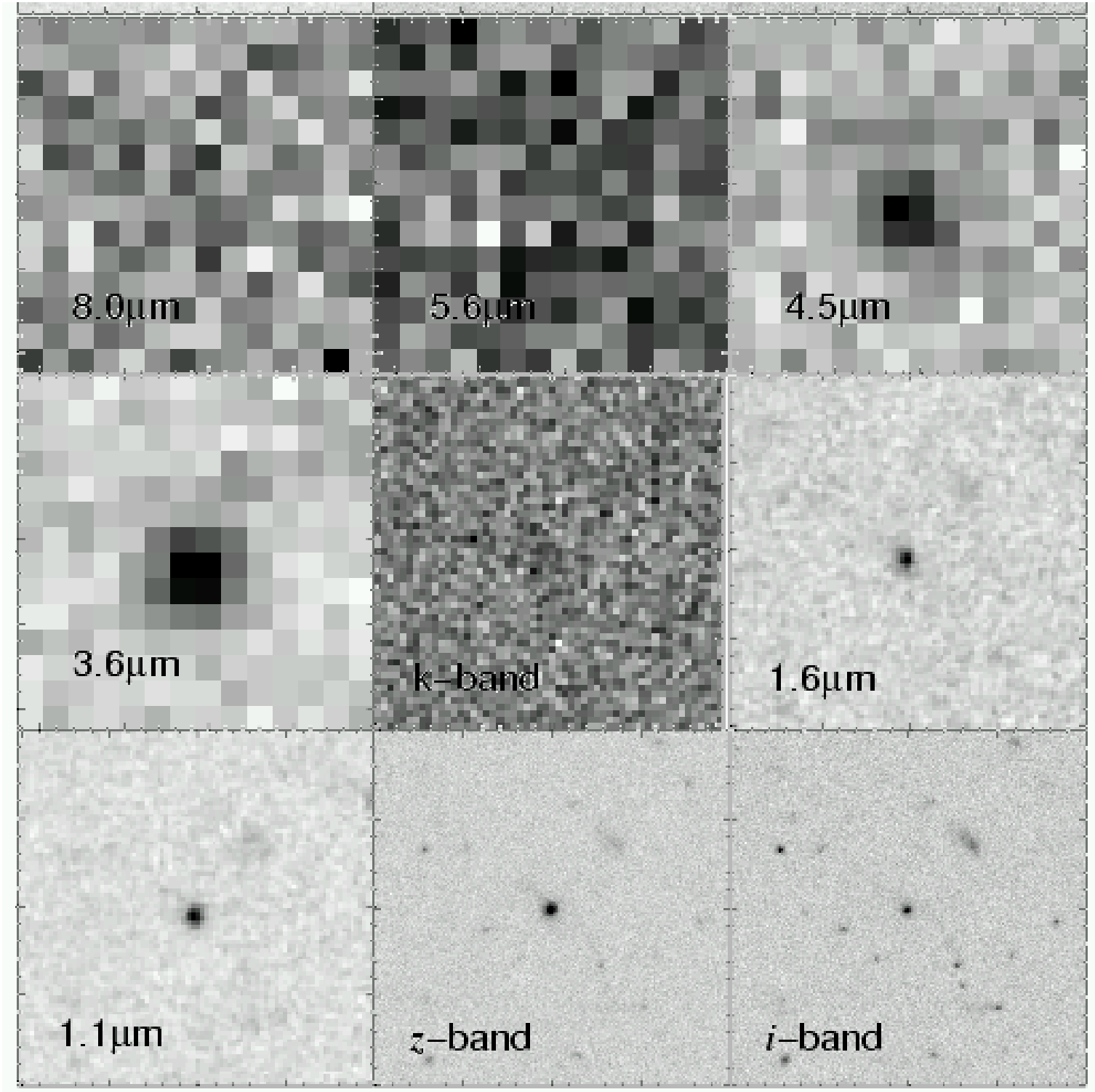
- Even fainter galaxies than we can reach with the UDF?

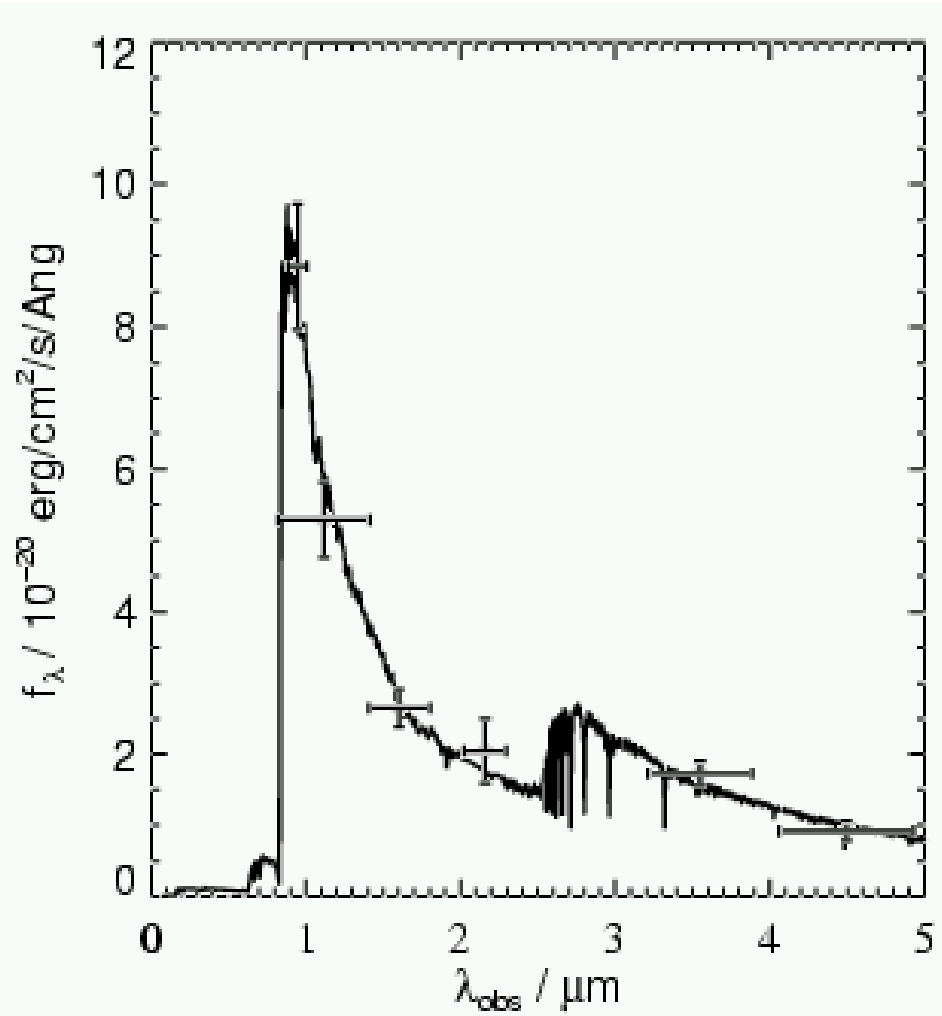


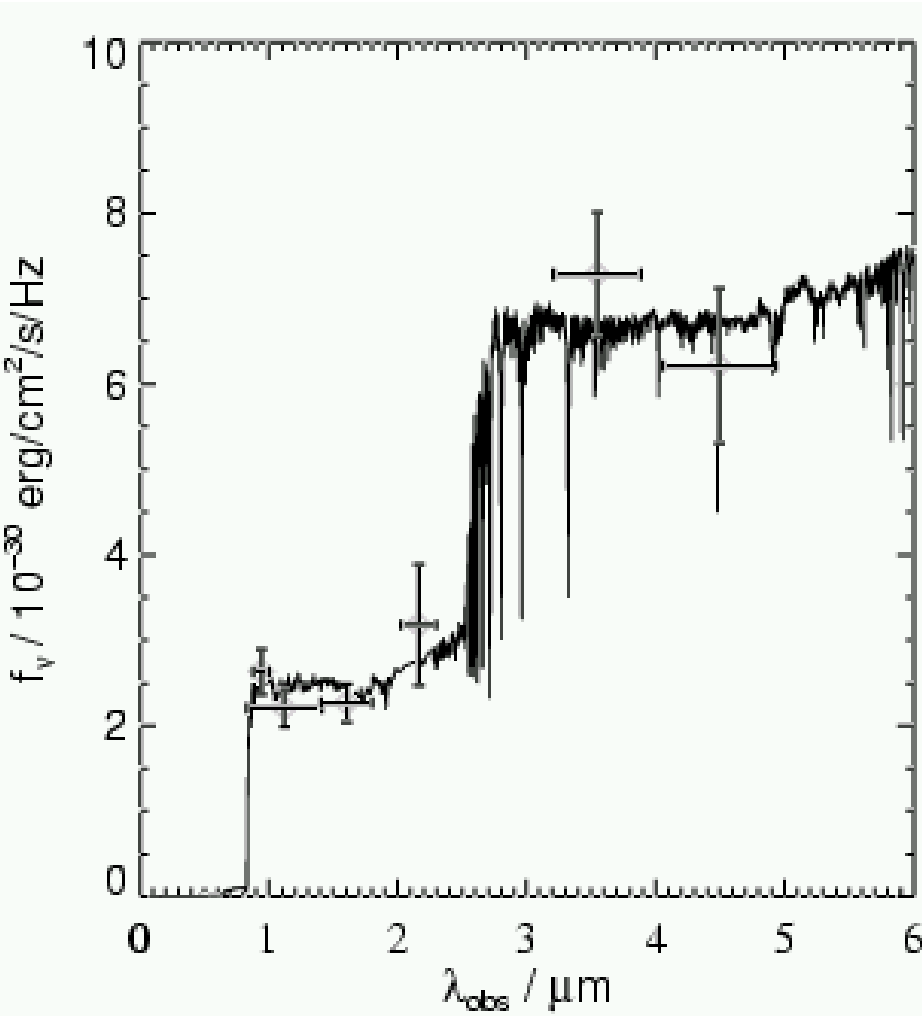
Spitzer – IRAC (3.6-8.0 microns)



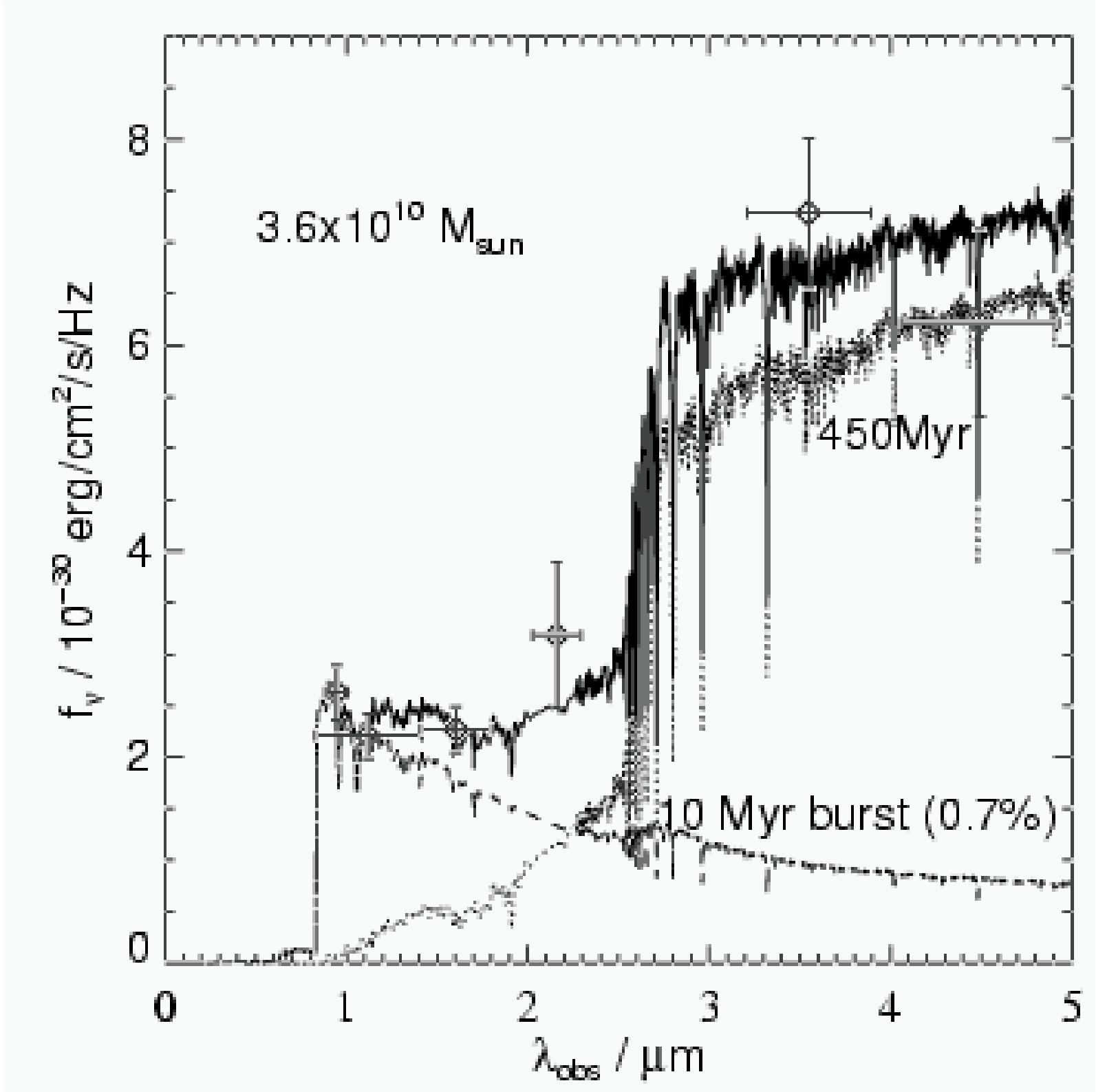
galaxy #2 from Stanway, Bunker & McMahon 2003 (spec conf from Stanway et al. 2004, Dickinson et al. 2004). Detected in GOODS IRAC 3-4μm: Eyles, Bunker,

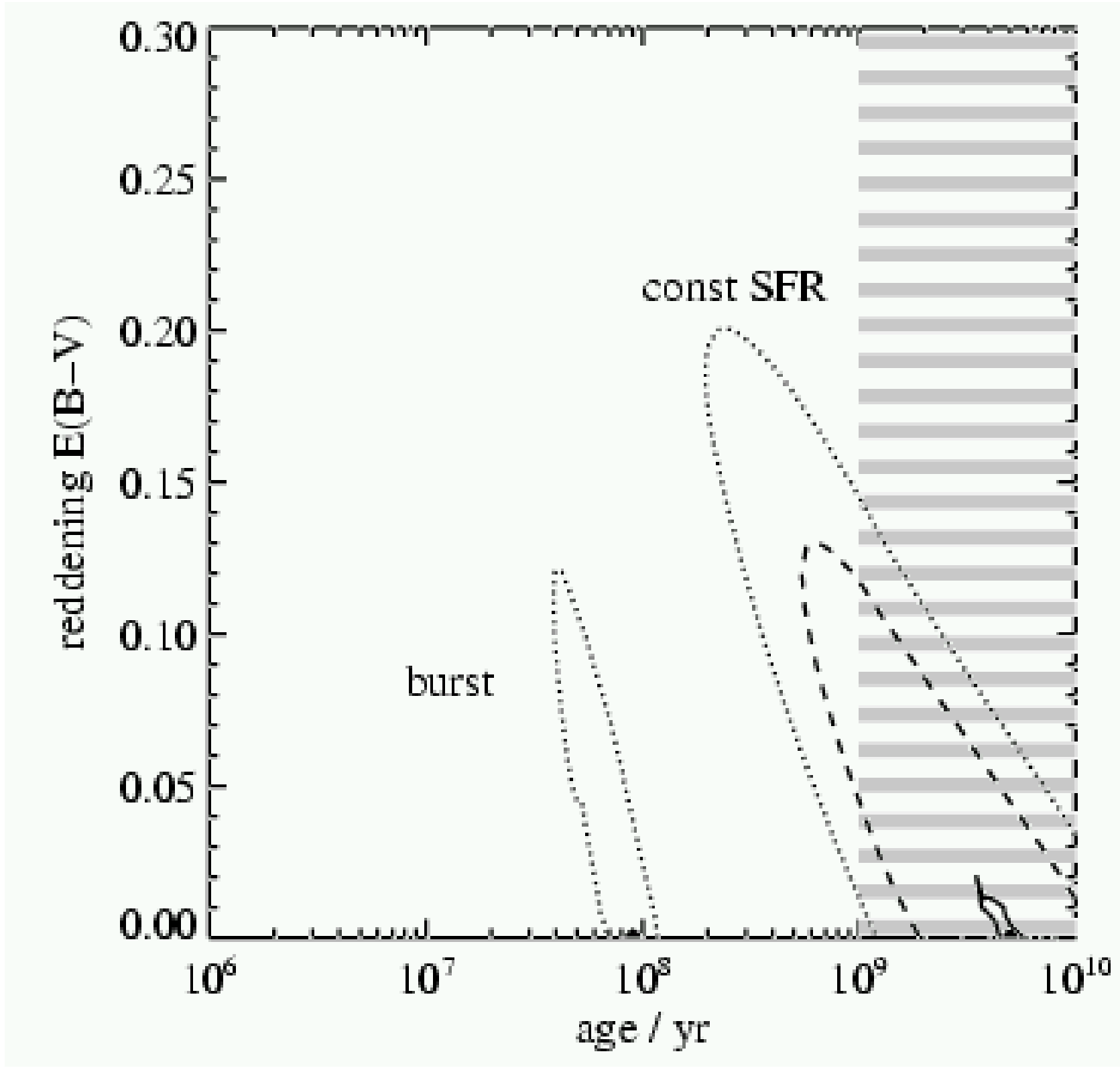

8.0μm
5.6μm
4.5μm
3.6μm
k–band
1.6μm
1.1μm
z–band
i–band





3.6microns, AB mag~24 (~1microJy)
for JWST/NIRSPEC: R=1000 S/N>10 in 100ksec
Ca H&K, G-band, MgIb (vel disp)


3.6x10^10 M_sun
450Myr
10 Myr burst (0.7%)
f_ν / 10^-30 erg/cm^2/s/Hz
λ_obs / μm
0
2
4
6
8
0
1
2
3
4
5


0.30
0.25
0.20
0.15
0.10
0.05
0.00
reddening E(B−V)
const SFR
burst
10^6
10^7
10^8
10^9
10^10
age / yr

JAMES WEBB SPACE TELESCOPE – successor to Hubble (2010)