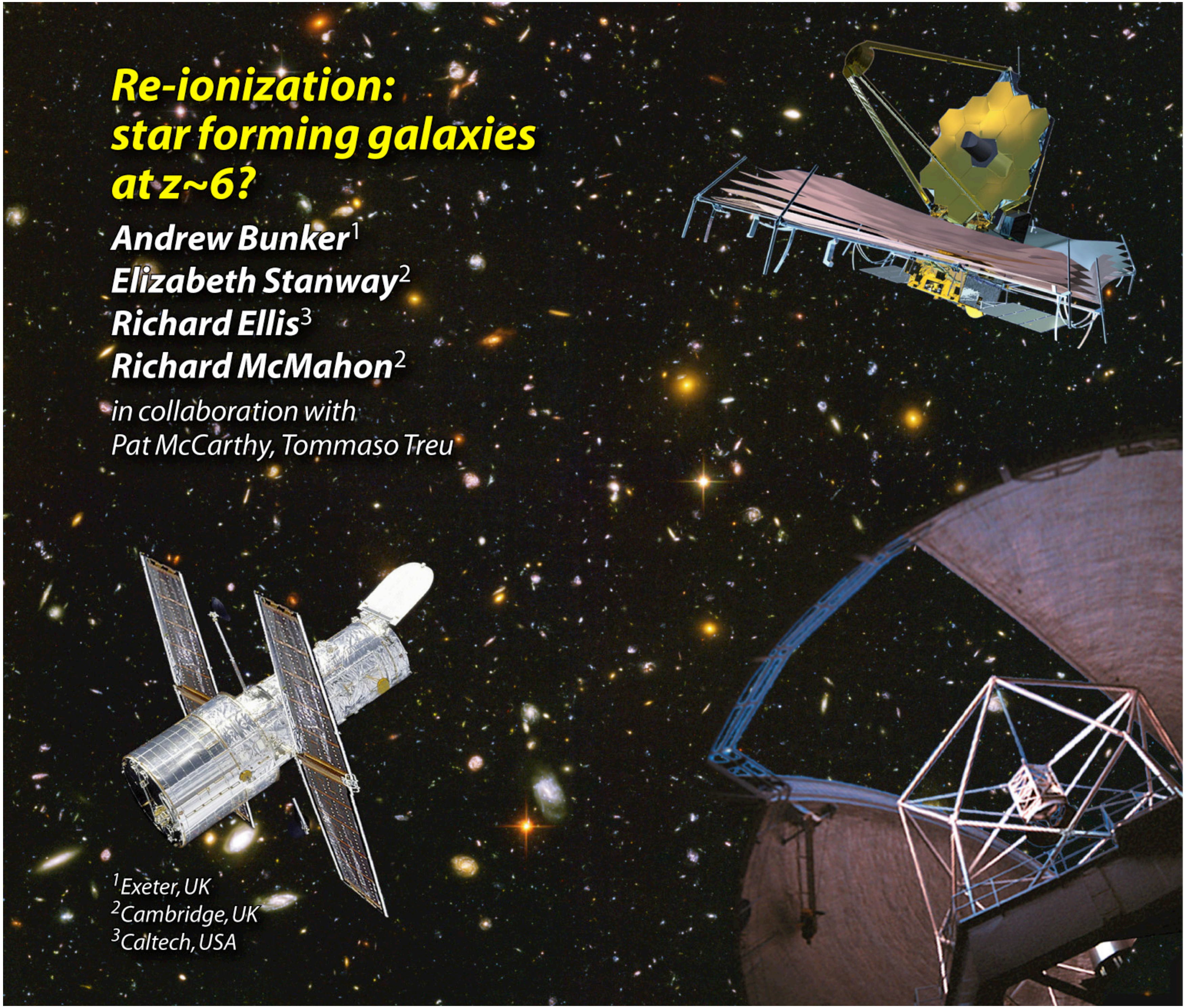

# Re-ionization: star forming galaxies at z~6?


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**Elizabeth Stanway**[2]
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*in collaboration with*
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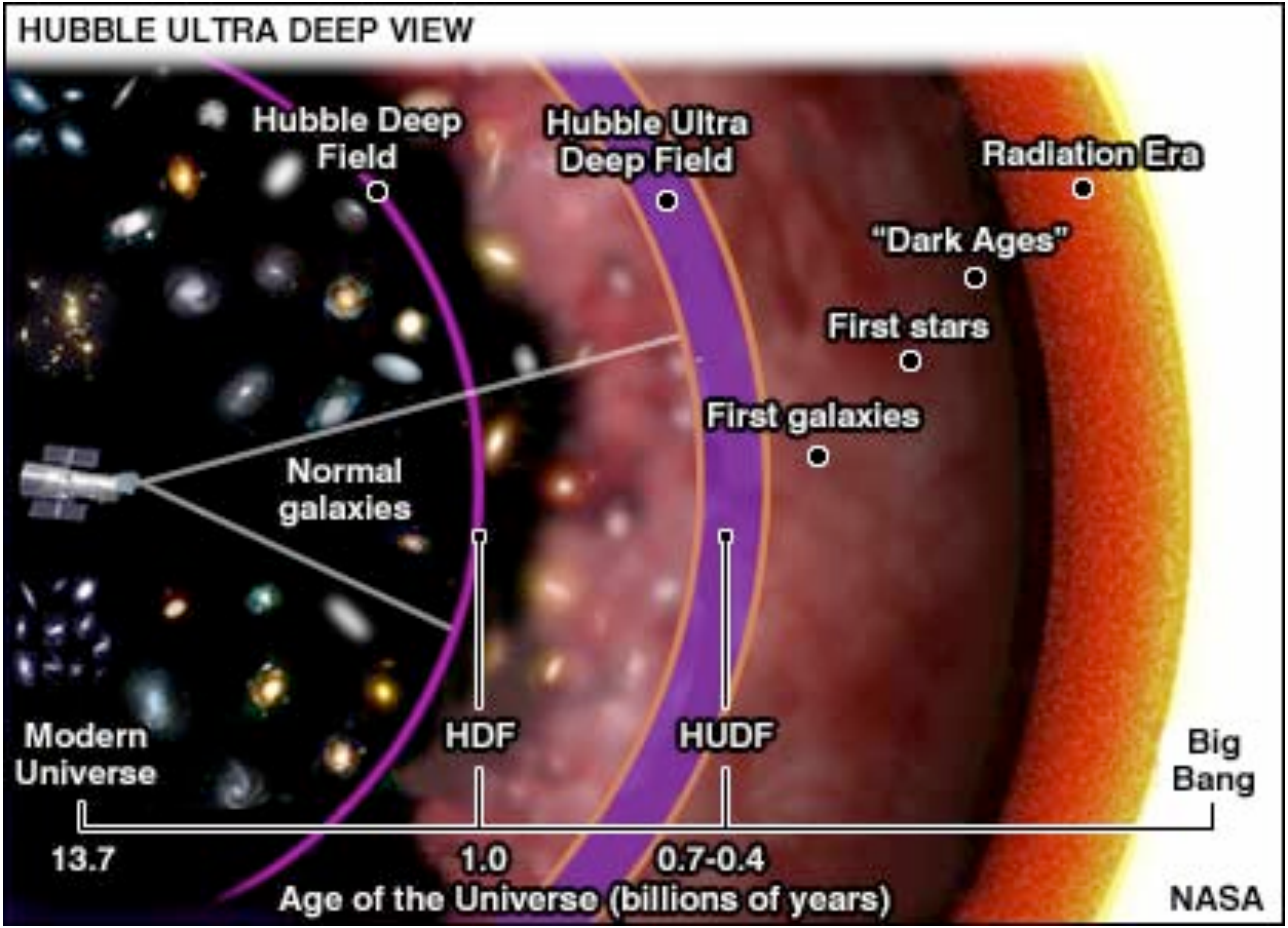
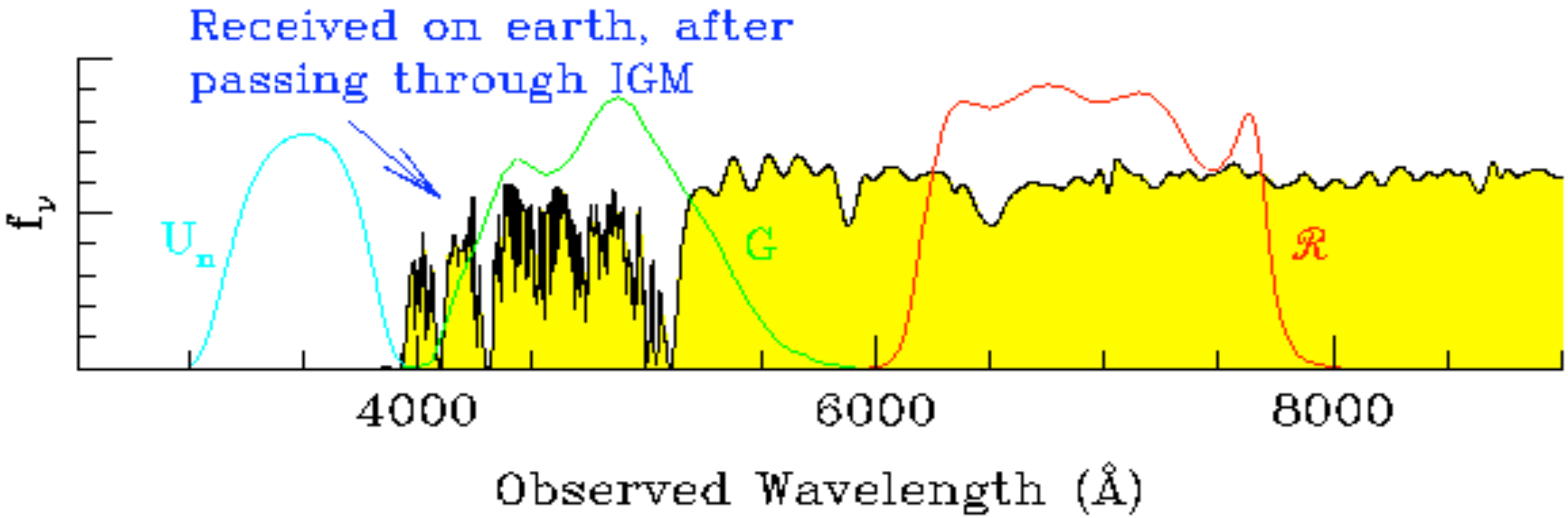
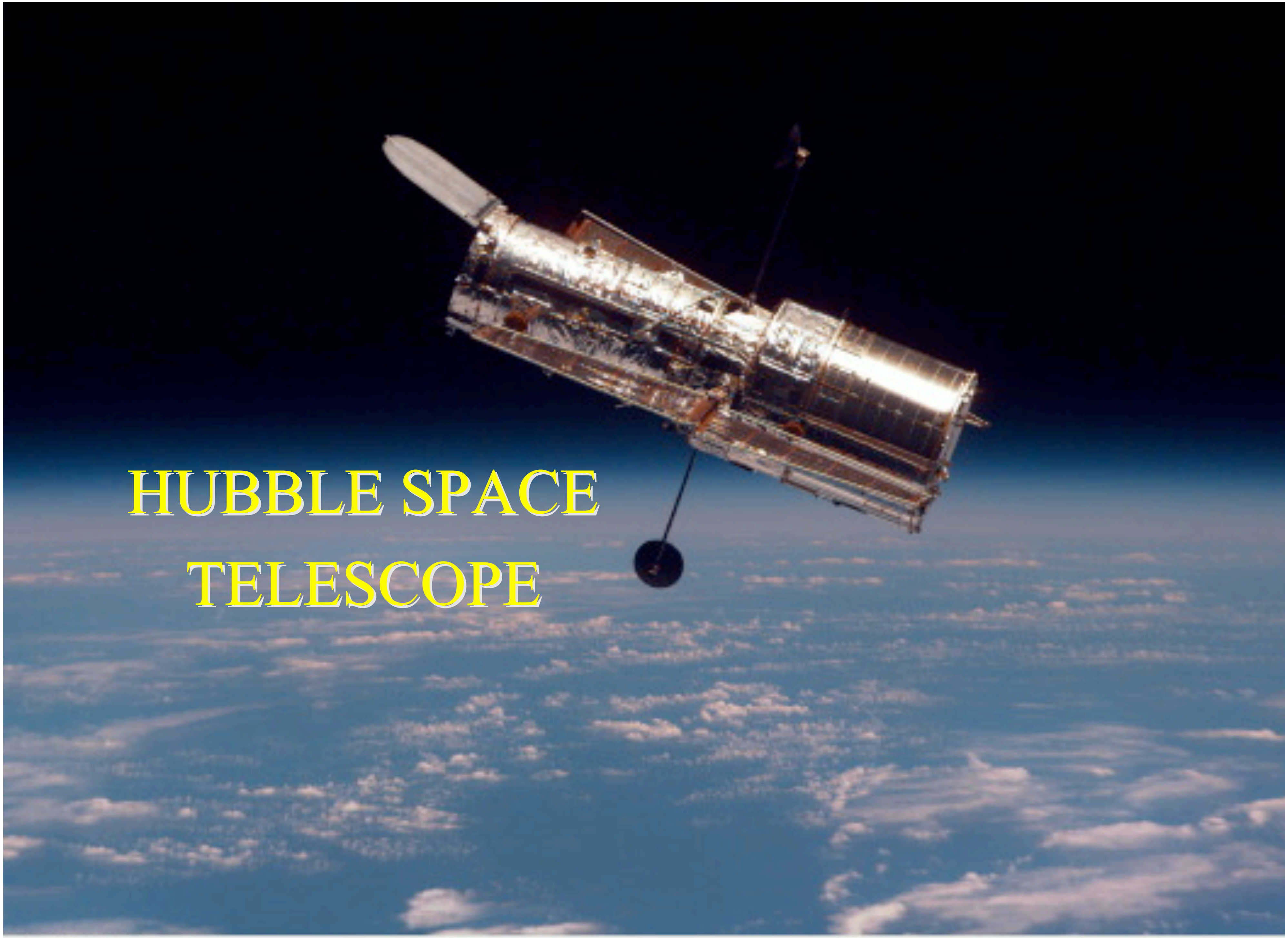
# Star formation history in the first billion years

Andy Bunker, Kuenley Chiu (AAO), Elizabeth Stanway (Bristol), Mark Lacy (Spitzer), Daniel Stark, Richard Ellis (Caltech), Laurence Eyles (Exeter) Richard McMahon (IoA, Cambridge)


HUBBLE ULTRA DEEP VIEW
Hubble Deep Field
Hubble Ultra Deep Field
Radiation Era
"Dark Ages"
First stars
First galaxies
Normal galaxies
Modern Universe
HDF
HUDF
Big Bang
13.7
1.0
0.7-0.4
Age of the Universe (billions of years)
NASA




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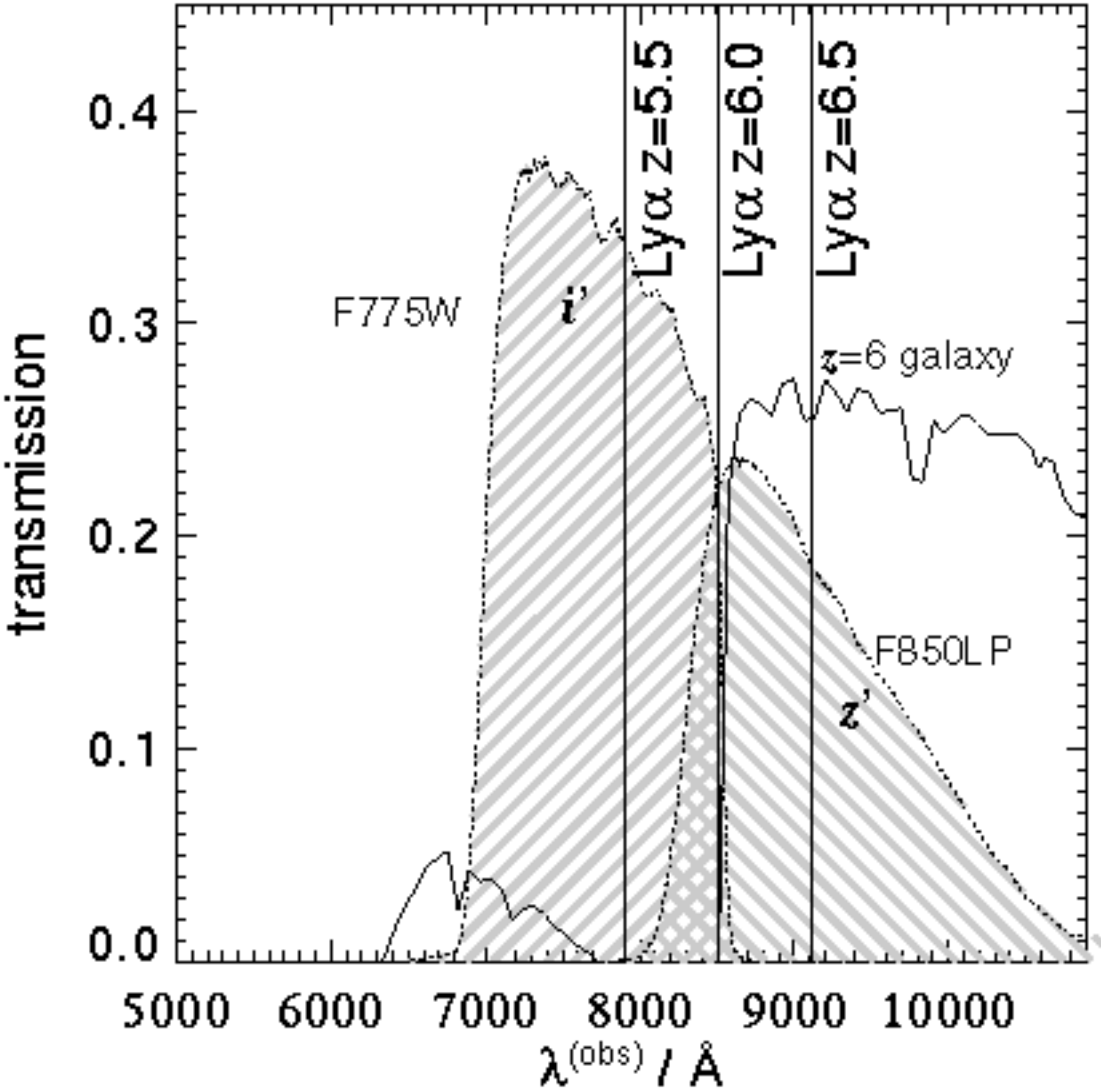
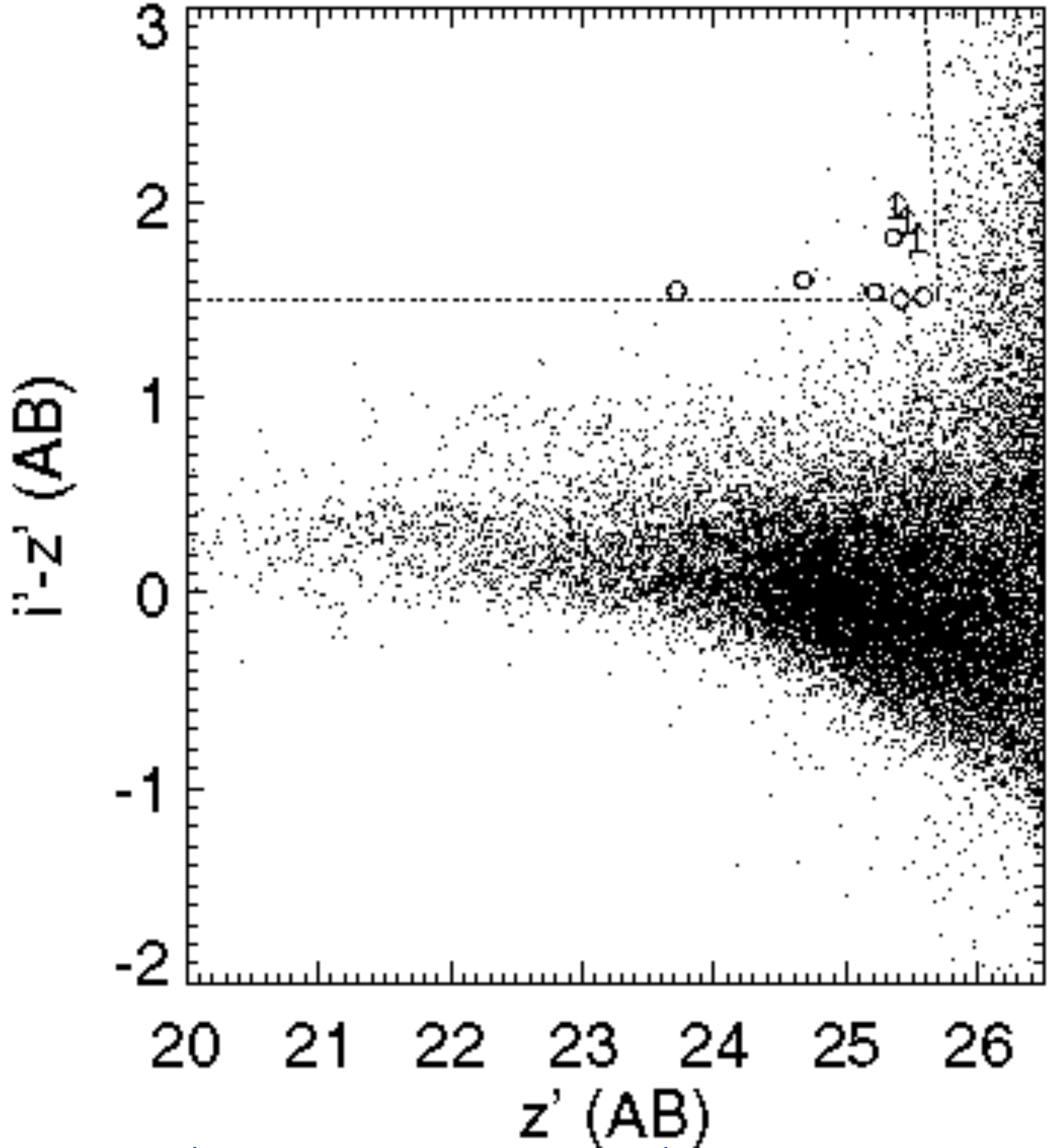
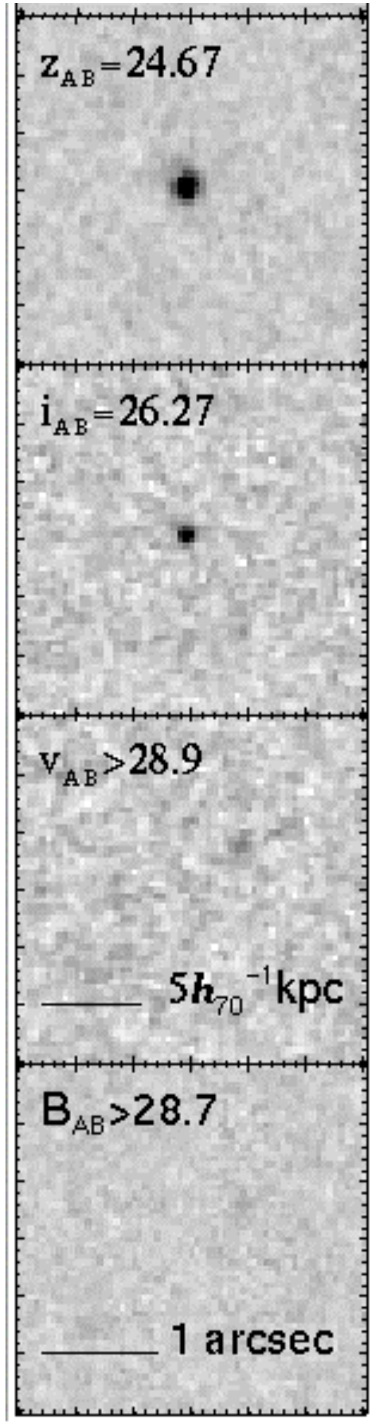
"Lyman break technique" - sharp drop in flux at λ below Ly-α. Steidel et al. have >1000 z~3 objects, "drop" in U-band.

Pushing to higher redshift- Finding Lyman break galaxies at z~6 : using *i*-drops.

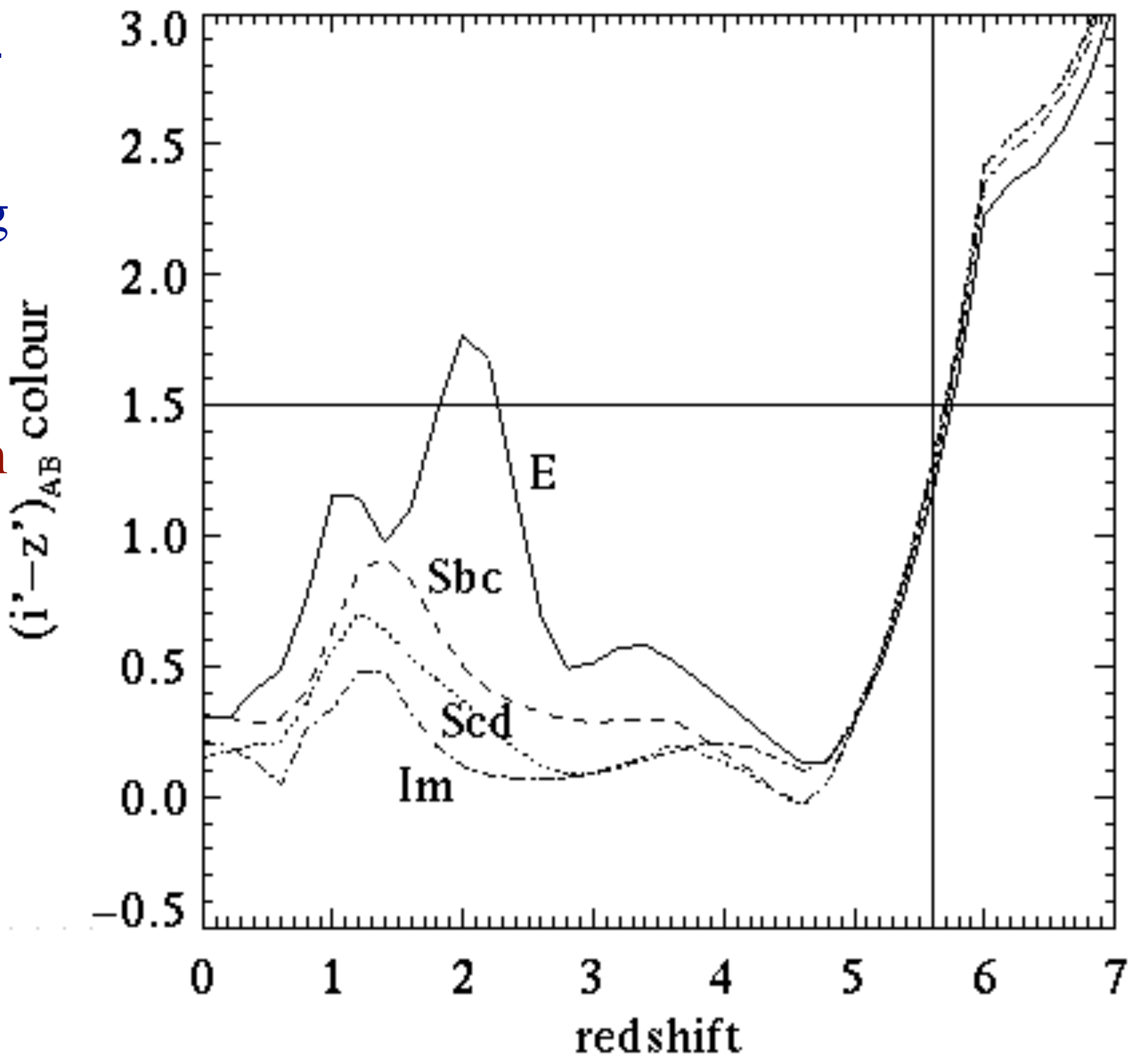





Using HST/ACS GOODS data - CDFS & HDFN, 5 epochs B,v,i',z'

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.

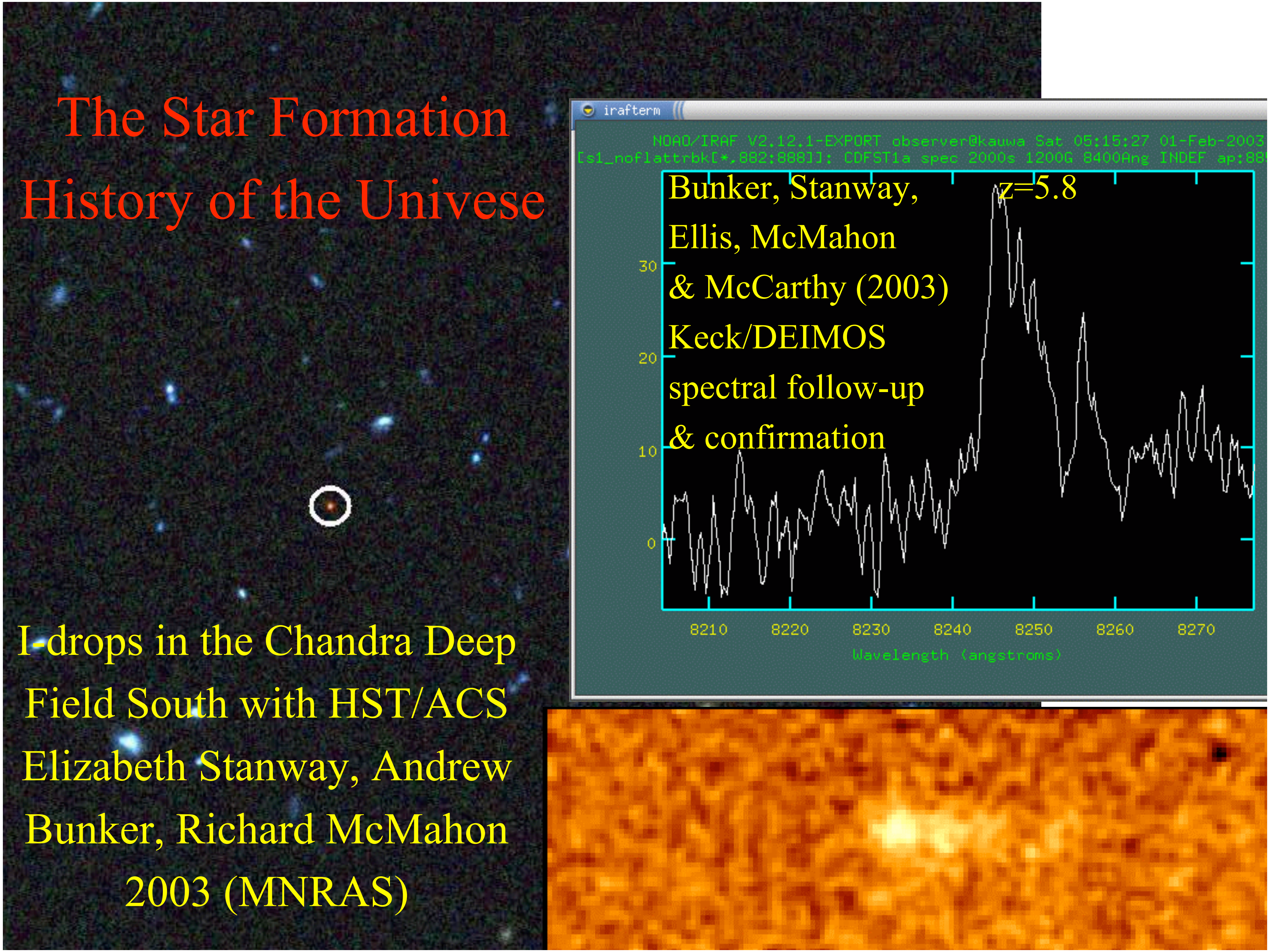



10-m Kecks

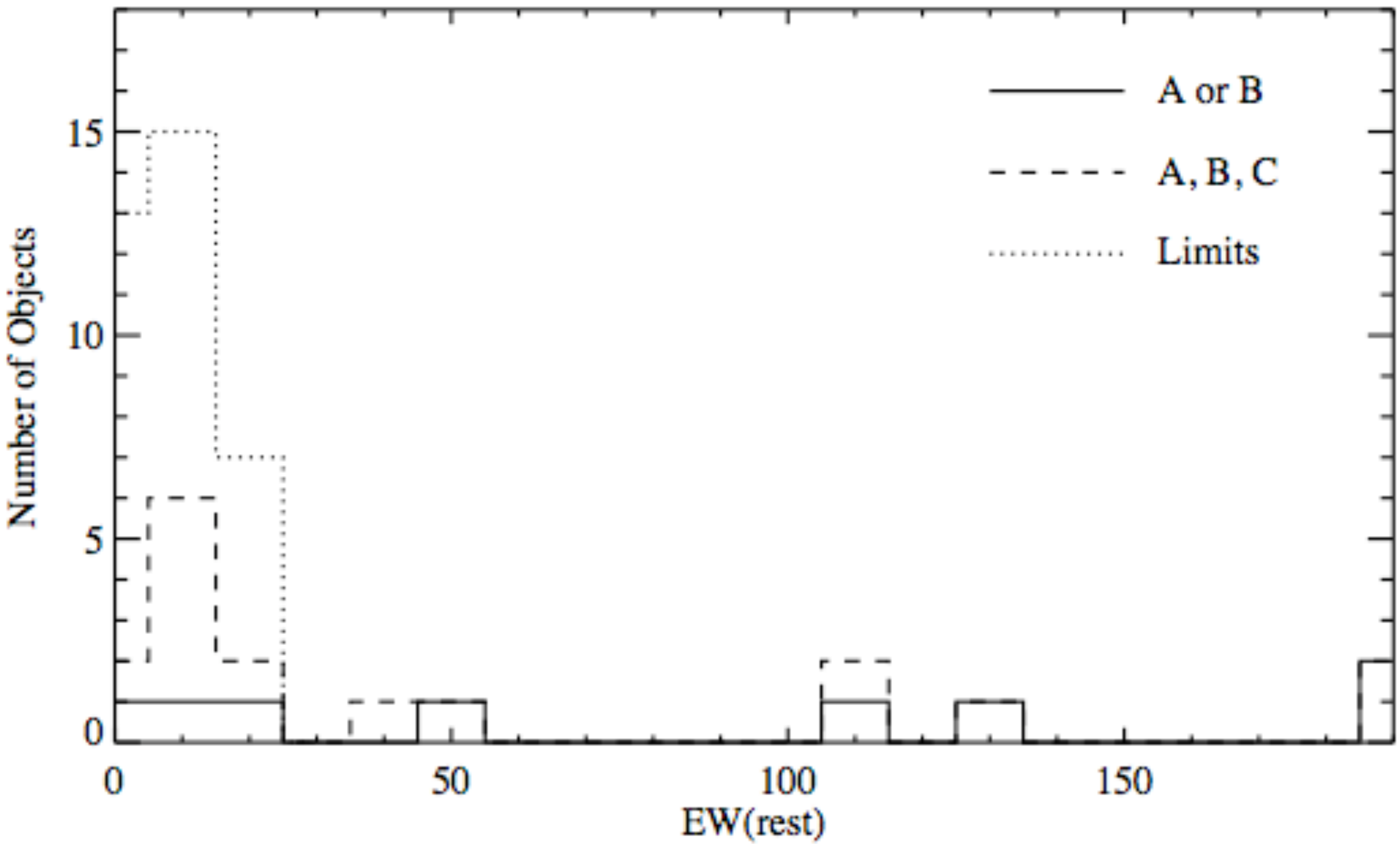

ESO VLTs


Photo © Neelon Crawford/Polar Fine Arts


8-m Gemini

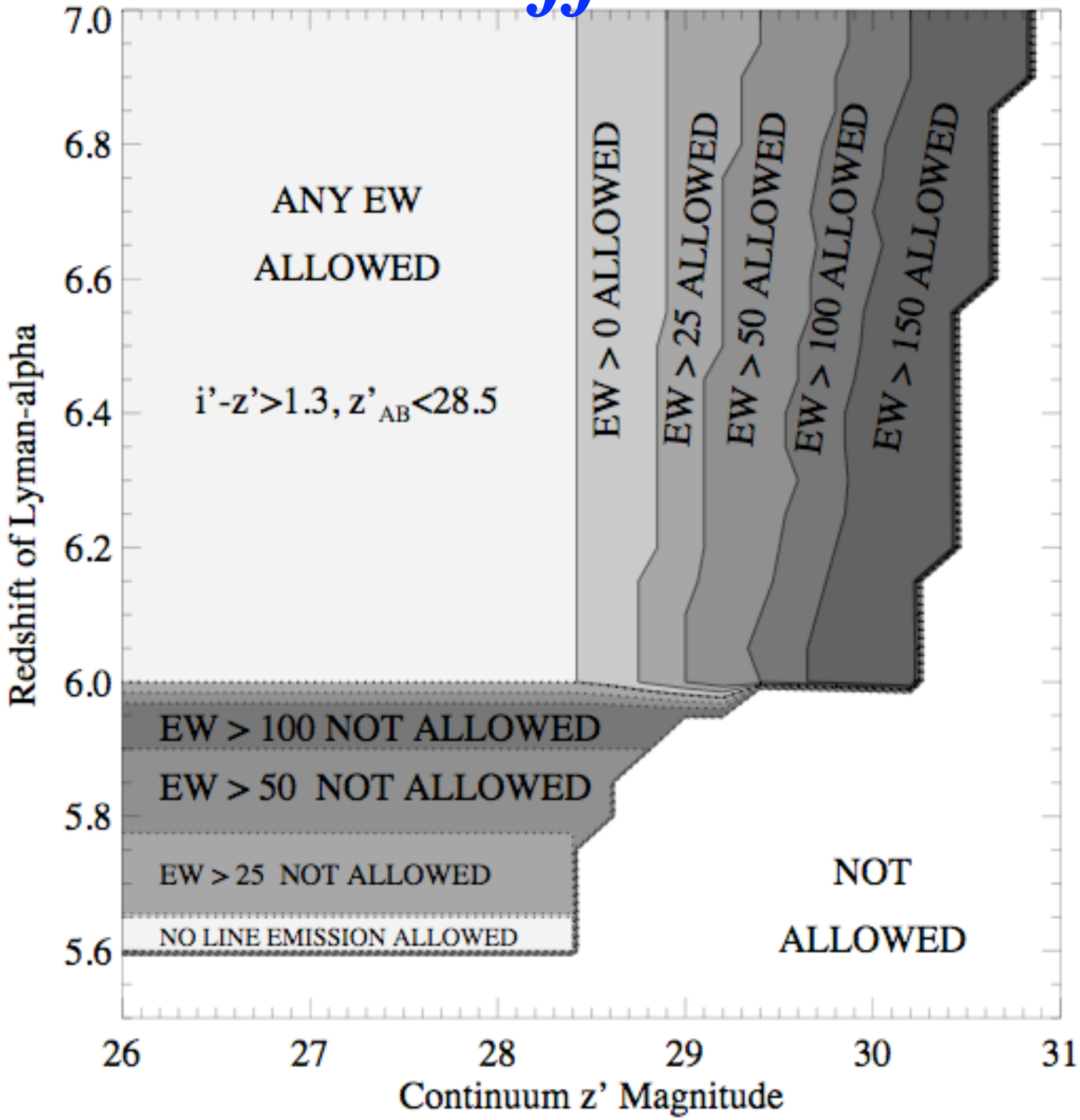

The Star Formation
History of the Univese
I-drops in the Chandra Deep
Field South with HST/ACS
Elizabeth Stanway, Andrew
Bunker, Richard McMahon
2003 (MNRAS)
irafterm
NOAO/IRAF V2.12.1-EXPORT observer@kauwa Sat 05:15:27 01-Feb-2003
[s1_noflattrbk[*,882:888]]: CDFST1a spec 2000s 1200G 8400Ang INDEF ap:88
Bunker, Stanway,
Ellis, McMahon
& McCarthy (2003)
Keck/DEIMOS
spectral follow-up
& confirmation
z=5.8
30
20
10
0
8210
8220
8230
8240
8250
8260
8270
Wavelength (angstroms)

# *High equivalent width tail at z~6 (for usual assumptions, EW<100Ang theoretically and <30Ang observationally at z~3)*

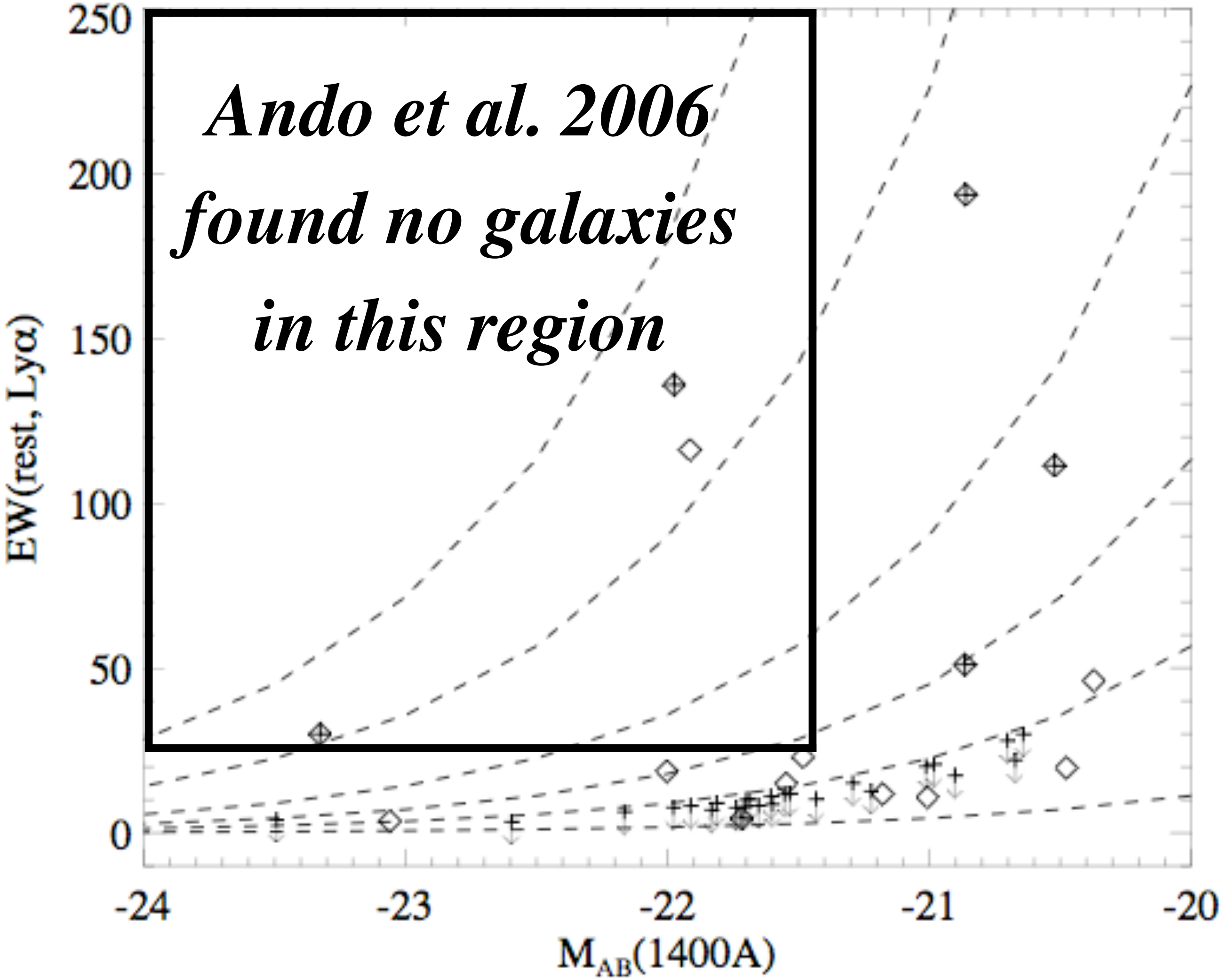


# *Line emission selection effects in LBGs*

***Stanway et al (2007) GLARE paper 2, Gemini GMOS***



# *No bright, high-EW z~6 galaxies?*

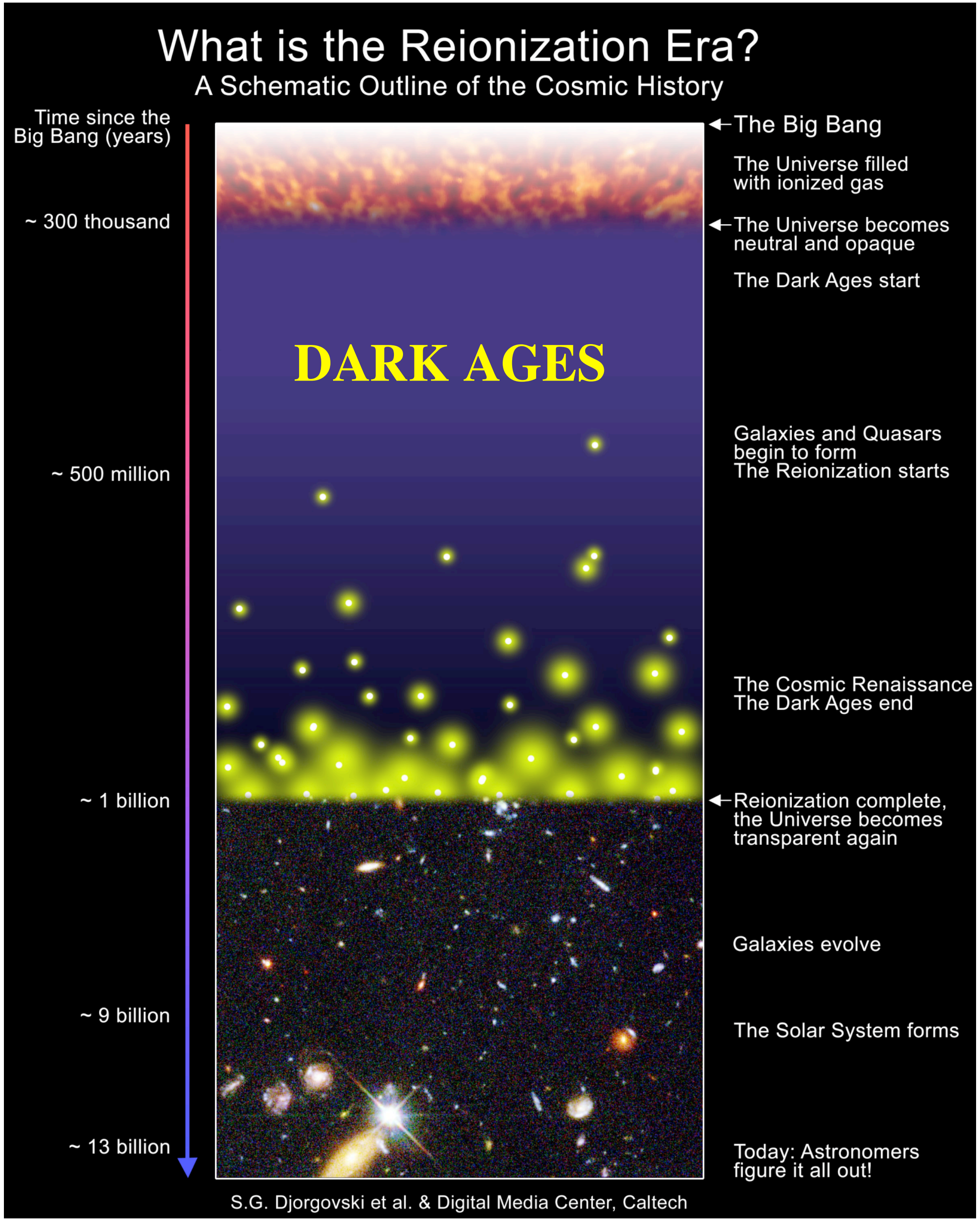


After era probed by CMBR the Universe enters the so-called “dark ages” prior to formation of first stars

Hydrogen is then re-ionized by the newly-formed stars

When did this happen?

What did it?




Redshift z

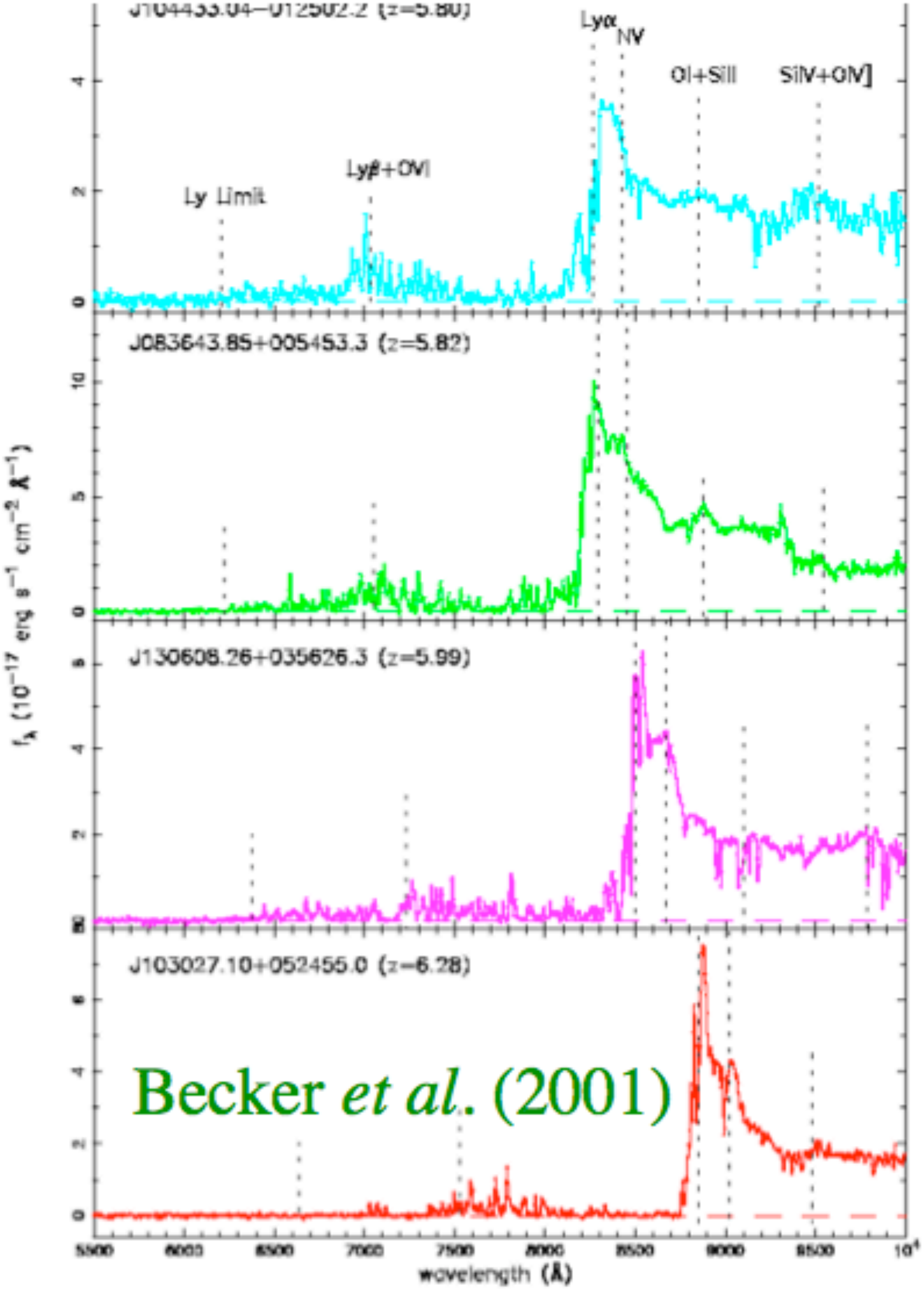
1100

10

5

2

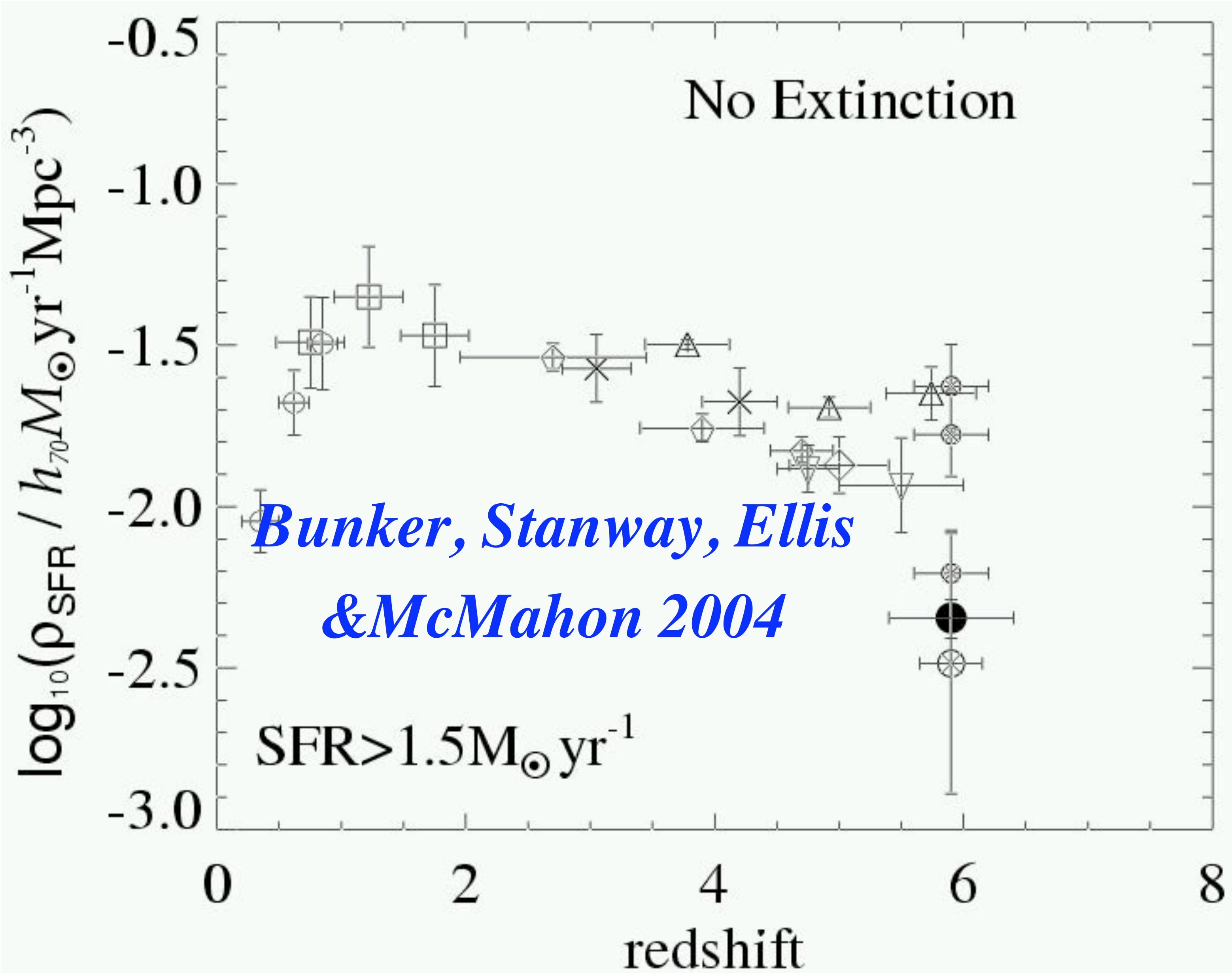
0




# Reionization

At high-redshift, the Lyman-α forest can absorb most of the flux below $\lambda_{rf}$=1216Å. Indications from *z*=6.3 SDSS QSO that Universe may be optically thick at z~6 (see talk by Fan). BUT confusing messages from WMAP CMB satellite: reionization z~10-30? (Kogut et al. 2003)

# *Looking at the UDF (going 10x deeper, z'=26 →28.5 mag)*




***Bunker, Stanway, Ellis &McMahon 2004***

# *Implications for Reionization*

$$\dot{\rho}_{\rm SFR} \approx 0.013\, f_{\rm esc}^{-1} \left(\frac{1+z}{6}\right)^3 \left(\frac{\Omega_b\, h_{50}^2}{0.08}\right)^2 C_{30}\, M_\odot\, {\rm yr}^{-1}\, {\rm Mpc}^{-3}$$

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

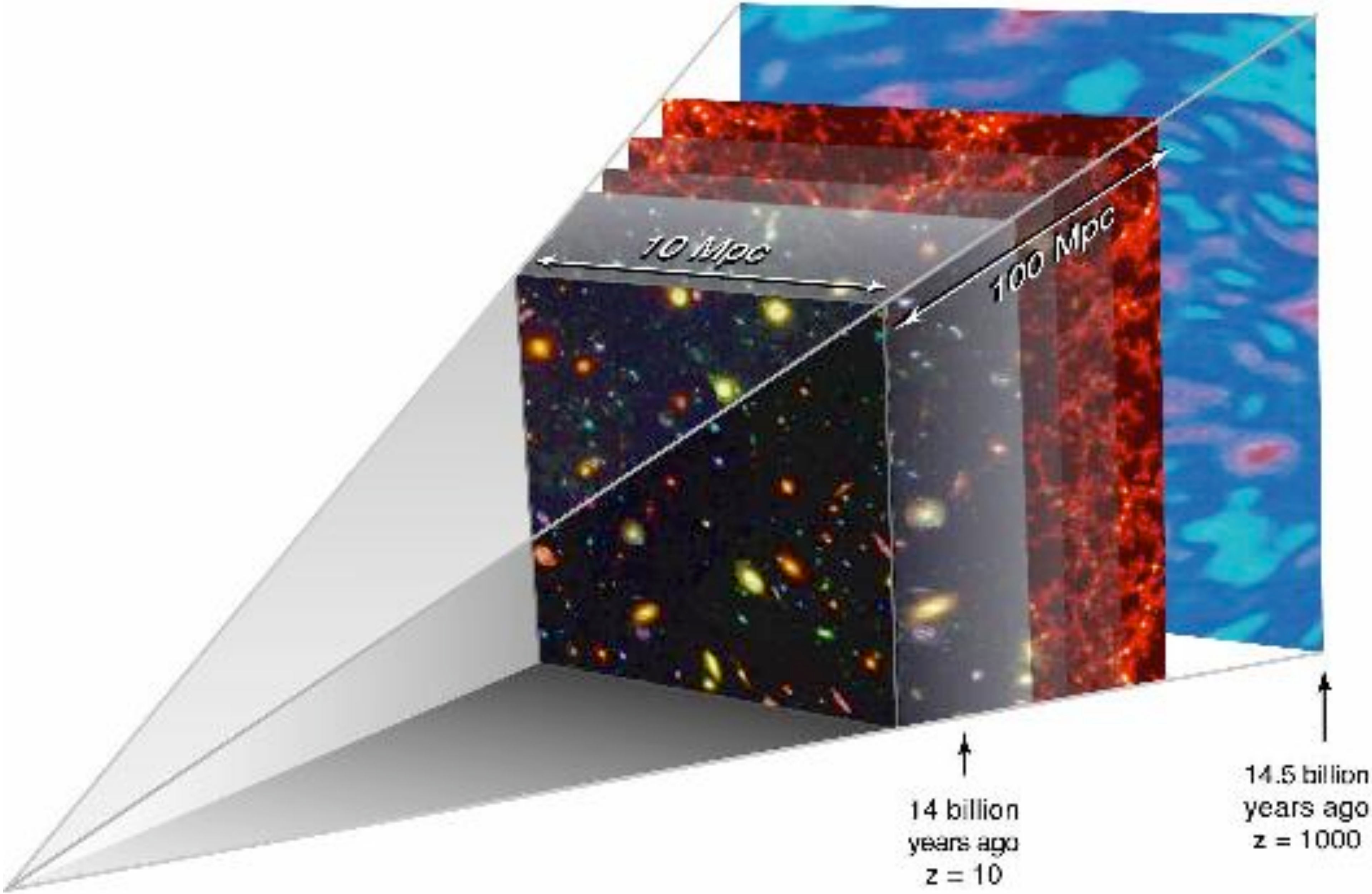
This assumes escape fraction=1 (i.e. all ionzing photons make it out of the galaxies)

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 $\alpha$ (lots of low luminosity sources - forming globulars?)

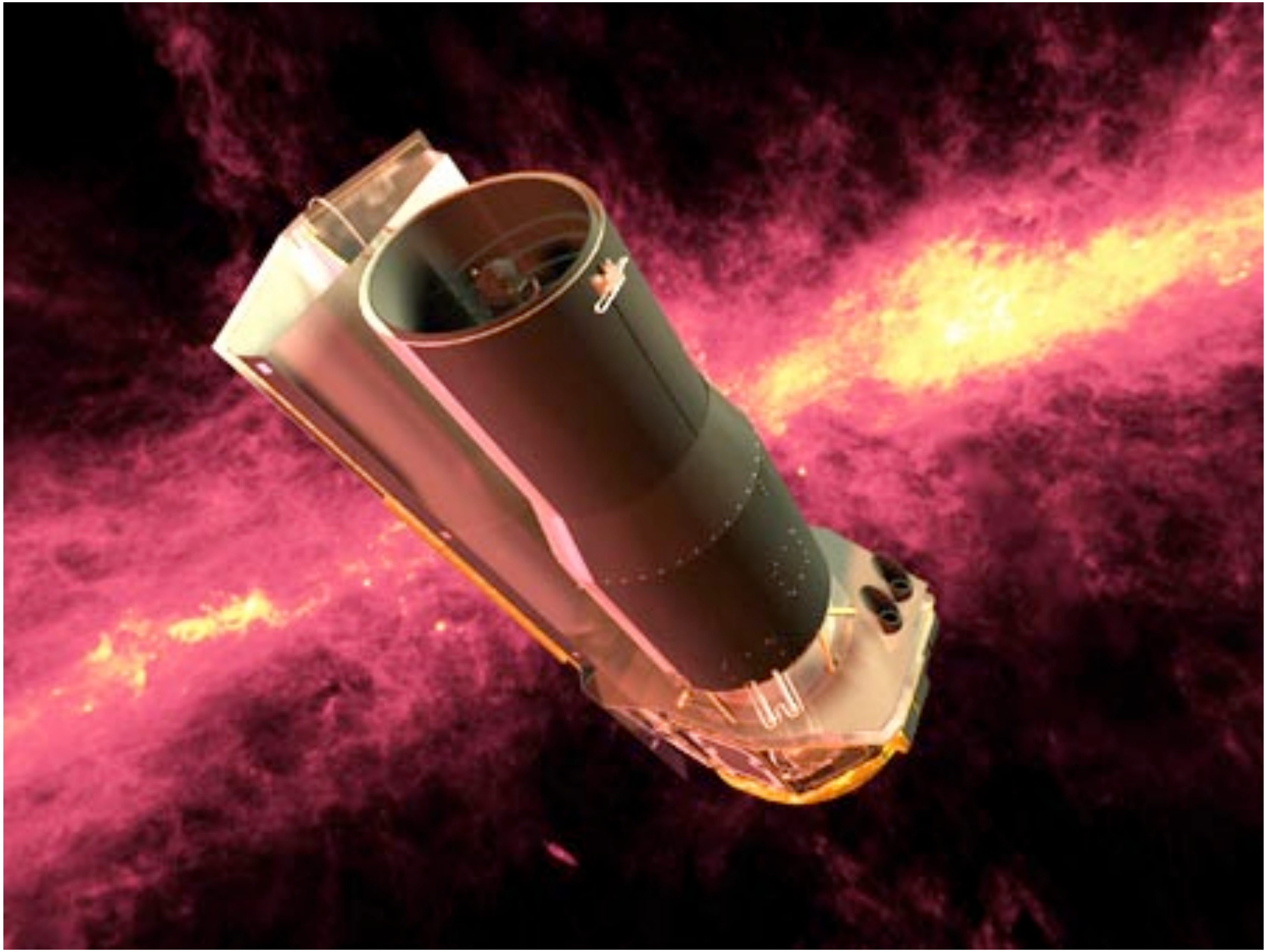
# *Ways out of the Puzzle*

- Cosmic variance
- Star formation at even earlier epochs to reionize Universe ($z$>>6)?
- Change the physics: different recipe for star formation (Initial mass function)? - some evidence for this in high EW Ly-alpha tail and blue rest-UV colours
- Even fainter galaxies than we can reach with the UDF?

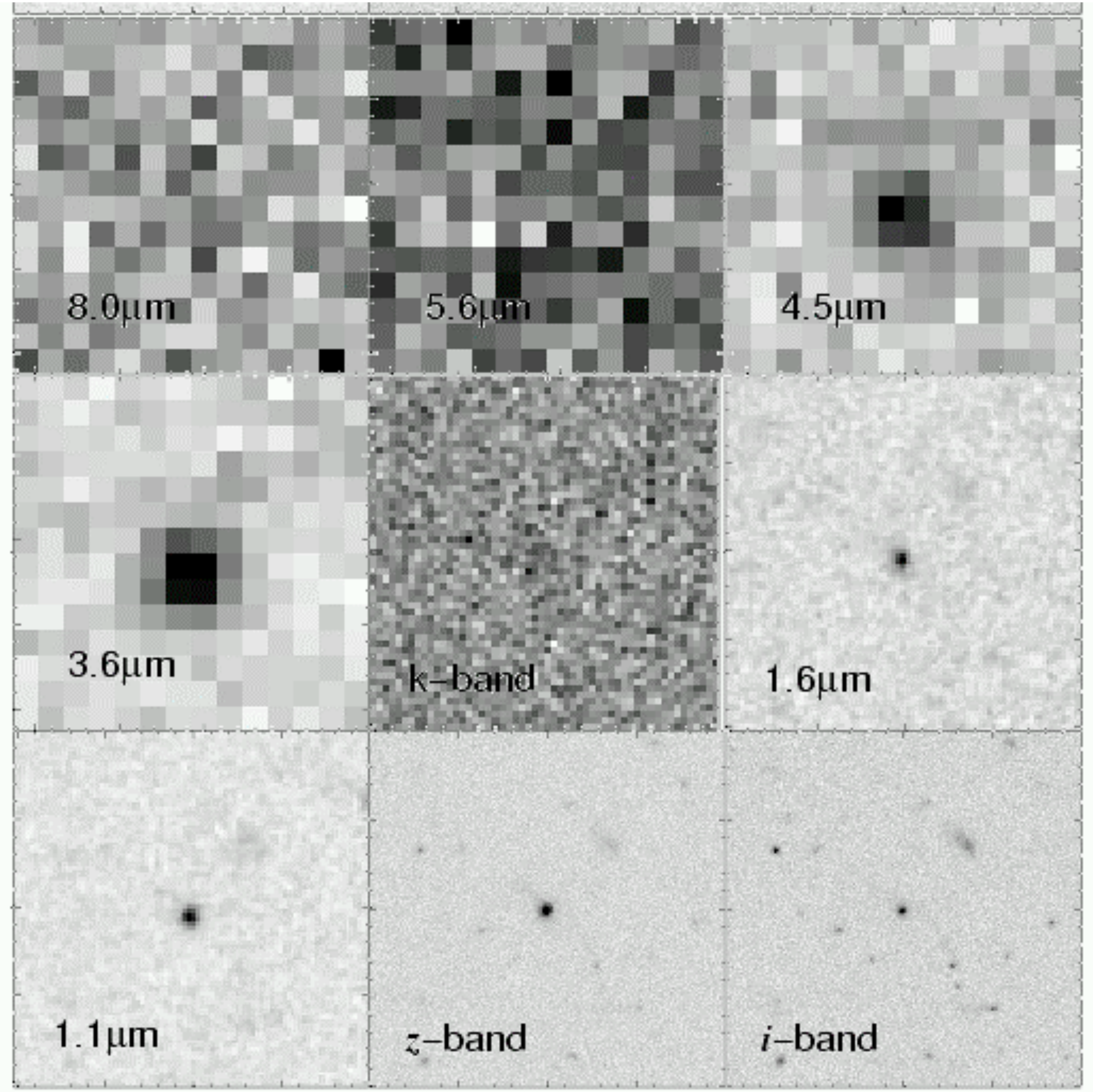



DAZLE - Dark Ages 'z' Lyman-alpha Explorer

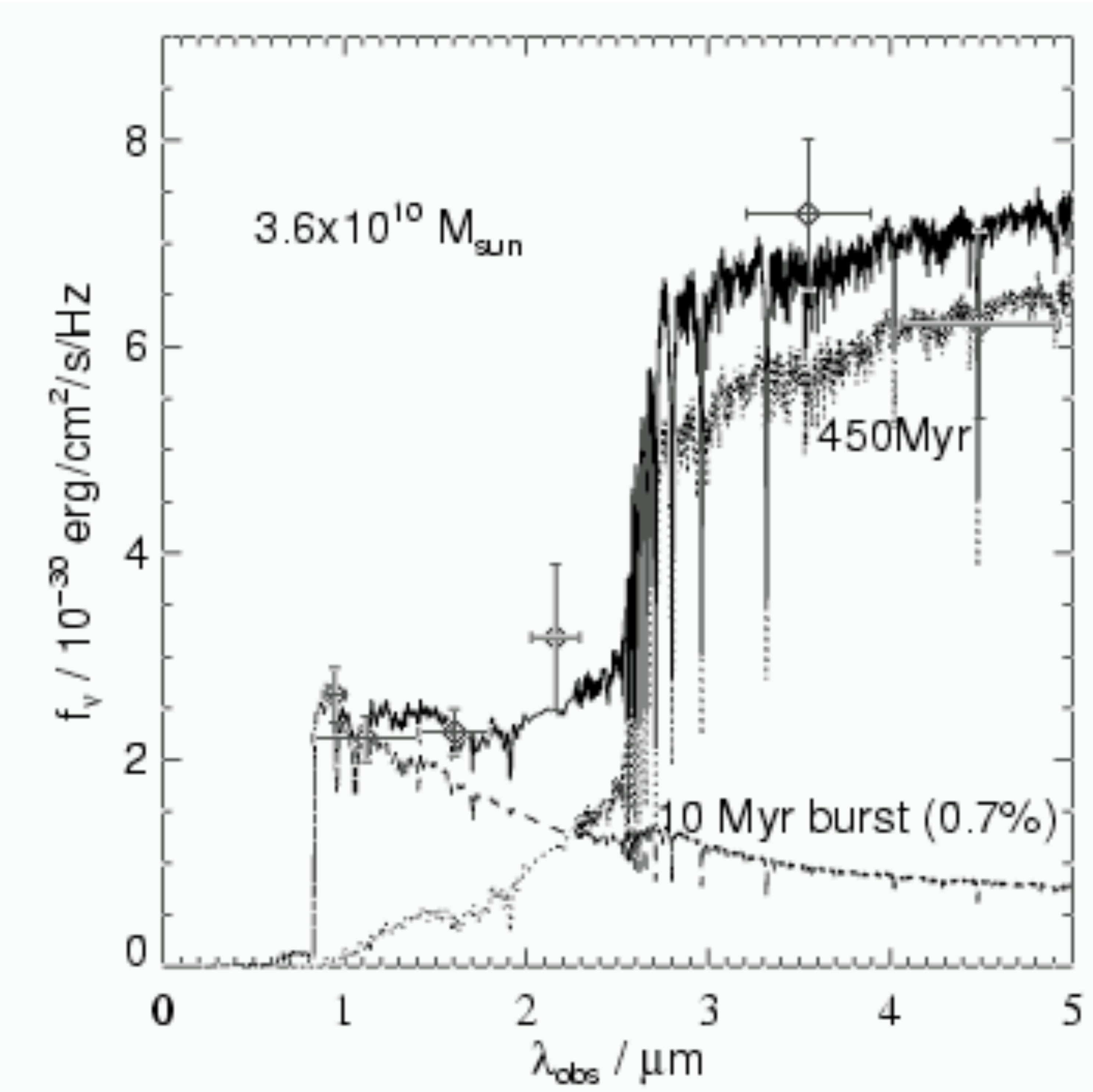
IoA - Richard McMahon, Ian Parry; AAO - Joss Bland-Hawthorne



*Spitzer – IRAC (3.6-8.0 microns)*

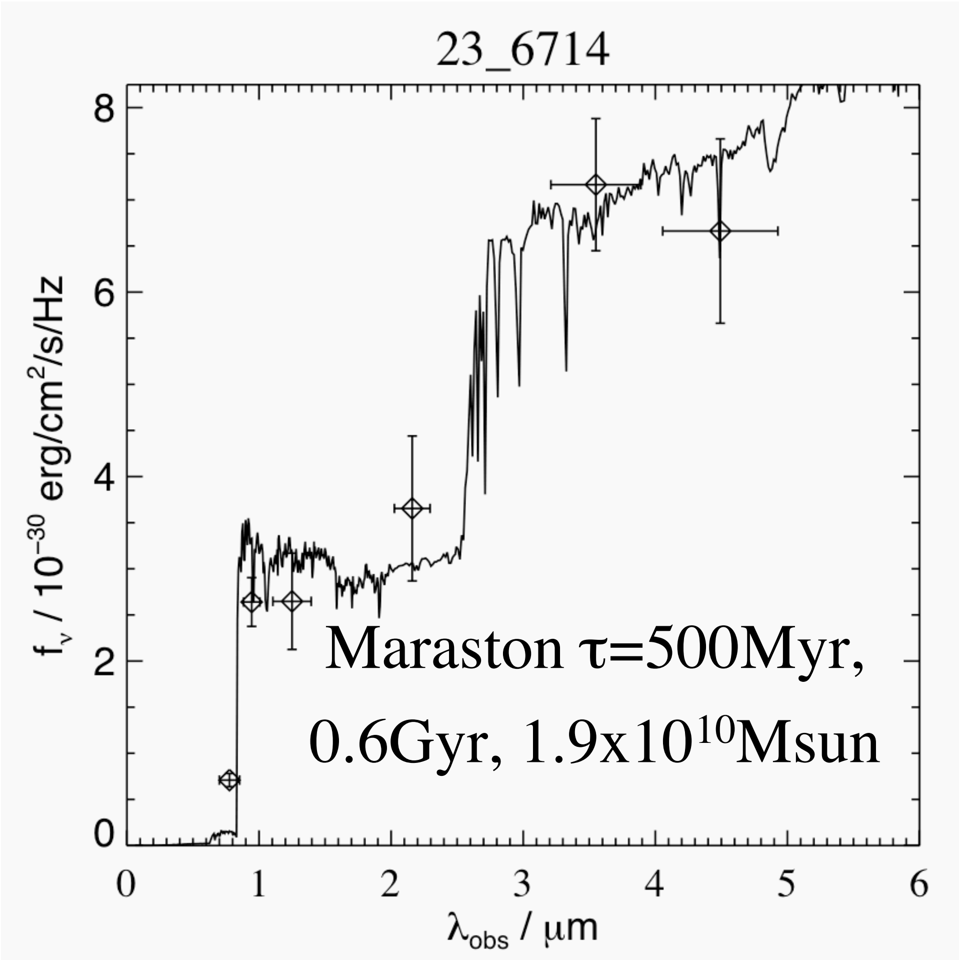


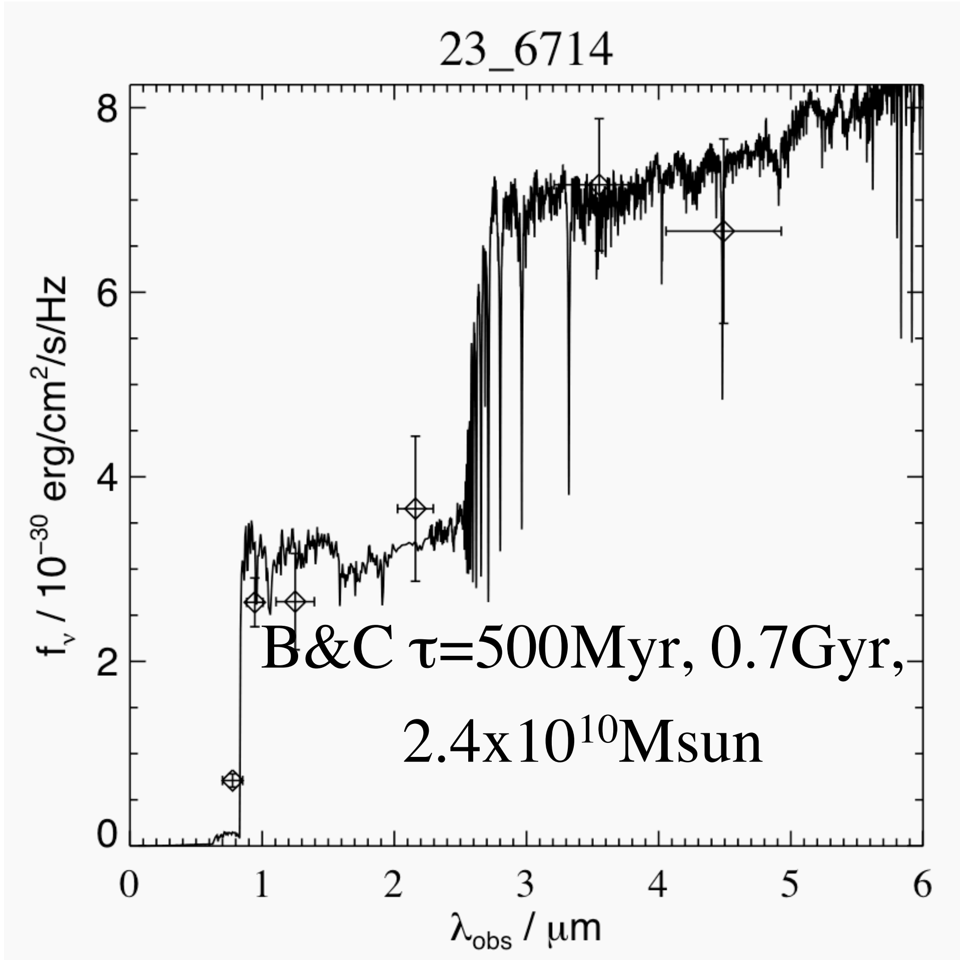

- z=5.83 galaxy #1 from Stanway, Bunker & McMahon 2003 (spec conf from Stanway et al. 2004, Dickinson et al. 2004). Detected in GOODS IRAC 3-4μm: Eyles, Bunker, Stanway et al.



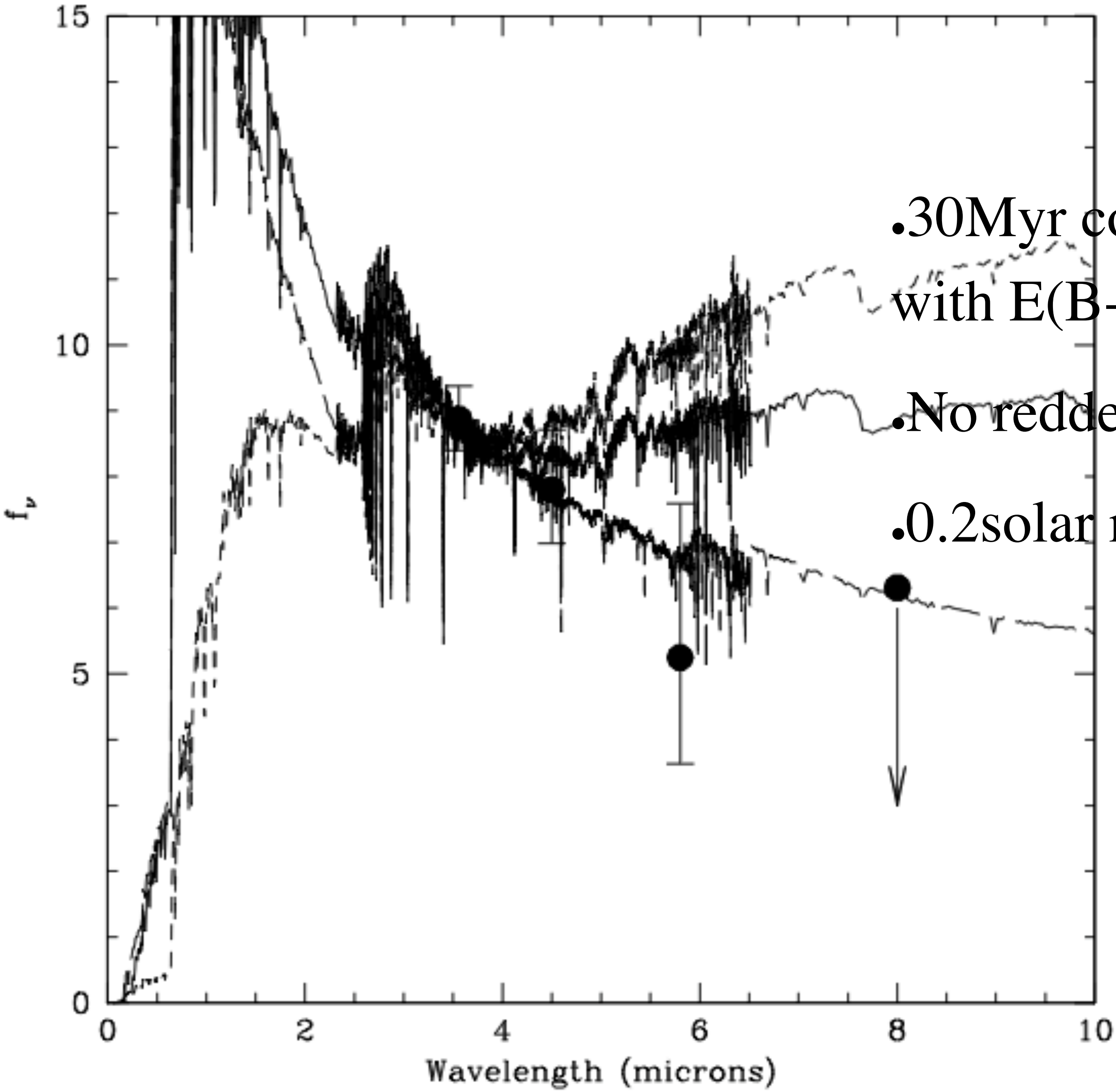
3.6x10^10 M_sun
450Myr
10 Myr burst (0.7%)
f_ν / 10^-30 erg/cm^2/s/Hz
λ_obs / μm
0
2
4
6
8
0
1
2
3
4
5

# Other Population Synthesis Models

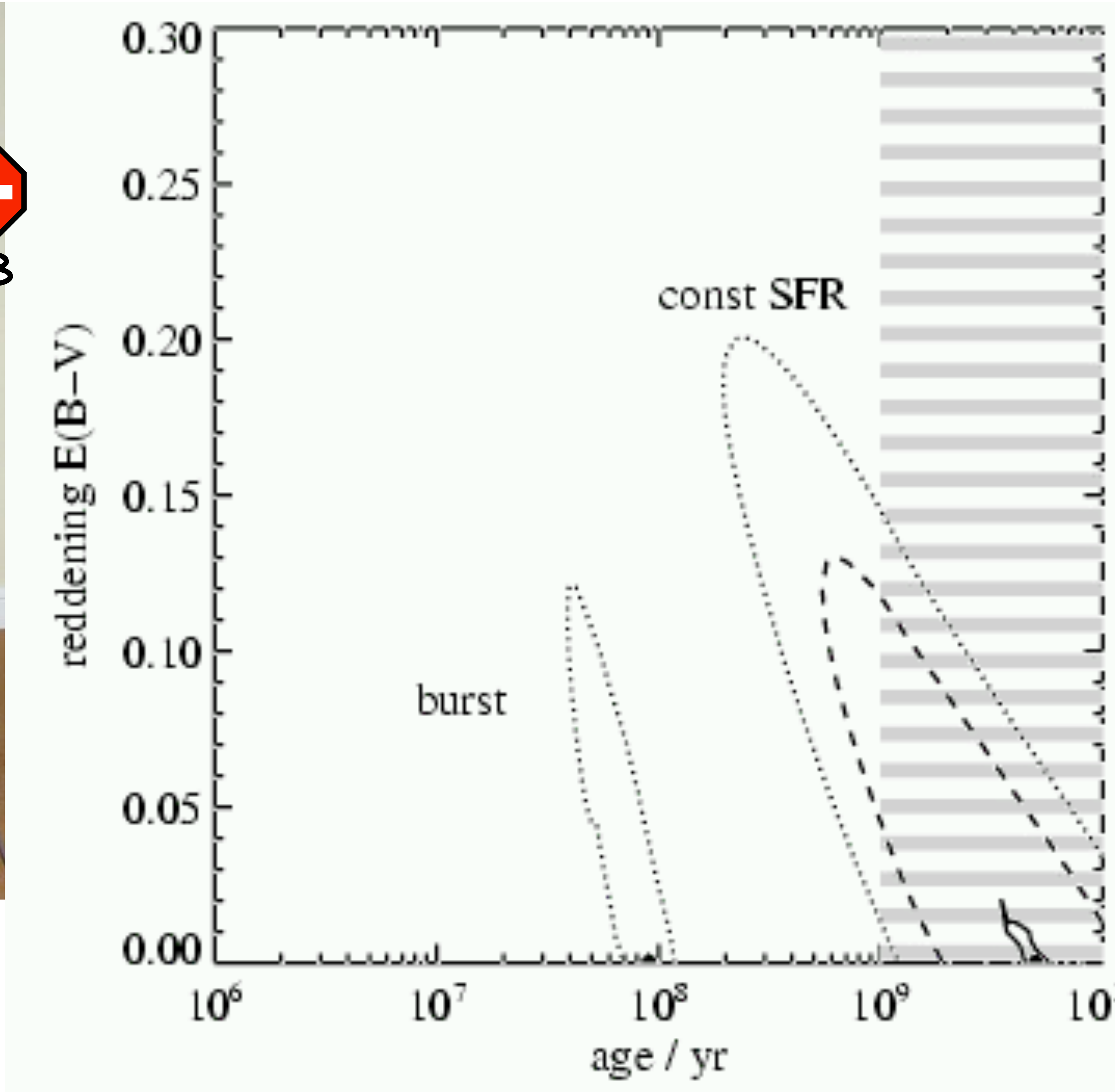



Maraston vs. Bruzual & Charlot




- 30Myr const SFR with E(B-V)=0.1
- No reddening
- 0.2solar metallicity



const SFR
burst
reddening E(B–V)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
$10^6$
$10^7$
$10^8$
$10^9$
$10^1$
age / yr

-Have shown that some z=6 I-drops have old stars and large masses

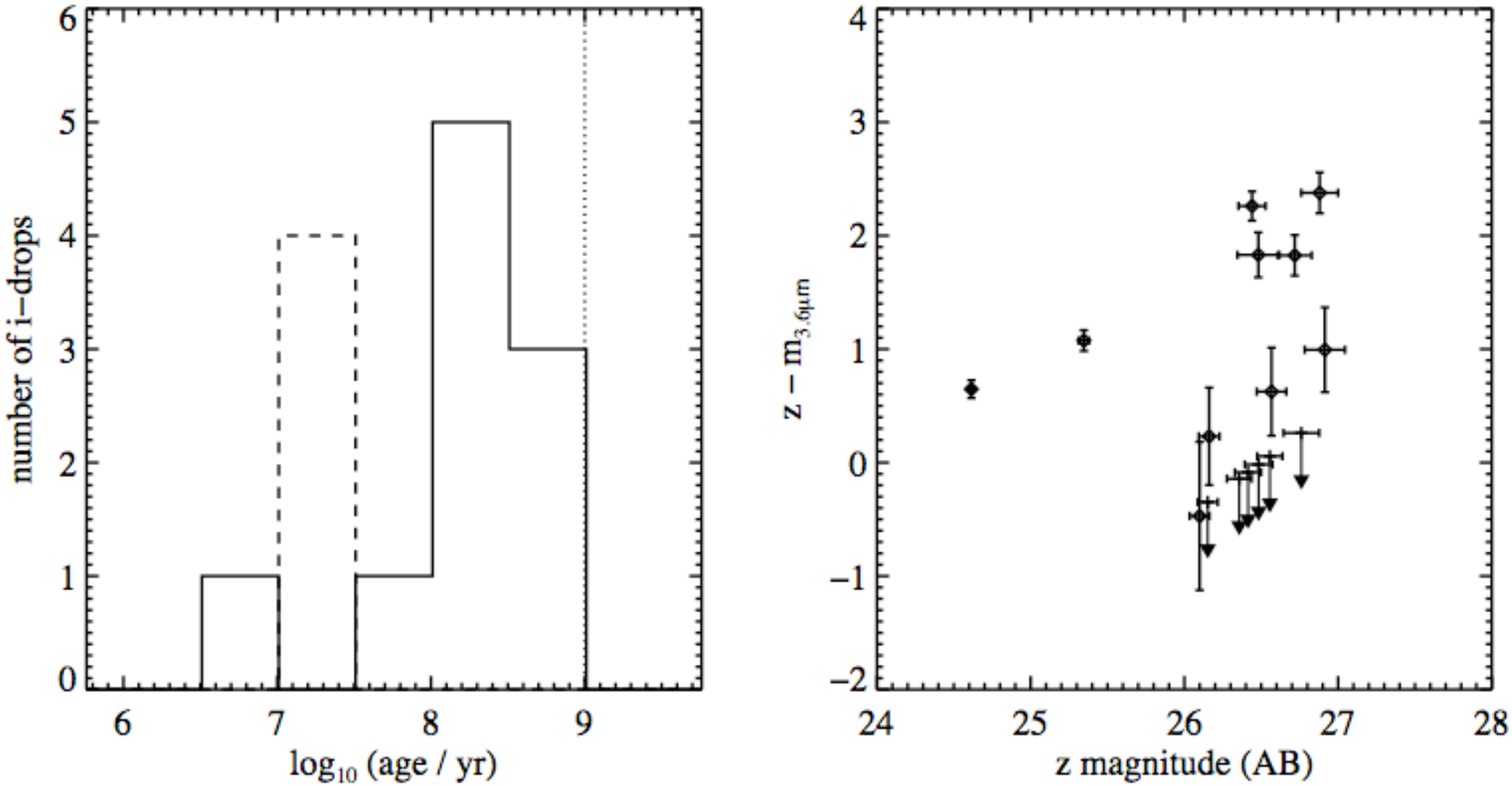
-Hints that there may be z>6 galaxies similar (Egami lens). Mobasher source - z=6.5??? (probably lower-z)

-Turn now to larger samples, to provide stellar mass density in first Gyr with Spitzer

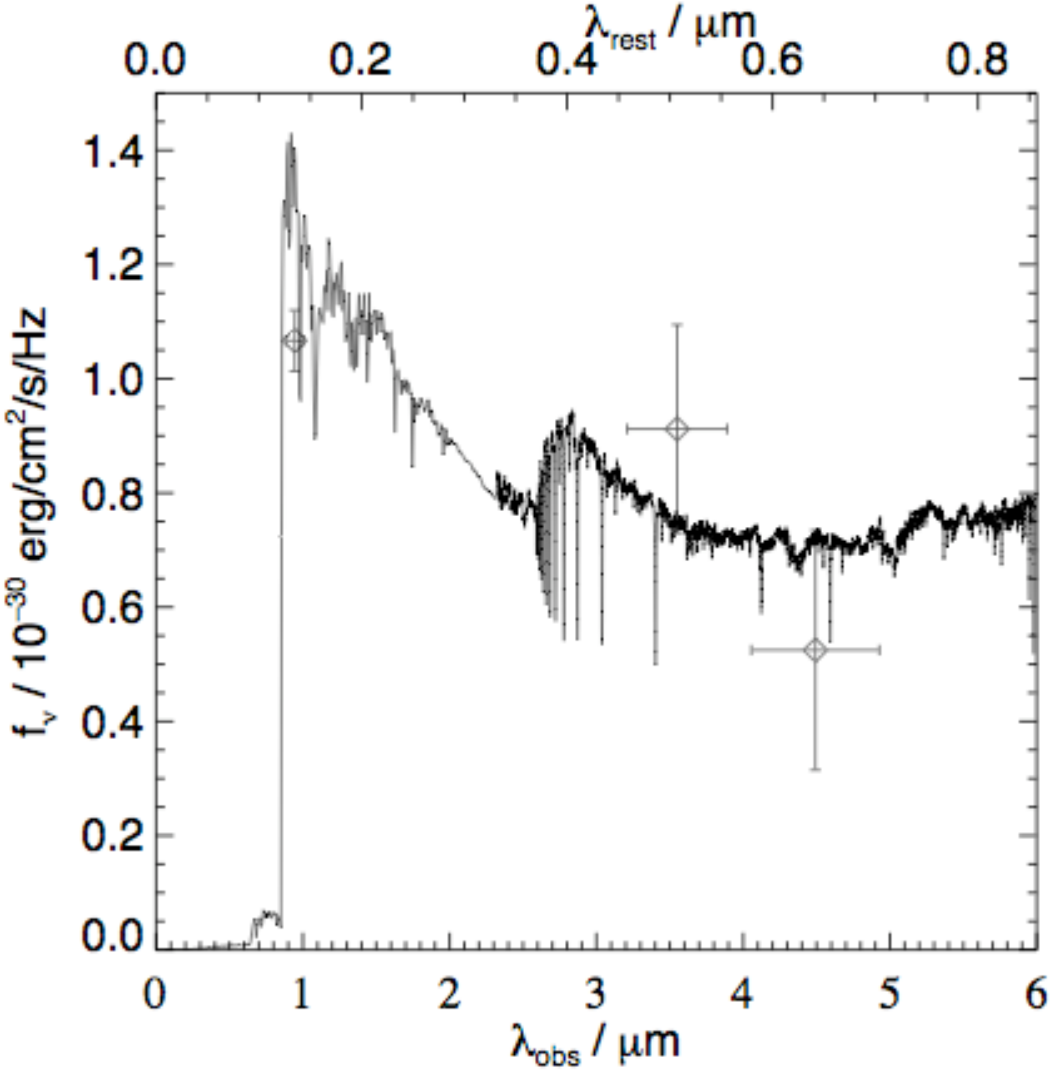
-- In Stark, Bunker, Ellis et al. (2006) we look at v-drops (z~5) in the GOODS-South

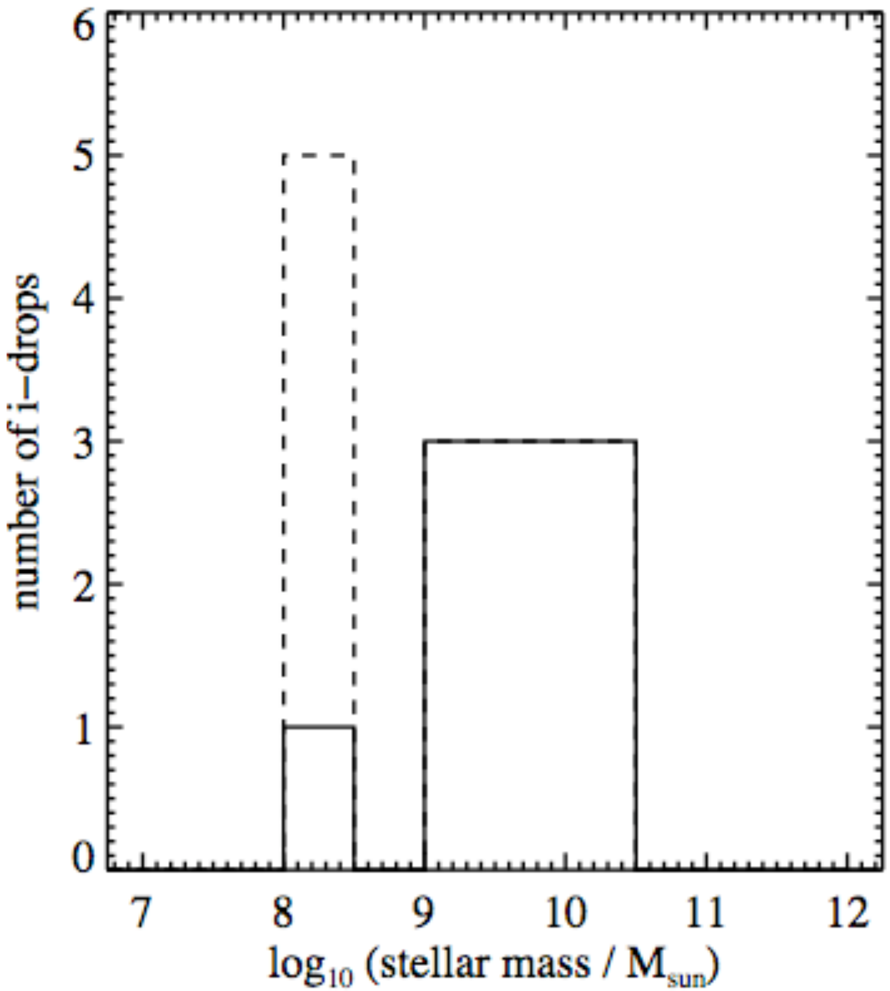
-21 have spectroscopic redshifts, 2/3rds unconfused at Spitzer resolution

-- Also use 200 photometric redshifts (going fainter), >50 unconfused

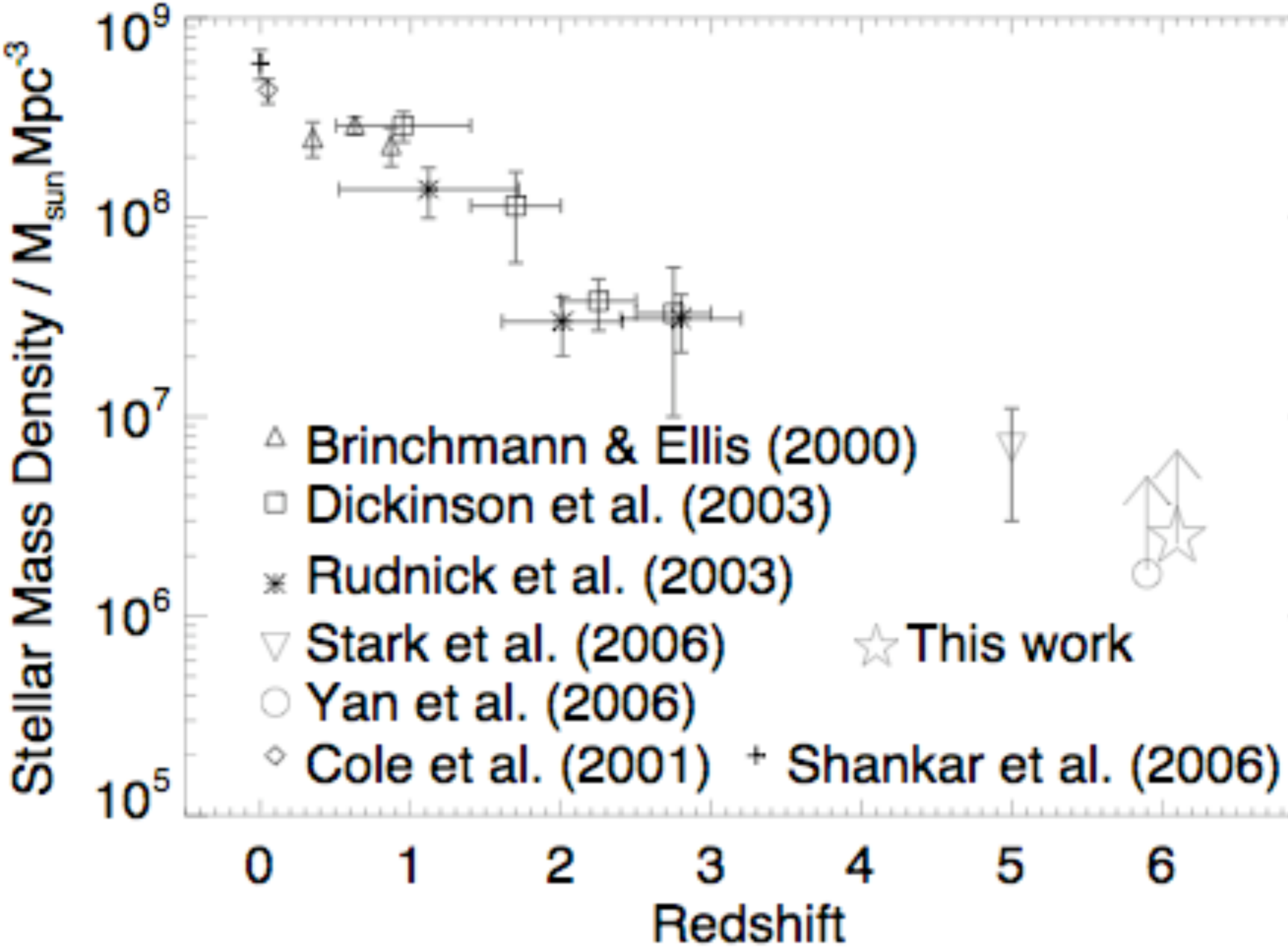



***Eyles, Bunker, Ellis et al. astro-ph/0607306***

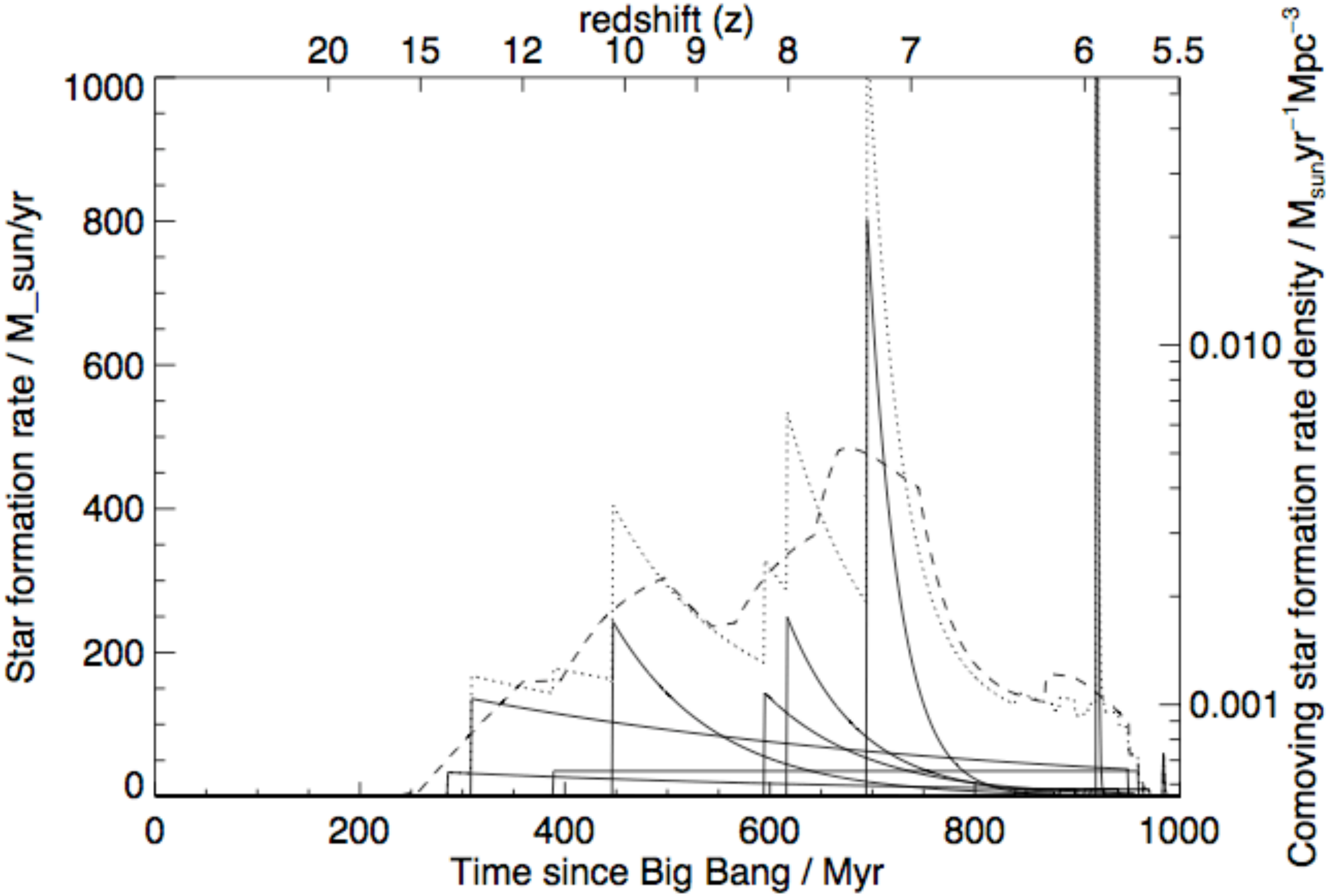


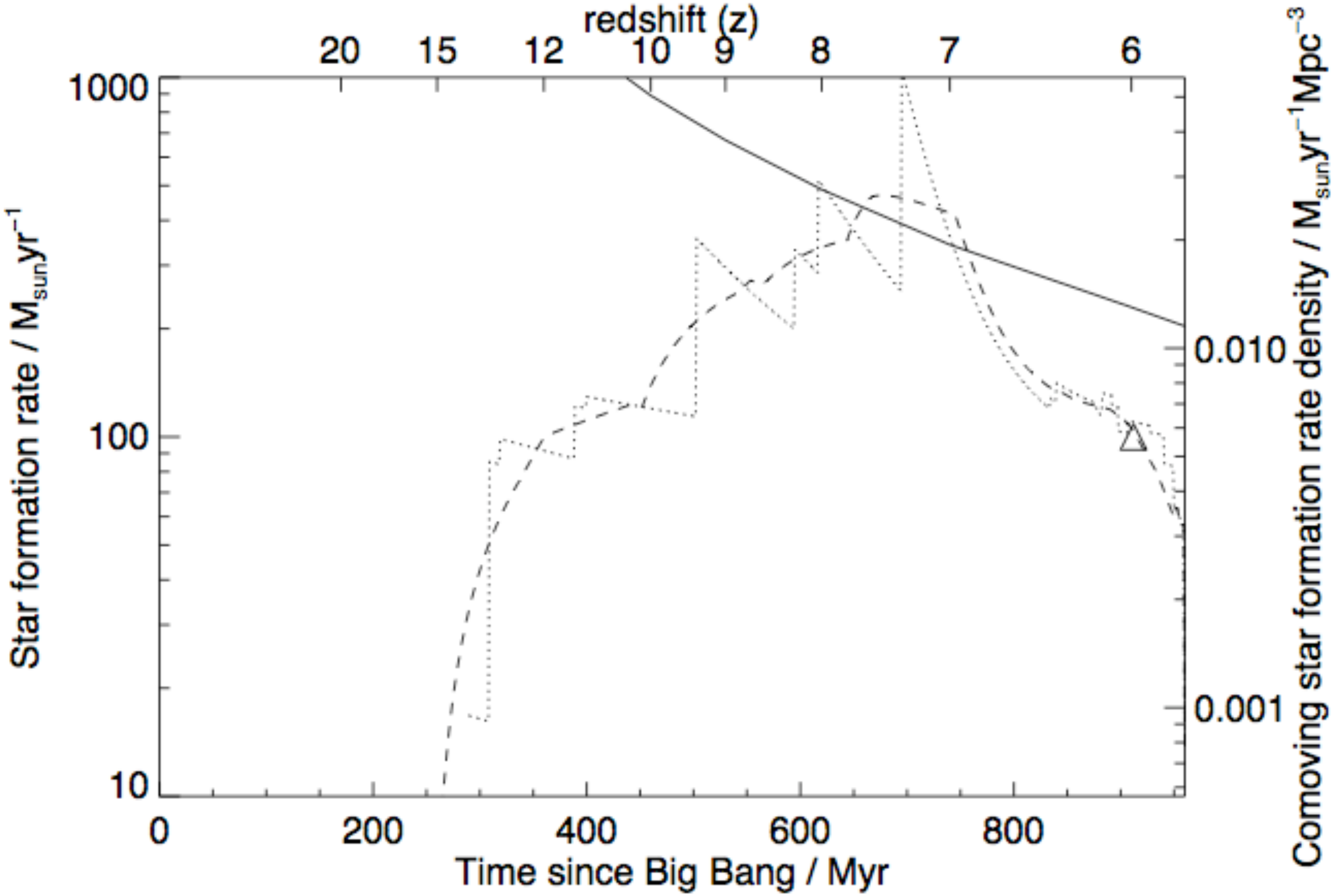

***Eyles, Bunker, Ellis et al. astro-ph/0607306***



Stellar Mass Density / M$_{sun}$ Mpc$^3$
Redshift
$10^9$
$10^8$
$10^7$
$10^6$
$10^5$
0
1
2
3
4
5
6
Brinchmann & Ellis (2000)
Dickinson et al. (2003)
Rudnick et al. (2003)
Stark et al. (2006)
This work
Yan et al. (2006)
Cole et al. (2001)
Shankar et al. (2006)




***Eyles, Bunker, Ellis et al. astro-ph/0607306***




***Eyles, Bunker, Ellis et al. astro-ph/0607306***

# JAMES WEBB SPACE TELESCOPE – successor to Hubble (2013+)