Star Formation and the Stellar Mass Density at z~6: Implications for Reionization

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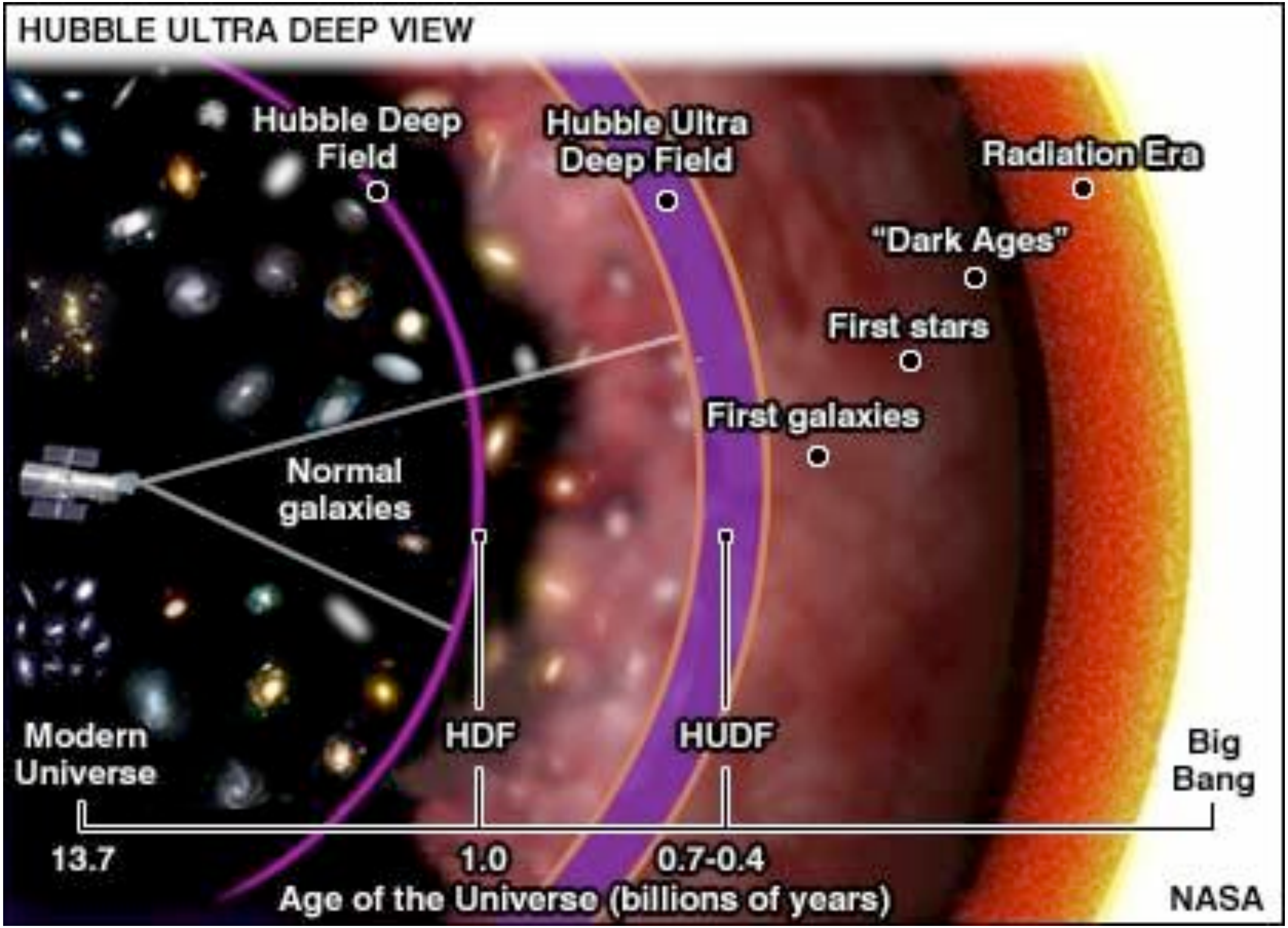
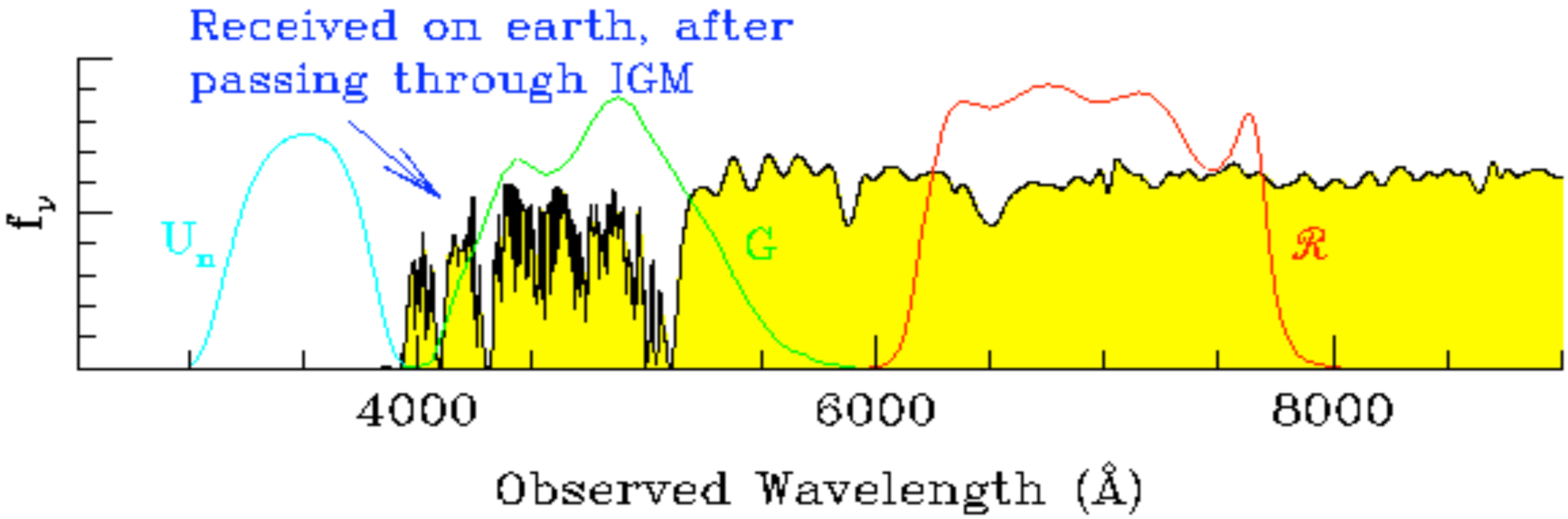
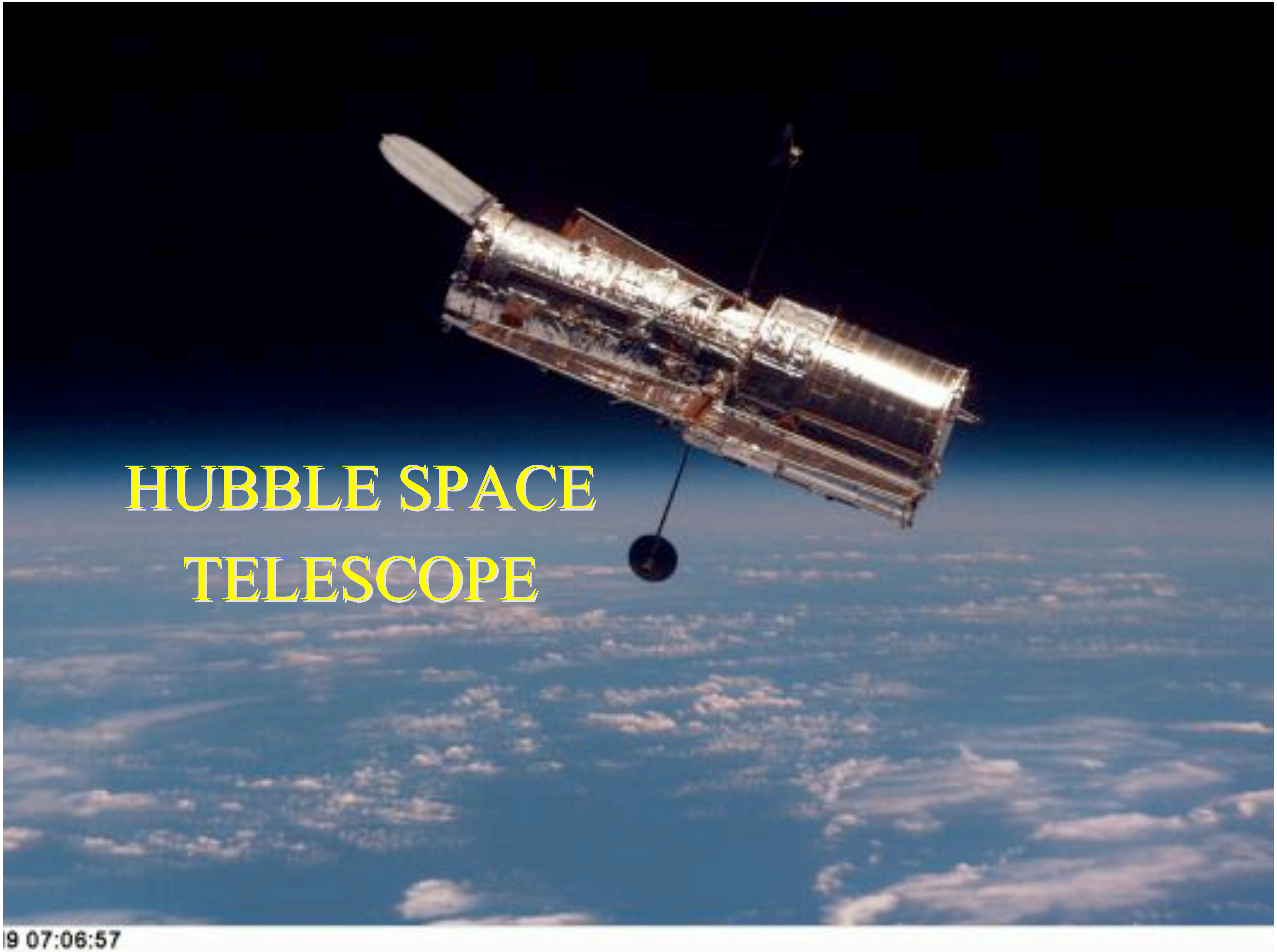

HUBBLE ULTRA DEEP VIEW
Hubble Deep Field
Hubble Ultra Deep Field
Radiation Era
"Dark Ages"
First stars
First galaxies
Normal galaxies
Modern Universe
HDF
HUDF
Big Bang
13.7
1.0
0.7-0.4
Age of the Universe (billions of years)
NASA



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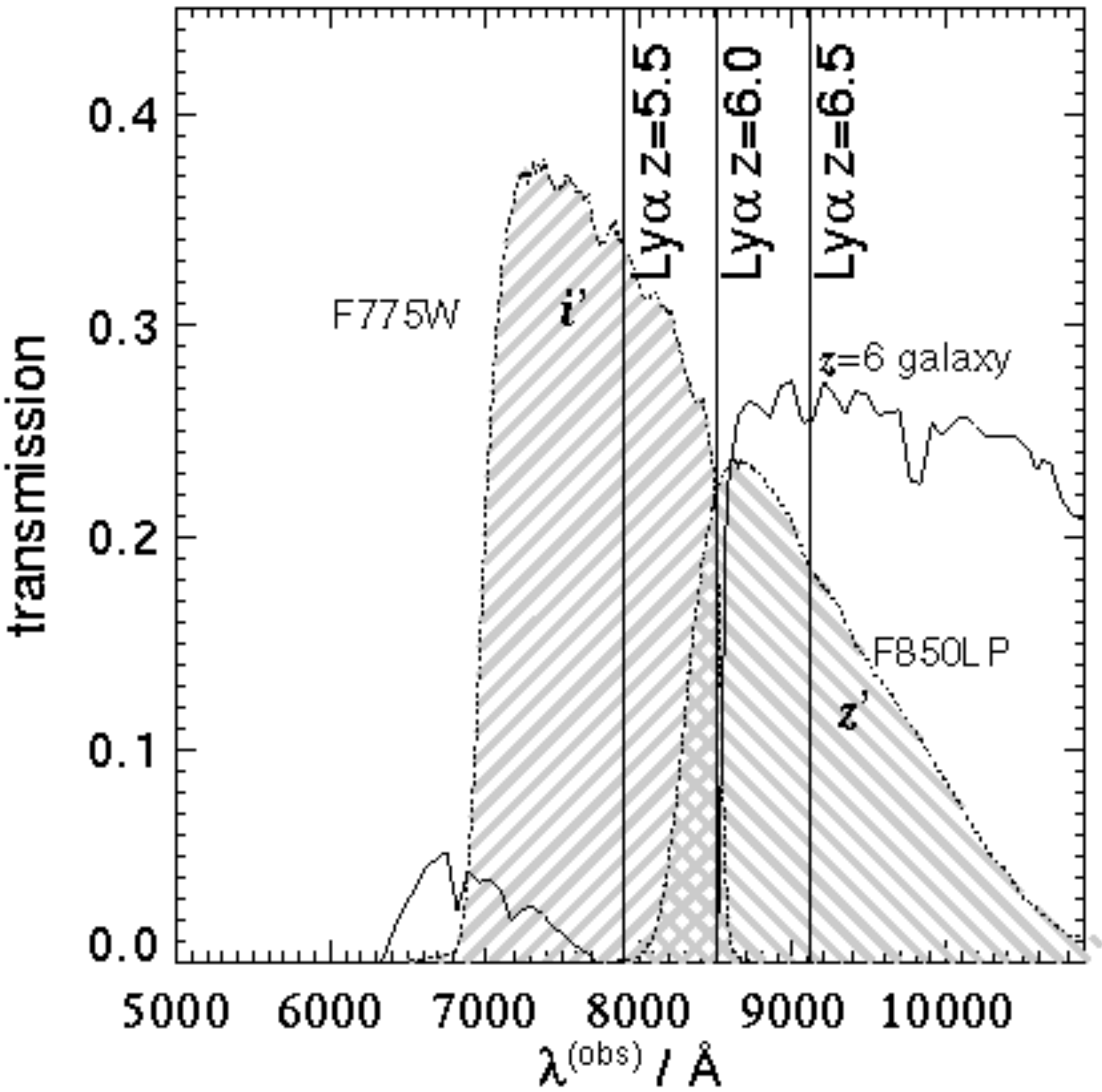
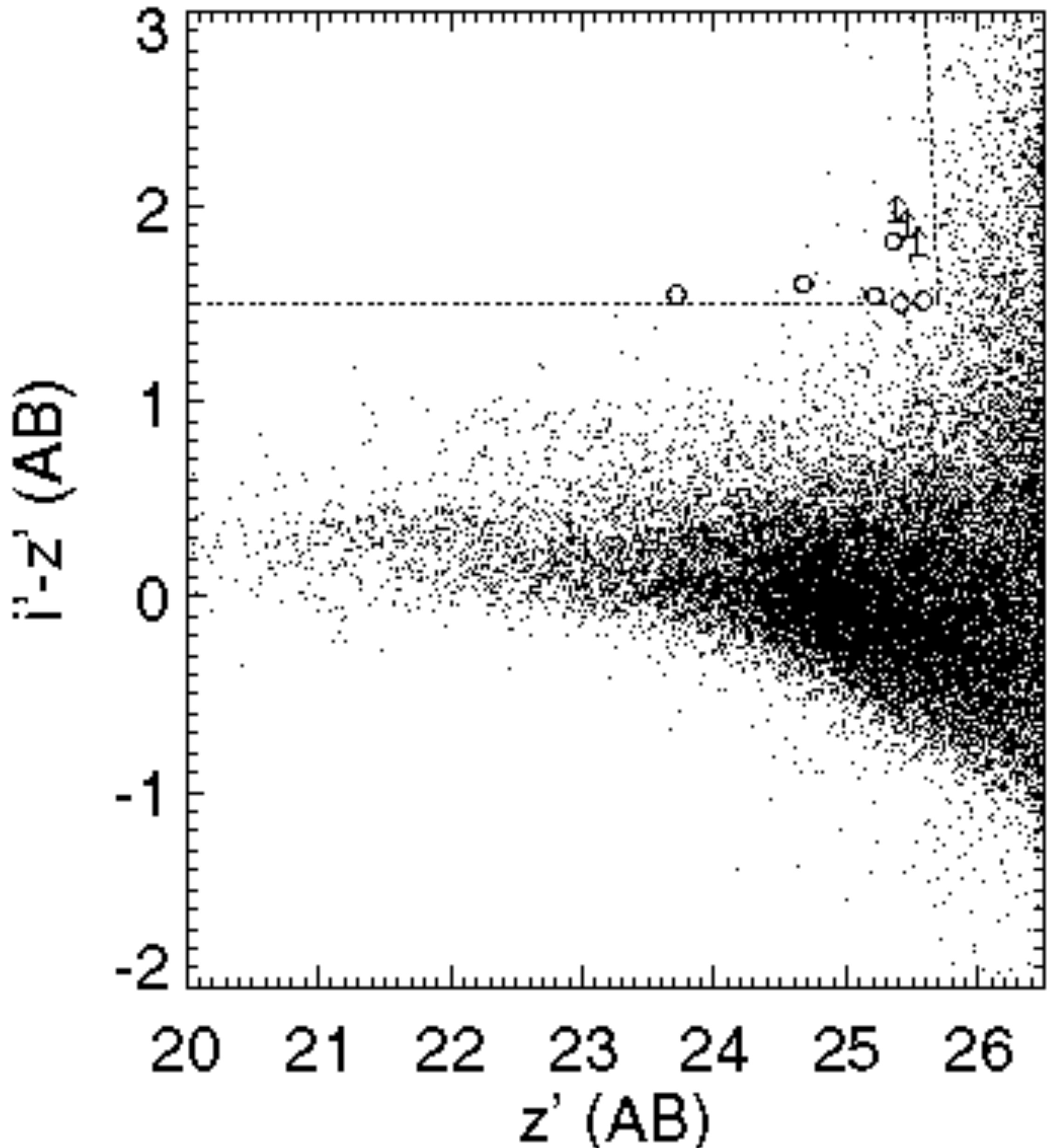
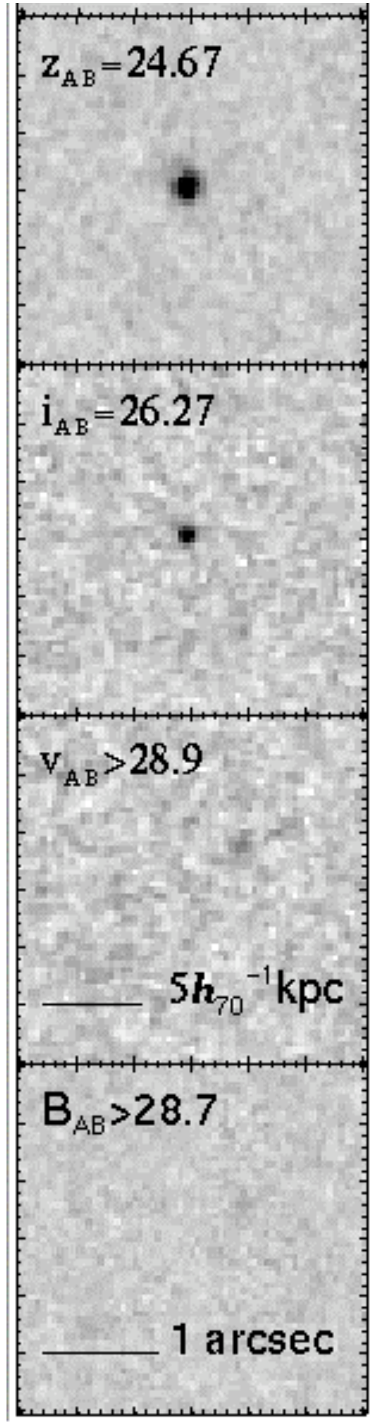
"Lyman break technique" - sharp drop in flux at λ below Ly-α. Steidel et al. have >1000 z~3 objects, "drop" in U-band.

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

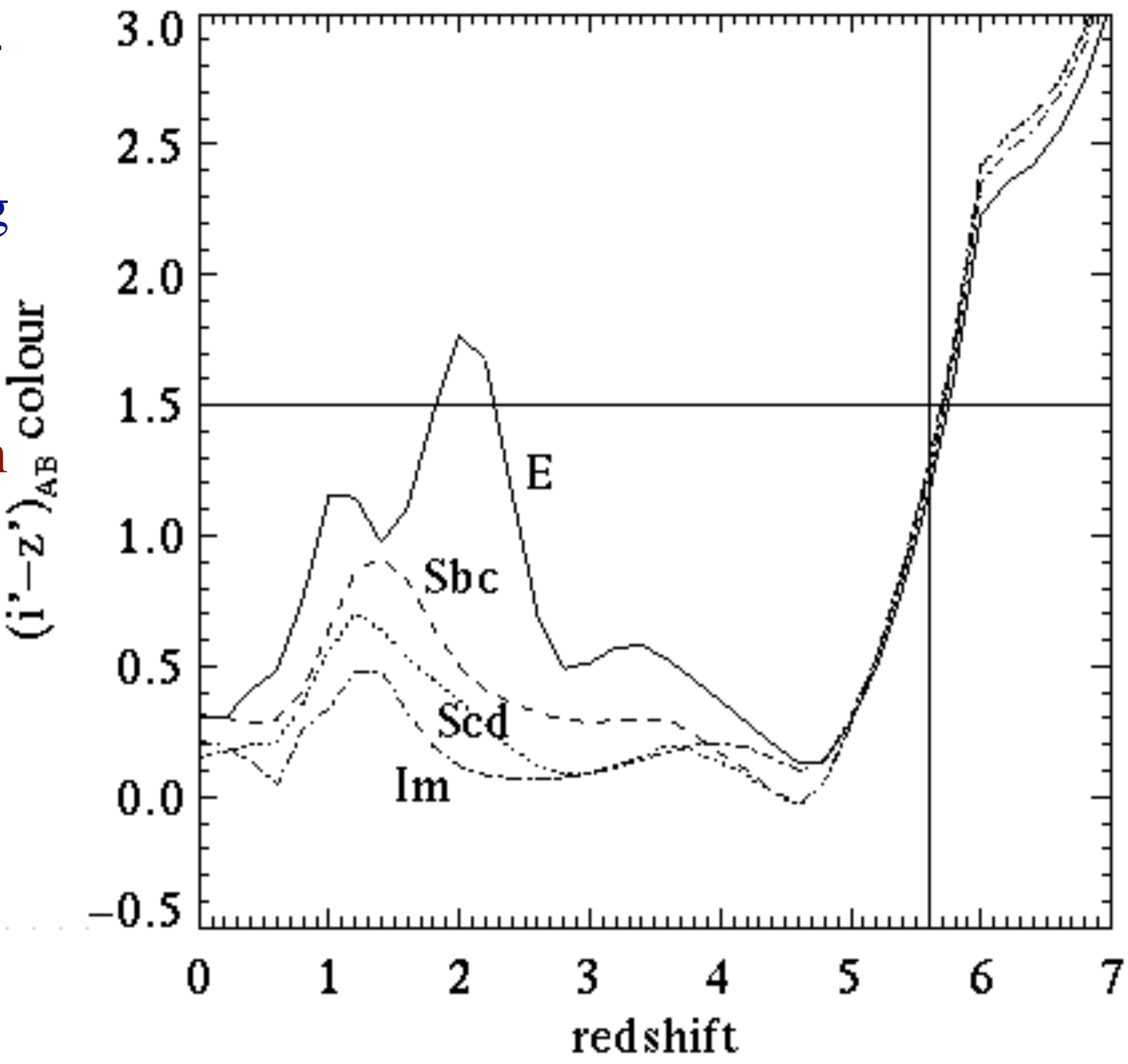






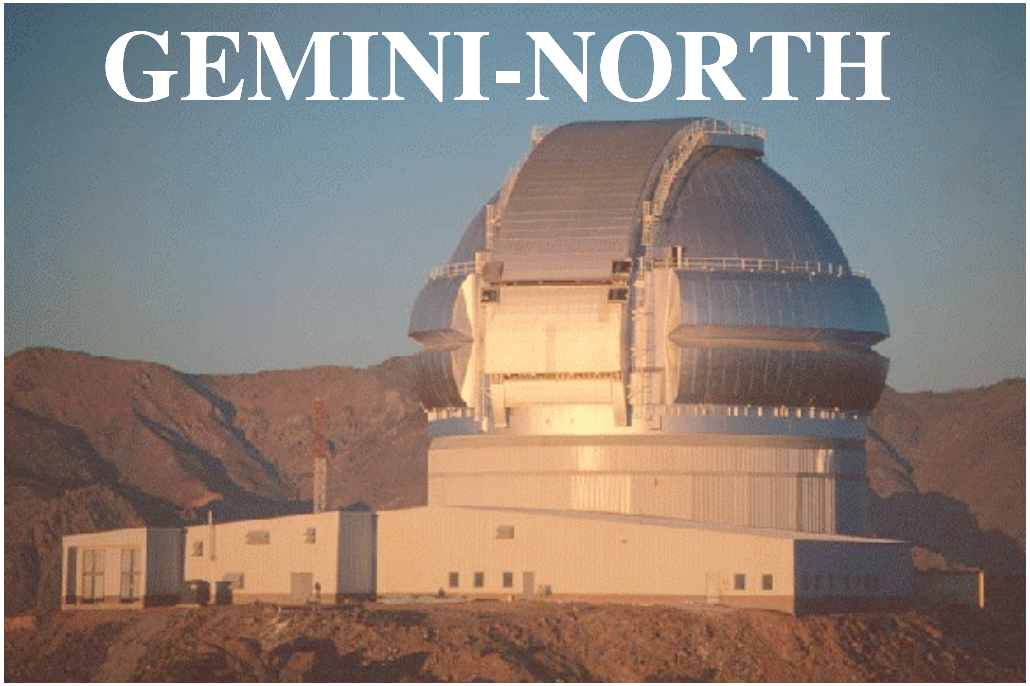
Using HST/ACS GOODS data - CDFS & HDFN, 5 epochs B,v,i',z'

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.



ESO VLTs

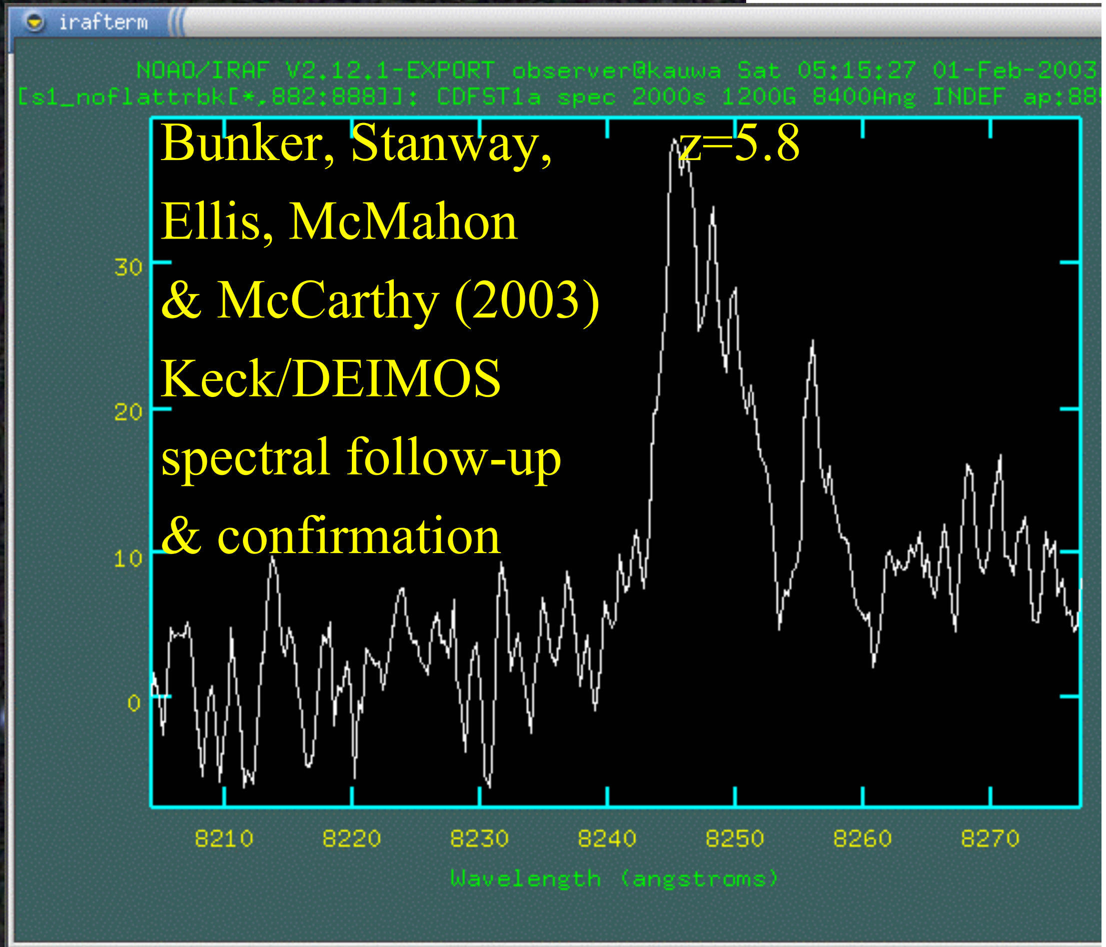
10-m Kecks

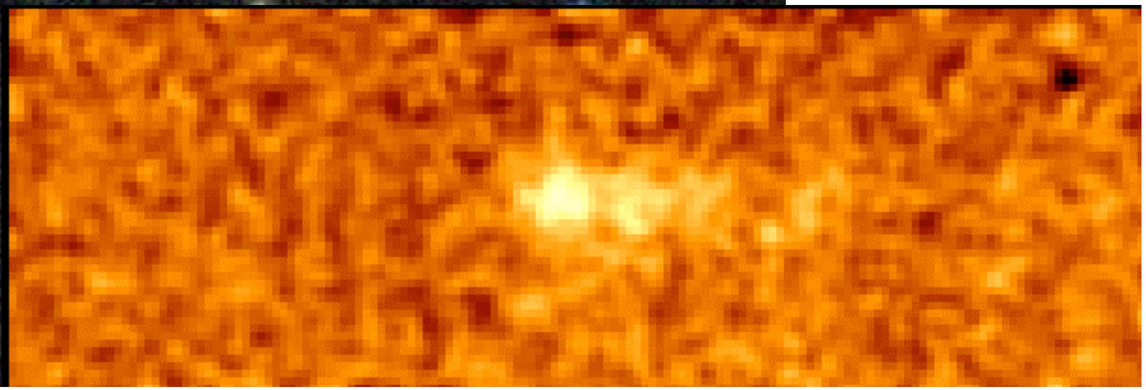

GEMINI-NORTH


GEMINI-SOUTH


Photo © Neelon Crawford/Polar Fine Arts

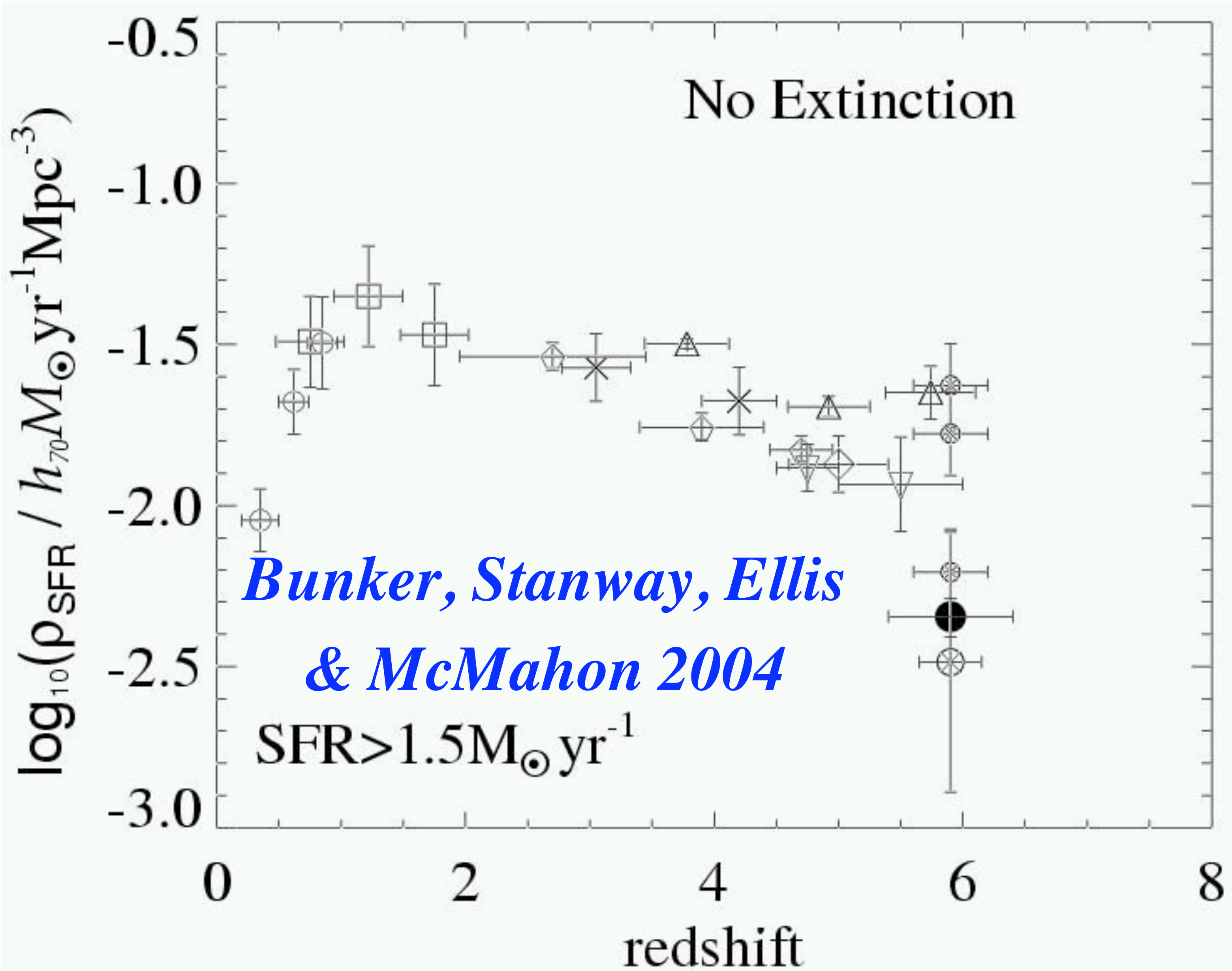
The Star Formation History of the Univese





I-drops in the Chandra Deep Field South with HST/ACS Elizabeth Stanway, Andrew Bunker, Richard McMahon 2003 (MNRAS)

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



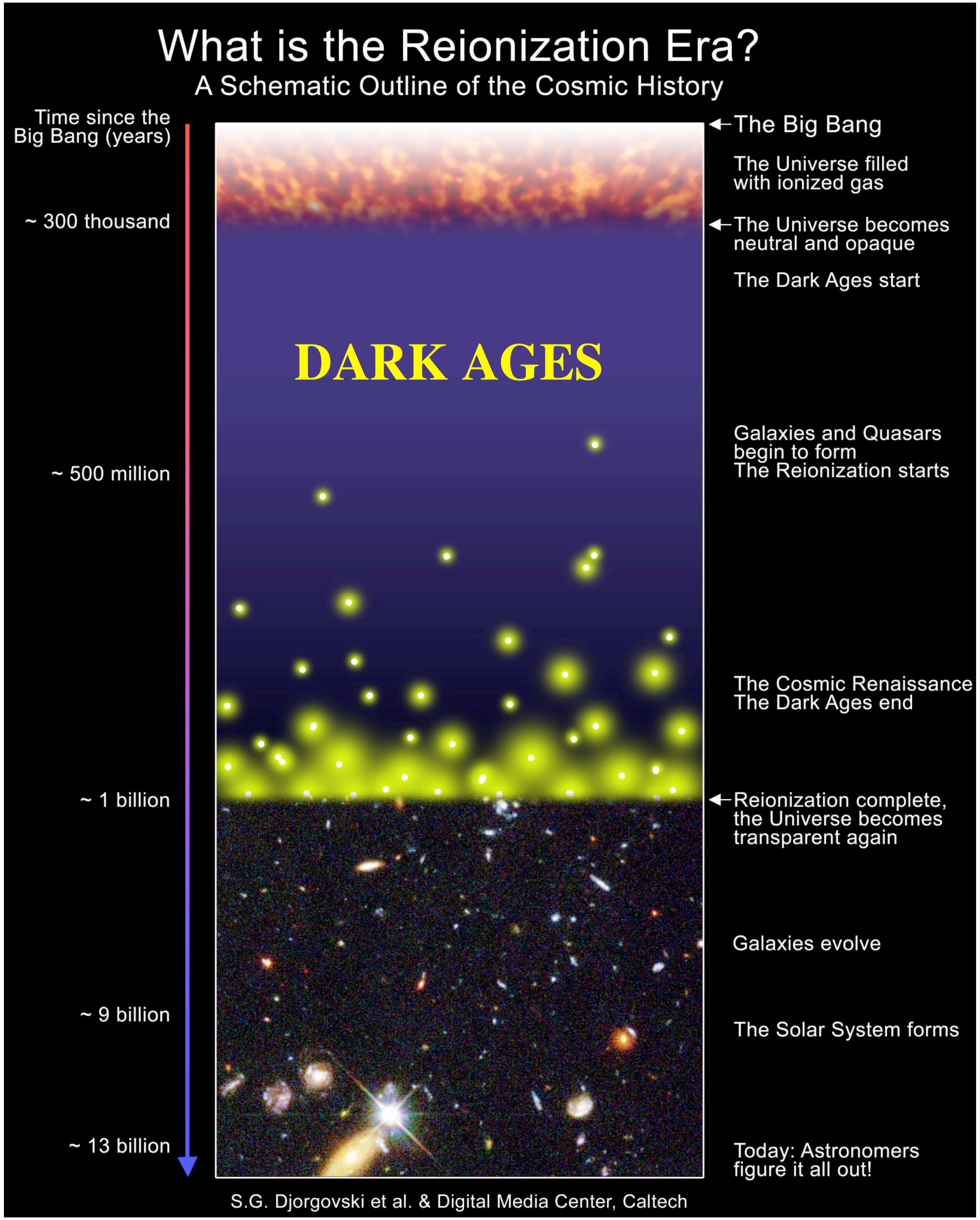
Bunker, Stanway, Ellis & McMahon 2004

After era probed by WMAP 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

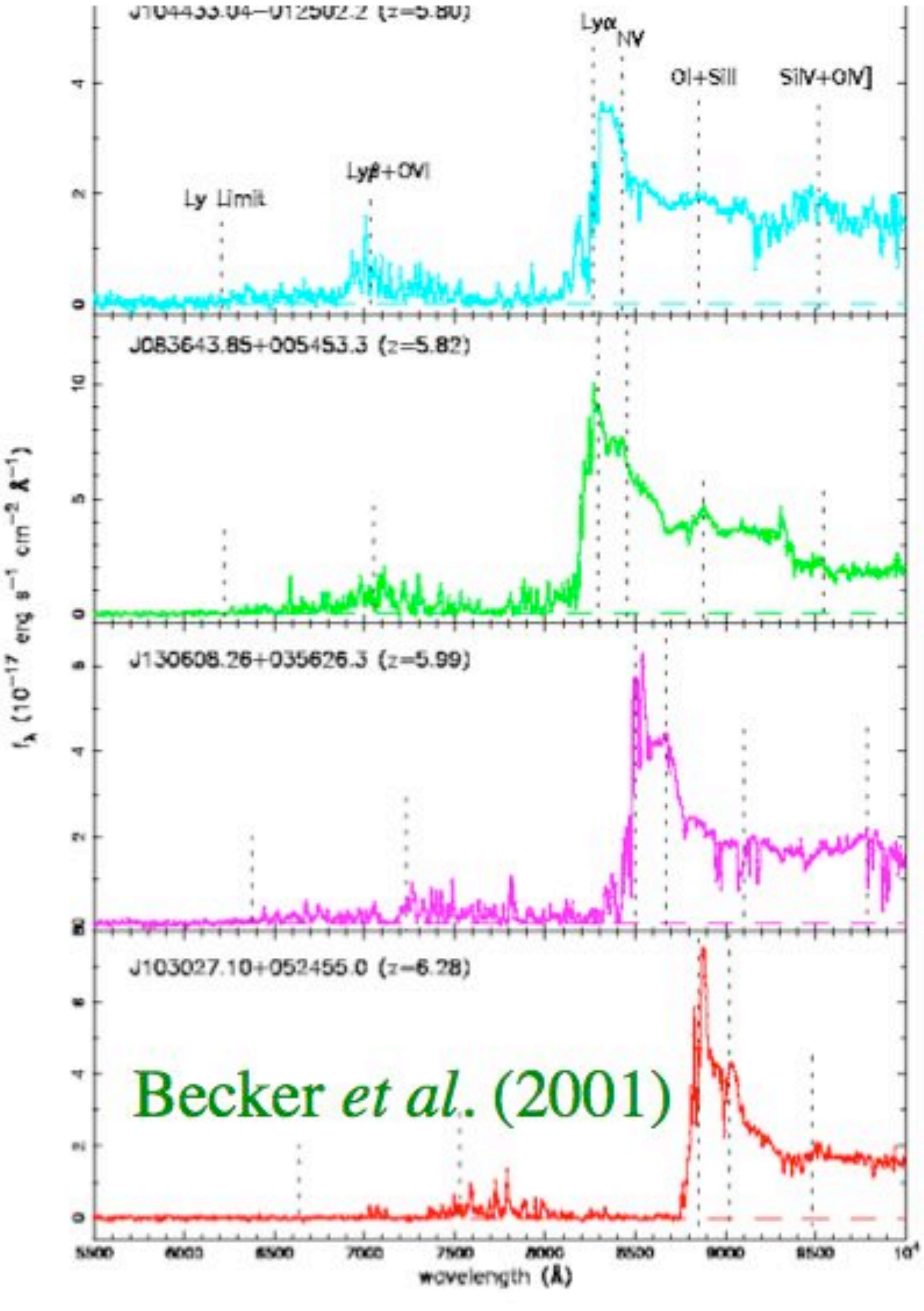
1100

10

5

2

0



Reionization

At high-redshift, the Lyman-α forest can absorb most of the flux below λ_{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)

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).

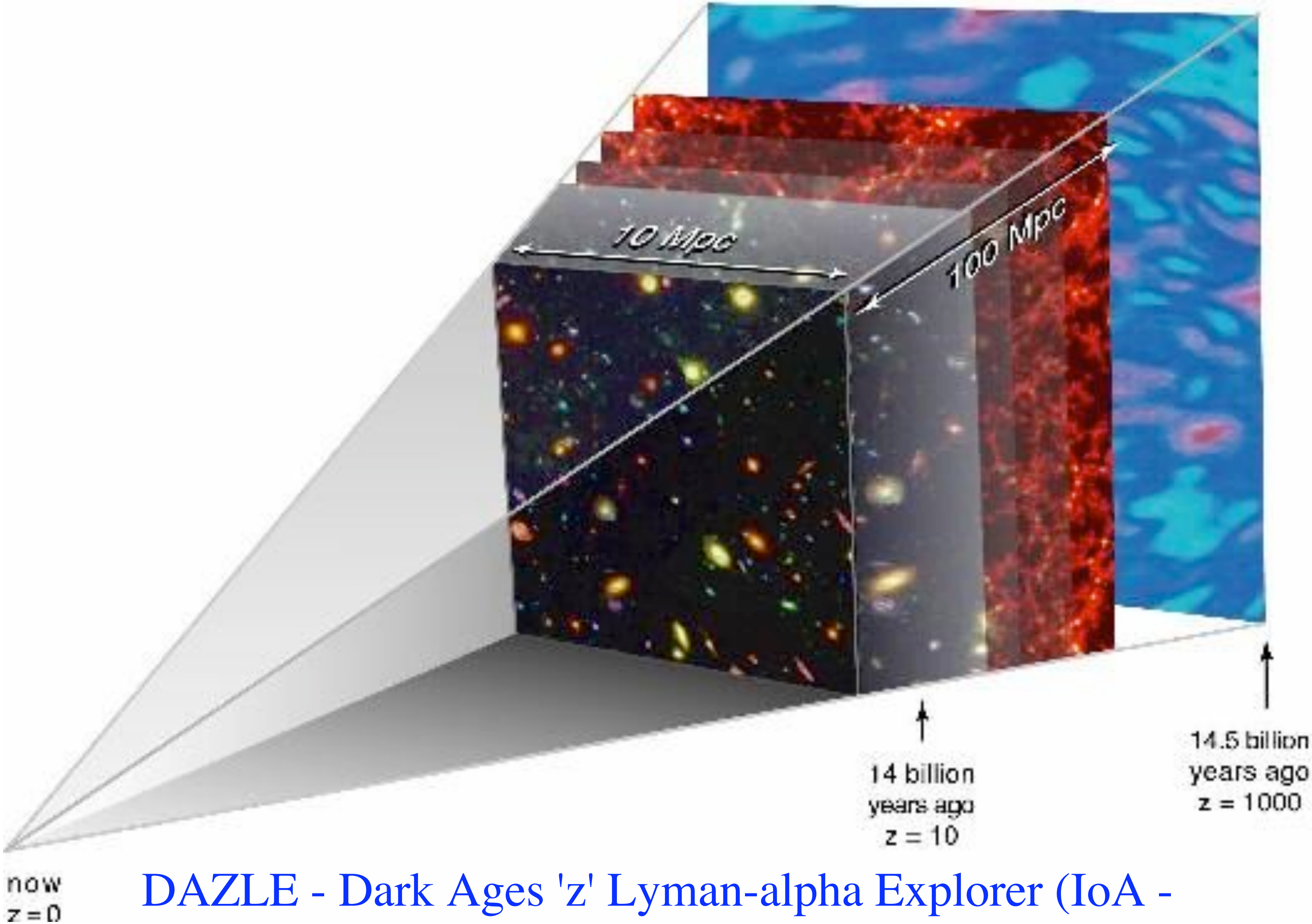
This assumes escape fraction=1 (i.e. all ionzing photons make it out of the galaxies)

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 α (lots of low luminosity sources - forming globulars?)

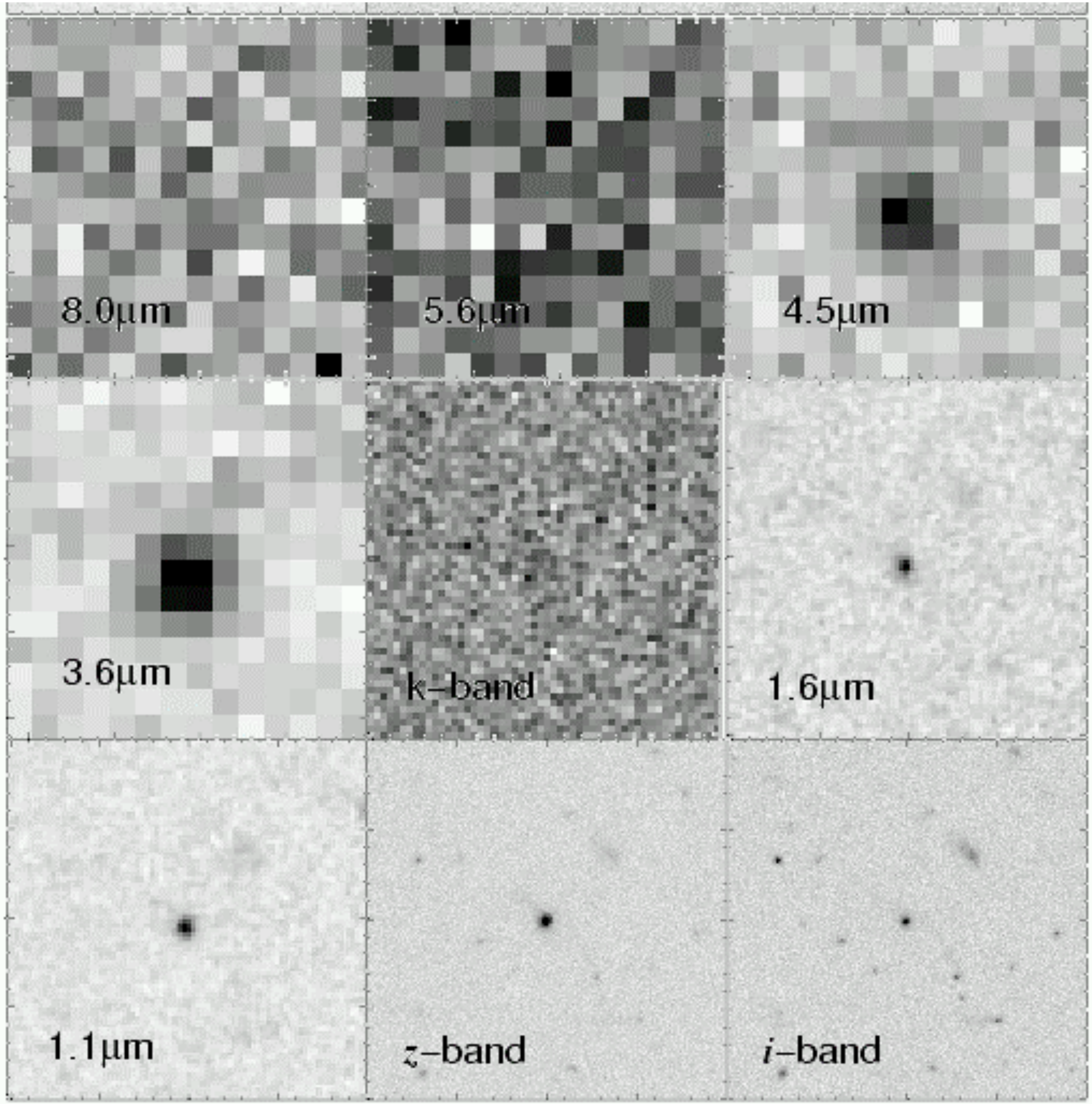
Ways out of the Puzzle

- Cosmic variance
- Star formation at even earlier epochs to reionize Universe (z>>6)?
- Change the physics: different recipe for star formation (Initial mass function)?
- Even fainter galaxies than we can reach with the UDF?

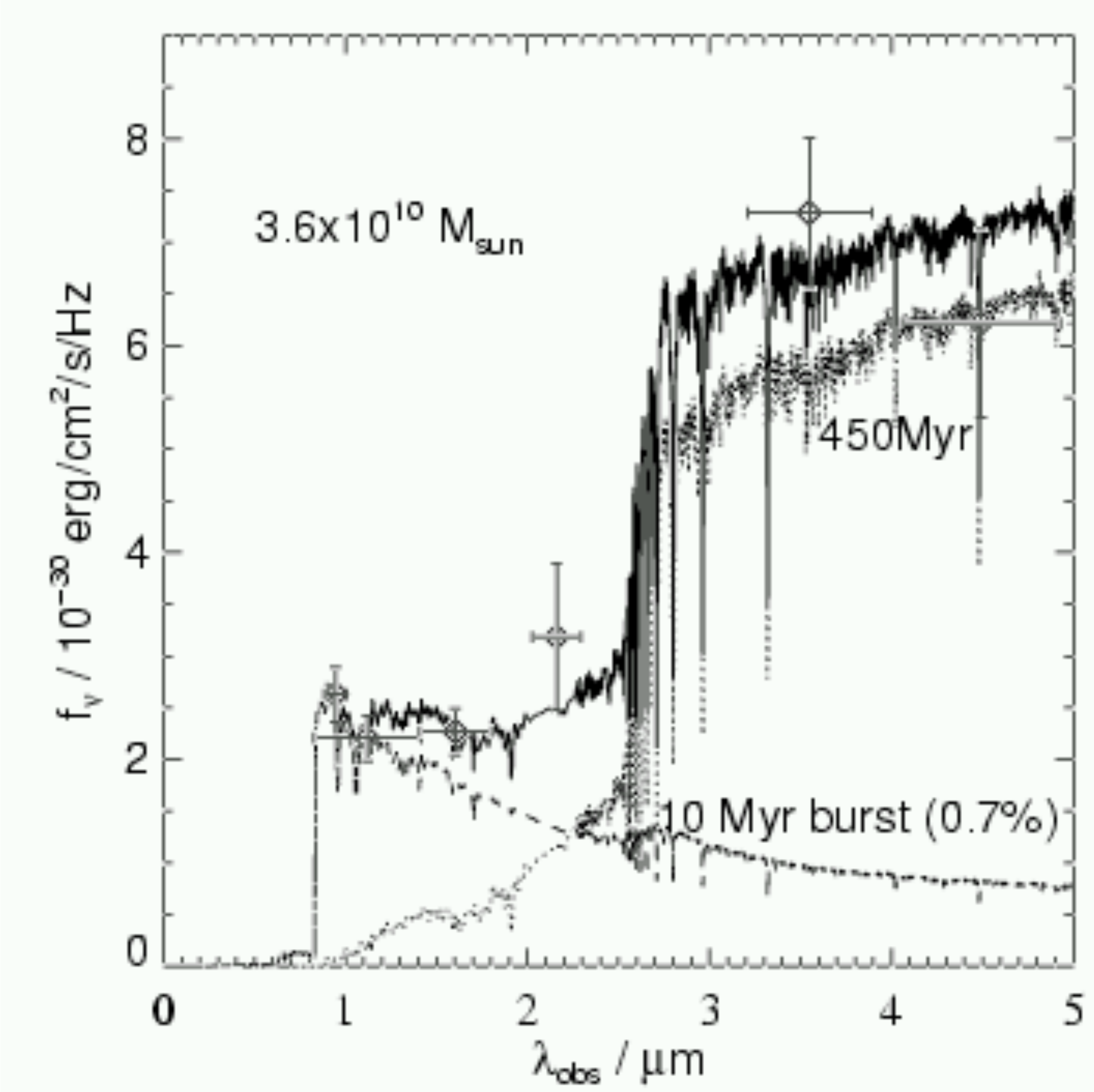


DAZLE - Dark Ages 'z' Lyman-alpha Explorer (IoA - Richard McMahon, Ian Parry; AAO - Joss Bland-Hawthorne

Spitzer – IRAC (3.6-8.0 microns)

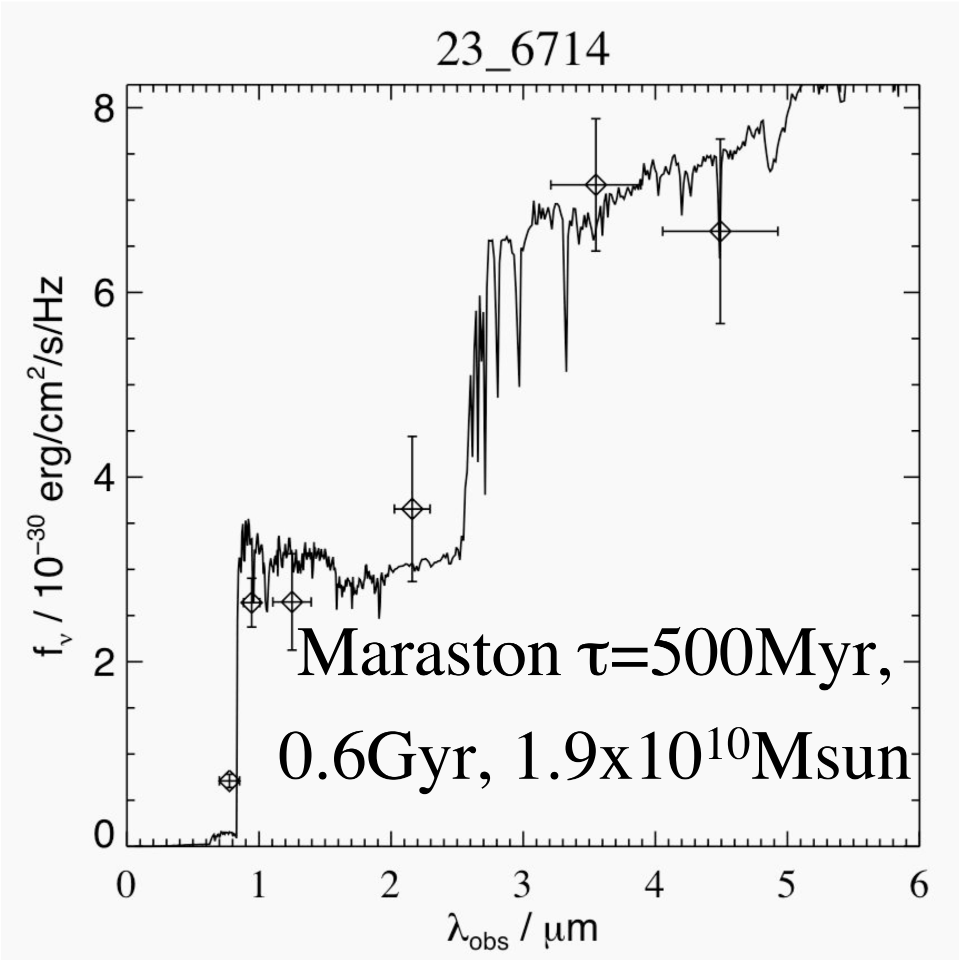


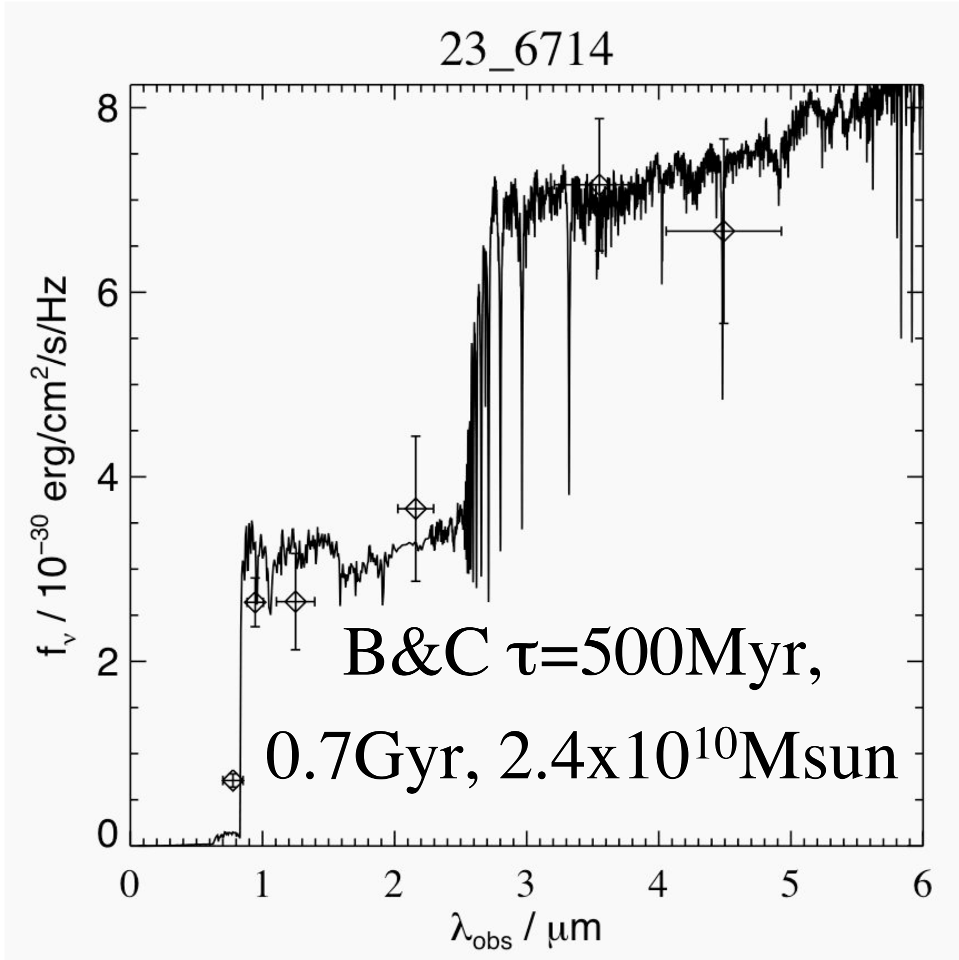
- z=5.83 galaxy #1 from Stanway, Bunker & McMahon 2003 (spec conf from Stanway et al. 2004, Dickinson et al. 2004). Detected in GOODS IRAC 3-4μm: Eyles, Bunker, Stanway et al.



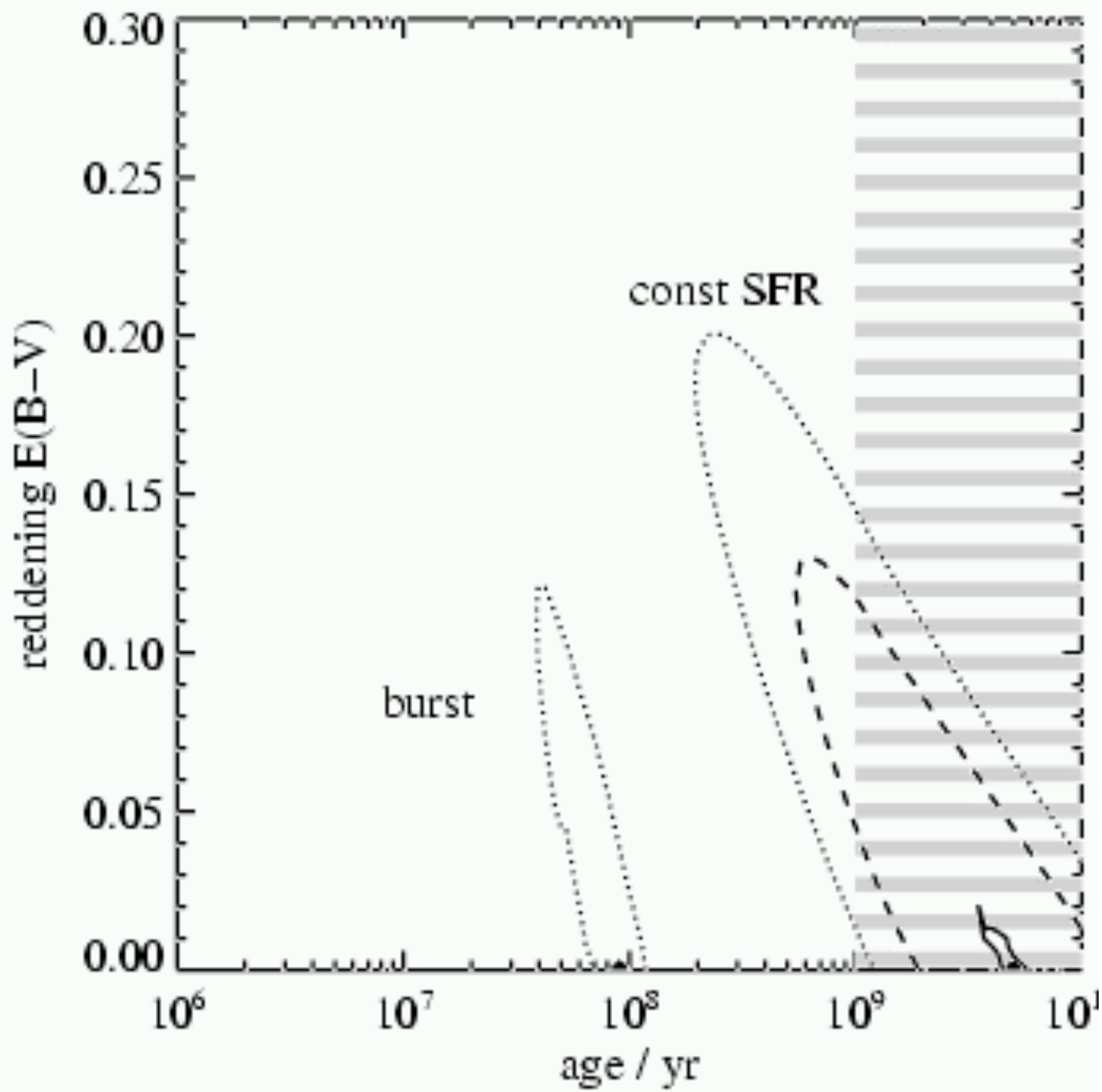
3.6x10^10 M_sun
450Myr
10 Myr burst (0.7%)
f_ν / 10^-30 erg/cm²/s/Hz
λ_obs / μm
0
2
4
6
8
0
1
2
3
4
5

Other Population Synthesis Models





Maraston vs. Bruzual & Charlot



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
10^1
age / yr

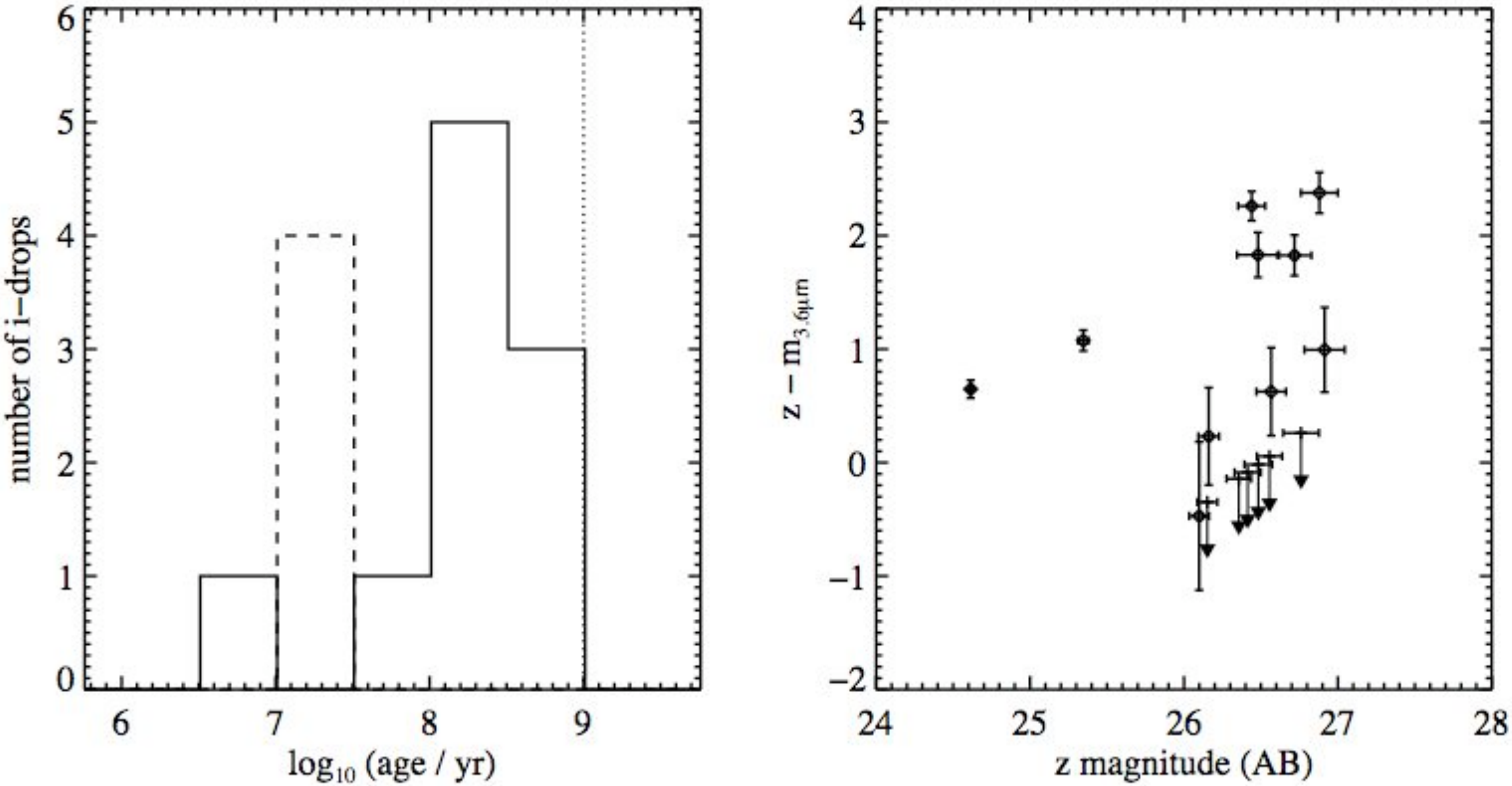
-Have shown that some z=6 I-drops have old stars & large masses (see also talk by H. Yan)

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

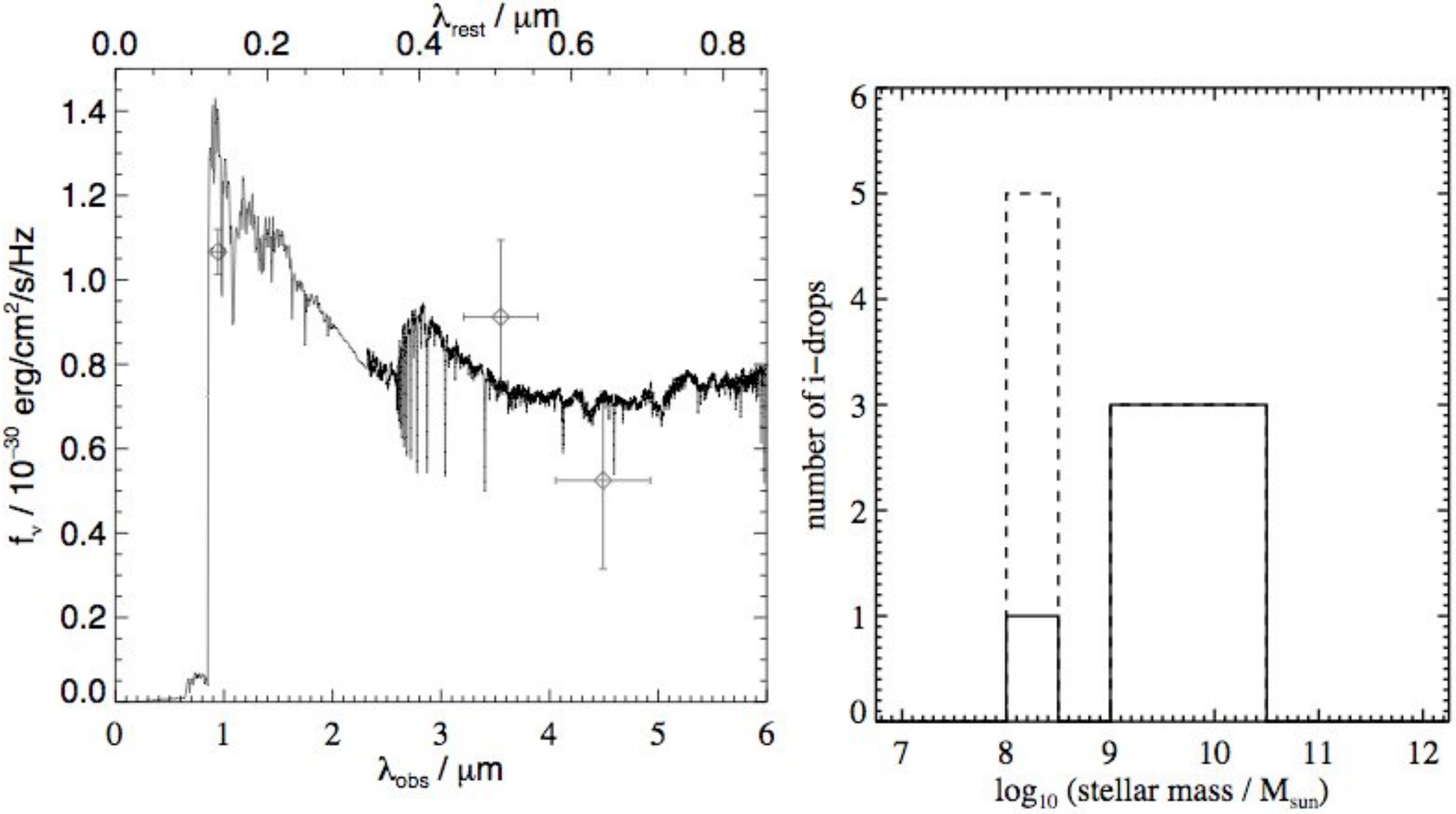
-Turn now to larger samples, to provide stellar mass density in first Gyr with Spitzer

-- In Stark, Bunker, Ellis et al. (2007) we look at v-drops (z~5) in the GOODS-South

-- In Eyles, Bunker, Ellis et al. (2007) we survey all the GOODS-S I-drops with Spitzer



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



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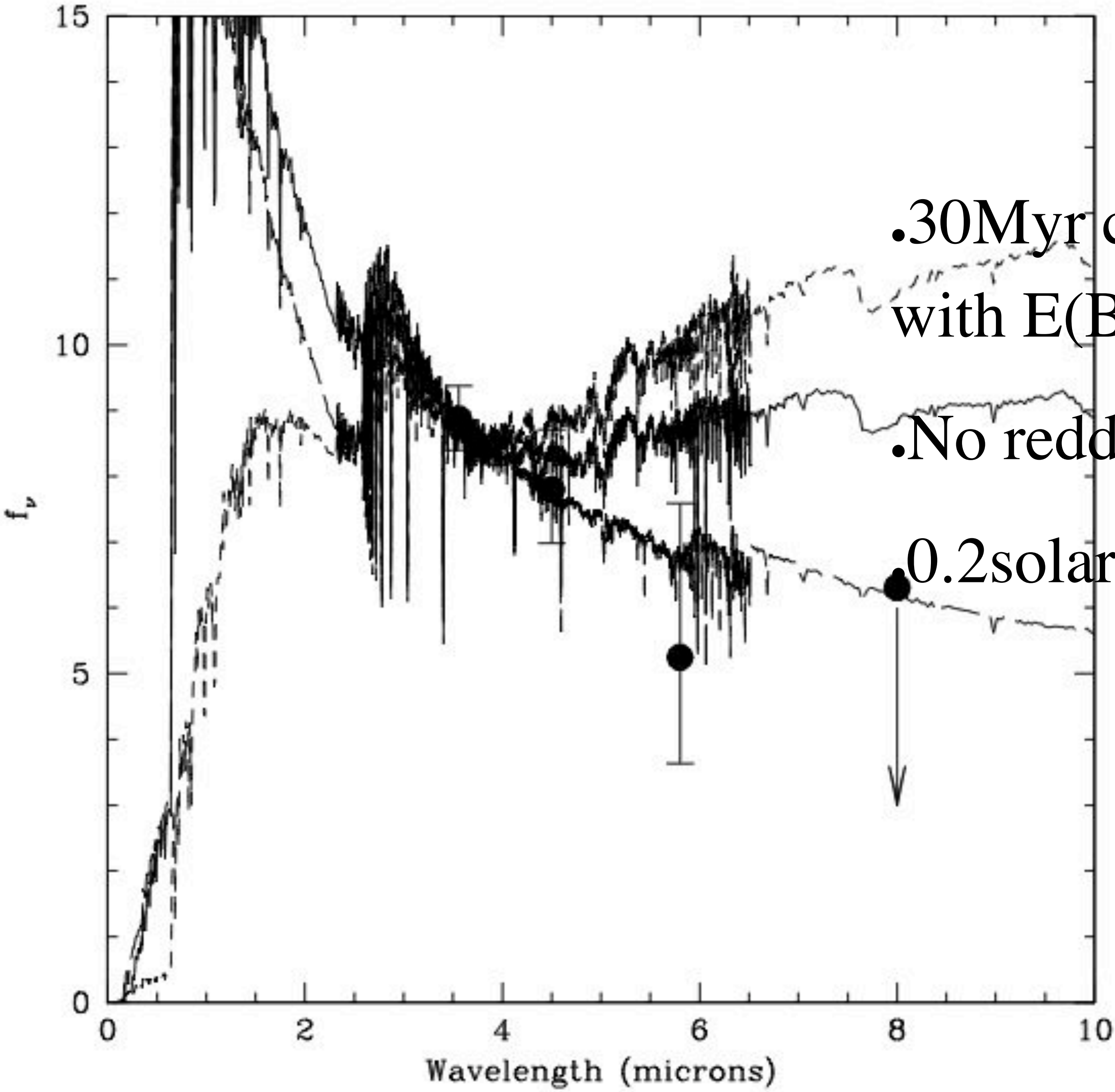
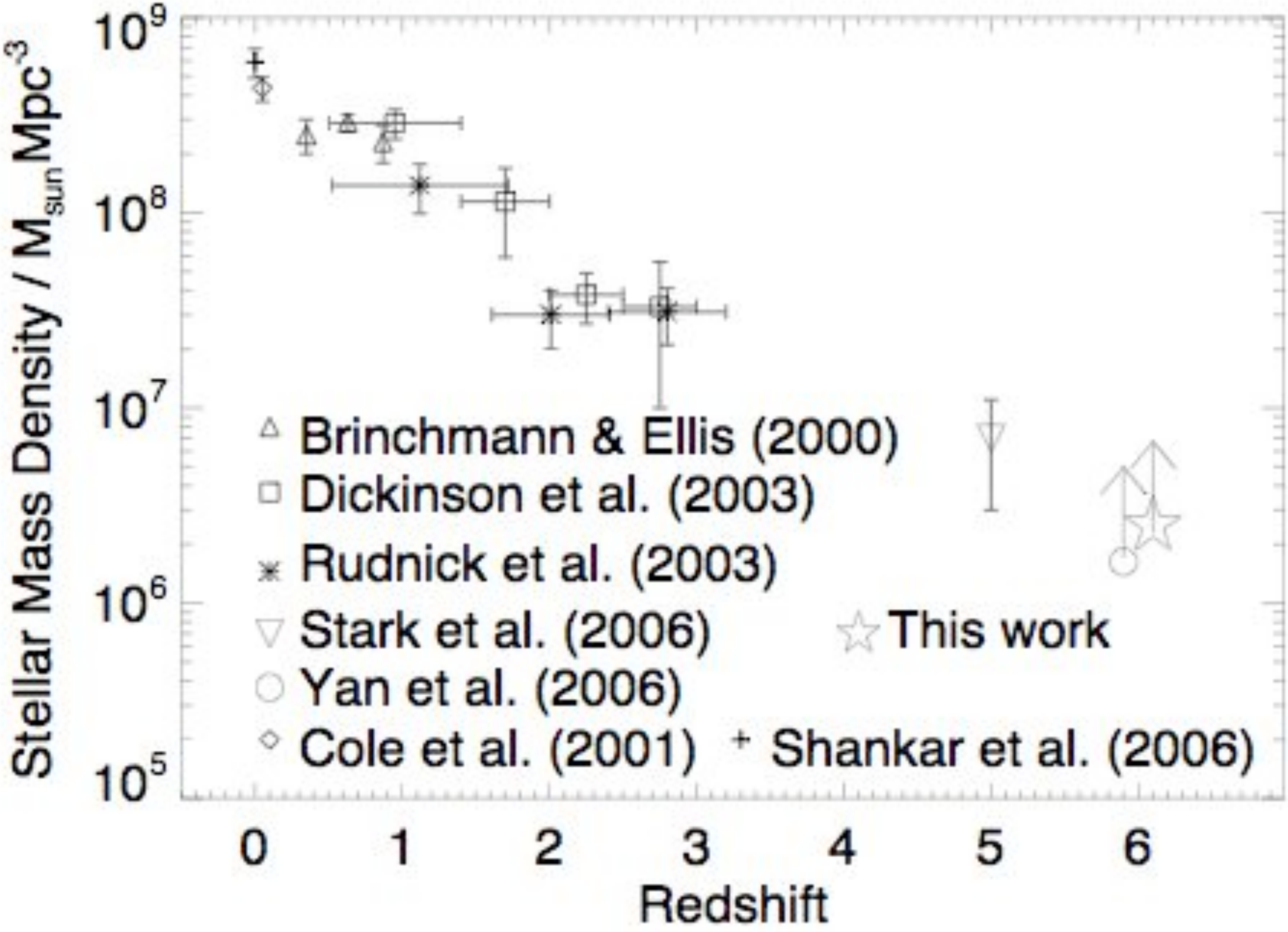
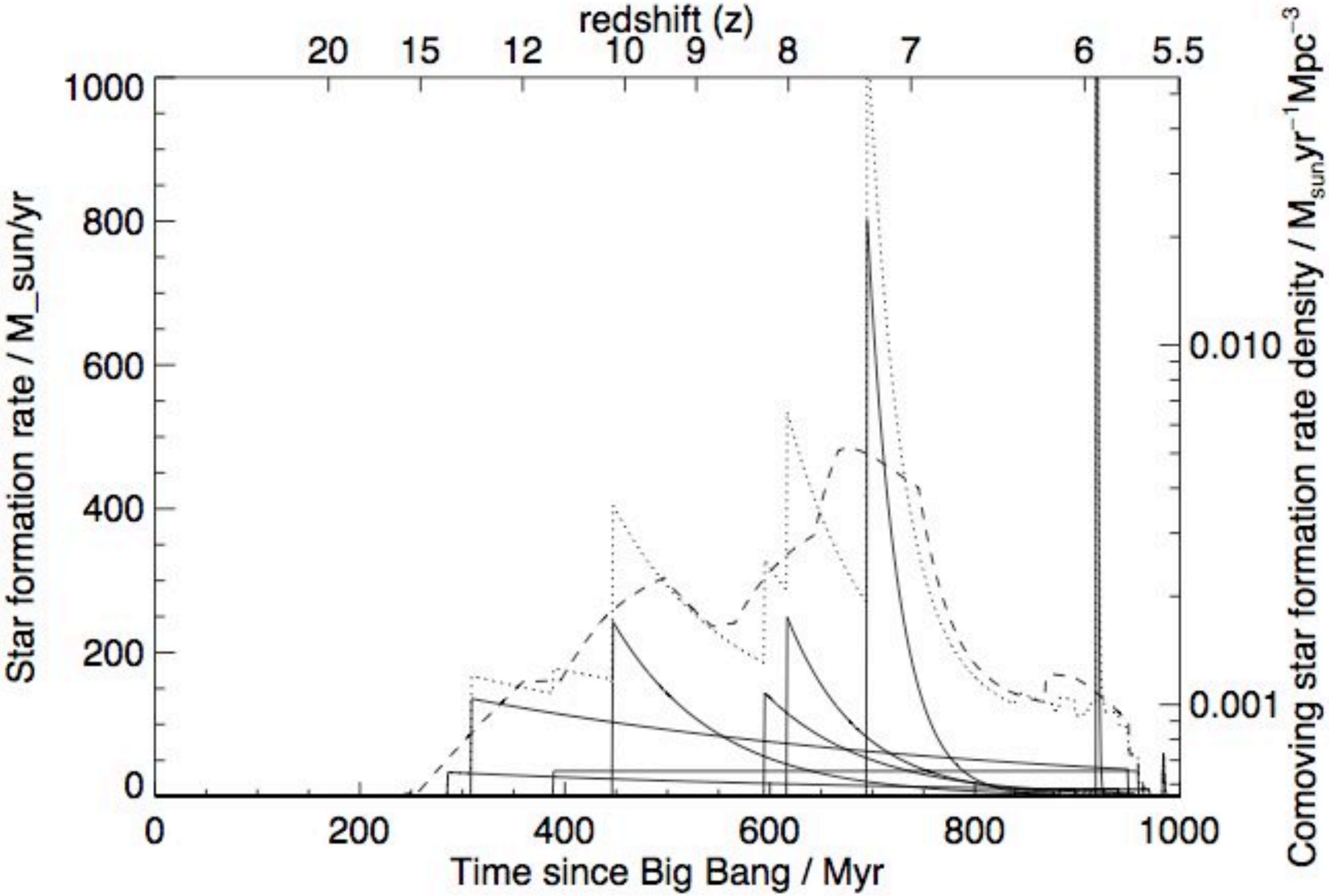


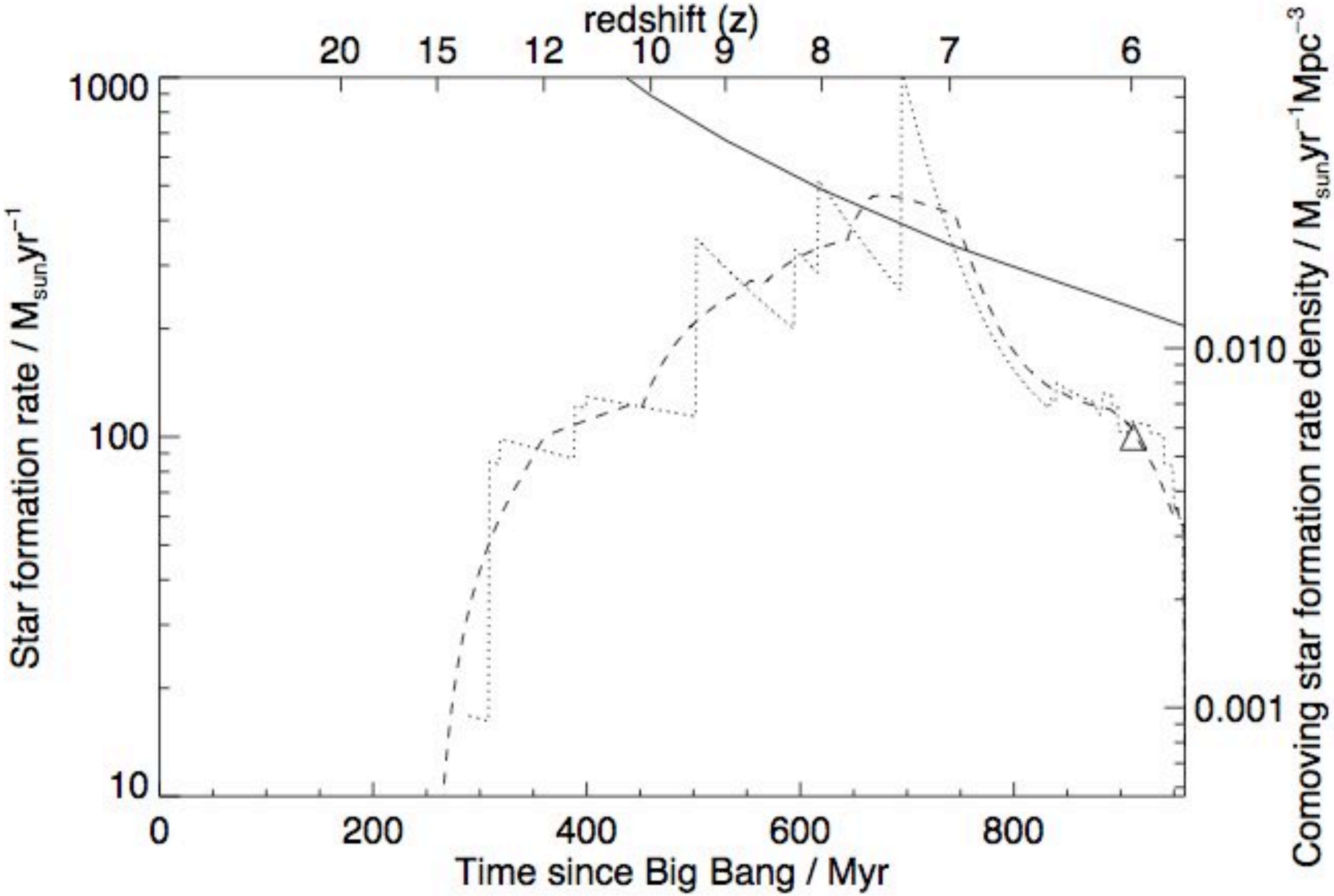
- 30Myr const SFR with E(B-V)=0.1
- No reddening
- 0.2solar metallicity



Stellar Mass Density / M_{sun} Mpc^3
10^9
10^8
10^7
10^6
10^5
0
1
2
3
4
5
6
Redshift
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)



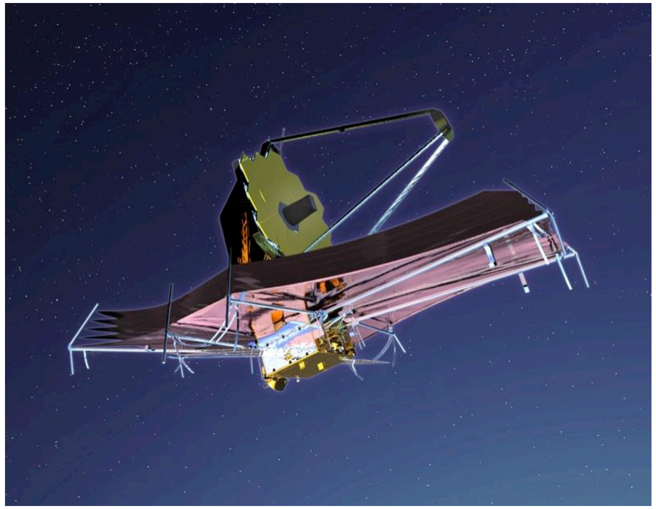
Eyles, Bunker, Ellis et al. astro-ph/0607306



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

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

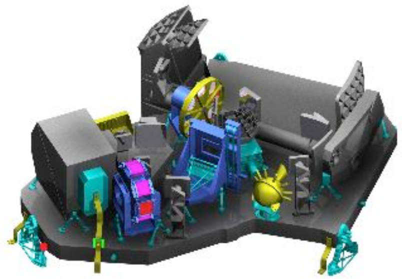
What is JWST?



- 6.55 m deployable primary
- Diffraction-limited at 2 μm
- Wavelength range 0.6-28 μm
- Passively cooled to <50 K
- Zodiacal-limited below 10 μm
- Sun-Earth L2 orbit
- 4 instruments
  - 0.6-5 μm wide field camera (NIRCam)
  - 1-5 μm multiobject spectrometer (NIRSpec)
  - 5-28 μm camera/spectrometer (MIRI)
  - 0.8-5 μm guider camera (FGS/TF)
- 5 year lifetime, 10 year goal
- 2014 launch

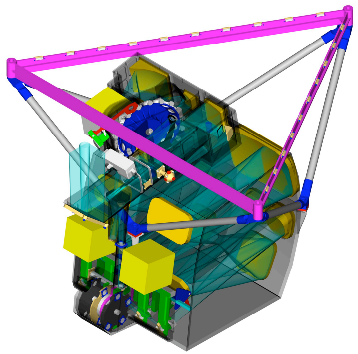
ESA Contributions to JWST

NIRSpec



- ESA Provided
- Detector & MEMS Arrays from NASA

MIRI Optics Module



- ESA Member State Consortium
- Detector & Cooler/Cryostat from NASA

Ariane V Launcher (ECA)

(closely similar to HST model…)

JWST NIRSpec IST (ESA)

Conclusions

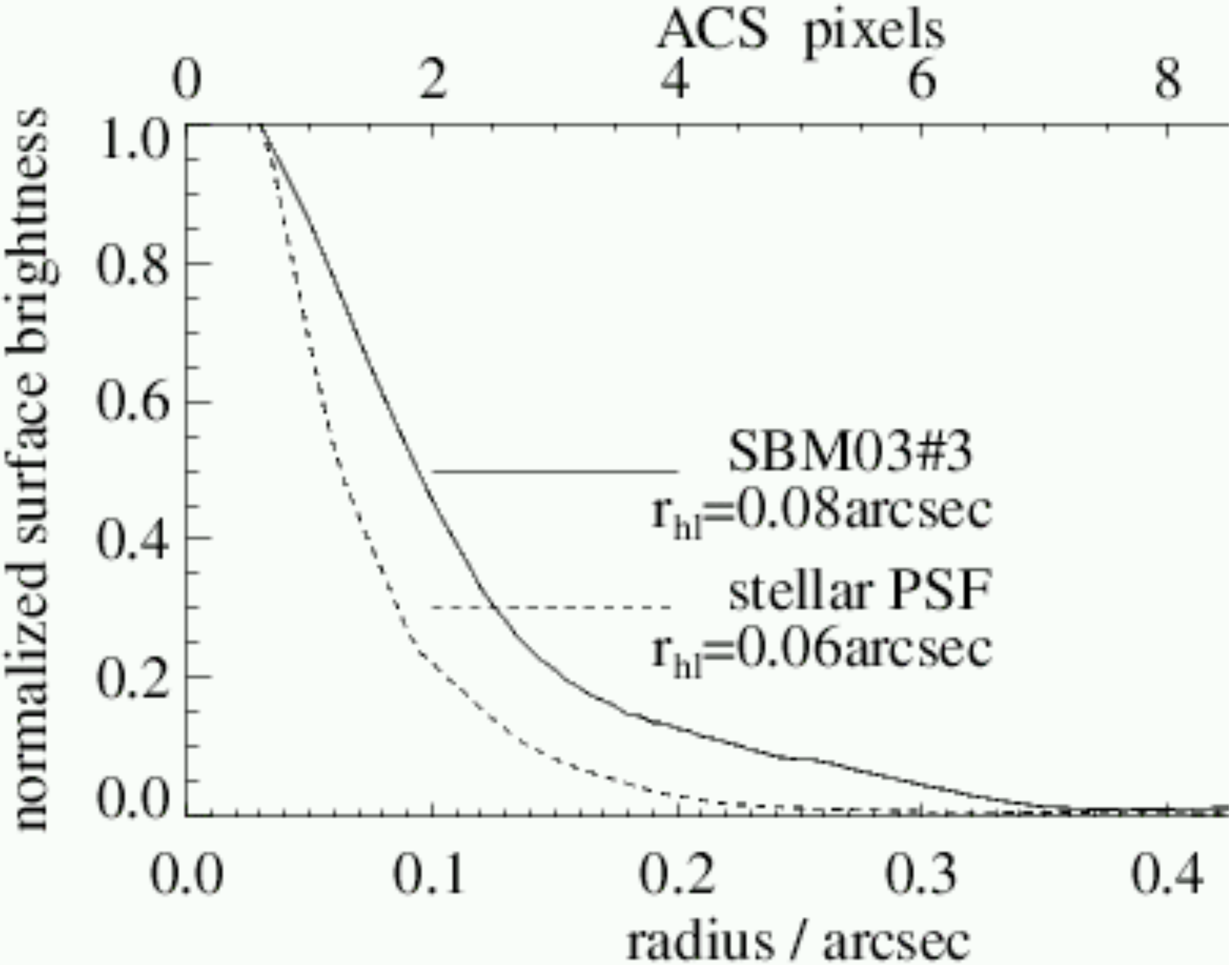
-Large fraction (40%) have evidence for substantial Balmer/4000 Ang spectral breaks (old underlying stellar populations that dominate the stellar masses).

- For these, we find ages of ~200−700Myr, implying formation redshifts of $7<z(\mathrm{form})<18$, and stellar masses ~ $1-3\times10^{10} M_{\odot}$.

- Analysis of I-drops undetected at 3.6μm indicates these are younger, considerably less massive systems.

- Emission line contamination does not seriously affect the derived ages and masses.

- Using the fossil record shows that at $z>8$ the UV flux from these galaxies may have played a key role in reionizing the Universe



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