Star-Forming Galaxies at z>5 & Reionization

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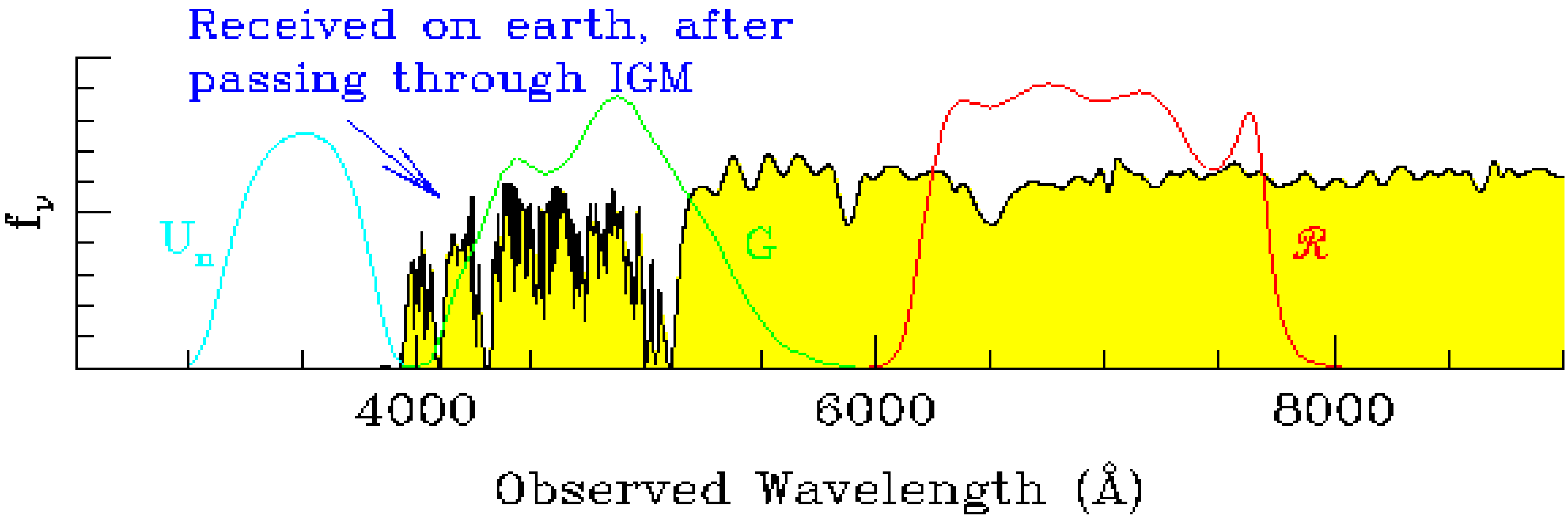
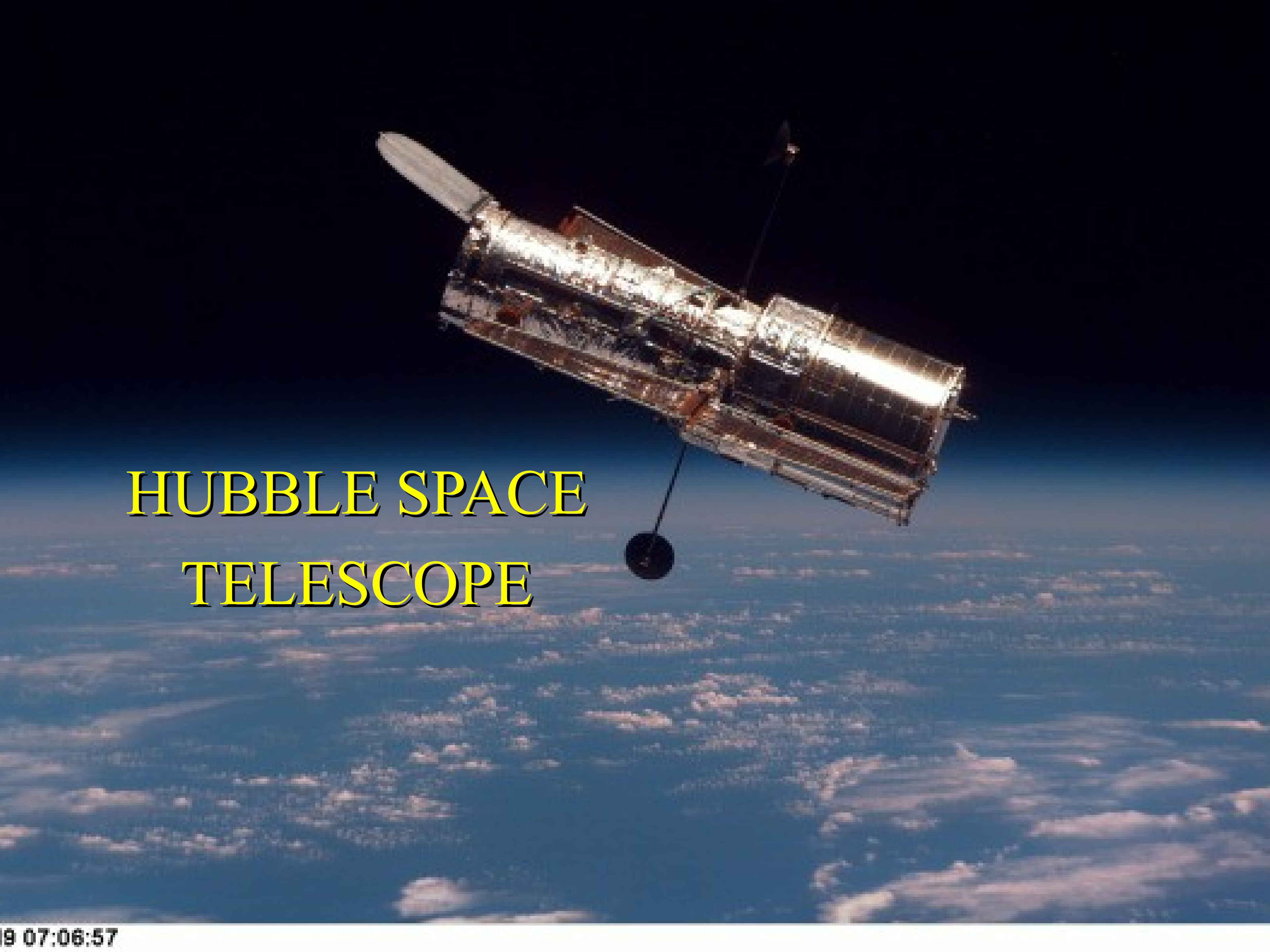


"Lyman break technique" - sharp drop in flux at below Ly- . Steidel et al. have >1000 z~3 objects, "drop" in U-band.


HUBBLE SPACE
TELESCOPE
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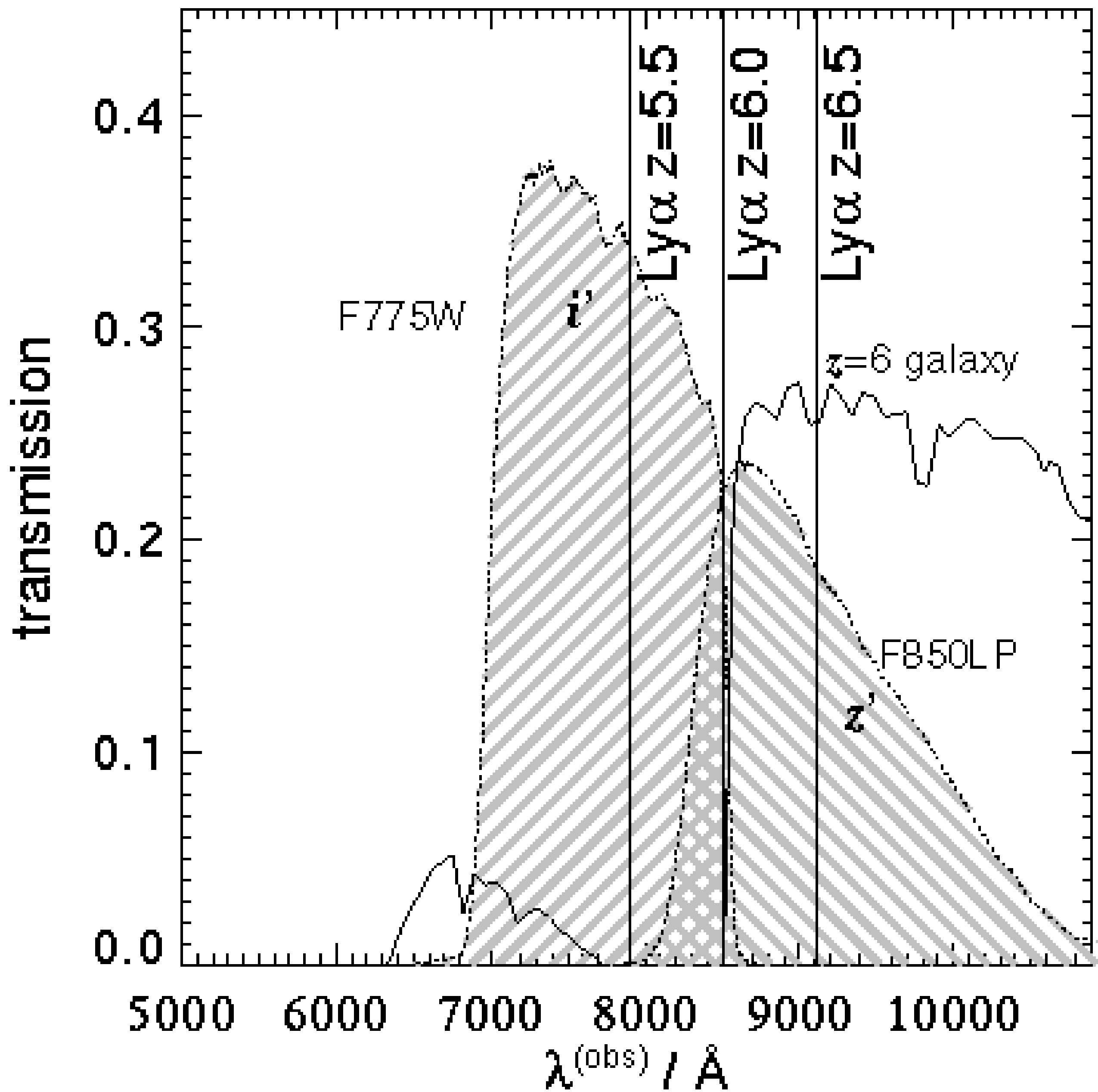
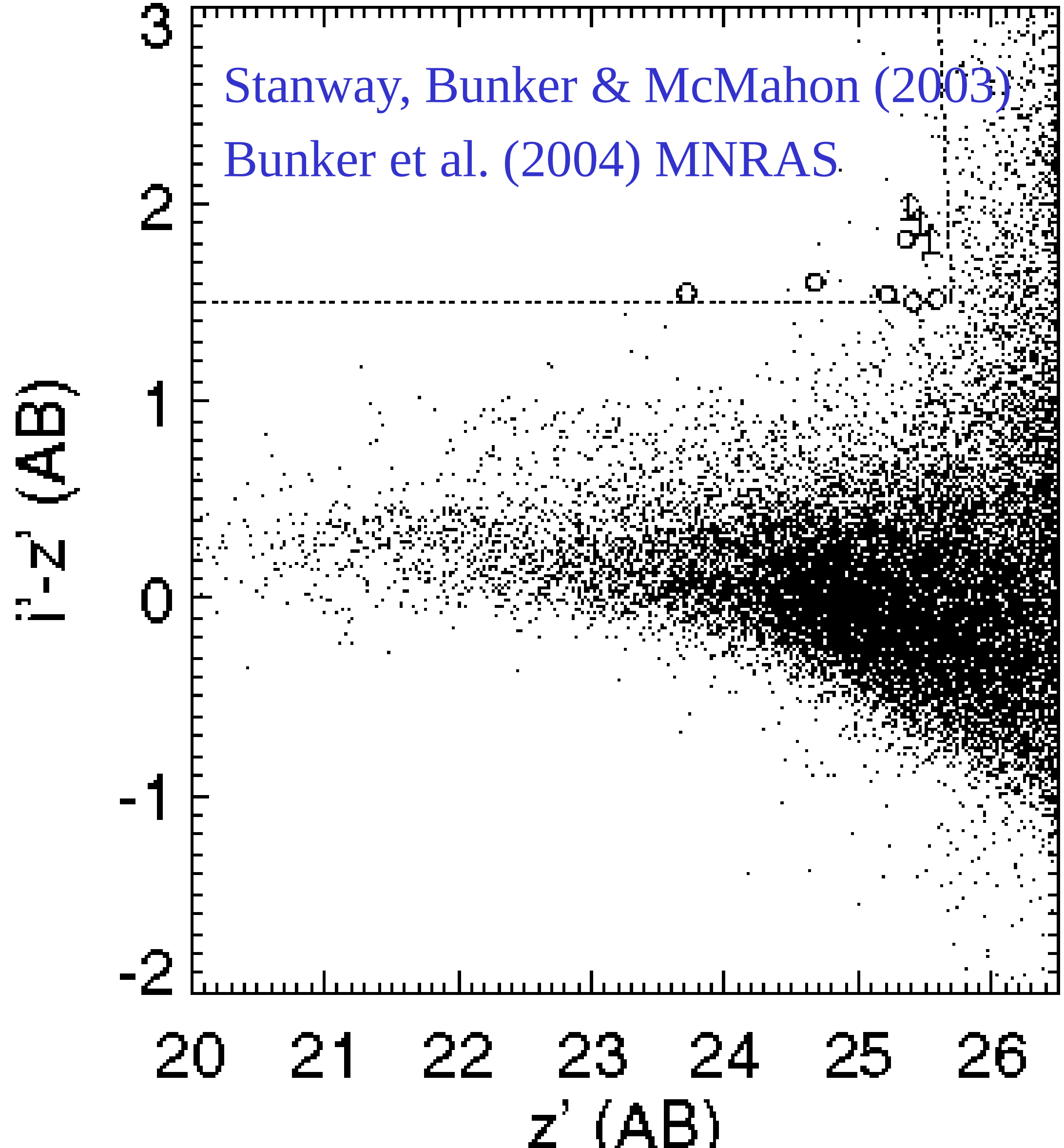
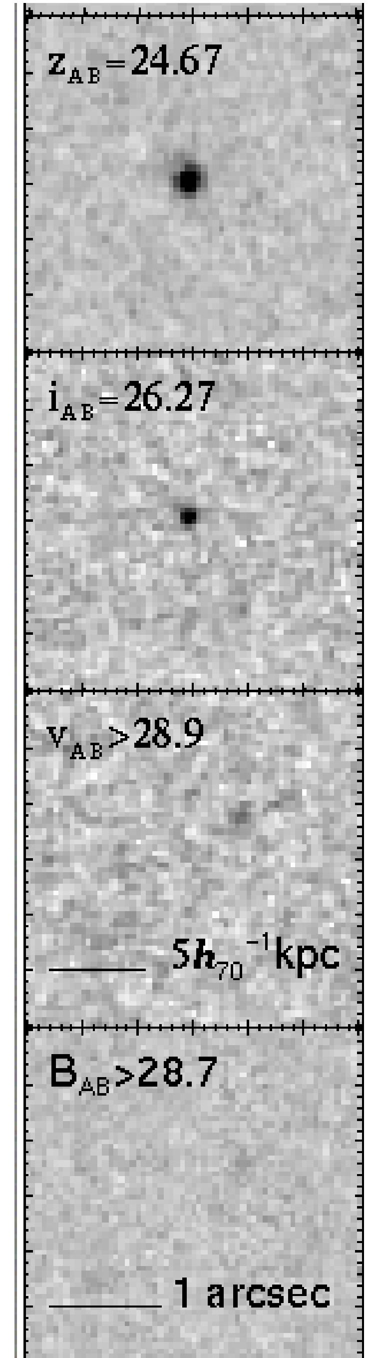
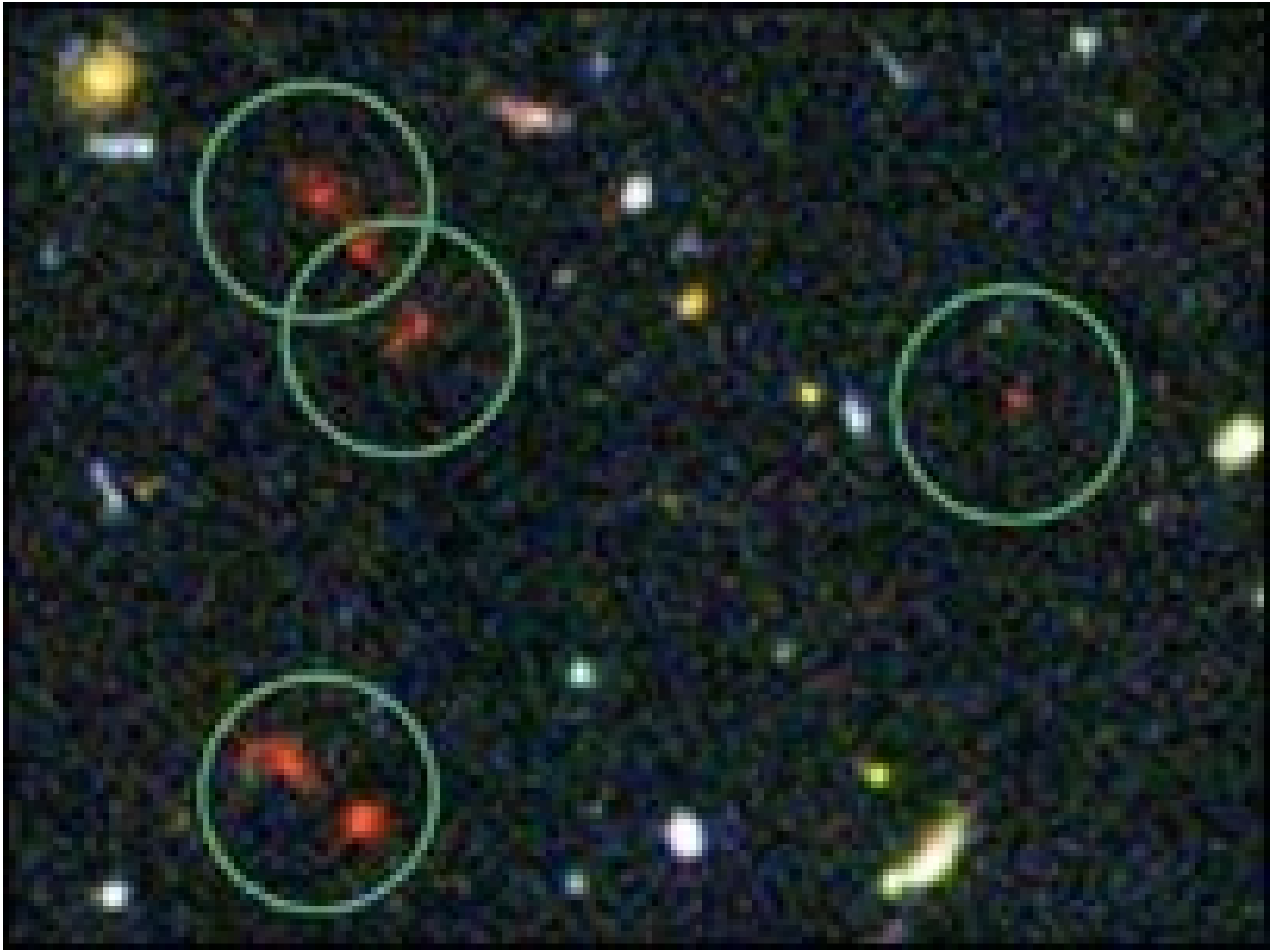
Pushing to higher redshift- Finding Lyman break galaxies at z~6 : using *i*-drops, enabled by HST/ACS (Stanway et al 2003, Bunker et al 2004, Bouwens et al 2004)

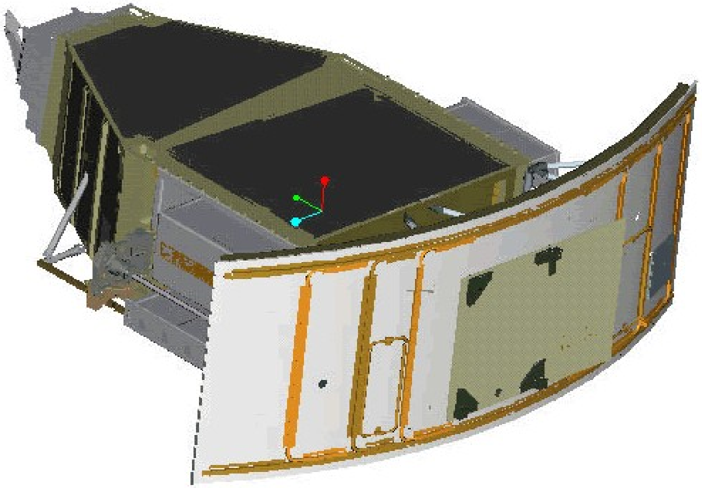




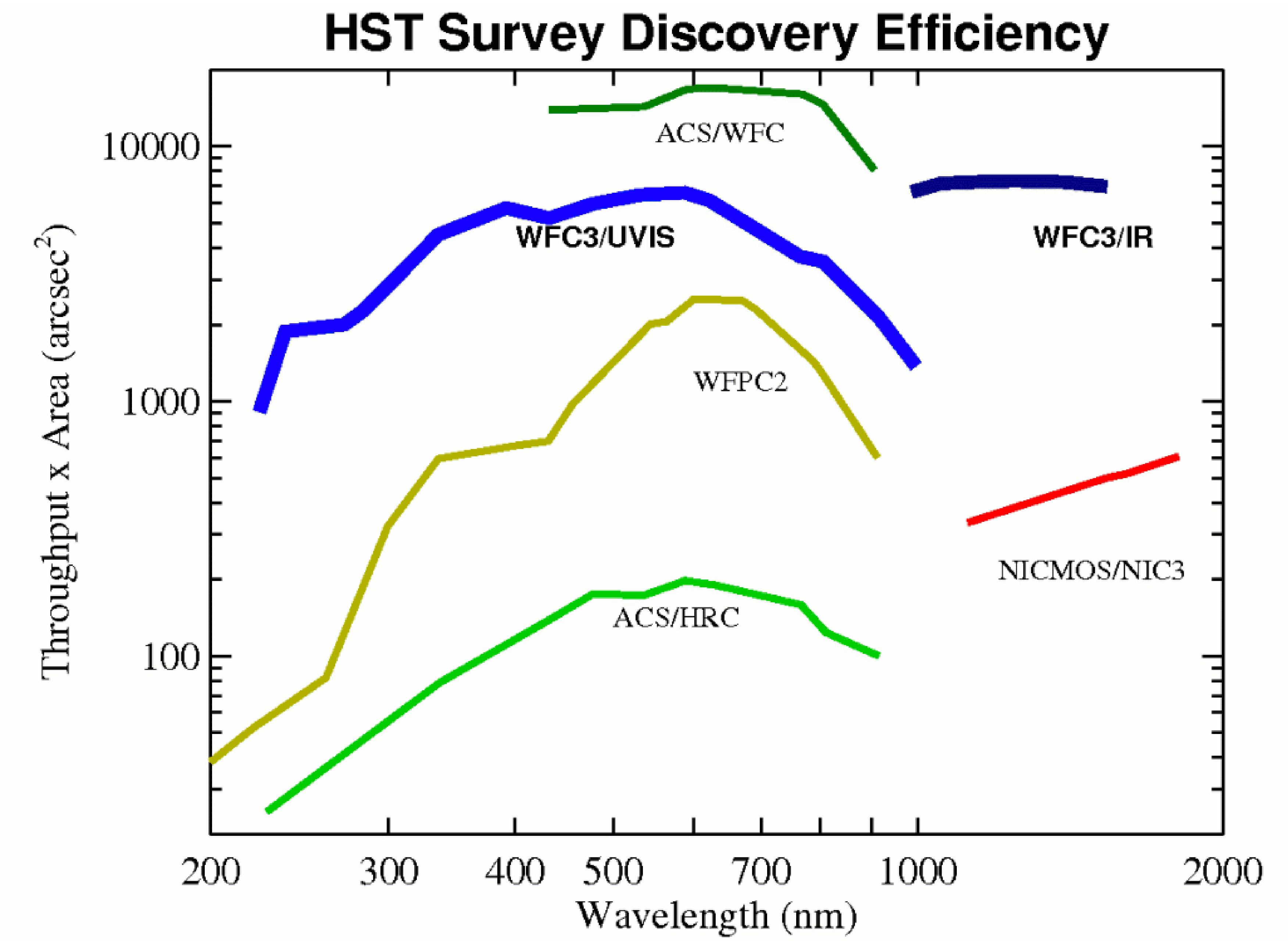


Using HST/ACS GOODS data - CDFS & HDFN, 5 epochs B,v,i',z'

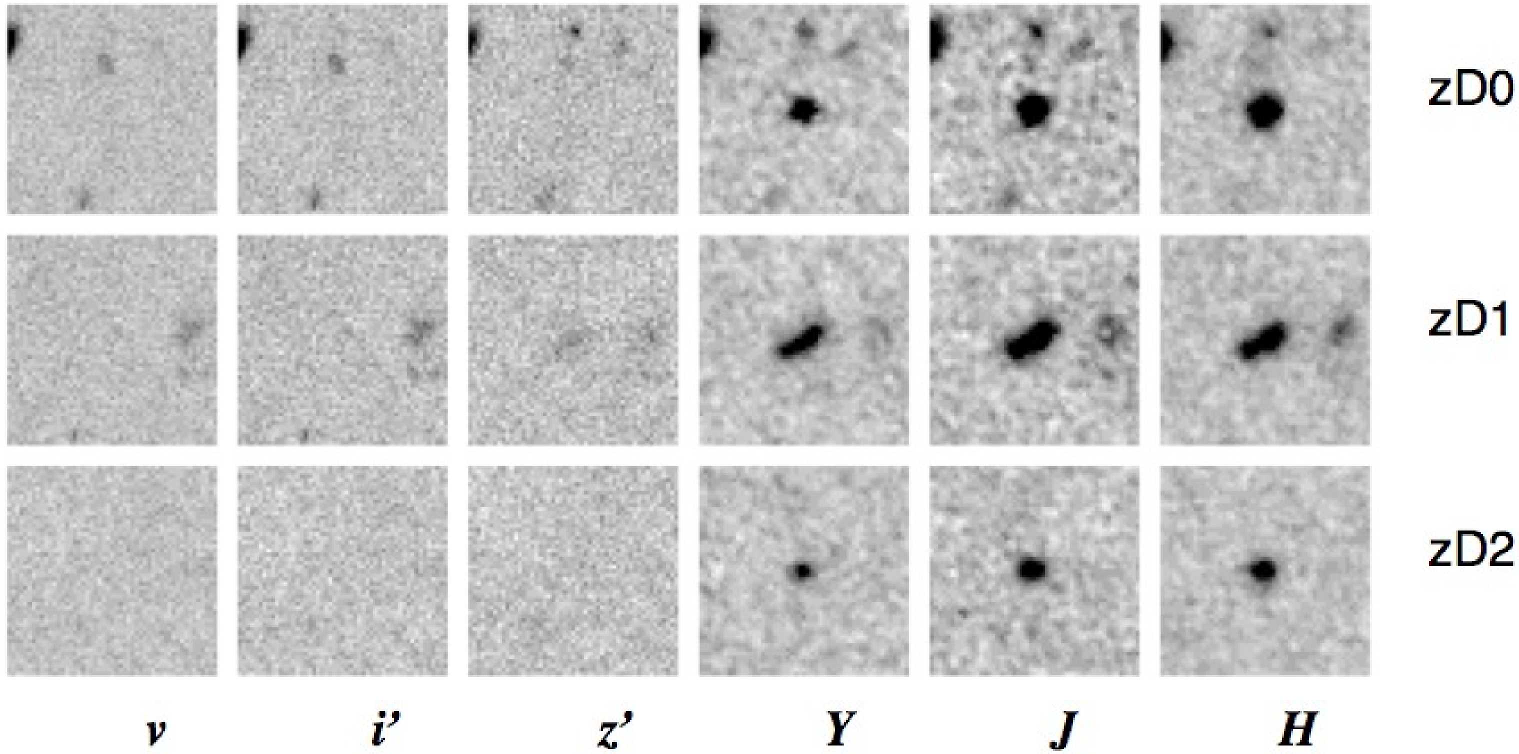




HST WFC3



HST Survey Discovery Efficiency
ACS/WFC
WFC3/UVIS
WFC3/IR
WFPC2
NICMOS/NIC3
ACS/HRC
10000
1000
100
200
300
400
500
700
1000
2000
Wavelength (nm)
Throughput x Area (arcsec^2)



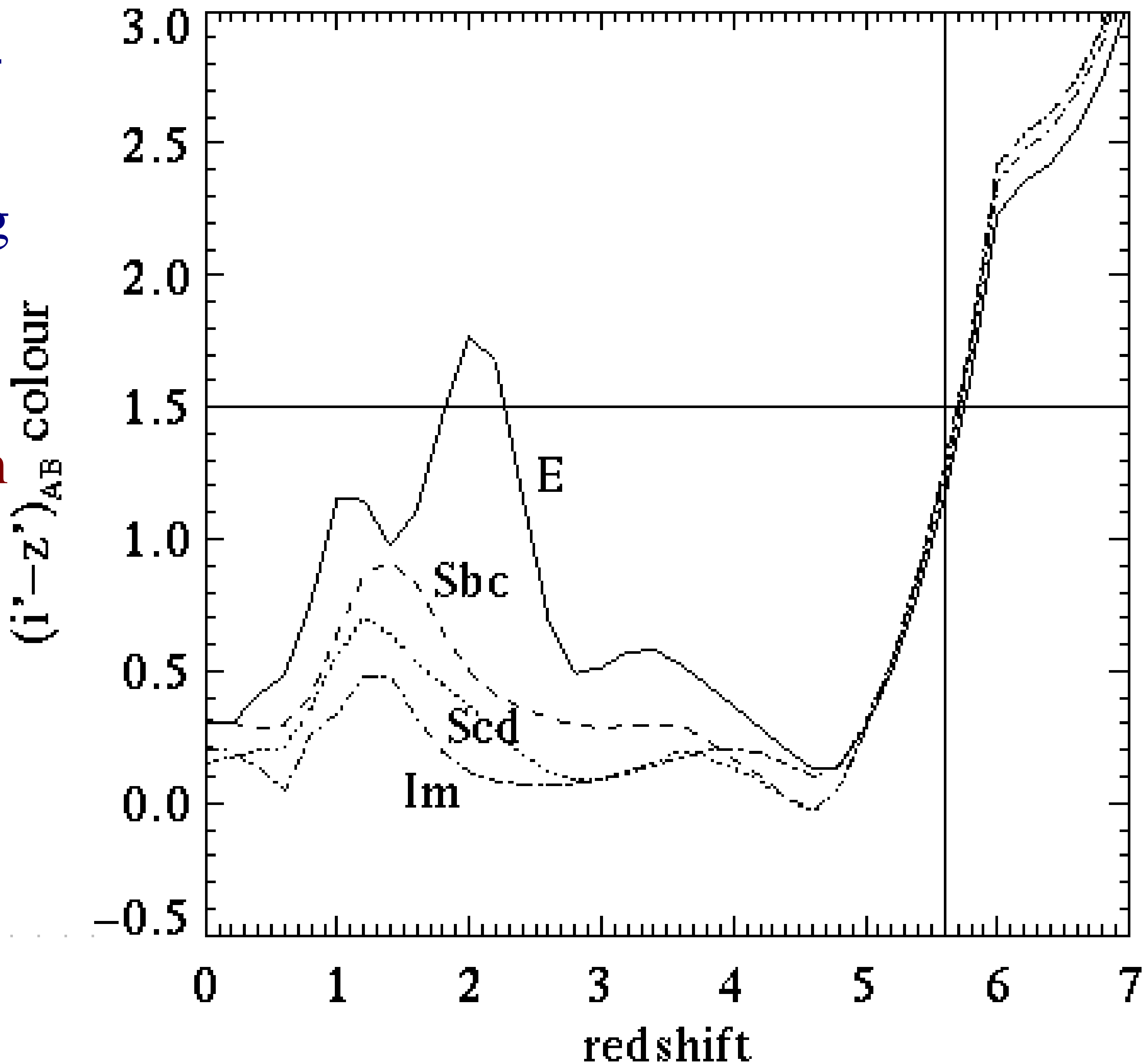
RECENT EXCITEMENT - 100 orbits of HST with WFC3 in 3 near-IR f lters on Hubble Ultra Deep Field.

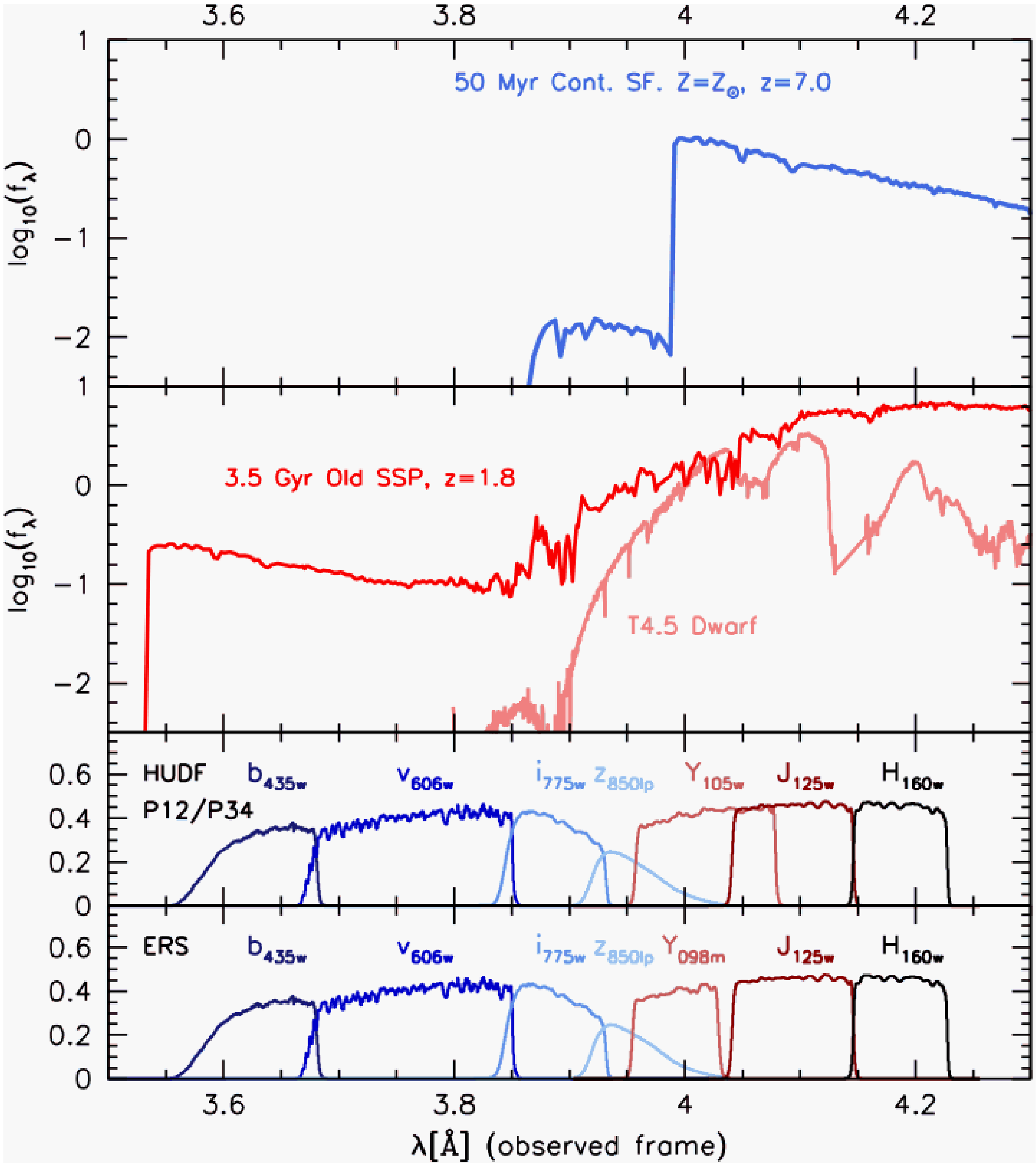
Galaxies at z=7-9! Data f rst taken in August-Sept. 2009

4 papers immediately (Bouwens et al., Bunker et al., McLure et al., Oesch et al.) and 9 more since.

3 large HST surveys (Illingworth UDF; WFC3 team – O’Connell; Faber - CANDELS)

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.

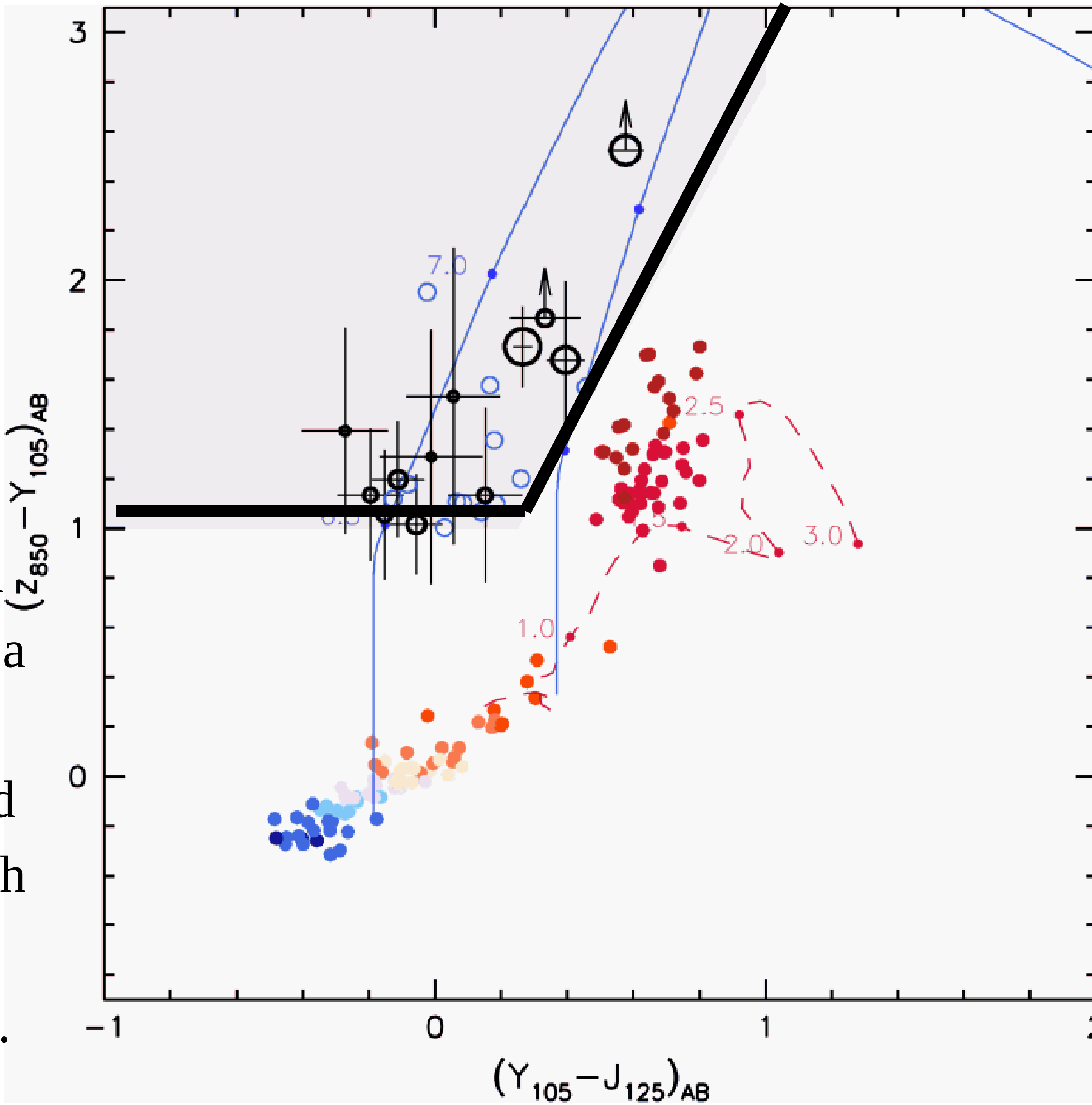




50 Myr Cont. SF. Z=Z⊙, z=7.0
3.5 Gyr Old SSP, z=1.8
T4.5 Dwarf
log10(fλ)
HUDF
P12/P34
ERS
b435w
v606w
i775w
z850lp
Y105w
Y098m
J125w
H160w
λ[Å] (observed frame)

Latest results:
Wilkins et al.
(2010) MNRAS
ArXiv:
1002.4866

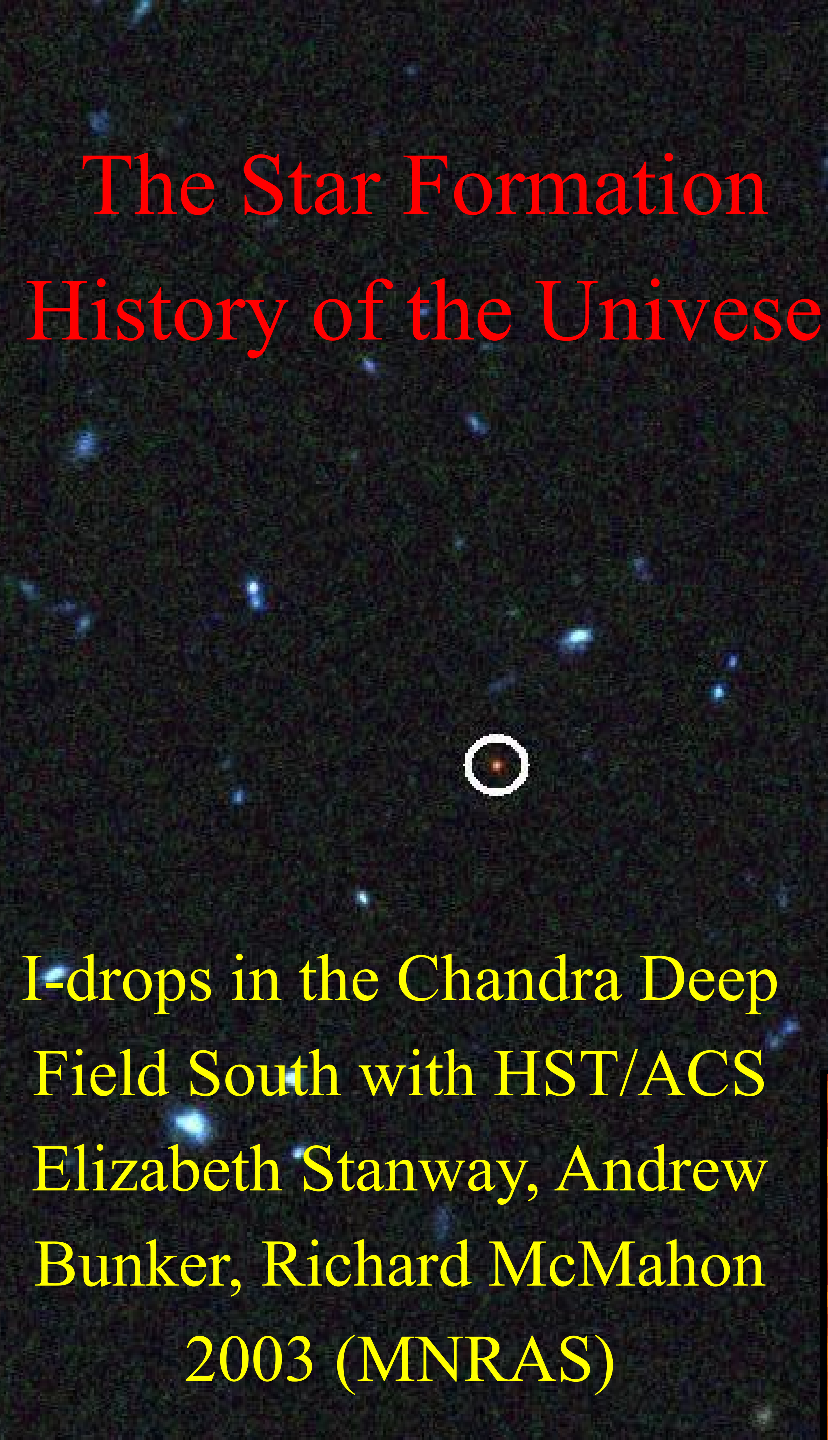
We studied 3 deep f elds (each 5sq.arcmin) and a larger 40sq.arcmin f eld in GOODS-South to search for $7<z<10$ galaxies. Found 44



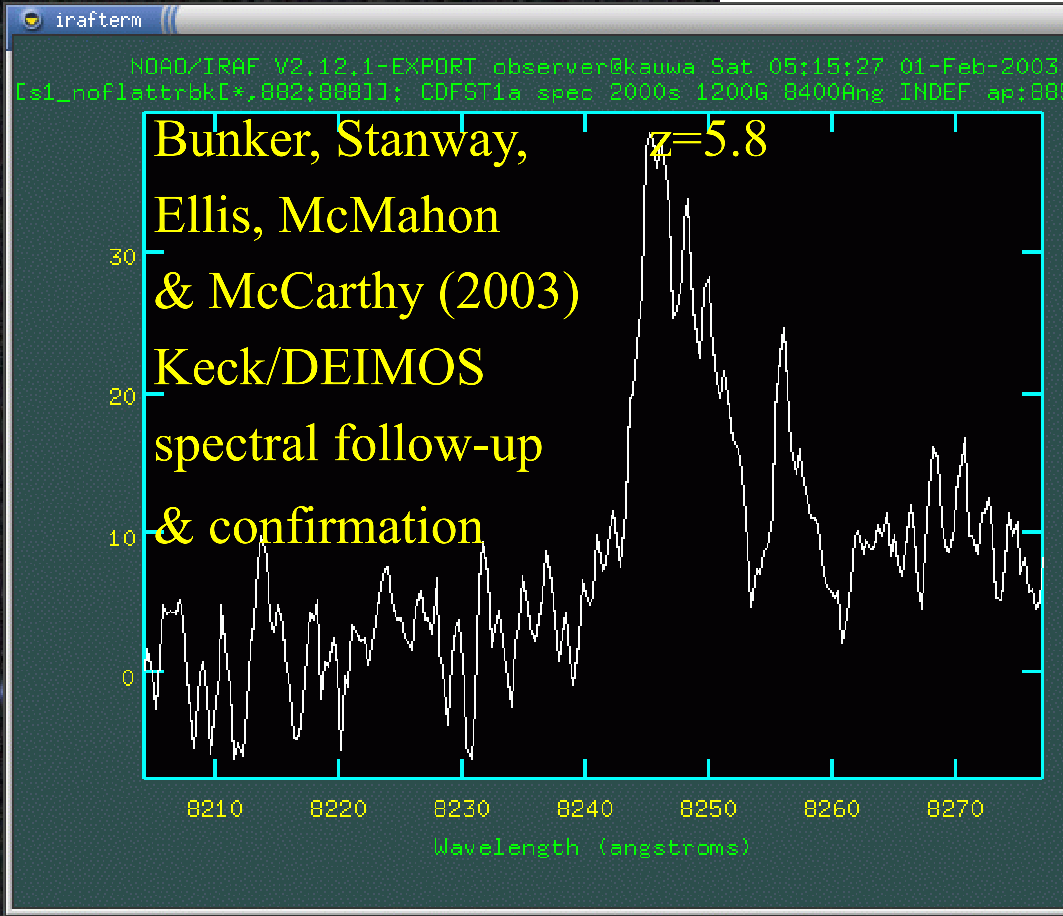
ESO VLTs

10-m Kecks

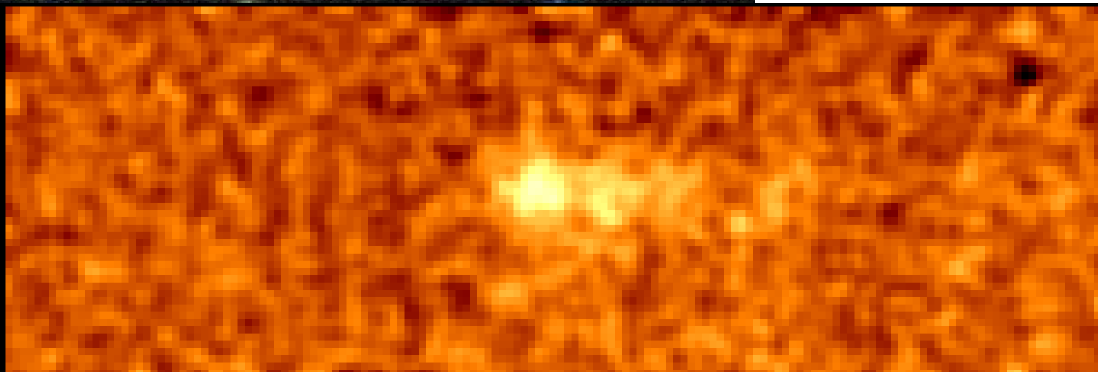
The Star Formation History of the Univese



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

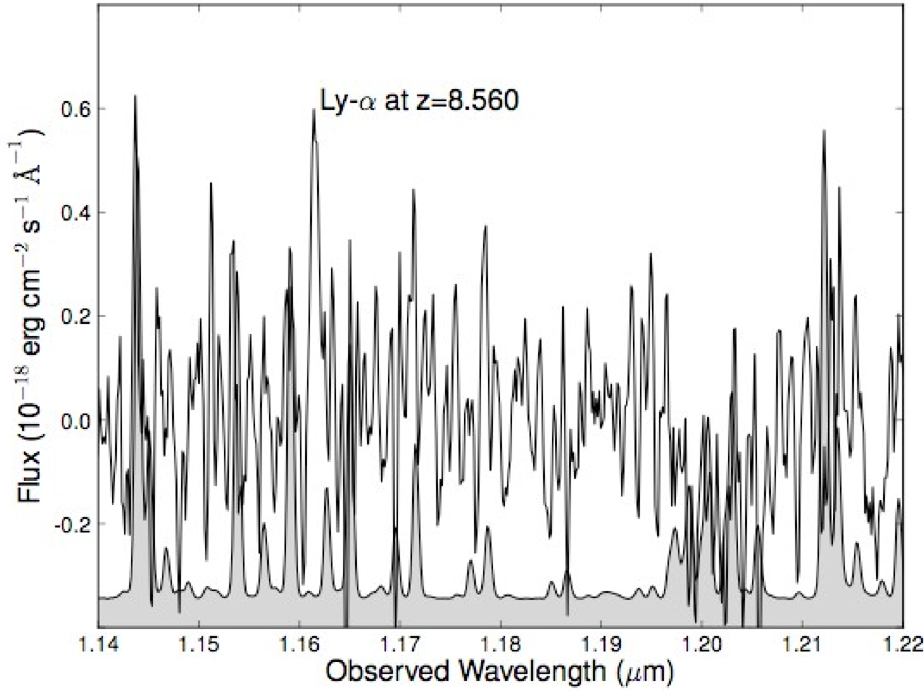


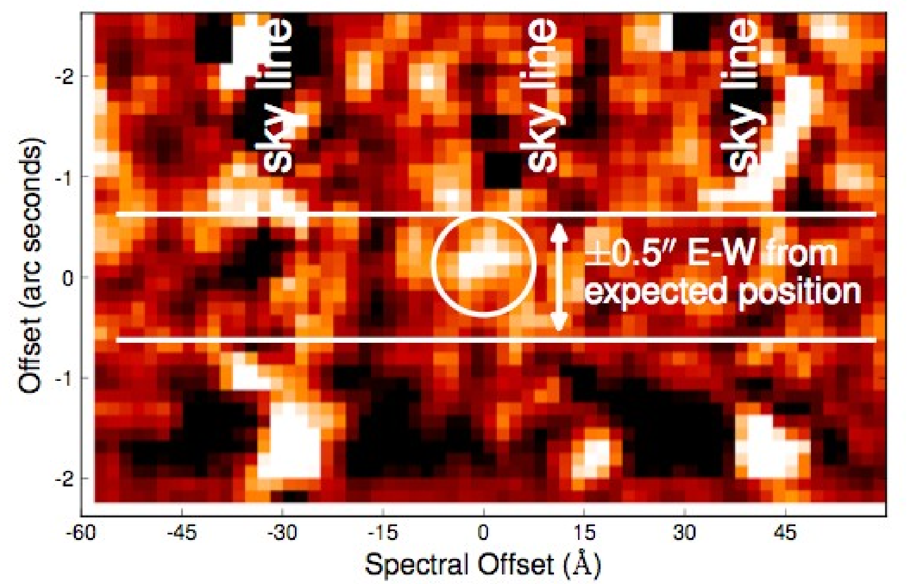
Bunker, Stanway, Ellis, McMahon & McCarthy (2003)
Keck/DEIMOS spectral follow-up & confirmation

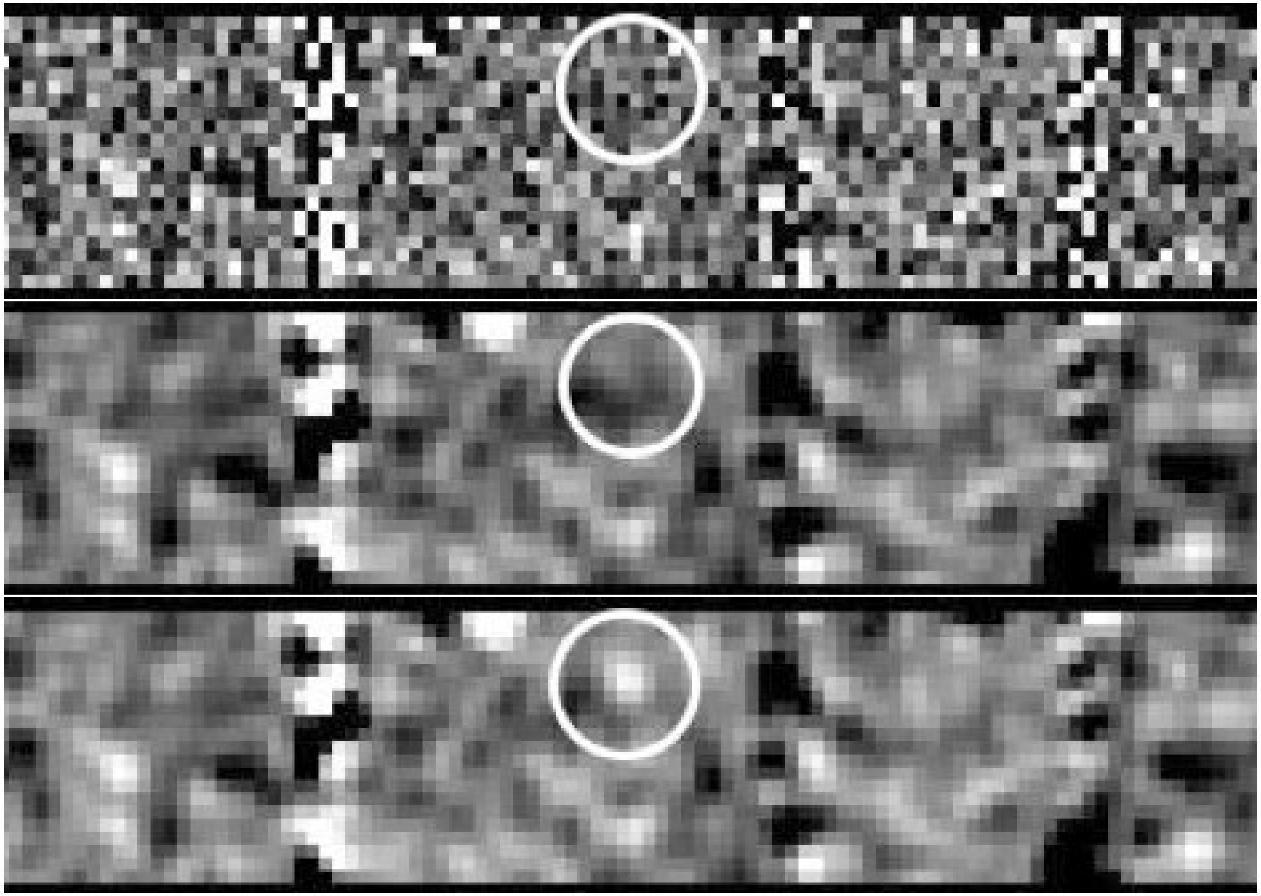


Brightest HUDF Y-drop
Found in Sept 2009:
YD3 in Bunker et al
UDFy-31835539 in
Bouwens et al.;
#1721 in McLure et al.

In late 2009, Nature paper
Lehnert et al. claiming
spectroscopic conf rmation
of Ly-alpha at z=8.55
with SINFONI-IFU on VLT



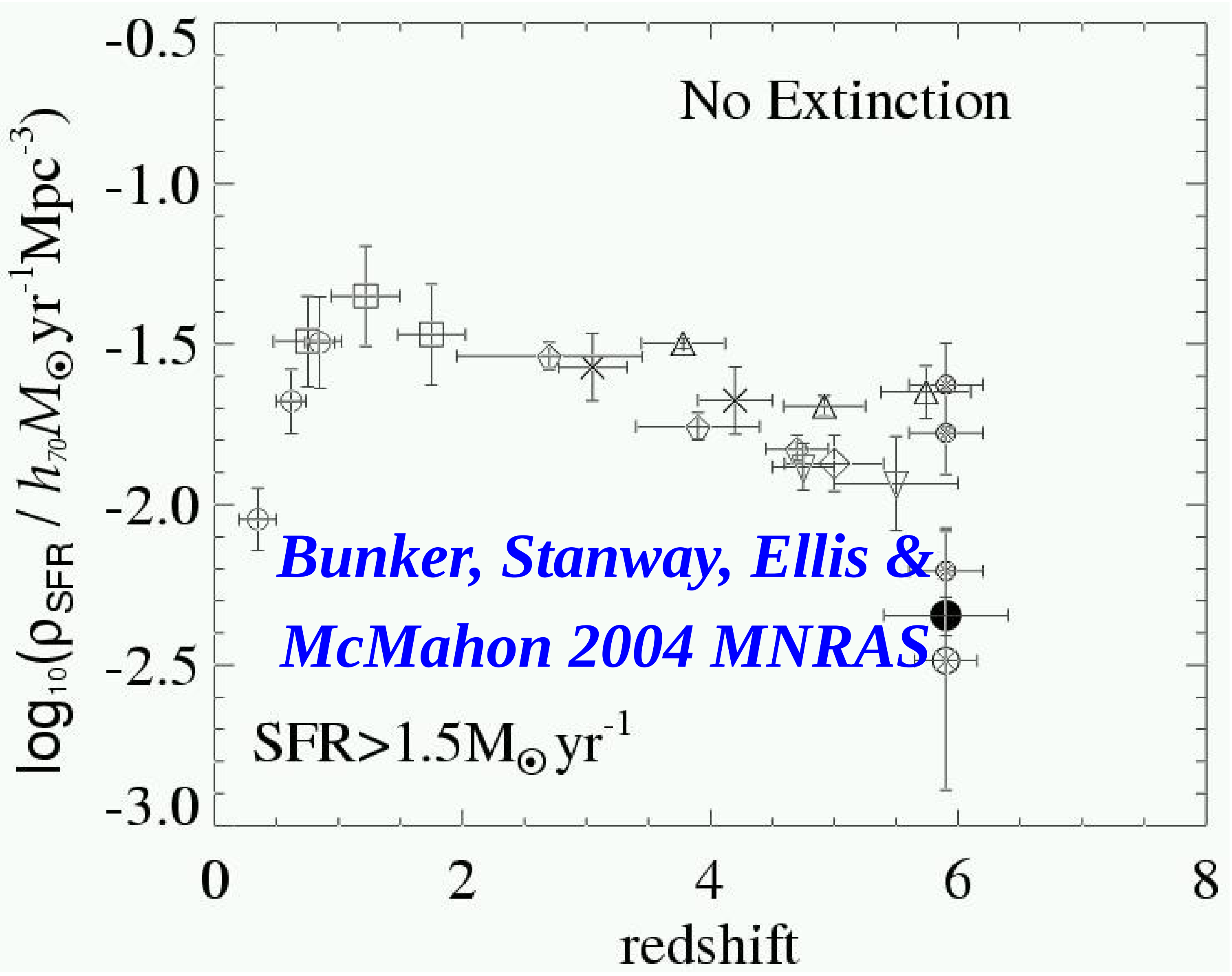




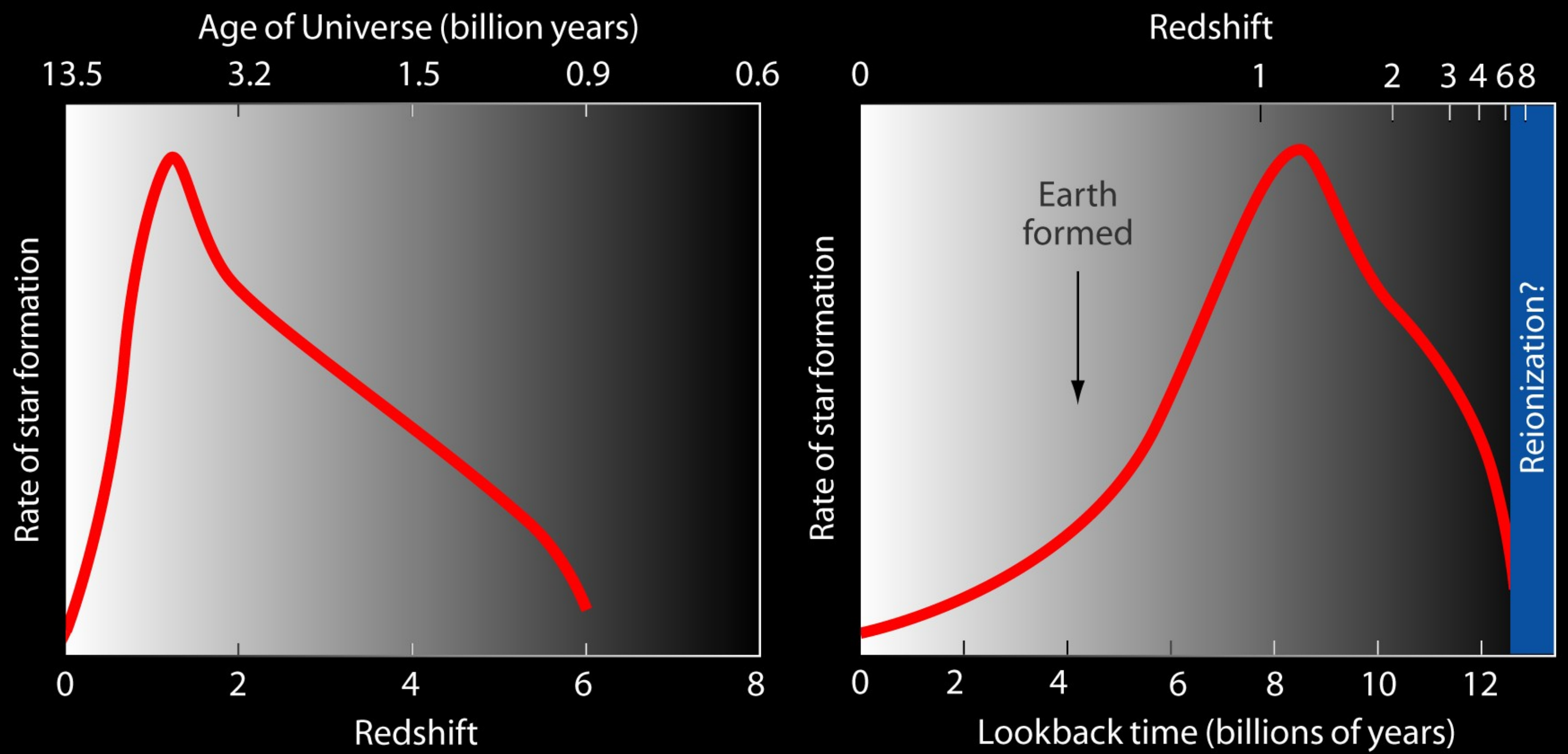
No evidence of Ly-alpha at z=8.55 in 5-hour VLT/XSHOOTER and 11-hour Subaru/MOIRCS spectrum.

Also, the deep HST/WFC3 Y-band encompasses Ly-alpha, should be detected at ~4sigma but is undetected

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



Star formation history of the Universe



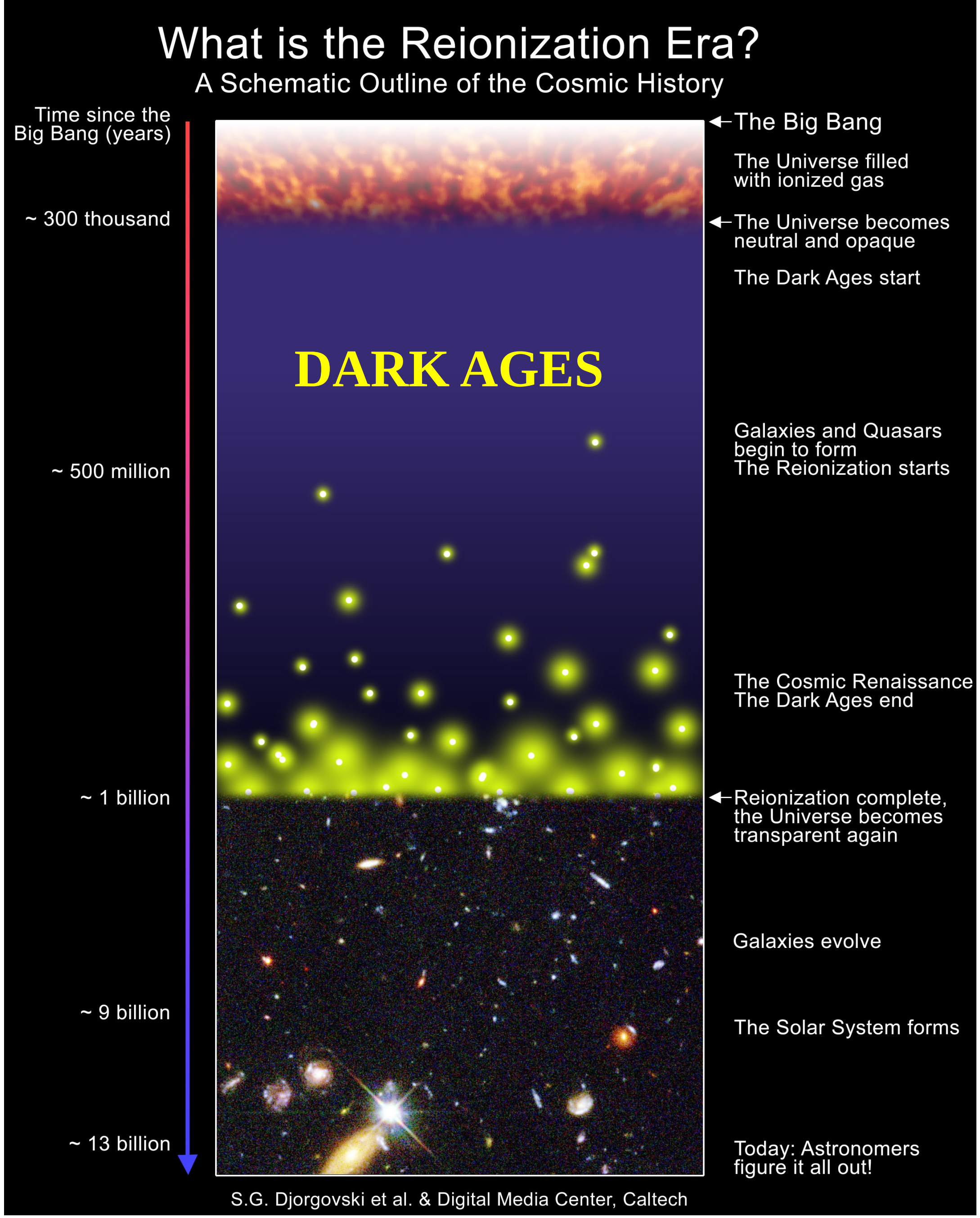
- ***UDF enables us to identify even fainter galaxies at these times*** *(end of dark ages)*
- ***We were first to analyse & publish 50 high redshift galaxies in the UDF***
- ***Confirms our previous work: much LESS star formation than in more recent past***

After era probed by WMAP the Universe enters the so-called “dark ages” prior to formation of f rst stars

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

When did this happen?

What did it?



Redshift z

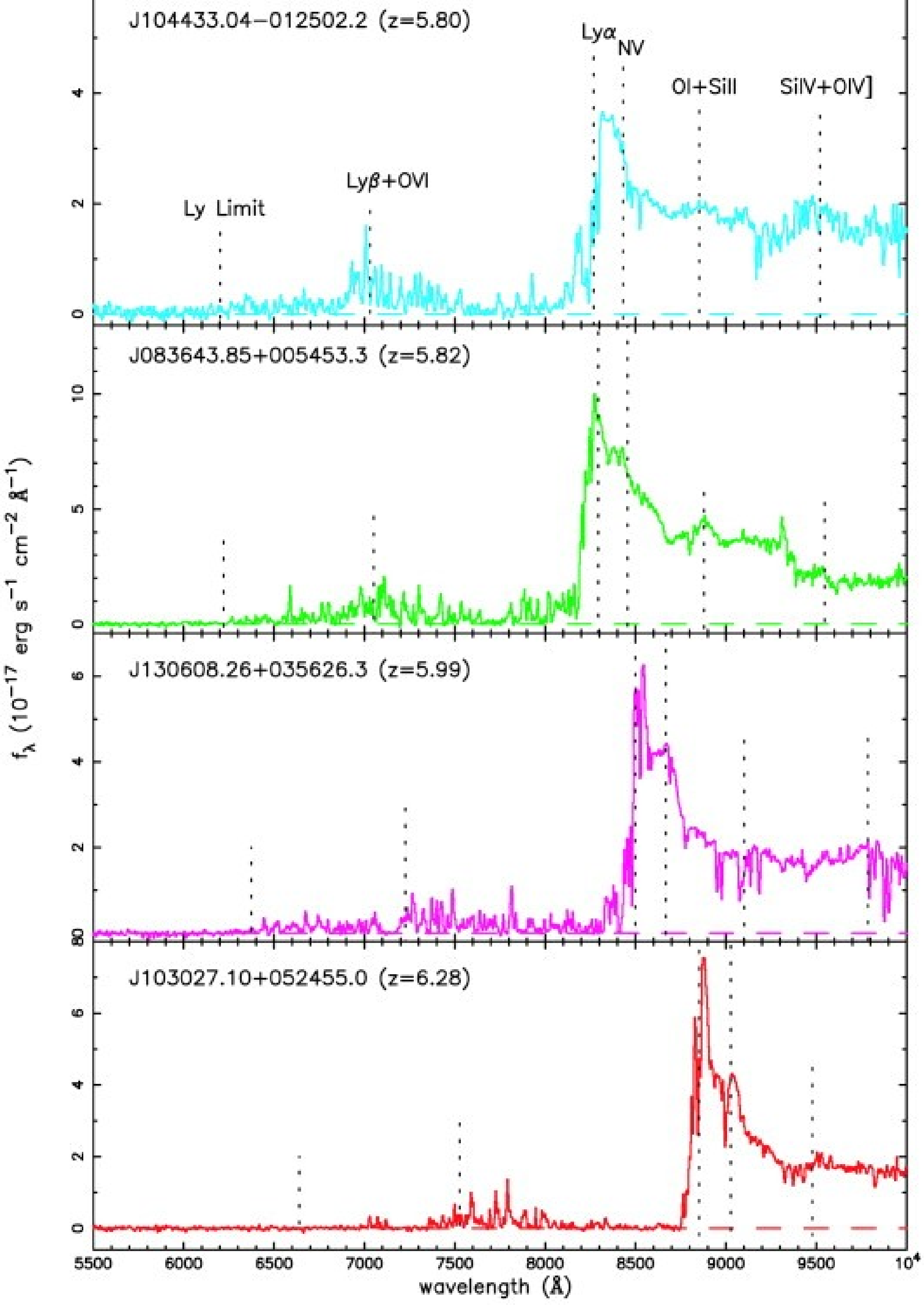
1100

10

5

2

0



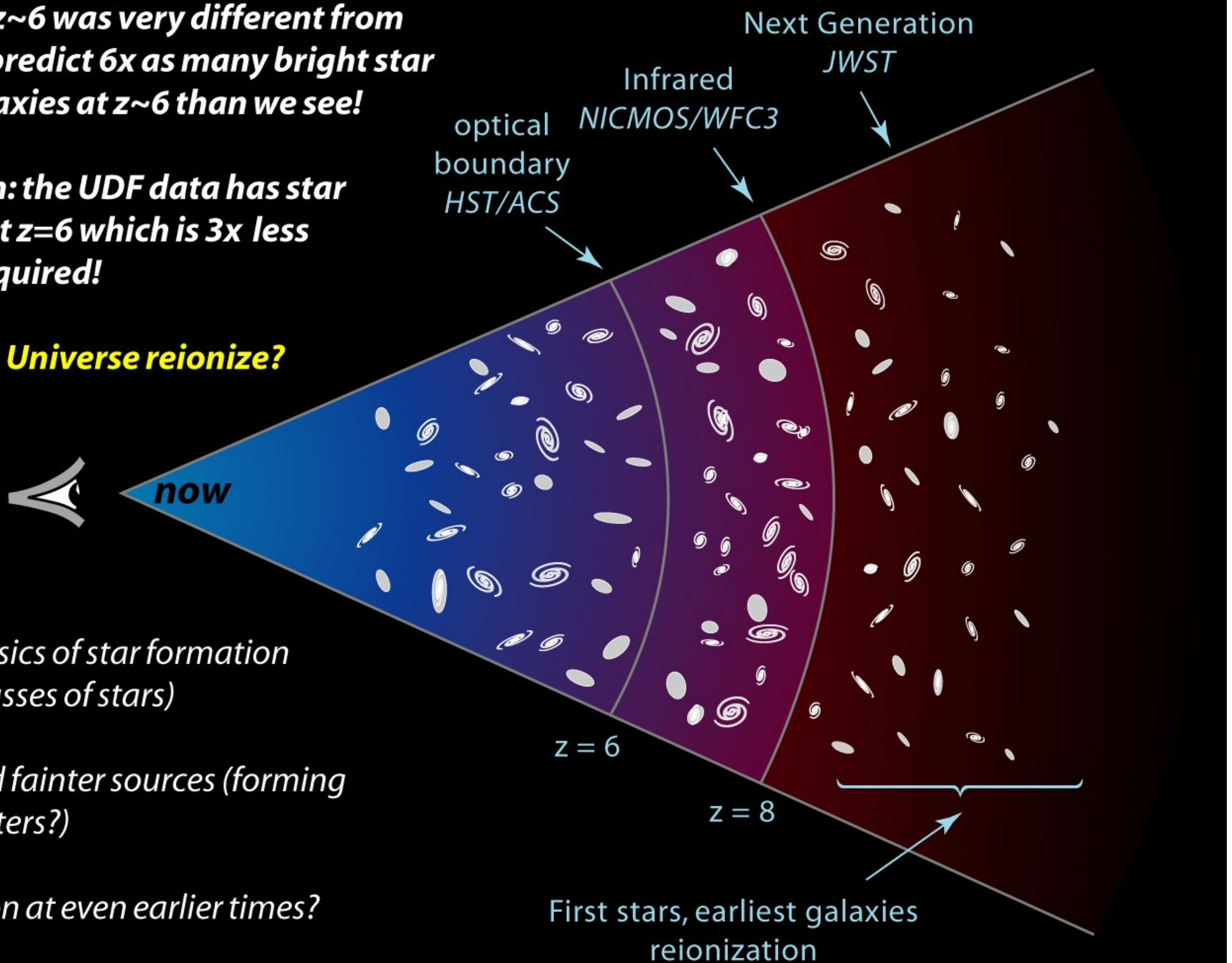
Reionization

At high redshift, the Lyman-   forest can absorb most of the flux below $_{rest}$=1216Å. Indications from z>6.3 SDSS QSOs that Universe many be optically thick (Fan et al. 2001; Becker et al. 2001). BUT confusing messaged from WMAP CMB - reionization at z~11? (Dunkley et al. 2010).

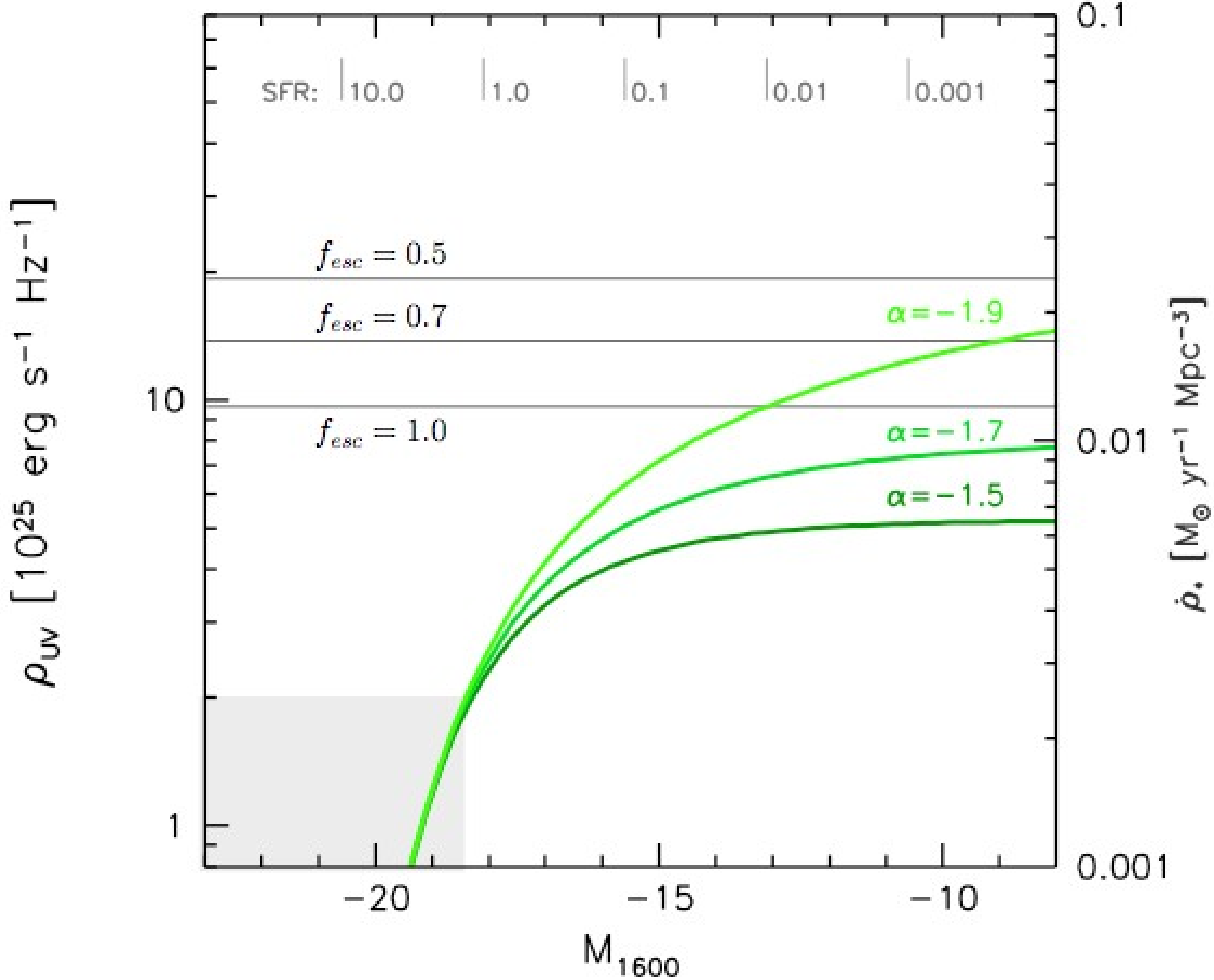
Probing the dark ages
reionization and distant galaxies

- ***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!***

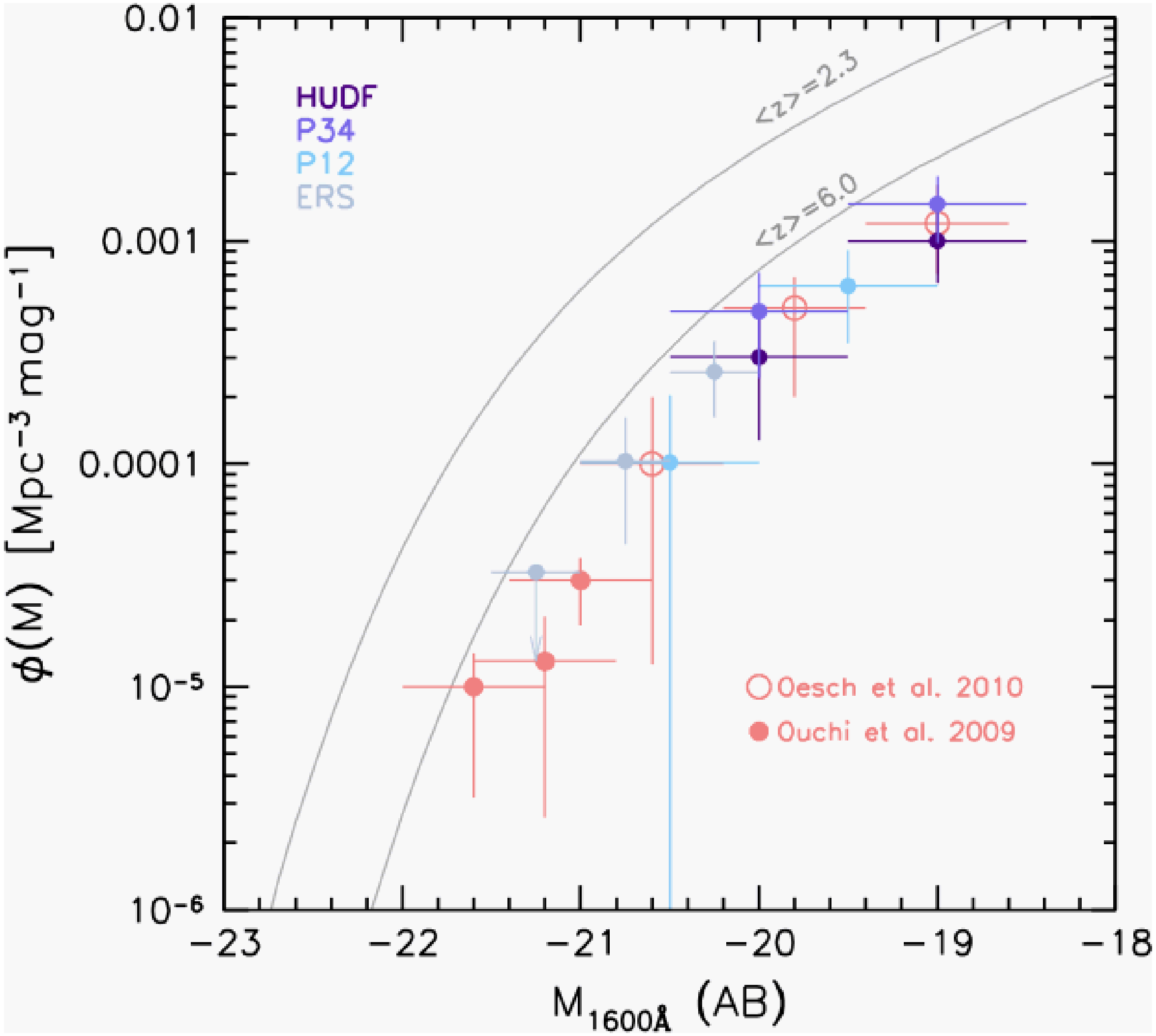
So how does Universe reionize?



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

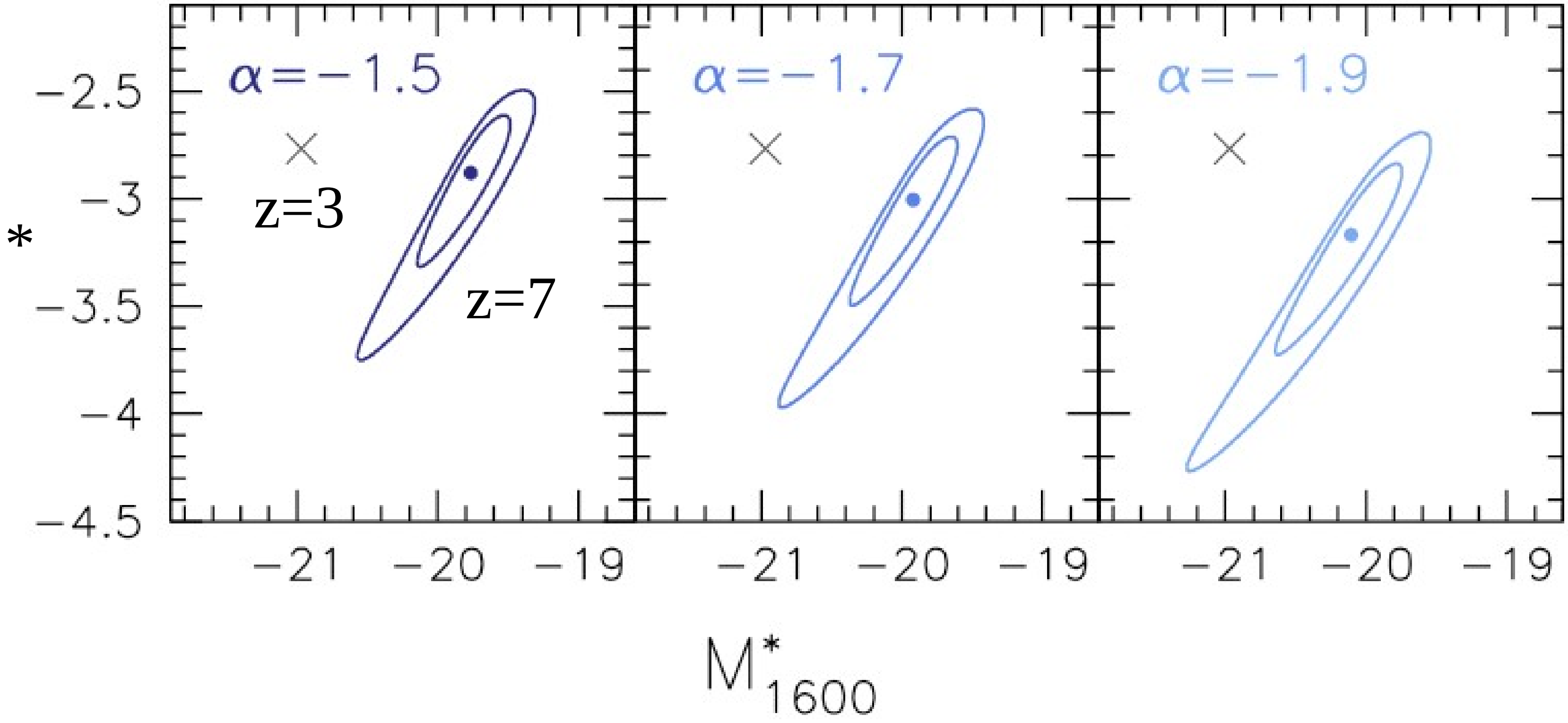


Wilkins et al. (2010)



Wilkins et al. (2010) MNRAS The Luminosity Function at z~7

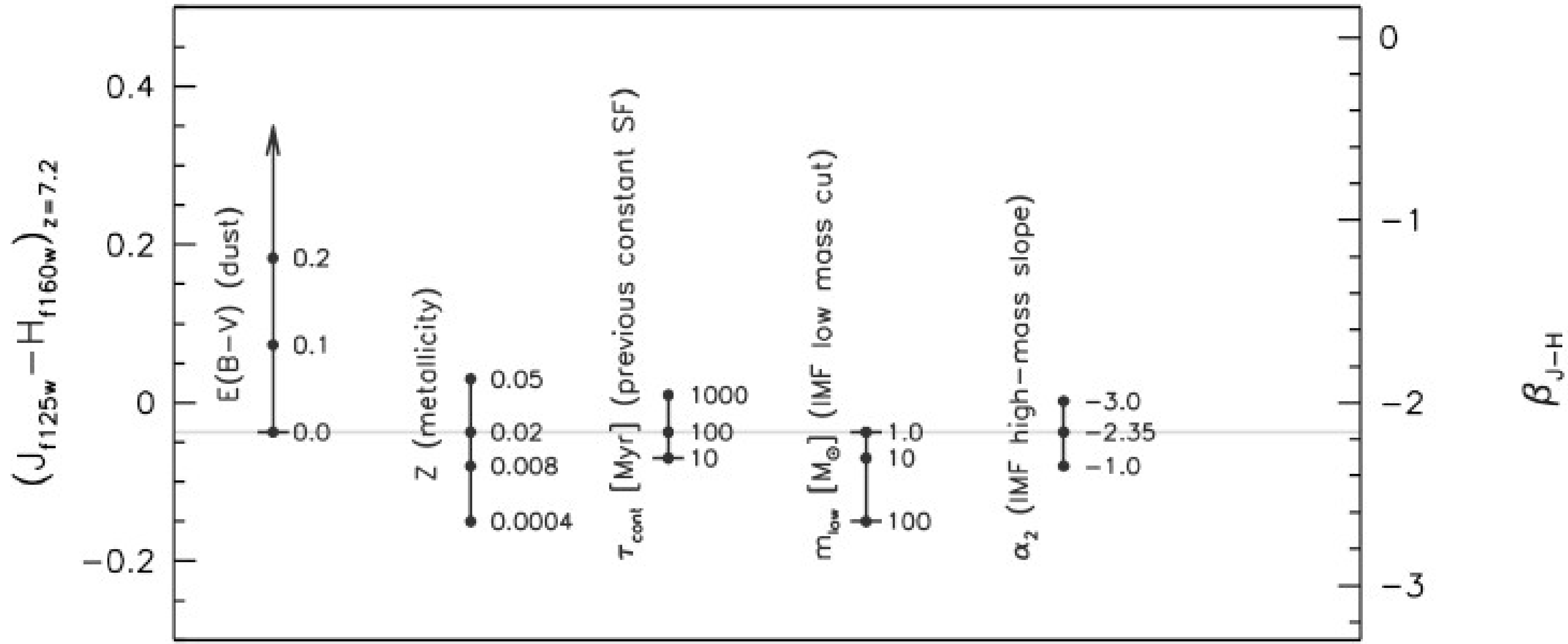
An increasing problem for reionization: requires steep faint-end slope (<-1.7), large contribution from unobserved faint galaxies, high escape fraction (f_{esc}>0.5) and very smooth IGM (low clumping, C~5)



Evolution of luminosity function
(note M* is correlated with *)

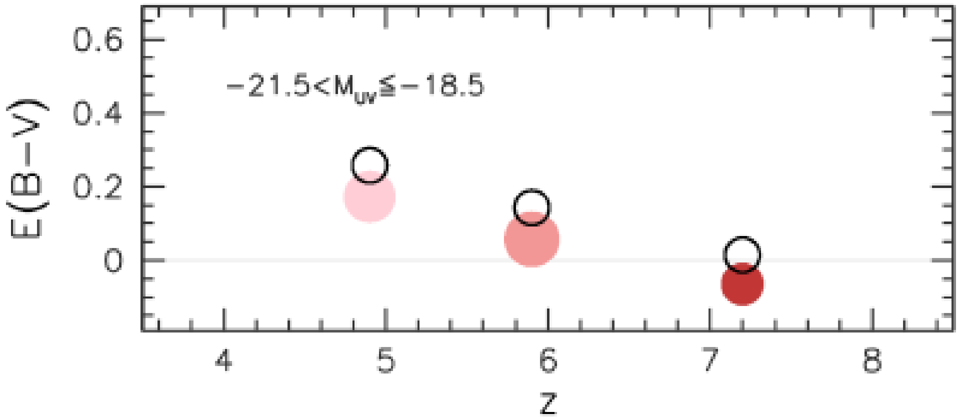
Wilkins et al. (2011)

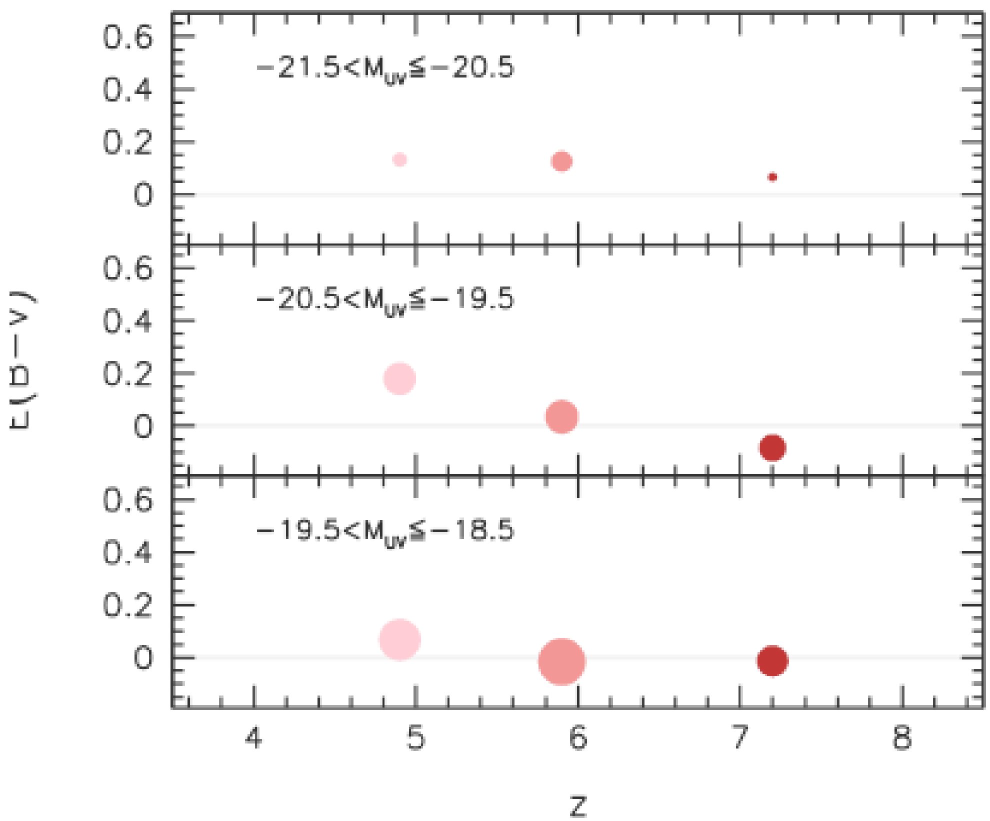
UV Spectral Slopes at z>6 : f ~ $^{-}$



Stanway, McMahon & Bunker (2005) - found very blue colours for i-drops in NICMOS UDF

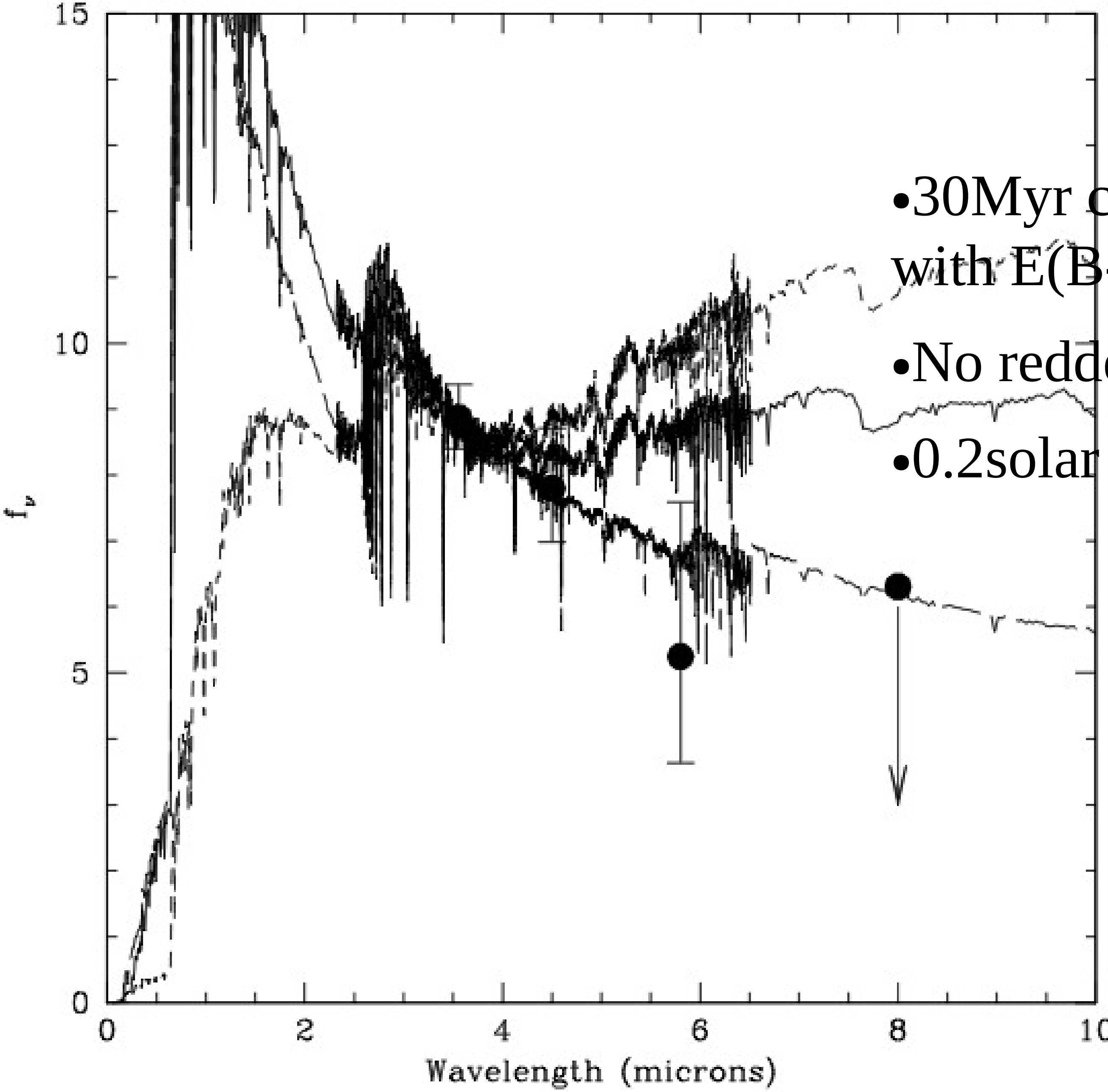
Also now seen in z-drops with WFC3 (Bouwens et al. 2011, Dunlop et al. 2011, Wilkins et al. 2011)



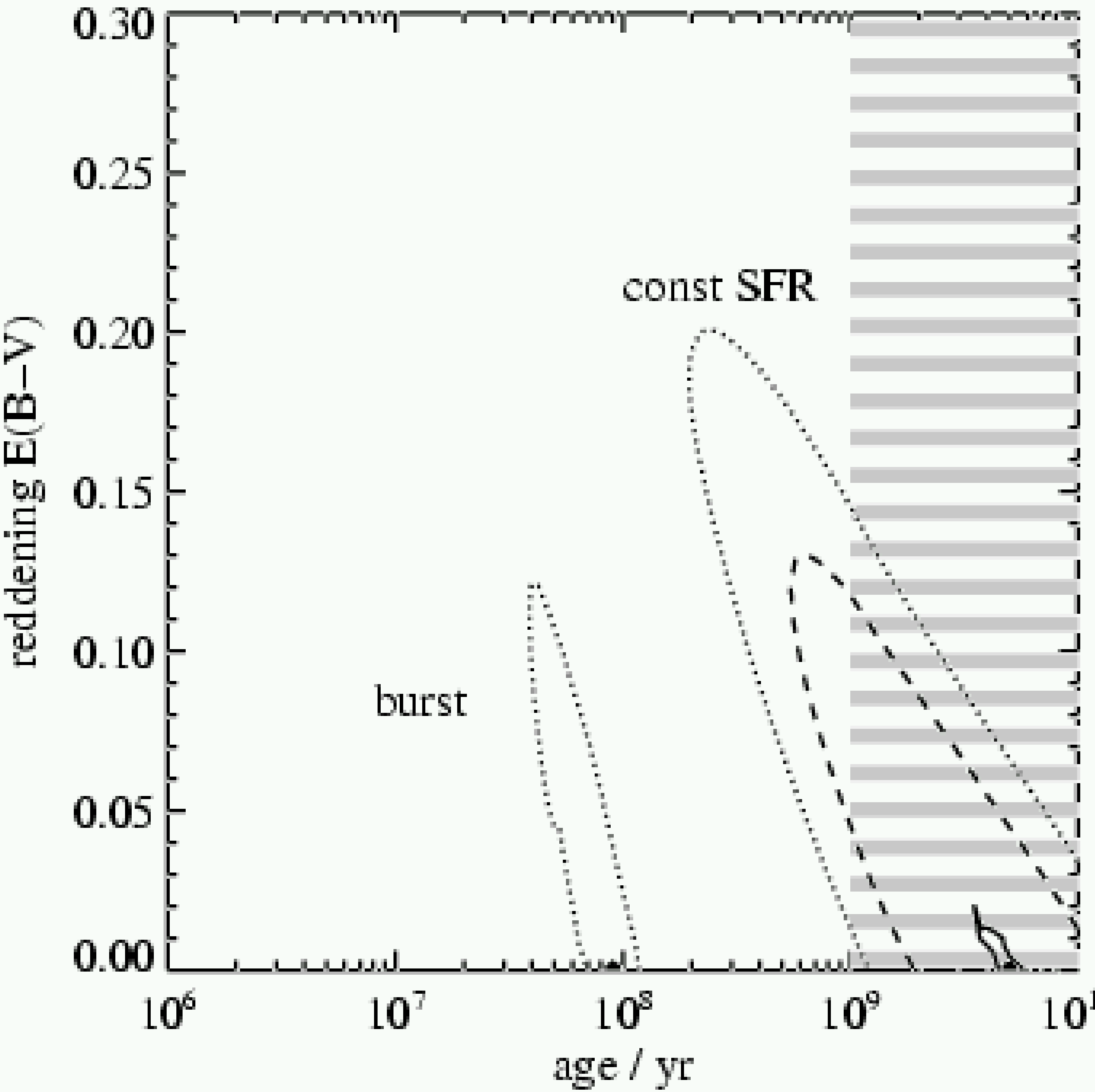


- From Wilkins et al. (2011) MNRAS
- Weak dependence of beta evolution on luminosity
- Careful on f lters - the Lyman-alpha break will redden intrinsic colours

Spitzer – IRAC (3.6-8.0 microns)

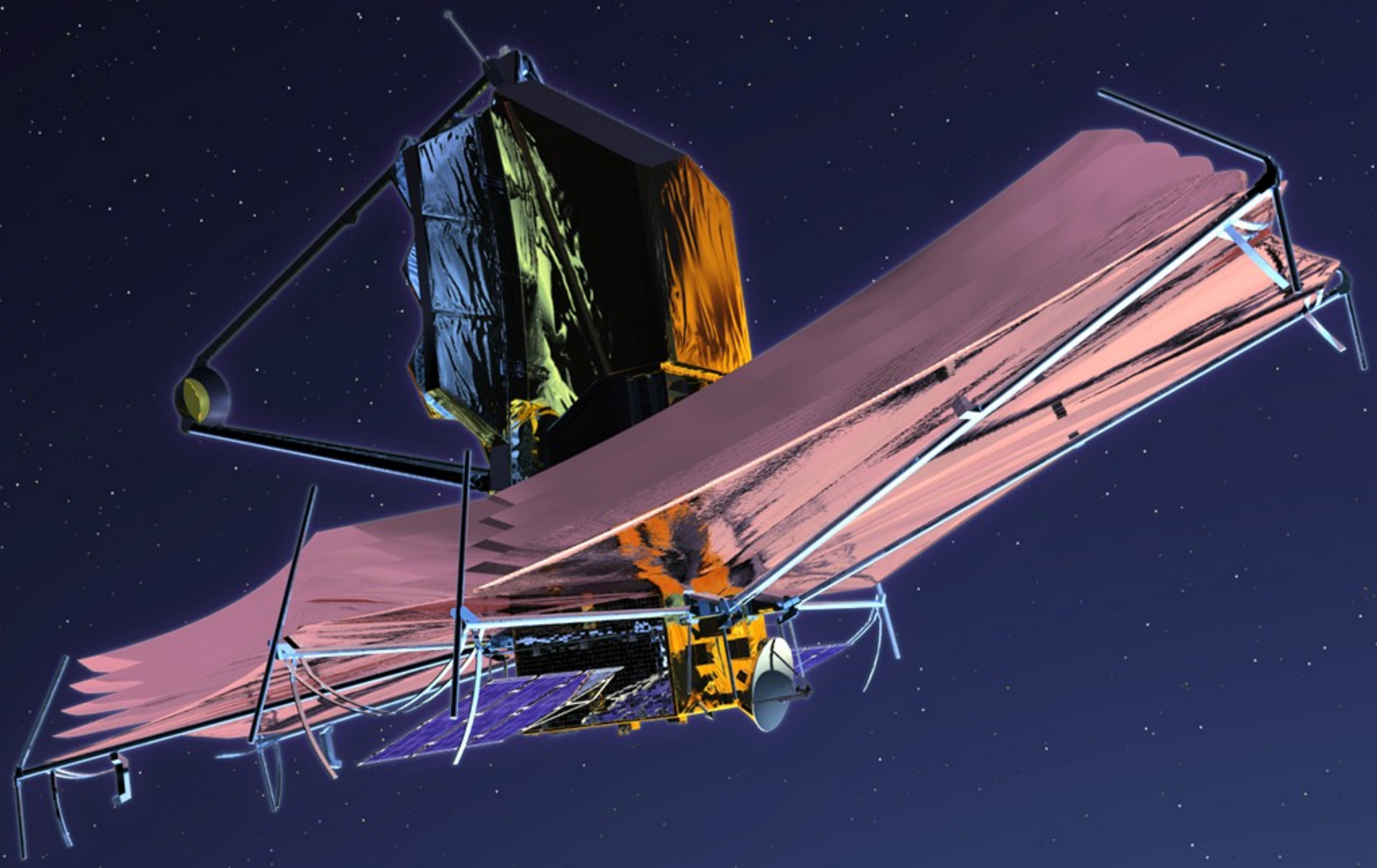


- 30Myr const SFR with E(B-V)=0.1
- No reddening
- 0.2solar metallicity



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
age / yr

JAMES WEBB SPACE TELESCOPE – successor to Hubble (???? 2016+ $$$$)



Conclusions

- Have found star-forming galaxies at z=6-10 (Lyman breaks), and spectroscopic conf rmation at z~6

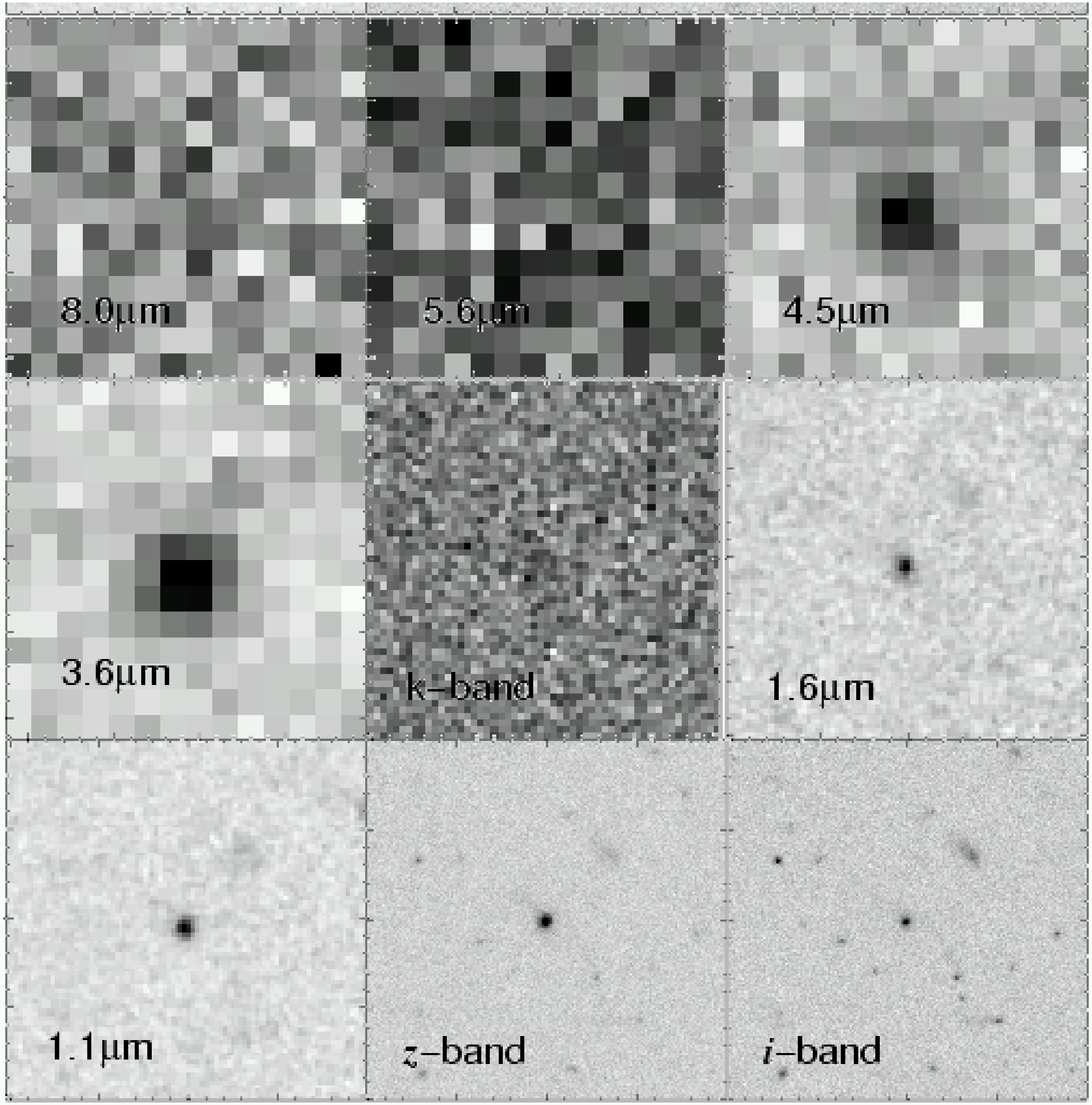
-- However, z>7 number counts from HST/WFC3 imply the newly-discovered galaxies would struggle to reionize

-- Many of these have very blue rest-UV spectral slopes

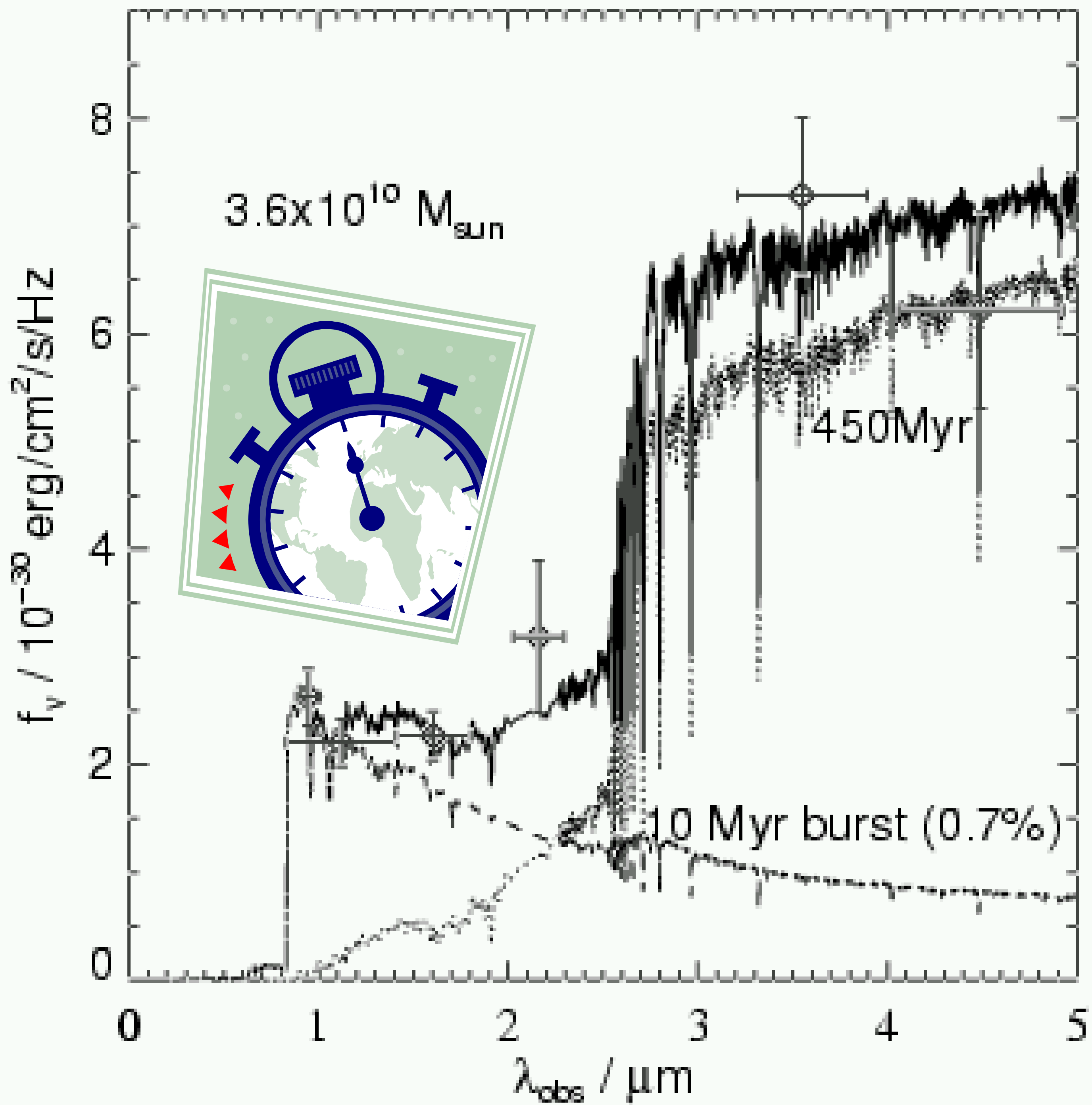
-- High escape fraction/Steep faint end slope/low metallicity/smooth IGM?

-- JWST and E-ELT spectroscopy should resolve many questions

-PLENTY OF CURRENT TARGETS TO FEED THE GIANTS



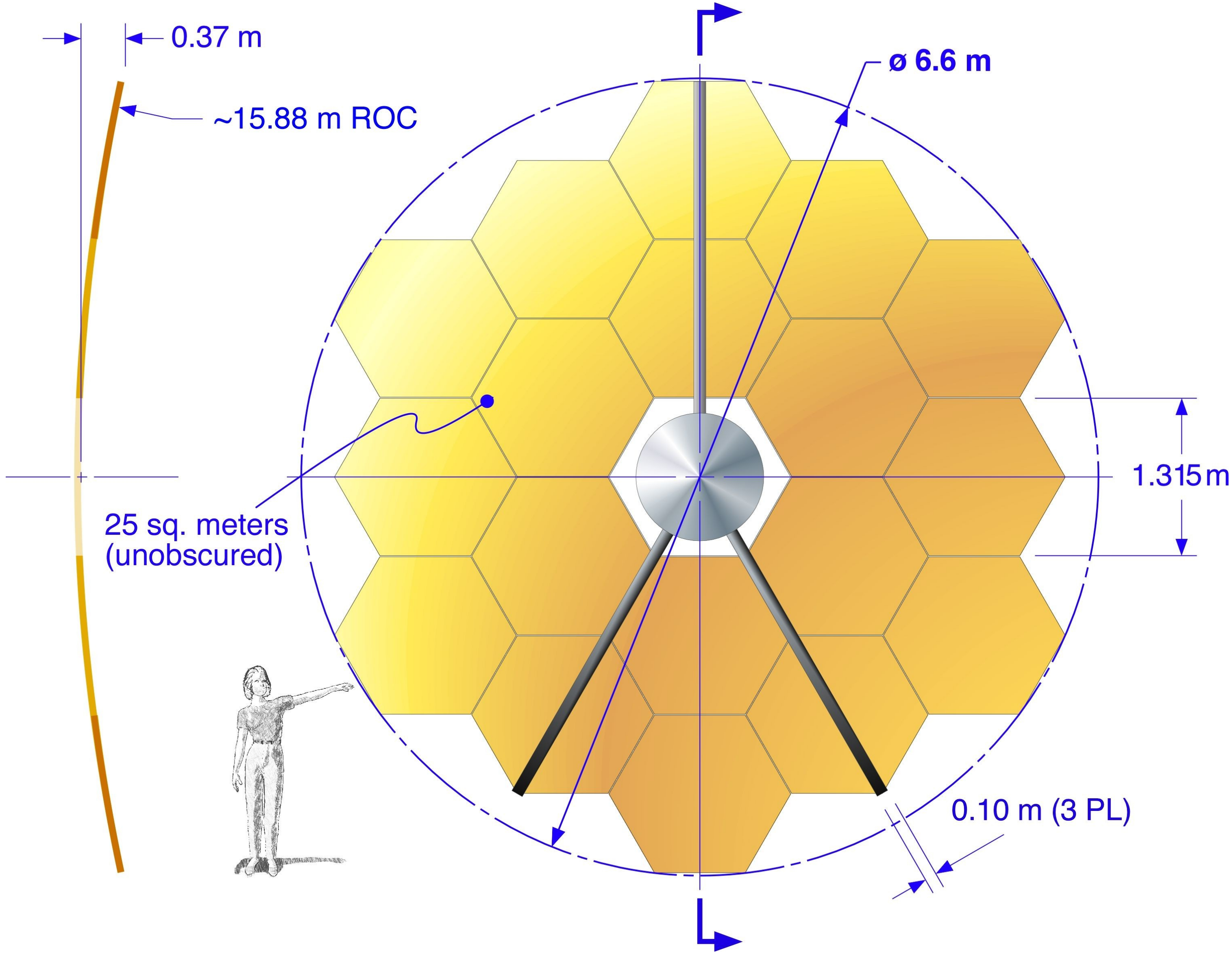
- z=5.83 galaxy #1 from Stanway, Bunker & McMahon 2003 (spec conf from Stanway et al. 2004, Dickinson et al. 2004). Detected in GOODS IRAC 3-4 m: Eyles, Bunker, Stanway et al '04



Eyles et al. (2005) MNRAS

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

Telescope

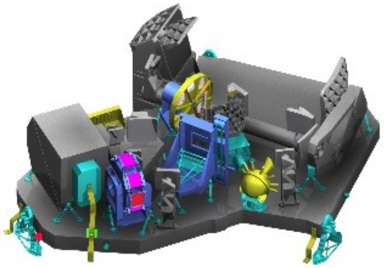


What is JWST?

- 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 f eld 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

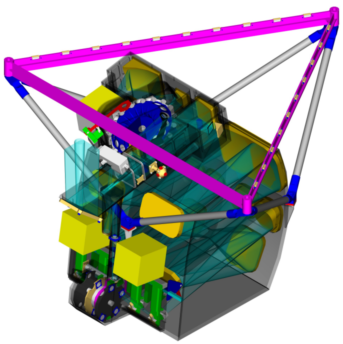
QuickTimeª and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

ESA Contributions to JWST



NIRSpec

- ESA Provided
- Detector & MEMS Arrays from NASA



MIRI Optics Module

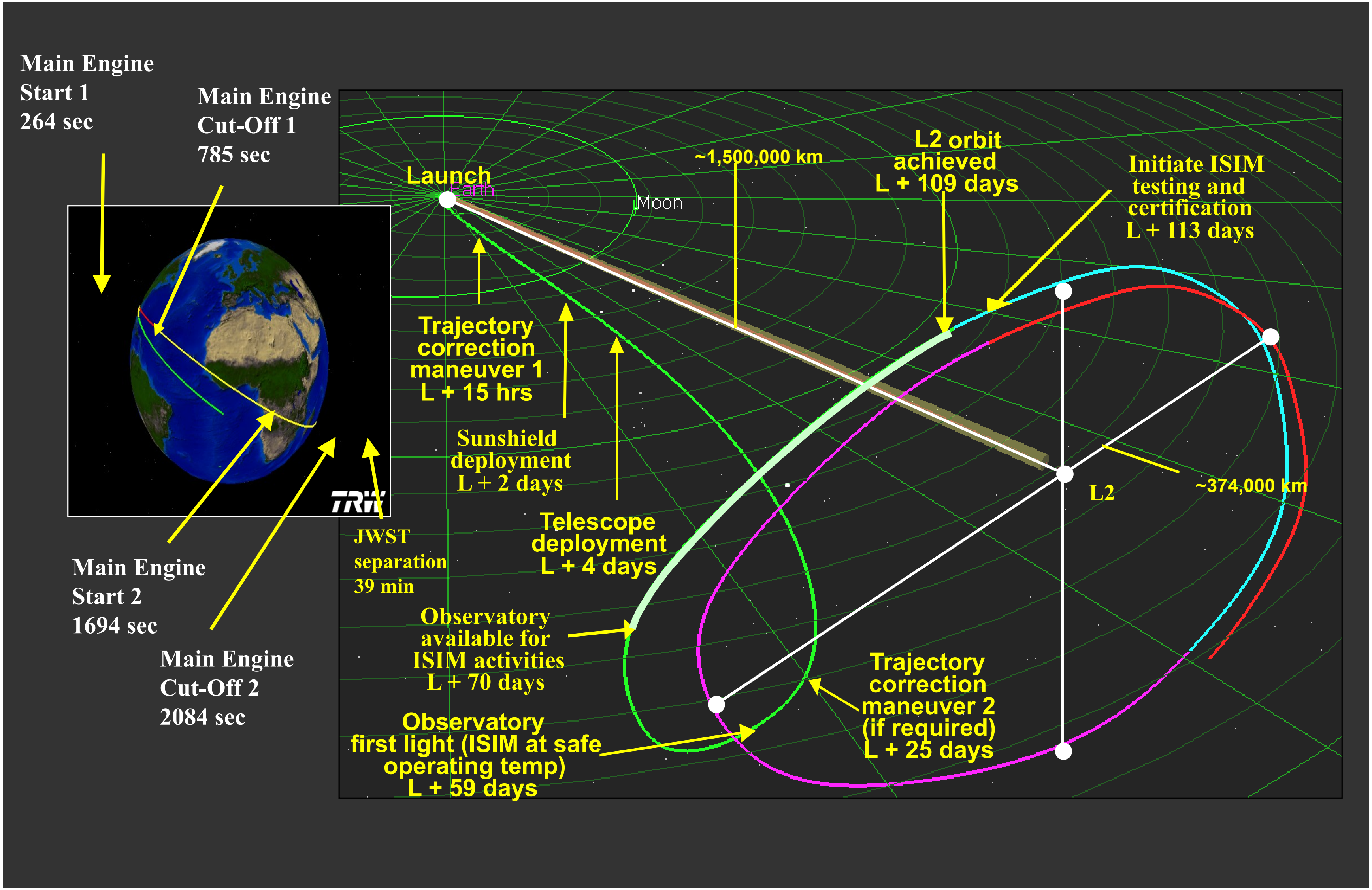
- ESA Member State Consortium
- Detector & Cooler/Cryostat from NASA

QuickTime[a] and a
TIFF (LZW) decompressor
are needed to see this picture.

Ariane V Launcher (ECA)

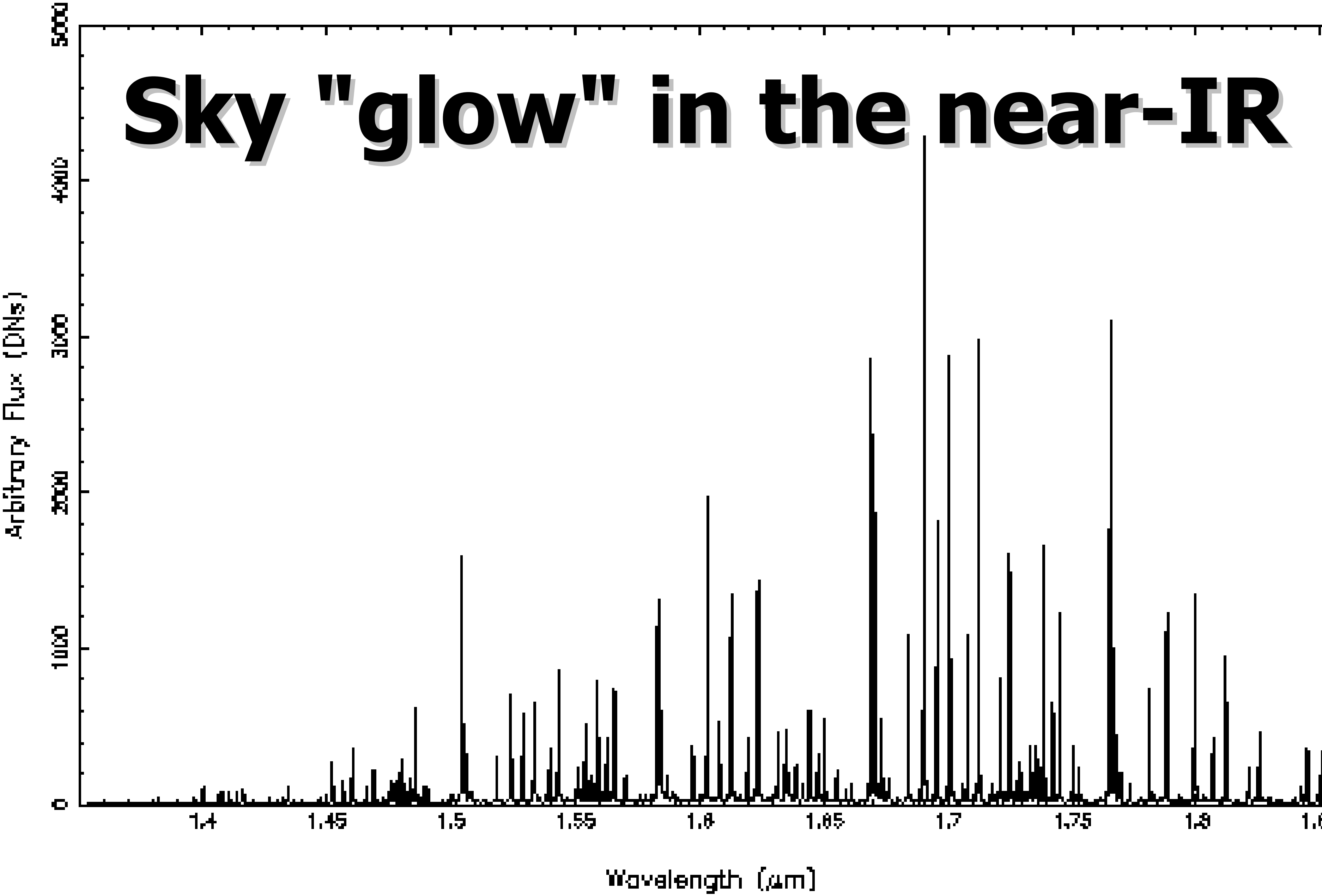
(closely similar to HST model…)

Orbit

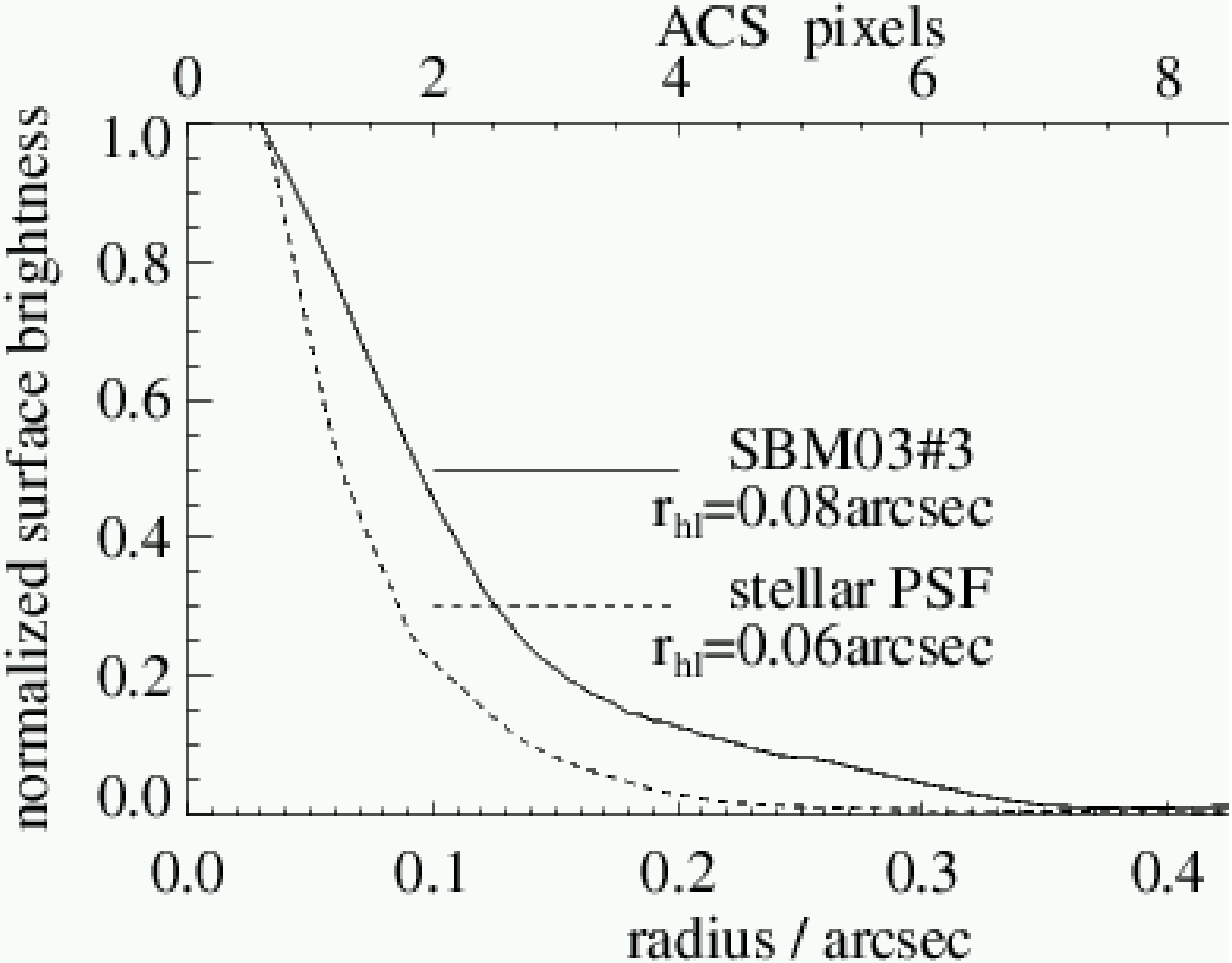


Main Engine Start 1 264 sec
Main Engine Cut-Off 1 785 sec
Main Engine Start 2 1694 sec
Main Engine Cut-Off 2 2084 sec
JWST separation 39 min
Launch
Earth
Moon
~1,500,000 km
L2 orbit achieved L + 109 days
Initiate ISIM testing and certification L + 113 days
Trajectory correction maneuver 1 L + 15 hrs
Sunshield deployment L + 2 days
Telescope deployment L + 4 days
L2
~374,000 km
Observatory available for ISIM activities L + 70 days
Observatory first light (ISIM at safe operating temp) L + 59 days
Trajectory correction maneuver 2 (if required) L + 25 days

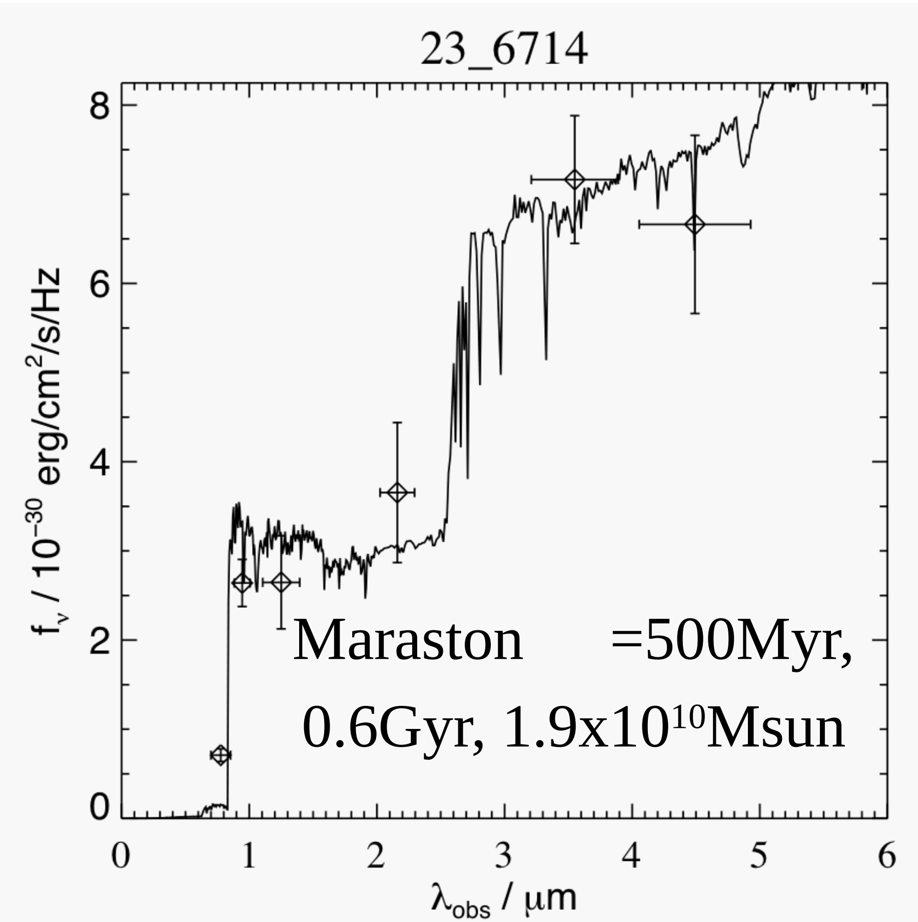
Sky "glow" in the near-IR

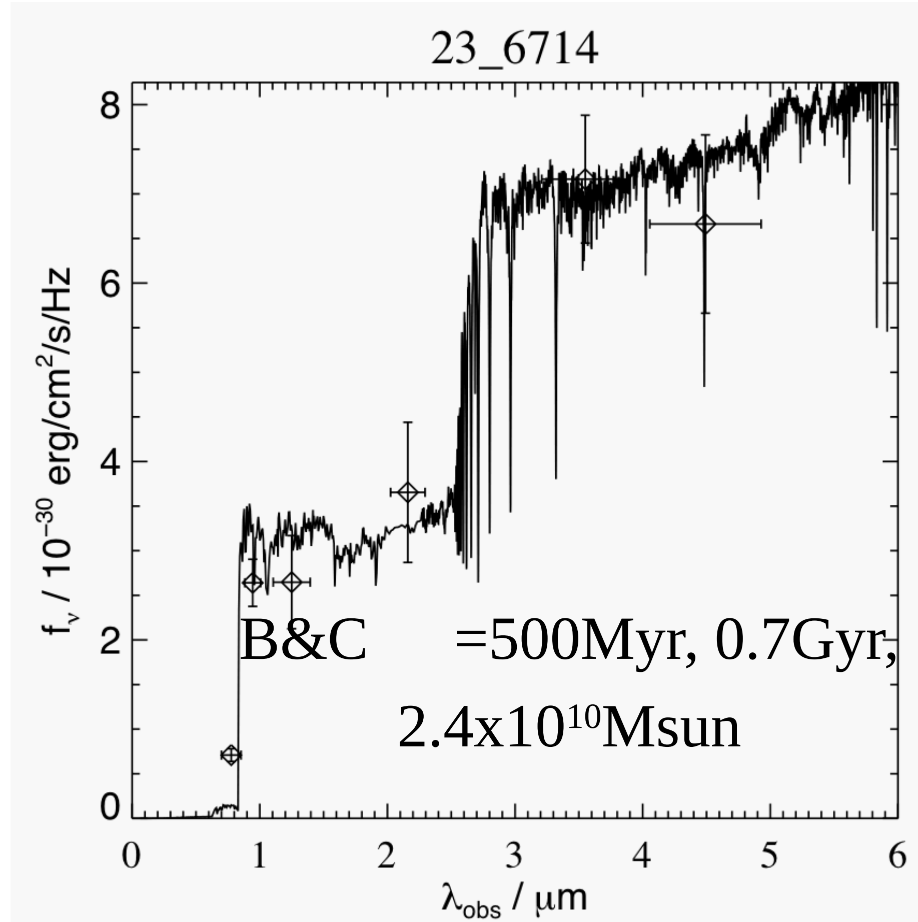


NIRSpec IST

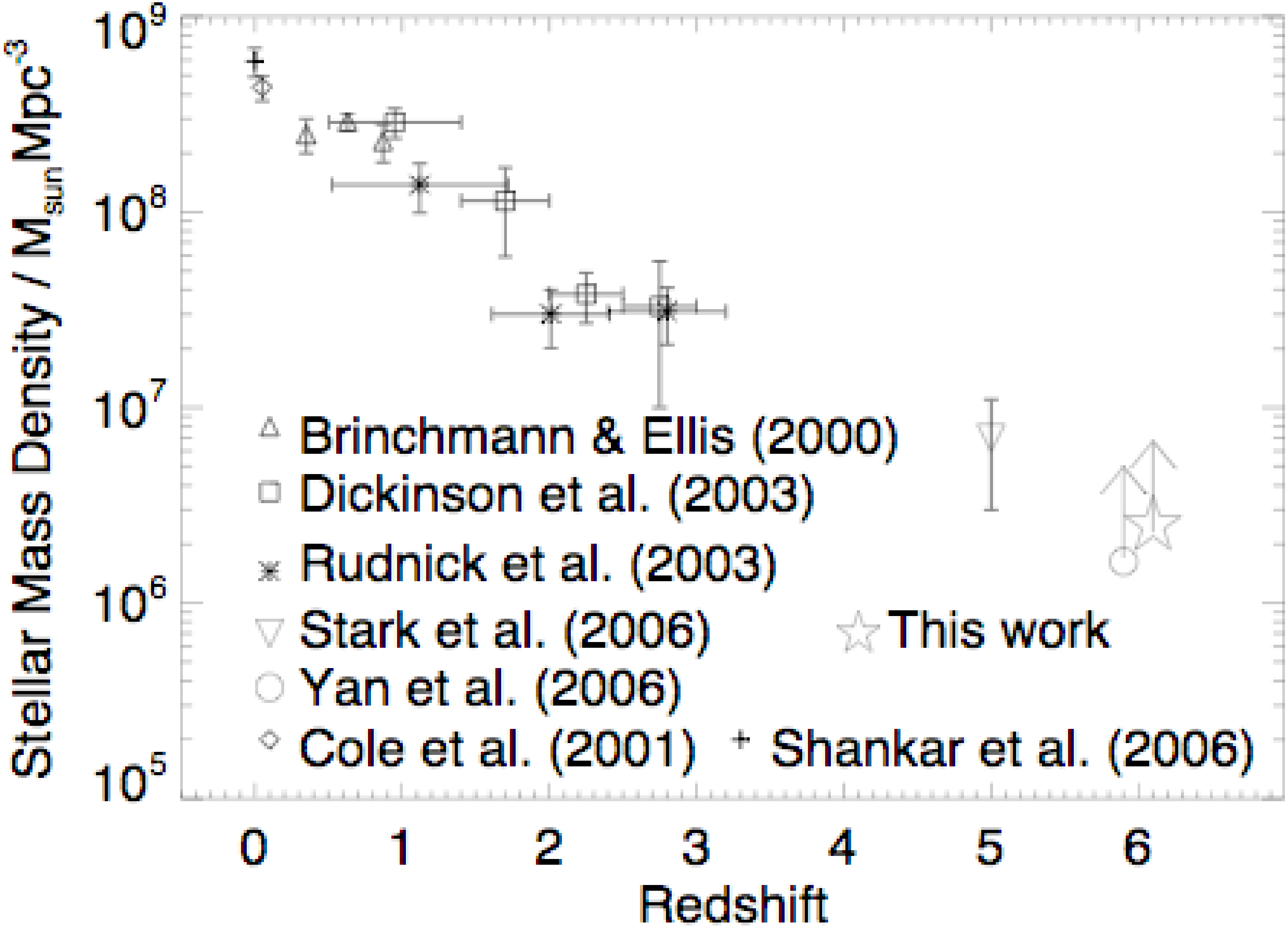

ACS pixels
0
2
4
6
8
1.0
0.8
0.6
0.4
0.2
0.0
normalized surface brightness
SBM03#3
r_{hl}=0.08arcsec
stellar PSF
r_{hl}=0.06arcsec
0.0
0.1
0.2
0.3
0.4
radius / arcsec

Other Population Synthesis Models

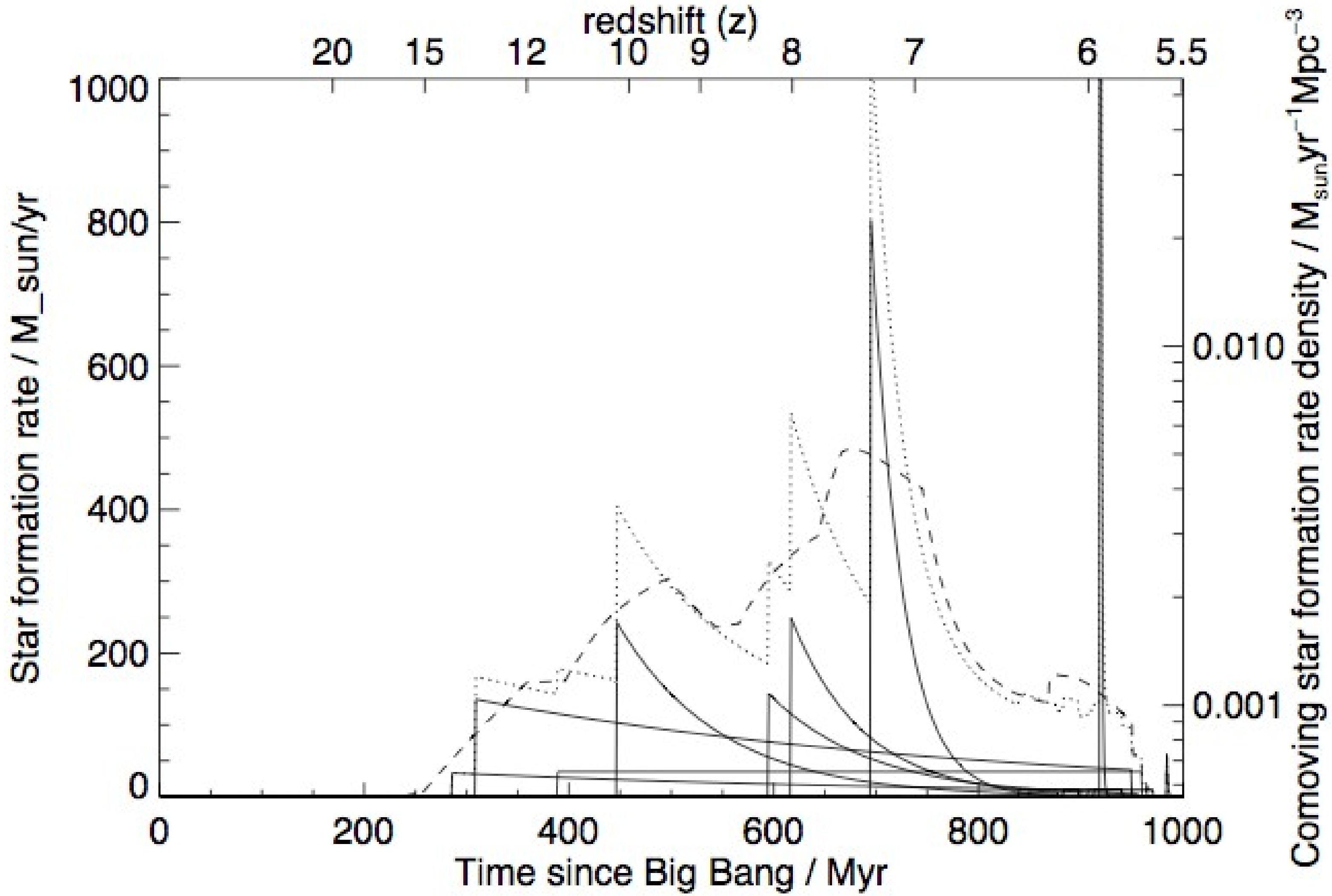




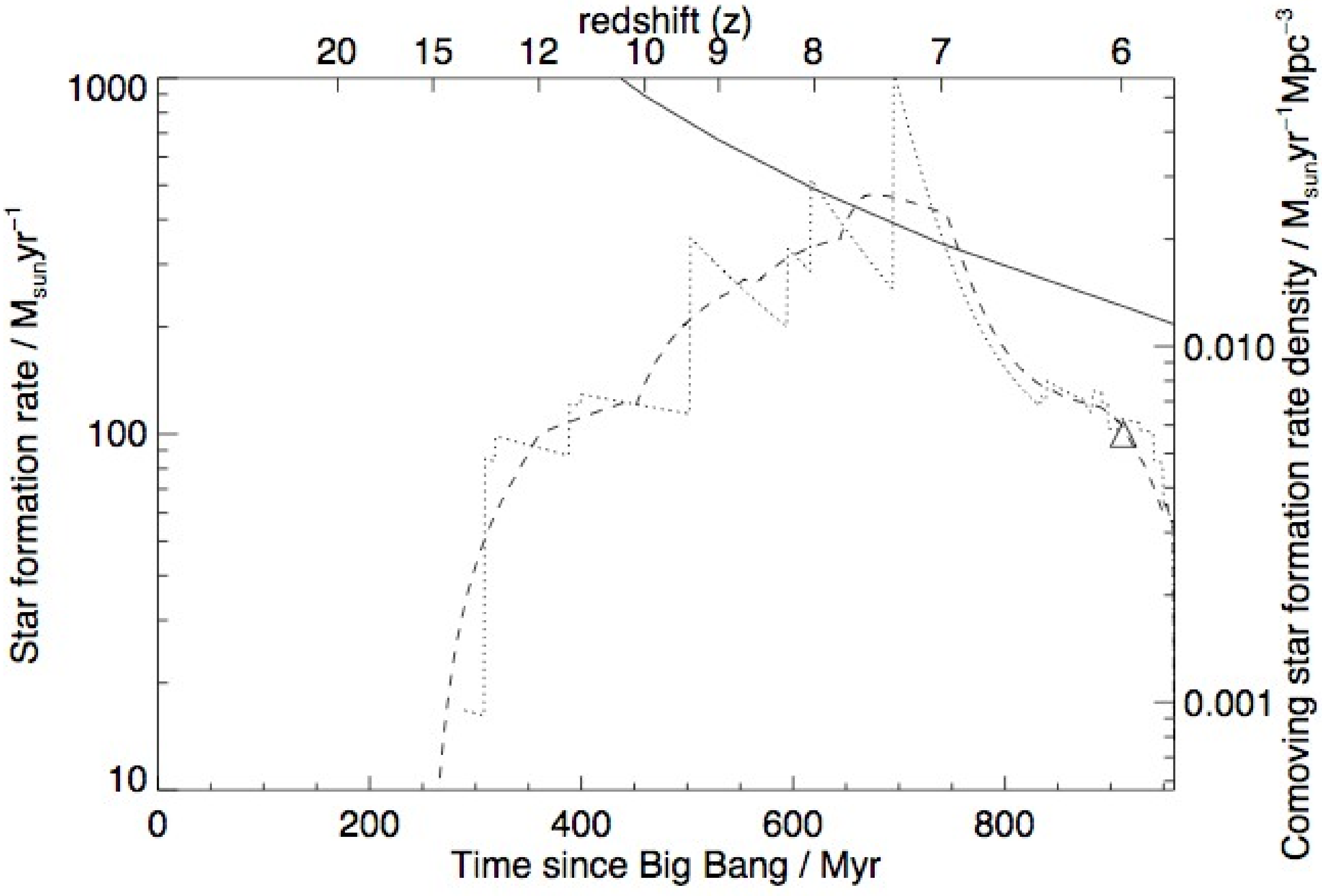
Maraston vs. Bruzual & Charlot - consistent



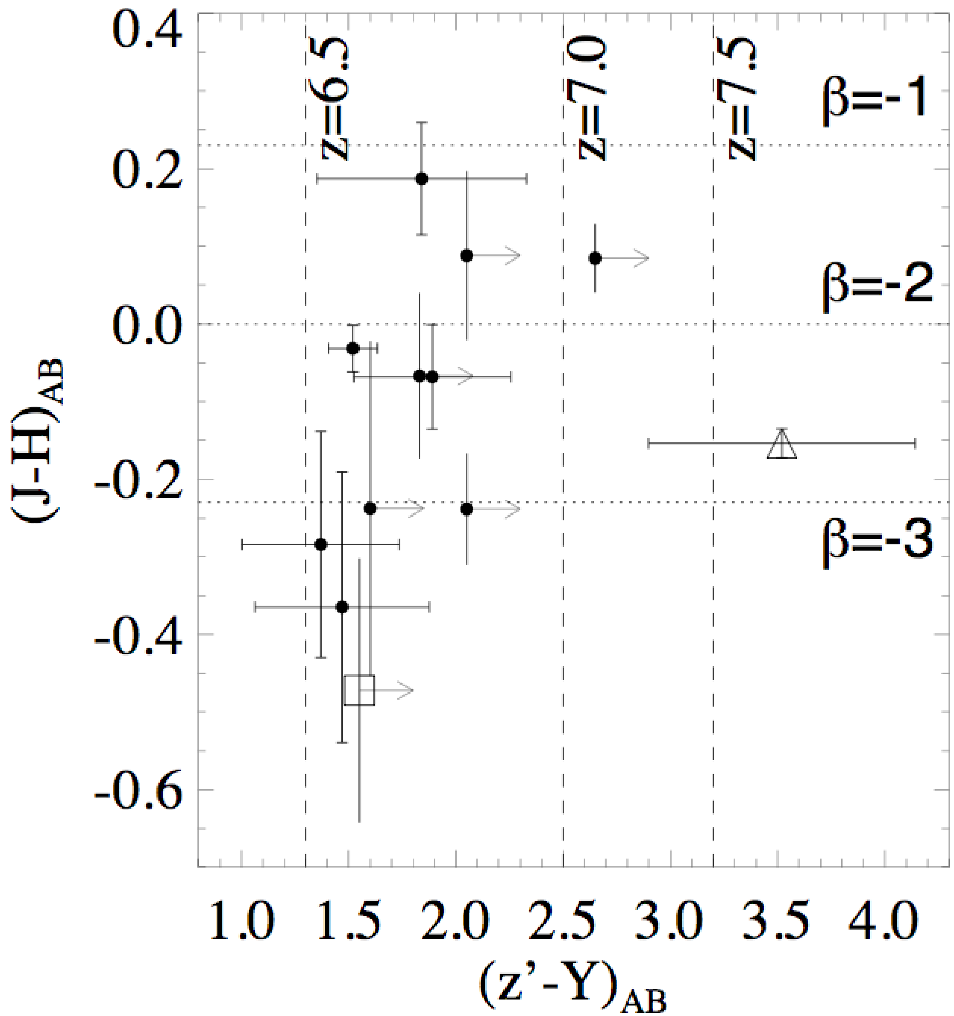
Stellar Mass Density / $M_{sun}Mpc^3$
10^9
10^8
10^7
10^6
10^5
0
1
2
3
4
5
6
Redshift
Brinchmann & Ellis (2000)
Dickinson et al. (2003)
Rudnick et al. (2003)
Stark et al. (2006)
This work
Yan et al. (2006)
Cole et al. (2001)
Shankar et al. (2006)



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

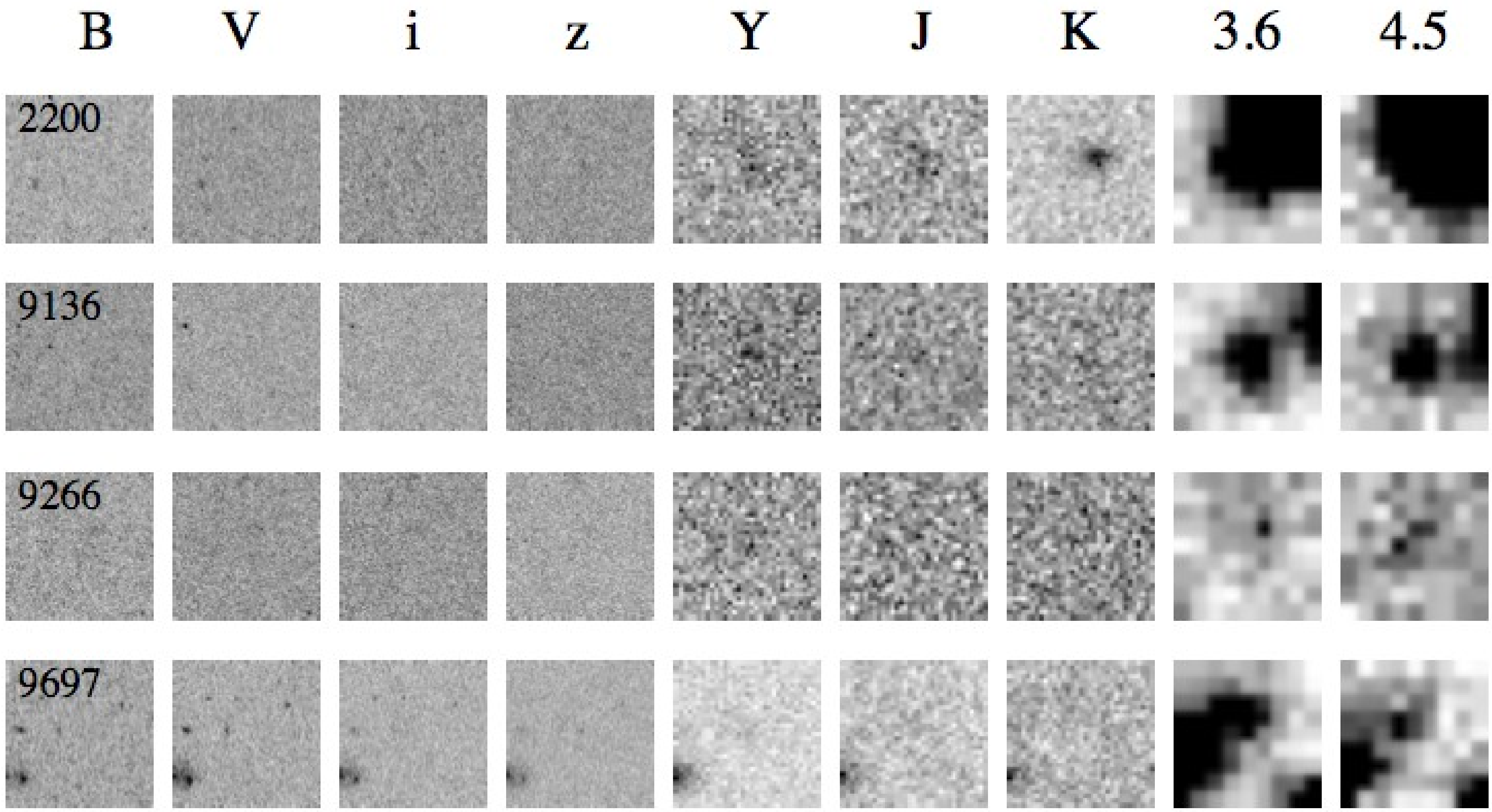


Eyles, Bunker, Ellis et al. astro-ph/0607306



Very blue colours - different IMF? No dust? Low metallicity?

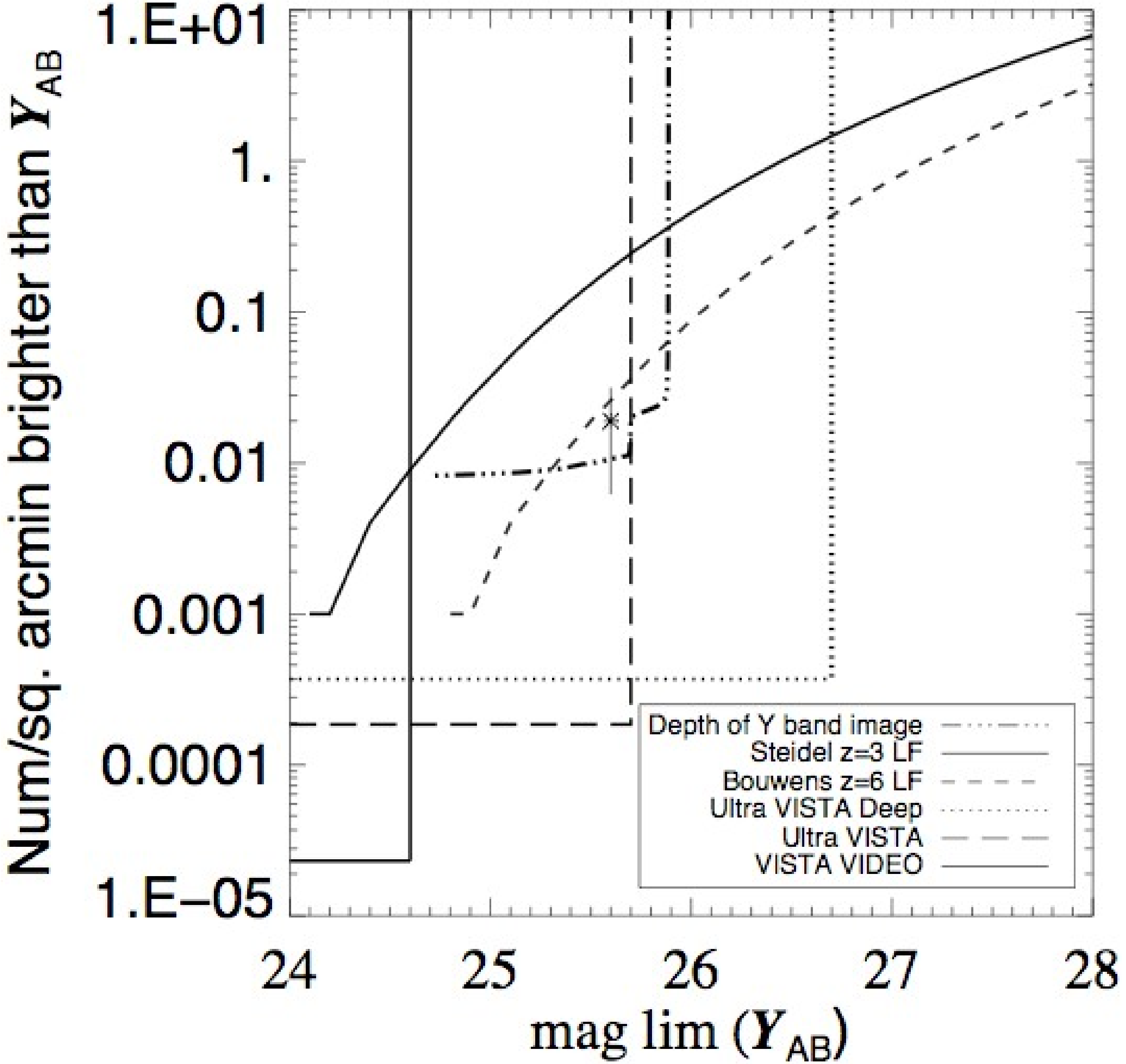
Bunker et al. (2010) MNRAS



Hickey, Bunker, Jarvis, Chiu & Bonf eld (2010 MNRAS):

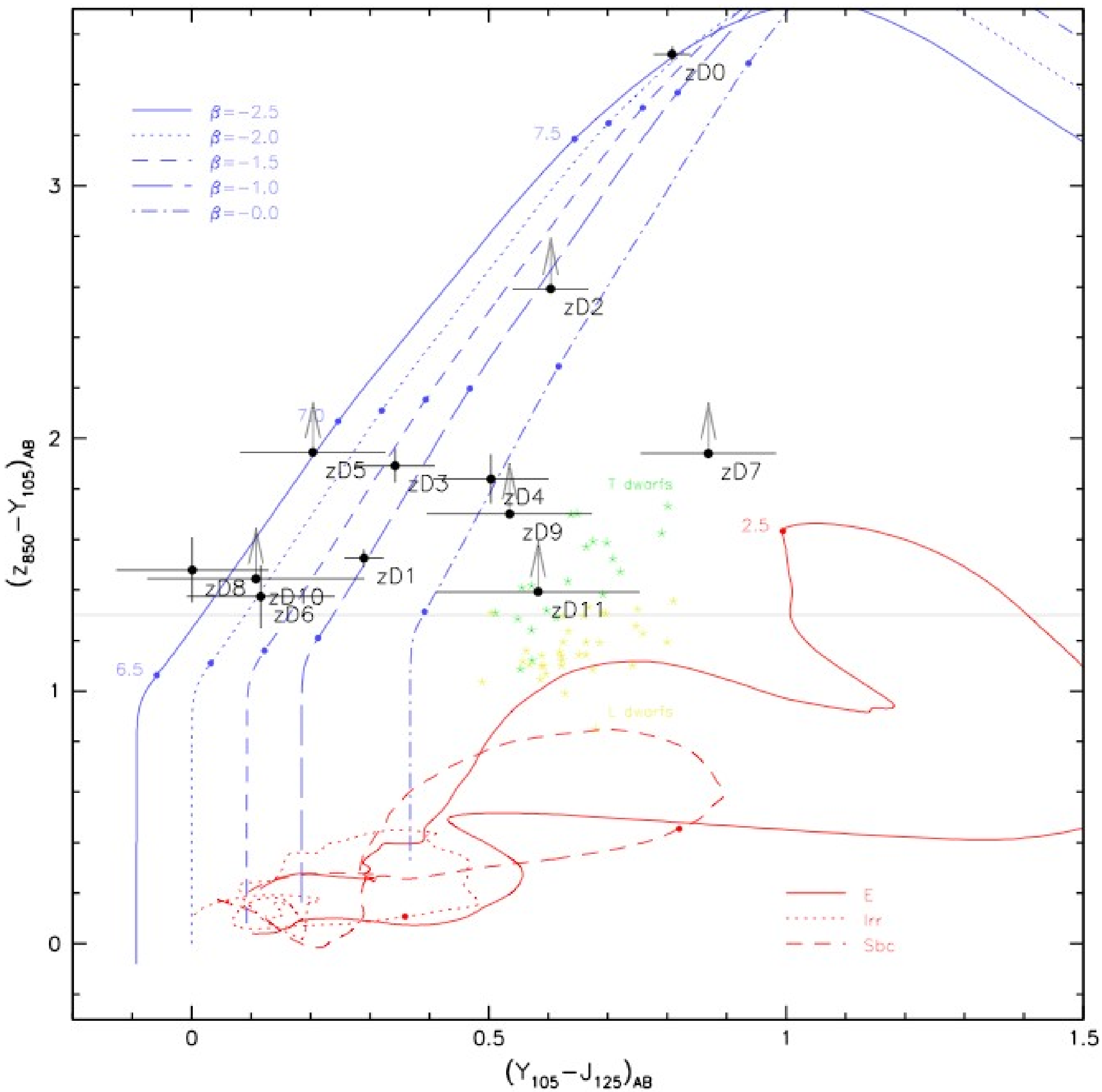
z-band dropout candidates in GOODS-South from HAWK-I

The next-step: f nding galaxies at z>7 to explore stellar pops



ESO/VLT HAWK-I Y-band: look for z-band dropouts At z>7

Samantha Hickey, A. Bunker, Matt Jarvis et al. (2010) MNRAS



Bunker et al (2009) - HST/WFC3 near-IR imaging of the HUDF