Selection of Galaxies at high-z: techniques and datasets

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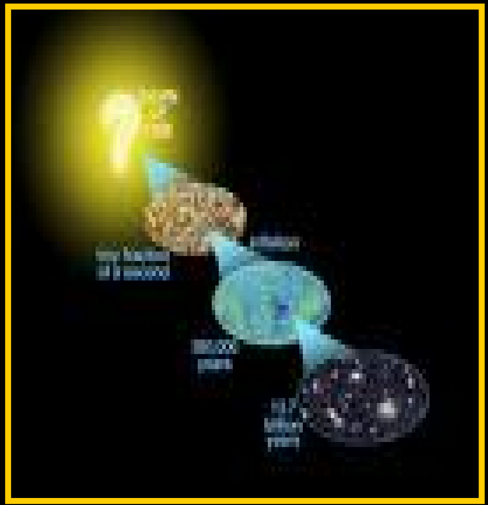
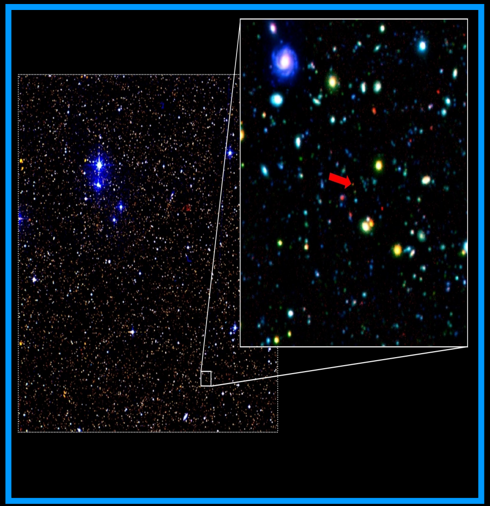
Outline

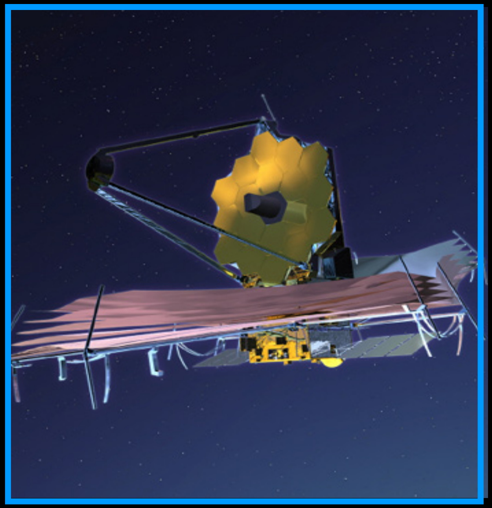


Motivation
Selecting high-z galaxies



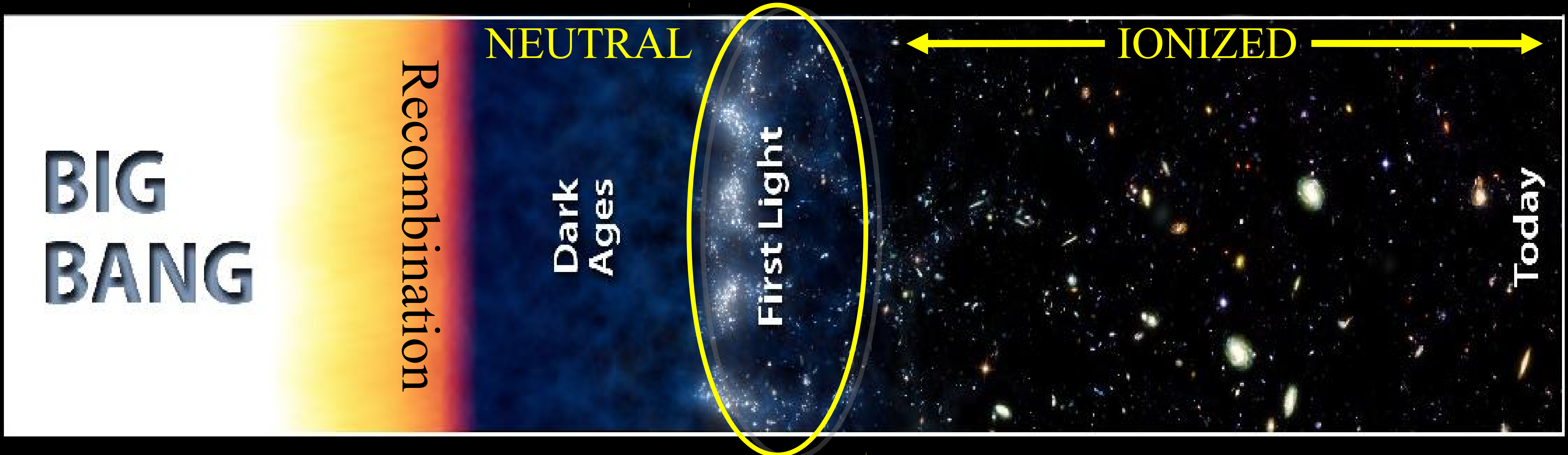
High-redshift galaxies:
$z>3$

Results: Physical properties

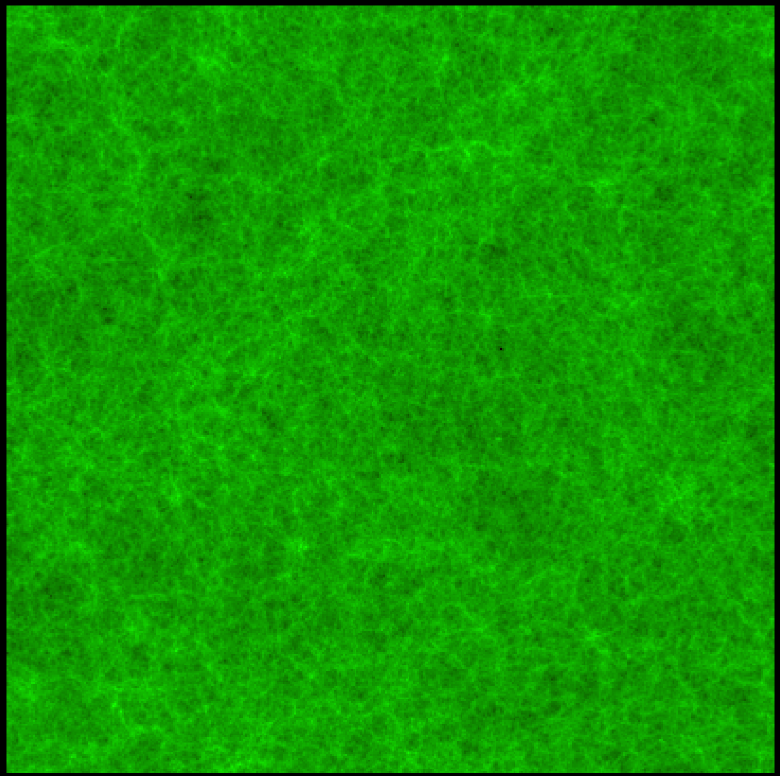


Future Prospects

Motivation



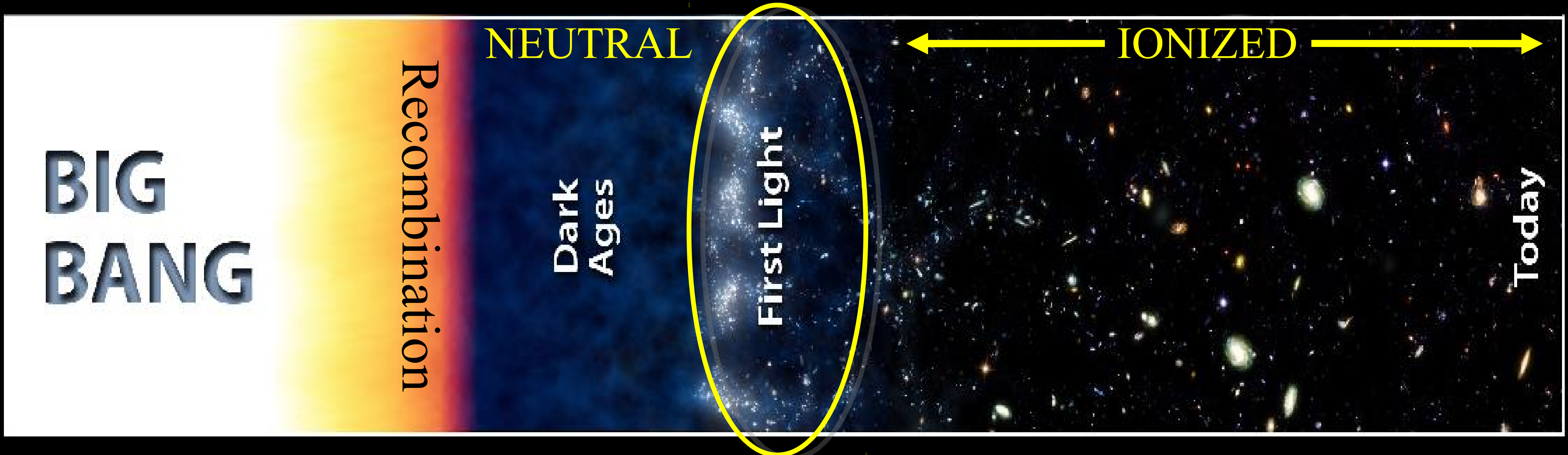
"EPOCH OF REIONIZATION"



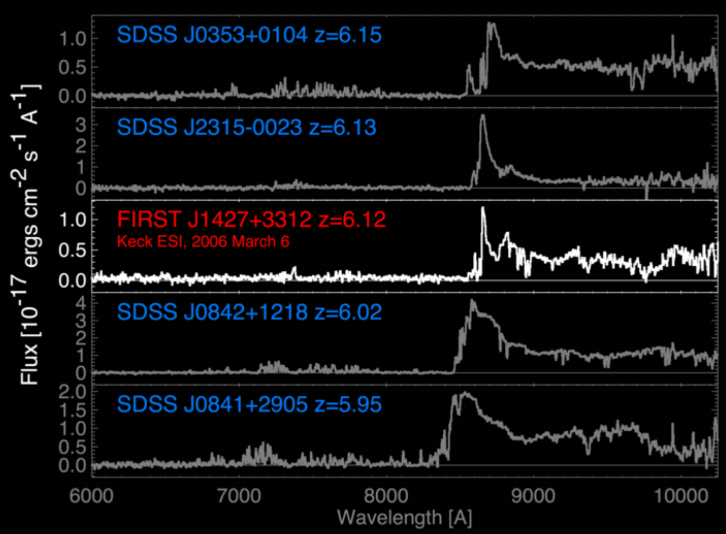
Neutral Hydrogen

Ionized Hydrogen

Motivation



"EPOCH OF REIONIZATION"



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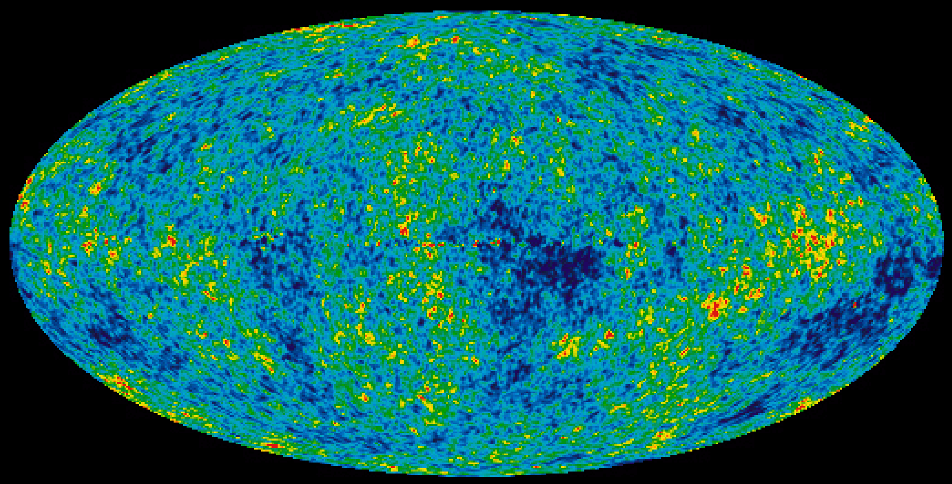
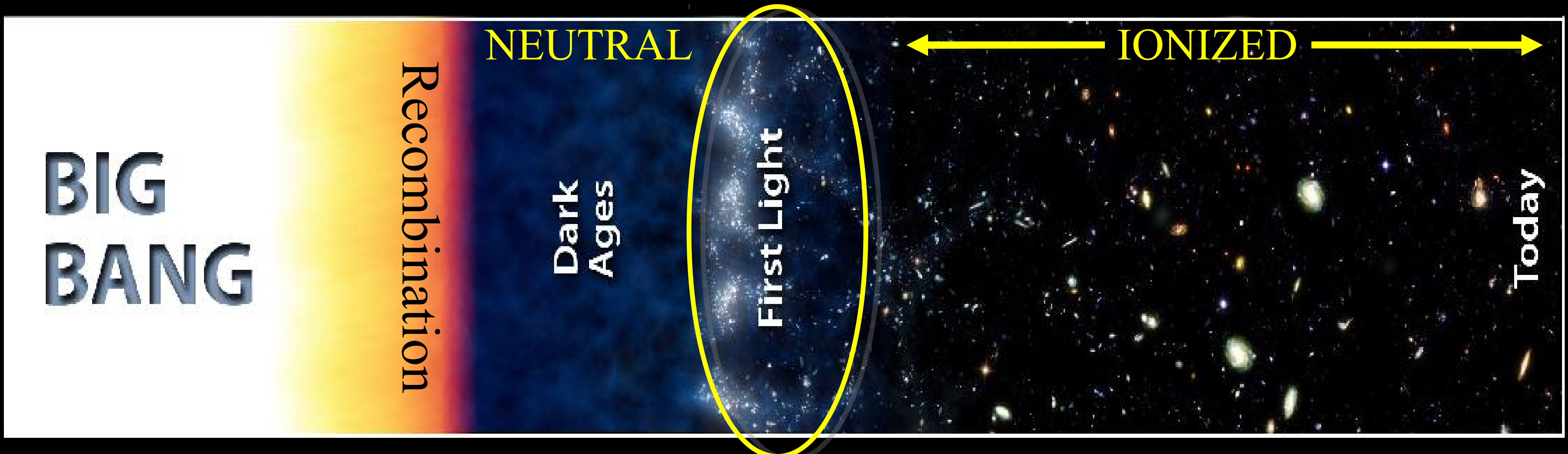


=> $6 < z < 10$

- Gunn-Peterson troughs suggest reionization ending at z=6

- WMAP 7-year results suggest τ=0.088+/-0.014
  Komatsu et al. (2011)
- Implies reionization at z=10.6 +/- 1.2

Motivation



"EPOCH OF REIONIZATION"

Obvious questions:

- What type of objects reionized the Universe?
- Are there enough galaxies/quasars to do the job?
- Can we measure their physical properties (masses, sizes, SFRs, extinction, ages, etc) ?
- Are they consistent with current galaxy formation models?

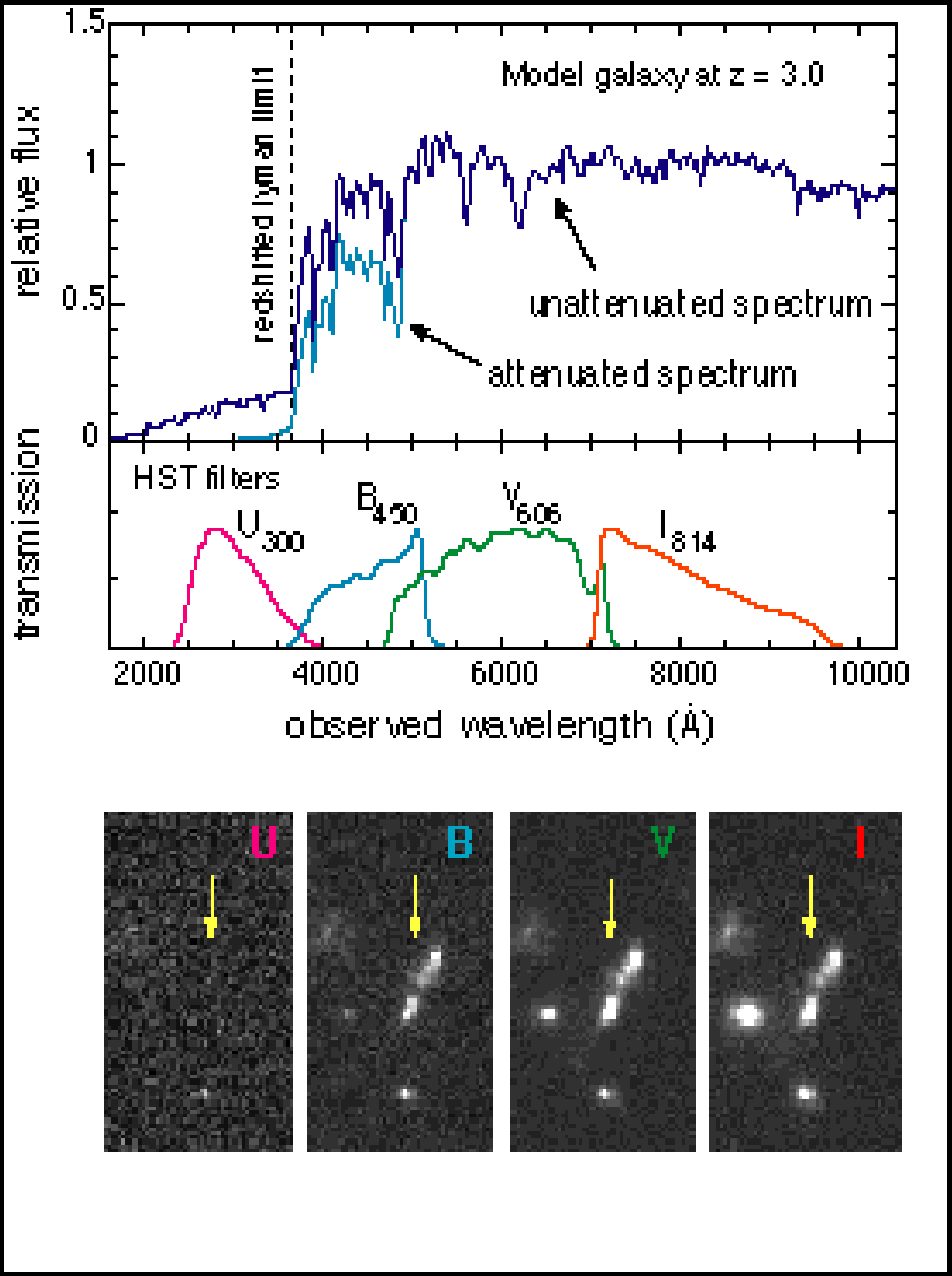
Selection of high-z galaxies

- How can we select galaxies at high-z ?

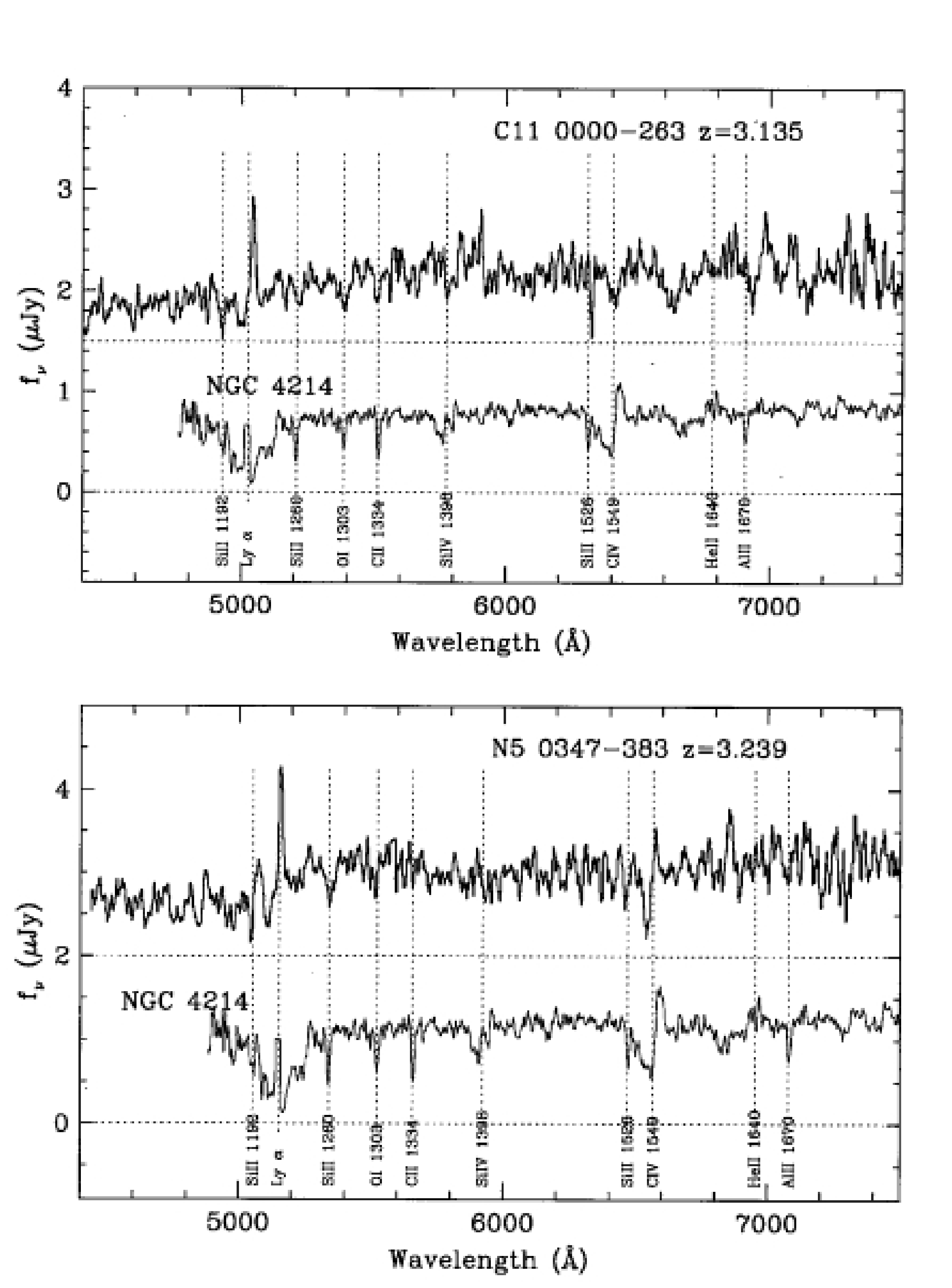
There are 9 (7 independent) methods to select high-z galaxies

The first galaxies at z>3 were selected ~20 years ago (first idea by Meier 1976):
-color selection (Steidel & Hamilton 1993)
-Radio galaxies (Lilly 1988; McCarthy 1993)

1-Lyman Break Galaxies (LBGs)

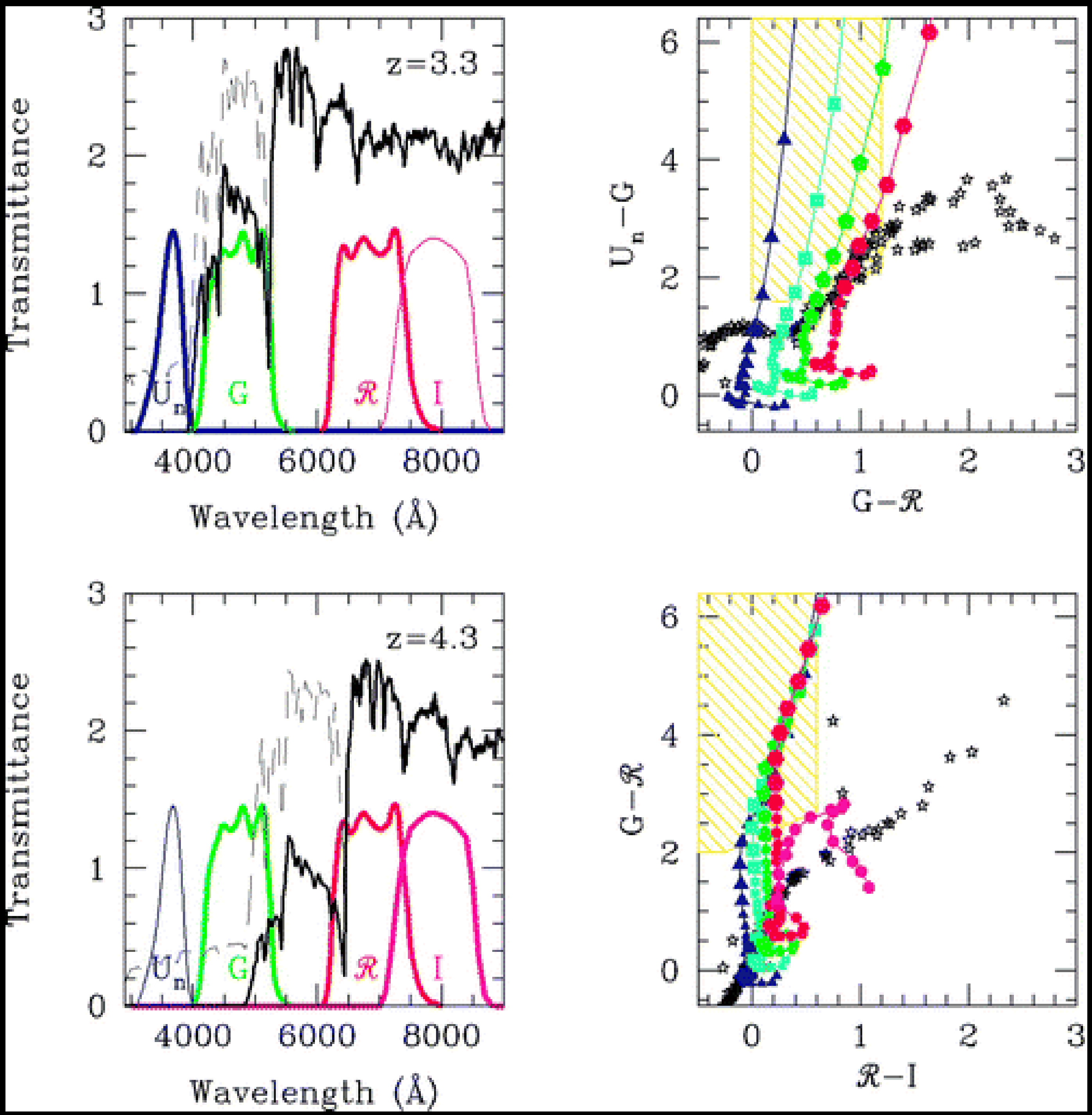


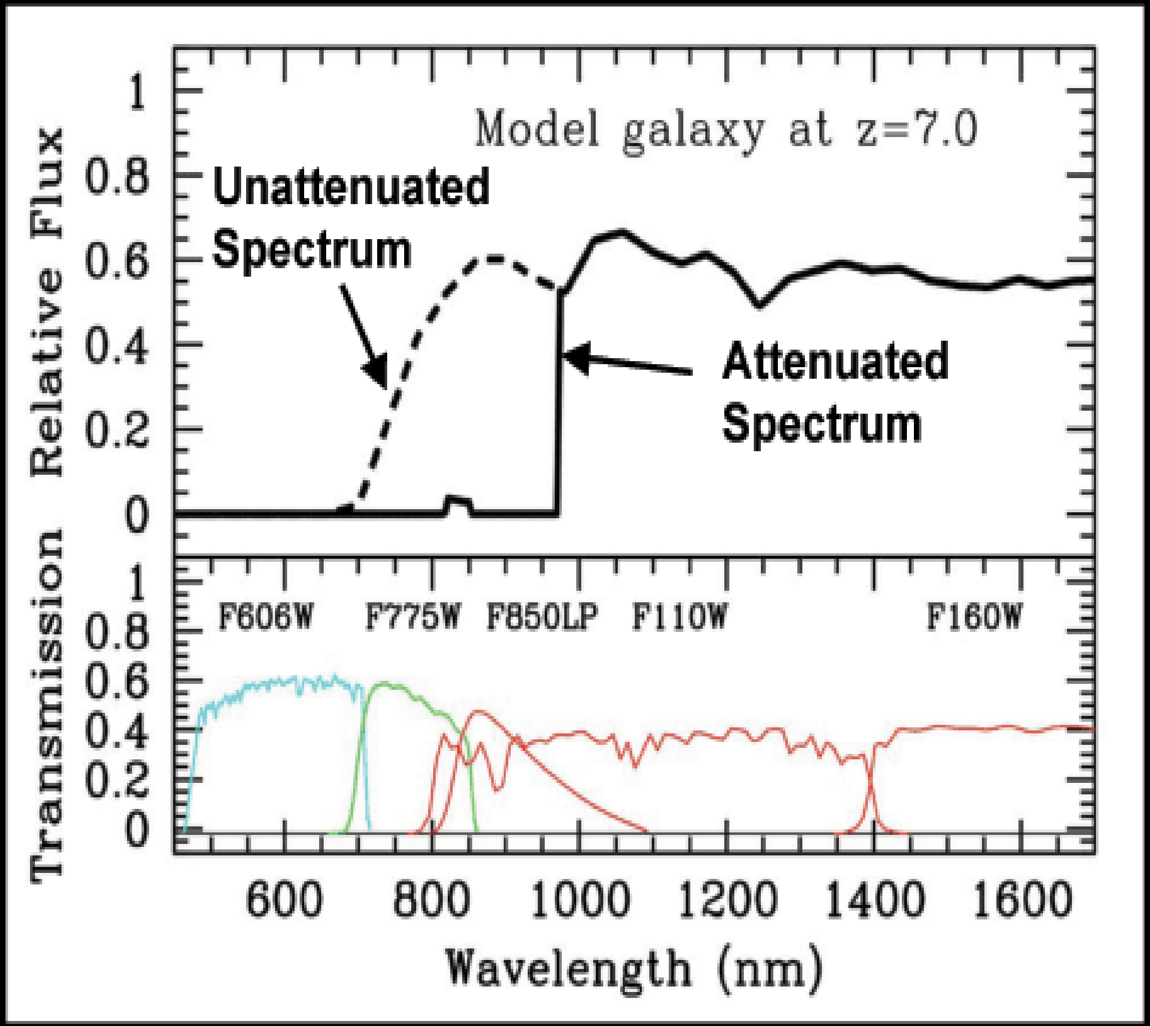
At lambda<912 A rest frame ISM absorbs all UV photons: dropout galaxy

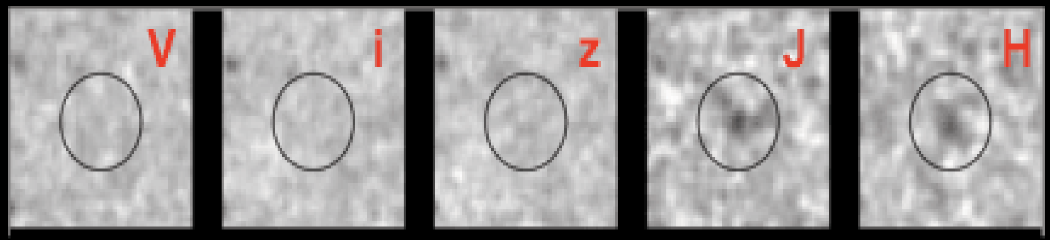


U-dropout z~3 (Steidel et al.1996)

LBGs





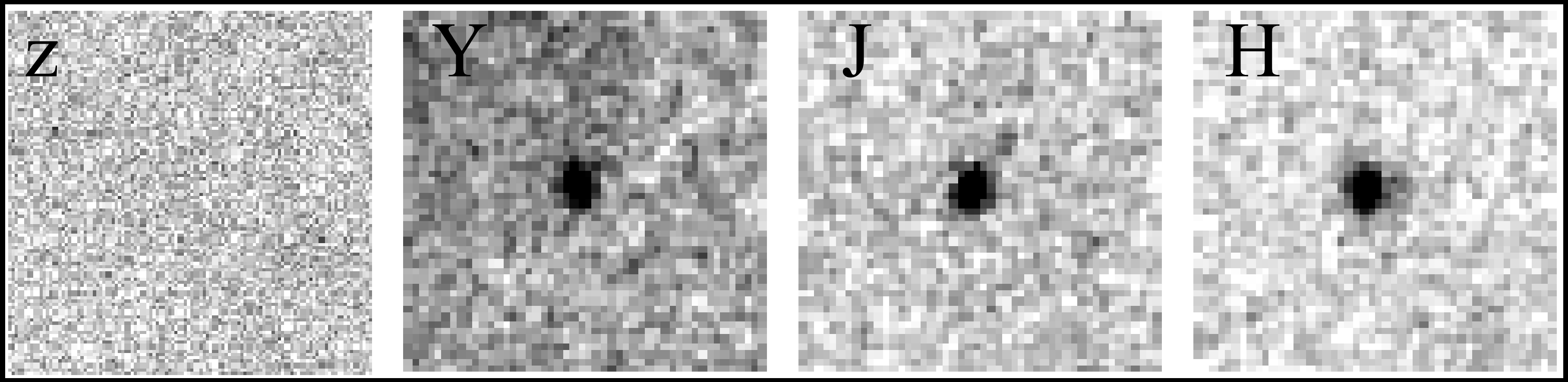


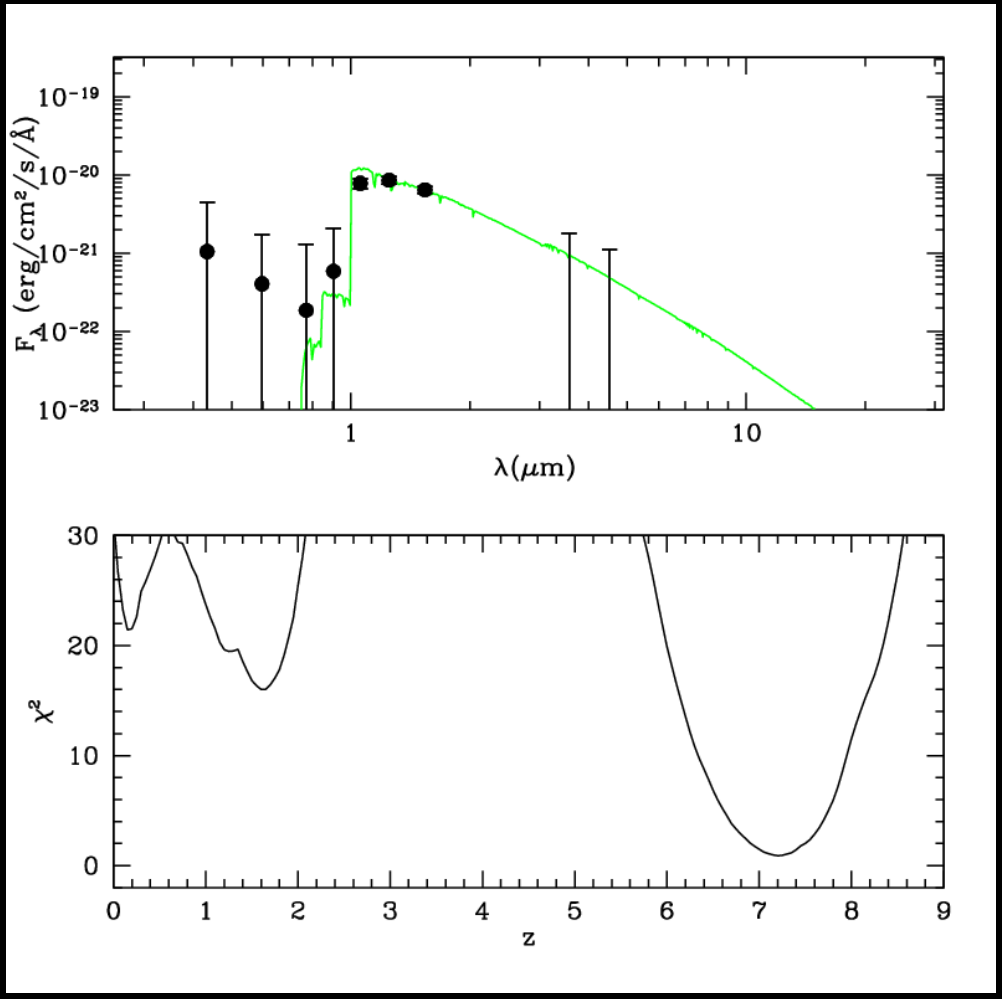
The dropout method works at all redshifts:
U-drop z~3, B-drop z~4, V-drop z~5, etc..

At z>6-7 the IGM starts to absorb completely at lambda<1216 A rest
z=6 i-dropout z=7 z-dropout

WFC3 Imaging of the HUDF: Example SED fits

McLure, Dunlop, Cirasuolo et al. 2009, MNRAS, accepted

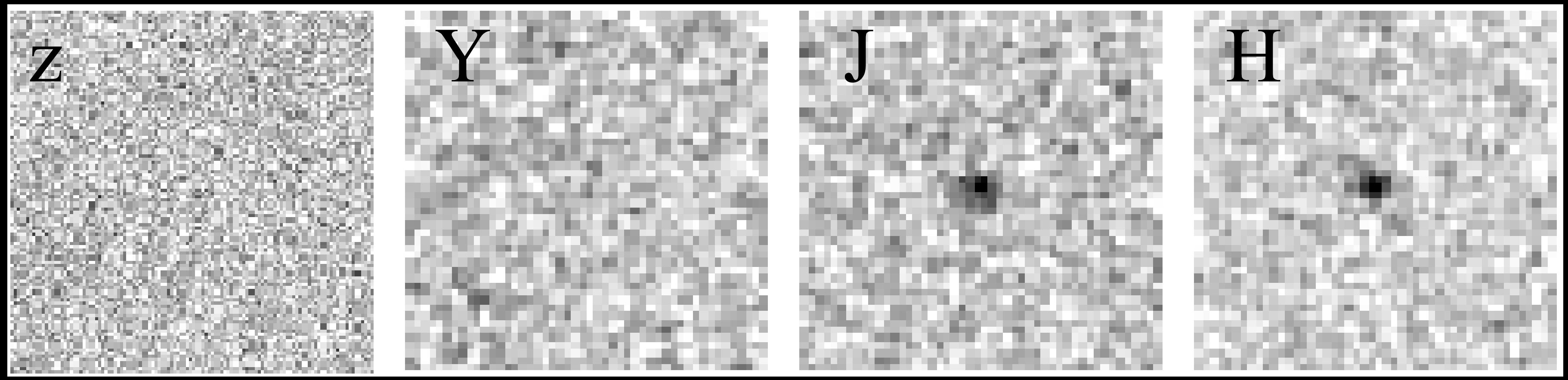


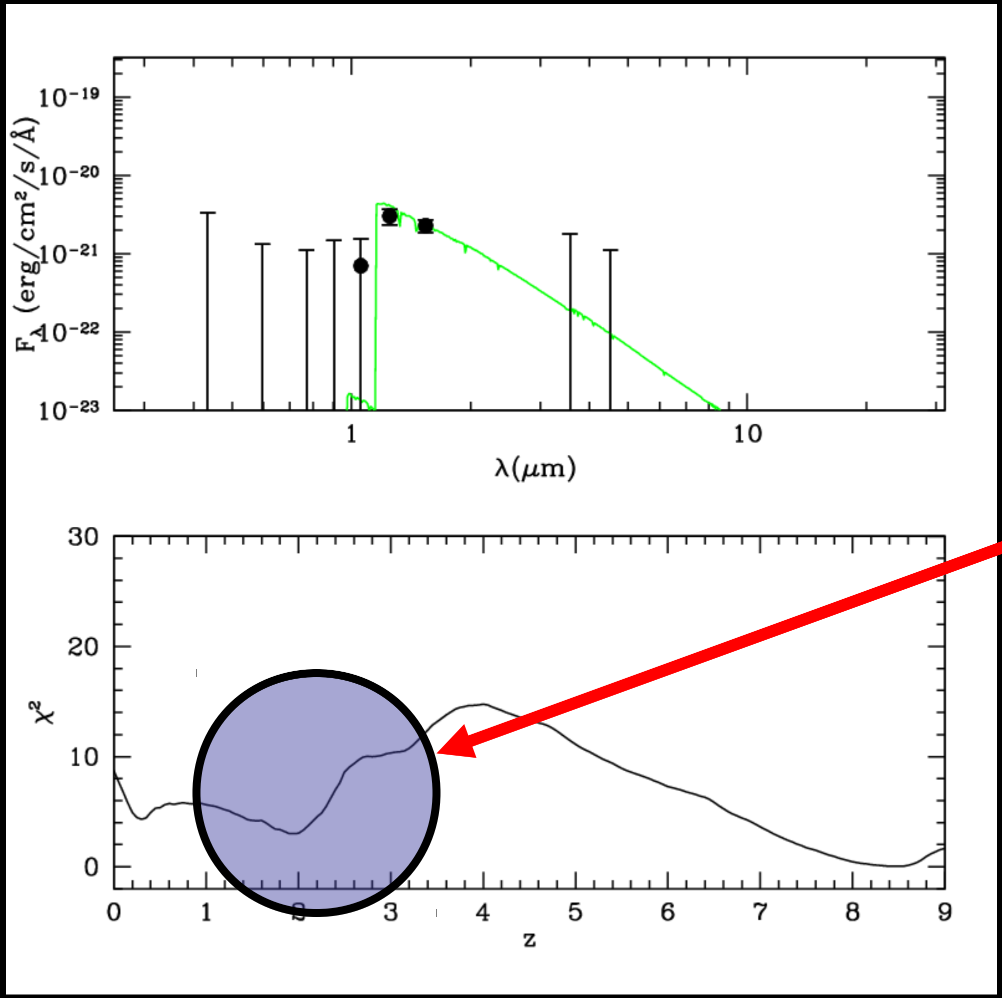


ID No. 835 z_{phot} = 7.20

WFC3 Imaging of the HUDF: Example SED fits

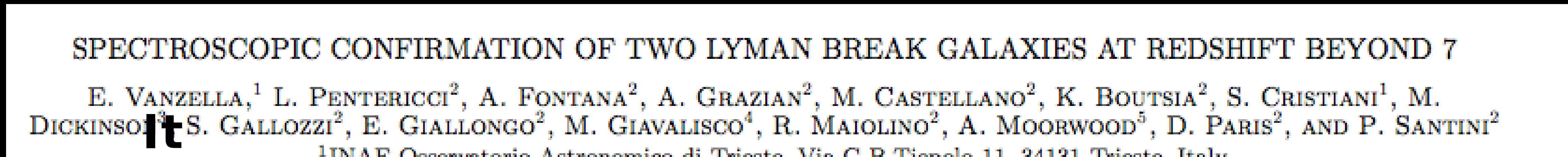
McLure, Dunlop, Cirasuolo et al. 2009, MNRAS, accepted





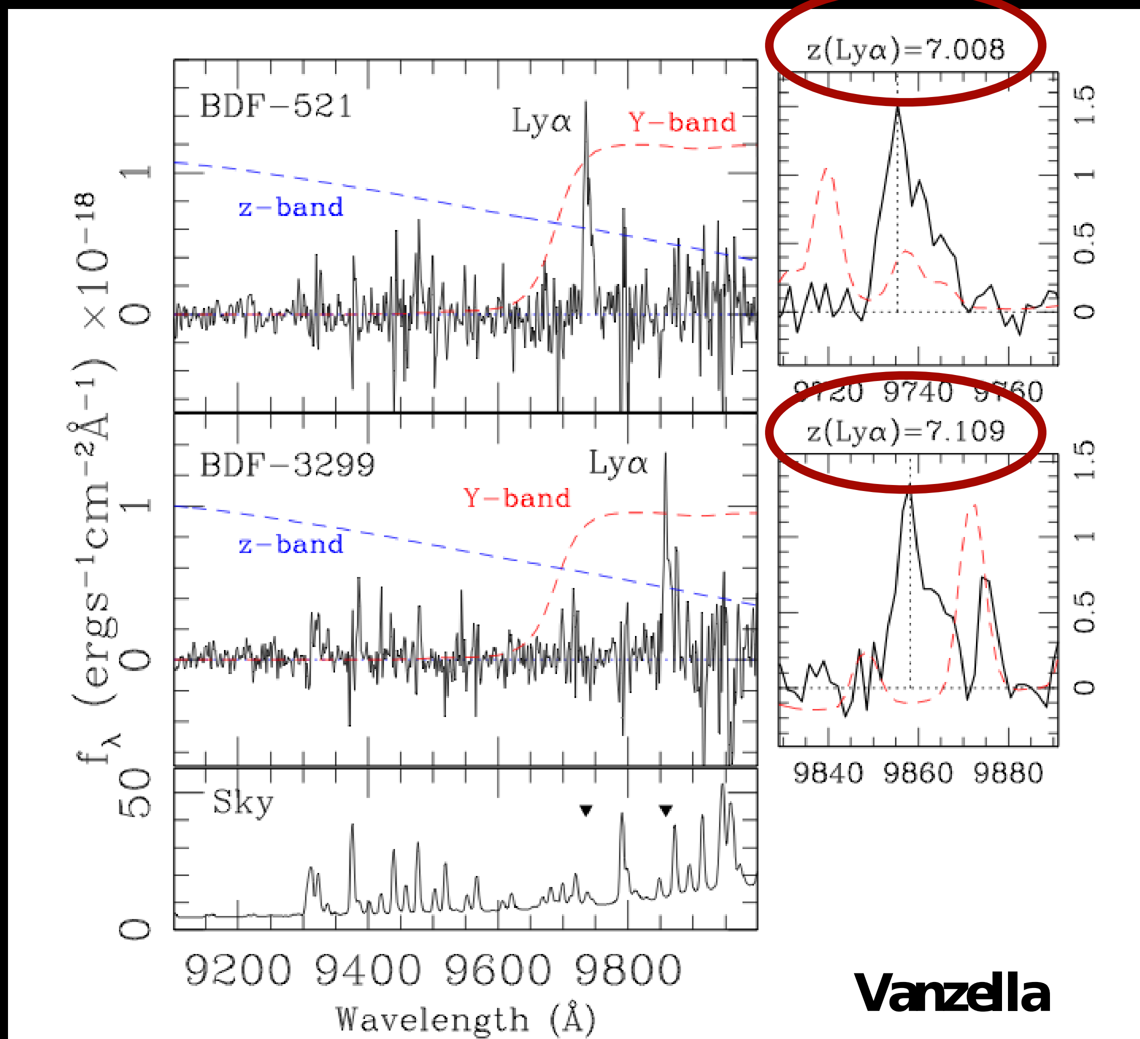
Can't rule-out plausible low-z alternative solution

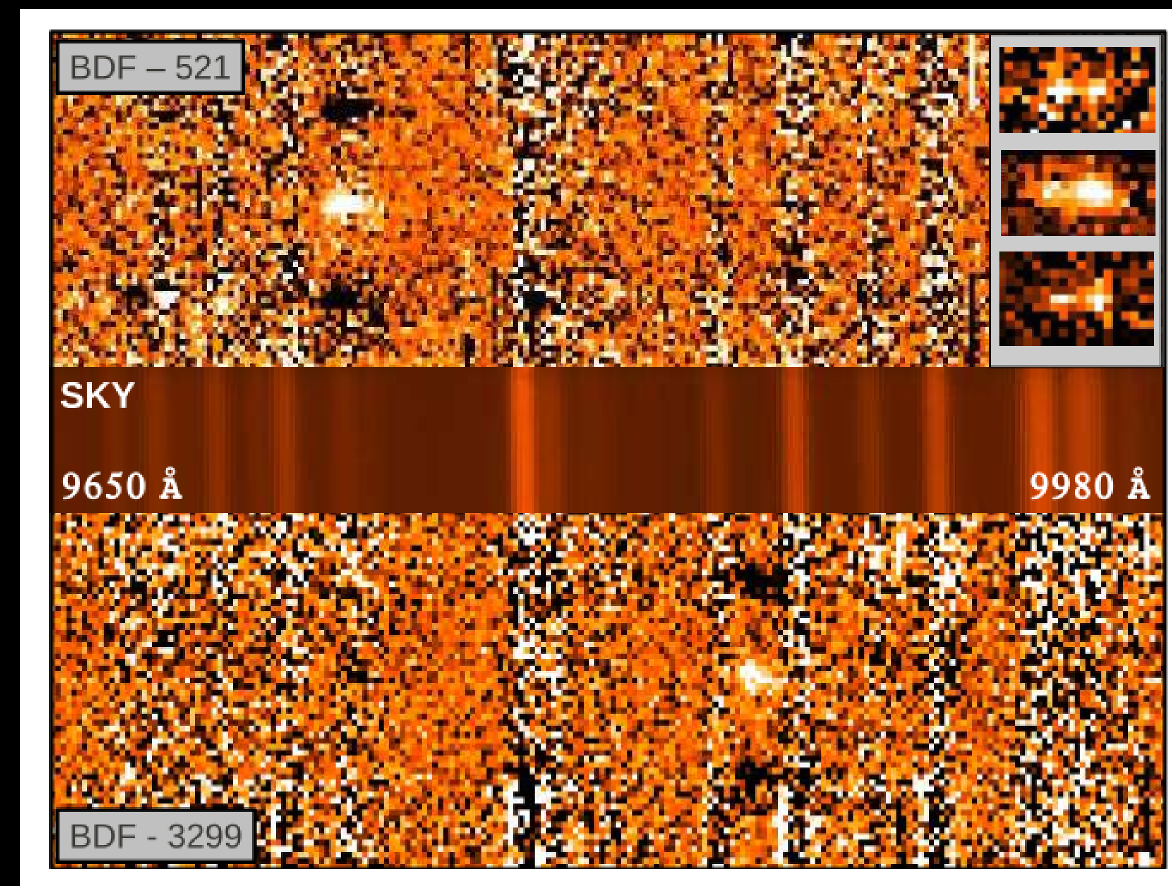
ID No. 1721 z_{phot} = 8.45


SPECTROSCOPIC CONFIRMATION OF TWO LYMAN BREAK GALAXIES AT REDSHIFT BEYOND 7

E. Vanzella,[1] L. Pentericci[2], A. Fontana[2], A. Grazian[2], M. Castellano[2], K. Boutsia[2], S. Cristiani[1], M. Dickinson[3], S. Gallozzi[2], E. Giallongo[2], M. Giavalisco[4], R. Maiolino[2], A. Moorwood[5], D. Paris[2], and P. Santini[2]

It





Emission lines show typical asymmetry expected for Lyα

EW =50-60Å

L ~ 10^42 erg/s/cm2

SFR (Lyα) ~ 5-10 M**sun**/yr

(Vanzella et al. 2011)

Final sample: combination of 3 fields
GOODS-S + NTTDF +BDF4

Targets: 20 high quality candidates

5 confirmed redshifts   6.7<z<7.1

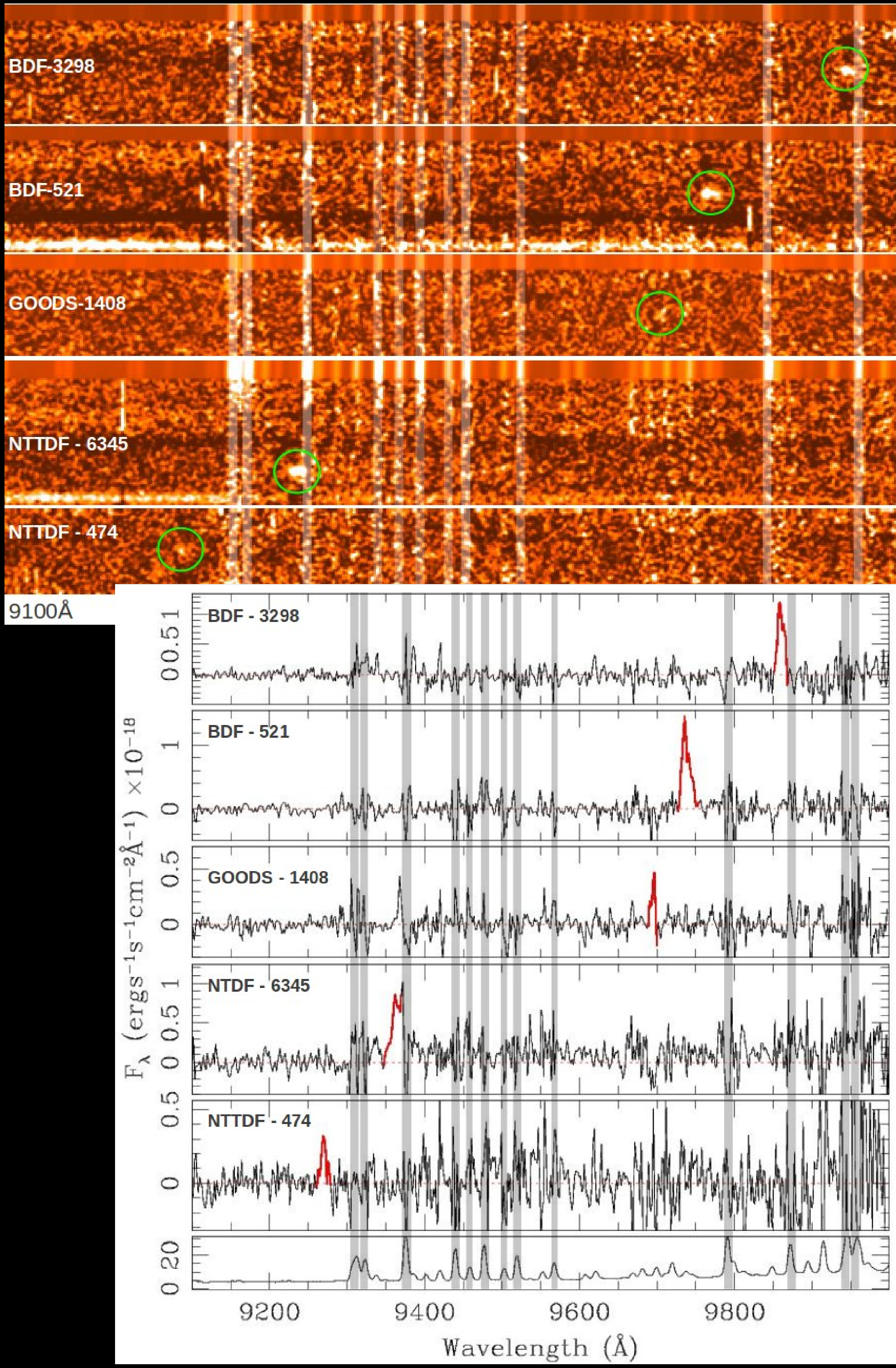
Only 2 with EW>50Å

1 confirmed interloper at lower   redshift (z=5.8)

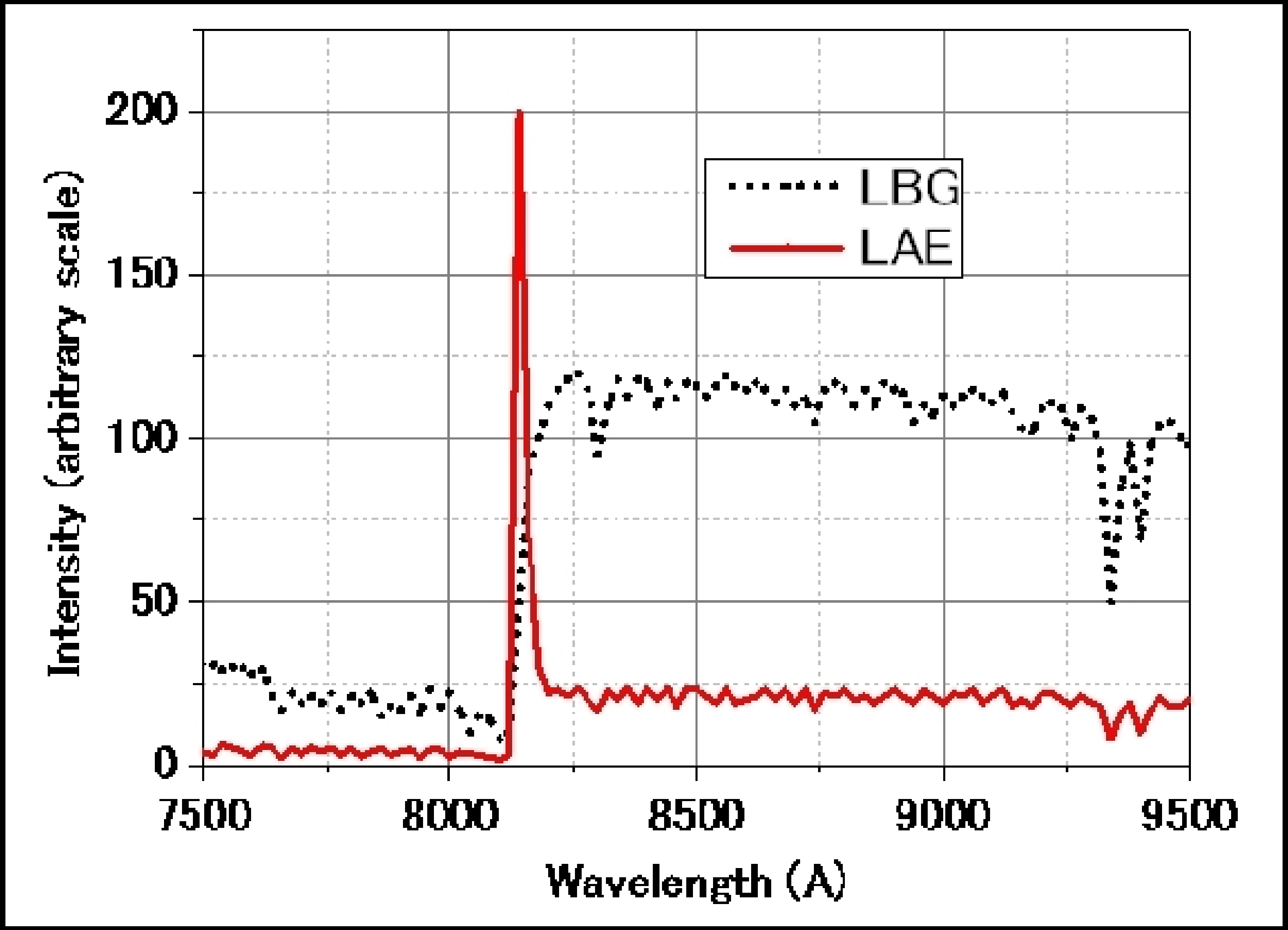
In addition, many i-dropout used as slit fillers were confirmed at z~6, including several faint continuum-only objects (with Lyman break)→ interloper rate is below 20%

(Pentericci et al. 2011; Vanzella et al. 2011)

Most distant LBG z=7.213 (Ono et al. 2012)



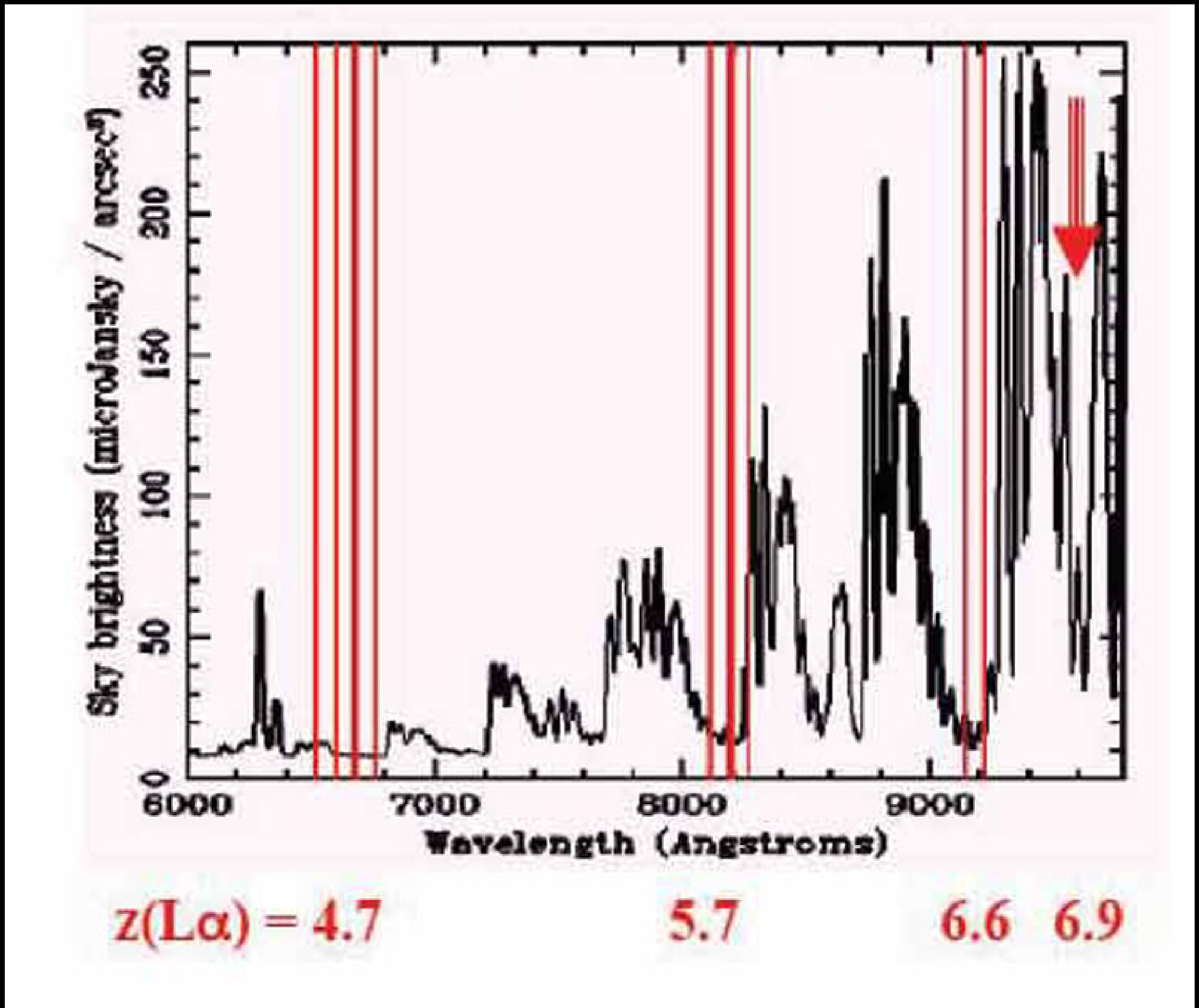
2-Lyman Alpha Emitters (LAEs)

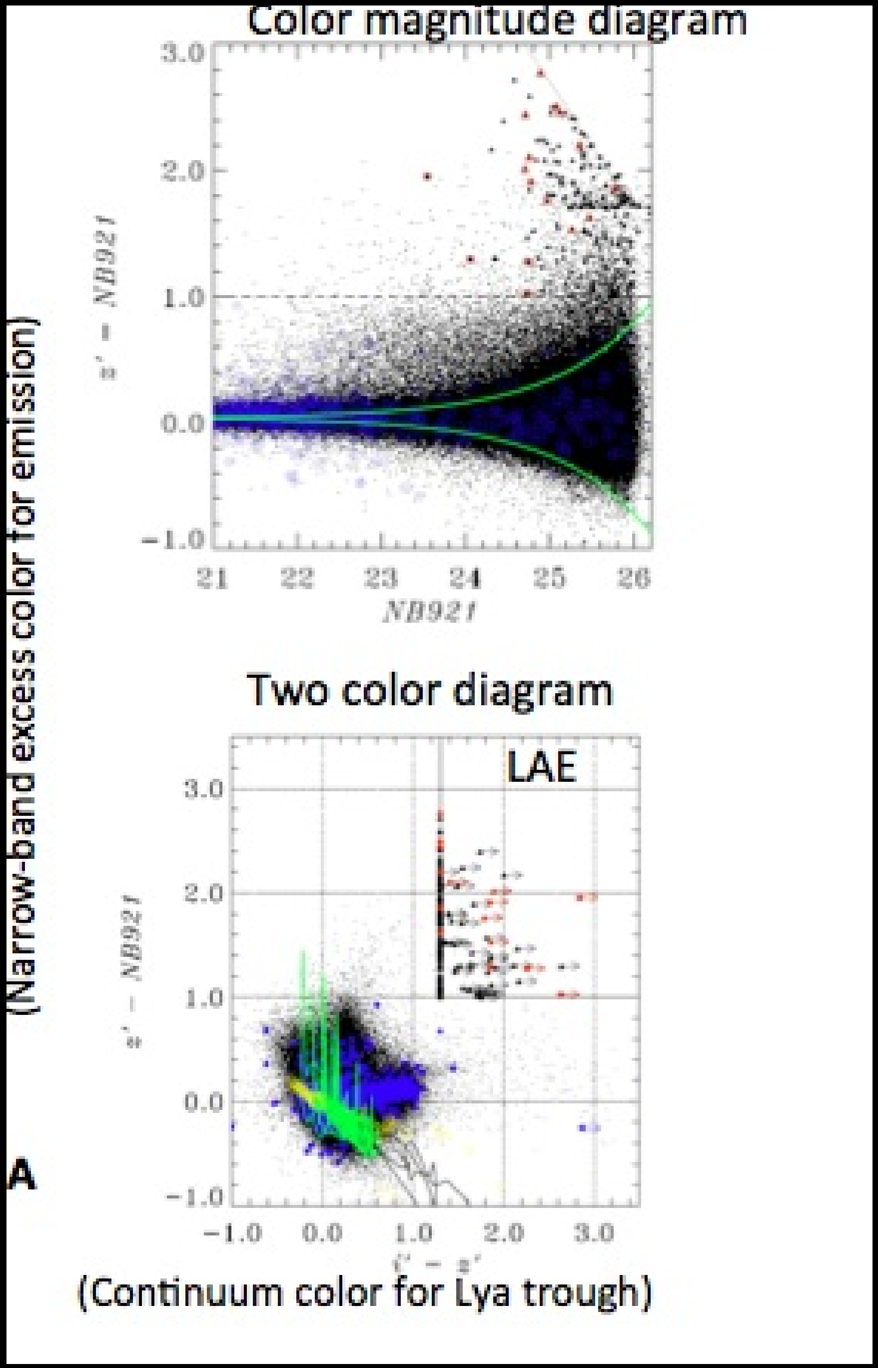


Lyman alpha by hydrogen atoms excited by UV photons from young stars

LAEs have strong Lyman alpha emission and weak UV continuum
LAEs are young galaxies and relatively dust free

It is still debated if LAEs and LBGs are the same type of galaxies (Dayal et al. 2011)

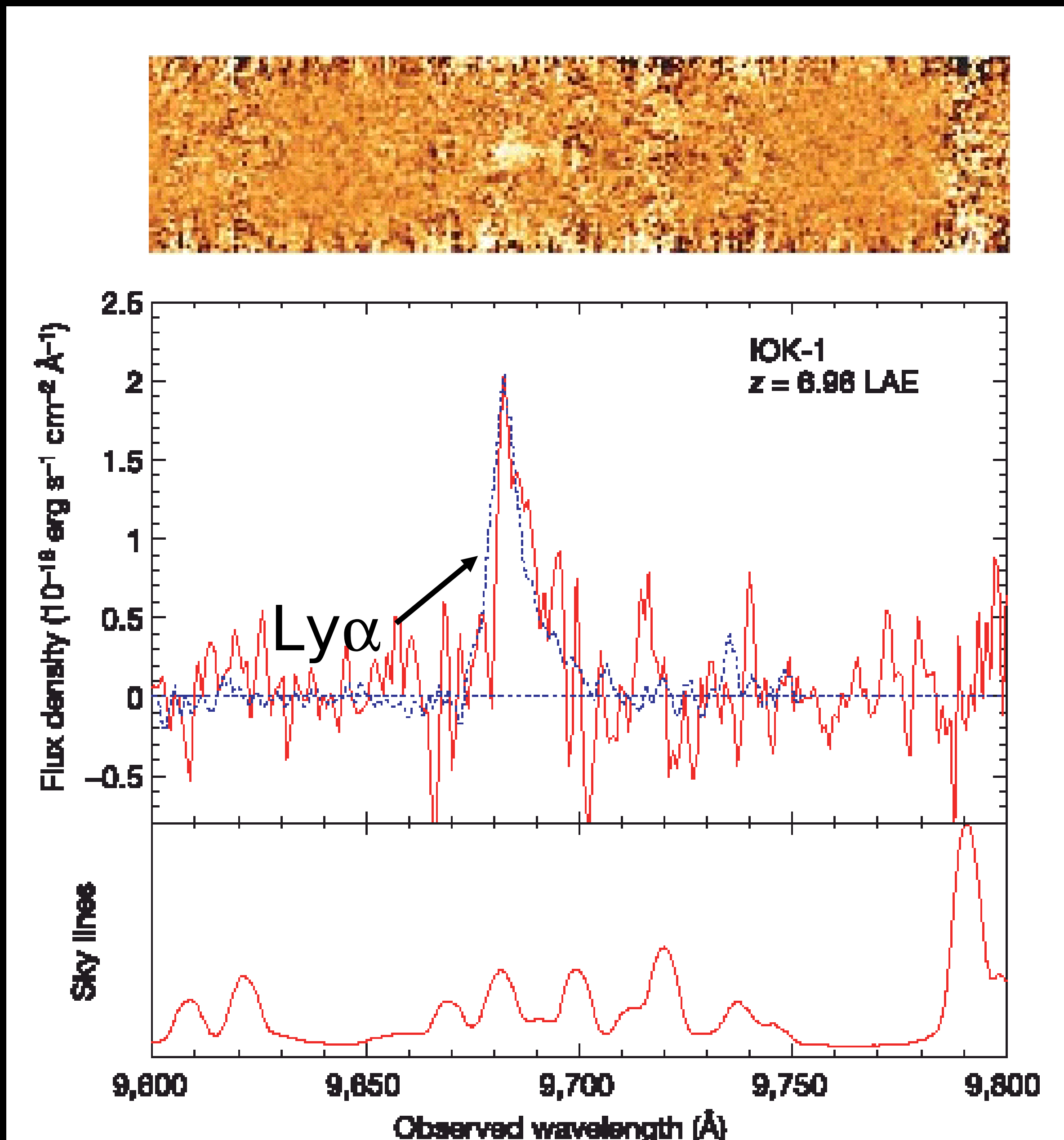




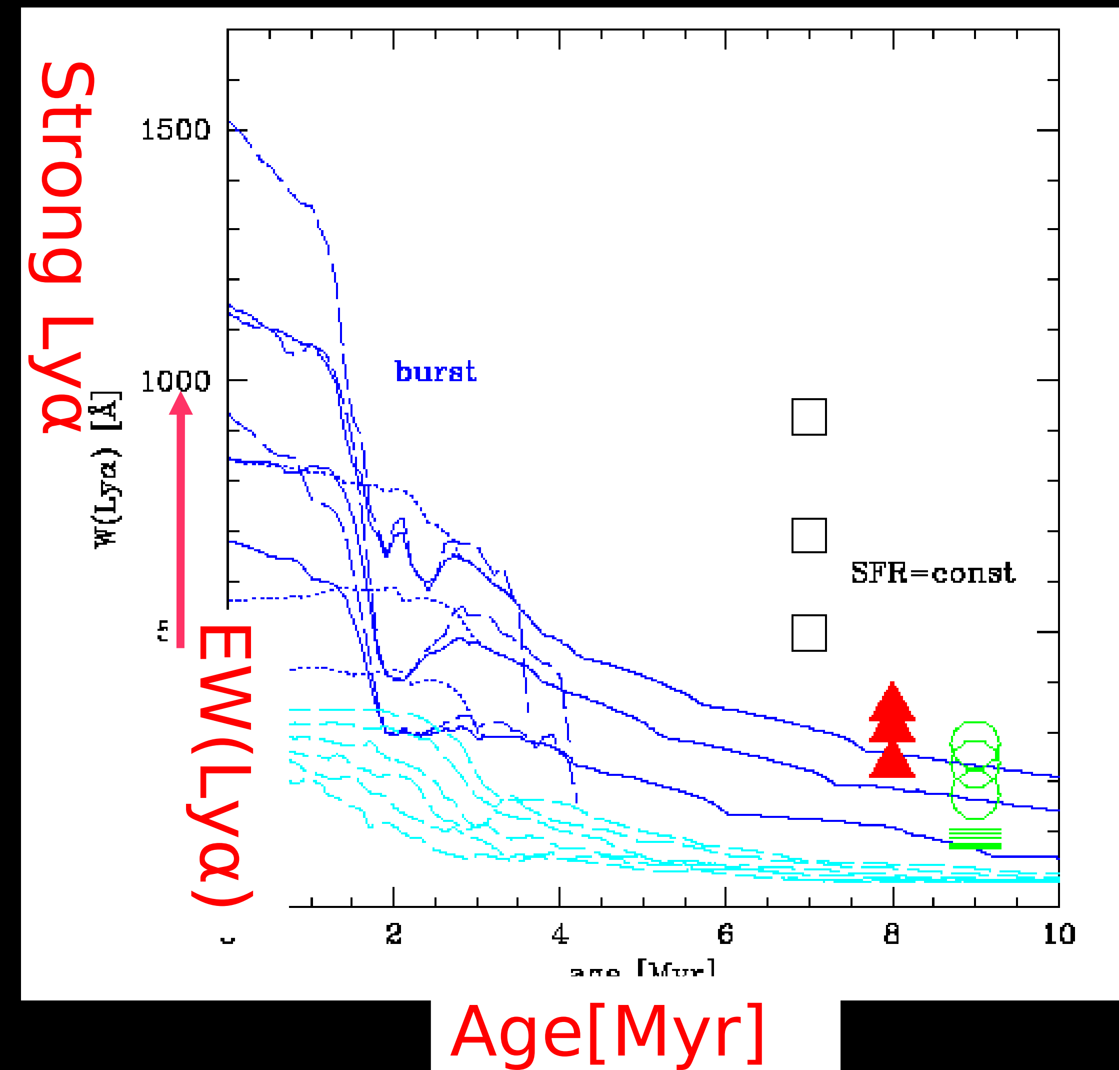
LYMAN ALPHA EMITTERS ARE STAR FORMING GALAXIES SELECTED THOUGH THE PRESENCE OF A STRONG LYMAN ALPHA EMISSION LINE IN THEIR SPECTRA; THE LINE GIVES A VERY HIGH FLUX IN THE DEDICATED NARROW BAND FILTER.
THESE OBJECTES ARE SELECTED TO HAVE VERY LARGE COLOR TERMS IN BROAD BAND –NARROW BAND AND ARE USUALLY VERY FAINT IN BROAD BAND

~1300 LAEs selected at 3<z<7 (~220 zspec)

Lyα Emitters (LAEs)



Model Prediction (Schaerer 2003)



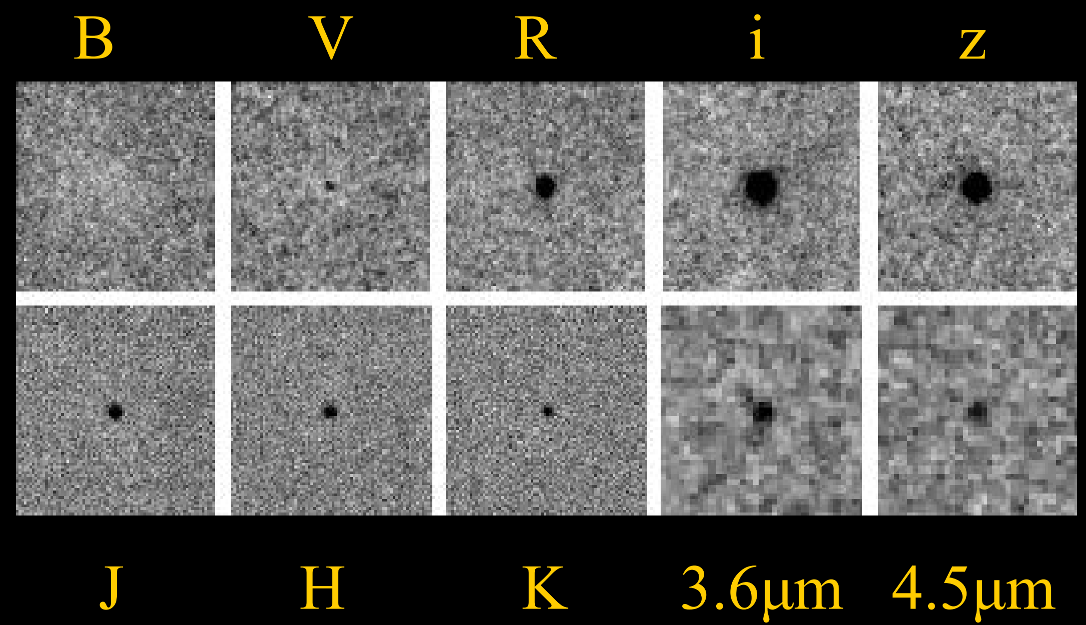
Iye et al. (2006)

i) Strong Lyα→ Very young (≲10-100Myr) and dust/metal poor star-formation.
ii) Faint continuum→high-z less-massive population with the avg. mass of M*=10^{7-9} Mo (Gawiser+07, Parzkal+07, Nilsson+07, Lai+08, Ono+09)

Useful to investigate the early stage of galaxy formation at high-z universe

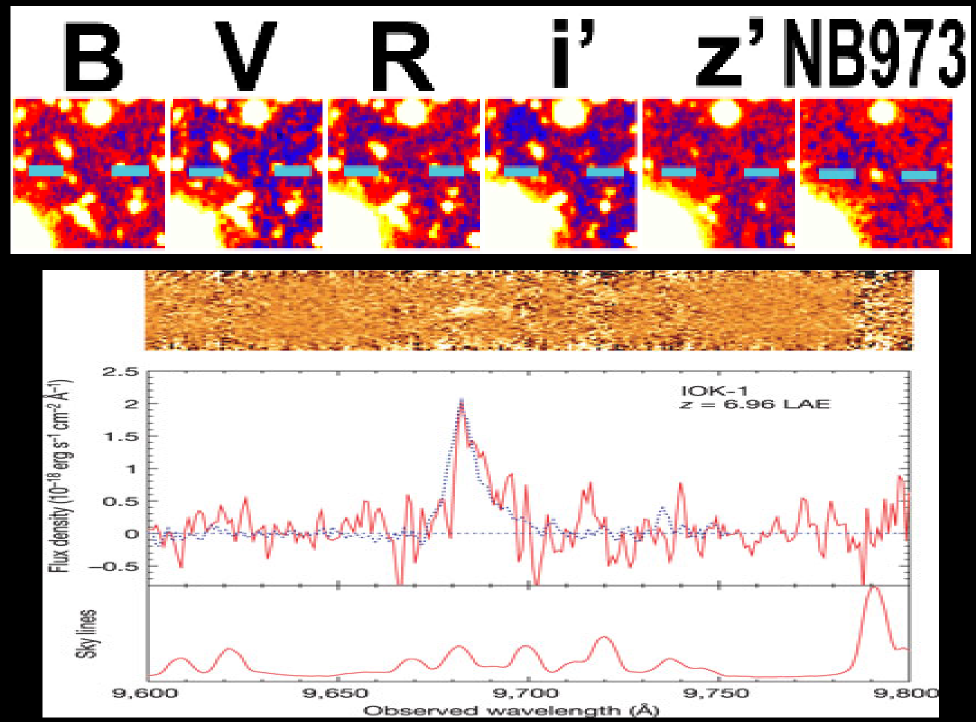
Comparison LBG-LAE selections

Broad-band



McLure et al. (2009)

Narrow-band



Iye et al. (2006)

Strengths:

1. More complete
2. Larger sample volumes

Problems:

1. Less precise redshift information
2. Potential for low-z contamination

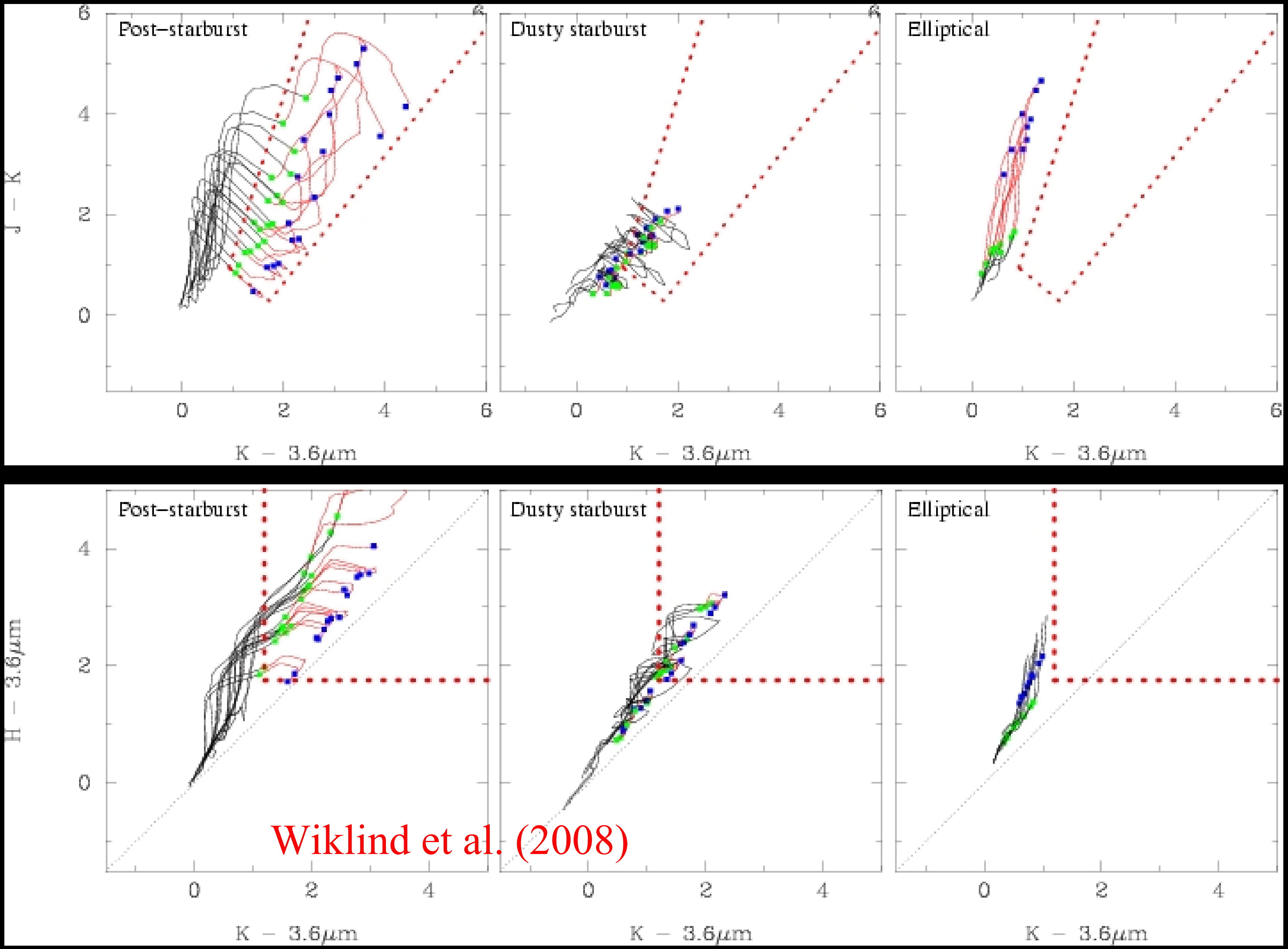
Strengths:

1. Precise redshift information
2. "Clean" selection method

Problems:

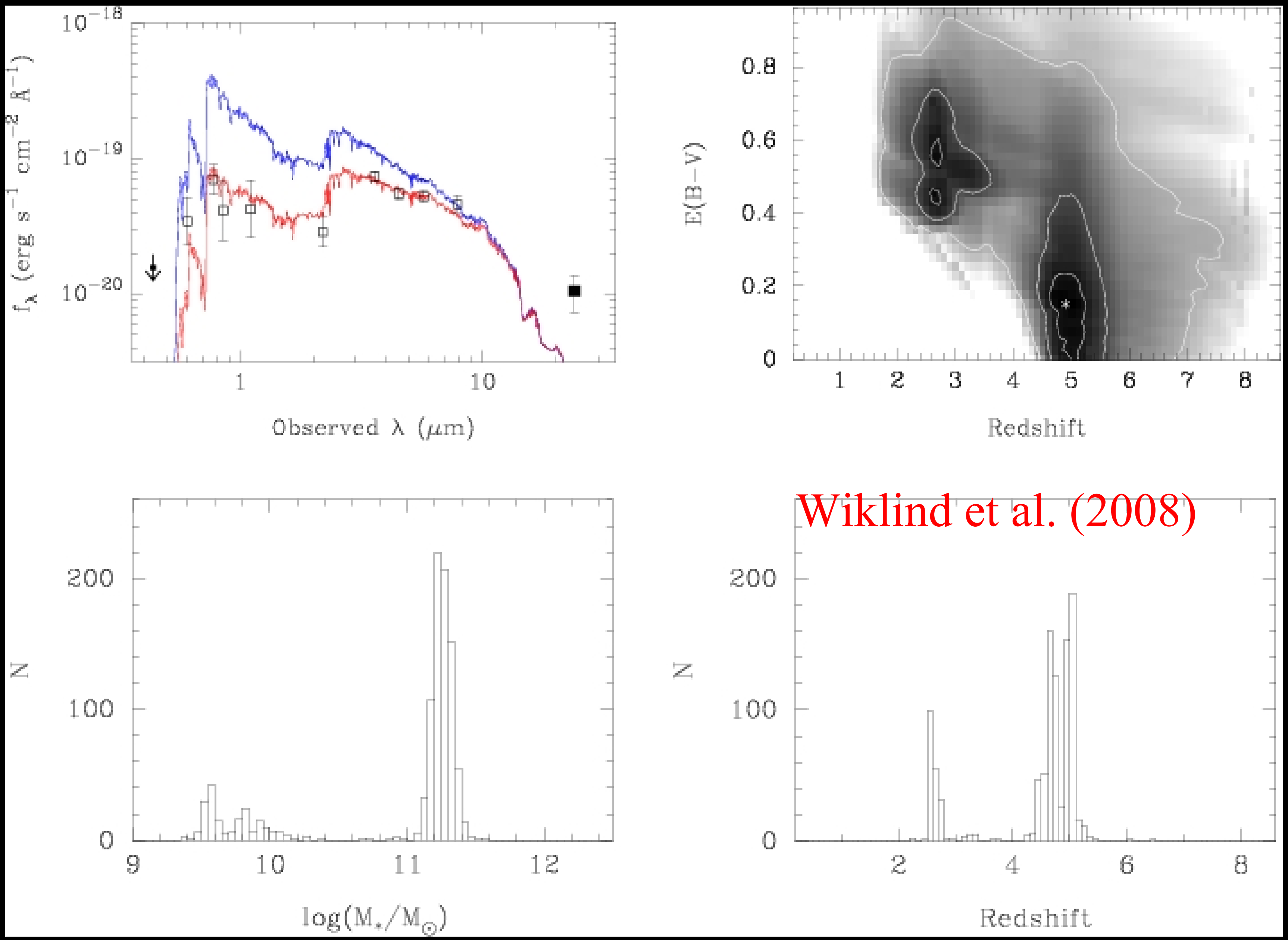
1. Sample very limited volume
2. Only select line emitters (<25%)
3. Contaminated by lower-z ELGs
4. No LAE at EoR (neutral IGM)

3-Balmer Break Galaxies (Post-starbursts)

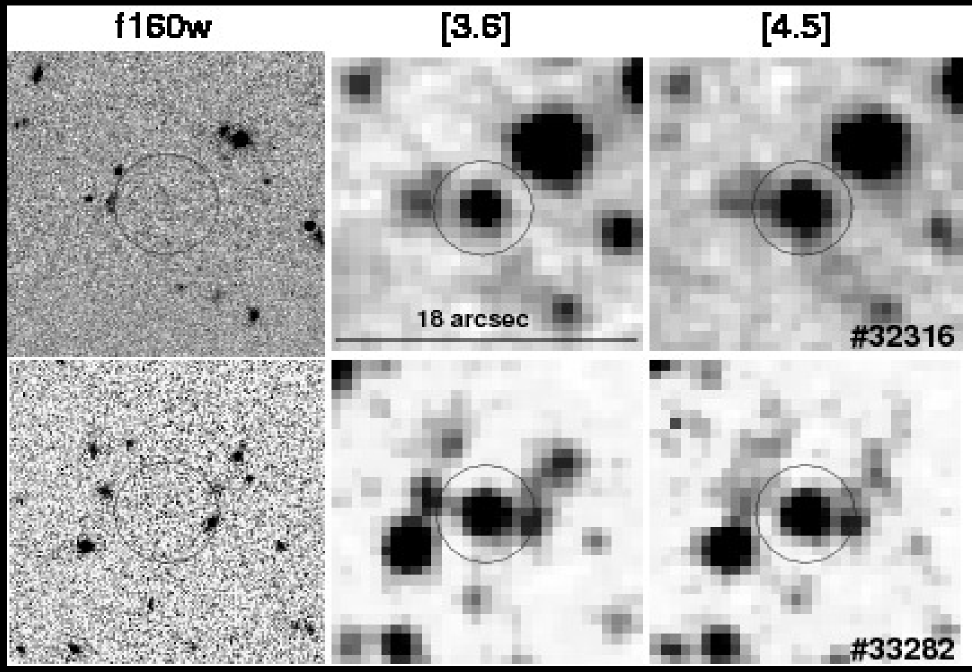


Post-starburts are passively evolving galaxies. They are old and can be selected in the NIR and MIR wavelengths.

Post-starbursts



Caputi et al. (2012)

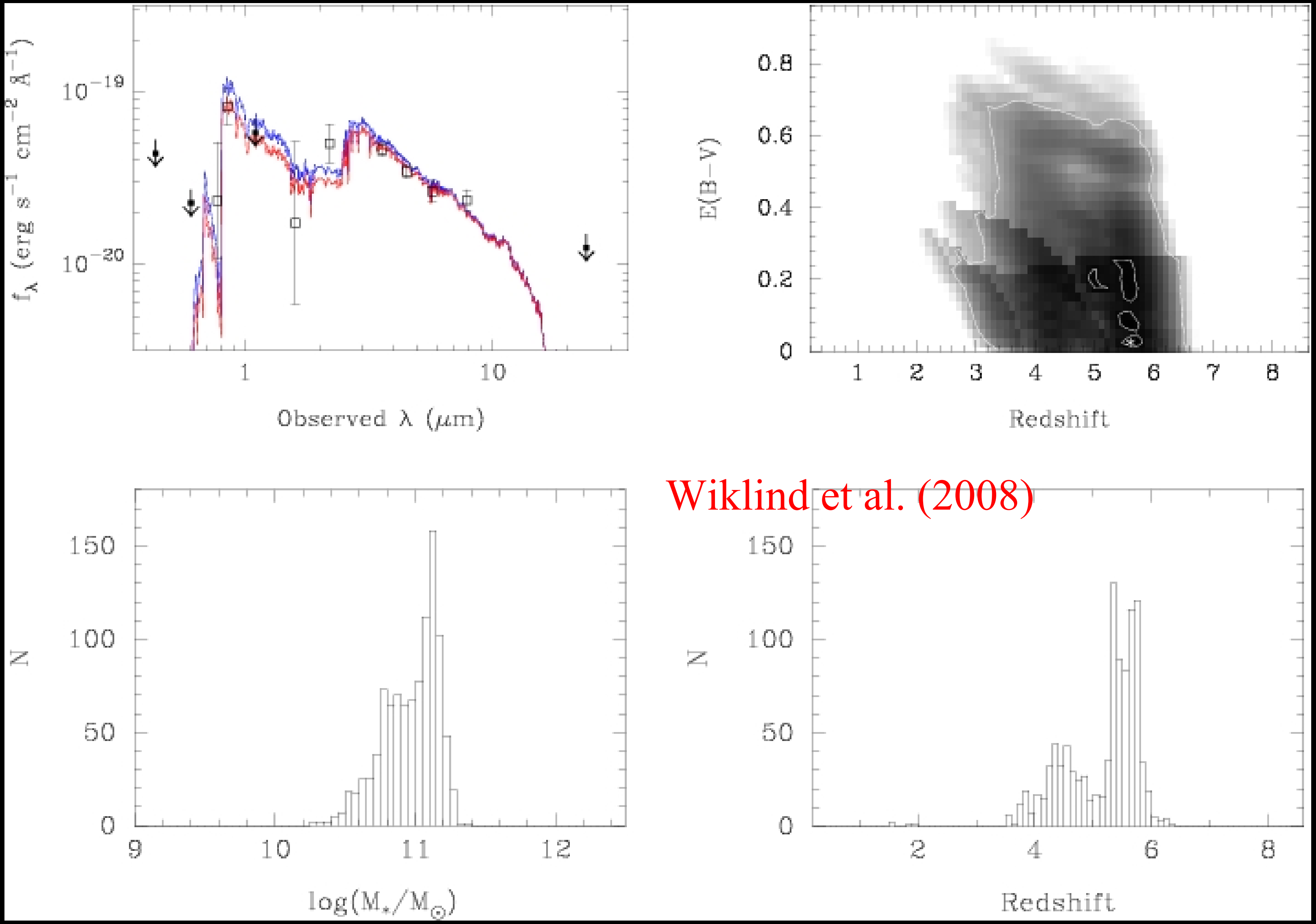


H 3.6μm 4.5μm

Weak break (~0.7 mag) at lambda~4000A rest. Massive/old galaxies (Wiklind et al. 2008; Rodighiero et al. 2008; Caputi et al. 2012).

However, in some cases they can be fitted also with dusty starburst SED.

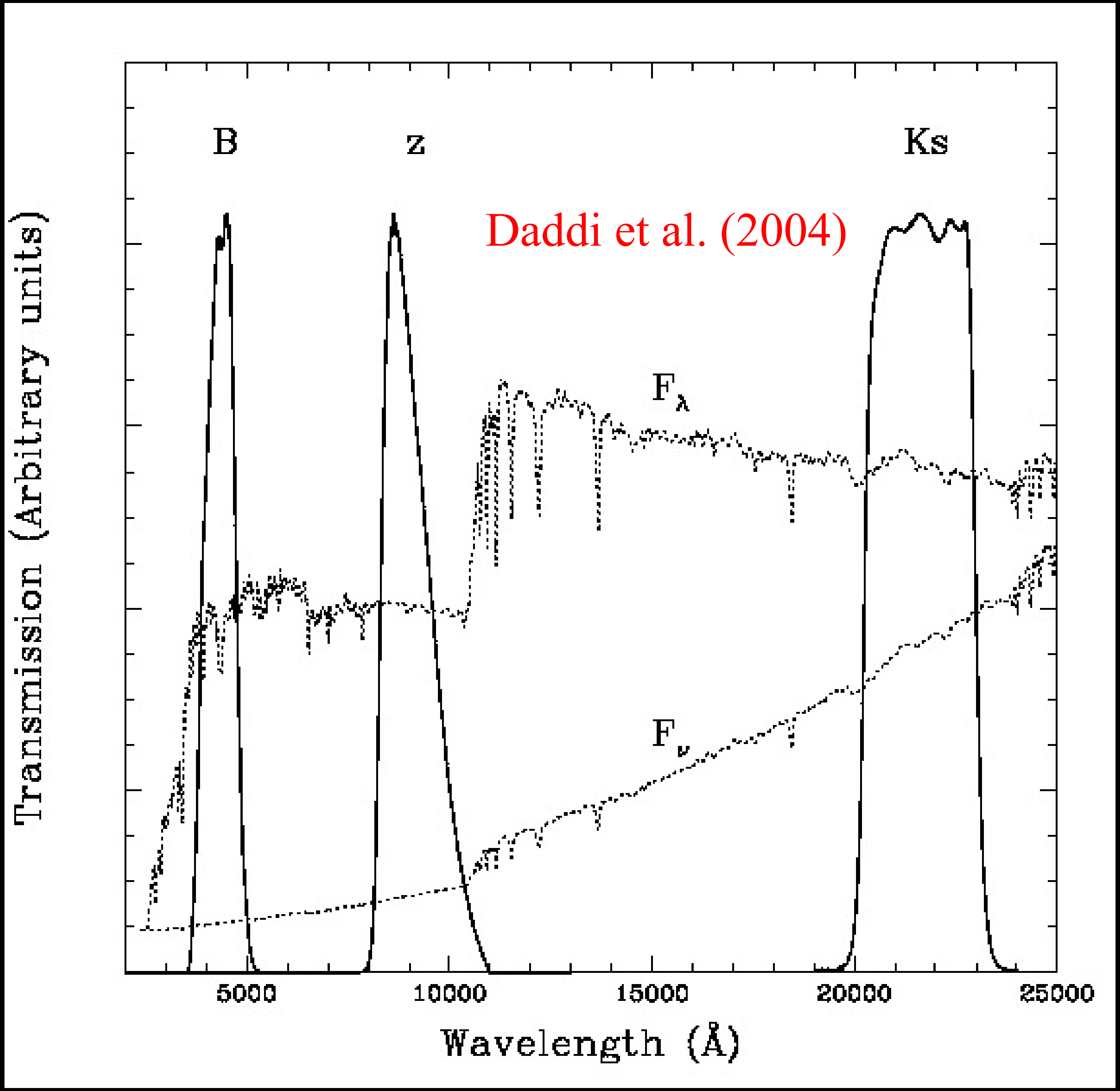
Warnings



Degeneracy Balmer Break vs Dusty Starburst.

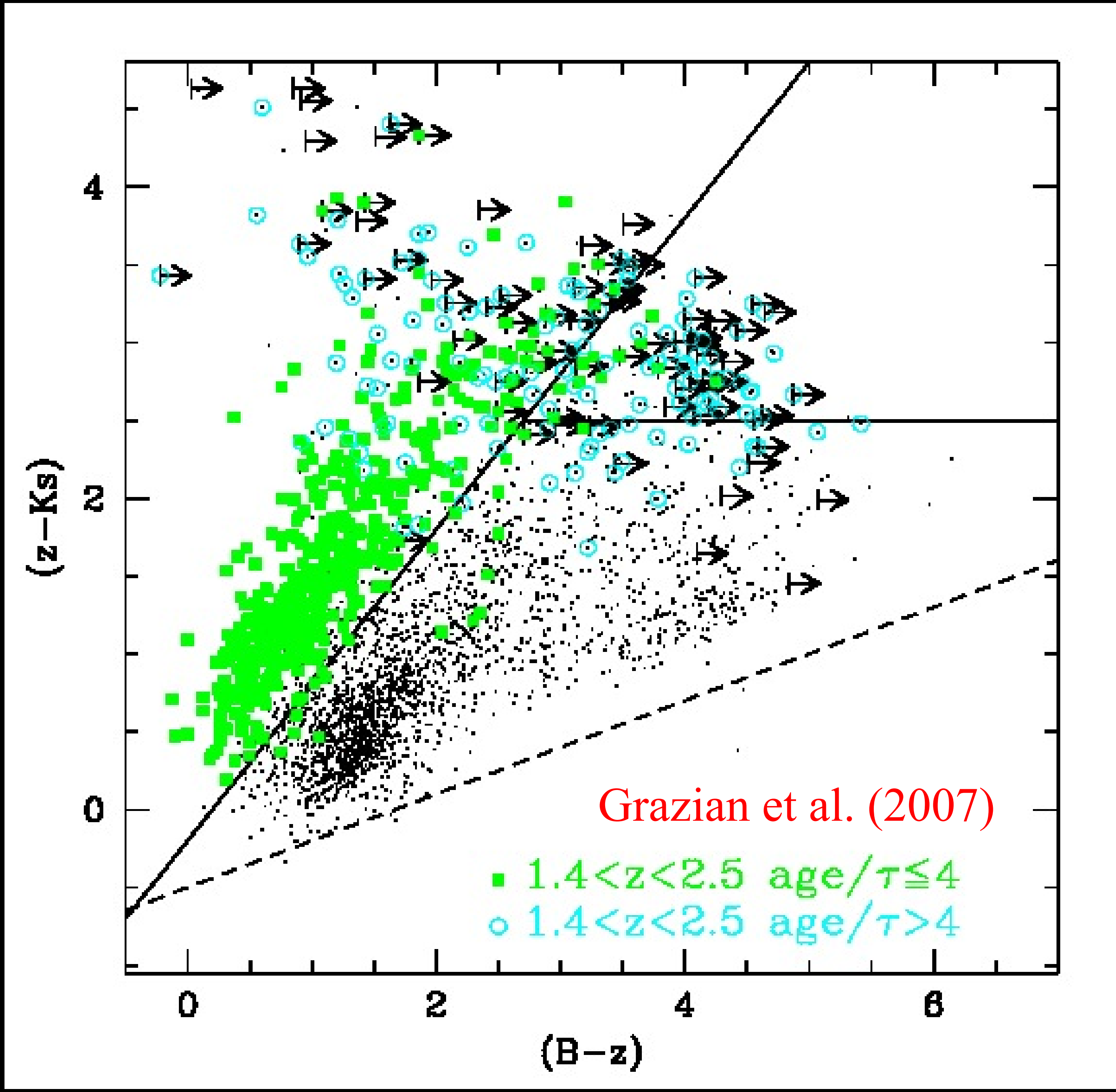
No purely selected Balmer Break Galaxies (they are also LBGs)

4-BzK Galaxies (at z>3 VJL)



Passively evolving galaxies and star forming galaxies at z~2 are Extremely different in B, z, and K filters.

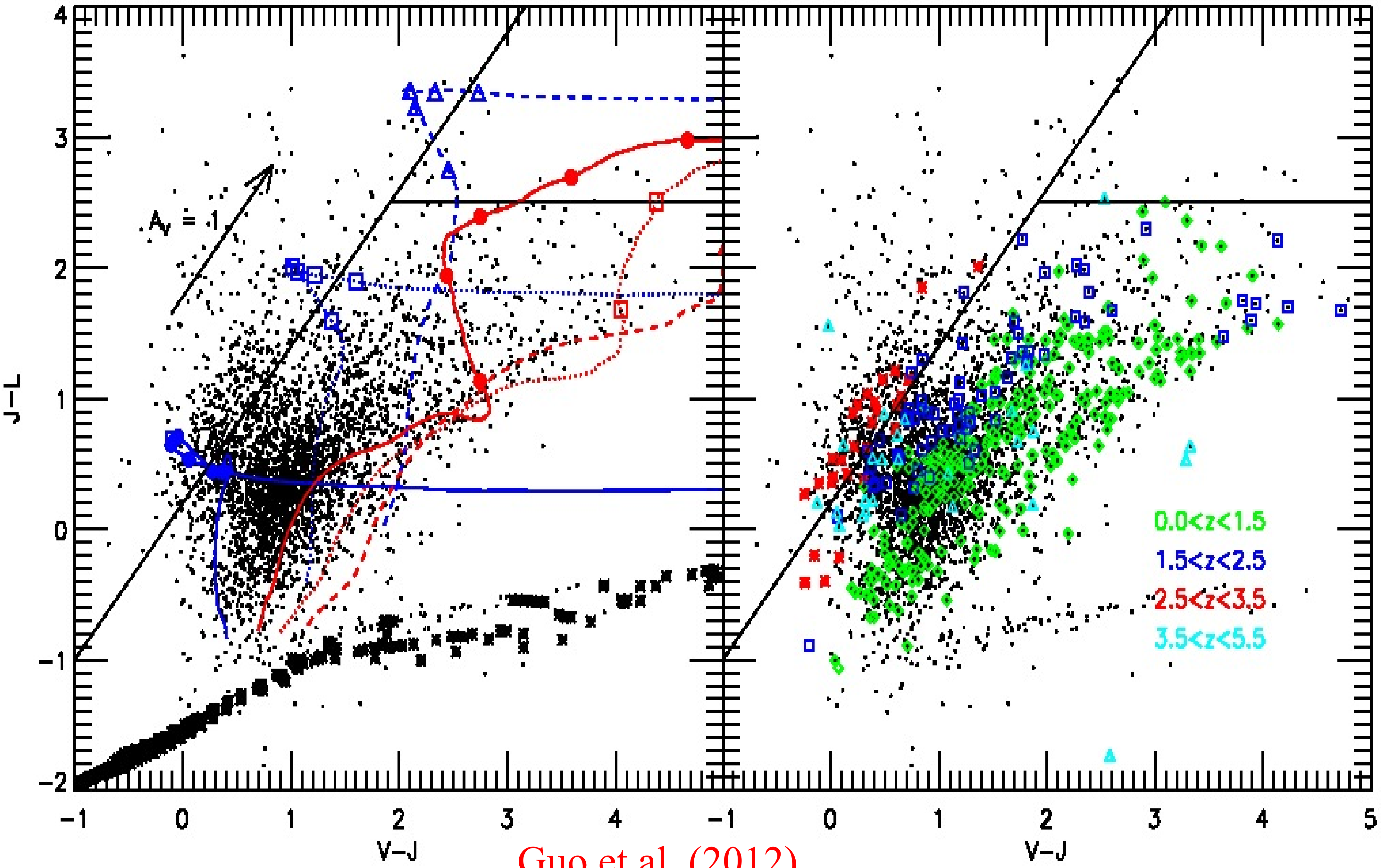
BzK Galaxies (1.4<z<2.5)



Extremely deep imaging is required. B-K>7 for old galaxies.

Deep imaging in the B band is fundamental to avoid mix of pBzK and sBzK.

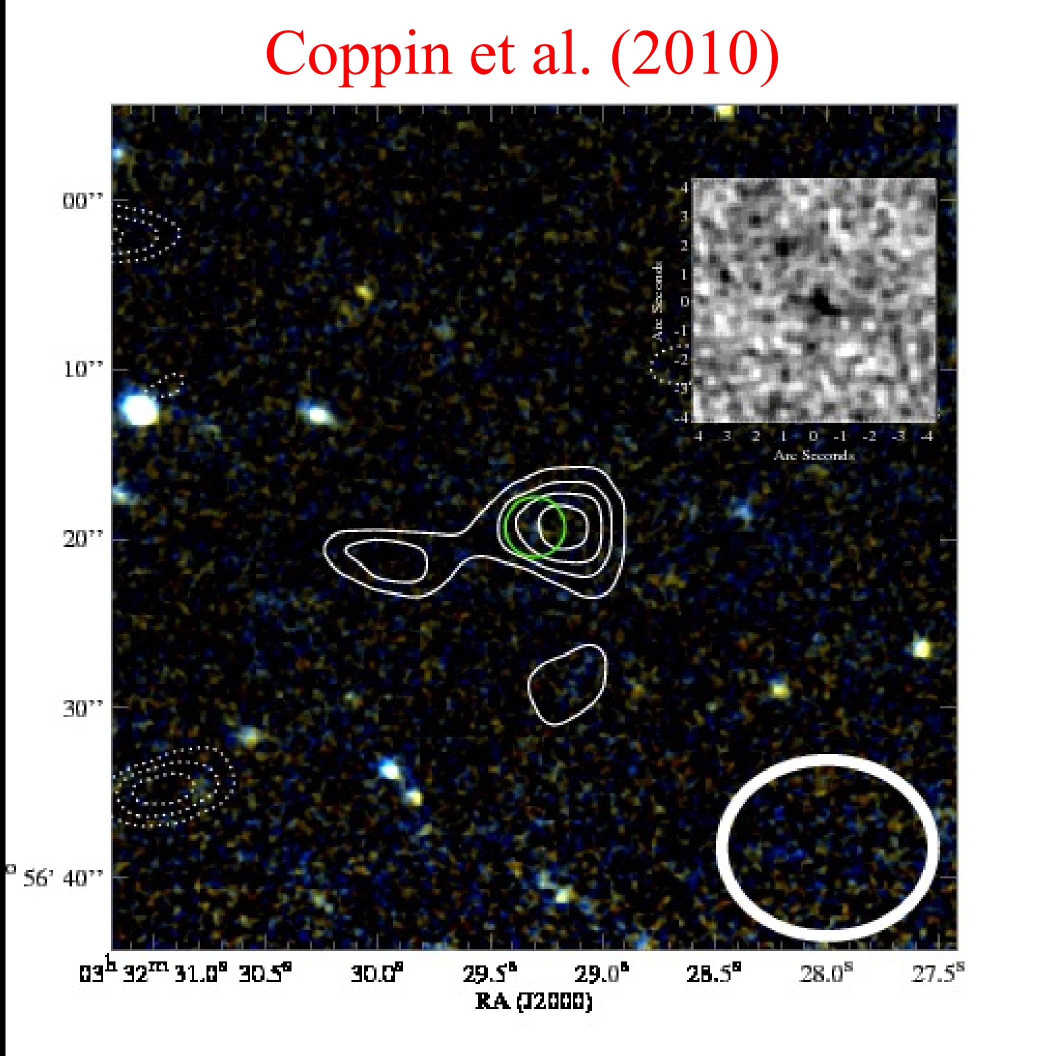
VJL Galaxies (2.5<z<3.5)

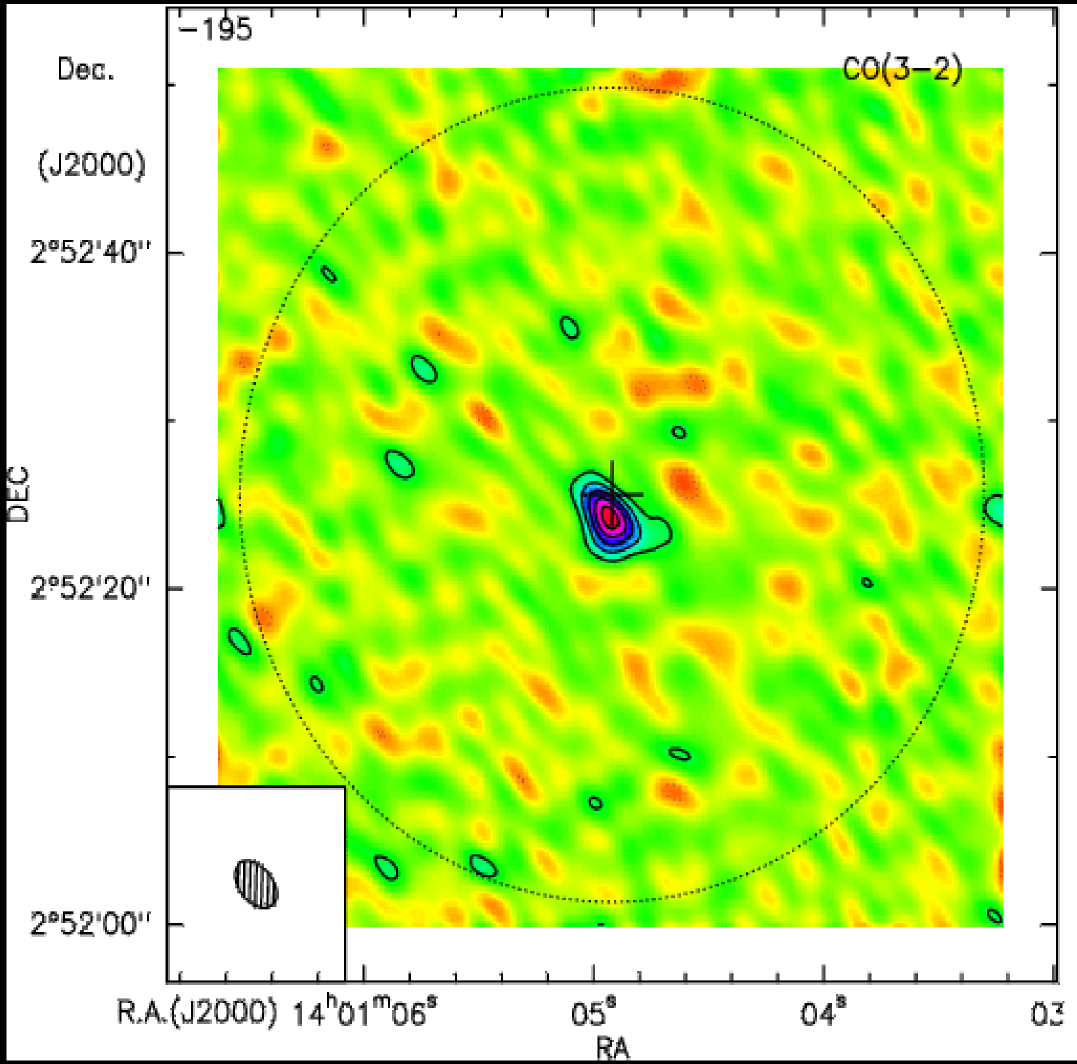


Guo et al. (2012)

As for the BzK criterion, the reddening vector is parallel to the dividing line.

5-Submm Galaxies



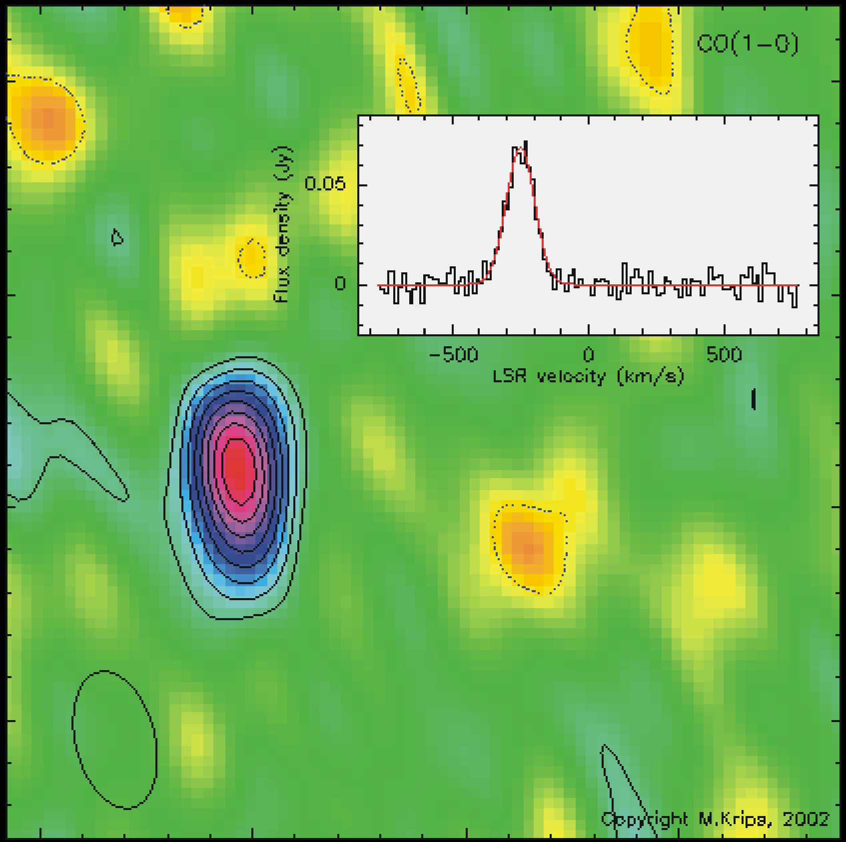


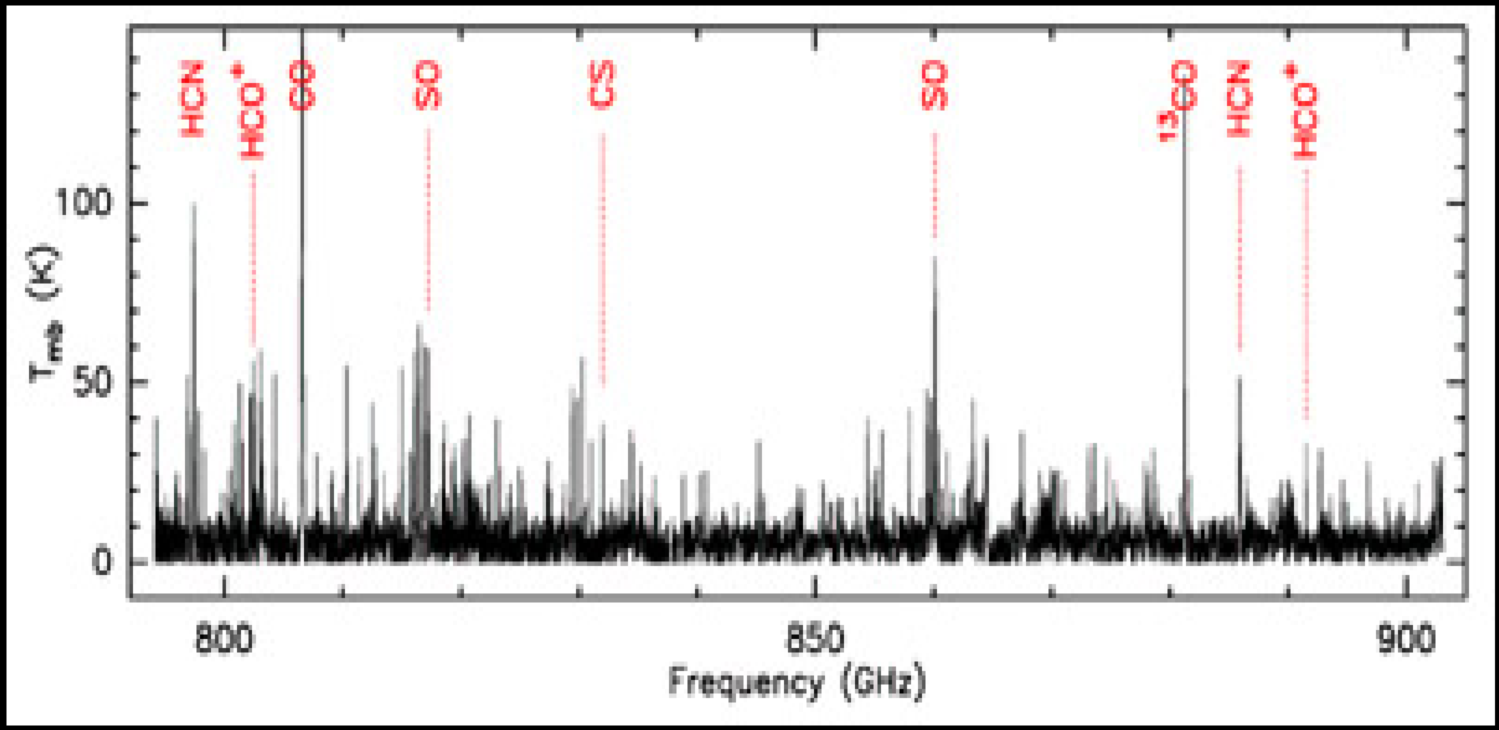
Submm galaxies are detected through their redshifted thermal dust emission. UV photons by young stars are absorbed by dust and light is re-emitted in submm wavelengths.

Instruments: SCUBA, ATCA, APEX, PdBI, ALMA, Herschel.

WARNING: dust is produced by metals. No metal around first stars

6-CO/C+ line emitters



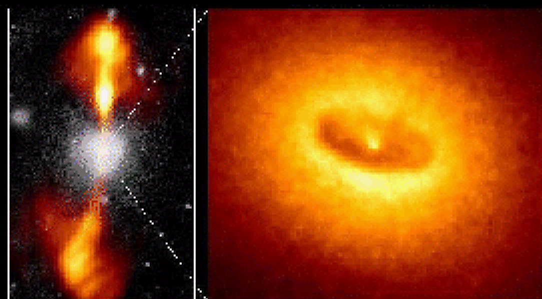


Spectrum of Orion

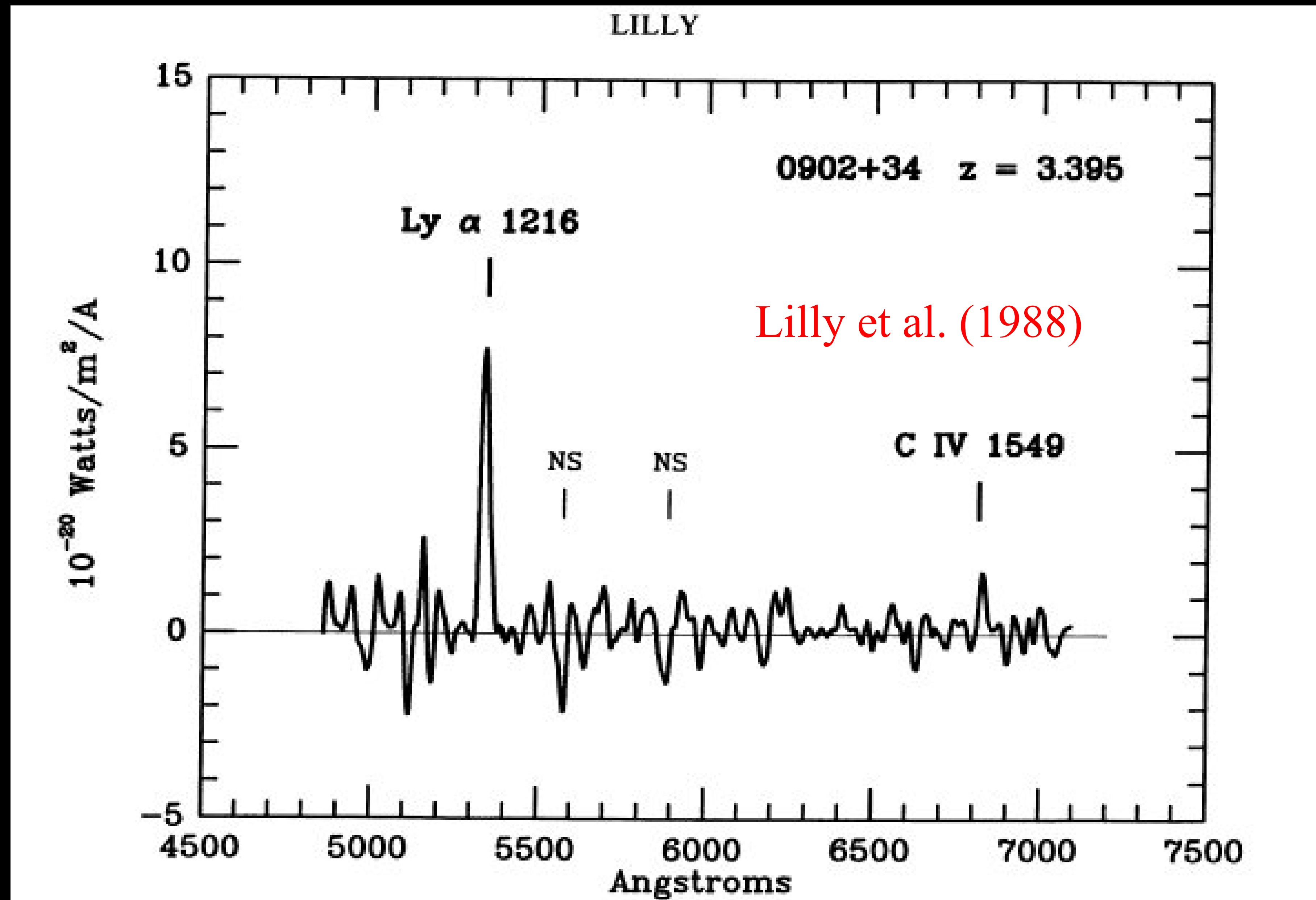
High-z galaxies can be detected through their emission lines in the mm wavelengths. PdBI and ALMA can detect CO lines.

(Riechers et al. 2010)

7-Radio Galaxies



NGC4261



Lilly 1988 discovered the first Radio Galaxy at z>3.

RGs show strong k-correction, due to the steep power law due to syncrotron emission.

Radio Galaxies

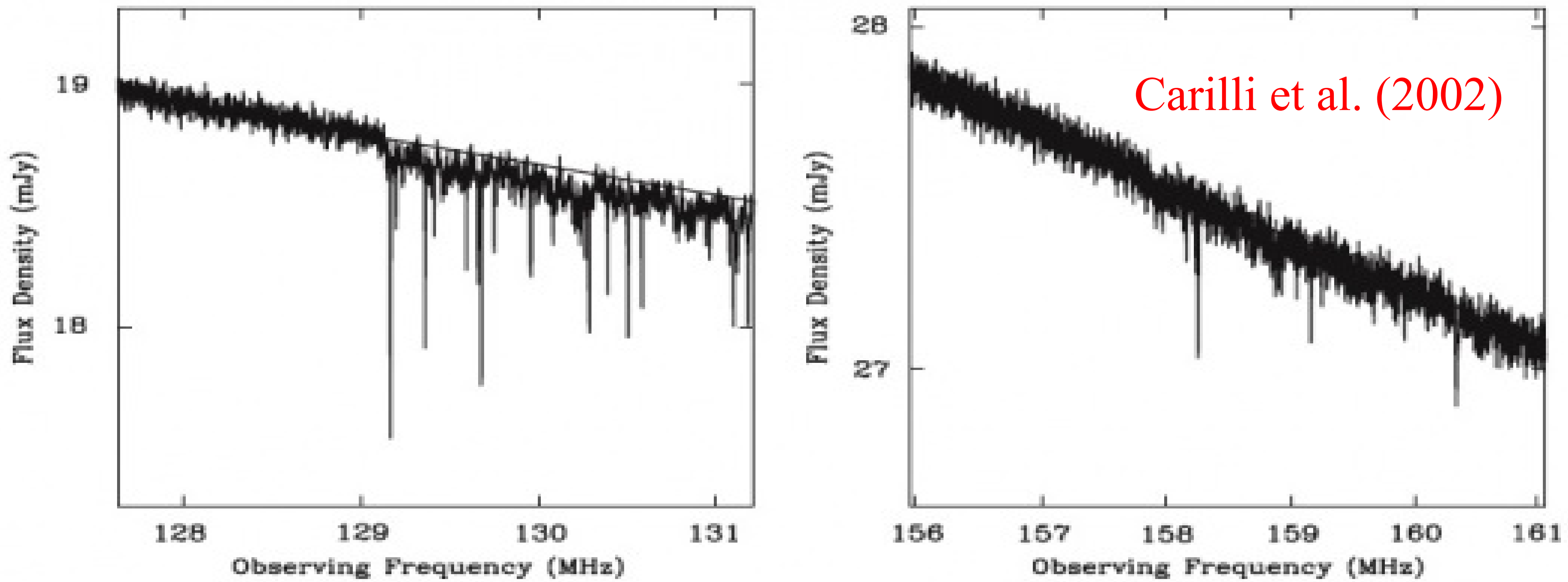
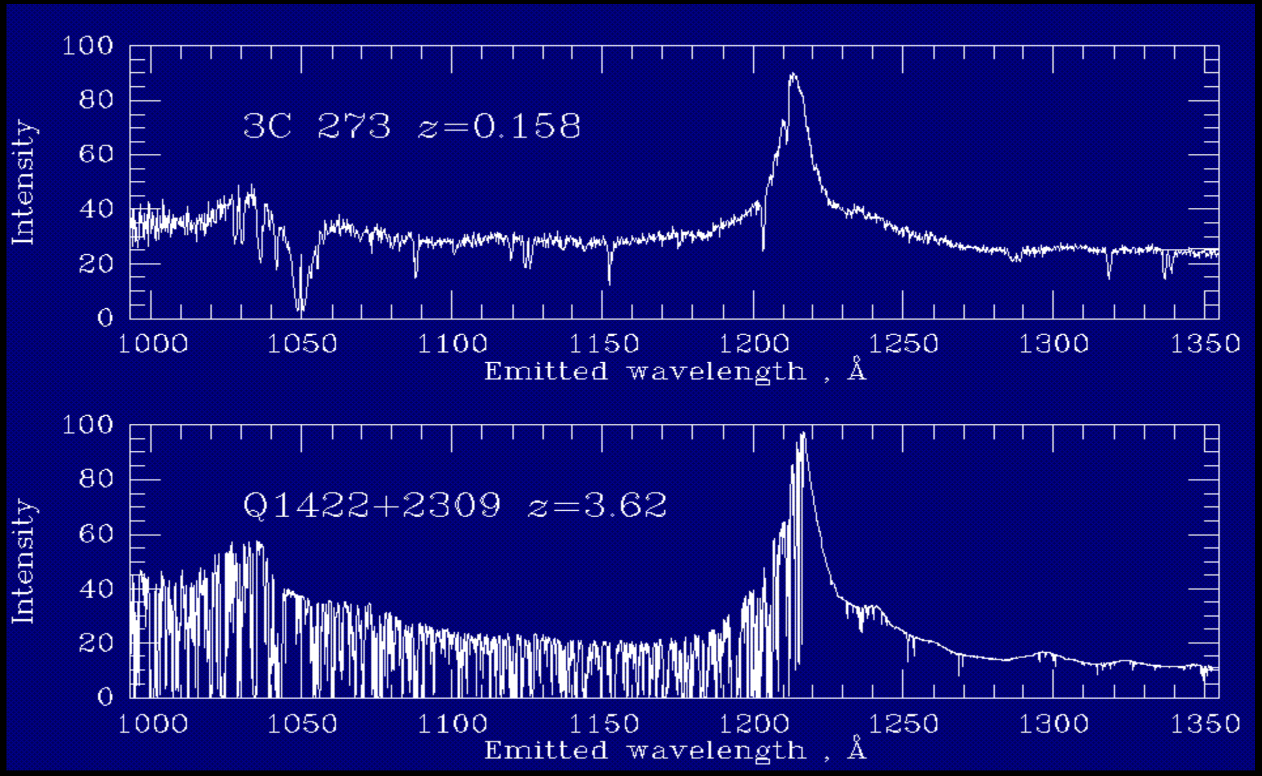
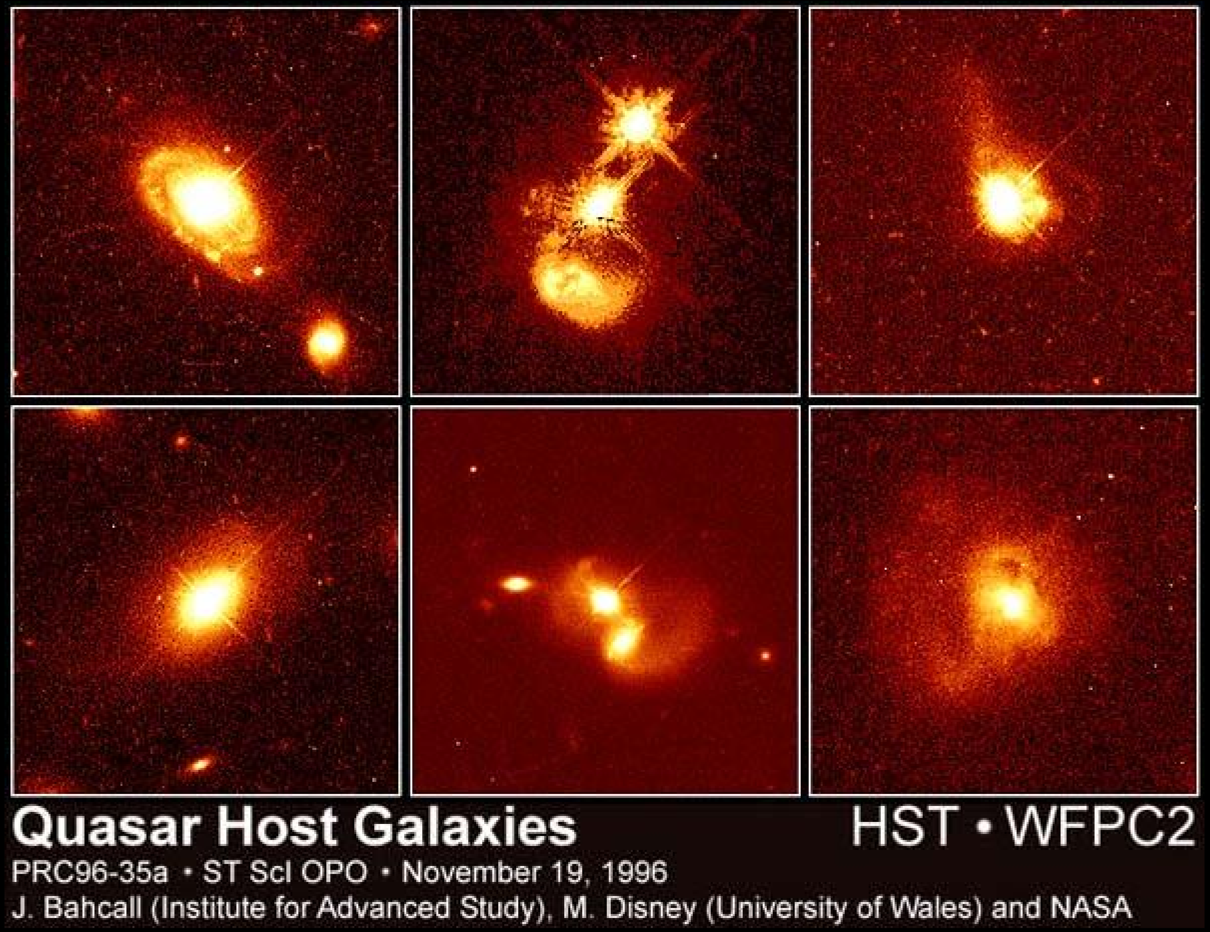


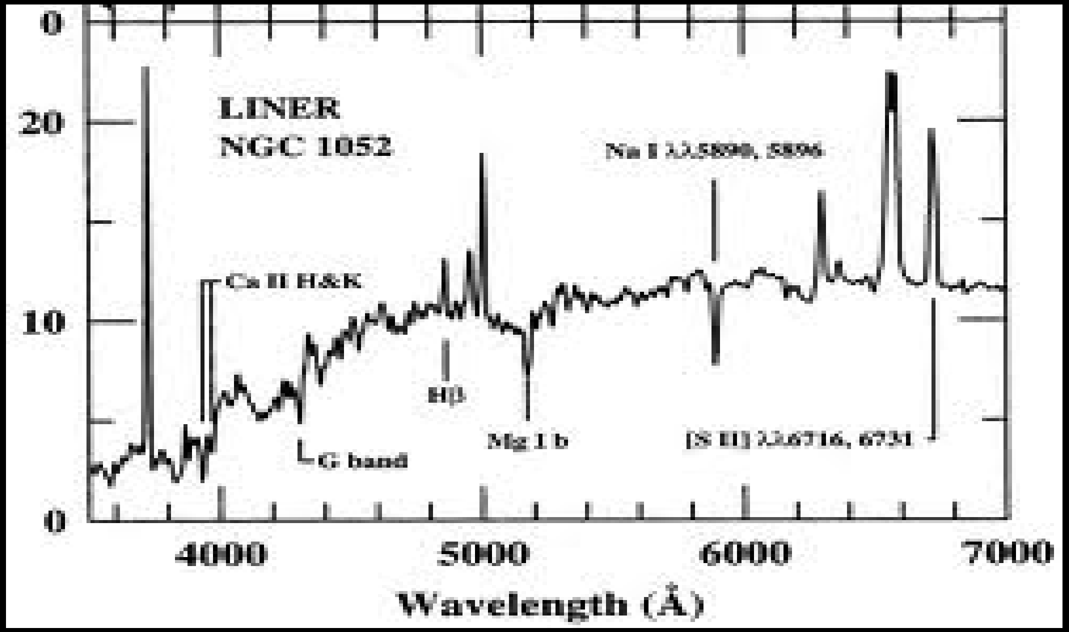
Fig. 37. Mock spectra of high-redshift radio sources at $z_s = 10$ (left panel) and $z_s = 8$ (right panel) produced from cosmological simulations. In each case a source (with intrinsic luminosity equal to Cygnus A) is placed at the appropriate redshift and "observed" in a week-long integration with an SKA-class instrument. A "forest" of absorption features appears blueward of $21(1 + z_s)$ cm, caused by the cosmic web. Note that the level of absorption depends sensitively on the assumed thermal and ionization history of the IGM. From [349].

With Radio Galaxies it is possible to study the 21cm forest and the signature of the End of Reionization with LOFAR, MWA, and SKA.

8-QSO Host Galaxies



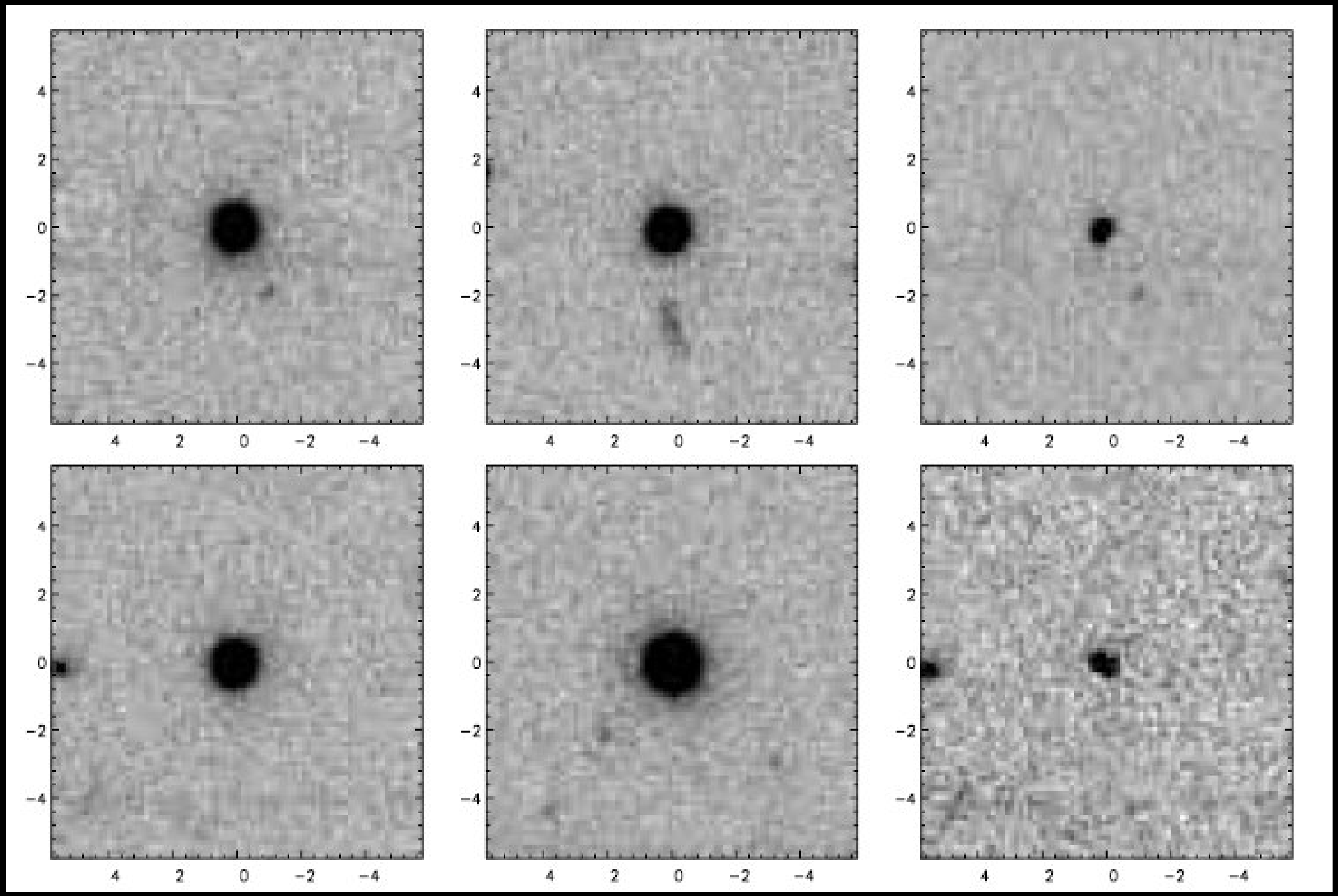


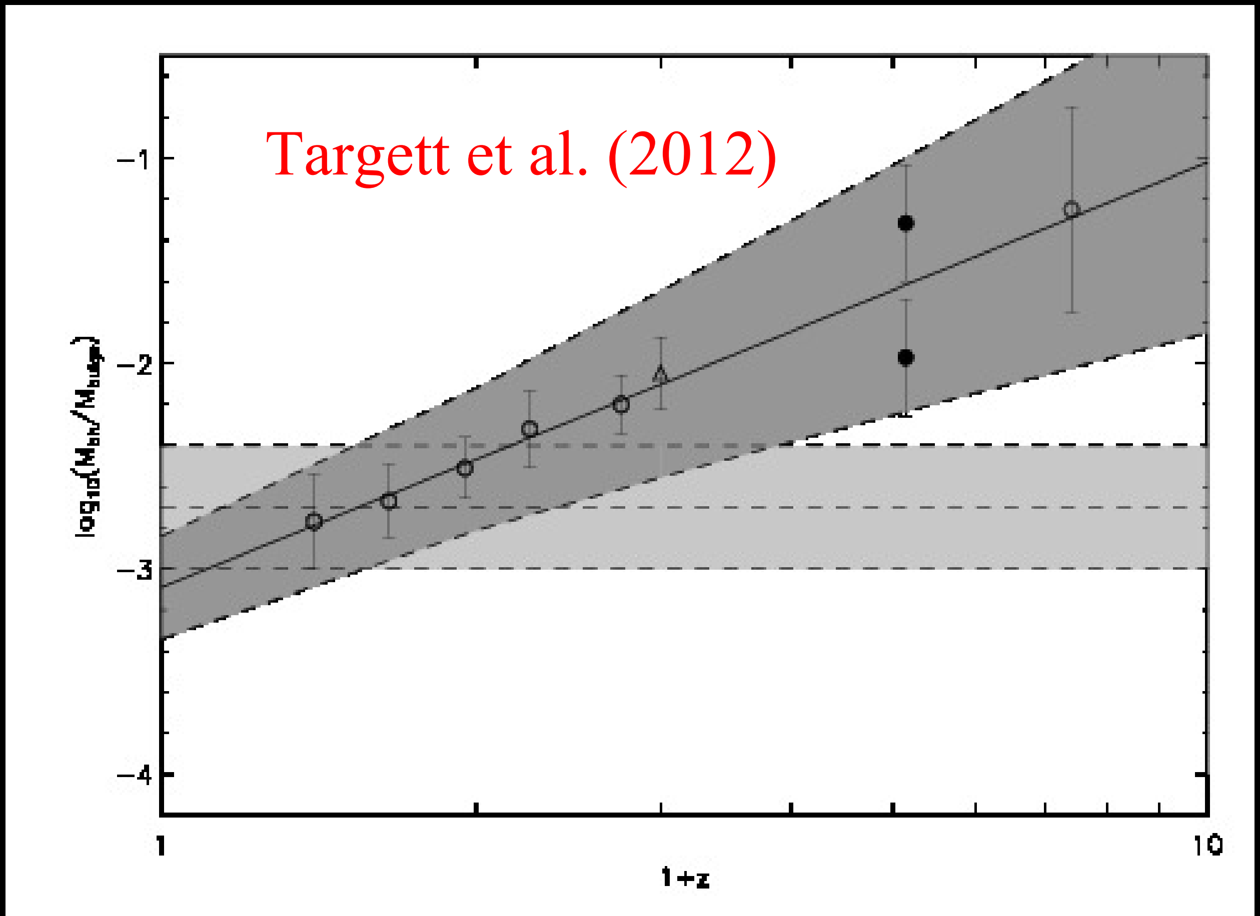


High-z QSOs can be used as cosmic lighthouses to study the IGM at lower-z

In local AGNs it is possible to detect and study their host galaxies.

QSO Host Galaxies

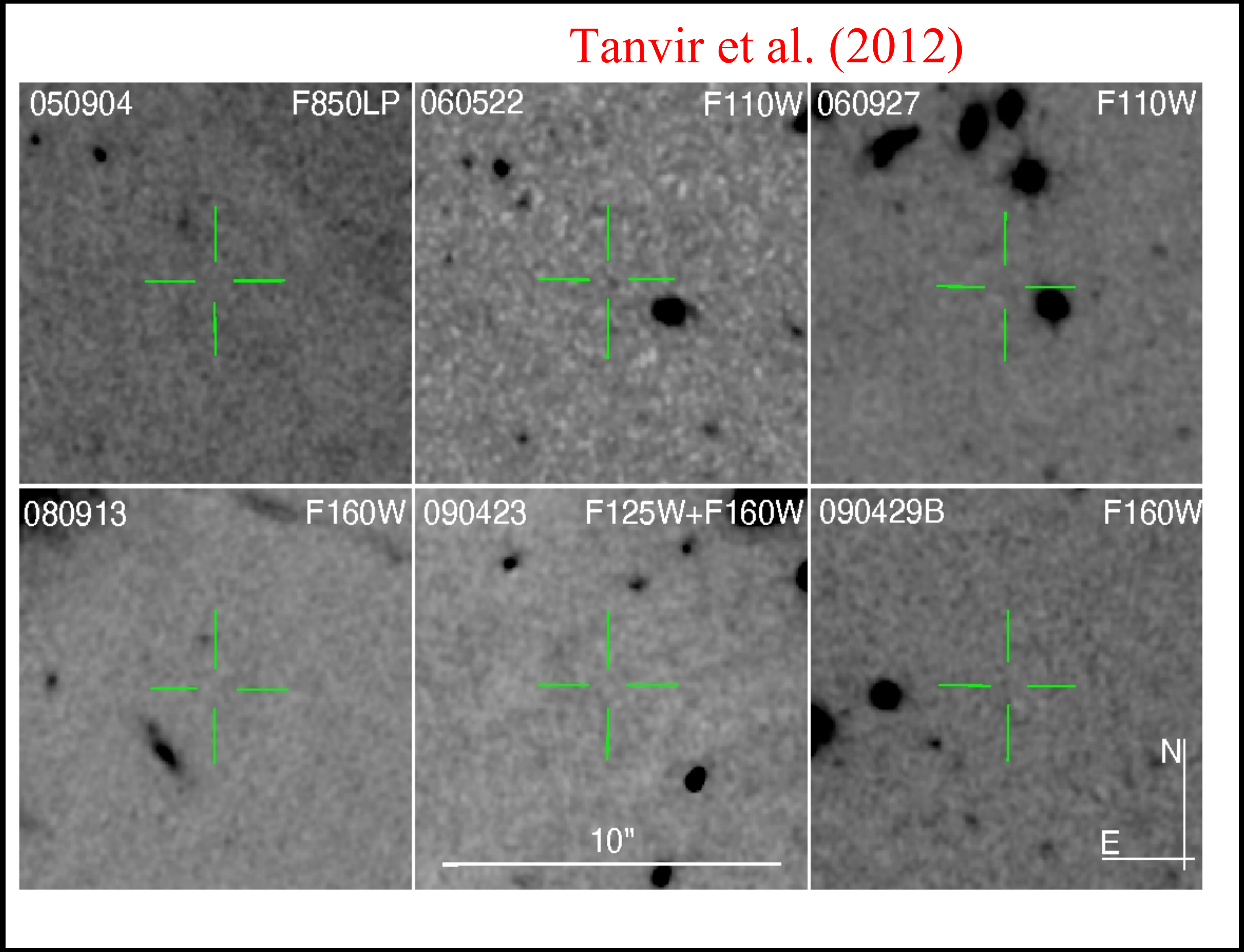


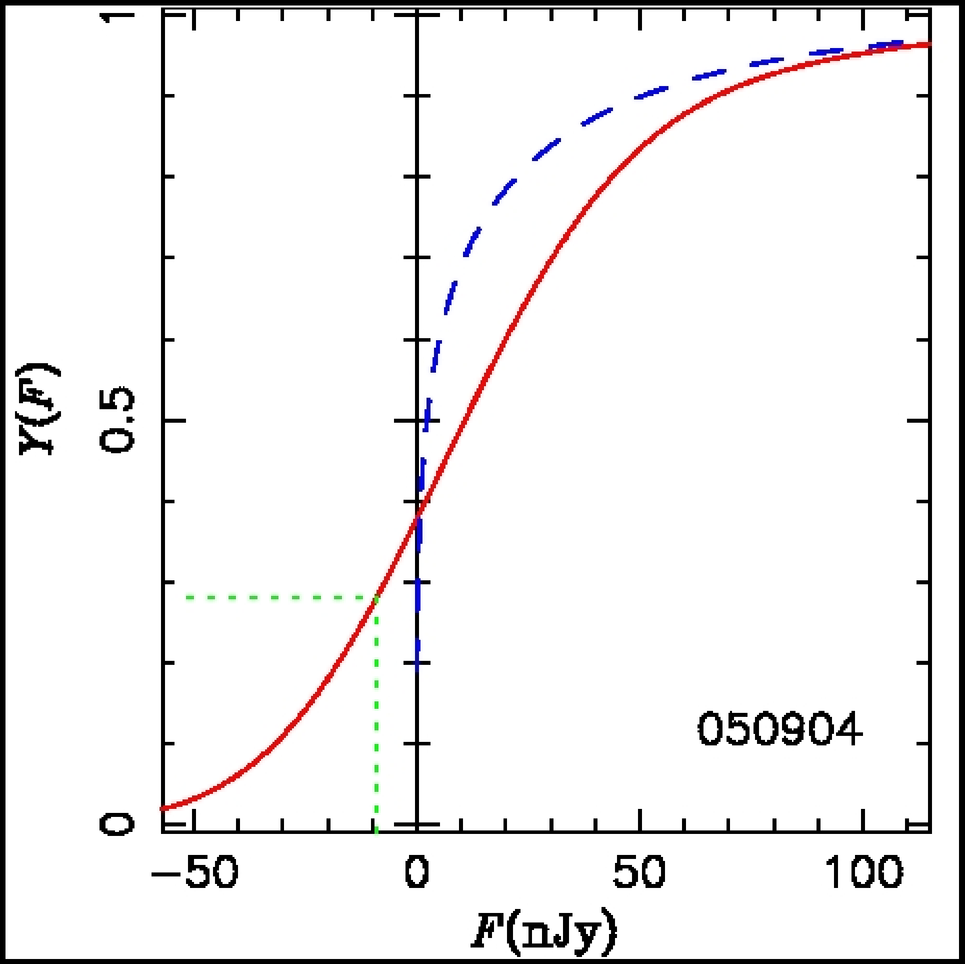


With AO assisted NIR instruments it is possible to detect and study their host galaxies: measurement of the BH/Bulge mass ratio at high-z.

SINFONI observations of 2 z=4 QSO hosts (Targett et al. 2012).

9-GRB Host Galaxies





The Swift satellite routinely finds GRBs at z~5-9. Knowing their positions, it is possible to search for their host galaxies.

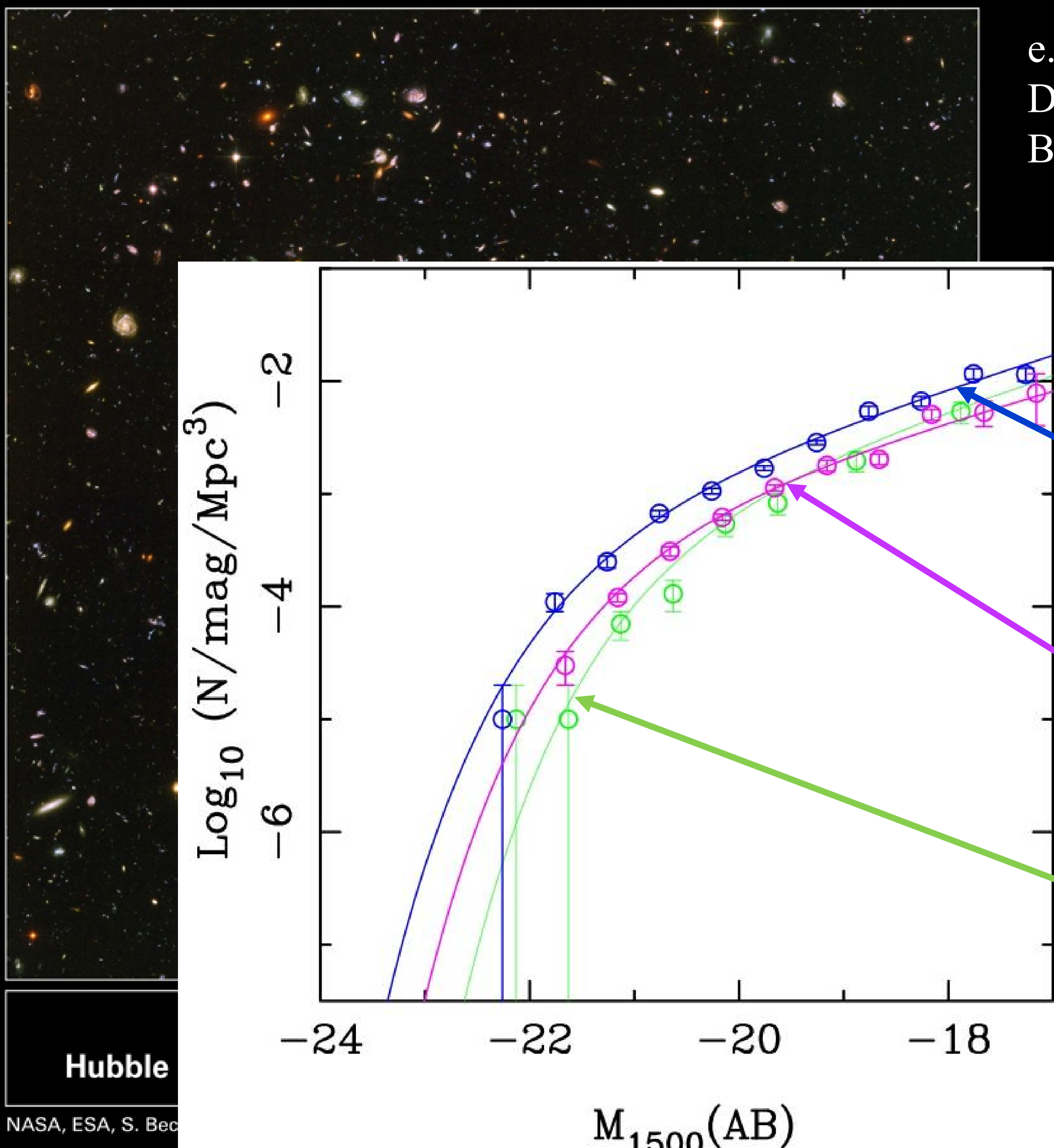
Tanvir et al (2012) failed to detect the host galaxies of 6 GRBs at z~6-9:

The LF of the host galaxies is steep (alpha=-2) or the GRB hosts are all faint dwarf galaxies (Trenti et al. 2012)

High redshift galaxies: 4.5<z<6.5

Over the last 7 years, many different authors have used the Lyman-break technique to study the luminosity function at z>4 in the UDF and GOODS fields:

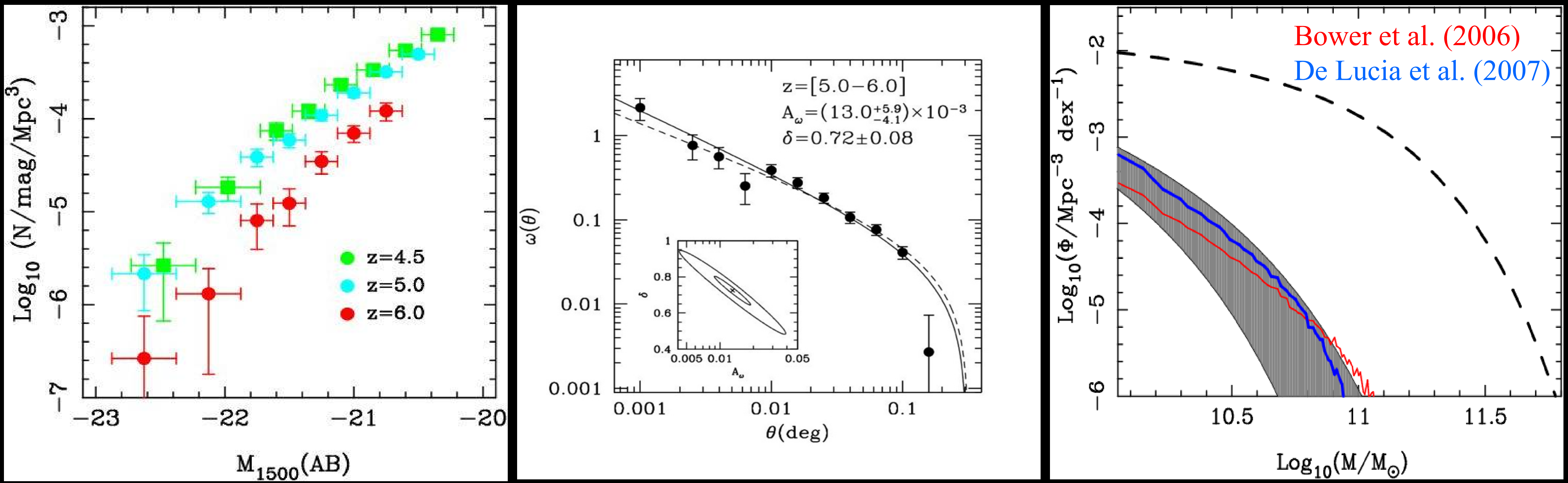
e.g. Bunker et al. (2004), Malhotra et al. (2005), Dickinson et al. (2004), Stanway et al. (2005), Bouwens et al. (2004,06,07), Yan et al. (2004,06)



Adapted from Bouwens et al. (2007)

High redshift galaxies: 4.5<z<6.5

McLure et al. (2009)

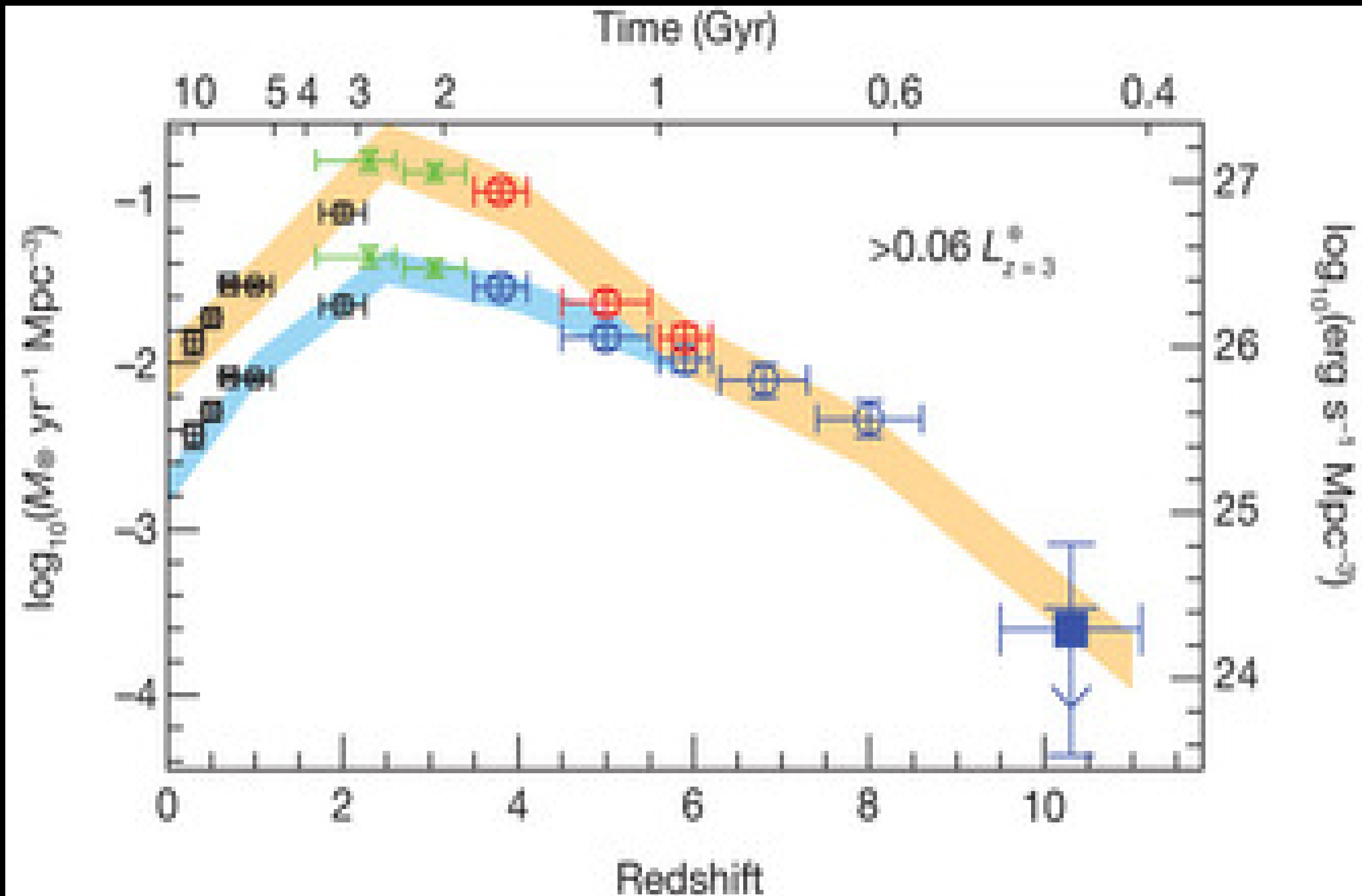


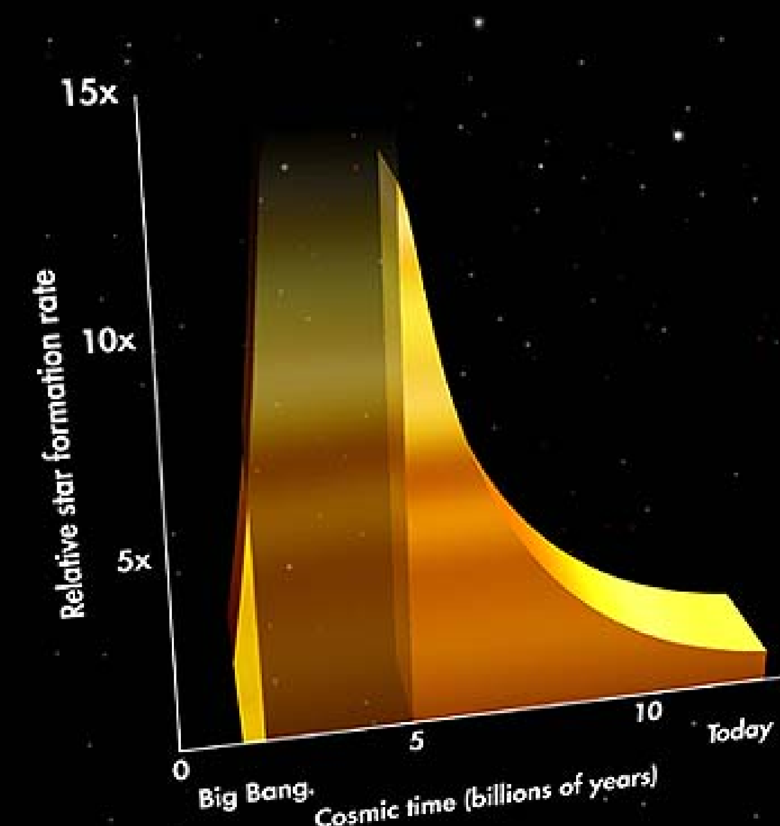
Results:

1. Can describe LF evolution 5<z<6 as pure luminosity evolution
2. Evolution quickest at bright-end, no sign of "downsizing"
3. Typical stellar mass of L* LBGs at z=5.5 is 10^{10} M
4. Typical halo mass of L* LBGs at z=5.5 is 5×10^{11} M
5. Numb. density of 10^{10} M galaxies at z=5.5 is ~5% local value
6. Can be accounted for be recent SAMs featuring AGN feedback

Cosmic Star Formation History

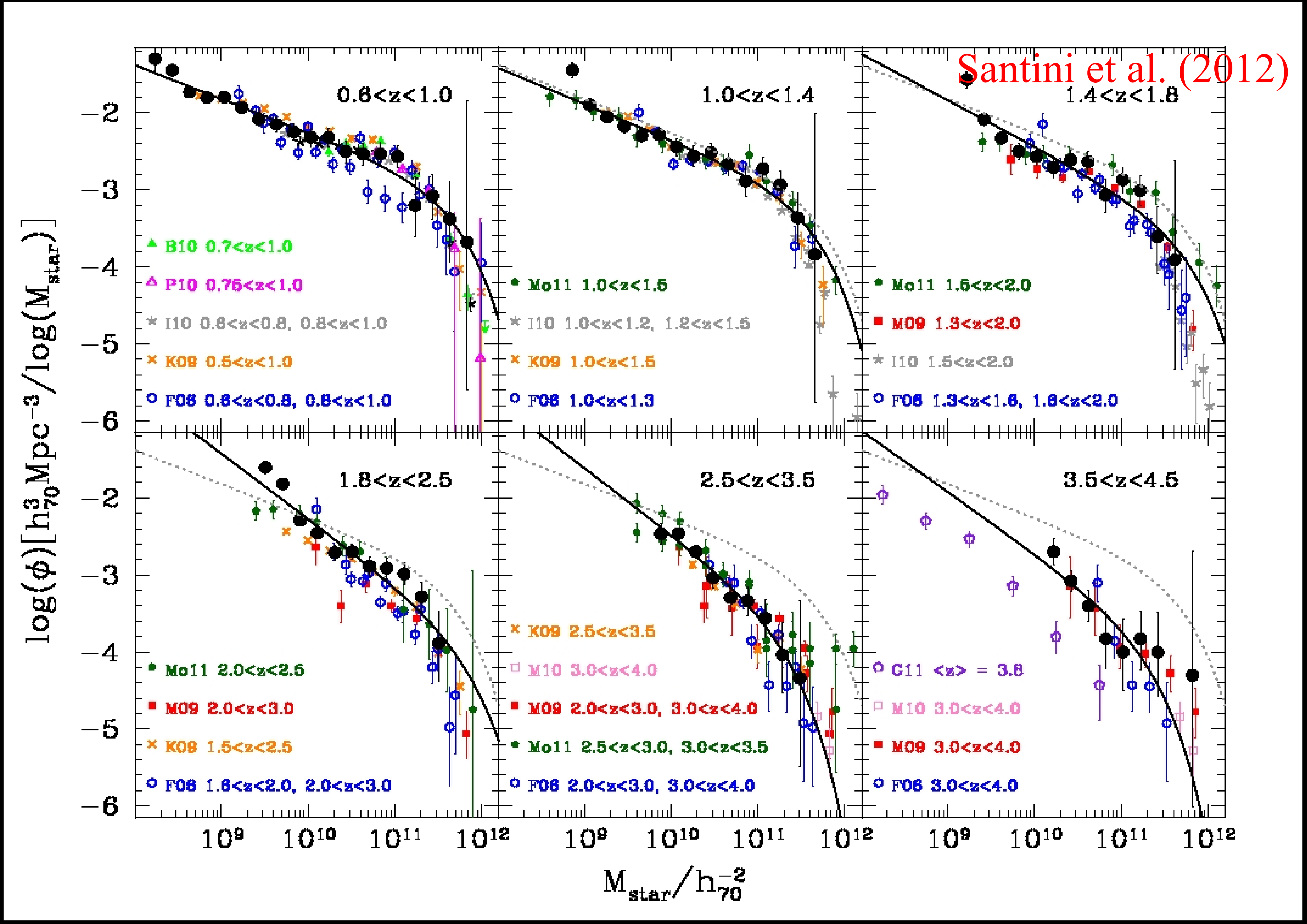
Bouwens et al. (2011)





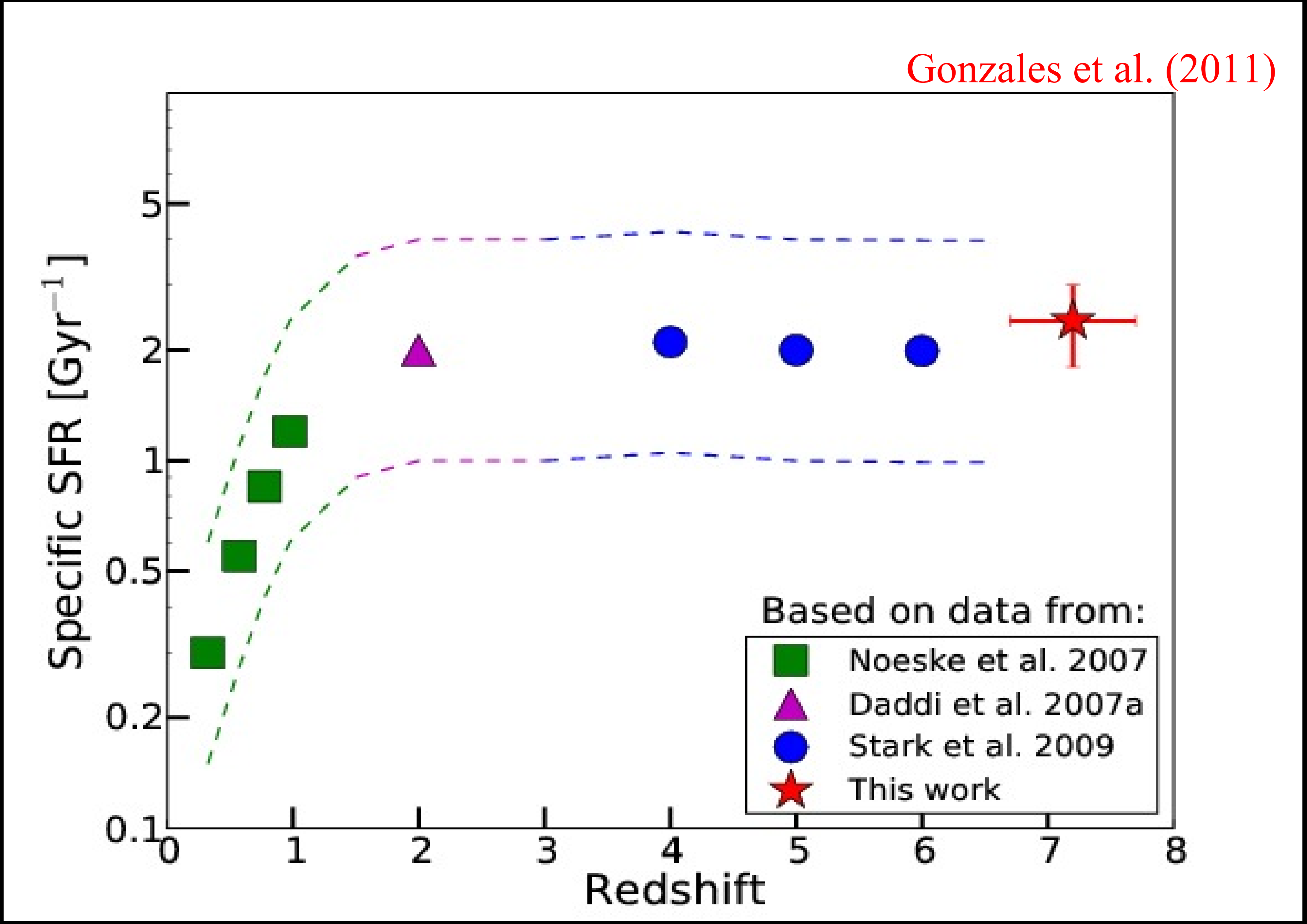
1. SFRD shows a mild rise from z=0 to z~2.5 (peak of SFH)
2. At z>3 there is a rapid decline of the SFH.
3. Dust correction to SFR is important at z<6 (?)

Stellar Mass Function



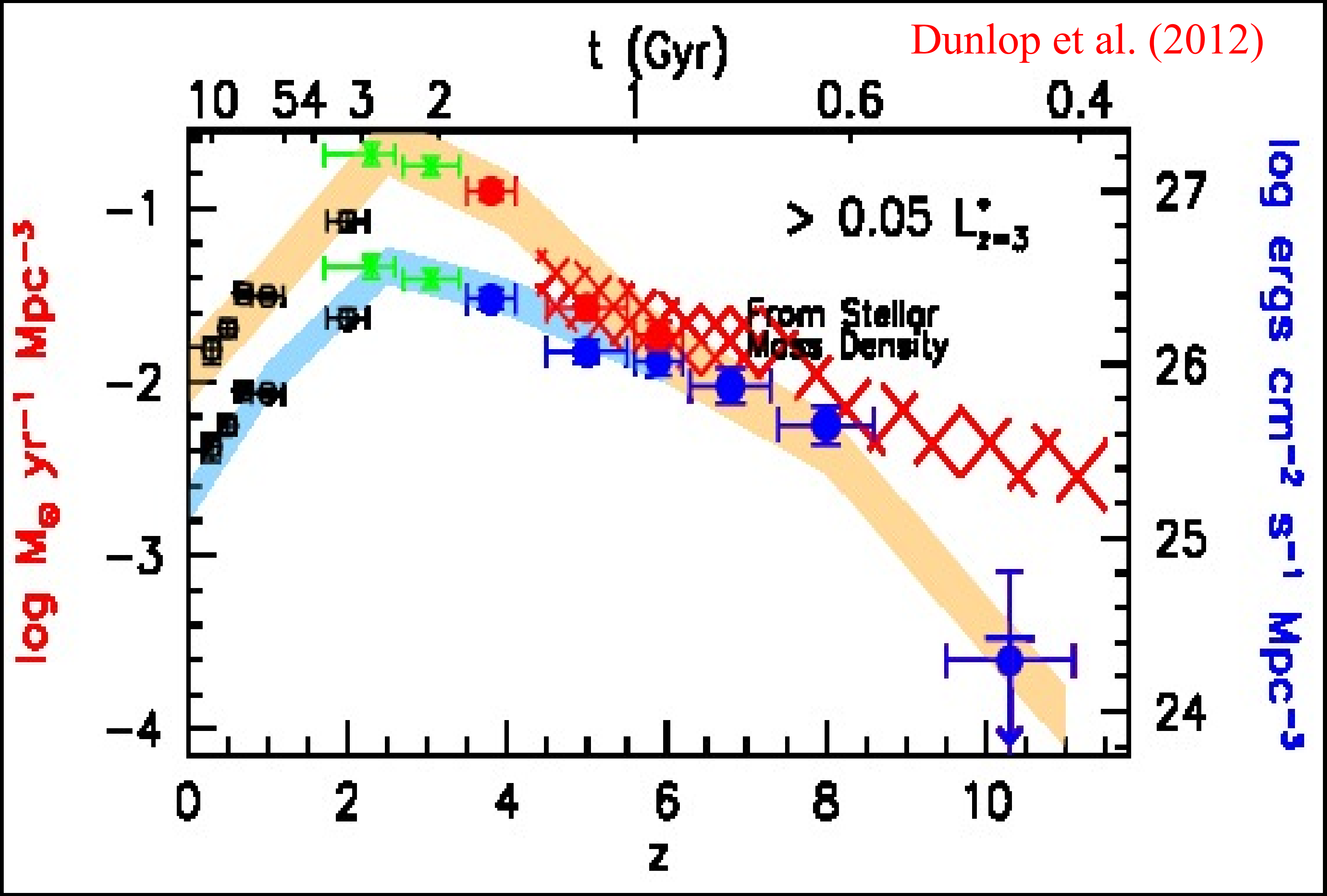
1. At z~1 the massive side of MF is close to the local value.
2. At z>1.5 there is a rapid decline of the MF massive side.
3. At z>2 the faint end of MF is steep.

Specific Star Formation Rate



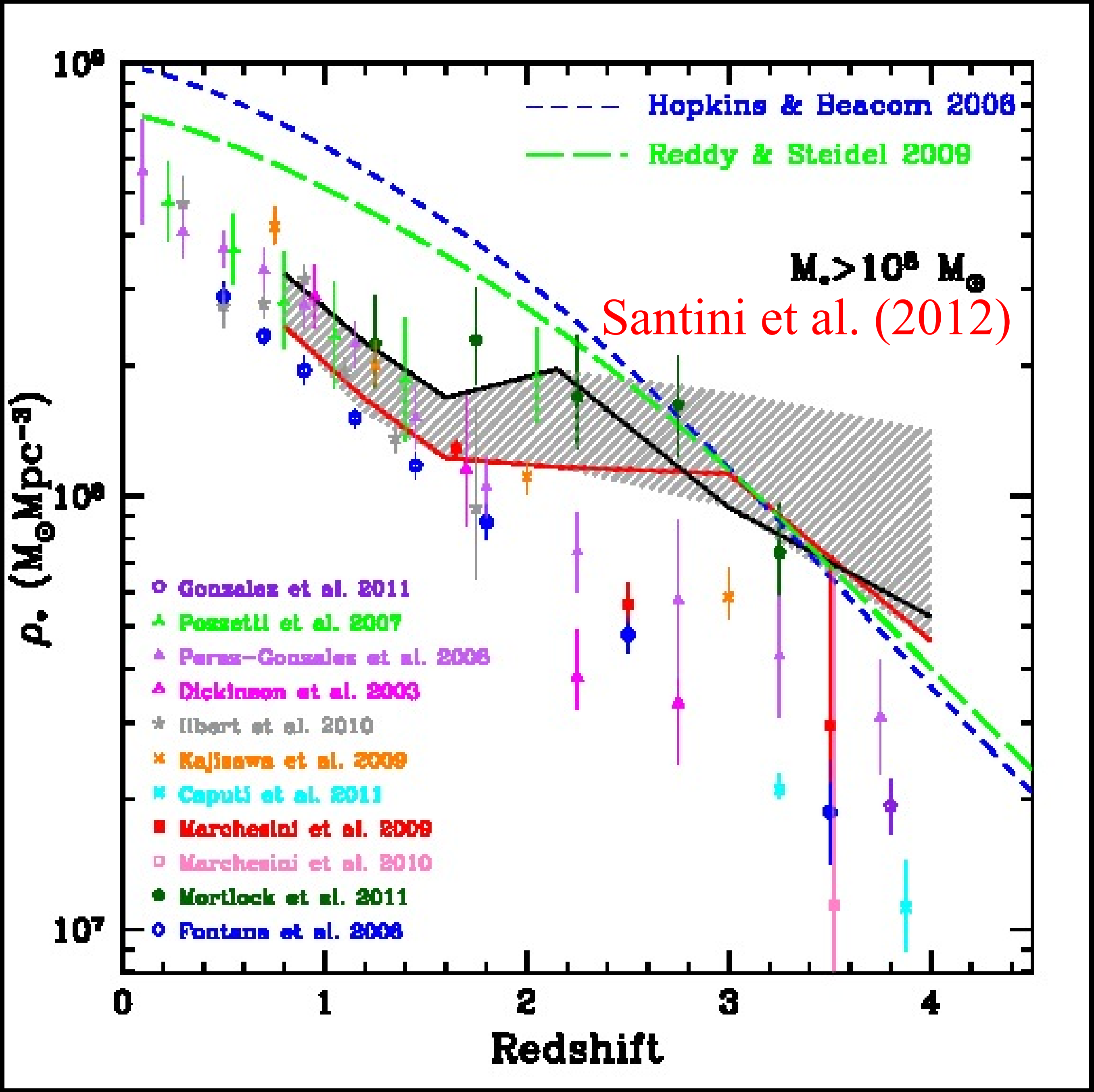
1.SSFR=SFR/Mass A rapid rise of SSFR from z=0 to z=2
2.SSFR is constant from z=2 to z=6-7
3.Related to main sequence of Star-forming galaxies ?

Comparison
Star Formation Rate vs Stellar Mass



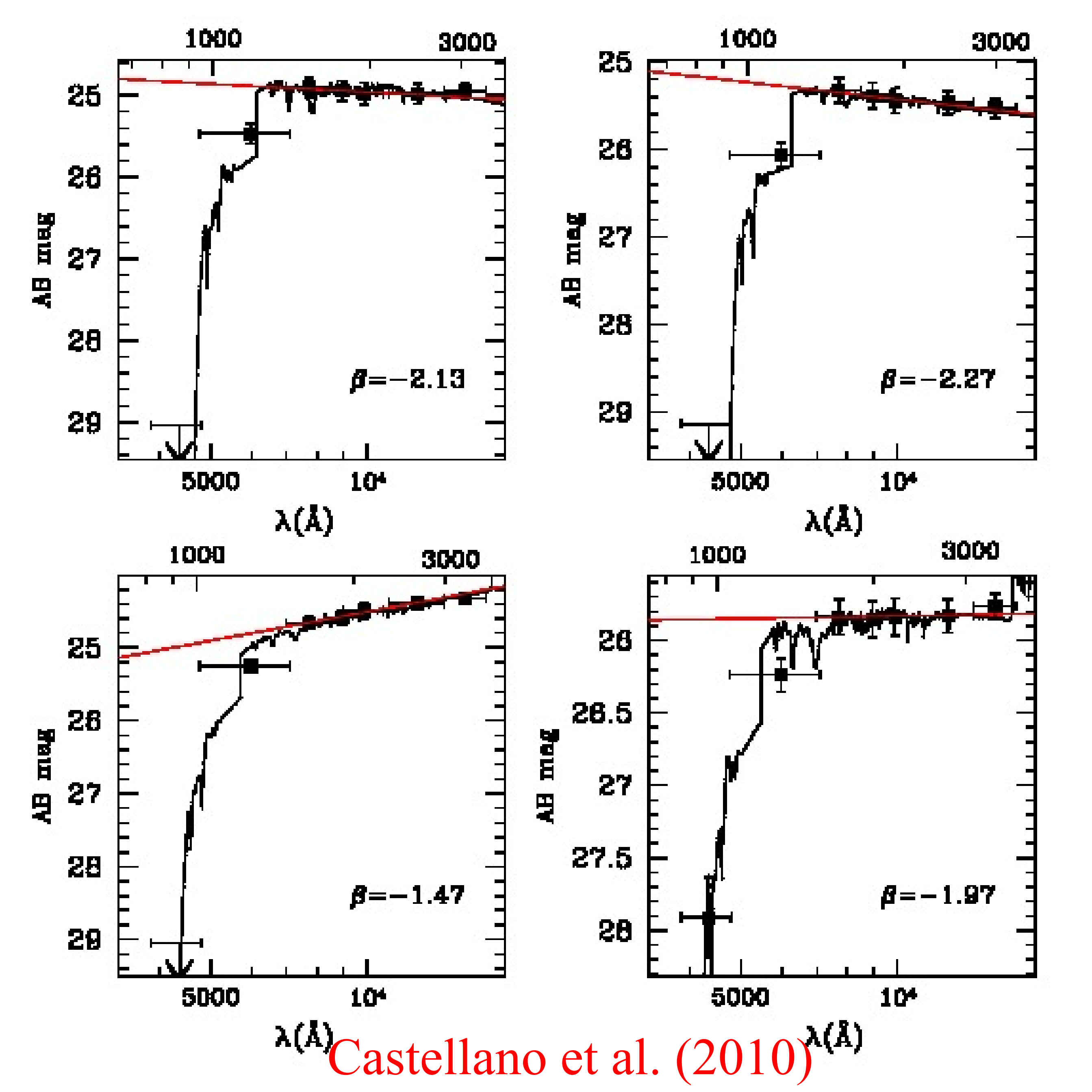
Time derivative of SMD is comparable to SFRD at z>4
WARNING: SMD at z>4 is derived mainly by UV rest frame light
Not a good proxy for stellar mass!!!

Comparison
Star Formation Rate vs Stellar Mass - 2



Integrating the SFRD at z<4 overproduces the SMD!!!
Change of IMF with time ? Is SMD underestimated ? Is SFR overestimated ?

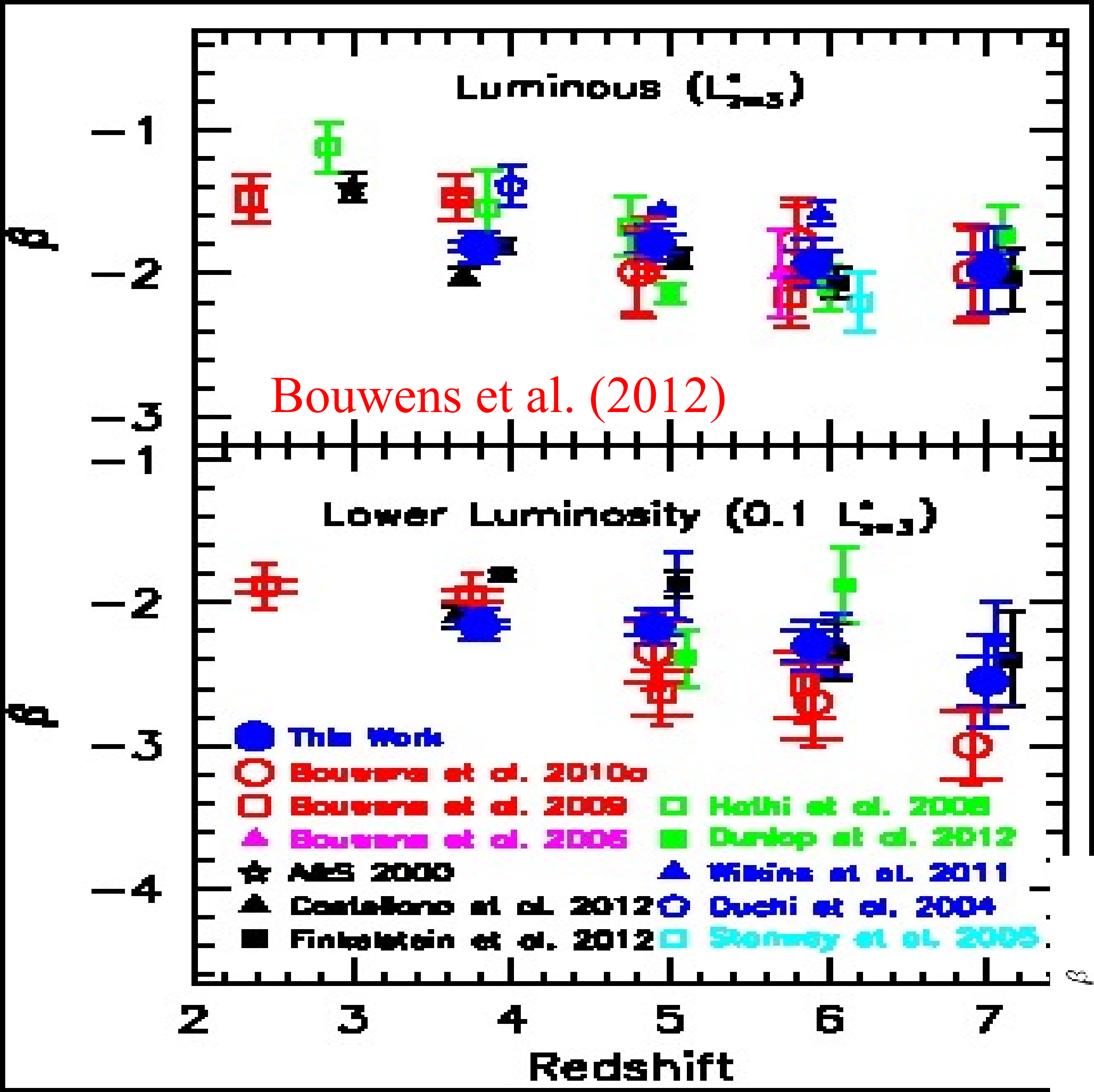
UV slopes

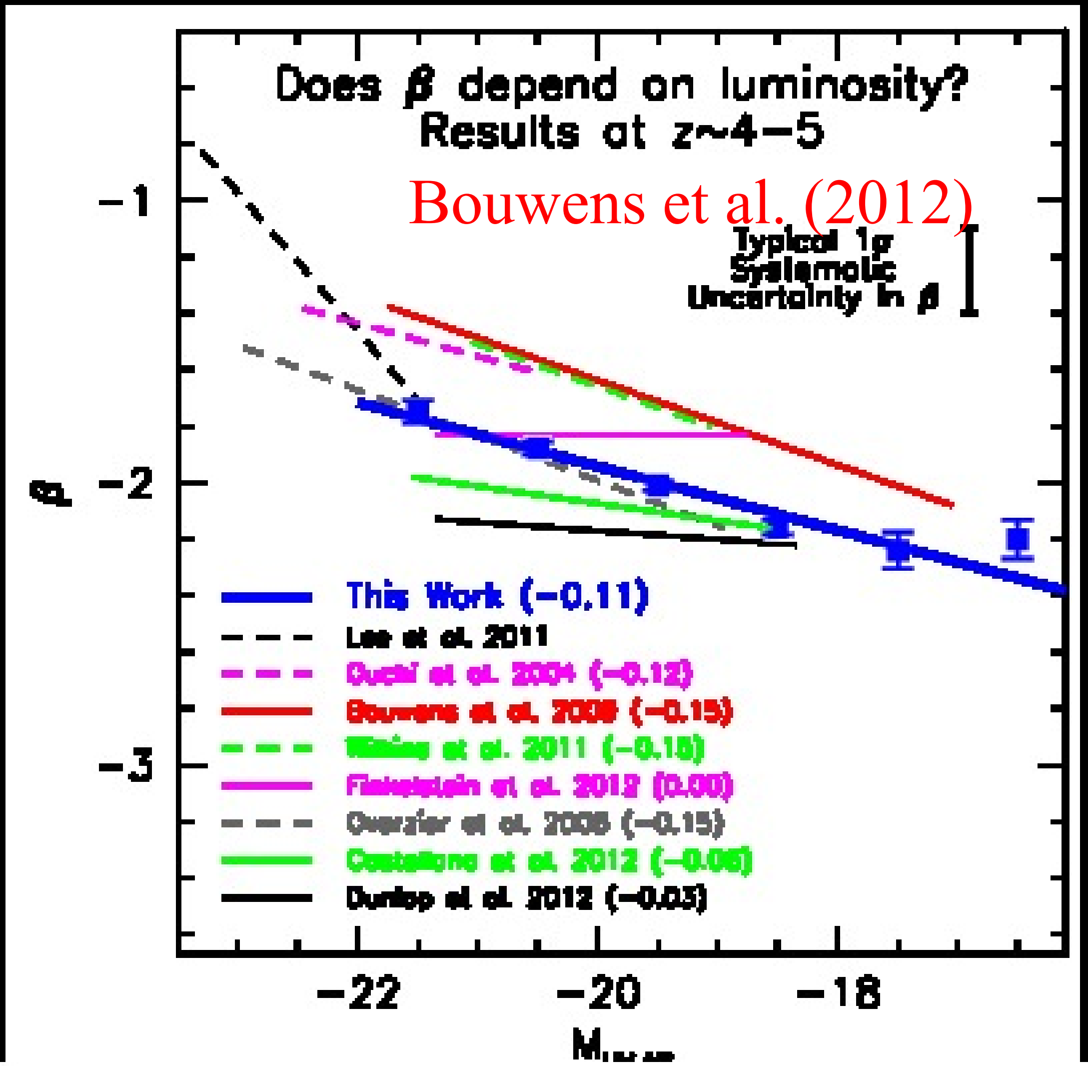


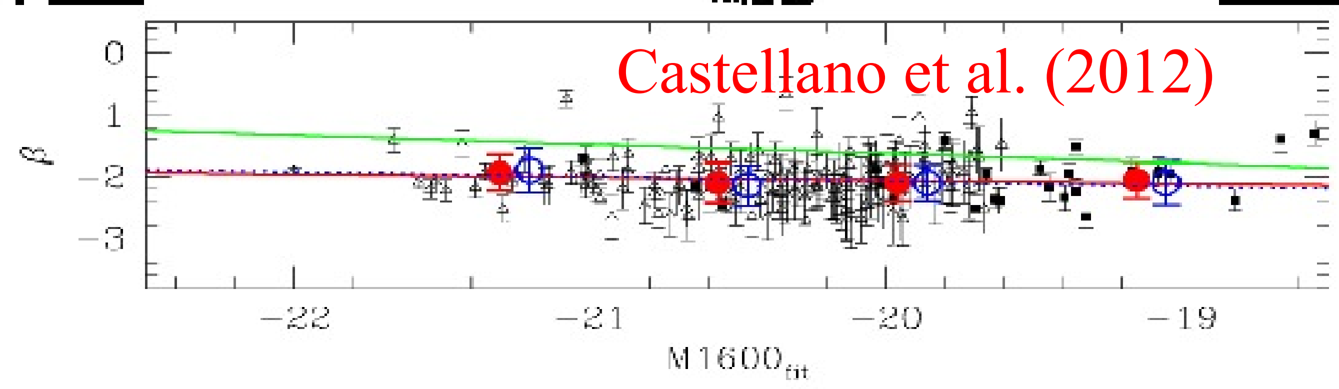
Castellano et al. (2010)

Fitting UV slopes with a power-law from 1500 A to 3000 A (rest frame)
Flat spectrum in F(nu) → beta=-2
Beta=-2.2 → E(B-V)=0.0 (Calzetti et al. 2000; Meurer 1999)

UV slopes - 2

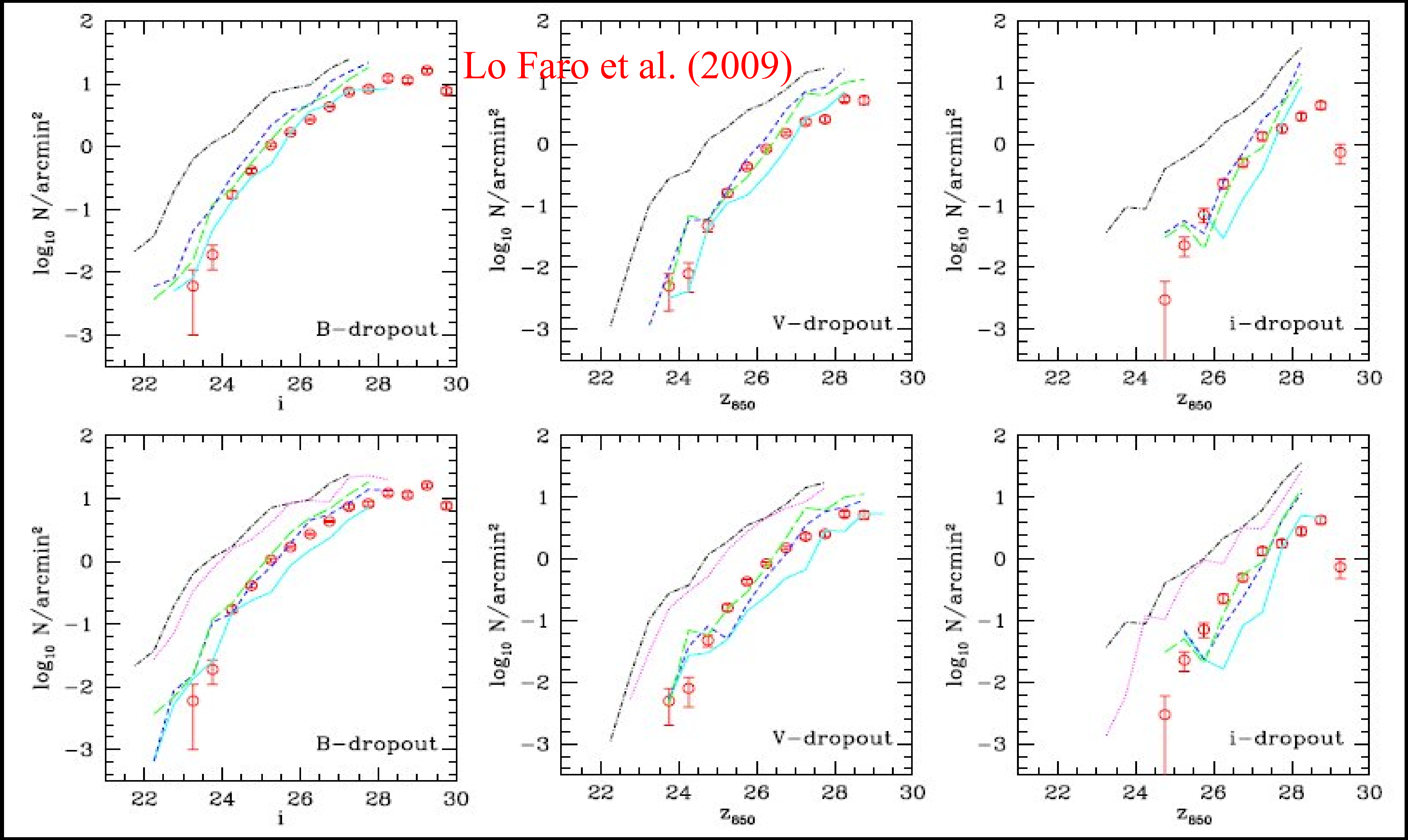






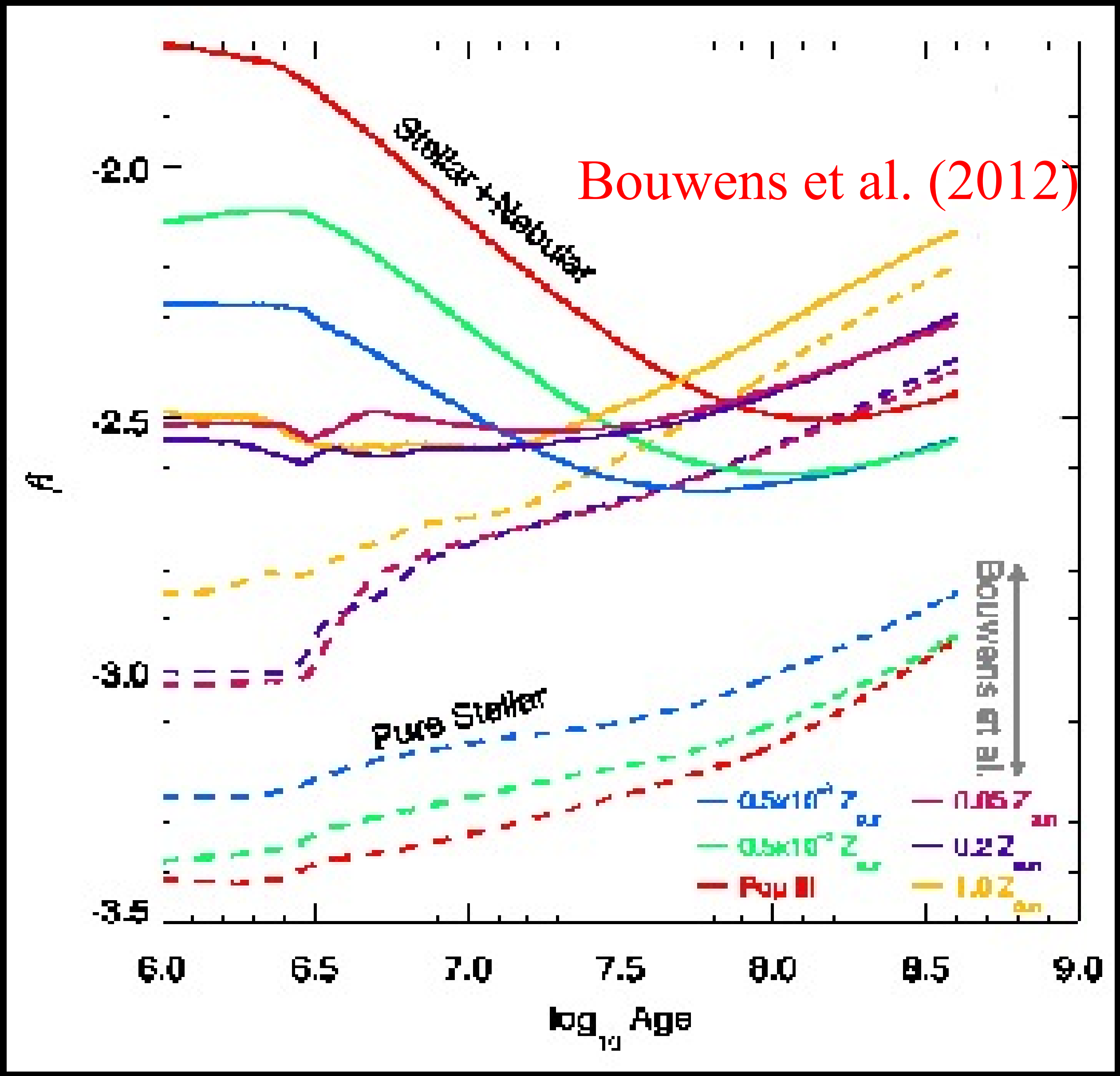
The UV slopes of LBGs evolve with redshifts: bluer galaxies at higher-z
Trend with luminosity: faint galaxies are bluer than brighter ones.
Escape fraction increasing for galaxies of low luminosities ?

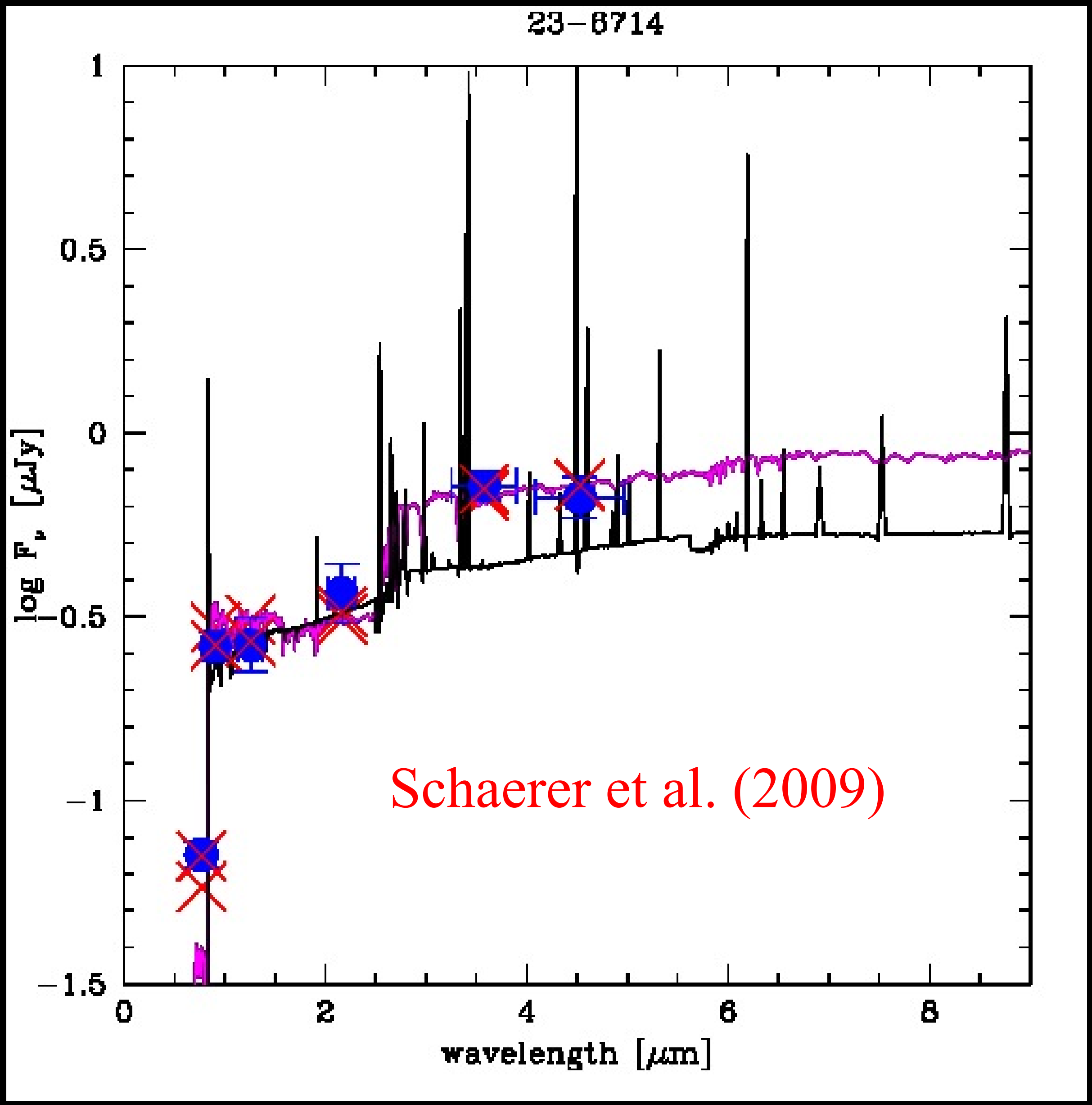
UV slopes - 3



Recent renditions of SAM models for the formation and evolution of high-z Galaxies are not able to reproduce the number counts of LBGs with Zero dust. Inconsistent with beta=-2 at z>6!!!

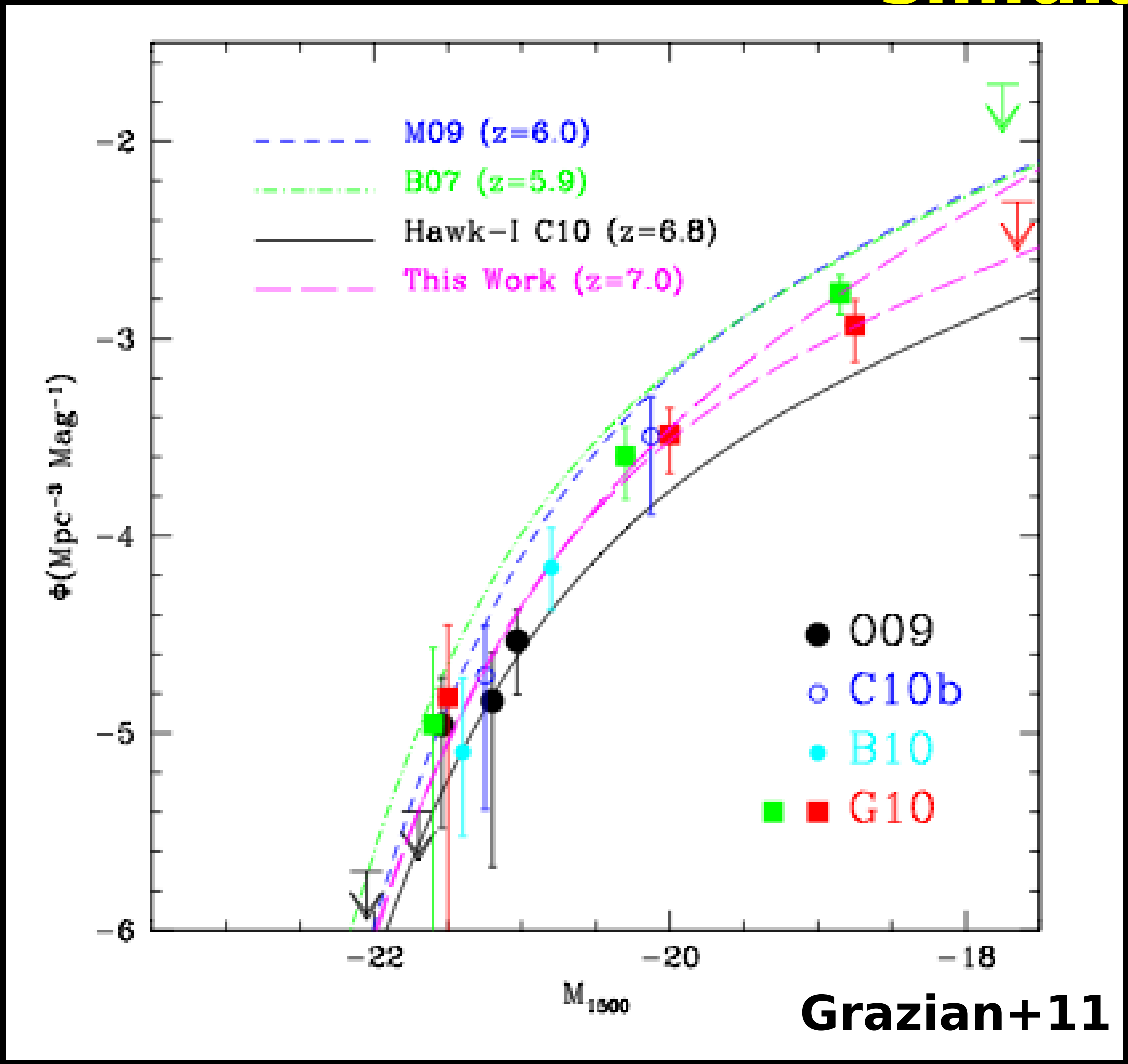
UV slopes - 4





Beta=-2.5 -3 can be explained by contribution from nebular lines or by
A pure stellar spectrum (escape fraction in Lyman Continuum = 0)

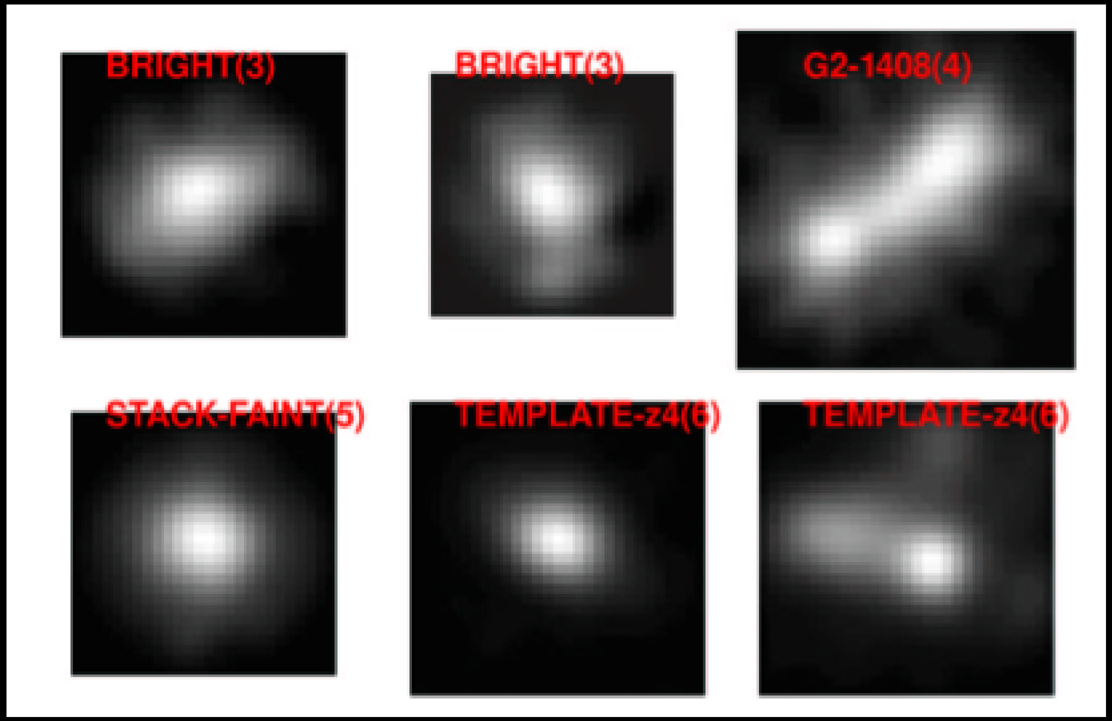
The estimate of the *faint* side of the LF is heavily affected by the uncertainties of simulations

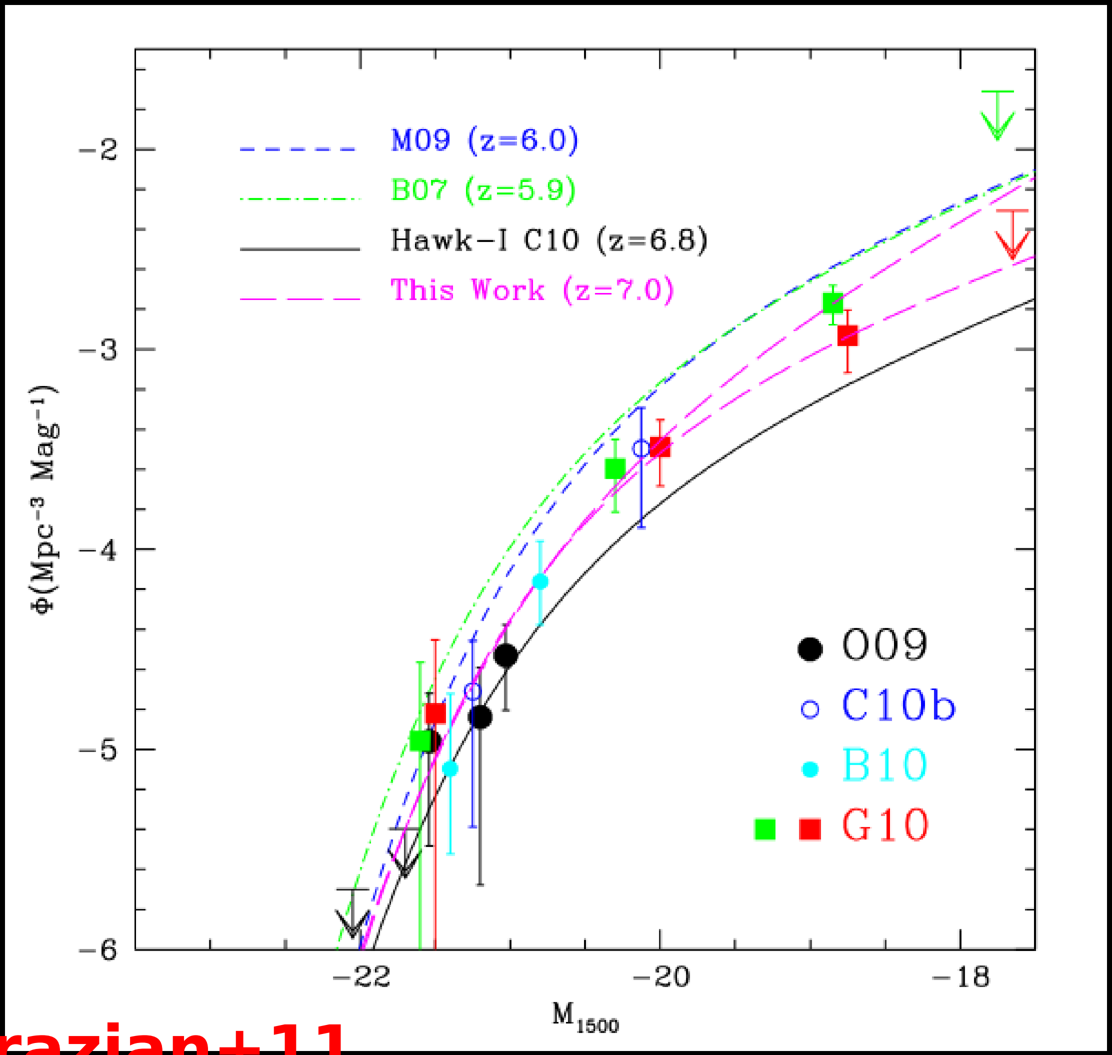


the slope is necessary to estimate the integral of the LF, i.e. the total luminosity density or SFRD

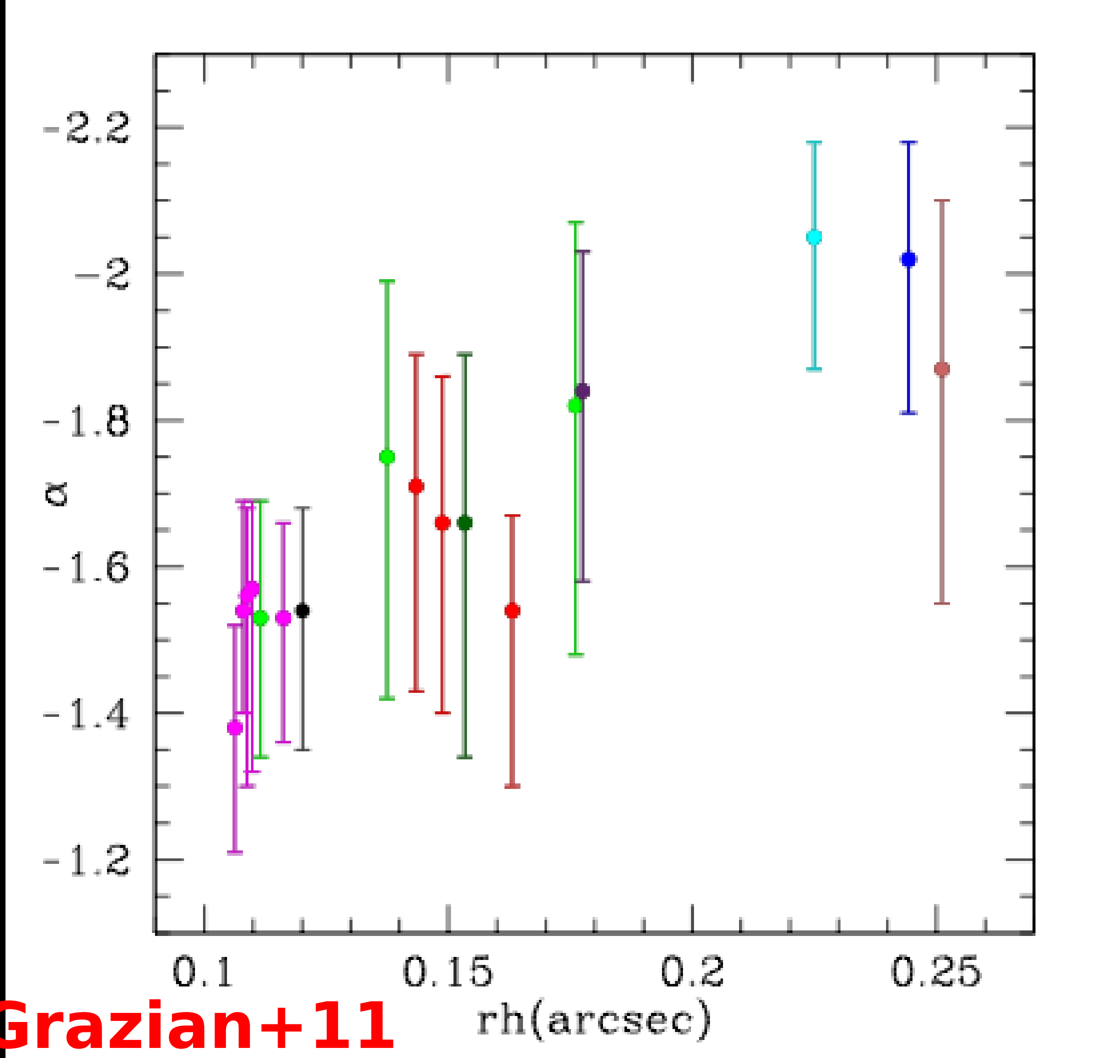
Two ways out:
increasing S/N at faint magnitudes
estimate the uncertainties

Completeness corrections at the faint side depend on the *assumed* morphology





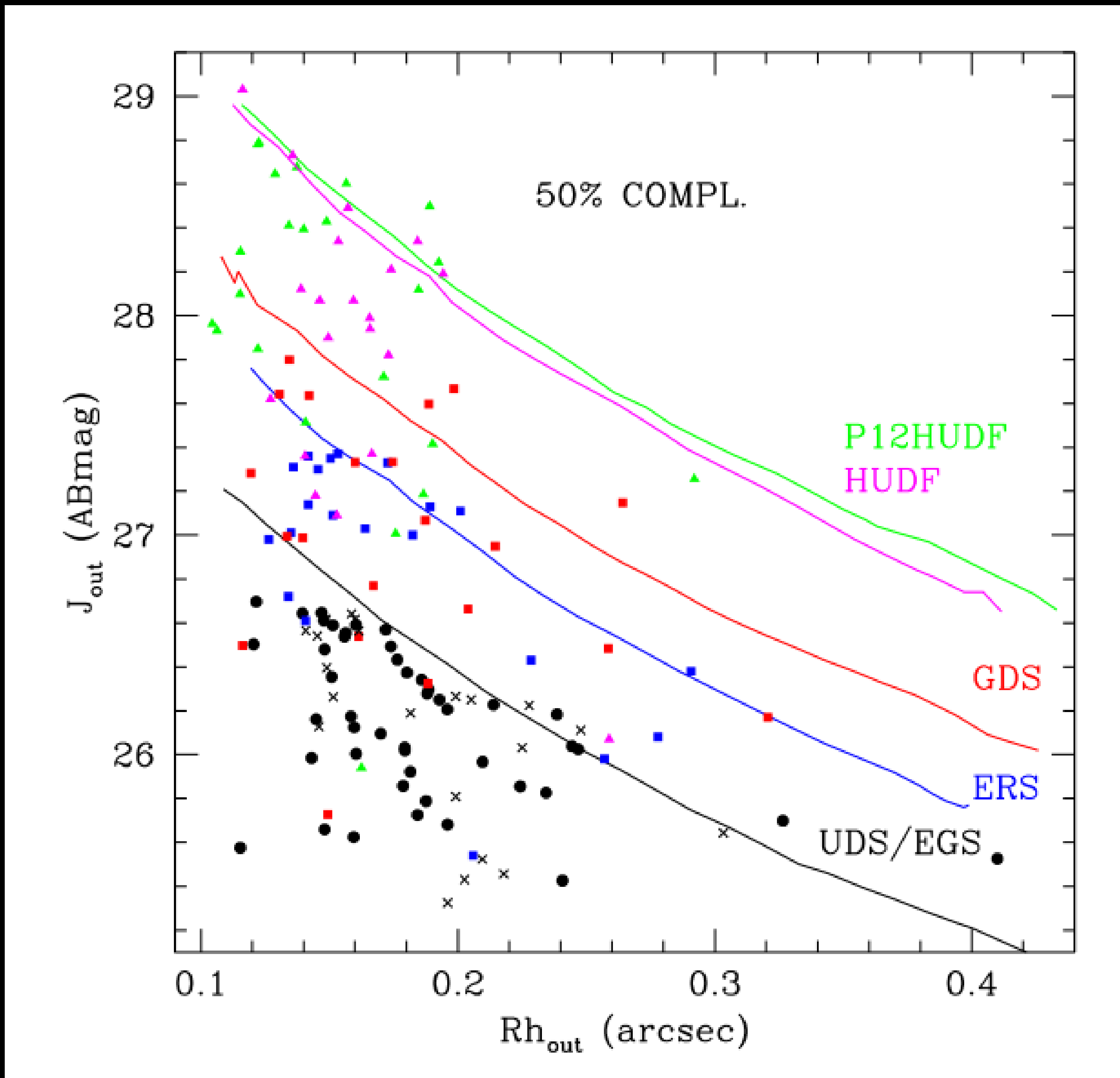
Grazian+11

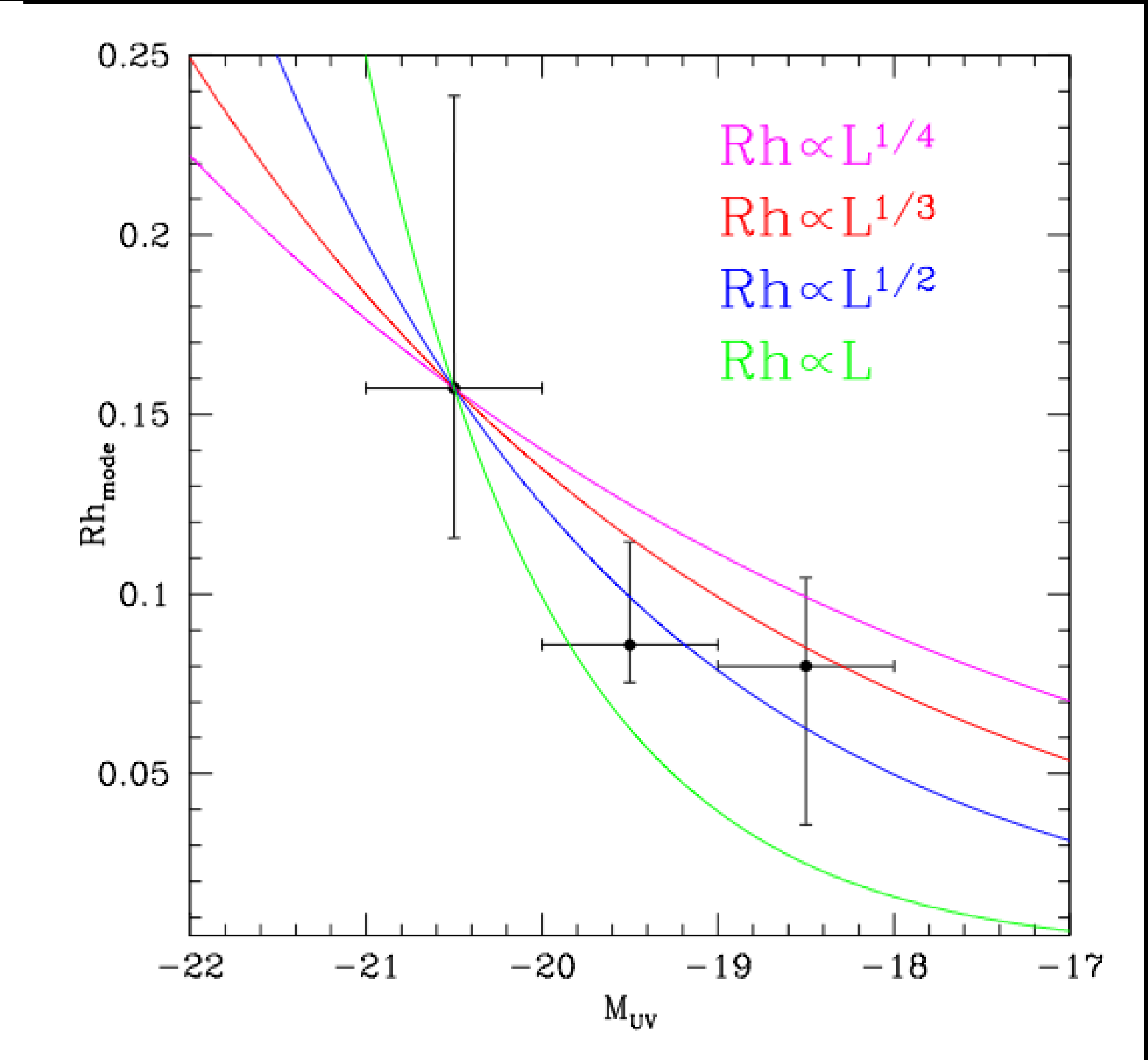


Grazian+11

Size of z~7 galaxies in CANDELS

(Grazian et al 2012, in prep)





Effects on reionization

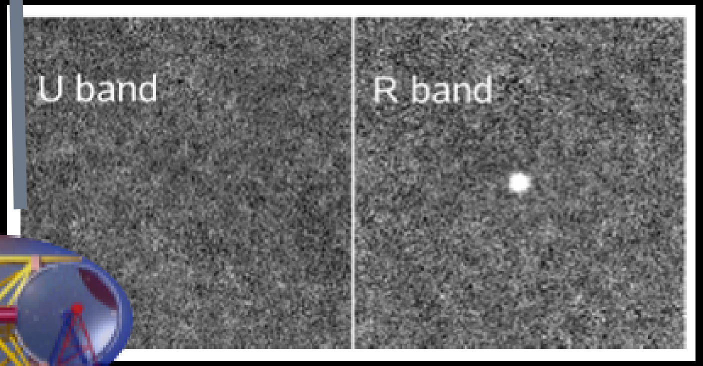
Production rate of ionizing photons:

reionizing photons/SFR/s; depends on IMF

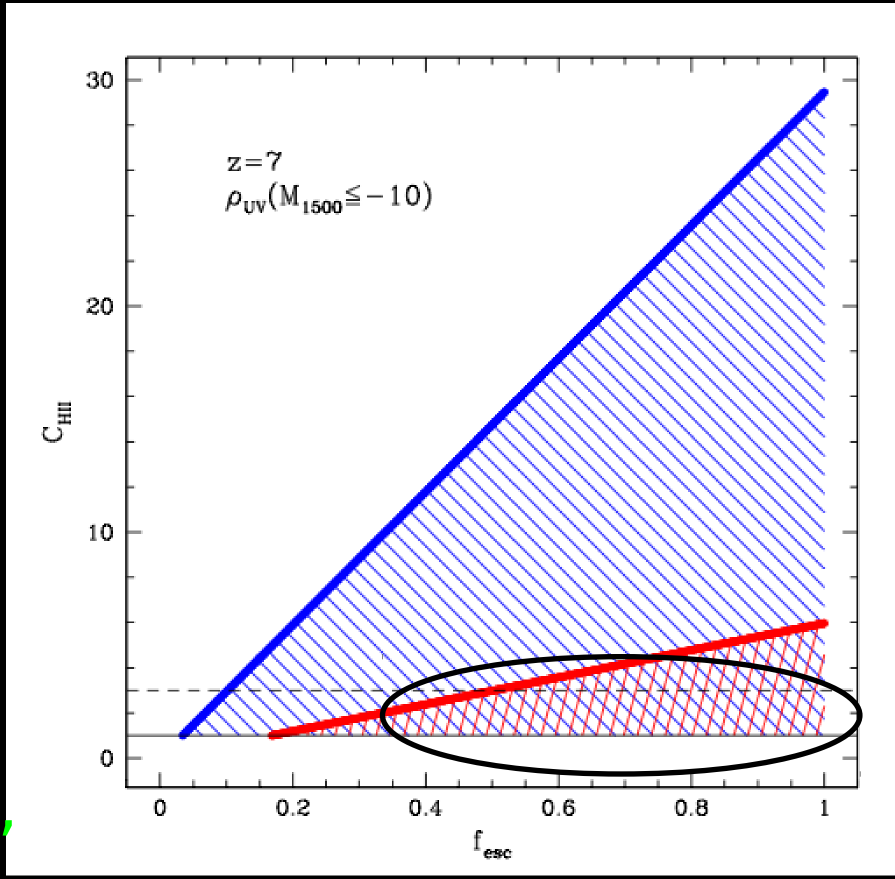
obtained integrating LF

currently unknown at z=7, and debated at z=3!

Recombination rate



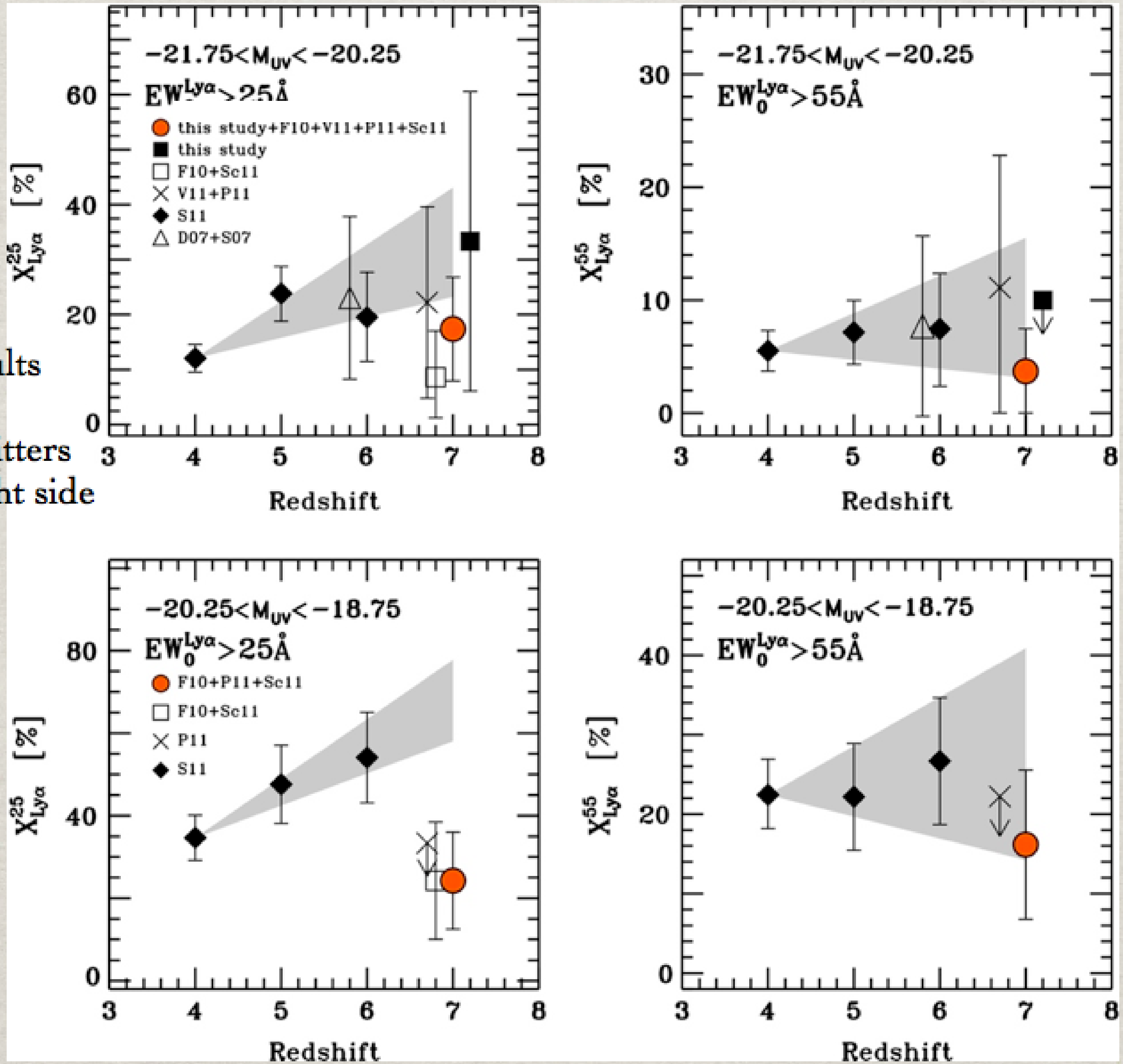
Boutsia+11
LBT data
11 gals at z~3.4
fesc<5%
(see also Vanzella+10,11,
but Nestor+11)



With the combination of the 3 samples (> 44 candidates observed) we can put even tighter constraints on the decrease of the Lyα emitters fraction

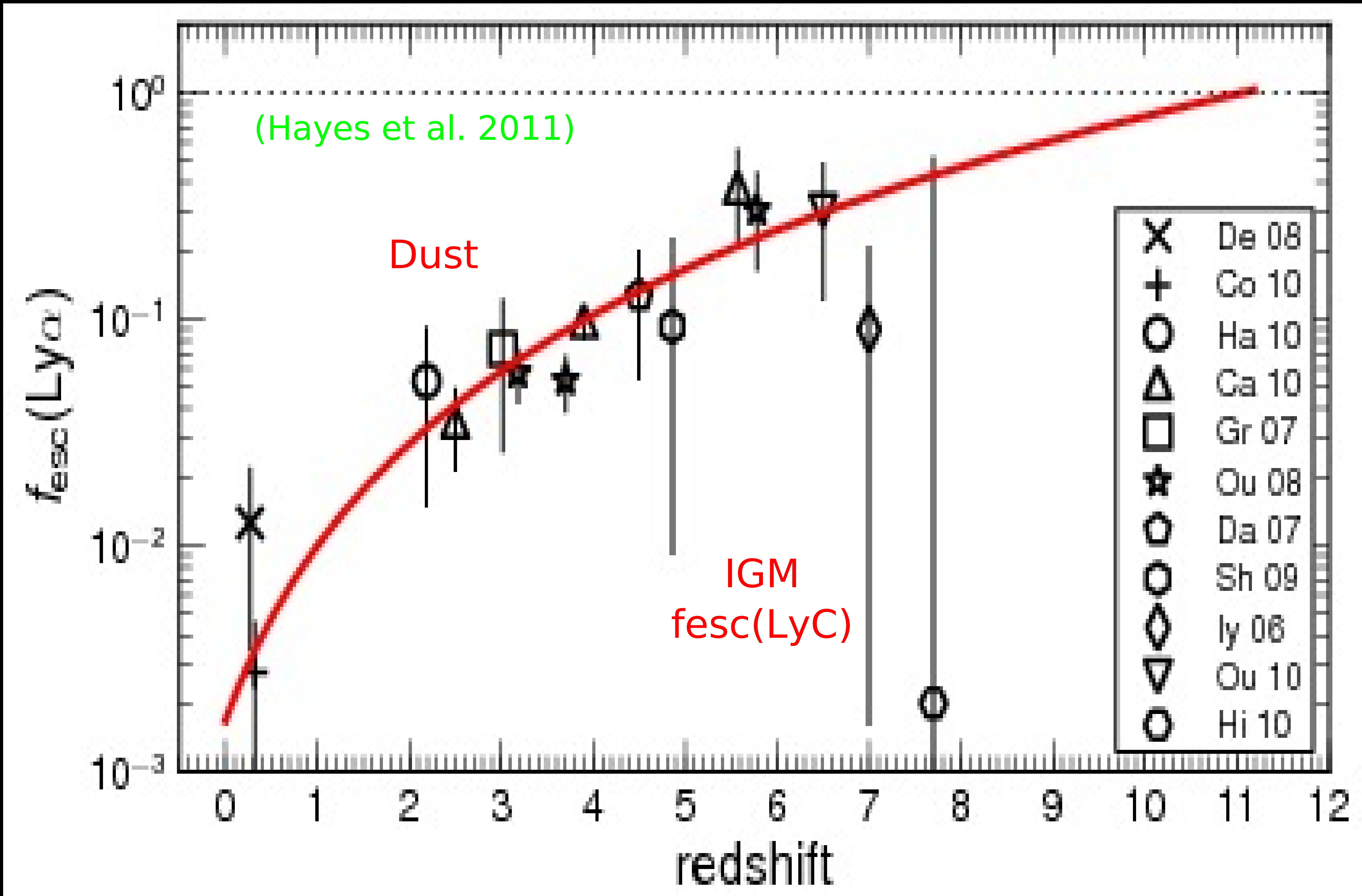
Red circles are combined sample

NB: SUBARU results are also consistent with increase in emitters fraction at the bright side

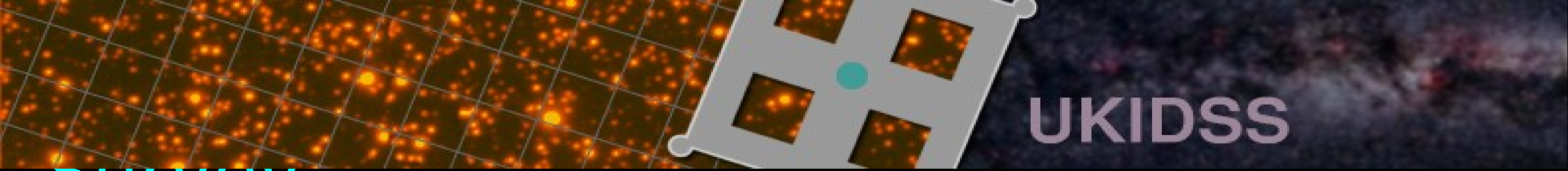


Bright sample (mostly Ono et al. 2012 +LP2011)

Faint sample (mostly from Schenker et al. 2012 +LP2011)



fesc(LyC)=0.0 at z<6



Survey

The UKIDSS Ultra-Deep Survey

PI: Omar Almaini

UKIRT (Mauna Kea, Hawaii)

WFCAM

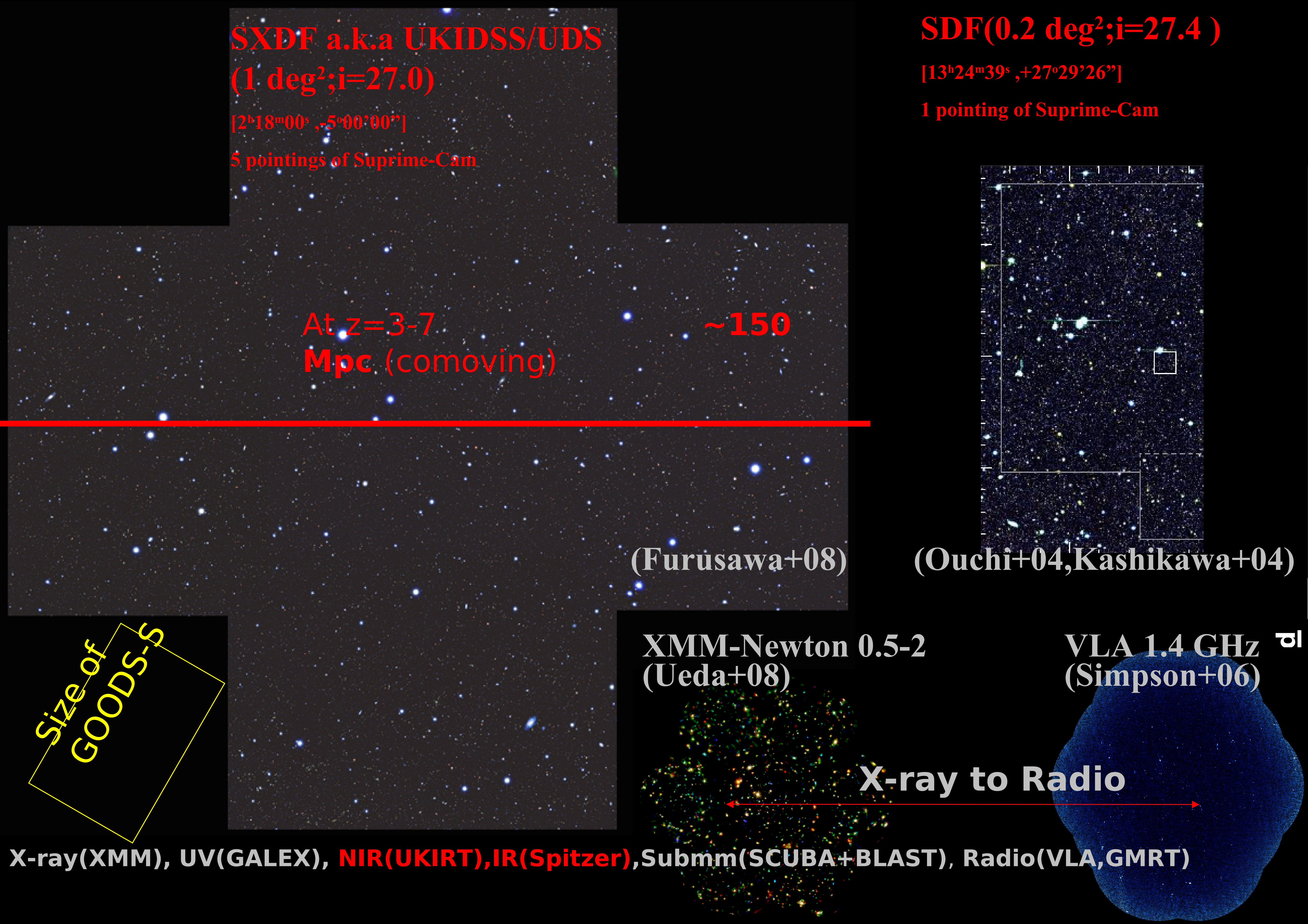
Ultra Deep	UDS	JHK	K=23.0	0.77 deg^2
Deep Extragalactic	DXS	JK	K=21.0	35 deg^2
Galactic Plane	GPS	JHK	K=19.0	1800 deg^2
Galactic Clusters	GCS	ZYJHK	K=18.7	1600 deg^2
Large Area	LAS	YJHK	K=18.4	4000 deg^2

Survey wedding cake

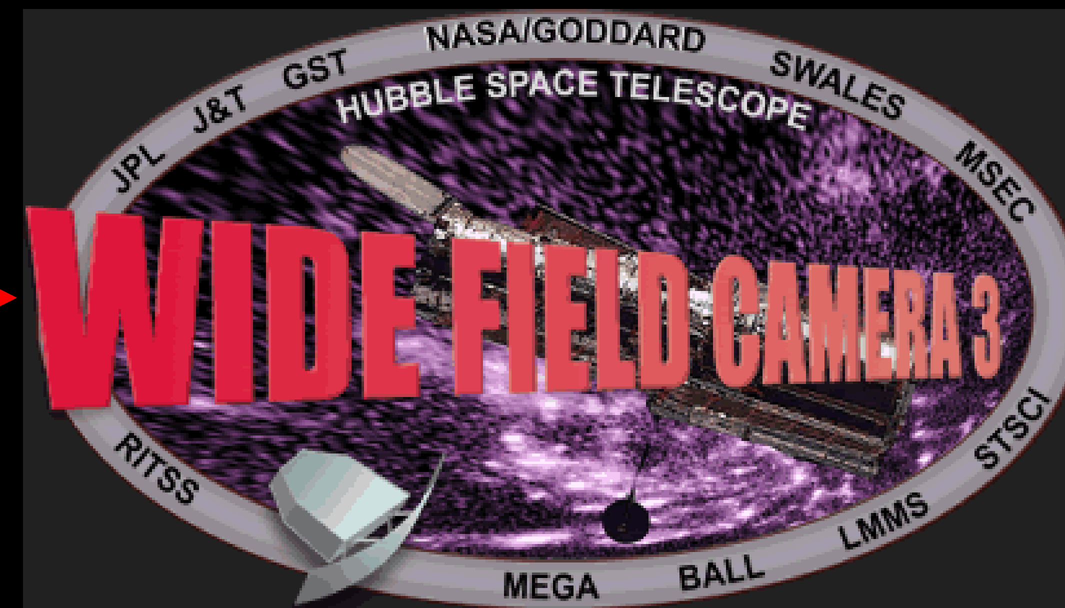
Near-IR (UKIRT): J=24.3, H=24.0, K=24.2
Optical (Subaru): B=28.2, V=27.6, R=27.5, i'=27.2, z'=26.3
Spitzer (spUDS legacy): 3.6µm=24.2 4.5µm=24.0, 24.0µm=100µJy
Spectroscopy: 10,000 optical spectra, 15-filter photo-z's for 150,000 galaxies

Unique depth+area in NIR plus strong + multi-wavelength coverage

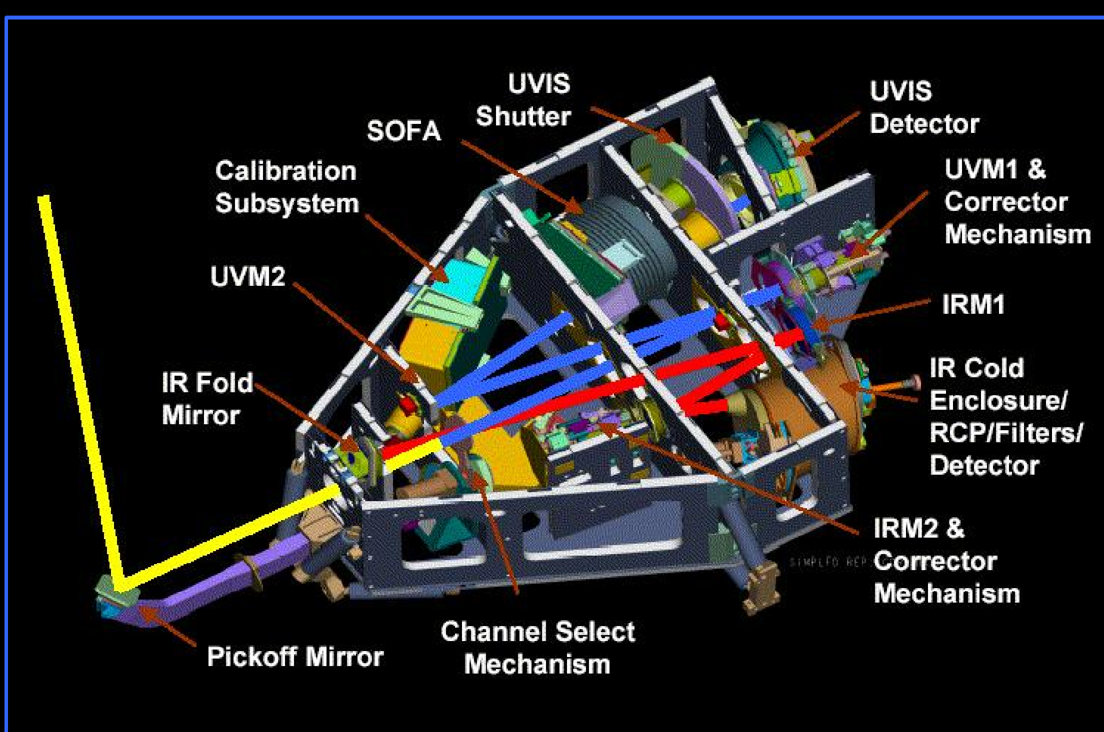
Key science goal: assembly of massive galaxies at 1<z<3


SXDF a.k.a UKIDSS/UDS
(1 deg^2;i=27.0)
[2^{h}18^{m}00^s ,-5^{o}00'00"]
5 pointings of Suprime-Cam
SDF(0.2 deg^2;i=27.4)
[13^{h}24^{m}39^s ,+27^{o}29'26"]
1 pointing of Suprime-Cam
At z=3-7 ~150
Mpc (comoving)
(Furusawa+08)
(Ouchi+04,Kashikawa+04)
Size of GOODS-S
XMM-Newton 0.5-2
(Ueda+08)
VLA 1.4 GHz
(Simpson+06)
X-ray to Radio
X-ray(XMM), UV(GALEX), NIR(UKIRT),IR(Spitzer),Submm(SCUBA+BLAST), Radio(VLA,GMRT)

High redshift galaxies: 7.0<z<9.0

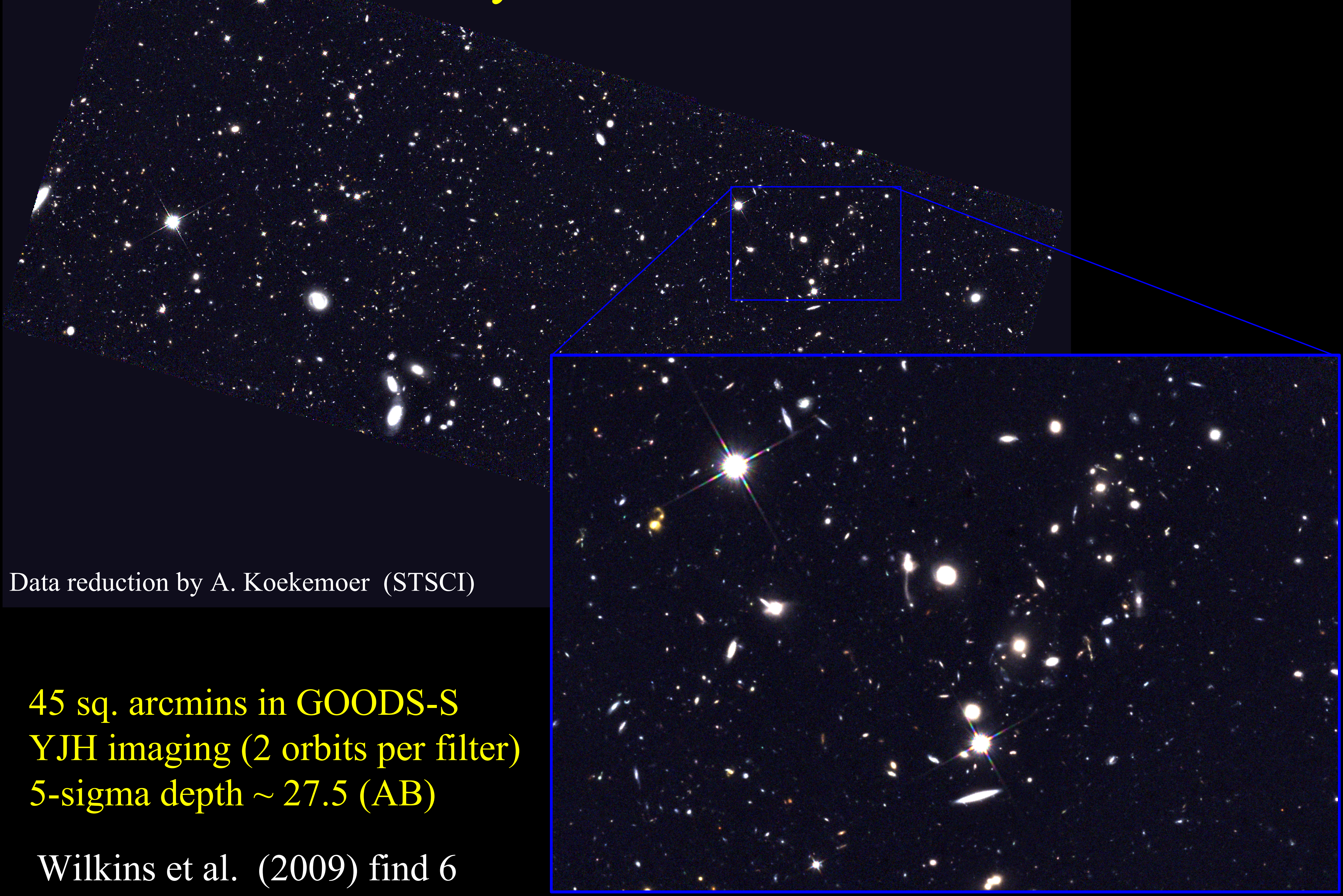


Service mission four installed a new camera – WIDE FIELD CAMERA 3



- Two channel, UVIS and NIR (YJH)
- NIR channel has 4.5 square arcmin FOV
- Image quality of ~0.15” FWHM
- Order of magnitude better that NICMOS

Early Release Science Data



45 sq. arcmins in GOODS-S
YJH imaging (2 orbits per filter)
5-sigma depth ~ 27.5 (AB)

Wilkins et al. (2009) find 6
z~7 zdrops in 5/10 pointings

WFC3 Imaging of the HUDF

Data reduction by A. Koekemoer & E. Sabbi (STSCI)

The basic numbers:

~11 hours in Y
~12 hours in J
~22 hours in H

FWHM: 0.15-0.18”

5σ depths: Y=29.0 (AB)
J=29.1
H=29.2

What do we find?

49 candidates at z>6.0
15 candidates at z>7.0
3 candidates at z>8.0

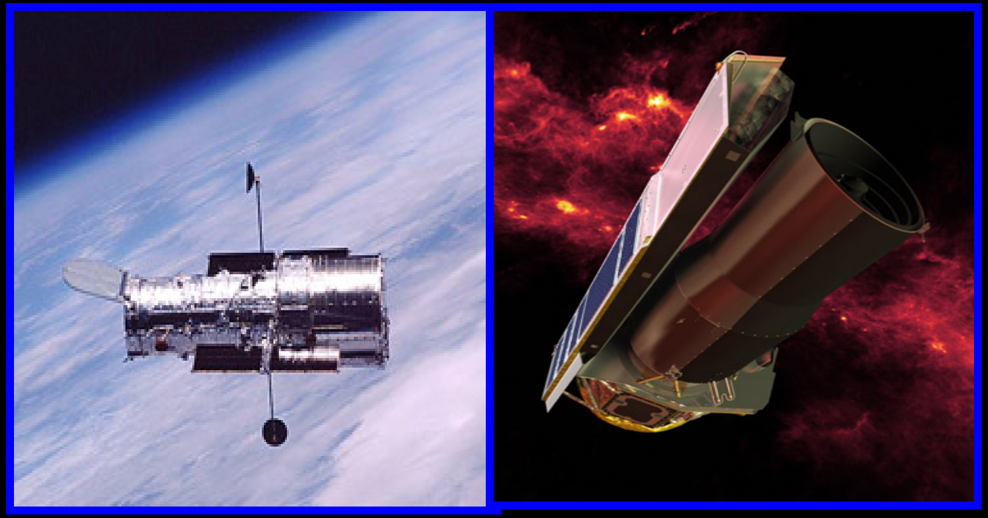
Future Prospects (near term)

1. Ground-based

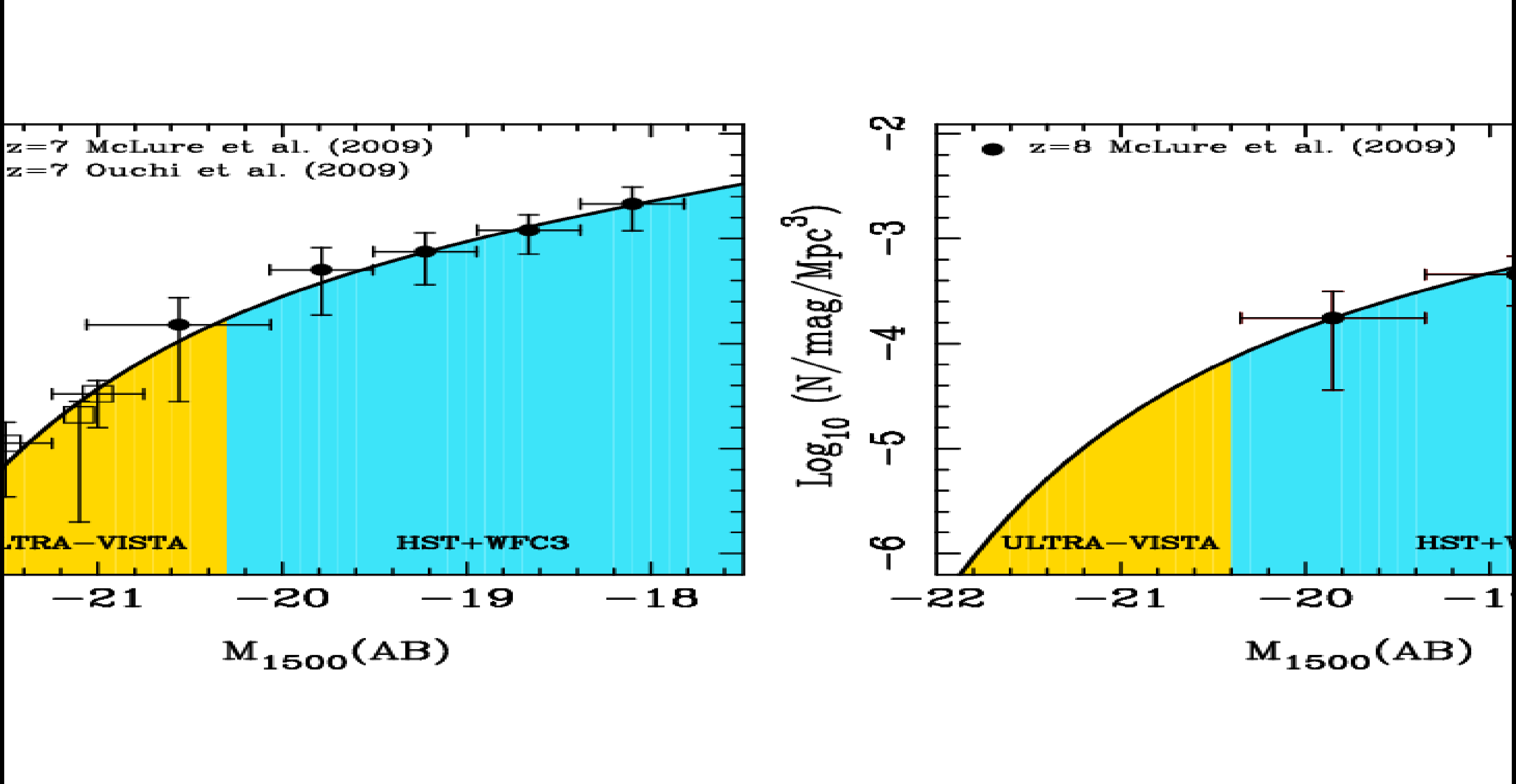
- VISTA surveys
- Suprime-cam zY imaging
- Hyper-Suprime cam

2. Space-based

- HST (ERS+MCT?)
- Spitzer SEDS



What will ULTRA-VISTA see at 6.5<z<8.5?



~ 500 zY-drops at 6.5<z<7.5

~ 100 Y-dropouts at 7.5<z<8.5

CANDELS

Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey

Co-PIs:

Sandra Faber

University of California Santa Cruz

Harry Ferguson

Space Telescope Science Institute

CANDELS: the largest HST program ever approved WFC3 deep/wide exposures over 5 extragal. fields P.I.: S. Faber, H. Ferguson.

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 197:35 (39pp), 2011 December GROGIN ET AL.

Table 1
CANDELS at a Glance

Field	Coordinates	Tier	WFC3/IR Tiling	HST Orbits/Tile	IR Filters[a]	UV/Optical Filters[b]
GOODS-N	189.228621, +62.238572	Deep	∼3 × 5	∼13	*YJH*	*UV,UI(WVz)*
GOODS-N	189.228621, +62.238572	Wide	2 @ ∼2 × 4	∼3	*YJH*	*Iz(W)*
GOODS-S	53.122751, −27.805089	Deep	∼3 × 5	∼13	*YJH*	*I(WVz)*
GOODS-S	53.122751, −27.805089	Wide	∼2 × 4	∼3	*YJH*	*Iz(W)*
COSMOS	150.116321, +2.2009731	Wide	4 × 11	∼2	*JH*	*VI(W)*
EGS	214.825000, +52.825000	Wide	3 × 15	∼2	*JH*	*VI(W)*
UDS	34.406250, −5.2000000	Wide	4 × 11	∼2	*JH*	*VI(W)*

Exposure Strategy

“Wedding cake” strategy: three layers of J+H

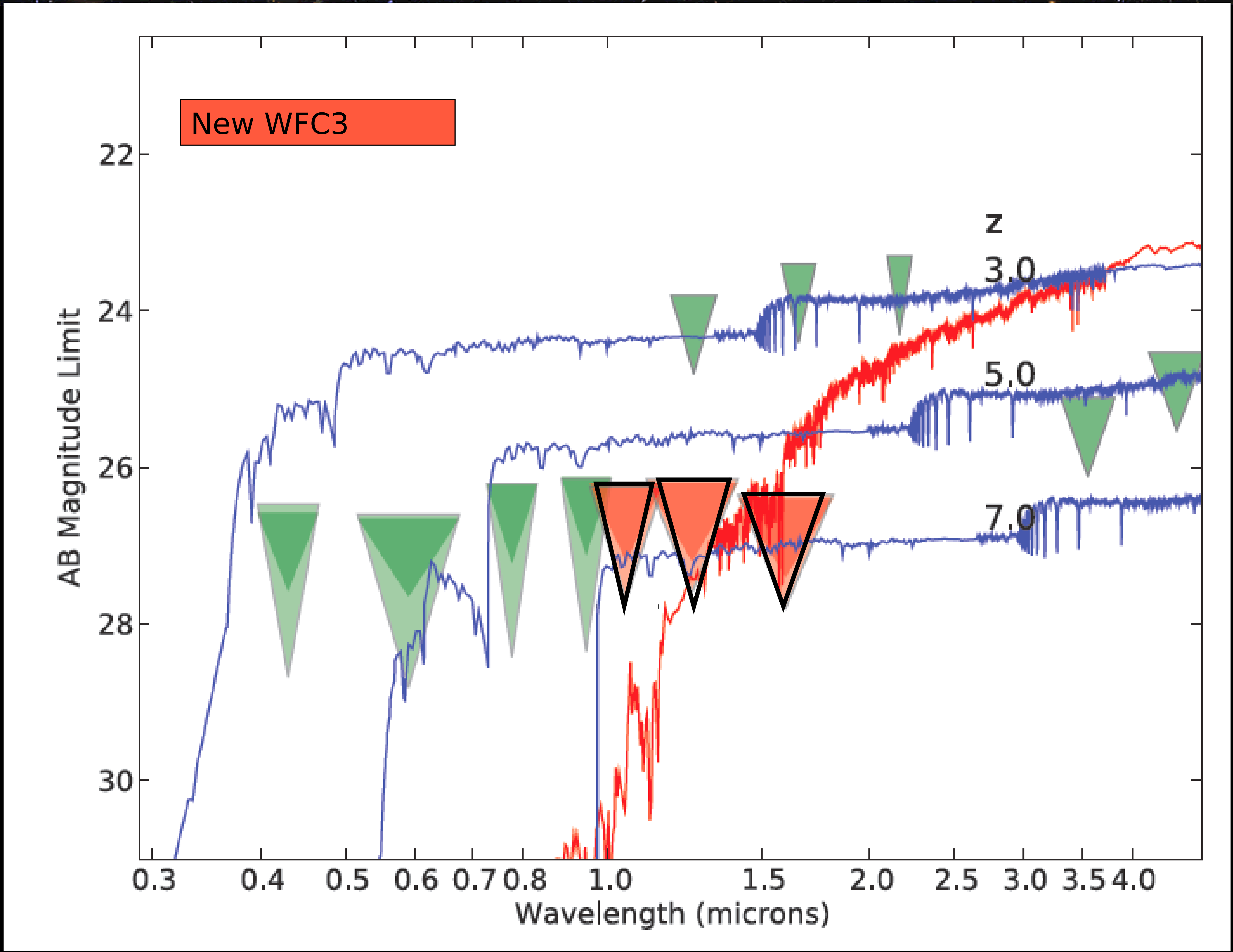
UDFs: 50-100 orbit depth over ~0.004 sq deg

DEEP: 8 orbit depth over ~0.04 sq deg

WIDE: 2 orbit depth over ~0.2 sq deg

CANDELS
Cosmic Assembly and Dark Energy Legacy Survey

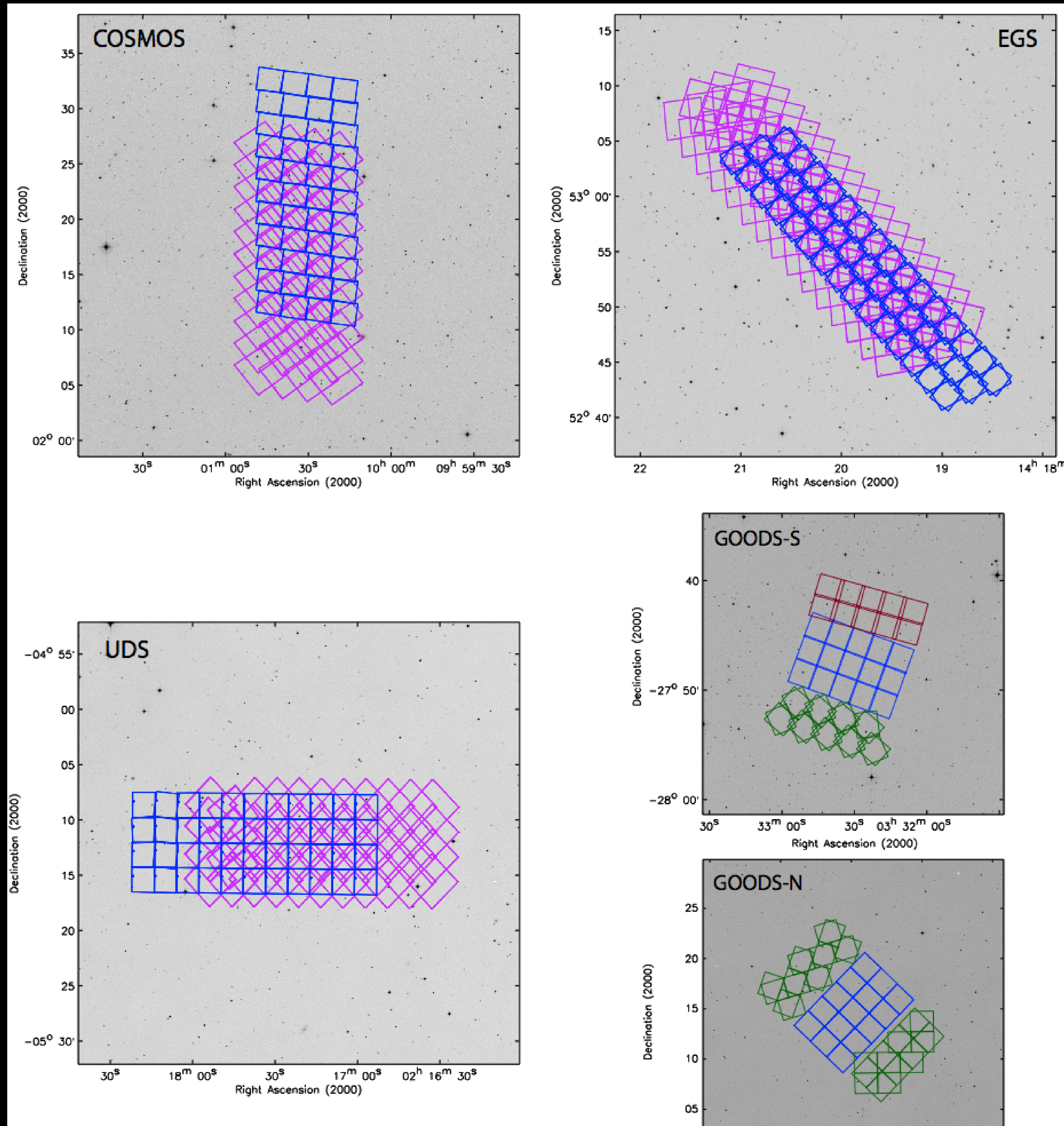
Photometry gains

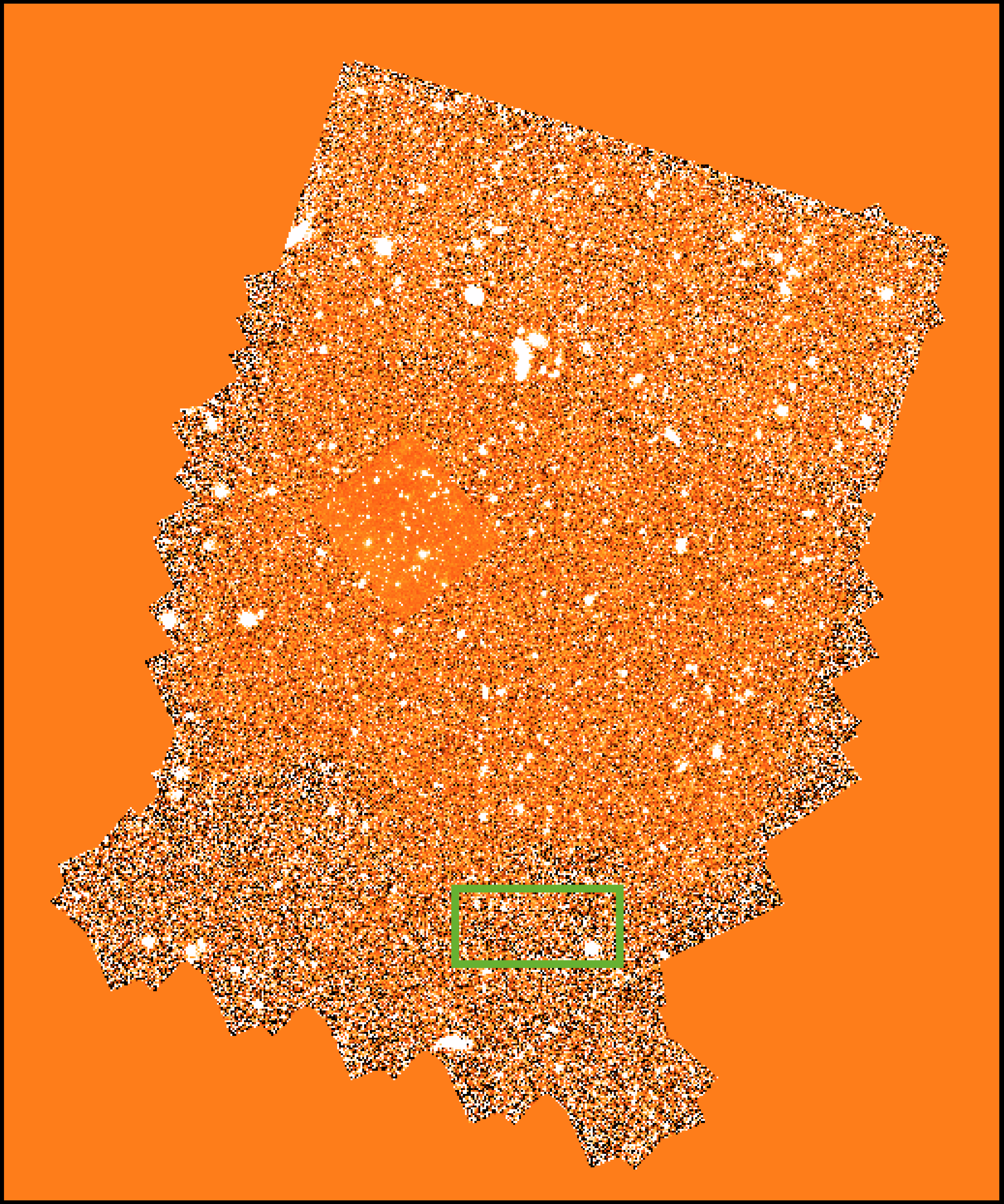


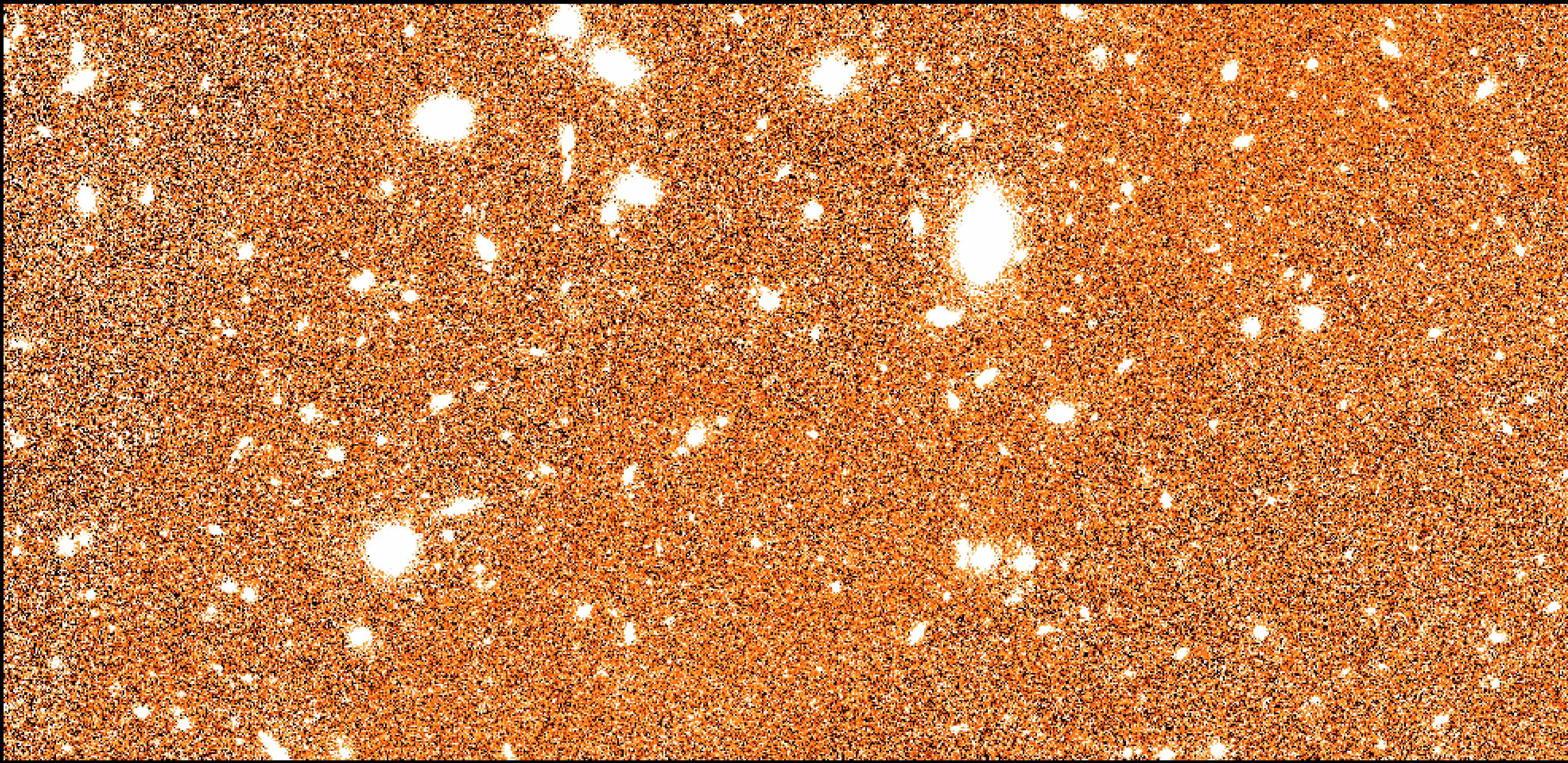
CANDELS
Cosmic Assembly and Dark Energy Legacy Survey

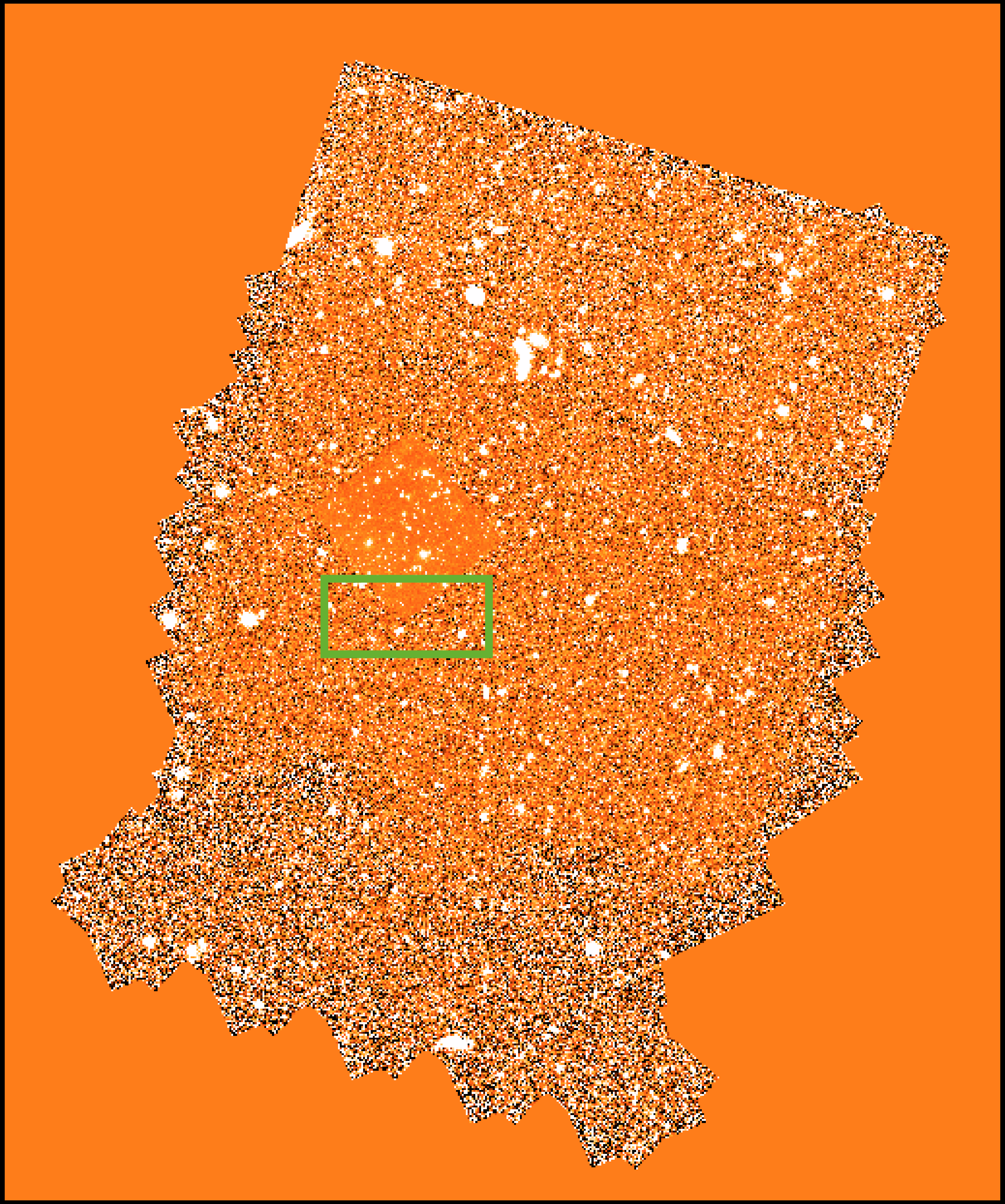
Highlights

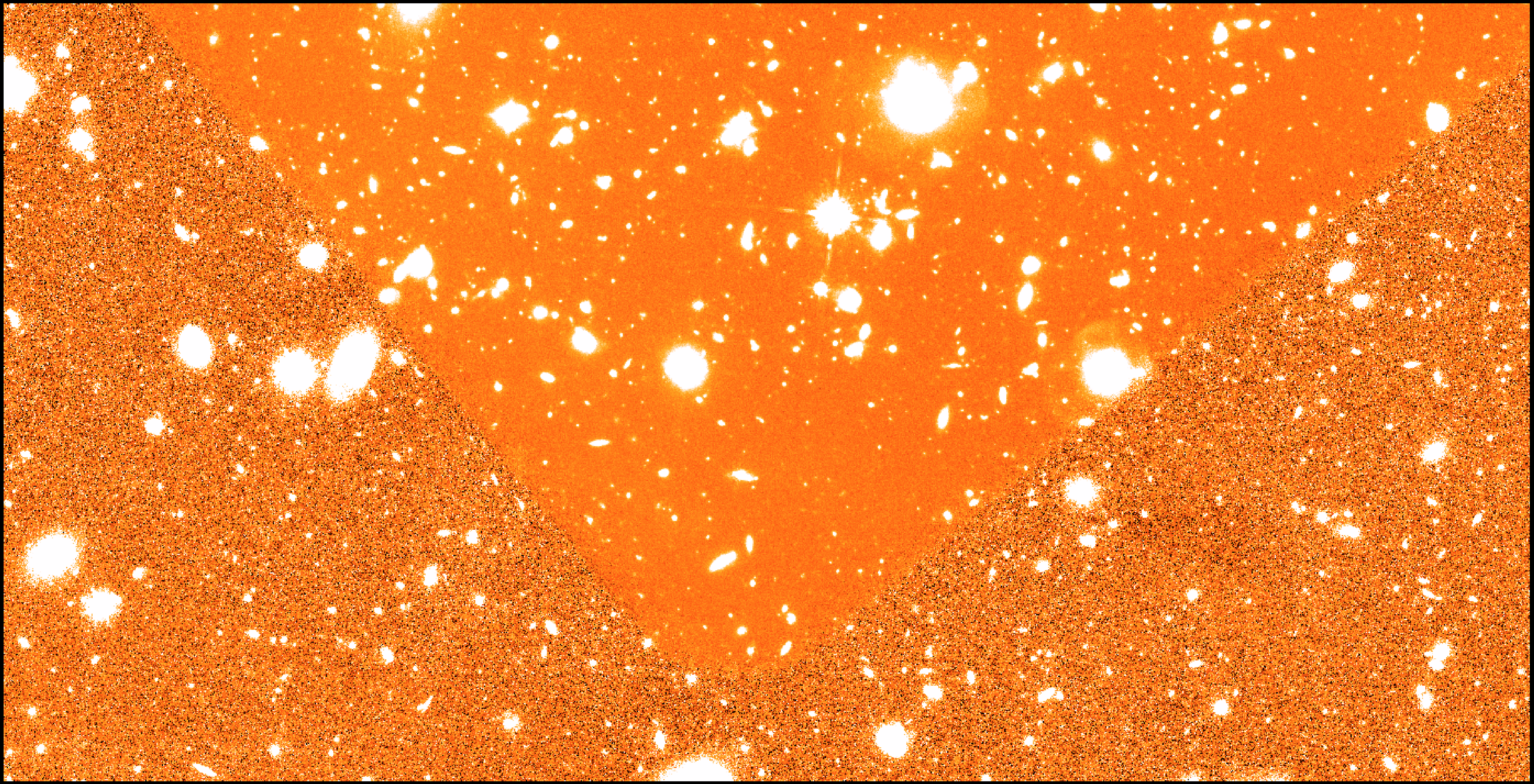
- Imaging data for 250,000 galaxies from z = 1.5 - 8
- WFC3 bridges the Balmer break out to z ~ 2.5
- WFC3 cuts through dust
- Spitzer Extended Deep Survey, SEDS: IRAC 26 AB (5σ); means stellar masses measured to ~3 × 10^9 $M_{\odot}$ to z ~ 7
- Overlapping ACS parallels: panchromatic imaging from V → H; new ACS imaging in UDS, deeper/multicolor ACS imaging in COSMOS and EGS . . . . . *photoz's!*
- UV in GOODS-N: 100 orbits of F275W, F336W
- Every pointing observed at least twice:
  - Search for variable AGN
  - First search for SNe beyond z ~ 1.5


COSMOS
Declination (2000)
Right Ascension (2000)
02° 00'
01m 00s
10h 00m
09h 59m 30s
EGS
53° 00'
52° 40'
14h 18m
UDS
−04° 55'
−05° 30'
18m 00s
17m 00s
02h 16m 30s
GOODS-S
−27° 50'
−28° 00'
33m 00s
03h 32m 00s
GOODS-N

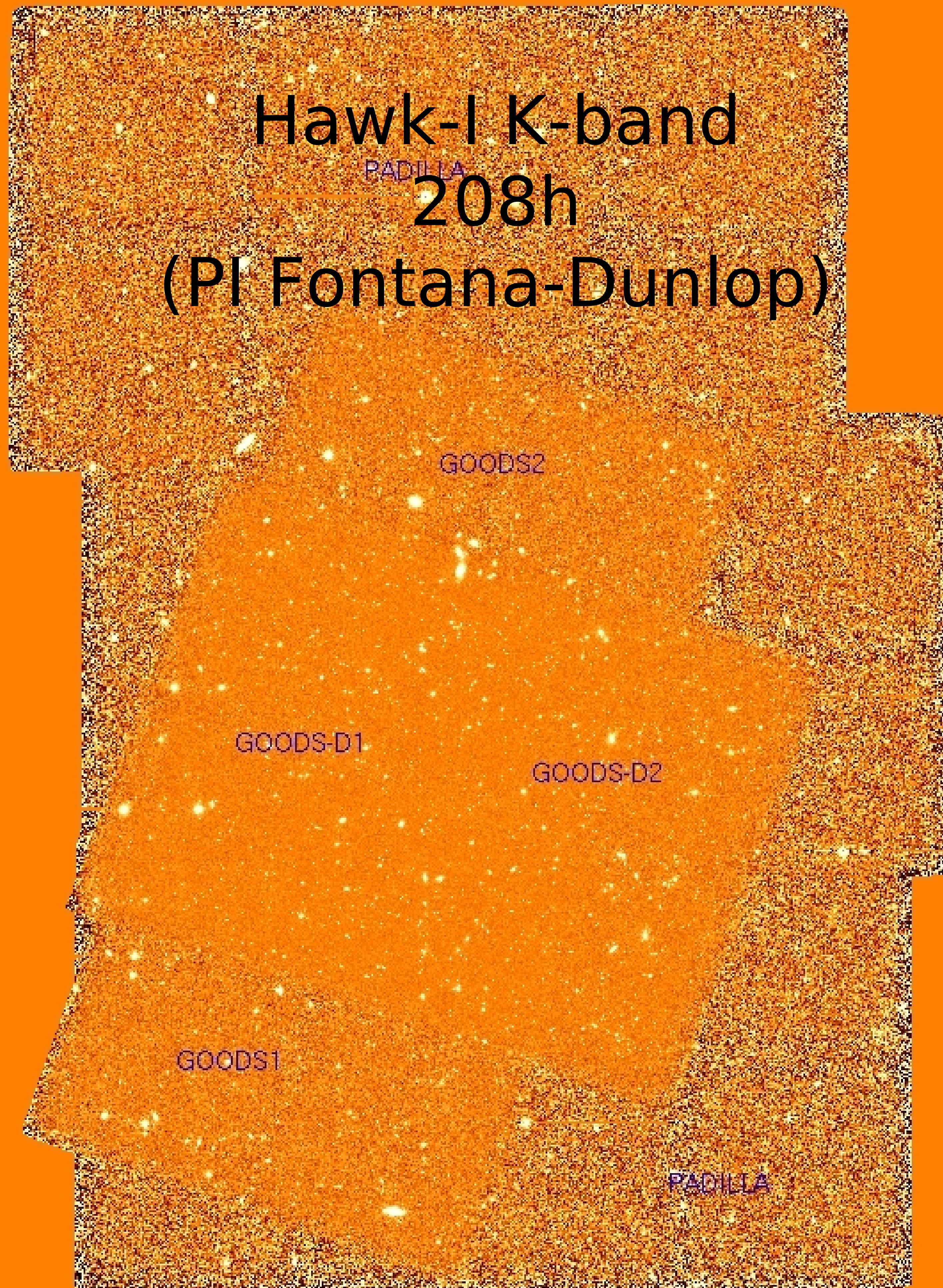




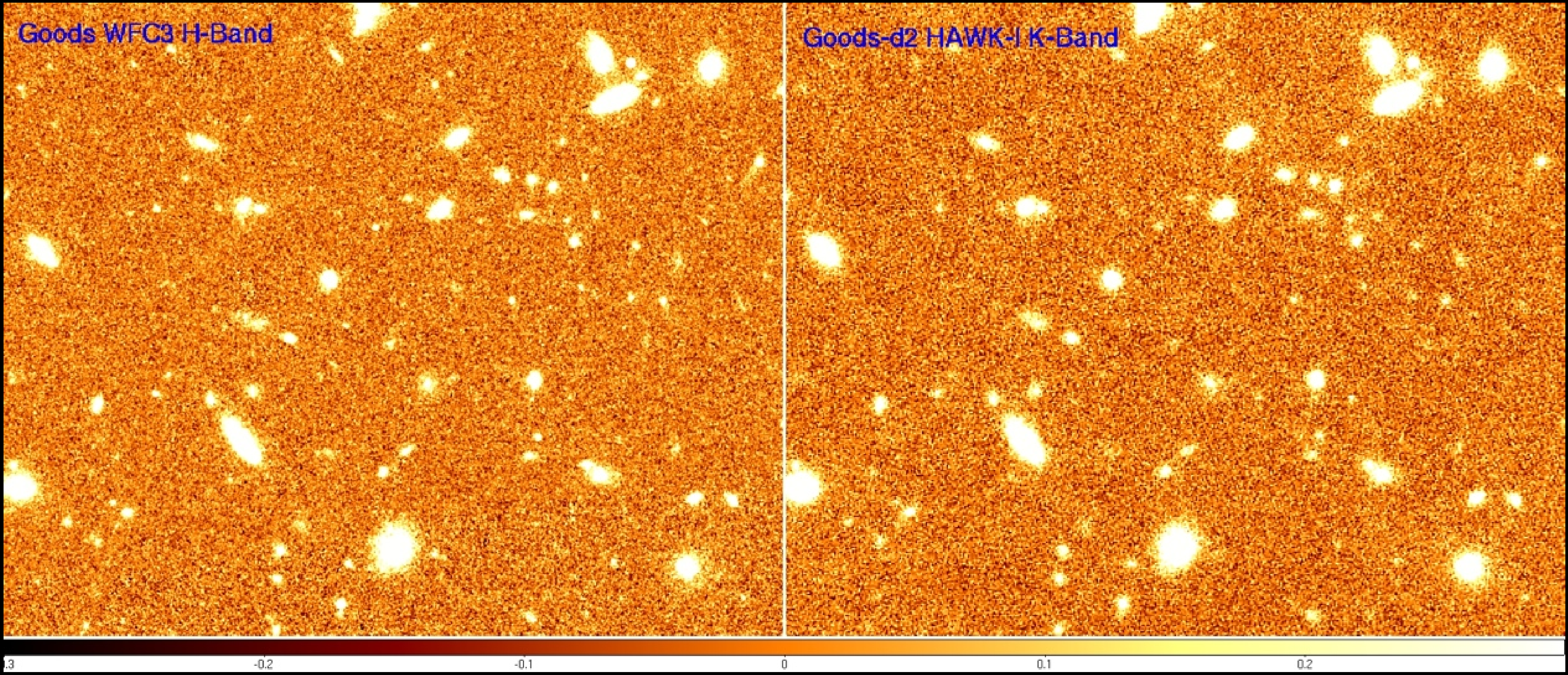




Hawk-I K-band
208h
(PI Fontana-Dunlop)



Seeing: 0.38”



maglim (1σ - 1sqarcsec): 27.88

maglim (5σ - 2FWHM): 27