Spectroscopic Searches for High-Redshift Lyman Alpha Emission

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October 11, 2007

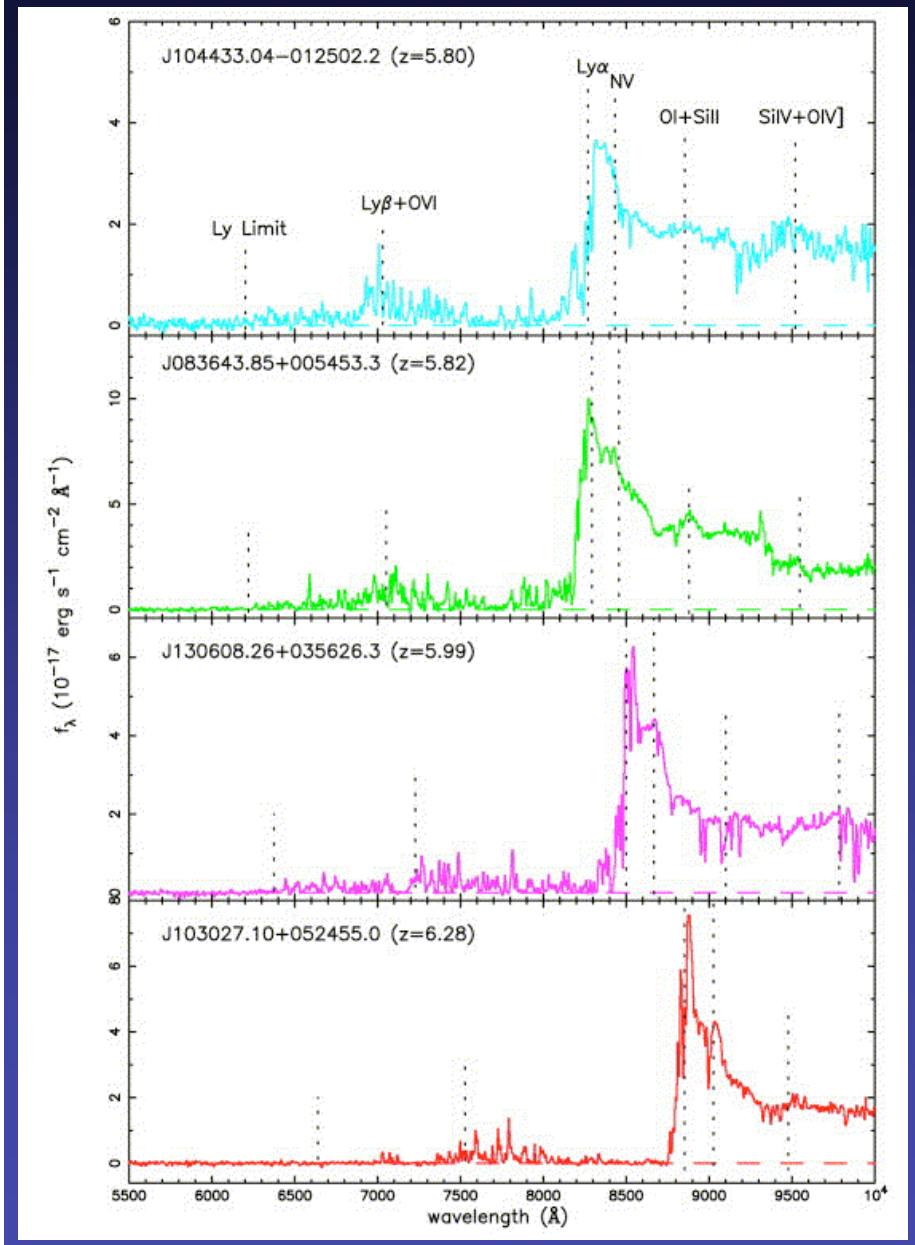
KITP Star Formation Program

What is the Reionization Era?

A Schematic Outline of the Cosmic History

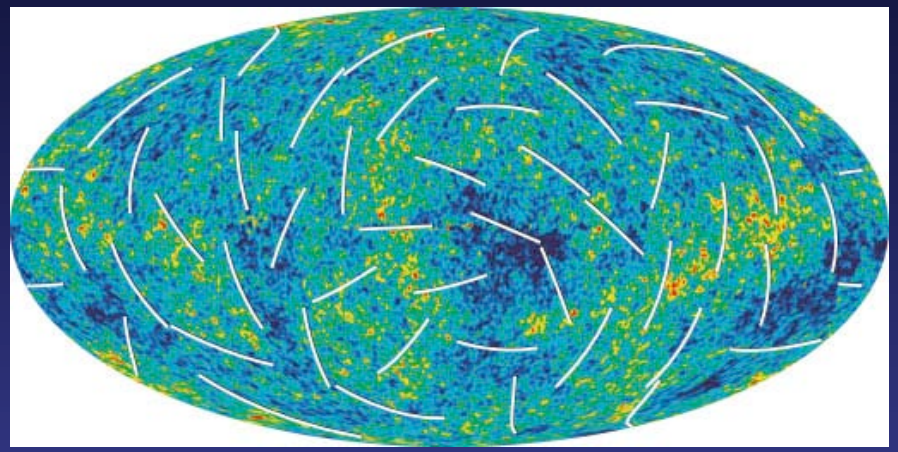
S.G. Djorgovski et al. & Digital Media Center, Caltech

1. Gunn-Peterson Troughs at z~6



SDSS QSOs Becker, Fan et al.

2. e- Optical Depth; z ~ 11



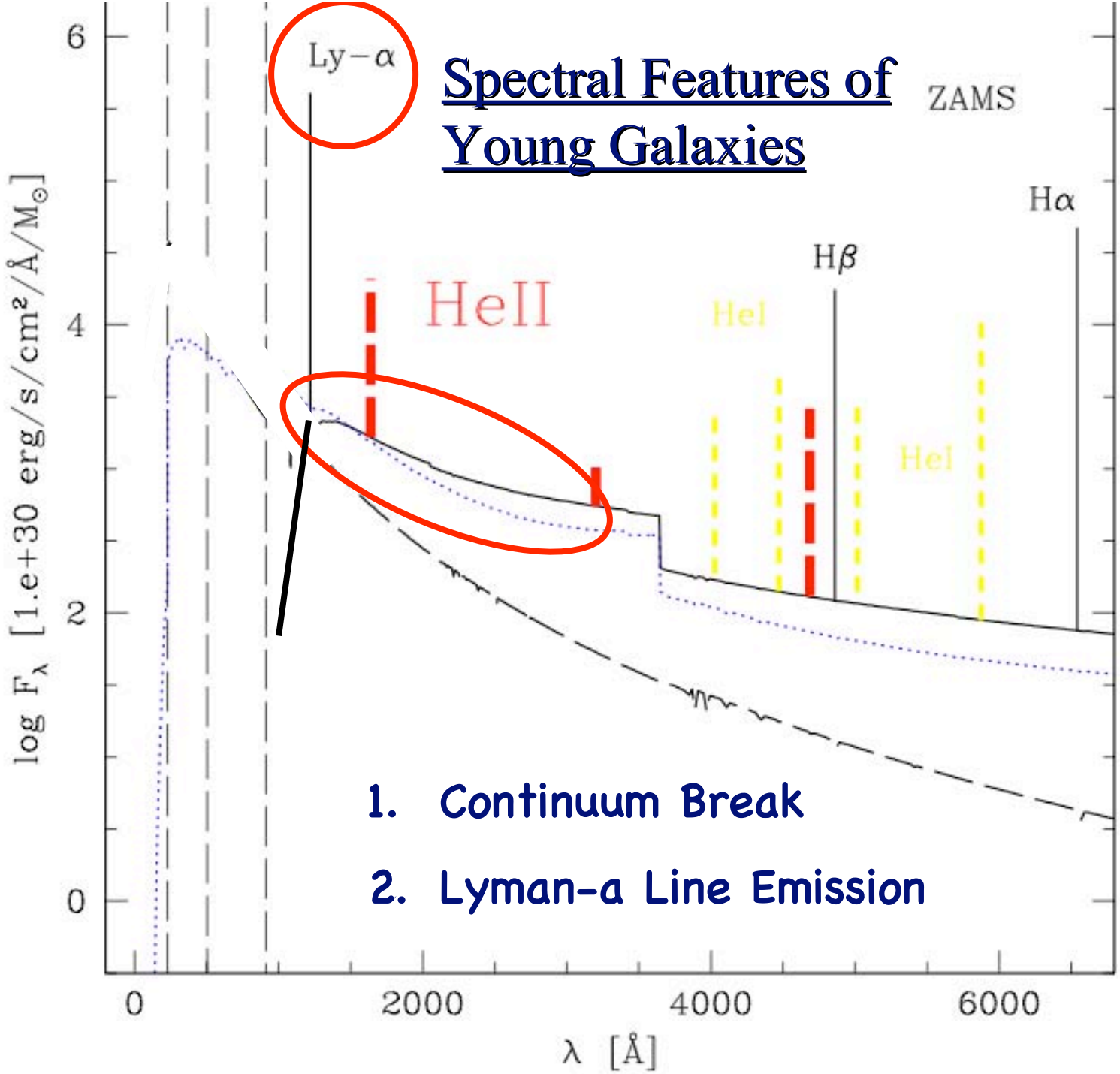
WMAP CMB Polarization (Spergel+07)

3. Evolution in the LAE LF

Malhotra & Rhoads 2004; Kashikawa

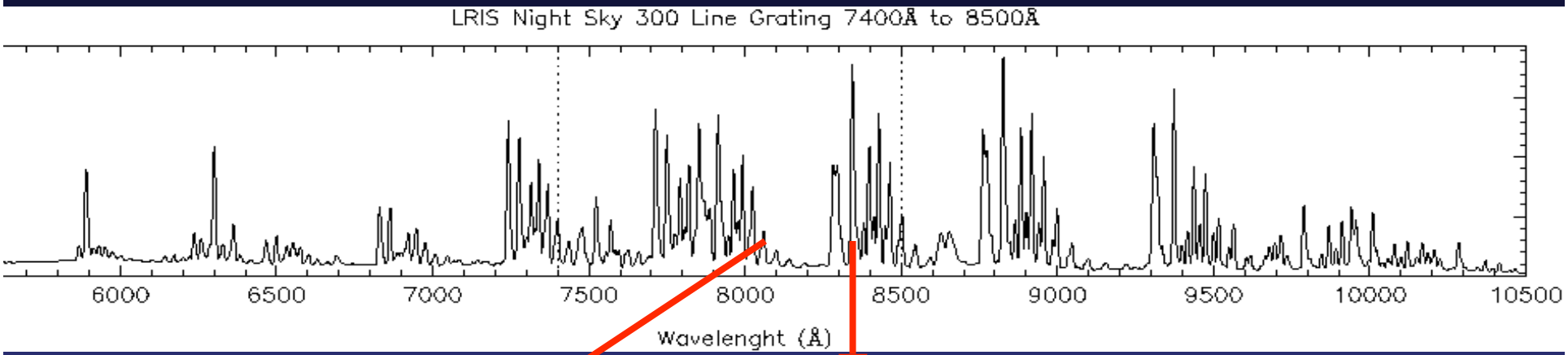
4. Clustering of LAEs
5. 21 cm

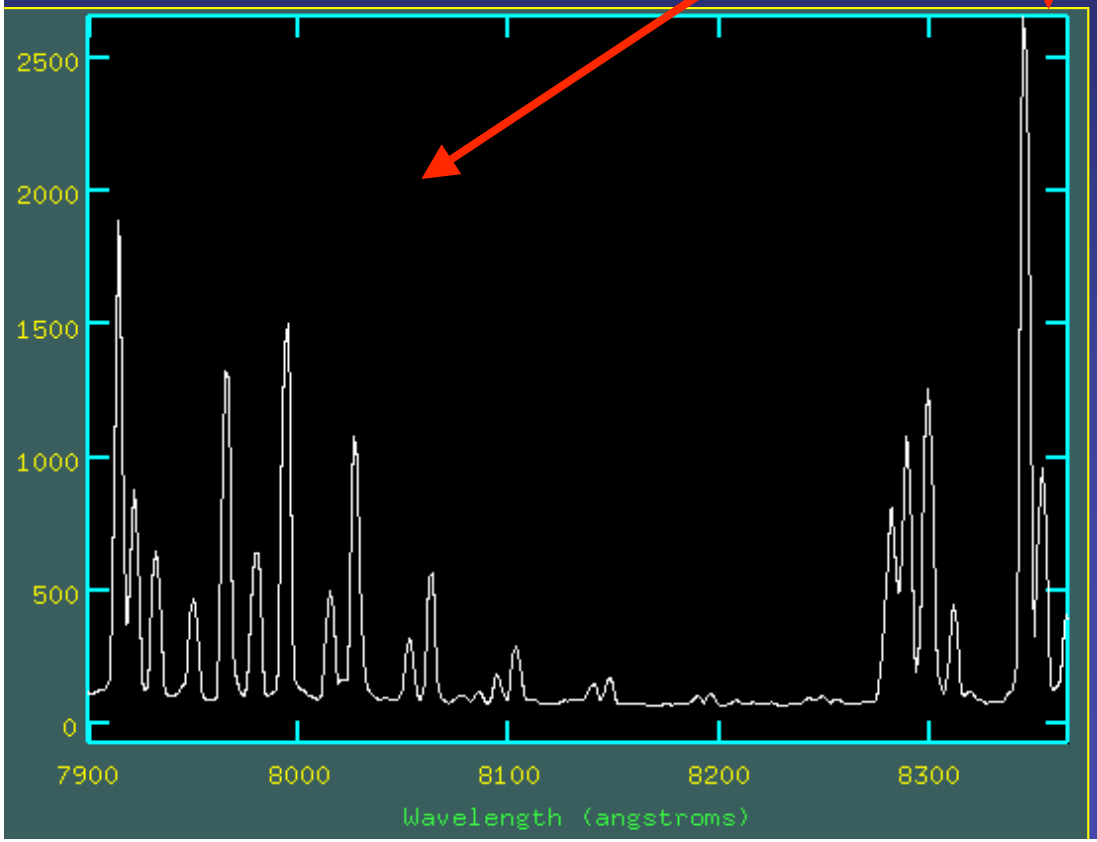
Spectral Features of Young Galaxies

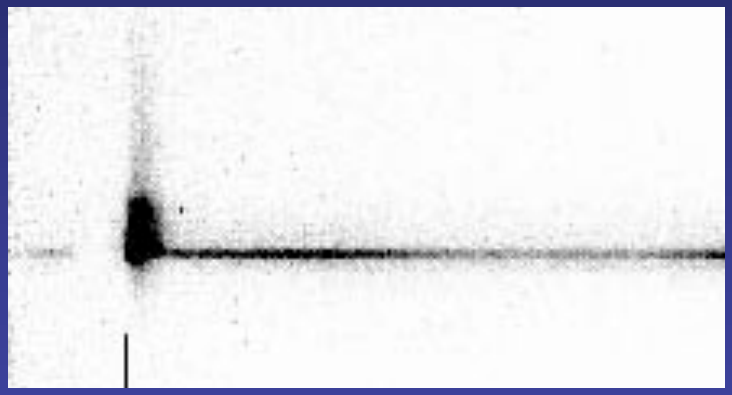


1. Continuum Break
2. Lyman-α Line Emission

Improve Contrast with Night Sky

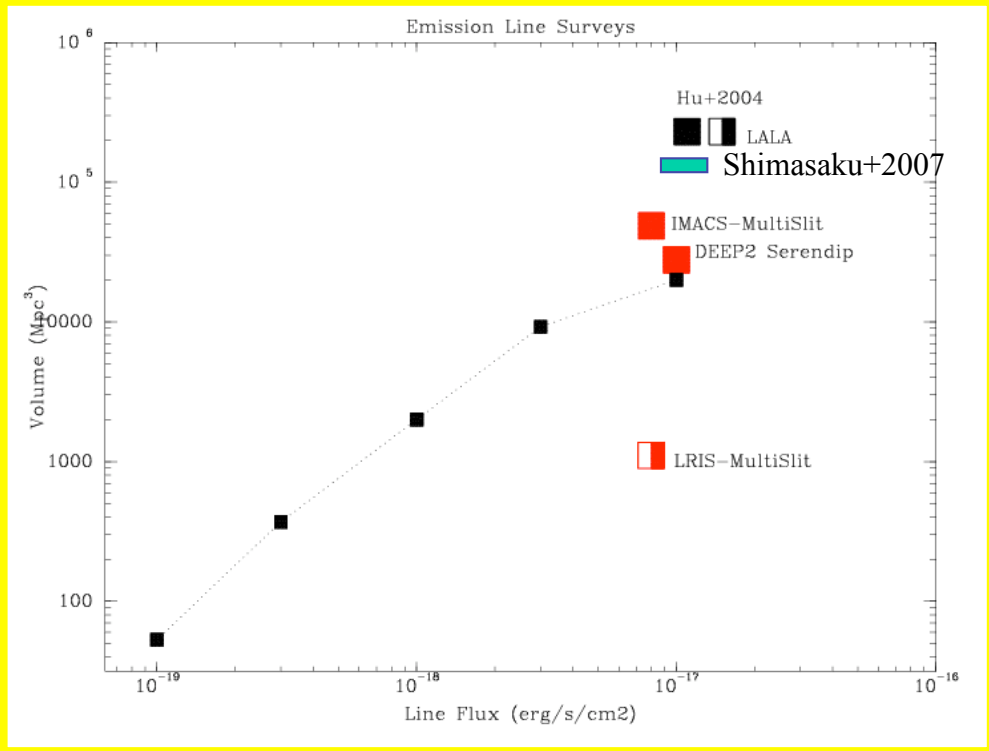


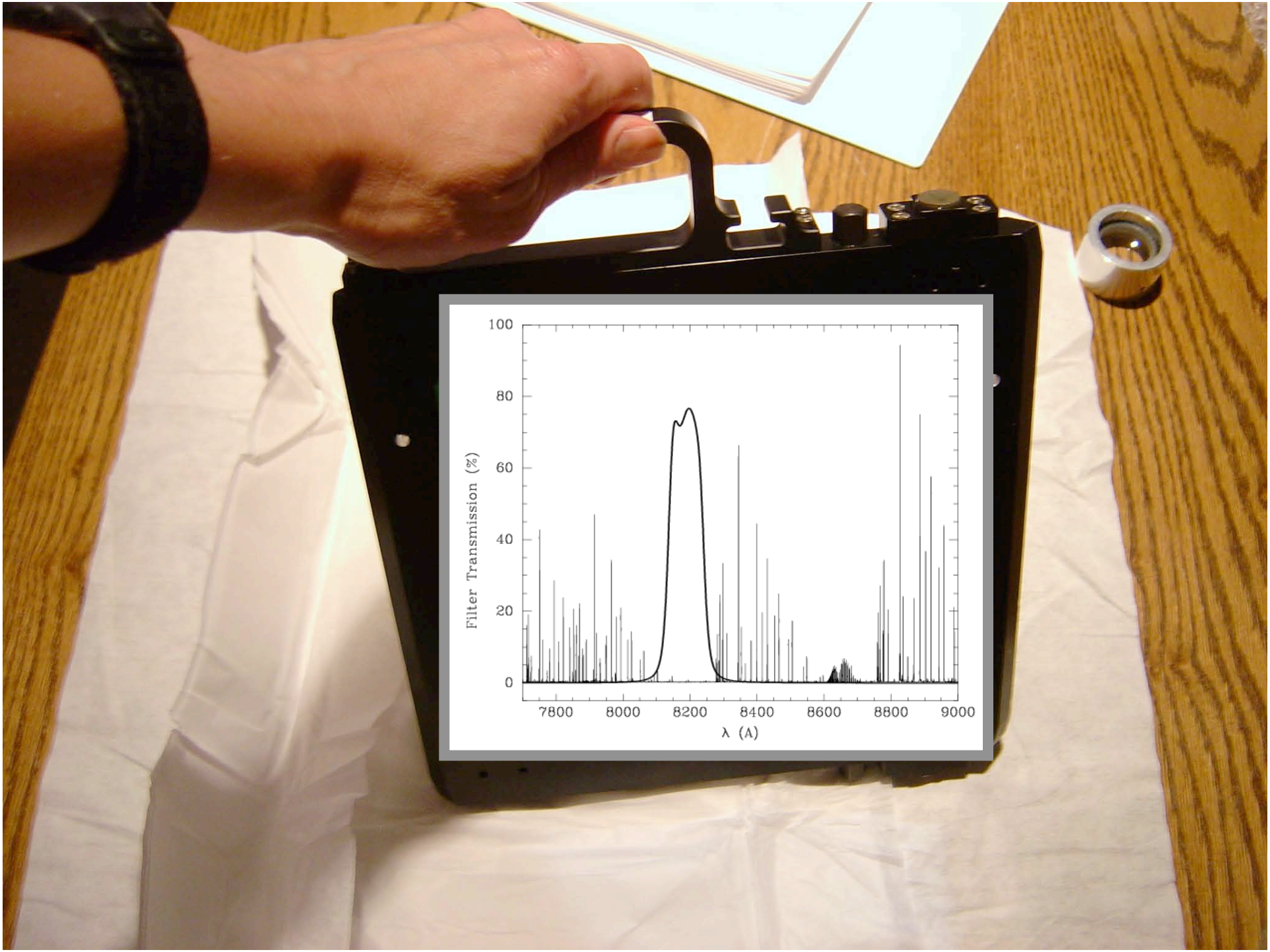




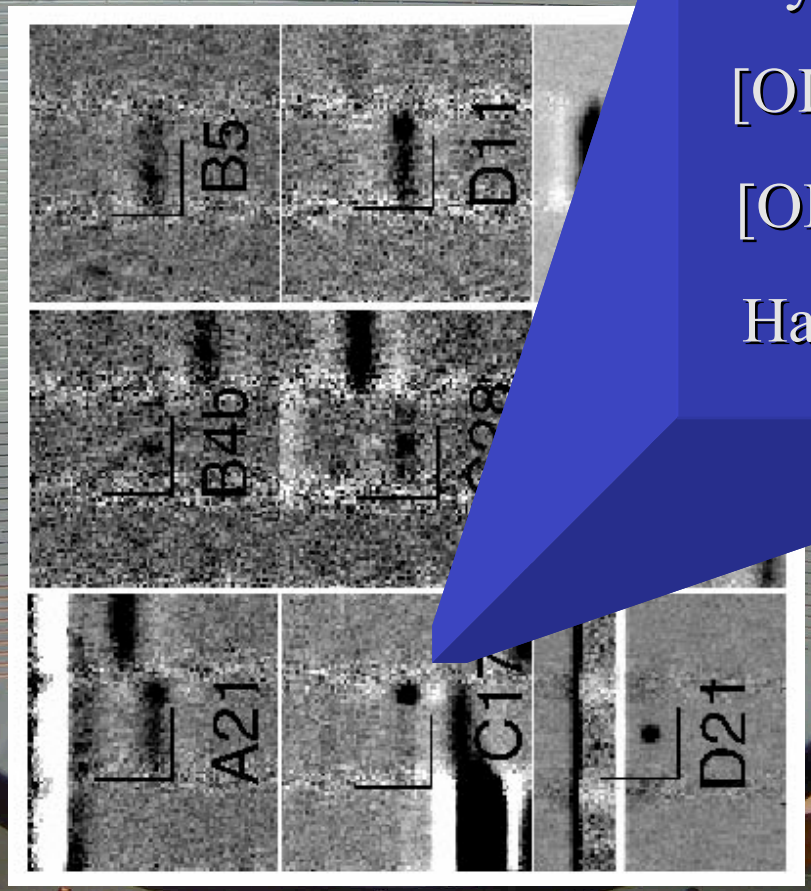
Pilot Program: Spectroscopic Lya Surveys

1. Martin & Sawicki 2004, ApJ 603, 414
   Venetian Blinds Spectroscopy with Keck/LRIS
2. Martin, Sawicki, Dressler, McCarthy 2007, preprint Venetian Blinds Spectroscopy with Magellan/IMACS
3. Sawicki, Lemaux, Kirby et al. 2007, preprint
   Serendipitous detections in DEEP2 spectra
4. Martin, Weiner, Rupke, Veilleux, Dressler, McCarthy
   Magellan Tunable Filter




Filter Transmission (%)
100
80
60
40
20
0
7800
8000
8200
8400
8600
8800
9000
λ (Å)

The Narrowband Spectroscopic Technique

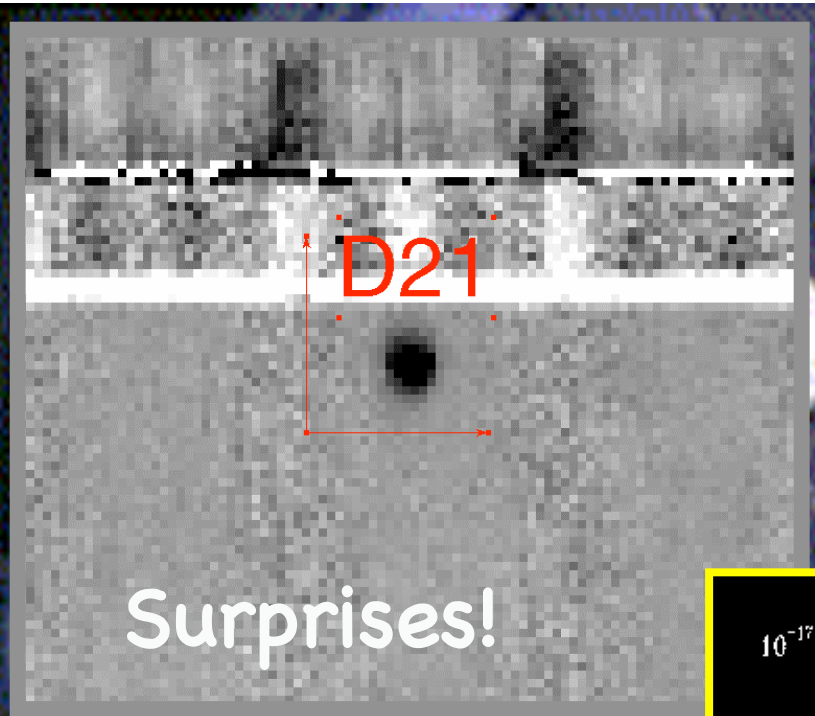


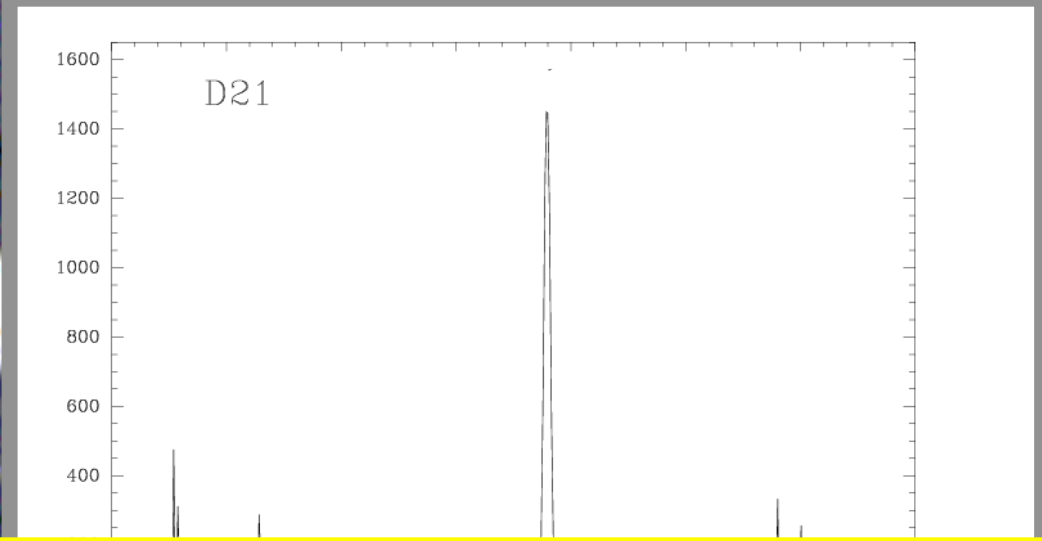
Lya @ z = 5.7

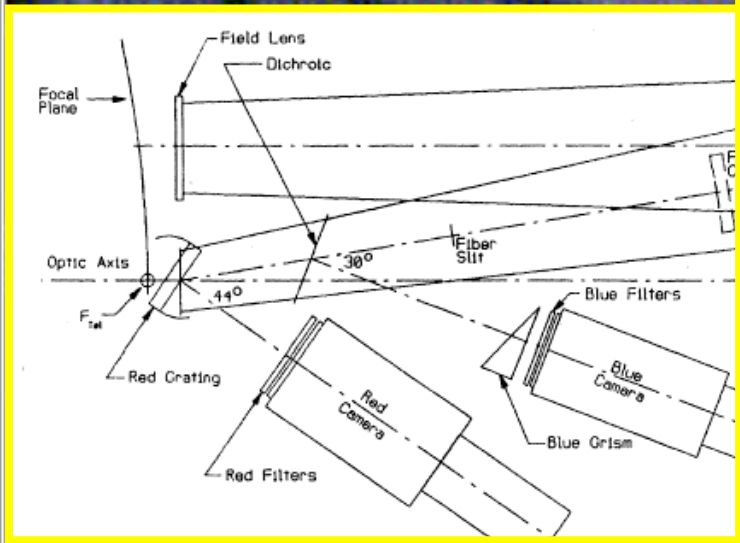
[OII] @ z = 1.2

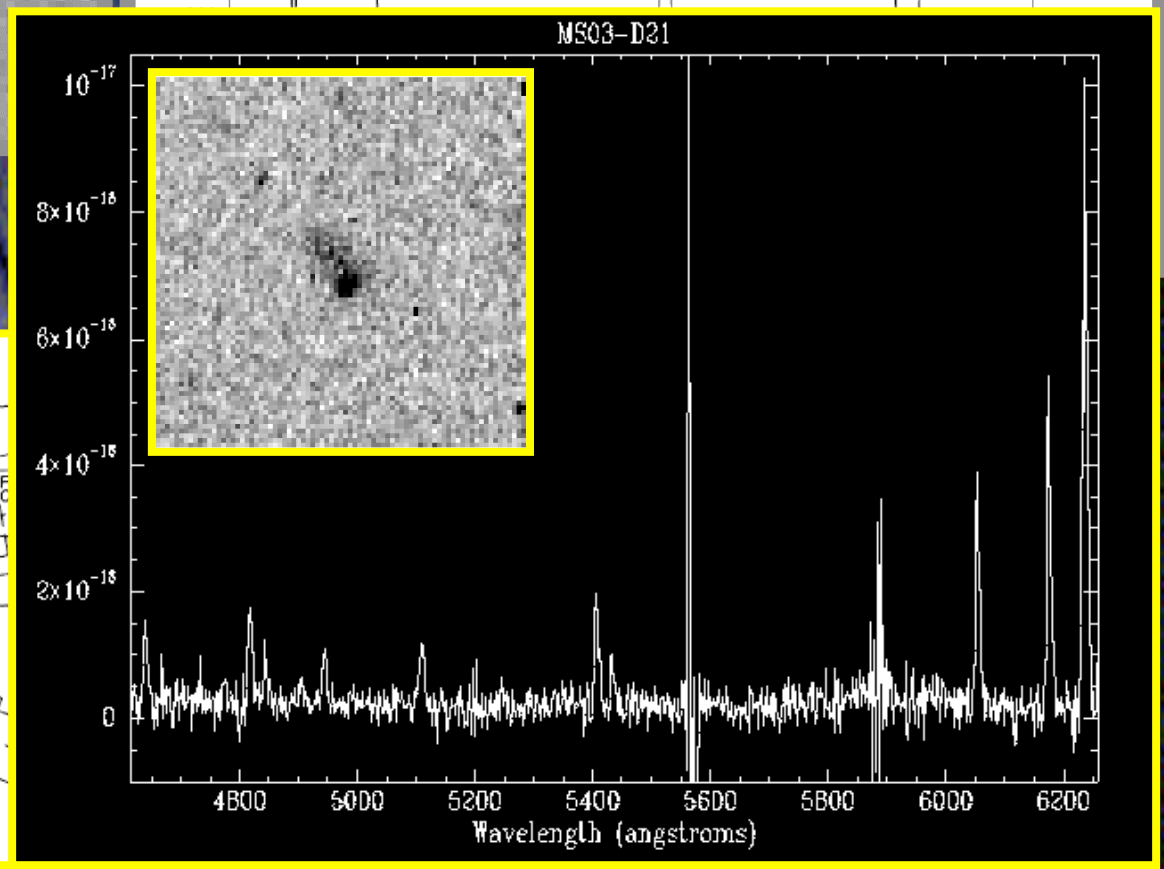
[OIII] @ z=0.6

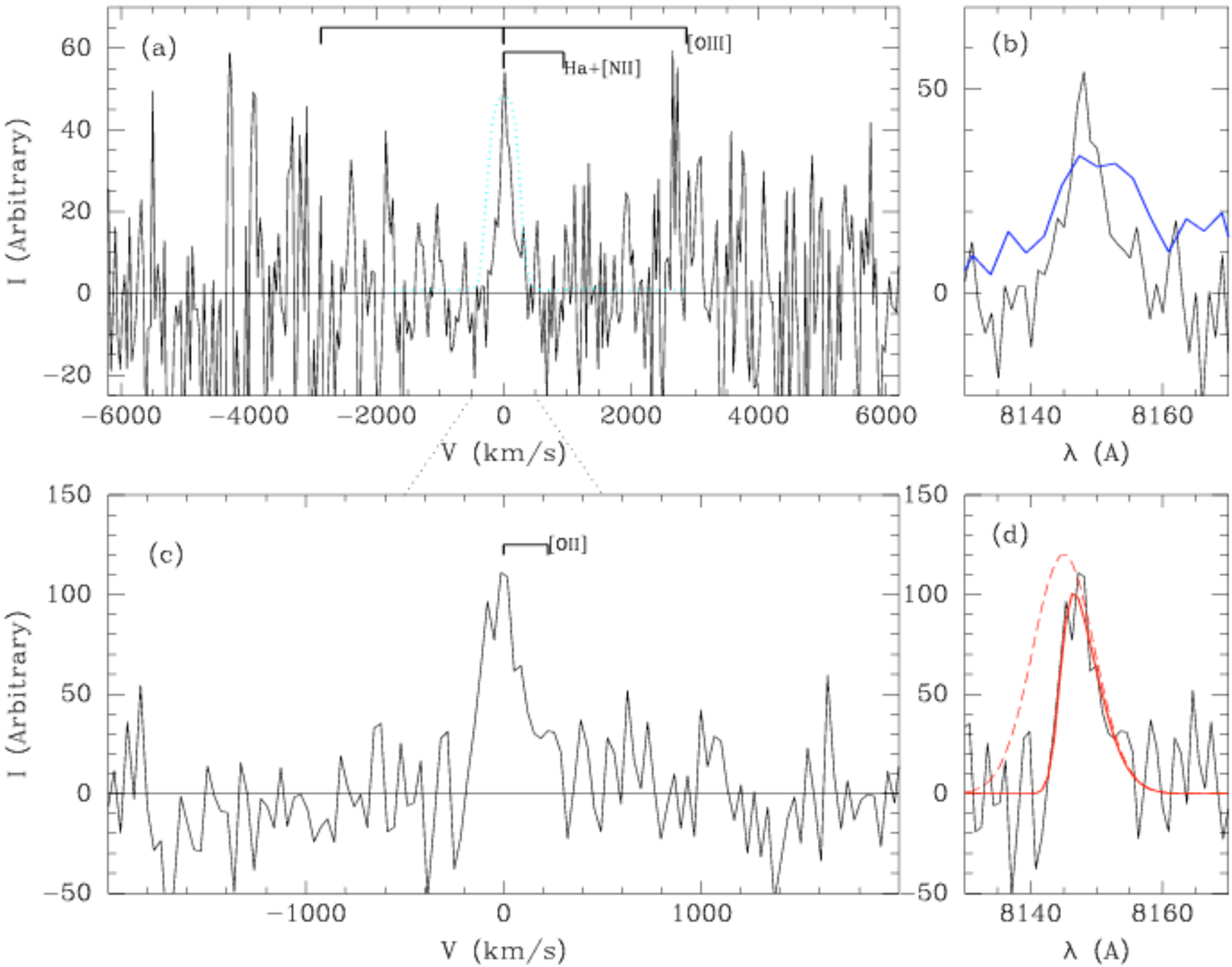
Ha @ z = 0.24

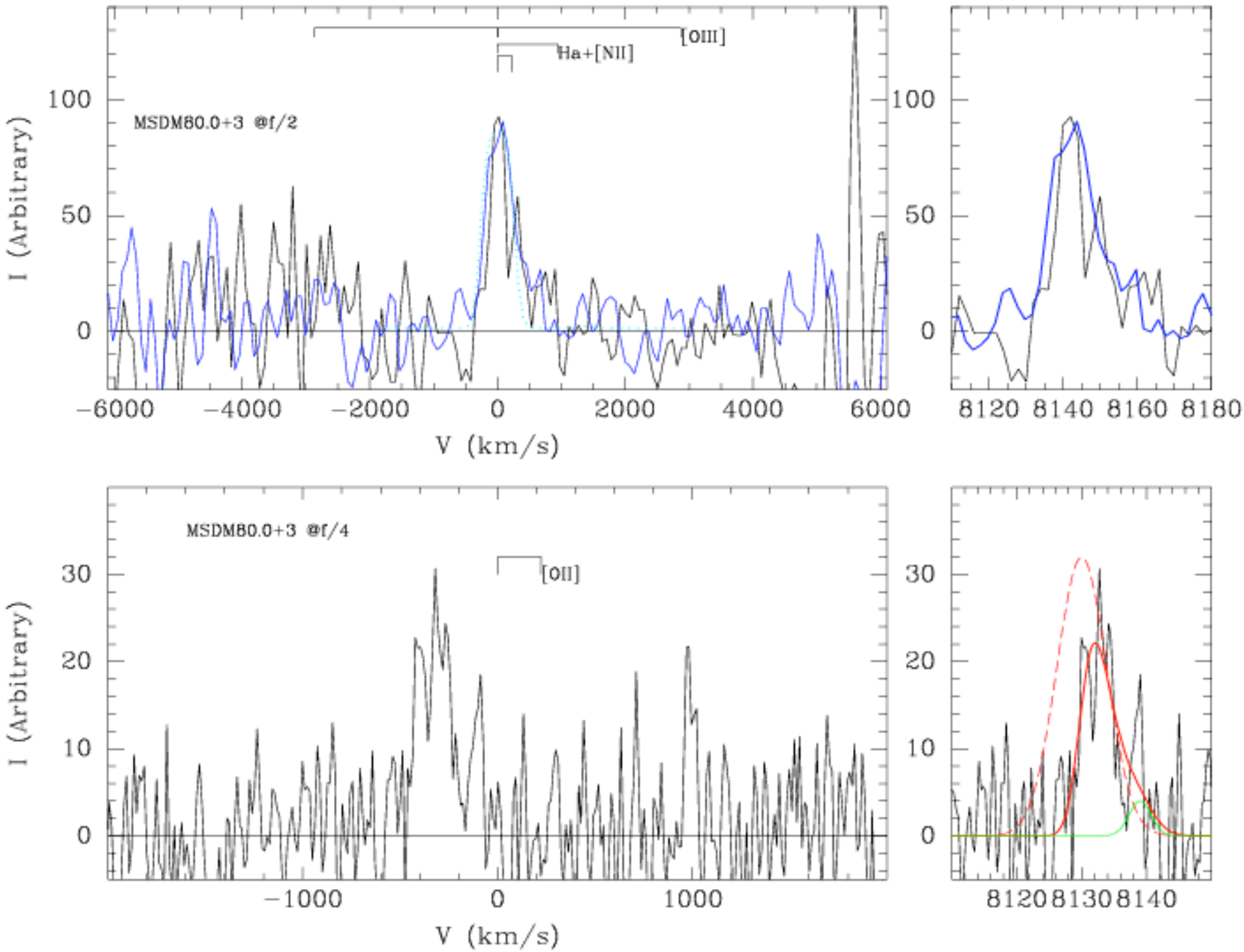

D21
Surprises!

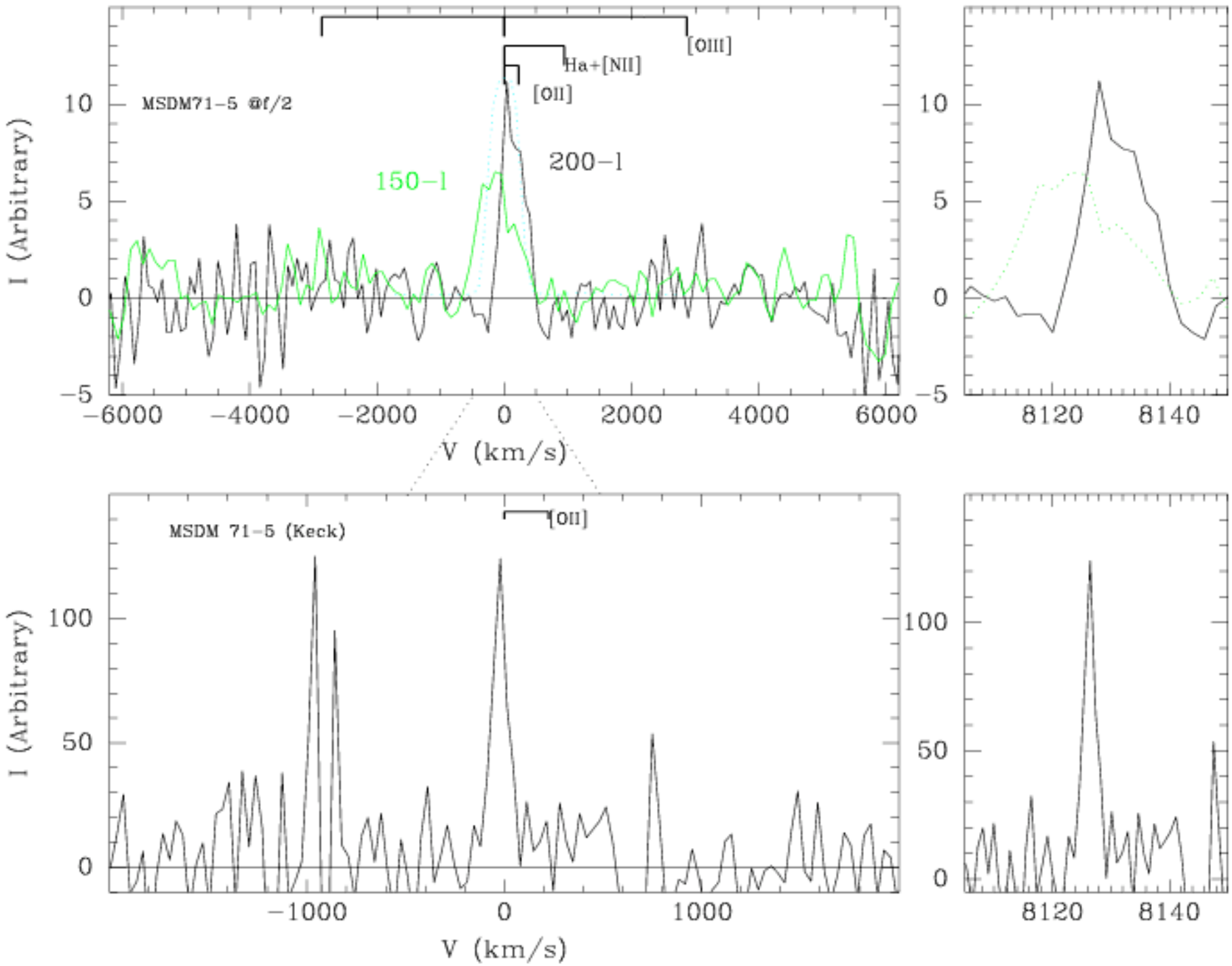

D21
1600
1400
1200
1000
800
600
400

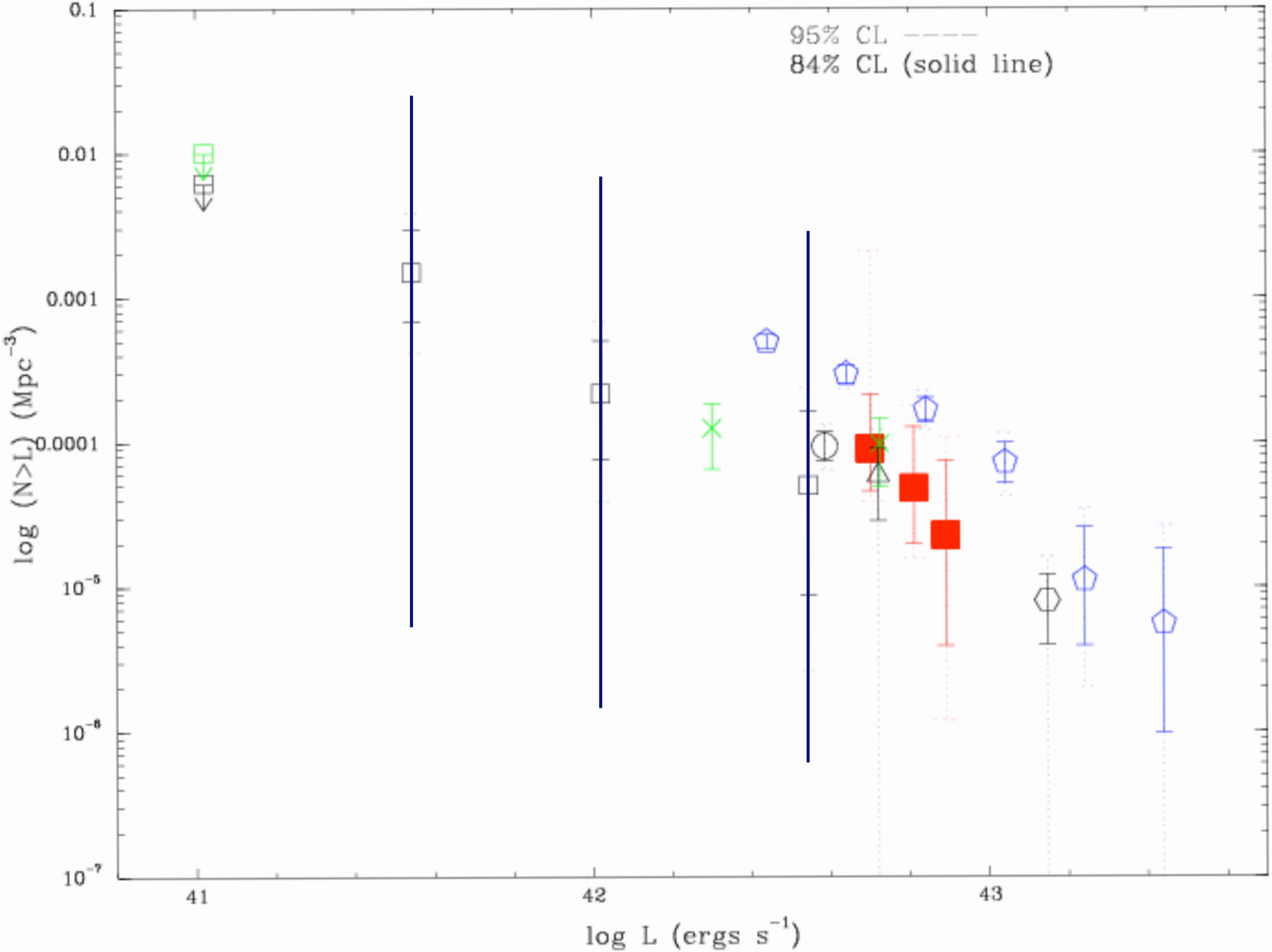

Field Lens
Dichroic
Focal Plane
Optic Axis
30°
44°
Fiber Slit
Blue Filters
Red Grating
Red Camera
Blue Camera
Blue Grism
Red Filters


MS03-D21
10^{-17}
8×10^{-18}
6×10^{-18}
4×10^{-18}
2×10^{-18}
0
4800
5000
5200
5400
5600
5800
6000
6200
Wavelength (angstroms)


(a)
[OIII]
Hα+[NII]
I (Arbitrary)
V (km/s)
(b)
λ (A)
(c)
[OII]
I (Arbitrary)
V (km/s)
(d)
λ (A)


MSDM80.0+3 @f/2
[OIII]
Ha+[NII]
I (Arbitrary)
V (km/s)
MSDM80.0+3 @f/4
[OII]
I (Arbitrary)
V (km/s)


MSDM71-5 @f/2
[OIII]
Ha+[NII]
[OII]
150-1
200-1
I (Arbitrary)
V (km/s)
MSDM 71-5 (Keck)
[OII]
I (Arbitrary)
V (km/s)

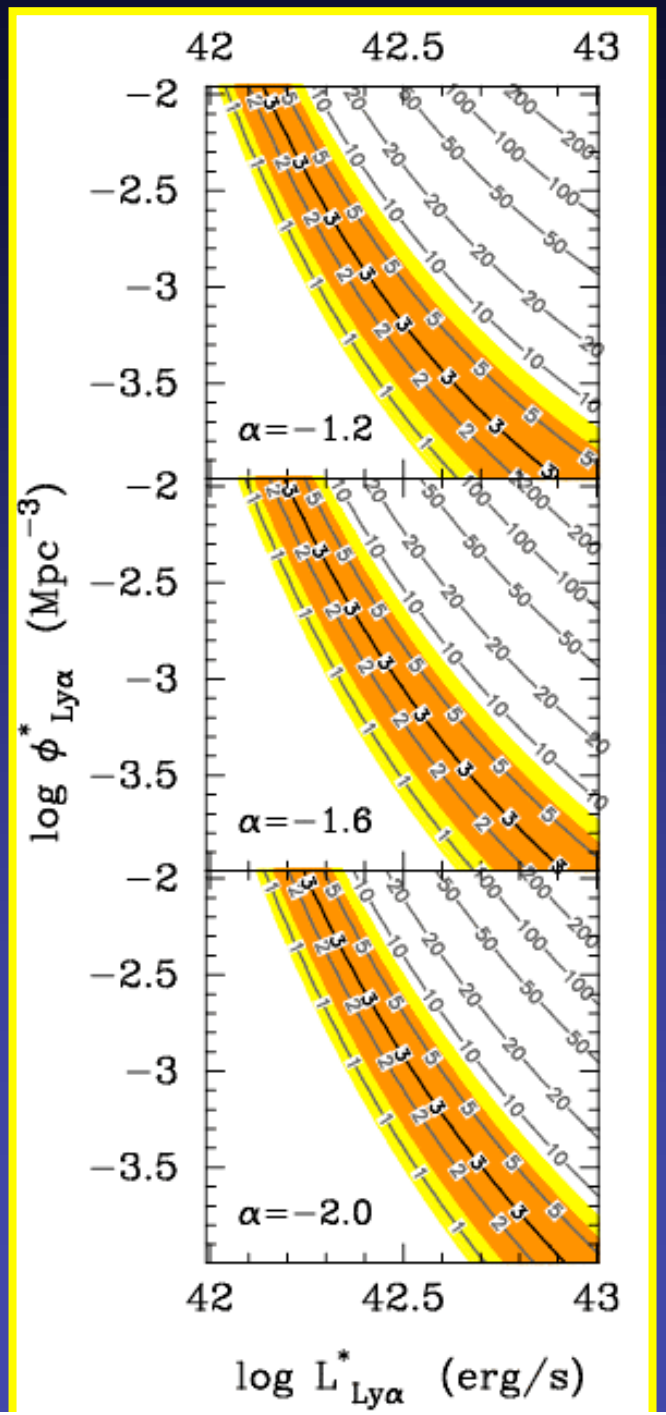

95% CL ----
84% CL (solid line)
0.1
0.01
0.001
0.0001
10^{-5}
10^{-6}
10^{-7}
log (N>L) (Mpc^{-3})
41
42
43
log L (ergs s^{-1})

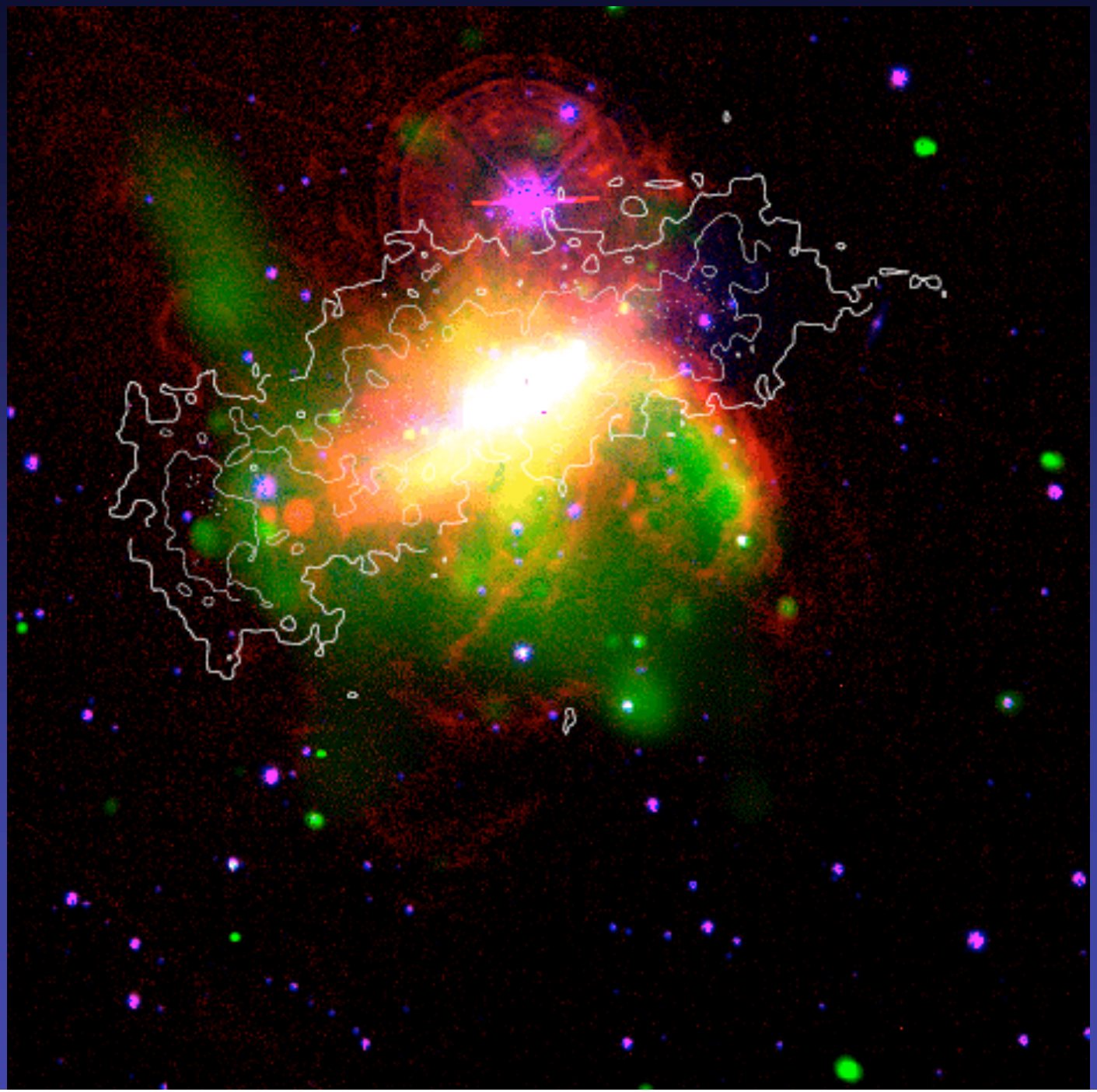
Constraints on LAE LF

$$d\Phi(L) = \Phi_0 \, (L/L^*)^{-\alpha} \, e^{(-L/L^*)} \, d(L/L^*)$$

- Faint-end slope
- Exponential cut off
- Normalization

- Fold model through experimental response function to get average number recovered.
- Poisson errors on our 3 confirmed LAEs define the range of acceptable LF parameters.





Lyα Luminosity Density

Integrate from Log L_{min}(Lya) = 42.57, 41.0

Photon production rate to ionize intergalactic gas…

$$\dot{N}_H = 10^{51.3}\ \mathrm{s}^{-1}\ \mathrm{Mpc}^{-3}\ C_{30} \left(\frac{1+z}{6.7}\right)^3 \left(\frac{\Omega_b h_{70}^2}{0.041}\right)^2$$

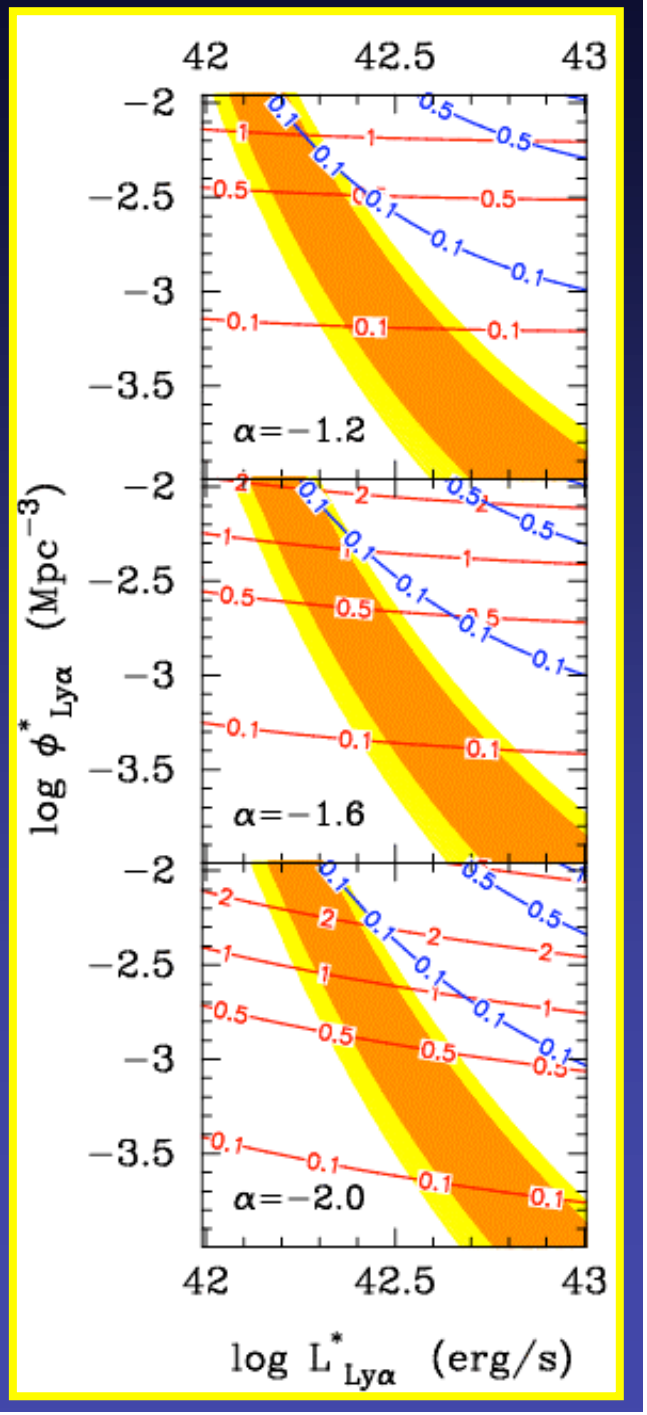
Assume stellar IMF to get SFR…

$$\dot{\rho}_* = 0.0079\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}\mathrm{Mpc}^{-3}\ C_{30} f_{LyC}^{-1} \left(\frac{1+z}{6.7}\right)^3 \left(\frac{\Omega_b h_{70}^2}{0.041}\right)^2$$

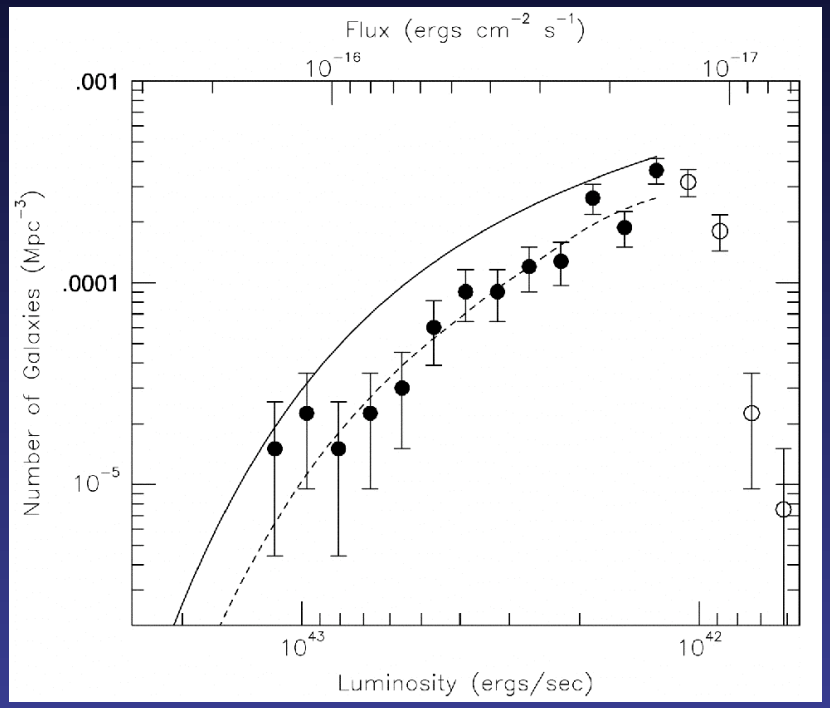
CASE B Recombination Lya emission…

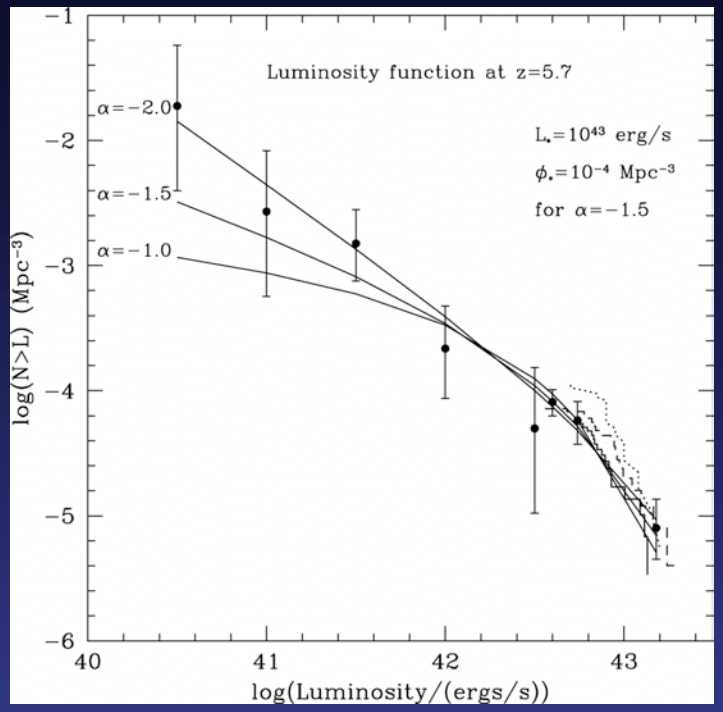
$$\mathrm{L}_{Ly\alpha} = 2.27\times10^{40}\ \mathrm{erg\ s}^{-1}\mathrm{Mpc}^{-3}\ C_{30}(1-f_{LyC}) \left(\frac{f_{Ly\alpha}}{f_{LyC}}\right) \left(\frac{1+z}{6.7}\right)^3 \left(\frac{\Omega_b h_{70}^2}{0.041}\right)^2$$

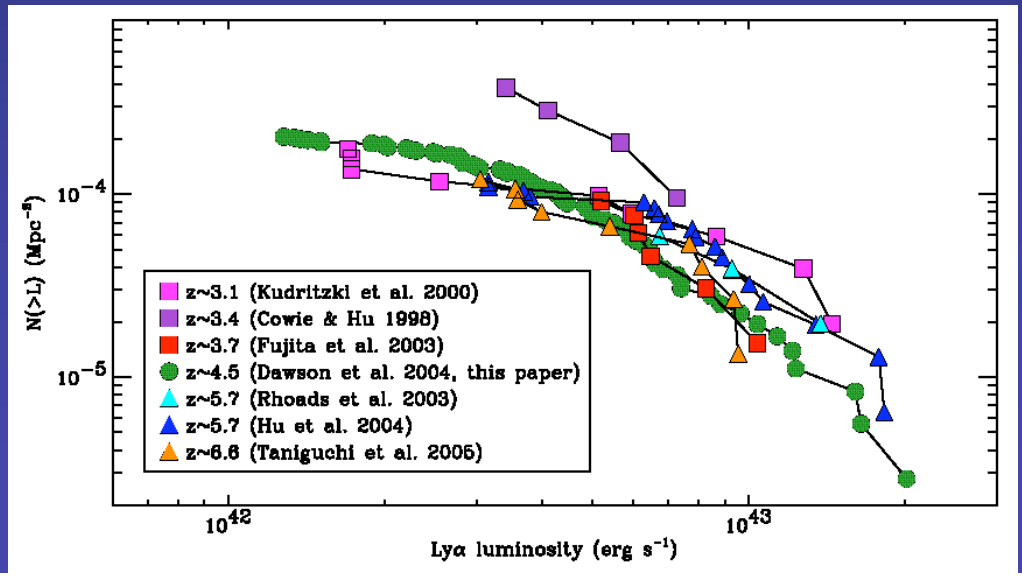
= 0.1, 0.5, 1, 2

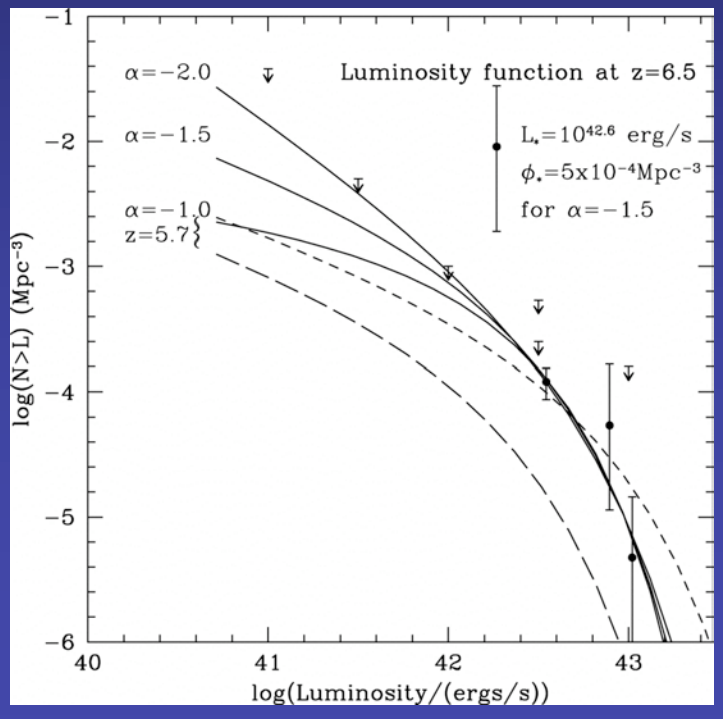


Is L*(Lya) Constrained?



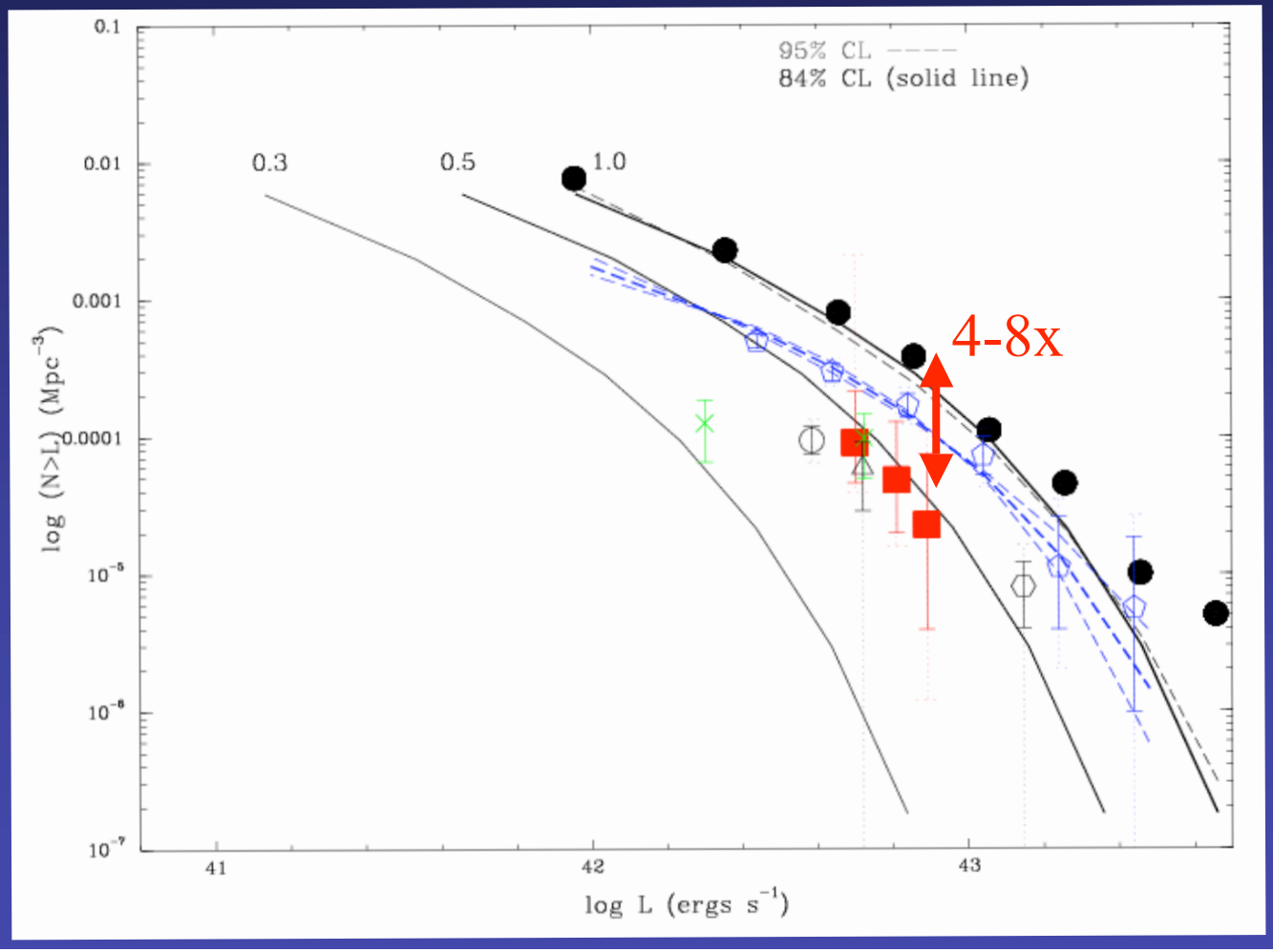






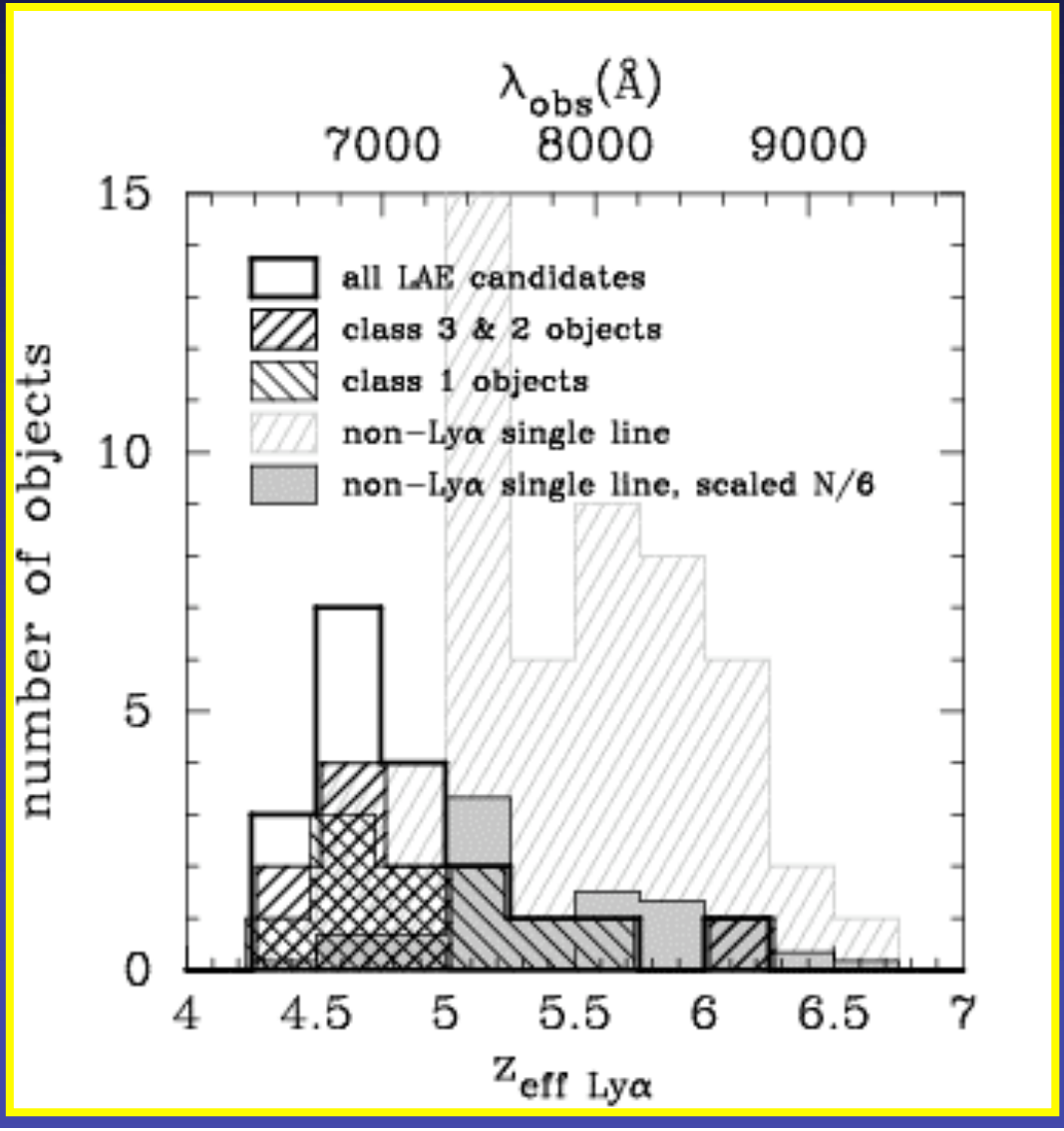
Suppose LAEs are drawn from the i-dropout population…

- Know only ~25% of LBGs at z~3 are LAEs
- Kashikawa+2006 say fraction is much higher at z~6.5
- UV Observations of LAEs give SFRs ~ 3-4x higher; L(Lya) = 1.5e42 erg/s $f_{Ly\alpha}$ (L_ν/1e28 erg/s/Hz)

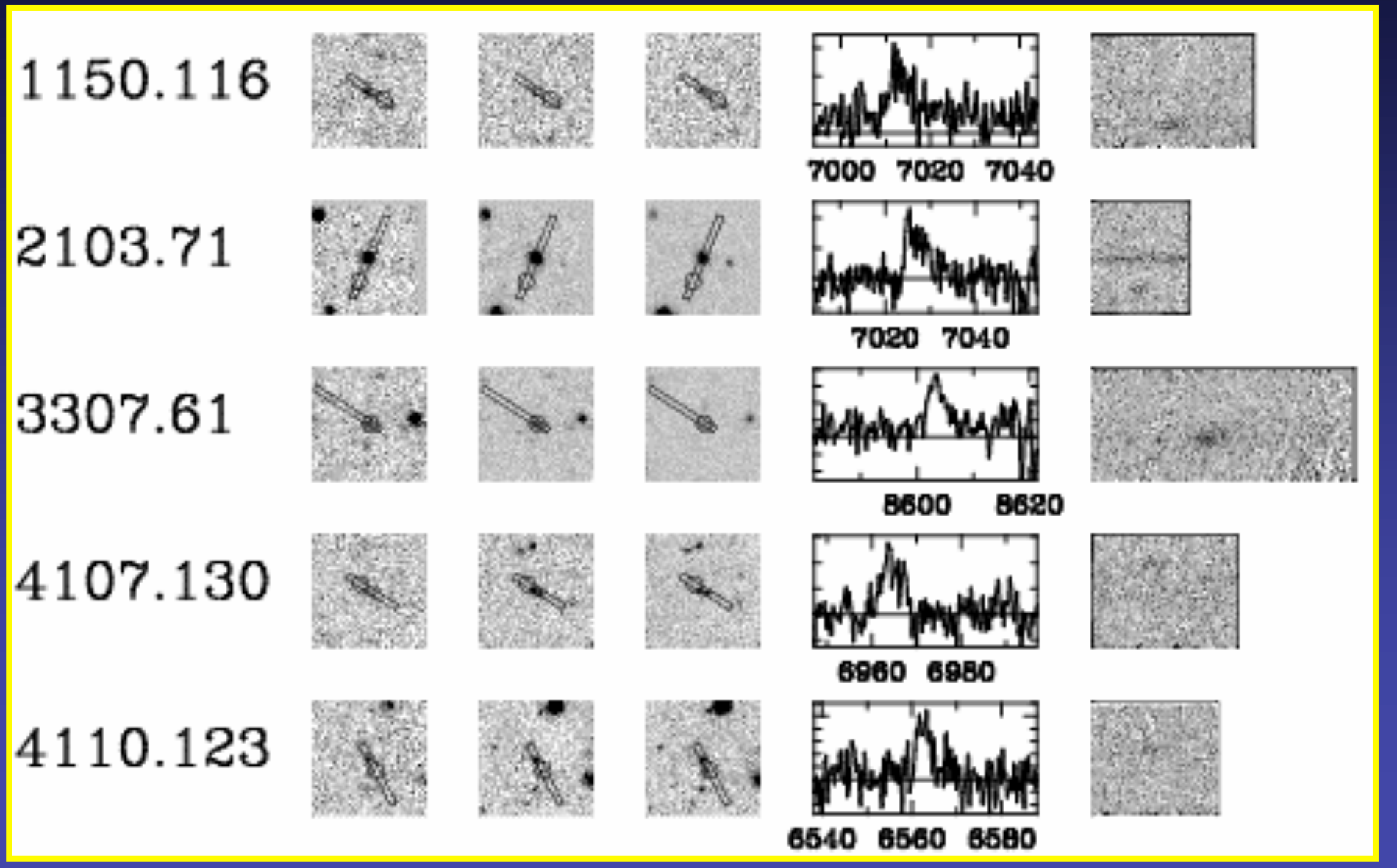


DEEP2 Serendipity Survey

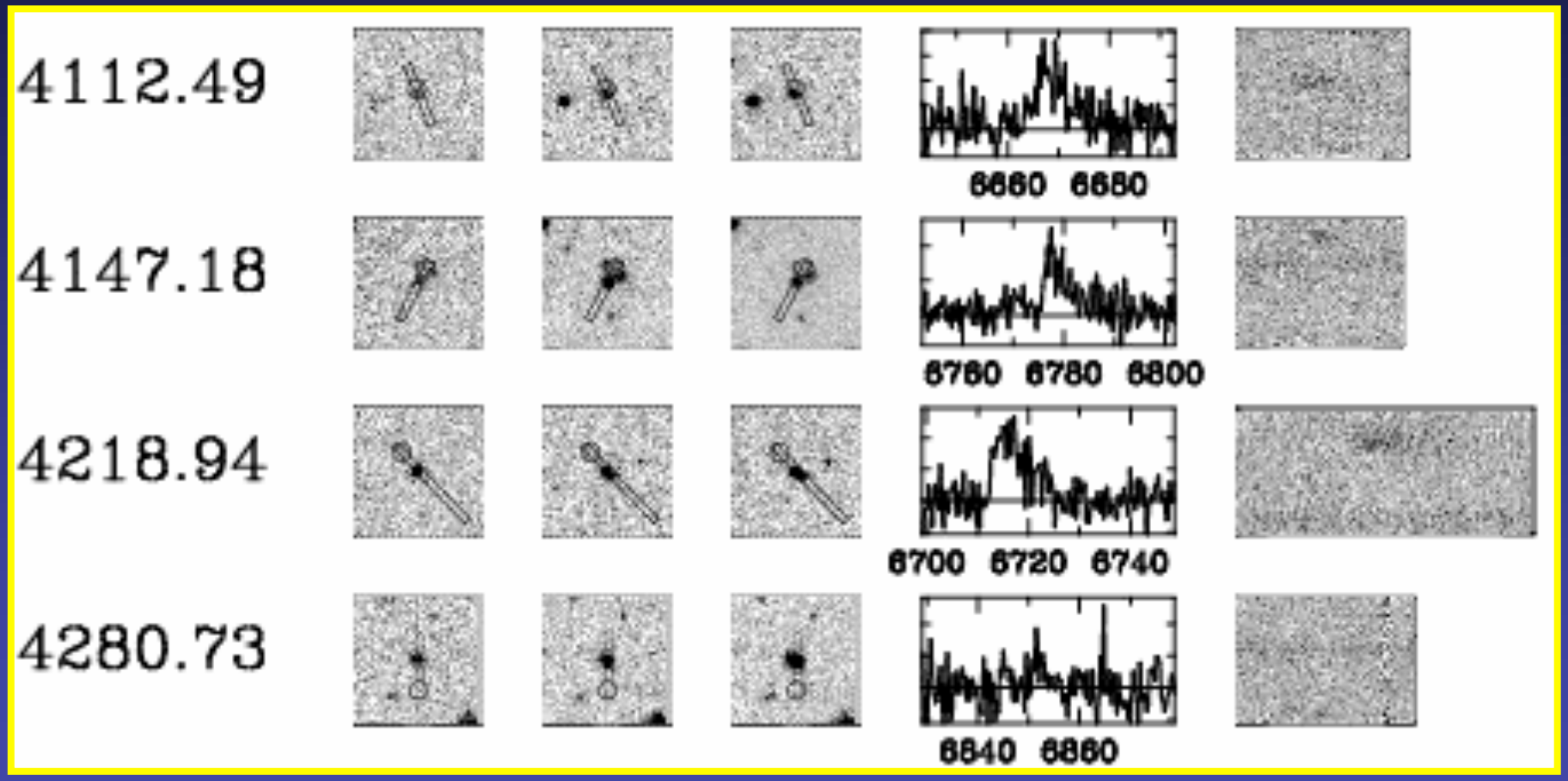
(see Sawicki et al. 2008)



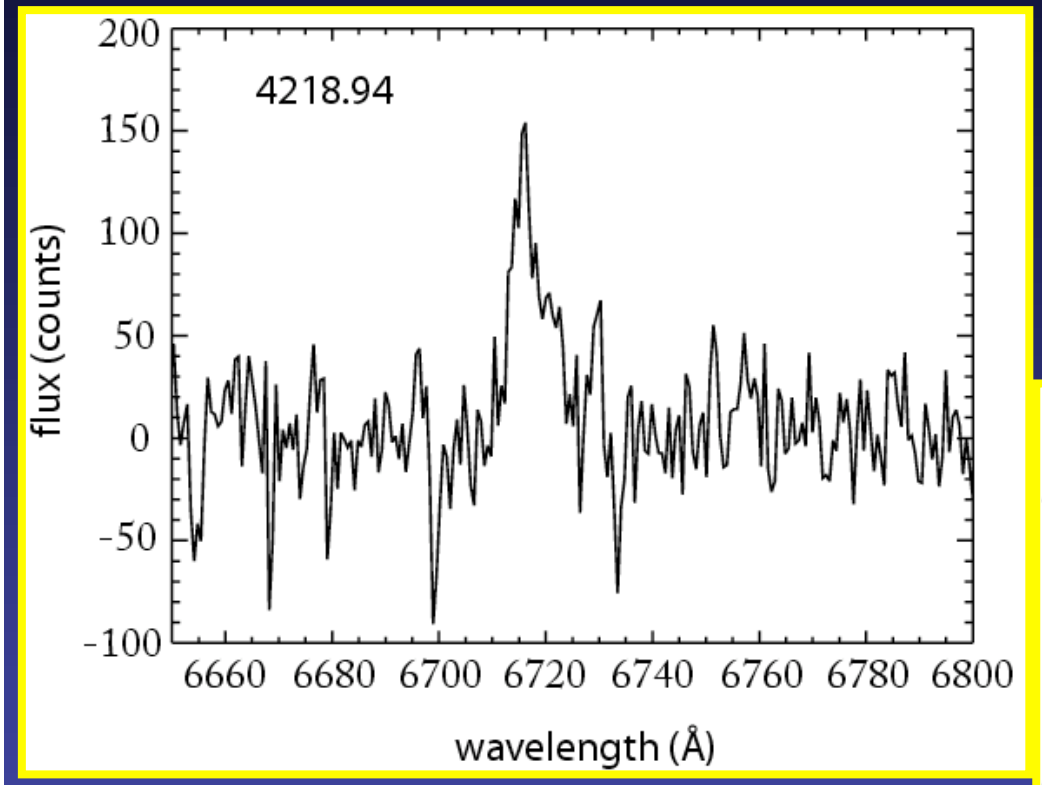
DEEP2 Serendips: Class 3 & 2 LAEs



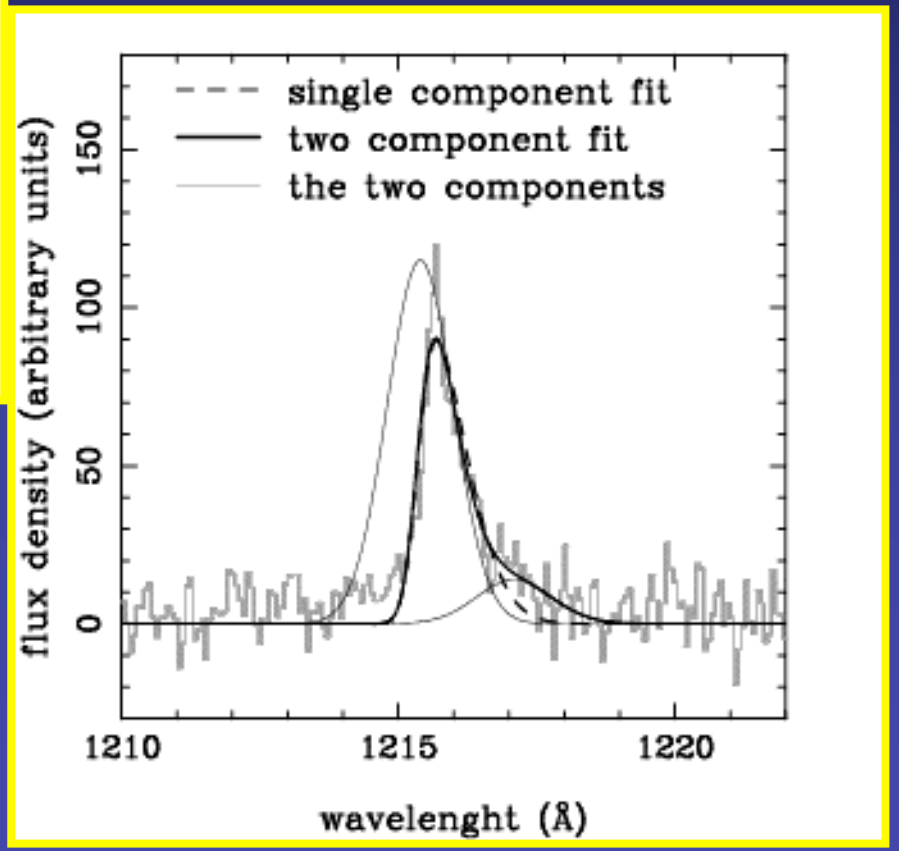
More DEEP2 Serendips: Class 3 & 2 LAEs



DEEP2 Serendips



<== Deeper follow-up spectrum



Average of 9 spectra ==>

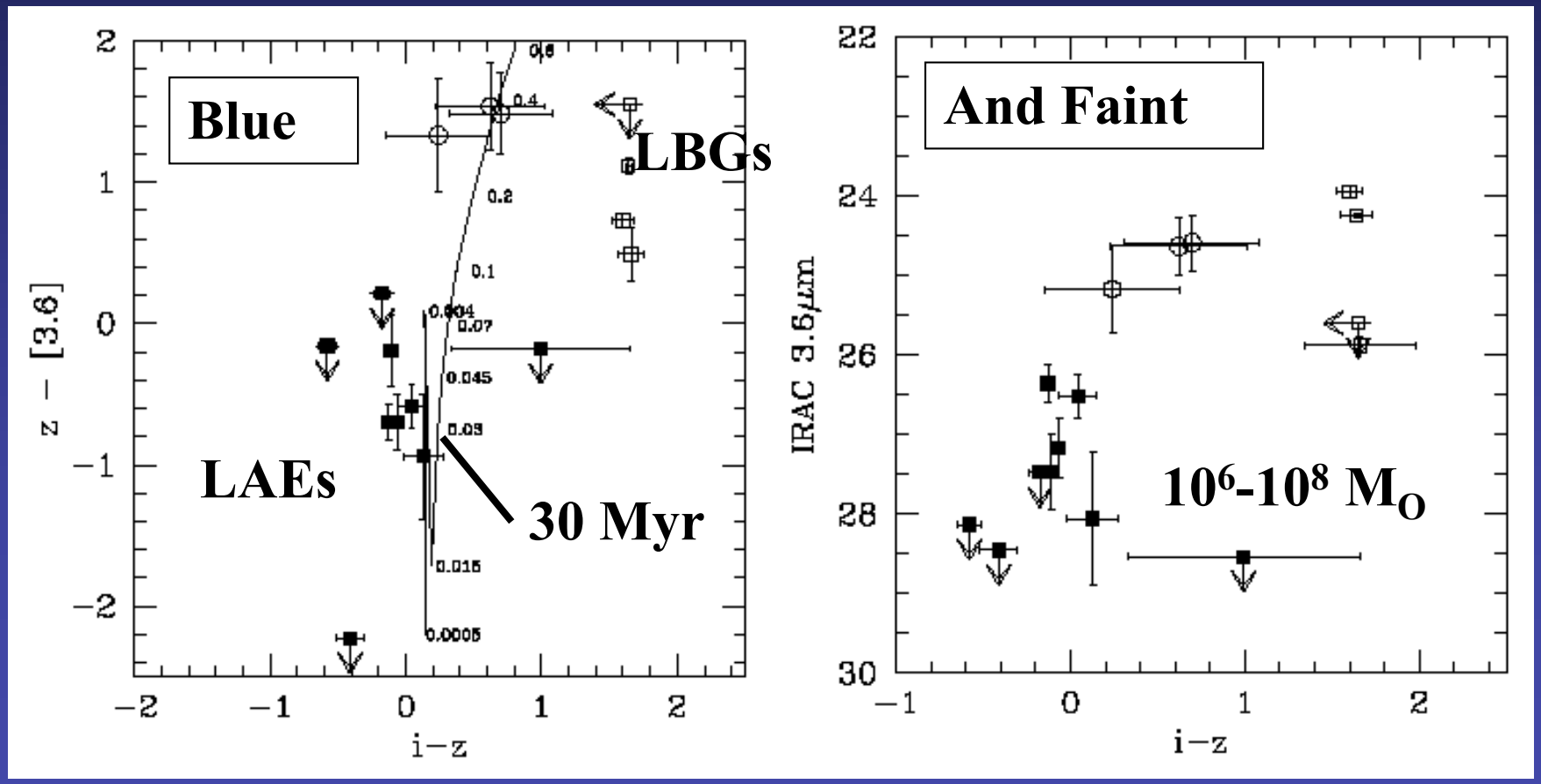
Mean <L(Lya)> = 6 x 10^{42} erg/s

Intrinsic FWHM ~ 350 km/s

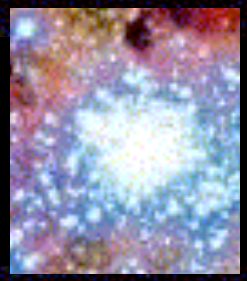
Offset of red line ~ 420 km/s

Lya Selects Primeval Galaxies

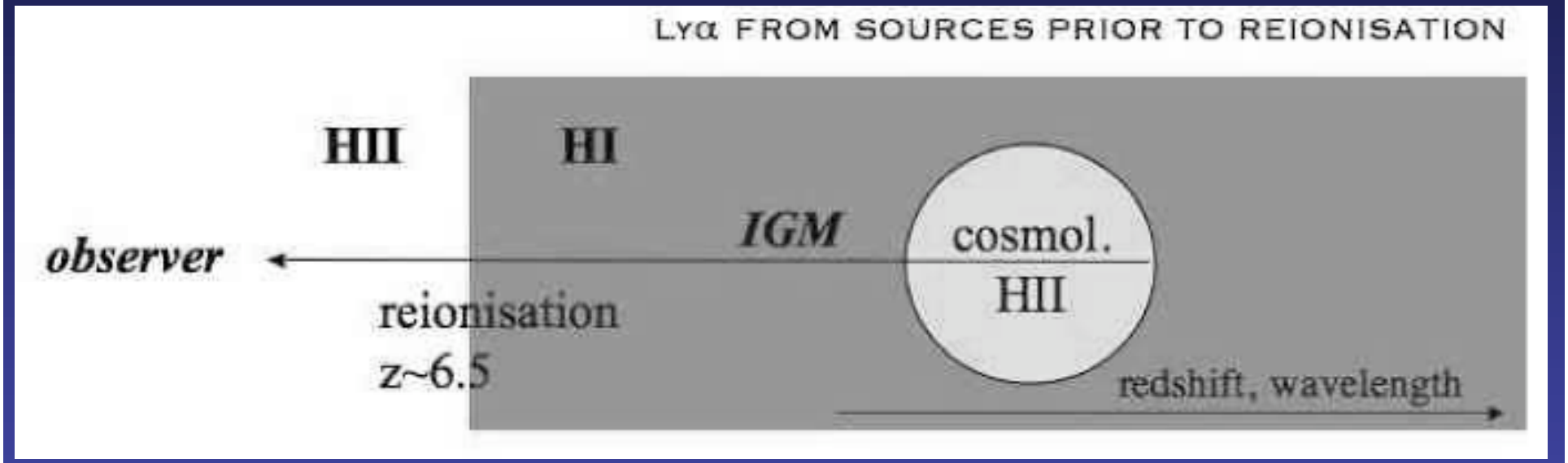
- Picks out low metallicity and low mass objects (Pirzkal et al. 2007; Santos et al. 2004)



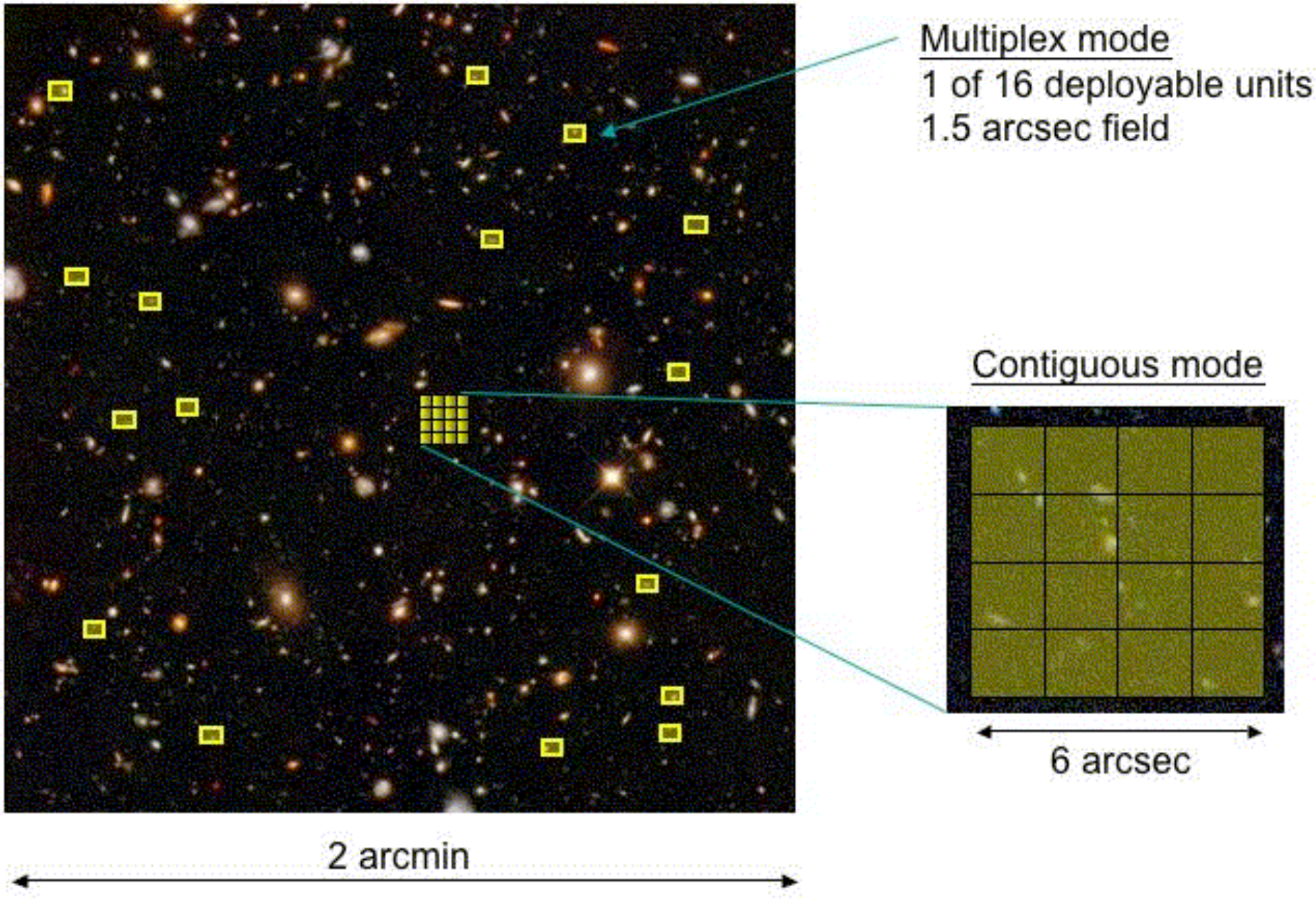
Visting….



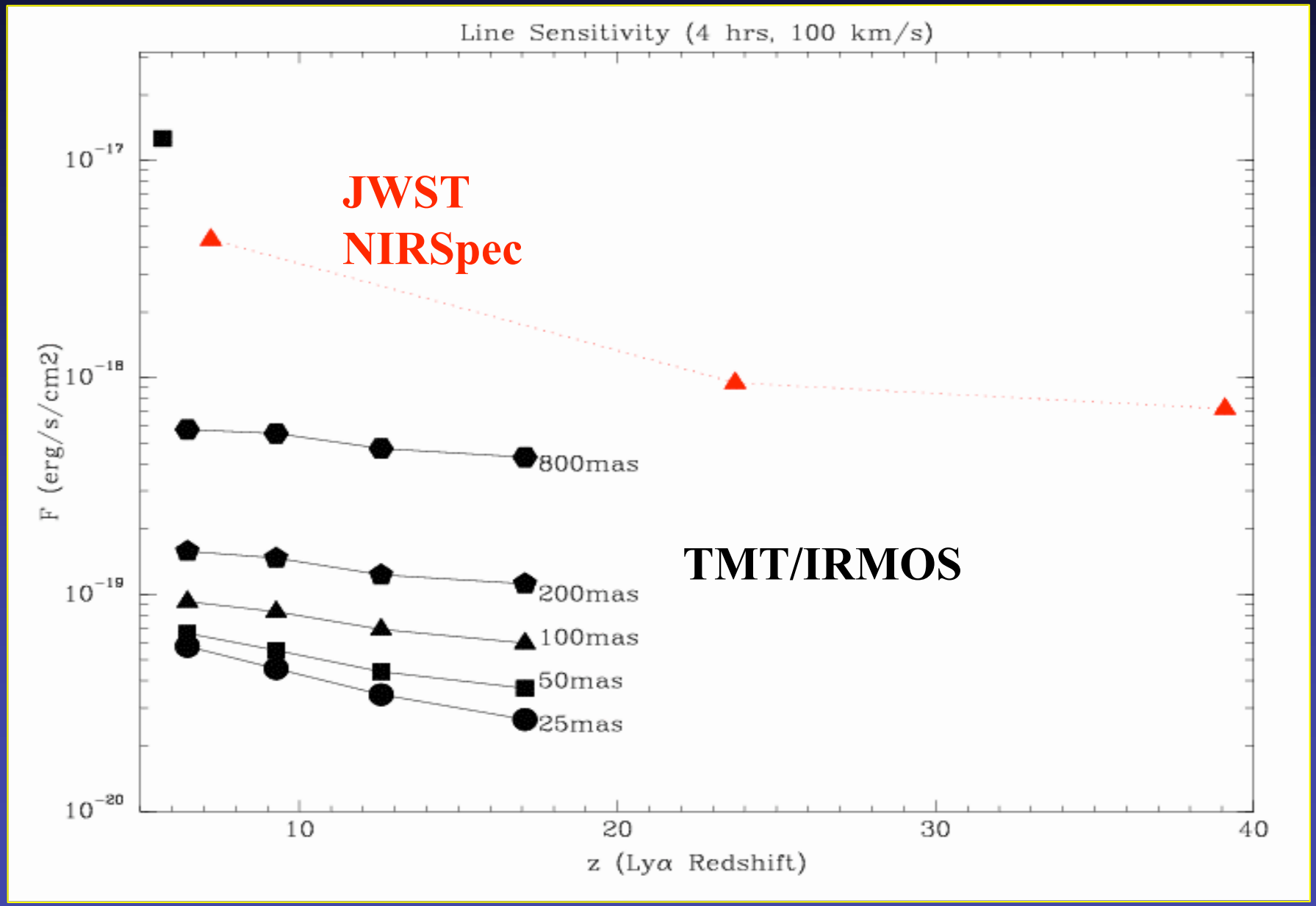
…...the Young Milky Way


Lyα FROM SOURCES PRIOR TO REIONISATION
HII
HI
IGM
observer
cosmol.
HII
reionisation
z~6.5
redshift, wavelength

Infrared Multiobject Integral Field Spectroscopy

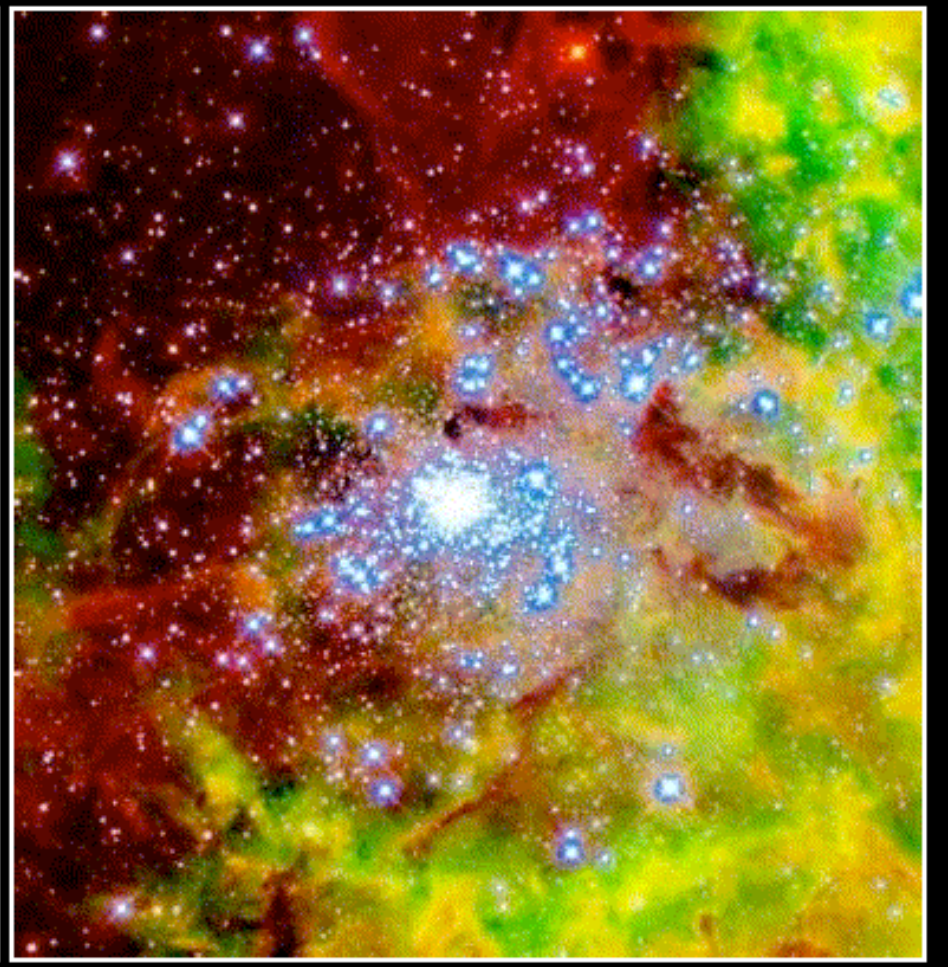


Line Detection at z > 6 in the Next Decade



Properties of Faint Lya Emitters

- Find ~ 1 kpc at z~6; R ~ 700 pc $(\sigma/150\ \mathrm{km/s})^2$ ~ 78 pc $(\sigma/50\mathrm{km/s})^2$
- Star Formation Rate < ~1 Msun/yr



(L) M55 (Hillary Mathis, REU Program/NOAO/AURA/NSF)
(R) R 136 (J. Maiz – Apellaniz & N. Walborn, STScI and R. Barba, Observatoria Astronomico de la Plata)

Emission-Line Survey Figure of Merit

1. Survey Time Required ~ $\Sigma_\lambda \Delta\lambda\, \theta^2 / A$ [Sky Area / Ω_{fov}]

(-) Reduce background by going to space (or visit Joss)

(+) Use a big light bucket

(-) Obtain a wide field of view

- Match spectral resolution to the linewidth
- Resolve the line-emitting region

2. Confirmation Time Required to Identify Line

- Imaging in multiple broad bands (Narrowband Imaging)
- Lens model (Spectra of Cluster Galaxies; X-rays Obs.)
- Resolved asymmetric line profile (Spectroscopic Surveys)

Strategies for Emission-Line Detection at z > 6

- Multislit Narrowband vs Tunable Filter (MMTF) -- Comes down to throughput in the 8190 or 9120 windows
- Tunable Filters win further to the red because the windows become more narrow (e.g. Gemini F2T2)
- Tunable Filters become severely read-noise limited in space (JWST FGS-TFI)