

Have we found the first stars in Lyman- α emitters?

Sangeeta Malhotra

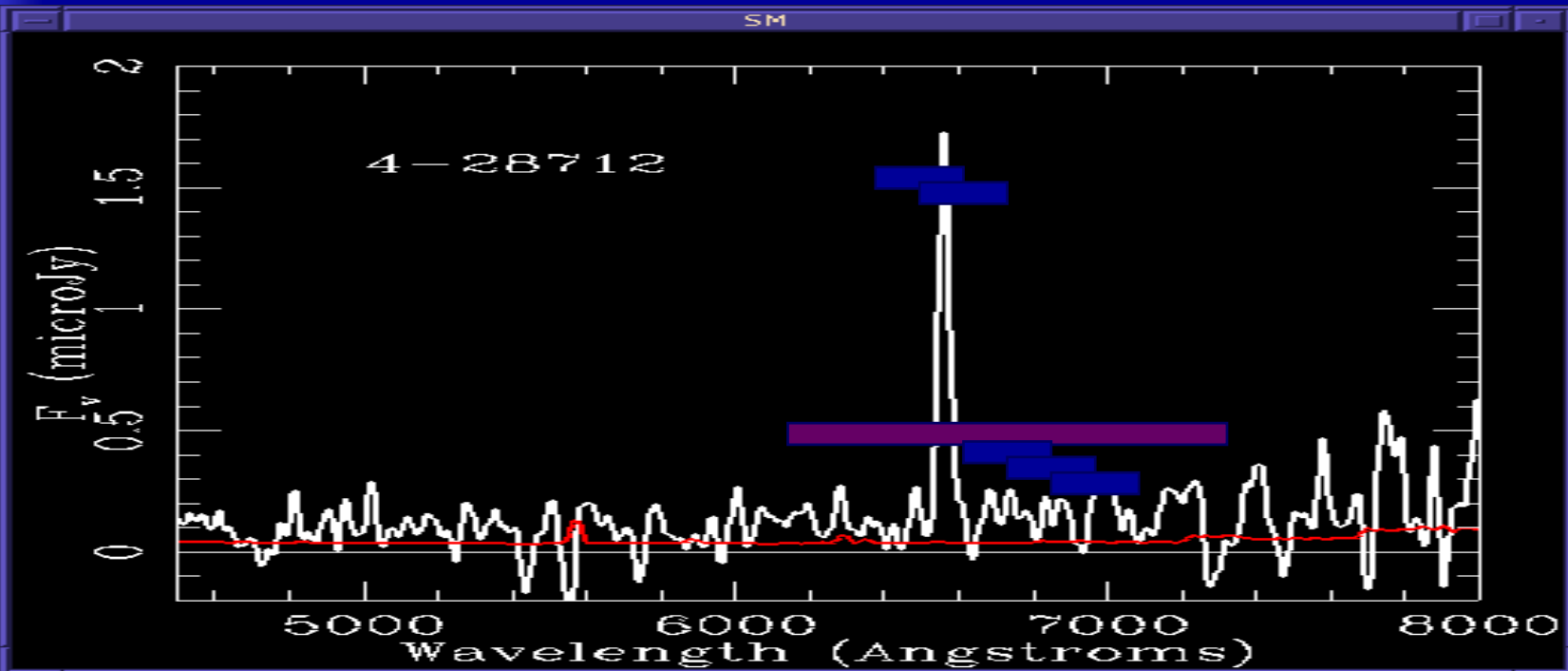
James Rhoads, Junxian Wang, Steve
Dawson, Arjun Dey, Buell Jannuzi, Daniel
Stern, Hy Spinrad and Chun Xu

Robust predictions for first stars

First stars should have ...

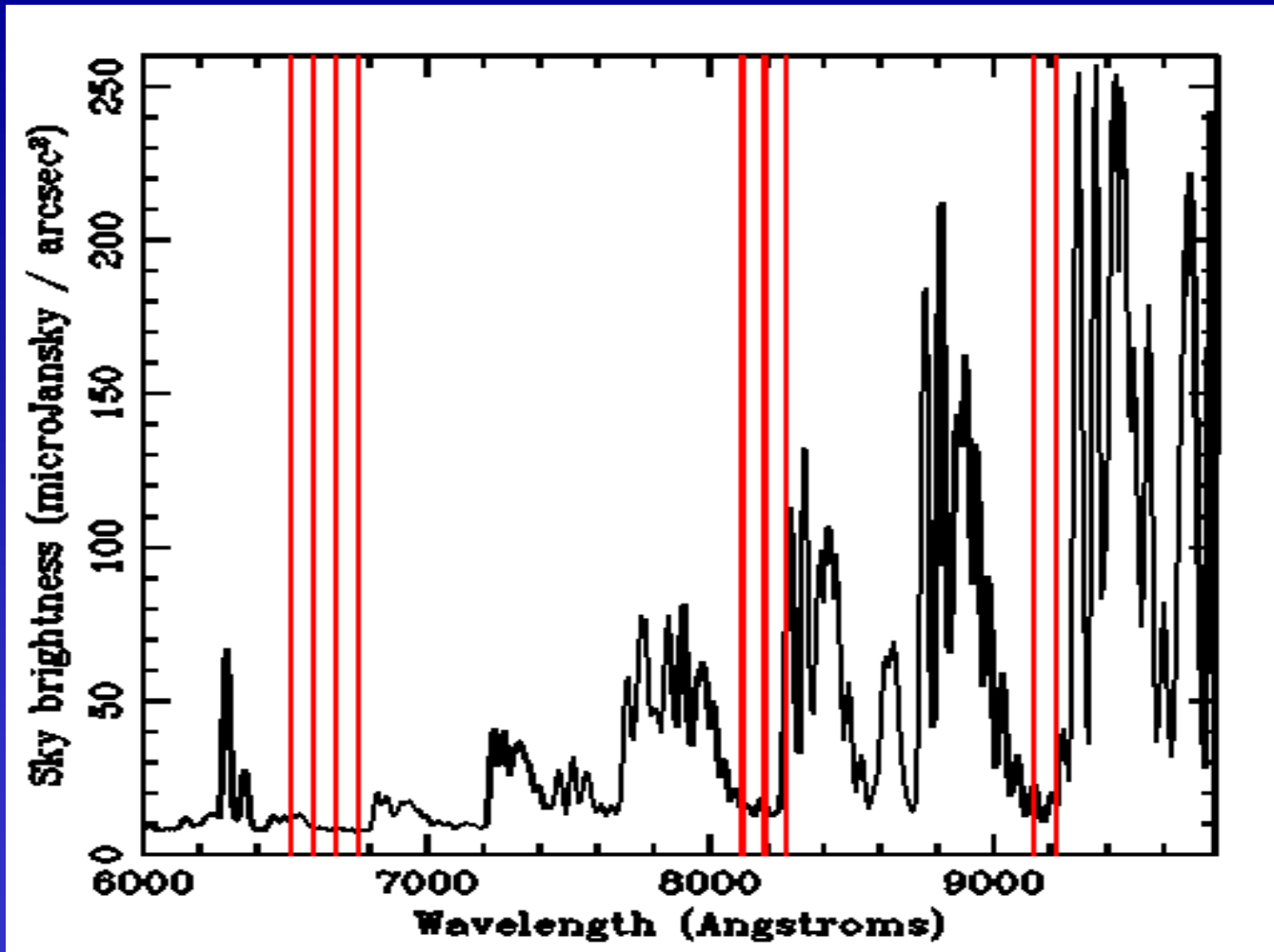
- Zero metallicity
 - IMF skewed towards more massive stars
 - Higher effective temperature.
- Observable predictions
 - Strong Lyman- α emitters, i.e. the EW (line/continuum ratio) should be high.
 - HeII line at 1640 Angstrom. (1%-10% of the Ly α line)

The Large Area Lyman Alpha (LALA) survey



z	Volume	Sensitivity	Candidates
4.5	1.4×10^6 Mpc	1.7×10^{-17} ergs/s/cm ²	350, 2/3
5.7	2×10^5 Mpc	1×10^{-17} ergs/s/cm ²	18, 3/4
6.6	2×10^5 Mpc	2×10^{-17} ergs/s/cm ²	3, 1/3-2/3

Windows for Narrowband Surveys



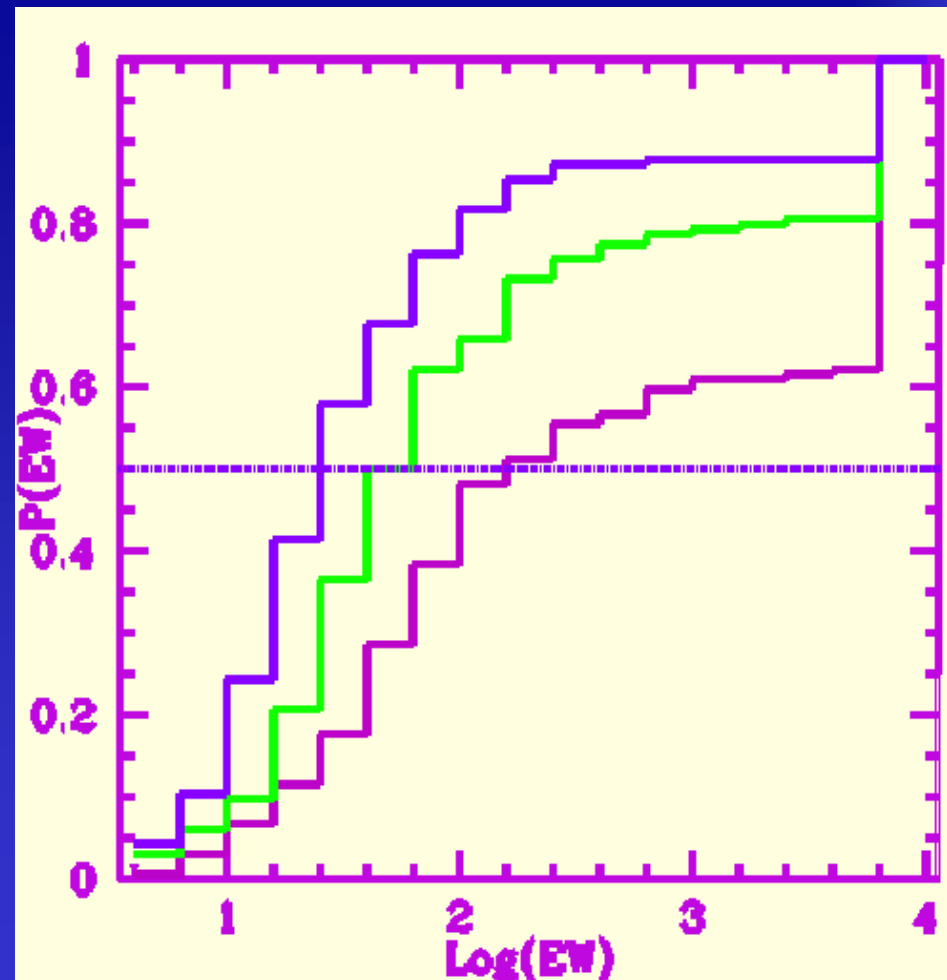
Red lines
mark LALA
survey filter
wavelengths

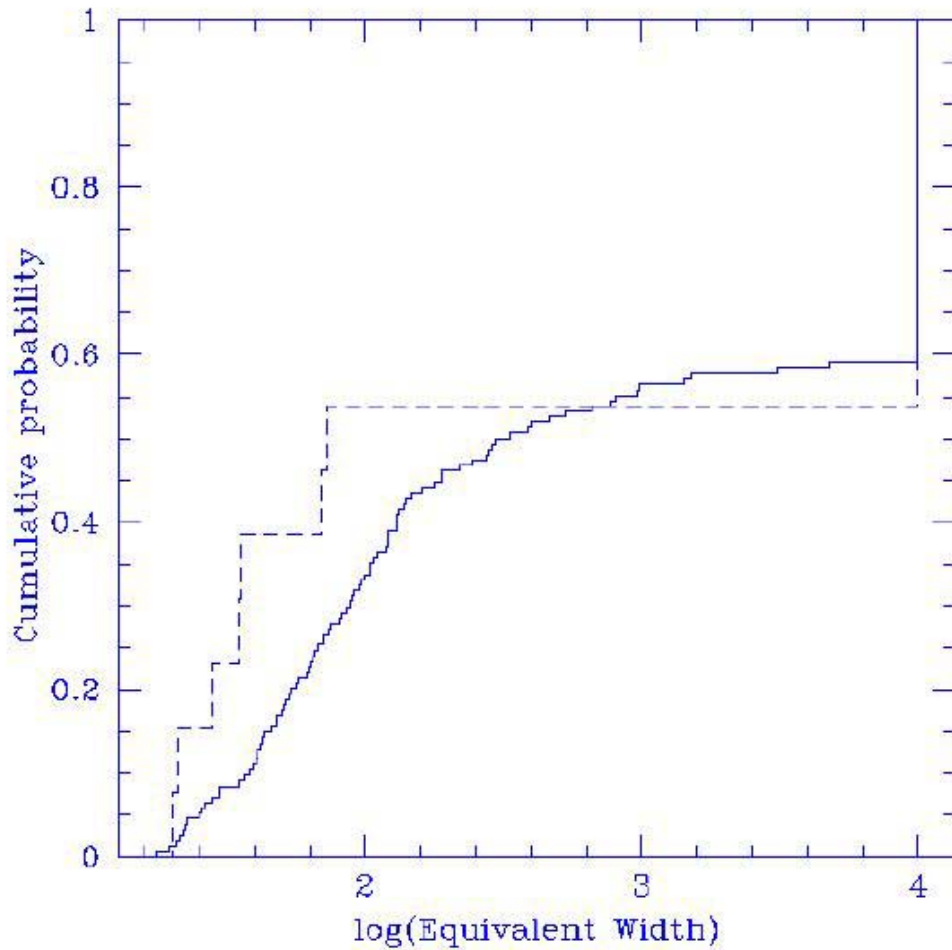
Observed equivalent widths:

Equivalent widths are derived from narrow and broad-band fluxes.

- About 50% of the observed population has $EW > 240 \text{ \AA}$, the maximum allowed for a stellar population.
- Purple line shows the cumulative distribution of equivalent widths in ~ 160 Lyman- α candidates.
- The green and blue lines shows the same but with 1σ and 2σ flux added to the R band.

(Malhotra & Rhoads 2002, ApJ Lett 565, L71)



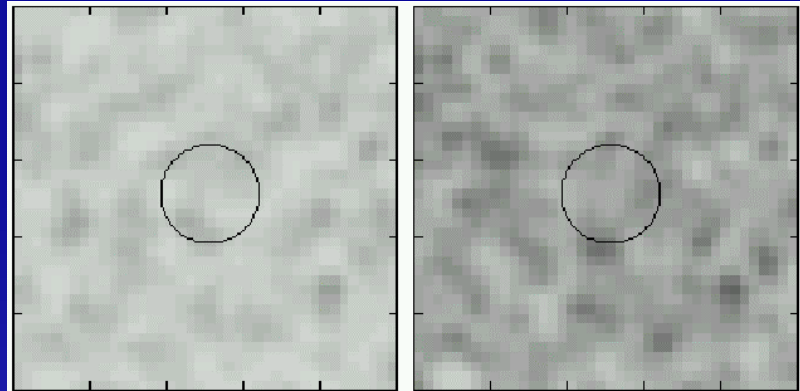


- $Z=5.7$ EW distribution similar to the $z=4.5$ sample

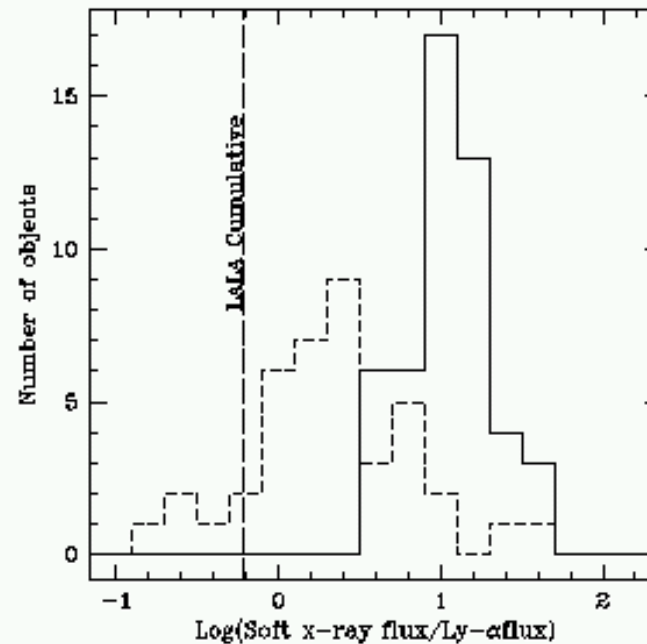
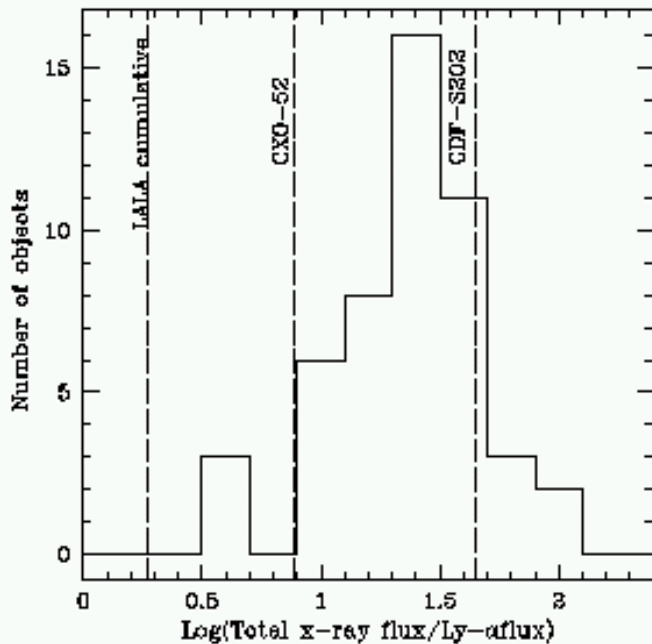
Explanations:

- Quasars?
 - The narrow band imaging, and spectra so far rule out broad line quasars.
 - No Chandra detection (Malhotra et al. 2003)
- Zero metallicity stars?
- Peculiar IMFs
- Young ages of stellar populations
- Peculiar geometry/winds

X-ray non-detections



- None of the 44 sources detected in a 172 Ks CXO image.
- Cumulative image showed no detection (Malhotra et al. 2003)



Explore young, metal-poor populations

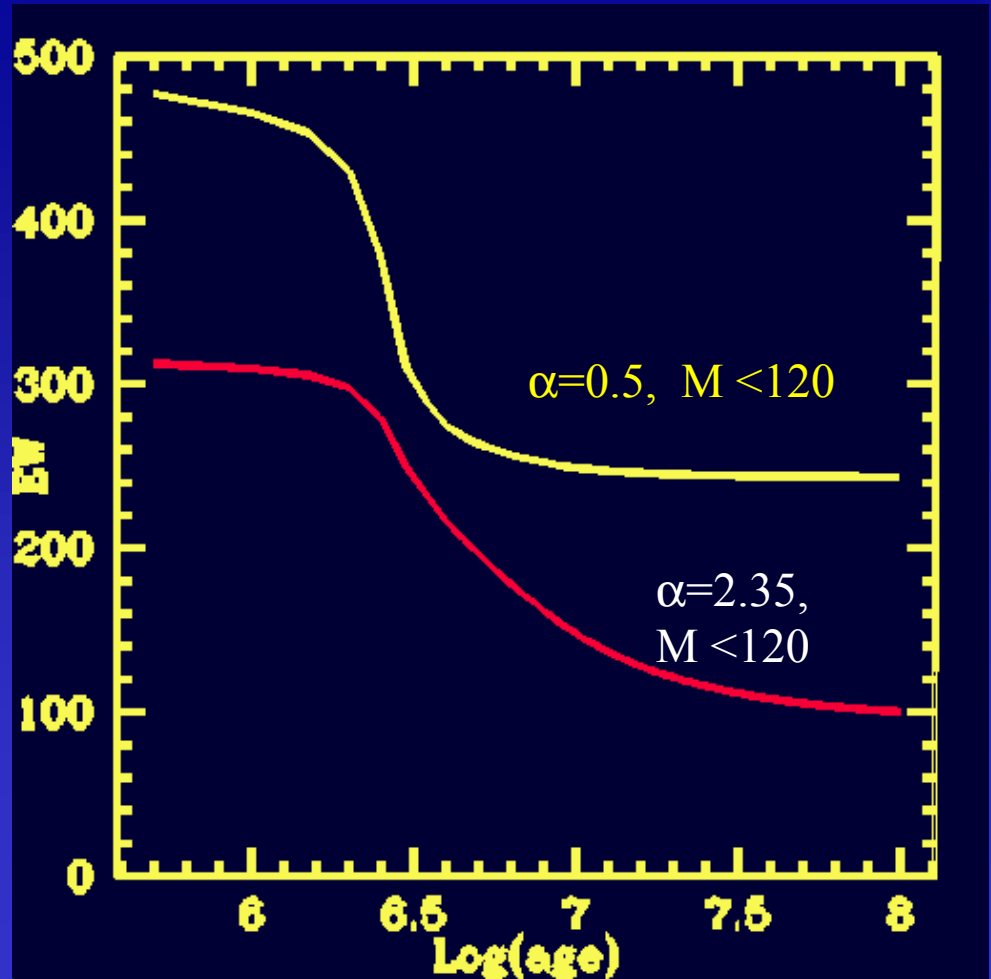
- Take Luminosity function from Lyman Break Galaxies at $z=4$ and extrapolate to fainter magnitude to get numbers expected for Lyman- α emitters
- Use stellar population models (Starburst 1999; Leitherer et al.) to calculate the distribution of EW of the Lyman- α line.
- Add sky noise, simulate observations.

(Malhotra & Rhoads 2002, ApJ Lett 565, L71)

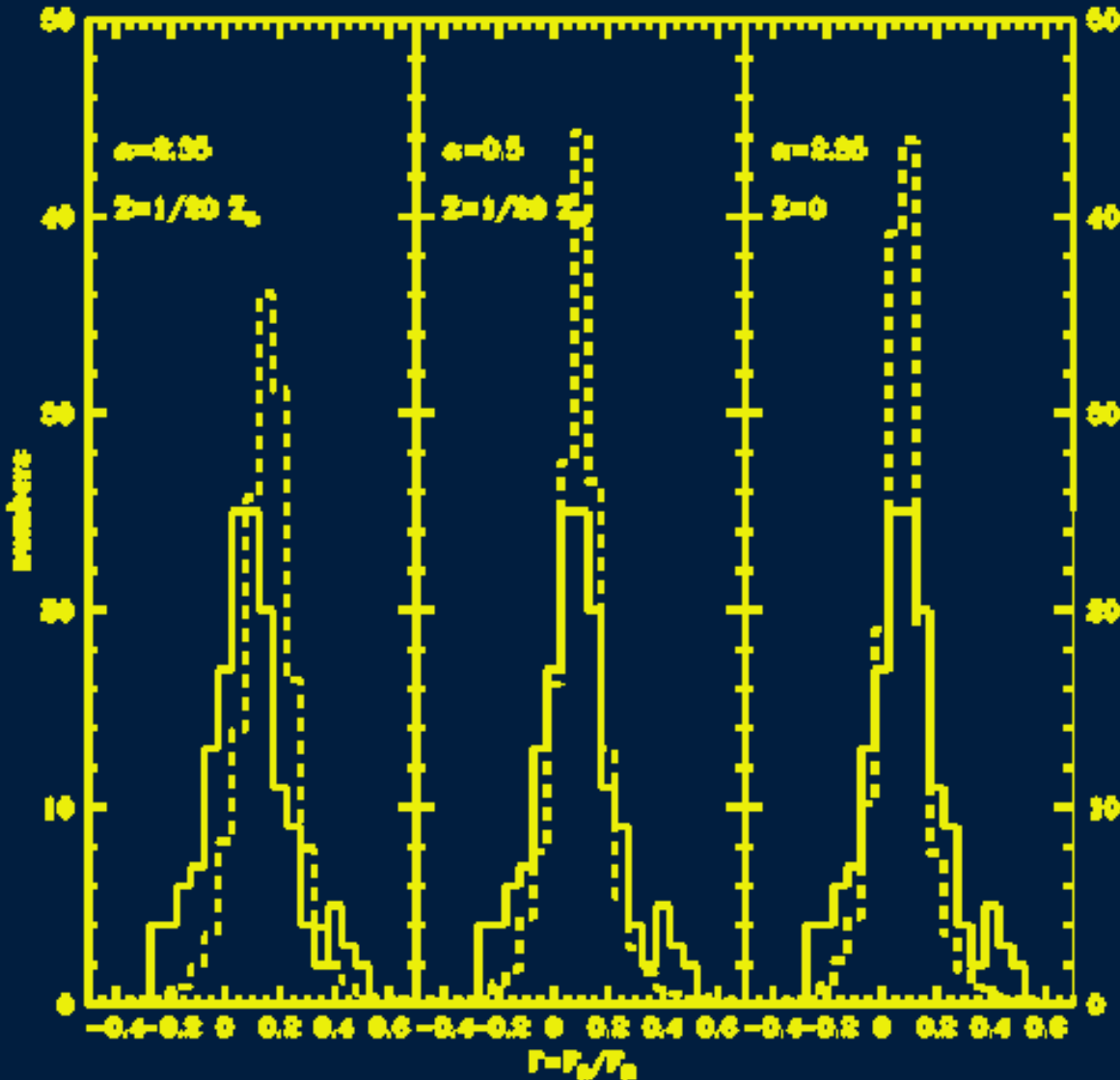
EW from population modelling

- Age vs equivalent width for continuous star-formation.
- If galaxy formation is random we should have 100 times as many 10^8 year old galaxies as 10^6 year old galaxies.

(Malhotra & Rhoads 2002, ApJ
Lett 565, L71)

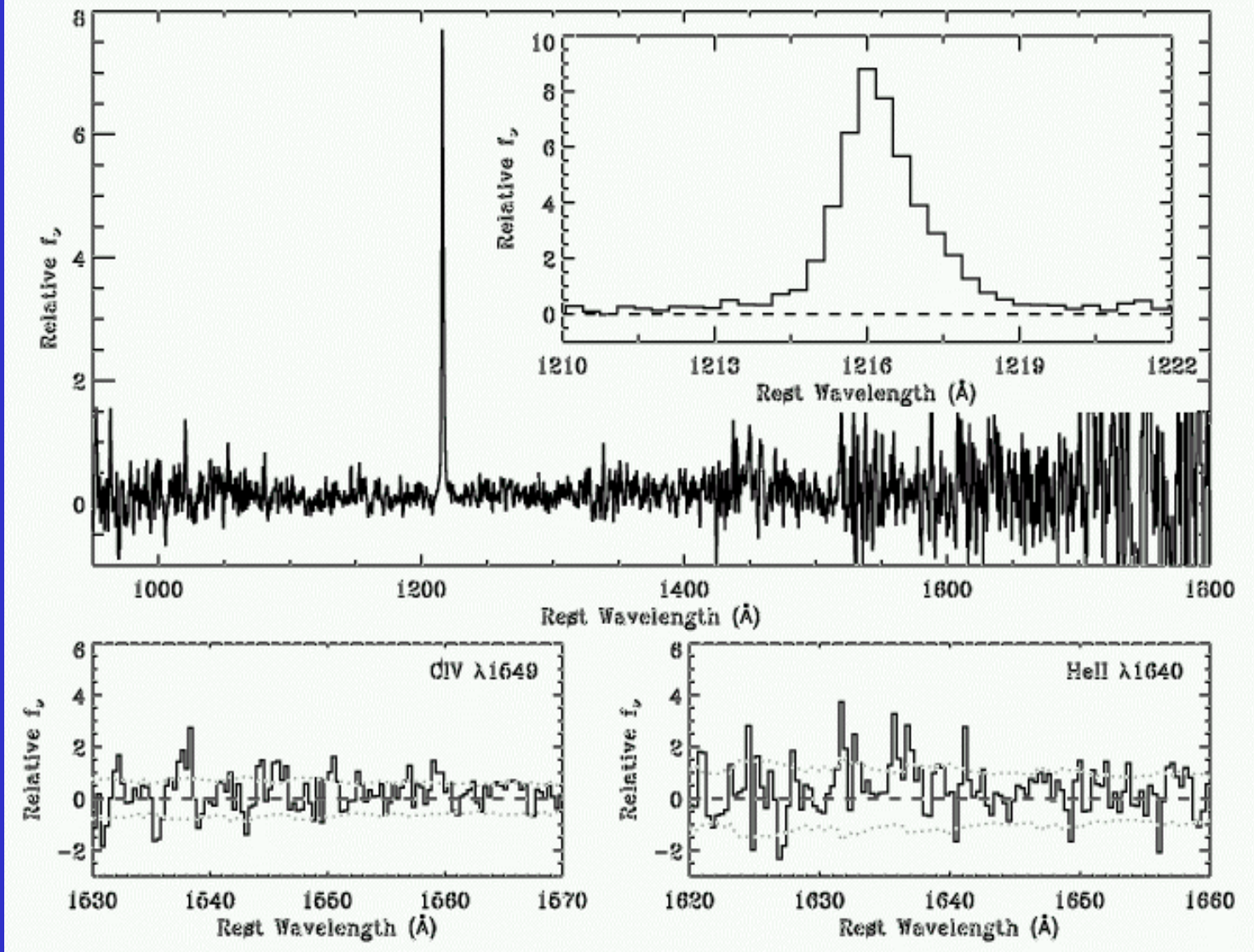


Use flux ratios, get better behaved errors



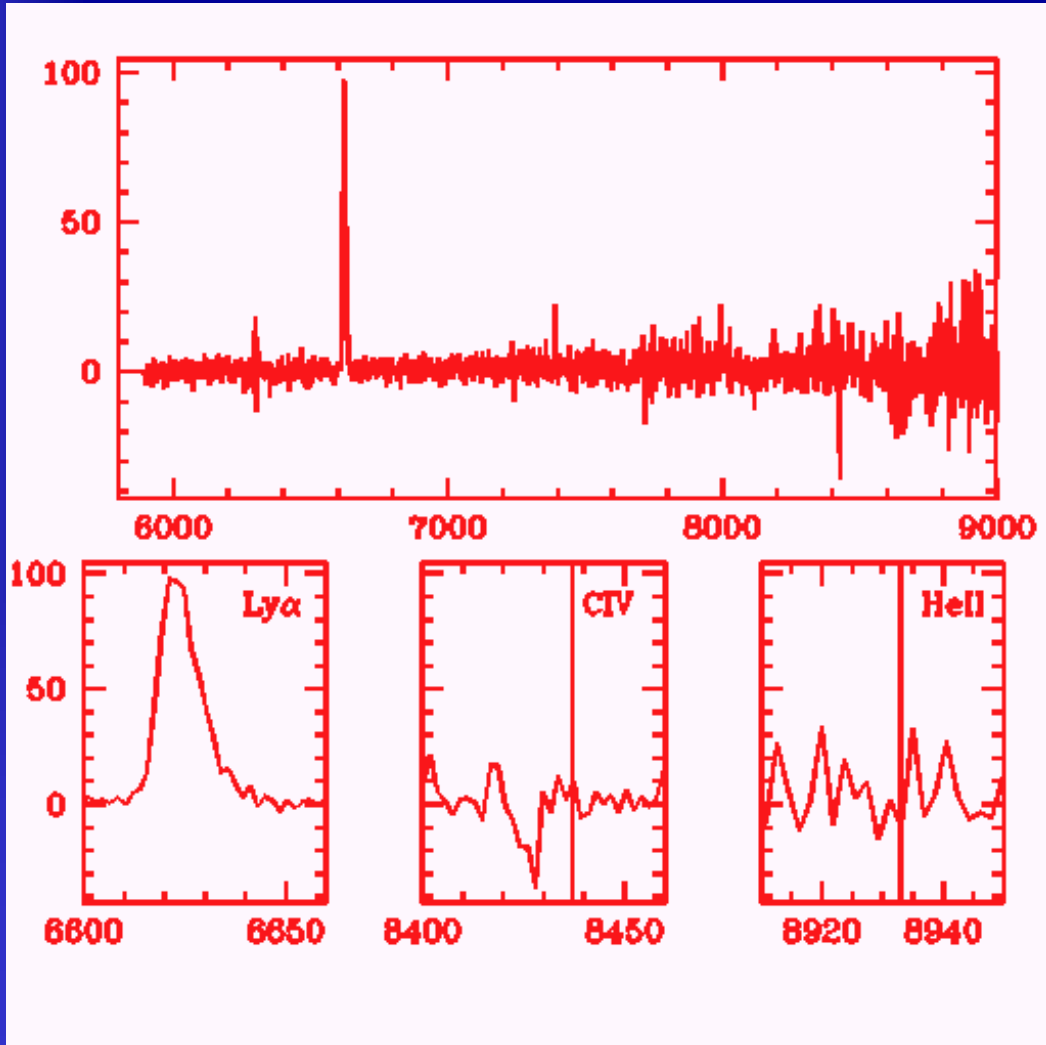
- IMF with $\alpha=2.35$, $z=1/20^{\text{th}}$ does not fit well
- IMF with $\alpha=0.5$, $z=1/20^{\text{th}}$ fits and so does
- IMF $\alpha=2.35$ and $z=0$

(Malhotra & Rhoads 2002, ApJ Lett 565, L71)



Composite spectrum: no CIV (1549), no HeII (1640)
(Dawson et al. 2003). HeII $< 0.16 \times$ Lyman- α line

A Bright High Equivalent Width Galaxy



- The current “poster child” of the high equivalent width set: a galaxy with a line flux of 10^{-16} erg cm $^{-2}$ s $^{-1}$ and no detectable continuum.
- Neither the CIV 1549Å line nor the HeII 1640Å line is visible.

High EW of Lyman- α line:

- No evidence of AGNs
- Models with Zero metallicity stars *AND* a top-heavy IMF (e.g. Bromm et al. 2001, Schaerer 2003) close to being ruled out (Dawson et al 2003).
- The stellar populations could still be either top-heavy IMF or Zero-metallicity
- Peculiar geometry, winds – essentially unconstrained.
 - But, no broad-band companions (R-drop outs) found

Conclusions

Lyman- α emitters at $z=4.5$, 5.7 , and 6.6 show large EW in the line-higher than you could reproduce with normal stellar populations.

These are not x-ray bright AGNs, nor is CIV (1549) line seen

The most optimistic predictions for HeII(1640)/Ly α are not consistent with the observations

There are indications that these are fairly young galaxies.

Lyman α Line Emission

- Ionizing flux + gas \rightarrow 2 Lyman α photons for every 3 ionizing photons absorbed by hydrogen.
- In principle, up to 6-7% of a young galaxy's luminosity may emerge in the Lyman α line.
- 1967: Partridge & Peebles proposed the Lyman- α line as a signpost of galaxy formation.

The Large Area Lyman Alpha (LALA) survey

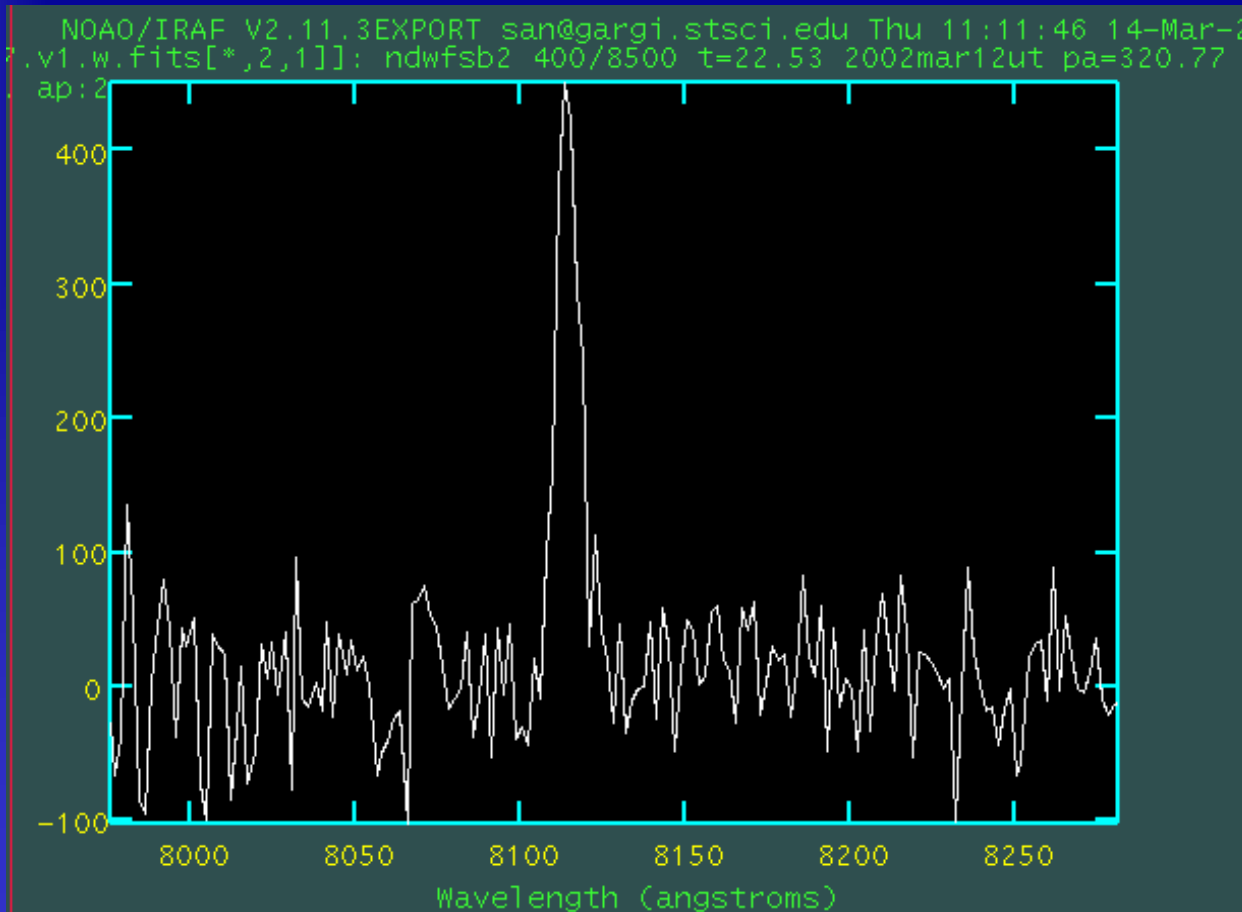


In 1998, James Rhoads and I started a new project to identify a large sample of infant galaxies at high redshift.

We achieve unprecedented survey efficiency by exploiting new large format detectors and narrow band filters.

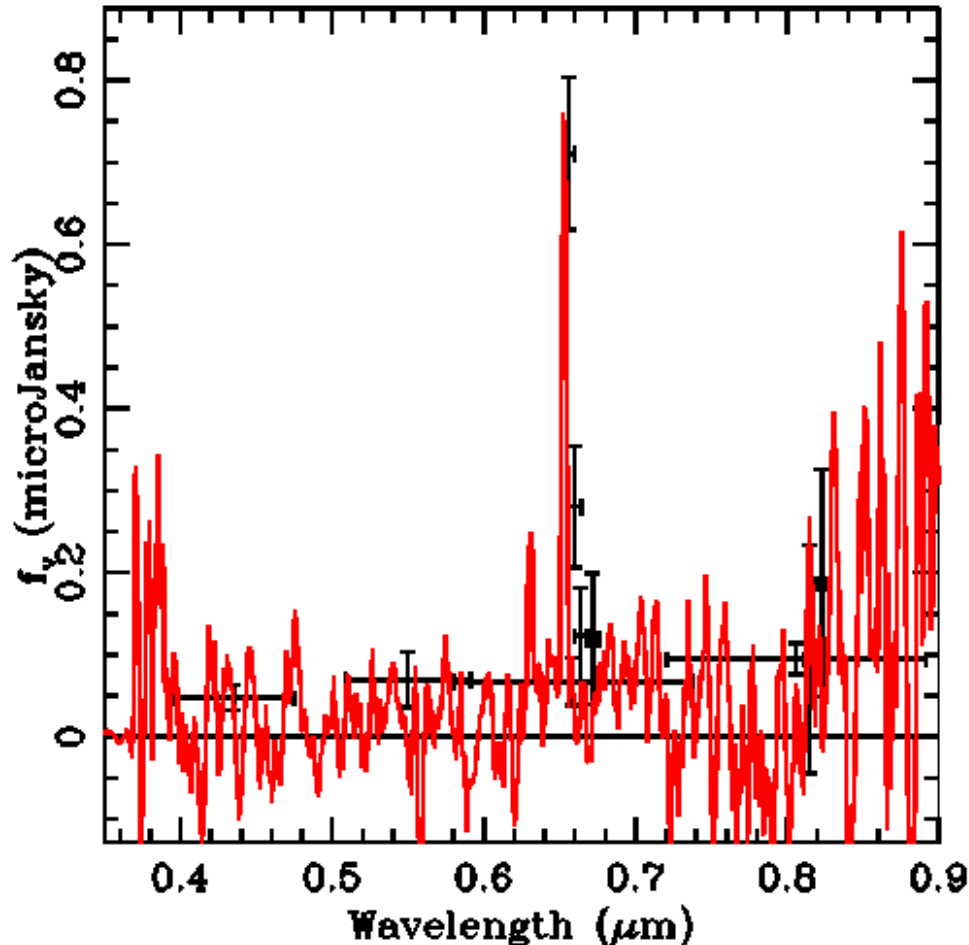
Resulting in a statistically useful sample

A $z=5.7$ Lyman Alpha Source



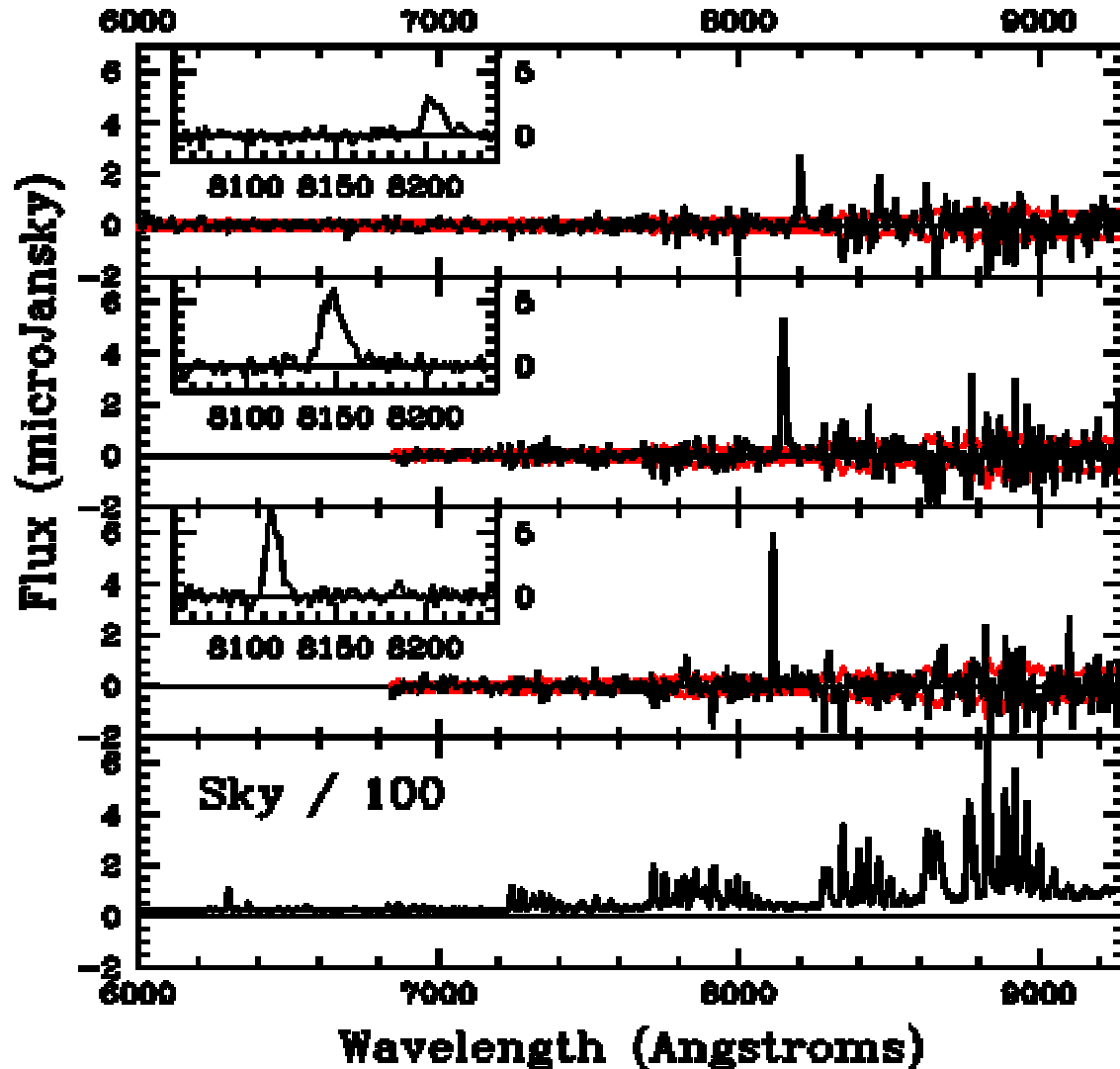
- A confirmed $z=5.7$ LALA source...
- Three of four spectroscopically confirmed at Keck this month.
- Five more observed w. Gemini.

Benefits of real spectroscopy



- Add a real spectrum (obtained at Keck by Dey, Spinrad, Stern, and collaborators).
- We can now confirm the presence of the line, look for other lines and/or continuum breaks, study line shapes, and measure precise redshifts.

Three $z=5.7$ Lyman Alpha Sources



- Confirmed $z=5.7$ LALA sources.
 - Three of four spectroscopically confirmed at Keck.
- (Rhoads et al 2002, submitted to AJ)