Characterising the Galaxy Population at z=5 and above

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Talk Structure

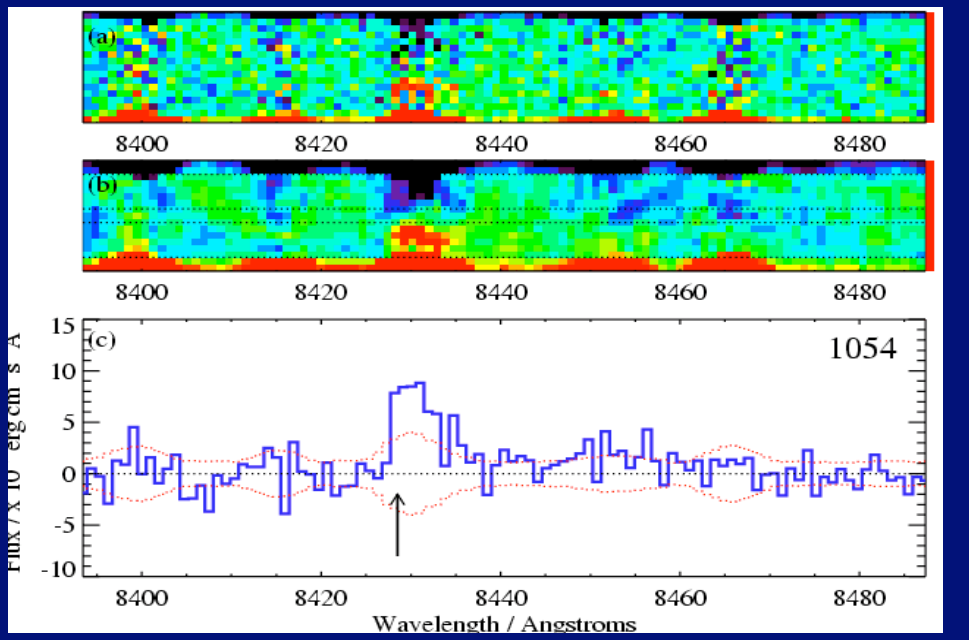
- Spectroscopic Surveys
- Equivalent Width Distributions
- Winds and Outflows in $z>5$ LBGs
- Massive Stars at High Redshift
- Tip of the Iceberg
- Future Work

Spectroscopic Samples

At z~6:

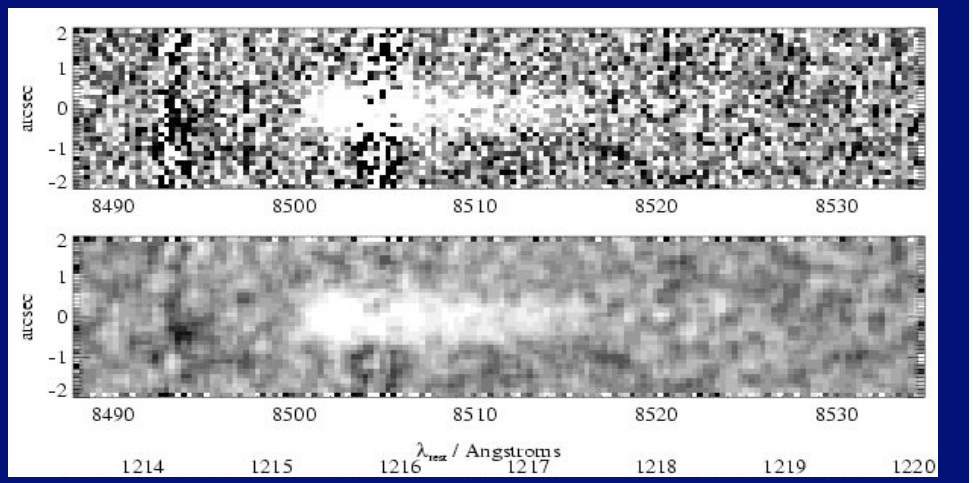
Gemini Lyman-α at Reionisation Era (GLARE)

- 5(+4) confirmed z~6 galaxies
- GMOS spectra
- Typically z_{AB}~27.5
- R ~ 1000



I-drops with DEIMOS

- 6(+4) confirmed z~6 galaxies
- 4 - 12 hours per slit
- HUDF and GOODS-S
- Typically z_{AB}~28
- R ~ 5000

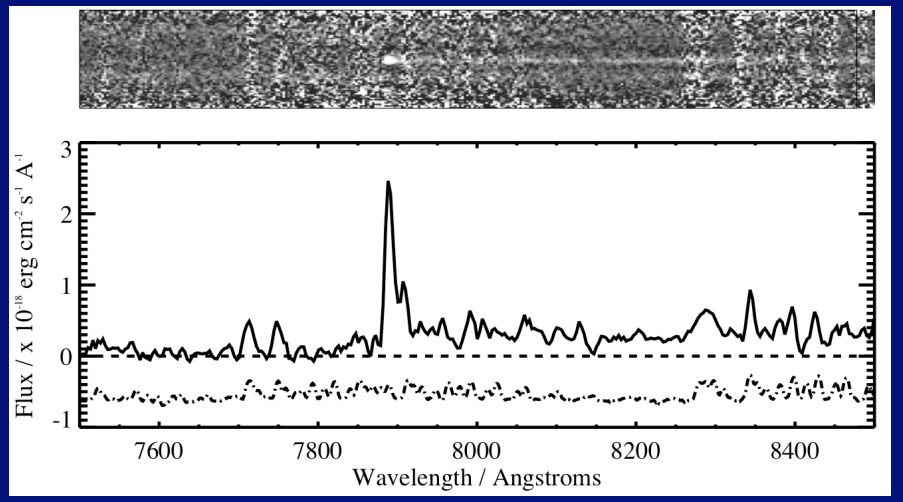


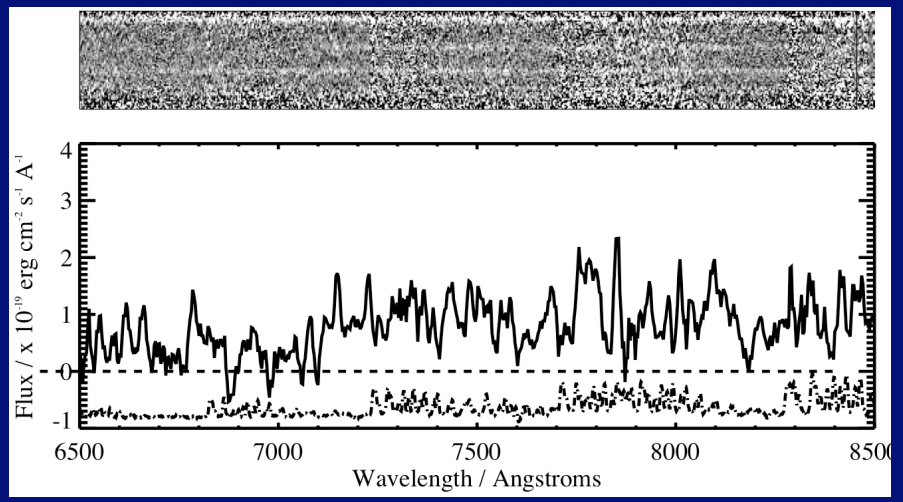
Spectroscopic Samples

At z~5:

ESO Remote Galaxy Survey (ERGS)

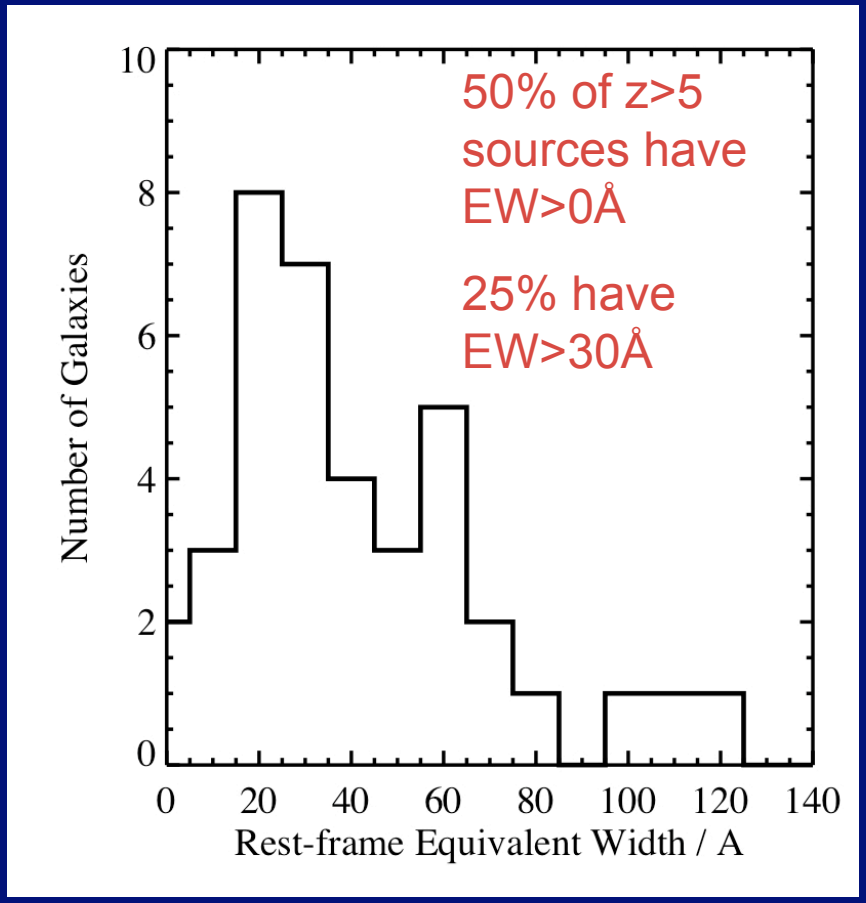
- ~64 spectroscopically confirmed z~5 galaxies
- FORS2 spectra
- Typically I_{AB}~25.5
- Continuum detection in individual sources
- R ~ 700

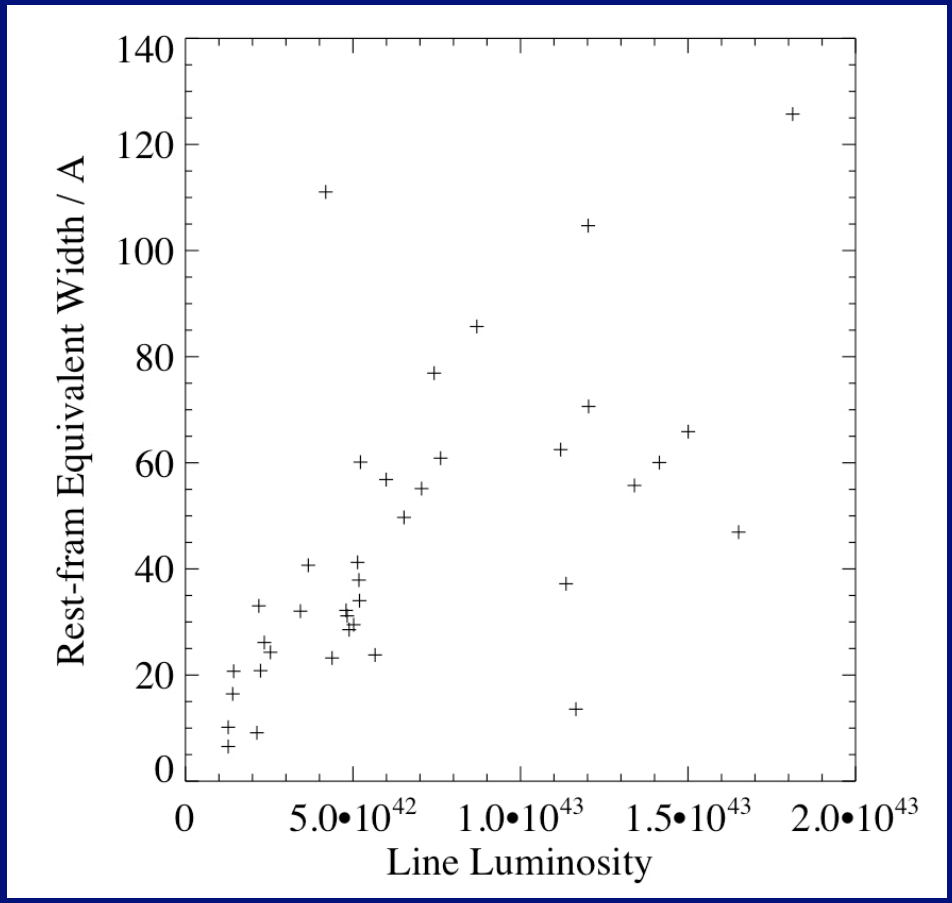




Not discussing 8 additional GMOS and ~20 additional FORS2/VIMOS sources

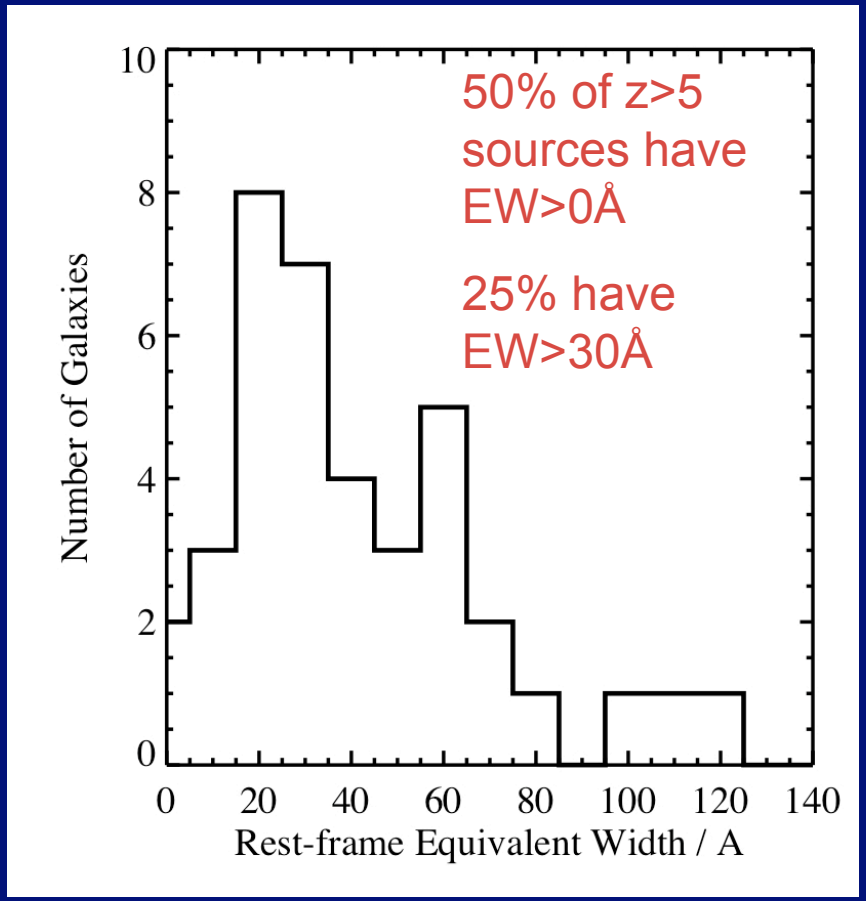
Line flux and EW

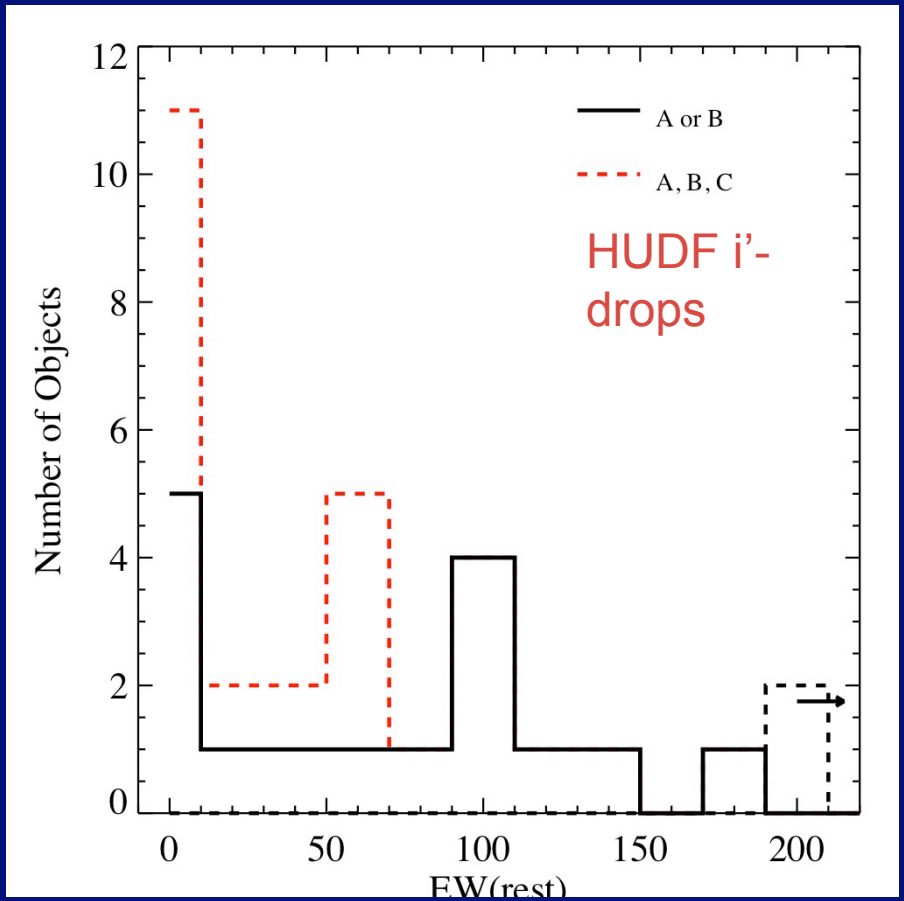




Unsurprisingly, the higher EW sources also tend to be more luminous. However, some relatively low luminosity sources can have EW>100Å

Line flux and EW





Line flux and EW

High EWs at z~6:

- Selection effect?

Yes, but that doesn't explain EWs>200A

- Age effect?

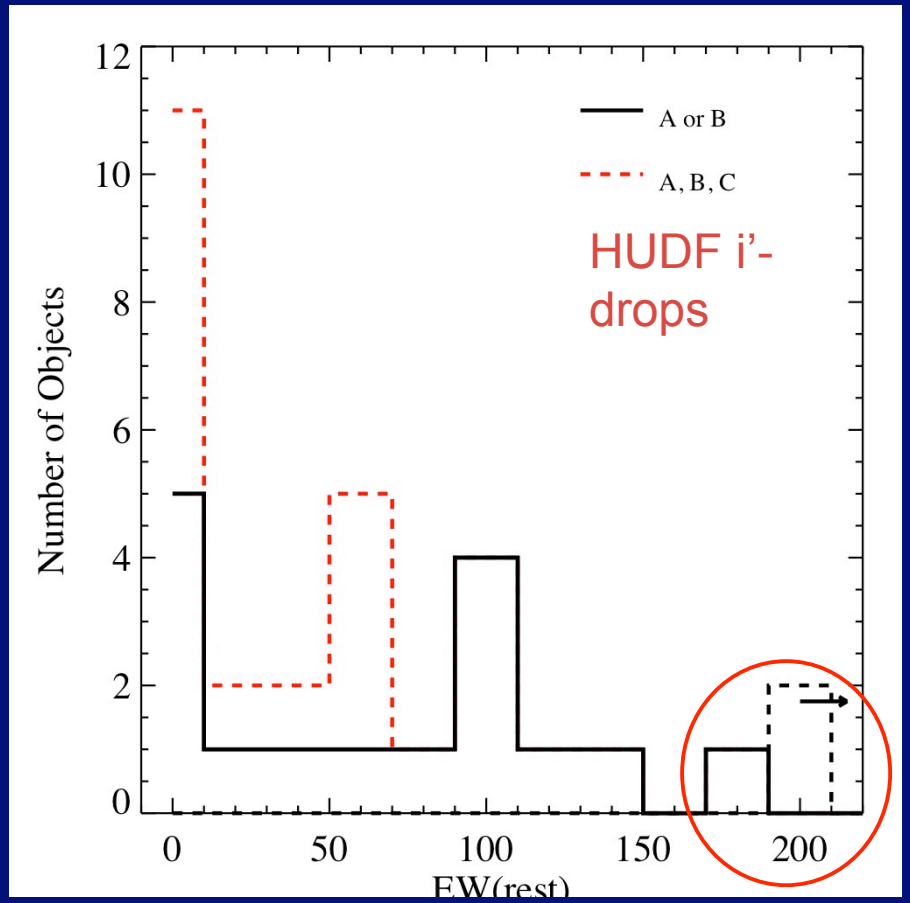
Requires unfeasibly small ages

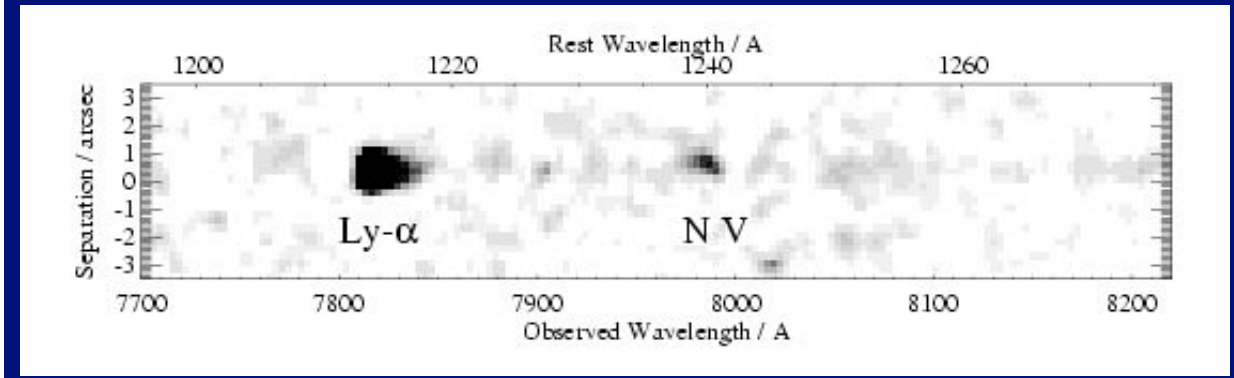
- IMF effect?

Top heavy IMF might contribute

- Geometry?

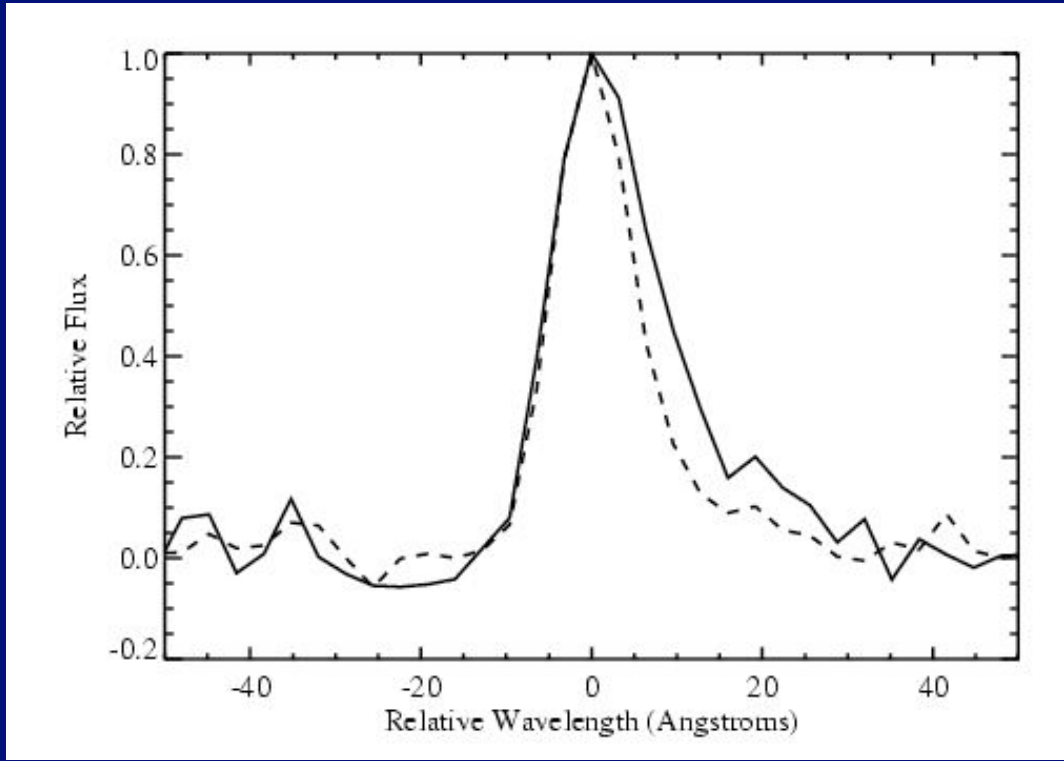
Would require significant dust contribution





A lone AGN at z=5.4

Only 1 of about 50 Ly-α emitters shows NV



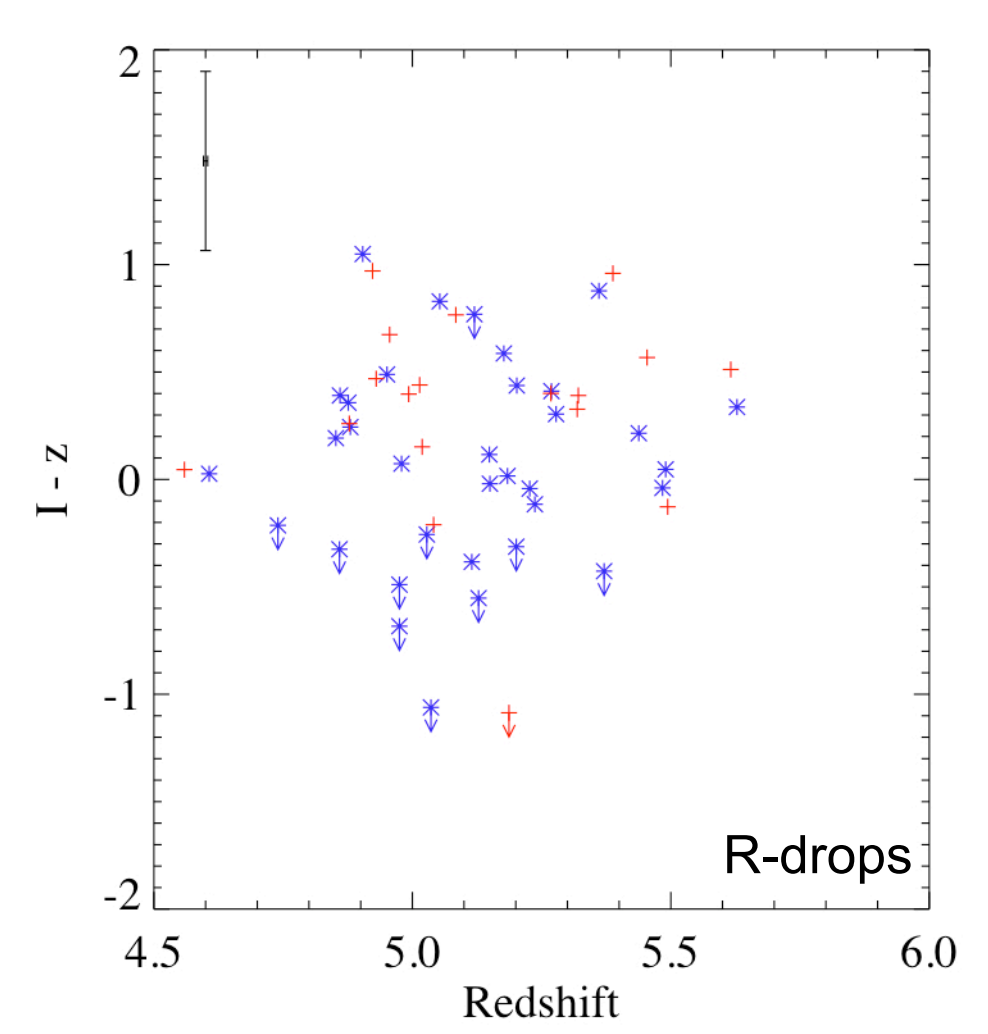
1 AGN in 150 arcmin^2 is consistent with predictions for the z~5 AGN LF.

The AGN emission here is matched by a large starburst (both contributing to Lyman-α emission.

X-ray nondetections

Douglas et al (2007)

Rest UV slope



At z=5, can determine rest-UV slope for sources with and without Ly-α

Galaxies without Ly-α emission are, on average, redder than those with line emission.

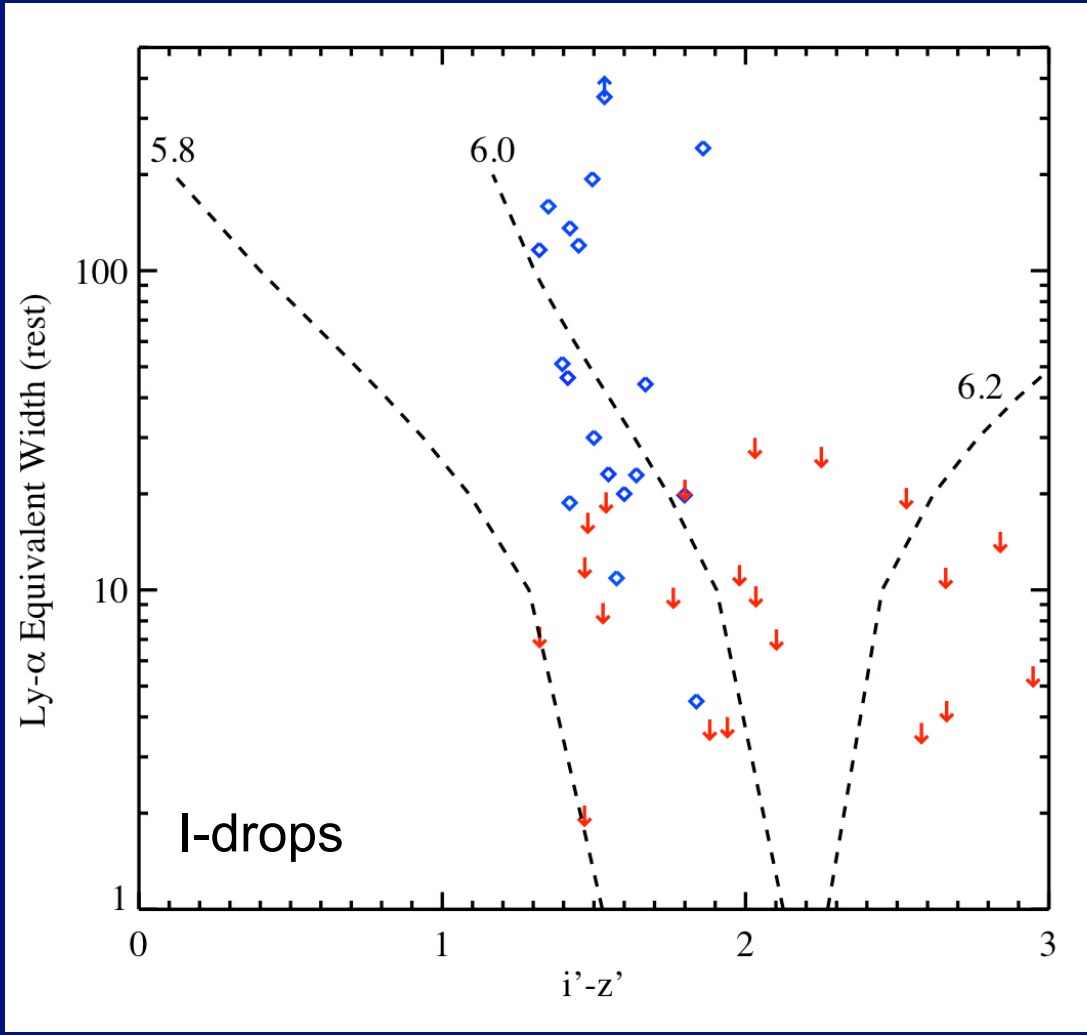
Line emitters are often bluer than flat in f_ν,

i.e. $f_\nu \propto \nu^\beta$, $\beta<-2$

$\Rightarrow$ Very young starbursts?

$\Rightarrow$ Steep IMF?

Rest UV slope



At z=6, very few objects have continuum-derived redshifts

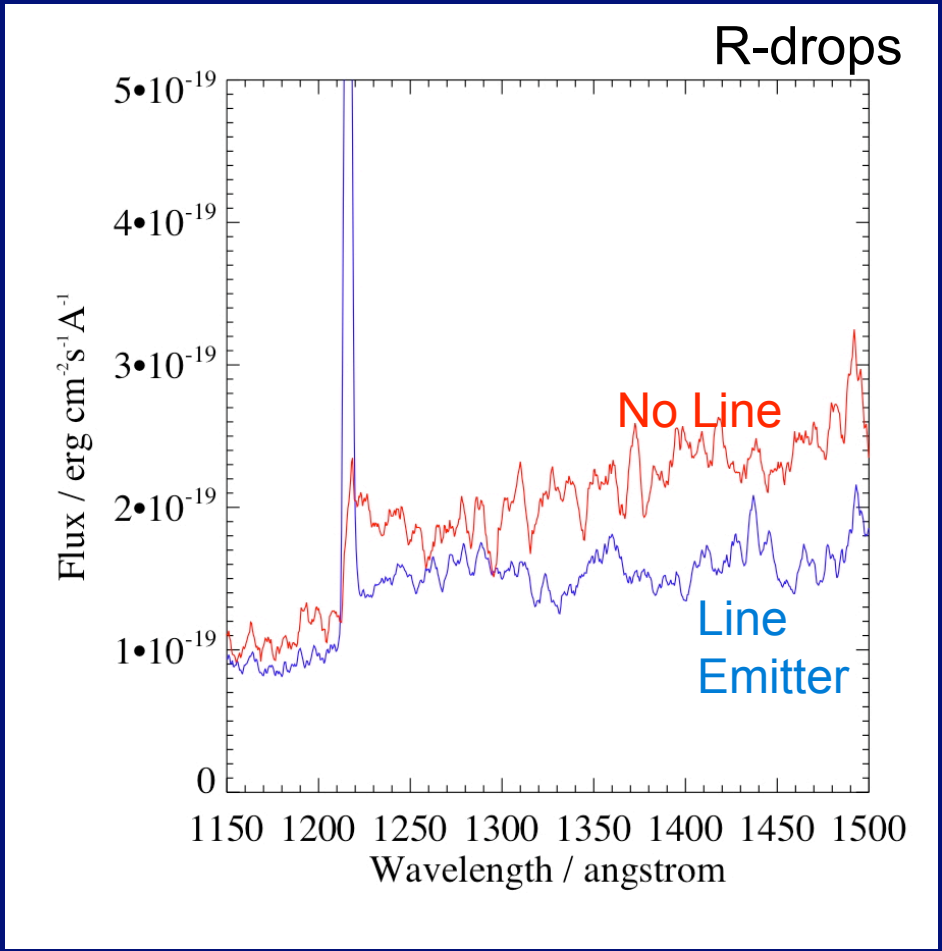
However, sample has high-resolution imaging, IR and optical => stars and low-z gals less of a problem in photometric sample

Compare Ly-a detections with upper limits

Line-emitters consistent with β~-2 at z=6

Sources without emission lines are redder - higher *z* or redder UV slope?

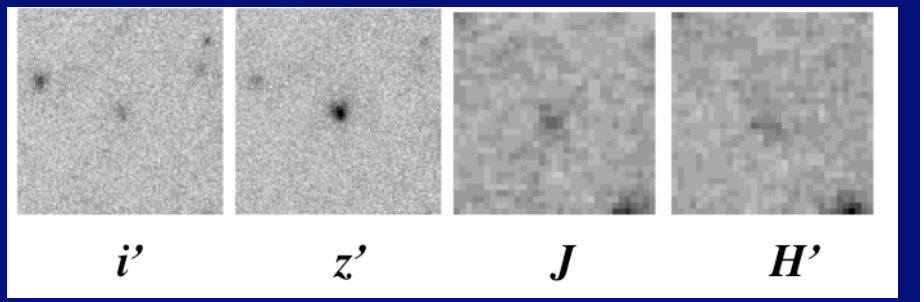
Rest UV slope



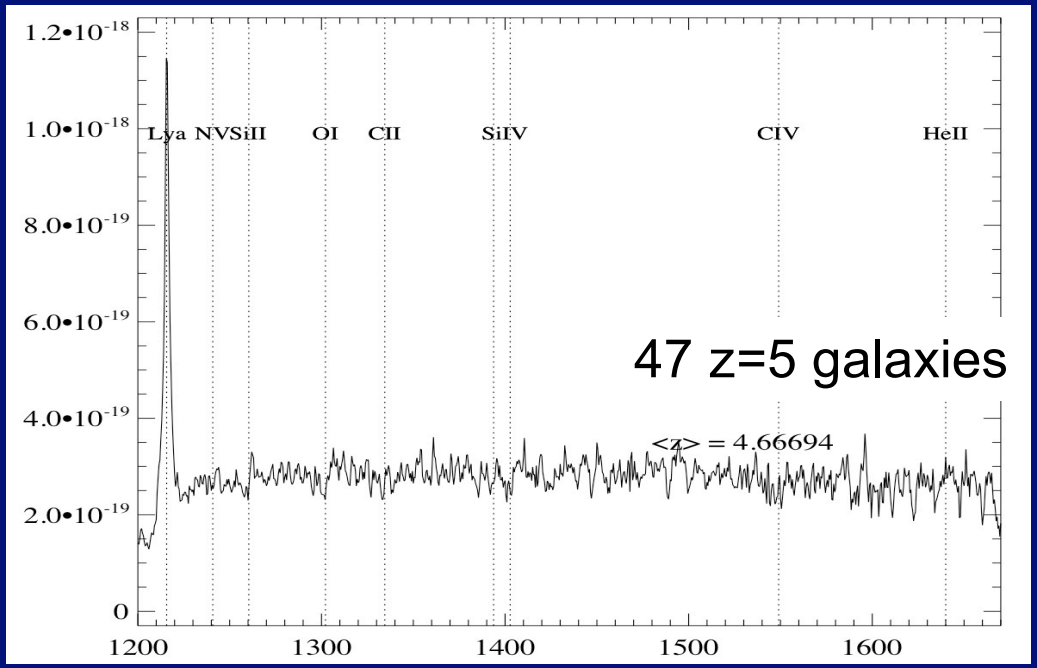
The very blue spectral slopes and difference between Ly-a emitters and break galaxies is also visible in stacked photometry and spectroscopy at z=5 and z=6

Stacked HUDF I-drops:

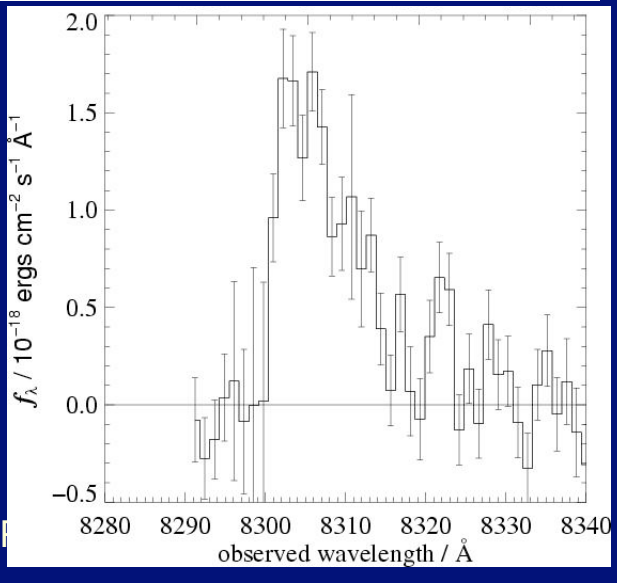
z'-J = -0.4±0.2, J-H = 0.1±0.3



Winds and Outflows



(work very much in progress)



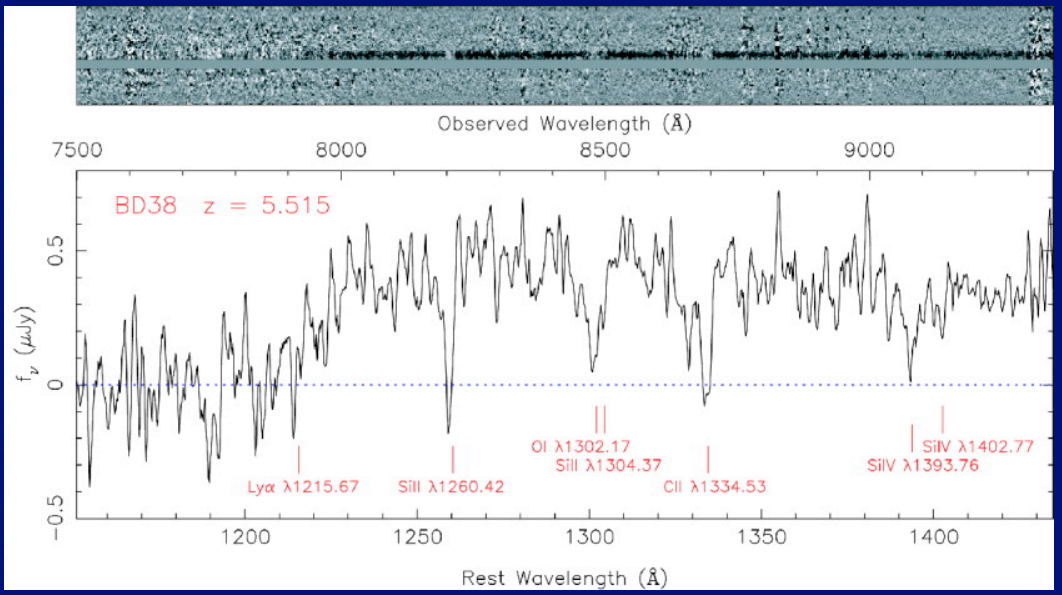
z=5.78, L* I-drop

- Ly-α, wind and interstellar lines can be seen in stacked or lensed data.
- The Lyman-α line is characteristically asymmetric
- Lyman-α is redshifted with respect to nebular emission lines

⇒ Lyman-α is heavily absorbed

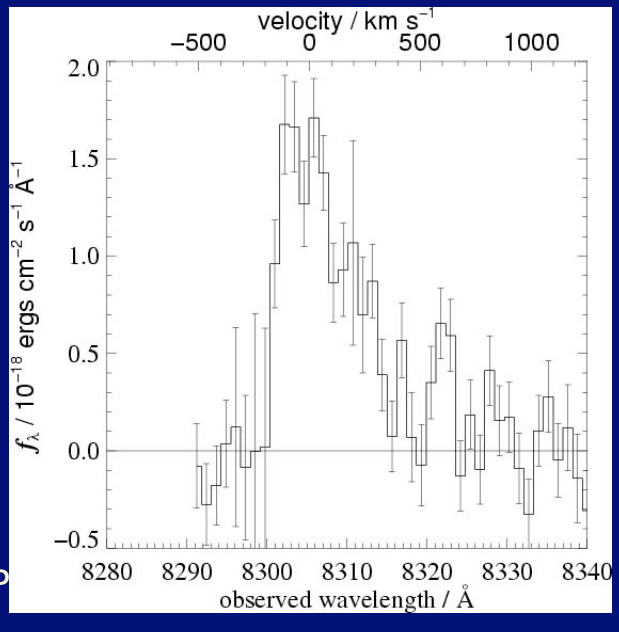
⇒ The galaxy is driving outflows

Winds and Outflows



z=5.5, 6L*

Dow-Hygelund et al 2005



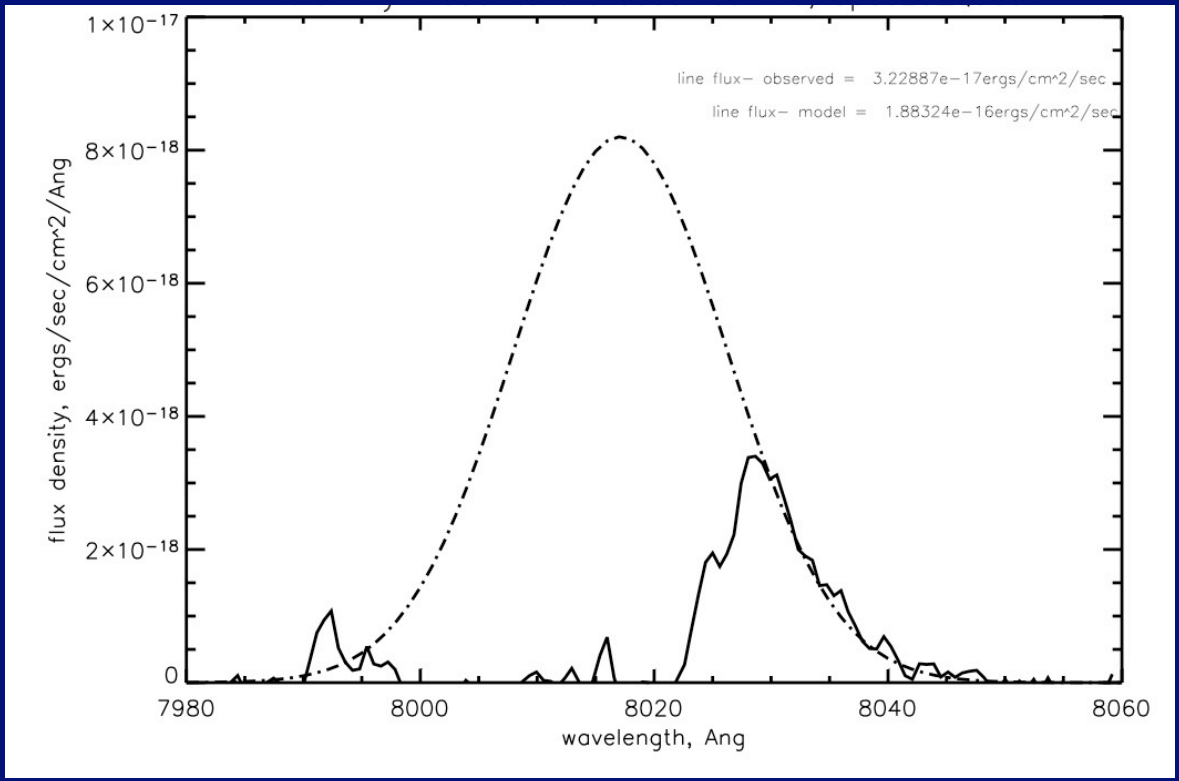
z=5.78, L* I-drop

- The Lyman-α line is characteristically asymmetric
- Lyman-α is redshifted with respect to nebular emission lines
- The interstellar medium is blue-shifted with respect to nebular emission lines

⇒ Lyman-α is heavily absorbed

⇒ The galaxy is driving outflows

Winds and Outflows



z=5.60

Δv~400 km/s

17% of Lyα transmitted

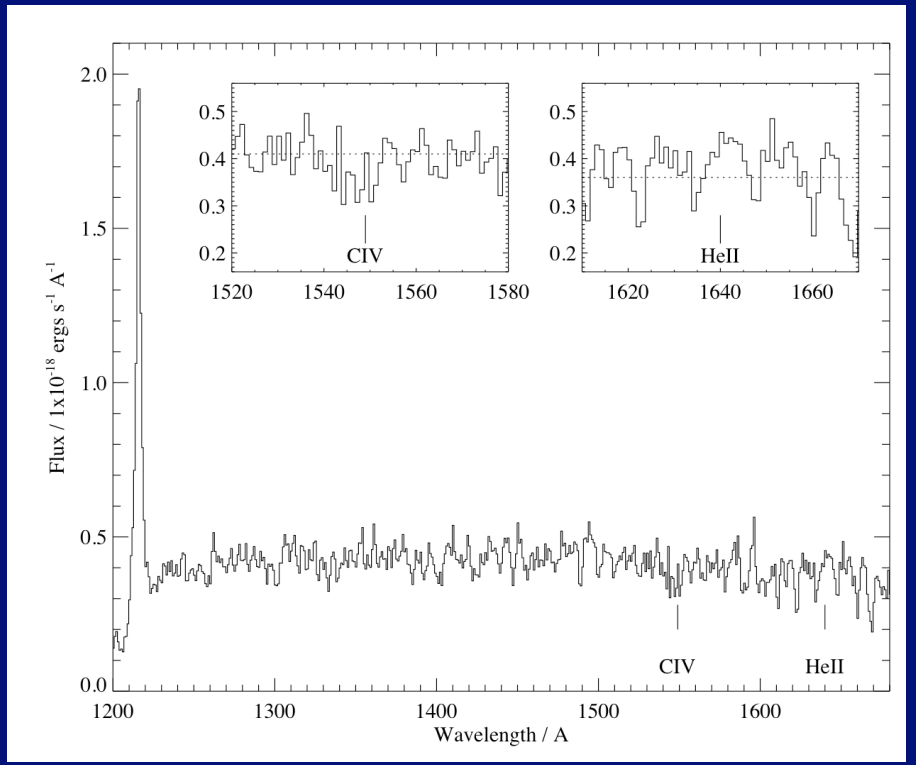
Davies, Bremer, Stanway et al (in prep)

- Fitting Dijkstra et al 2007 models at known redshift
- Using Verma et al 2007 SED fitting results as input galaxies
- Find Lyman-α flux is suppressed by a factor of 5-10 in z~5 galaxies => EWs> 200A

Constraints on Massive Stars at High Redshift

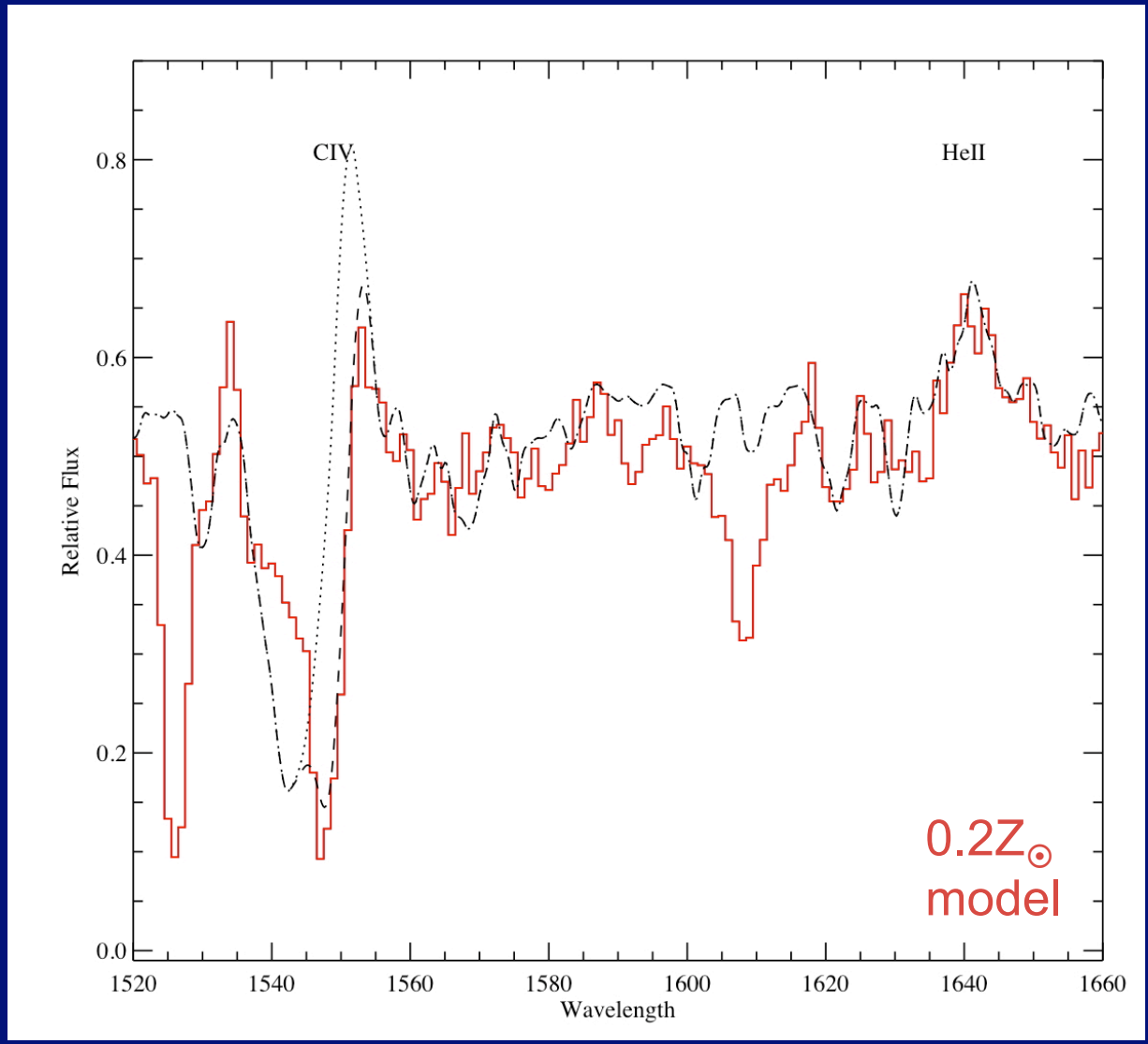
- Stack of 49 Lyman-α emitting LBGs with spectra to 1660A
- <z>=4.7
- W_0(HeII) < 2.7Å (3σ)
- HeII /Lyα < 8% (c.f. 11% at z=3)
- New models for WR stars (including binaries) provide reasonable fit for *z*=3 emission line
- Fit is only weakly sensitive to metallicity

Stanway, Eldridge et al, in prep



=> No strong evidence for Pop III at z~5

Fitting the HeII line at z~3



Stack of ~900 LBGs from Shapley et al 2003

Kroupa IMF

A Top Heavy IMF?

- z>5 LBGs show very high Ly-α EWs
- Wind effects mean these are probably underestimates
- Even discounting Ly-α, rest-UV slopes are very blue
- Massive star signatures can be fit with a Kroupa IMF - but barely

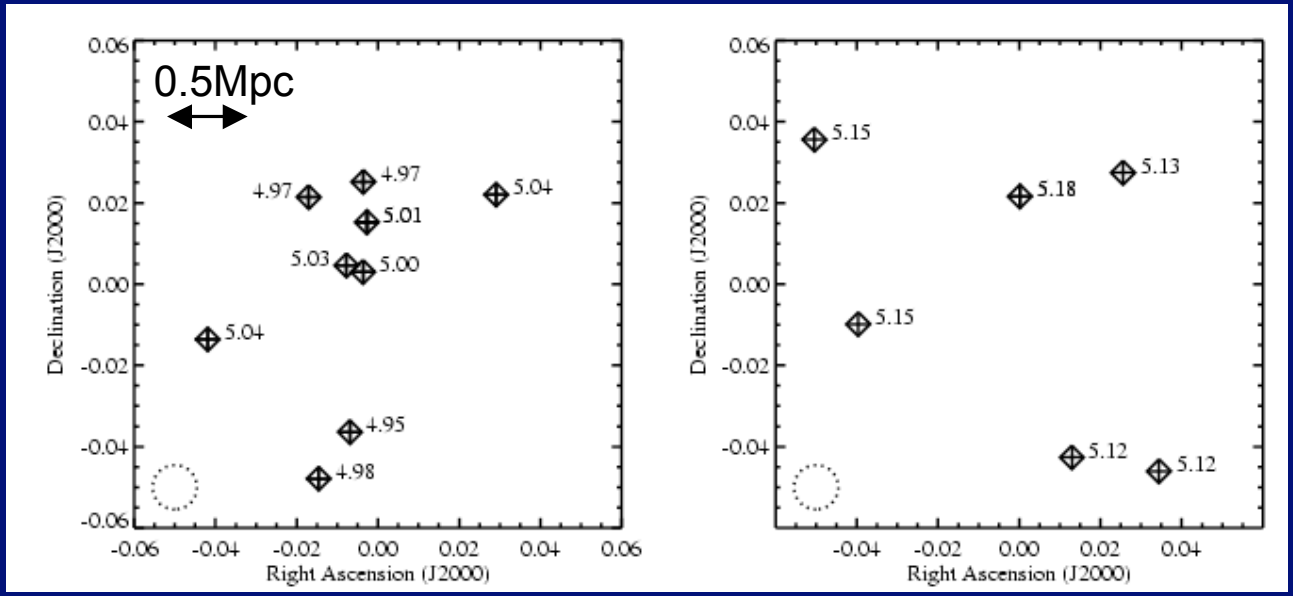
=> Are we seeing evidence for a top-heavy IMF at high-z?

Large Scale Structure at z>5

- LSS seen in both LAEs and LBGs

  (e.g. Douglas et al 08, Malhotra et al 05, Stanway et al 04, Wang et al 05, Zheng et al 06, Ota et al 08, Shimasaku et al 2003 ….)
- Structures on tens of Mpc scales
- Sources too far apart to be triggered bursts

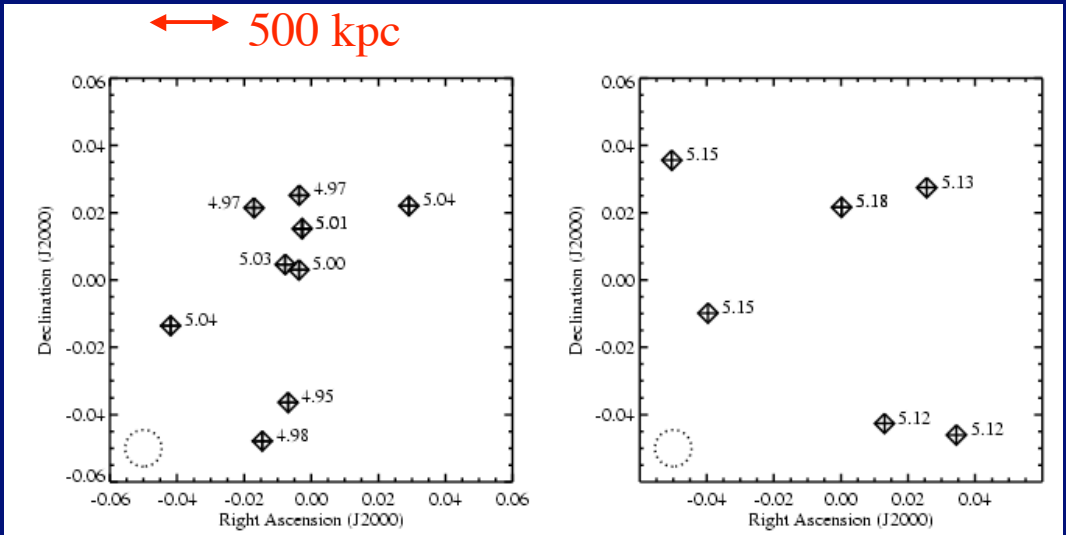
  => Marking out underlying UV-dark structures?

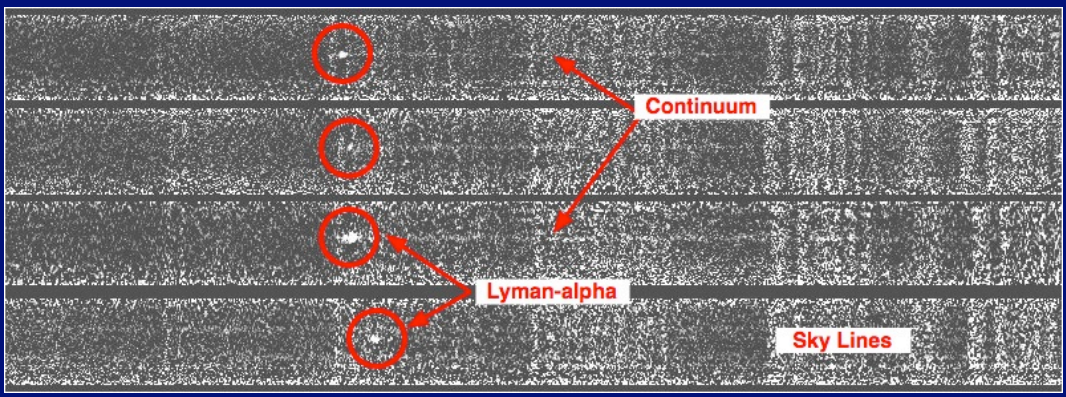


Structures from ERGS at z~5

(Douglas et al 2008)

Overdensities at z=5.00 and z=5.15





Examples of Lyman Break galaxy spectra in the z=5.00 field

- These structures may extend beyond the limits of the imaging fields
- One of the fields shows evidence for spatial as well as redshift clustering
- Redshift precision is better than 0.002
- The redshift spikes are not in skyline-free wavelength regions

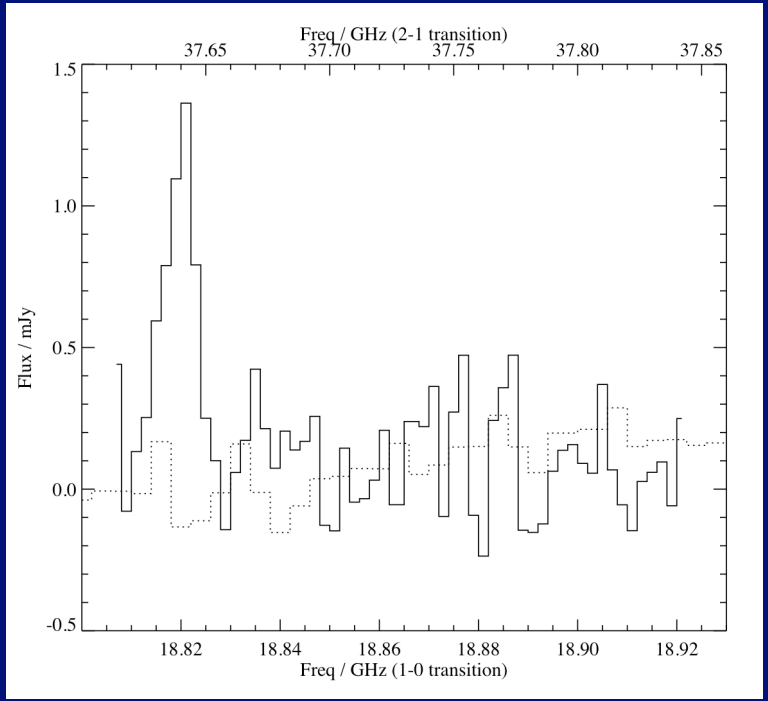
Tip of the Iceberg?

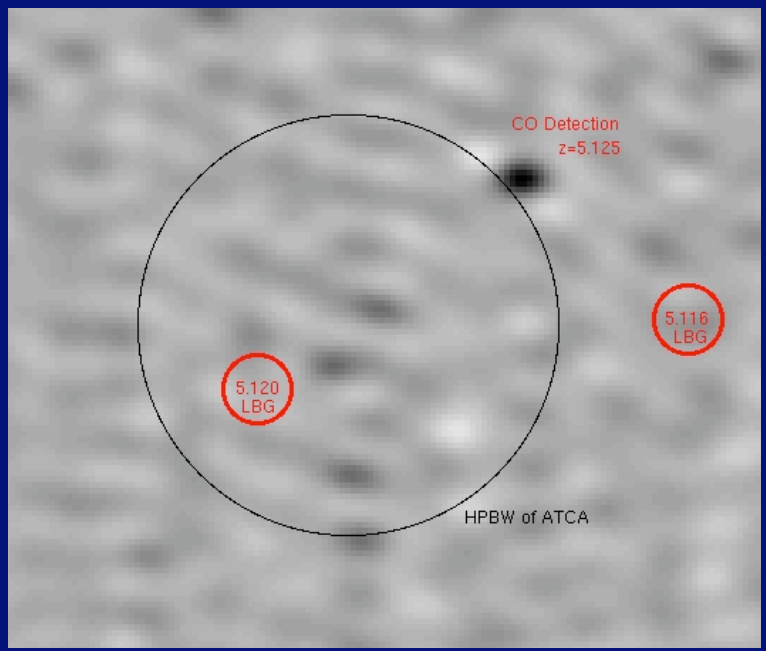
Everything seen at high-z so far is UV-luminous, so is this the tip of an iceberg?

- Clustering
- Duty Cycle
- Old stellar pops (Eyles et al, Yan et al, Verma et al, Stark et al)
- Metals and gas in QSO Hosts
- Metals in the IGM / early CIV enrichment

Cool Gas at High Redshift

- Pilot test
  - Single pointing
  - 24 hours at 12mm
  - 44 hours at 7mm
  - Bandwidth $\Delta z \sim 0.03$ (240 MHz)
  - Detection: CO(2-1) at z=5.125
  - LBGs in same field are not detected to sensitive limits.
  - Results still in analysis





Future Work

- Gas and Dust
  - Dust and radio continuum
  - CO, CII and other line emission
- mm / sub-mm work
  - most detected SMGs are at z<4, but is that still true at fainter limits?
- Large near-IR surveys (WFC3?)
- JWST
  - but will there be matching optical data?
- ELTs
  - Resolution + Sensitivity, but not area

Conclusions

- There is now sufficient spectroscopic data at z=5 and above to examine properties of statistical samples.
- These show anomalously blue colours and high Ly-α EWs.
- The AGN and Pop III contributions are likely to be small
- Possible evidence for a top heavy IMF?
- Clustering and stellar populations suggest that Lyman break galaxies are tracing large scale structure at high-z
- Preliminary results from the ATCA suggest that UV-dark material can be probed at mm wavelengths