z~6 Lyman Break Galaxies

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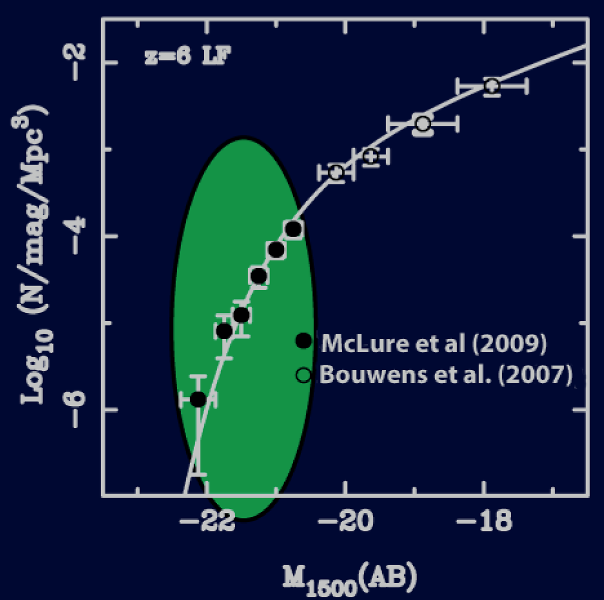
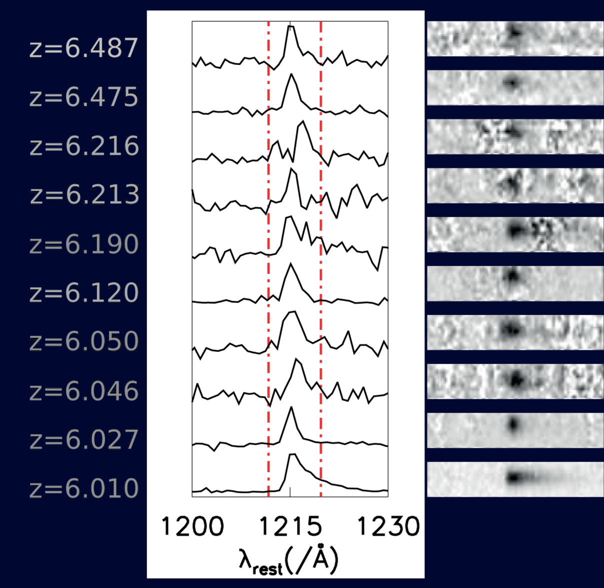
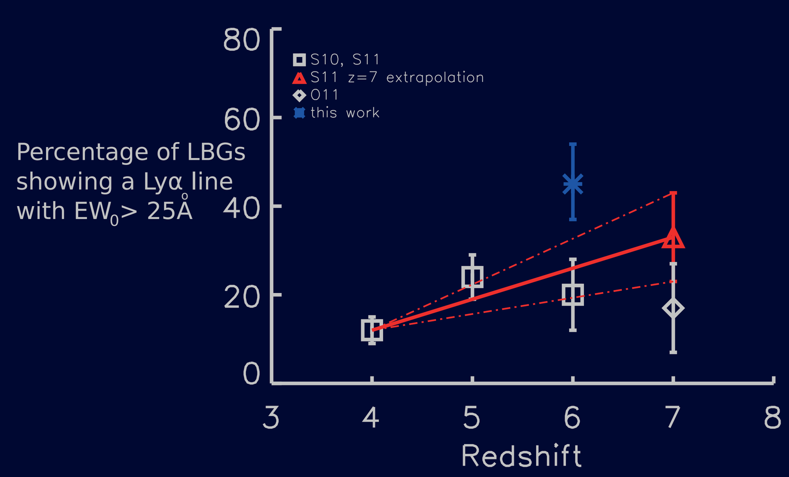
As tracers of neutral Hydrogen





14 galaxies were selected, using a photometric redshift technique (McLure et al., 2009), for spectroscopic follow up from the bright end ($L > 2L^*$) of the UV-luminosity function (top left) as part of the UDSz campaign. 10 of 14 targetted galaxies were spectroscopically confirmed (top right) providing strong vindication of the photometric redshift analysis used to define the original sample.

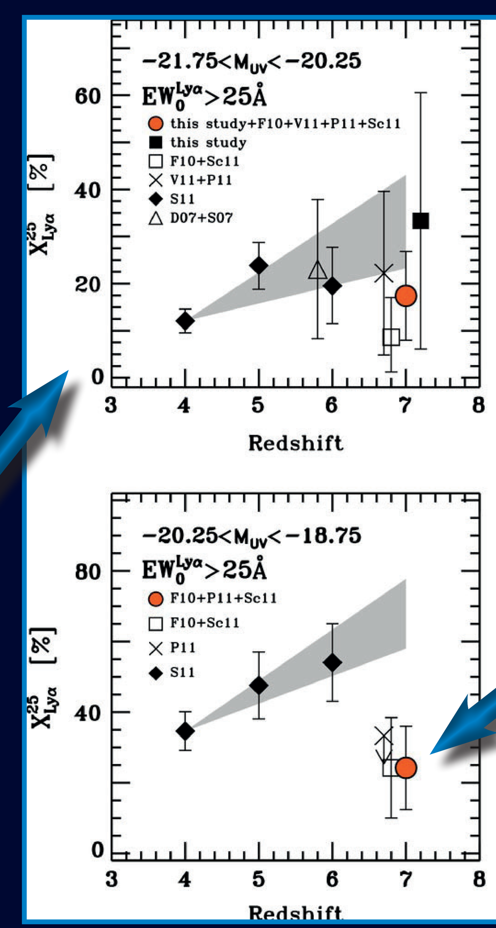
After careful consideration of the potential uncertainties and biases, we find that 40–50 per cent of our sample of $L \geq 2L^*$ galaxies at $6.0 < z < 6.5$ display strong Lyα emission (rest-frame equivalent width ≥25 Å), a fraction which is a factor of ~2 higher than previously reported at z~6. Our results suggest that, as the epoch of reionization is approached, it is plausible that the LAE fraction amongst luminous ($L \geq 2L^*$) LBGs shows a similarly sharp increase to that observed in their lower luminosity ($L \leq L^*$) counterparts.



UV luminous LBGs show higher fraction of strong Lyα emitters than previously measured (blue point).

Curtis-Lake et al. (2012)

The Ly α emitting fraction of LBGs



Ono et al. (2012)

The fraction of Lyman break galaxies showing strong Lyα emission (EW > 25Å) was measured over the redshift range 4<z<6 by Stark et al. (2011) with the view to tracking any intrinsic evolution within the population.

For fainter LBGs (bottom panel), the trend clearly shows an increasing fraction of strong Ly α emitters with increasing redshift. This is attributed to lower attenuation due to dust in higher redshift LBG samples.

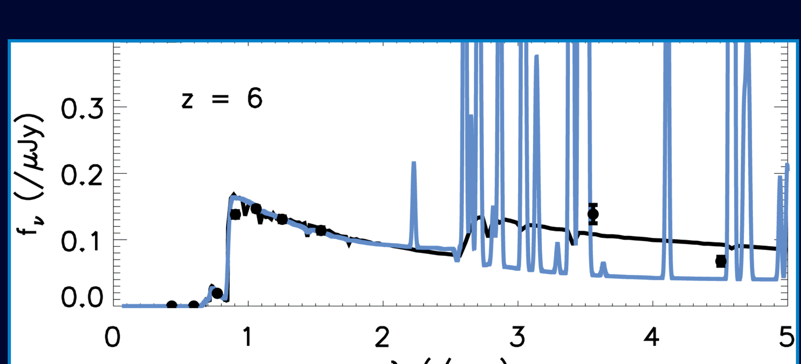
Recent results for samples at z~7 (Fontana et al., 2010, Pentericci et al., 2011, Schenker et al., 2012, Ono et al., 2012) indicate much lower observed Lyα EWs than the extrapolated trend from lower redshift. This is tentatively attributed to a higher fraction of neutral Hydrogen at z~7 than at z~6.

The results are not so clear for the brighter luminosity bin (top panel), yet our results (right box, Curtis-Lake et al., 2012) show a much higher fraction of strong Ly α emitters in the z~6 LBG population than previously measured. The wider area covered by the UDS survey allows for better sampling of the population at the very bright end than provided by previous studies.

The intricacies of Spectral Energy Distribution (SED) fitting at high redshift

Higher equivalent widths of nebular emission lines at high redshift mean that they can have a significant effect on broad-band photometry. At z~6, in particular, Hβ and [OIII] contribute to IRAC 3.6μm fluxes and Hα contributes to IRAC 4.5μm fluxes, allowing them to mimic a deep balmer-break (Schaerer et al., 2009 and see figure below).

This produces uncertainties in derived physical properties (mass and star-formation rate), with nebular models supplying smaller best-fit masses (see box to the right).

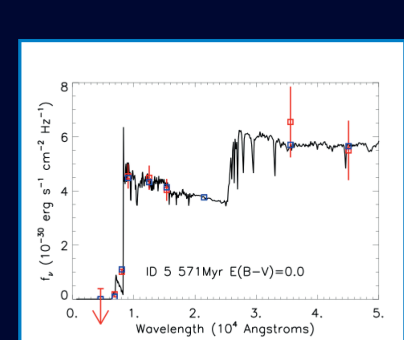


As galaxies in their own right

SED-fitting to 13 spectroscopically confirmed LBGs in the CANDELS fields (11 GOODS-S, 2 UDS) using HST ACS (Subaru) optical data, CANDELS WFC3 near infrared and archival (SEDS) Spitzer data in GOODS-S (UDS). We performed SED-fitting with three different template sets: a wide range of smoothly varying SFHs (burst, exponentially decreasing, constant, exponentially increasing); more general two-compoent models (burst + recent star formation); two component models with nebular emisison (single escape fraction of ~ 0.2). Each template set samples a coarse grid of metallicities and allows for reddenning with the Calzetti et al. (2000) extinction law.

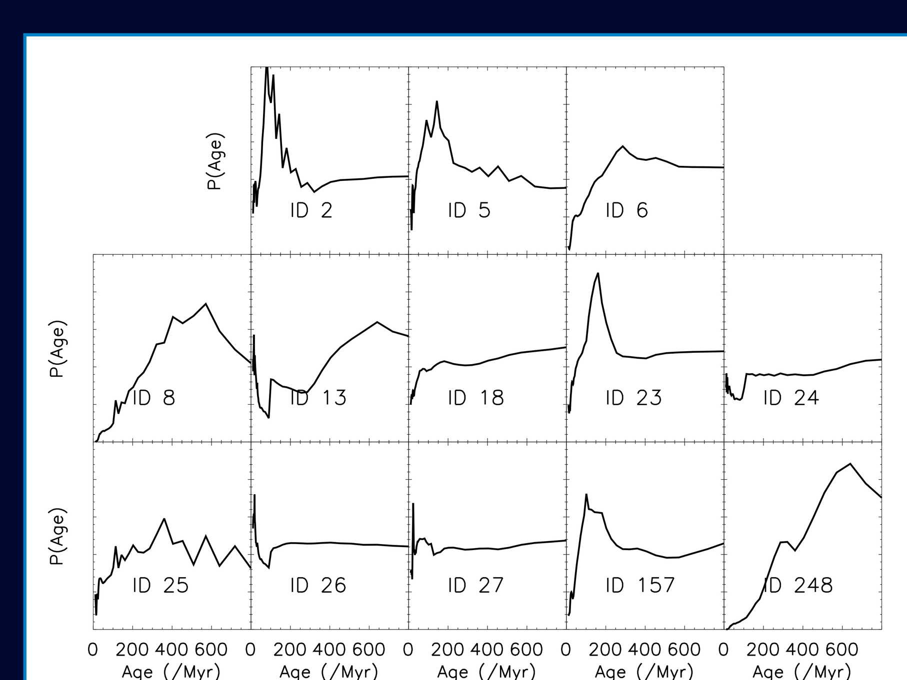
Ages:

A combination of near-infrared (near-IR) and Spitzer Infrared Array Camera (IRAC) observations have shown that many high-redshift (z ≥ 5) Lyman break galaxies (LBGs) have red rest-frame ultraviolet (UV)–optical colours (e.g. Eyles et al. 2005). If this red colour is taken to indicate the strength of the Balmer break, then old stellar ages (>300 Myr) are inferred for these objects, indicating a formation redshift at z>8.



If we restrict our template set to a single metallicity, few star-formation histories and no reddening, we also fit old ages to these galaxies.

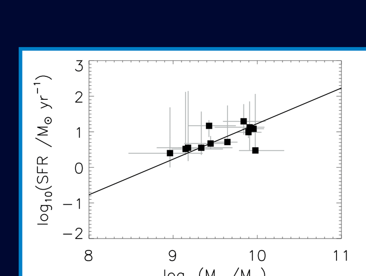
These results are dependent on chosen star formation history (SFH) of templates and whether or not they include nebular emission.



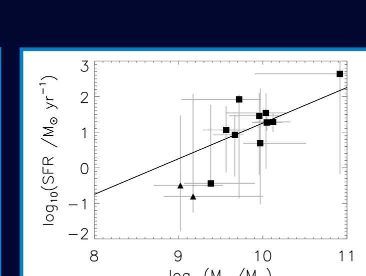
Allowing for more general SFHs (two component models), reddening and nebular emission, however, the full probability distribution functions show that we do not *require* very young or very old ages to fit to the observed SEDs (above).

Curtis-Lake et al. (2013)

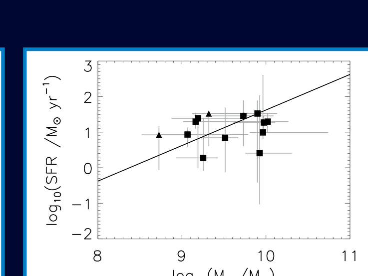
Specific Star-formation Rates:



Median sSFR ~ 2Gyr^{-1} all smoothly-varying SFHs



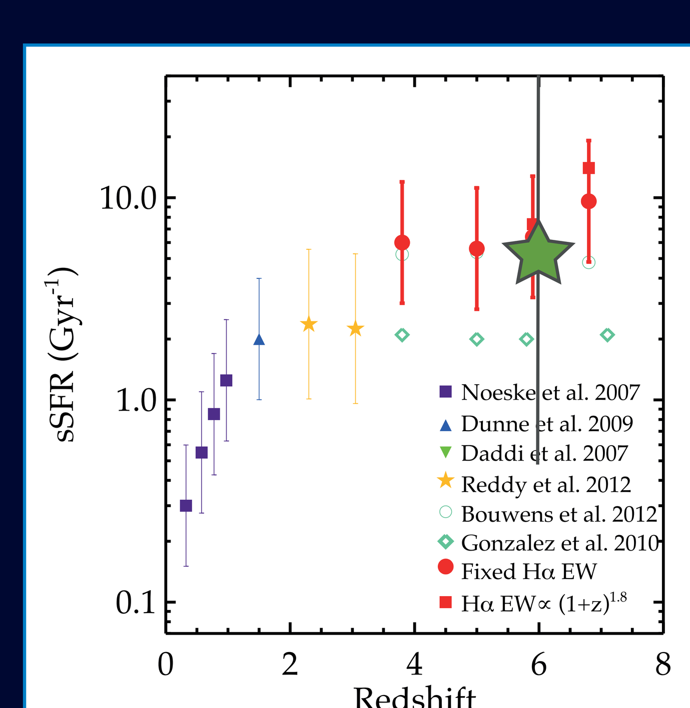
Median sSFR ~ 2Gyr^{-1} two component SFHs



Median sSFR ~ 4Gyr^{-1} two component SFHs with nebular emission.

More general SFH (two component models) show more scatter in SFR vs. mass plot but similar median sSFR ~ 2 Gyr^{-1}. Allowing for nebular emission in the models gives lower best-fit masses by ~1.8 dex, giving a correspondingly higher median sSFR of ~4 Gyr^{-1}.

In context (right): previously measured flat sSFR from $4 < z < 6$ provides tensions with models that predict a rising sSFR to higher redshifts. Allowing for nebular emission, however, can go some way to alleviating this tension (Stark et al., 2013, right (fig. 9), see also de Barros et al., 2012). Our results (green star and balck error bar) are in good agreement, although with a small, heterogeneous sample, we have little constraining power.



Stark et al. (2013)

References

• Curtis-Lake + 2012, MNRAS, 422, 1425 • Curtis-Lake + 2013, MNRAS, 429, 302 • Eyles + 2005, MNRAS, 364, 443 •
• Fontana + 2010, ApJ, 725L, 205 • McLure + 2009, MNRAS, 395, 2196 • Ono + 2012, ApJ, 774, 83 •
• Pentericci + 2011, ApJ, 743, 132 • Schaerer + 2009, A&A, 502, 423 •
• Schenker + 2012, ApJ, 744, 179 • Stark + 2011, ApJ, 728, L2 • Stark + 2013, ApJ, 763, 129 •

CANDELS papers: • Grogin + 2011, ApJS, 197, 35 • Koekemoer + 2011, ApJS, 197, 36 •

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