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High Equivalent Width of Hα+[N II] Emission in $z \sim 8$ Lyman-break Galaxies from IRAC 5.8μm Observations: Evidence for Efficient Lyman-continuum Photon production in the Epoch of Re-ionization

ABSTRACT

We measure, for the first time, the median equivalent width (EW) of Hα+[N II] in star-forming galaxies at $z \sim 8$. Our estimate leverages the unique photometric depth of the *Spitzer*/IRAC 5.8μm-band mosaics (probing $\approx 5500-7100$Å at $z \sim 8$) of the GOODS Reionization Era Wide Area Treasury from Spitzer (GREATS) program. We median stacked the stamps of 102 Lyman-break galaxies in the 3.6, 4.5, 5.8 and 8.0μm bands, after carefully removing potential contamination from neighbouring sources. We infer an extreme rest-frame $\mathrm{EW_0(H\alpha+[N\ II])} = 2328^{+1326}_{-1127}$ Å from the measured red [3.6]−[5.8] $= 0.82 \pm 0.27$ mag, consistent with young ($\lesssim 10^7$ yr) average stellar population ages at $z \sim 8$. This implies an ionizing photon production efficiency of $\log \xi_{\mathrm{ion,0}}/\mathrm{erg\ Hz^{-1}} = 25.97^{+0.18}_{-0.28}$. Such a high value for photo production, similar to the highest values found at $z \lesssim 4$, indicates that only modest escape fractions $f_{\mathrm{esc}} \lesssim 0.3$ (at 2σ) are sufficient for galaxies brighter than $M_{\mathrm{UV}} < -18$ mag to re-ionize the neutral Hydrogen at $z \sim 8$. This requirement is relaxed even more to $f_{\mathrm{esc}} \leq 0.1$ when considering galaxies brighter than $M_{\mathrm{UV}} \approx -13$ mag, consistent with recent luminosity functions and as typically assumed in studies addressing re-ionization. These exceptional results clearly indicate that galaxies can be the dominant source of reionizing photons, and provide us with an exciting glimpse into what we might soon learn about the early universe, and particularly about the Reionization Epoch, from forthcoming *JWST*/MIRI and NIRCam programs.

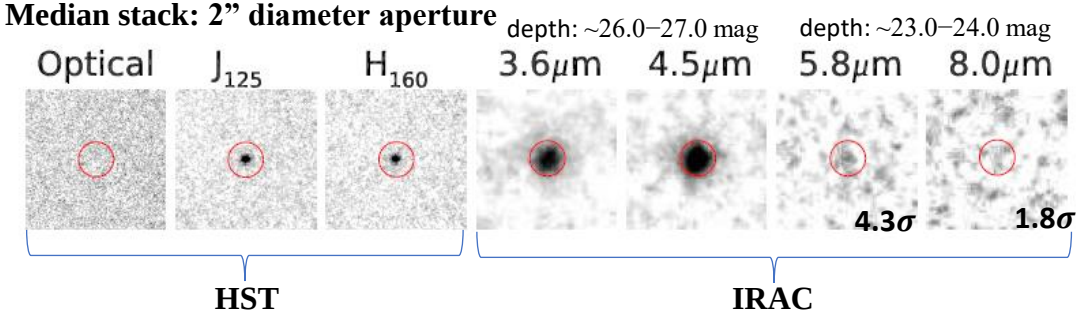
Constraining **Hα at z > 6** is quite challenging:

1. The flux densities in both the IRAC 3.6 and 4.5μm bands are enhanced by nebular emission lines. **Continuums or Emission lines ?**
2. Still unconstrained line ratios at these early epochs

At 7.0 < z < 8.7, [O III]+Hβ and Hα+[N II] drop into 4.5 and 5.8μm band, respectively. However, 5.8μm band suffer from lower sensitivities.
Solution: Combining the imaging available for samples of galaxies, and extracting their average properties.

Sample: 102 candidate LBGs at $7.3 < z_{phot} < 8.7$, Y−dropout (Bouwens et al. 2015b)

Median stack: 2" diameter aperture



Stacking:
Excluding neighboring objects by **Mophongo** (Labbe et al. 2006);
For IRAC imaging, stacking was done after exluding neighbours.

Table 2. Flux densities for our median-stacked photometry

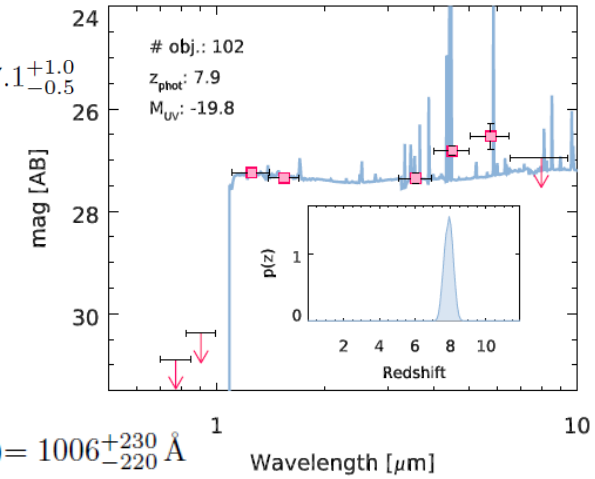
	V_{606} (nJy)	i_{775} (nJy)	z_{850} (nJy)	J_{125} (nJy)	H_{160} (nJy)	3.6μm (nJy)	4.5μm (nJy)	5.8μm (nJy)	8.0μm (nJy)
Stack	-0.4 ± 0.7	-0.5 ± 0.8	-1.3 ± 1.3	46.0 ± 2.4	41.8 ± 1.7	41.5 ± 3.9	68.0 ± 5.4	88.5 ± 20.3	56.3 ± 30.0

NOTE—We only list the flux densities in those bands available for at least 90% of the sources in our sample.

The aperture photometry was corrected to total using the median of the PSFs
Correction factors are 2.2, 2.2, 2.9 and 3.3 for the 3.6, 4.5, 5.8 and 8.0μm bands.

SED fitting result: (FAST)

$M_\star = 10^{8.12^{+0.86}_{-0.28}} M_\odot \quad A_V = 0.2^{+0.1}_{-0.2}$ mag $\quad \log(\mathrm{age/yr}) = 7.1^{+1.0}_{-0.5}$



Color:

1. The [3.6] − [5.8] = 0.82 ± 0.27mag

→ $\mathrm{EW_0(H\alpha+[N\ II])} = 2328^{+1326}_{-1127}$ Å

→ $\mathrm{EW(H\alpha)} = 1960^{+1089}_{-927}$ Å

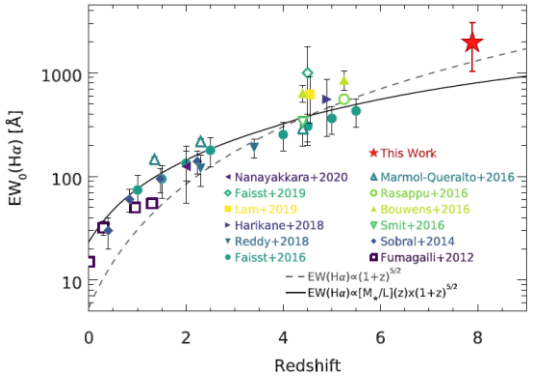
$\log(L_{\mathrm{H}\alpha}/[\mathrm{erg\,s^{-1}}]) = 42.62^{+0.15}_{-0.23}$ $\quad \mathrm{SFR} = 36^{+14}_{-15} M_\odot \mathrm{yr^{-1}}$

The first detection of Hα from broad-band photometry in normal star-forming galaxies at z > 6.5

2. The [3.6] − [4.5] = 0.54 ± 0.13mag → $\mathrm{EW_0([O\ III]+H\beta)} = 1006^{+230}_{-220}$ Å
Hα is very strong in these z~8 LBGs

3. The J − H = −0.10 ± 0.07mag → β ~ -2.4, blue UV slope

Evolution of the EW(Hα):

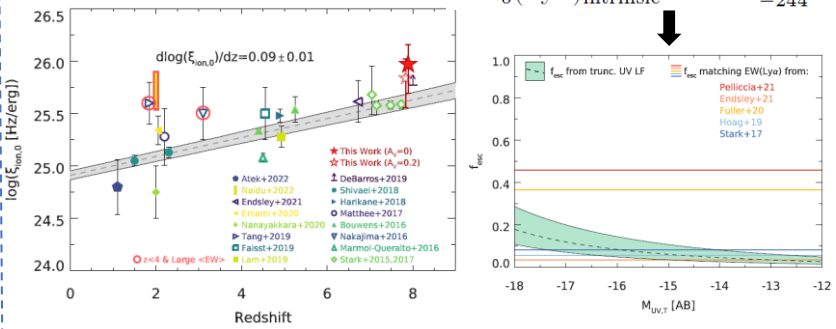


Overall agreement, but 1σ above the expected values from sSFR ∝ $(1+z)^{5/2}$ (Dekel et al. 2013) → Personal comment: bias from 10 very bright sources in the COSMOS and UDS fields

Implications on reionization:

$\xi_{\mathrm{ion}} = \frac{\dot{N}_{\mathrm{ion}}}{L_{UV}}\ [erg^{-1}\ Hz]$ $\quad L(H\alpha)\ [erg\ s^{-1}] = 1.36 \times (1 - f_{esc})\ 10^{-12}\ \dot{N}_{\mathrm{ion}}\ [s^{-1}]$

$\dot{N}(H^0) = \rho_{\mathrm{UV}} \xi_{\mathrm{ion}} f_{\mathrm{esc}}$ $\quad \mathrm{EW_0(Ly\alpha)_{intrinsic}} = 517^{+287}_{-244}$ Å



Escape fractions f_{esc} ~ 10% are sufficient for star-forming galaxies to fully ionize the neutral H at z ~ 8 through escaping LyC radiation.