Three perspectives on the physical properties of Ly$\alpha$-emitting galaxies

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AST 592 Journal Club
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The papers:

- Lai et al., 2008 (henceforth L08)
  - Age, SFR and mass, dust extinction of 76 IRAC detected and undetected LAEs from Gronwall’s (henceforth Gr07) sample of 162 LAEs at z ~ 3.1

- Gawiser et al., 2007 (henceforth Ga07)
  - Correlation length, bias, number density, mass, SFR, dust extinction and age of Gronwall’s sample of 162 LAEs at z ~ 3.1

- Pentericci et al., 2009 (henceforth P09)
  - EW, mass, SFR, dust extinction, age and FWHM of 68 LBGs with Ly\(\alpha\) emission at redshifts between ~ 3.5 and ~ 6
Quick primer on LAEs and LBGs

**LAEs**
- Detected via narrowband imaging - require large ratio of Ly$\alpha$ flux to continuum flux
- Ly$\alpha$ line (1216 Å) redshifted to optical window for $z \sim 2 \rightarrow \sim 7$

**LBGs**
- High redshift galaxy is detected in broadband filters redward of Lyman break but is not detected blueward of Lyman break
- Lyman break at rest frame 912 Å

Some (not well understood) overlap between the two high redshift galaxy populations!
GR07 Sample

- MOSAIC II CCD Camera on CTIO Blanco 4m
- 28.17 hrs in ECDF-S
- 998 arcmin²
- Narrowband filter = \( \lambda_{5000} \) filter, FWHM = 50 Å
- \( z \sim 3.091 \) to \( z \sim 3.132 \)
- Broadband image = MUSYC B+V image

- 259 LAE candidates selected (line - continuum \( \leq -1.03 \), visual inspection)
- 162 candidates below completeness limit
- 52 candidates with large enough S/N in spectra to determine redshift
- All 52 at \( z \sim 3.1 \)
- 2 candidates with x-ray detections

Final Sample of 160 LAE candidates (excludes 2 possible AGN)

![Figure 5](from Gronwall et al., 2007, ApJ, 667, 79)
L08 Sample

Start with 162 Gr07 LAEs:
- Only uncontaminated sources (≥4” radius) → 76 LAEs
- Separate into IRAC 3.6μm detected and undetected sources
  → 52 undetected, 24 detected
- X-ray detected LAE rejected → 23 detected
- 18 detected in most conservative sample (excluding outlying red/possibly dusty objects)

Investigate average properties by stacking detected and undetected samples (stacks in IRAC and optical/nir bands)

UBVRIzJK images from MUSYC Collaboration (Gawiser et al., 2006a)

Fit with BC03 SPS models with Salpeter IMF → yields ages and masses, SFR, dust
Ga07 Sample

- **Start with 162 Gr07 LAEs:**
  - Only use 159 LAEs w/o x-ray detections
  - Clustering analysis with angular correlation function estimator (Landy and Szalay, 1993) using entire sample of 59 Gr07 LAEs
    - yields correlation length, bias factor, halo masses, density, and Halo occupation
  - Fit two-population Maraston SPS models (Salpeter IMF, Calzetti dust law) to stacks of 52 IRAC undetected LAEs
    - yields mass, SFR, dust extinction, age of dominant population
P09 Sample

Start with z detected sample of galaxies from GOODS-MUSYCY Survey in GOODS south field:

- Use B, V, i dropout criteria of Giavalisco et al. (2004) to define LBGs at redshifts 3.5-4.5, 4.5-5.5, ≥5.5
- Remove known AGNs
- Keep only LBGs with spectroscopic observations
- Finally, keep only LBGs with Lyα emission (68 LBG+LAE)

\[
\begin{align*}
(B_{450} & \; V_{606}) \geq 1.2 \quad 1.4 \times (V_{606} \; z_{850}) \land \\
(B_{450} & \; V_{606}) \geq 1.2 \land (V_{606} \; z_{850}) \leq 1.2,
\end{align*}
\]

\[
\begin{align*}
[(V_{606} \; i_{775}) > 1.5 \quad 0.9 \times (i_{775} \; z_{850})] \lor \\
[(V_{606} \; i_{775}) > 2.0] \land (V_{606} \; i_{775}) \geq 1.2 \land \\
(i_{775} \; z_{850}) \leq 1.3,
\end{align*}
\]

\[
(i_{775} \; z_{850}) \geq 1.3
\]

- Characterize EW, FWHM and line flux of Lyα
- Use BC03 and CB07 (Calzetti/SMC for dust, Salpeter IMF) models on individual galaxy SEDs to extract SFR, age, mass, and dust extinction

Fig. 1. The redshift distribution of LBG galaxies in our sample: blue are the B dropouts, red are the V dropouts and green are the i-dropouts (see text for details).
L07 Results

- R - m_{3.6} color to probe stellar pop. age
- Average undetected color ~ 0, detected color ~ 1.2
- As UV-NIR color approaches zero, UV mag getting smaller, hence UV getting brighter
- 0 < 1.2 means undetected are more UV bright
L07 Results continued…

**SED Fitting Results (constant SFR, Z_⊙)**

- Detected have higher mass, SFR, age
- Undetected have higher specific SFR (SFR/unit mass)
- Detected LAEs represent more massive, more luminous, older end of LAE spectrum

**Conclusions:**

LAE properties lie on a continuum

Observations could support hypothesis of multiple periods of Lyα emission in galaxies

IRAC Detected LAEs occupy faint blue end, and low mass end of LBG spectrum
Ga07 Results continued…

SED fitting Results:

- Best fit includes underlying old population (2 Gyr)
- Could be fit with 100% mass in one population though (age 60-350 Myrs)

Dust extinction = Calzetti, IMF=Salpeter
Ga07 Results continued…

**Conclusions:**

- LAEs appeared to be observed during starburst
- Old population could be evidence of merger history
- Much lower SFR, age, mass, dust extinction than LBG pop at $z \sim 3.1$ (Shapley et al., 2001)
  - Much lower SFR, age, mass, dust extinction than DRG population (Webb et al., 2006 and others)
  - Similar to dim LBGs at $z \sim 5$ (Verma et al., 2007)
- Analysis of MilliMillenium merger simulations indicates LAEs at 3.1 may be beginning of evolution to $L^*$ galaxies today
P09 Results

**Equivalent Width Distribution**
- Average EW less than Finkelstein (2007) sample (z ~ 4.5)

**Age Distribution**
- 50% of sample have ages ≤ 300Myr
- Significant fraction have old ages (700Myr - 1.5Gyr)
- Ages determined from best fit and probability distribution function
- Clearly not all LAEs can be primordial galaxies

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Average EW slightly less than Gr07 sample
P09 Results continued…

Stellar Mass

- Mean best fit = $6 \times 10^9 M_\odot$, range is $10^9 - 10^{11} M_\odot$
- Larger than typical LAEs ($10^6-10^9 M_\odot$) (Gawiser, Finkelstein, Pirzkal ($z \sim 3.1, 4.5, 5$ respectively))
- All w/ EW over 80 Å have lower masses

SFR from Lyα luminosity and UV luminosity:

- Range few - few tens of $M_\odot$ yr$^{-1}$
- Agrees with Tapken (2007) LBG+LAE sample and with LAEs at 5.7 (Ajiki, 2003)
- Looks slightly higher than solely LAE samples

$$SFR = 7.9 \times 10^{-42} L_{H_\alpha} M_\odot \text{ yr}^{-1}, \quad L_{Ly\alpha} = 8.7 \times L_{H_\alpha}$$

$$SFR_{UV} = 1.4 \times 10^{-29} L \ M_\odot \text{ yr}^{-1}, \quad L_\nu \text{ is the luminosity at rest-frame 1400 Å}$$
Dust

- Best fit values of $A_v$ are modest
  - non-zero in 2/3 of sample
  - Range is 0 - 1, mean is .25
- Larger extinction $\rightarrow$ smaller EW
- LAEs can’t all be primordial, dust-free galaxies!

**Conclusions:**

- Spectrum of LBG+LAE properties
- There are old and massive LAEs
- Masses and ages of LBG+LAE sample consistently larger than LAE samples
- SED fit of some LAEs requires dust
- Stacked photometry studies can/do miss some of part of the spectrum of these properties
<table>
<thead>
<tr>
<th></th>
<th>AGE</th>
<th>MASS</th>
<th>SFR</th>
<th>DUST</th>
<th>COMMENTS</th>
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<tbody>
<tr>
<td><strong>L08</strong></td>
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<tr>
<td>18 IRAC detected</td>
<td>1600 Myr</td>
<td>$9 \times 10^9$ $M_\odot$</td>
<td>$6 \ M_\odot \text{ yr}^{-1}$</td>
<td>0.0</td>
<td>High mass, age, SFR end of LAEs</td>
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<tr>
<td>LAEs (stacked)</td>
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<td>Blue faint end of LBGs</td>
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<td>Maybe second/recurrent Ly-alpha phase</td>
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<tr>
<td>52 IRAC undetected</td>
<td>160 Myr</td>
<td>$3 \times 10^6$ $M_\odot$</td>
<td>$2 \ M_\odot \text{ yr}^{-1}$</td>
<td>0.0</td>
<td>Low mass, low SFR, low age end of LAEs</td>
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<tr>
<td>LAEs (stacked)</td>
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<td>High specific SFR</td>
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<td>Maybe initial Ly-alpha phase, primordial</td>
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<td><strong>Ga07</strong></td>
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<tr>
<td>52 IRAC undetected</td>
<td>20 Myr</td>
<td>$1 \times 10^9$ $M_\odot$</td>
<td>$2 \ M_\odot \text{ yr}^{-1}$</td>
<td>0.0</td>
<td>Two population fit produces younger age</td>
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<td>LAEs (stacked, two pop.)</td>
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<td>LAEs can have underlying old population</td>
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<td>These LAEs have potential to be L $\leq 2.5L^*$ galaxies at z=0</td>
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<td><strong>P09</strong></td>
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<td>68 LBGs+LAE</td>
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<td>Most clearly shows spectrum of LAE properties</td>
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<td>(individually fit)</td>
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<td>Individual fits are best to tease out full spectrum</td>
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<td>50% less</td>
<td>$10^9$ $M_\odot$ - $10^{11}$ $M_\odot$</td>
<td>Few-few tens $M_\odot \text{ yr}^{-1}$</td>
<td>Range is 0-1</td>
<td>Not all LAEs can be dust free</td>
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<td>than 300 Myr Old pop. With 700Myr-1Gyr</td>
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<td>Mean is .25</td>
<td>LBG+LAE population is older, more massive than LAEs</td>
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