Probing the earliest galaxies and reionization with deep spectroscopy

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First Galaxies, Ringberg, 27/06/2011
Why do we need spectroscopy?

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Neutral Hydrogen in IGM Scatters Lyα Photons

- Lyα line is weakened by neutral hydrogen in the intergalactic medium
- The fraction of strong Lyα emitters within LBG population should decrease as observations probe the reionization era.

This technique can constrain reionization immediately with current facilities
Lyα Emitter Luminosity Function


- Decrease in number of Lyα emitting galaxies over just 150 Myr

- Little evolution seen in LF over 1 Gyr spanning 3.1<z<5.7 (Ouchi et al. 2008)

- Signal of increased neutral HI fraction?
Interpreting Decline in LF


- Evolution in dust?
- changing stellar populations?
- Structure and kinematics of HI?
- Number density evolution of galaxies?
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Must extend to z>7 & understand galaxy evolution
Studying Ly$\alpha$ Emission within LBG Population

Large, robust samples to $z \sim 8-9$ with Similarly faint continuum magnitudes.
Studying Lyα Emission within LBG Population

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UV continuum properties (luminosity, slope) already known
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Spectroscopy reveals Ly\(\alpha\) (or its absence) and evolution of neutral gas kinematics.
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Spectroscopy reveals Lyα (or its absence) and evolution of neutral gas kinematics.

Evolution in EW distribution not affected by number density evolution
Keck+VLT spectroscopy of $3 < z < 6$ LBGs

Stark et al. 2010, Stark et al. 2011 (see also Vanella et al. 2009)

~650 spectra of $3 < z < 6$ LBGs, 6-12 hr exposures
Lyα Emission in faint galaxies

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<th>Keck/DEIMOS</th>
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Faint galaxies frequently have high S/N Lyα!
The Lya Fraction in LBG samples

Lya fraction greater in low luminosity LBGs.

Reflects lower dust content?

Younger stellar populations?

Stark et al. 2010
Dust Governs Escape of Ly\(\alpha\) Radiation

**Stark et al. 2010**

- Strong Ly\(\alpha\) emitters tend to have bluer UV slopes
- Low luminosity galaxies less obscured, more Ly\(\alpha\) than luminous systems
- Galaxies less obscured at \(z \sim 6\) than at \(z \sim 3\), higher Lya fraction?

**Bouwens et al 2009**

![Graph showing the relationship between dust extinction and UV luminosity.](image)

Limiting Luminosity
- \(> 0.3L^*\)
- \(> 0.04L^*\)
- \(> 0\)

Systematic Error

![Graph showing the decrease in dust extinction factor with increasing redshift.](image)
Evolution of Lyα Line Profiles

- Line profile becomes more asymmetric at earlier times.
- Lower fraction of line luminosity escapes at $z \sim 6$ than $z \sim 3$
- IGM effects transmission even when fully ionized
Redshift dependence of Ly\(\alpha\) emission

\(~50\%\) of \(z\sim6\) LBGs have strong Ly\(\alpha\) emission.

Increased fraction of Ly\(\alpha\) emission at higher redshift.

Suggests Ly\(\alpha\) emission should be detectable in \(z>7\) galaxies.

Spectroscopy of WFC3 LBGs at $6<z<8$

Schenker, DPS, RSE et al. 2011

12 hours on 8 targets with Keck/LRIS

2-6 hours on 11 sources with NIRSPEC

Include 7 VLT/HAWK-I selected objects studied by Fontana et al.

Absolute magnitudes span similar range as our control sample at $z\sim6$
Difficulty in Extending Method to $z>7$

Photometric redshift distributions span larger range than covered by single NIR filters.

Object-by-object at $z>7$

$OH$ sky lines reduce completeness.

*Spectroscopic study at $z>7$ still quite inefficient!*
A New Era: Redshift Confirmation at $z \sim 7$

2 Ly$\alpha$ detections at $z > 6.4$, 1 marginal candidate.

rest-frame $\text{EW} > 50$ Å

$z = 5.28$ source is serendipitous, corresponds to faint $V$-band dropout near $z \sim 7$

LBG
Galaxies with and without Ly$\alpha$ have blue rest-frame colors

Compact morphology

Photometry is best-fit with Ly$\alpha$ emission.
Evolution in Lya emission at $z \sim 7$

Schenker, DPS, RSE et al. 2011

Assume $z \sim 6$ EW distribution.

Monte Carlo simulations indicate we should have detected 7-8 objects.

Probability of detecting Ly$\alpha$ in 2(4) sources is 0.2-0.6% (3-9%).
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$z \sim 7$ EW distribution appears significantly different.
Why do we need spectroscopy?

- Lyα emission provides knowledge of when reionization occurred.
- Understanding of properties (kinematics, covering fraction) of gas around young stars helps break degeneracies in Lyα reionization test.
- Understand nature of Lyα emitters, relationship to underlying star forming galaxy population.
- Galaxies in reionization era are low mass and low luminosity. The nature (feedback, star formation) of these galaxies is unknown.
- Contribution of galaxies to reionization depends on escape fraction of ionizing radiation, which may be different in lower mass systems.
BX418: Unique Window on Low Mass Galaxy Formation at z=2

Strong Lya, OIII], CIII] emission lines.

Weak low ionization interstellar absorption lines. Yet lines are saturated.

Outflowing gas is primarily highly ionized.

He II emission ( stellar wind and nebular component) + CIII] indicates much higher ionization parameter
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*Is BX 418 typical of Low Mass Population?*
Reionization-Era ‘Analogs’ at z~2-5

(w/ J. Richard, B. Siana, J-P Kneib)

Target $10^7$-$10^9$ M$_\odot$ galaxies at z~2-3 where they can be studied in much greater detail with VLT/Keck.

Characterize outflow properties, escape fraction of ionizing radiation, presence of He II emission, Ly$\alpha$ physics.
Clusters provide multiple targets in each field of view - easy to assemble sample of ~100 low mass galaxies.

Pilot program behind one cluster (Abell 1689) and deep optical spectra of low mass galaxies soon arriving for 4 more clusters.
Implications of UV spectra of Low Mass Galaxies

Siana, DPS, J. Richard

• low ionization absorption lines significantly weaker: greater escape fraction of ionizing radiation?

• Very strong CIV, CIII], OIII] emission, yet He II emission absent in yet lower mass systems.
Radiative feedback from low mass galaxies

• Ongoing HST WFC3/UVIS survey (PI: Siana) for ionizing radiation from 13 z~2.6 lensed low mass galaxies.
• Final F275W (LyC) image will be 3x deeper
• Comparison to UV spectra will help understand what governs escape of ionizing radiation
Summary

• Fraction of Lyα emitters within star-forming galaxy population is much greater for low luminosity galaxies. Likely reflects lower dust content.

• Reliable confirmation of WFC3 z>6.5 dropouts now emerging from pilot Keck and VLT programs. Expect many more redshifts to come in next few years.

• Fraction of Lya emitters decreases in ~200 Myr spanning 6<z<7. Consistent with expectations for increased neutral HI fraction.

• Early galaxies are low mass and low luminosity systems. Little is known about the detailed physics of how these galaxies form.

• Unclear whether z>6 galaxies contribute enough ionizing radiation to achieve reionization by z~6. More information required on detailed physics of early galaxies.

• Spectra of low mass gravitationally lensed galaxies at high redshift reveal very weak low ionization absorption lines and uniquely strong nebular emission lines in rest-UV. Both may reflect greater contribution to reionization.