Observing galaxies across the EoR boundary

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Goal: to characterize the transition from neutral to ionized.

1) The evolution of the Ly$\alpha$ visibility: what is telling us?

2) What is the topology of reionization? Is it patch? Which are the sources?
Lack of Lyα emission as a tracer of increasingly neutral IGM/CGM

Since the beginning interpreted as an increased IGM absorption -> onset of re-ionization

(Stark+10, Fontana+10, Pentericci+11, Ono+12, Treu+12, 13 ,Schenker+12, 14)
What does it mean?

Modelling the reionization process is complicated.


- **Small scale - Web (damped-like systems)**
- **Large scale - Ionized Bubbles**
- **Web+Bubble**

The fast evolution from z=6 to z=7 may be difficult to explain: **needed also an evolution of rest-frame properties?**

(Dijkstra+13, Mesinger+15 etc)

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**Intrinsic Ly$\alpha$ fraction**
- **REW > 50 Å**
- **$<f_{HI}>_V = 0.676$**
- **$<f_{HI}>_V = 0.032$**
- **Web-bubble model, B1+W2, $<f_{HI}>_V = 0.373$**
- **Pentericci+14 z~7**

**$M_{UV} > -20.25$, $\langle \Delta v_{HI} \rangle = 200 \text{ km/s}$**

$X_{Ly\alpha}(z=7)$

**$x_{Ly\alpha}(z=7)$ vs $M_{UV}$**

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*Mesinger*+15

*Kakiichi*+16
CANDELSz7: an ESO Large Program to probe the reionization epoch.

- 200 galaxies at 5.5<photo-z-<7.3; 70 z-dropout (candidate z~7)
- COSMOS/UDS/GOODS-S
- Homogeneous color-selection criteria from CANDELS data
- H-selected - no influence of Lyα in selection
- “adaptive” integration time (15-25hr) to reach uniform EW limit
- Analysis 90% complete as of today (results are PRELIMINARY)

- 17 new galaxies at 6.5<z<7.3
- 40 new galaxies at 5.5<z<6.5 with Lyα
- several galaxies at z~6 with no Lyα
Some new z~7 galaxies

Stack of $z=7$ Ly$\alpha$ emitters showing a clear line asymmetry
Deep spectroscopy starts to reveal faint $z \sim 6$ non-$\text{Ly} \alpha$ emitters

Confirms reliability of LBG technique at $z \sim 6$ -> corroborates evidence that the $\text{Ly} \alpha$ drop is not due to interlopers
Faint galaxies ($M_{UV} > -20.25$) 

Bright galaxies ($M_{UV} < -20.25$)

"Small" 
EW(Ly$\alpha$) > 25 Å

"Large" 
EW(Ly$\alpha$) > 55 Å

Ly$\alpha$ decline “softer” than previous estimates: starts at z~6

CANDELSz7 + earlier + archival observations
120 z-dropouts + 180 i-dropouts in 5 independent fields.
The largest spectroscopic sample at z>6

new z=7 limits
new z=6 limits

PRELIMINARY
A space oddity at $z \sim 7$

In the overall paucity of Ly$\alpha$ lines, one line of sight with twin bright emitters among the 8 l.o.s. investigated in Pentericci+ 14

The BDF field hosts two close-by (4.4 proper Mpc) EW>50Å emitters. (Vanzella+11).

A random fluctuation is unlikely. These objects likely reside in a region of high transparency -within an ionized bubble
Galaxy density drives reionization

Comparison with SPH model (Hutter+14,+15).

Relation between density and HI fraction
LAE pairs live in overdense regions with low HI
- analogs of BDF pairs reside in reionized, overdense bubbles

Castellano+16, ApJL
Faint z~7 LBGs in the BDF field

Previous Hawk-I data limited to Y~26.5.

Six new robust LBGs recovered down to Y105~27.5 (at S/N>10)

\[(S/N(I_{814}) < 1) \land (I_{814} - Y_{105} > 2.2) \land Y_{105} - (J + K) < 0.8 \land (S/N(Y_{105}) > 10) \land (S/N(V_{606})) < 1\]

HST Cycle 22 program (PI MC) to look for surrounding, fainter LBGs.

14 orbits with V606, I814, Y105.
Observed 8 objects in two pointings. Expected ~1.8-2.9 objects.

No clustering around z~7 GOODS-S galaxies (objects lacking Lyα emission).

The BDF field is 3-4x overdense wrt average: consistent with a positive relation between line visibility and galaxy density as in inside-out reionization scenarios. (e.g. McQuinn+ 07, Wyithe&Loeb 07, Dayal+ 09).
Conclusions

1) The evolution of the Ly\(\alpha\) visibility: what is telling us?
   - Ly\(\alpha\) decline softer than previous estimates: starts at \(z \sim 6\)
   - Might eventually allow us to discriminate between reionization models - probably needed a combination of small-scale ("web-") and large-scale ("bubble-") absorbers.

2) Is reionization patchy? Which are the sources?
   - Yes! Overdensity of faint galaxies can be connected with ionized bubbles (Castellano + 2016, ApJL)