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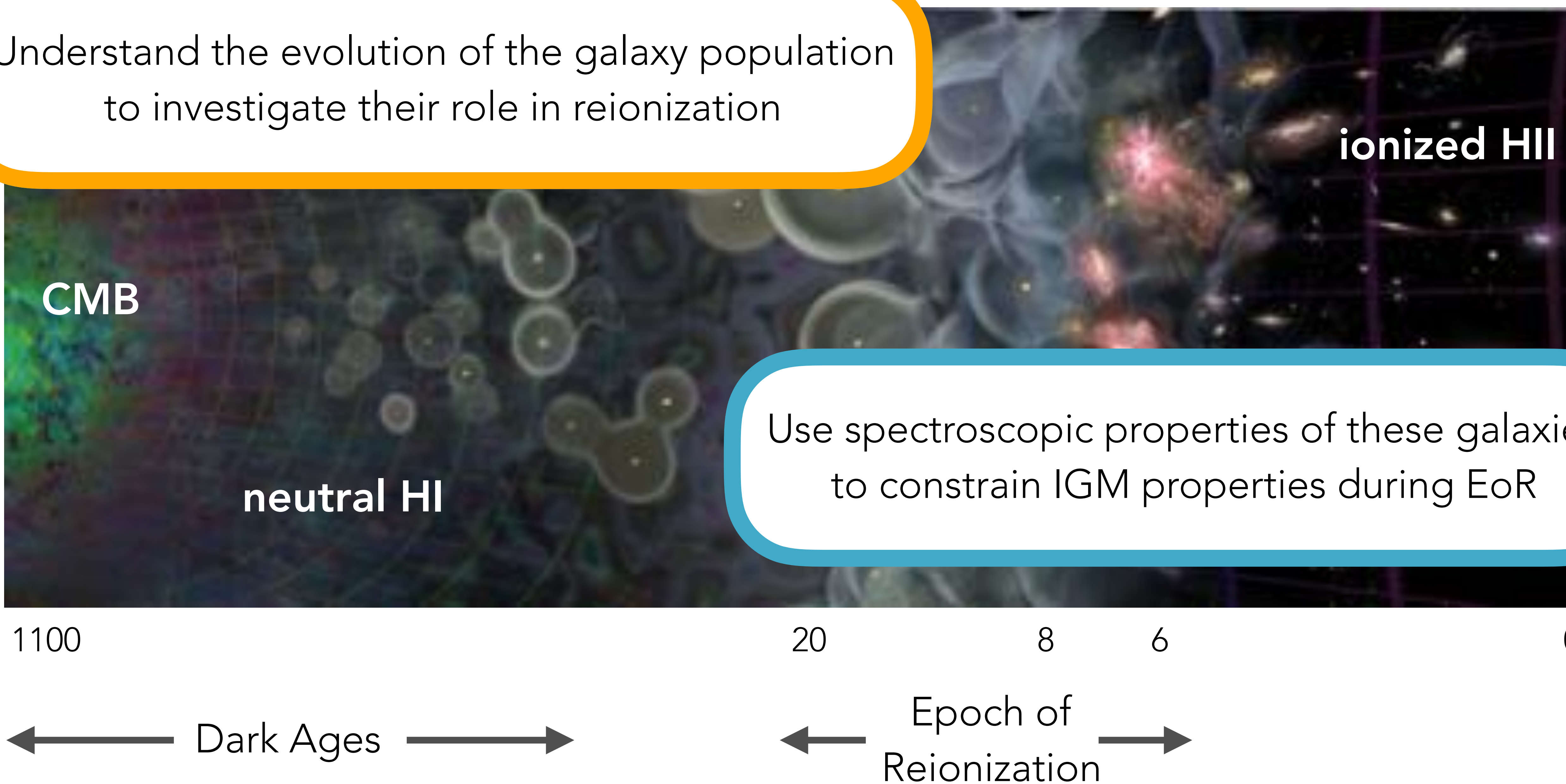
Aspen, 7 Feb 2016

The First Galaxies: Evolution drivers via luminosity functions and spectroscopy through a magnifying GLASS

with Tommaso Treu (UCLA), Michele Trenti (U. Melbourne), Kasper Schmidt (AIP), Adriano Fontana (OAR) and the GLASS and BoRG teams

Reionization was likely associated with the formation of the first stars and galaxies

Understand the evolution of the galaxy population to investigate their role in reionization



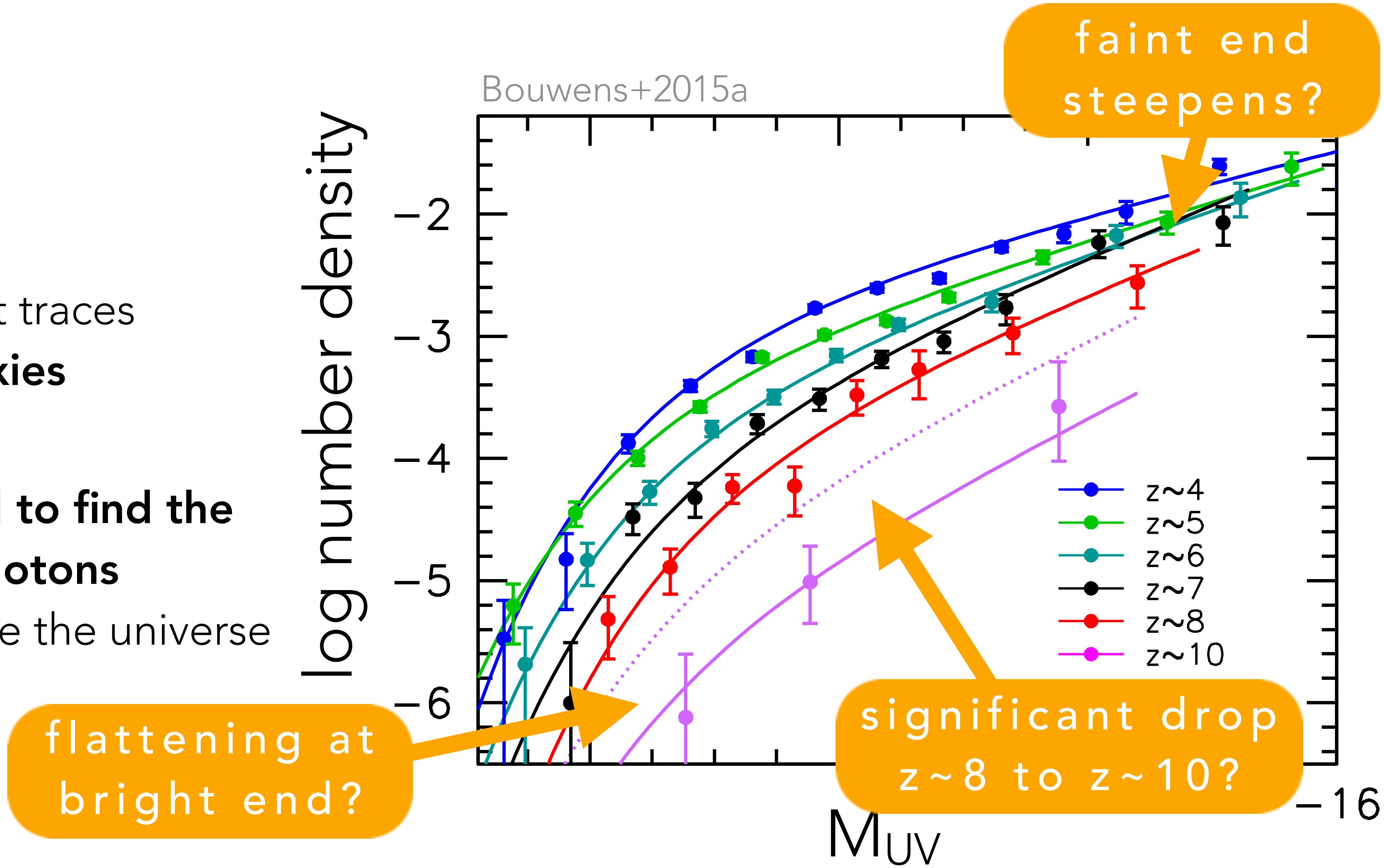
Use spectroscopic properties of these galaxies to constrain IGM properties during EoR

Loeb (2006)

UV Luminosity functions are one of our best tools for studying high z galaxy populations and their evolution

Rest frame UV light traces **star forming galaxies**

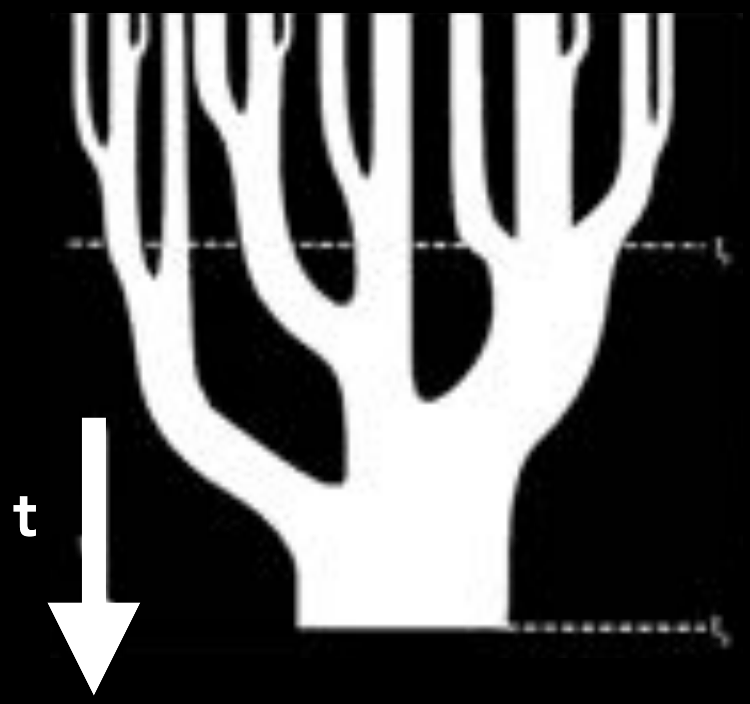
Can be **integrated to find the flux of ionizing photons** available to reionize the universe



Are there enough galaxies at z>8 to reionize the universe? What will JWST see?

What drives evolution in the LF?

halo mass function + star formation + physical conditions



What is the simplest theoretical model to connect halo growth to star formation rate?

Mason, Trenti & Treu, ApJ, 2015

- minimal degrees of freedom
- self-consistency over redshift

$$SFR(M_h, z) \sim M_h \times \text{gas accretion rate} \times \boldsymbol{\varepsilon}(M_h)$$

halo mass
from cosmology

assume gas follows DM
~ mass doubling rate
from cosmology

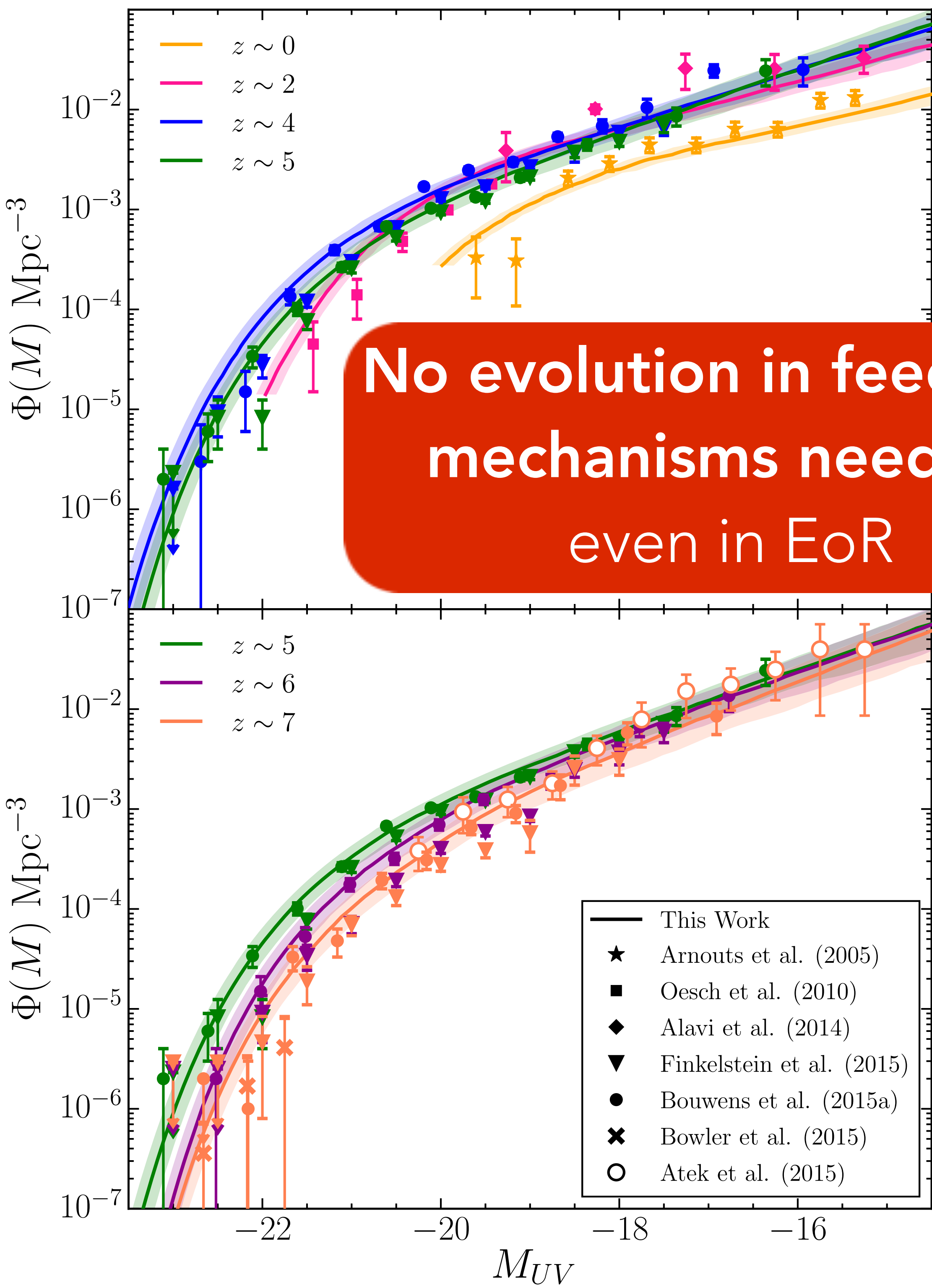
(Planck ΛCDM + ellipsoidal collapse, Sheth+2001 Lacey & Cole 1993)

SF efficiency ~ $M_\star/M_h$
fixed from calibration at one redshift via abundance matching

very weakly evolving (Behroozi+2013)

Trenti+2010, Tacchella+2013

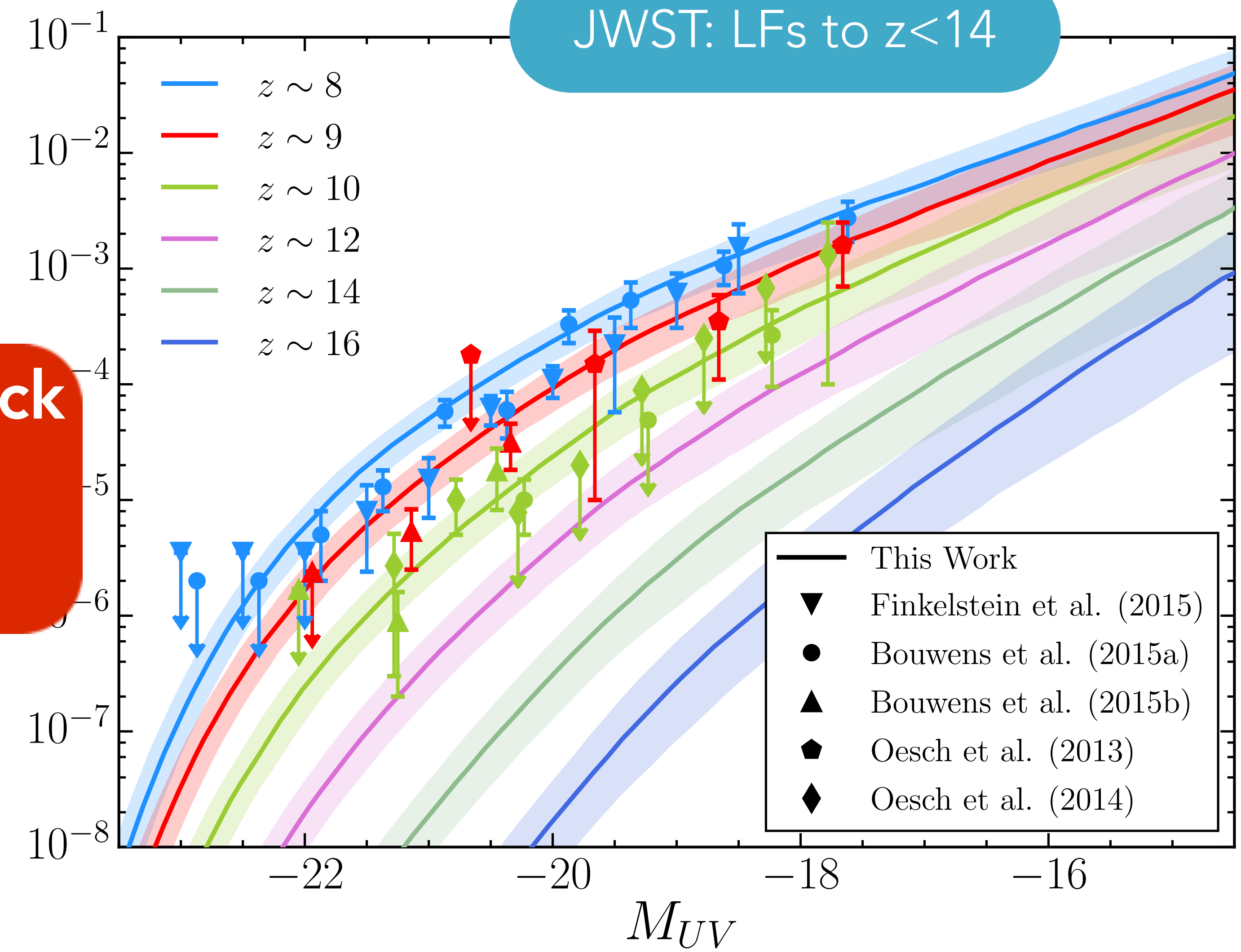
Our simple model is remarkably **consistent with observed luminosity functions over 13 Gyr of cosmic time!**



Mason+2015b

No evolution in feedback mechanisms needed, even in EoR

JWST: LFs to z<14



also consistent with:
luminosity density
stellar mass density
luminosity-halo mass

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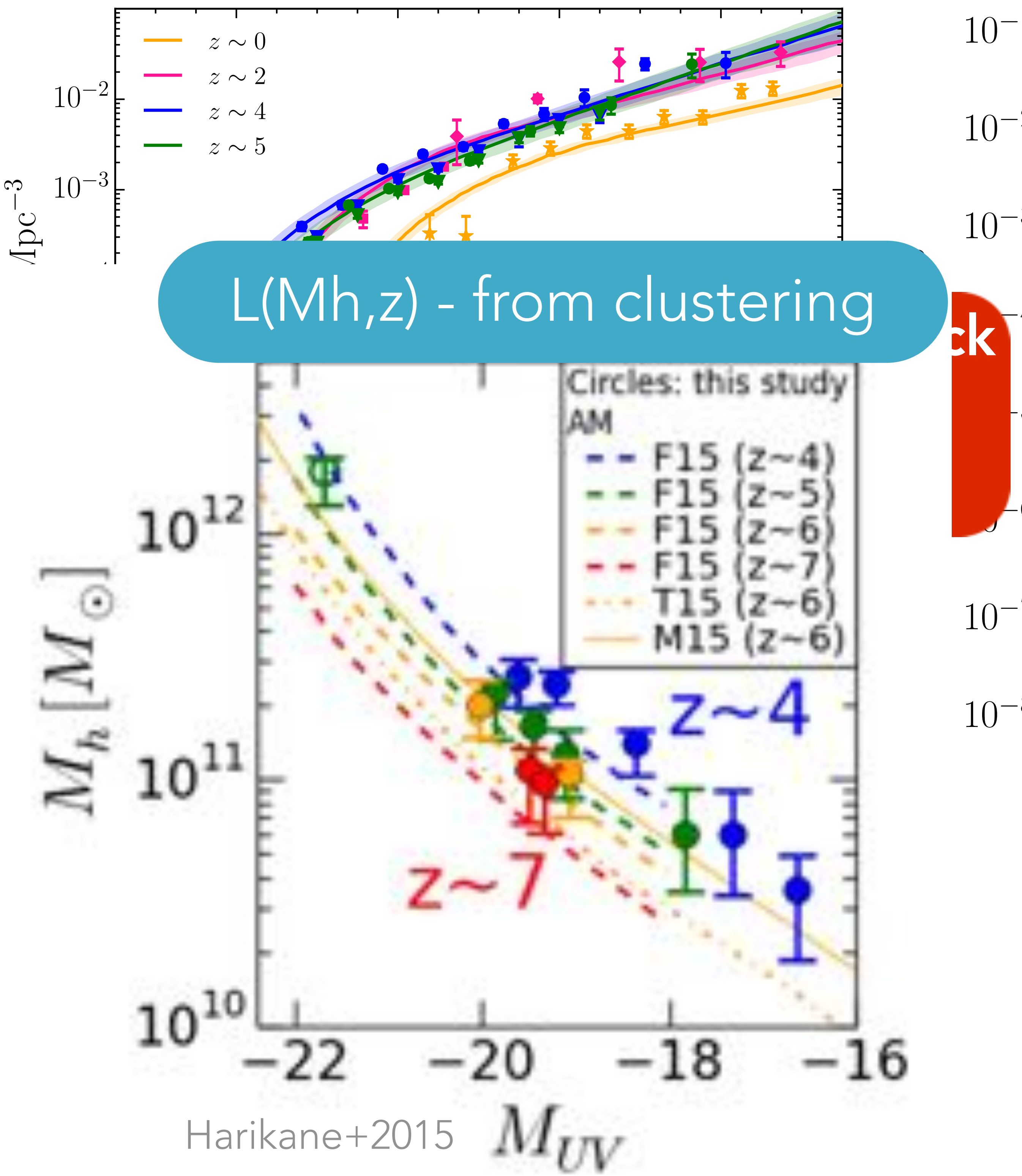
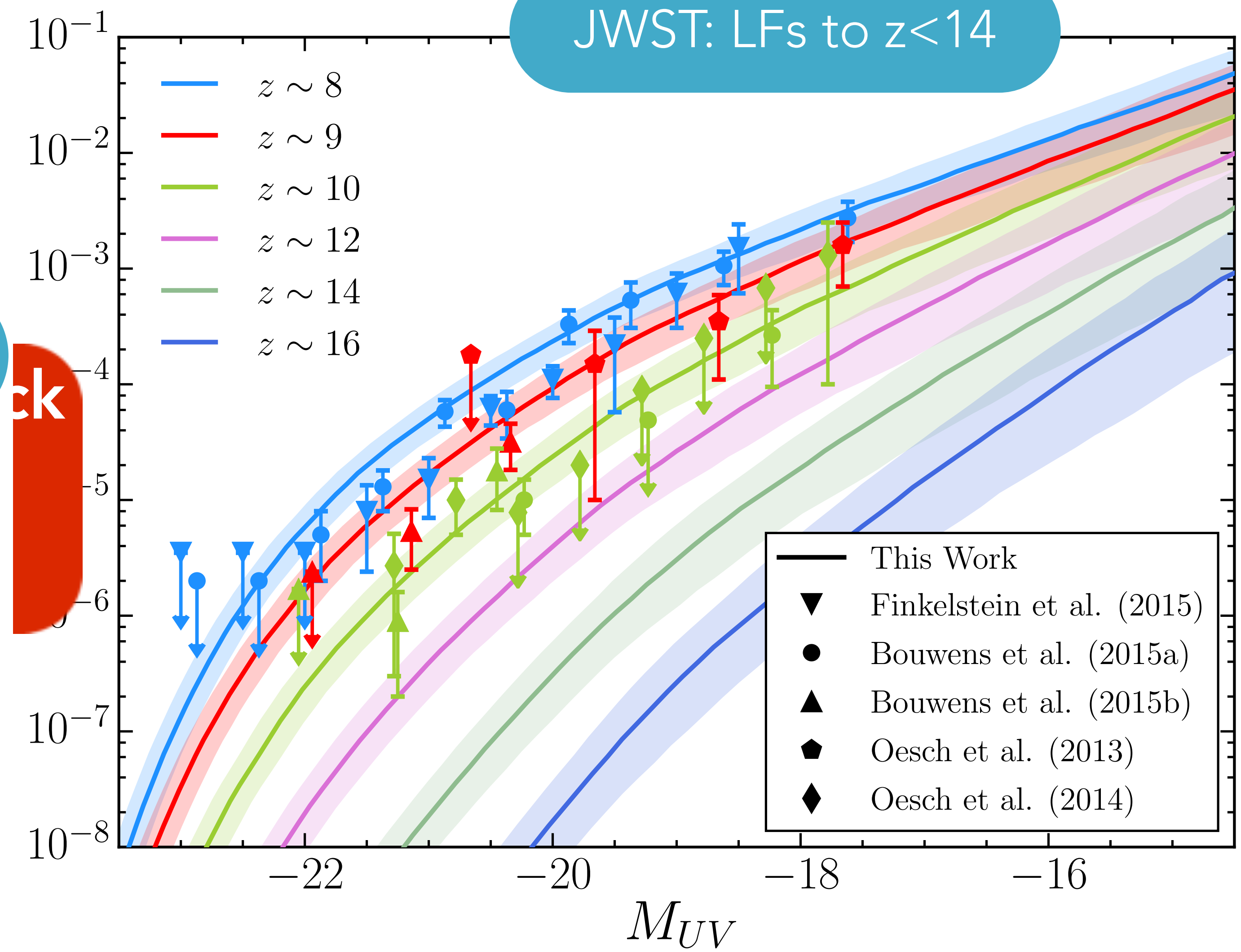


L(Mh,z) - from clustering

Harikane+2015

JWST: LFs to z<14



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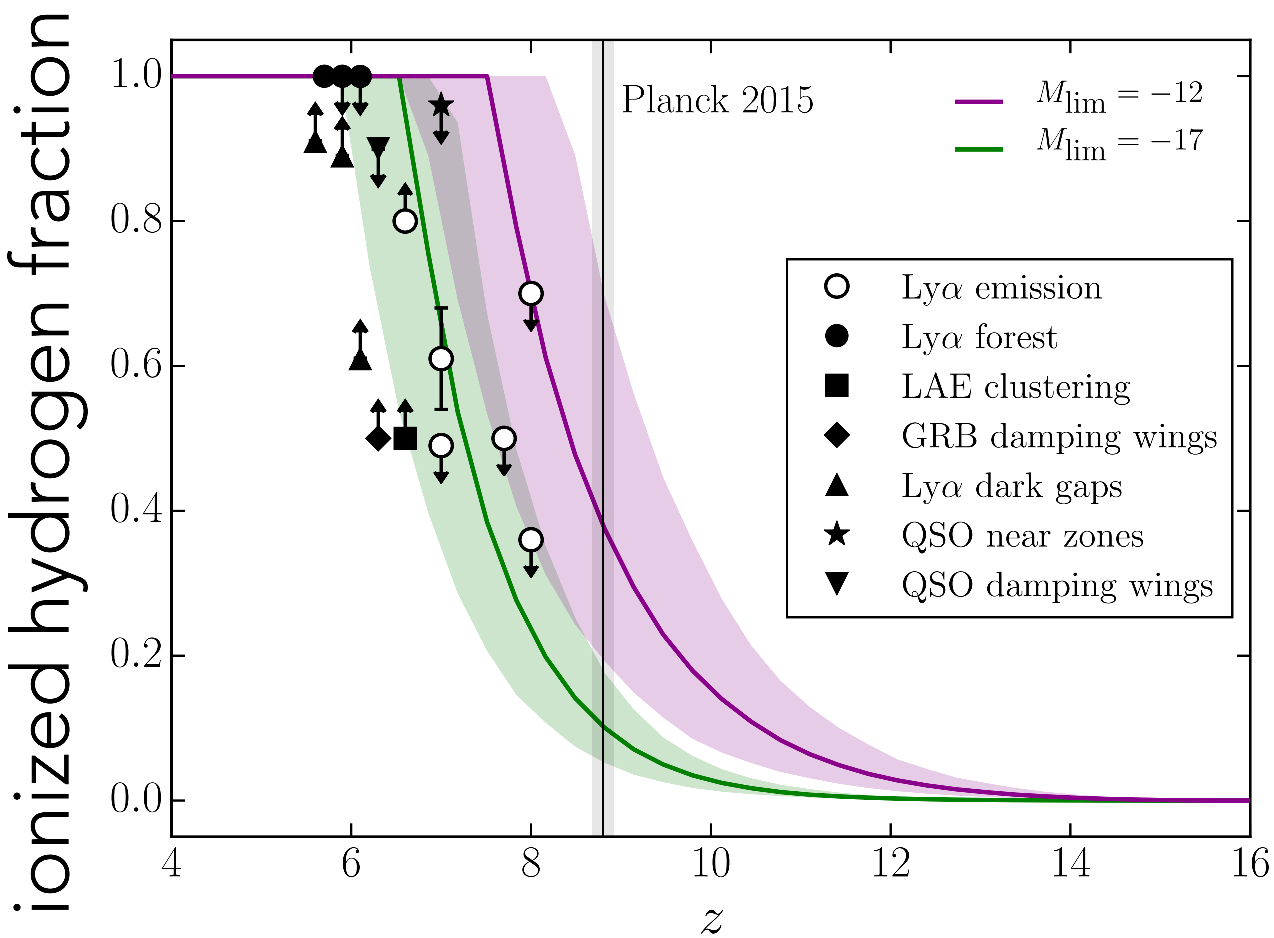
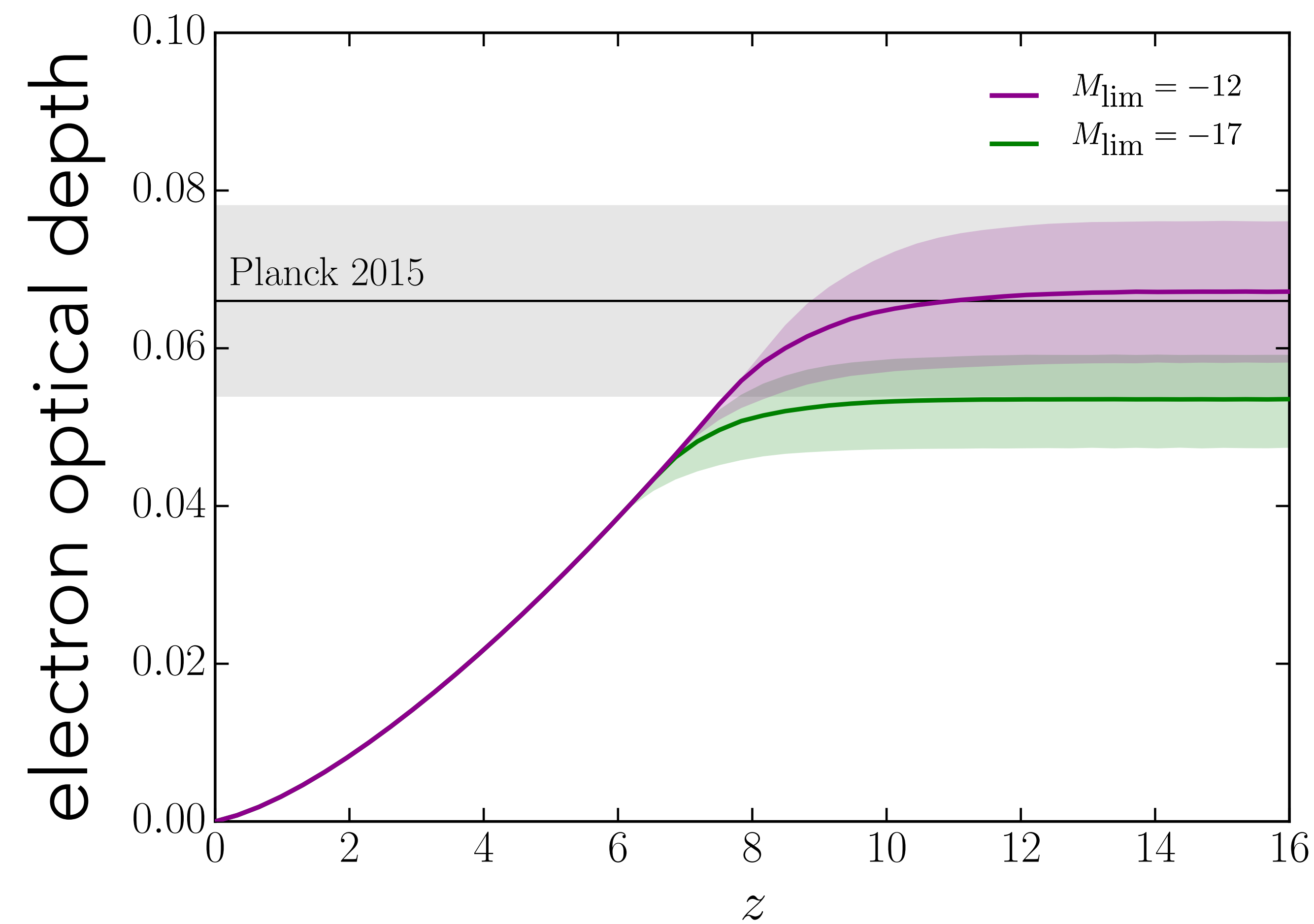
Faint galaxies are probably needed to reionize the universe

all galaxies

detectable galaxies





Mason+2015b

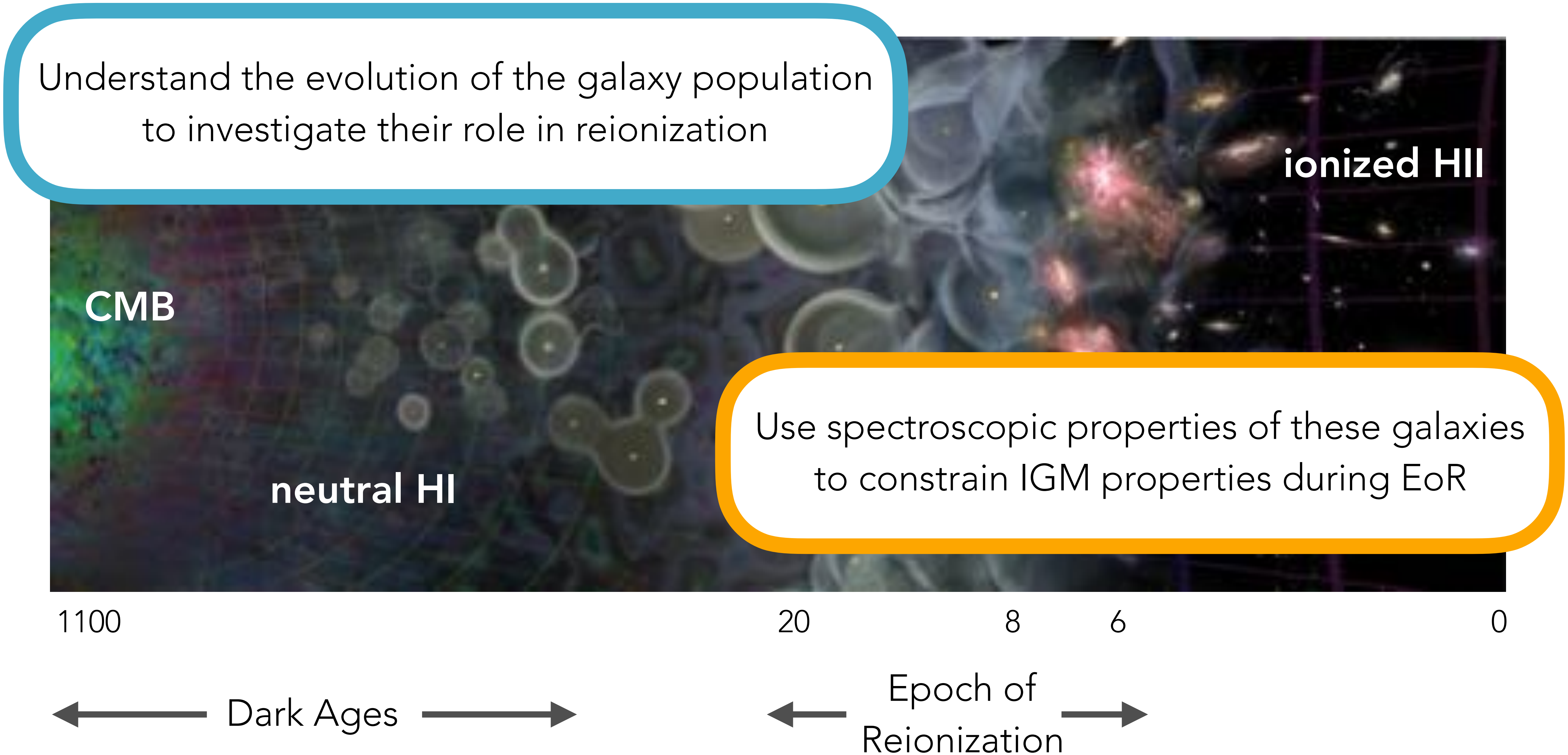
f_{esc} = 0.1 - 0.3

C = 1 - 6

log ξ_{ion} ~ 25.2 (± 0.15 dex)

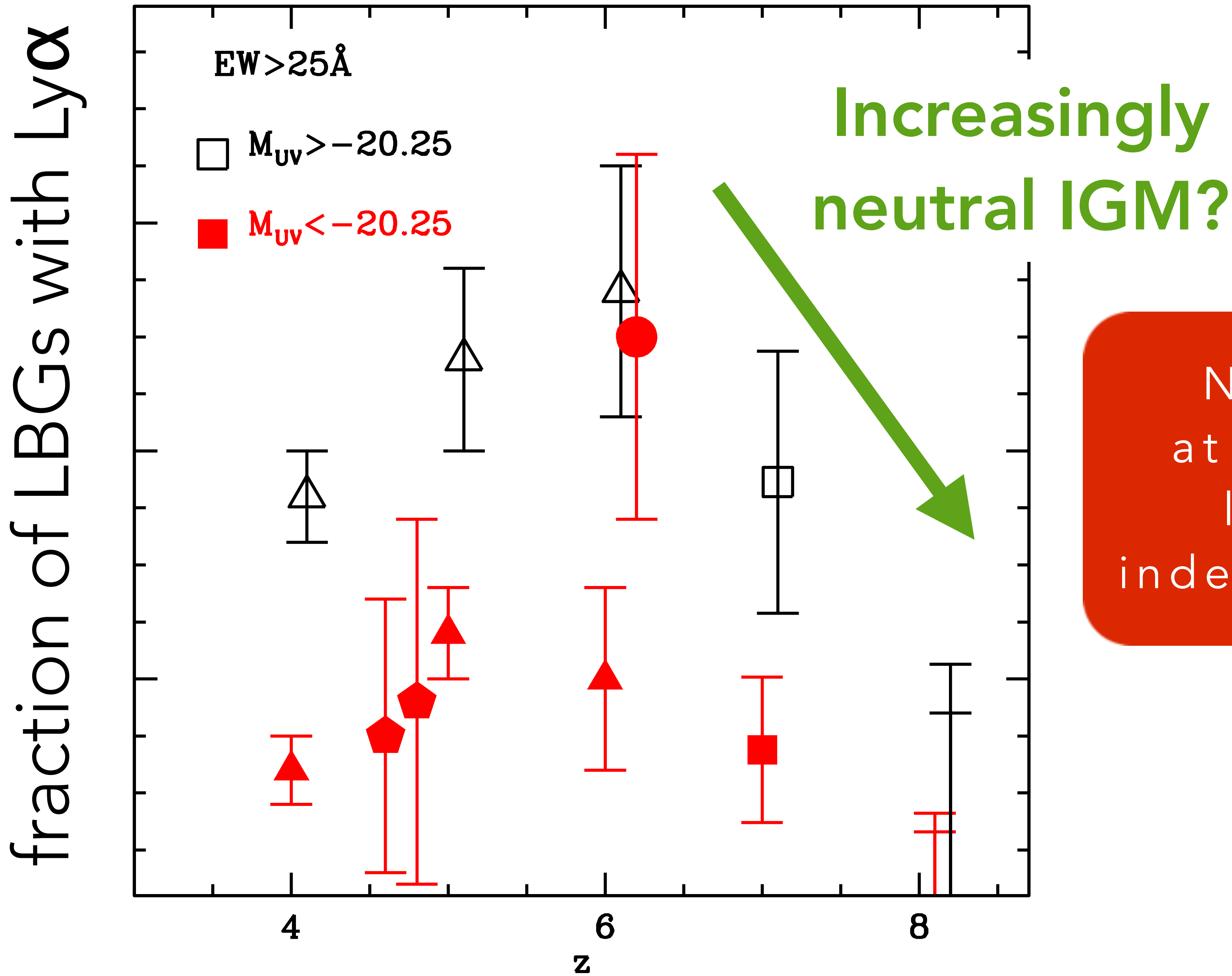
Ouchi+2009, Robertson+2013, Schmidt+2014

Reionization was the last major phase transformation of the universe and likely associated with the formation of the first stars and galaxies



Loeb (2006)

Is the sudden evolution in Lyα emission at z>6 the smoking gun of Reionization?



Need more data, at a wider range in luminosity, and independent sightlines

Treu et al. (2013)

We are expanding the search for Lyα at z>7 by exploiting the power of cluster lenses

Grism Lens-Amplified Survey from Space
glass.astro.ucla.edu

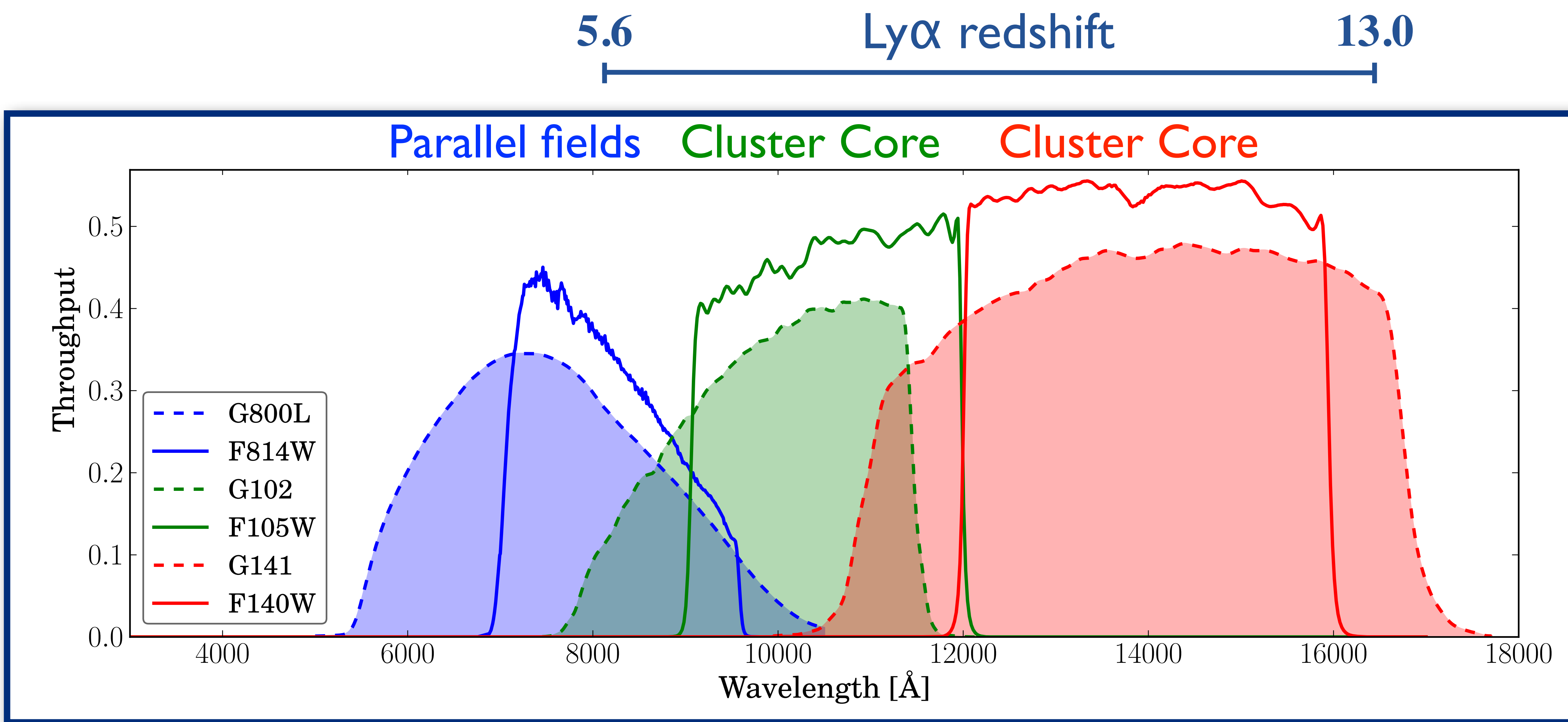
HST Grism Spectroscopy of 10 massive clusters

PI Treu, see Schmidt+2014,Treu+2015
140 orbits in Cycle 21
Including the 6 HFF and 8 CLASH clusters

Data released for 7/10 clusters
https://archive.stsci.edu/prepds/glass/

- **Investigate galaxies and IGM at EoR [Schmidt+(incl CM) 2016]**
- Environmental dependance on galaxy evolution [Vulcani+2015]
- Metallicity cycles in and out of galaxies [Jones+2015, Wang+in prep]
- SN searches, e.g. SN Refsdal [Kelly+2015]
- Cluster mass maps [Wang+2015, Hoag+in prep]

GLASS observing strategy

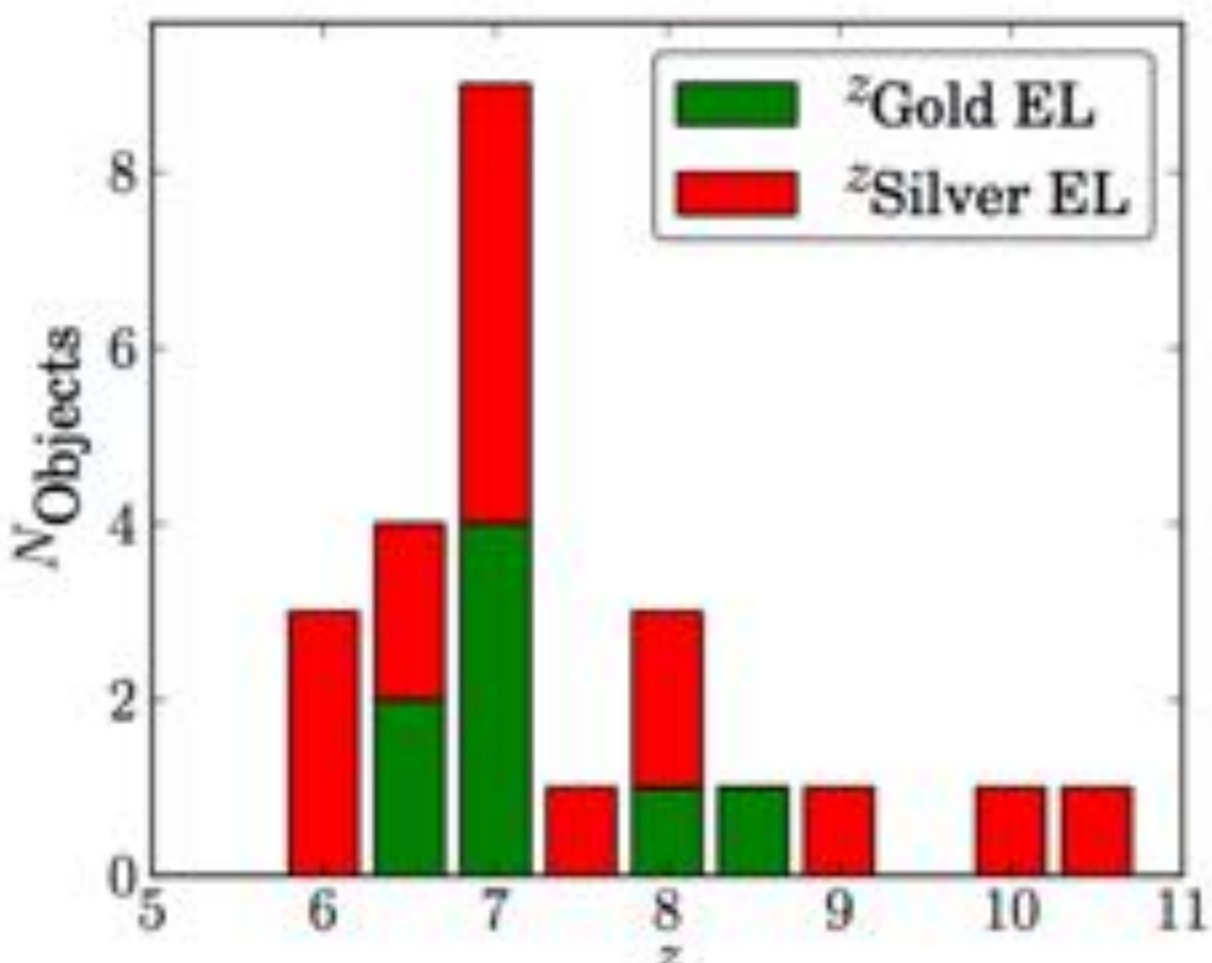


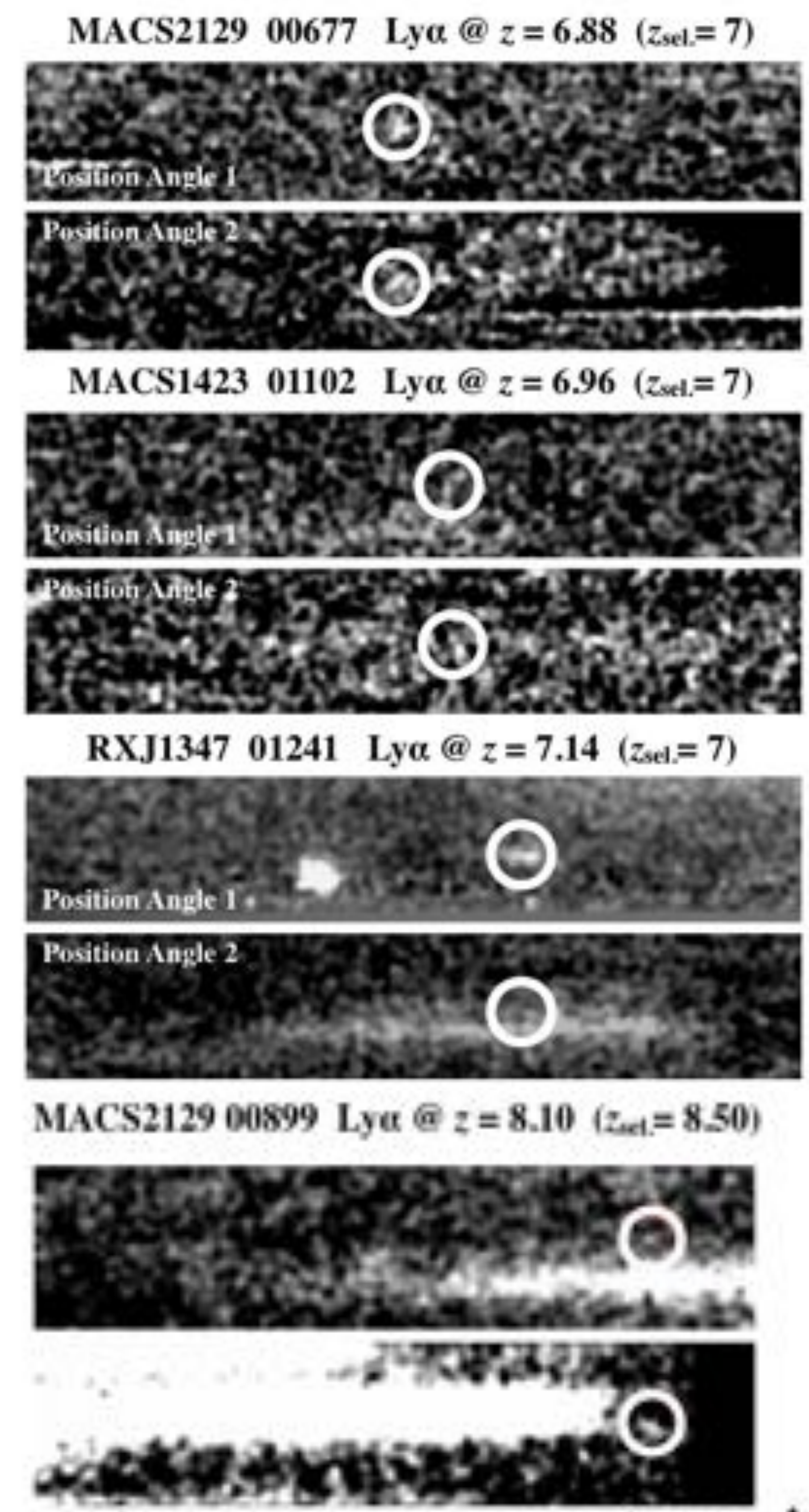
- Uninterrupted wavelength coverage
- 2 position angles to minimise contamination and better line identification
- Spectra of 1000s of objects with $m_{F140W} < 24$
- Probes intrinsically faint objects due to cluster magnification
- Spectroscopic 1σ limits ~ 5×10^{-18} erg/s/cm^2 (not accounting for lensing)

GLASS can efficiently look for Lyα candidates at z>6

In 6 clusters, using >20 photometric selections for LBGs
- 24/159 dropouts have Lyα (Schmidt+2016)
- **consistent with drop from z~6**

Largest statistically well-defined spectroscopic sample of Lyman break galaxies at z>6





Schmidt et al. (2016)

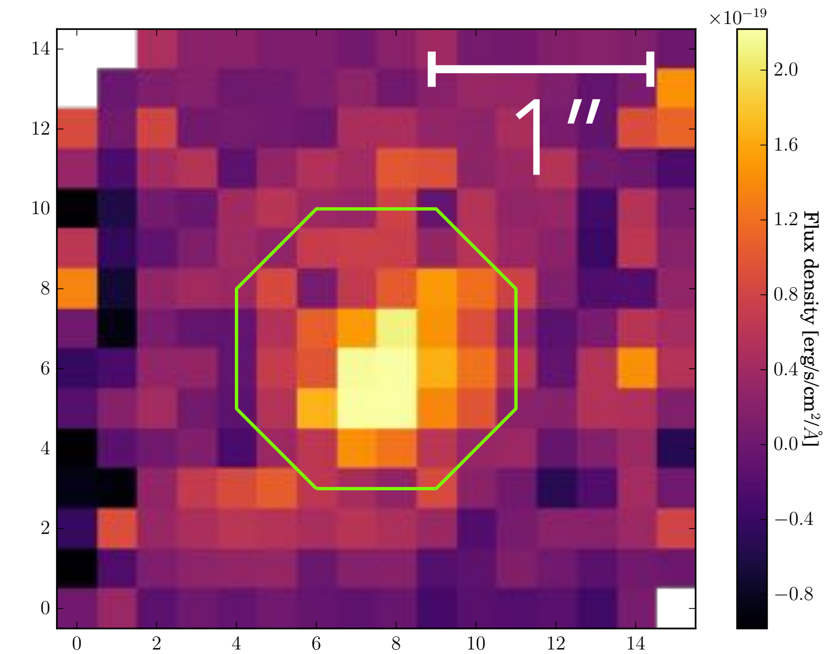
But higher spectral resolution is needed to confirm Lyα and constrain HST grism purity & completeness

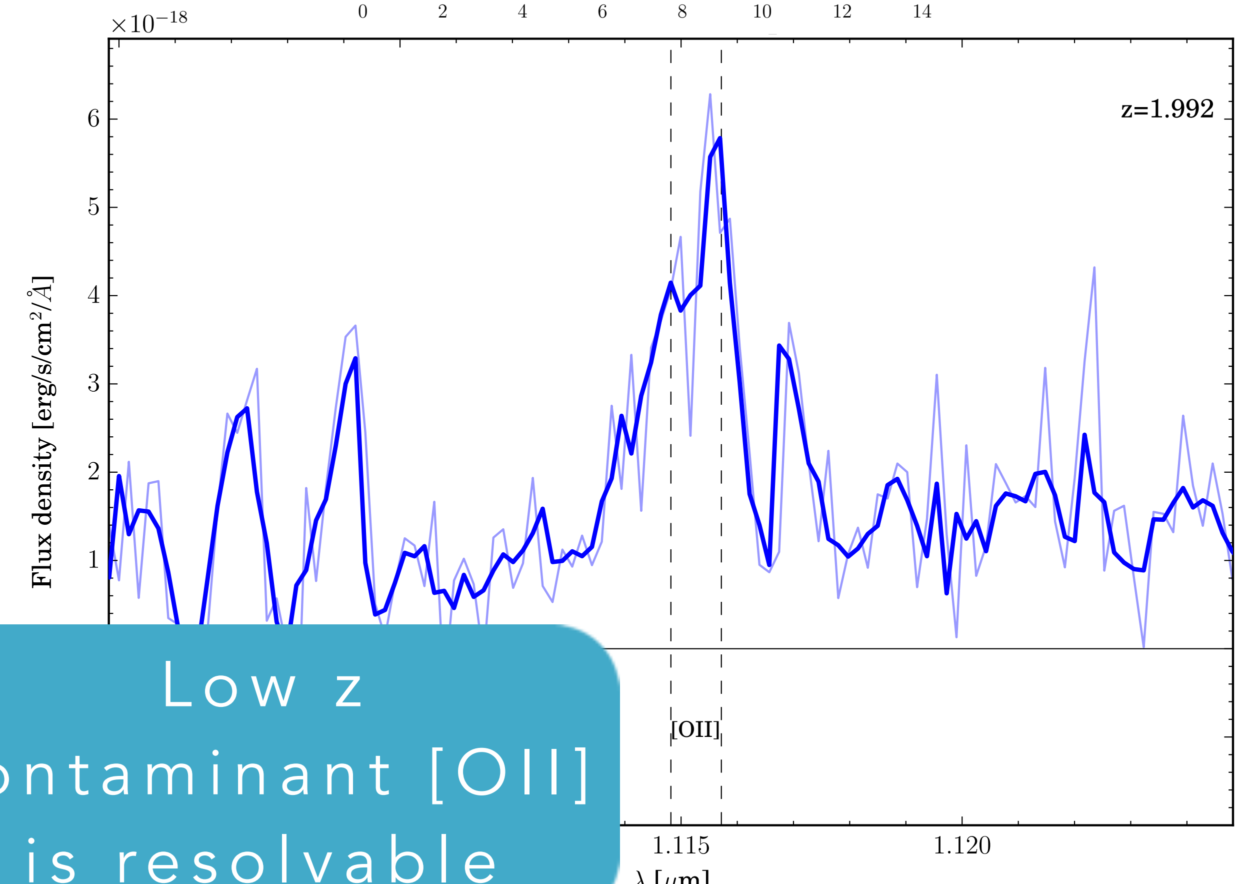
VLT KMOS large program (PI Fontana)

- 7 clusters ongoing until March 2017
- 10 - 15 hrs integration per source
- YJ band: 1 - 1.35 μm
  - ~70 z>7 sources (~1/3 grism Lya)
  - ~70 sources 1<z<3

Keck DEIMOS and MOSFIRE (PI Bradač)

- 1 secure detection (Huang+2015)
- 3 more potential confirmations





Low z contaminant [OII] is resolvable

Conclusions

UV LF and other global galaxy properties at $0 \lesssim z \lesssim 10$ can be easily modelled by assuming **halo growth is the dominant driver of galaxy growth**

Apart from dust, no evolution of physical conditions/feedback is needed!

GLASS is providing the **largest spectroscopic follow-up of LBGs at $z>6$**

Lensing allows us to see intrinsically faint galaxies

24/159 Lya candidates in 6/10 clusters consistent with significant drop from $z\sim6$

Extensive ground based follow-up is ongoing at VLT and Keck