Probing Galaxy Formation and Evolution with Lyman α Emitters

Joseph Caruana

Department of Physics
Institute of Space Sciences & Astronomy (ISSA)
University of Malta

L-Università ta' Malta

outside

gas in galaxiesconference.com

outside

gas galaxiesconference.com

$X_{Ly\alpha}$

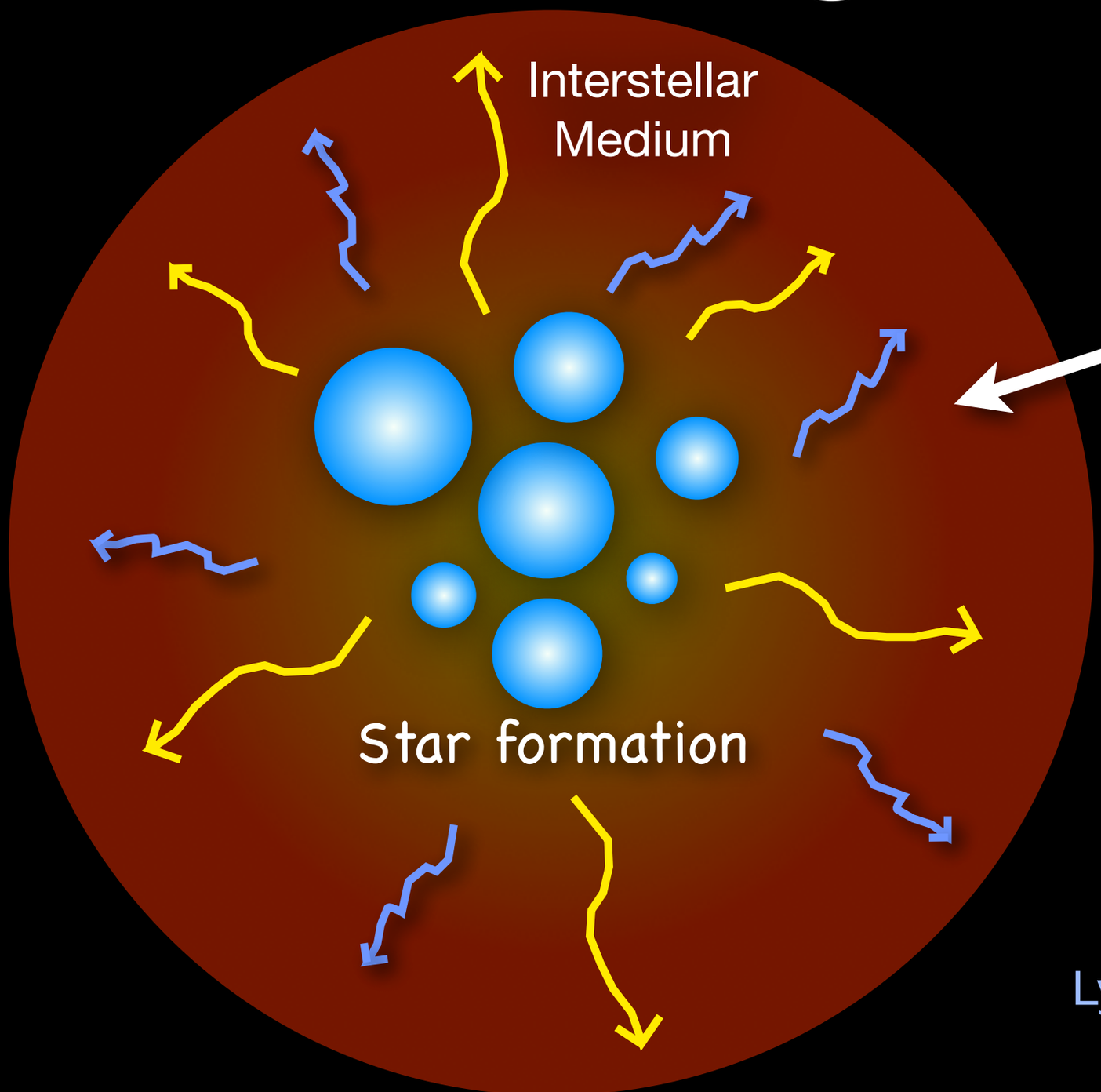
(1) Evolution of the fraction of Lyα emitters amongst rest-frame UV-selected galaxies.

(2) Using Lyα emitters to constrain the fraction of neutral hydrogen gas in the early universe.

(3) New insights gleaned from recent MUSE observations of Lyα emitters (in press).

Joseph Caruana, University of Malta

The Origin of Lya



ionized

recombination
timescale is short!

electron soon
falls back

n=2 -> n=1
Lyman-alpha emission!

Joseph Caruana, University of Malta

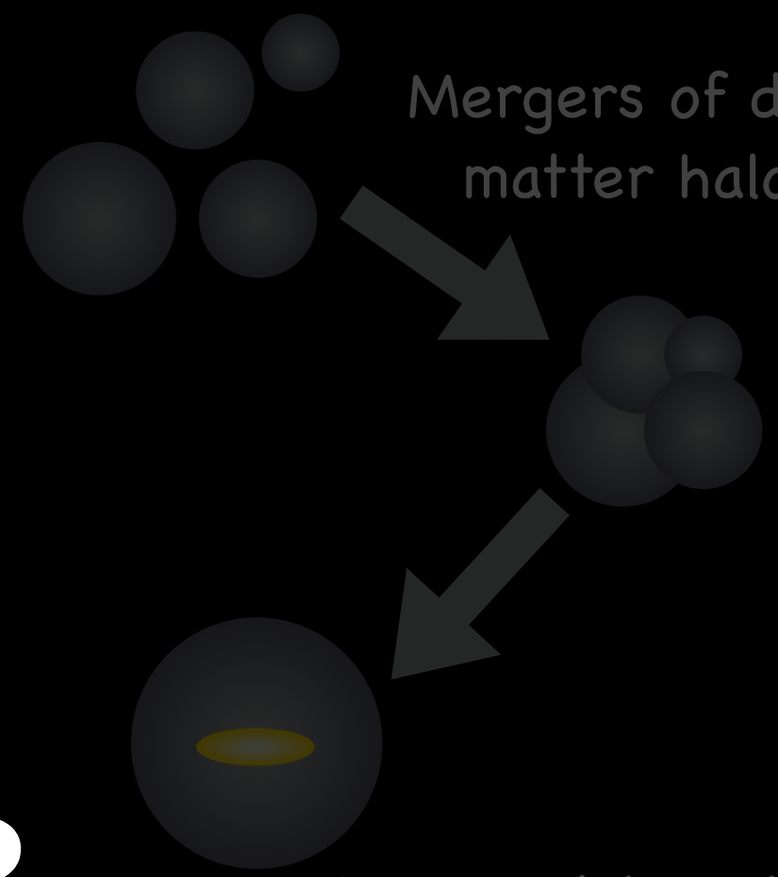
Lyα Emission in the z>3 Universe

Joseph Caruana, University of Malta

Why Lya?

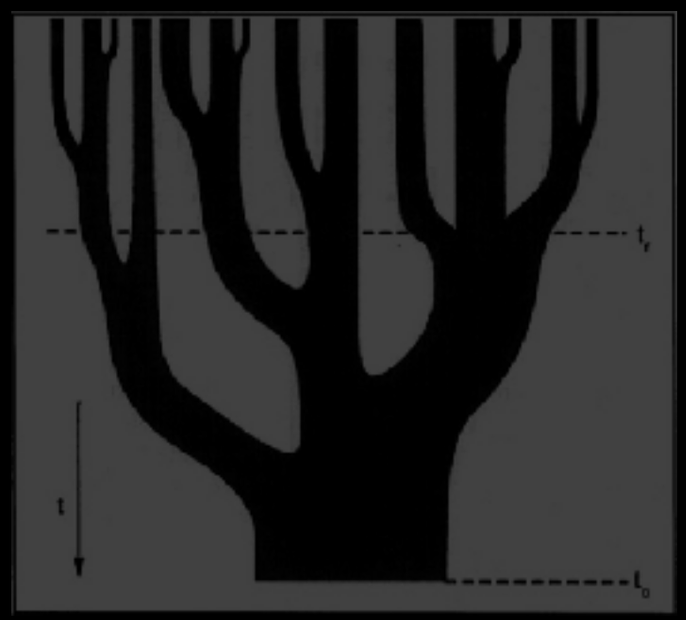
Lambda-CDM

Structure formation predictions

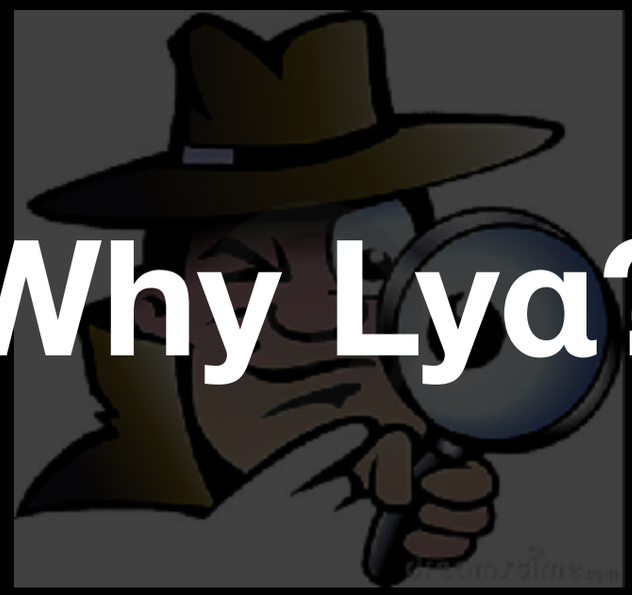


Mergers of dark matter halos

We need to put galaxies in there!



Merger tree



Observe!

?

Baryonic Physics
(not well understood)

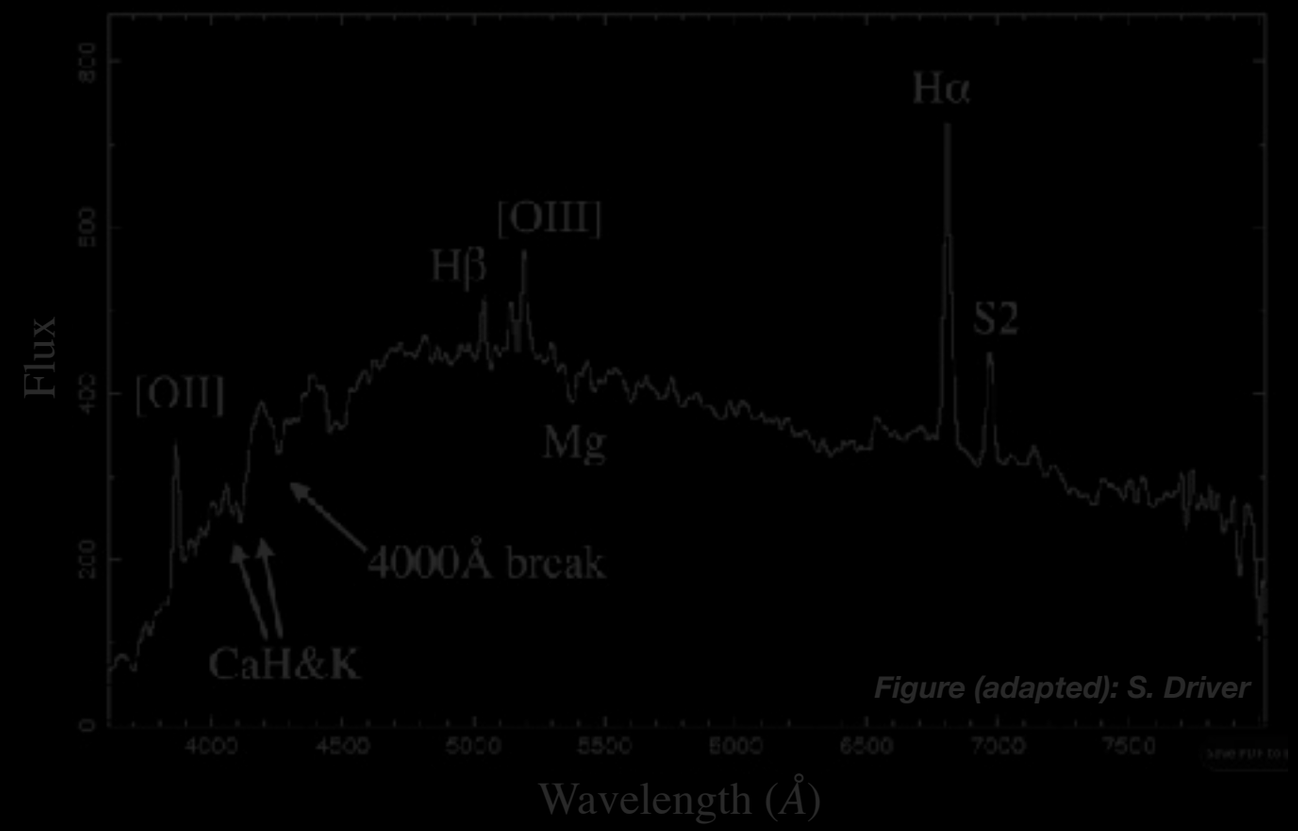
Semi-analytic models

predictions

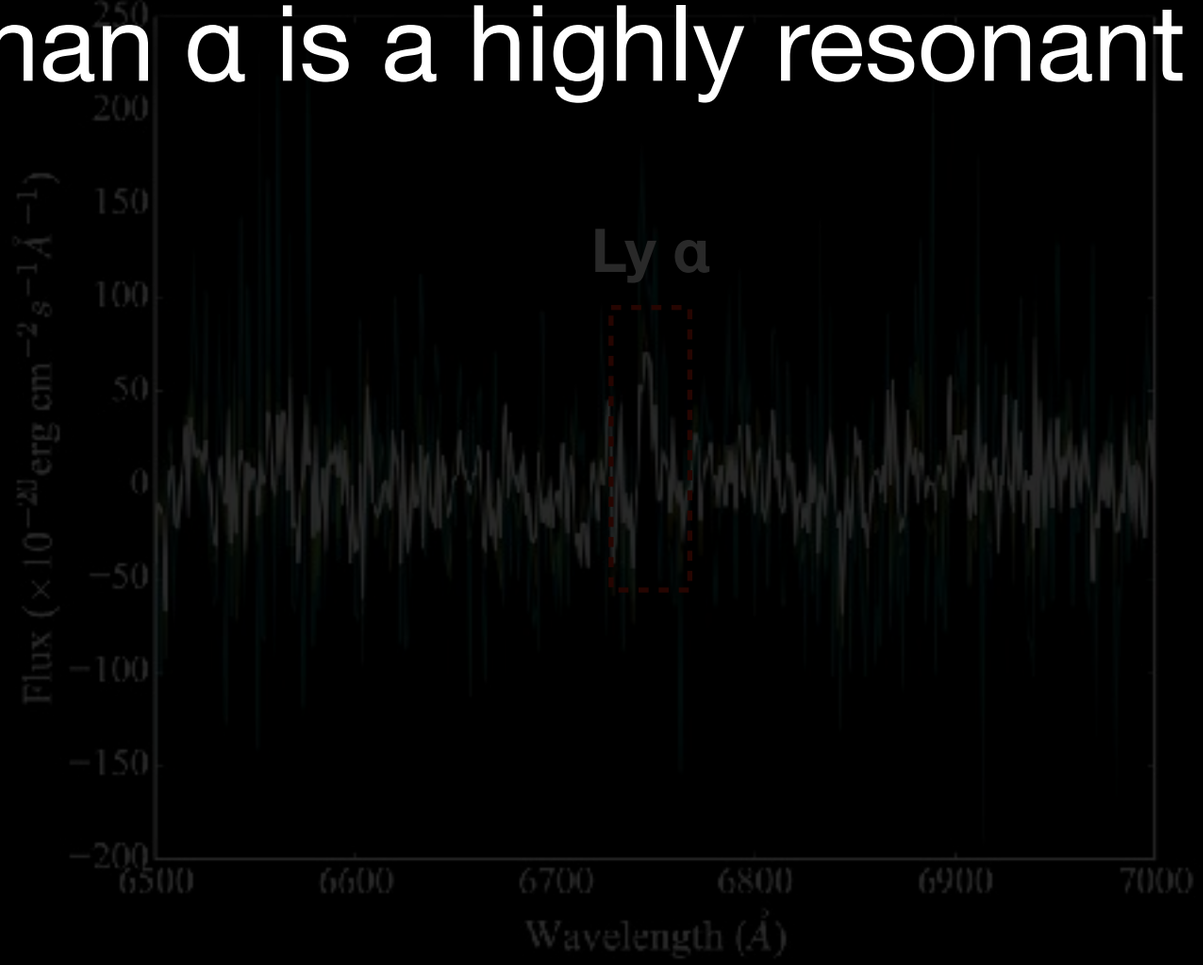
> Masses
> Sizes
> Luminosities

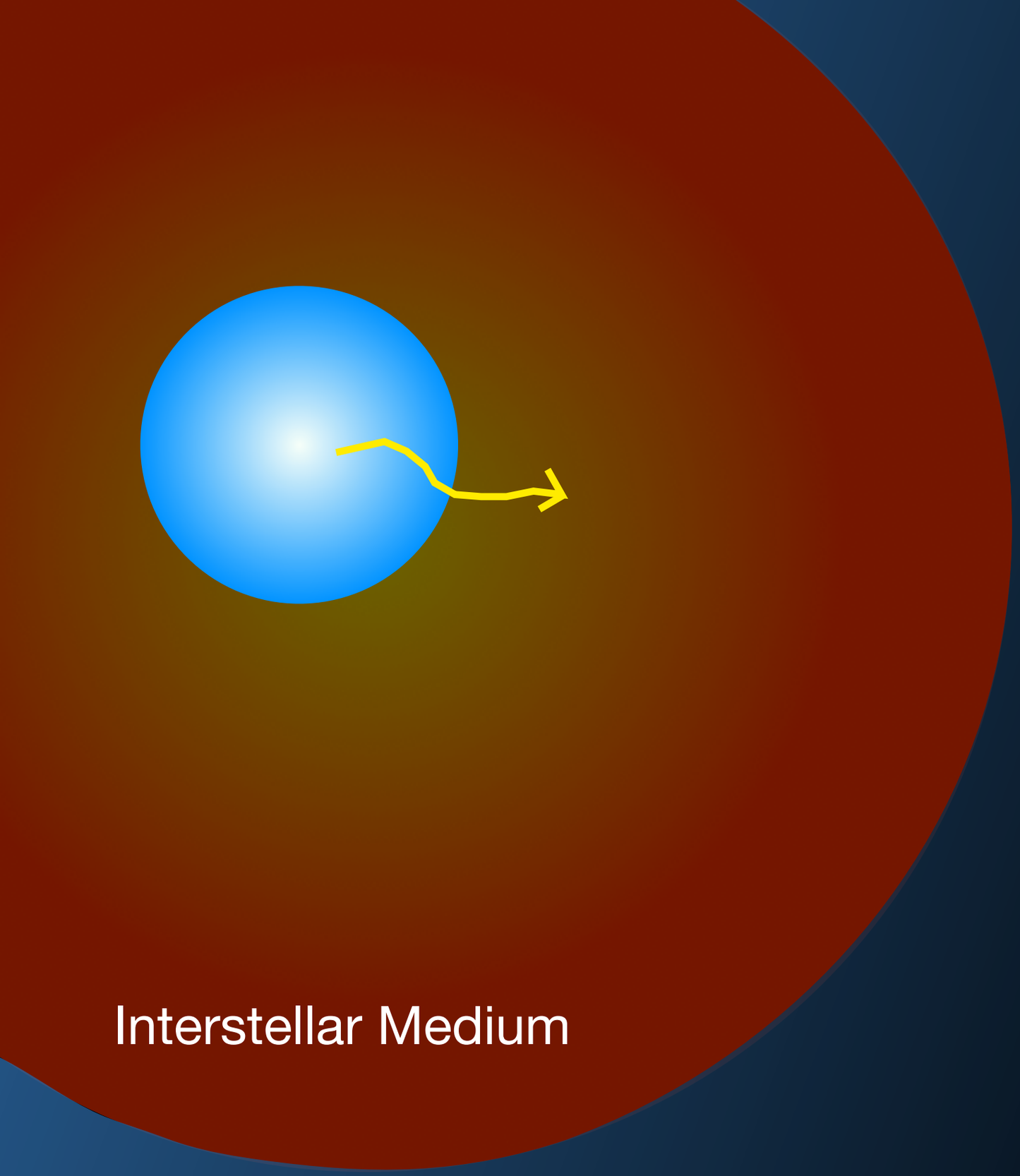
Joseph Caruana, University of Malta

Observe!



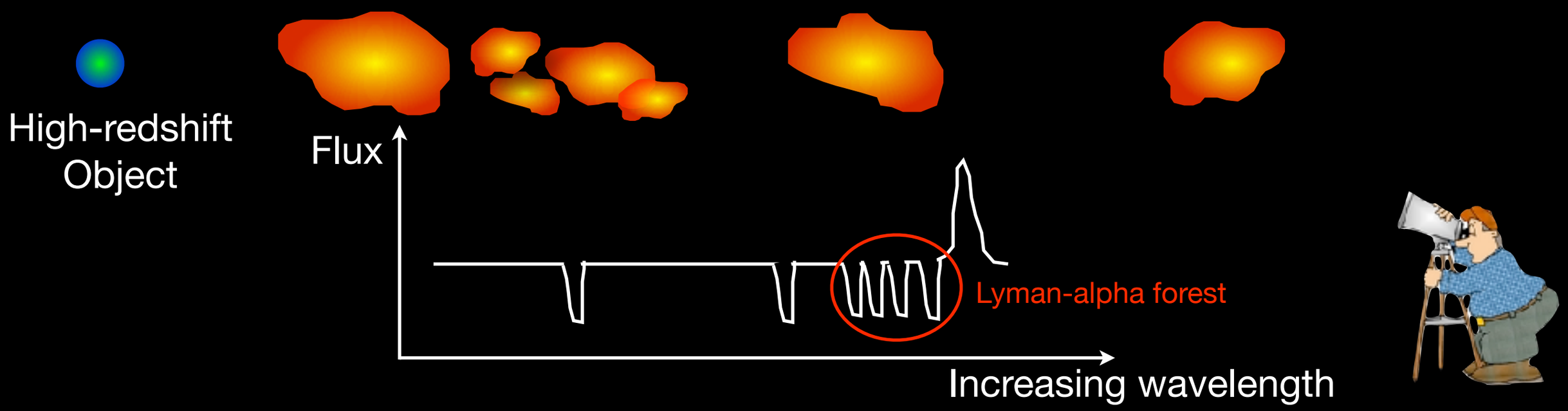
Lyman α is a highly resonant line.



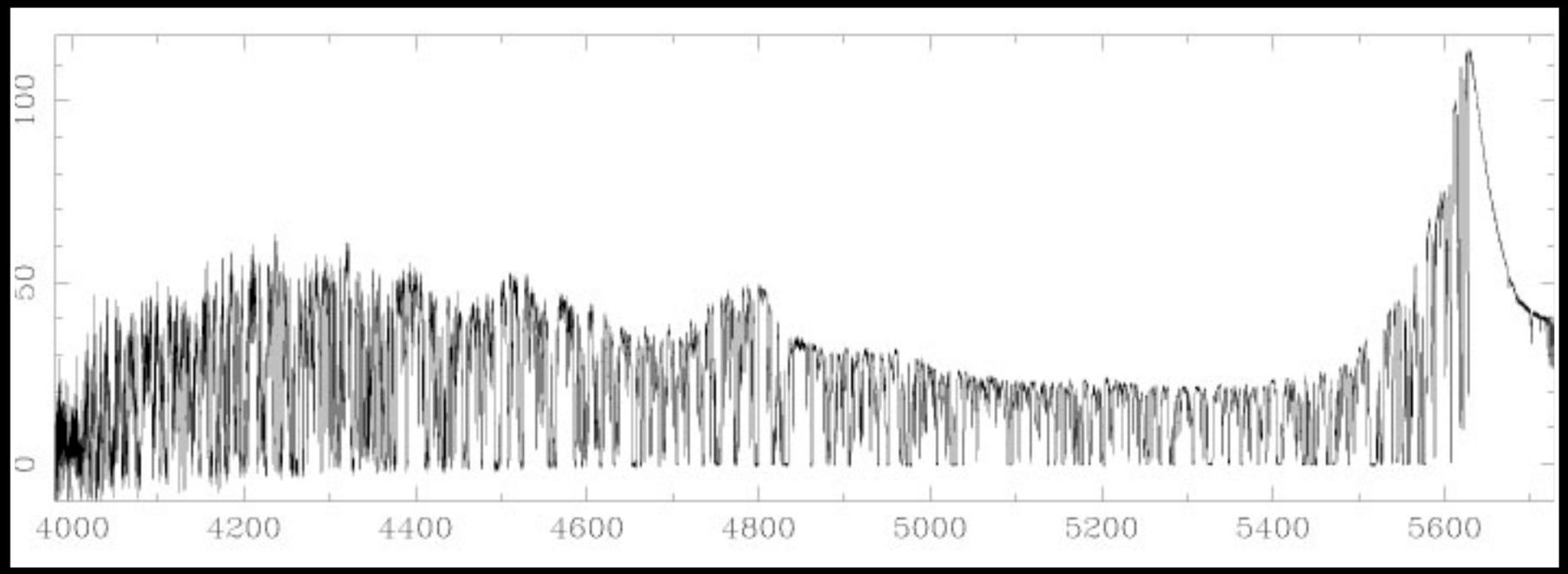


Joseph Caruana, University of Malta

What should an observer expect to see at very high z?

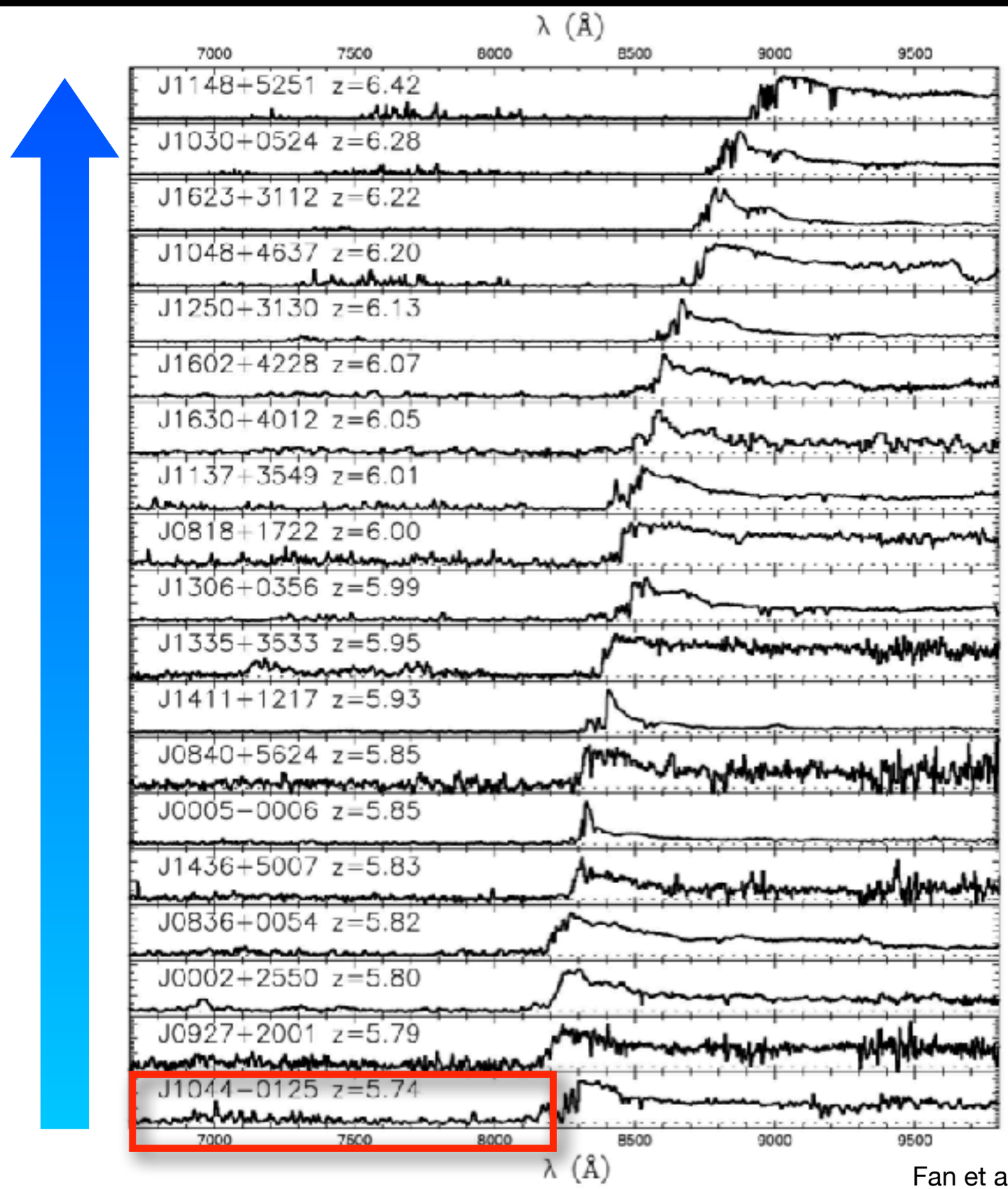


What should an observer expect to see at very high z?

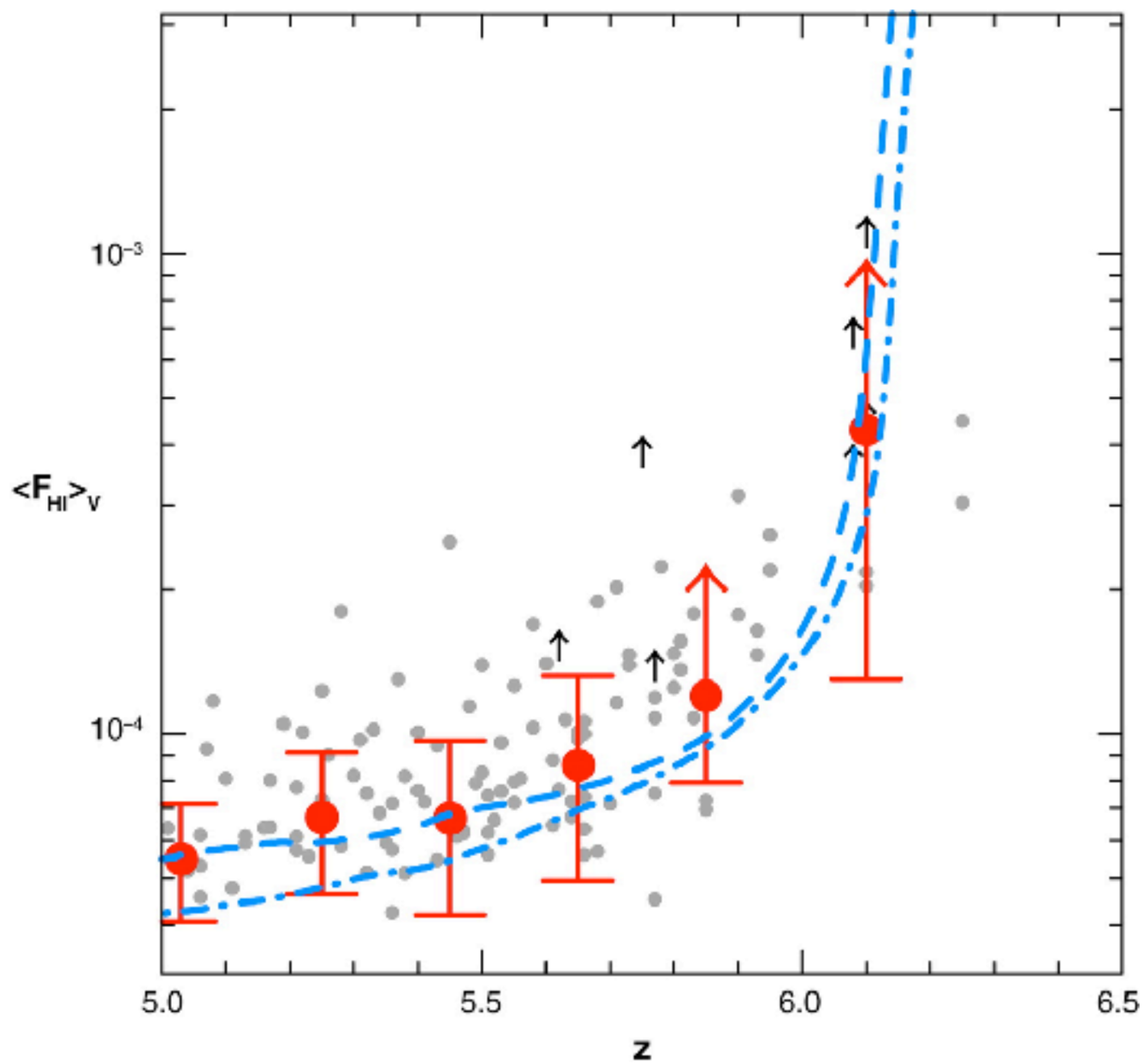


High resolution spectrum of QSO 1422+23 (Womble et al. 1996)

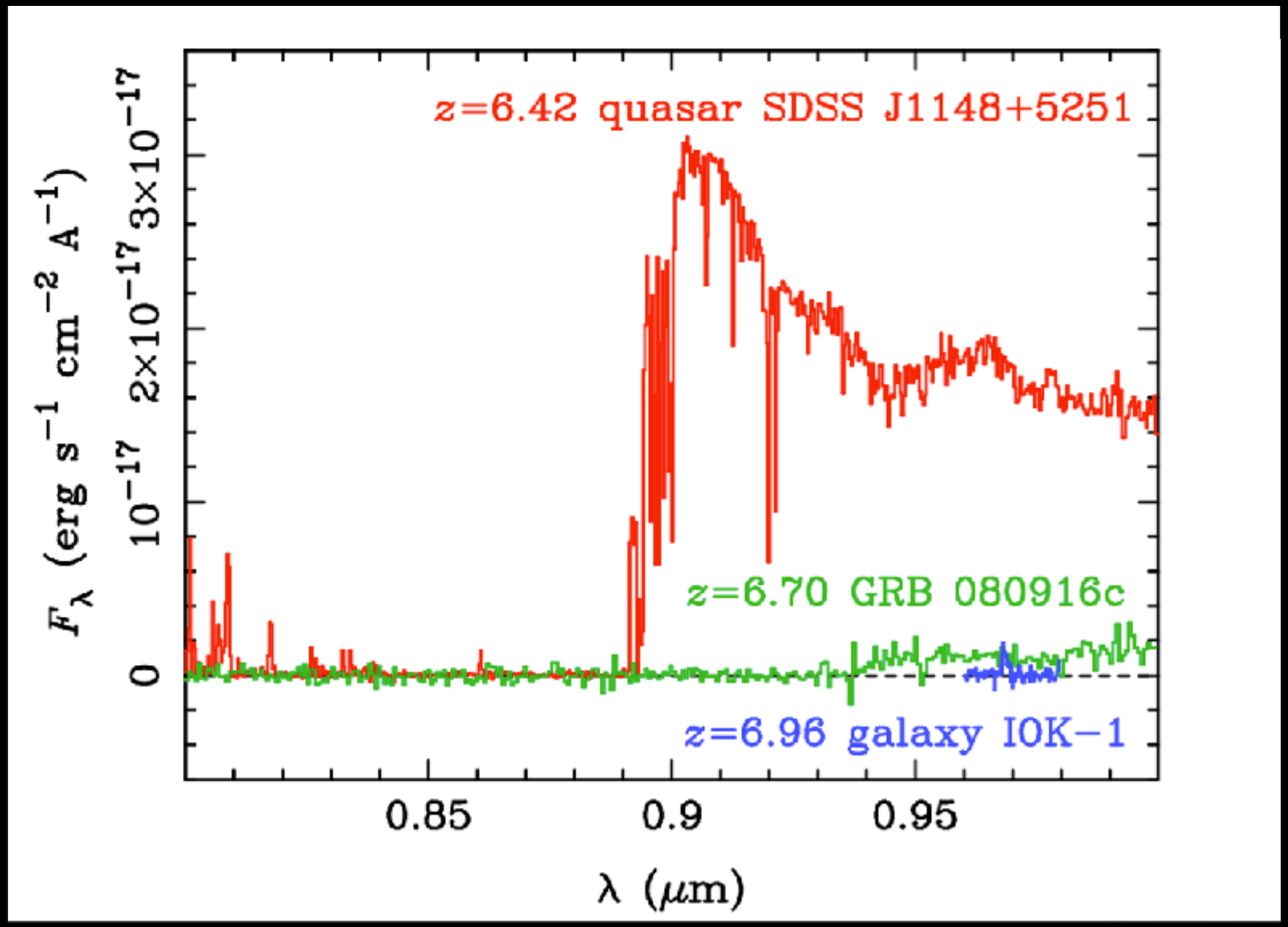
increasing redshift



Fan et al. (2006)

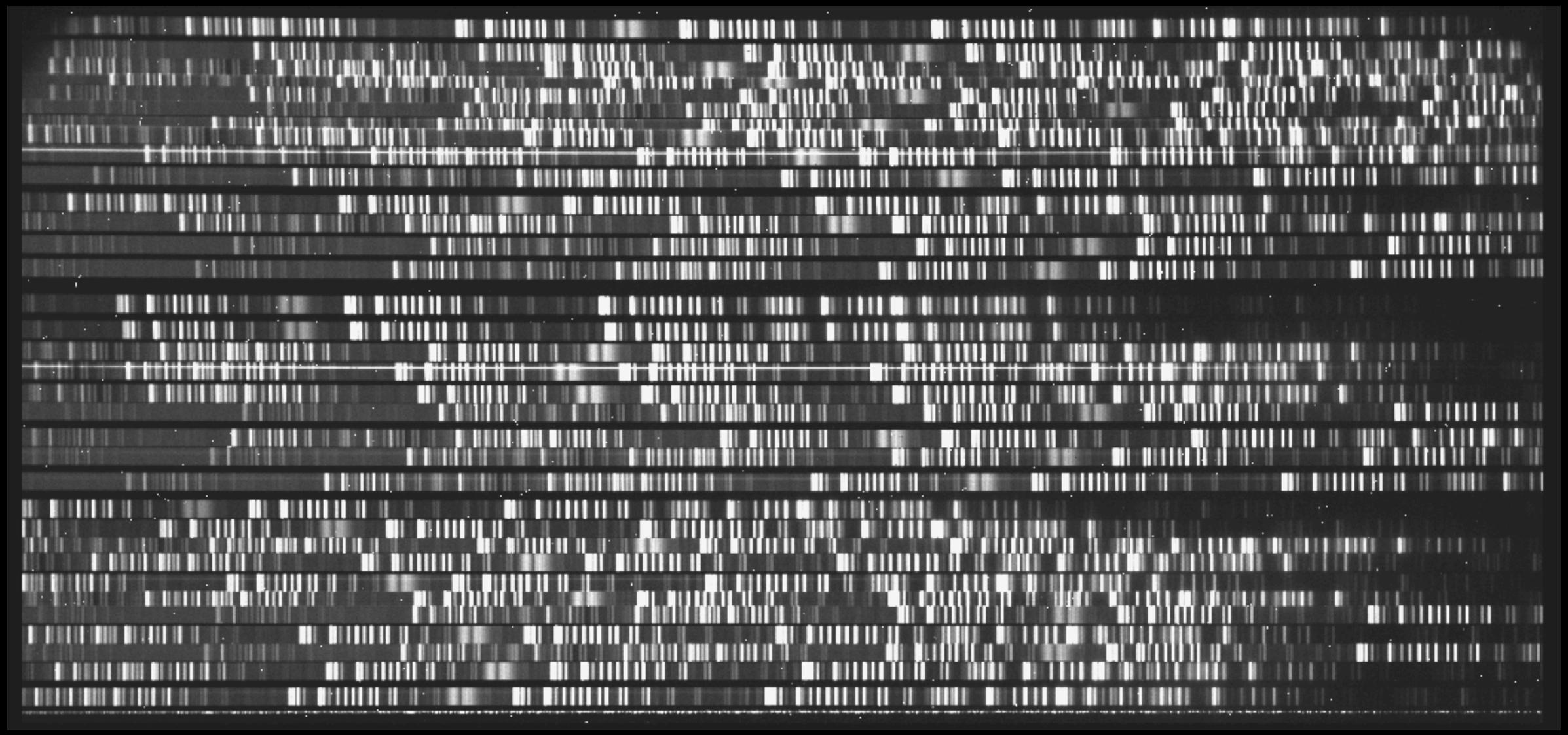


Fan et al. (2006)

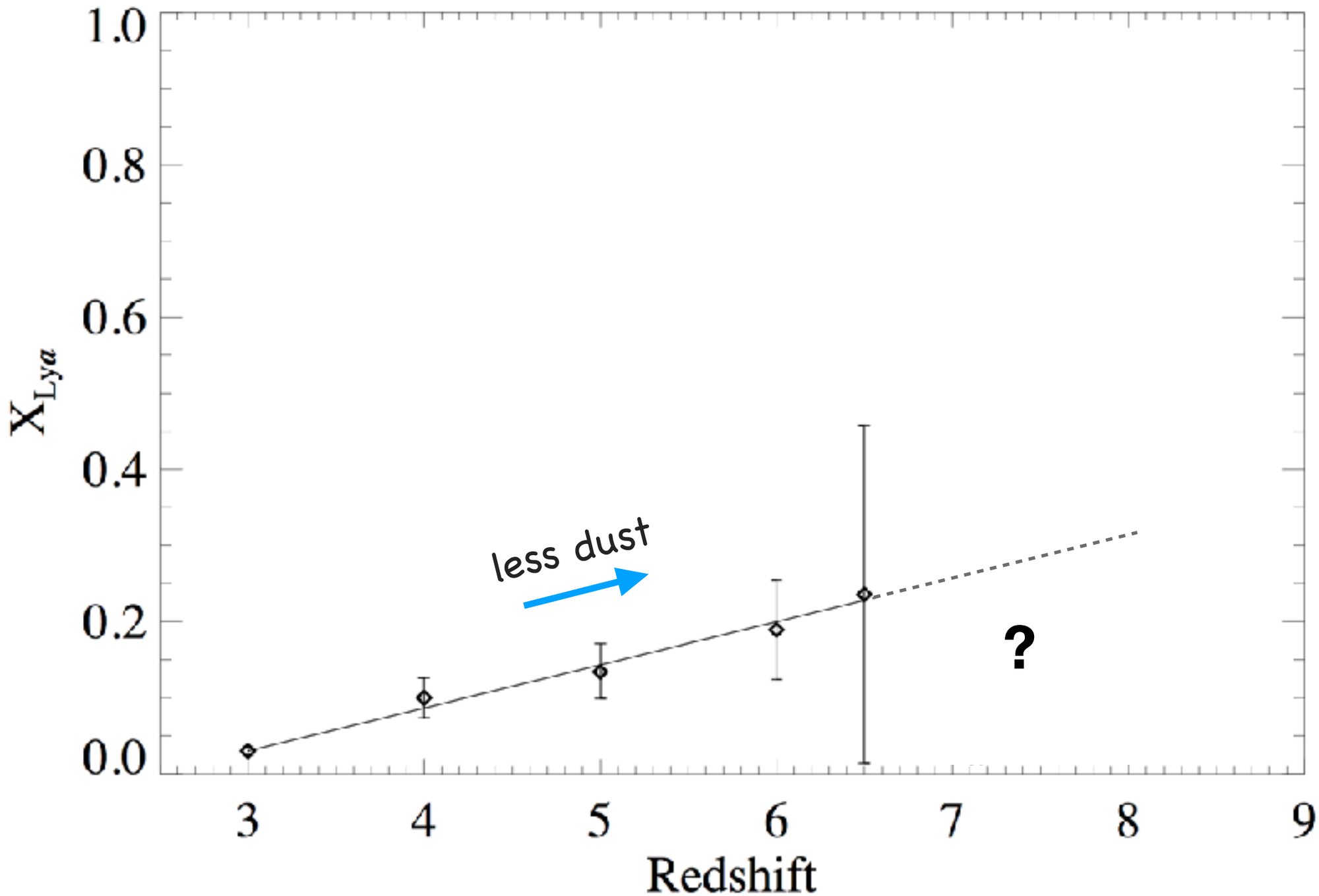


Daniel Mortlock

Spectroscopy with VLT/FORS2



Joseph Caruana, University of Malta


1.0
0.8
0.6
0.4
0.2
0.0
$X_{Ly\alpha}$
less dust
?
3
4
5
6
7
8
9
Redshift

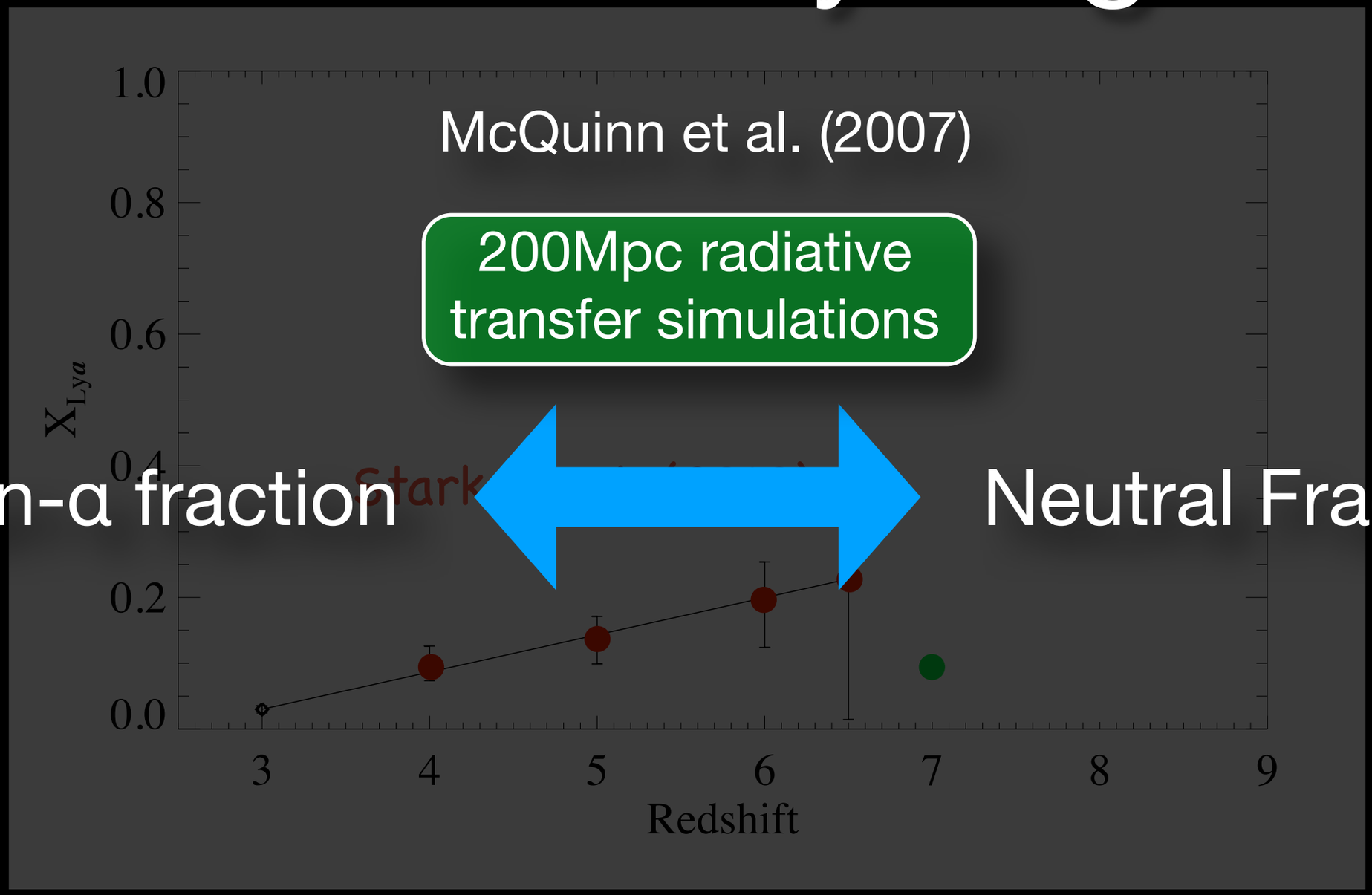
Constraining the neutral fraction of Hydrogen

Predictions from simulations

Need to simulate:

- The growth of structure in the early Universe.
- The patchy reionization of the IGM (where many essential parameters are still poorly constrained)
- Star formation in the first galaxies
- Complicated radiative transfer of Lyman-alpha photons.

Constraining the neutral fraction of Hydrogen



Lyman-α fraction

Neutral Fraction

Caruana et al. (2014)

Constraining the neutral fraction of Hydrogen

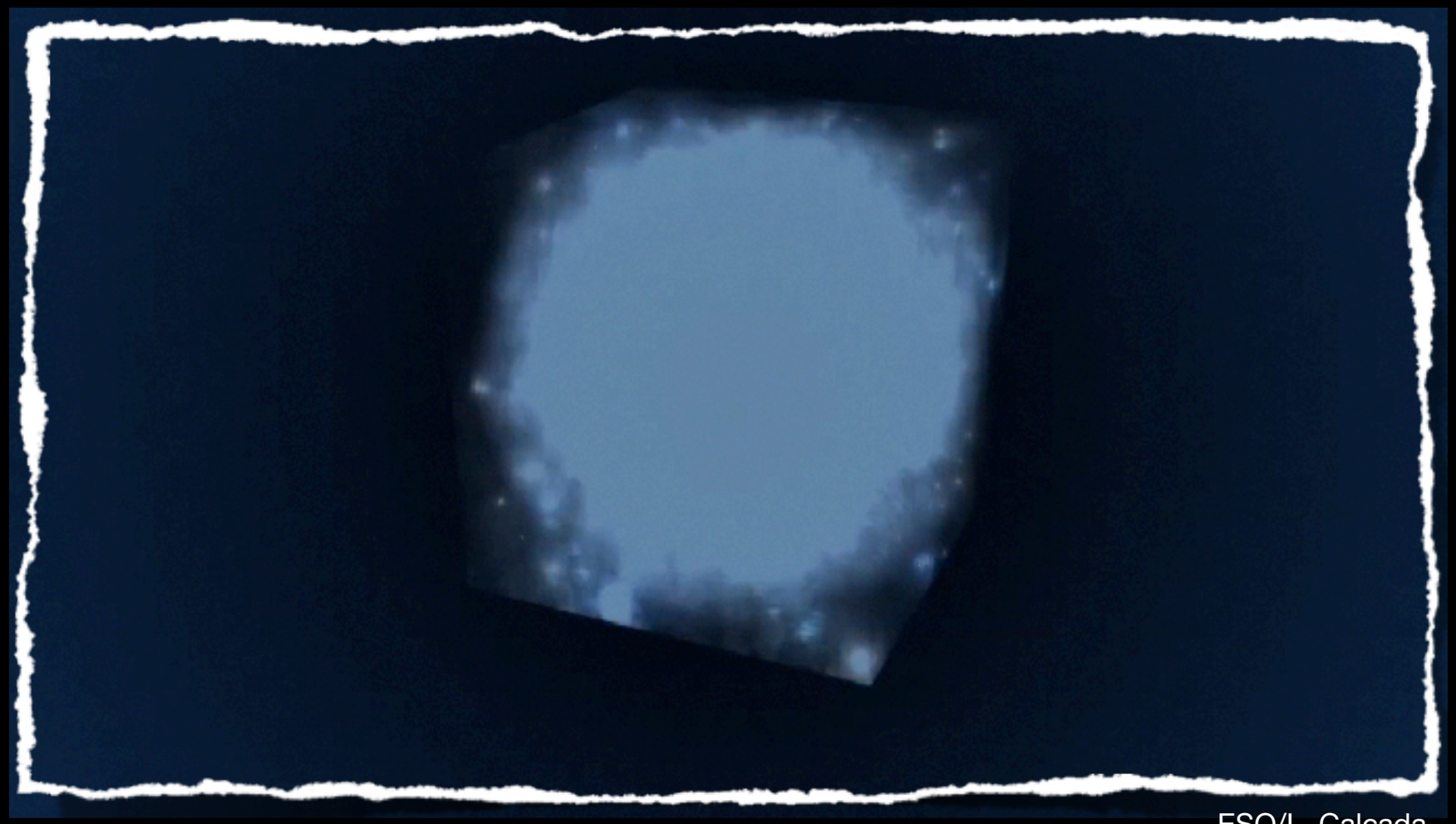
$\chi_{HI} = 0.5$

$\chi_{HI} = 0.44\text{-}0.51$ (Schenker et al. 2012)
McQuinn et al. (2007)

$\chi_{HI} = 0.6\text{-}0.9$ (Ono et al. 2012)
Dijkstra et al. (2011)

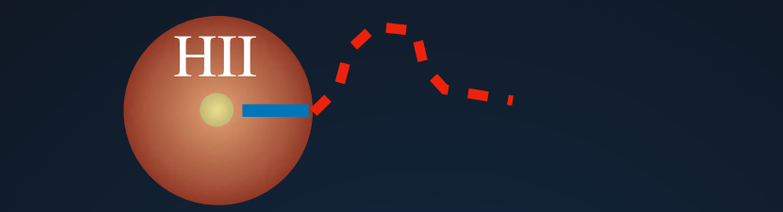
$\chi_{HI} = 0.32 - 0.62$ (Ota et al. 2008, 2010)
Santos (2004)

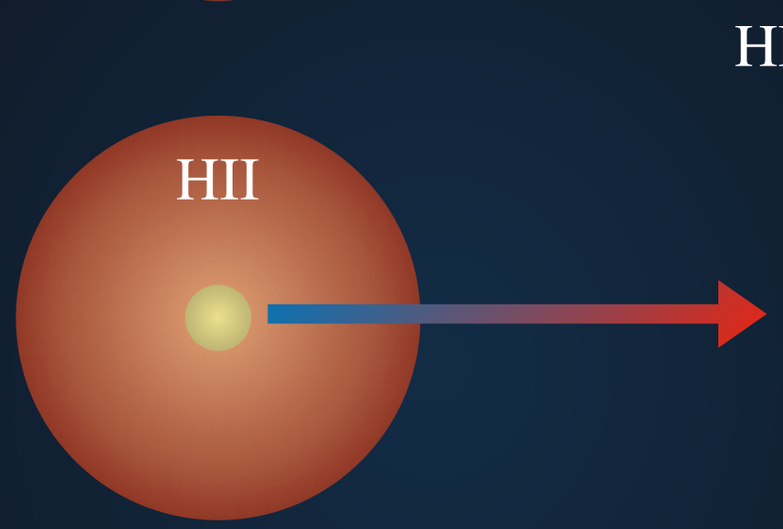
$\chi_{HI} \geq 0.3$ (Tilvi et al. 2014)
Bolton & Haehnelt 2013, Dijkstra et al. (2014)

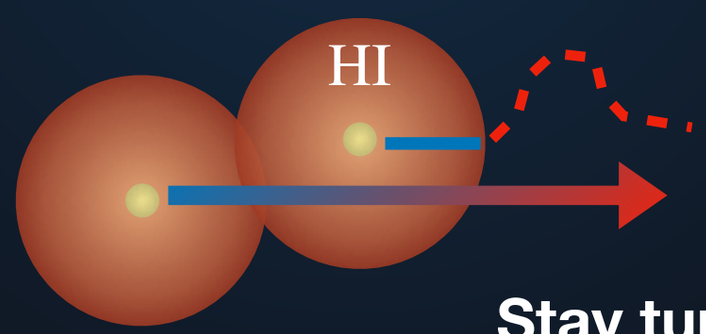


ESO/L. Calçada

The Escape of Lyα







Stay tuned!

Joseph Caruana, University of Malta

Lyα attenuation: IGM opacity or dust?

Compare shape of Lyman-alpha line with that of the non-resonant Balmer line.

Dust

perhaps more (due to extra path length before escaping)

Lyman-alpha photons

UV continuum photons

possibly affected by equal amounts

Balmer line

affected less

Joseph Caruana, University of Malta

Lyα attenuation: IGM opacity or dust?

1) Pick a galaxy with measured Lyman-alpha and UV continuum

no more dependence on f_{esc} like when converting between Lyman-alpha flux and SFR

Derive SFR

2) Measure [H-alpha/H-beta] → Derive SFR

Agreement?

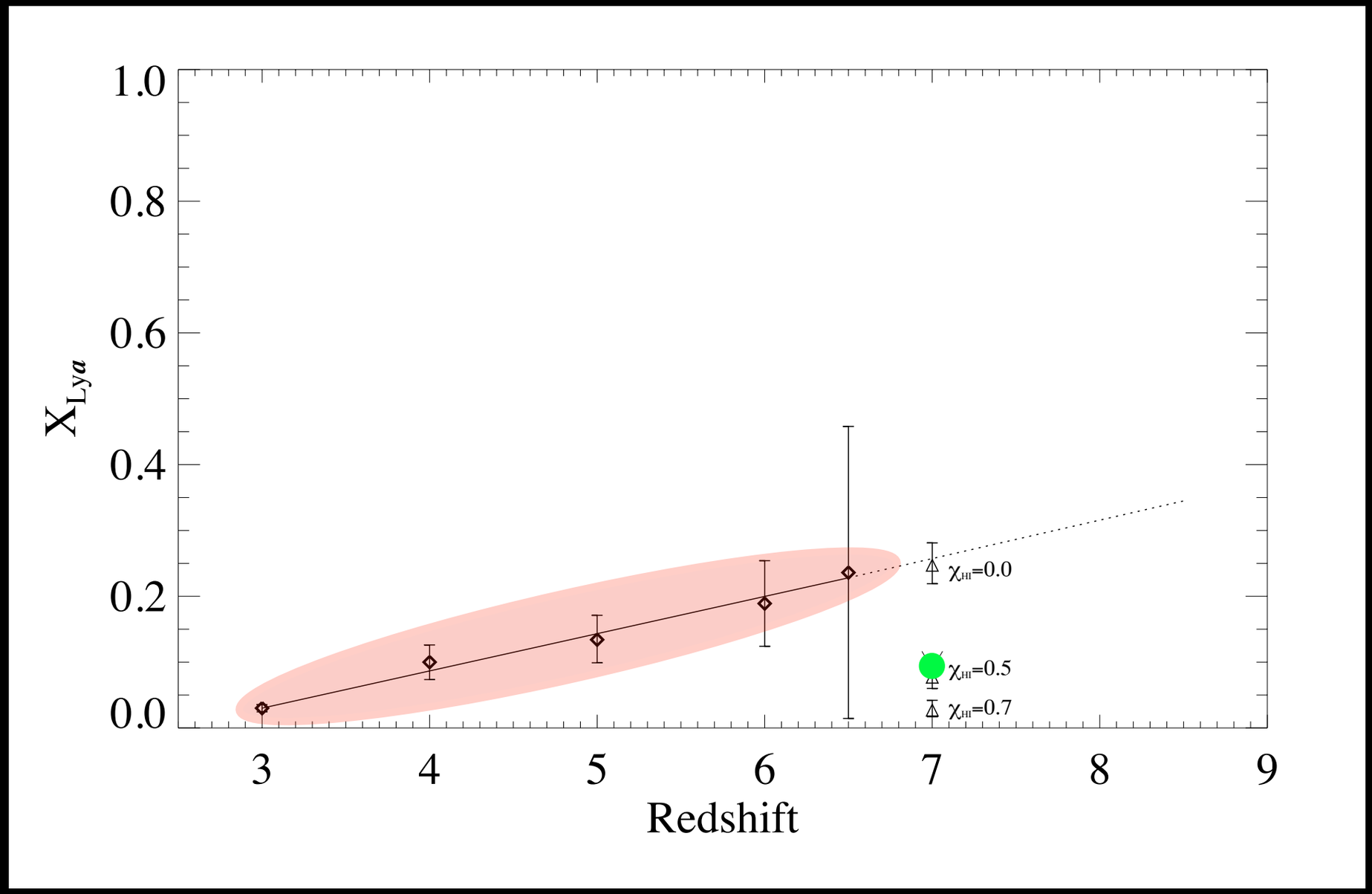
Agreement?

Predictions for no extinction

Then ignore dust! Yay!

Joseph Caruana, University of Malta

Returning to this plot…



Caruana et al. (2014)

(1) Multi-object slit spectroscopy

Entails choosing an observing setup configured
to target the required wavelength space.

or

(2) Narrow-band searches

Tuned to specific redshift.
(More suited to surveying a narrow redshift slice.)

MUSE
(Multi-Unit Spectroscopic Explorer)

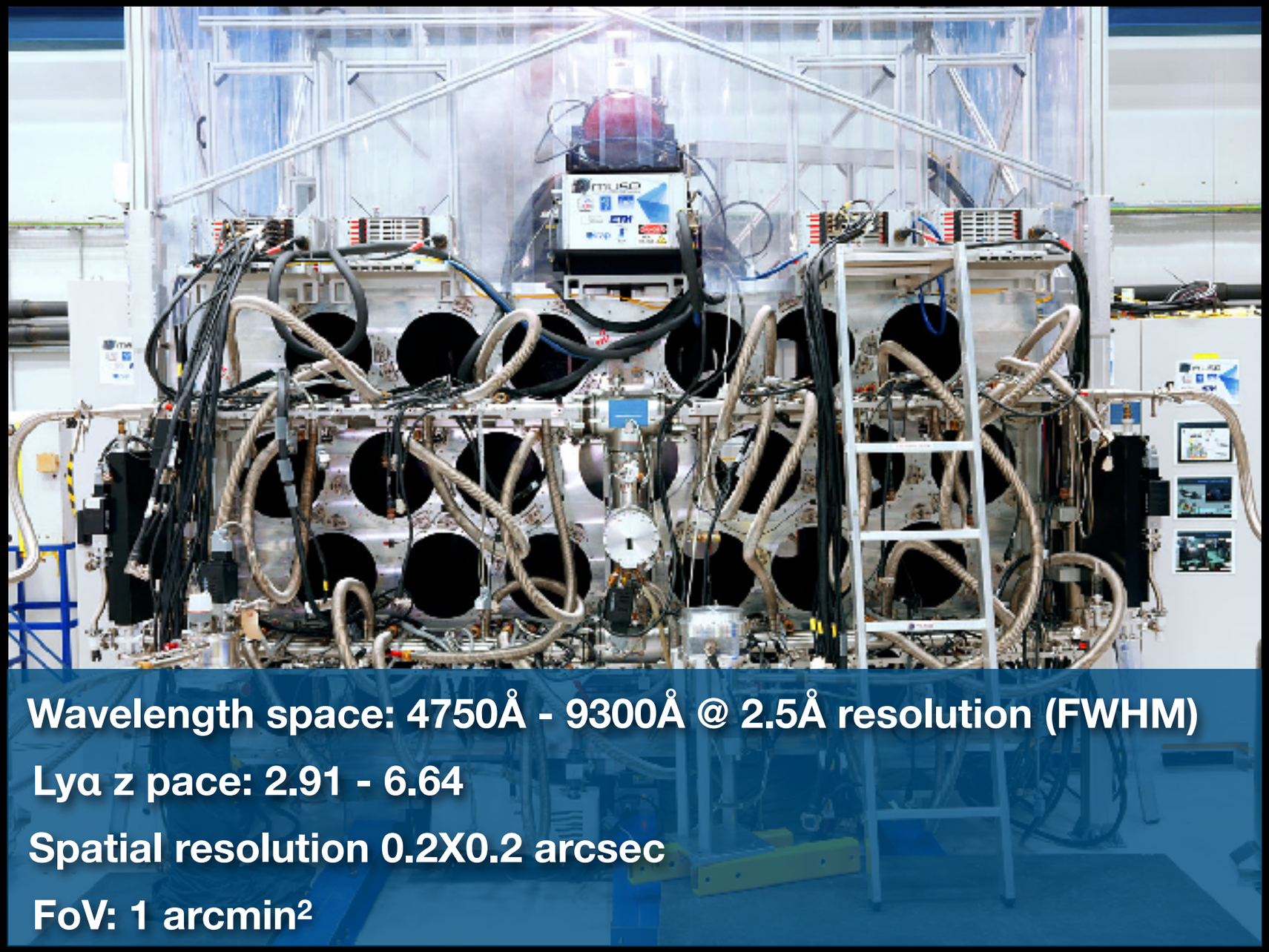
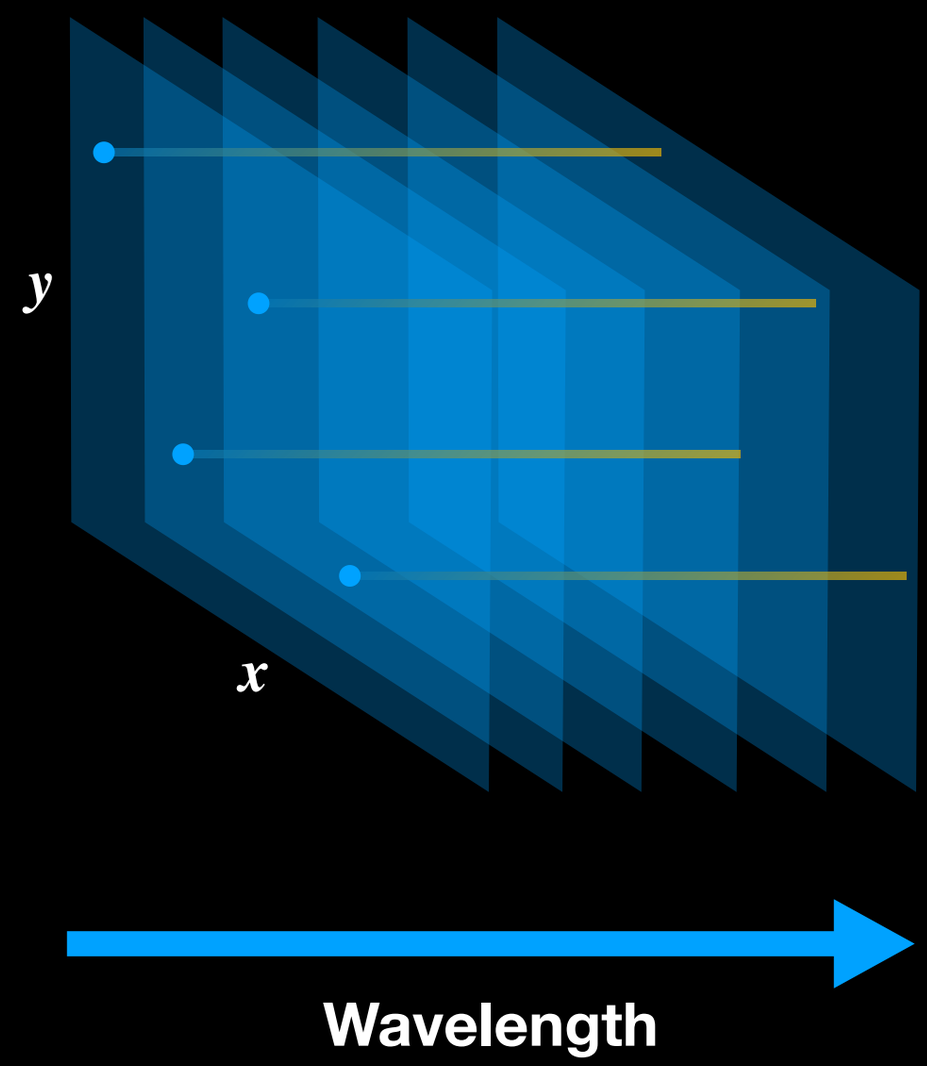


Image Credit: M. Najjar / ESO

MUSE
(Multi-Unit Spectroscopic Explorer)



Joseph Caruana, University of Malta

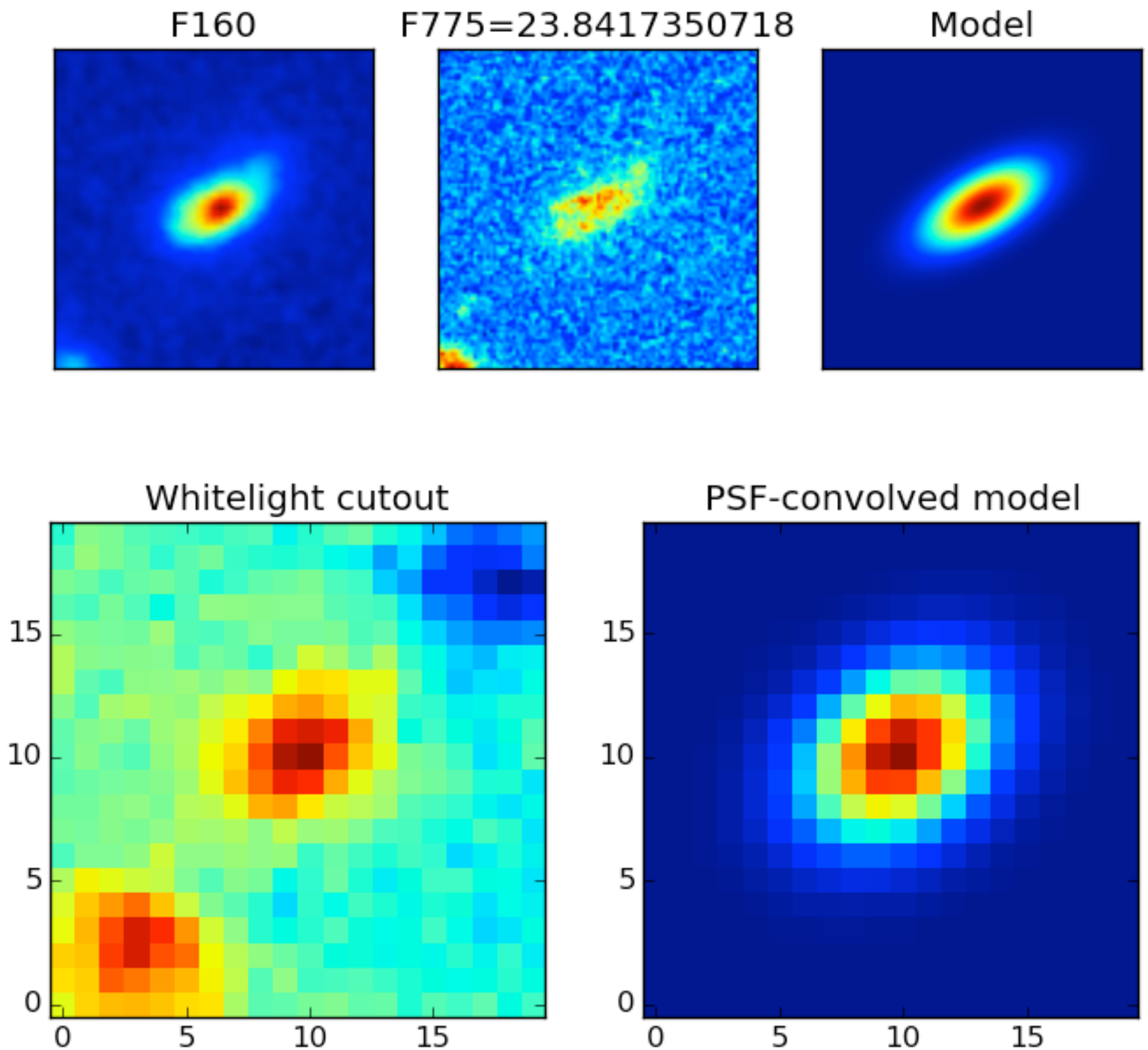
MUSE-Wide: Measurement of the Lyα fraction

- MUSE-Wide is a relatively shallow (1h) survey with MUSE as part of GTO.
- Final survey covers 100 arcmin^2 in areas with deep HST imaging and complementary multi-wavelength data, with the CDFS as the primary region of interest.
- The following study uses data from the first 24 pointings in the CDFS-Deep part of the CANDELS *HST* imaging survey (Grogin et al. 2011, Koekemoer et al. 2011) built on top of earlier GOODS imaging campaign (Giavalisco et al. 2004).

MUSE-Wide: Measurement of the Lyα fraction

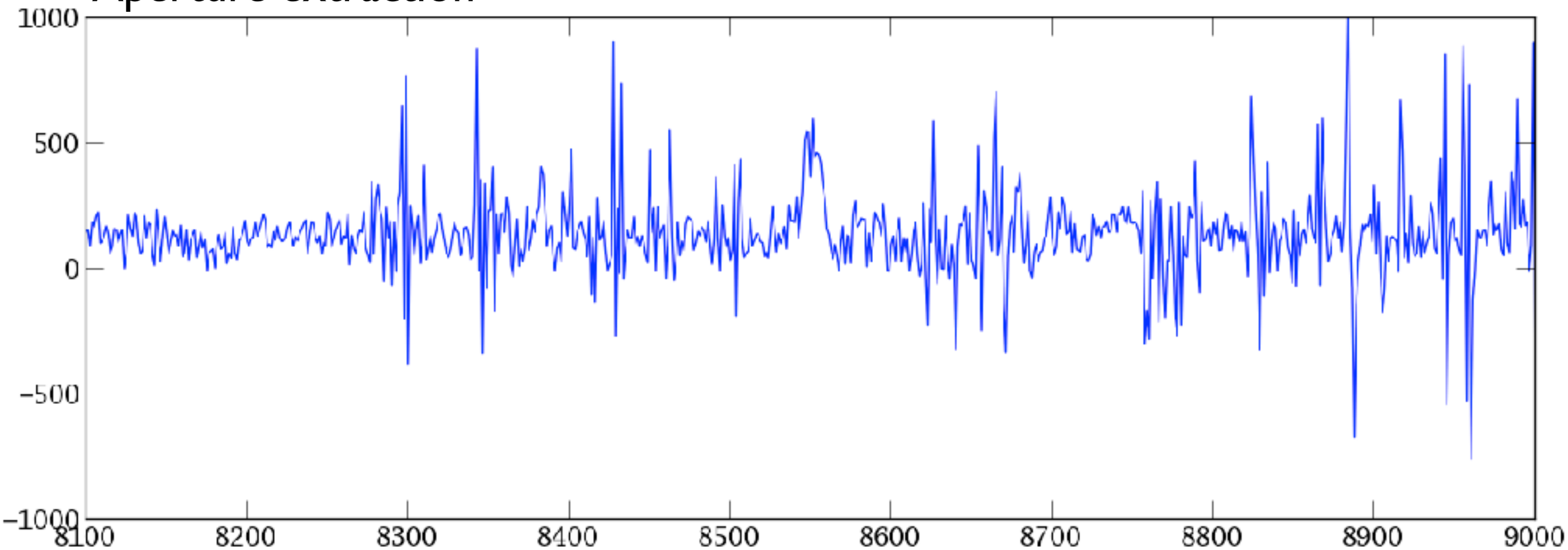
- Catalogue of all HST continuum-detected sources in GOODS South (Guo et al. 2013).
- Apply magnitude cut $m_{775W} < 26.5$.
- CANDELS/3D-HST (near-IR-detected) catalogue includes photometric redshifts (Skelton et al. 2014).
- Apply photo-z cut of z>2.
- We ended up with a final list of 532 objects to inspect for Lyα.

cross-match

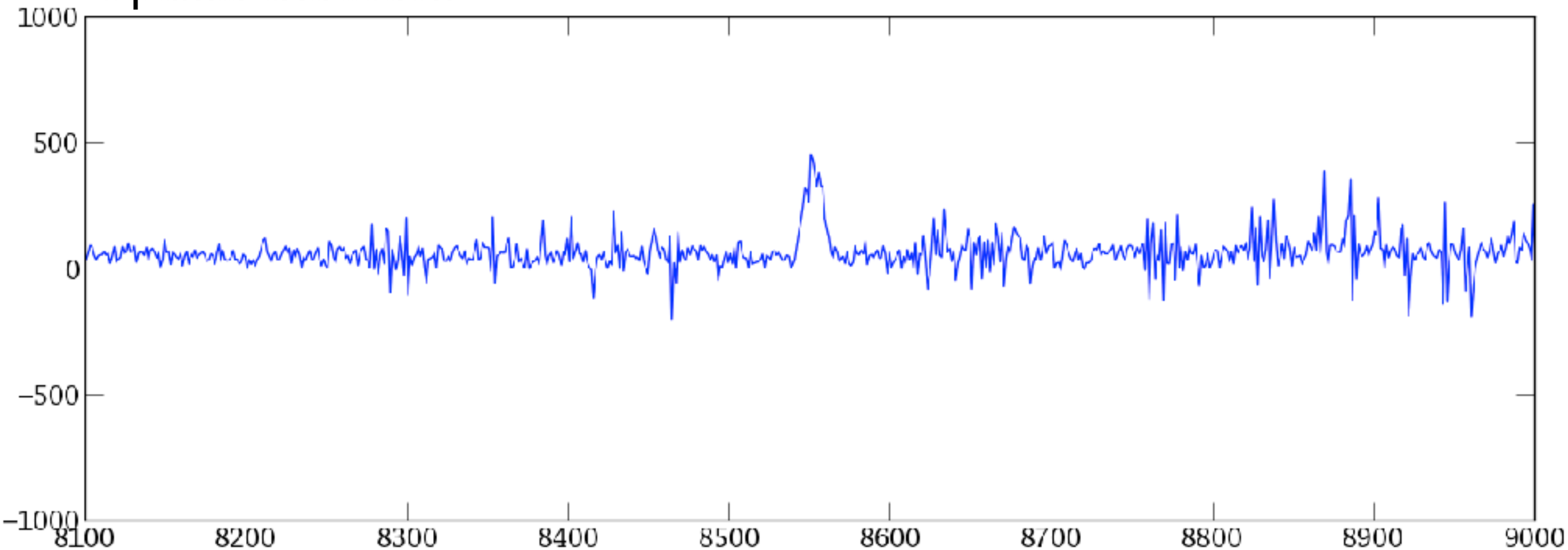


$$\alpha_k = \frac{\sum_{ij}\left\{(d_{ijk} \times t_{ijk}) / \sigma_{ijk}^2\right\}}{\sum_{ij}\left\{t_{ijk}^2 / \sigma_{ijk}^2\right\}}$$

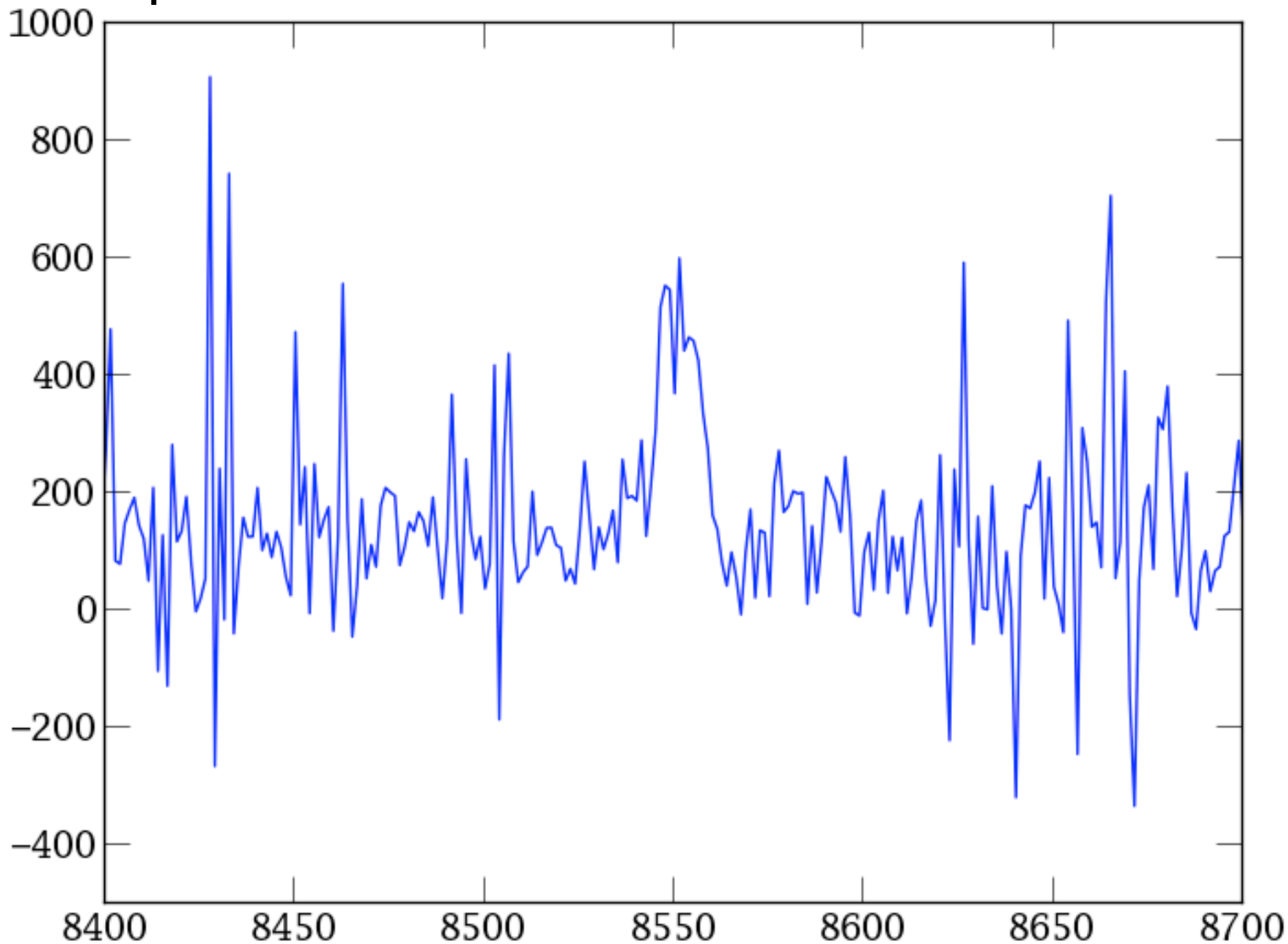
Aperture extraction



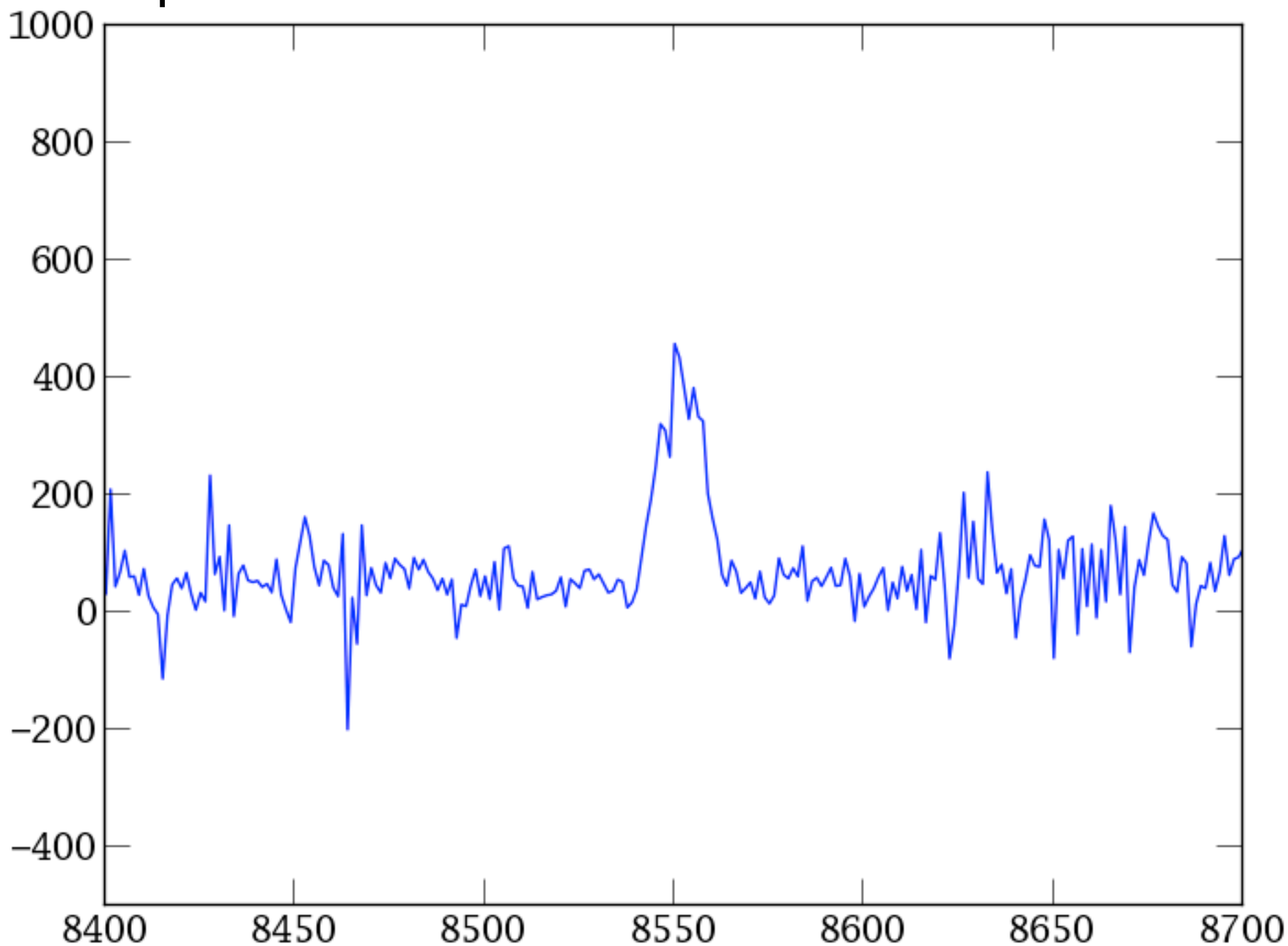
Optimal extraction



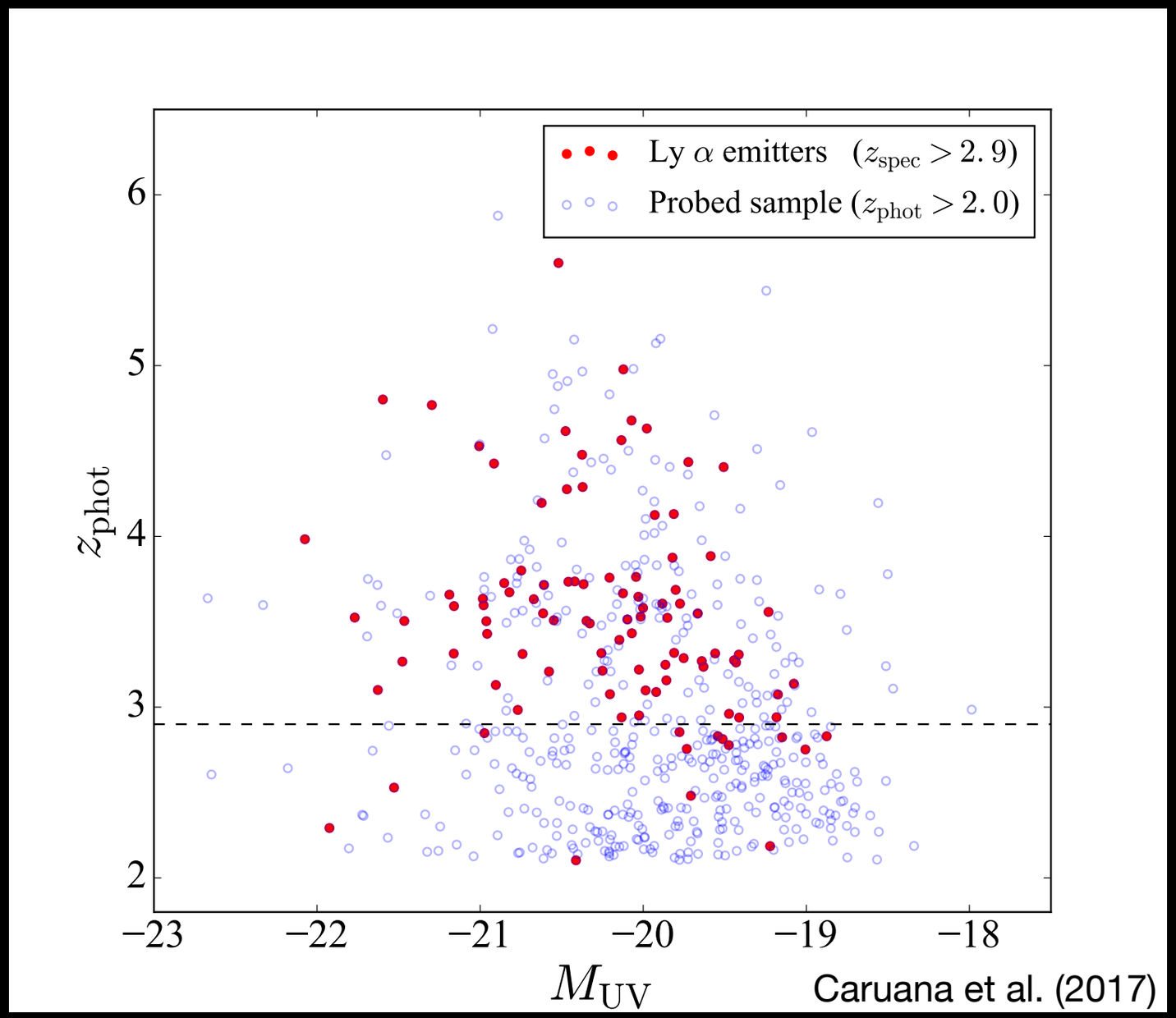
Aperture extraction



Optimal extraction



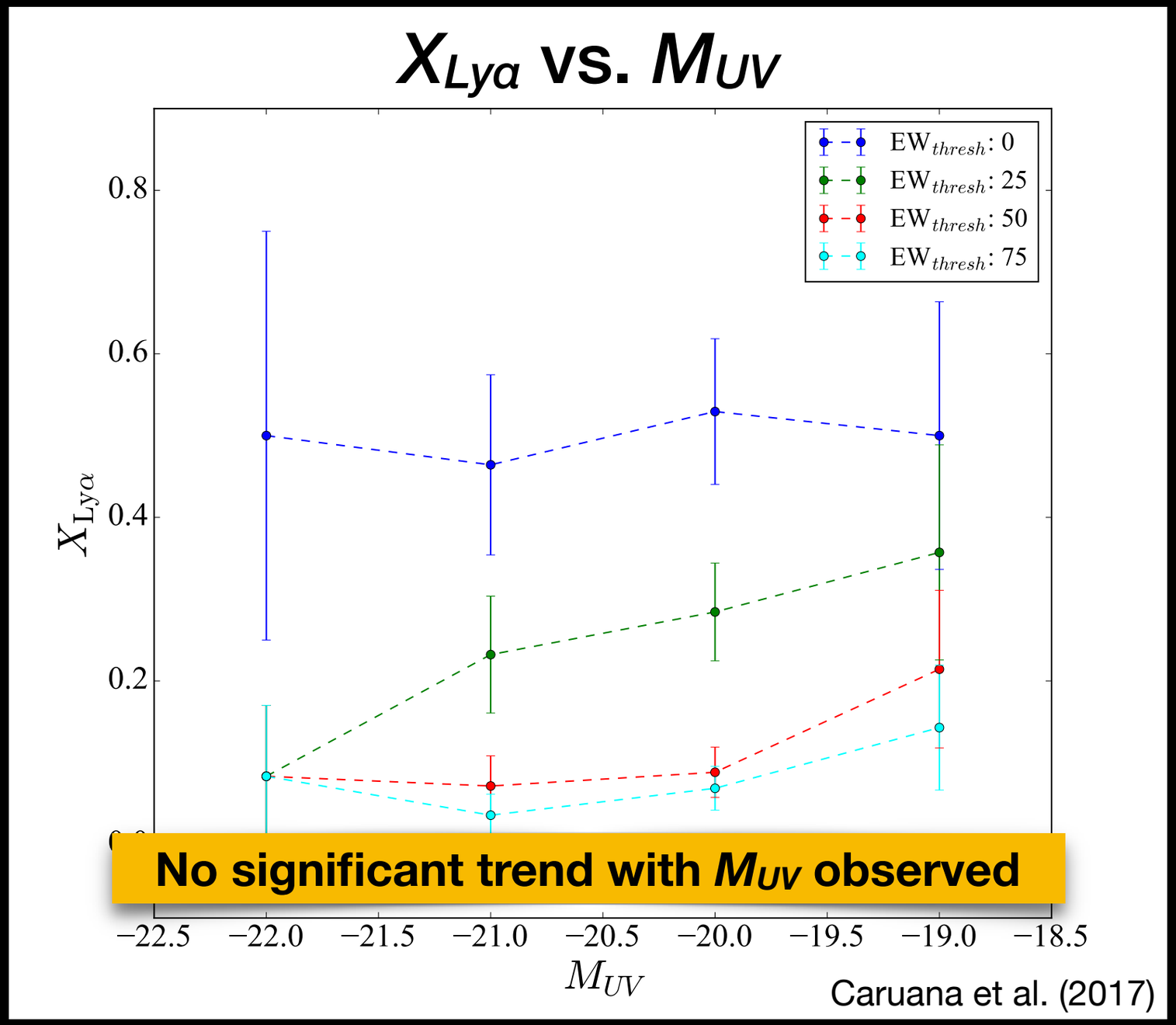
MUSE-Wide: Measurement of the Lyα fraction



MUSE-Wide: Measurement of the Lyα fraction

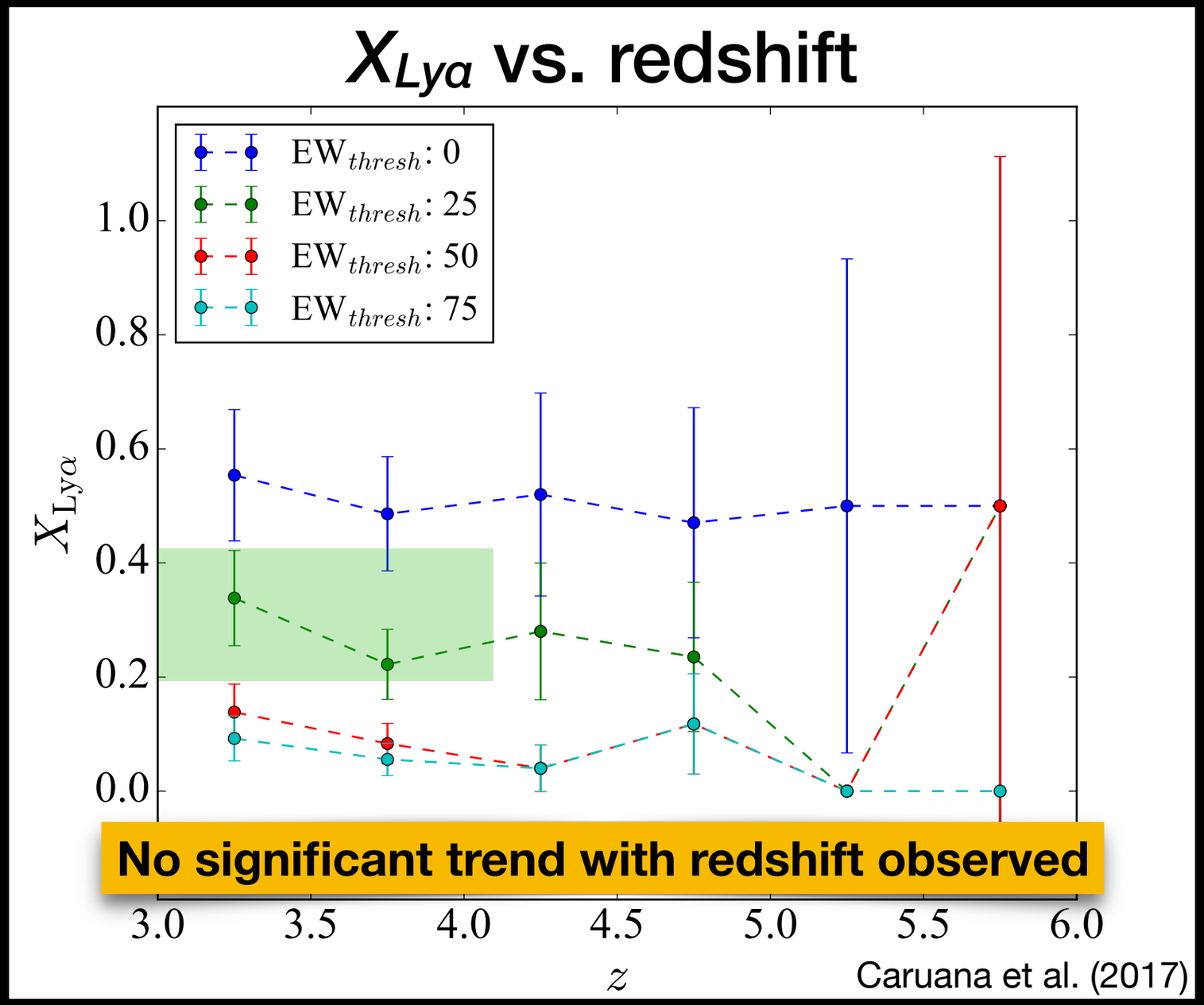
- Applying a S/N cut of 4.0, we find Lyman α in 100 out of 198 sources with z_phot>2.9.
- The fraction of Lyman α emitters, $X_{Ly\alpha} \geq 0.5$ for most of the redshift range covered.
- 29% of the Lyα sample exhibits rest-EW ≤ 15Å.
- No evidence of $X_{Ly\alpha}$ evolution with either redshift or M_{UV}.

MUSE-Wide: Measurement of the Lyα fraction



MUSE-Wide: Measurement of the Lyα fraction

Twice the number found by Cassata et al. (2015)
$X_{Ly\alpha} \geq 0.22$ vs. 0.12



MUSE-Wide: Measurement of the Lyα fraction

Two interesting questions are raised

MUSE-Wide: Measurement of the Lyα fraction

(1) Lack of a trend of $X_{Ly\alpha}$ with redshift

↓

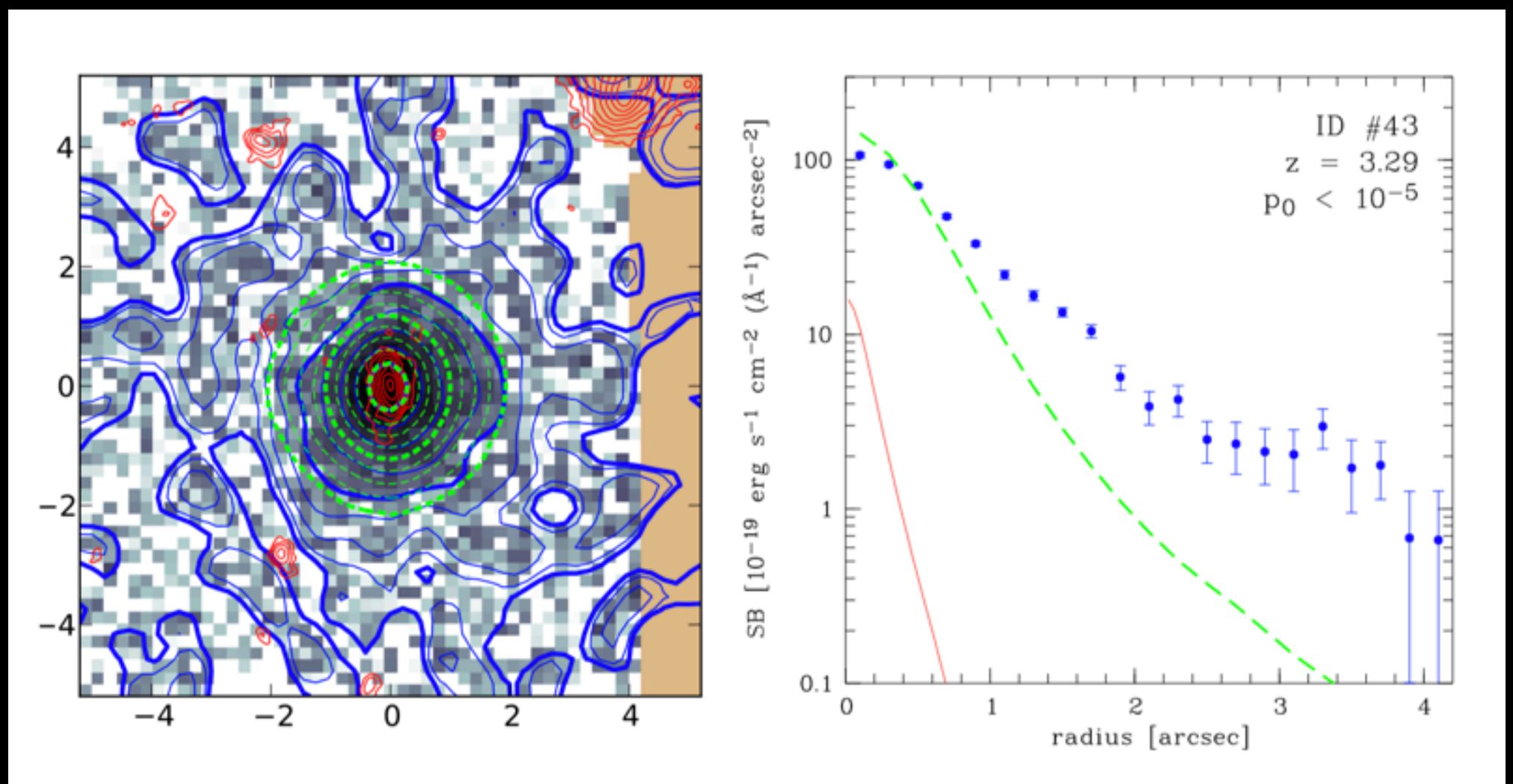
Potentially a significant component of extended Lyα residing in the halos surrounding these sources (see also Wisotzki et al. 2016)

↓

Missed by previous studies utilising slit spectroscopy? (Slit not large enough to encompass this emission?)

MUSE-Wide: Measurement of the Lyα fraction

(1) Lack of a trend of $X_{Ly\alpha}$ with redshift

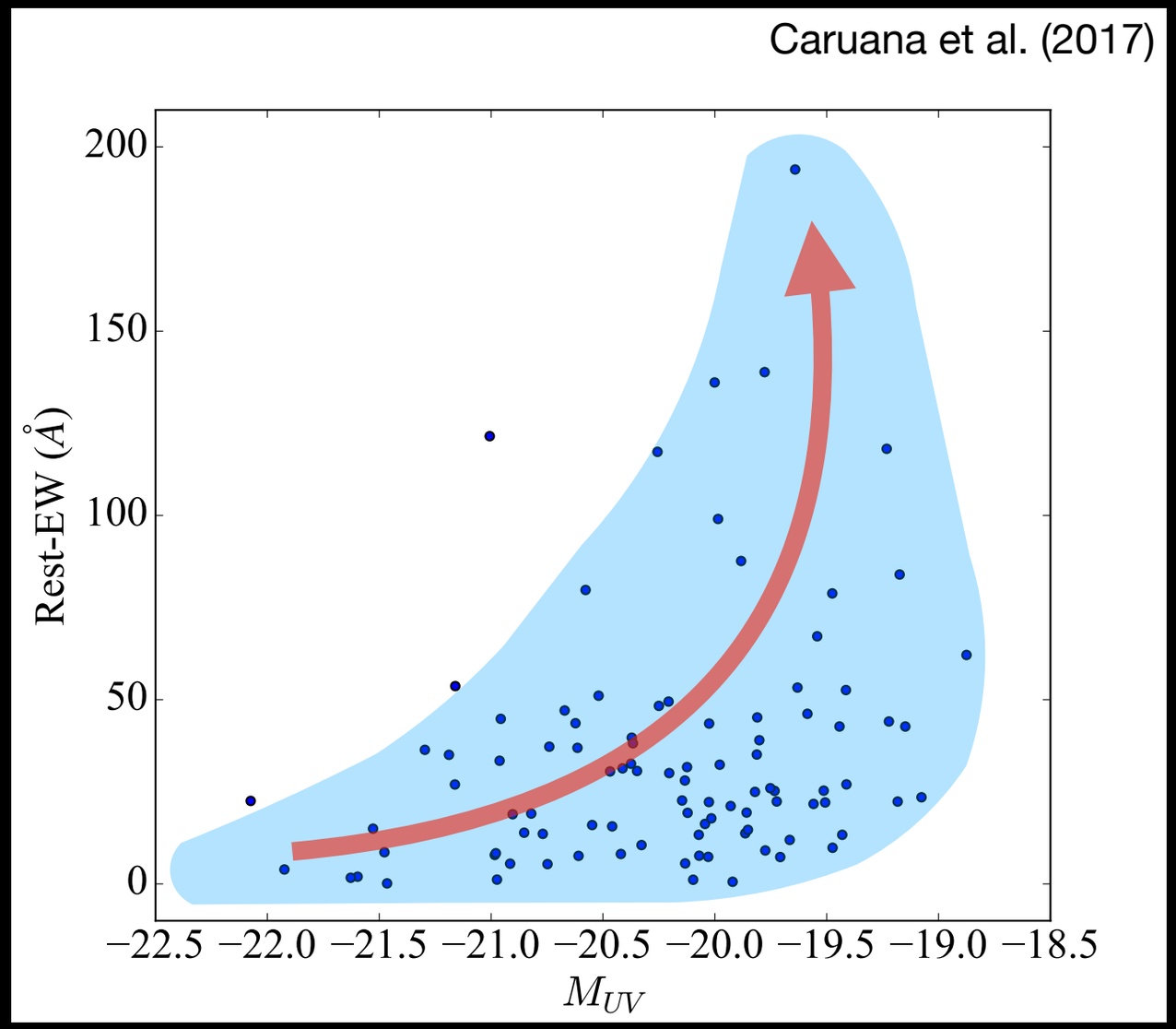


(Slit not large enough to encompass this emission?)

Joseph Caruana, University of Malta

MUSE-Wide: Measurement of the Lyα fraction

(2)



Search for Lyα more fruitful if one looks at fainter galaxies?
(Open question as ionised bubble might then not be large enough.)

MUSE-Wide: Measurement of the Lyα fraction

- Take home point:

  By adding sensitivity to the low-EW regime, (even shallow) MUSE surveys can clearly provide new insights into the overall fraction of Lyα emitters.

Conclusions

- Demonstrated benefits of IFU spectroscopy combined with optimal spectral extraction, capturing flux from sources that would otherwise go undetected.
- Extended halos of Lyα emission harbour flux that could be missed in slit spectroscopy.
- $X_{Ly\alpha}$ at $3 < z < 4$ for rest-EW > 25Å found to be twice the number found by Cassata et al. (2015).
- A number of detected objects have sub-10Å rest-EWs.
- Caution is required with regards to interpretation of Lyα statistics at $3 < z < 6$.
- More studies (large number statistics) are needed of Ly α emitters in this redshift range. MUSE is very well poised to answer some long-standing questions in this regard.
- Interesting questions to be answered with regards to visibility of Lyα in $z > 7$ objects that are in close proximity (i.e. galaxy pairs). Stay tuned!
- JWST will allow us to account for dust via measurement of Hα & Hβ.