

Chasing Ly α Halo



Team QSOs @MPIA:

- Fabian Walter
- Bram Venemans
- Roberto Decarli
- Eduardo Bañados
- Emanuele Paolo Farina
- Chiara Mazzucchelli

Extended Team QSOs:

- Xiaohui Fan
- Benjamin Weiner
- Joe Hennawi
- Fabrizio Arrigoni-Battaia
- Sebastiano Cantalupo

History of the Universe

Time since the Big Bang (years)

~ 300 thousand

~ 500 million

~ 1 billion

~ 9 billion

~ 13 billion



← The Big Bang

The Universe filled with ionized gas

← The Universe becomes neutral and opaque

The Dark Ages start

Galaxies and Quasars begin to form
The Reionization starts

← $z \sim 7.5$

The Cosmic Renaissance
The Dark Ages end

← Reionization complete, the Universe becomes transparent again

← $z \sim 6.0$

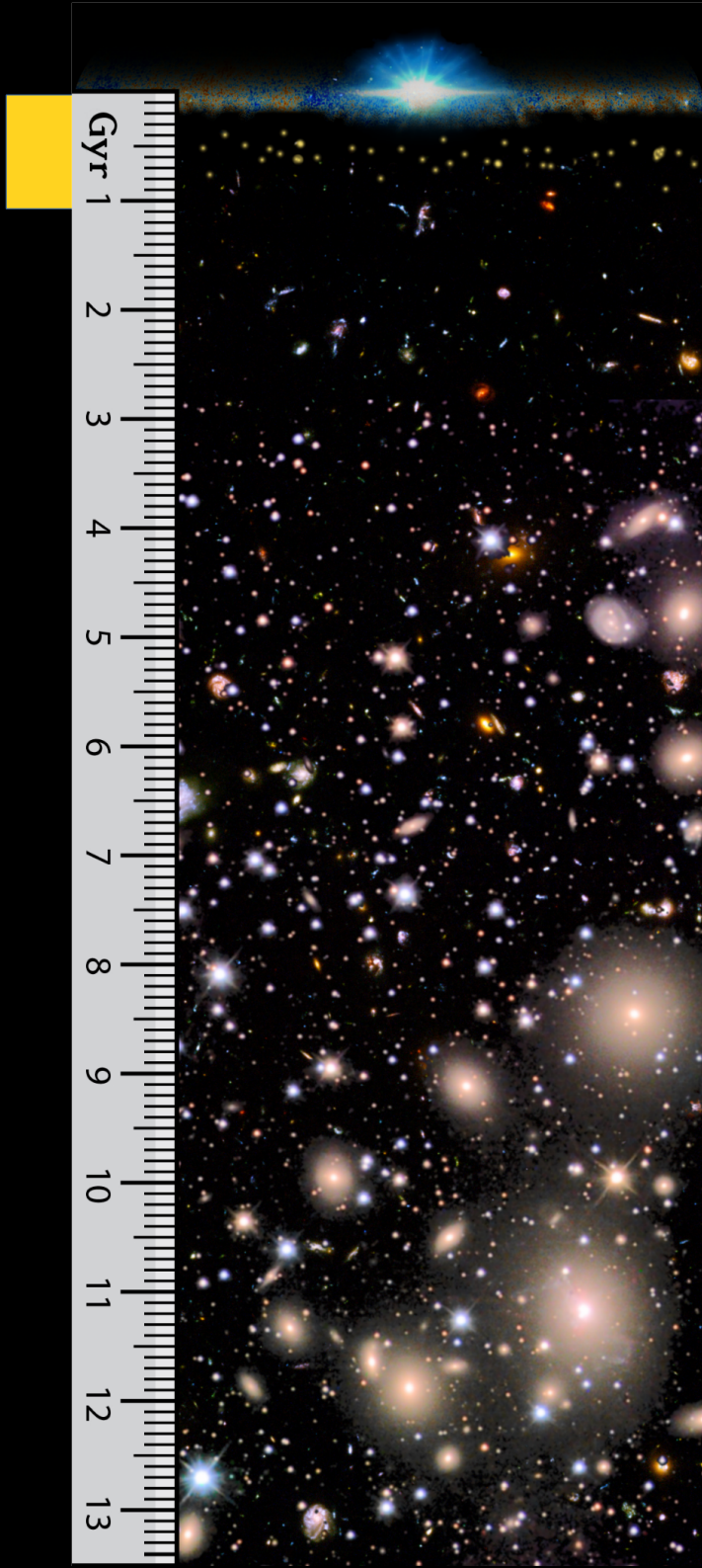
Galaxies evolve

The Solar System forms

Today: Astronomers figure it all out!

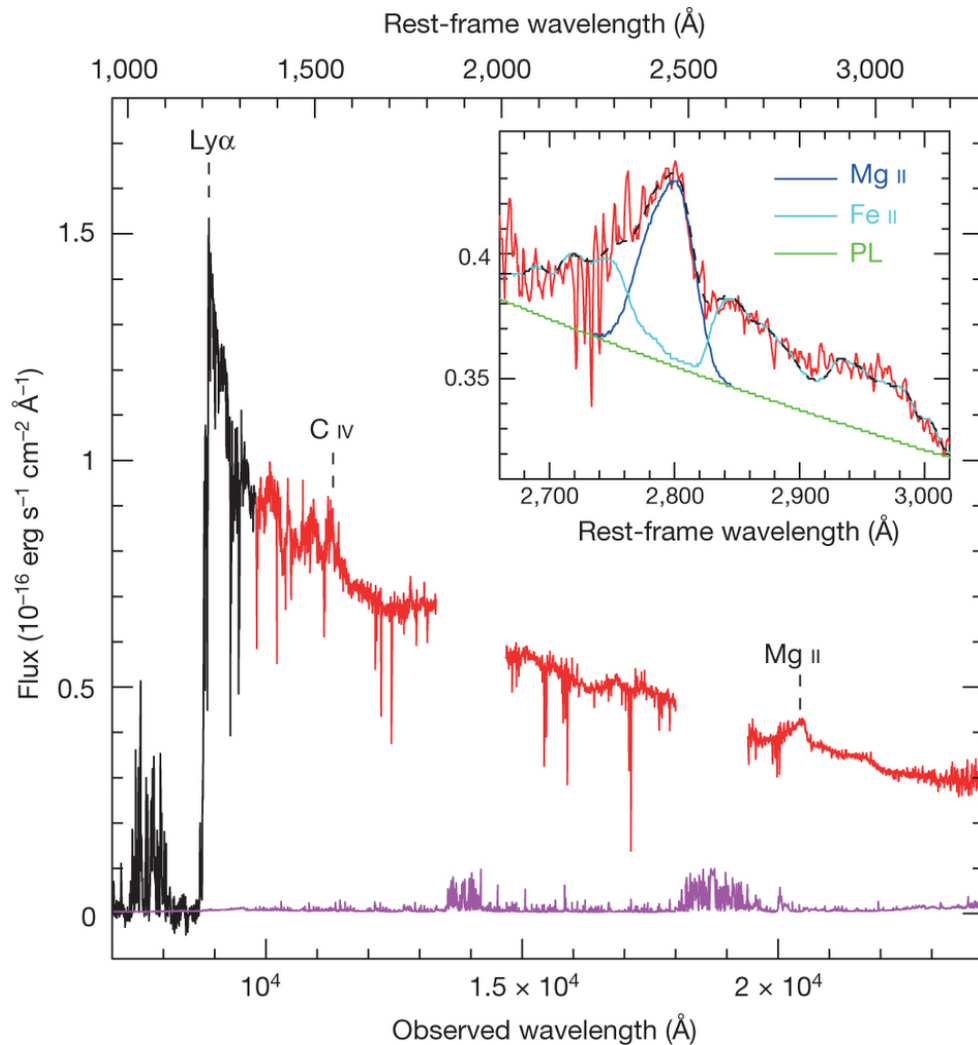
History of the Universe

$z \sim 5.5$ →

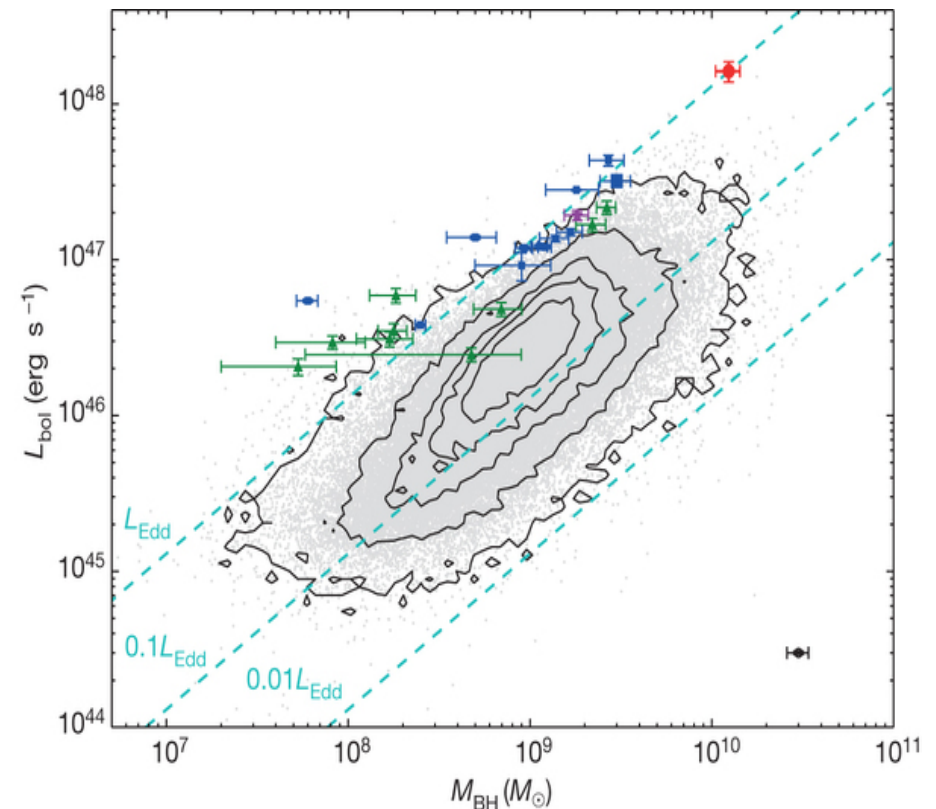


← $z \sim 7.5$

Supermassive Black Holes



accreting at Eddington
(or more..)

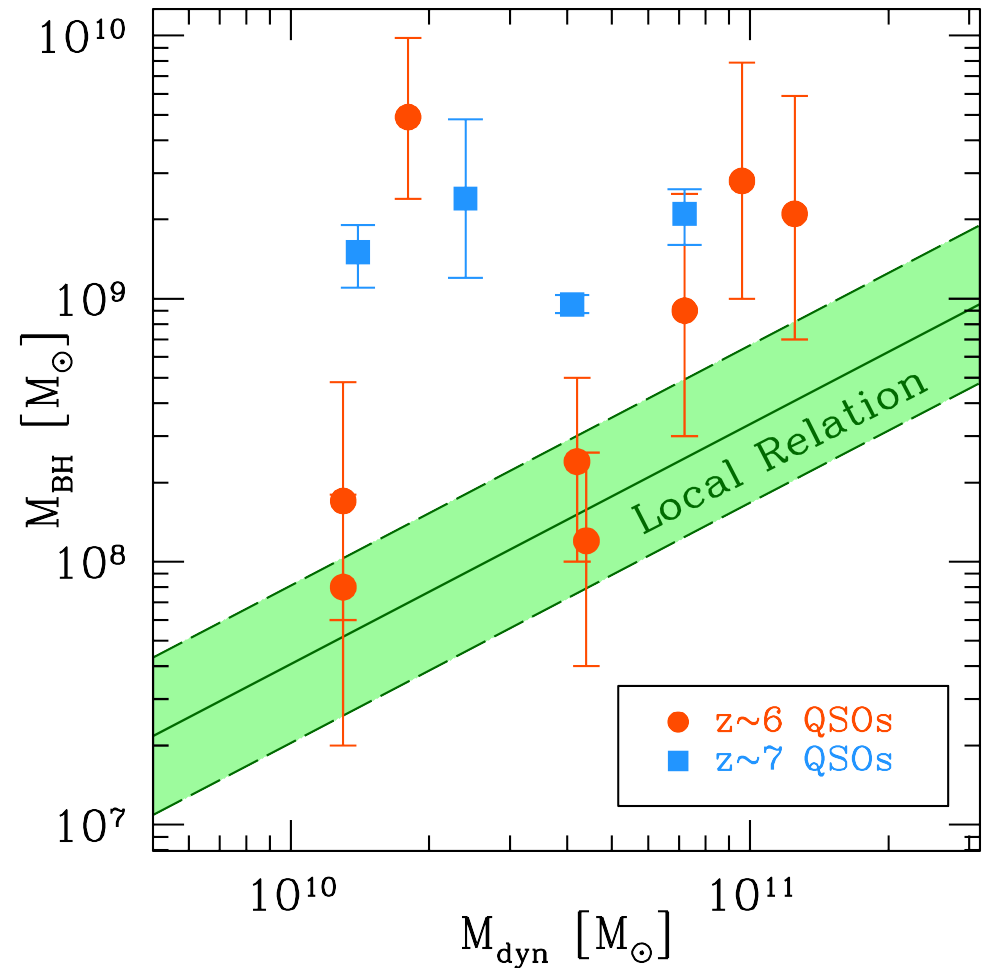
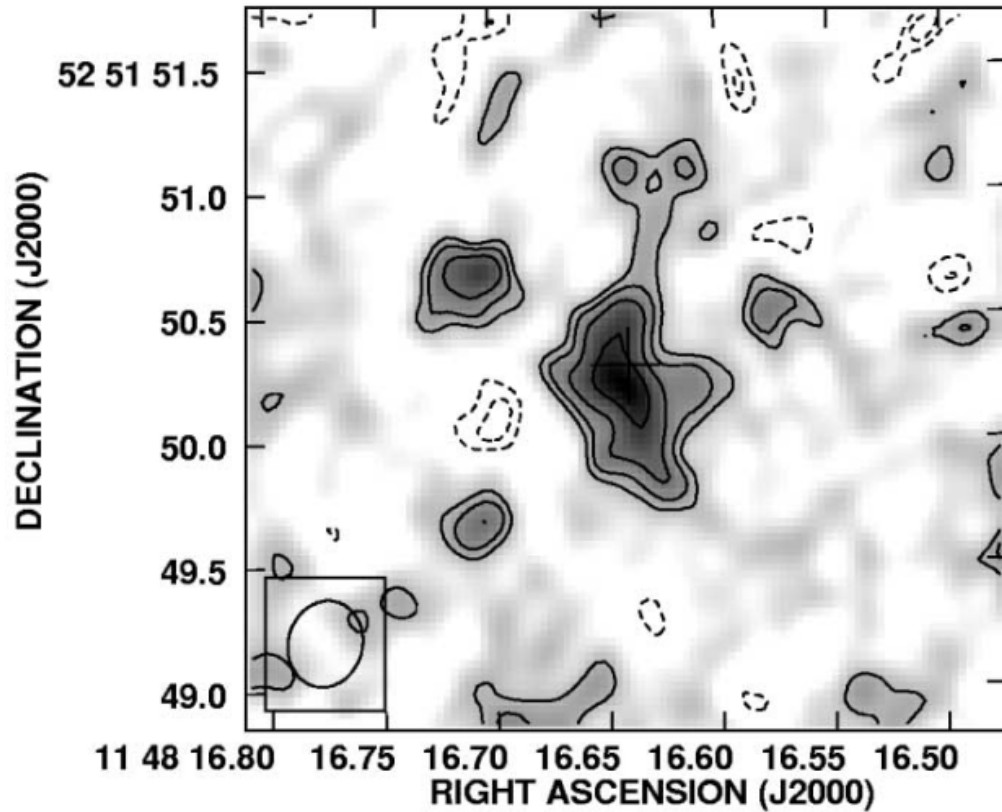


$$M_{\text{BH}} \sim 10^8 - 10^{10} M_{\text{SUN}}$$

Wu et al. 2015
Volonteri talk

QSO Host Galaxies

CO(3-2) map of J1148+5251

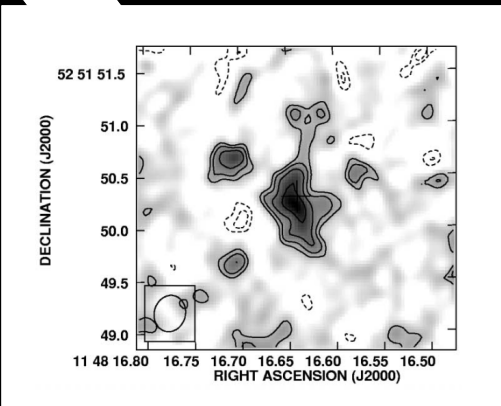


SFR \sim 100 – 1500 M_{SUN}/yr

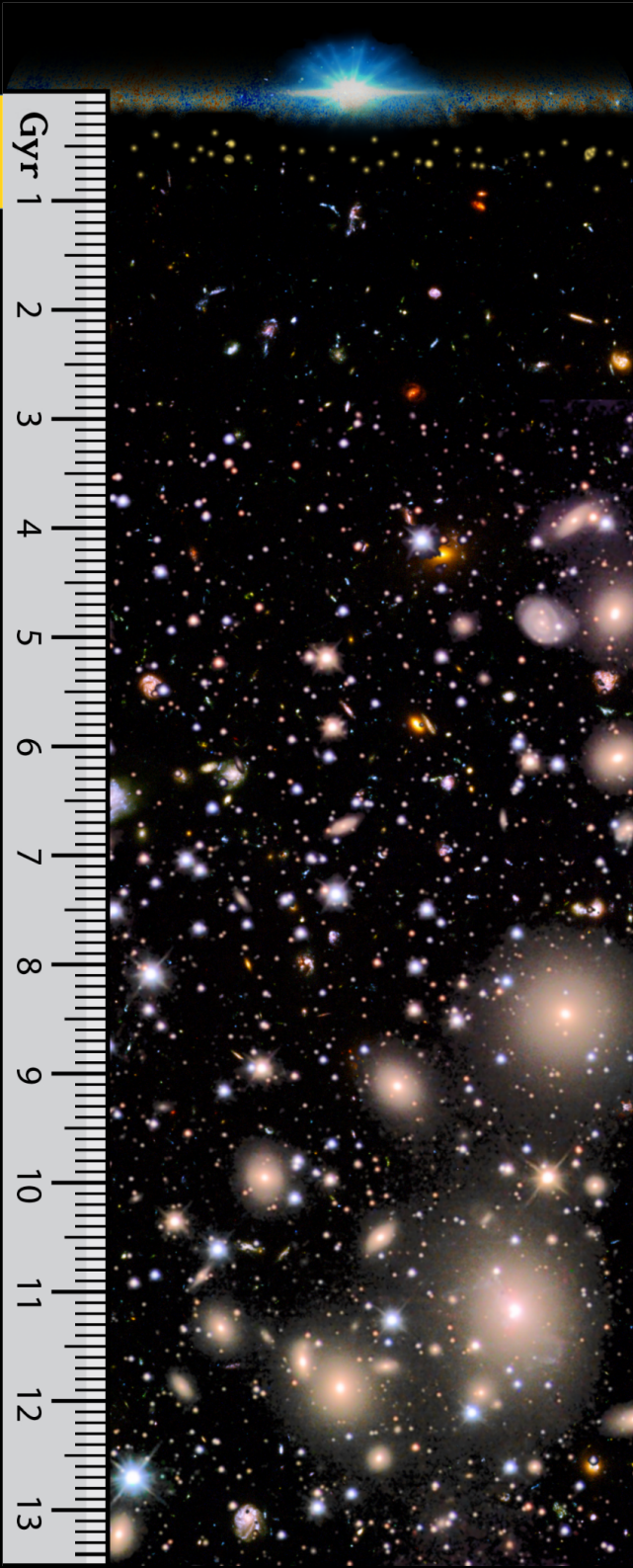
adapted from Venemans et al. 2016
Venemans, Decarli, Wang talks

History of the Universe

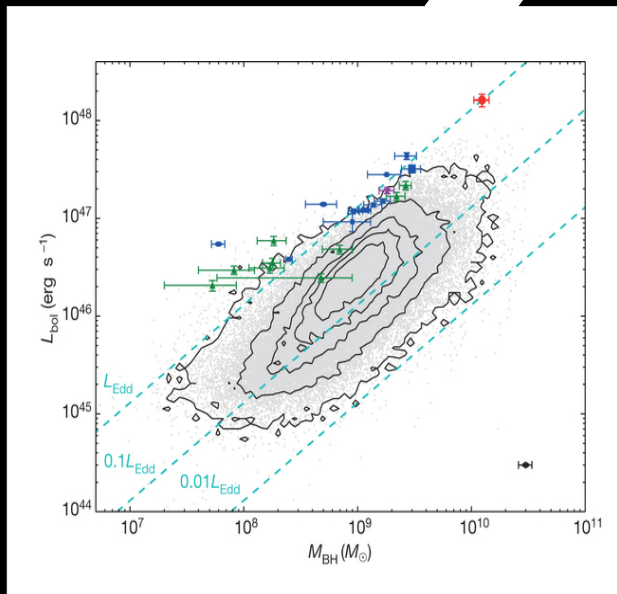
$z \sim 5.5 \rightarrow$



Gyr 1
2
3
4
5
6
7
8
9
10
11
12
13



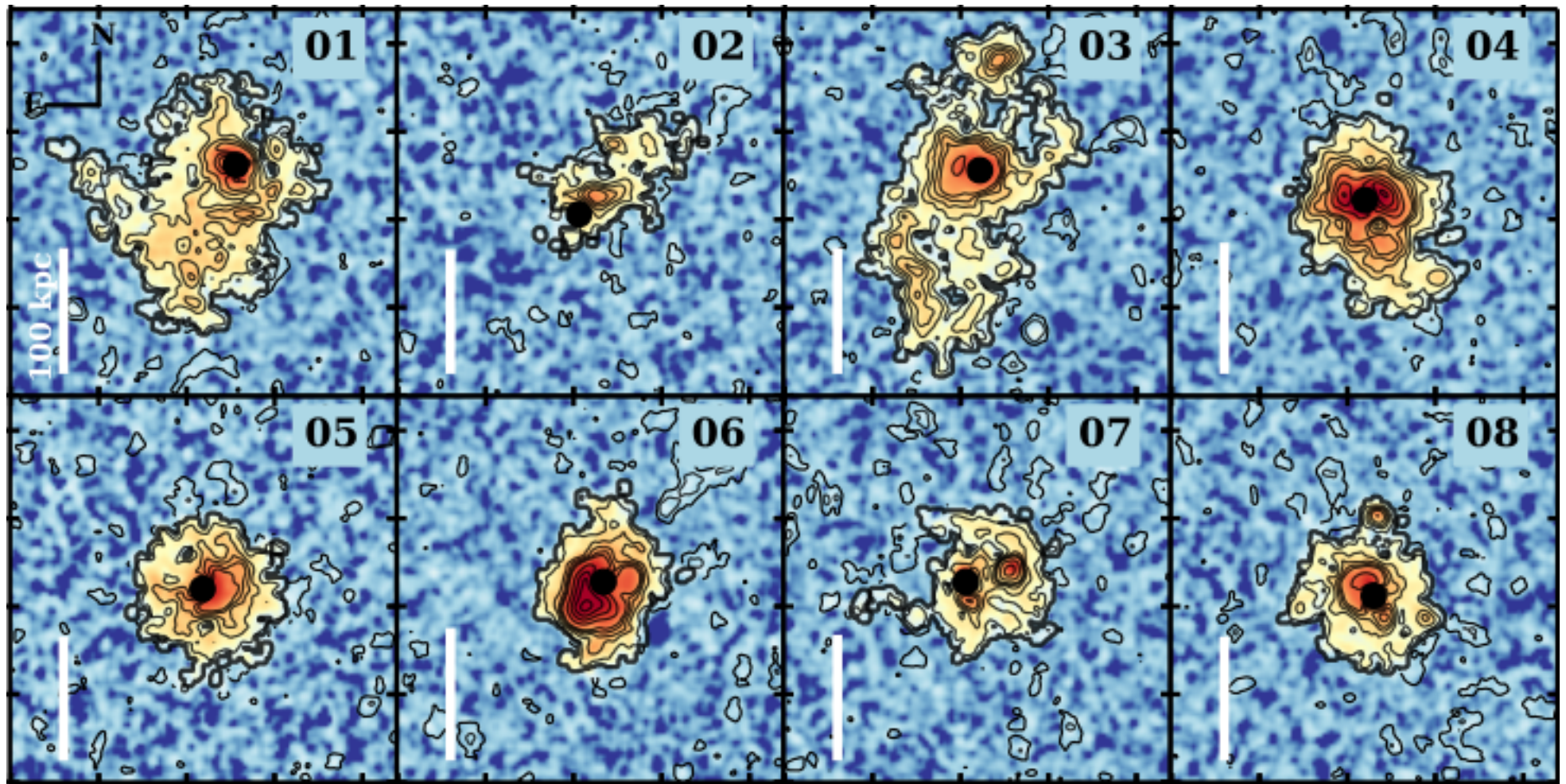
$\leftarrow z \sim 7.5$









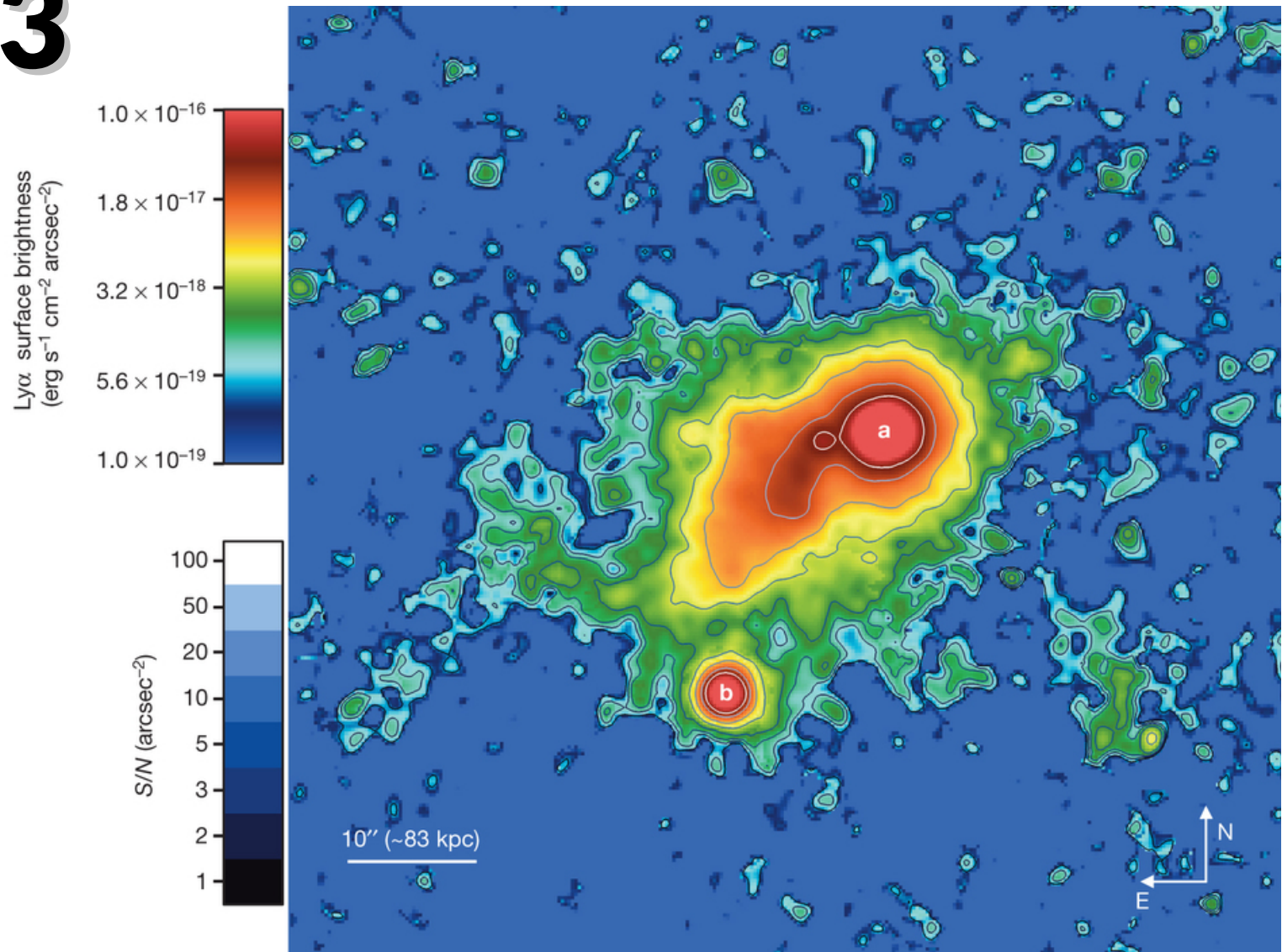


$z \sim 2-3$

50%–100% 10–100 kpc Ly α Nebulae

Hennawi & Prochaska 2013, Arrighi-Battaia et al. 2016, Borisova et al. 2016

$z \sim 2.3$

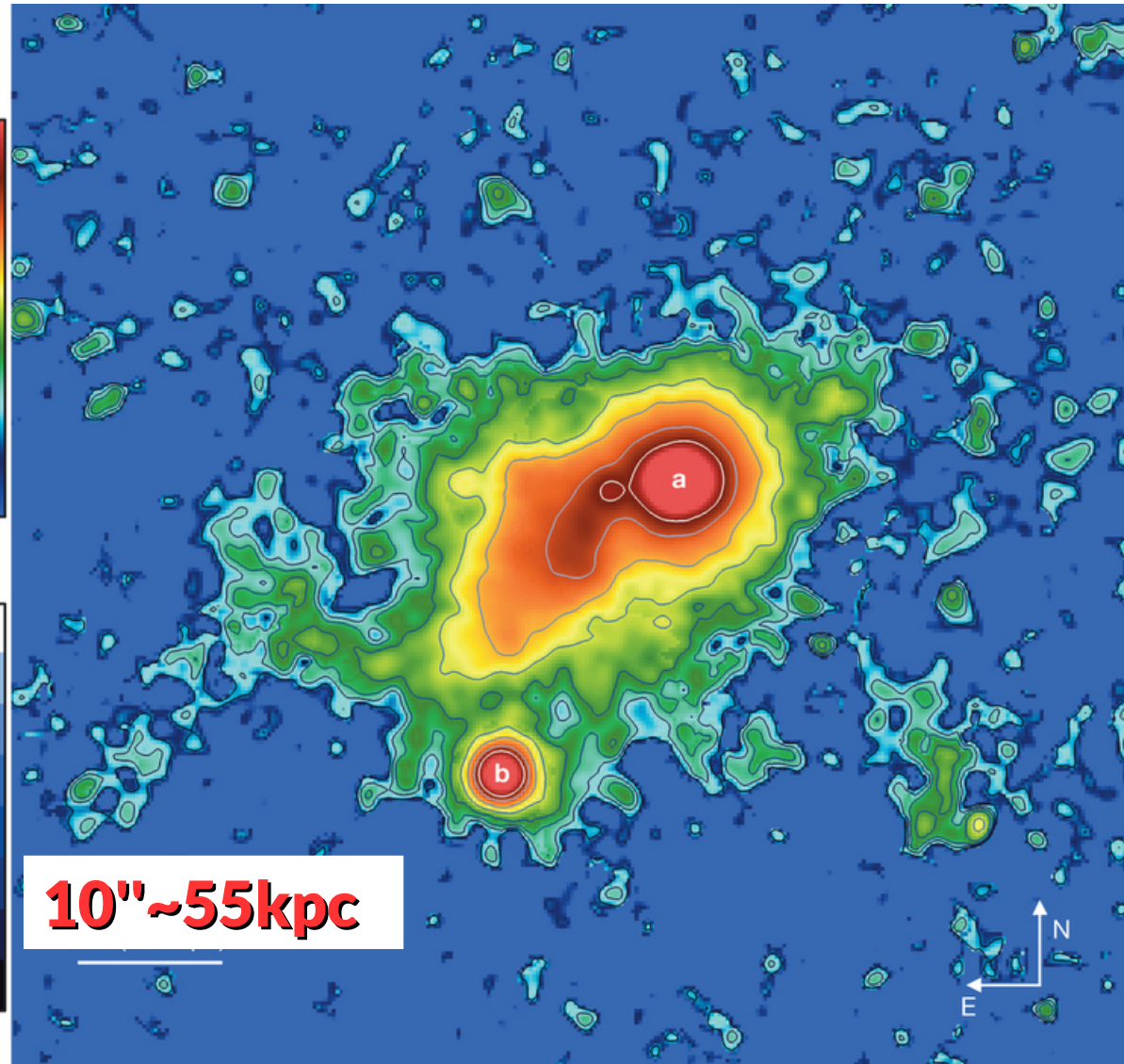
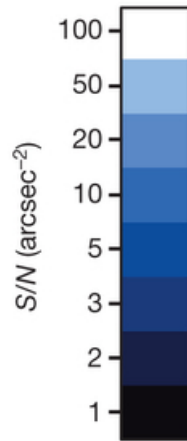
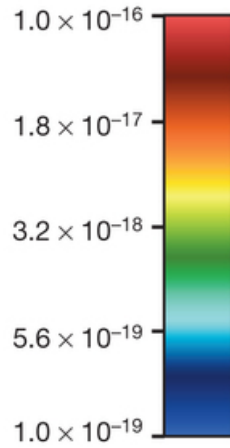


$\sim 10\% > 100 \text{ kpc Ly}\alpha \text{ Nebulae}$

$z \sim 2.3 \rightarrow 6.5$

SB x 0.04

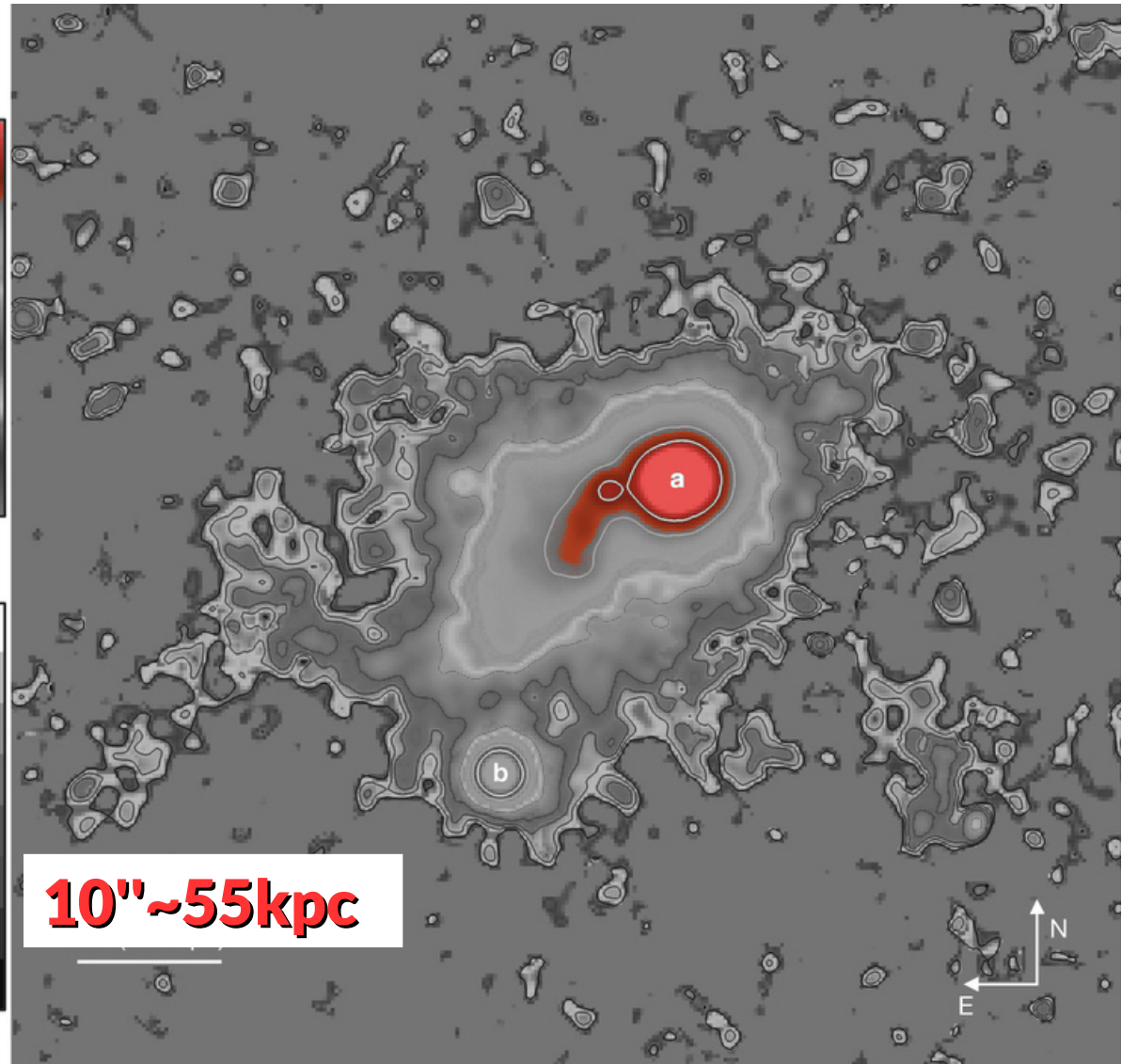
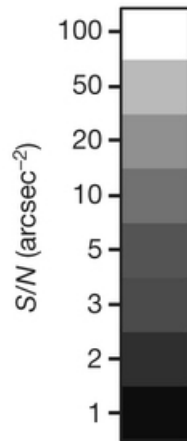
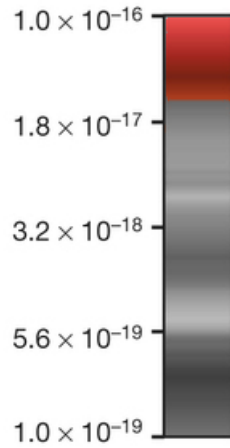
Ly α surface brightness
($\text{erg s}^{-1} \text{cm}^{-2} \text{arcsec}^{-2}$)

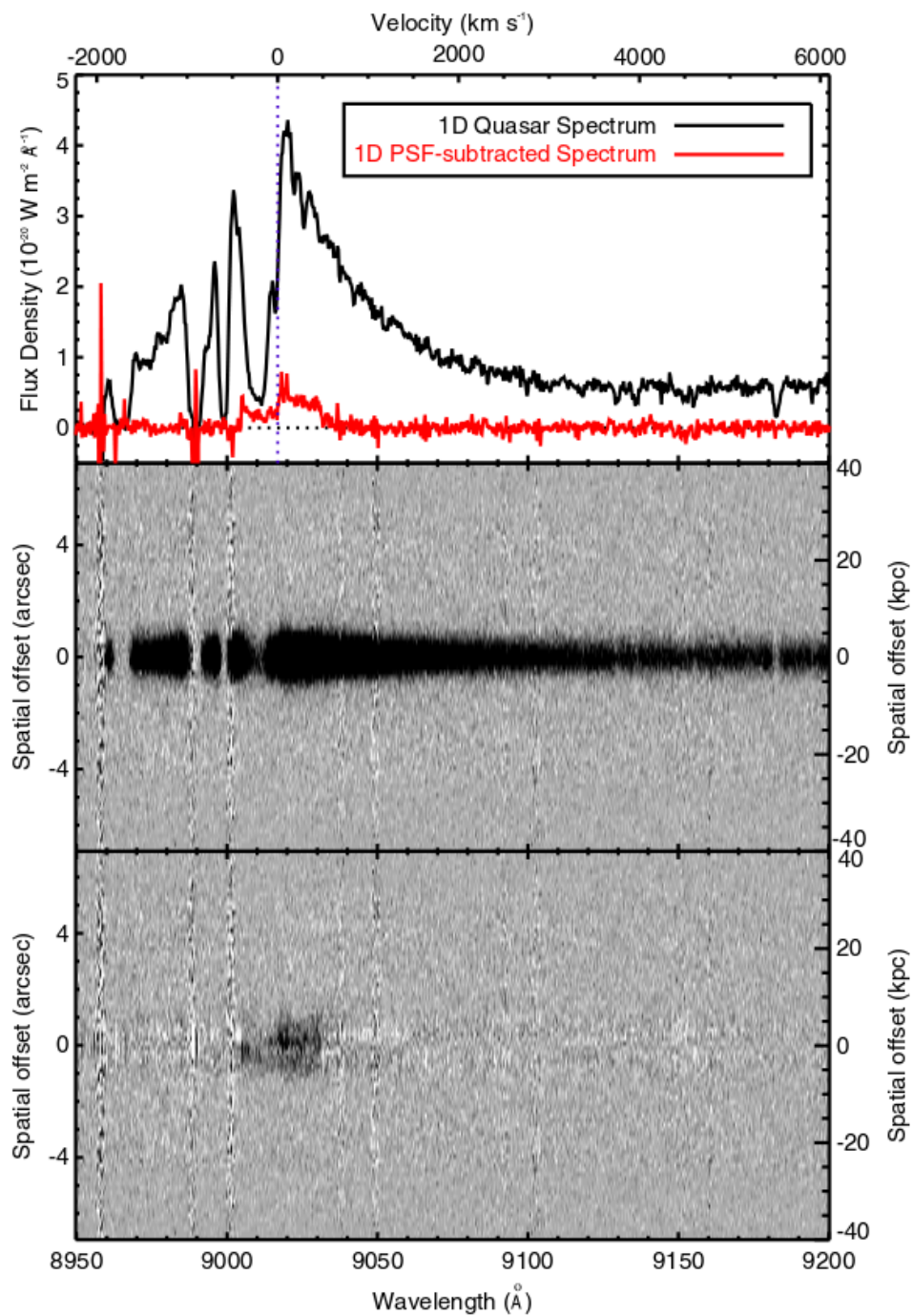


$z \sim 2.3 \rightarrow 6.5$

SB x 0.04

Ly α surface brightness
($\text{erg s}^{-1} \text{cm}^{-2} \text{arcsec}^{-2}$)





@ z=6.4
~15 kpc Ly α Nebula
 $L(\text{Ly}\alpha) = 2 \times 10^{43} - 4 \times 10^{44}$ erg/s

Goto et al. 2012, Willott et al. 2011, Roche et al. 2014

a Multi-Technique Approach

2D Spectroscopy

Narrow Band Imaging from Space

Grism Spectroscopy from Space

Integral Field Spectroscopy

a Multi-Technique Approach

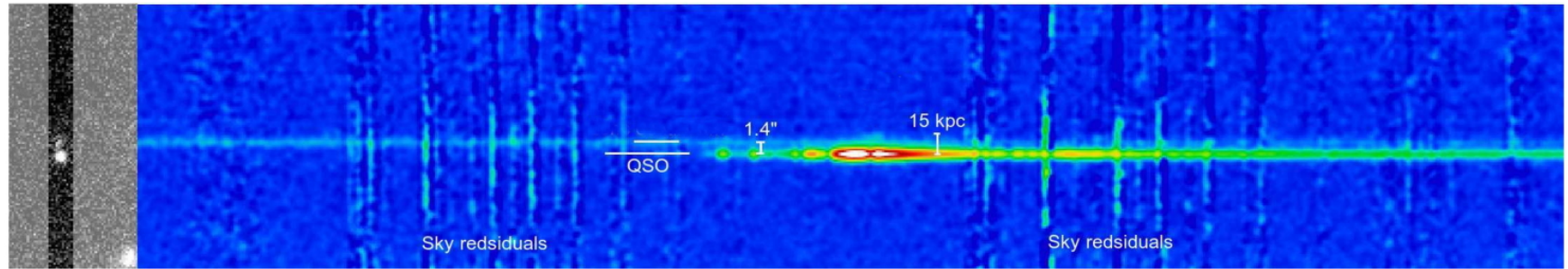
2D Spectroscopy

Narrow Band Imaging from Space

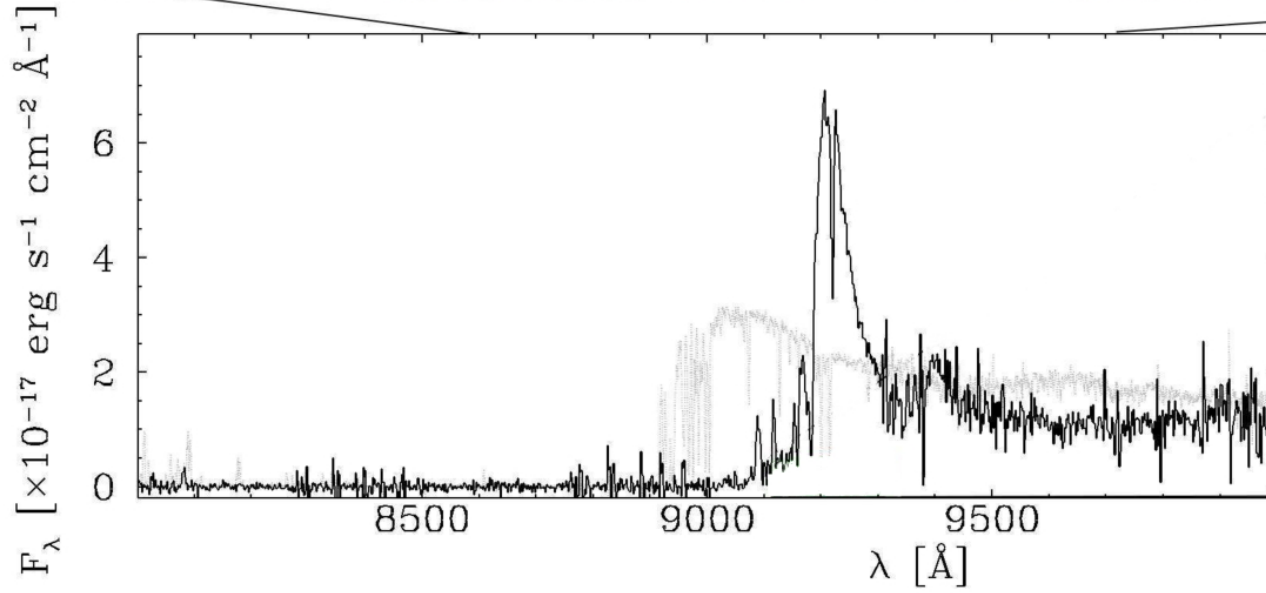
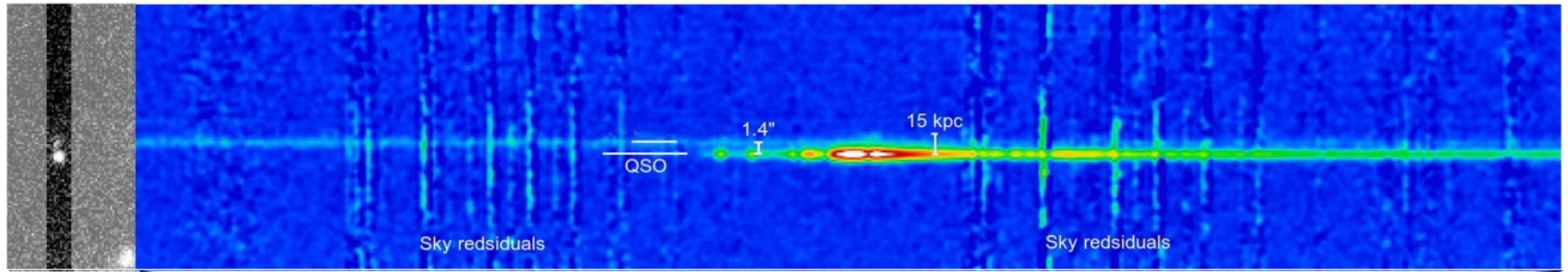
Grism Spectroscopy from Space

Integral Field Spectroscopy

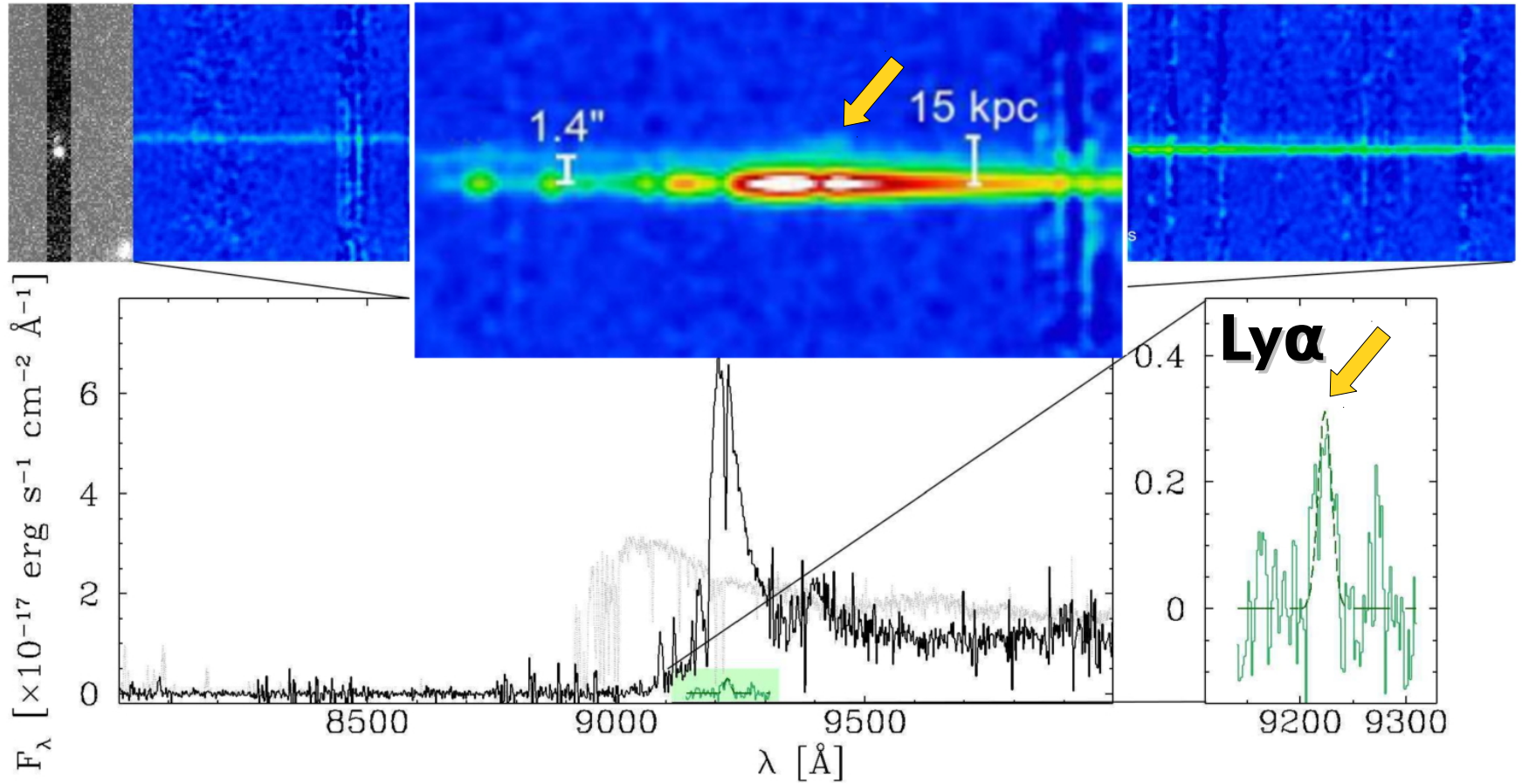
$z=6.6$



$z=6.6$

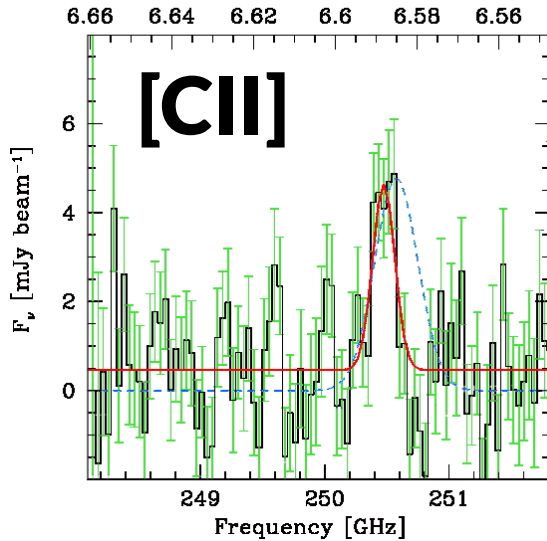
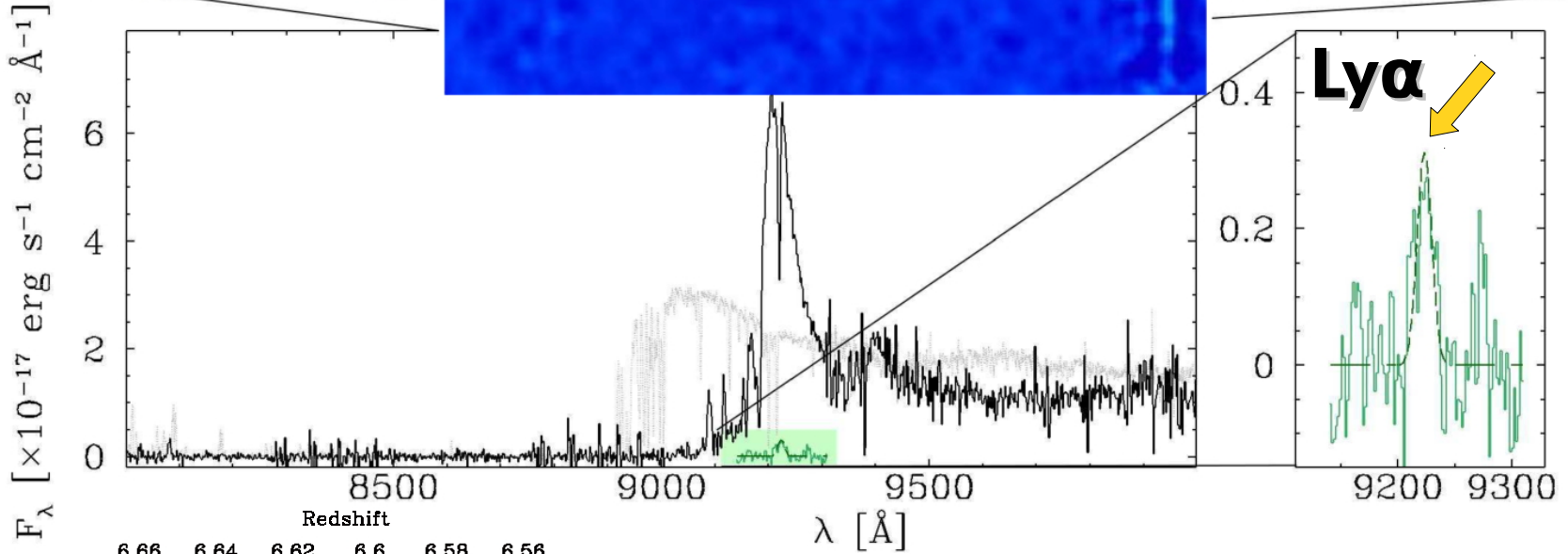
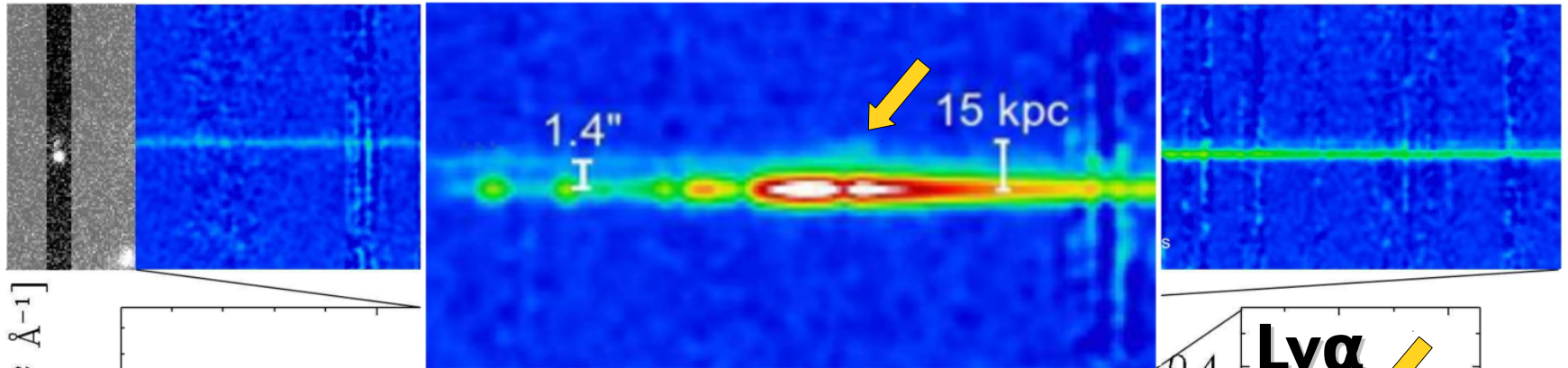


z=6.6



~15 kpc Ly α Nebula
 $L(\text{Ly}\alpha)=2.5 \times 10^{43}$ erg/s

z=6.6



~15 kpc Ly α Nebula
L(Ly α)=2.5x10⁴³ erg/s

Team QSO in prep.

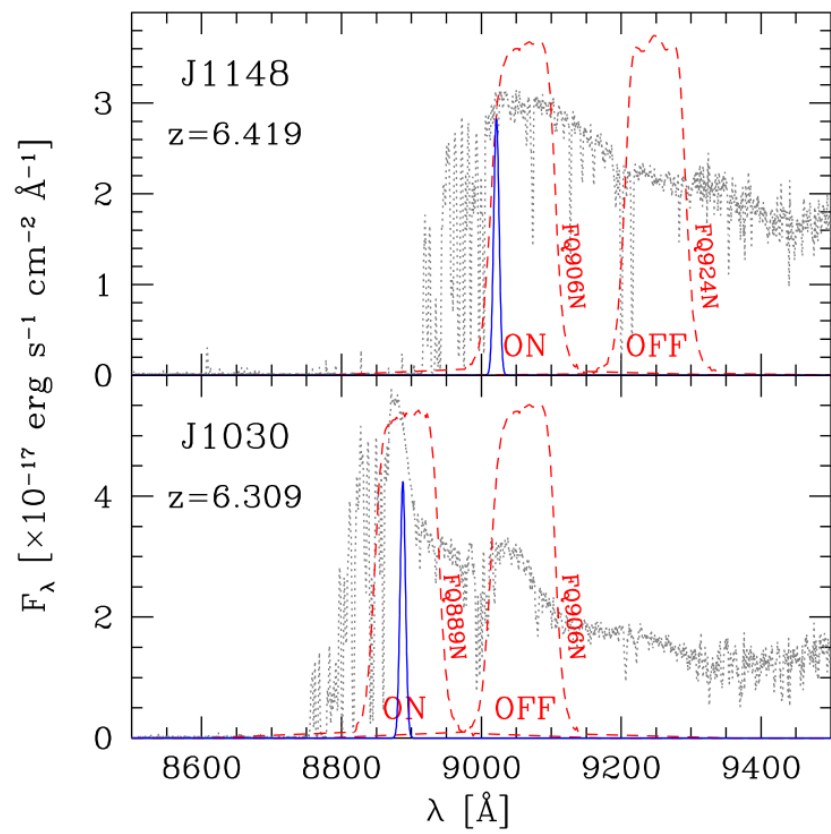
a Multi-Technique Approach

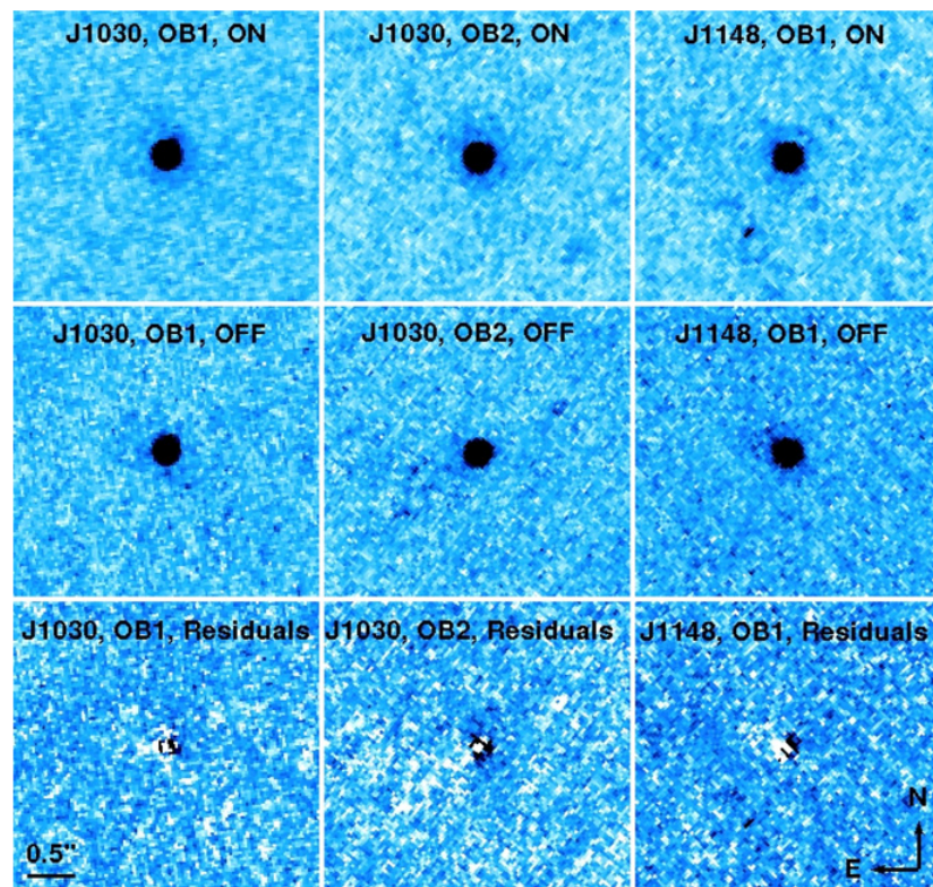
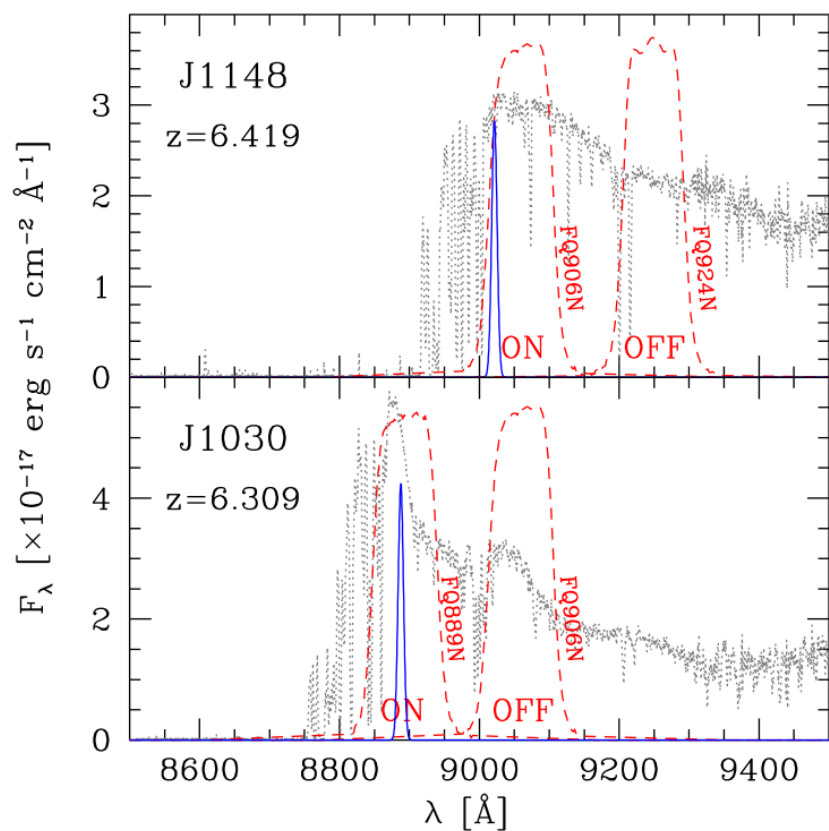
2D Spectroscopy

Narrow Band Imaging from Space

Grism Spectroscopy from Space

Integral Field Spectroscopy





NO Ly α Nebulae
 $L(\text{Ly}\alpha) < 3 \times 10^{44}$ erg/s

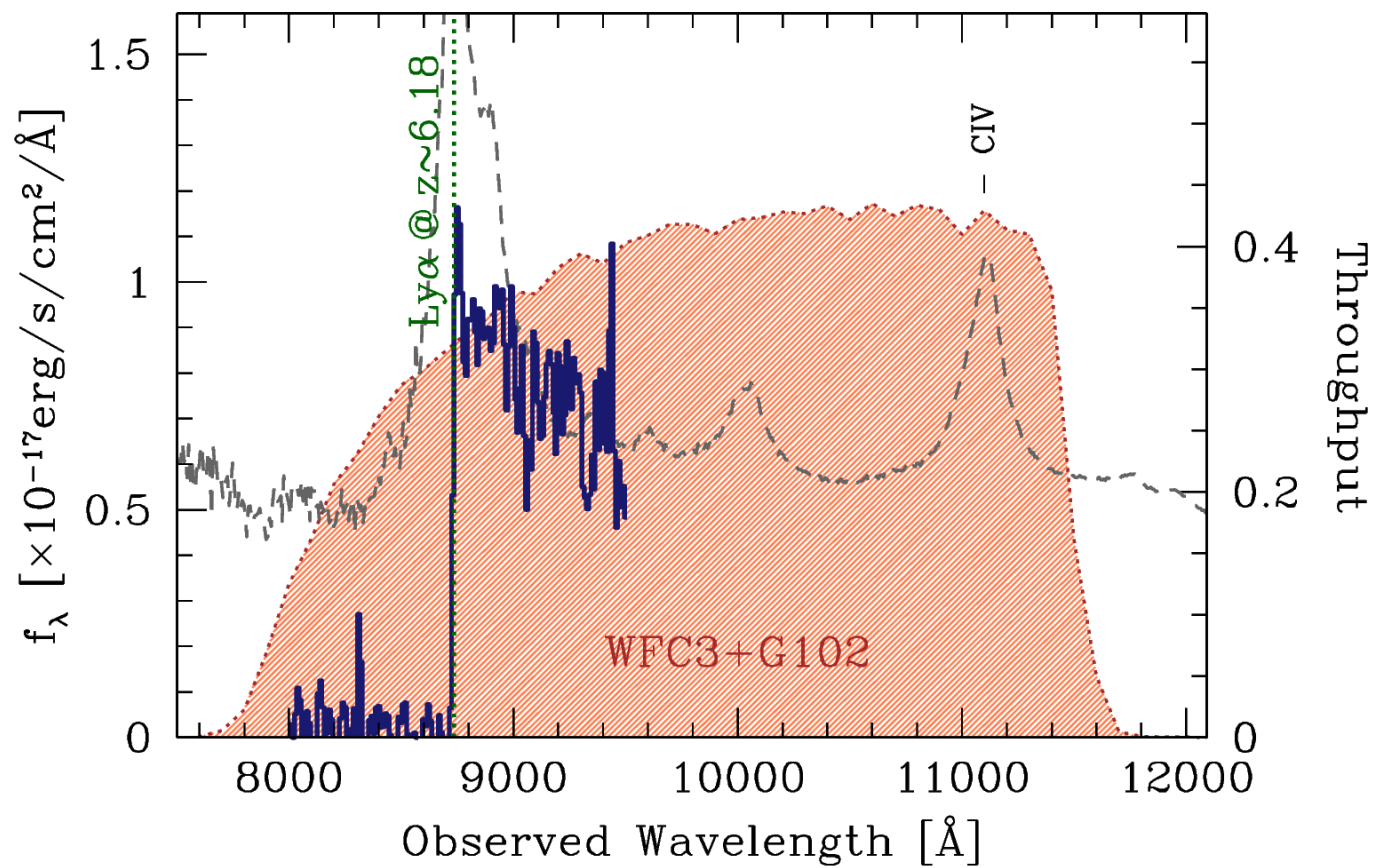
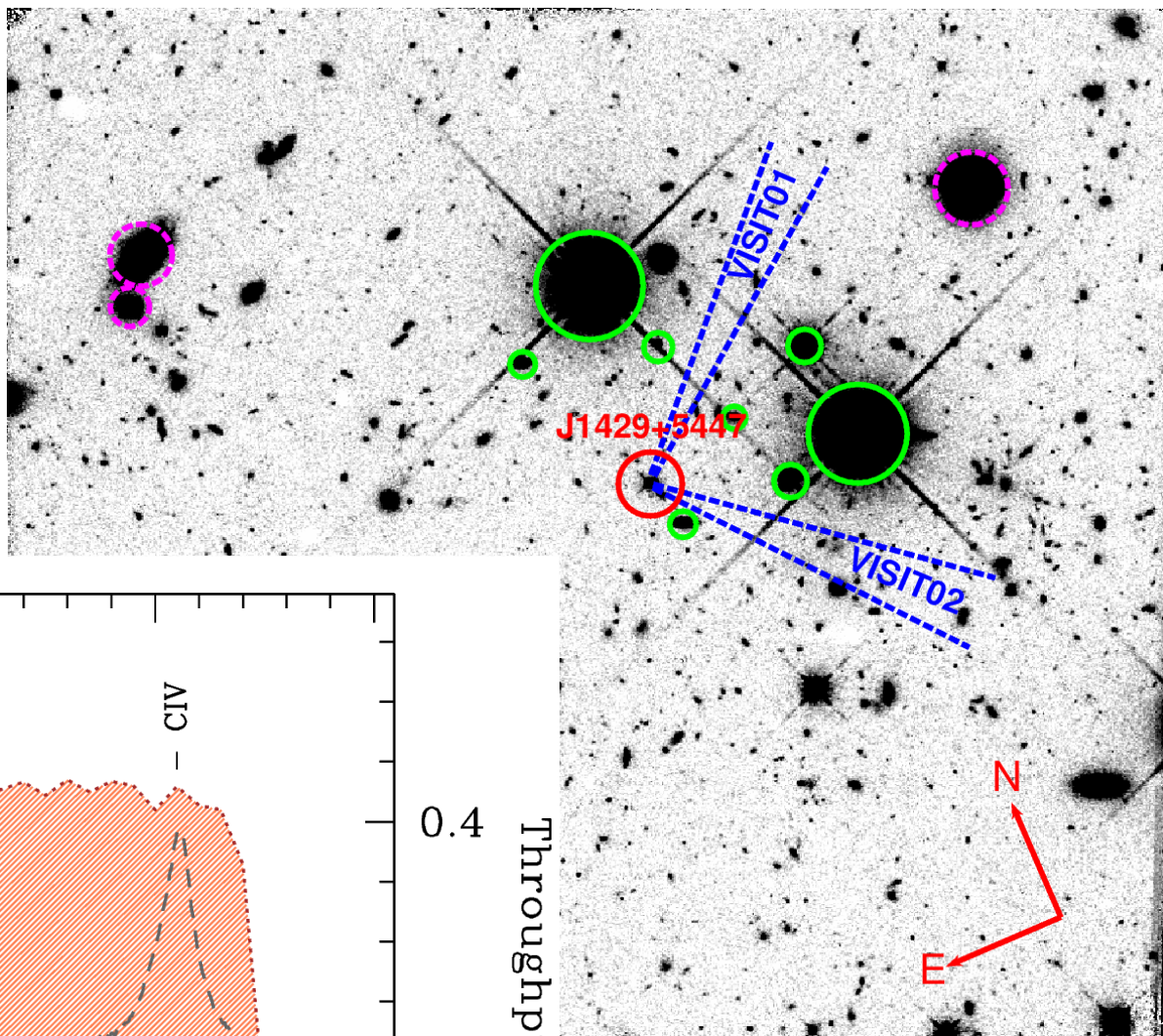
a Multi-Technique Approach

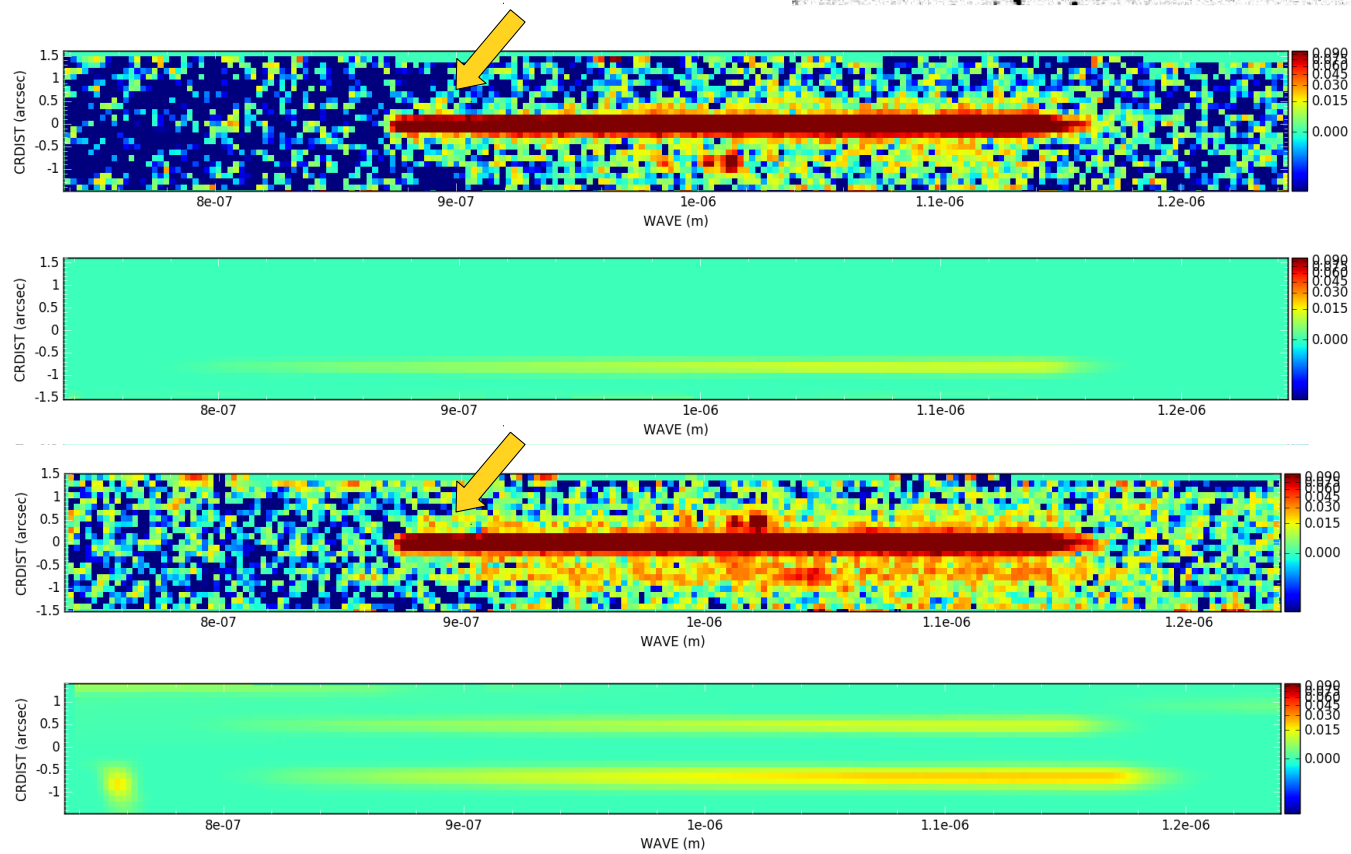
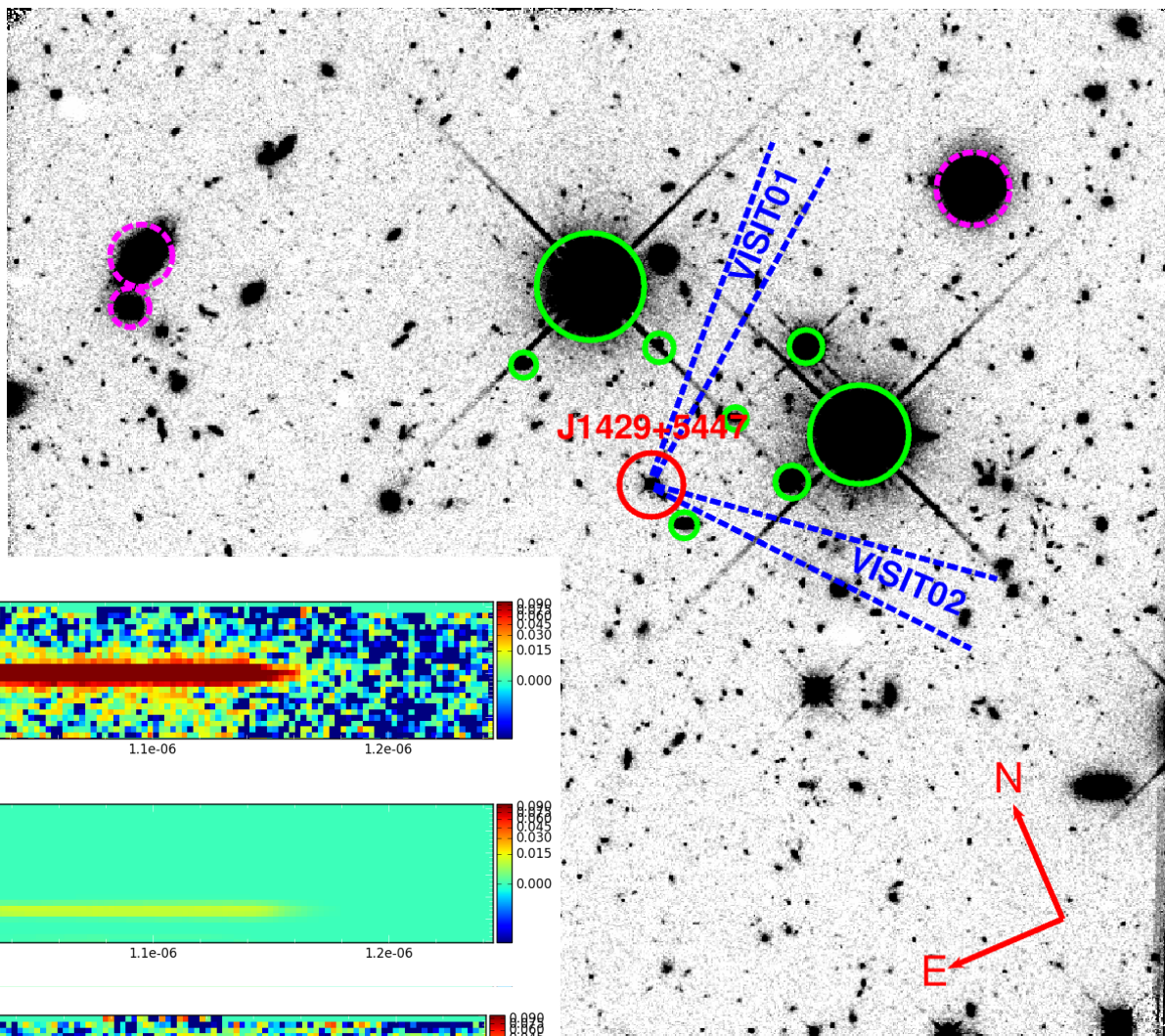
2D Spectroscopy

Narrow Band Imaging from Space

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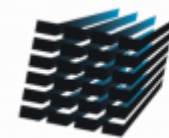
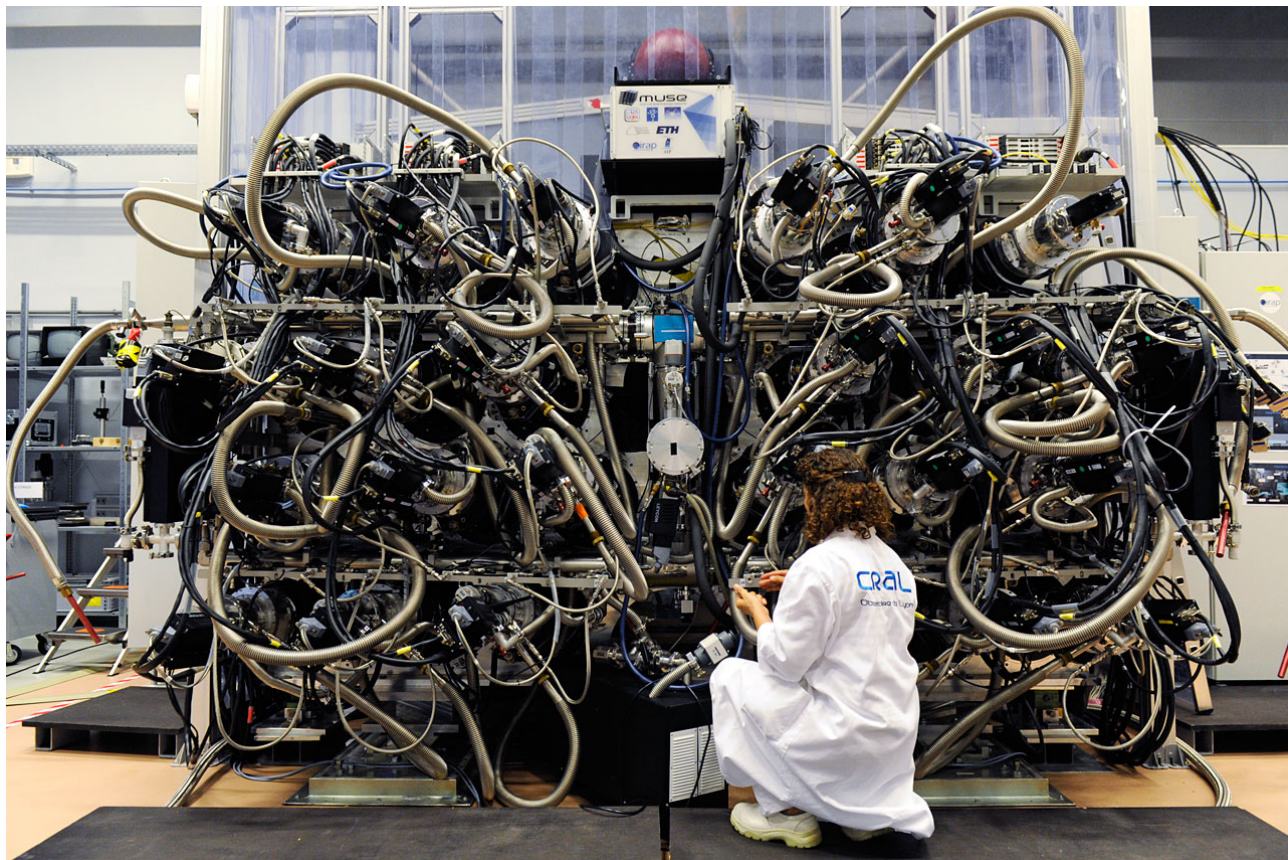
a Multi-Technique Approach

2D Spectroscopy

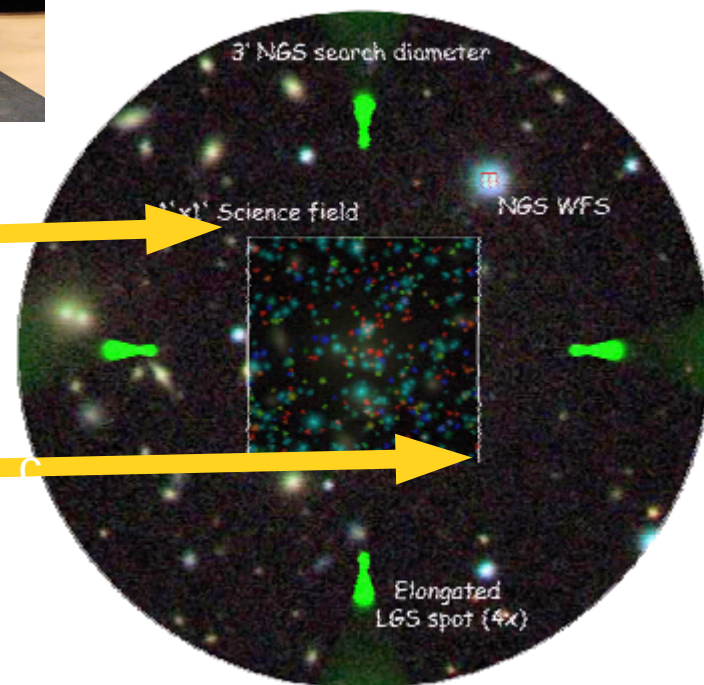
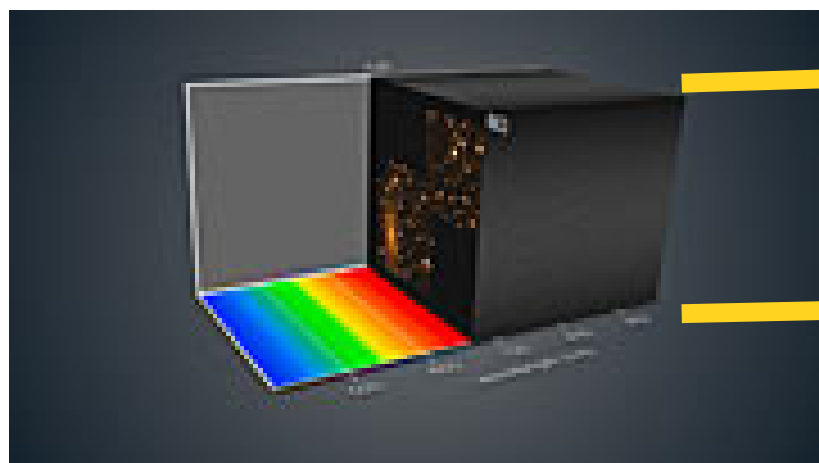
Narrow Band Imaging from Space

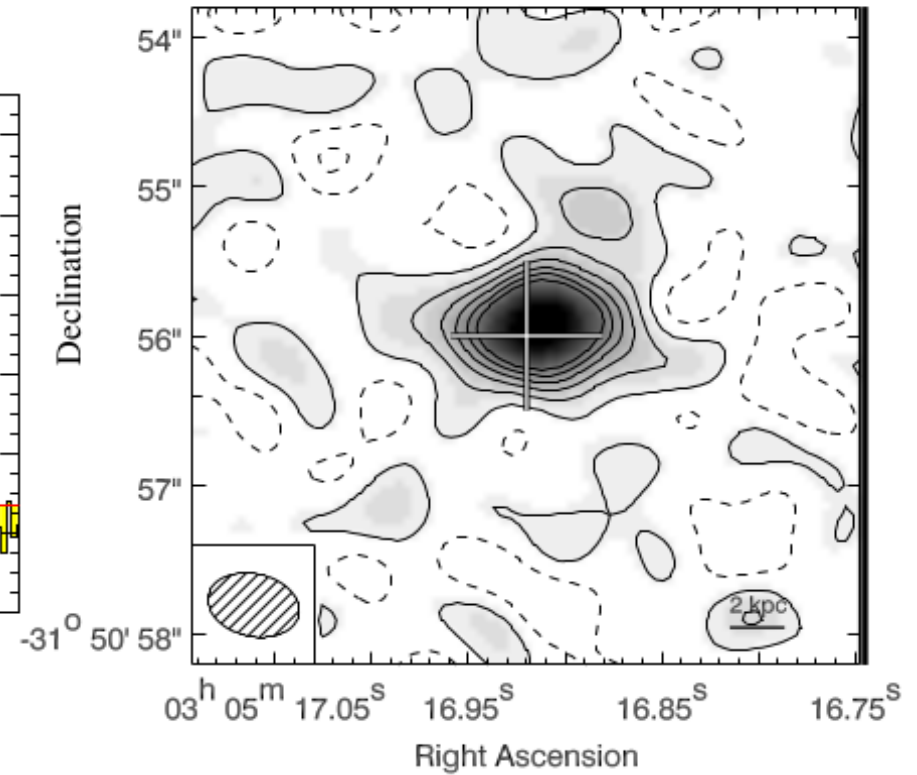
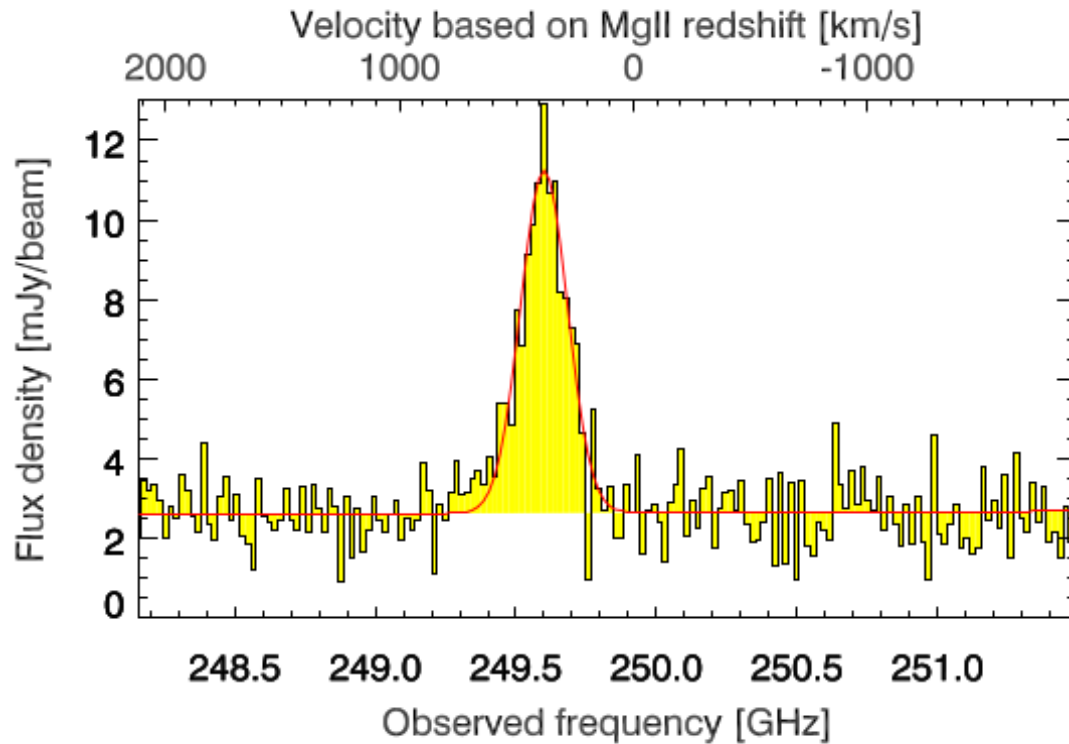
Grism Spectroscopy from Space

Integral Field Spectroscopy



MUSE
multi unit spectroscopic explorer



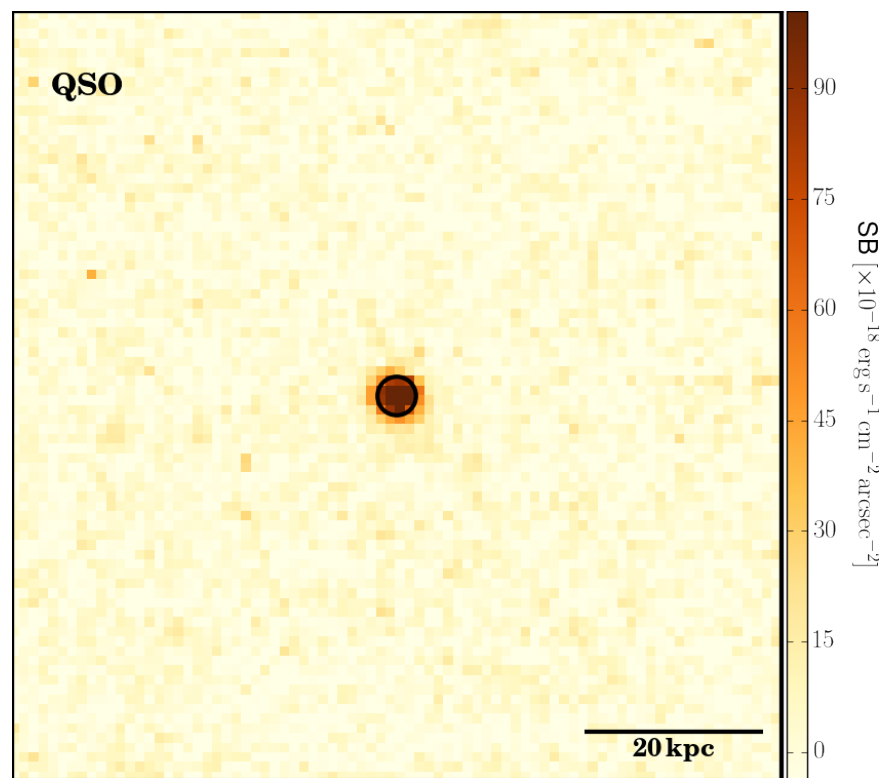
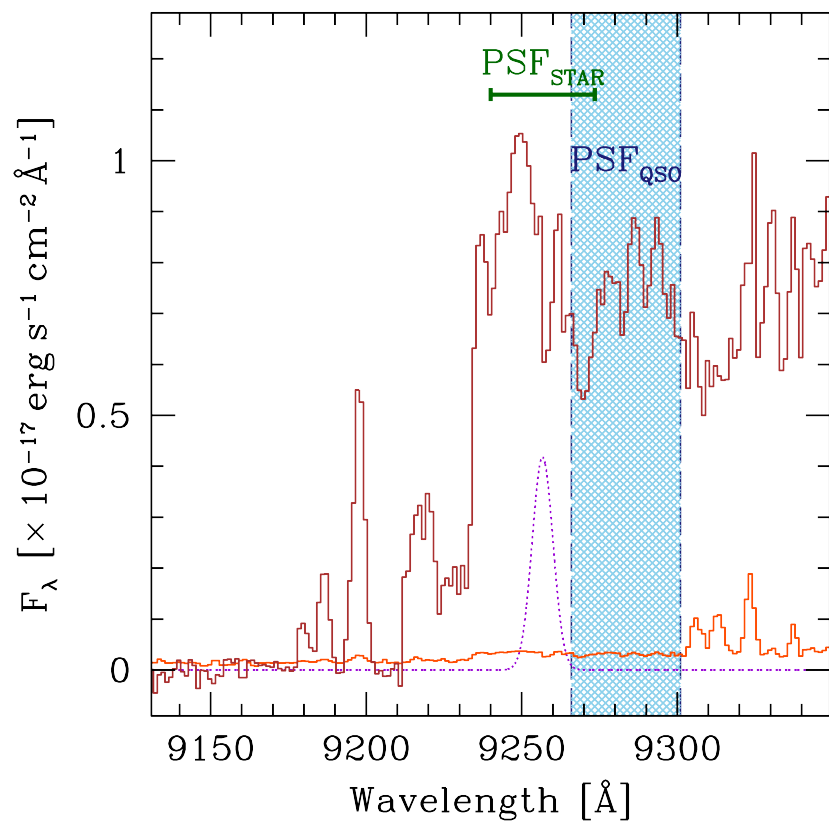


$z \sim 6.6$

$\text{SFR} \sim 600 M_{\text{SUN}}/\text{yr}$

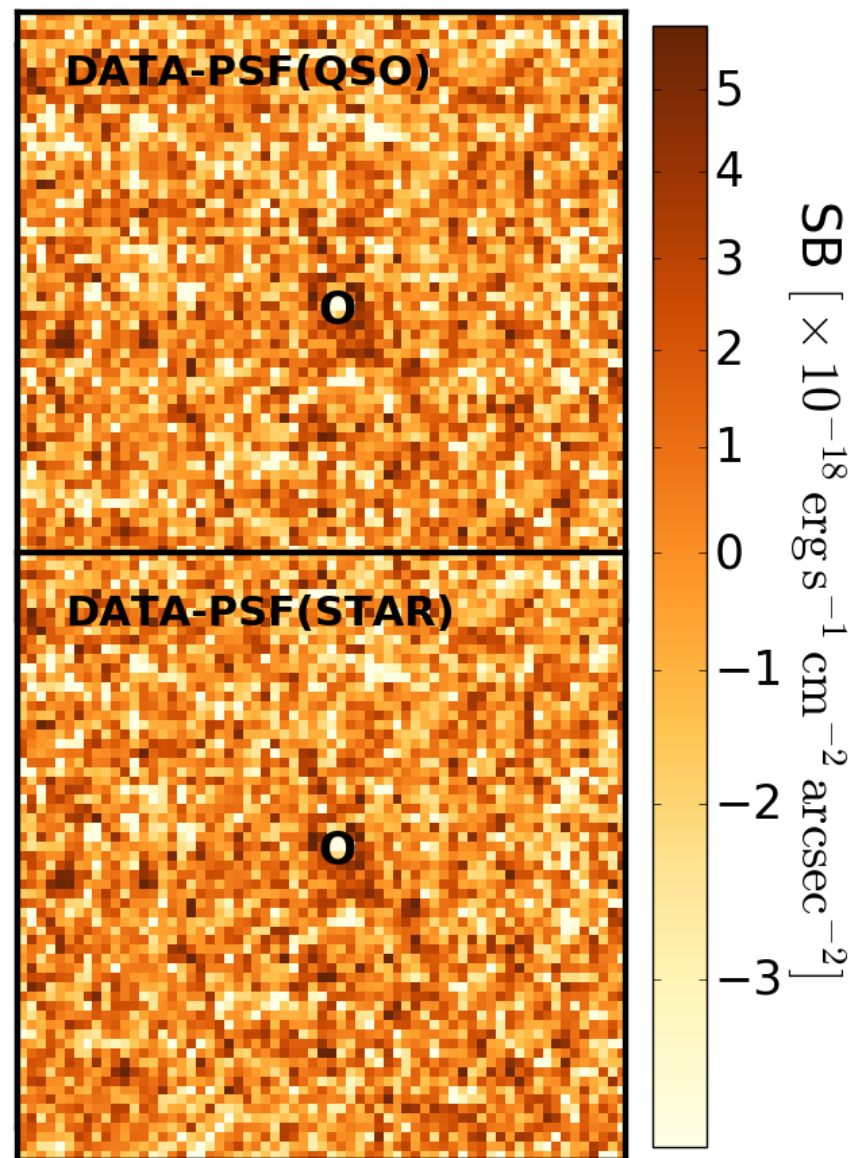
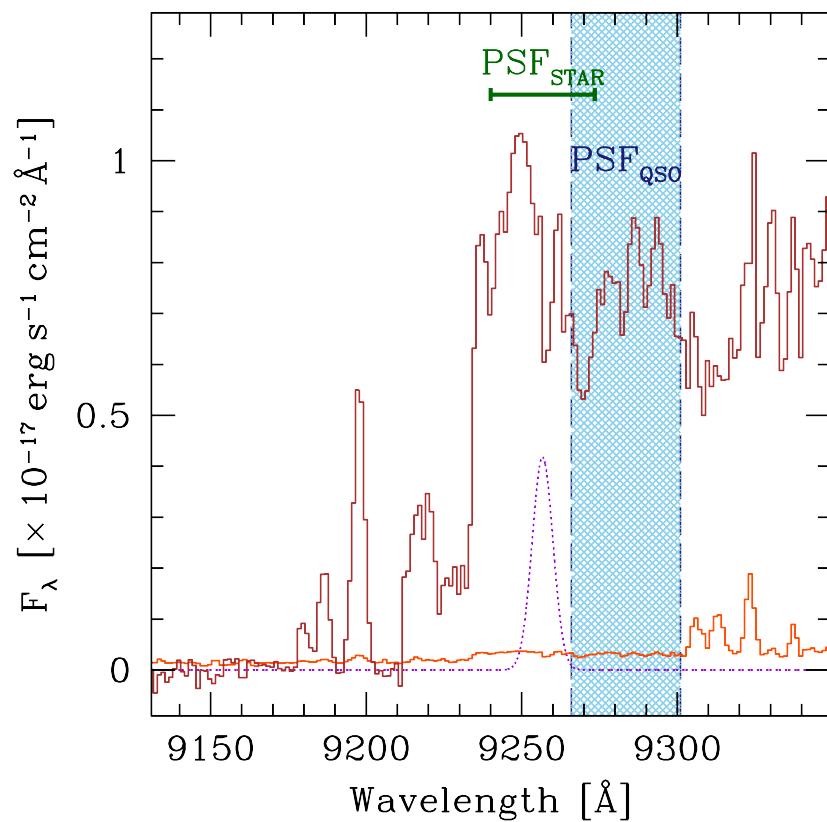
$M_{\text{BH}} \sim 10^9 M_{\text{SUN}}$

Venemans et al. 2016
and Venemans talk

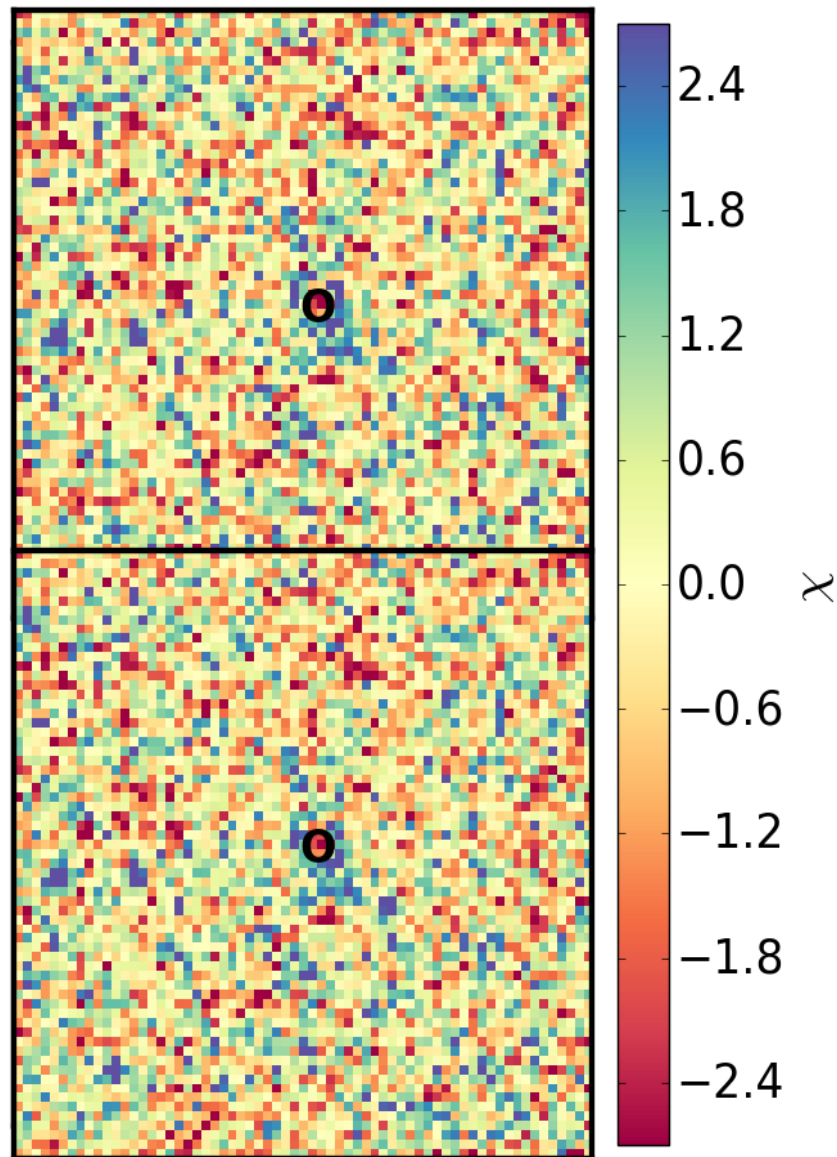
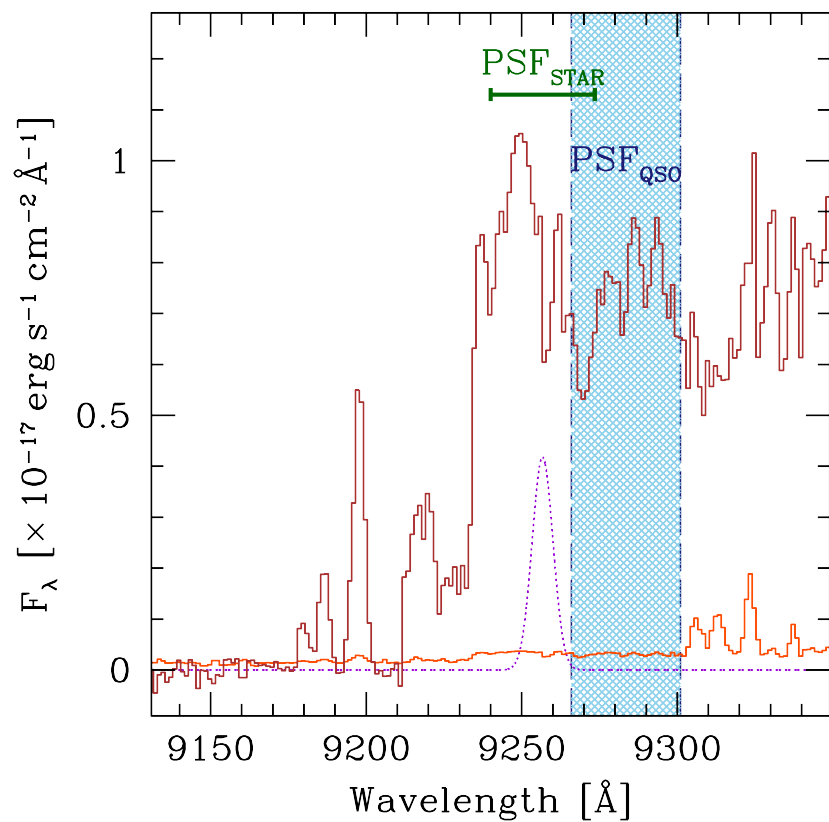


$$SB_{\text{lim}} = 3 \times 10^{-18} \text{ erg/s/cm}^2/\text{arcsec}^2$$

Farina et al. in prep.

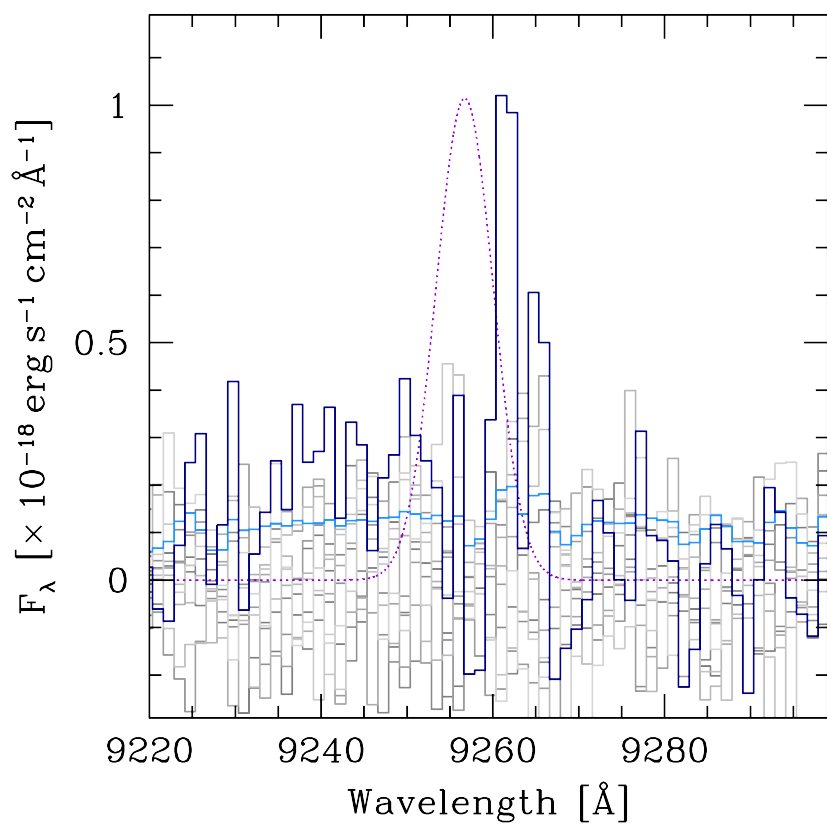


$$SB_{\text{lim}} = 3 \times 10^{-18} \text{ erg/s/cm}^2/\text{arcsec}^2$$

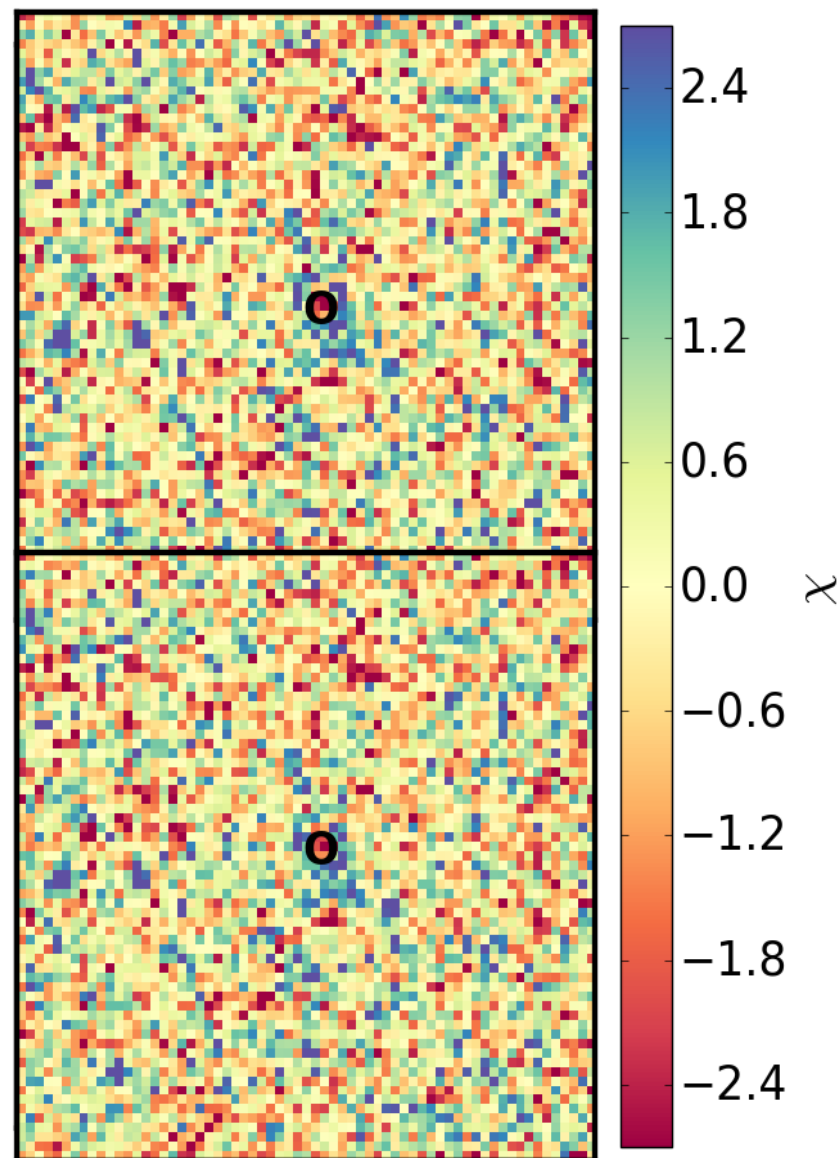


$$\text{SB}_{\text{lim}} = 3 \times 10^{-18} \text{ erg/s/cm}^2/\text{arcsec}^2$$

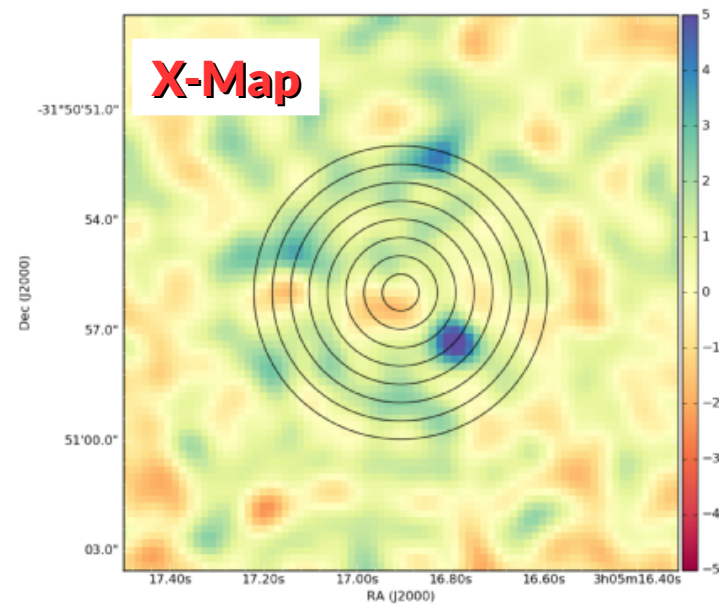
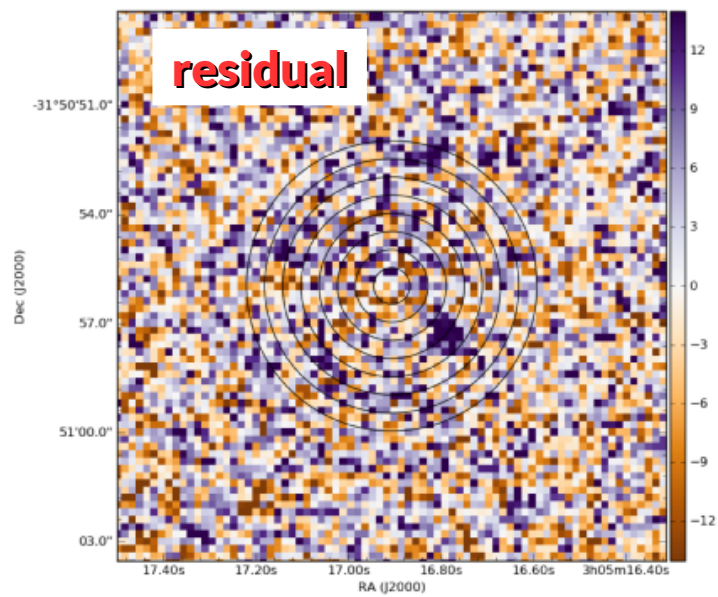
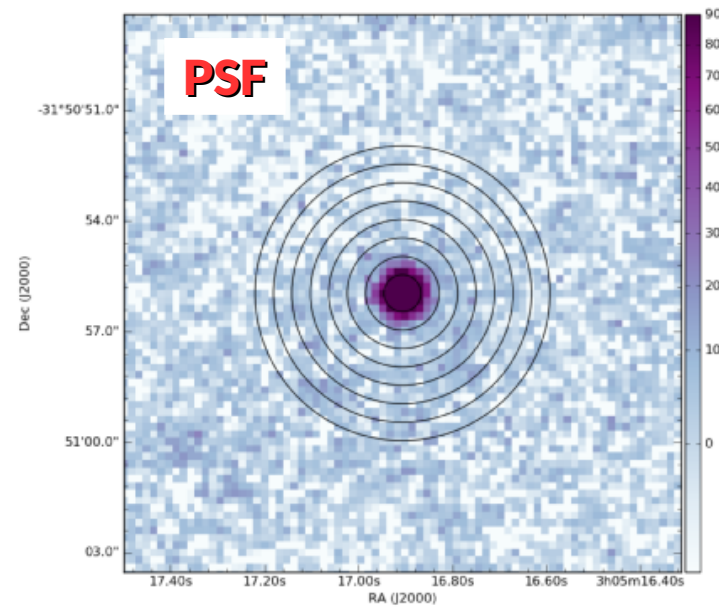
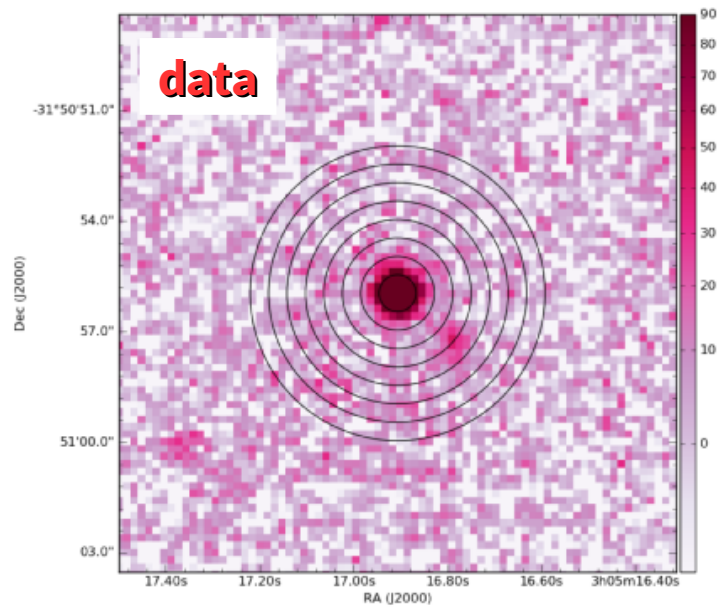
Farina et al. in prep.

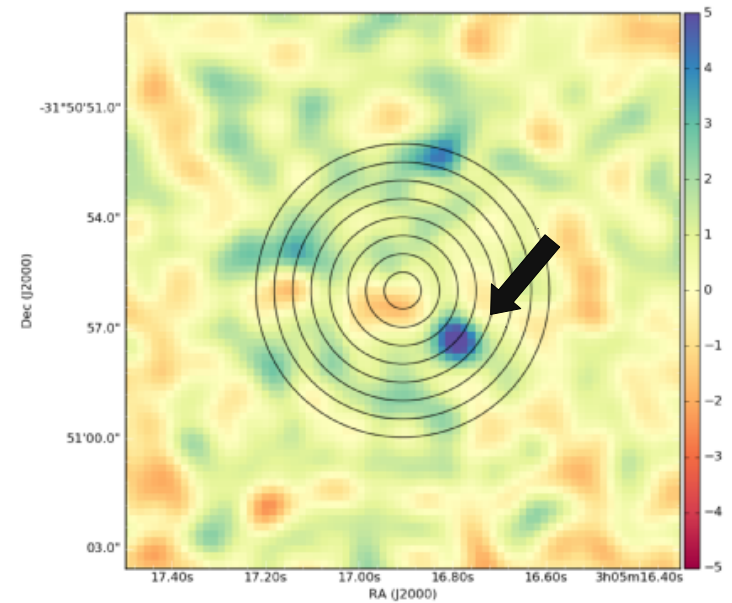
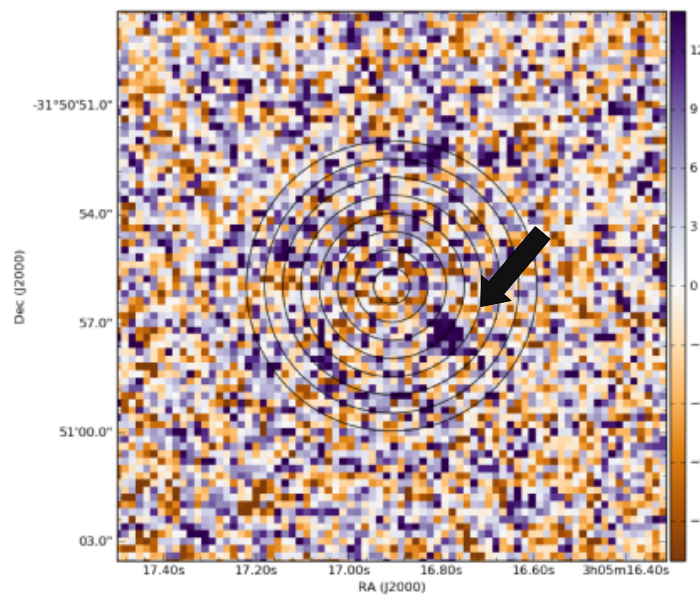
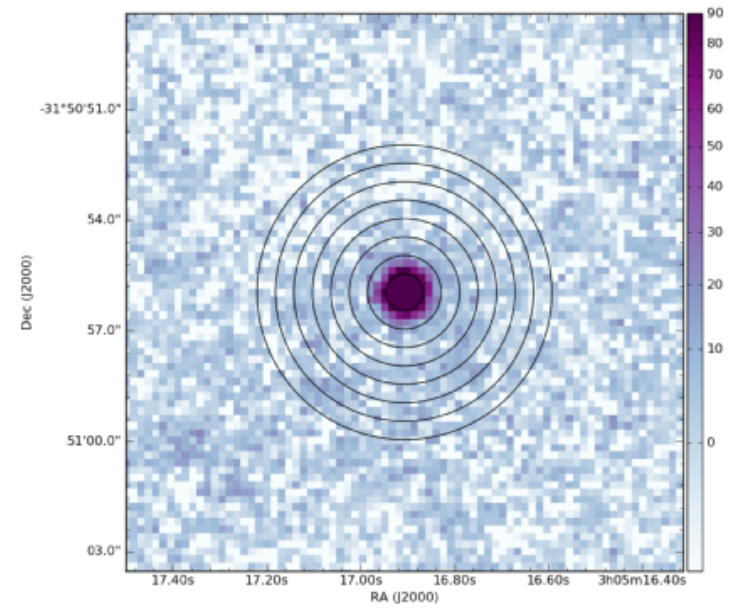
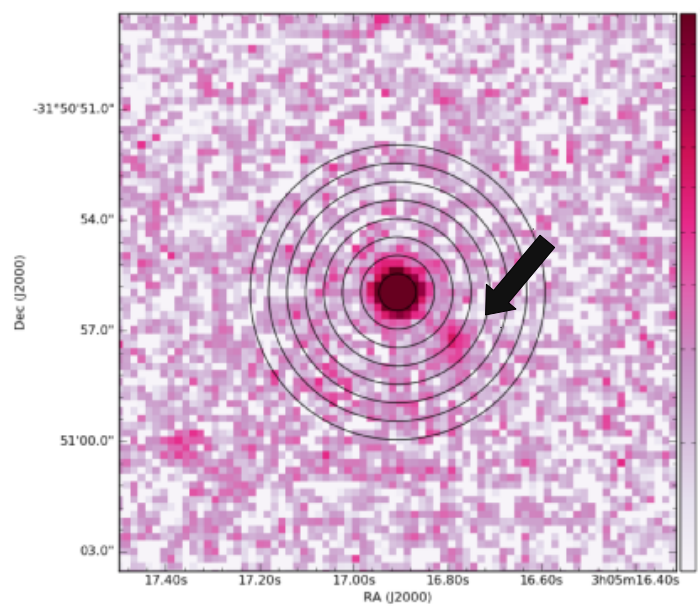


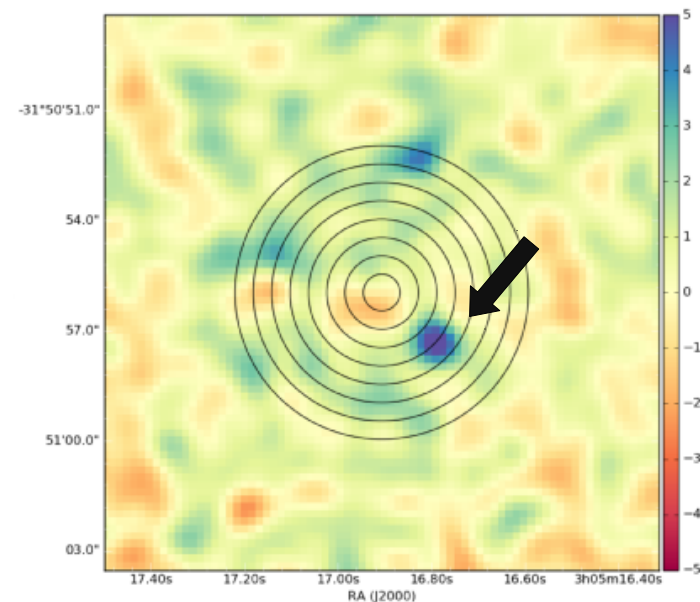
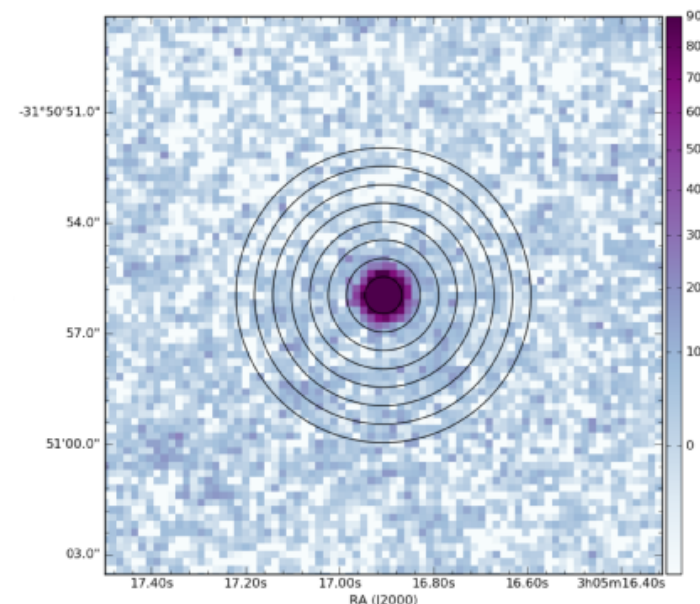
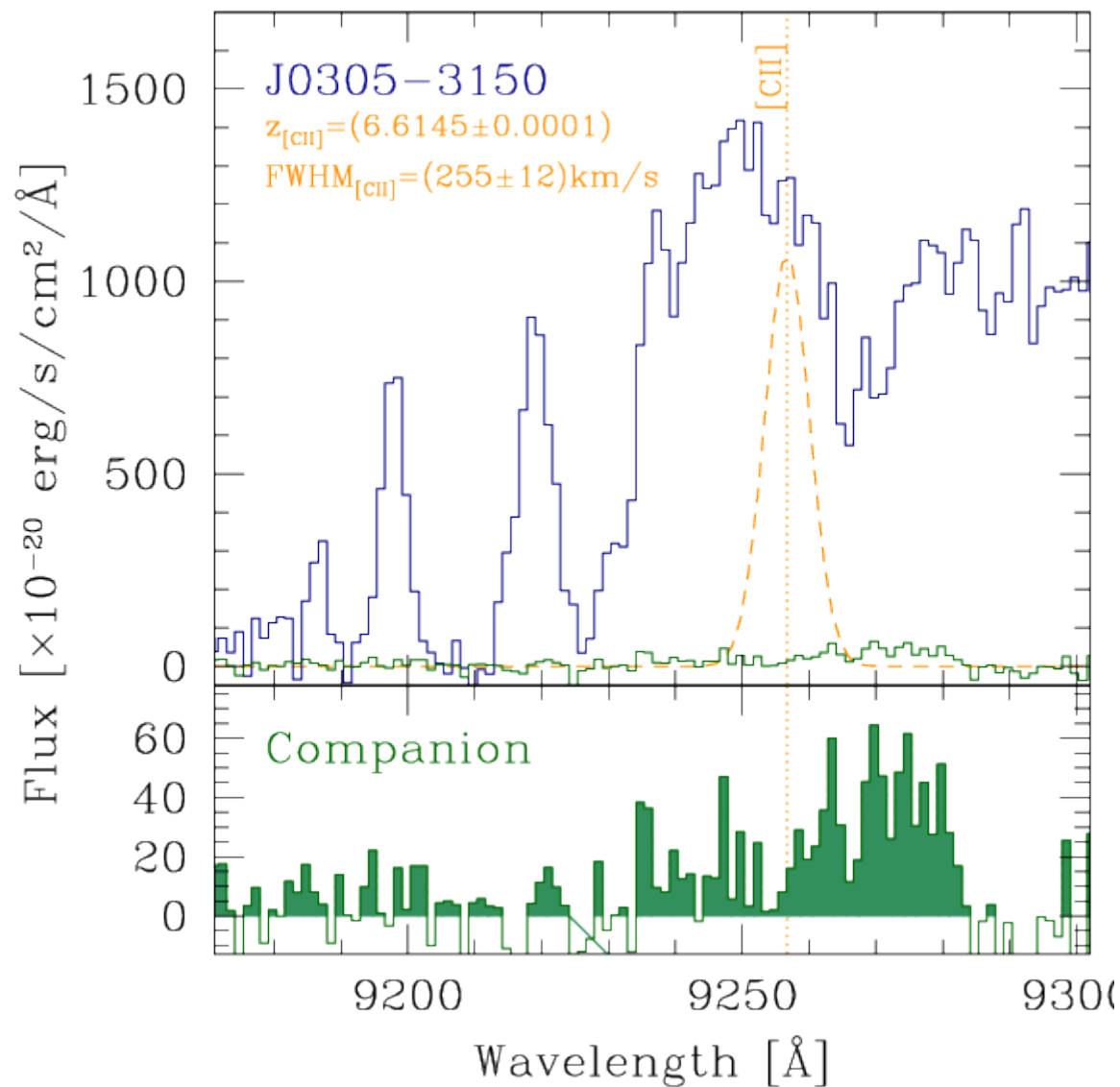
~10 kpc Ly α Nebula
L(Ly α) = 2×10^{42} erg/s



Farina et al. in prep.



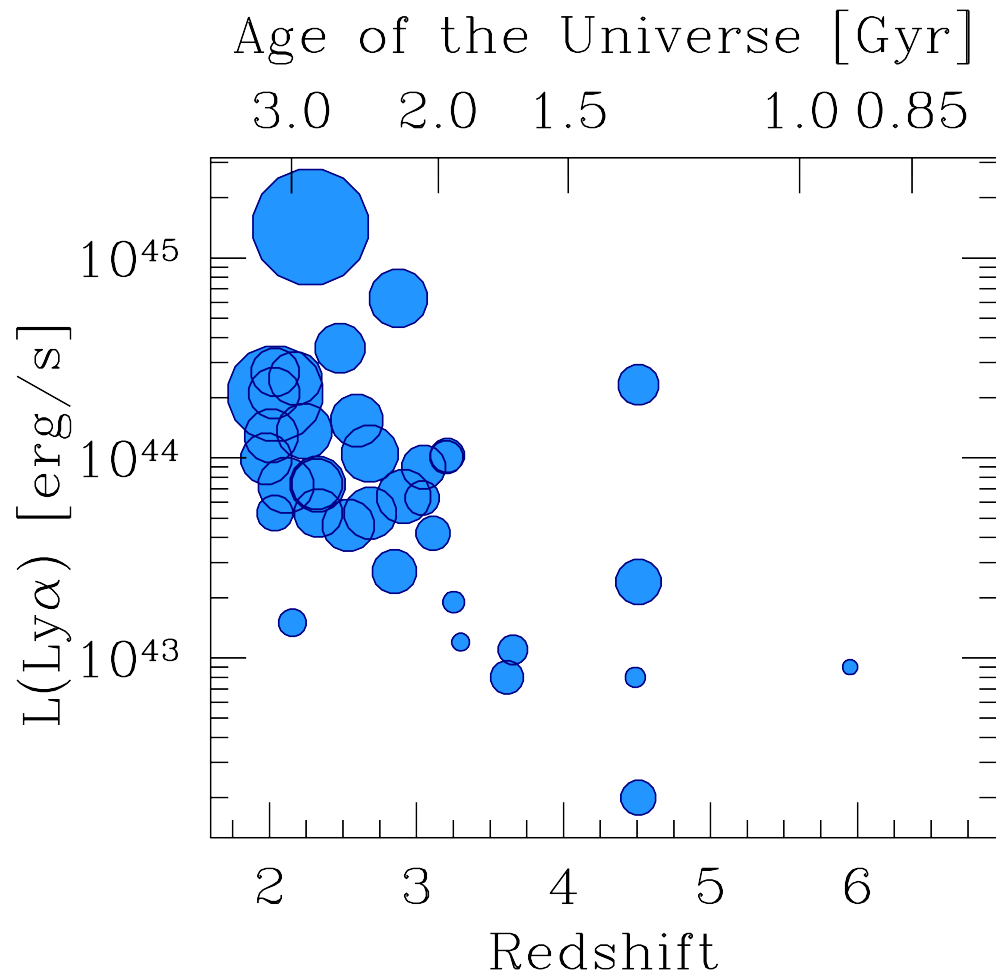




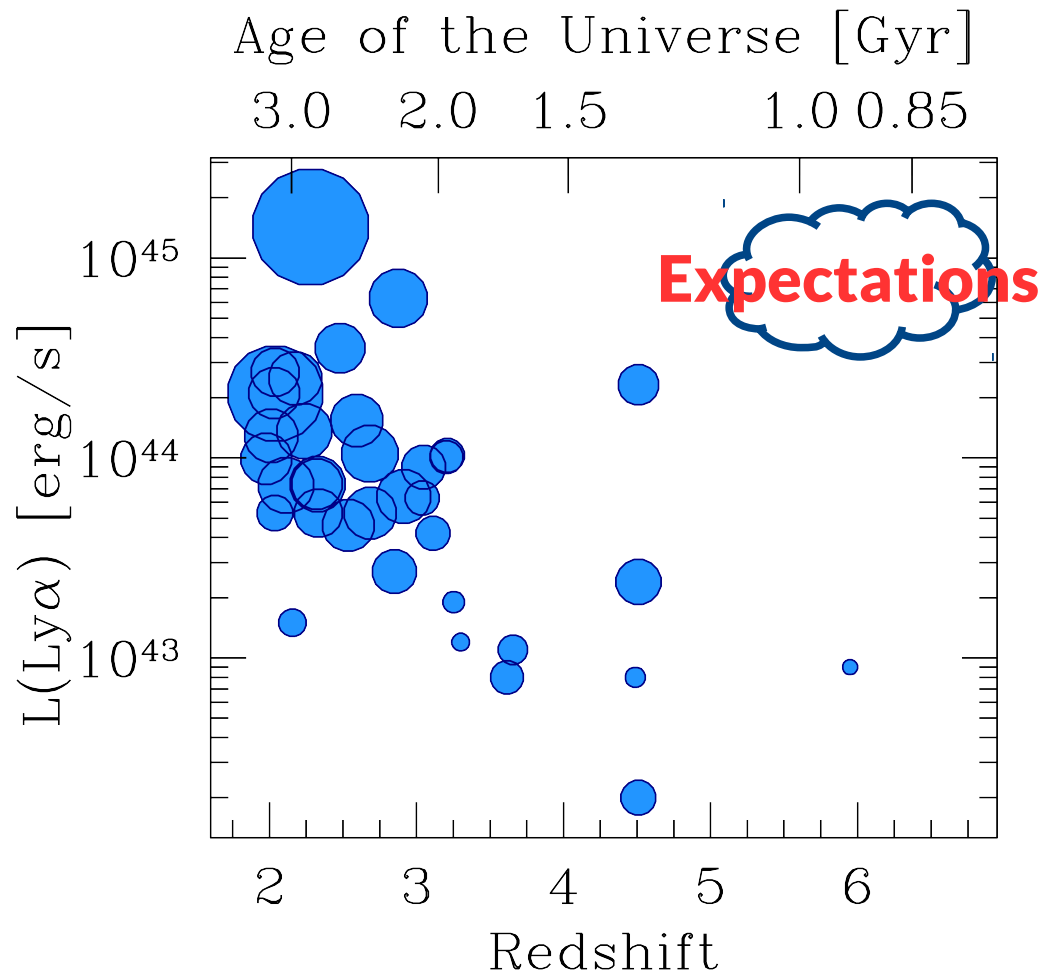
LAE companion →

$\Delta V \sim 500 \text{ km/s}$
 $\text{FWHM} \sim 570 \text{ km/s}$
 $F \sim 10^{-17} \text{ erg/s/cm}^2$

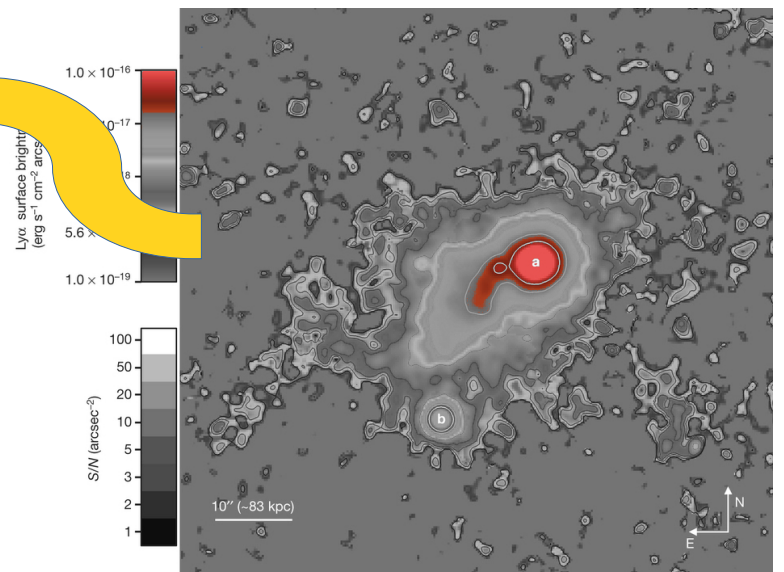
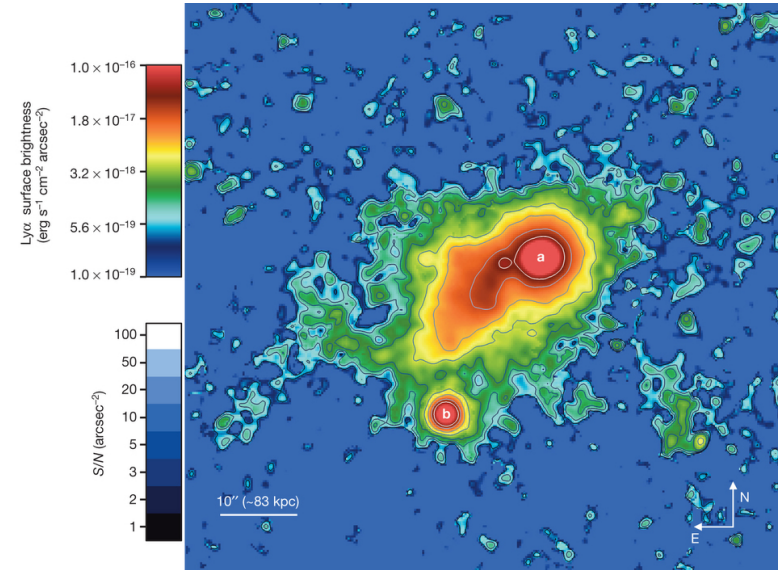
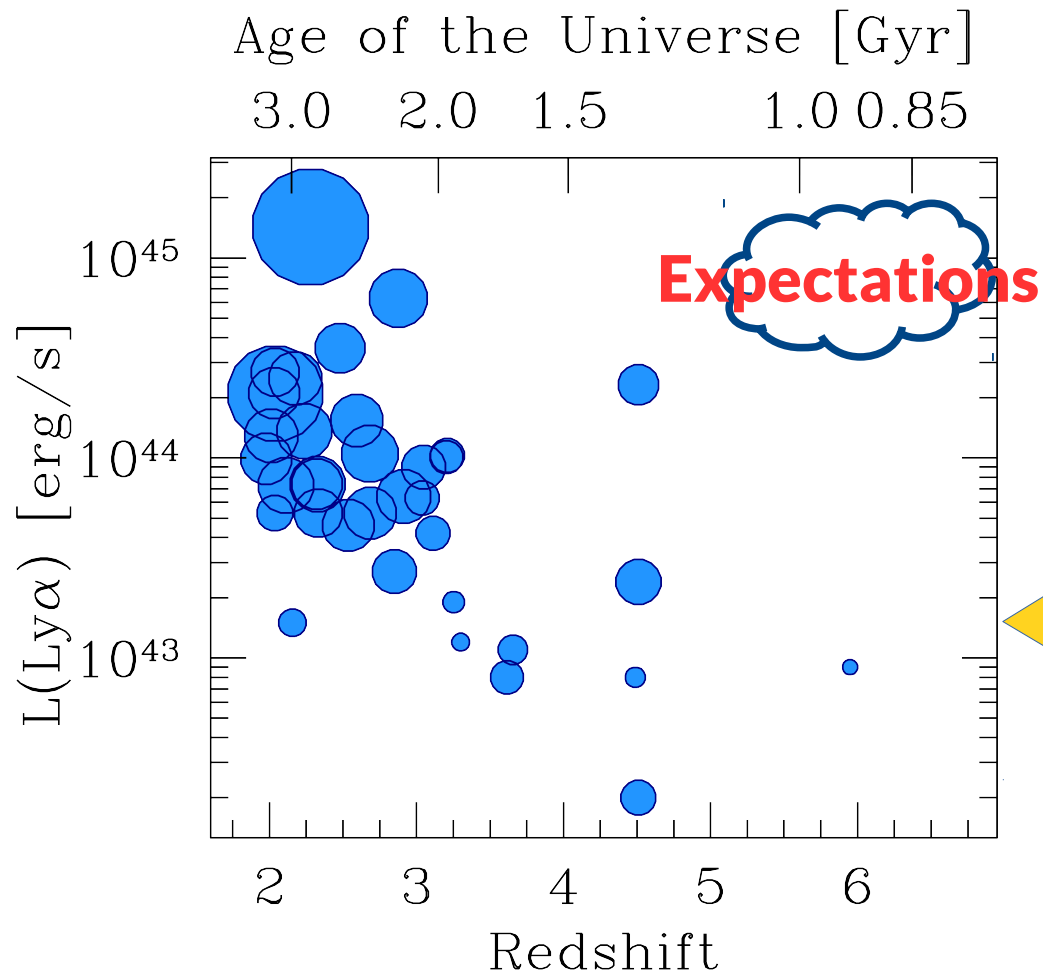
Ly α Haloes at $z > 6$



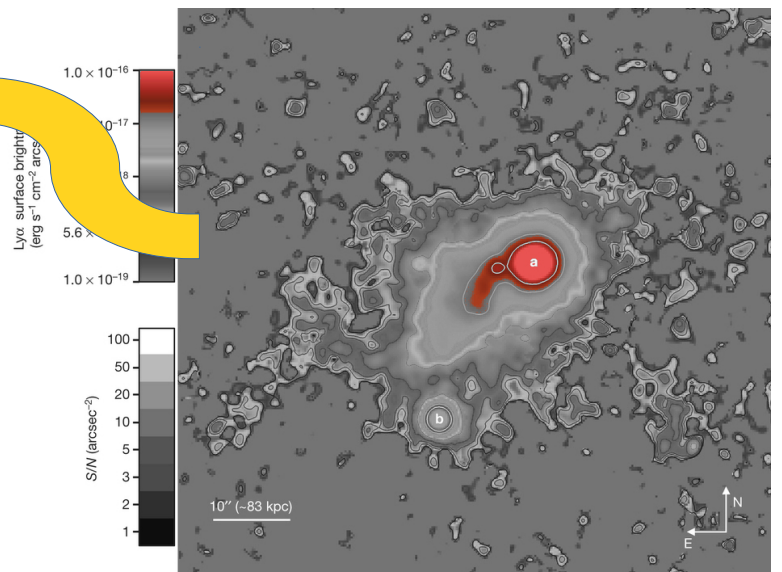
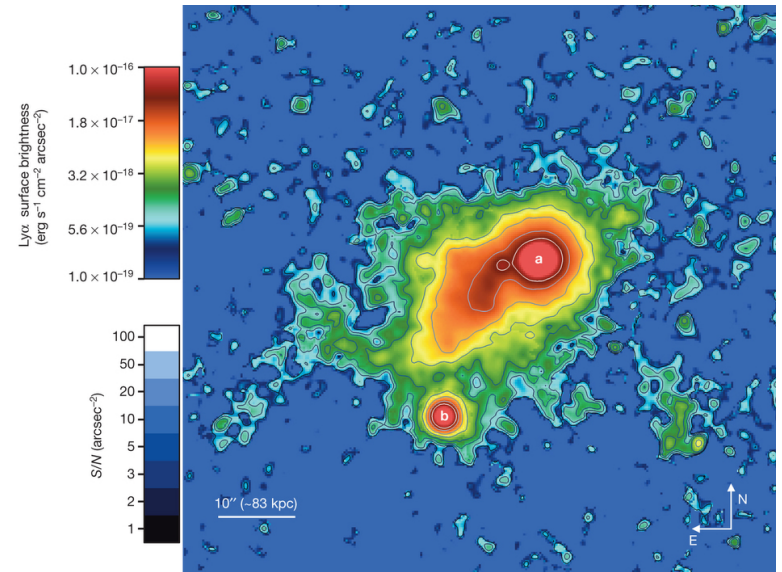
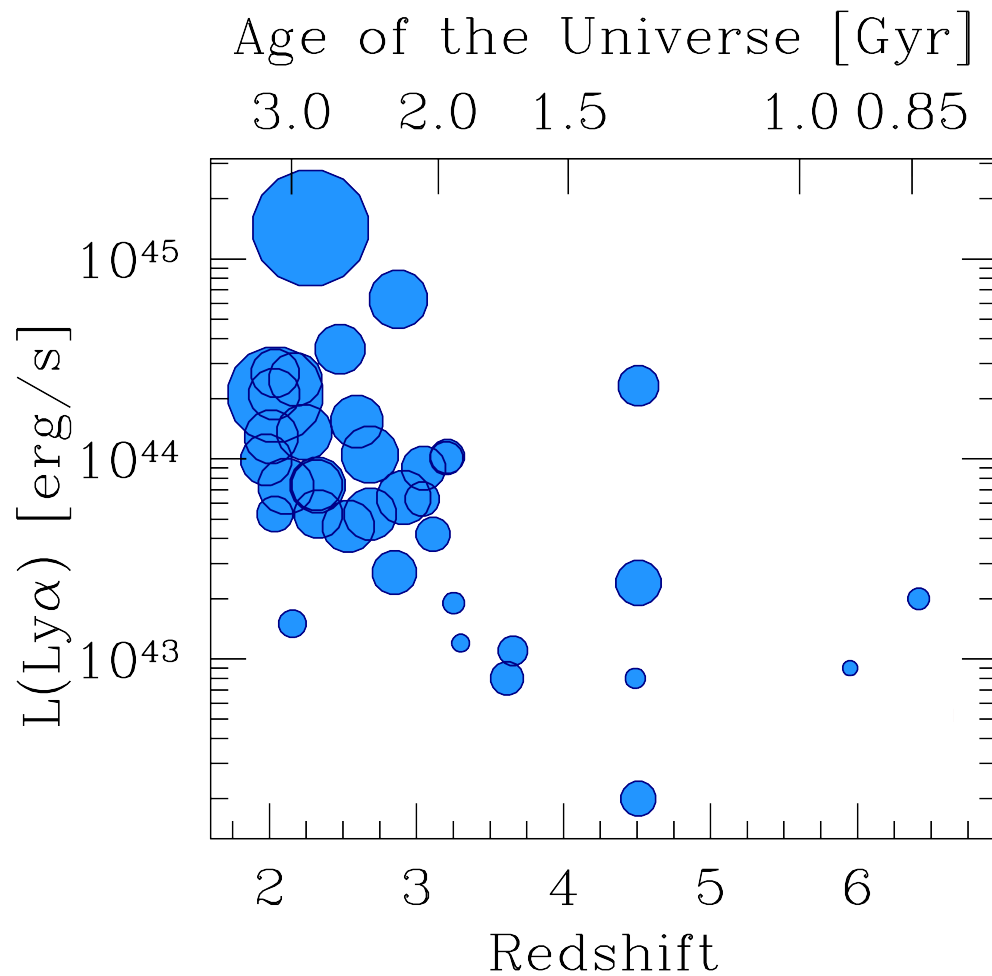
Ly α Haloes at $z > 6$



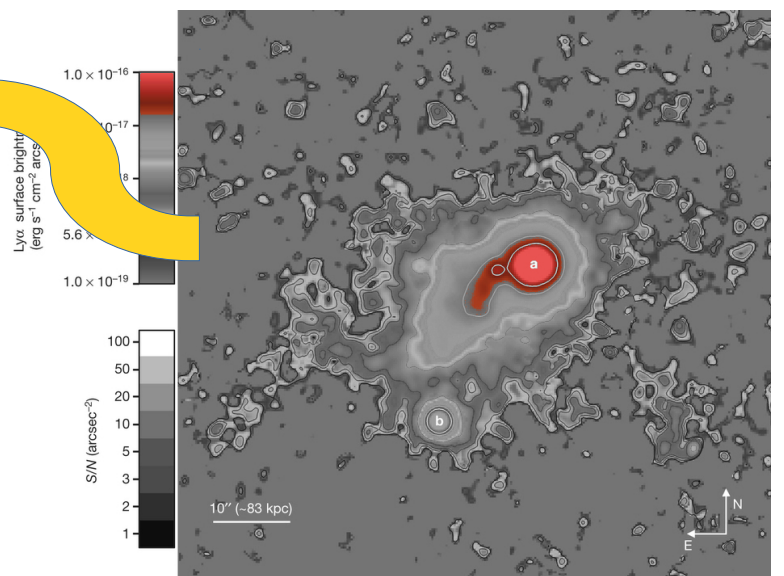
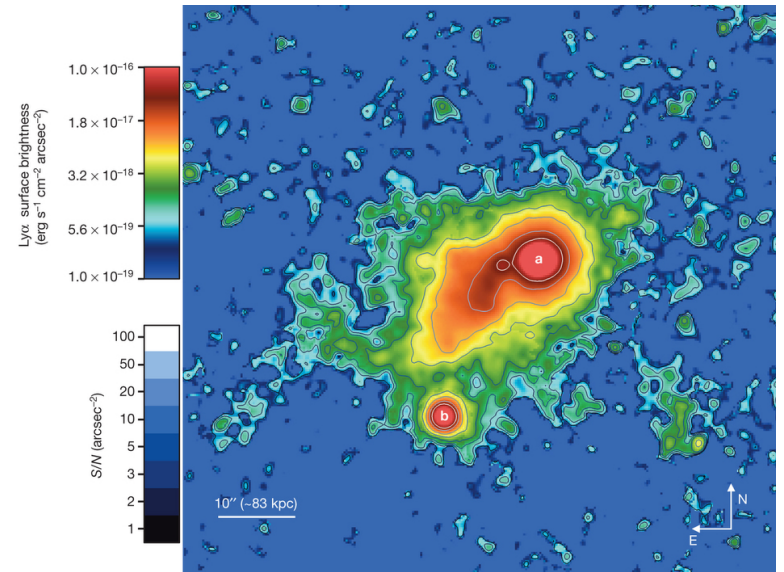
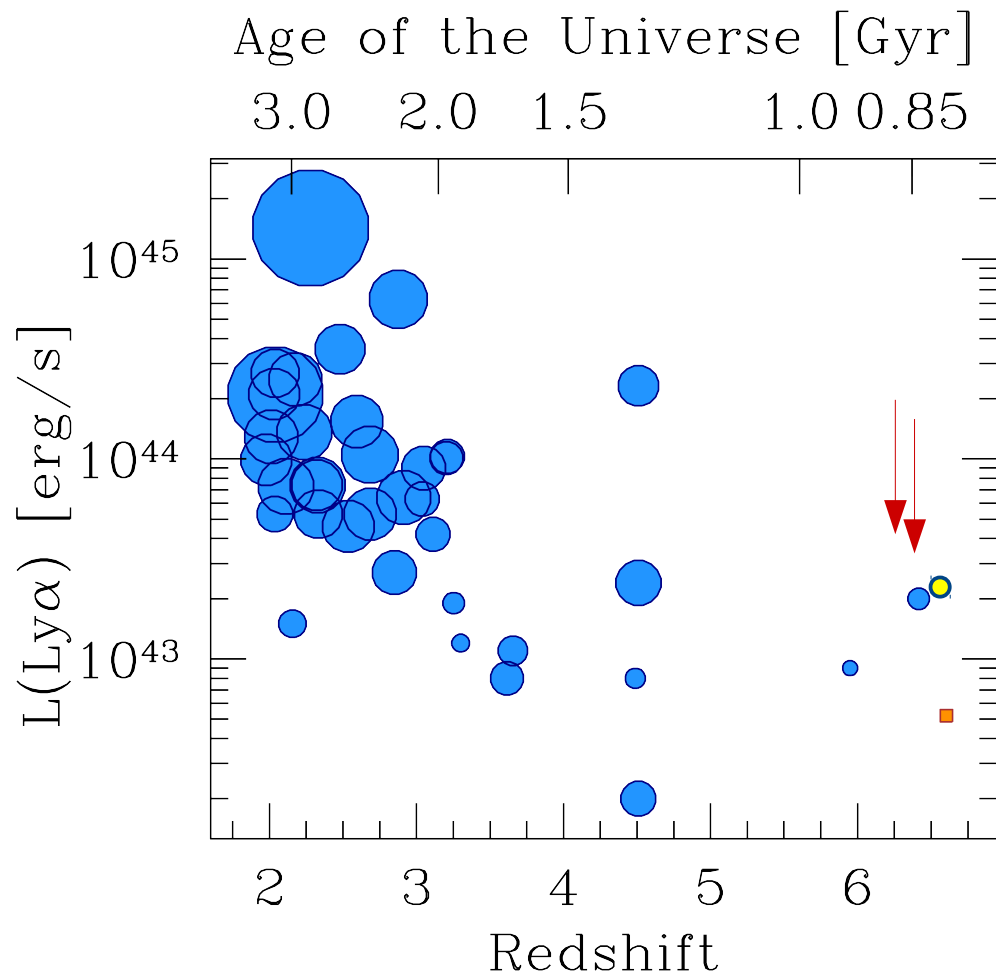
Ly α Haloes at $z > 6$



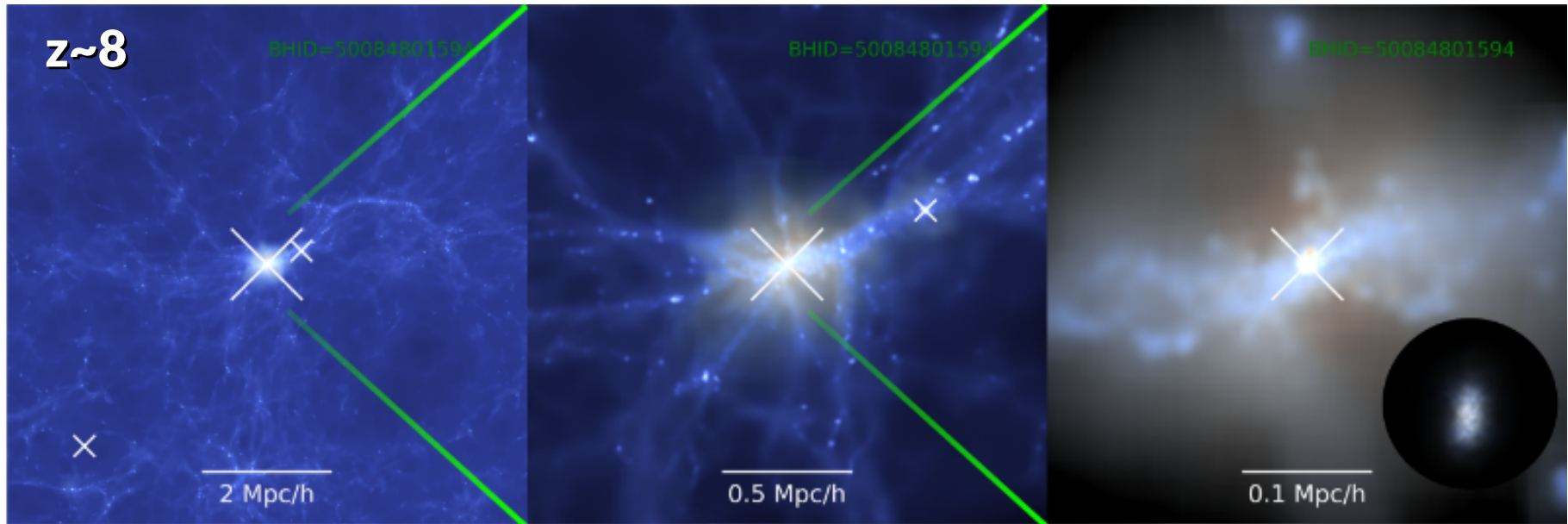
Ly α Haloes at $z > 6$



Ly α Haloes at $z > 6$



Summary



**some evidence for extended structures
[in 4 QSOs at $z > 6$]**

rule out compact halos/filaments

waiting for MUSE AO