

The birth of the giants: Where do the first quasars form?

Emanuele Paolo Farina [MPIA]

THQ:

- Fabian Walter
- Bram Venemans
- Roberto Decarli
- Eduardo Bañados
- Chiara Mazzucchelli

Extended THQ:

- Xiaohui Fan
- Benjamin Weiner
- Joe Hennawi
- Fabrizio Arrigoni-Battaia
- Sebastiano Cantalupo
- and many more..

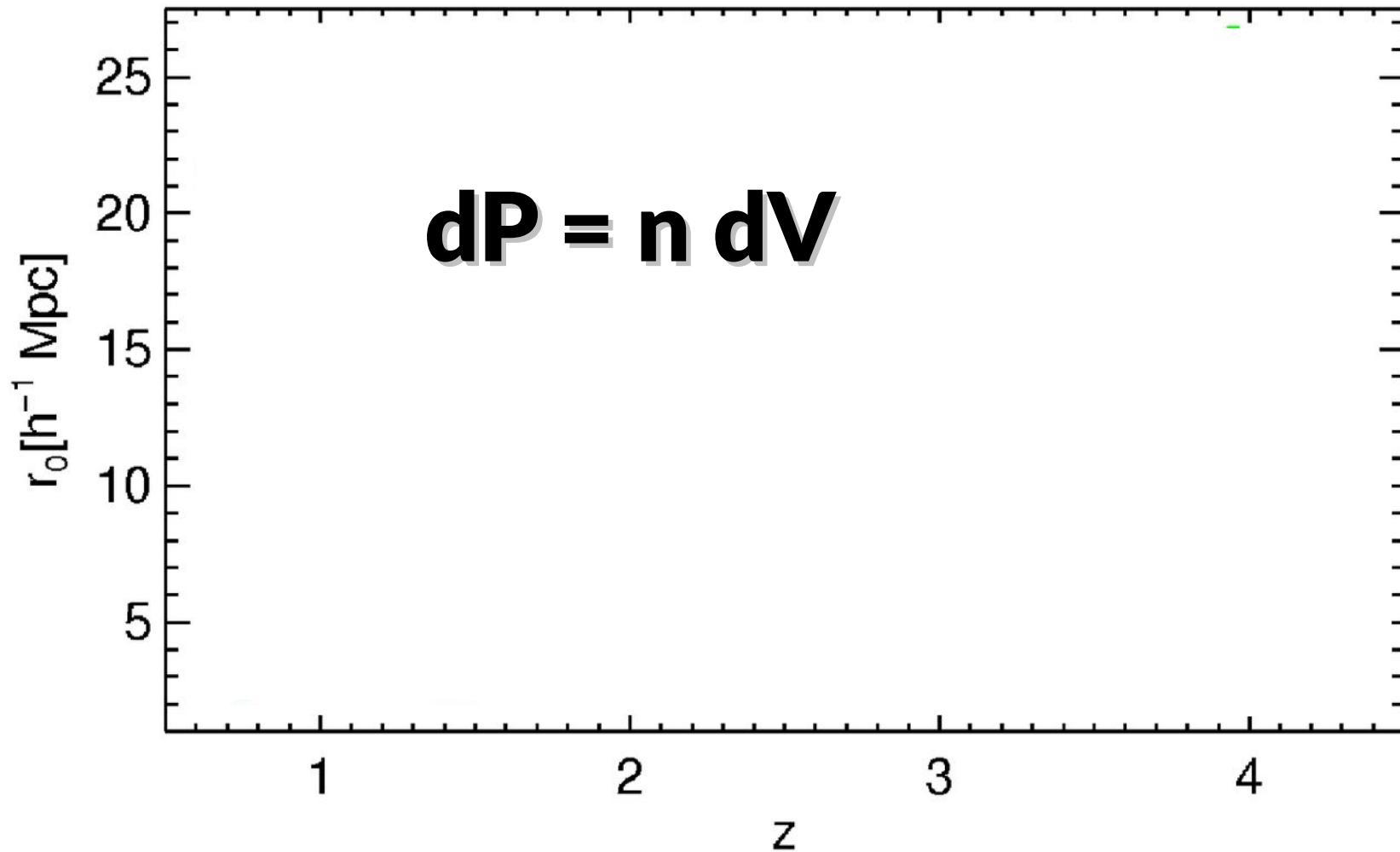
ABELL 1689



$M_{\text{vir}} \sim 2 \times 10^{15} M_{\text{sun}} @ z \sim 0.2$

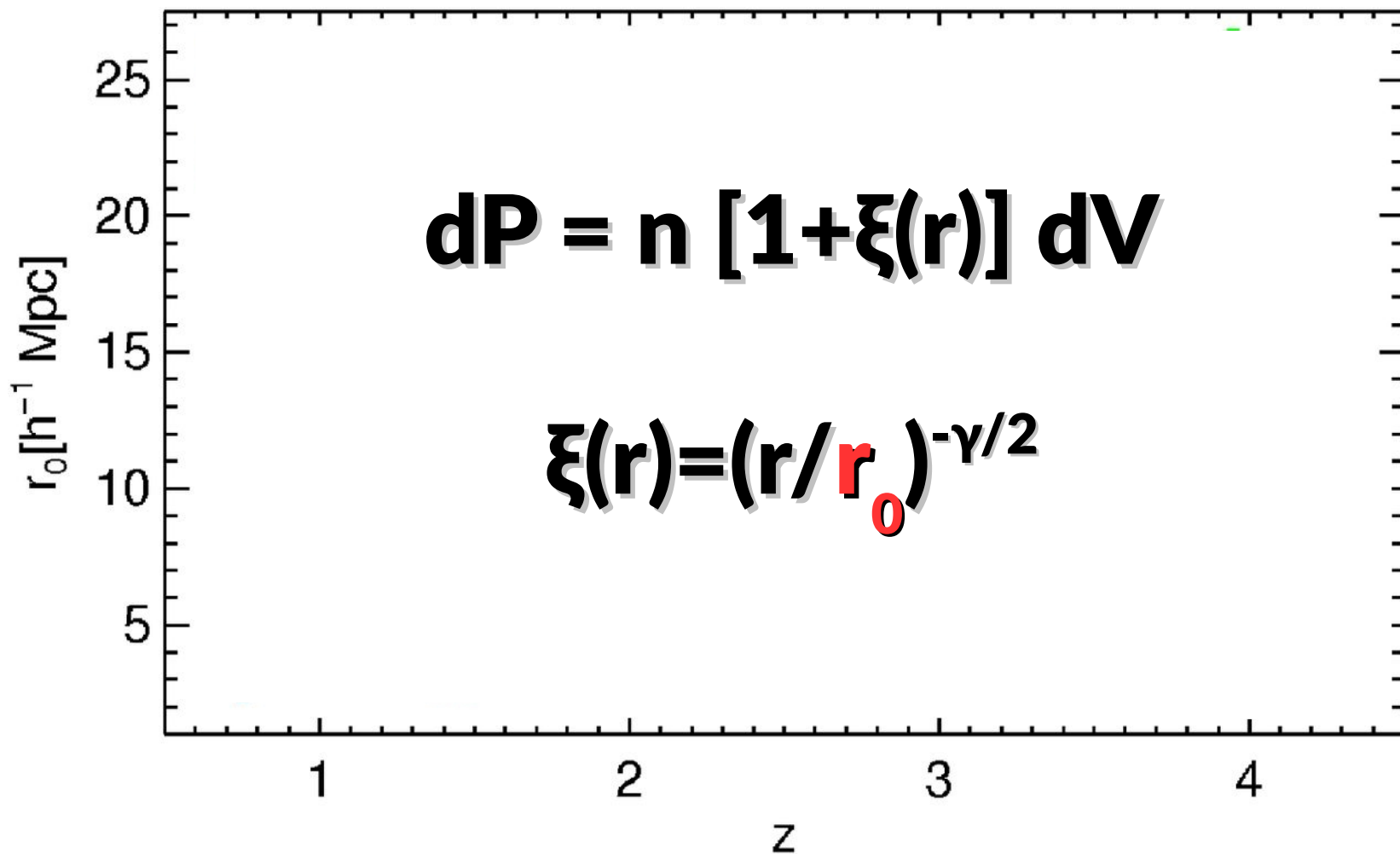
QSO Clustering

QSO-QSO Correlation Length vs. Redshift



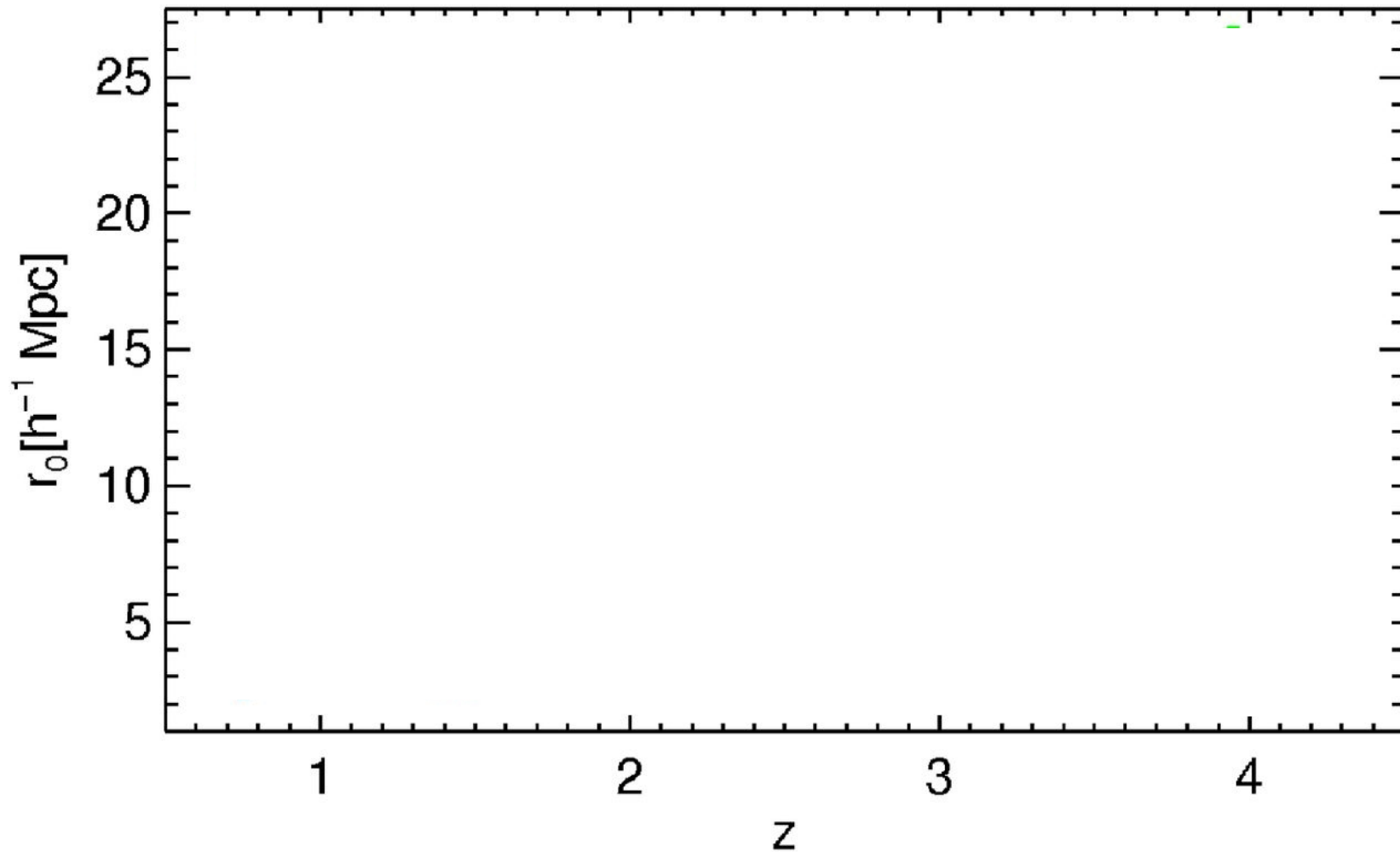
QSO Clustering

QSO-QSO Correlation Length vs. Redshift



QSO Clustering

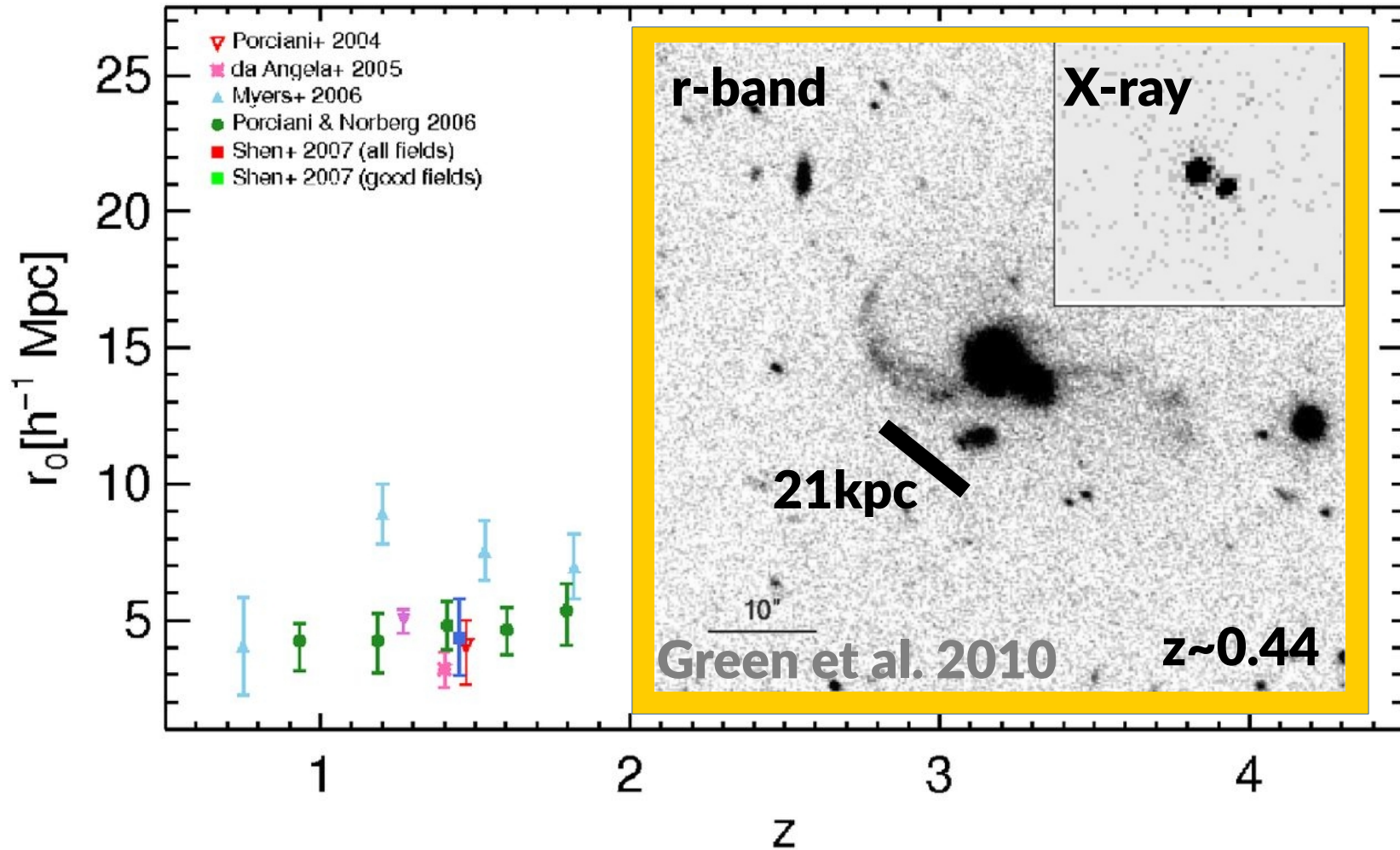
QSO-QSO Correlation Length vs. Redshift



Eftekharzadeh et al. 2015

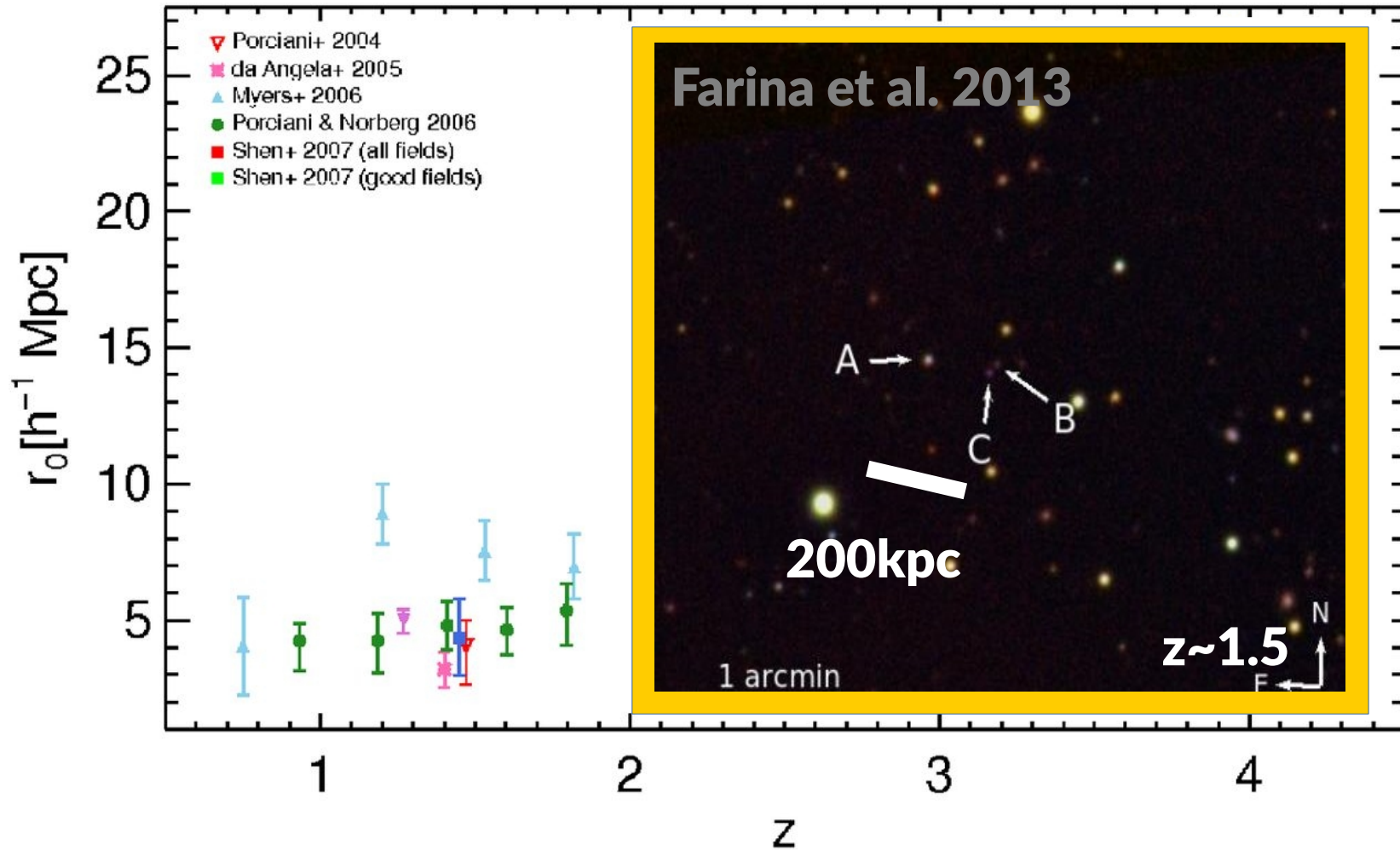
QSO Clustering

QSO-QSO Correlation Length vs. Redshift



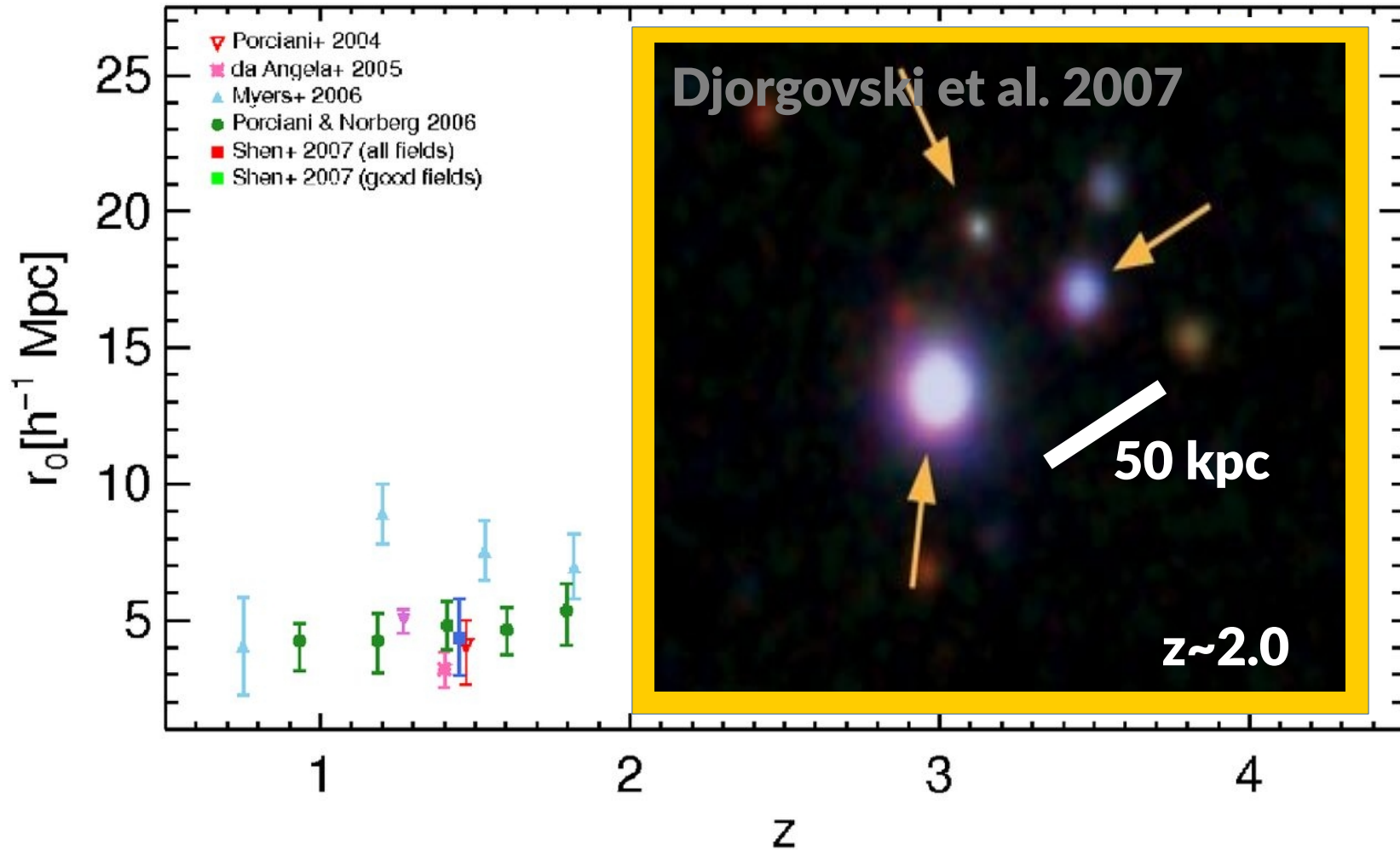
QSO Clustering

QSO-QSO Correlation Length vs. Redshift



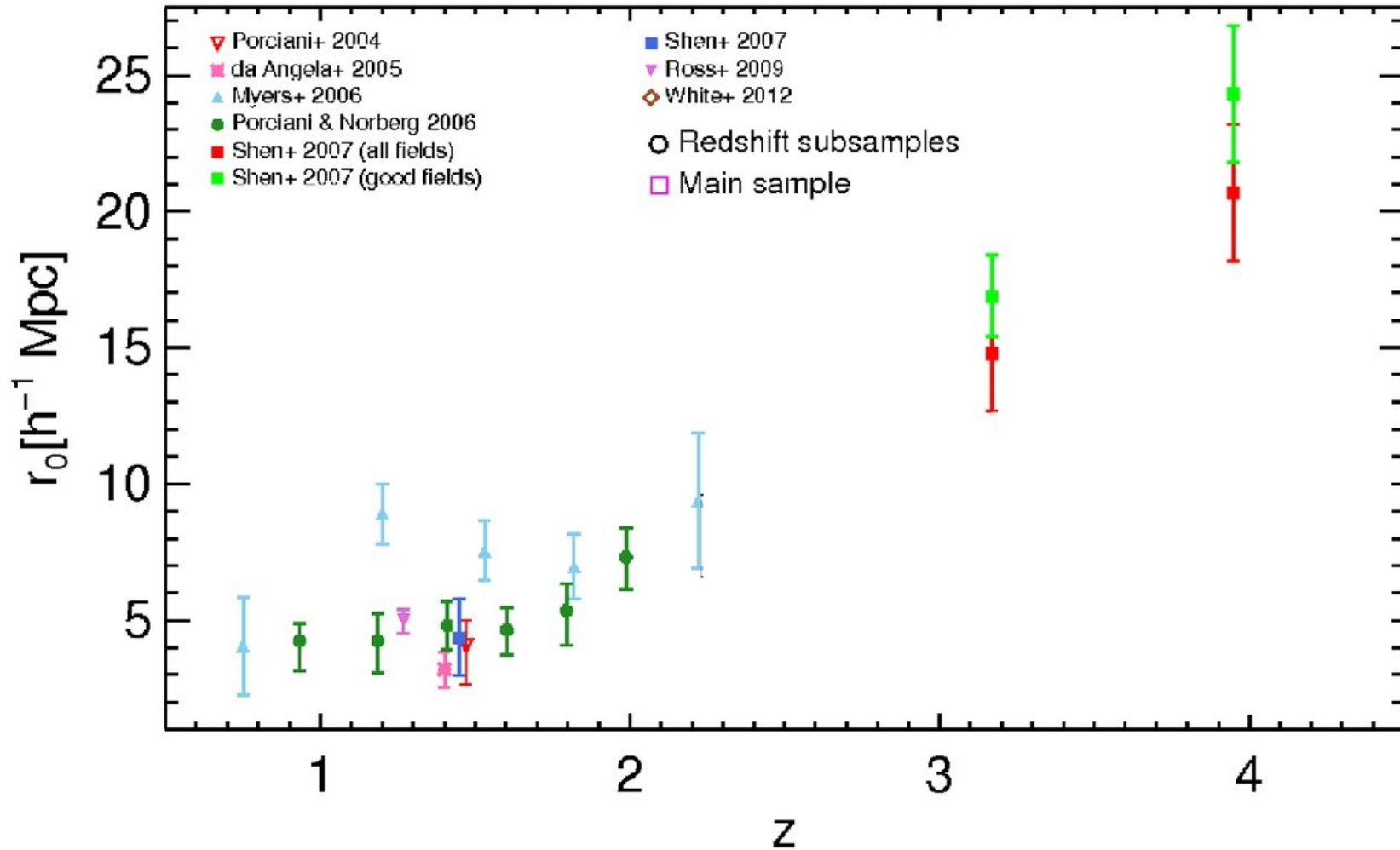
QSO Clustering

QSO-QSO Correlation Length vs. Redshift



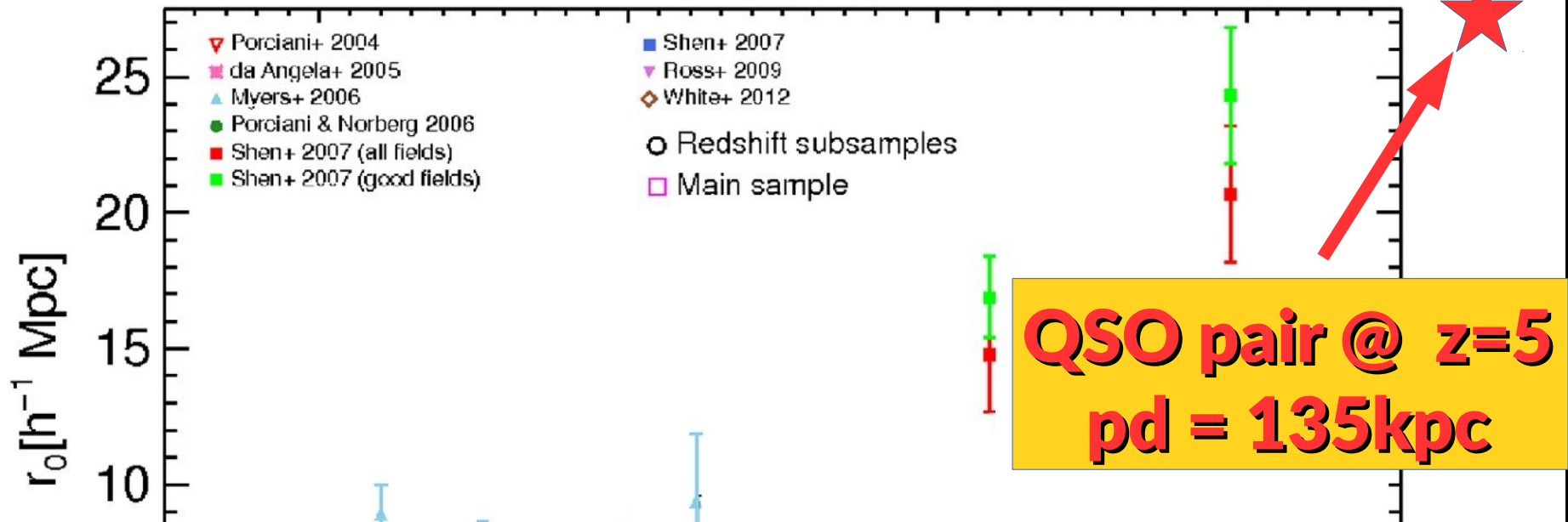
QSO Clustering

QSO-QSO Correlation Length vs. Redshift

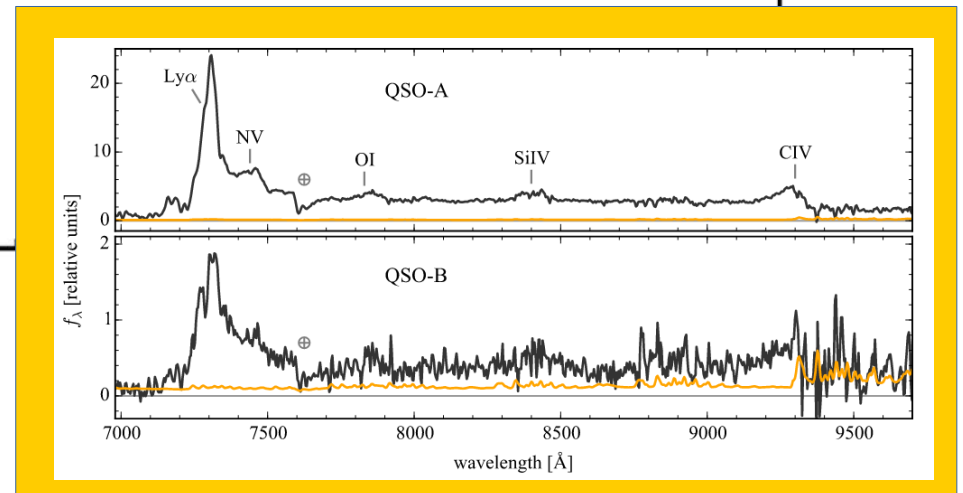


QSO Clustering

QSO-QSO Correlation Length vs. Redshift

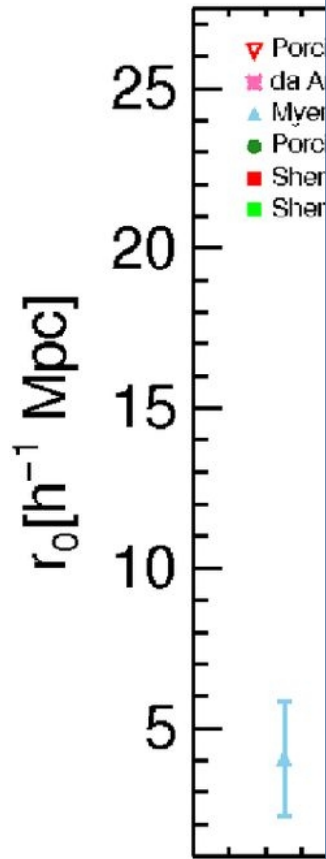


McGreer et al. 2016
Eftekharzadeh et al. 2015



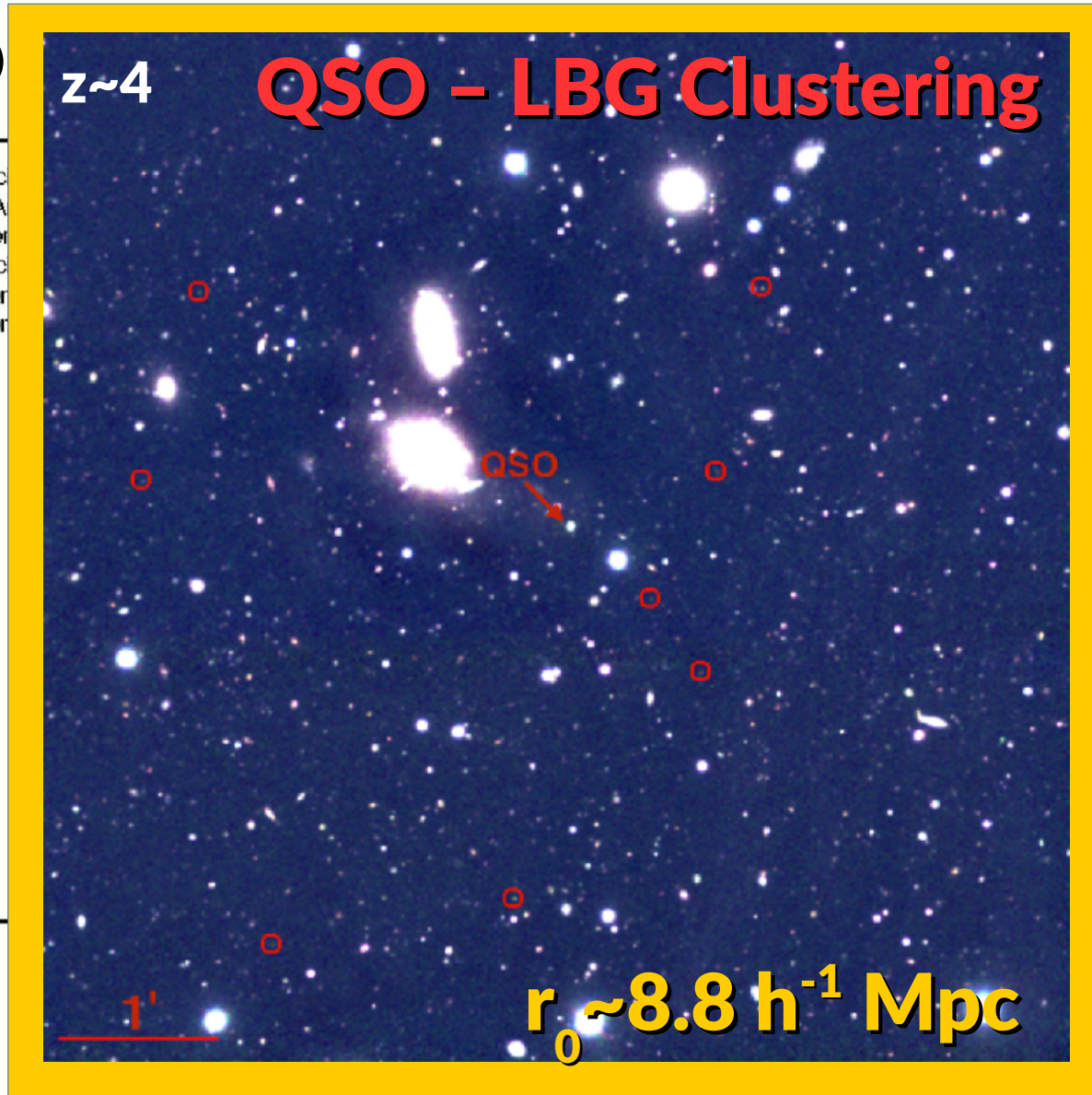
QSO Clustering

QSO-QSO



$z \sim 4$

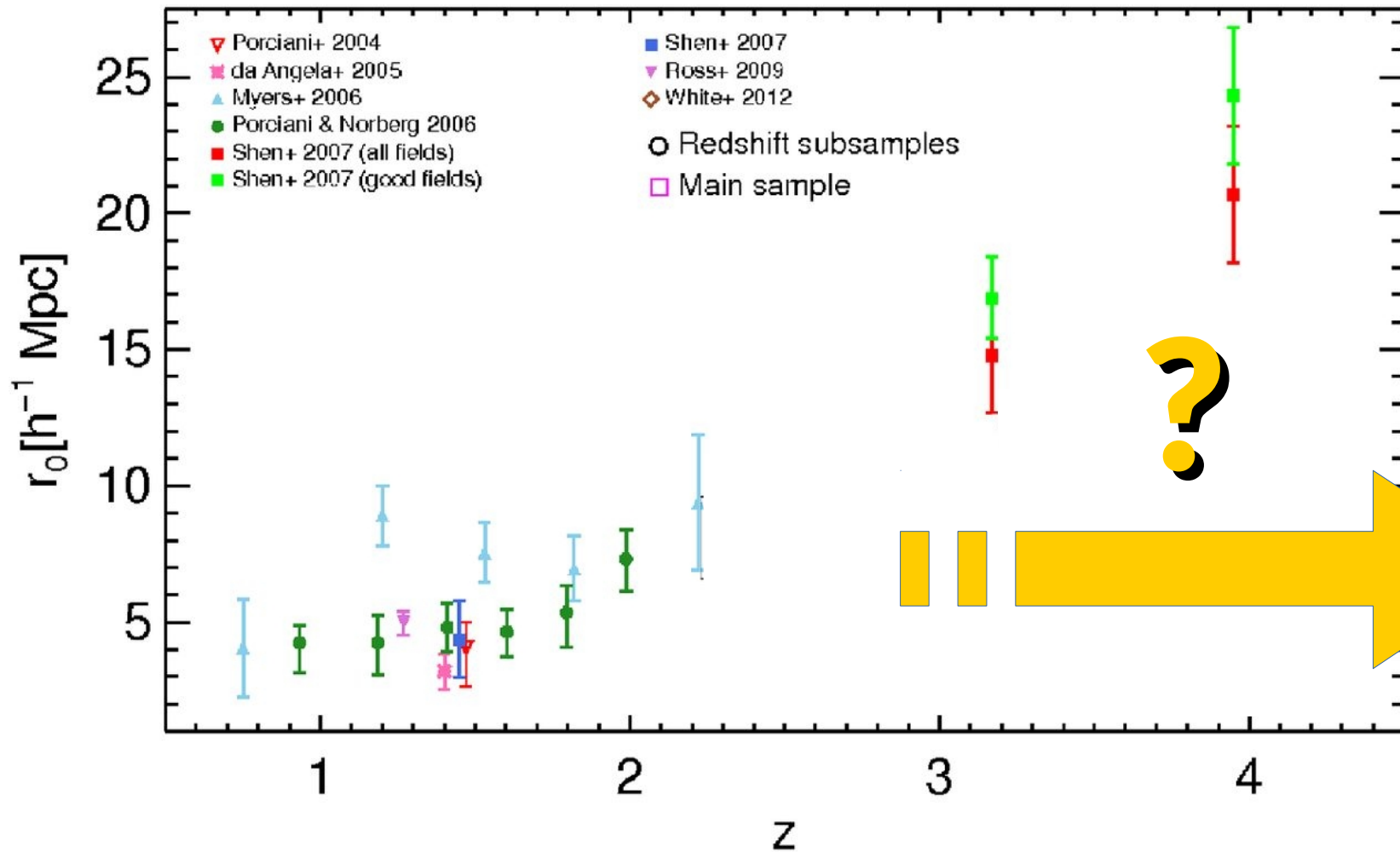
QSO - LBG Clustering



Garcia-Vergara et al. 2017

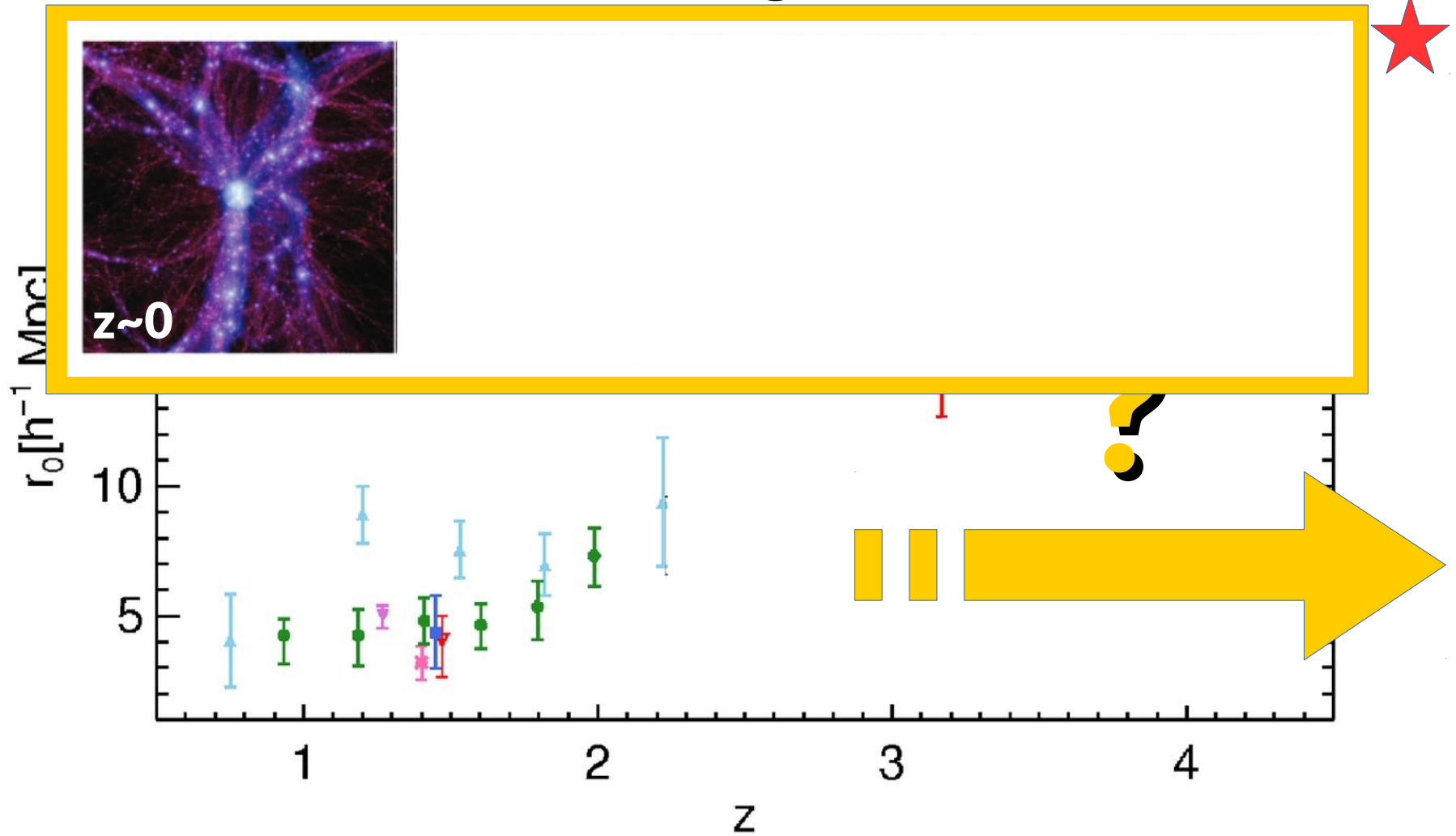
QSO Clustering

QSO-QSO Correlation Length vs. Redshift



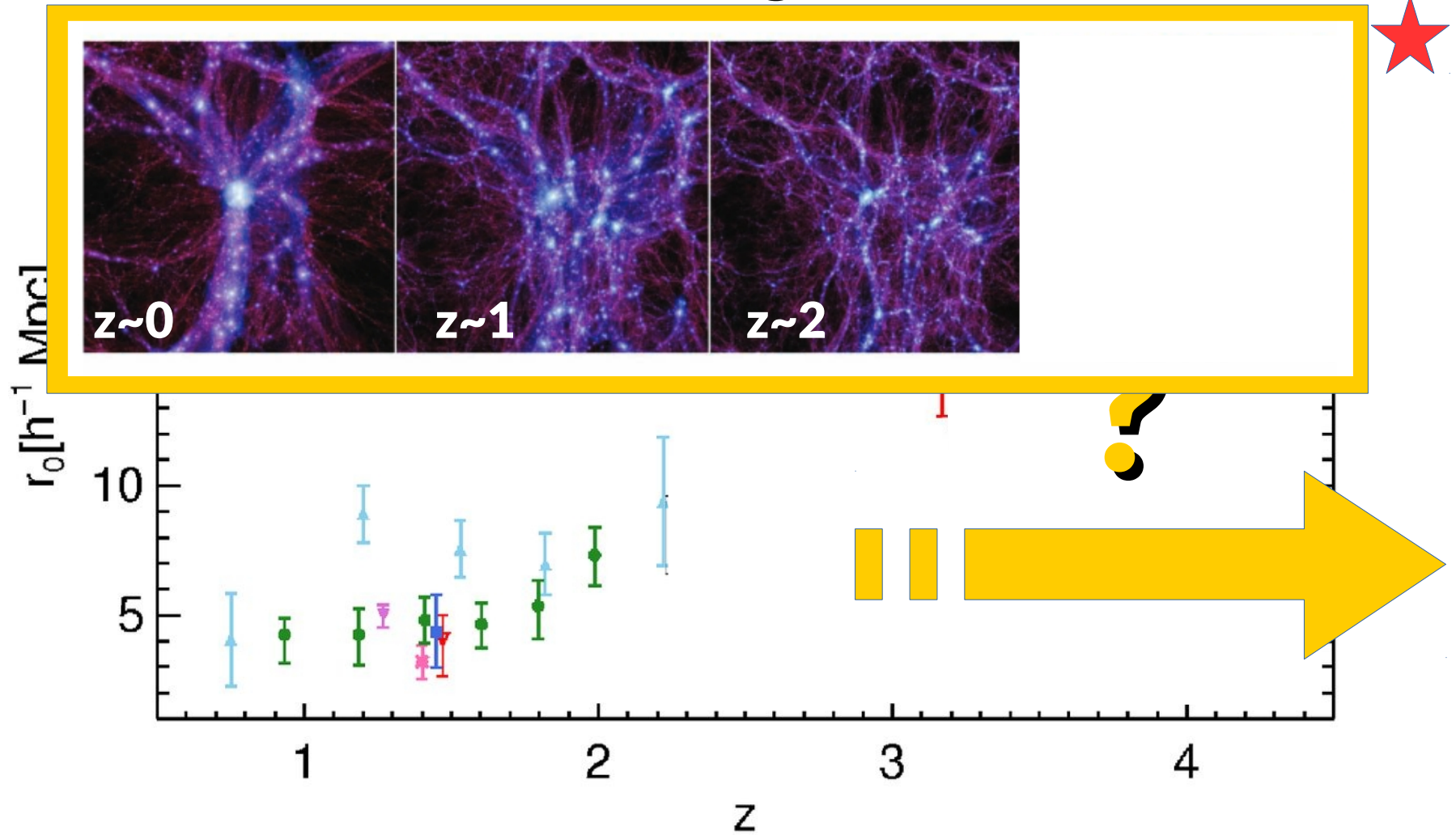
QSO Clustering

QSO-QSO Correlation Length vs. Redshift



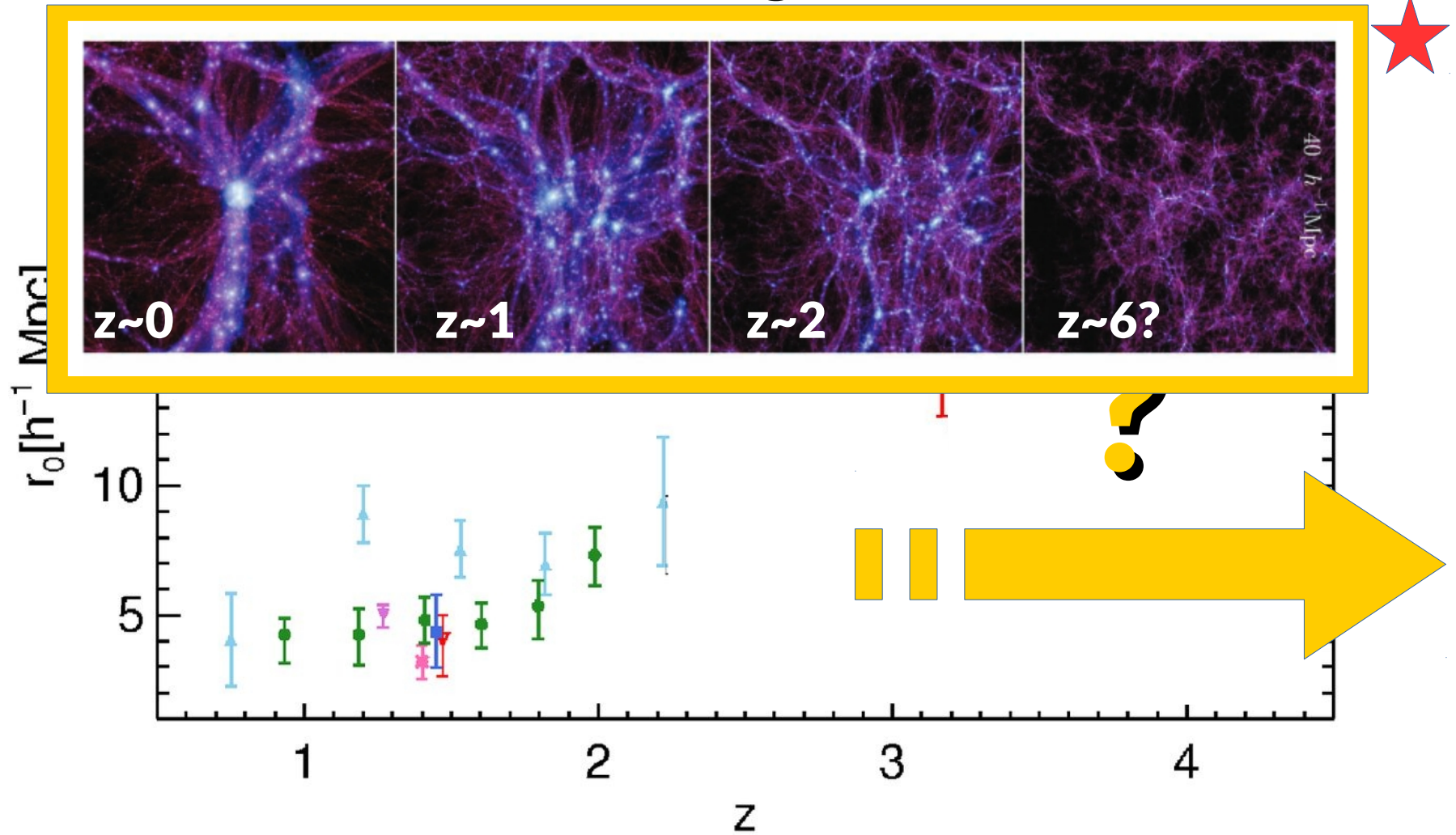
QSO Clustering

QSO-QSO Correlation Length vs. Redshift



QSO Clustering

QSO-QSO Correlation Length vs. Redshift



Boylan-Kolchin et al. 2009

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

The Cosmic Renaissance
The Dark Ages end

← Reionization complete, the Universe becomes transparent again

Galaxies evolve

The Solar System forms

Today: Astronomers figure it all out!

History of the Universe

$z \sim 5.5 \rightarrow$
[~1Gyr]

Time since the Big Bang (years)

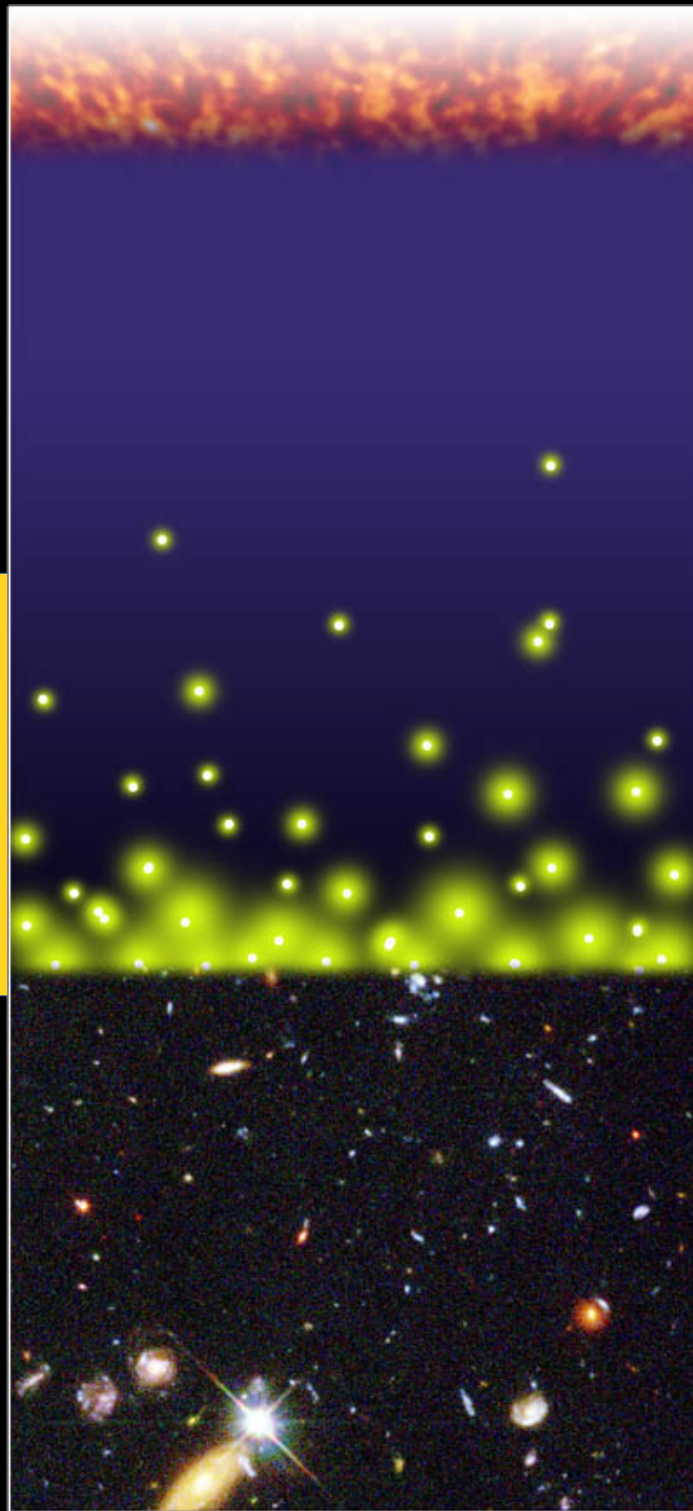
~ 300 thousand

~ 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

← $z \sim 7.5$
[~0.7Gyr]

The Cosmic Renaissance
The Dark Ages end

← Reionization complete, the Universe becomes transparent again

Galaxies evolve

The Solar System forms

Today: Astronomers figure it all out!

History of the Universe

Time since the Big Bang (years)

~ 300 thousand

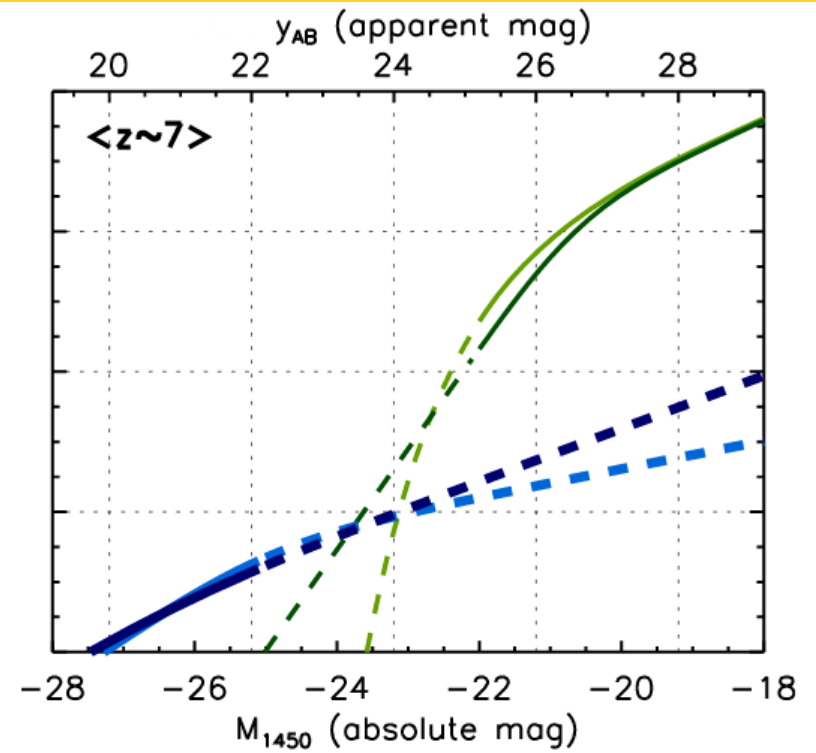
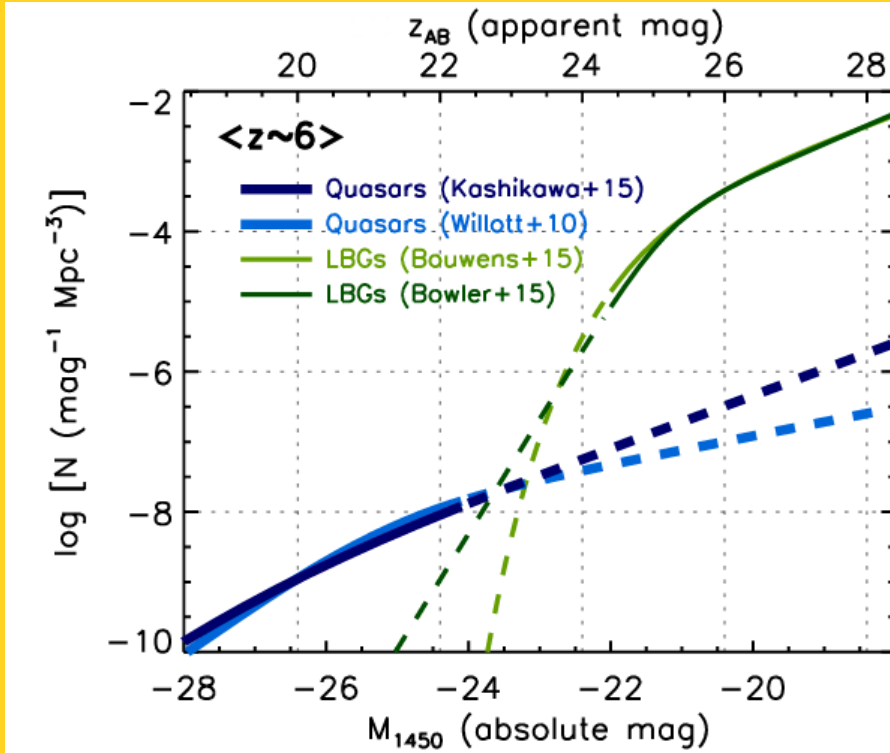


← The Big Bang

The Universe filled with ionized gas

← The Universe becomes neutral and opaque

The Dark Ages start



~ 9 billion

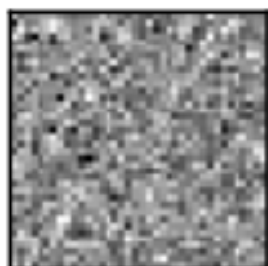
~ 13 billion



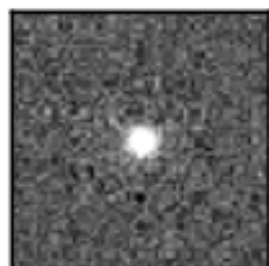
The Solar System forms

Today: Astronomers figure it all out!

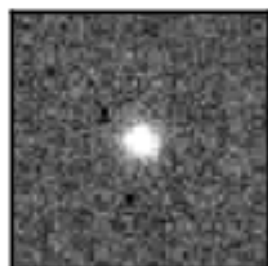
$z_{\text{DE}, 3\sigma} > 23.$



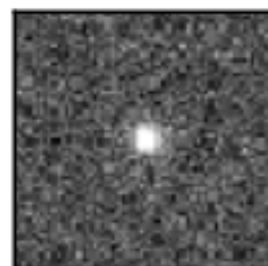
$J_1 = 20.$



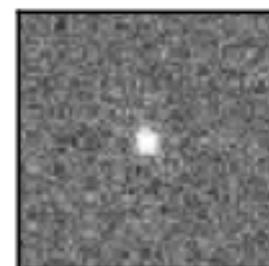
$J = 20.3$



$H = 20.$



$K_s = 20.$



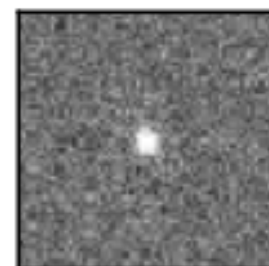
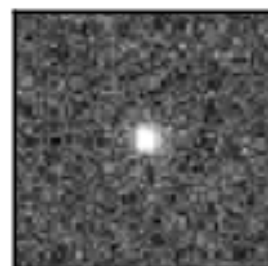
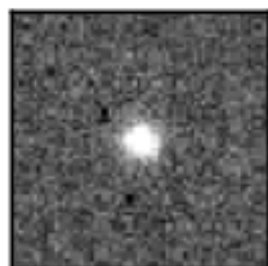
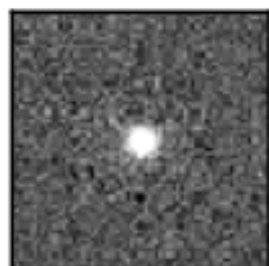
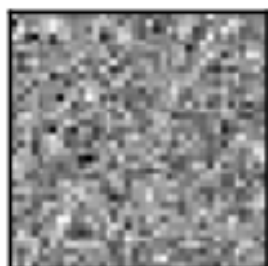
$z_{\text{DE}, 3\sigma} > 23.$

$J1 = 20.$

$J = 20.$

$H = 20.$

$Ks = 20.$



Observed wavelength (μm)

1.0

1.2

1.4

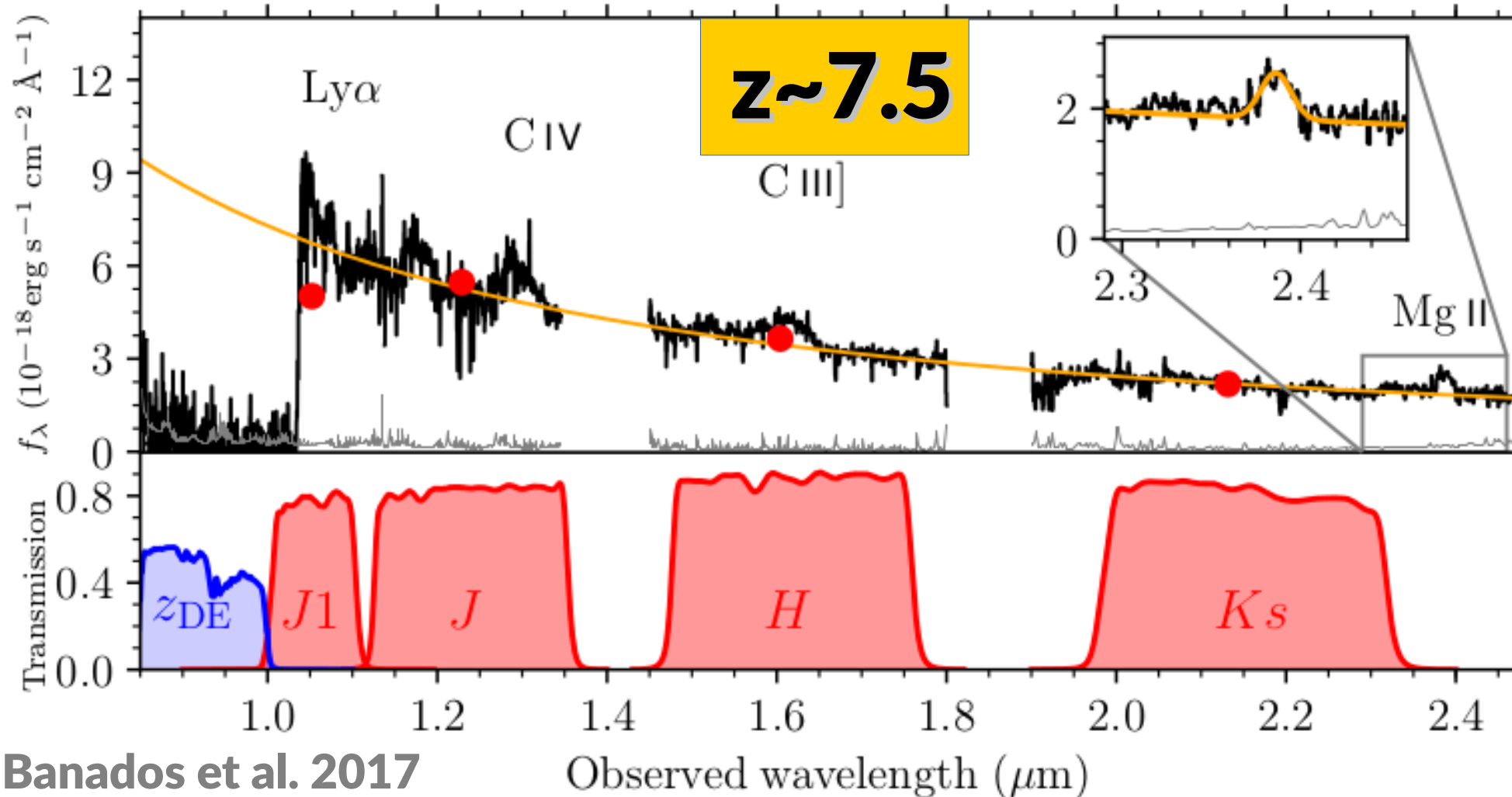
1.6

1.8

2.0

2.2

2.4



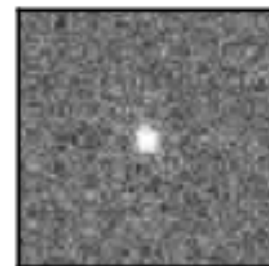
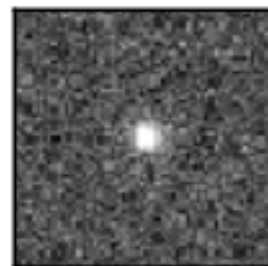
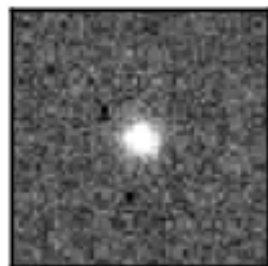
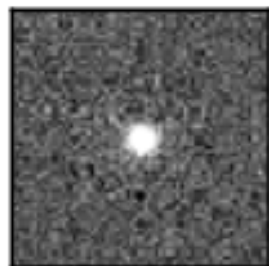
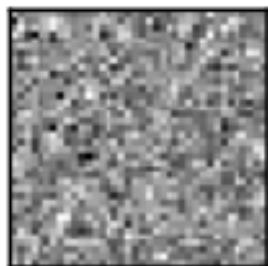
$z_{\text{DE}, 3\sigma} > 23.$

$J1 = 20.$

$J = 20.$

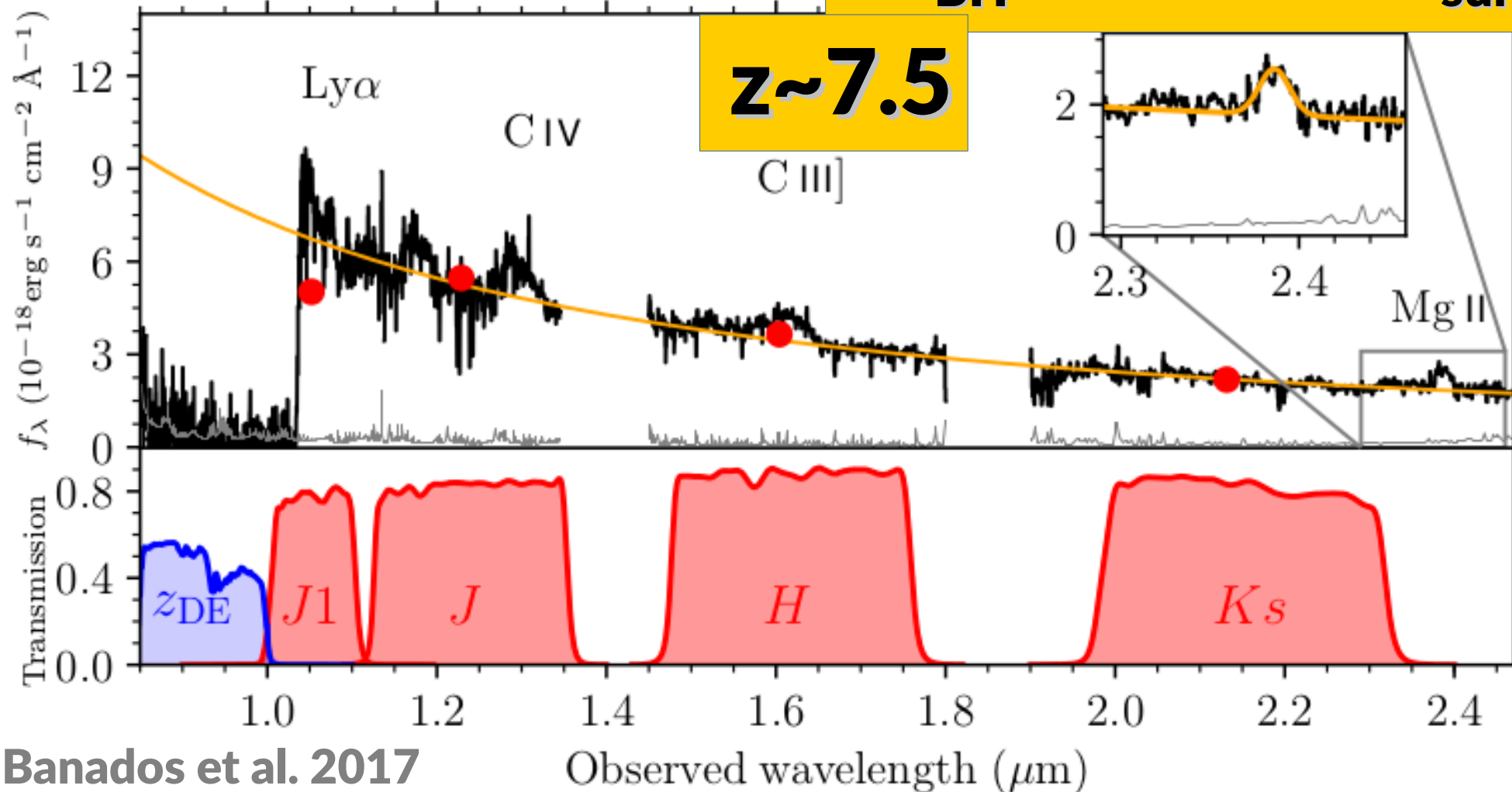
$H = 20.$

$Ks = 20.$



Observed wavelength (μm)

$M_{\text{BH}} \sim 8 \times 10^8 M_{\text{sun}}$



History of the Universe

$z \sim 5.5 \rightarrow$
[~1Gyr]

Time since the
Big Bang (years)

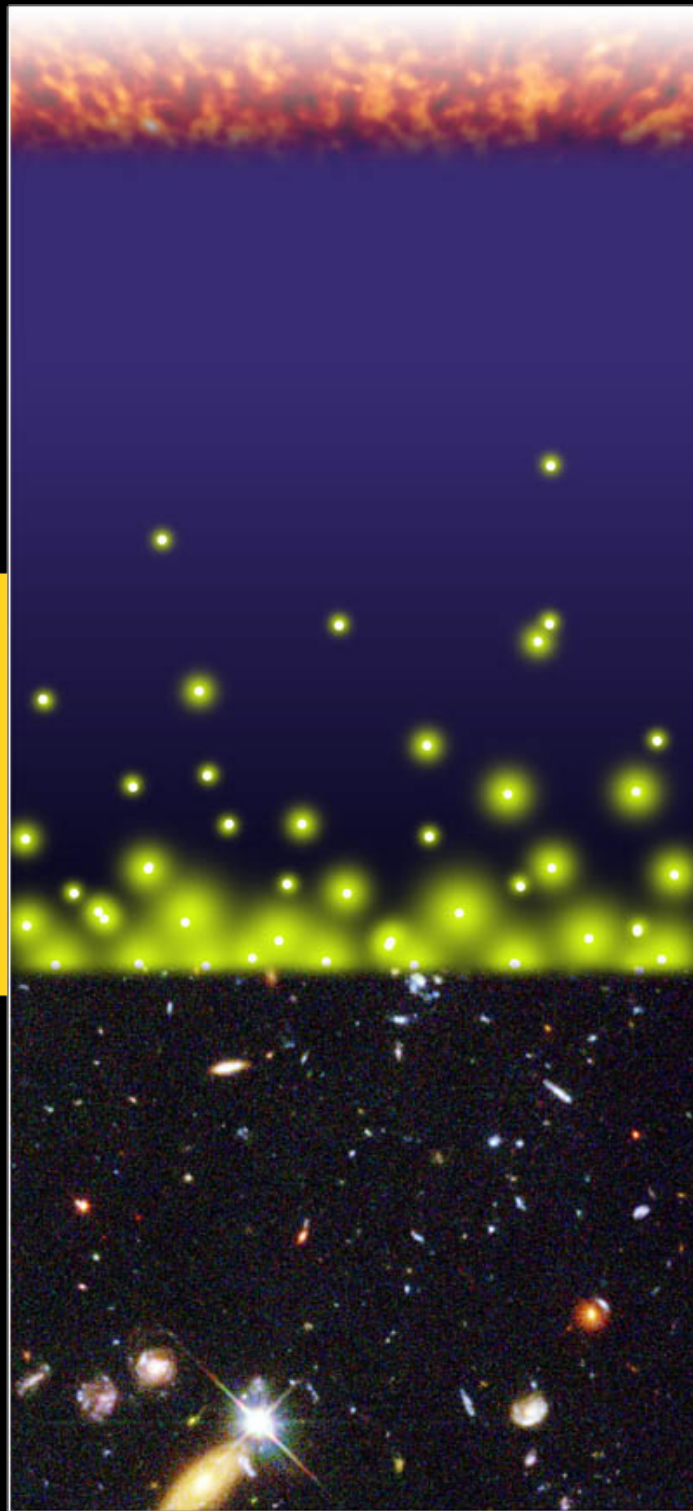
~ 300 thousand

~ 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

← $z \sim 7.5$
[~0.7Gyr]

The Cosmic Renaissance
The Dark Ages end

← Reionization complete,
the Universe becomes
transparent again

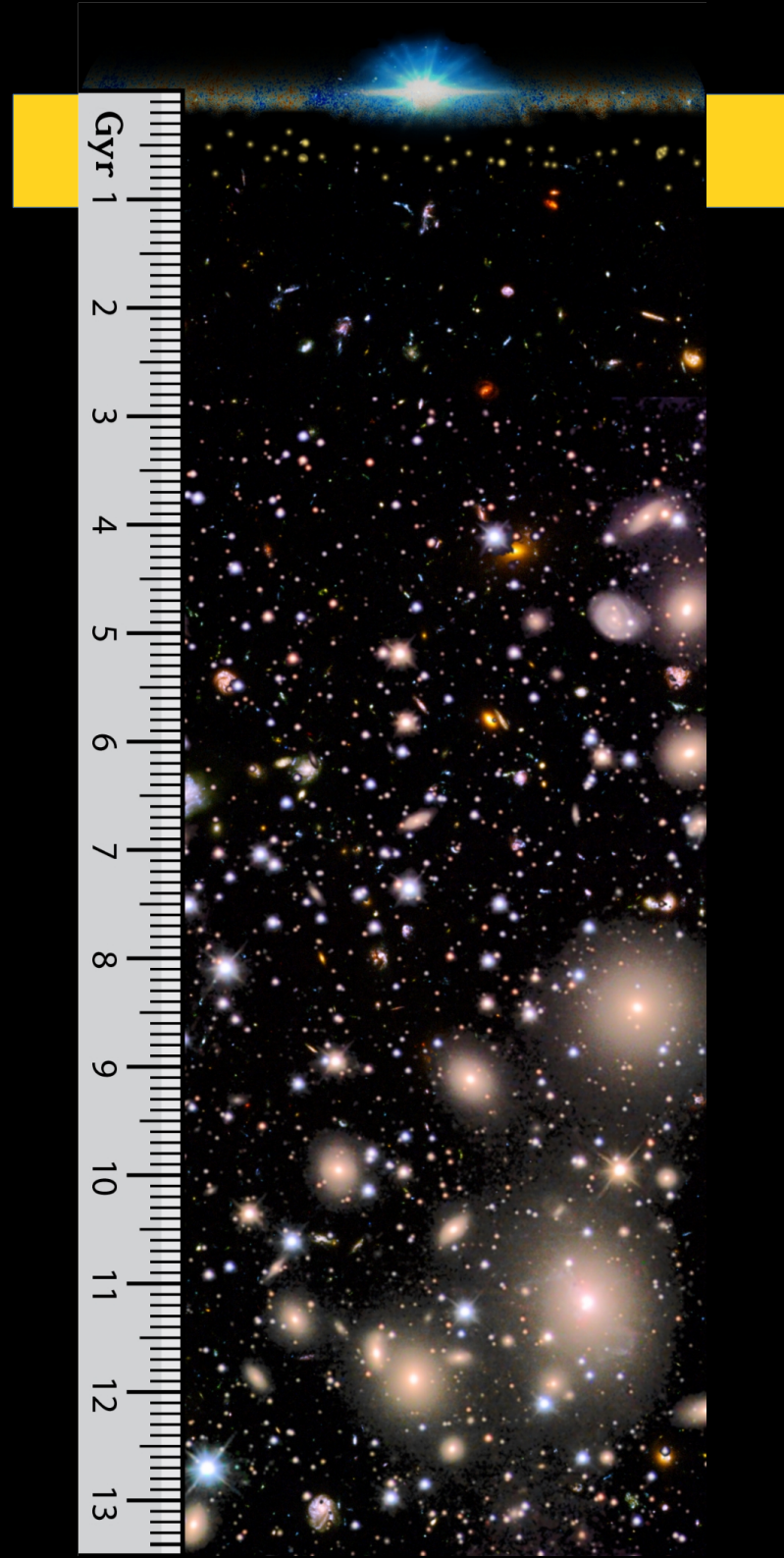
Galaxies evolve

The Solar System forms

Today: Astronomers
figure it all out!

History of the Universe

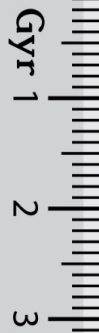
$z \sim 5.5 \rightarrow$
[~1Gyr]



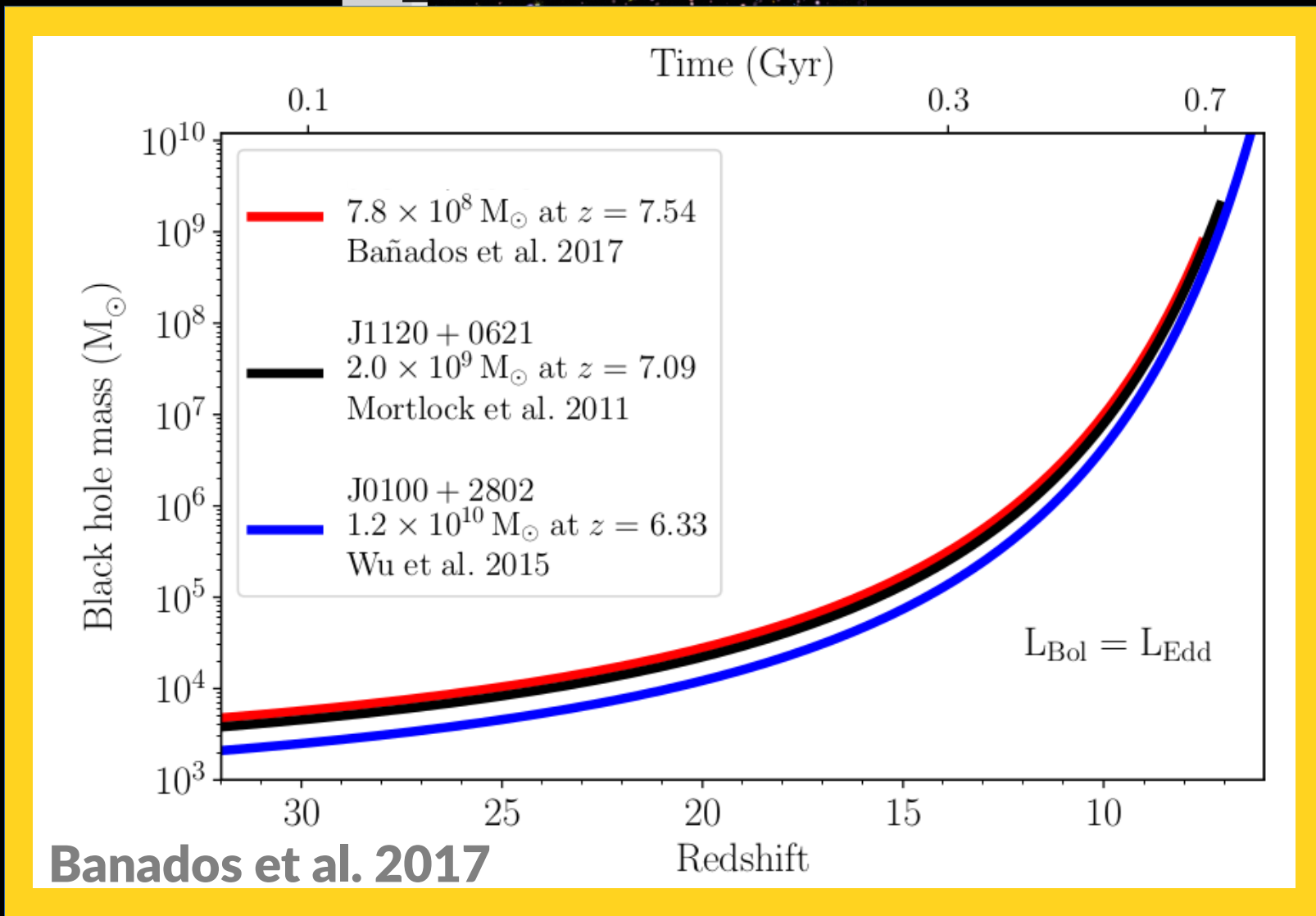
$\leftarrow z \sim 7.5$
[~0.7Gyr]

History of the Universe

$z \sim 5.5 \rightarrow$
[~1Gyr]

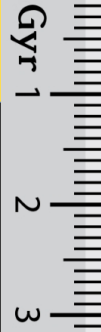


$\leftarrow z \sim 7.5$
[~0.7Gyr]

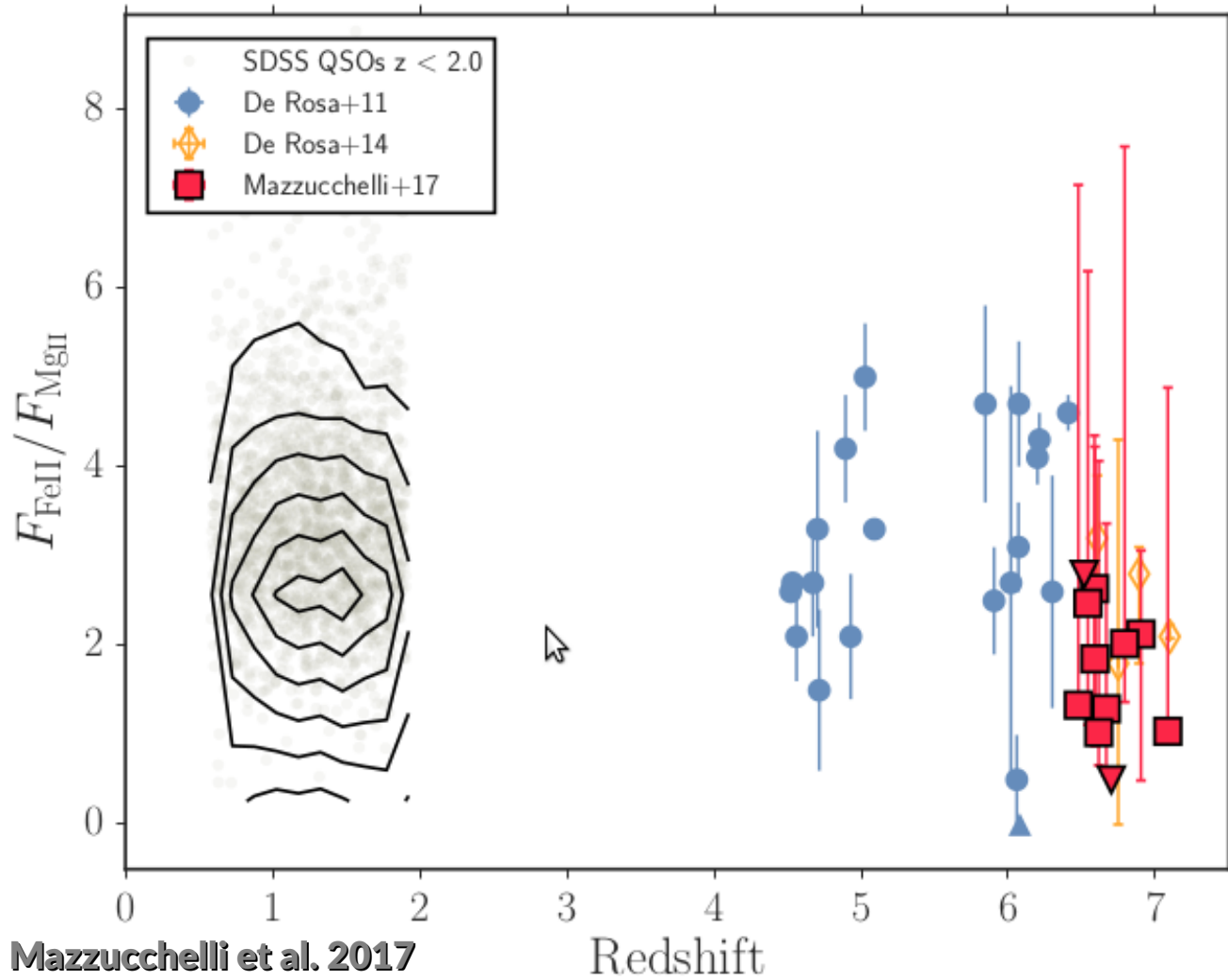


History of the Universe

$z \sim 5.5 \rightarrow$
[~1Gyr]

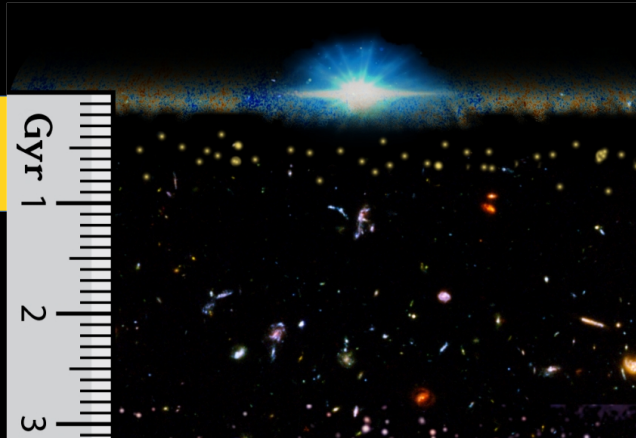
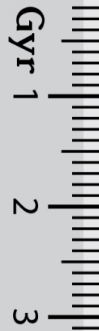


$\leftarrow z \sim 7.5$
[~0.7Gyr]

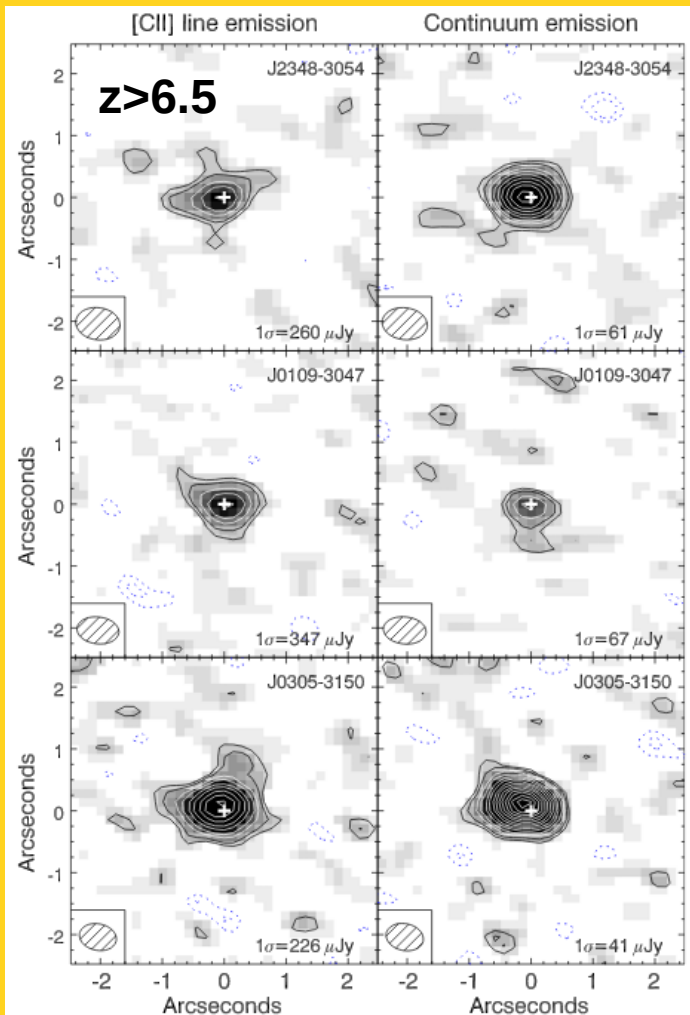


History of the Universe

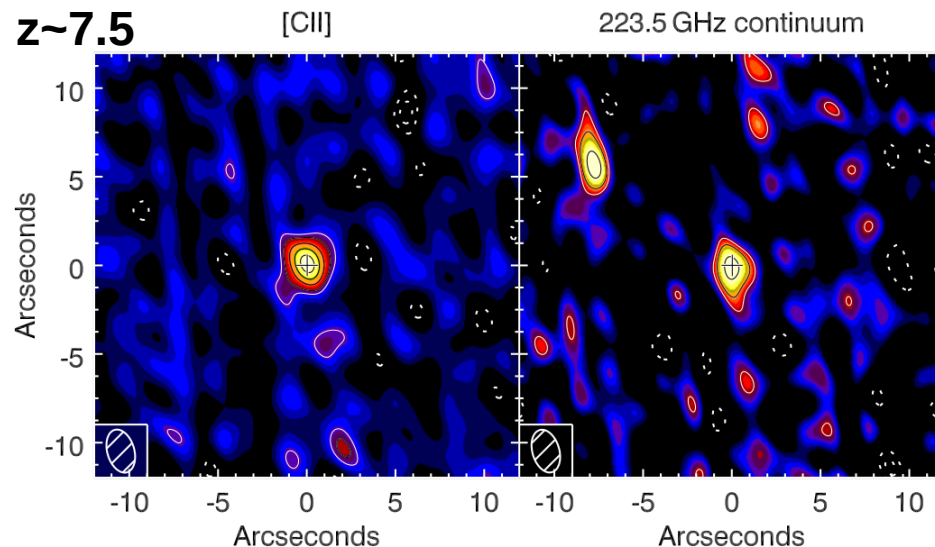
$z \sim 5.5 \rightarrow$
[~1Gyr]



$\leftarrow z \sim 7.5$
[~0.7Gyr]



$M_{\text{dust}} \sim 10^8 M_{\text{sun}}$



$\text{SFR} > 100 M_{\text{sun}} \text{yr}^{-1}$

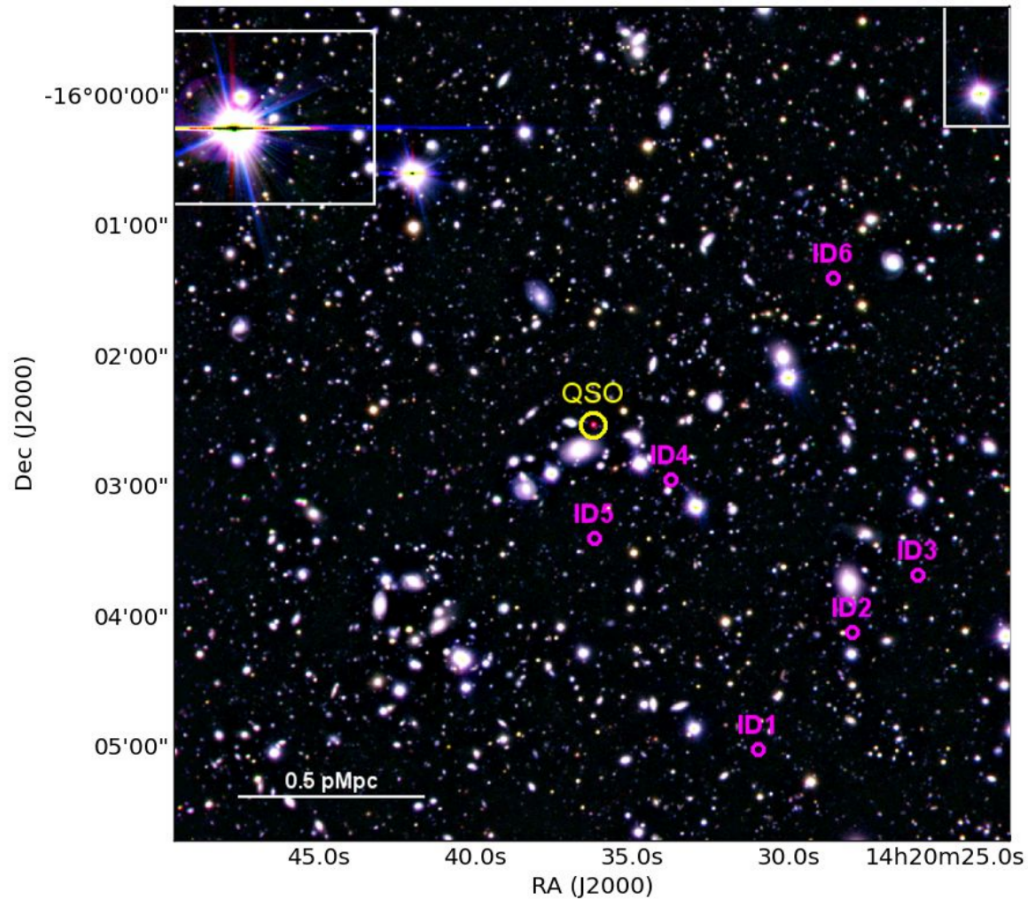
Venemans et al. 2016, 2017

A deep-field astronomical image showing a vast field of galaxies in various colors and orientations against a dark background. The galaxies are scattered across the frame, with some appearing as bright, distinct points of light and others as faint, elongated structures. The colors range from blue and white to orange and red, indicating different stages of galaxy evolution or different types of galaxies. The overall scene is a rich, multi-colored field of distant celestial objects.

Where do the first Quasars form?

Large Scale Clustering

14 cMpc x 14 cMpc

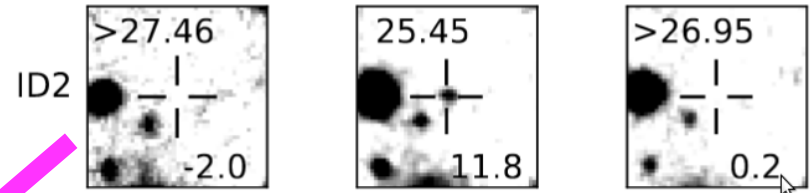
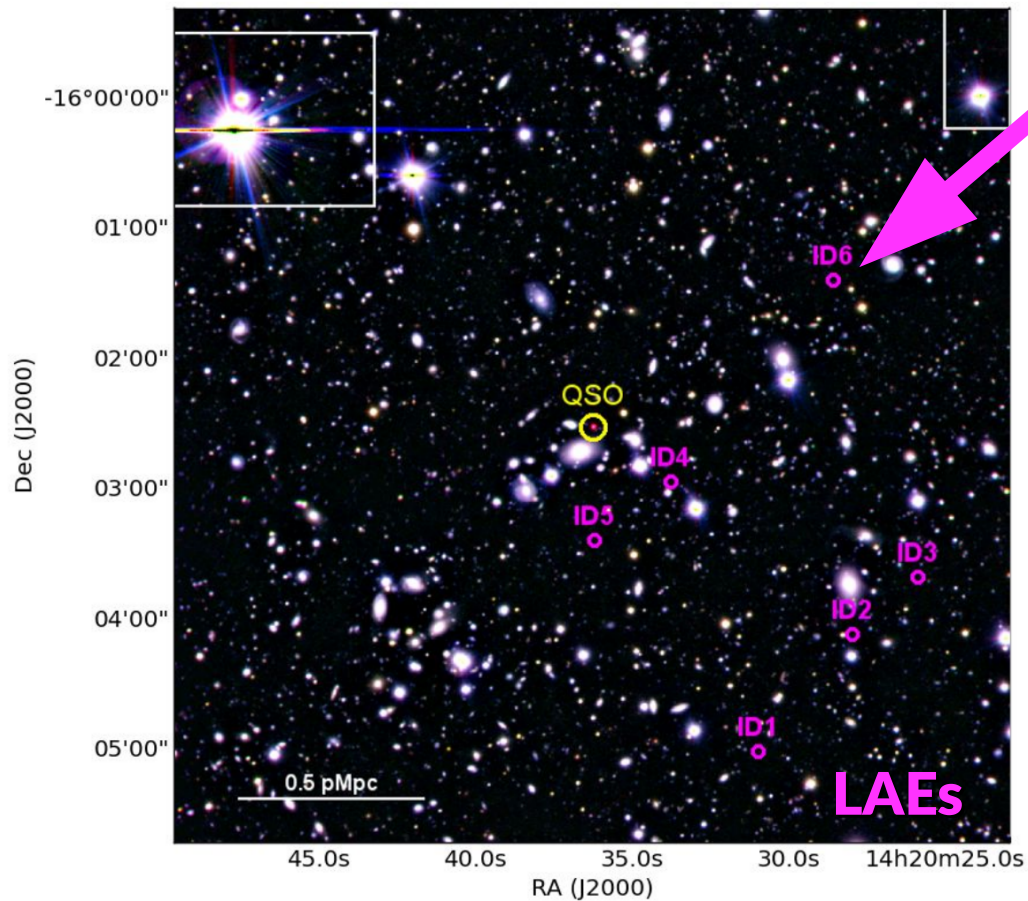


$$M_{\text{BH}} \sim 7 \times 10^9 M_{\text{sun}} @ z \sim 5.7$$

Mazzucchelli et al. 2017

Large Scale Clustering

14 cMpc x 14 cMpc

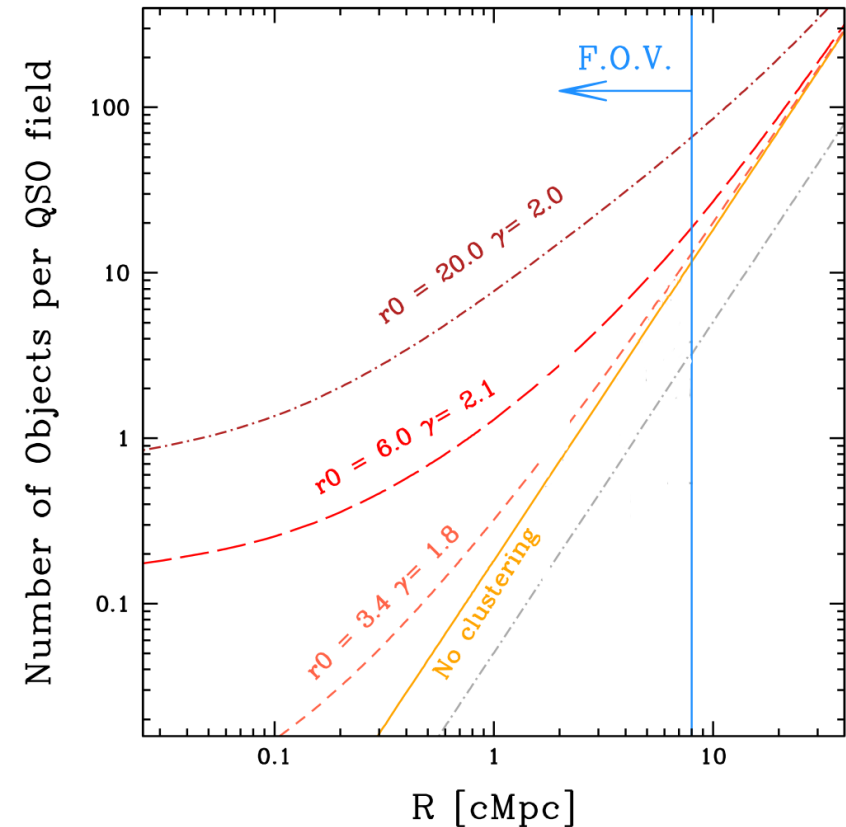
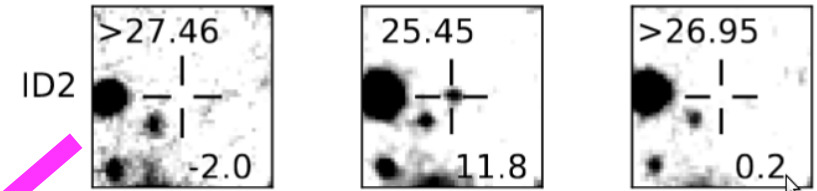
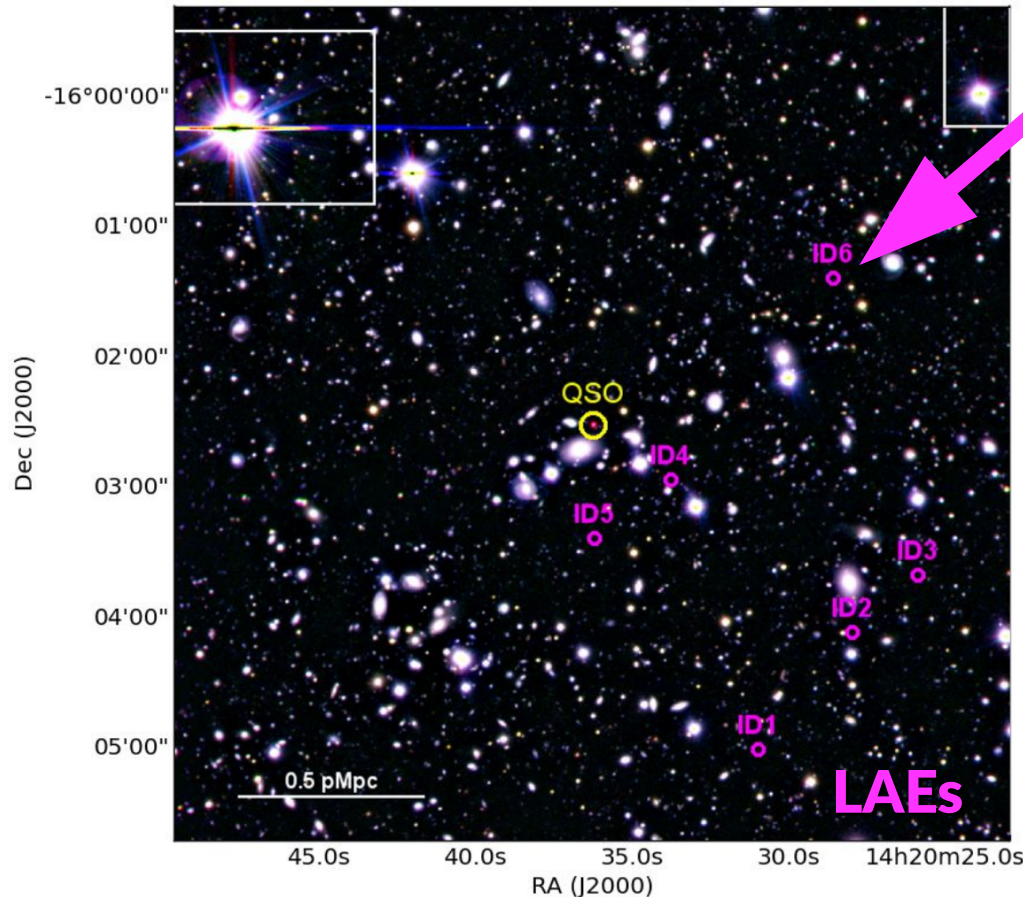


$$M_{\text{BH}} \sim 7 \times 10^9 M_{\text{sun}} @ z \sim 5.7$$

Mazzucchelli et al. 2017

Large Scale Clustering

14 cMpc x 14 cMpc

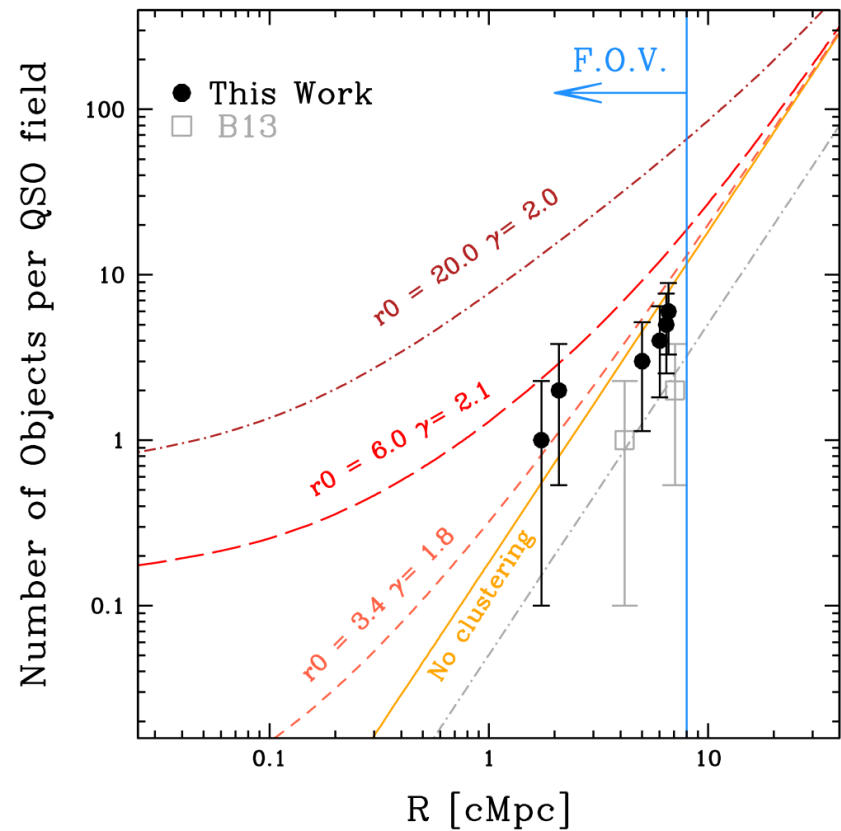
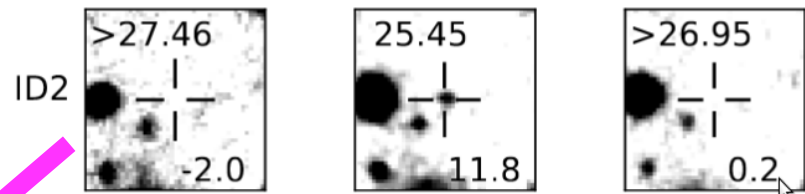
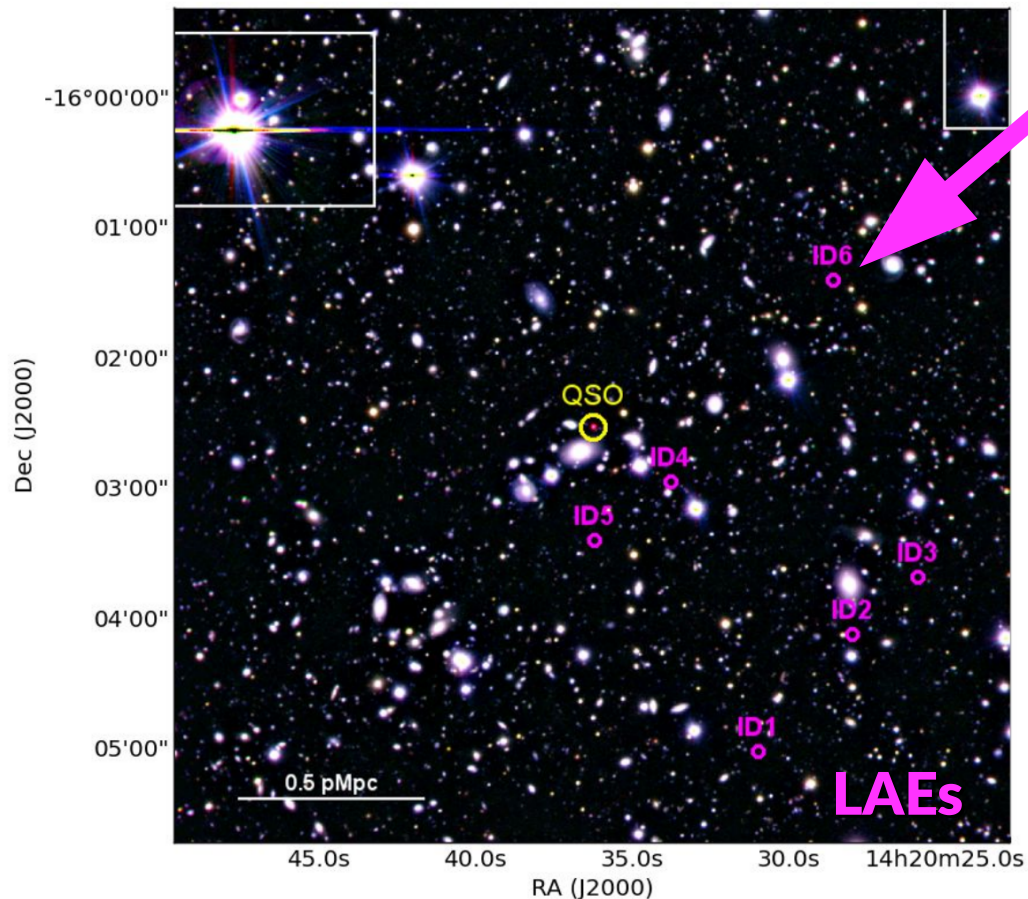


$$M_{BH} \sim 7 \times 10^9 M_{sun} @ z \sim 5.7$$

Mazzucchelli et al. 2017

Large Scale Clustering

14 cMpc x 14 cMpc

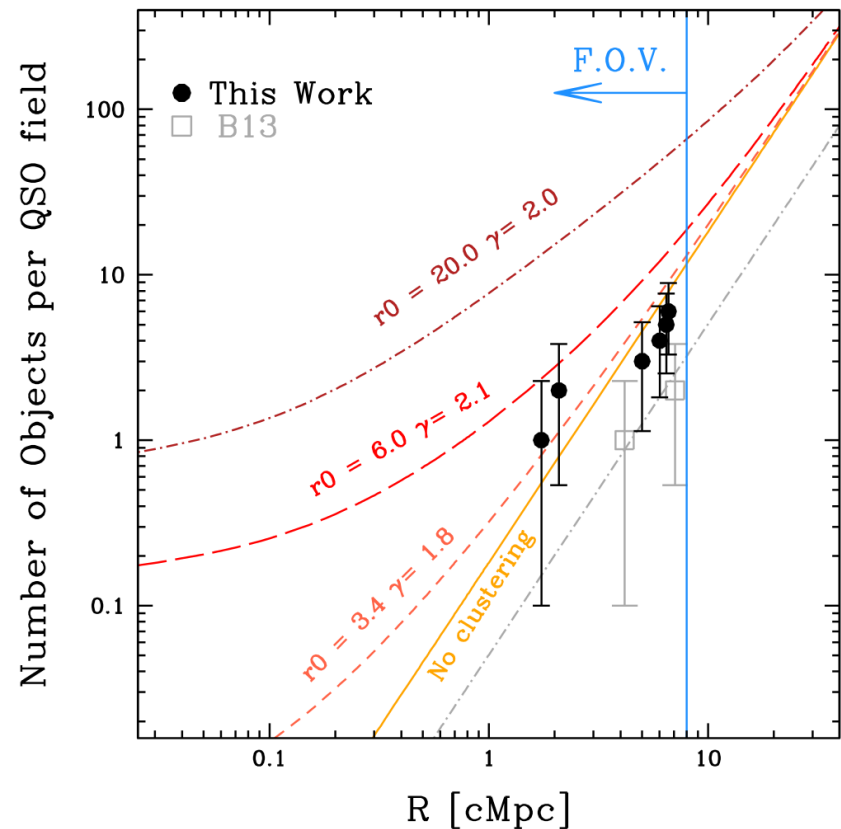
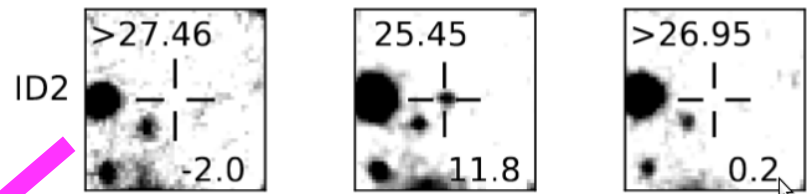
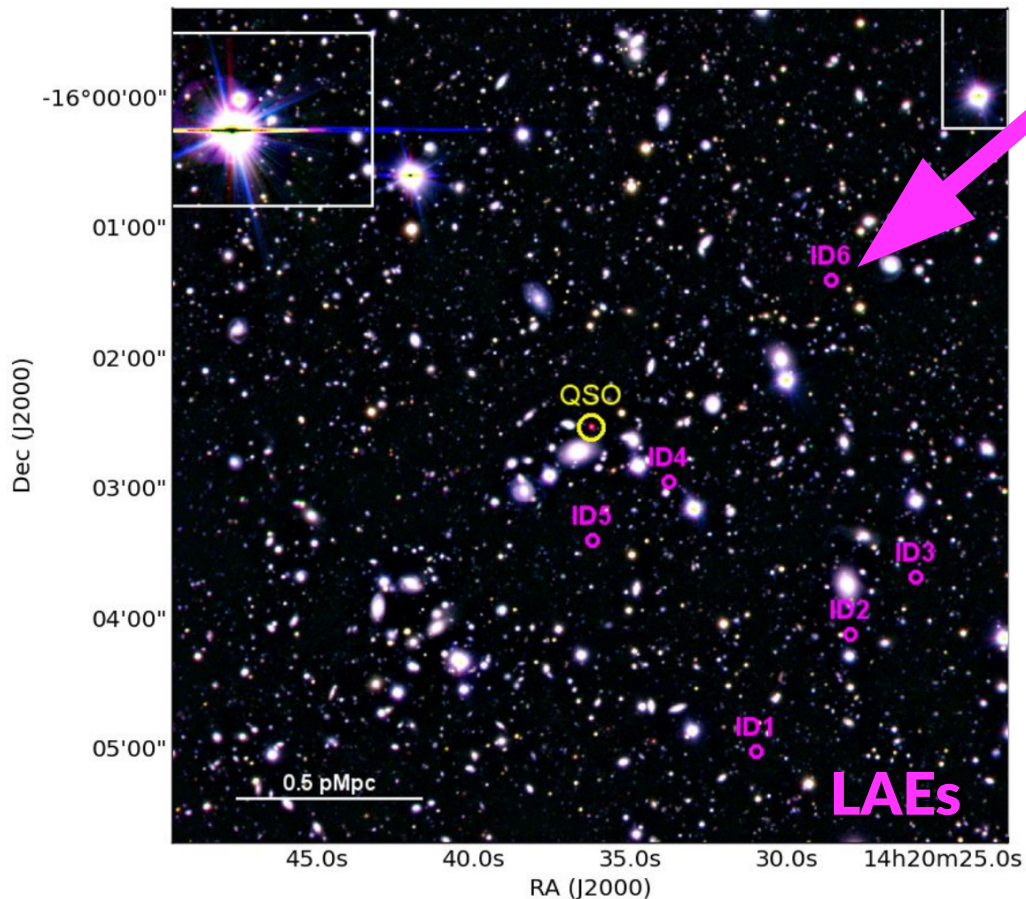


$$M_{BH} \sim 7 \times 10^9 M_{sun} @ z \sim 5.7$$

Mazzucchelli et al. 2017

Large Scale Clustering

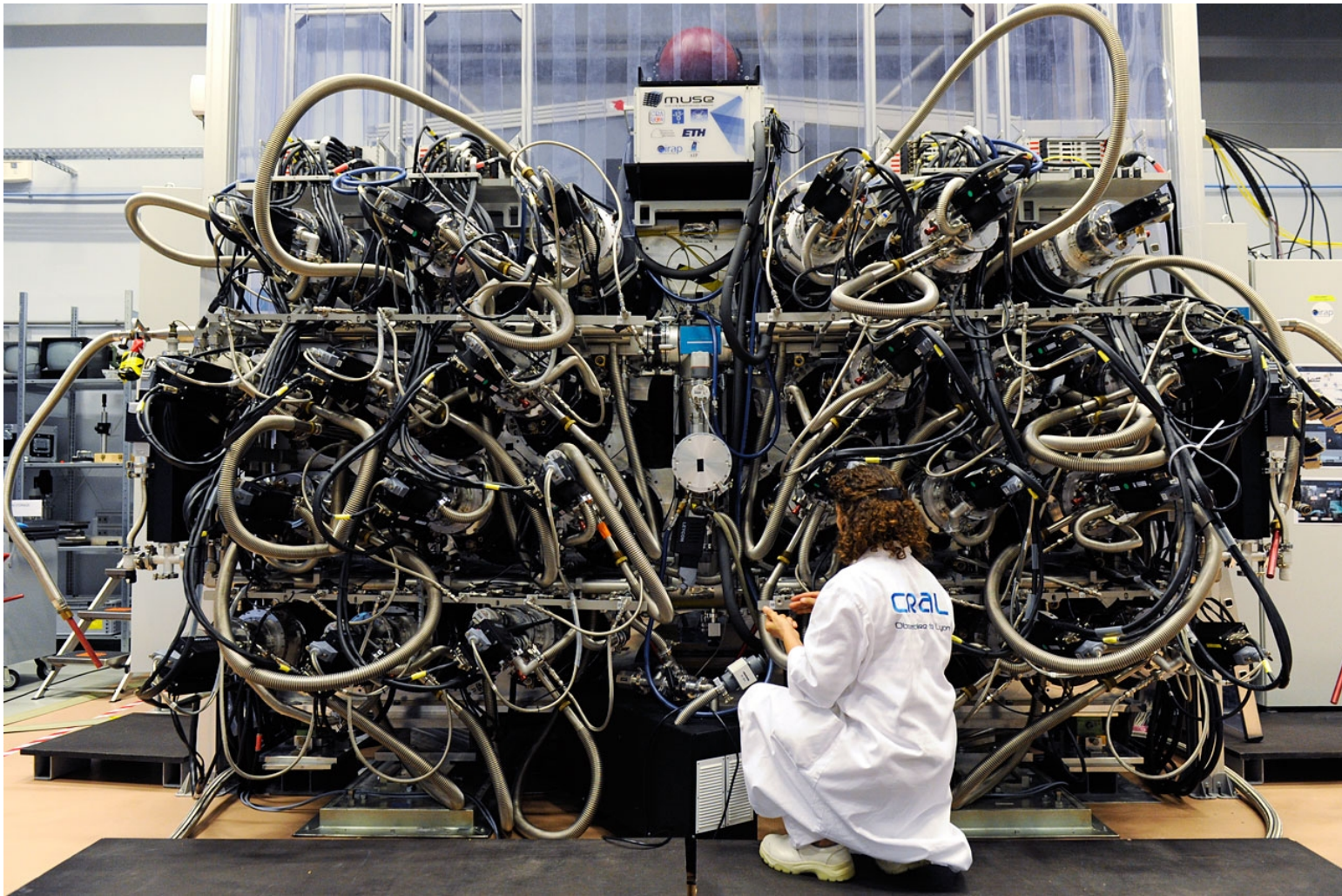
14 cMpc x 14 cMpc



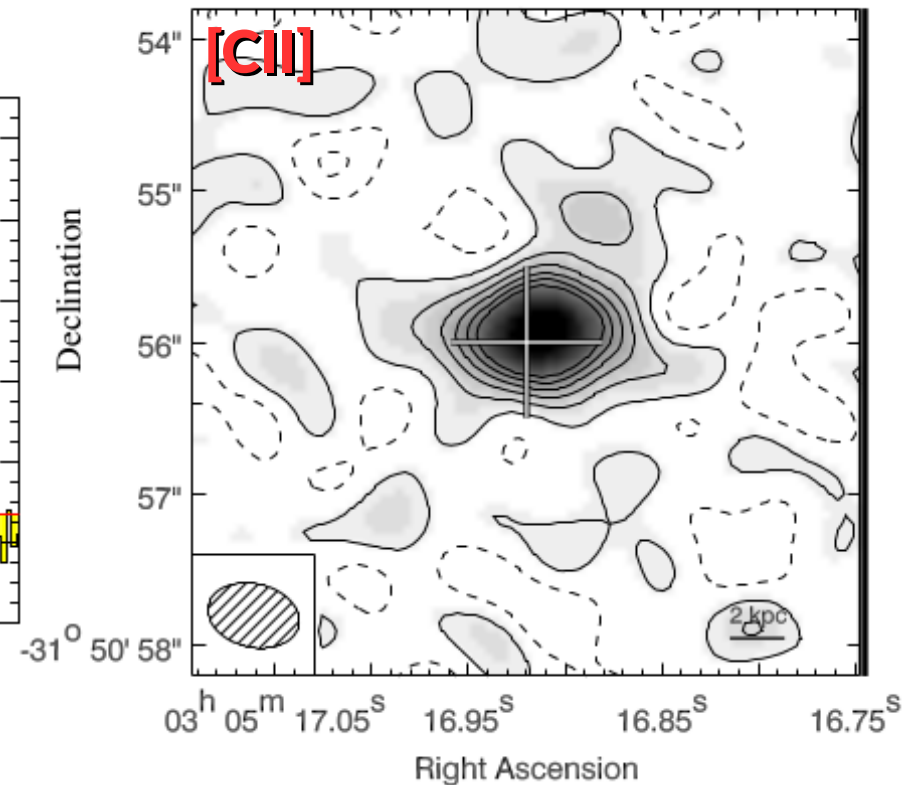
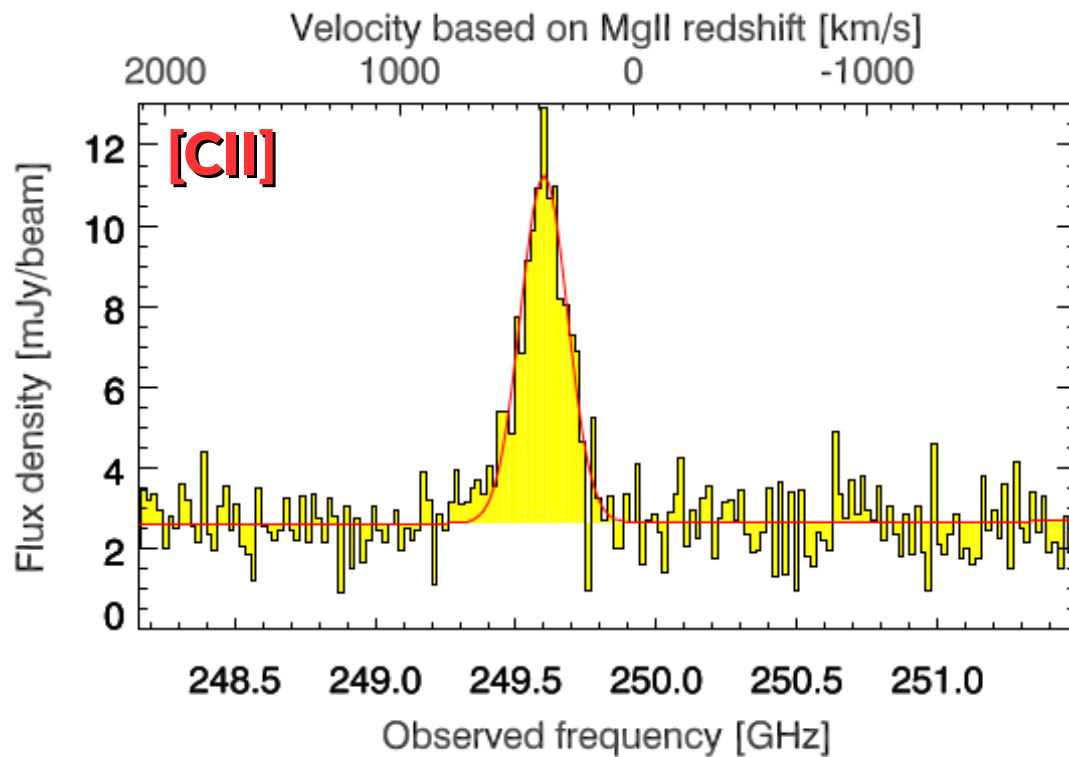
$$M_{\text{BH}} \sim 7 \times 10^9 M_{\text{sun}} @ z \sim 5.7$$

Mazzucchelli et al. 2017

Small Scale Clustering → MUSE



Small Scale Clustering → MUSE



$z \sim 6.6$

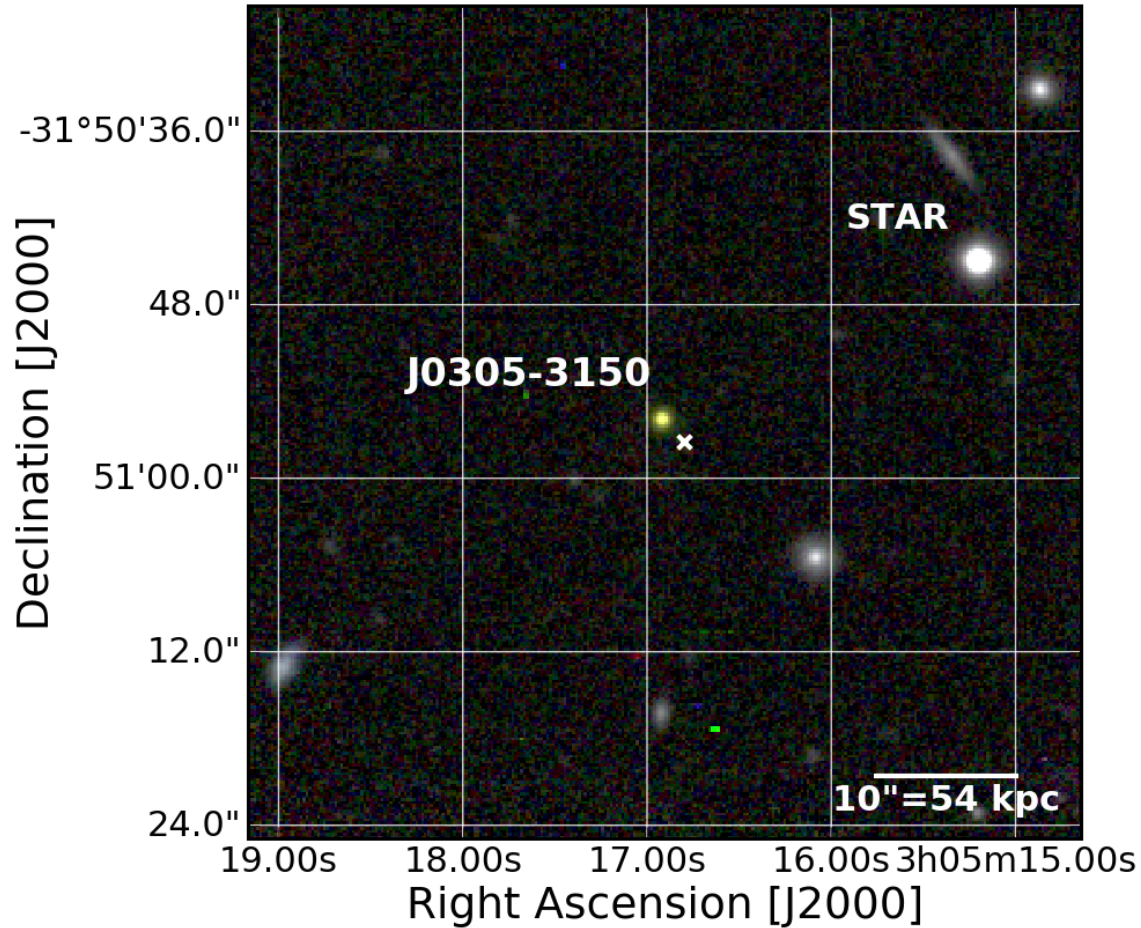
**Age of the Universe:
800 Myr**

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

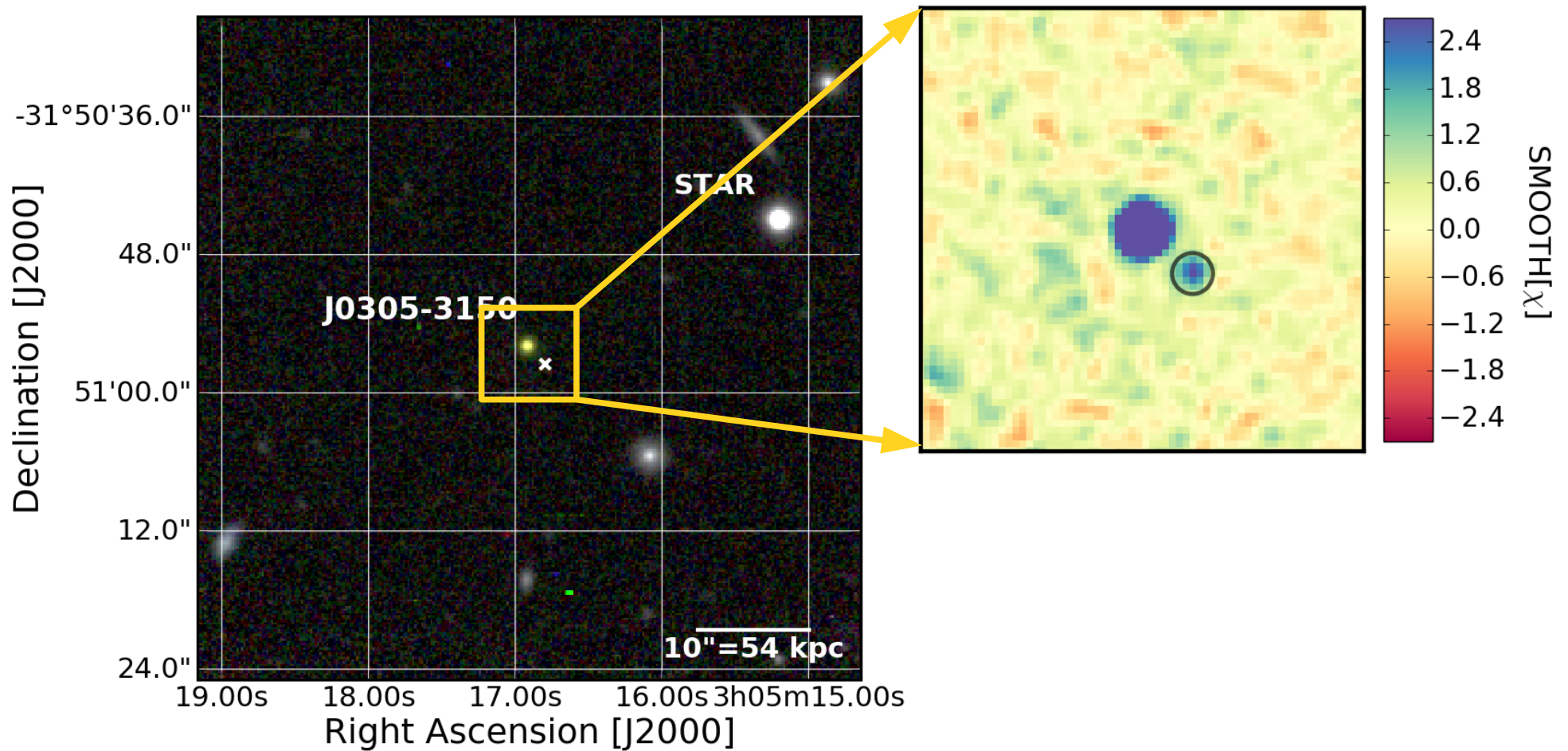
$M_{\text{BH}} \sim 10^9 M_{\text{SUN}}$

Venemans et al. 2016

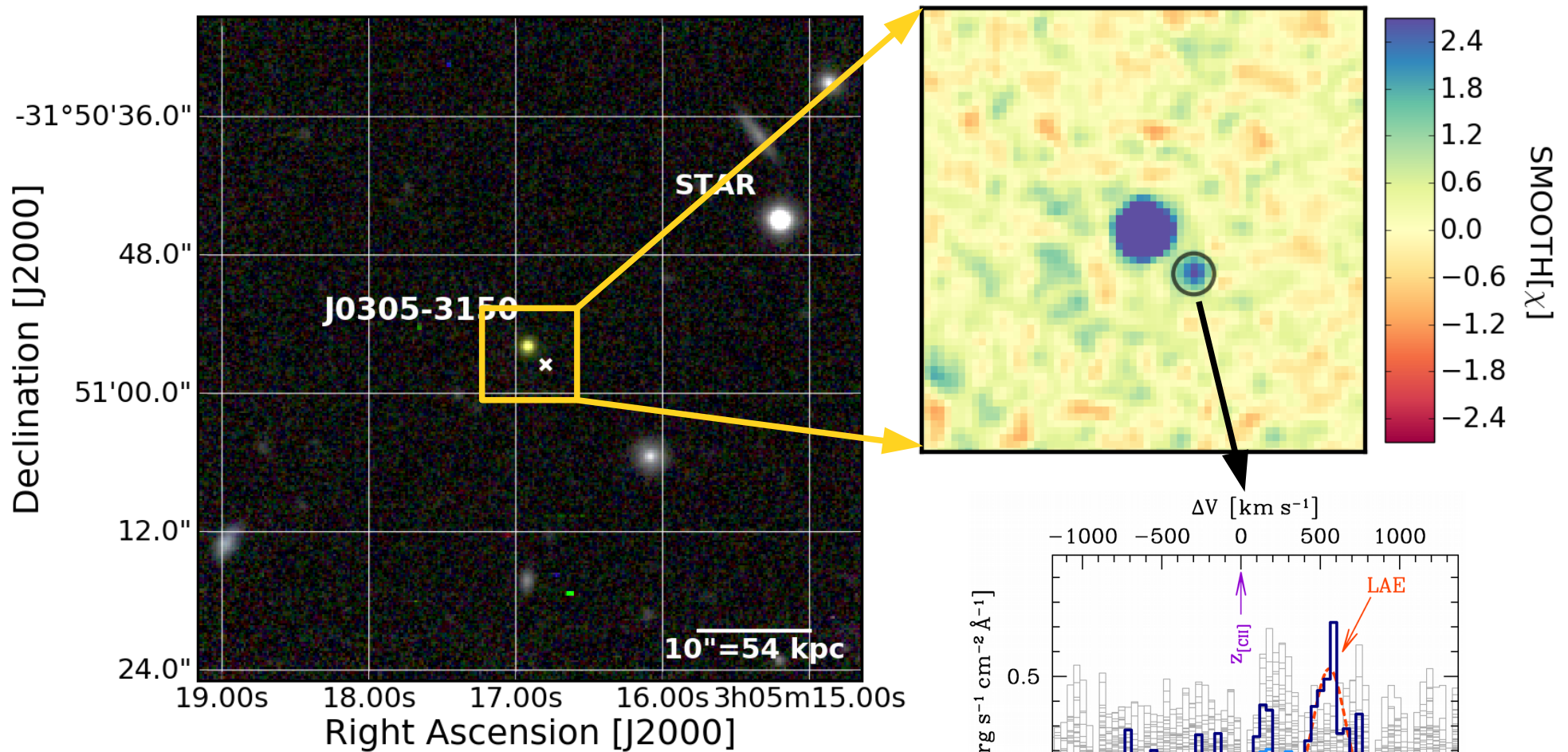
Small Scale Clustering → MUSE



Small Scale Clustering → MUSE



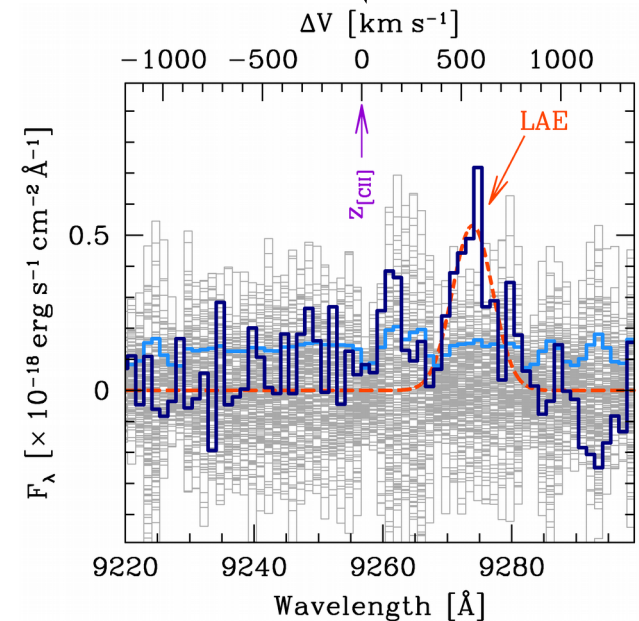
Small Scale Clustering → MUSE



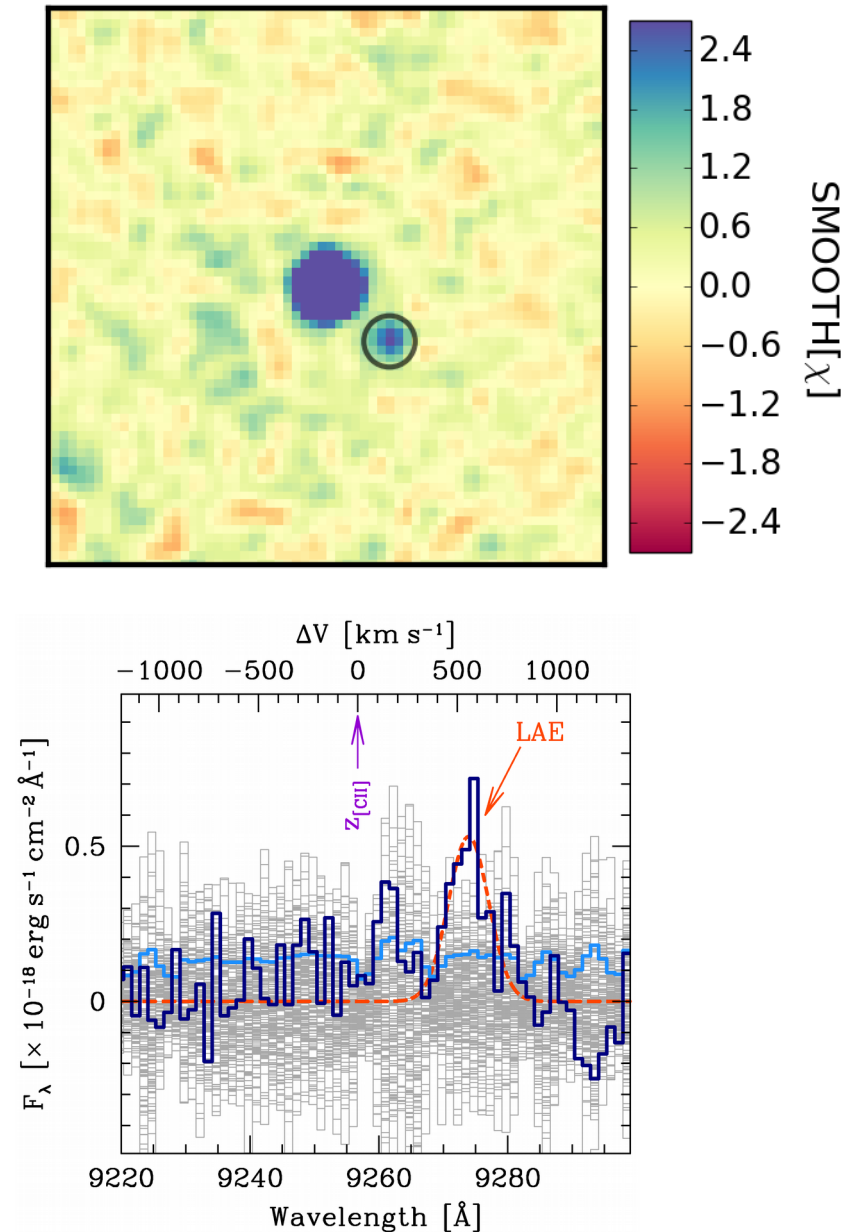
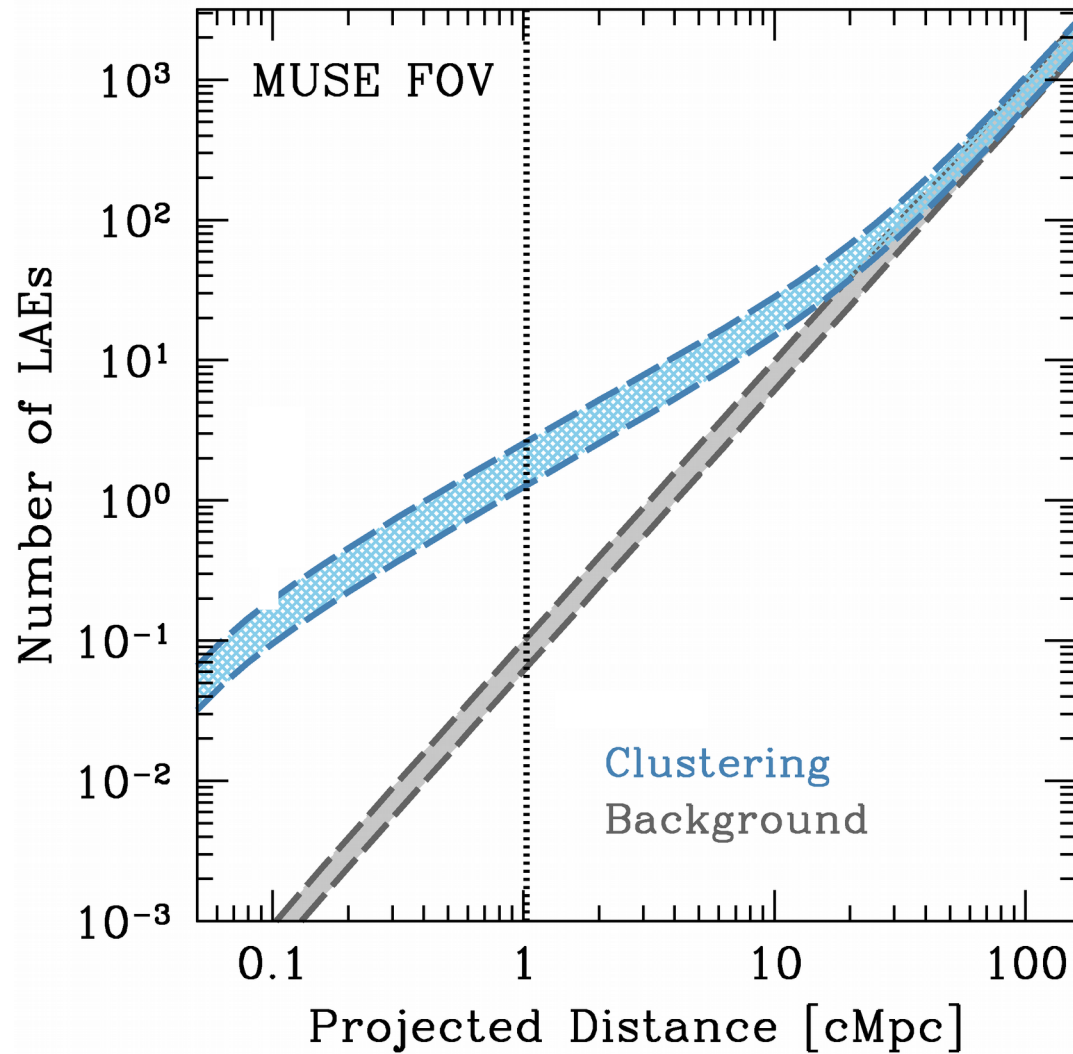
LAE:

pd = 12.5kpc

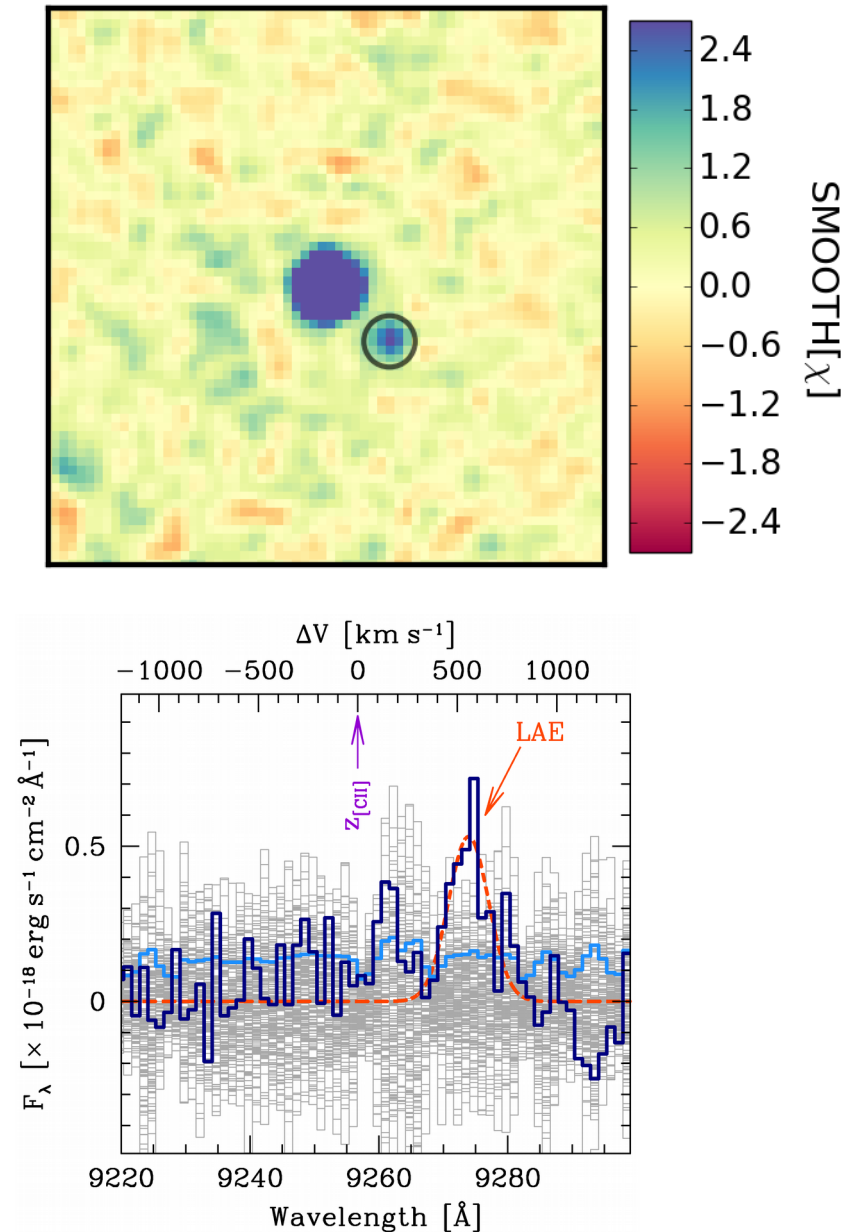
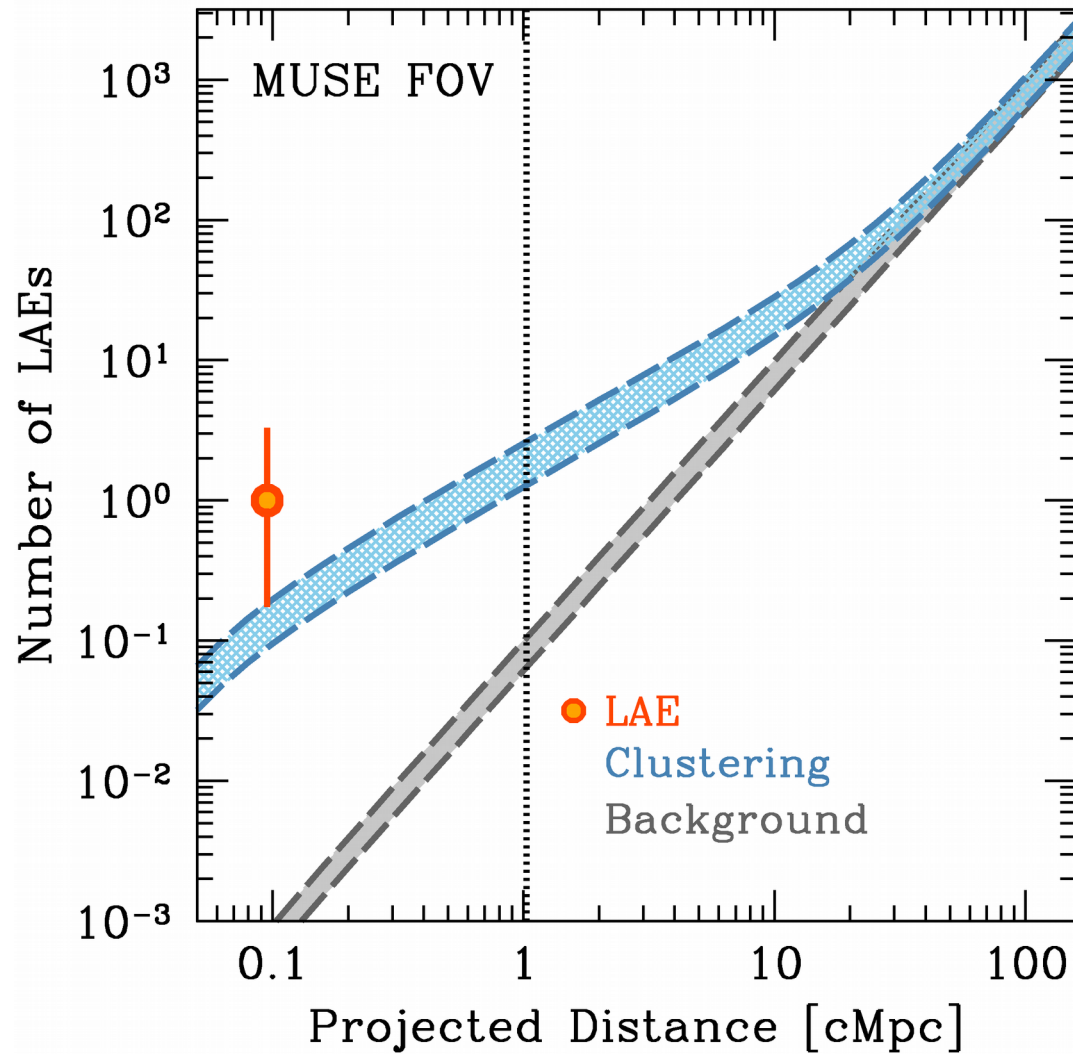
$\Delta V = 560\text{km/s}$



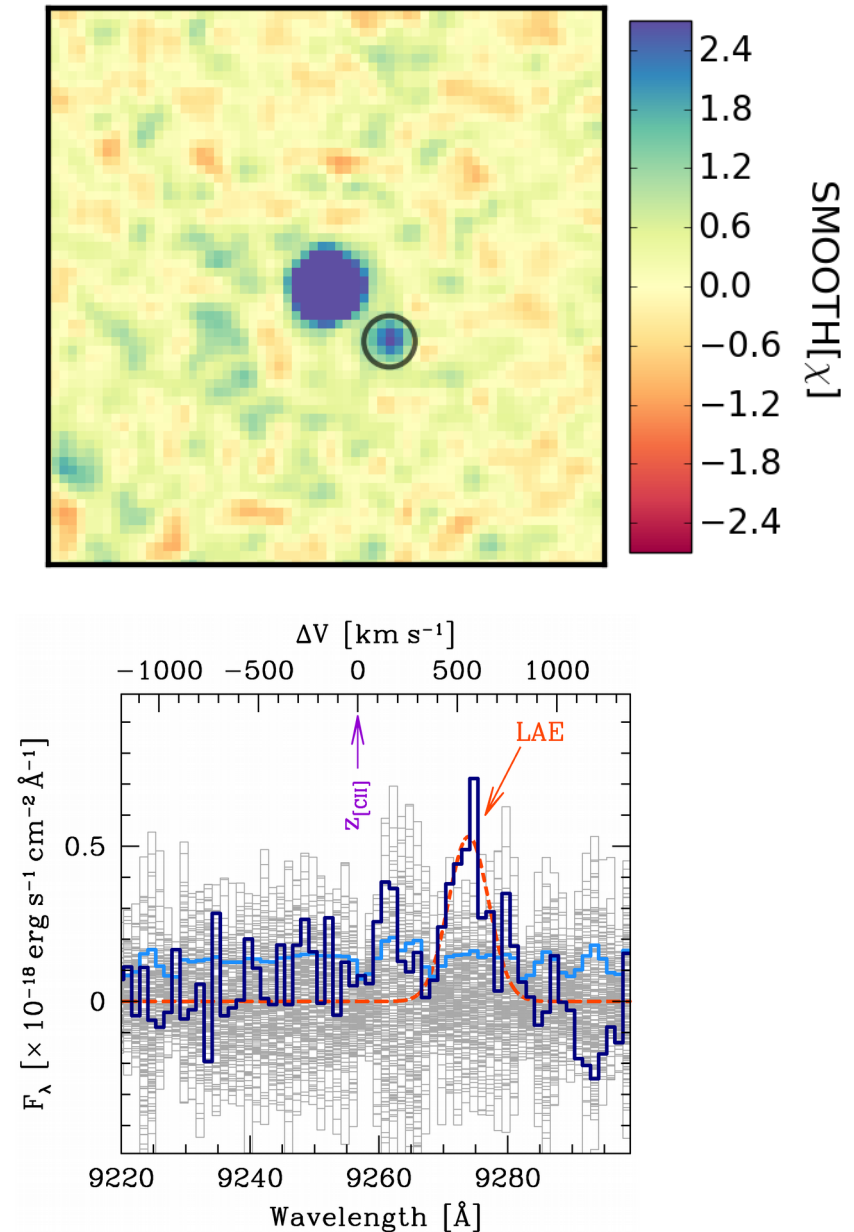
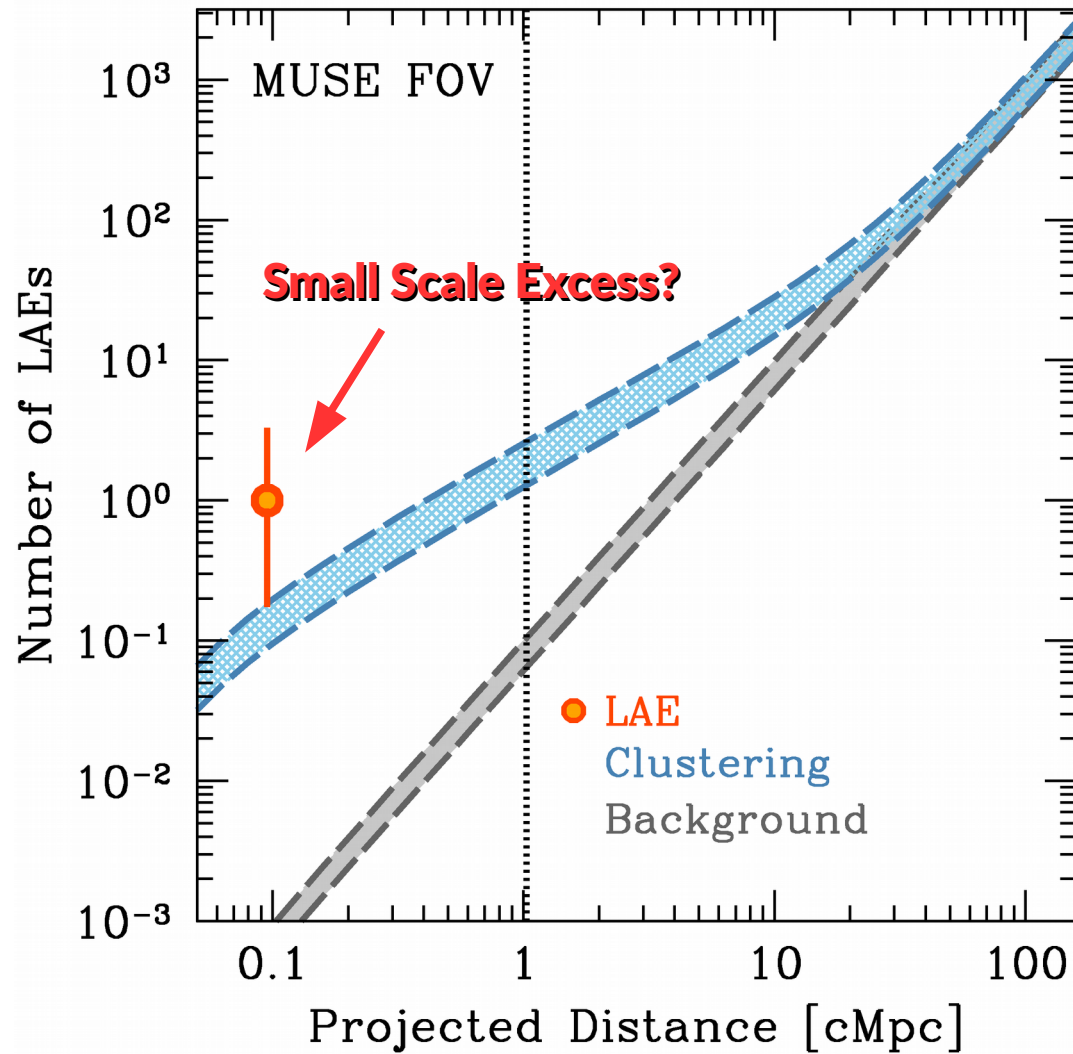
Small Scale Clustering → MUSE



Small Scale Clustering → MUSE



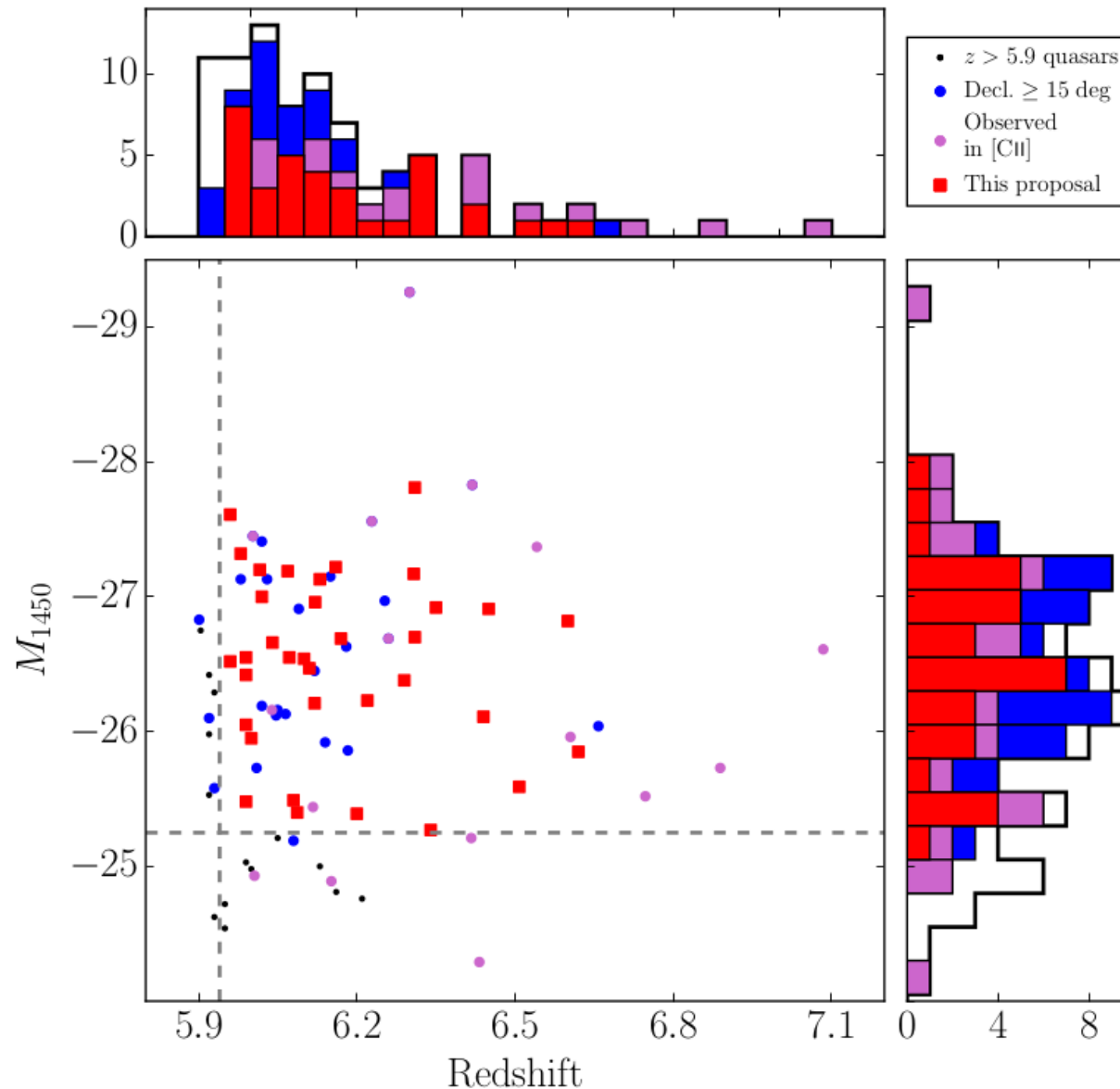
Small Scale Clustering → MUSE



Small Scale Clustering → ALMA

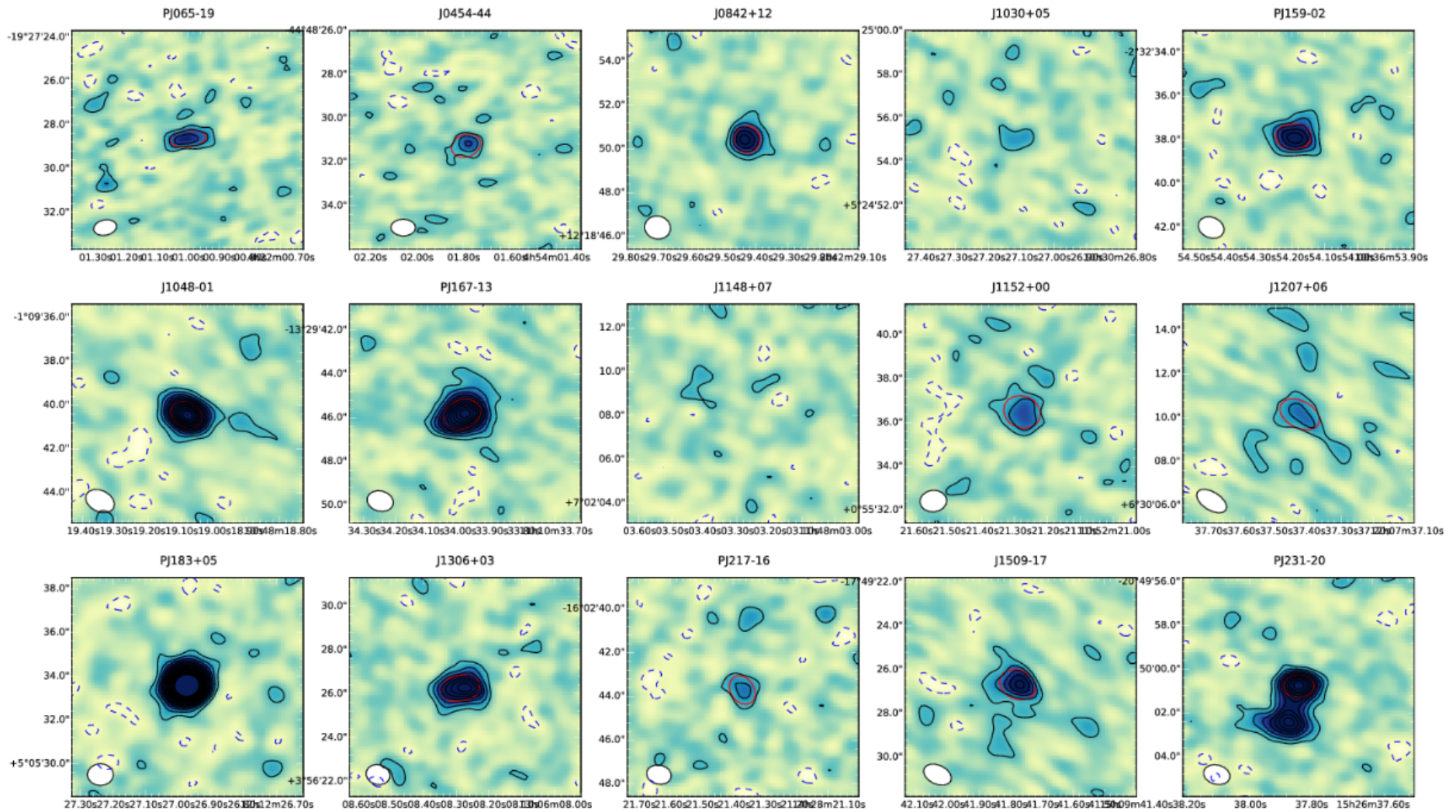


Small Scale Clustering → ALMA



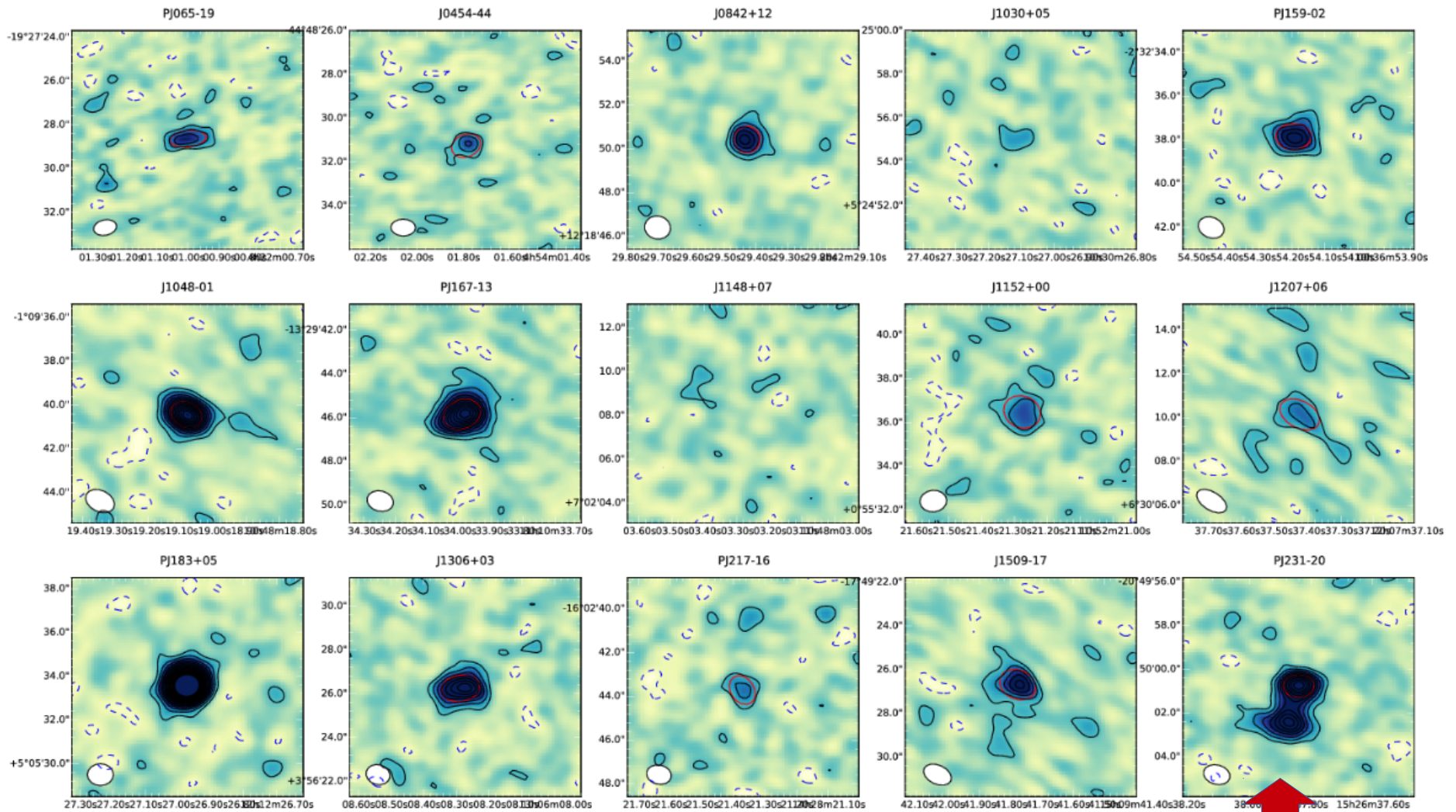
Decarli et al. + Venemans et al.

Small Scale Clustering → ALMA



Decarli et al. + Venemans et al.

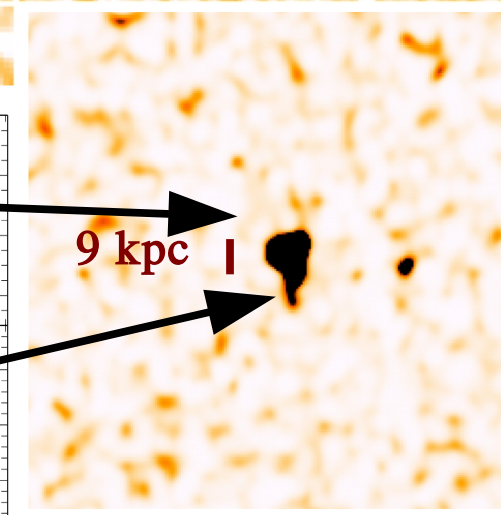
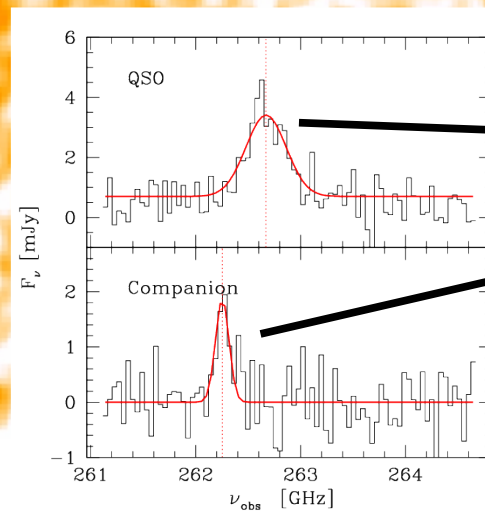
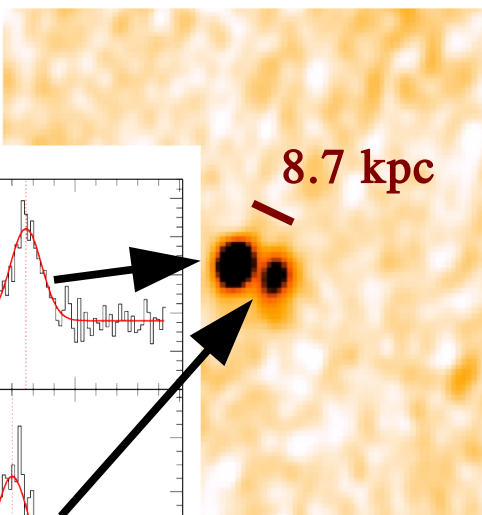
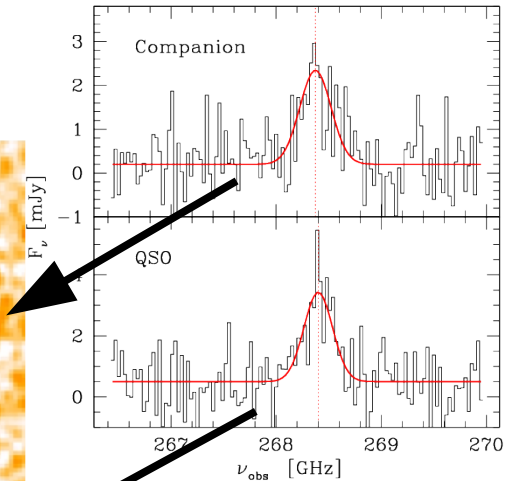
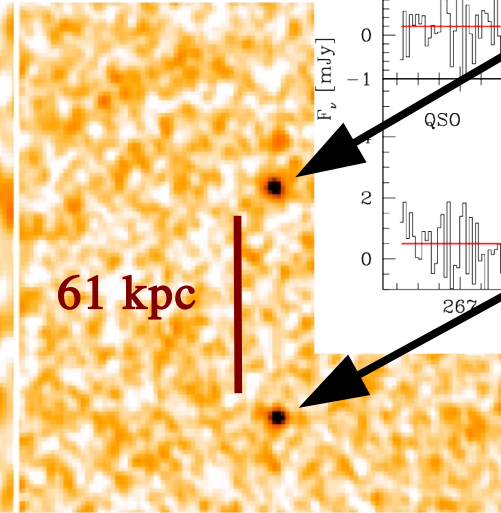
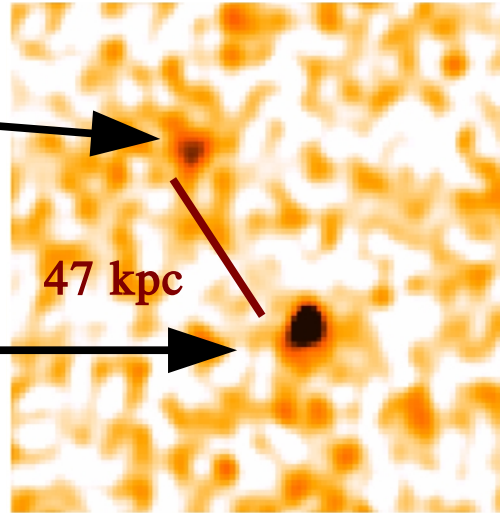
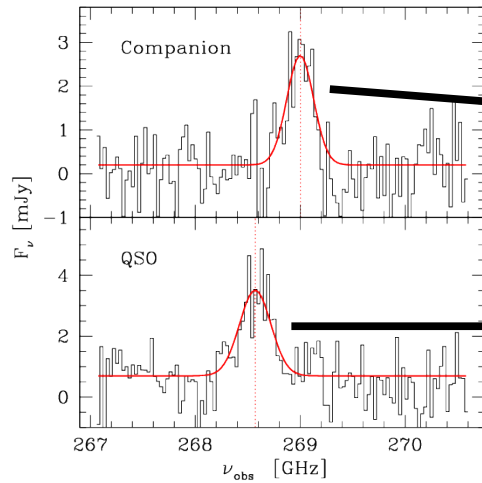
Small Scale Clustering → ALMA



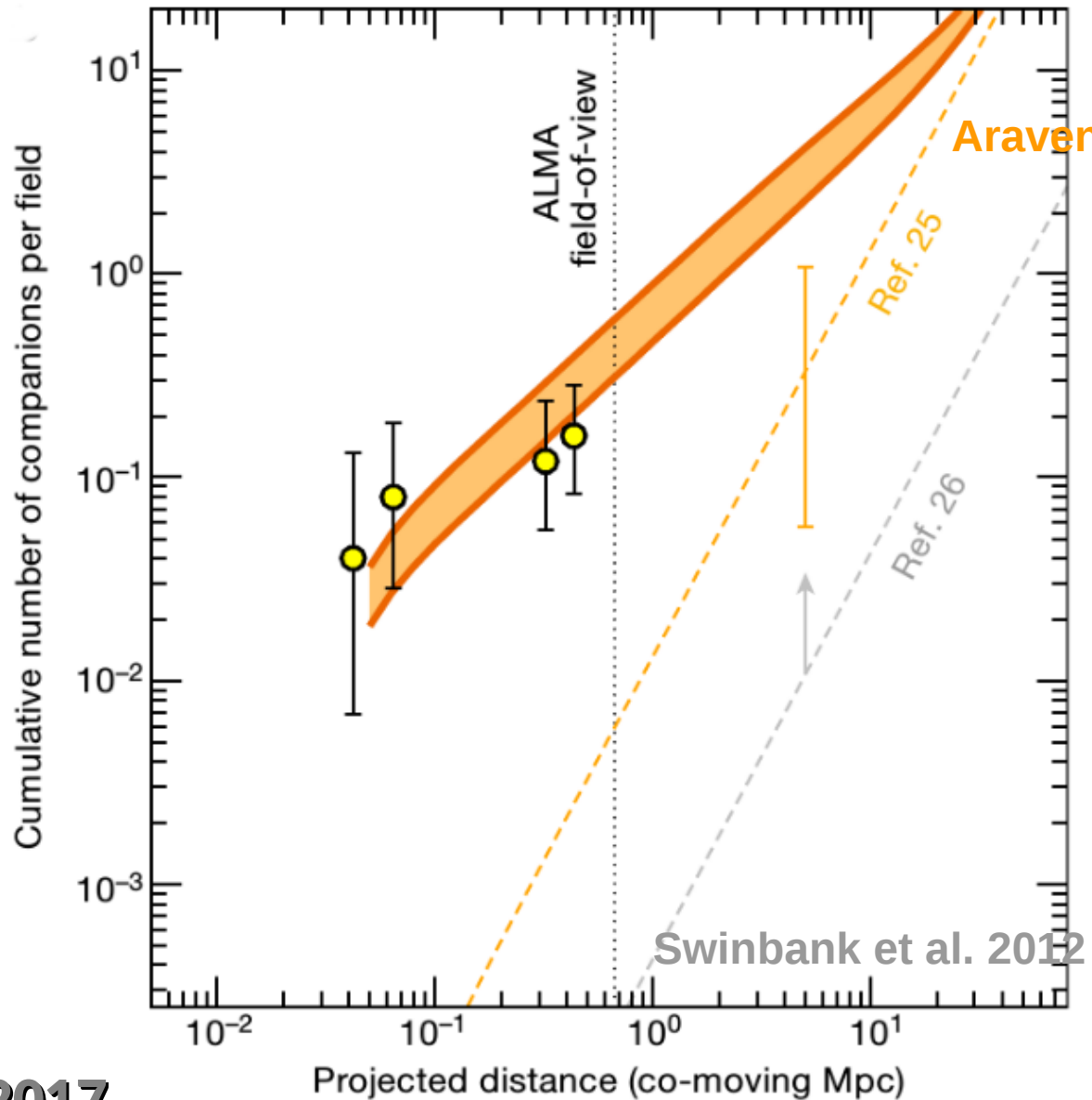
Decarli et al. + Venemans et al.



Small Scale Clustering → ALMA



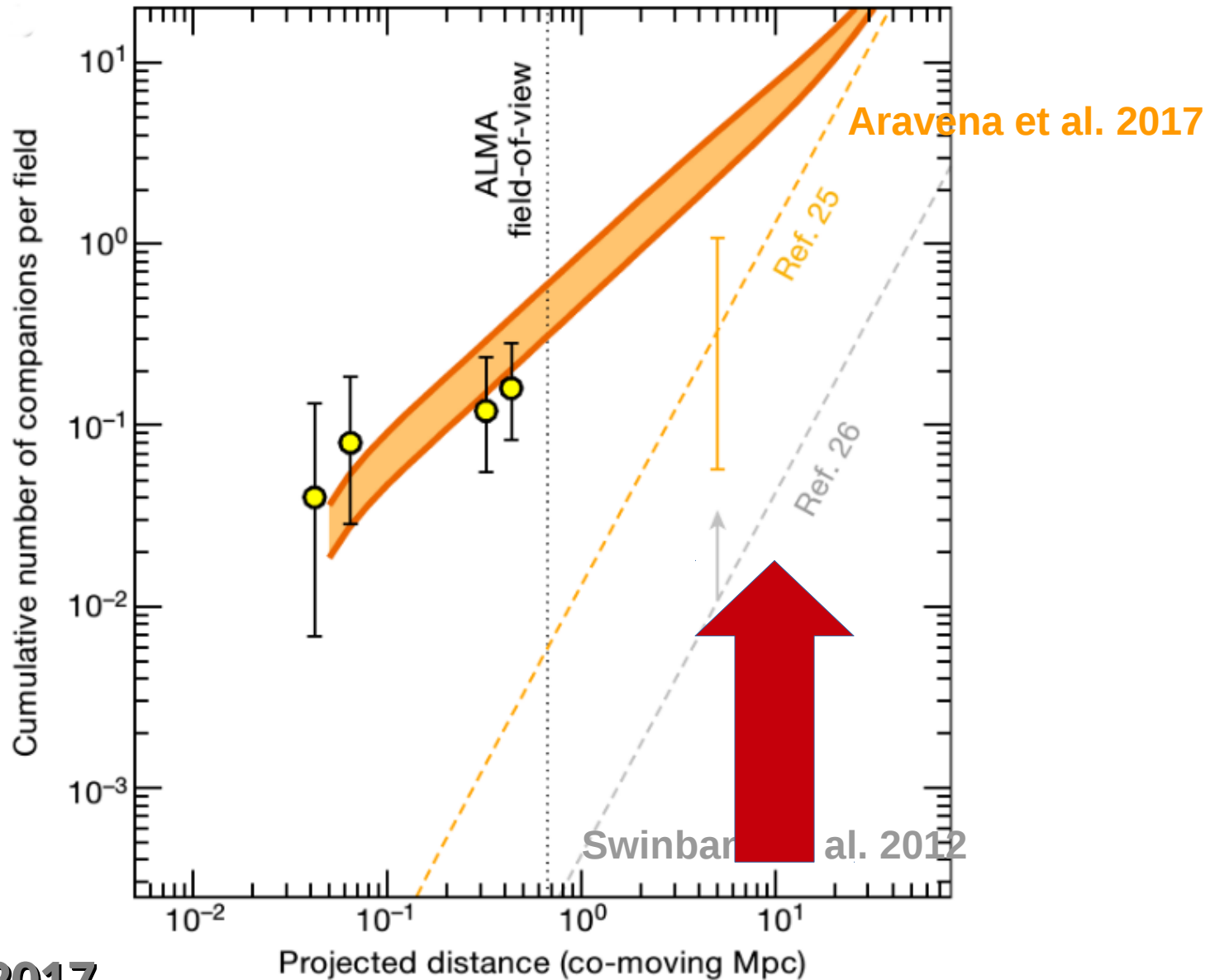
Small Scale Clustering → ALMA



Aravena et al. 2017

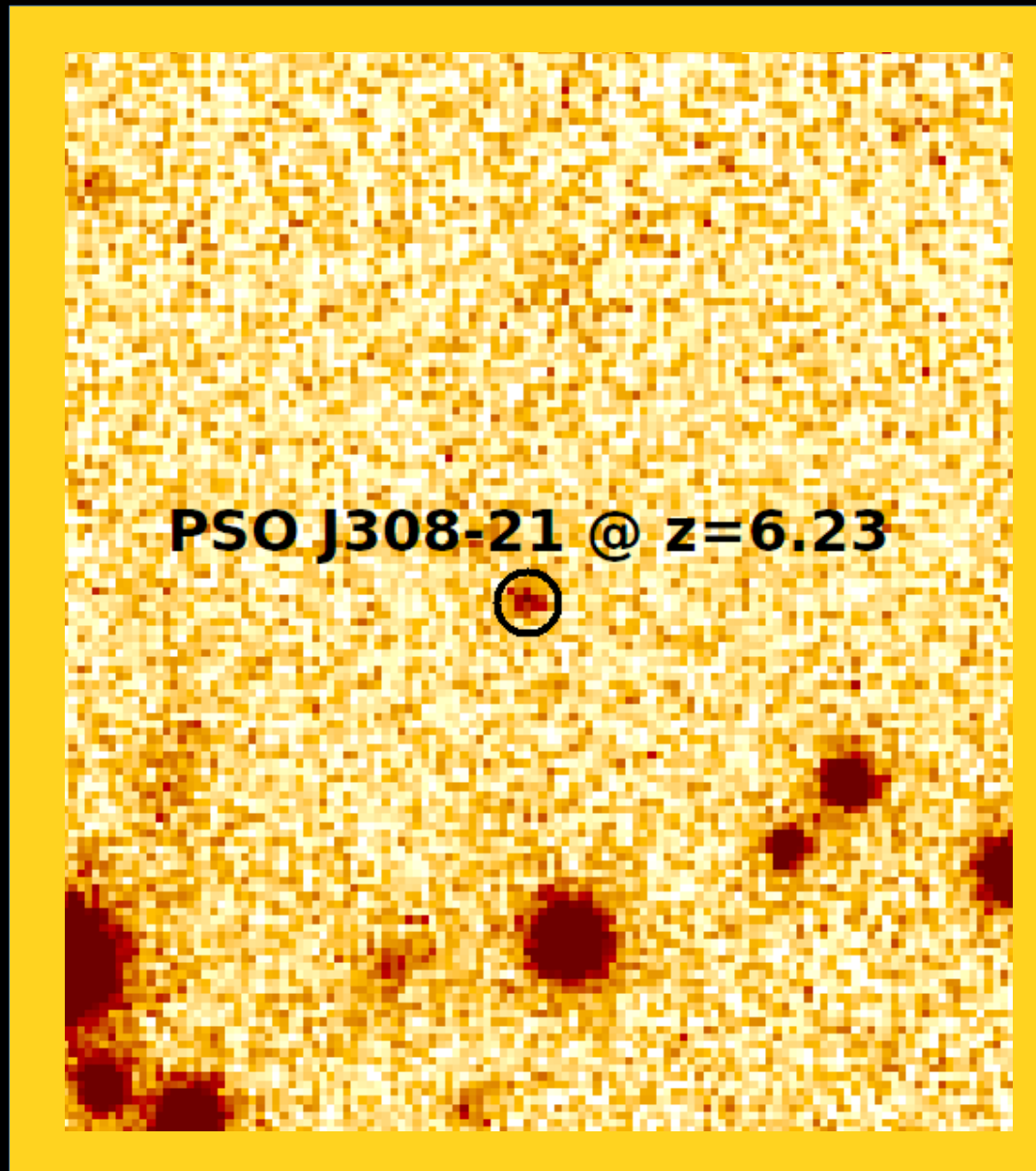
Decarli et al. 2017

Small Scale Clustering → ALMA



Decarli et al. 2017

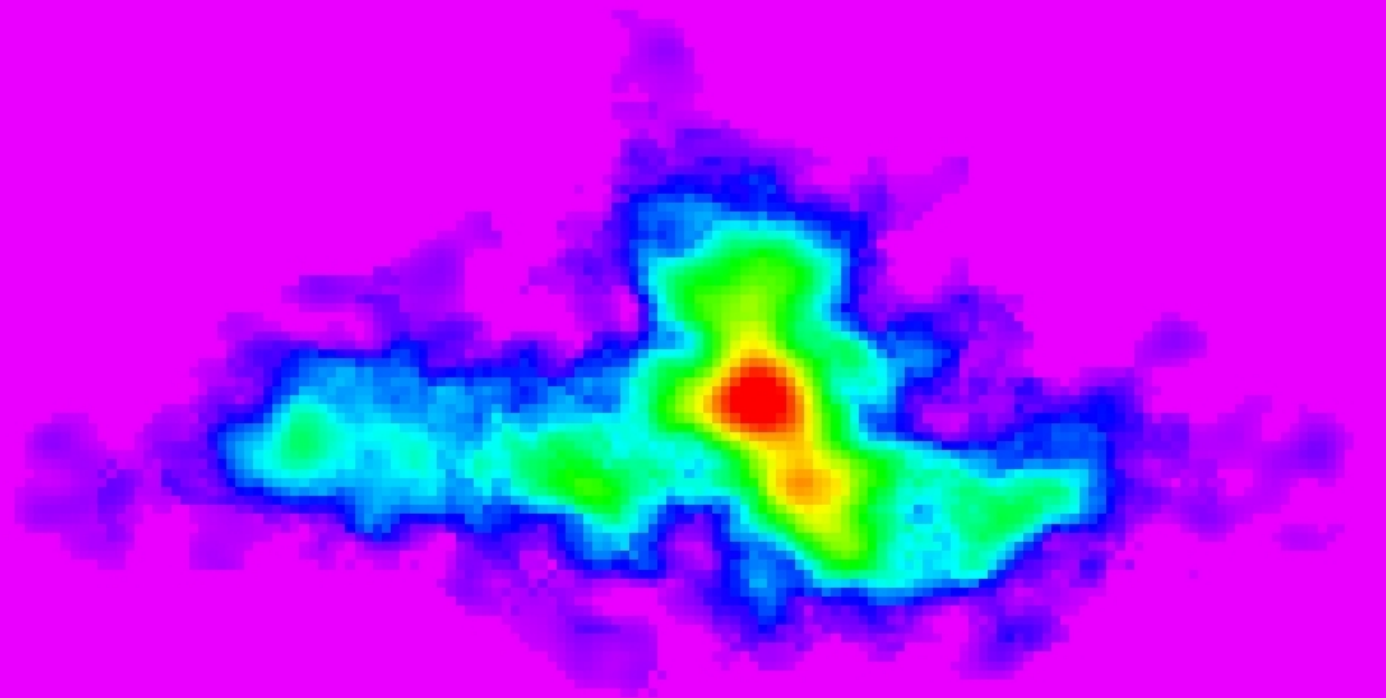
Evidence for Mergers?



Evidence for Mergers!

Decarli et al. 2017

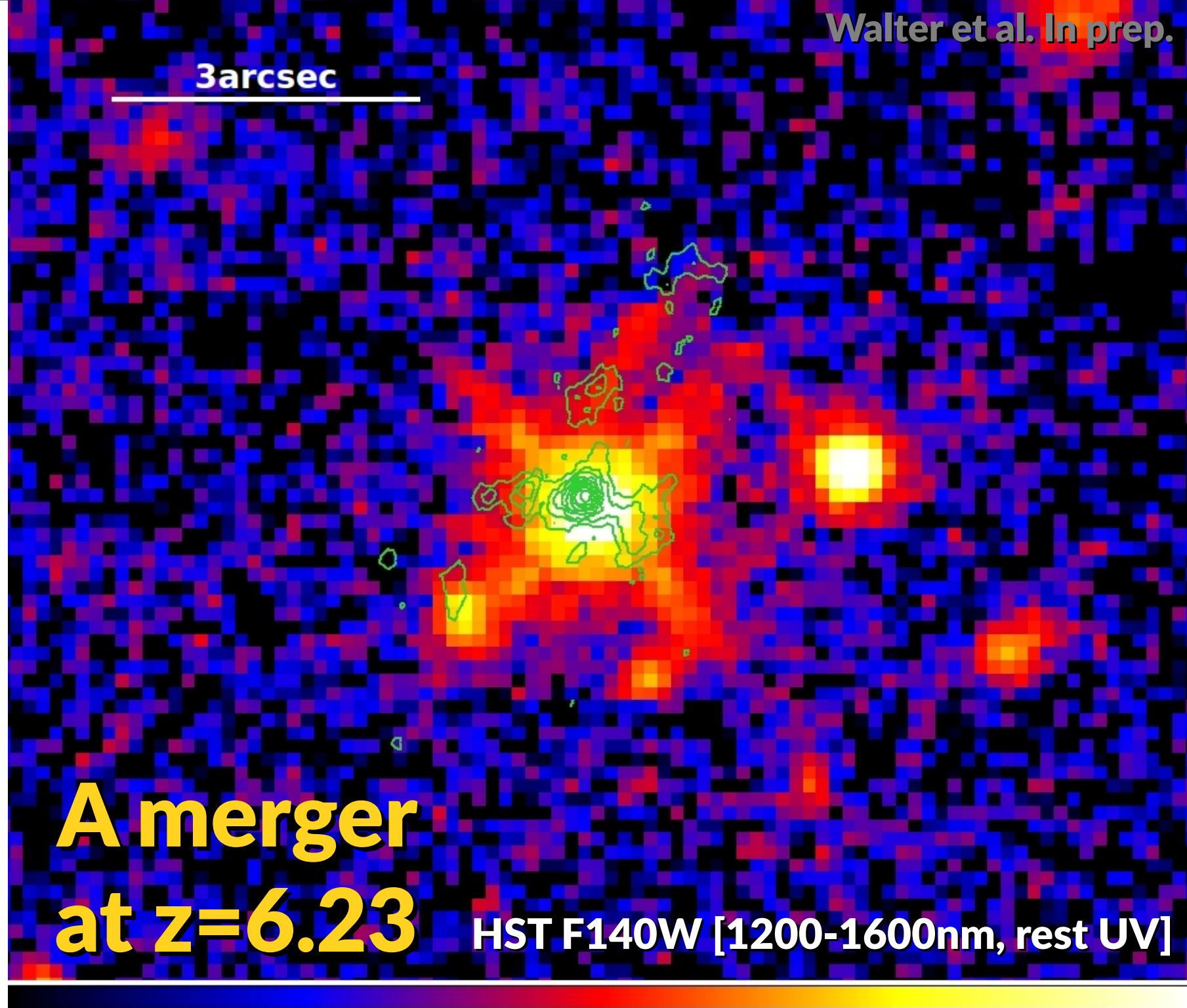
5.3arcsec [30kpc]



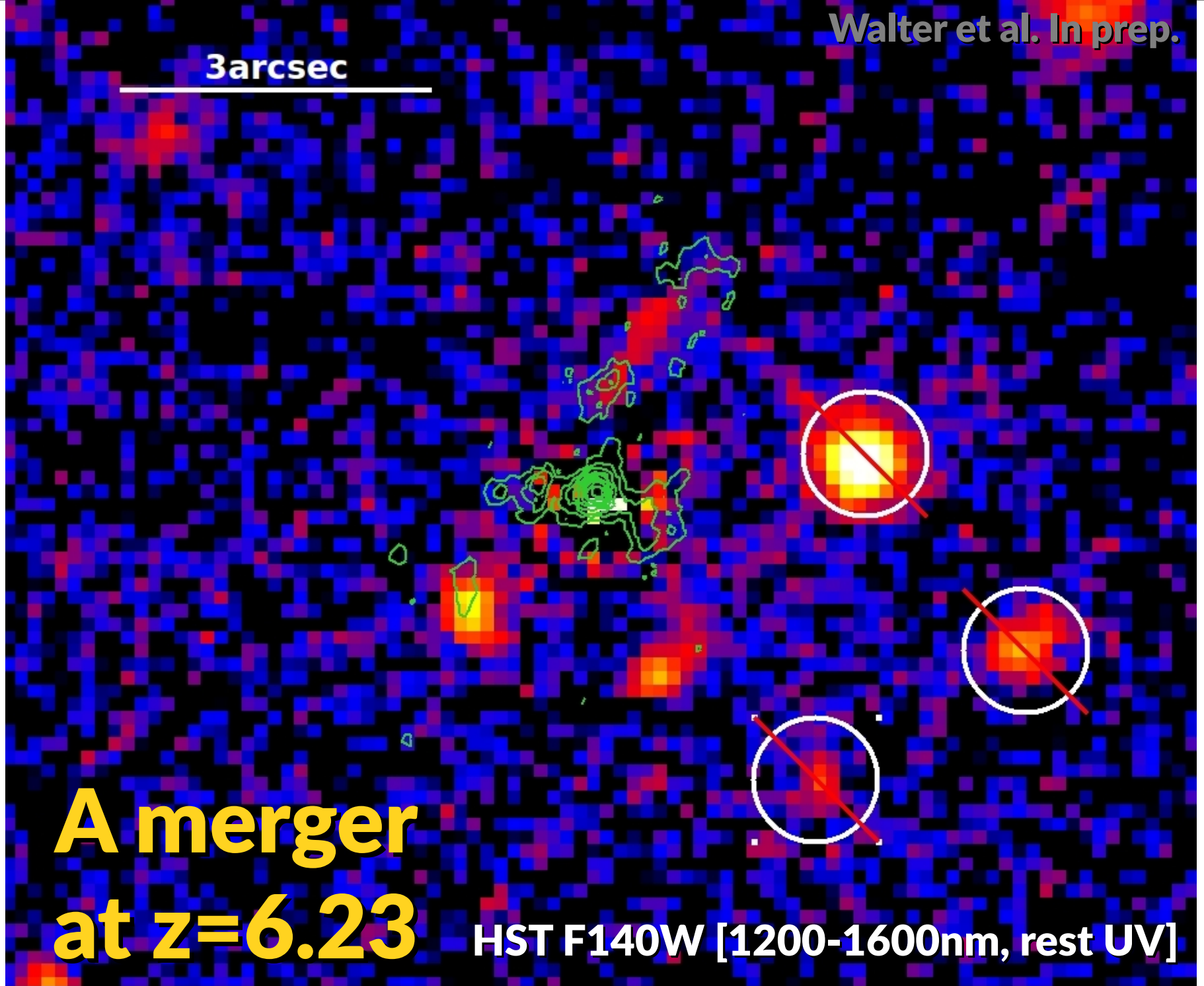
[CII] line map
0.85''x0.65'' beam

0.025 0.053 0.086 0.13 0.18 0.25 0.34 0.46 0.62

3arcsec



3arcsec



**A merger
at $z=6.23$**

HST F140W [1200-1600nm, rest UV]

0.003 0.0089 0.021 0.044 0.092 0.19 0.37 0.75 1.5

3arcsec

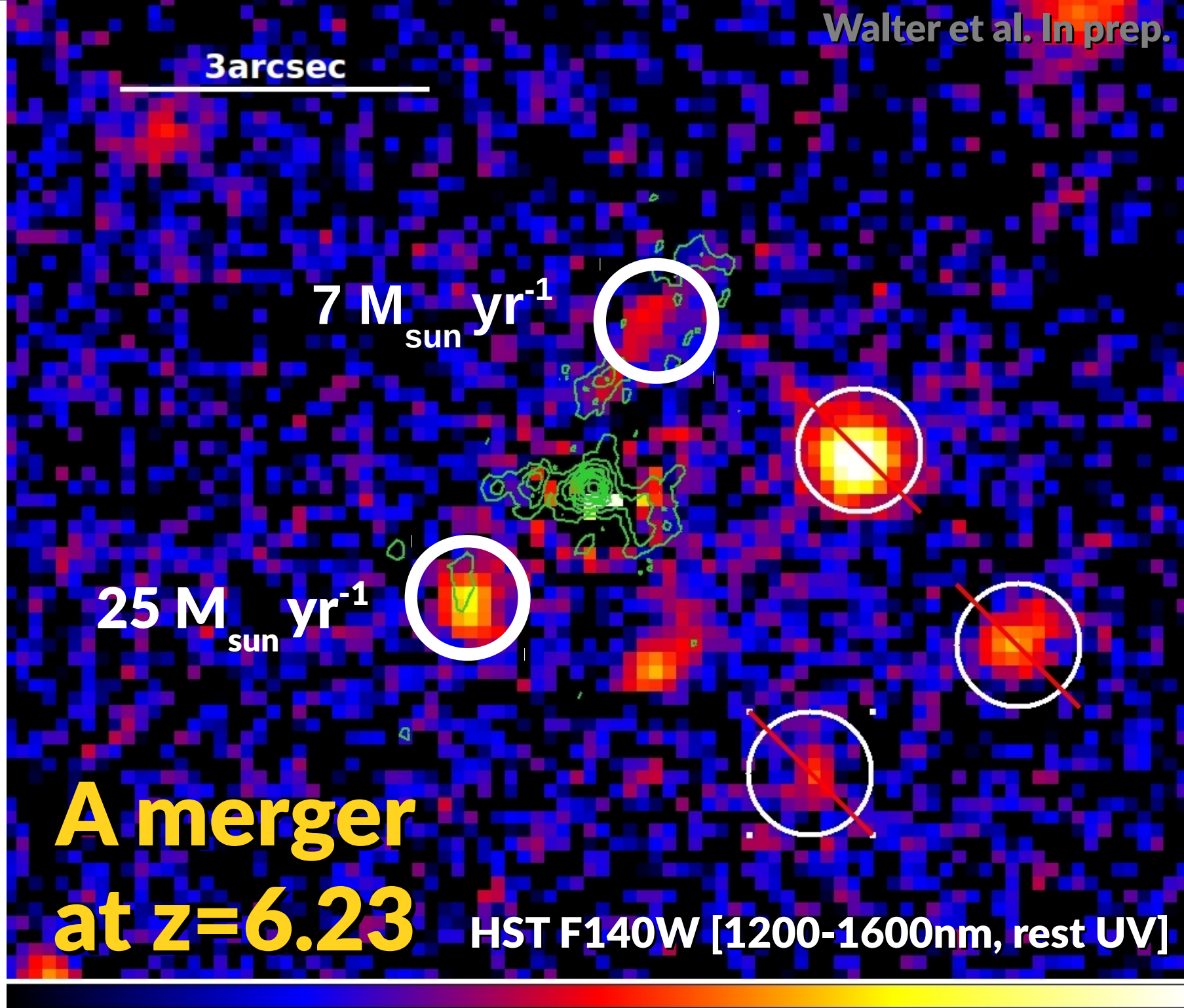
$7 M_{\text{sun}} \text{ yr}^{-1}$

$25 M_{\text{sun}} \text{ yr}^{-1}$

**A merger
at $z=6.23$**

HST F140W [1200-1600nm, rest UV]

0.003 0.0089 0.021 0.044 0.092 0.19 0.37 0.75 1.5



5.3arcsec [30kpc]

6h of VLT/MUSE

NB image @ z_{merger}

$SB_{\text{lim}} \sim 1.3 \times 10^{-18} \text{erg/s/cm}^2/\text{arcsec}^2$

A merger at $z=6.23$

PSF SUBTRACTED

6h of VLT/MUSE

NB image @ z_{merger}

$SB_{\text{lim}} \sim 1.3 \times 10^{-18} \text{ erg/s/cm}^2/\text{arcsec}^2$

A merger at $z=6.23$

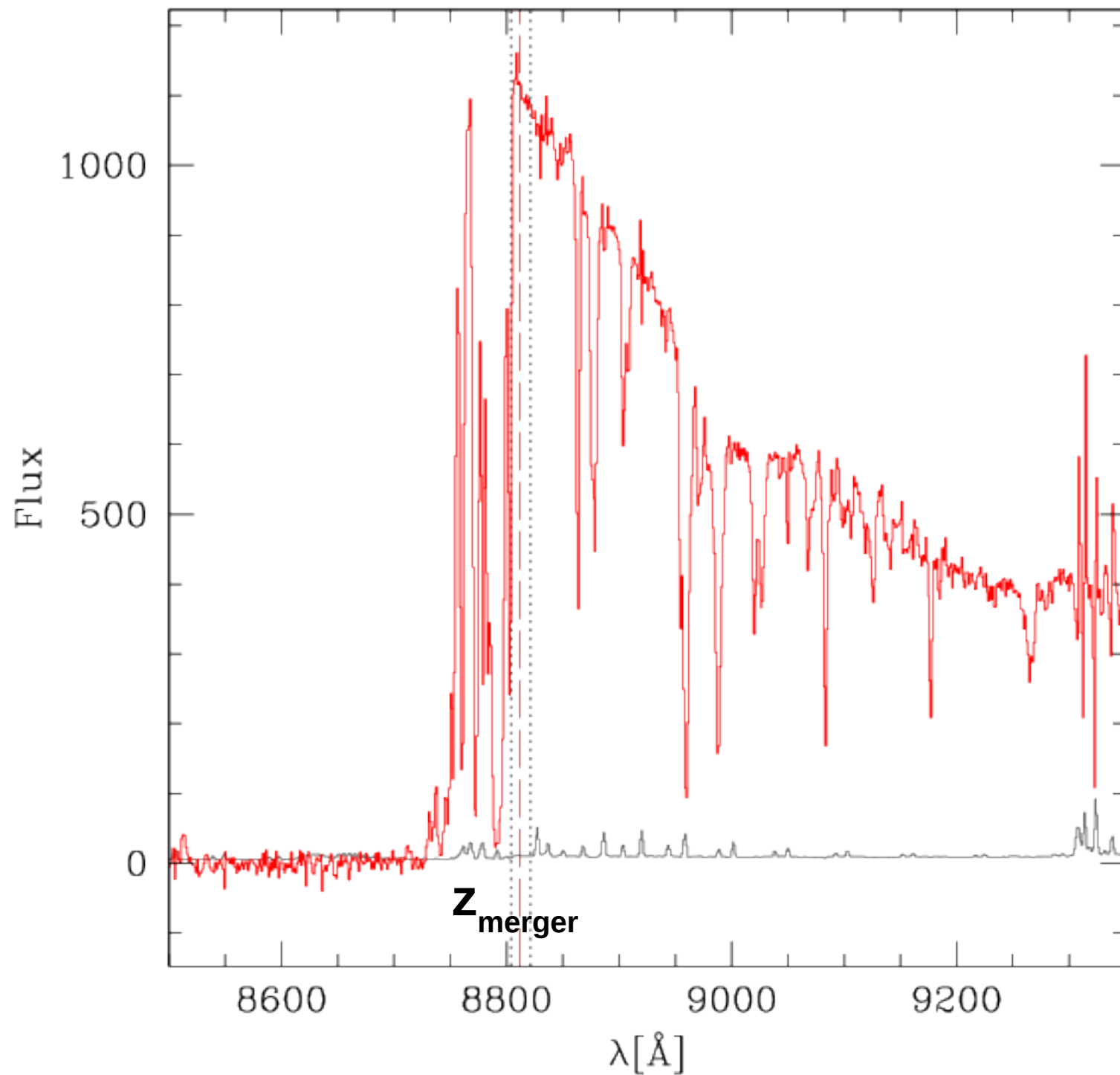
PSF SUBTRACTED

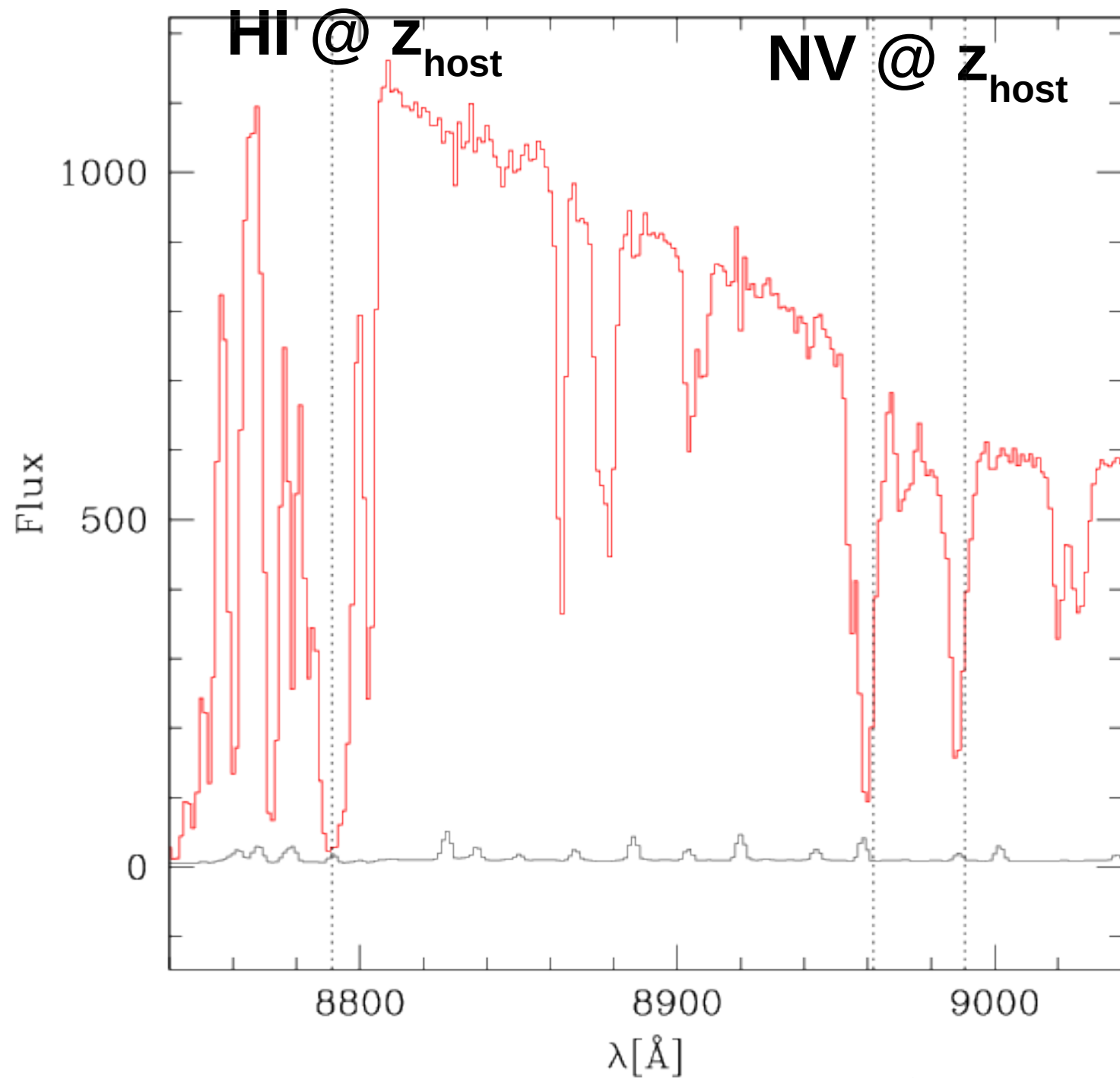
X-map

5.3arcsec [30kpc]

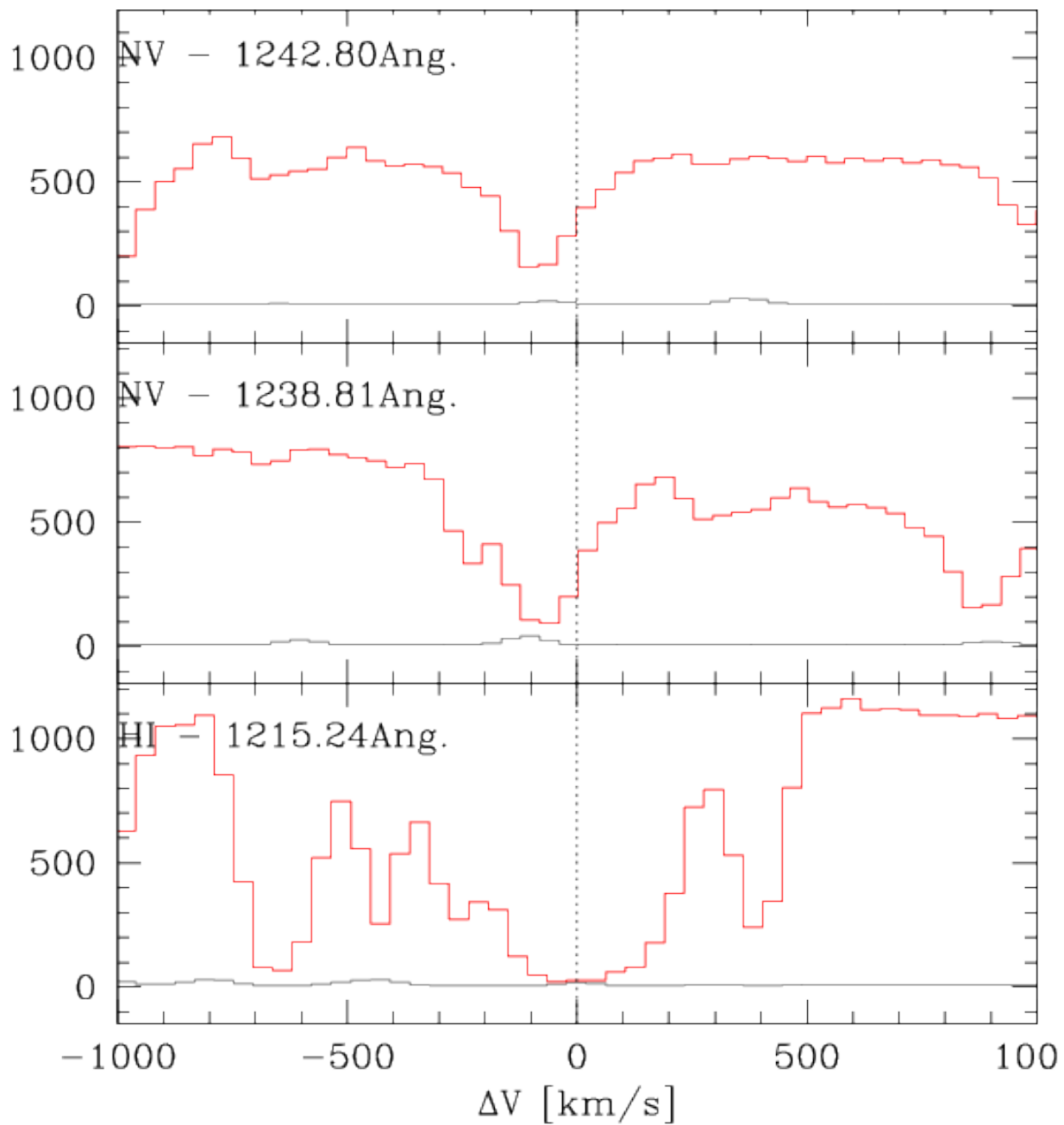
$L \sim 10^{42} \text{erg/s}$ - $\text{SFR} \sim 2 M_{\text{sun}} \text{yr}^{-1}$

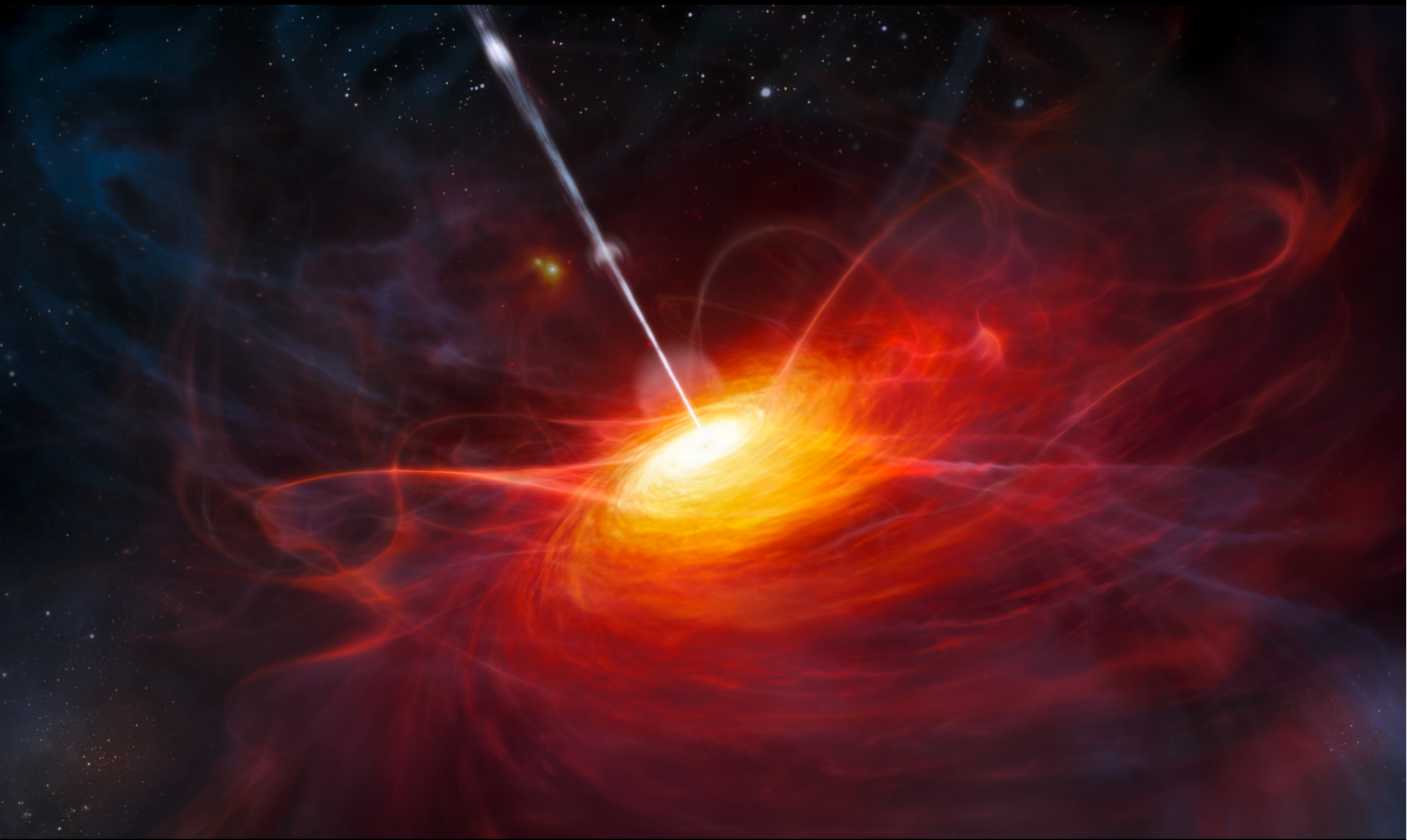
A merger at $z=6.23$





**~100km/s
outflow?**





The First QSOs live in High Density Environment

[protoclusters?]

..looking forward to JWST..



