UNIVERSITÉ DE GENÈVE

OBSERVATOIRE DE GENÈVE — FONDÉ EN 1772

Exploring AGN-feedback on circumgalactic scales with MUSE

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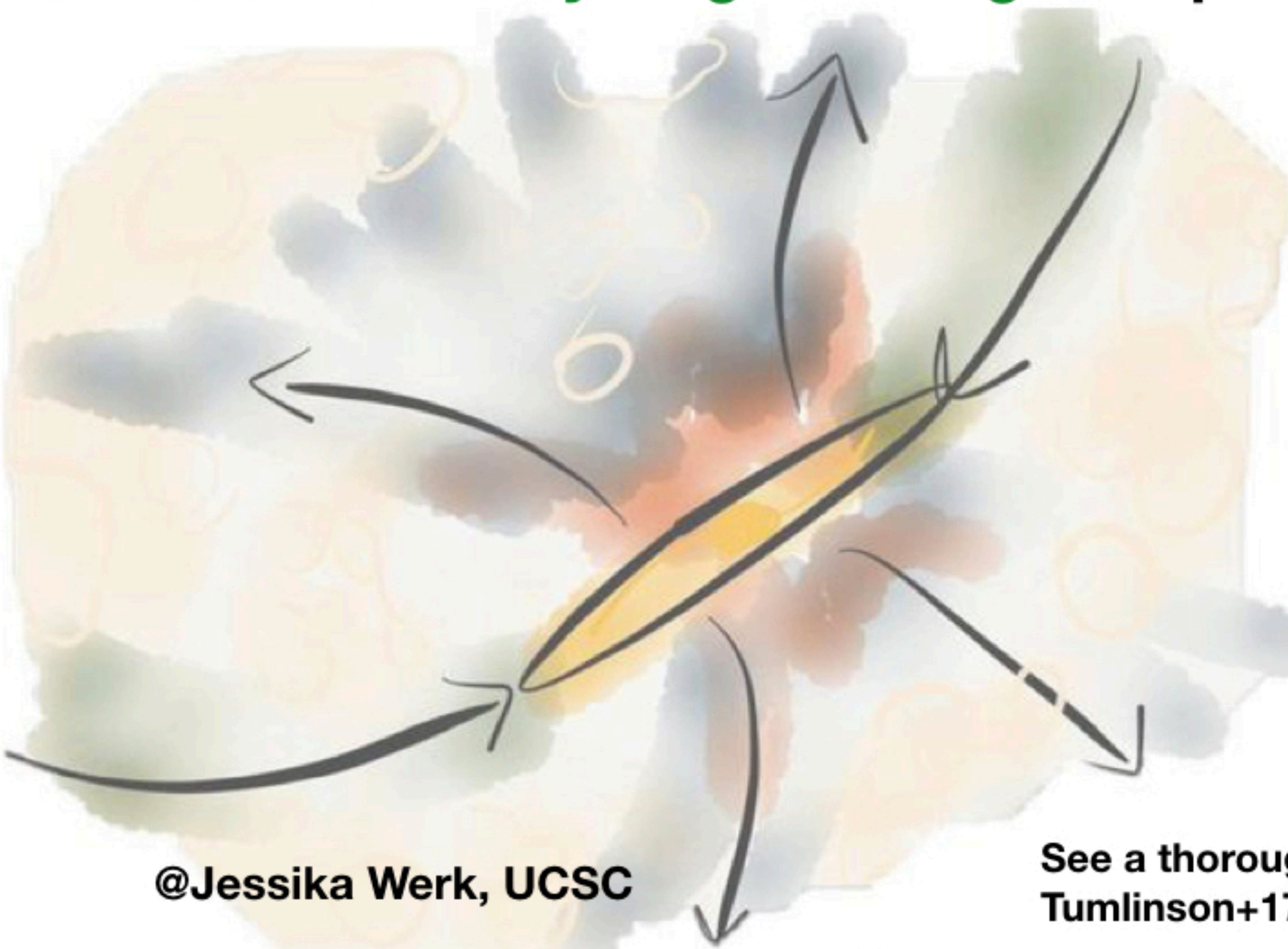
+ R. Maiolino, S. Carniani, L. Zappacosta, E. Piconcelli, R. Schneider, F. Arrigoni-Battaia, S. Cantalupo

The CGM is both (i) a source for supplying gas to galaxies and fuel their star formation, and (ii) the site where galactic feedback and recycling & mixing take place.

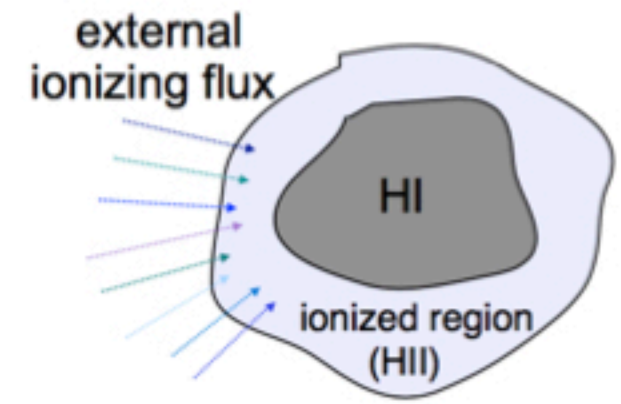


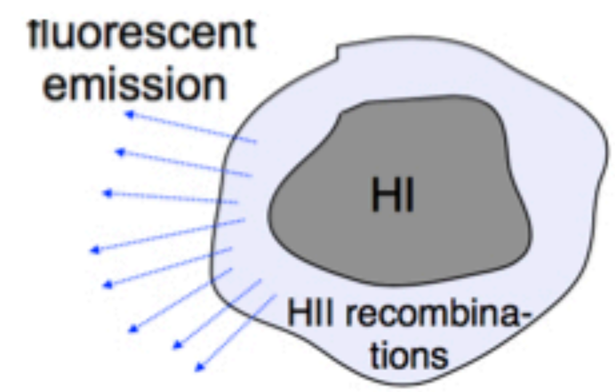
See a thorough review by Tumlinson+17

Leroy+08; Sancisi+08; Cresci+09,10; Genzel+10; Tacconi+13; Schinnerer+16; Genzel +06,10,13,14,15,17; Gnerucci 11; Hodge+12; Saintonge+11,12,14,16; Crocker+12 Tacconi+13,14,18; Fang+13; Nelson+13,15; Tacchella+15a,b; Daddi+15; Cicone+16; Borisova+16; Scoville+17; Ginolfi+17,+18; Tumlinson+17; Arrigoni-Battaia+18; Peeples+19.

Observing the CGM in emission

An alternative approach is to map the CGM through direct imaging of the **Lya line**.





Main mechanisms able to generate circumgalactic Lya emission:

- cooling radiation of gravitationally heated gas *(see e.g., Haiman et al. 2000; Yang et al. 2006; Dijkstra & Loeb 2009)*;
- UV photons produced through shock mechanisms *(see e.g., Taniguchi & Shioya 2000; Mori et al. 2004)*;
- **recombination radiation following photoionization (often referred as fluorescence) powered by UV sources** *(see e.g., Cantalupo et al. 2005; Geach et al. 2009; Kollmeier et al. 2010)*.

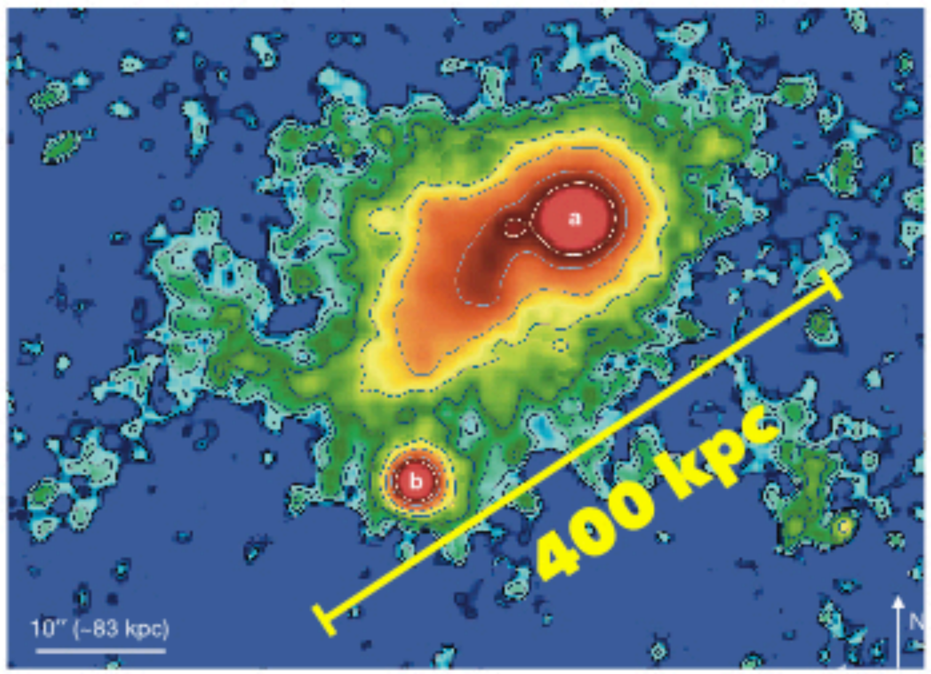
Fluorescence is boosted up into the detectable regime in the vicinity of bright ionizing sources, as luminous QSOs.

Hogan & Weymann 1987; Binette et al. 1993; Gould & Weinberg 1996; Haardt & Madau 1996; Cantalupo et al. 2005; Rauch et al. 2008 ; Gallego et al. 2017 ; Rees 1988; Haiman & Rees 2001; Alam & Miralda-Escude 2002; Cantalupo et al. 2005; Haiman et al. 2000; Yang et al. 2006; Dijkstra & Loeb 2009; Taniguchi & Shioya 2000; Mori et al. 2004…

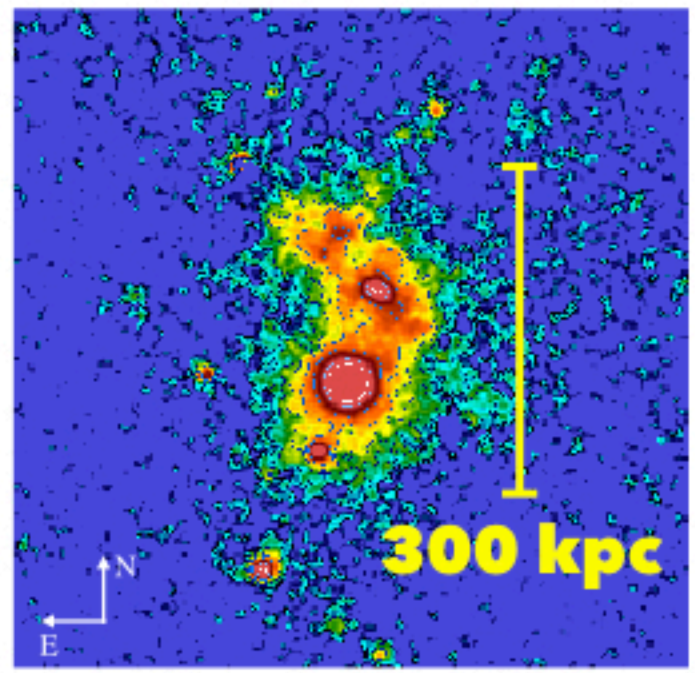
Observing the surrounding of QSOs

Techniques: **narrow-band filters** on 8m telescopes and **long-slit spectroscopy**

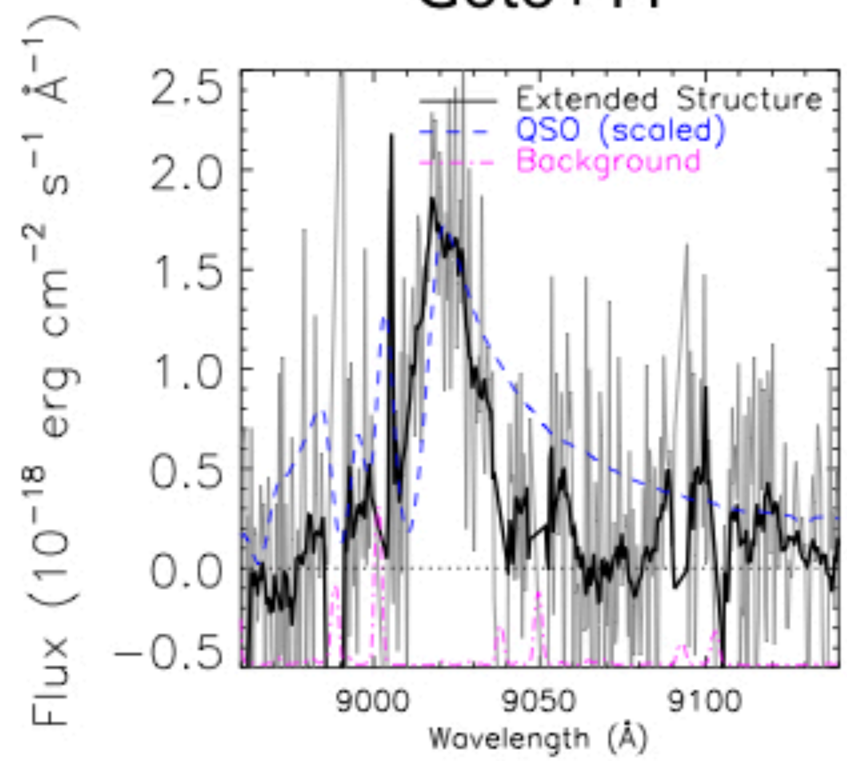
Cantalupo+14



Hennawi+15



Goto+11



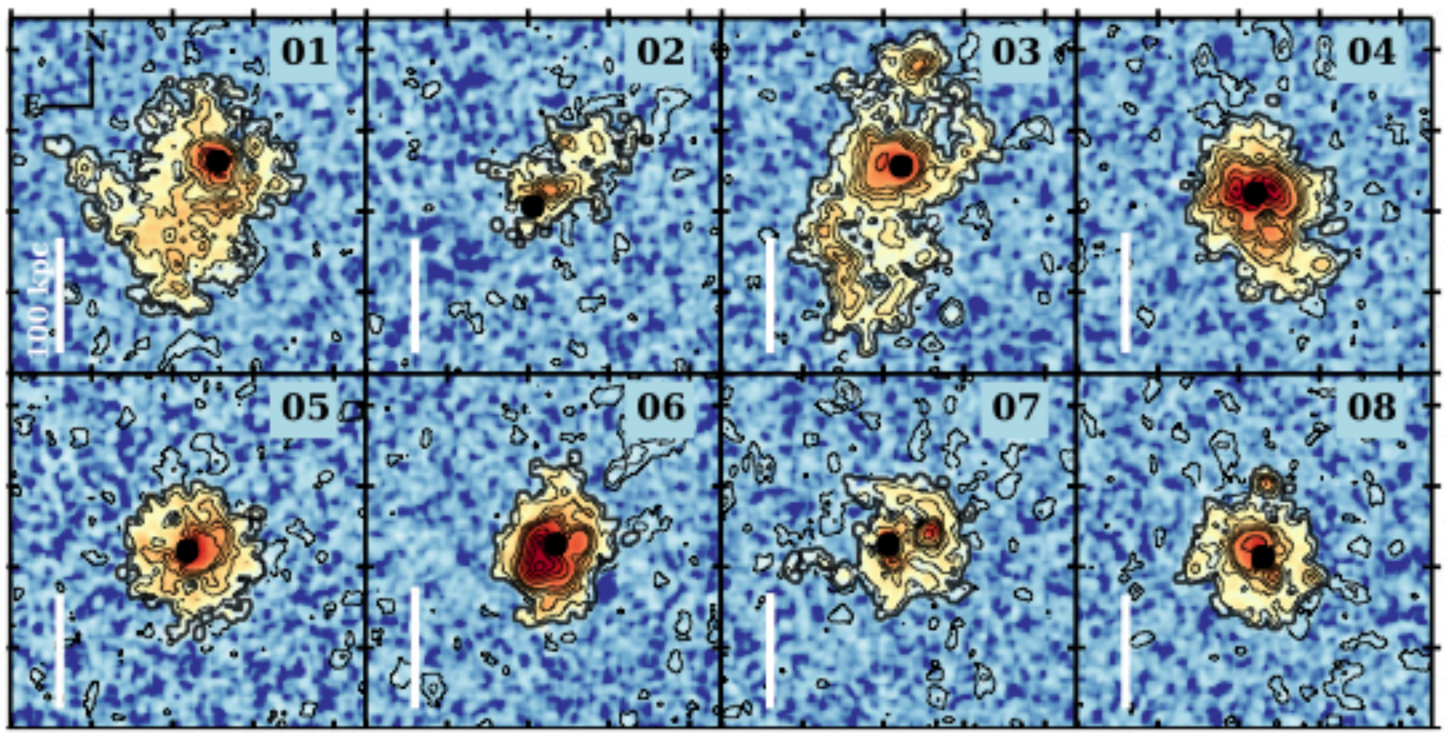
- **time consuming:** ~ 10 h of integration time
- **low detection-rate:** Lya Nebulae larger than 100 kpc only in less than 10% of the targets; emission on smaller scales (~50 kpc) only in about 50% of the cases.

Cantalupo et al. 2012, 2014; Martin et al. 2014; Arrigoni Battaia et al. 2016; Christensen et al. 2006; North et al. 2012; Herenz et al. 2015; Hennawi et al. 2015…

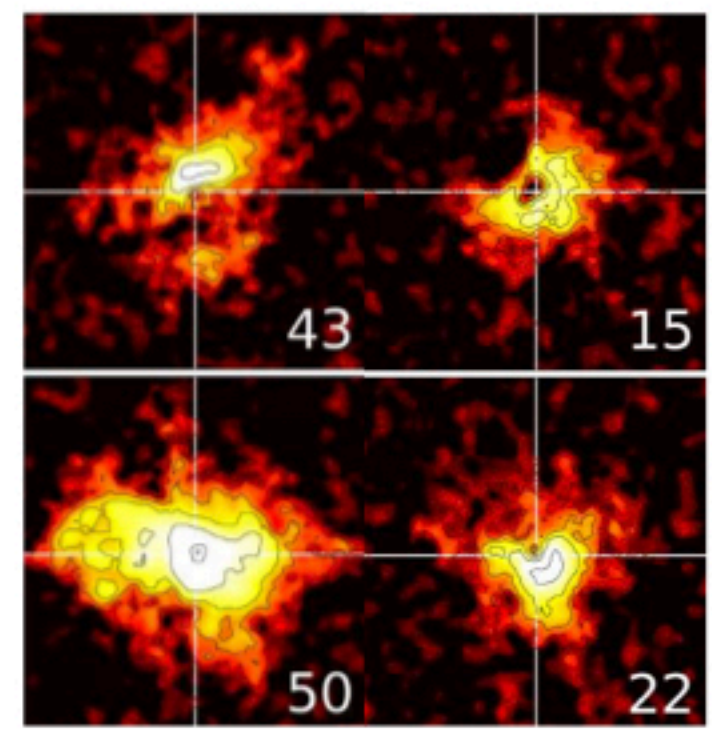
Observing the surrounding of QSOs with MUSE

Technique: MUSE IFU at VLT

- high sensitivity (~10^{-18} erg/s/cm^2/arcsec^2 for a 1 arcsec^2 , in 1 h);
- no filter/slit losses by design;
- careful PSF modelling;
- large FOV (1"x1"), ideal to to search for giant Lya Nebulae.



Borisova+16



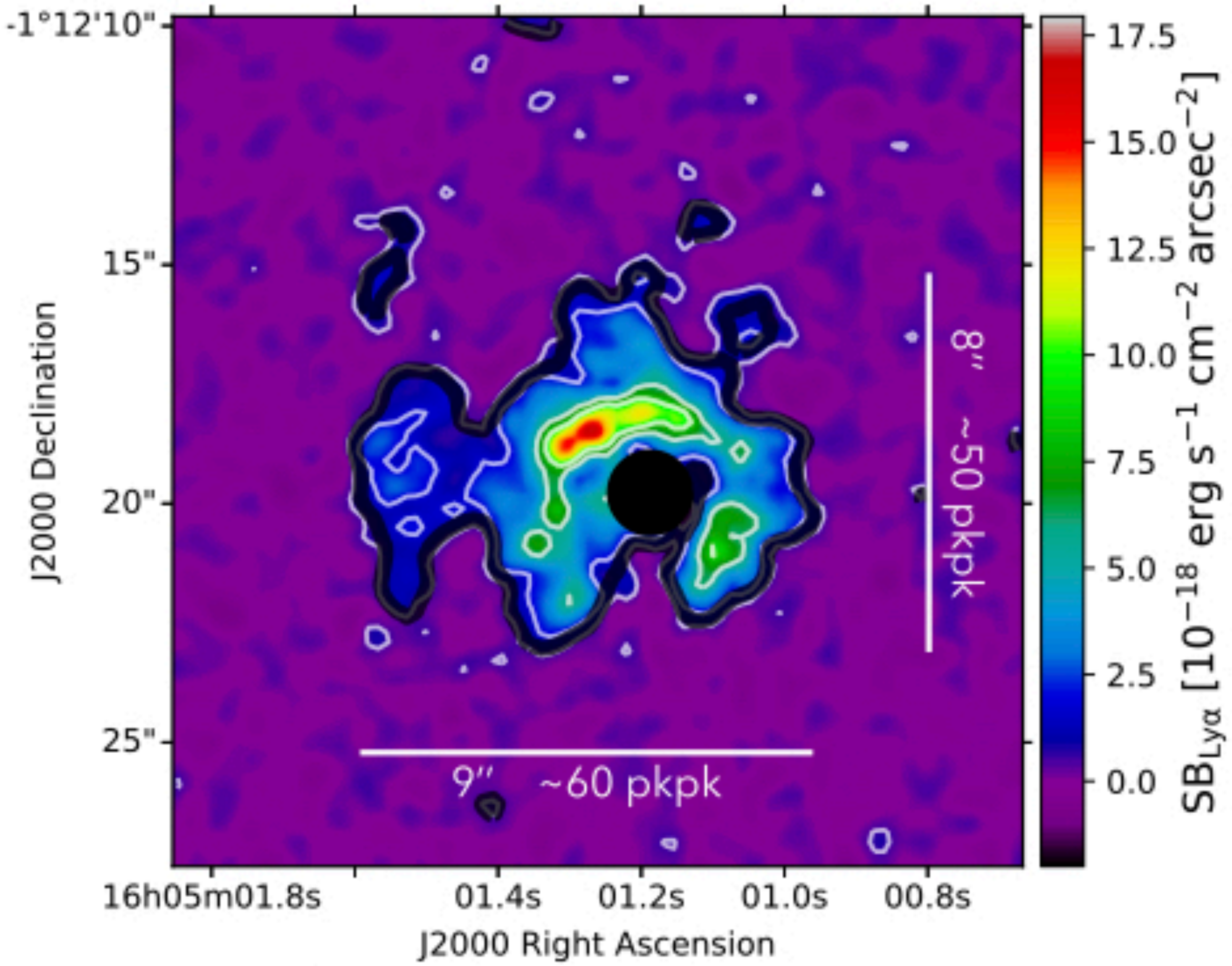
Arrigoni-Battaia+18

Ubiquitous Lya Nebulae around QSOs at z~3-4

- **Some Nebula showing filamentary morphology;**
- **No clear kinematic patterns, e.g., rotation, inflow or outflows;**
- **Generally quiescent kinematics (low velocity dispersion)**

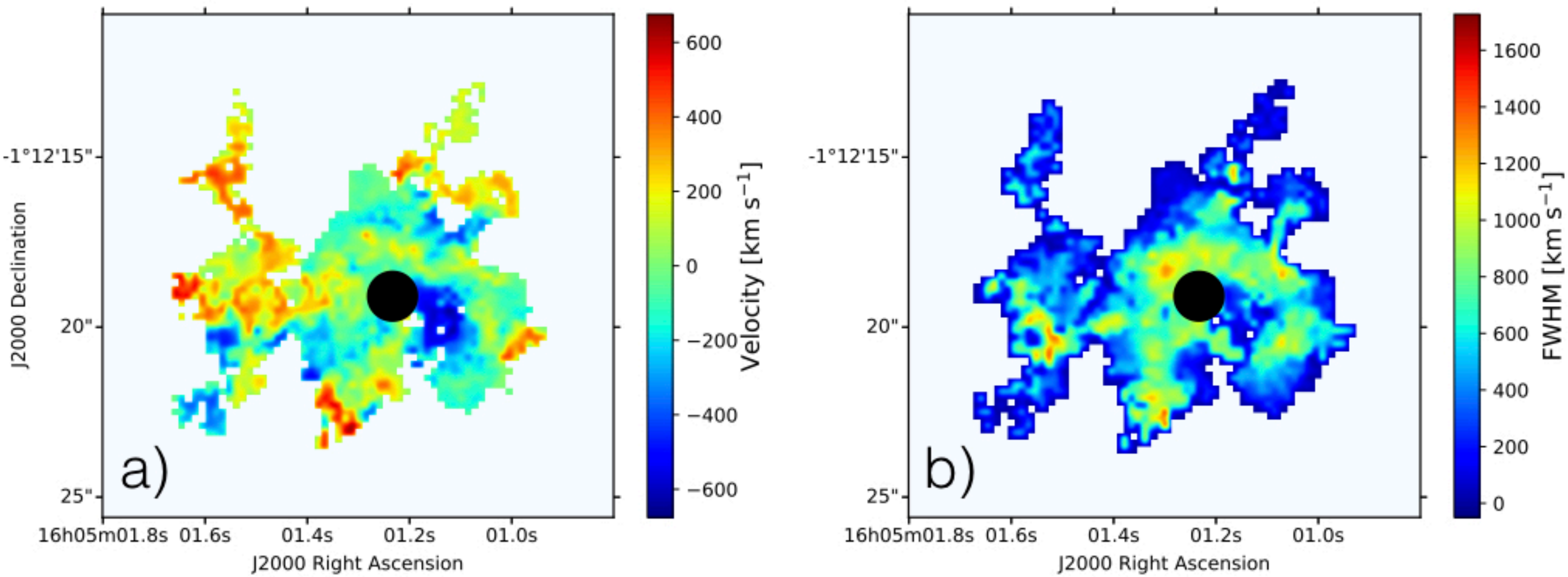
Borisova+16; Farina+18; Ginolfi+18; Arrigoni-Battaia+18a,b; Cantalupo+19; Marino+19; Drake+19…

Ginolfi+18



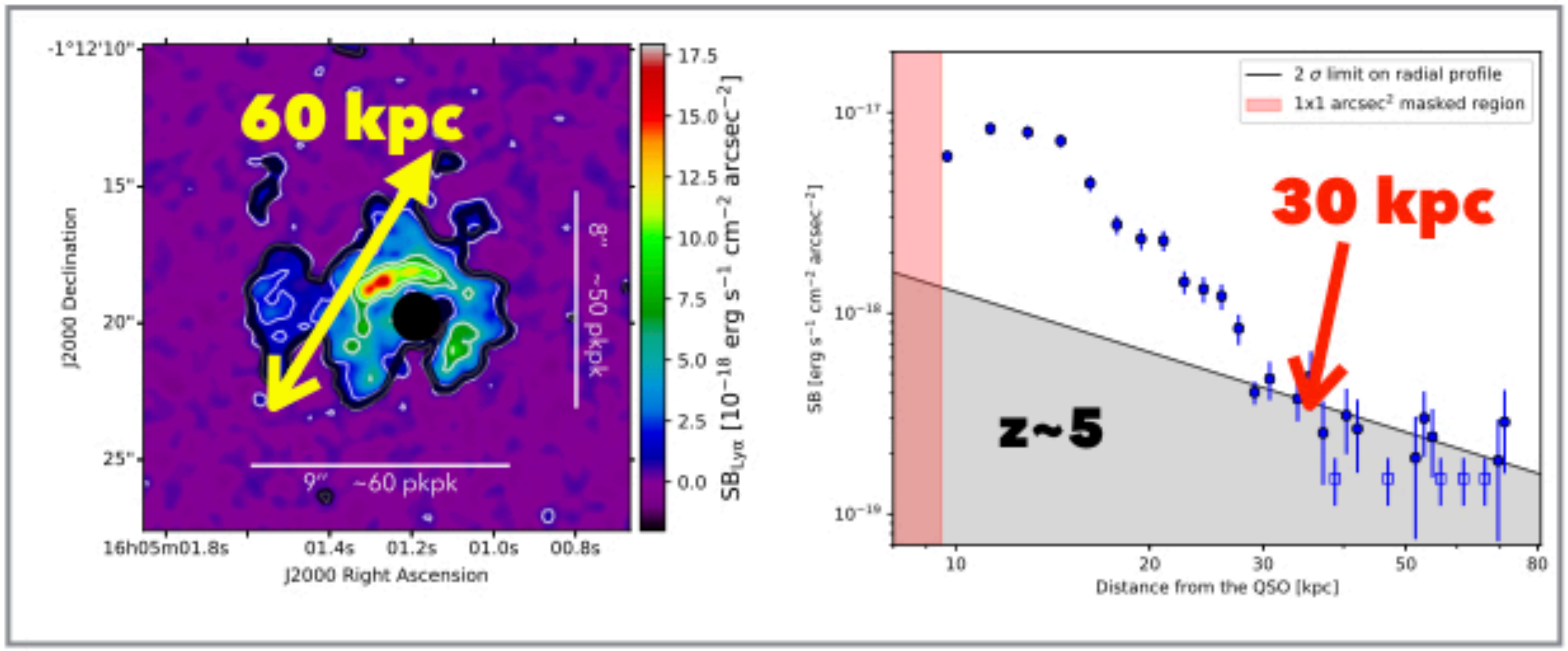
Deep **MUSE** observations of J1605-0112, a Broad Absorption Line **(BAL)** QSO at **z~5**.

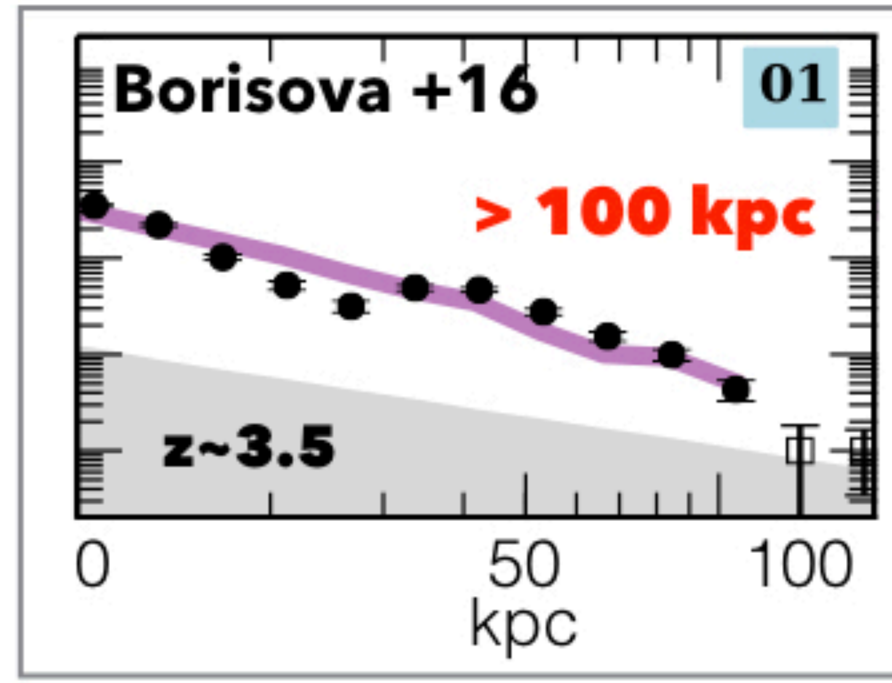
This Lya Nebula is quite interesting; it shows two peculiar properties… let's see!

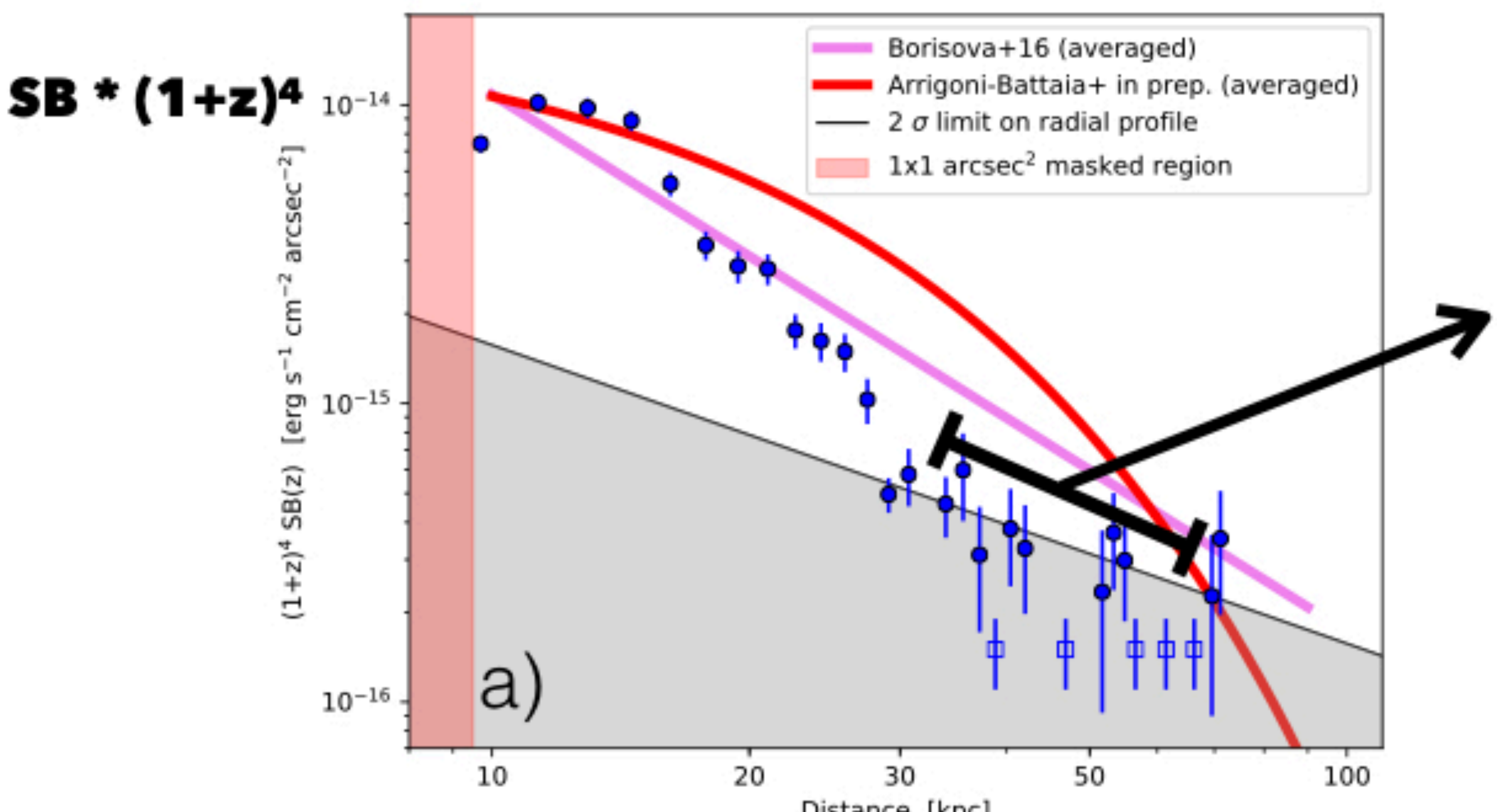


1) Morphology - Size Discrepancy

Our Nebula at z~5, has a redshift-corrected, less extended distribution of Lya emission than typical nebulae at lower redshifts (z~3-3.5).



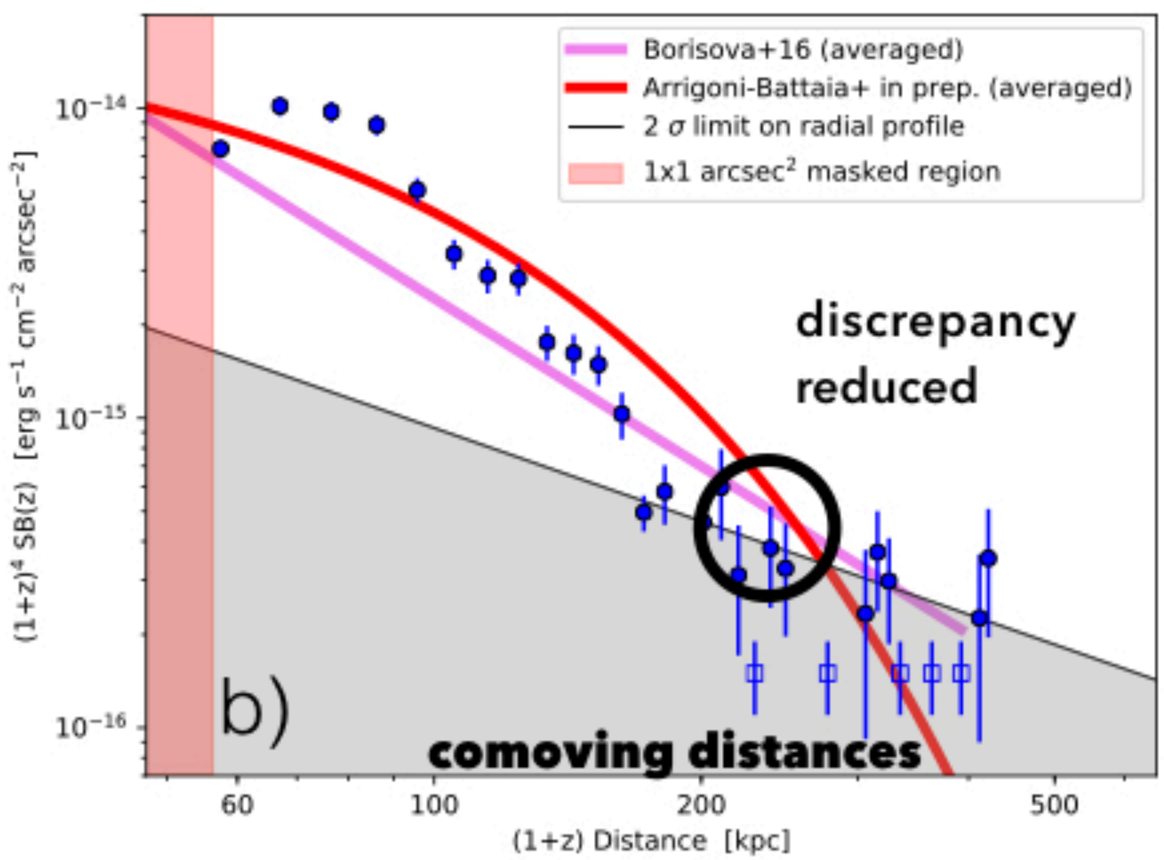




Our Nebula is ***intrinsically*** smaller than lower-z nebulae.

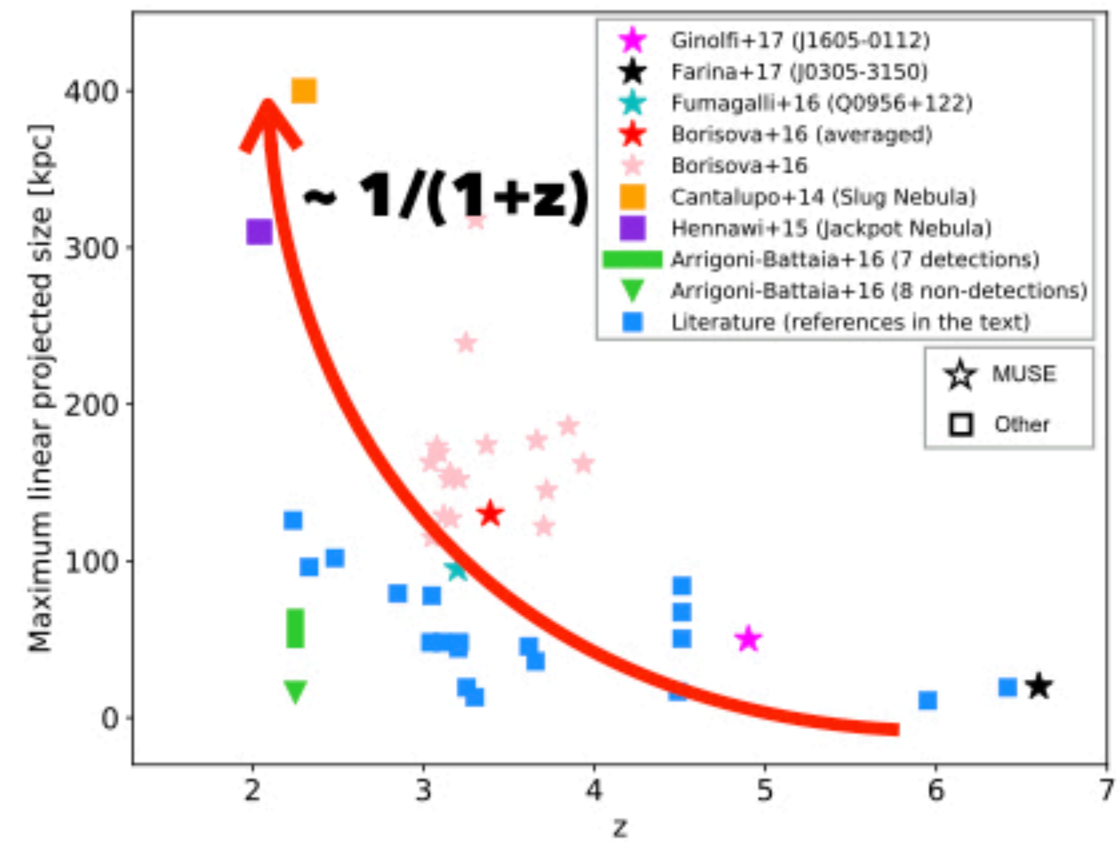
1) Morphology - Size Discrepancy

Our Nebula at z~5, has a redshift-corrected, less extended distribution of Lyα emission than typical nebulae at lower redshifts (z~3-3.5).



$r_{vir} \sim M^{1/3} (1+z)^{-1}$

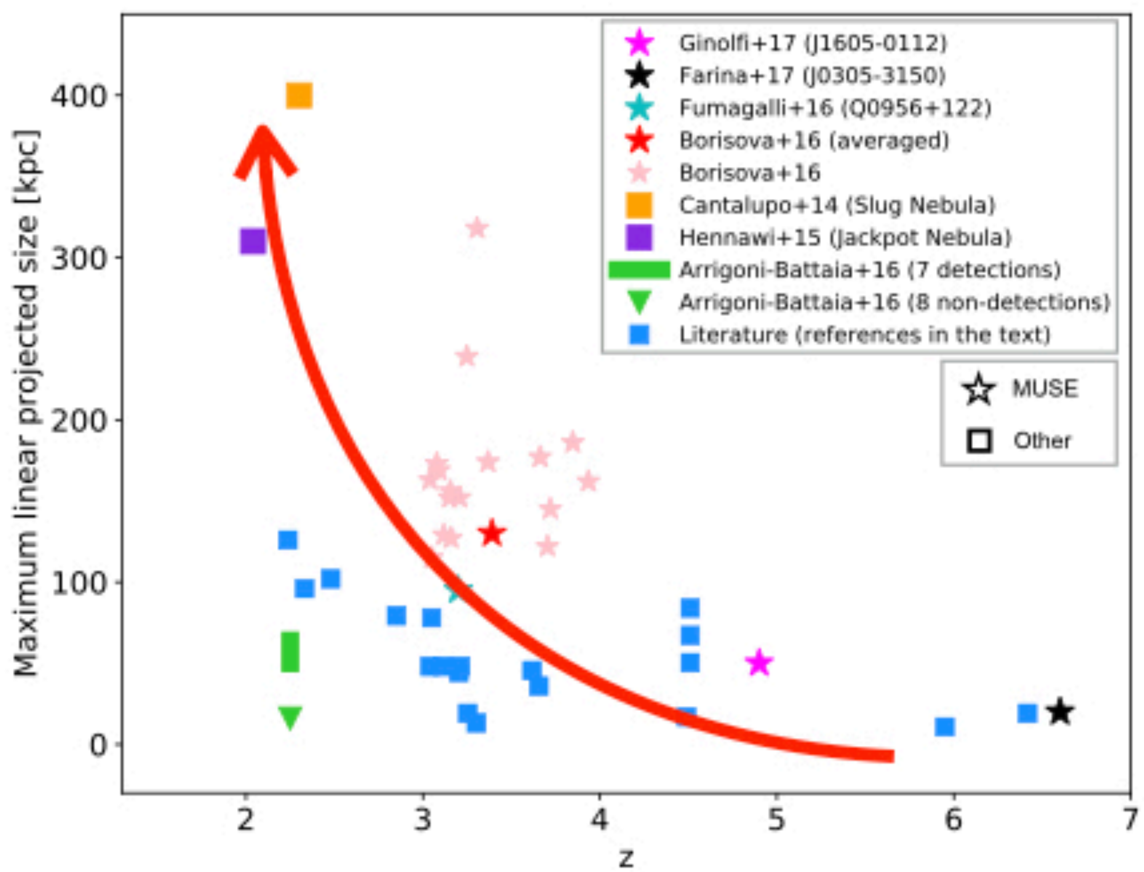
(Barkana & Loeb 2001)

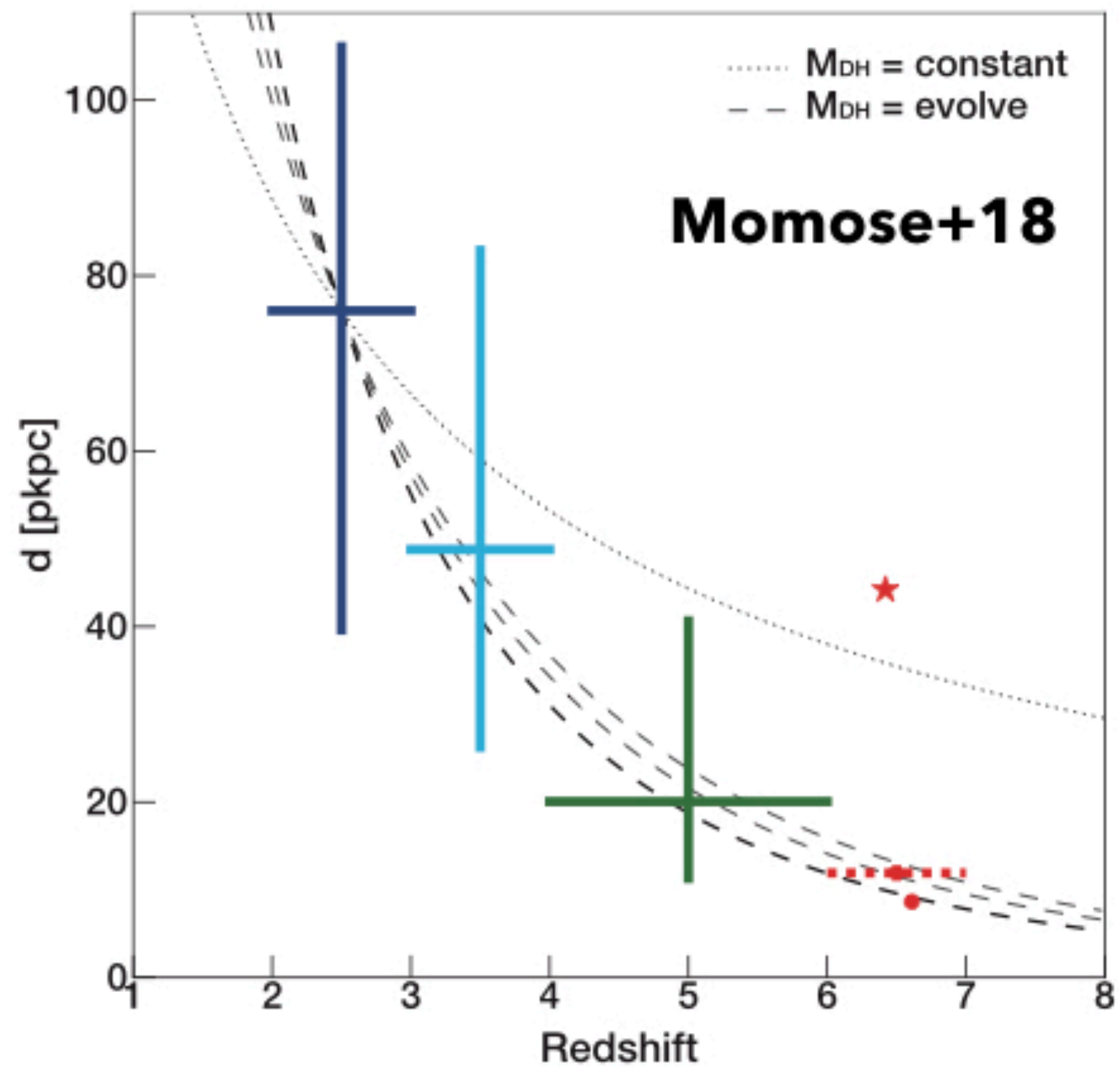


Ginolfi+18

This suggests that the size-discrepancy may be ascribed to the smaller size of DM haloes with comparable mass at higher *z*, implying an interesting **empirical relation between the size of Lyα nebulae and sizes of DM haloes around QSOs**.

"Lya-halo size" — "DM-halo size/mass" relation ?!!





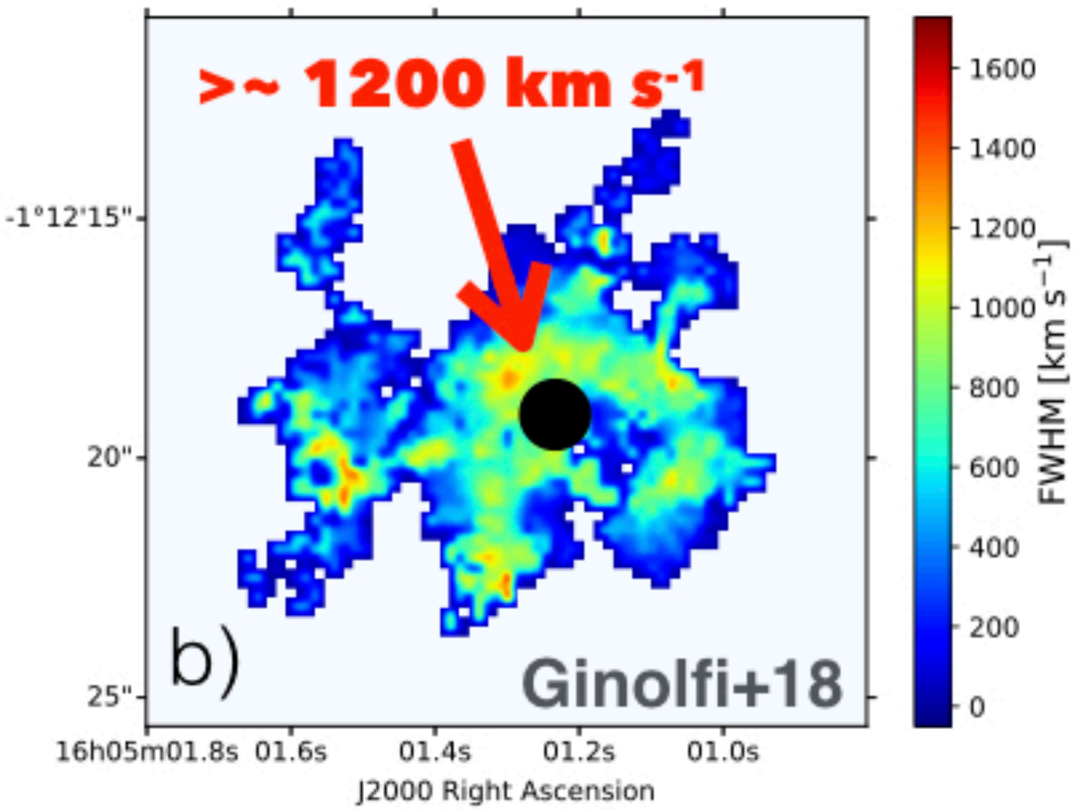
SUBARU (Narrow Band) + literature

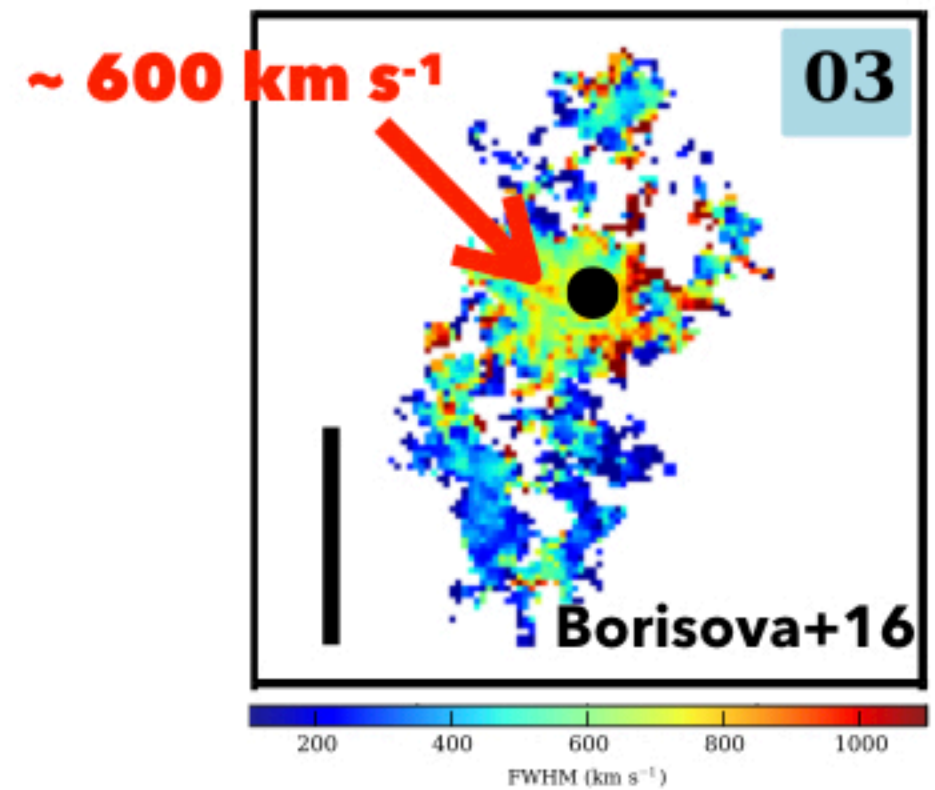
The extent of Lya halos is also found to increase at a rate scaling with the virial radius of growing dark matter halos, $\mathbf{r_{vir} \sim M^{1/3} (1+z)^{-1}}$. These increases are consistent with a scenario in which the CGM around QSOs evolves in mass and size keeping pace with hosting dark matter halos.

Ginolfi+18; Farina+18; Momose+18; Arrigoni-Battaia+18b; Drake+19

2) Kinematics - high Lya broadening

The Lya velocity dispersion map shows a particularly high broadening of the line **(FWHM>1000 km s^{-1})**, especially in the inner regions of the CGM, at ~10 kpc from the QSO. *Typical* Nebulae show FWHM>500-700 km s^{-1} (e.g., Borisova+16; Arrigoni+18).



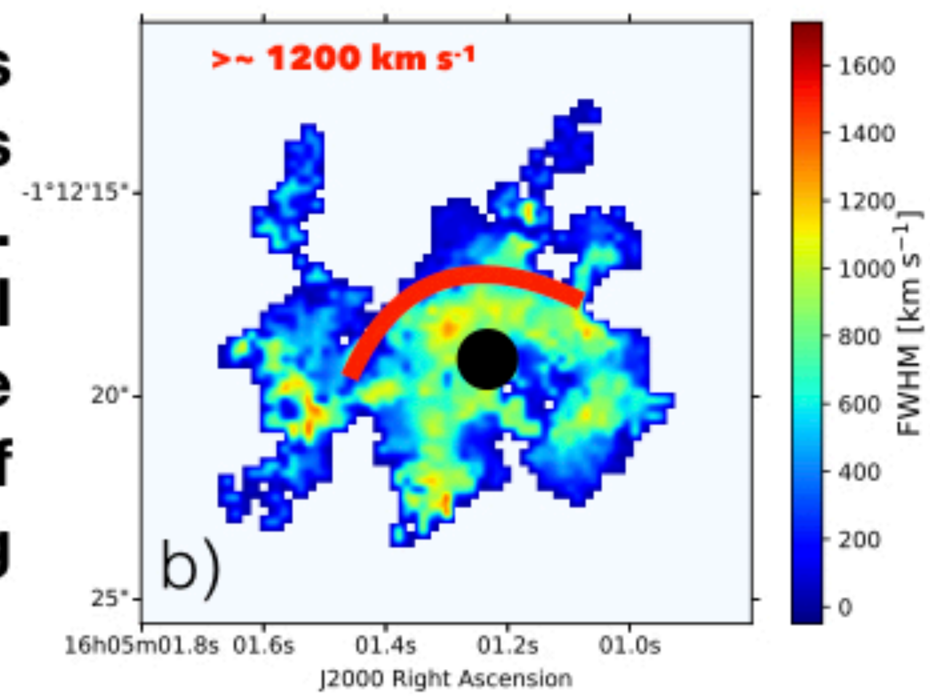


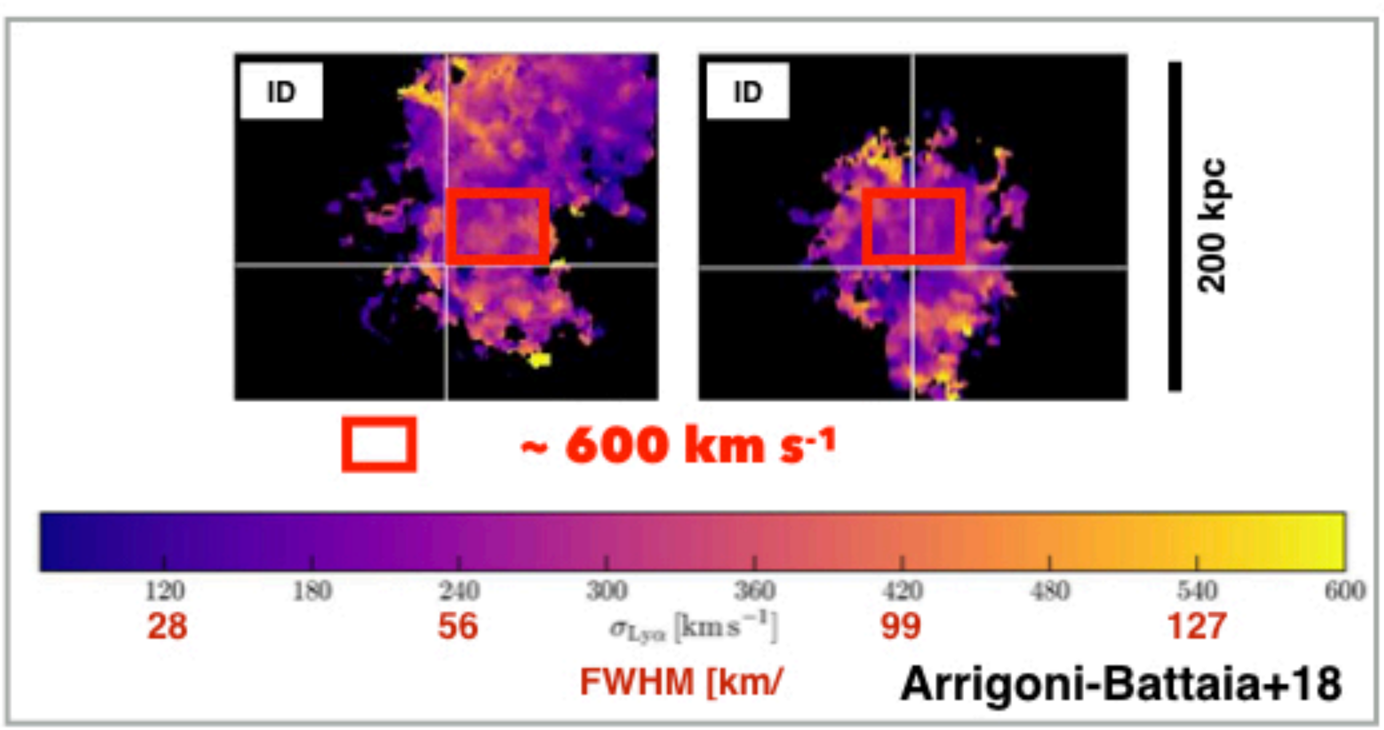
<u>suggested scenario</u>

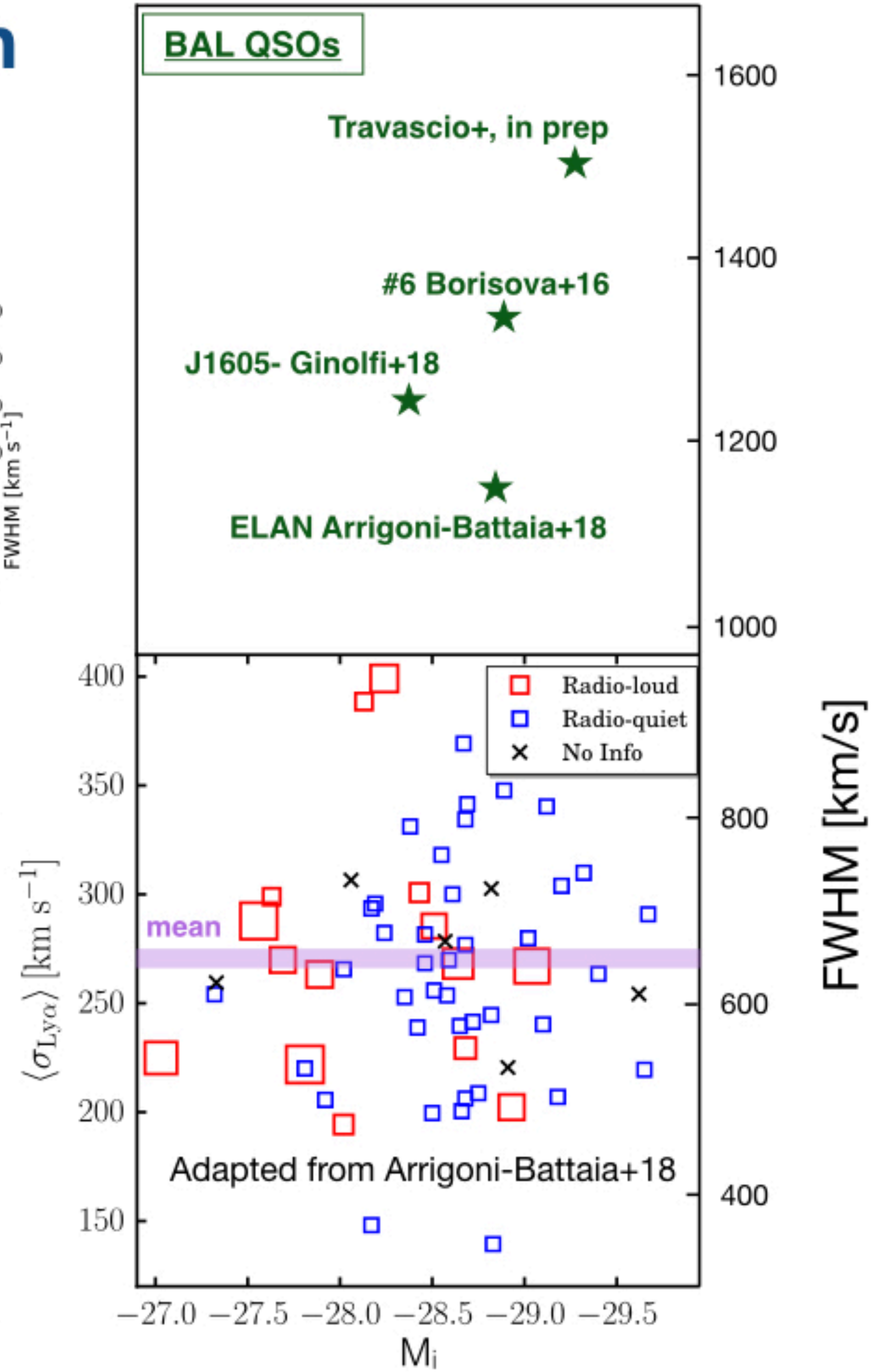
- BALs have been observed to experience powerful outflows; J1605-0112 shows CIV λ1549 absorption troughs blueshifted by more than 30.000 km/s, tracing very high velocity outflowing gas.
- the observed large Lya broadening may trace a significant **turbulence introduced into the CGM by the powerful outflow**.

Traces of AGN feedback on CGM scales?

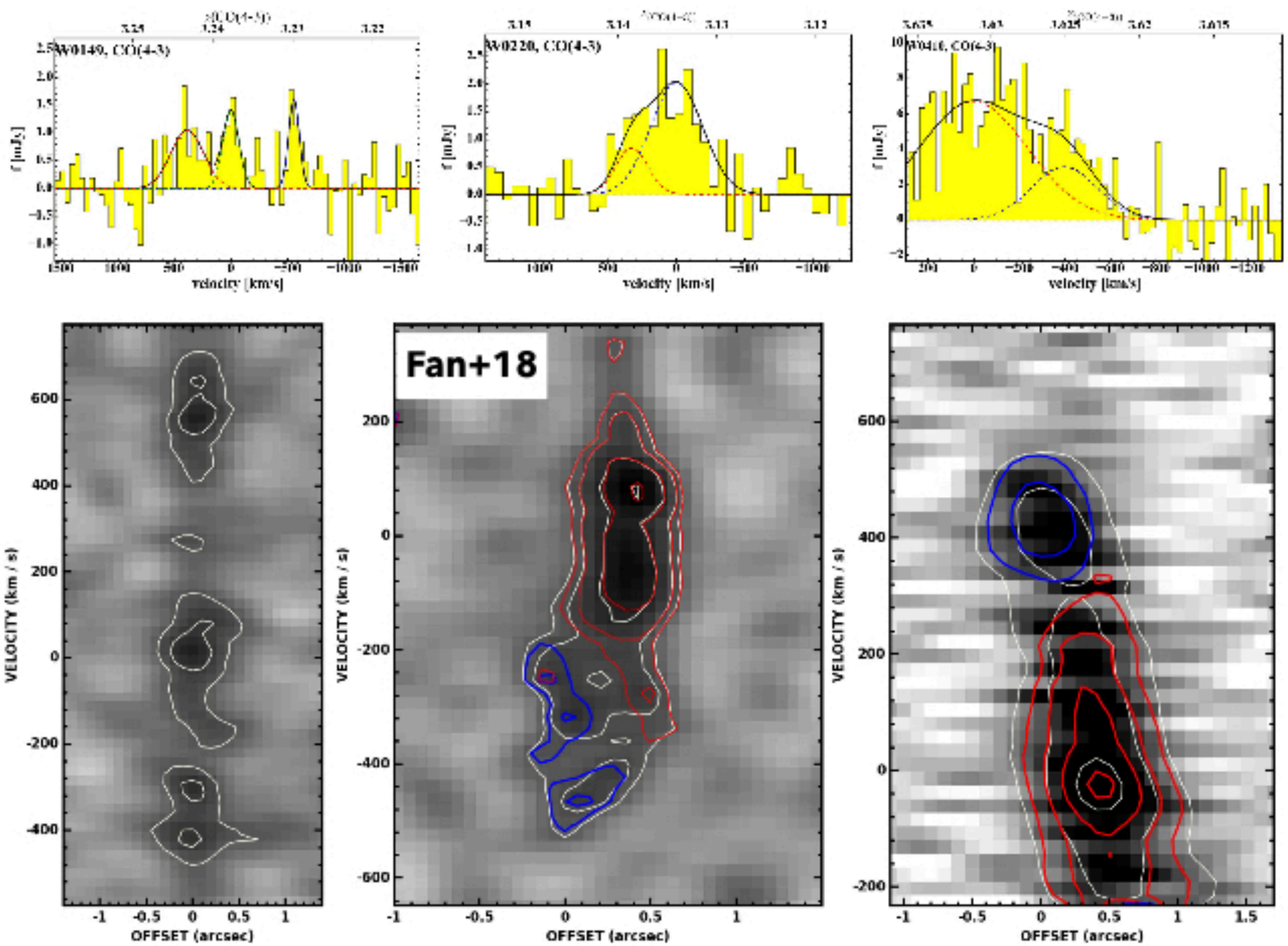
Kinematics from Lya is challenging. But powerful outflows leave signatures of Lya-broadening in the CGM.







Searching for the Hot-DOGs ingredients: a **MUSE** look at the gas reservoir surrounding hyper-luminous, dust-obscured, outflow-dominated z > 3 QSOs.



- asymmetric velocity structures, showing evidence for molecular outflows

Deep **MUSE** observations (~1 h per source) of three Hot-DOGs (Lbol > 10^{14}L⊙) at z = 3.1 – 3.6.

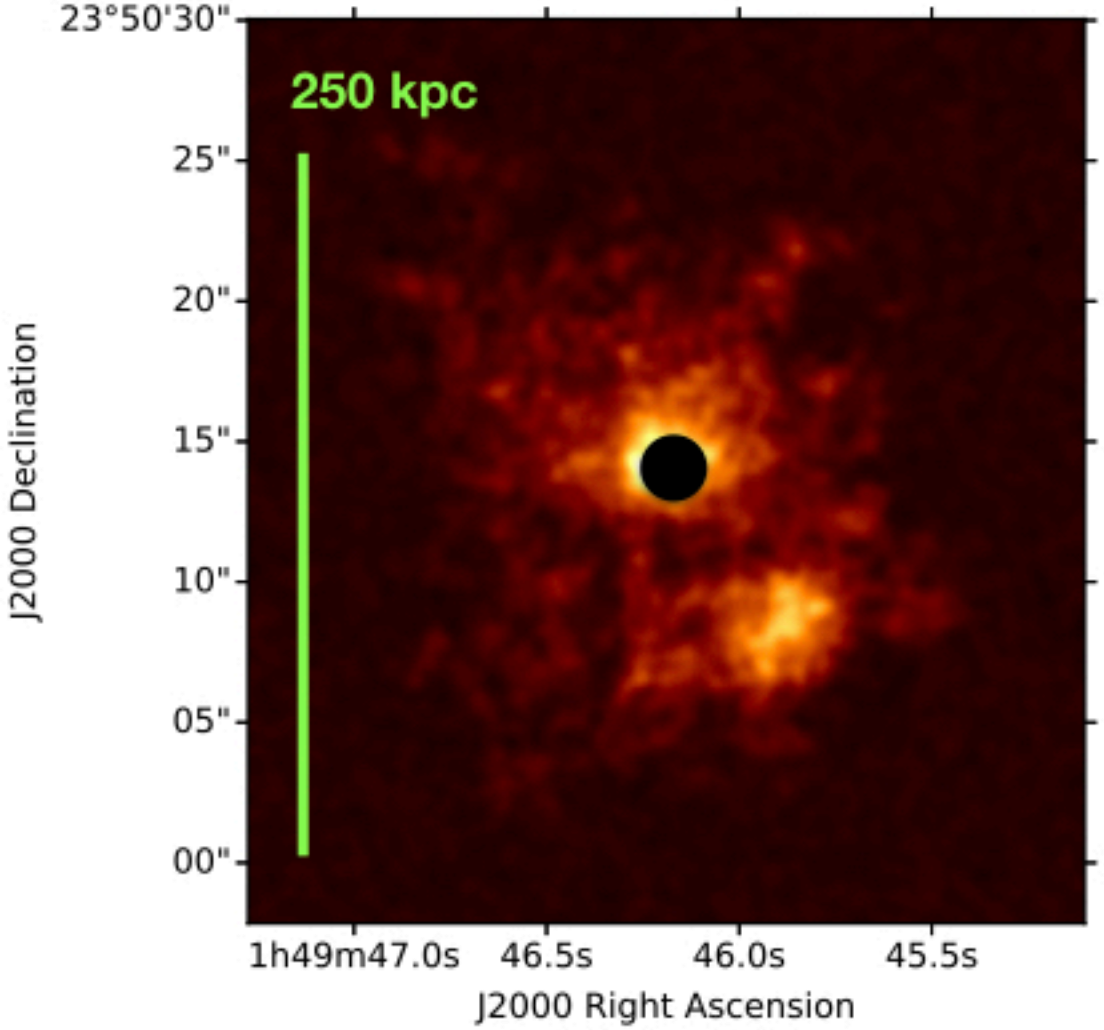
- study the impact of AGN-driven outflows on the CGM, looking at the Lya kinematics;
- study the environment of Hot-DOGs, and their growth mechanisms.

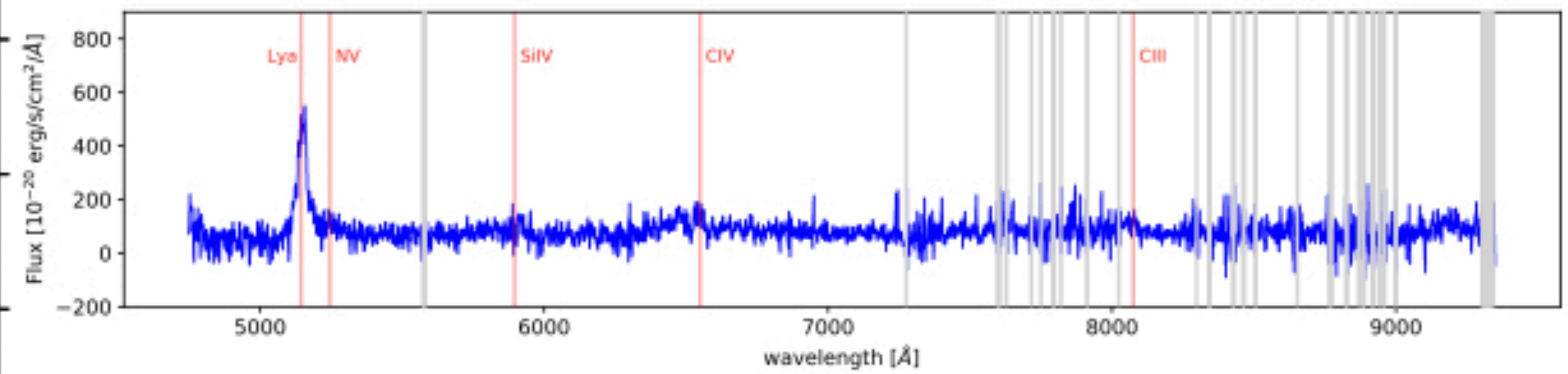
Ginolfi+, in prep

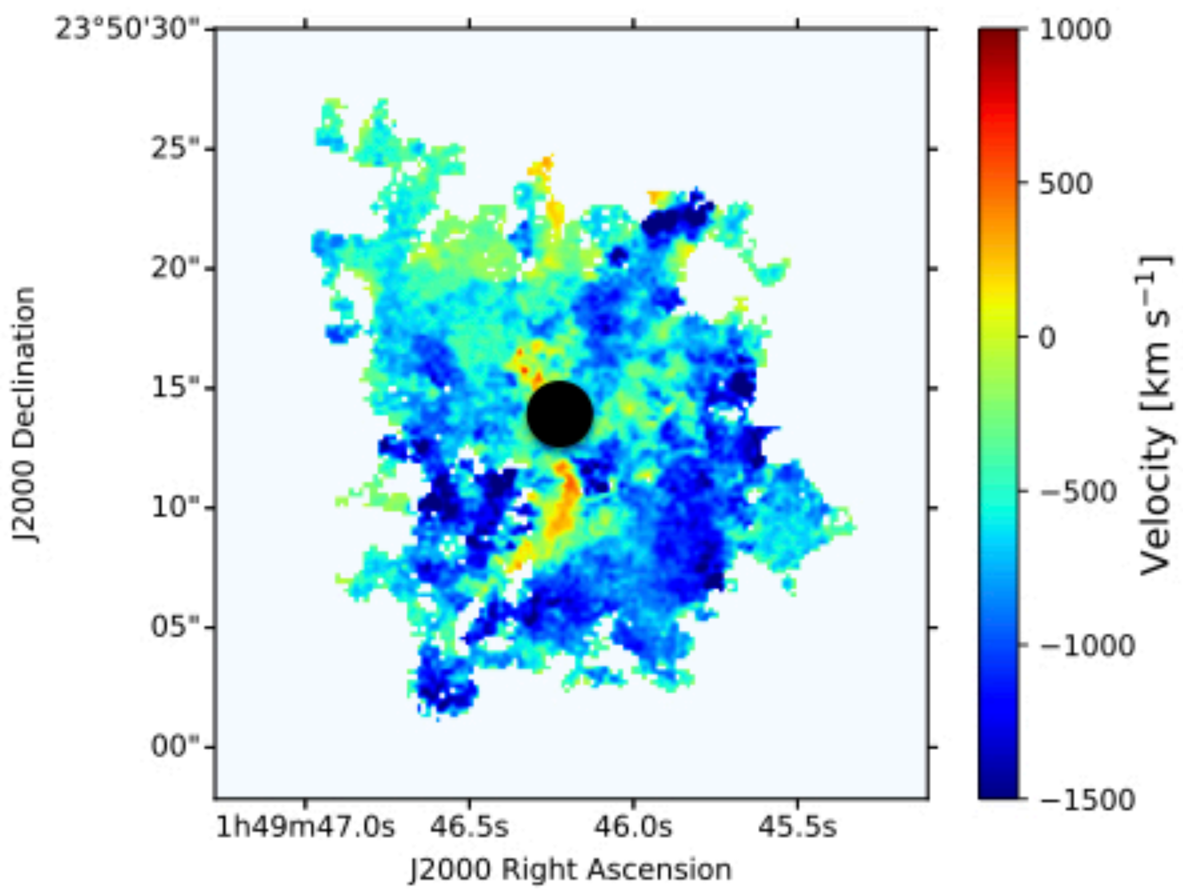
W0149+2350

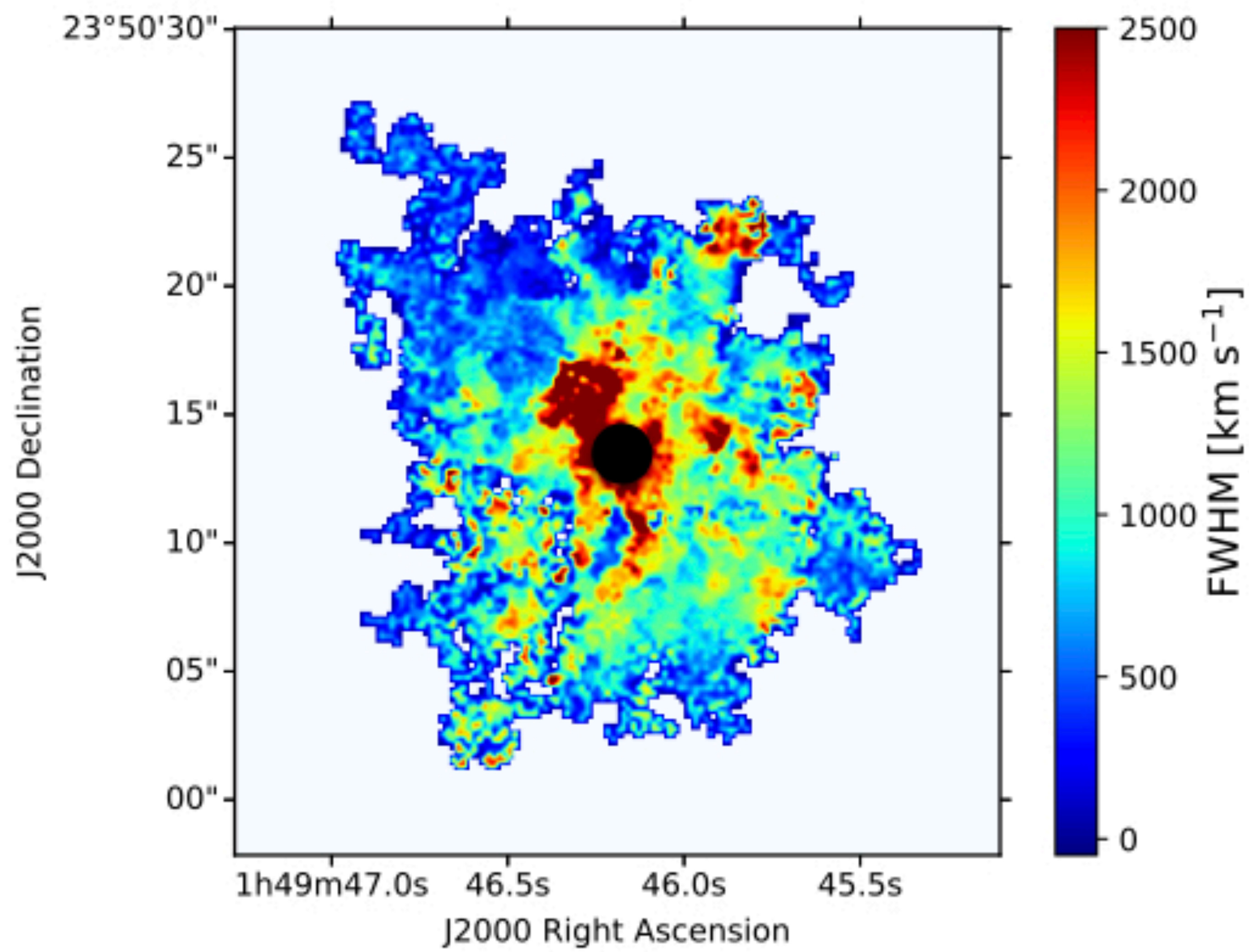
z = 3.24

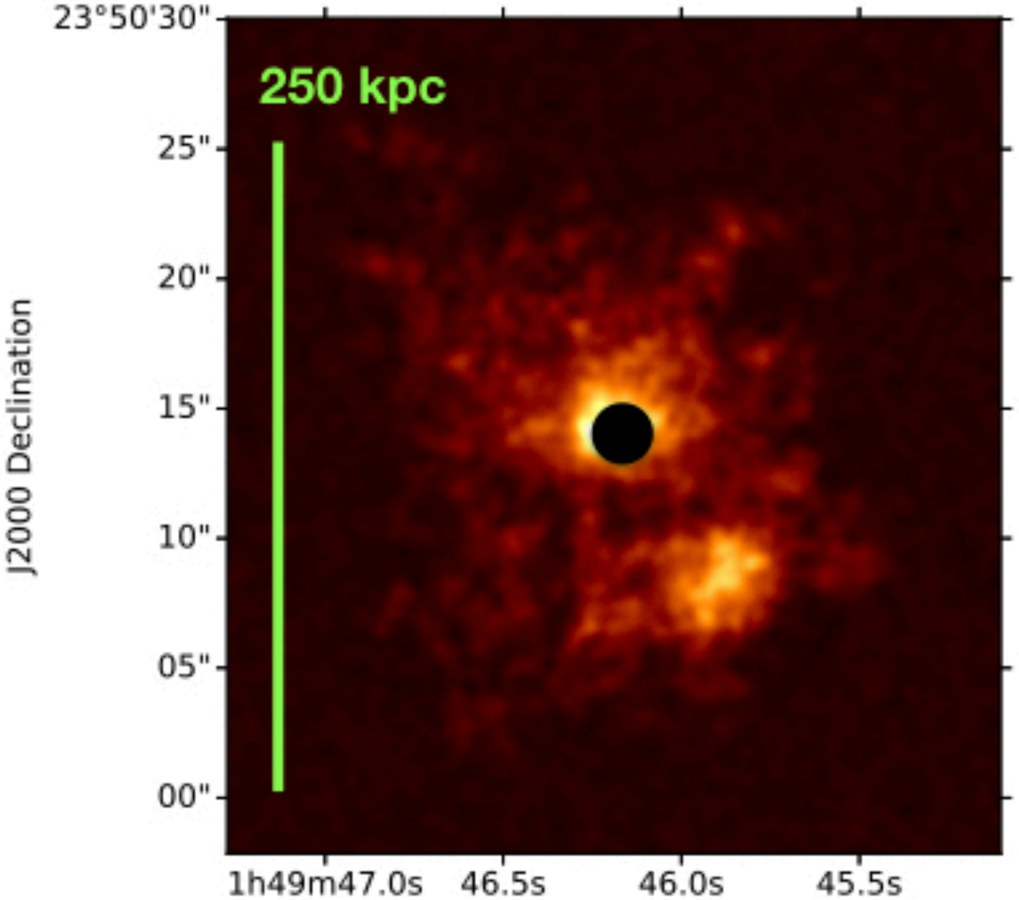
$L_{bol} > 10^{14}\ L_{\odot}$



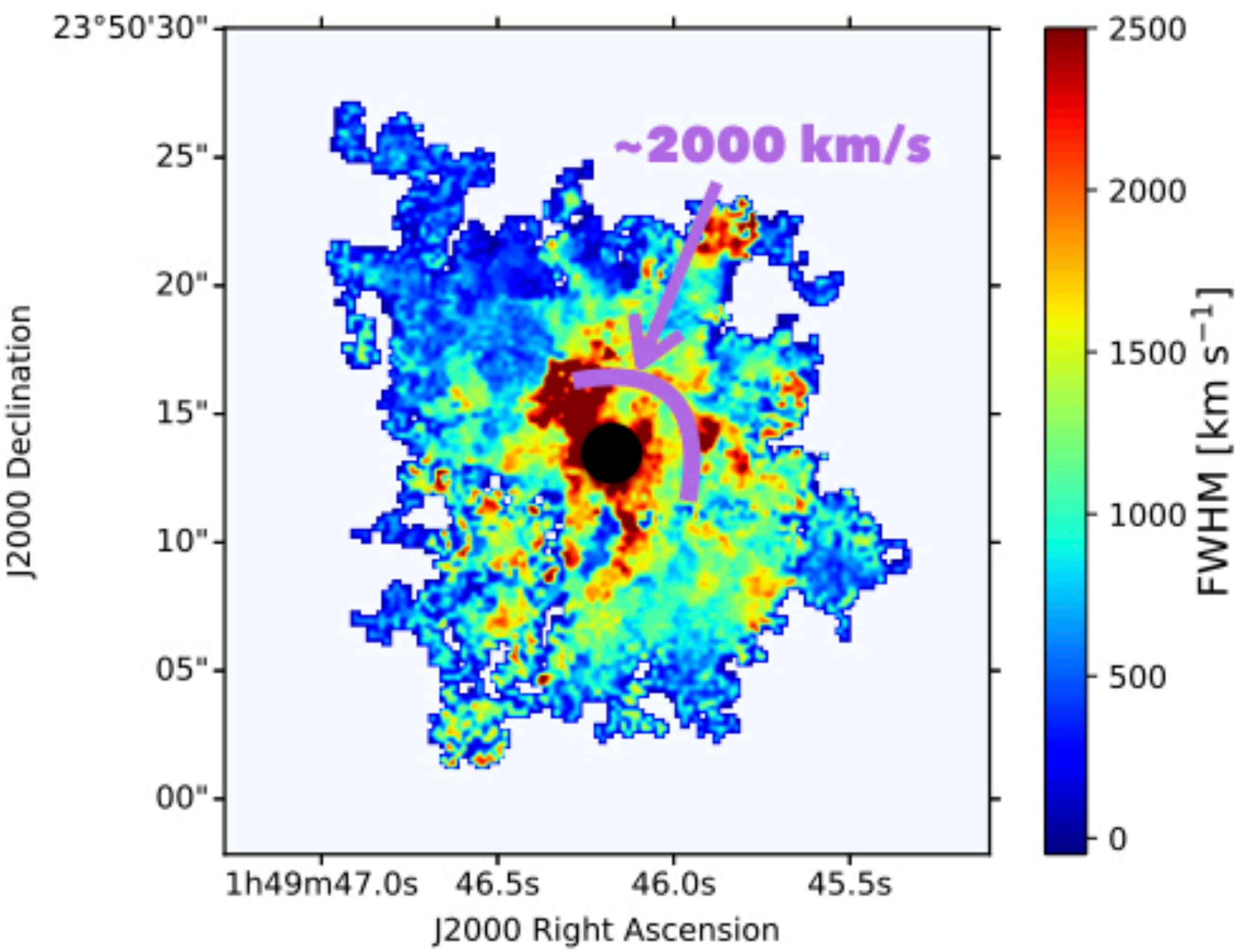


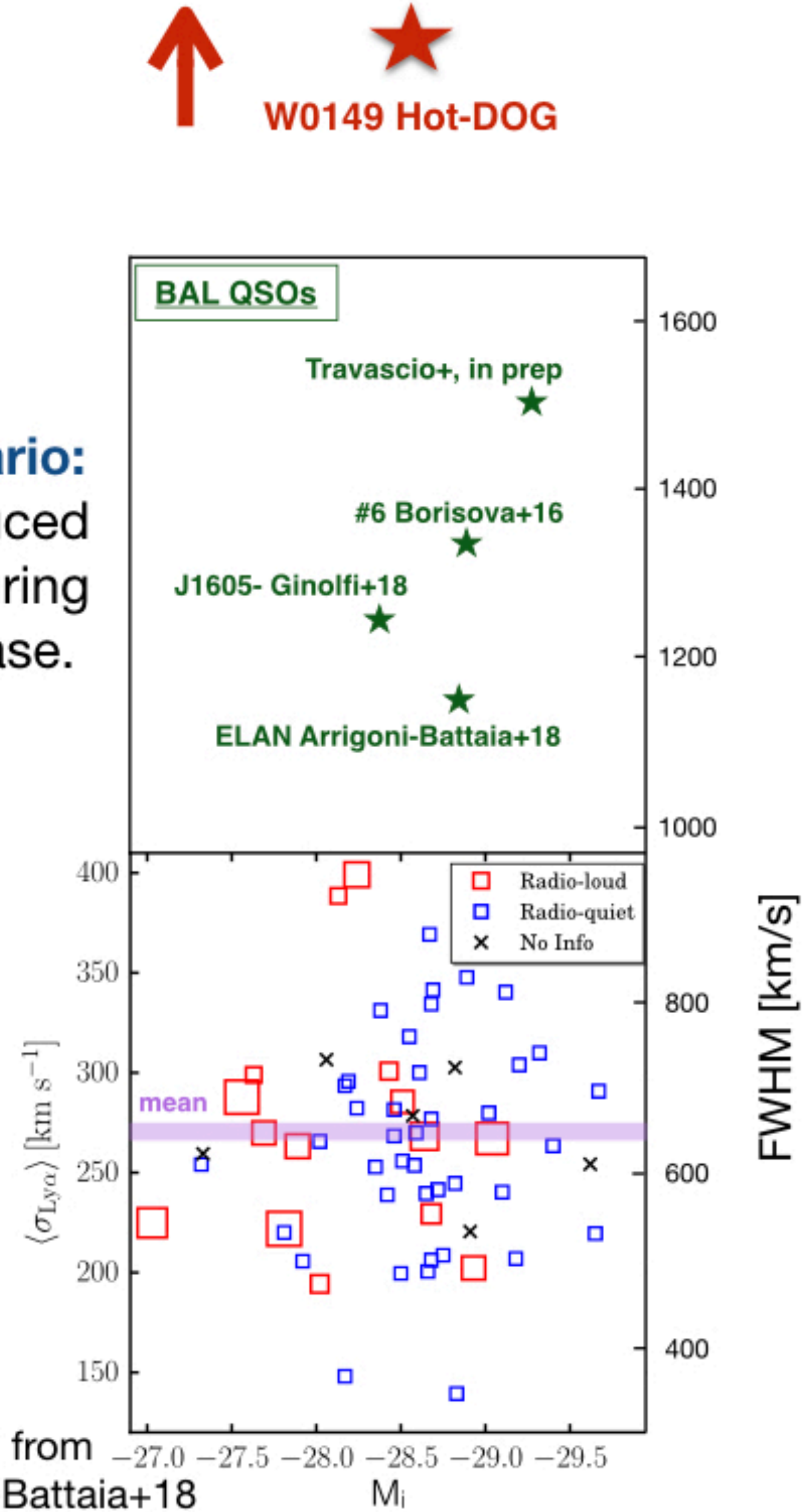




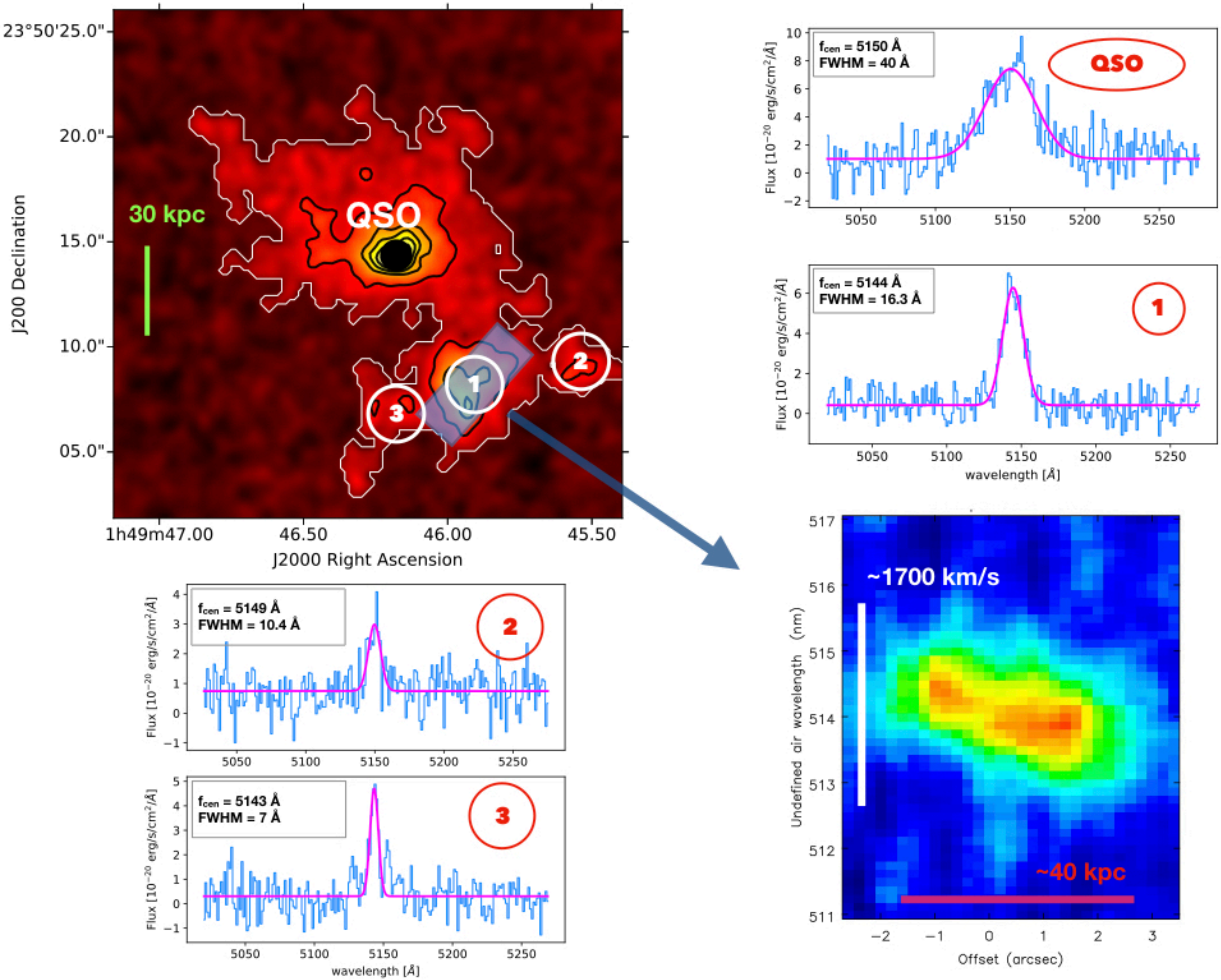


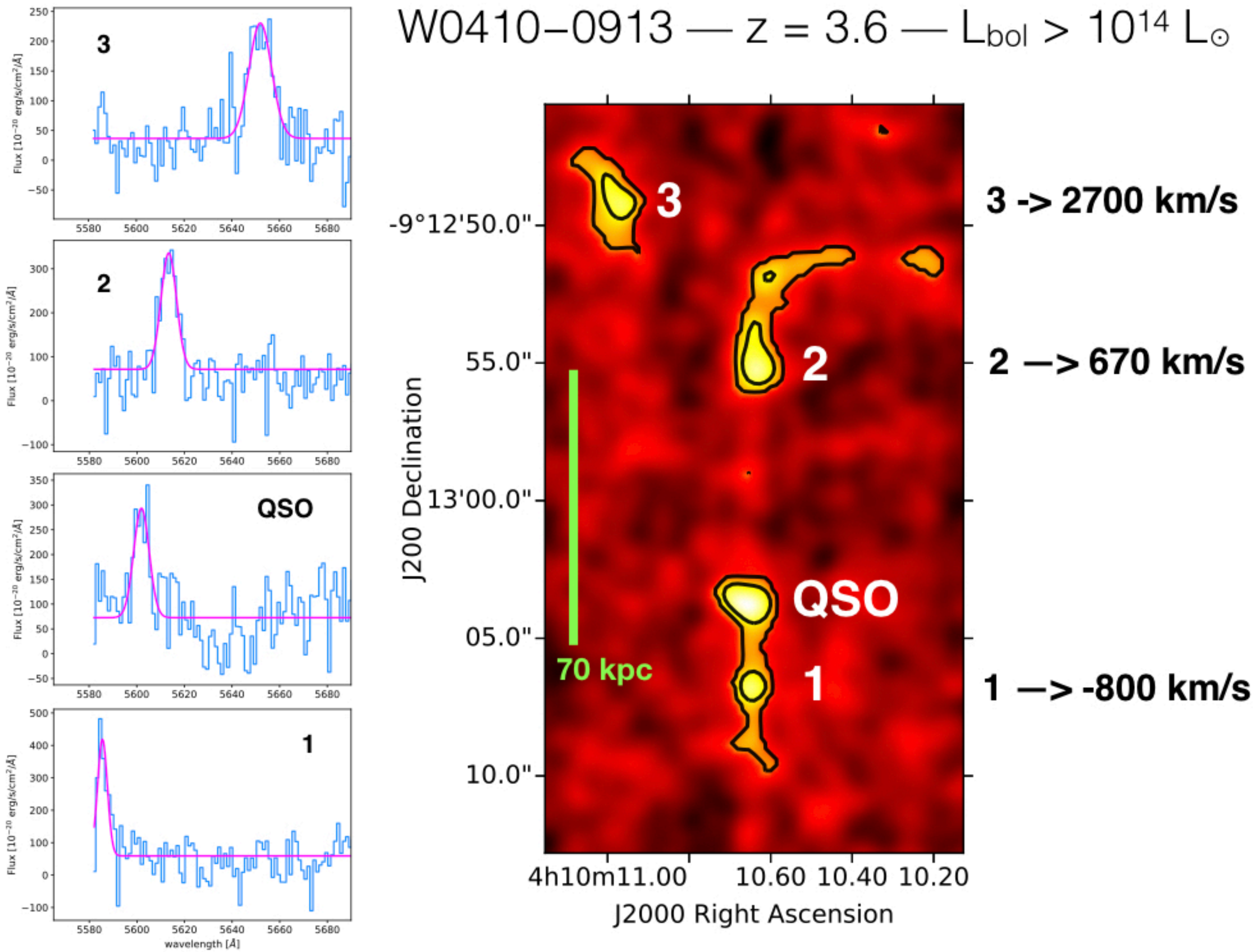
Plausible scenario:
Turbulence induced in the CGM during the blow out phase.





Adapted from
Arrigoni-Battaia+18

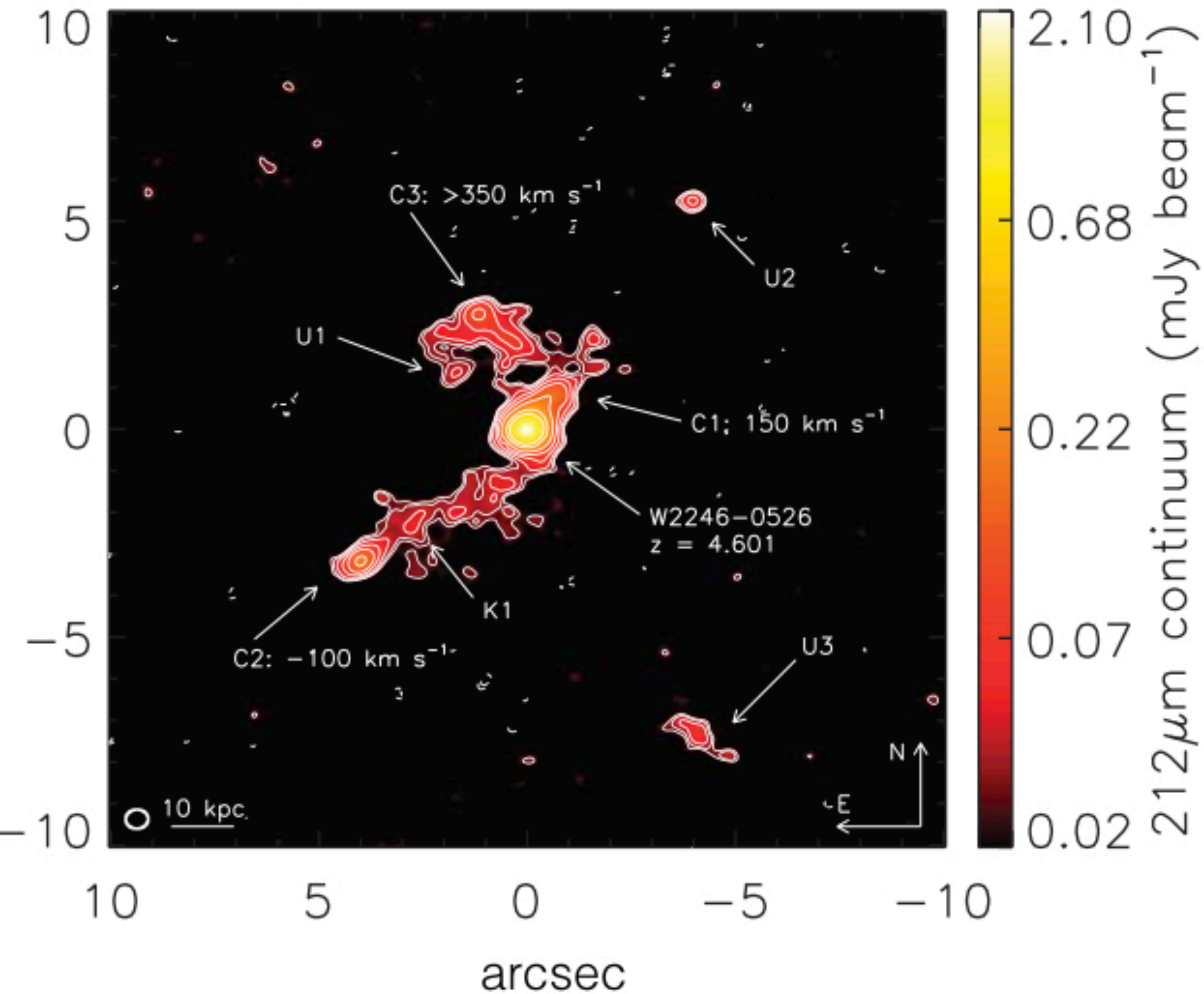

23°50'25.0"
20.0"
15.0"
10.0"
05.0"
J200 Declination
30 kpc
QSO
1
2
3
1h49m47.00
46.50
46.00
45.50
J2000 Right Ascension
f_cen = 5150 Å
FWHM = 40 Å
QSO
Flux [10^-20 erg/s/cm²/Å]
f_cen = 5144 Å
FWHM = 16.3 Å
wavelength [Å]
f_cen = 5149 Å
FWHM = 10.4 Å
f_cen = 5143 Å
FWHM = 7 Å
~1700 km/s
~40 kpc
Undefined air wavelength (nm)
Offset (arcsec)

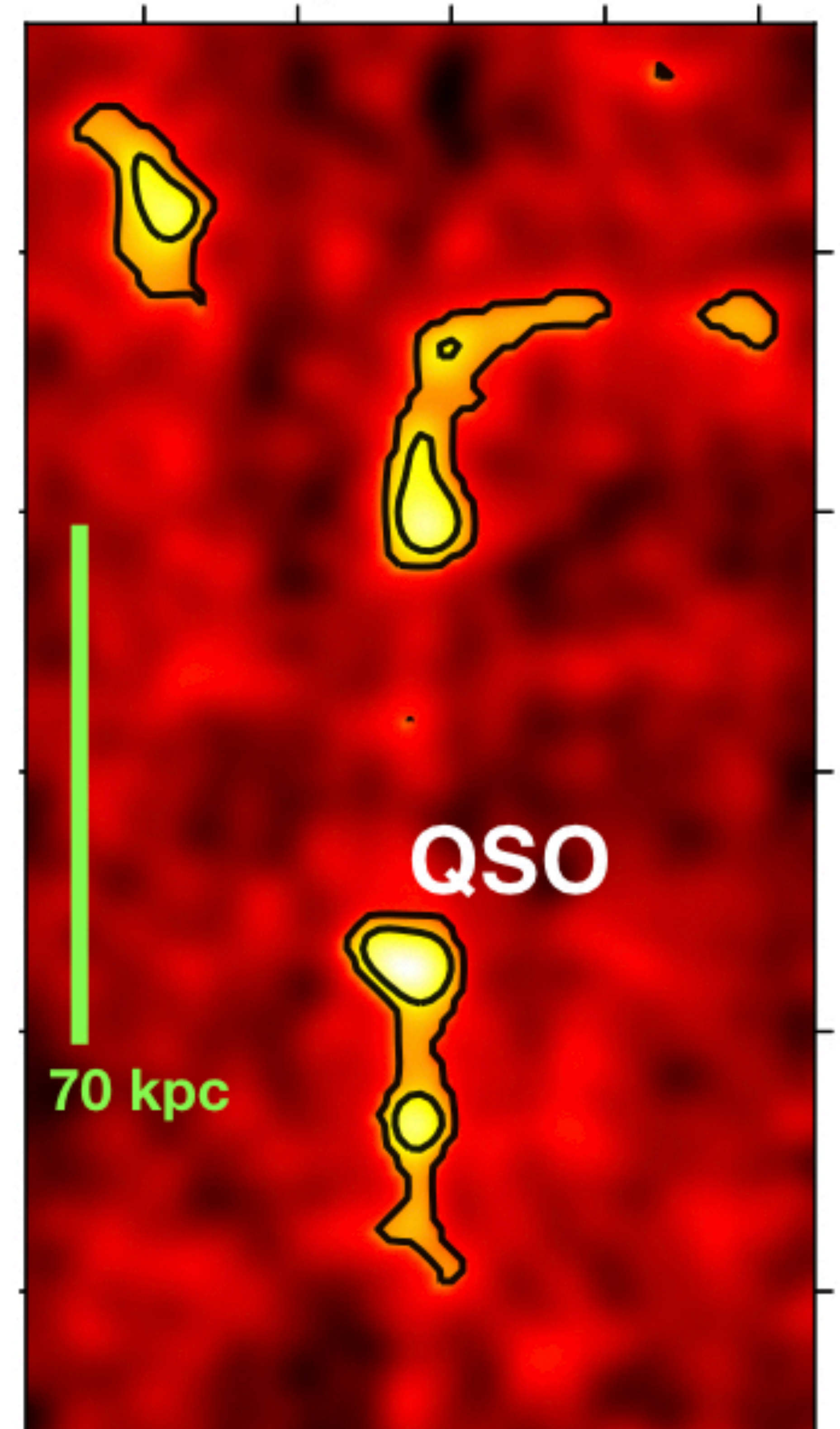

W0410−0913 — z = 3.6 — Lbol > 10^14 L⊙
3
2
QSO
1
Flux [10^−20 erg/s/cm²/Å]
wavelength [Å]
3 -> 2700 km/s
2 —> 670 km/s
1 —> -800 km/s
70 kpc
-9°12'50.0"
55.0"
13'00.0"
05.0"
10.0"
J200 Declination
4h10m11.00
10.60
10.40
10.20
J2000 Right Ascension

W2246–0526
z=4.6
L_{bol} = 3.5 × 10[14] $L_\odot$

Díaz-Santos et al. 2018

W0410–0913
z = 3.6
L_{bol} > 10[14] $L_\odot$





Tidal dusty bridges show that W2246–0526 is accreting its neighbours, suggesting that merger activity may be a dominant mechanism in feeding the growth of Hot-DOGs.

Ginolfi+, in prep

Summary

- MUSE is routinely detecting extended Lya Nebulae around quasars at z>3, extended on circumgalactic scales;
- we find a trend of decreasing size of Lya halos towards higher redshift, suggesting a correlation with the extent of DM haloes/structures around quasars;
- Lya halos can be used to study the impact of AGN-feedback on circumgalactic scales, since powerful outflows can influence their kinematics on scales of (at least) tens of kpc around the quasars;
- MUSE observations of the Lya halos surrounding hyper-luminous Hot-DOGs indicate that the growth of these *monster* is triggered by mergers with close companions in ultra-dense environments.