Observing the cold gas surrounding AGN-host galaxies with MUSE

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Collaborators:

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Ginolfi et al. 2018, MNRAS, 476, 2421

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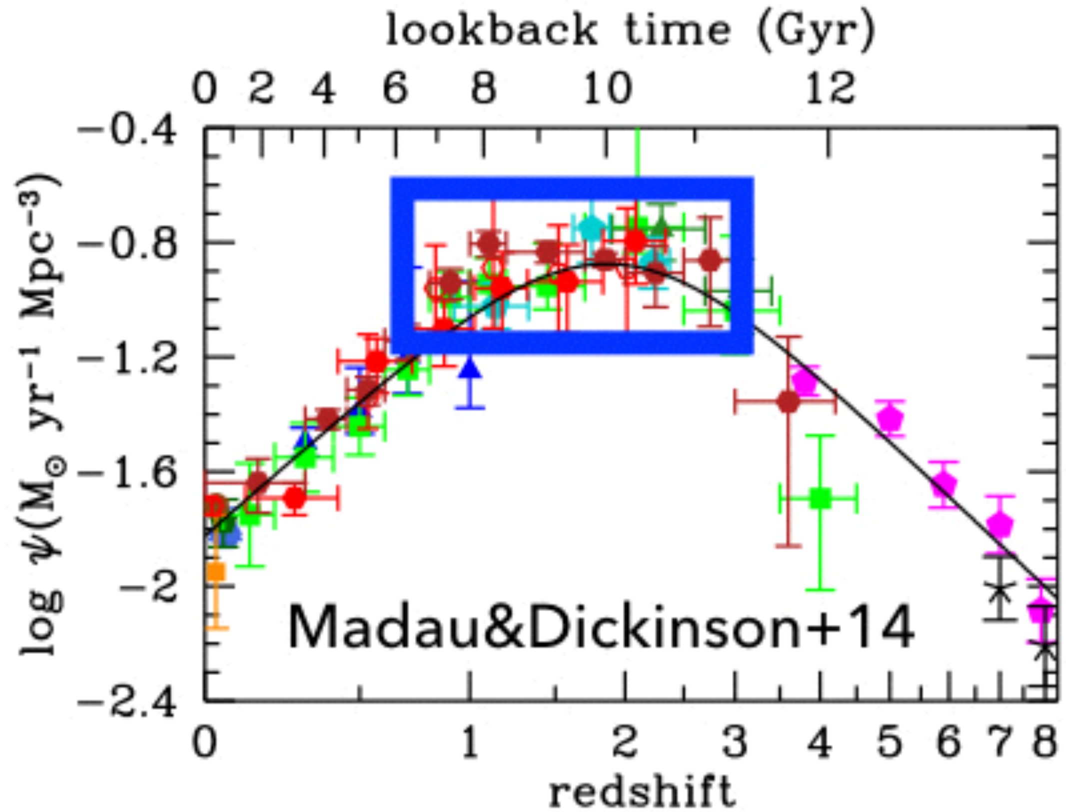
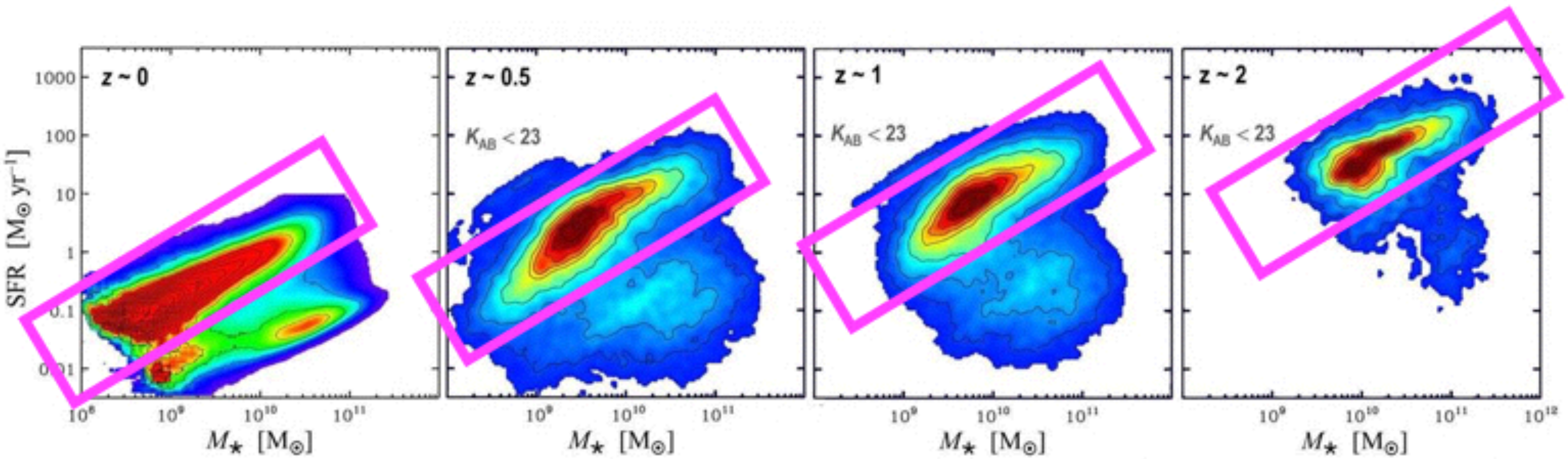
mic_sundance



Why should we care about the CGM?

SFR ~ 10^2 - 10^3 $M_\odot yr^{-1}$

t_{depl} ~ 1 Gyr << $t_H(z)$

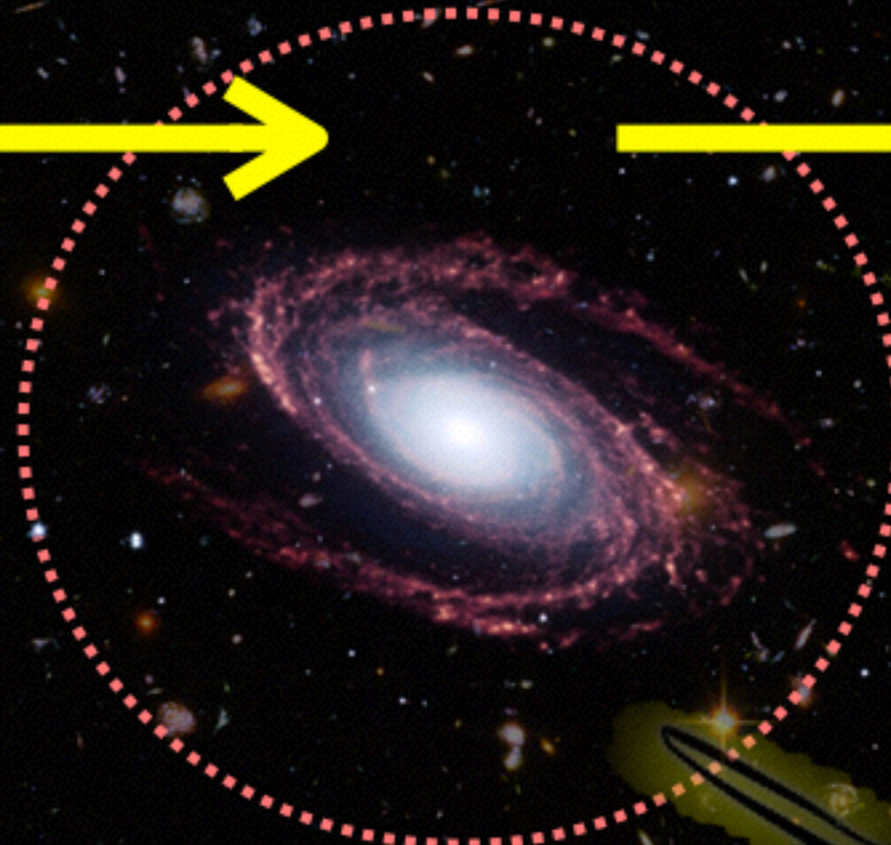


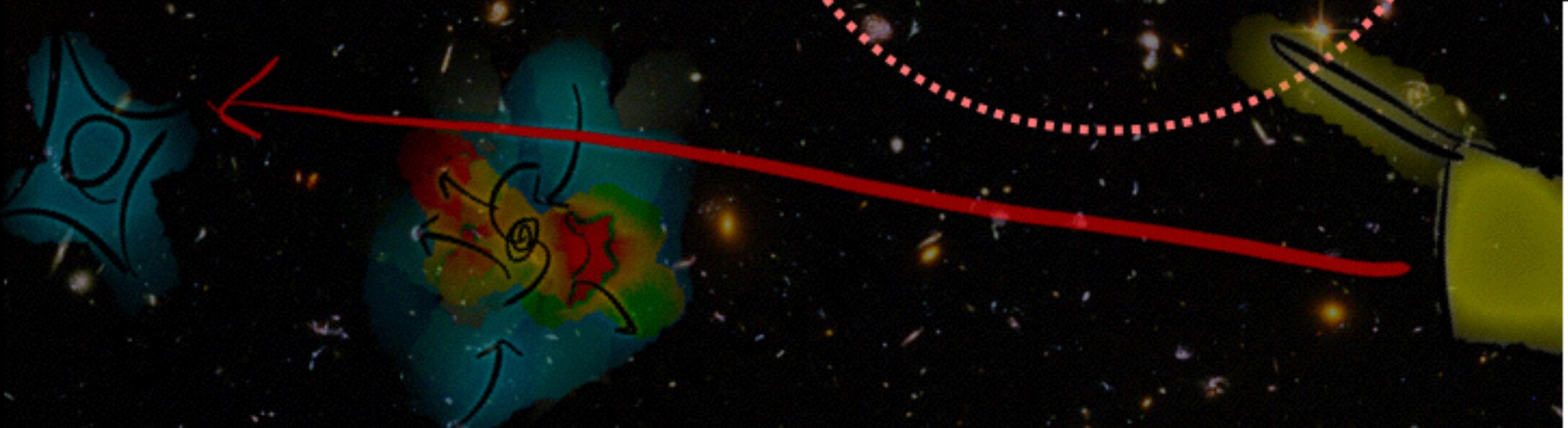
Renzini & Peng +15

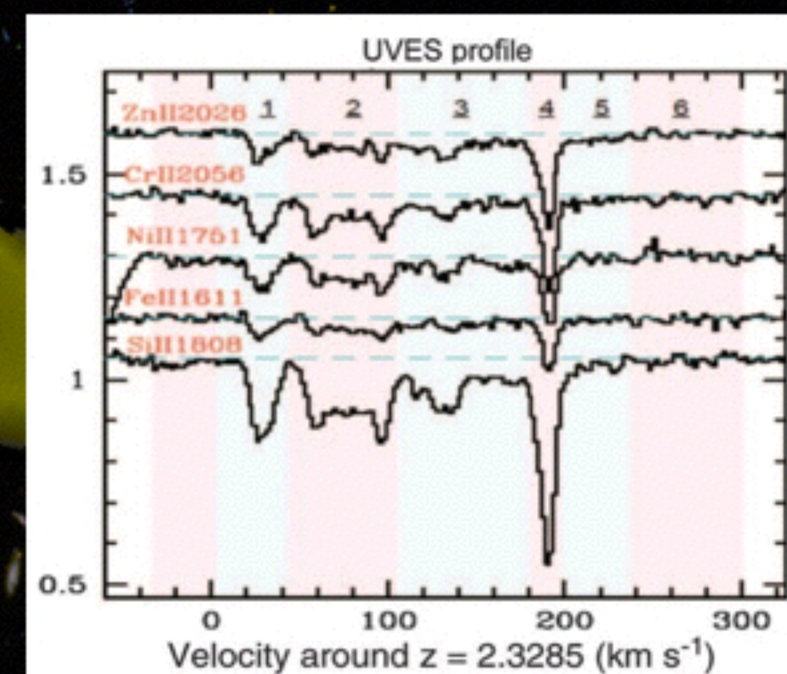
Additional gas reservoir is needed to fuel star formation; continuous replenishment of gas required… **an huge reservoir of gas is available from the CGM/IGM!!!**

Leroy+08; Sancisi+08; Cresci+09,10; Genzel+10; Tacconi+13; Saintonge+13; Schinnerer+16; Ginolfi+17; 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; Bluck+14; Tacchella+15a,b; Daddi+15; Scoville+17…

- Observing the circumgalactic medium







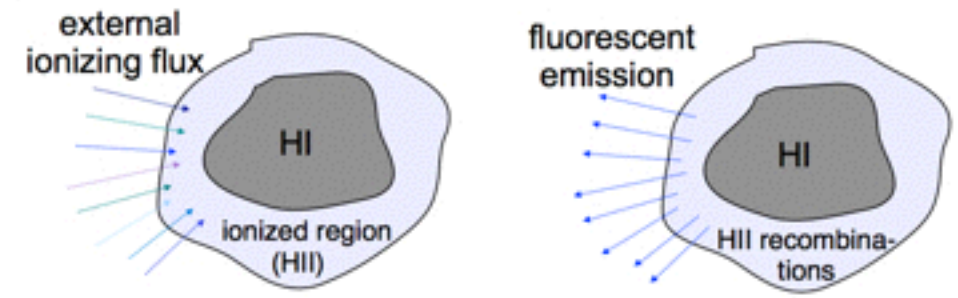
Bouche+13

See papers from the "Quasar Probing Quasar Survey"!

Hennawi+06; Prochaska & Hennawi 09; Bouche+12,13,16; Goerdt +12; Hennawi & Prochaska 13; Farina+13; Prochaska+13,14,15,17; Fumagalli+16, 17; Lau +16,17; Péroux +17…..

• Observing the circumgalactic medium

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)*.

At z~3, the intensity of the diffuse ionizing background corresponds to a Lya surface brightness of 10^{-20} erg cm^{-2} s^{-1} $arcsec^{-2}$

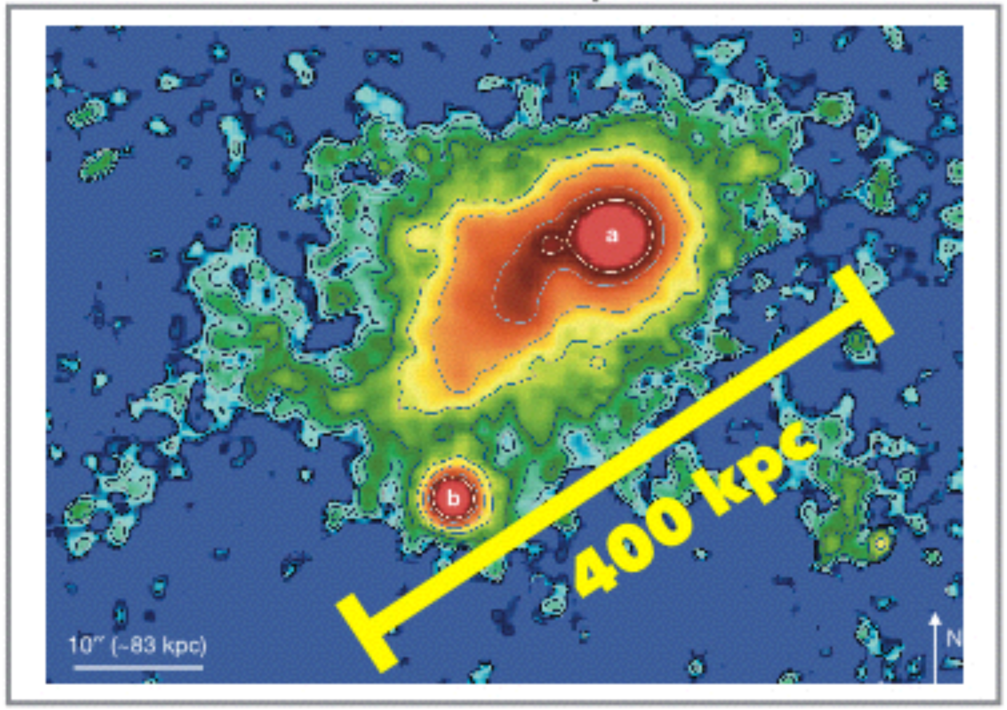
Fluorescence is boosted up into the detectable regime in the vicinity of bright ionizing sources, as luminous QSOs!

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…

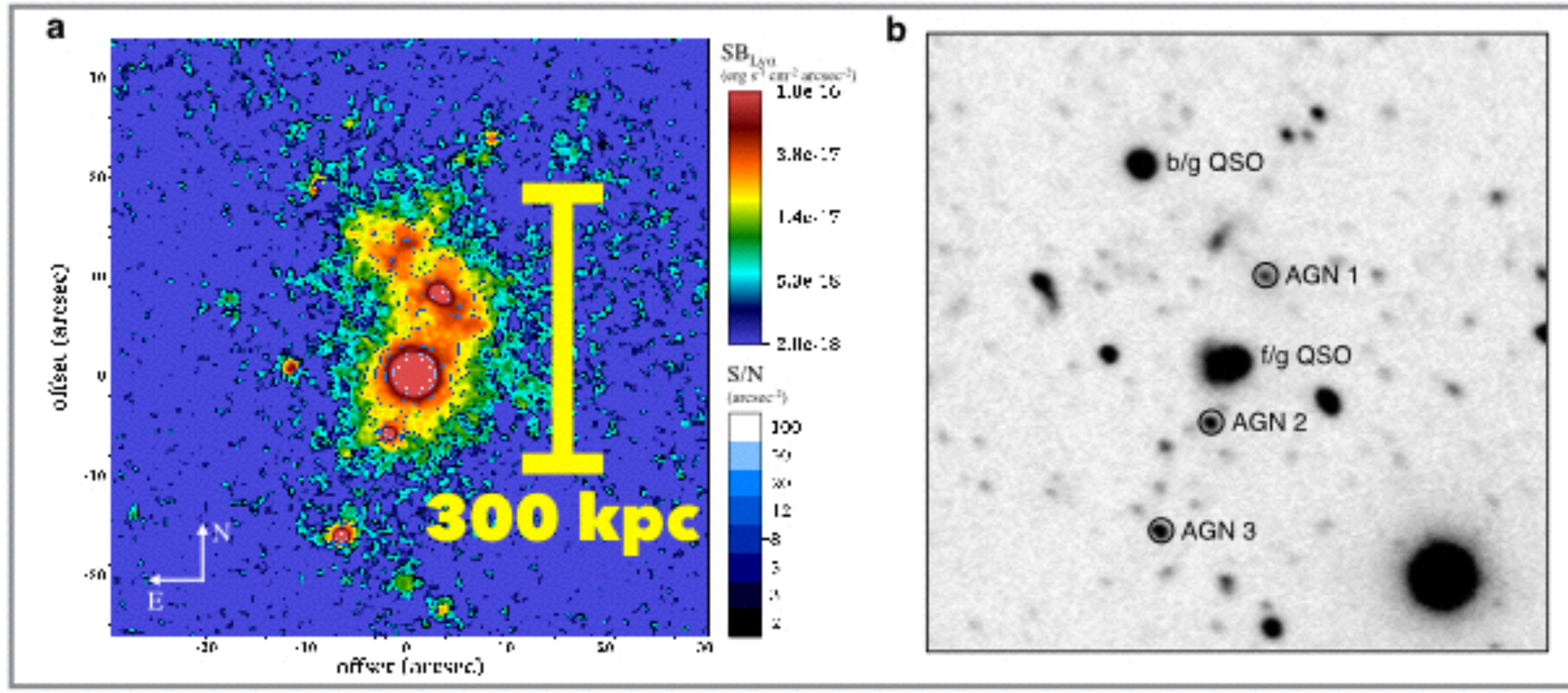
• Observing the CGM surrounding AGN-host galaxies

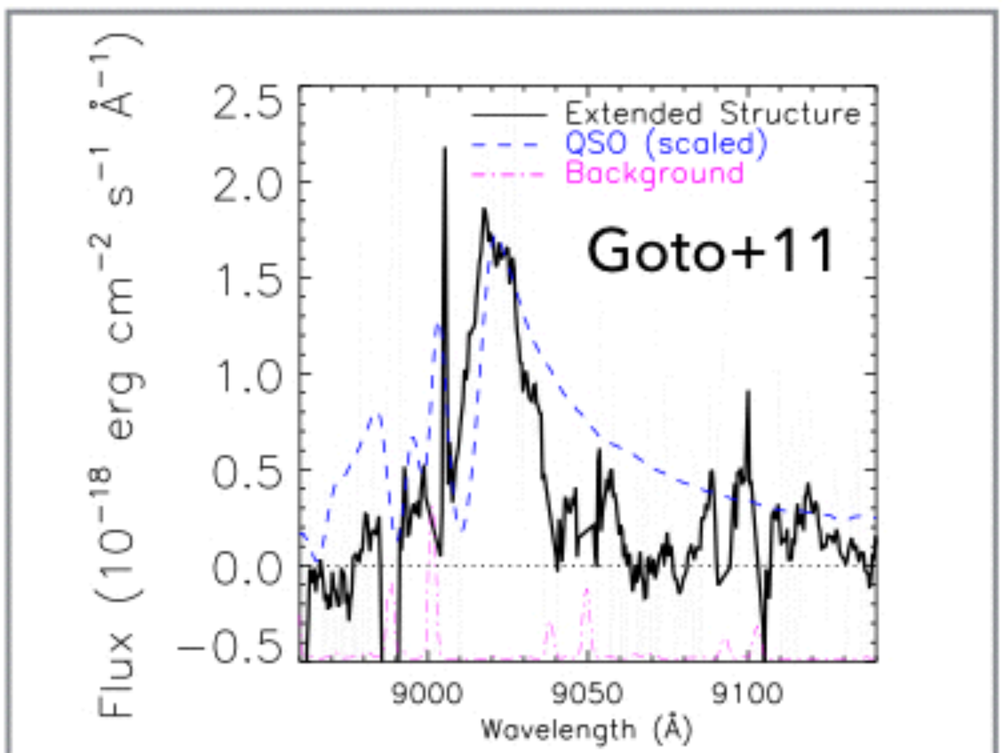
techniques: **narrow-band filters** on 8-m optical telescopes and **long-slit spectroscopy**

Cantalupo+14, Nature



Hennawi+15, Science





- **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

NB filters / long-slits

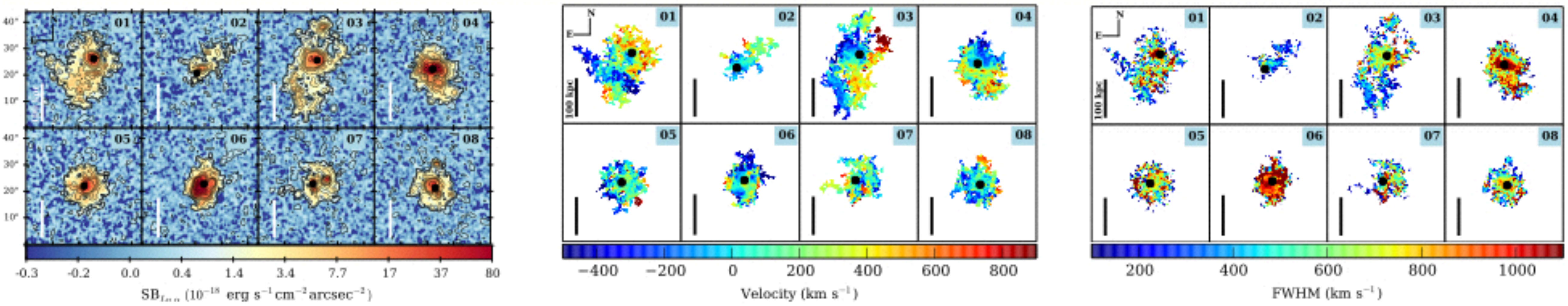
- NB filter / spectroscopic slit losses;
- point spread function (PSF) losses;
- dilution of the signal of the Lya line into the continuum flux (both background and from the host galaxy) encompassed by the width of the filter.
- small uncertainties in the QSO systemic redshift can mess everything up.

MUSE

multi unit spectroscopic explorer

- high sensitivity; (SB limit ~10^{-18} erg/s/cm^2/arcsec^2 for a 1 arcsec^2 , in 1 h)
- no filter/slit losses by design;
- IFS provides us images of the QSO and its surrounding at different wavelengths, including spectral regions where no extended line emission is expected, thus allowing for a careful PSF modelling;
- large FOV (1"x1"), ideal to to search for giant Lya Nebulae;
- any QSO with Lya redshifted between the blue and red edges of the MUSE wavelength range ($2.9 < z < 6.5$) can be observed, without need of ultra-precise systemic redshift.

- Observing the surrounding of QSOs with MUSE



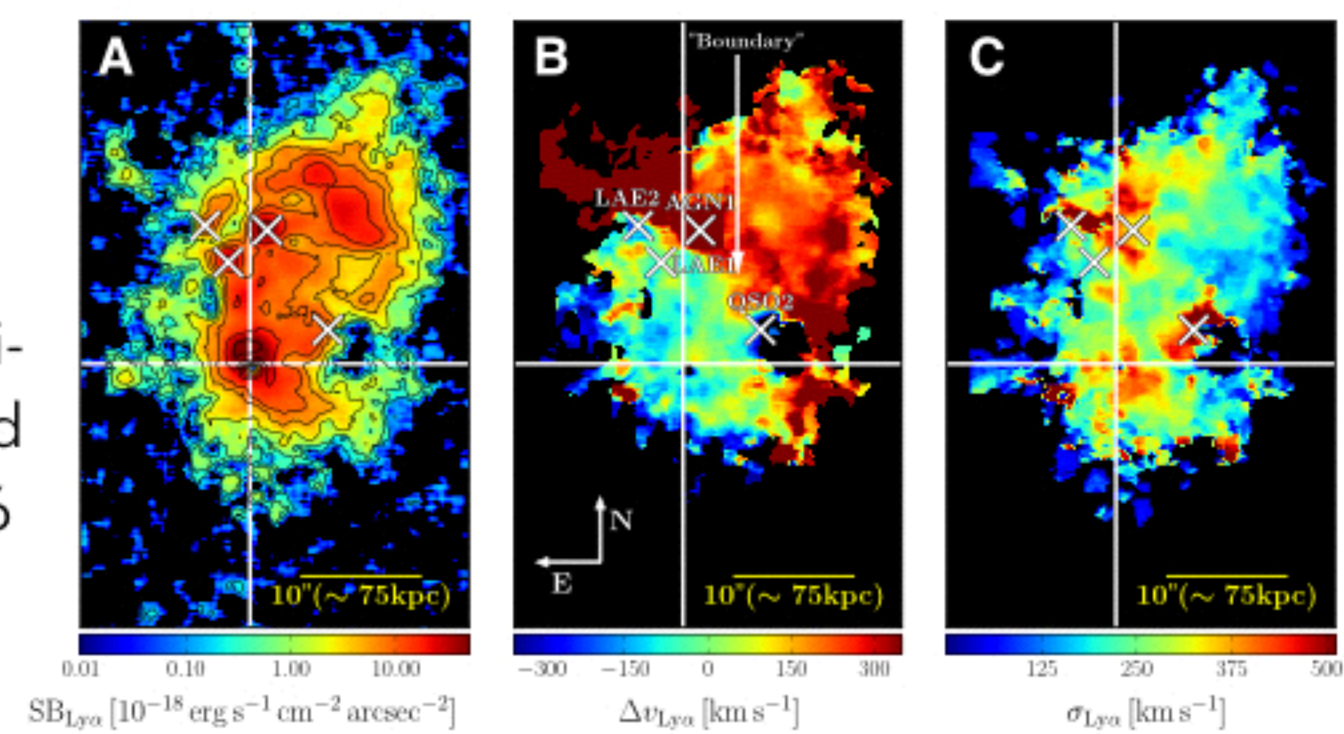
They find giant Lya nebulae with projected linear sizes **larger than 100 kpc** and (extending up to 320 pkpc) around 17 bright radio-quiet quasars at $3 < z < 4$ **(detection rate 100%).**

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

Borisova +16

Arrigoni-Battaia +17

Nebula around the quasar SDSS J1020+1040, part of the survey **QSO MUSEUM** (Arrigoni-Battaia, in prep.); 48 radio-quiet quasars and 11 radio-loud objects spanning $3.03 < z < 3.46$



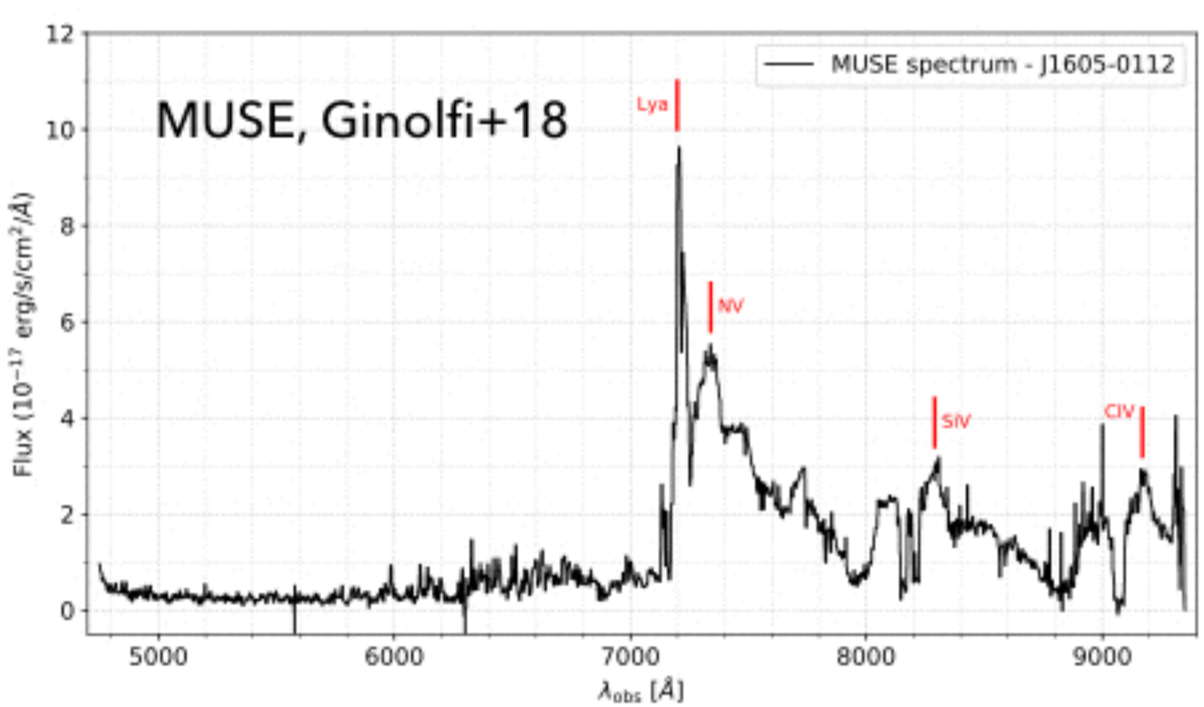
• Observing the surrounding of QSOs with MUSE

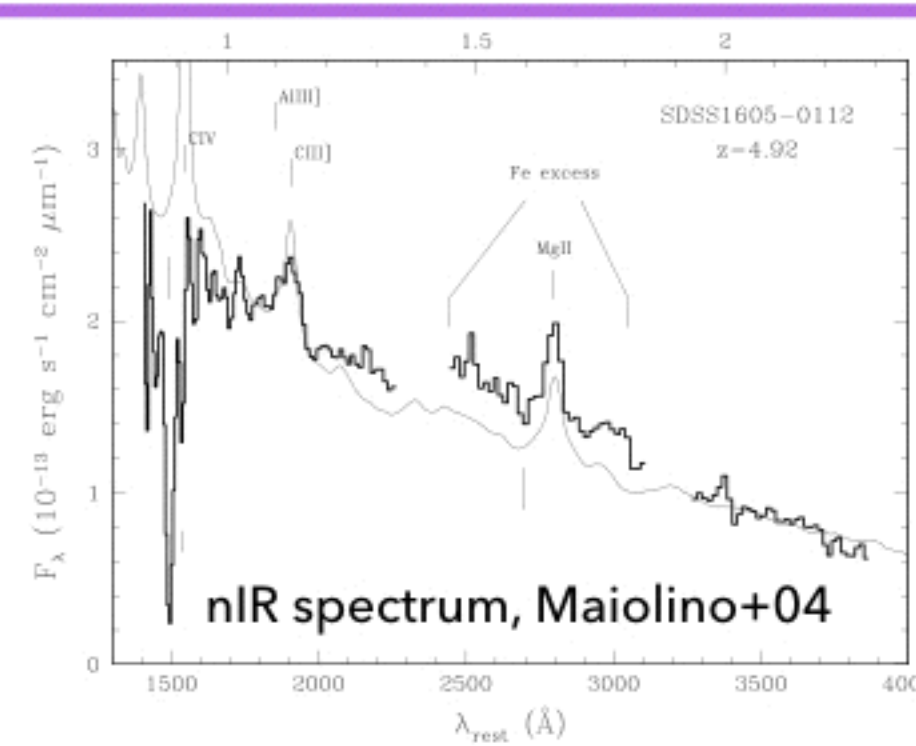
Deep **MUSE** observations of J1605-0112, a Broad Absorption Line **(BAL) QSO** at **z~5**. → We extended the analysis towards higher-z and another class of objects...

Some properties to keep in mind (needed later)

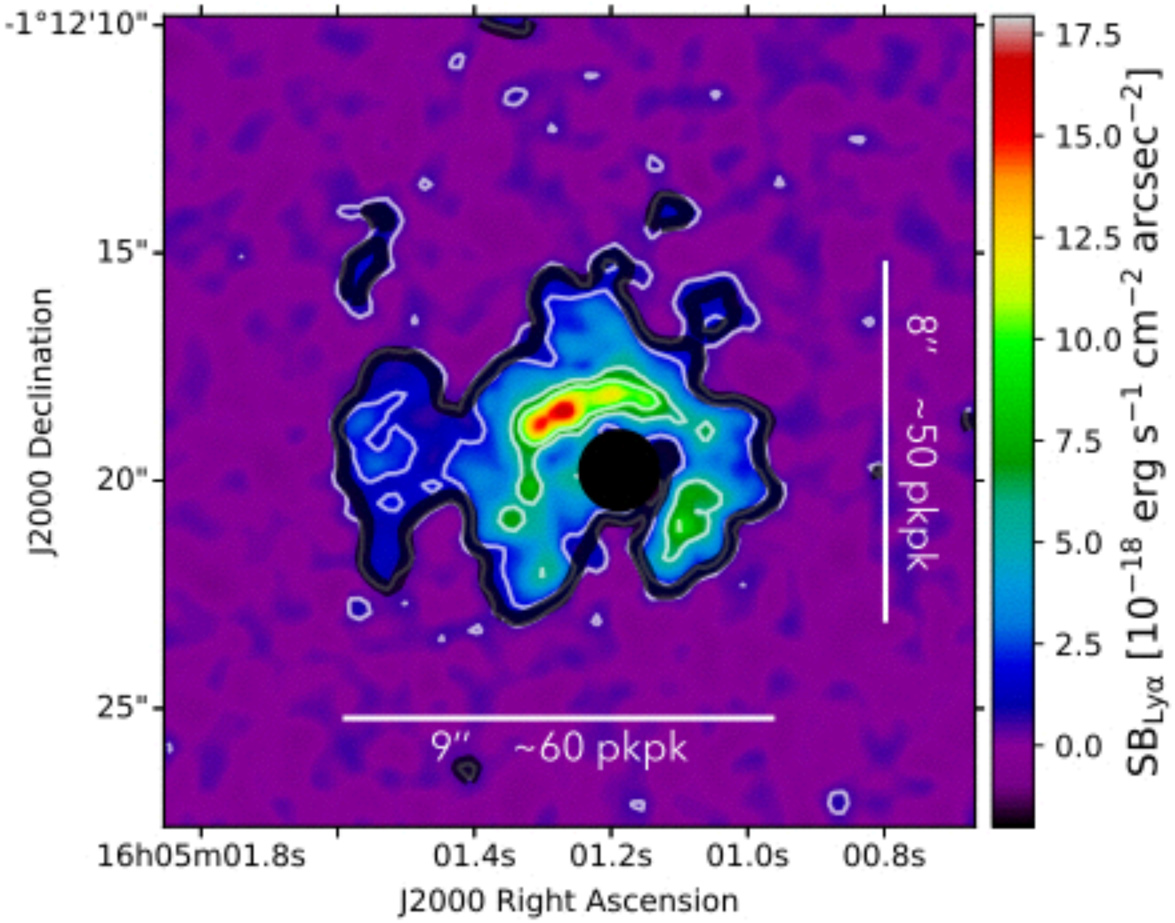
1. J1605-0112 shows an high reddening in the UV rest-frame spectrum (E_{B-V} = 0.03; Maiolino et al. 2004), most likely associated to **high dust column densities** in the circumnuclear regions around the AGN.

2. J1605-0112 shows CIV λ1549 absorption troughs blueshifted by more than 30.000 km/s, tracing **very high velocity outflowing gas** (Maiolino et al. 2004).





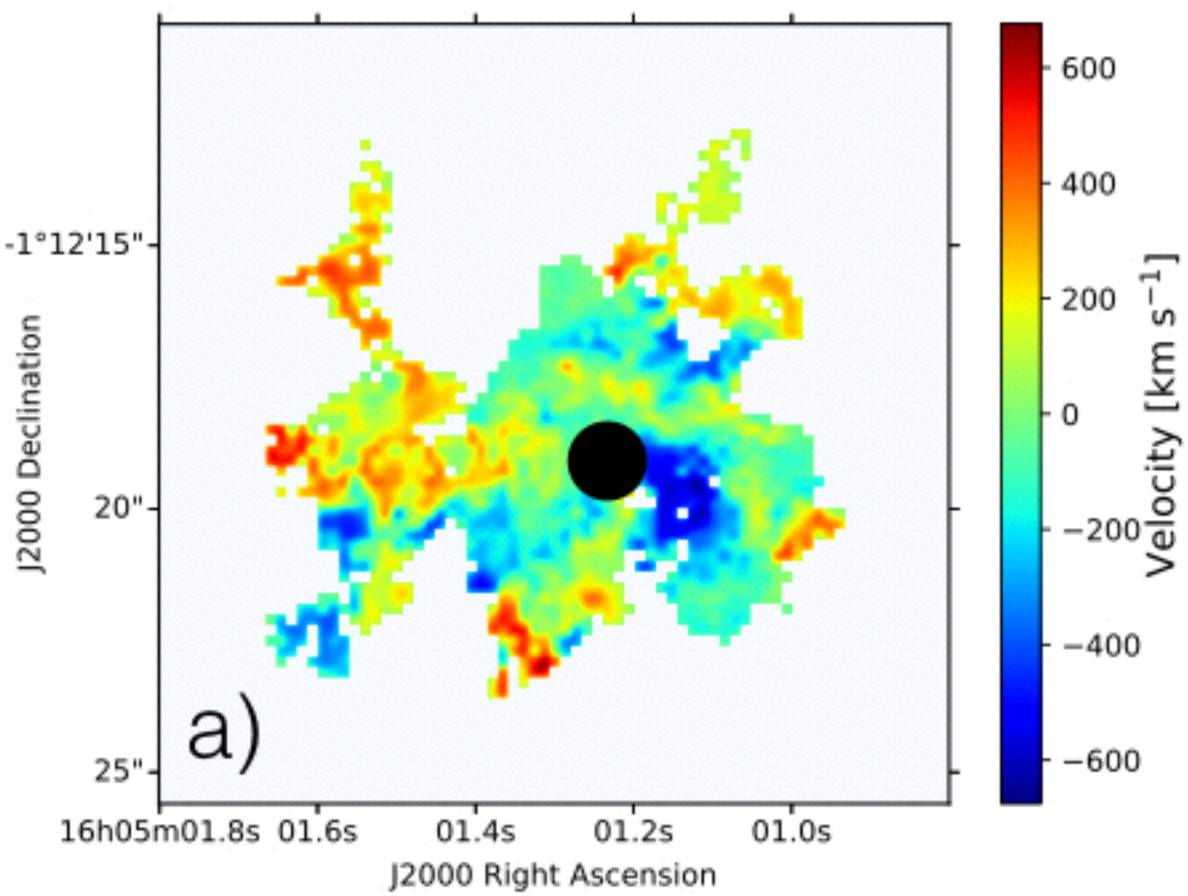
- Observing the surrounding of QSOs with MUSE

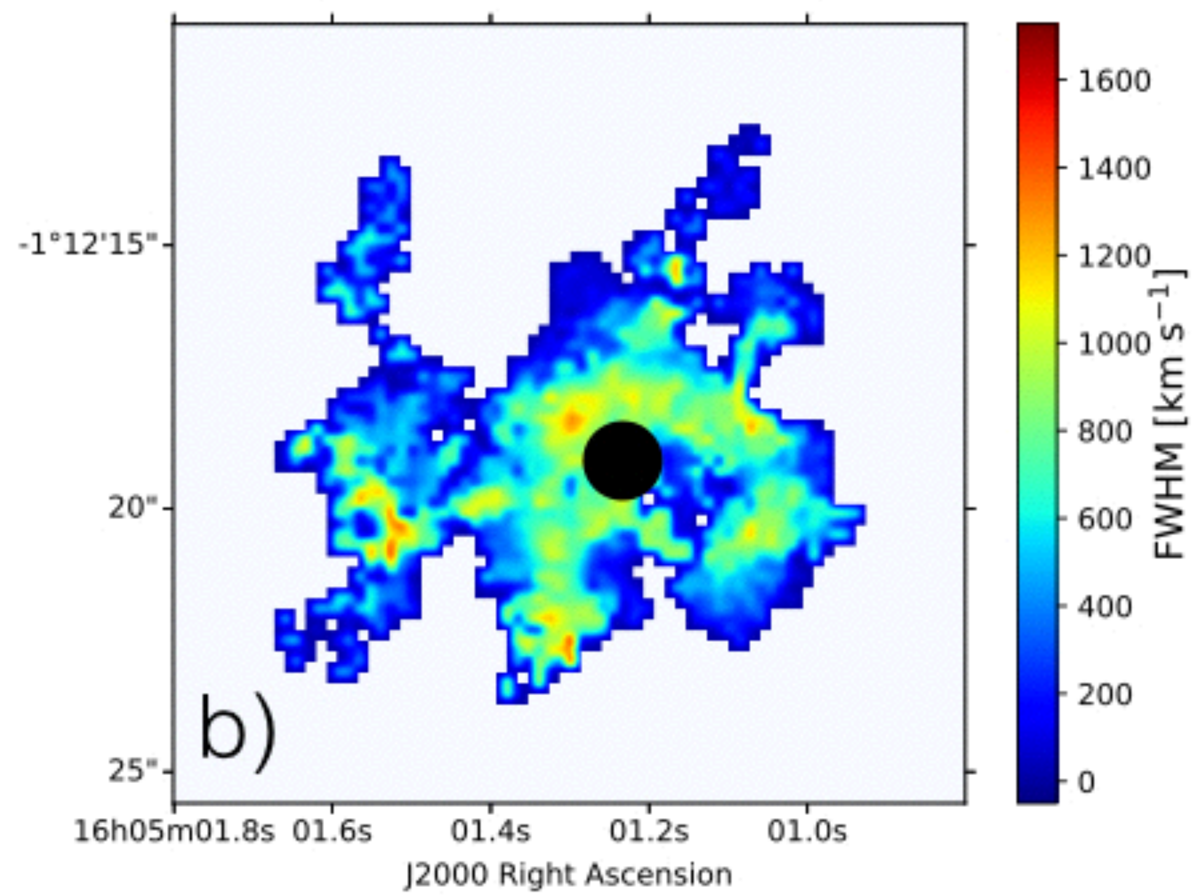


Deep **MUSE** observations of J1605-0112, a Broad Absorption Line (BAL) QSO at **z~5**.

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

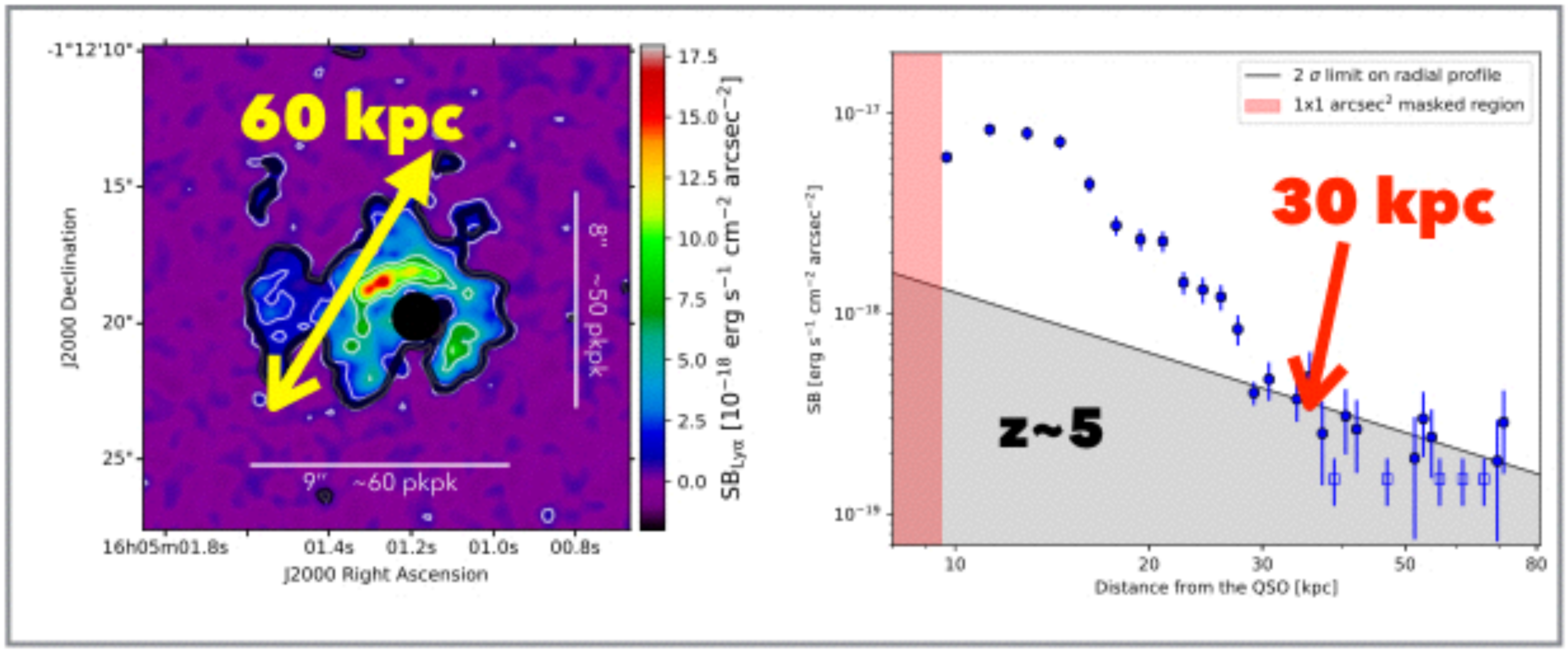
Ginolfi et al. 2018, MNRAS, 476, 2421

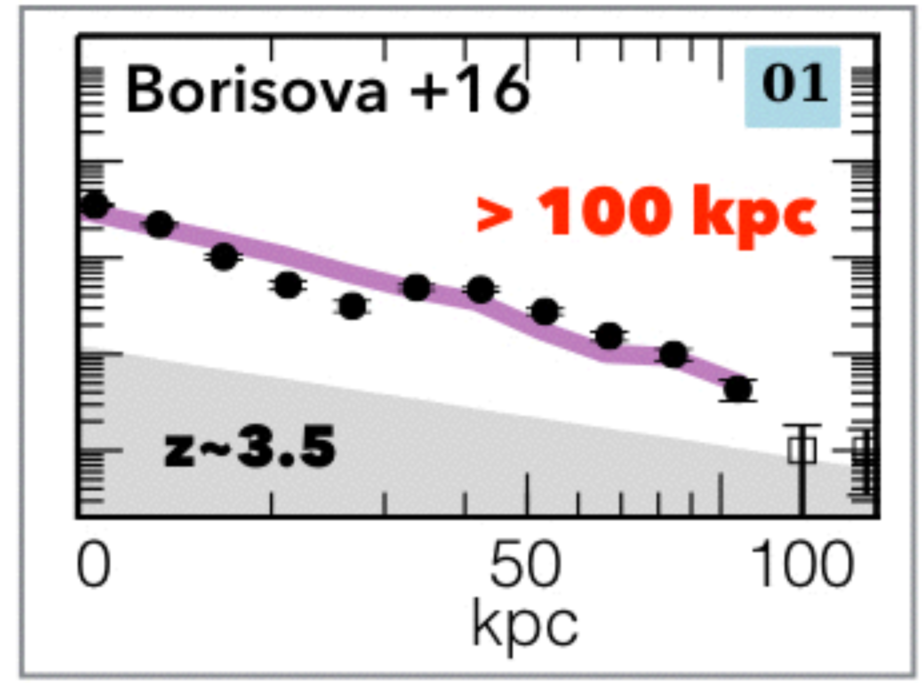


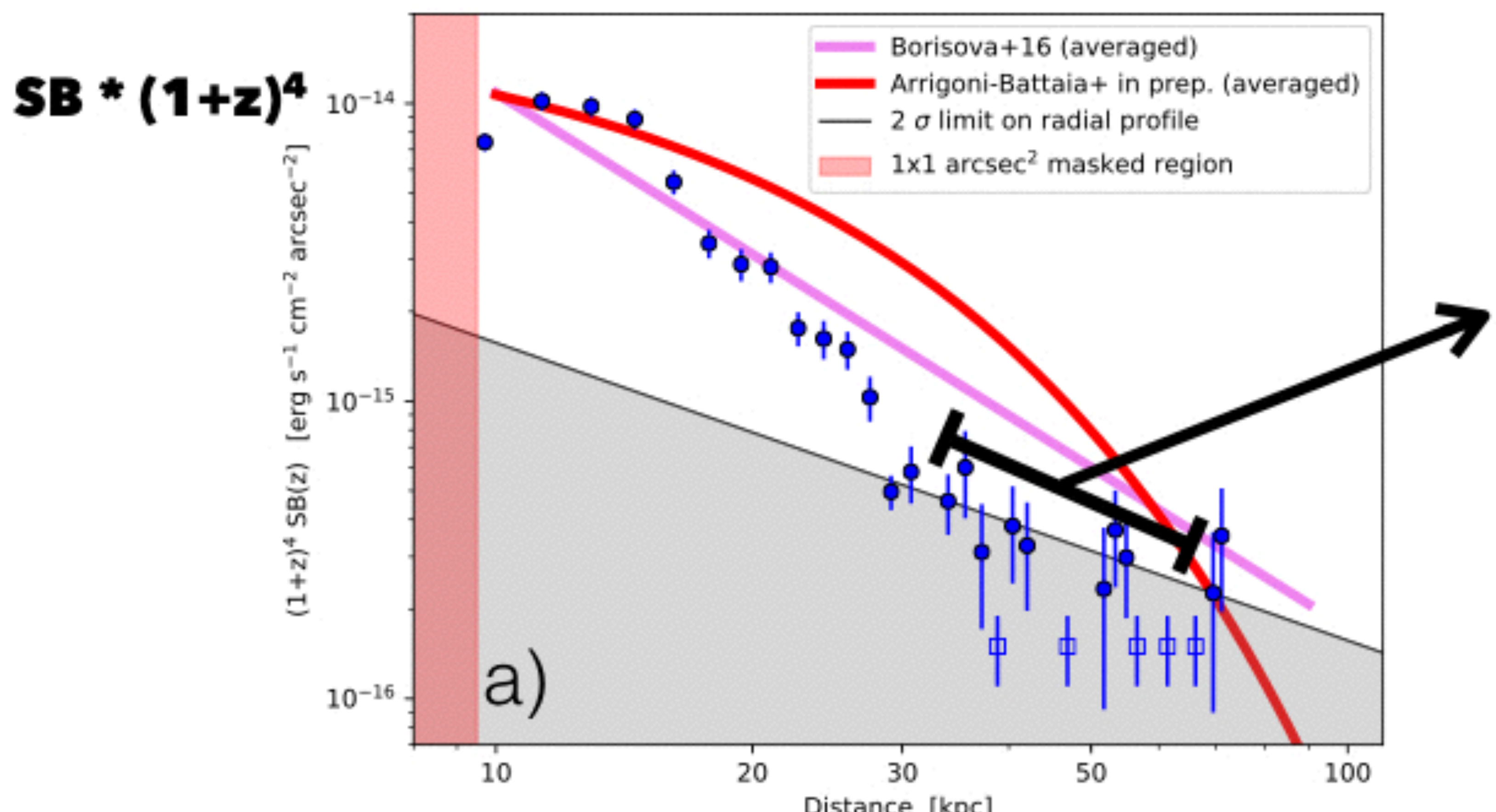


1) Morphology - Size Discrepancy

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).





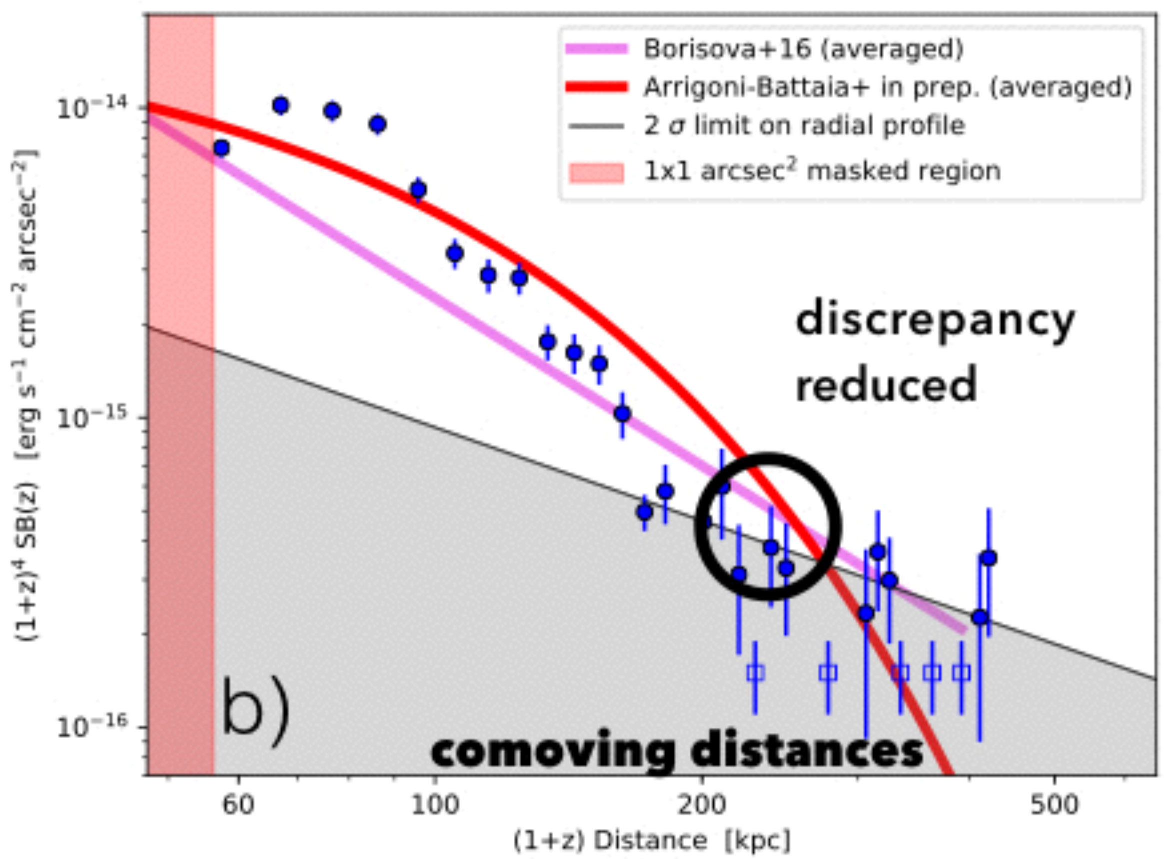


Our Nebula is ***intrinsically*** smaller than lower-z nebulae!

1) Morphology - Size Discrepancy

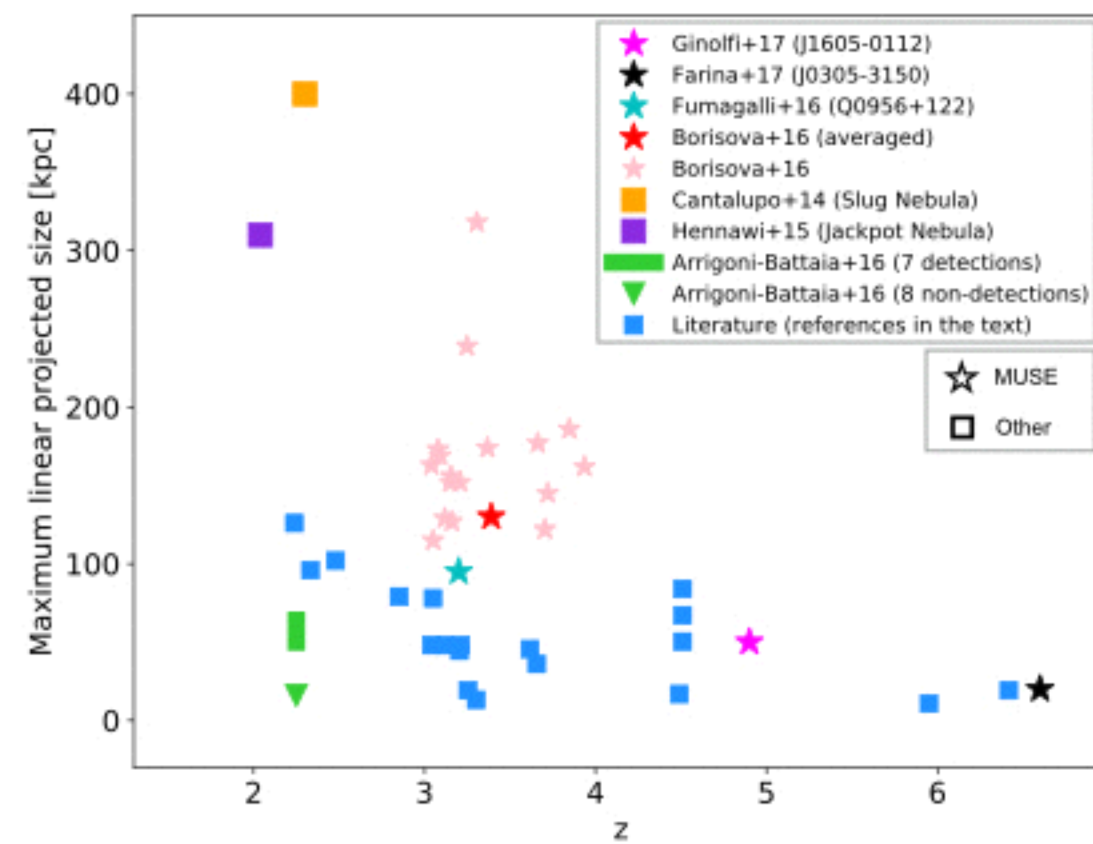
Our Nebula at z~5, has a redshift-corrected, less extended distribution of Lya emission than typical nebulae at lower redshifts (z~3-3.5).

First suggested scenario



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

(Barkana & Loeb 2001)



Ginolfi et al. 2018, MNRAS

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**. This conjecture is supported by a qualitative analysis of other observations of Lya nebulae in a larger redshift range.

1) Morphology - Size Discrepancy

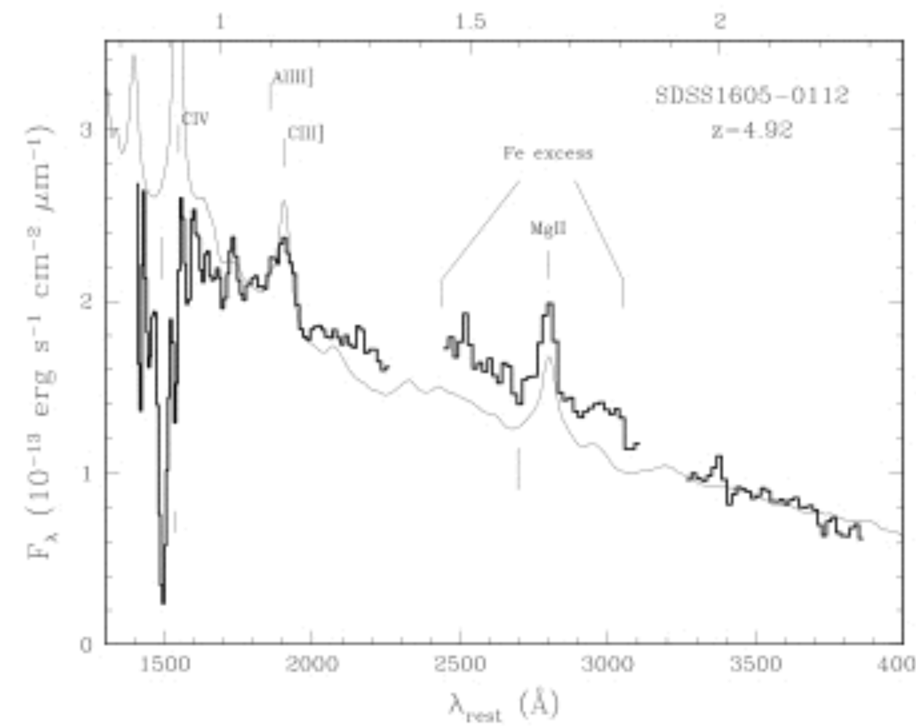
Our Nebula at z~5, has a redshift-corrected, less extended distribution of Lyα emission than typical nebulae at lower redshifts (z~3-3.5).

Second suggested scenario

- J1605-0112 shows an high reddening in the UV rest-frame spectrum, likely associated to **high column densities of dust** in the circumnuclear regions around the AGN.

dust-obscuration can efficiently absorb the AGN-powered UV photons and suppress the escape fraction of the ionizing radiation necessary to induce fluorescence in the neutral circumgalactic gas.

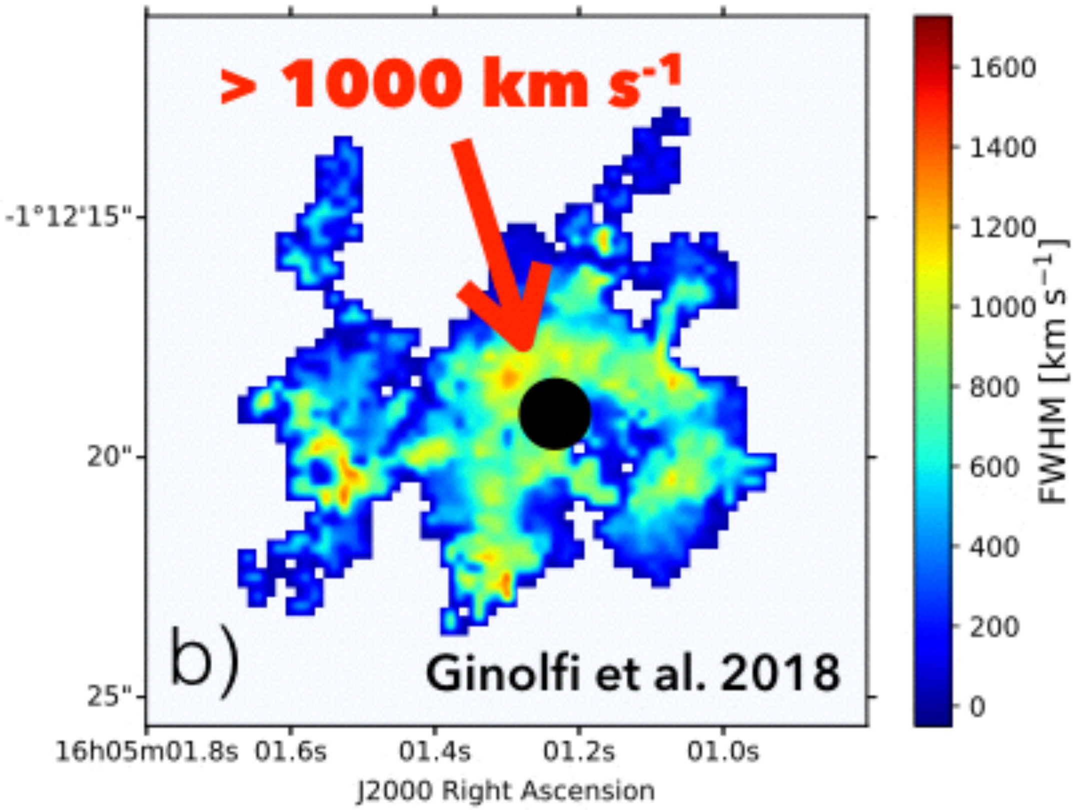
near-IR spectrum, Maiolino+04

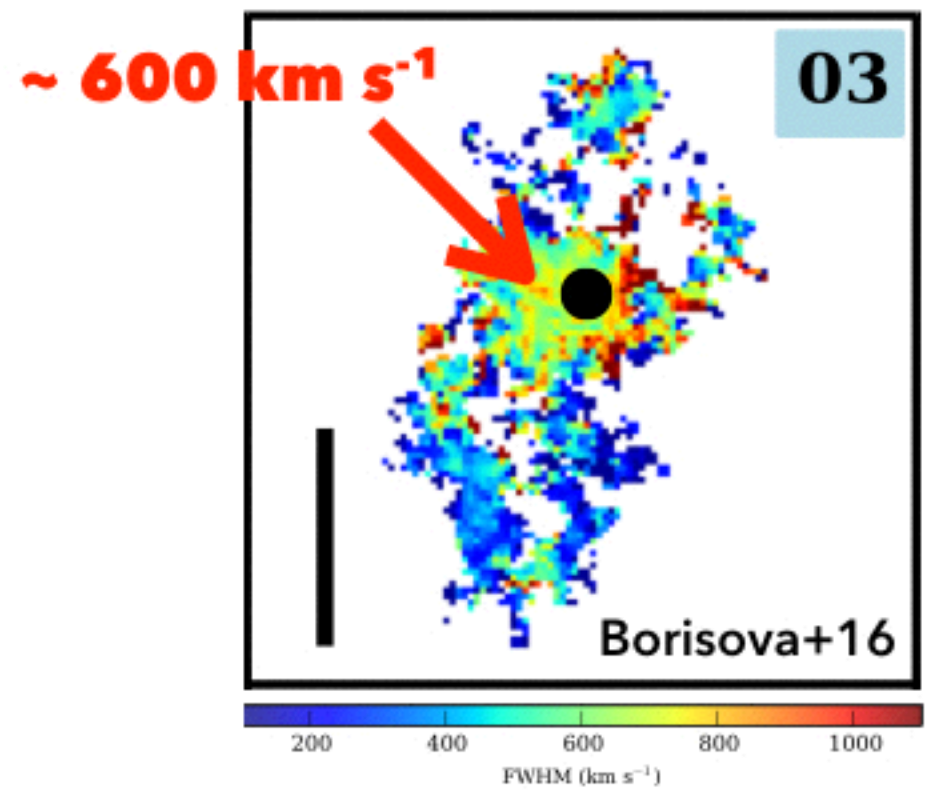


J1605-0112 requires a reddening E_{B-V} = 0.03 of SMC extinction curve in order to match the observed-frame near-IR continuum slope.

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).



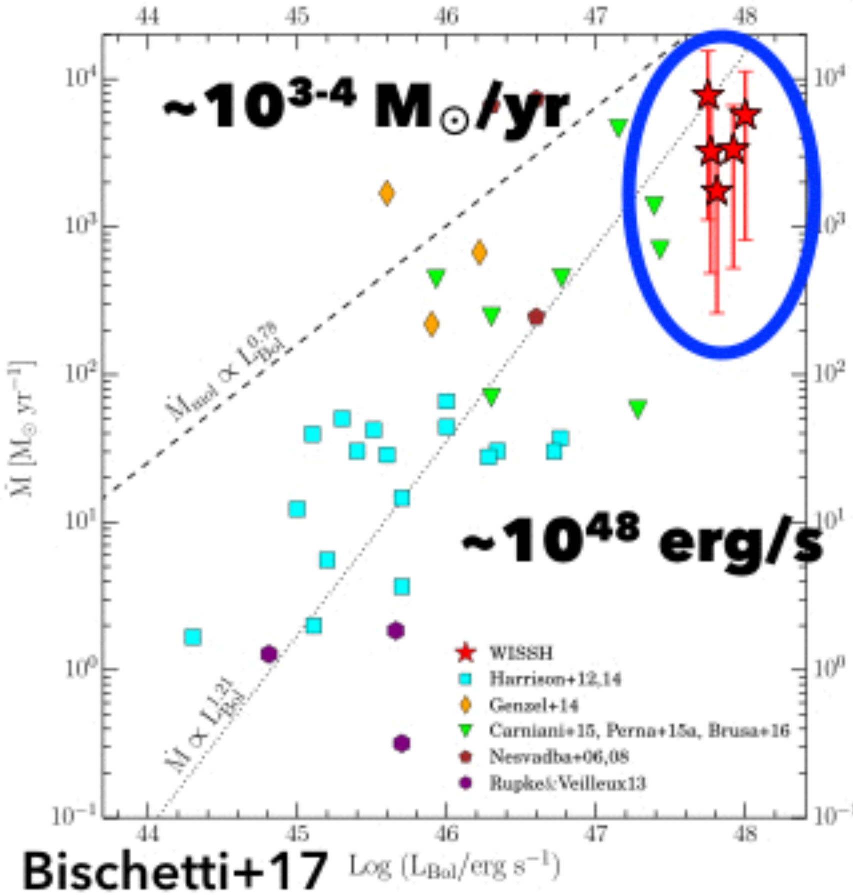


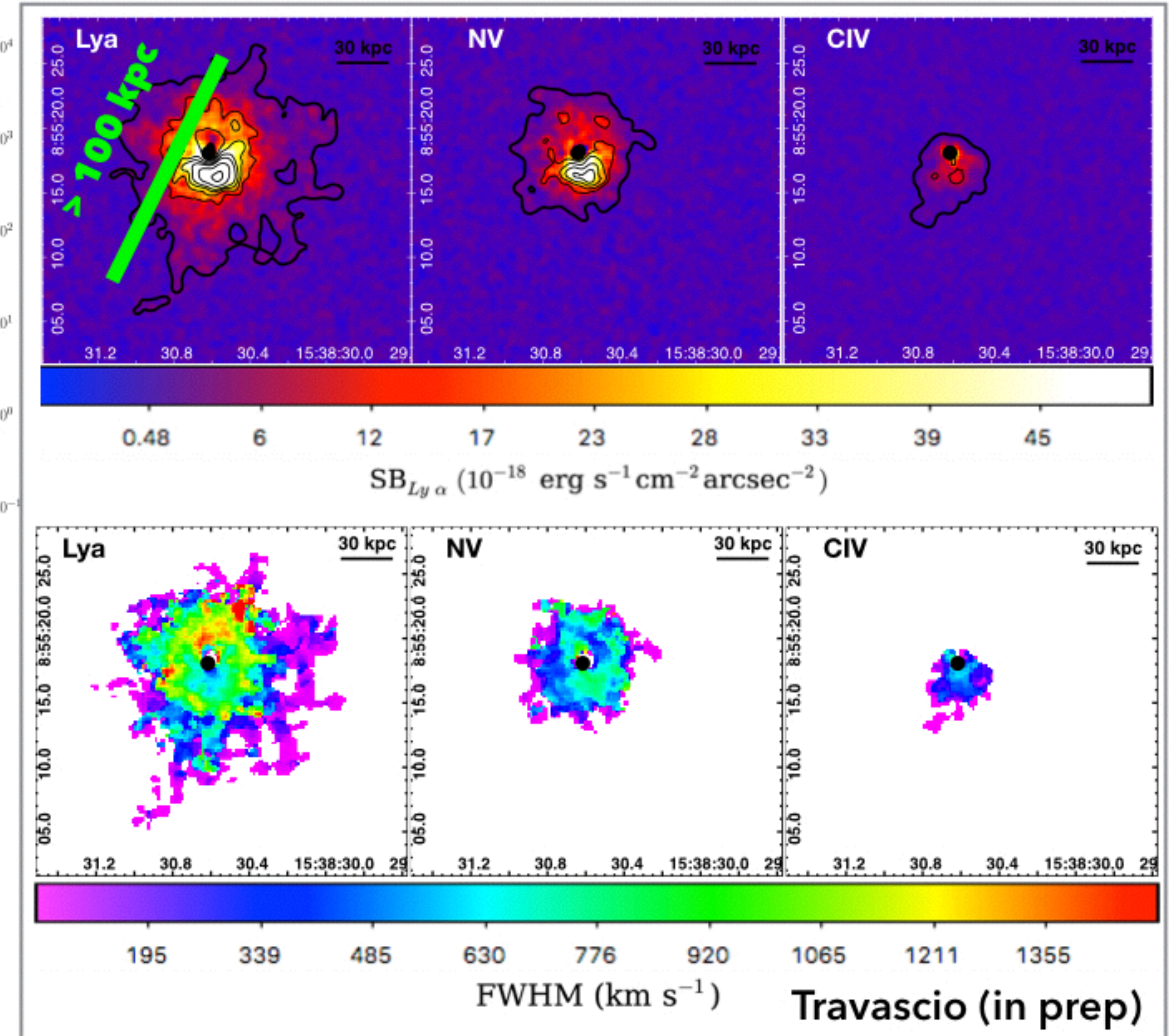
<u>suggested scenario</u>

- 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**.

Program to detect Giant Lya Nebulae around WISE/SDSS Hyper-luminous (WISSH) Quasars (*Data analysis is on-going*)

Travascio +18 in prep. "Three Giant Nebulae around a BAL WISSH QSO"





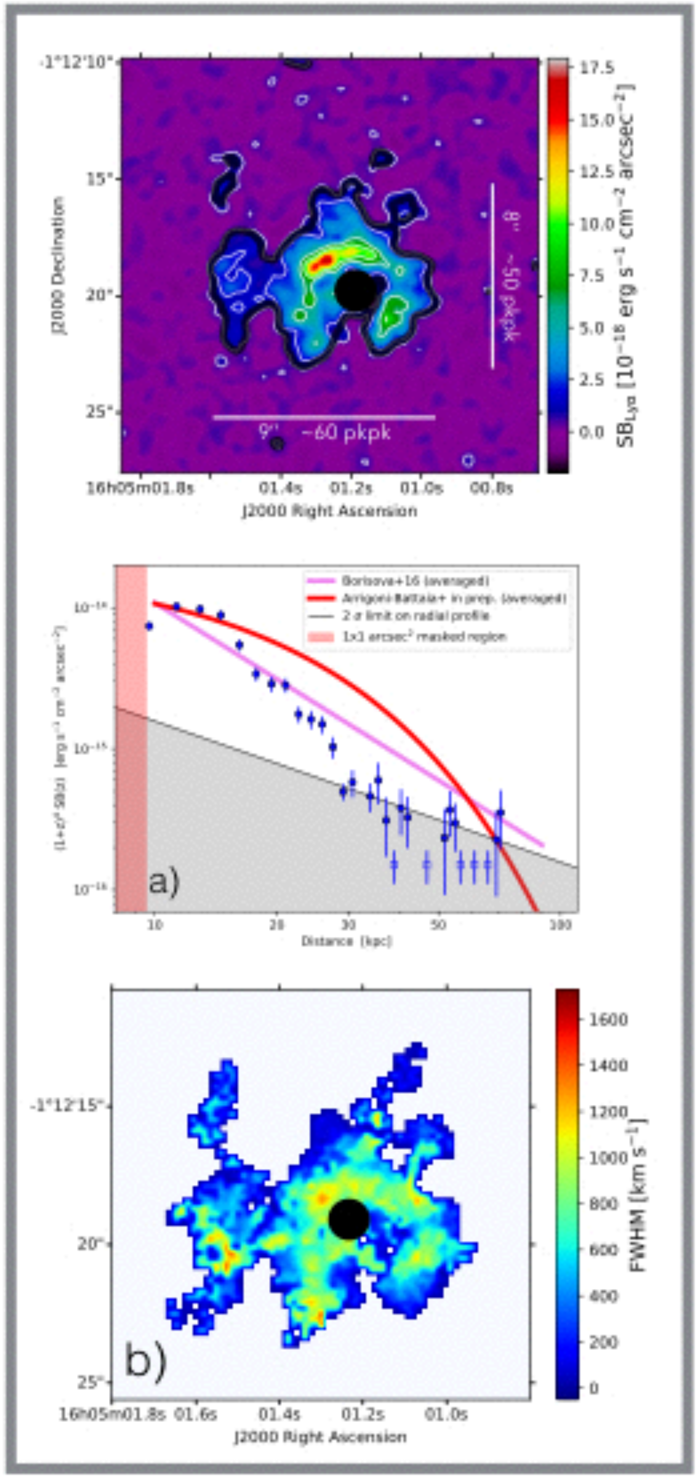
Again, high Lya broadening in Nebulae surrounding BALs experiencing powerful ionized outflows ([OIII]). Also, hints of extended NV and CIV on CGM scales

- Trying to recap…

…we reported **deep MUSE observations** of J1605-0112, a BAL QSO at **z~5**, revealing a Lya nebula with a maximum projected linear size of ~60 kpc. This nebula shows two peculiar properties:

(1) **SIZE DISCREPANCY**: it has a z-corrected, less extended distribution of Lya emission than typical nebulae at lower z;

(2) **BROAD LINE KINEMATICS:** it shows a high broadening of the Lya (FWHM> 1000 km/s) exceeding by a factor of ~2 the typical FWHM observed in other works) in the inner regions (~10 kpc scales).



The actors likely playing the leading roles are…

- **redshift/cosmology:** smaller DM halos at higher z;
- **dust obscuration:** lower UV escape fraction;
- **powerful outflows:** introduction of turbulence in the CGM.

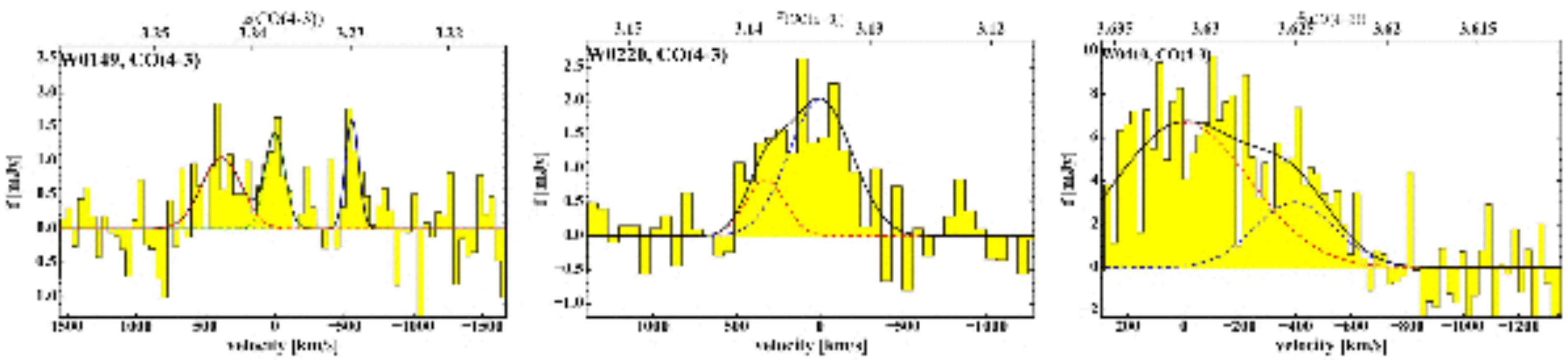
Our findings suggest that dust obscuration and powerful outflows may influence the morphology and the kinematics of the Lya emission in the CGM on scales of (at least) tens of kpc around the QSOs, pointing to a profound link between the observed properties of Lya Nebulae and their host QSOs.

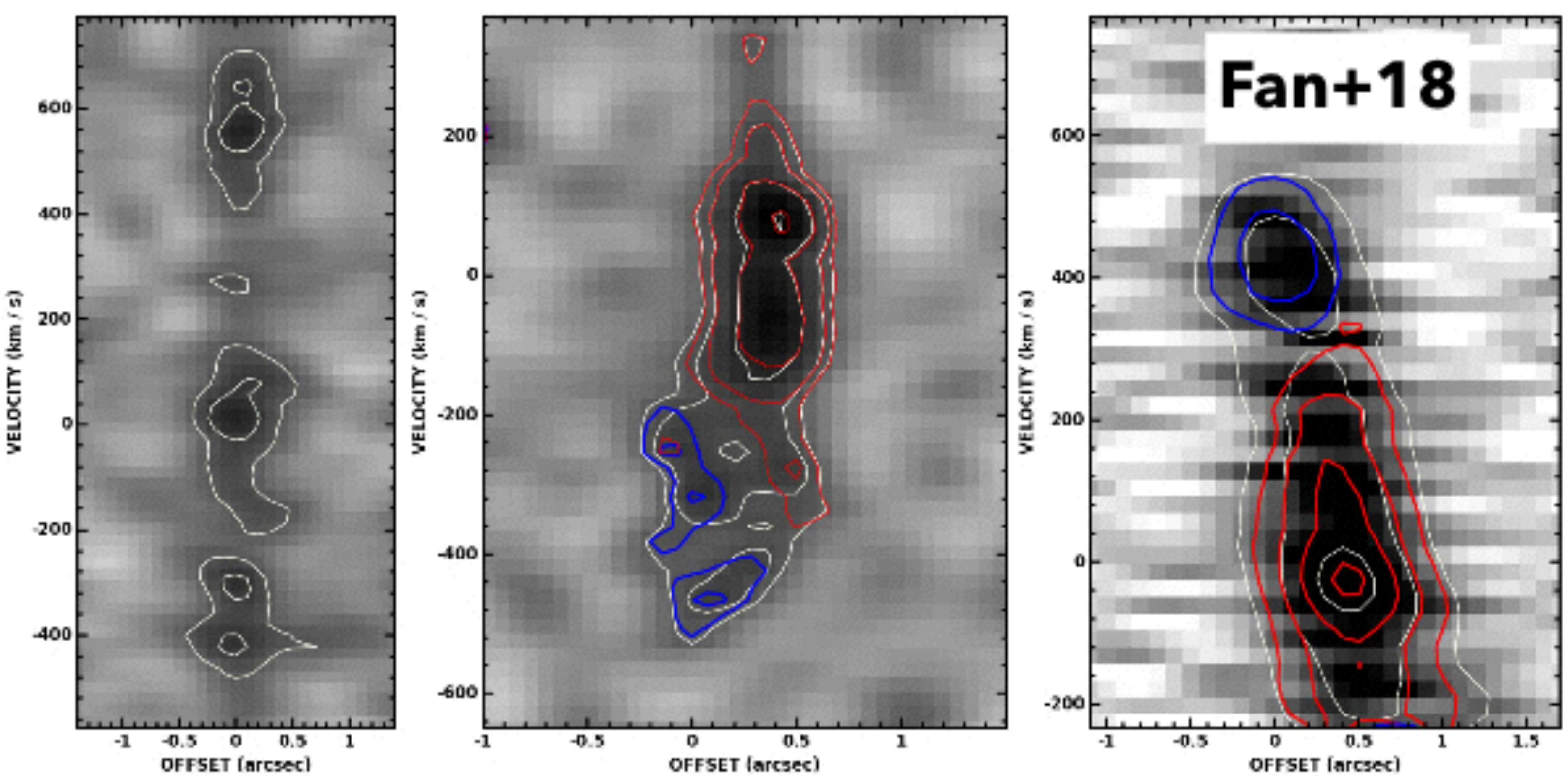
but this is not the end of the story…

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

PI: Ginolfi; accepted for Period 102

Deep MUSE observations (~1 h per source) of three hyper-luminous ($L_{bol} > 10^{14} L_{\odot}$), Hot-DOGs at z = 3.1 – 3.6.





- asymmetric velocity structures, showing evidence for molecular outflows (first case consistent also with merger)

Objectives

1) study the impact of dust attenuation on the morphology of the Lya nebulae around heavily obscured QSOs;
2) study the impact of AGN-driven outflows on the CGM, looking at the Lya kinematics;
3) observe how efficient are outflows in enriching the CGM;
4) explore how the circumgalactic Lya emission can be influenced by strong dynamical interactions.

Looking forward to have data!

Stay tuned…


Thank you for your attention
my picture of Durham