# Near-IR Integral Field Spectroscopy Of High-Redshift Quasar Host Galaxies

Mariana Cano Díaz
*INAF-Osservatorio Astronomico di Roma*
*Supervisor: Roberto Maiolino*

**Alessandro Marconi, Angela Bongiorno, Hagai Netzer, Ohad Shemmer, Giovanni Cresci**

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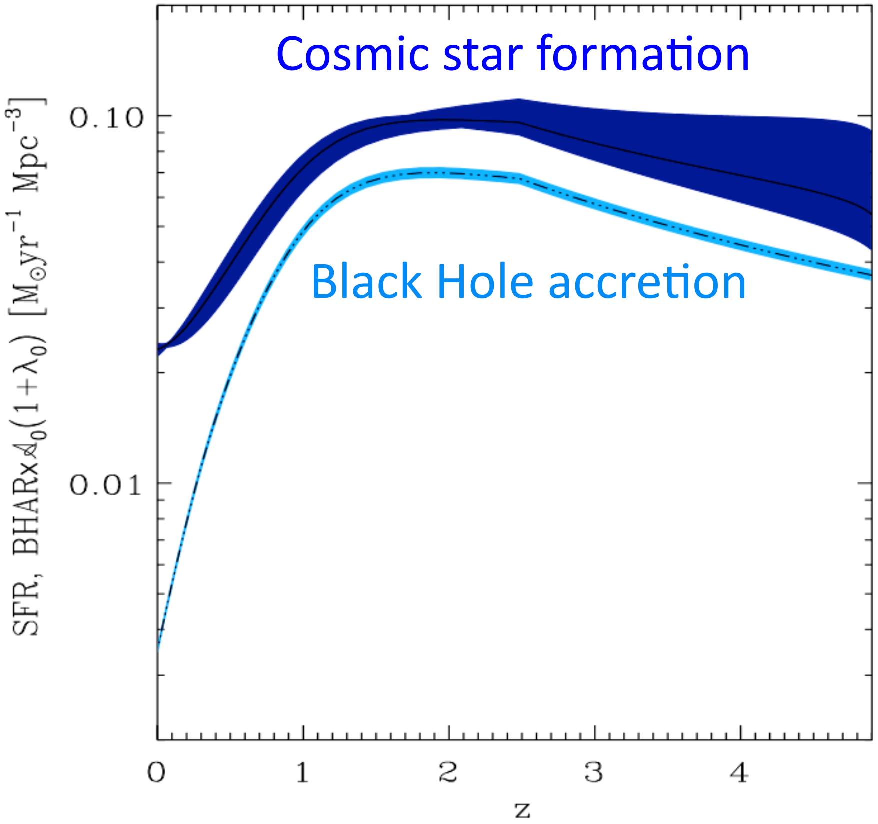
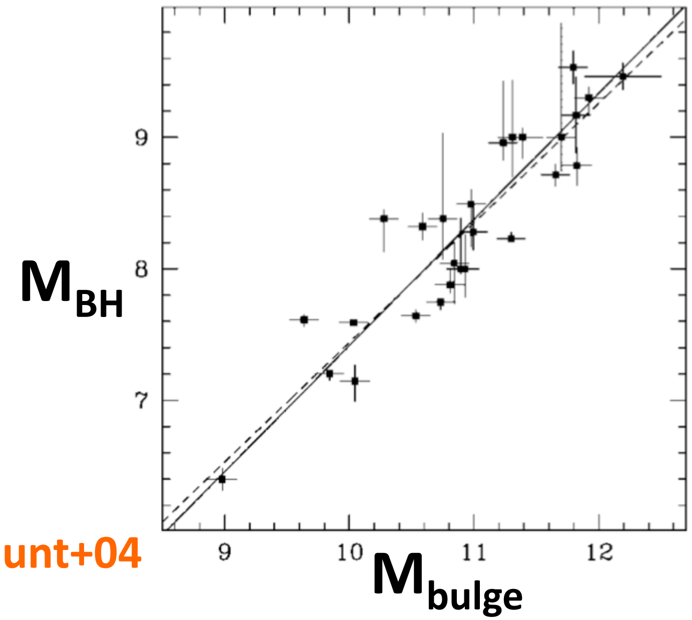
# GENERAL CONTEXT

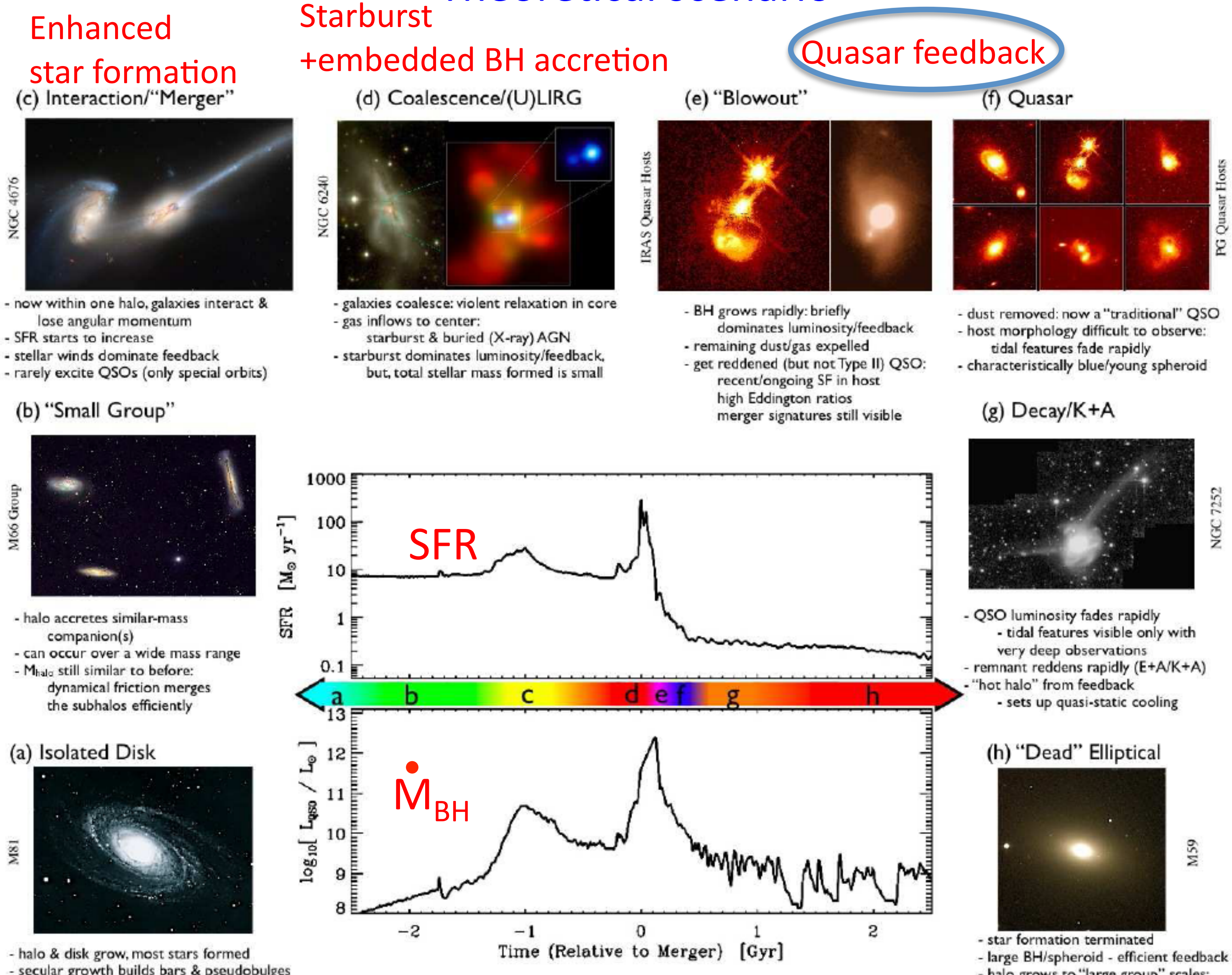



Merloni+06



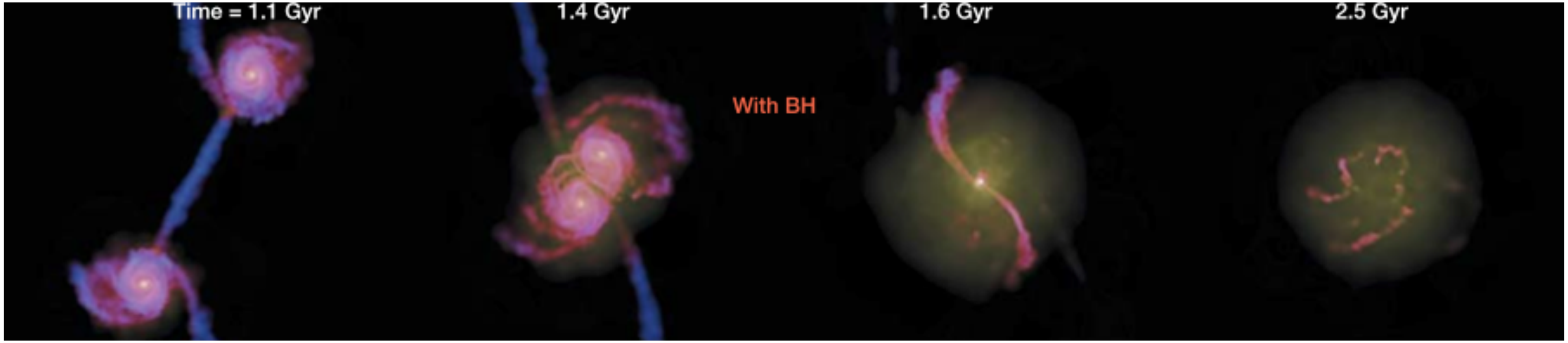

Marconi & Hunt+04

# Theoretical scenario

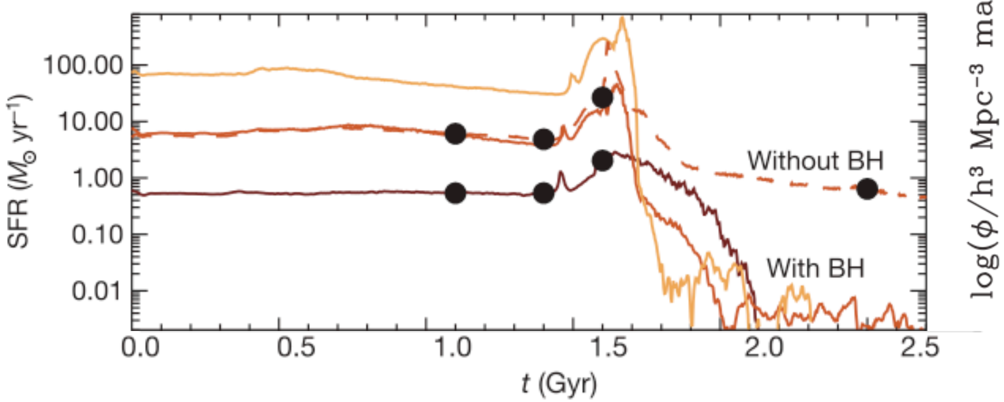


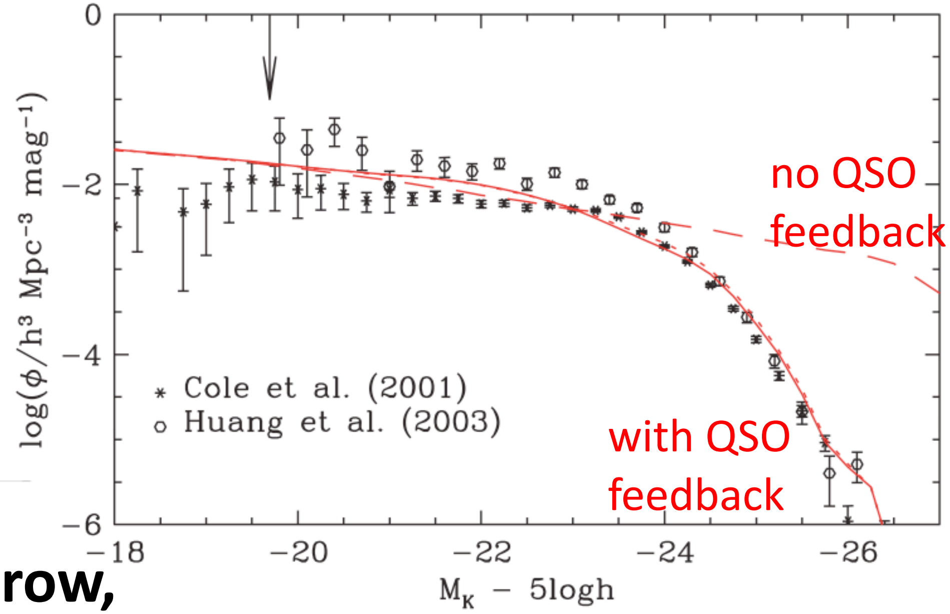

Hopkins+08

# Quasar feedback: invoked by most theoretical models to quench star formation in massive galaxies




Di Matteo+05, Granato+04, Springel+08, Menci+06,08, Narayanan+06,08, Bower+06, Hopkins+08, Lapi+06

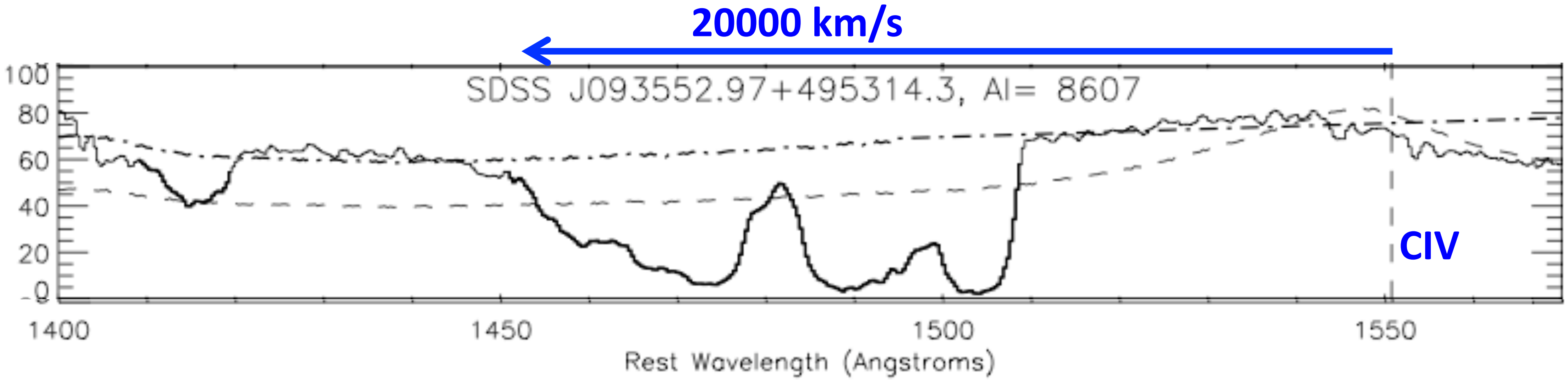



**Prevents massive galaxies to overgrow, hence explains the steep decline of the density of local massive galaxies and their red colors**

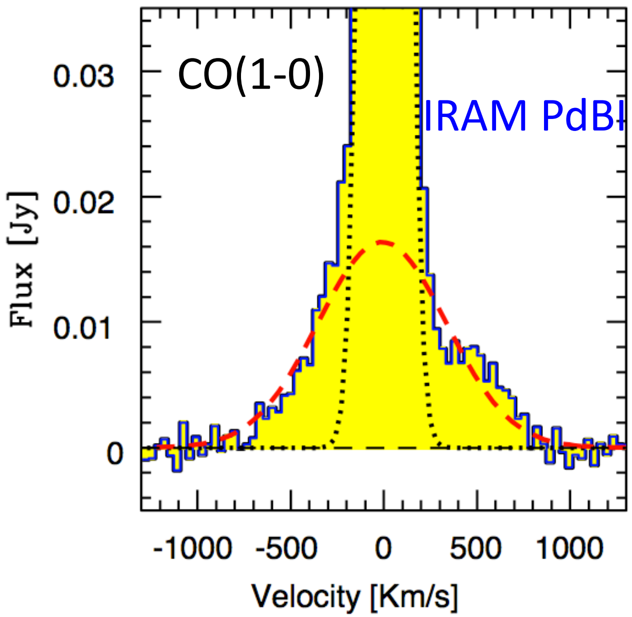
Until recently little/NO observational evidence for quasar feedback at work...
winds observed through blueshifted UV absorption lines of quasars, but these only trace nuclear gas (<pc) not really tracing feedback onto the host galaxy

(e.g Broad Absorption Line QSOs)



# Recent evidence for massive quasar driven outflows in a few local quasars

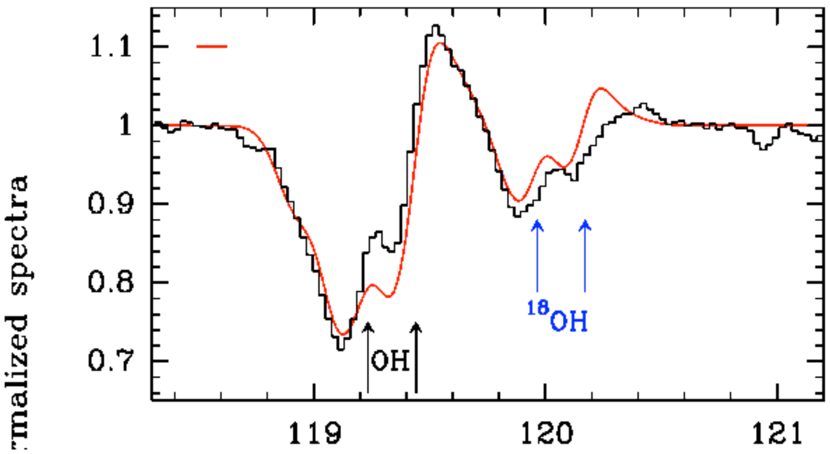
Feruglio+10

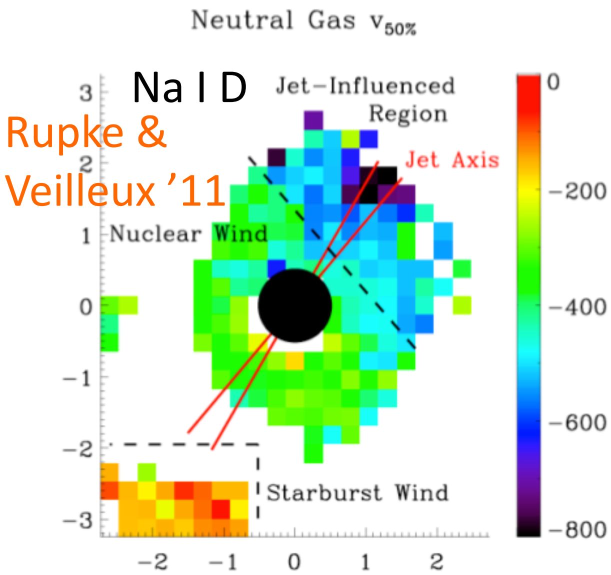



Mrk231

Herschel+PACS

Fischer+10




Molcular outflow on kpc scale

$\dot{M}_{outflow} \sim 700\ M_\odot/yr > SFR = 200\ M_\odot/yr$
=> hence quenching of star formation

Depletion timescale: ~$10^7$ yrs

Kinetic power:

$P_K$~ 1-3 $10^{44}$ erg/s ➔ ~ 0.02-0.06 x $L_{bol}$(AGN)

as expected by quasar feedback models

# Quasar feedback at high redshift

At high redshift (z~ 2) the star formation and black hole accretion reach their peak.

Also, at high redshift (z~ 2) massive galaxies are expected to experience the strongest effect from quasar feedback.

Little/no observational evidence for quasar outflows has been found yet.

(the only few investigations are Nesvadba+10,11, but outflow driven by the interaction with the *rare* radio jets, and Alexander et al. 2010 which is probably driven by star formation and not AGN).

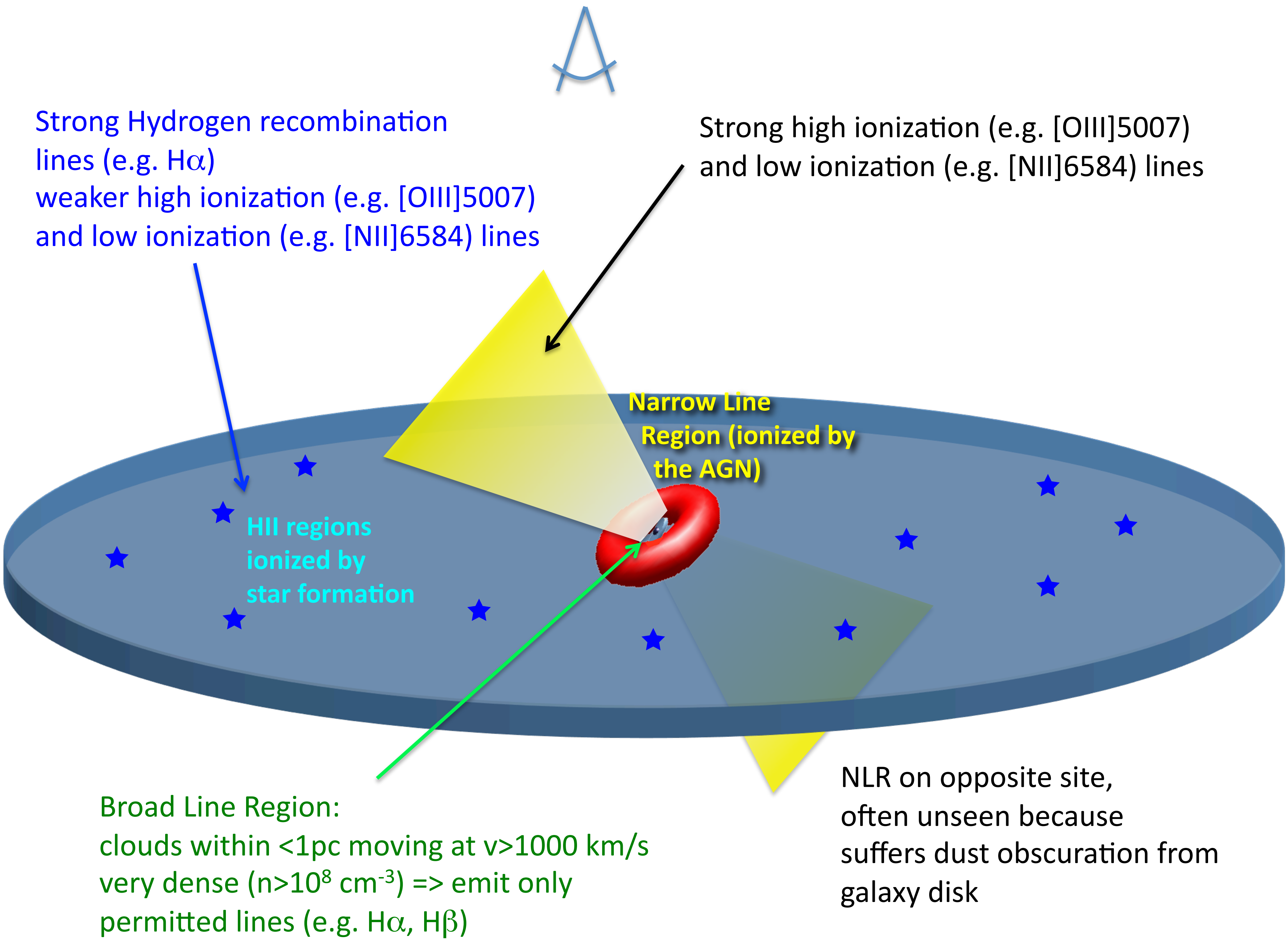
# Our observing program:

We are looking to track the influence of the AGN on its host galaxy for that purpose we have undertaken an IFU near-IR spectroscopic investigation of z~2 quasars.

Key diagnostics:

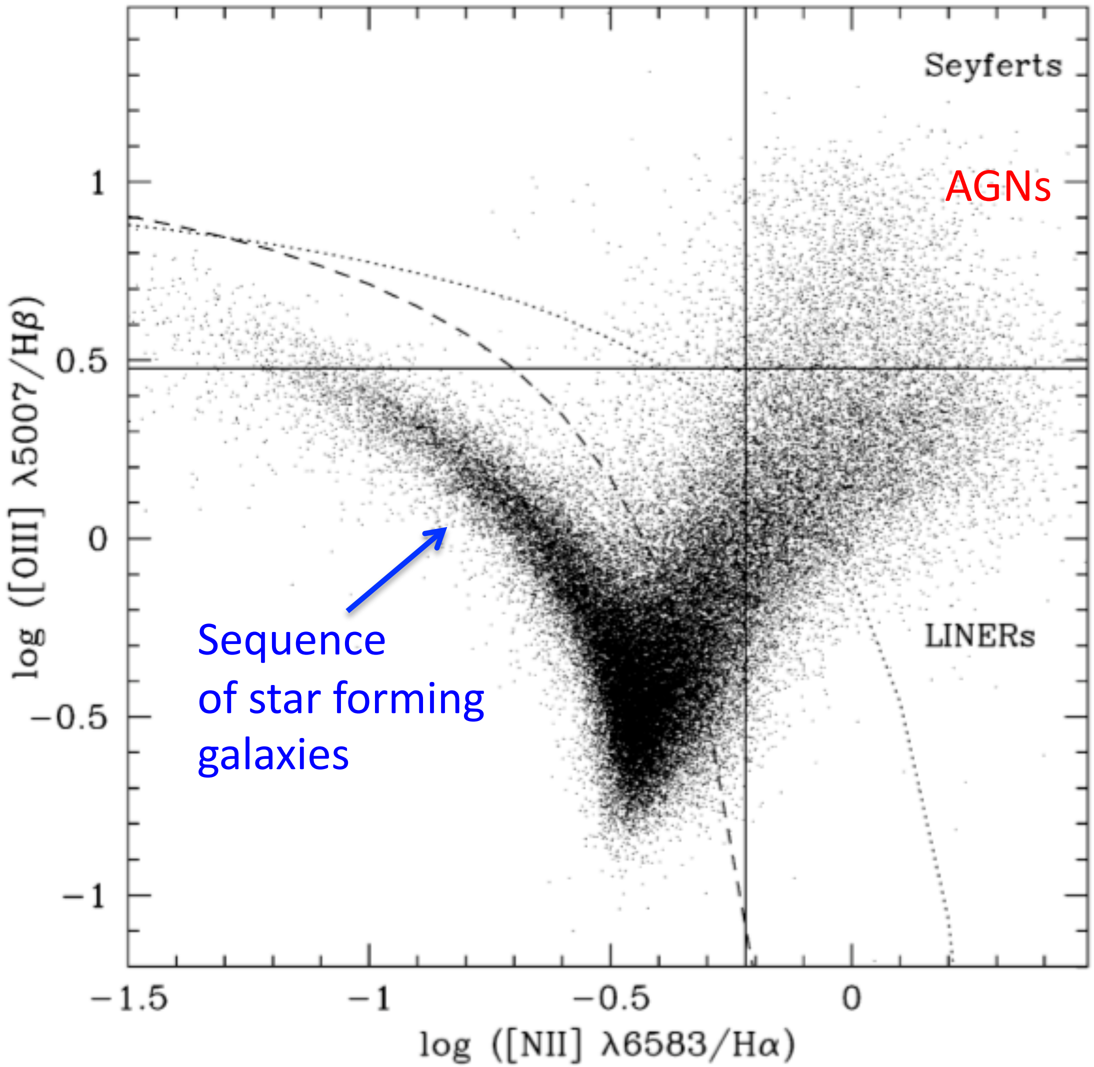
[OIII]5007 emission line (redshifted into the H band) to trace the gas kinematics of the NLR and look for evidence of quasar driven outflows

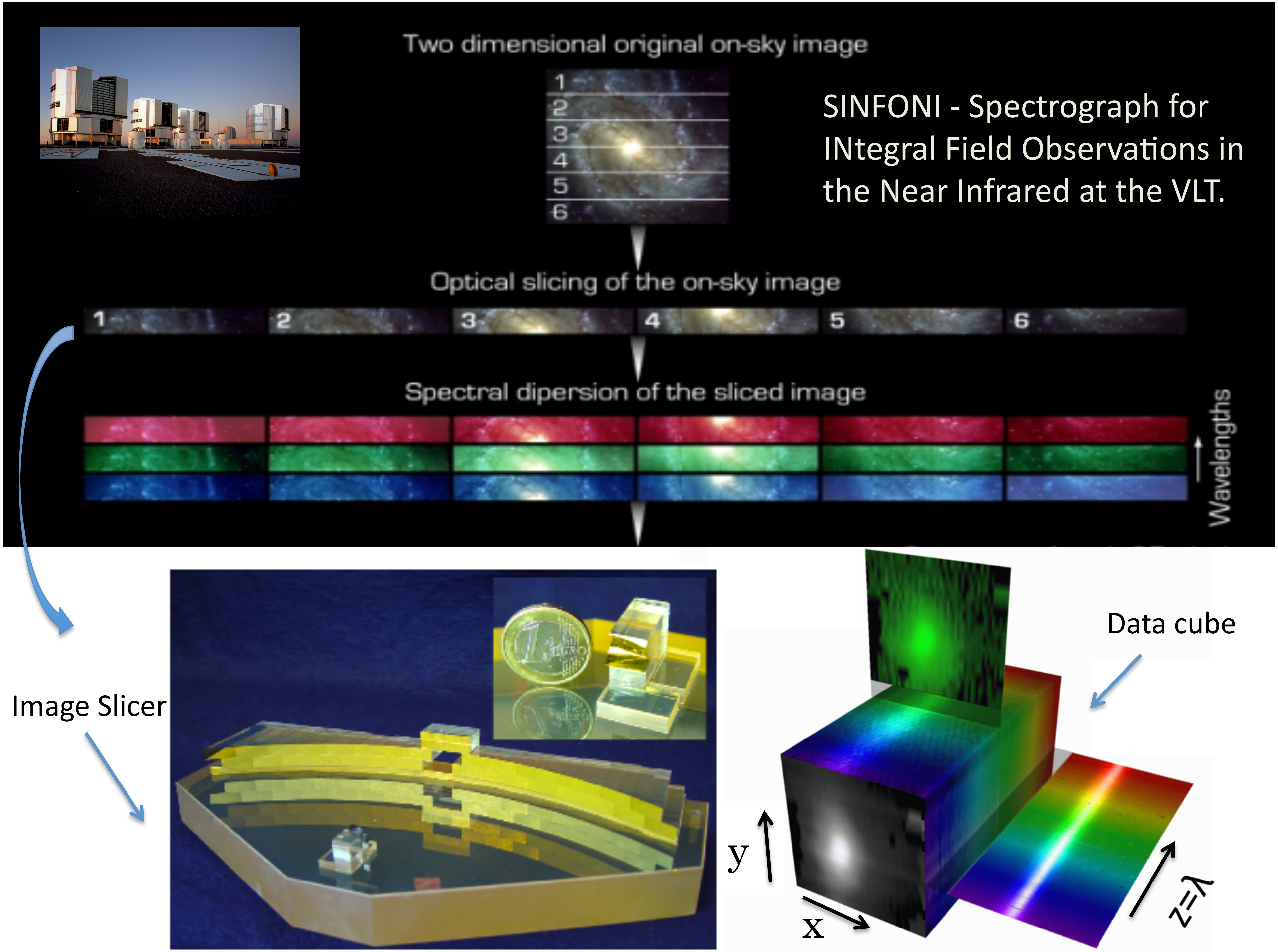
H$\alpha$ emission (narrow component, redshifted into K band) to trace star formation



Strong Hydrogen recombination
lines (e.g. Hα)
weaker high ionization (e.g. [OIII]5007)
and low ionization (e.g. [NII]6584) lines
Strong high ionization (e.g. [OIII]5007)
and low ionization (e.g. [NII]6584) lines
Narrow Line
Region (ionized by
the AGN)
HII regions
ionized by
star formation
Broad Line Region:
clouds within <1pc moving at v>1000 km/s
very dense (n>10⁸ cm⁻³) => emit only
permitted lines (e.g. Hα, Hβ)
NLR on opposite site,
often unseen because
suffers dust obscuration from
galaxy disk

# Diagnostic diagrams (e.g. Kauffman et al. 2003)




Two dimensional original on-sky image
1
2
3
4
5
6
SINFONI - Spectrograph for INtegral Field Observations in the Near Infrared at the VLT.
Optical slicing of the on-sky image
1
2
3
4
5
6
Spectral dipersion of the sliced image
Wavelengths
Image Slicer
Data cube
y
x
z=λ

# DATA

- We have observed a sample of 8 QSOs (H, K and H+K bands).
- All under excellent (rare) seeing conditions (0.4”-0.6”).

- The whole data reduction process was performed.

  - Flat field correction.
  - Sky subtraction.
  - Cosmic ray cleaning.
  - Wavelength calibration.
  - Distortion correction.
  - Alignment of the slitlets.
  - Flux calibration.
  - Final cube construction.

# DATA

## SPECTRAL FITTING:

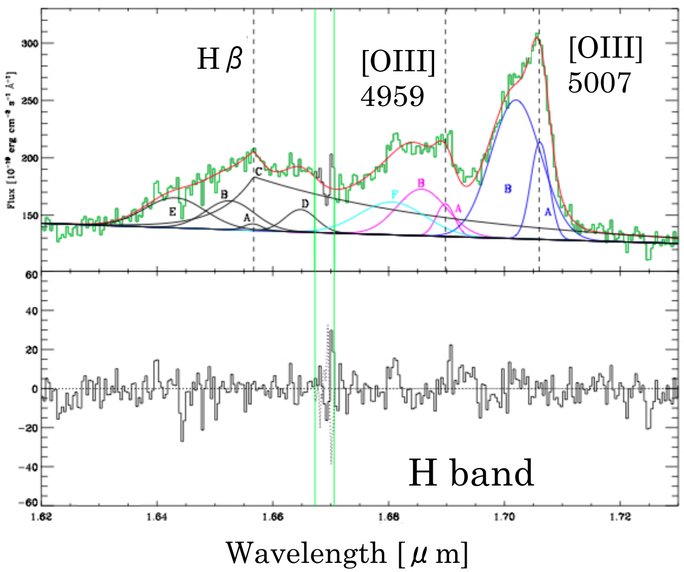
- At first the fitting is performed only in a single (central) aperture in order to select and optimize the required spectral components (multiple Gaussians and power-laws to reproduce the shape of the emission lines and continuum).

- Then the same components are used to fit the spectrum in each spatial pixel of the cube (by constraining some of the components).

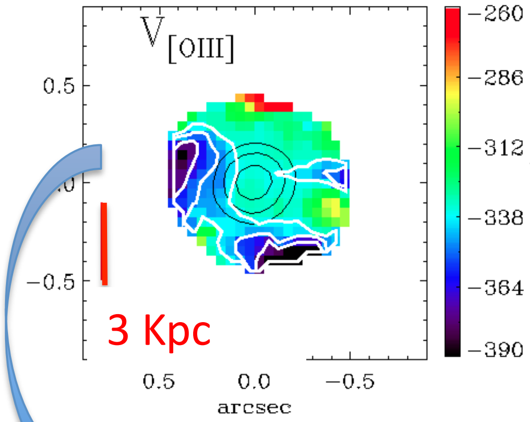
- The shape of the "broad lines" (from the BLR) is kept fixed (only intensity is allowed to vary, and it's tracing the seeing, since the BLR is unresolved).

- The output are: flux maps, velocity field and velocity dispersion of each line/component.

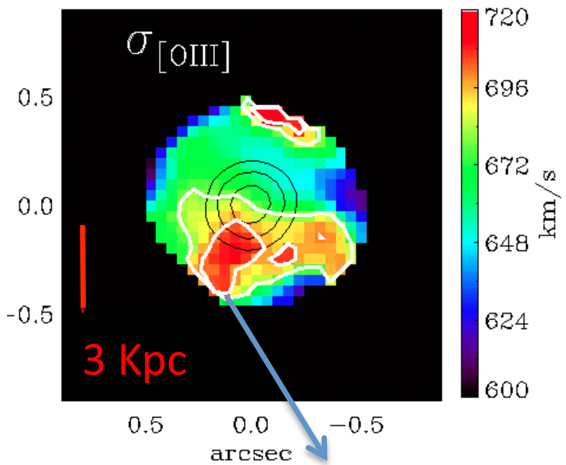
# 2QZJ002830.4-28170




[OIII] Velocity field




[OIII] Velocity dispersion




Evidence of (quasar-driven) outflow

$V_{outflow}$(max)~1000 km/s

Mass of ionized outflowing gas

↓

$10^8\ M_\odot$

Mass outflow rate of ionized gas

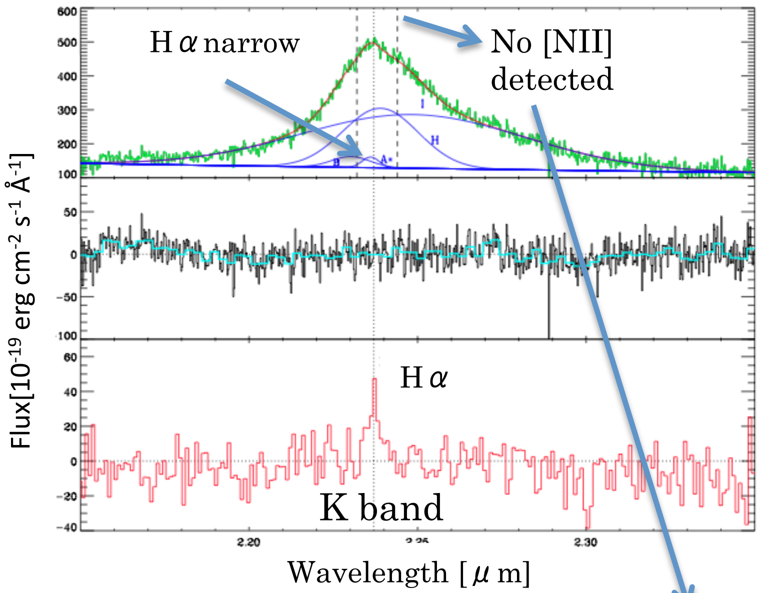
↓

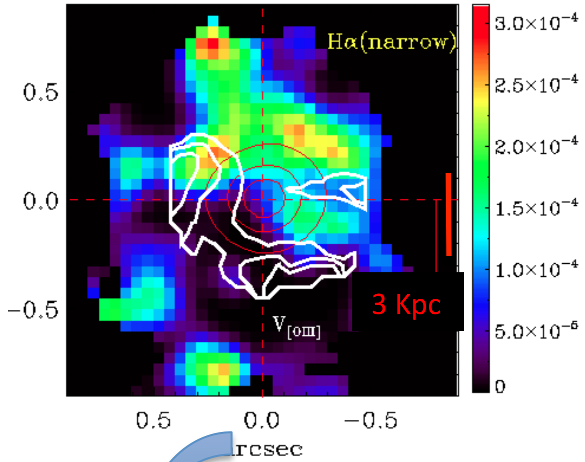
$\sim 200\ M_\odot/yr$

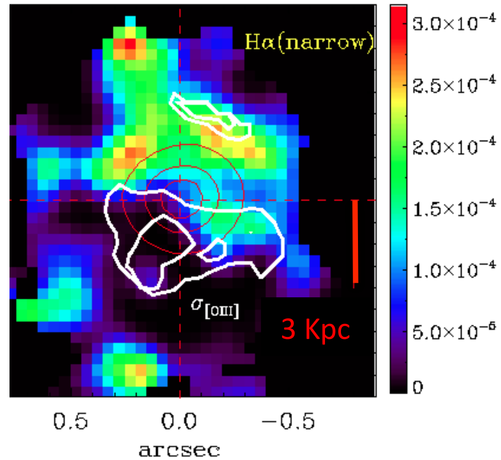
Kinetic power $P_K \sim 3\ 10^{43}$ erg/s $\sim 0.005\ L_{Bol}$

But this is only the ionized component…
The total outflow rate and power may be much higher

# 2QZJ002830.4-28170



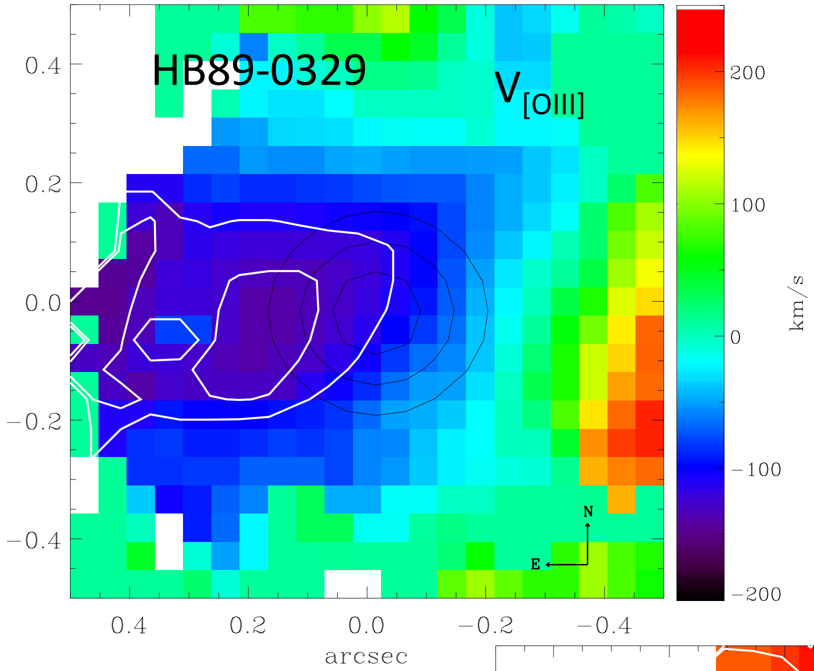

H α narrow is tracing Star Formation

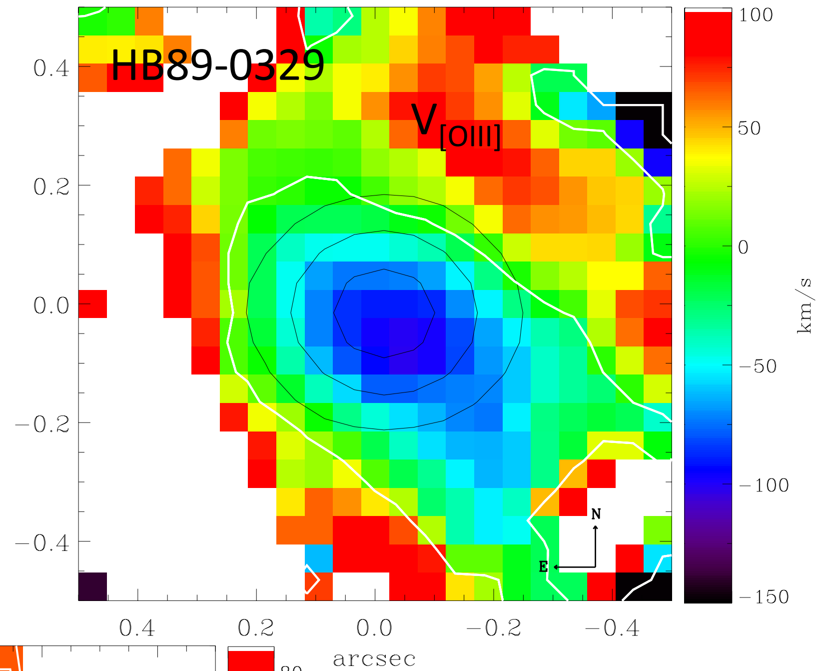
SFR~100$M_\odot$/yr

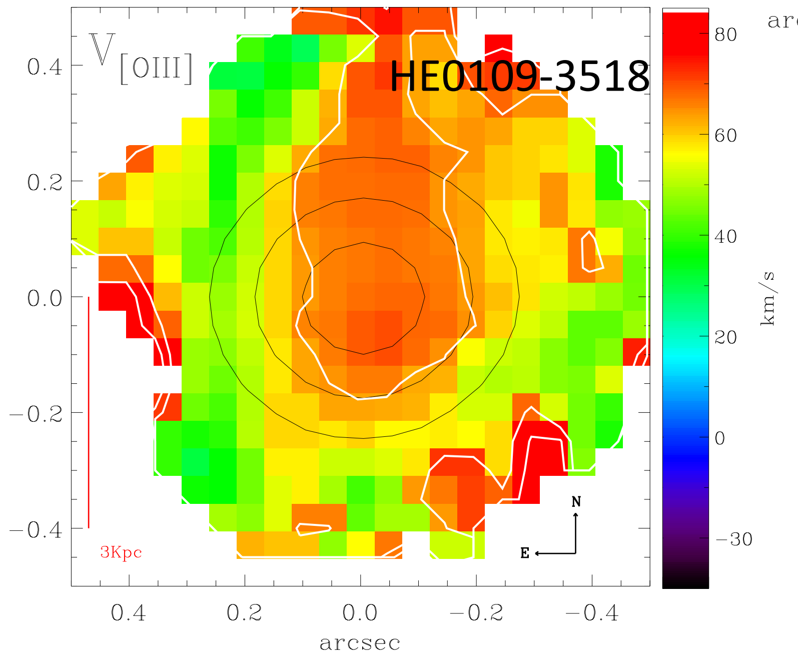
Quenched star formation in correspondence of the outflow

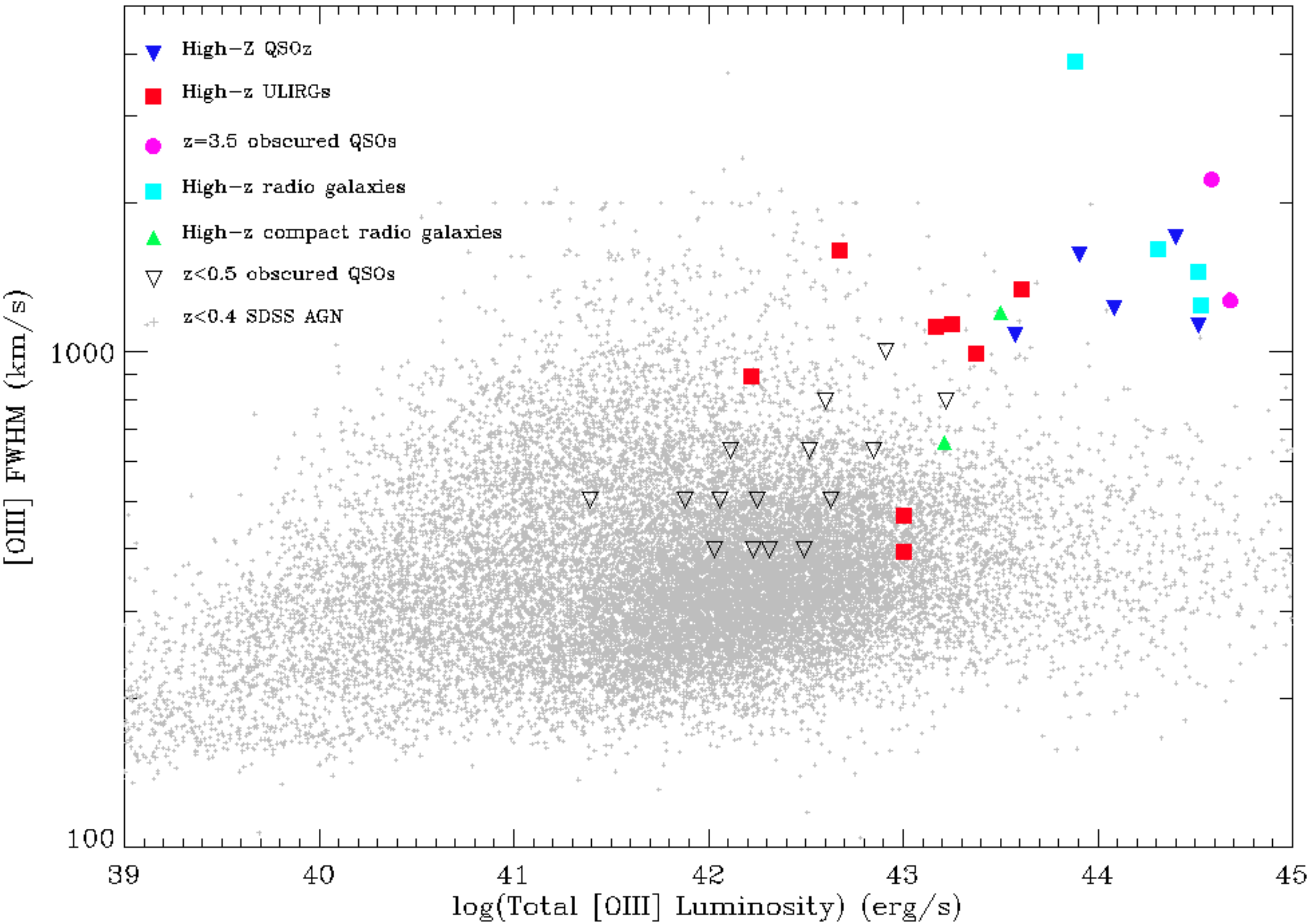
First Observational evidence for quasar feedback quenching Star formation at high-z!

# Sources showing outflow signatures

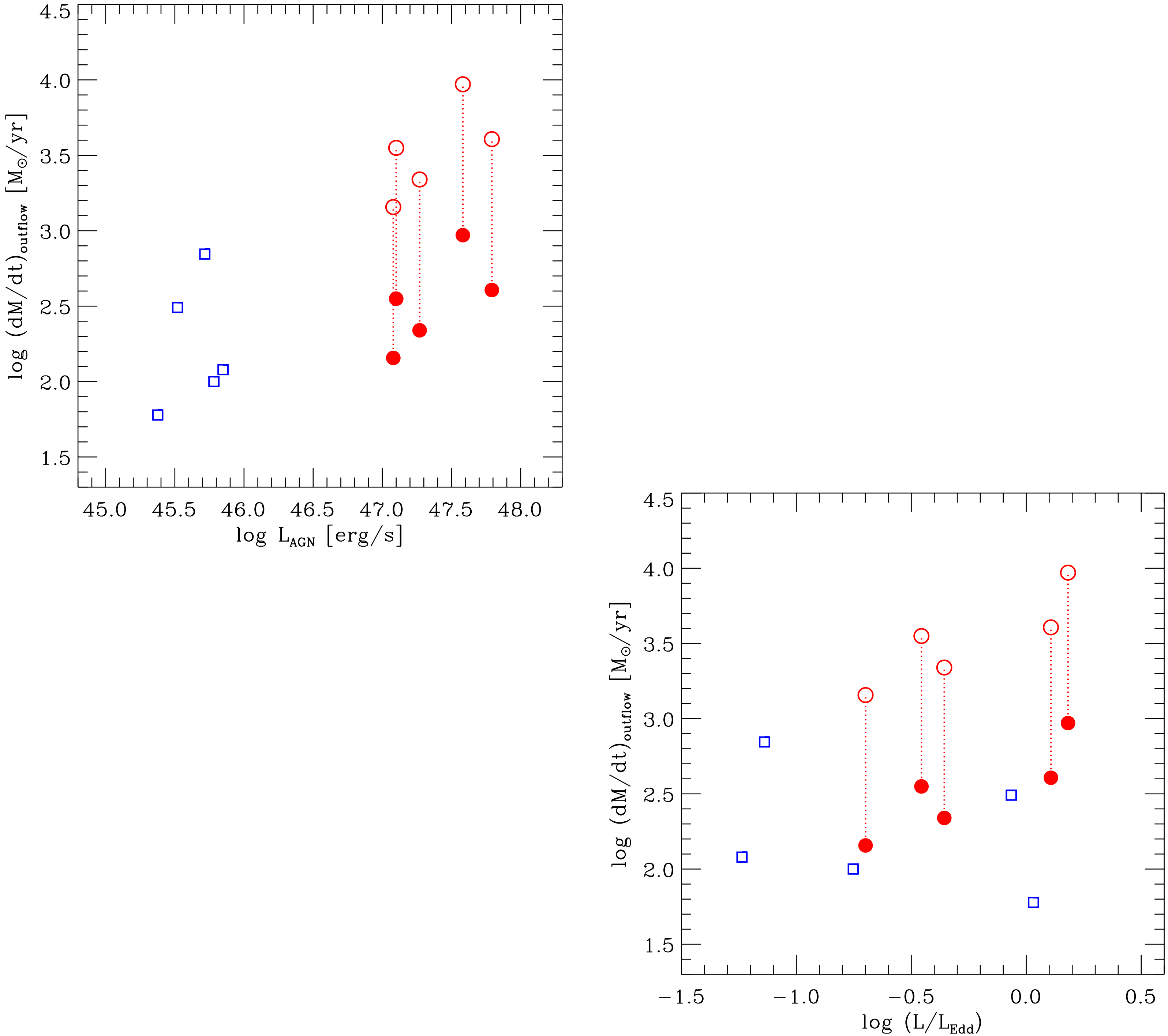


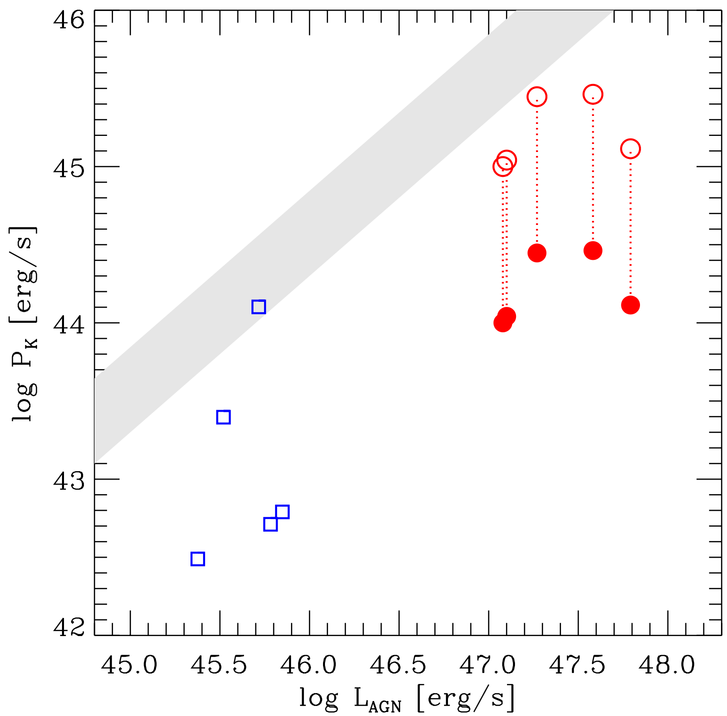





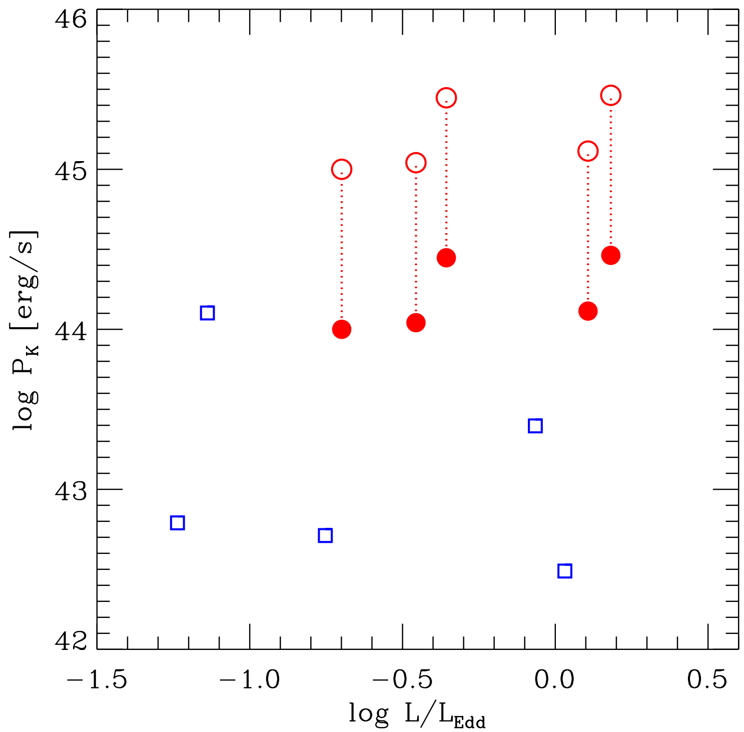
High−Z QSOz
High−z ULIRGs
z=3.5 obscured QSOs
High−z radio galaxies
High−z compact radio galaxies
z<0.5 obscured QSOs
z<0.4 SDSS AGN
1000
100
39
40
41
42
43
44
45
log(Total [OIII] Luminosity) (erg/s)
[OIII] FWHM (km/s)



log (dM/dt)outflow [M☉/yr]
log LAGN [erg/s]
log (dM/dt)outflow [M☉/yr]
log (L/LEdd)

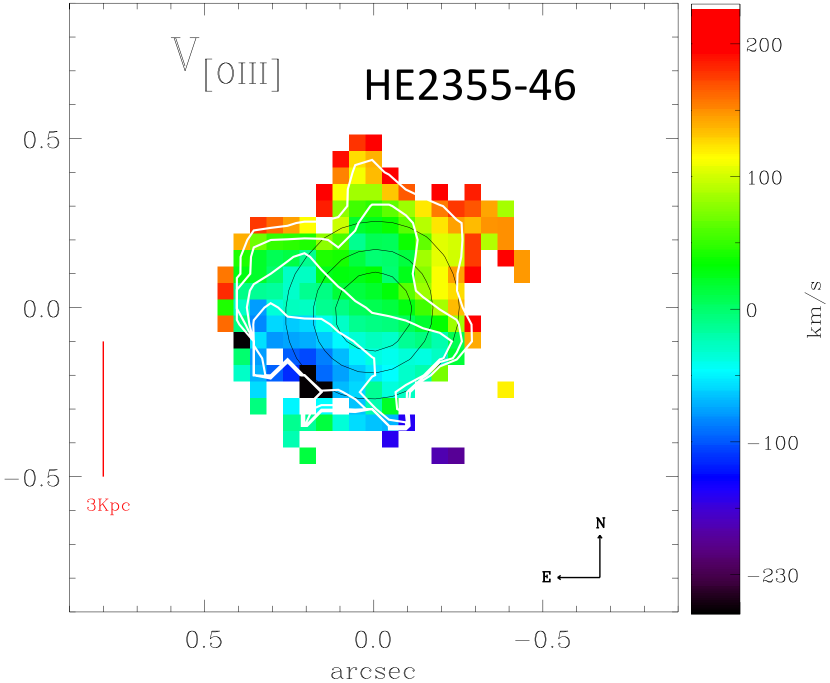


log $P_K$ [erg/s]
log $L_{AGN}$ [erg/s]

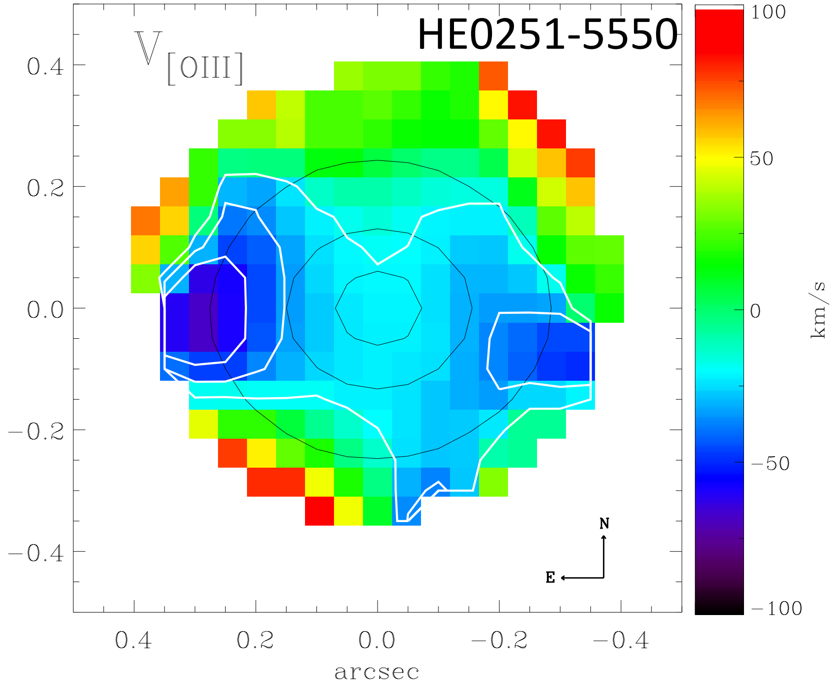
log $P_K$ [erg/s]
log $L/L_{Edd}$

# SOURCES NOT SHOWING OUTFLOW SIGNATURES




Rotation?

Merging?

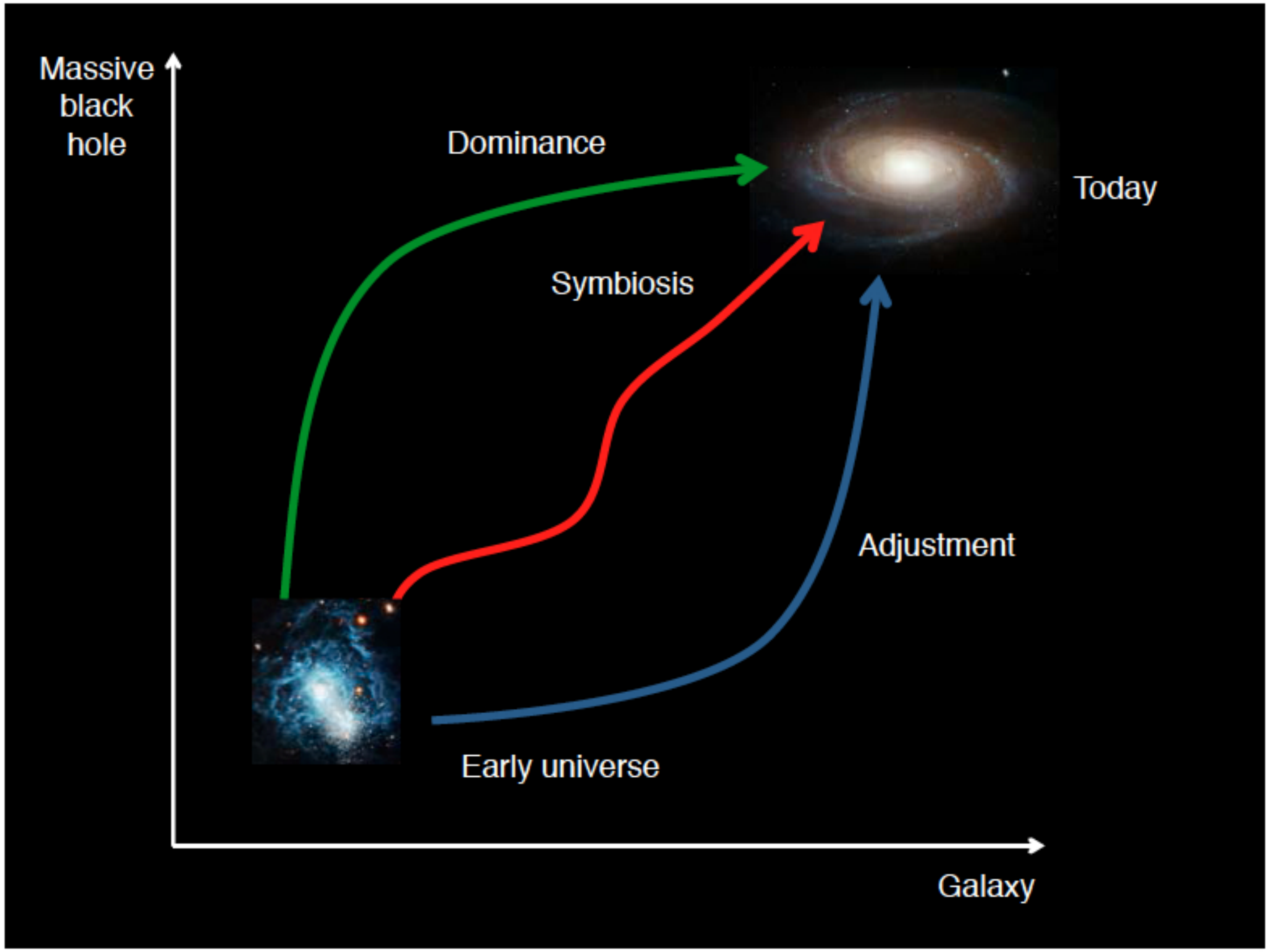


# OBSCURED AGNs $M_{BH}$-$M_*$ RELATIONS

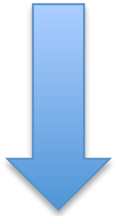
What evolutionary path have followed the BH-galaxy system?

Does the BH has been dominating? or the galaxy? or may be it has been a compromise?

Study the BH-galaxy relations at different redshifts might give us some answers.




The general finding is that at high redshift, the galaxies tend to have BHs more massive than expected from the local relation.



This supports the green scenario.

# Obscured AGNs $M_{BH}$-$M_*$ relations

Type 1 AGN are likely to be in a late unobscured peculiar phase of the BH-galaxy co-evolution that has clear all the gas from the circumnuclear region.

Instead in type 2 AGN, the BH is expected to be accreting, as is still embedded in their ISM.

Type 2 AGNs are much more numerous than type 1 → Type 2 AGNs may represent the bulk of the BH-accretion phase

However measuring the BH masses in obscured, high-z AGN is not trivial,

↓

Little work has been done at trying to study the $M_{BH}$-$M_*$ for obscured AGN.

# SAMPLE OF OBSCURED AGNS.

Observations:

- For a sample of 11 observed obscured AGNs with SINFONI (J, H, K bands, depending where the Hα line is redshifted) we detected a broad component in 4 sources.
- We have observations for one source with LBT-LUCIFER (H+K band) for which it was detected a broad Hα.

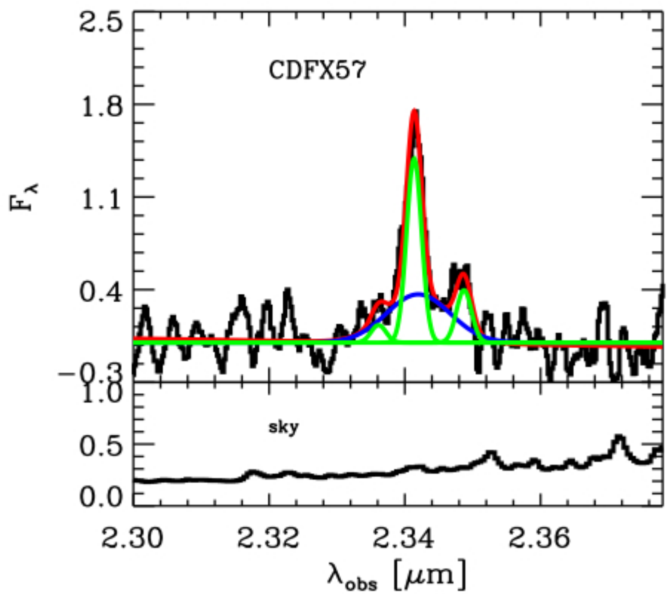
Enlarging the sample:

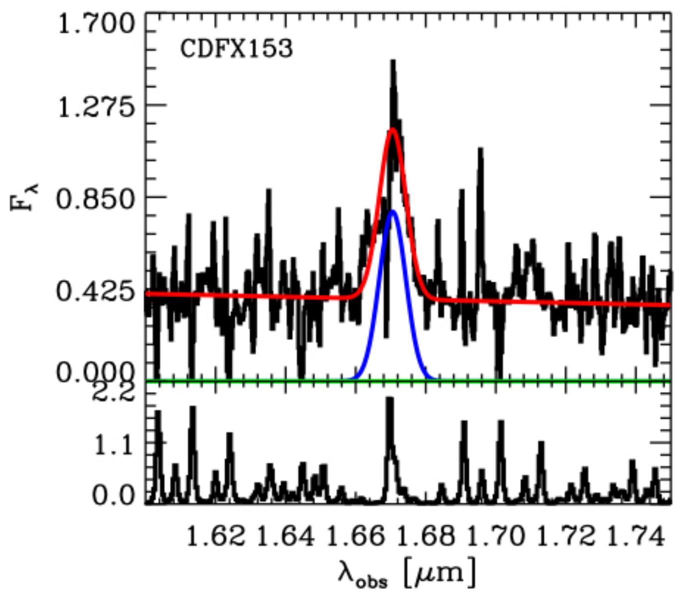
- We included in our sample, 15 sources from the literature, that have a broad Hα line detected in the Near-IR, and hard X-ray detection.

- The final sample is of 20 sources.

## SPECTRAL FITTING OF OUR OBSERVED OBSCURED AGNS.

- Multiple Gaussian profiles that allow to fit the Hα line (broad and narrow components), plus the [NII] doublet associated if found.
- The components fitting analysis is somehow simpler than for the luminous sources (Our main interest focuses on measuring the broad Hα component in order to estimate the BH mass)



## MBH AND STELLAR MASSES OF THE OBSCURED AGNs. (COLLABORATION WITH A. BONGIORNO @ OAR)

$M_{BH}$:

- We used a virial relation (Marconi, et.al. 2013 in prep.)

$$\log M_{BH} = 6.73 + 2\log\left(\frac{FWHM_{H\beta}}{10^3 \mathrm{km\,s^{-1}}}\right)^2 + 0.5\log\left(\frac{\lambda L_\lambda(5100)}{10^{44} \mathrm{erg\,s^{-1}}}\right)$$

- To be able to use the Hα line, we used a correlation between Hα and $\mathrm{H}\,\beta$ (Greene et. al. 2005).

$$FWHM_{H\beta} = (1.07 \pm 0.07) \times 10^3 \left(\frac{FWHM_{H\alpha}}{10^3 \mathrm{kms^{-1}}}\right)^{(1.03\pm0.03)} \mathrm{km\,s^{-1}}$$

- As we are using obscured sources, the continuum luminosity at 5100Å, is expected to be absorbed, so, we replaced it with the absorption corrected at X-ray 2-10 Kev (Maiolino, et.al. 2007)

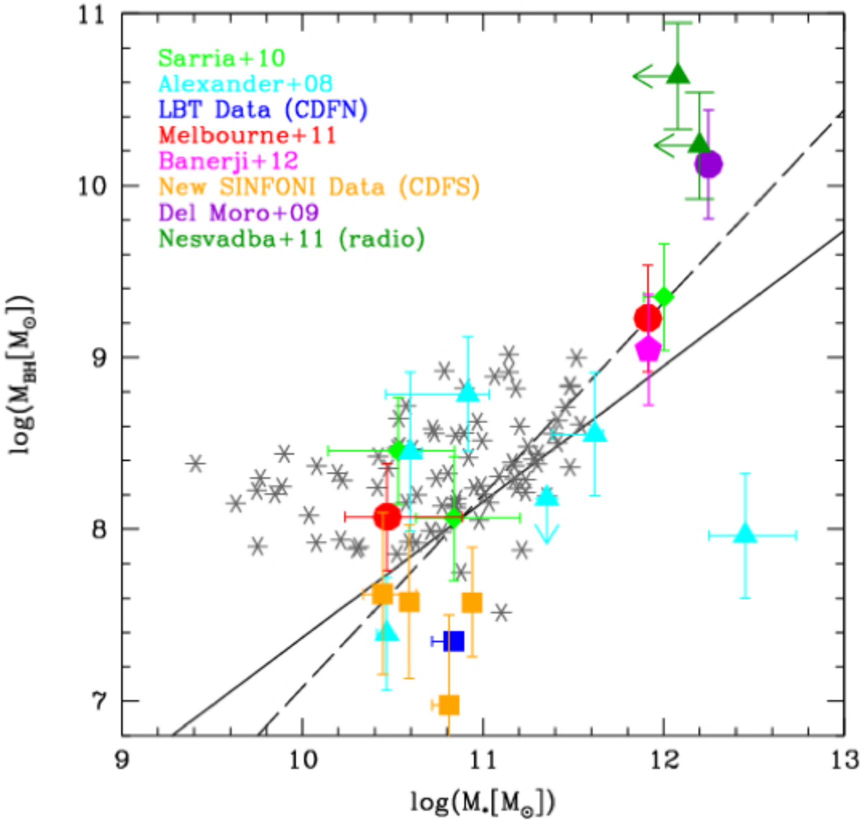
$$\log[L(2-10\,\mathrm{keV})] = 0.721 \cdot \log[\lambda L_\lambda(5100\,\text{Å})] + 11.78$$

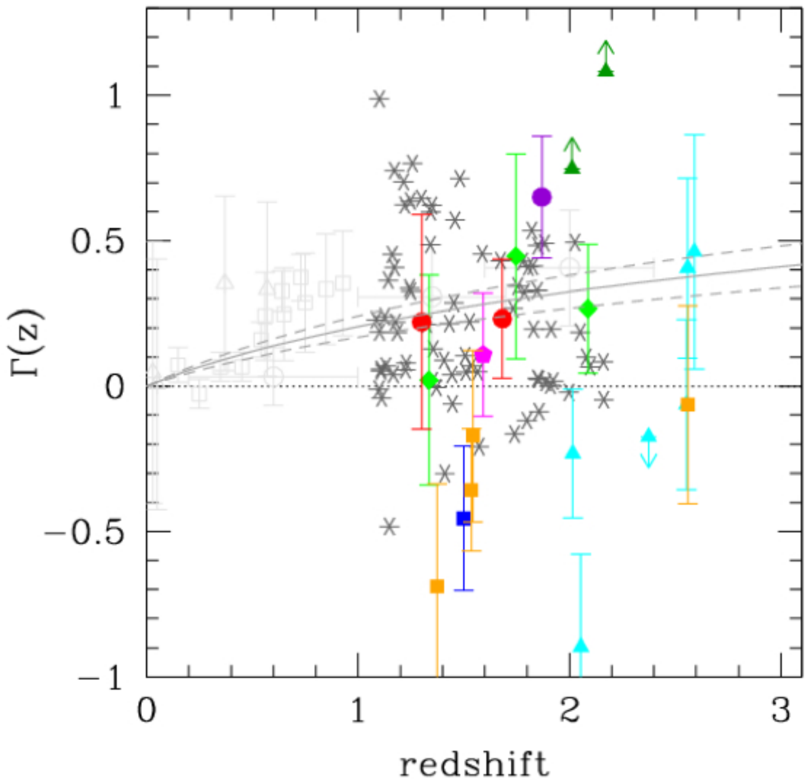
$$\log M_{BH} = 7.11 + 2.06\log\left(\frac{FWHM_{H\alpha}}{10^3 \mathrm{Km\,s^{-1}}}\right)^2 + 0.693\log\left(\frac{L_{[2-10\mathrm{keV}]}}{10^{44} \mathrm{erg\,s^{-1}}}\right)$$

$M_{star}$:

- Those were derived using an optical-NIR SED fitting procedure (Bongiorno, et. al. 2012) that uses galaxy and AGN templates.

# OBSCURED AGNS MBH-MSTAR RELATION



# CONCLUSIONS

- Using near-IR Integral Field Spectroscopy we revealed the presence of a powerful outflow in the host galaxy of the 2QZJ002830.4-28170 quasar, by [OIII]5007 velocity and velocity dispersion maps.
- The outflow rate of ionized gas is ~ 300 $M_{\odot}$/yr (lower limit).
- The high outflow velocity and high velocity dispersion suggest that this is a quasar-driven outflow.
- $\mathrm{H}\alpha$ narrow flux map (tracing star formation) shows that the peaks of the emission anticorrelates with the position of the outflow. This suggest that we may have the first observational evidence for Star formation being quenched by quasar feedback.

# CONCLUSIONS

- We found other 4 sources showing outflow signatures but no clear evidences of quenched star formation.
- One source may be showing traces of rotation and the other two show disordered kinematics, which makes them consistent with a merging scenario.
- I suggest that the next step to follow from this work with luminous quasars is to develop a model to fit the velocity fields in order to try to extract more information about the host galaxies and/or the outflows.
- We were able to place points in the $M_{BH}$-$M_*$ relation for obscured type 2 AGNs, we see in general that there are clear traces from the evolution of this relation with z, however in order to understand fully the picture we may need expand this kind of studies with larger samples.