ALMA and SINFONI high redshift observations to test AGN feedback

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Abstract

The epoch between redshift of 1-3 has become the prime focus of many galaxy evolutionary studies as the accretion rates of super massive black holes at the galactic center and the star formation rates of their hosts peaked around this period, pointing to their co-evolution throughout cosmic history. We present two different approaches to study the impact of AGNs on their host galaxies at high redshift (z~1.5): a) SINFONI-IFU observations of a representative sample of high redshift quasars for which we observe intermediate to high velocity outflows using [OIII]5007 line diagnostics. These outflows are extended up-to kiloparsec scales and have an asymmetric geometry. b) CO(2-1) observations from ALMA in a sample of "main sequence" AGNs to compare the star formation efficiency and gas fractions in active and inactive galaxies. With these approaches, one is able to test the effect of AGN feedback on the ionized as well as the molecular gas phases.

Tracing outflows in AGN forbidden region with SINFONI, Kakkad et al. (2016); ArXiv: 1605.08631

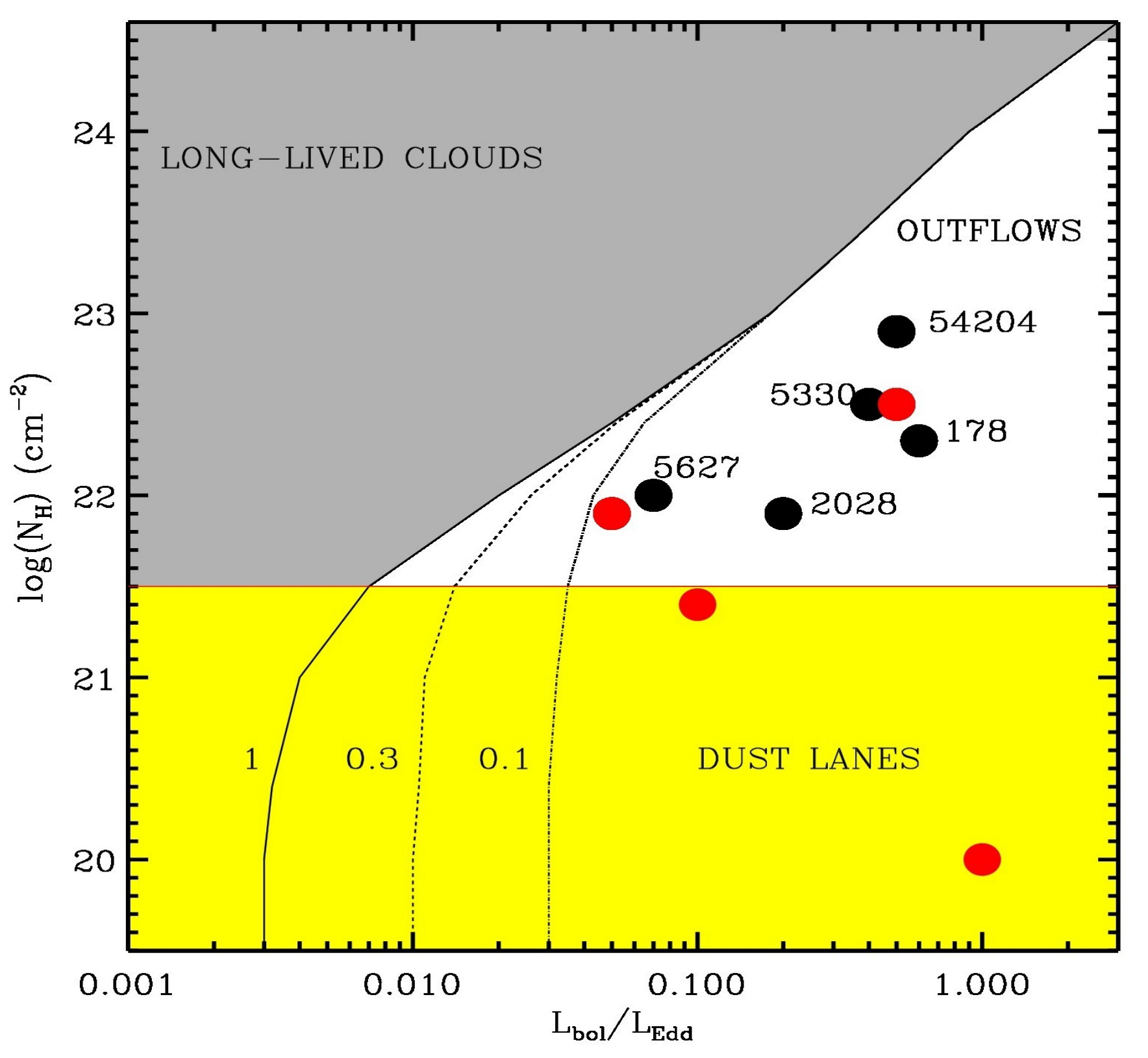

Fig.1: Sample selection

Our sample has been pre-selected to maximize the chance of observing outflows, based on peculiar values of the black hole mass accretion rate and the column density of the surrounding medium. For a typical quasar spectrum exposed to Galactic dust-to-gas ratio, the effective Eddington limit could be a factor of 1000 lower than the classical Eddington limit (Fabian et al. 2008). The result is that long-lived clouds would avoid a region of intermediate column densities and high Eddington ratios (forbidden-region for long-lived clouds), shown by the unshaded area in Fig. 1. Black circles are the sample from this study while the red circles are previously known outflows. We use IFU spectroscopy for this purpose as it allows us to get spatially resolved information.

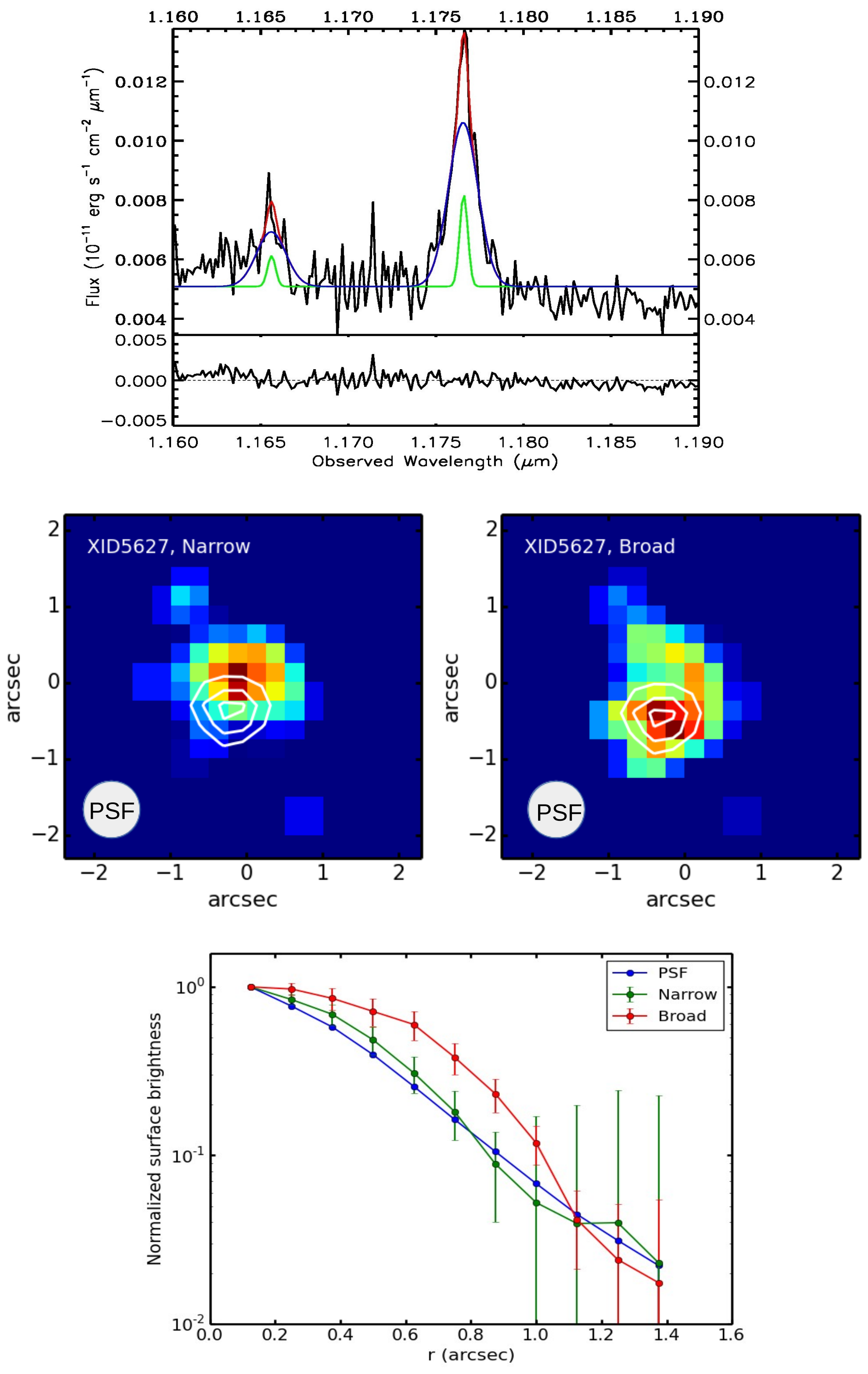

Fig. 2: XID5627

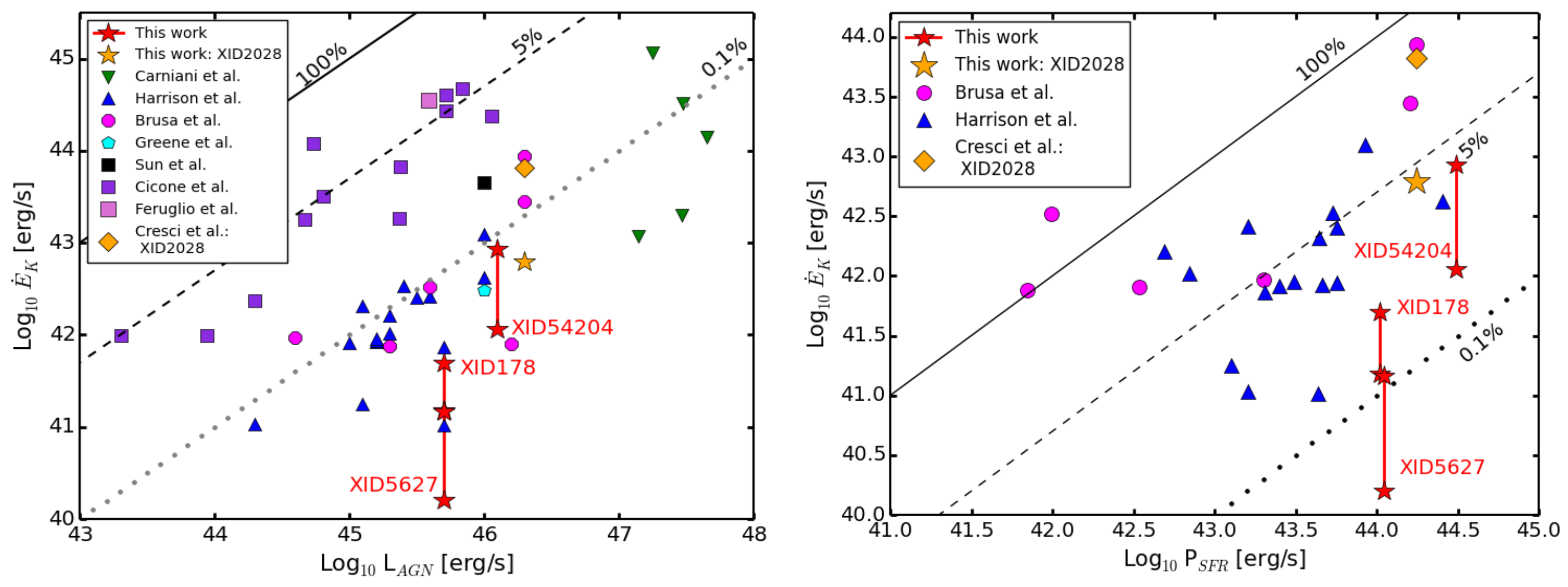

Fig. 3: Outflows AGN or Star formation driven ?

At least 3 out of 5 objects in our sample show evidence of extended outflows. Fig. 2 shows an example object, XID5627 for which presence of outflows is inferred from the extended [OIII]5007 profile shown in the top panel. Narrow and Broad components are emitted from different spatial locations as apparent from the middle panel. Their extension up to 8.5kpc is confirmed by comparing the surface brightness profiles of the individual components with that of the Point Spread Function (Lower panel).

Fig. 3 shows the coupling between the outflow kinetic power and the AGN luminosity (left) and power due to star formation (right). The squares represent the observed molecular outflows while the other symbols denote the ionized outflows. Our sample falls in the low energy regime (~0.1% coupling) which could potentially be driven by both AGN and star formation. The exact source of these outflows could be confirmed through observation of outflows in other gas phases, namely molecular and neutral phase.

The quantities derived for ionized outflows are affected by significant uncertainties. Apart from the lack of 3D information, inconsistencies in velocity, electron density and temperature measurements introduce errors as large as 2 orders of magnitude which make it challenging to infer the exact source of outflows in AGN host galaxies. Hence, we stress on the importance of further detailed observations to constrain the outflow energetics.

ALMA observations of cold gas content in AGN hosts in the Main Sequence, Kakkad et al. (in prep)

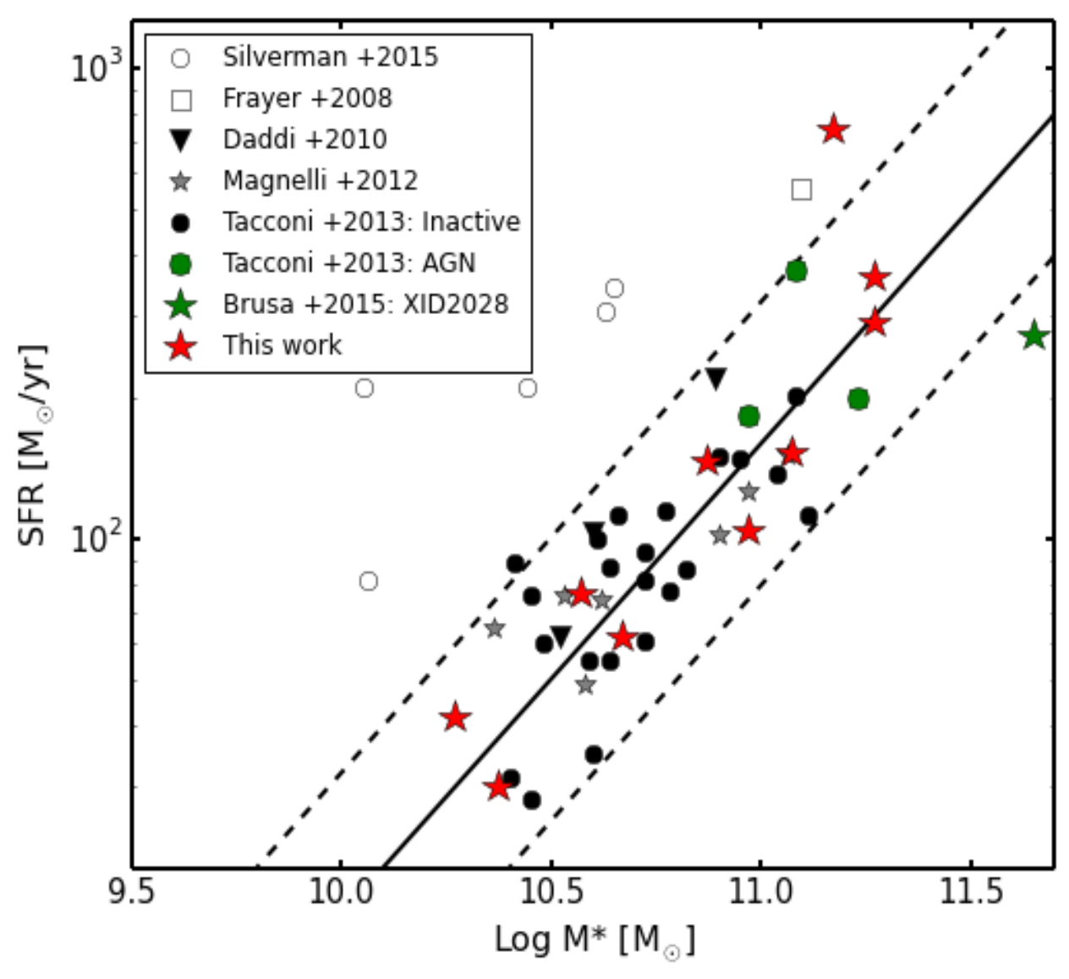

Fig. 4: Inactive and Active galaxy sample

We use a representative sample of 11 AGNs drawn from the COSMOS field in the “main sequence” of galaxies at z~1.5 to test if the presence of an active SMBH affect the cold gas content of their host galaxies. This high redshift regime presents an interesting laboratory to test radiative feedback from AGN since the volume average accretion rate peaked during this epoch. We measure CO(2-1) in these galaxies using Band-3 of ALMA. Our comparison sample of inactive galaxies are drawn from Tacconi +2013, Magnelli +2012 and Daddi +2010 such that they cover the same region of SFR-M* plane as shown in Fig. 4.

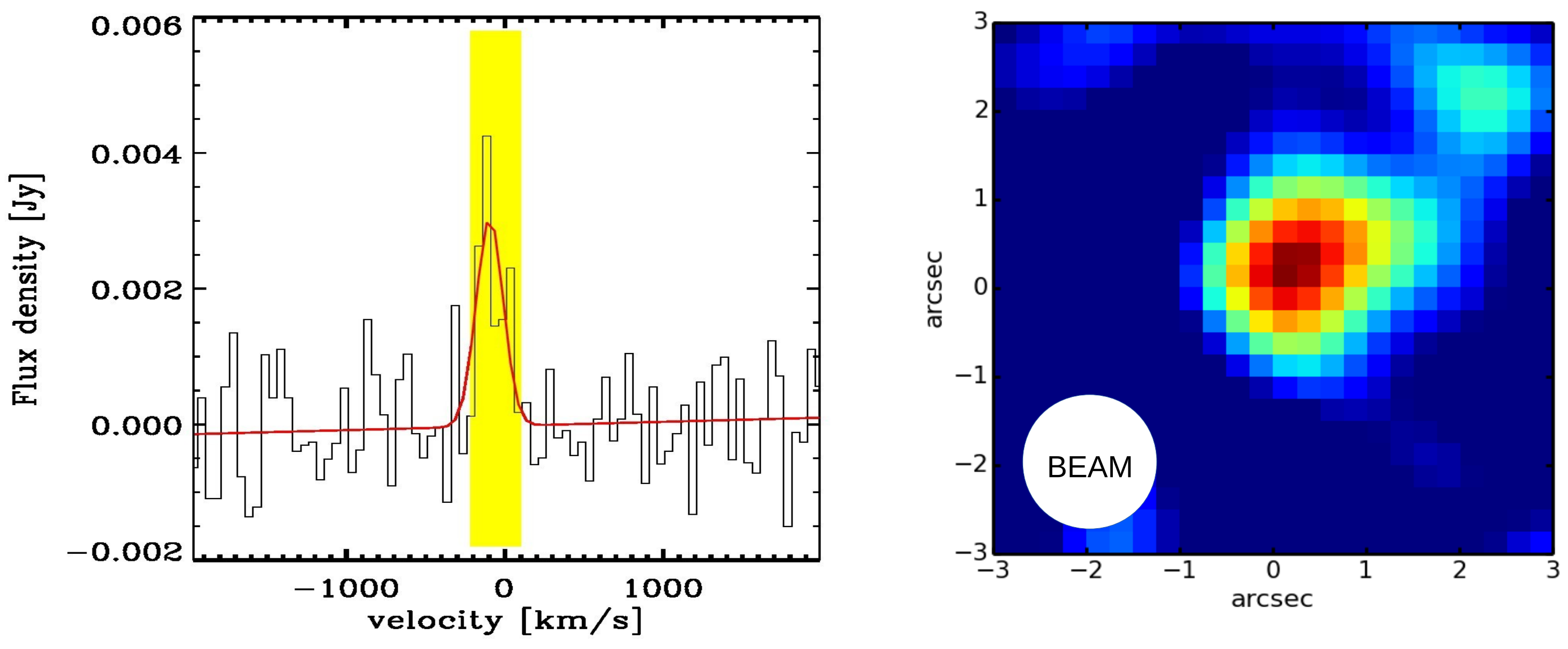

Fig. 5: CO(2-1) spectra of one of our sample and the corresponding moment 0 map in channels shaded by yellow

We detect CO(2-1) in at least 3 out of the 11 objects in our ALMA sample (>5σ detection in two and >3σ in one). An example of the spectrum obtained with ALMA for one of our objects is shown in Fig. 5, left panel. The flux of CO(2-1) obtained from the spectra and UV plane analysis are consistent with each other. The right panel in Fig. 5 shows the moment 0 map collapsed in the channels shown by the yellow region in the spectrum. The continuum remained undetected for all of our sample.

To obtain the molecular gas mass, we use the canonical relation $M_{H2} = \alpha_{co} L_{co}$.

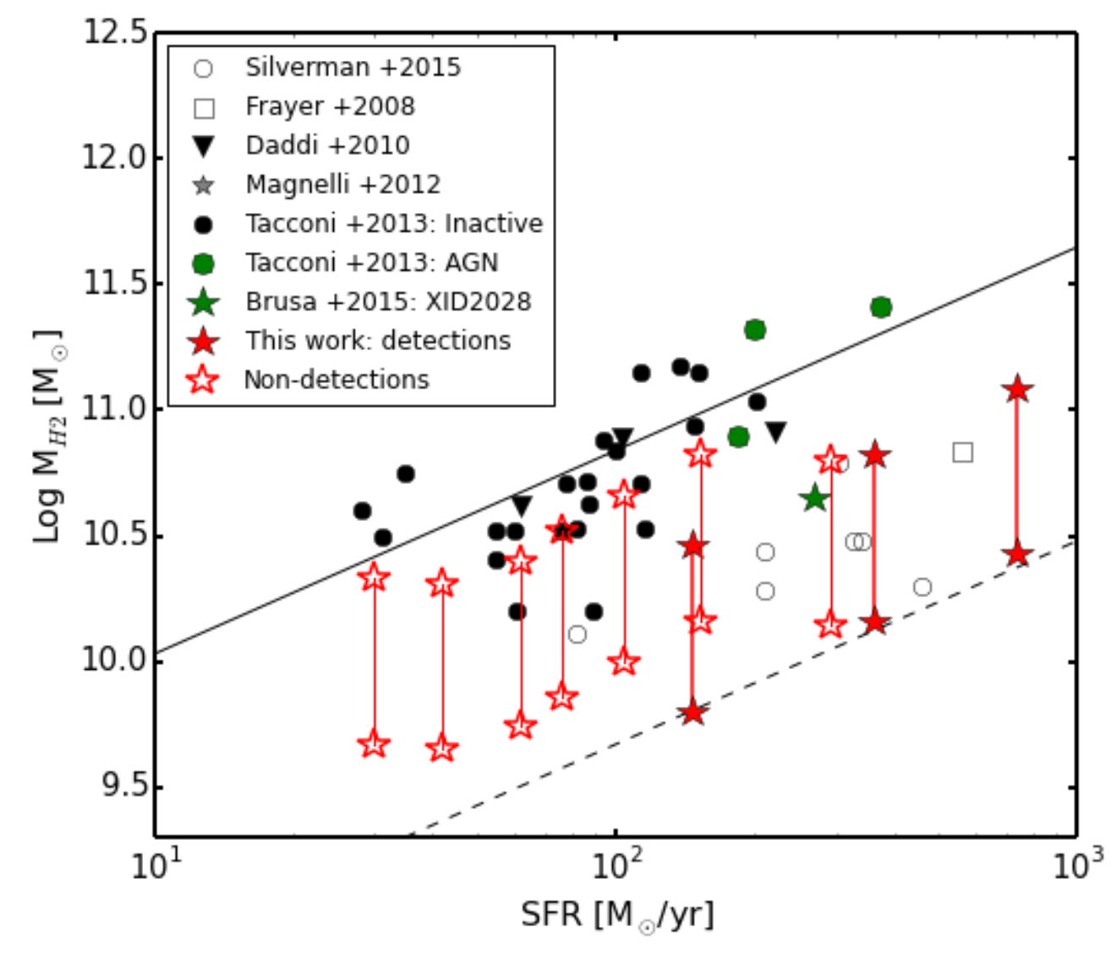

Fig. 6: Molecular mass vs. SFR for our sample.

We explore a range of α parameter (0.8-3.6) for our analysis based on the previous literature values. Normal star forming galaxies are known to show a correlation between the molecular mass and SFR as shown by the solid black line in Fig. 6. Starbursts, on the other hand, occupy the region shown by the dashed line. Our molecular mass estimates of the AGN sample lie in an intermediate region between the starbursts and the inactive population pointing to an efficient star formation process or depleted gas in AGN hosts. Could this be an indirect evidence of AGN feedback at play ?

Conclusions

- Our SINFONI observations indicate the presence of kiloparsec scale outflows in AGN host galaxies, which shows the efficiency of the selection procedure used.
- Whether these ionized outflows are driven by AGN or star formation can be confirmed by further observations in other gas phases such as the molecular and neutral. Also there is a need for detailed observations to minimize the uncertainties associated with the outflow powers.
- Preliminary results from our AGN sample observed with ALMA shows depleted gas content or a higher star formation efficiency in AGN host galaxies. Is this an indirect evidence of AGN feedback at play ?

- Future work will focus on a blind survey of AGN population to check how common are the outflows in AGN hosts. Sinfoni survey for Unveiling the Physics and Effect of Radiative feedback (SUPER) is one such undergoing survey which aims to trace ionized outflows and their effect on star formation in a sample of AGN hosts in the COSMOS field.