AGN-driven outflows in the early Universe

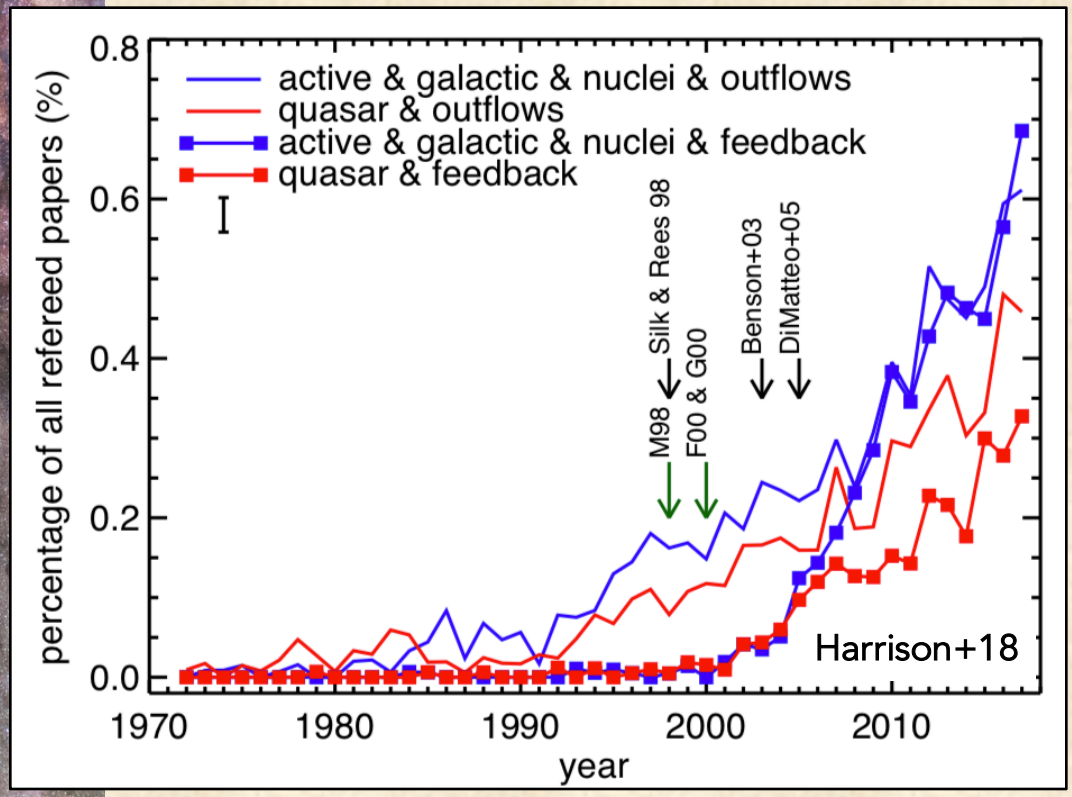
Stefano Carniani

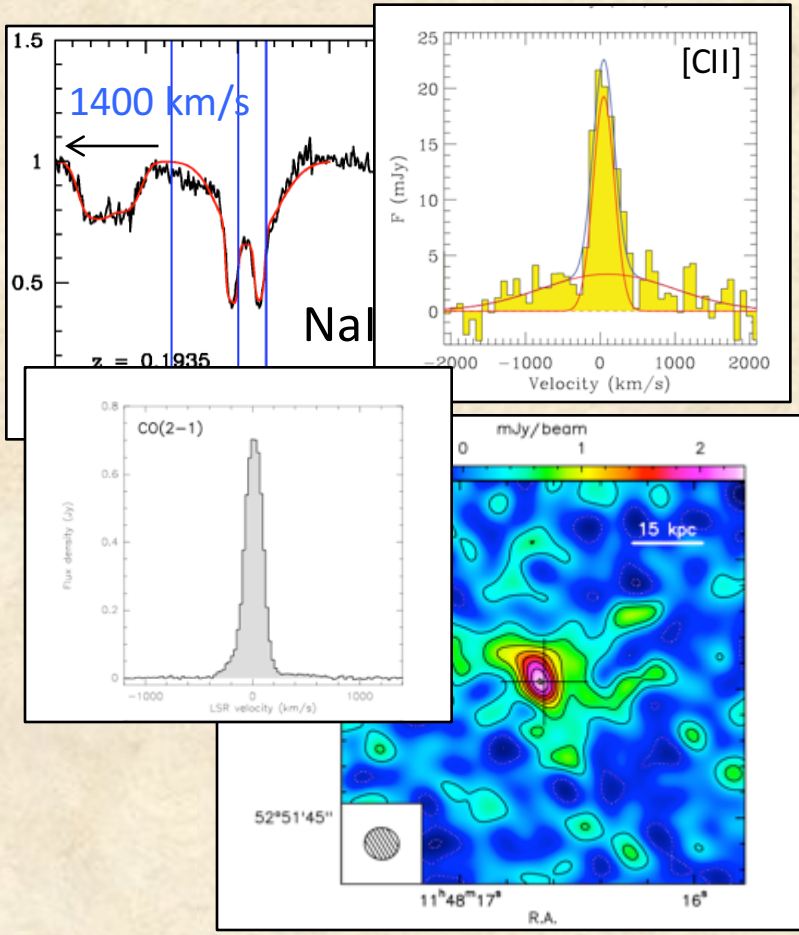
Maiolino R., Marconi A., Venturi G., Cresci G., Brusa M., Fluetsch A., Ferrara A., Gallerani S., Fiore F., Cicone C., Ohad S., Netzer H., Schneider R., Balmaverde B., Nagao T., La Franca F., Comastri A., Mannucci F., Risaliti G., Piconcelli E., Feruglio C., Cano-Diaz M., Mainieri V., Testi L., Sani E.,

SCUOLA NORMALE SUPERIORE

Galactic Outflow

In the last few years, extensive observing programs have been dedicated to the detection and characterization of galactic outflows





Rupke+11,13, Spoon+11, Muller-Sanchez+11, Maiolino+12, Cicone+15,+16,+17,+18, Feruglio+15, Cano-Diaz+12, Alexander+10, Harrison+12,+14,+17,+18, Urrutia+14, Perna+15, Brusa+15, Cresci+15,+16, Kakkad+16,

z~0.1 z~2.5 z~6

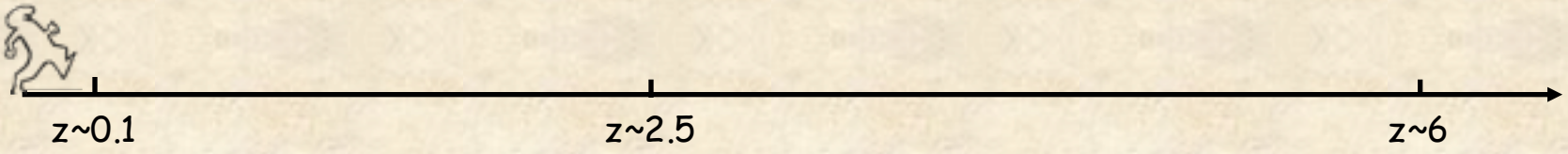
Galactic Outflow

We know….

Galactic outflows driven either AGN or starbursts are capable of expelling ionized, atomic neutral and molecular gas from galaxies

We don't know…

how galactic outflows affect the evolution of host galaxies



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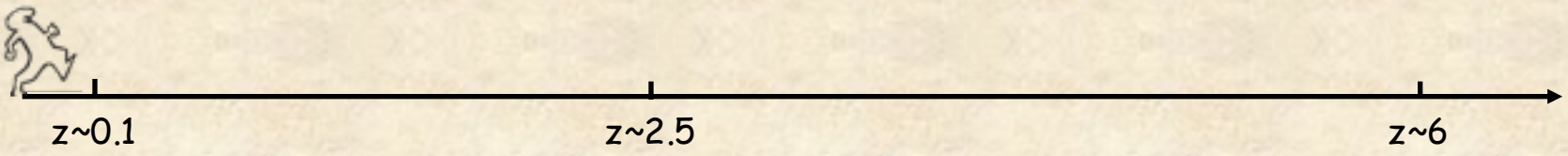
Searching evidence of AGN feedback at

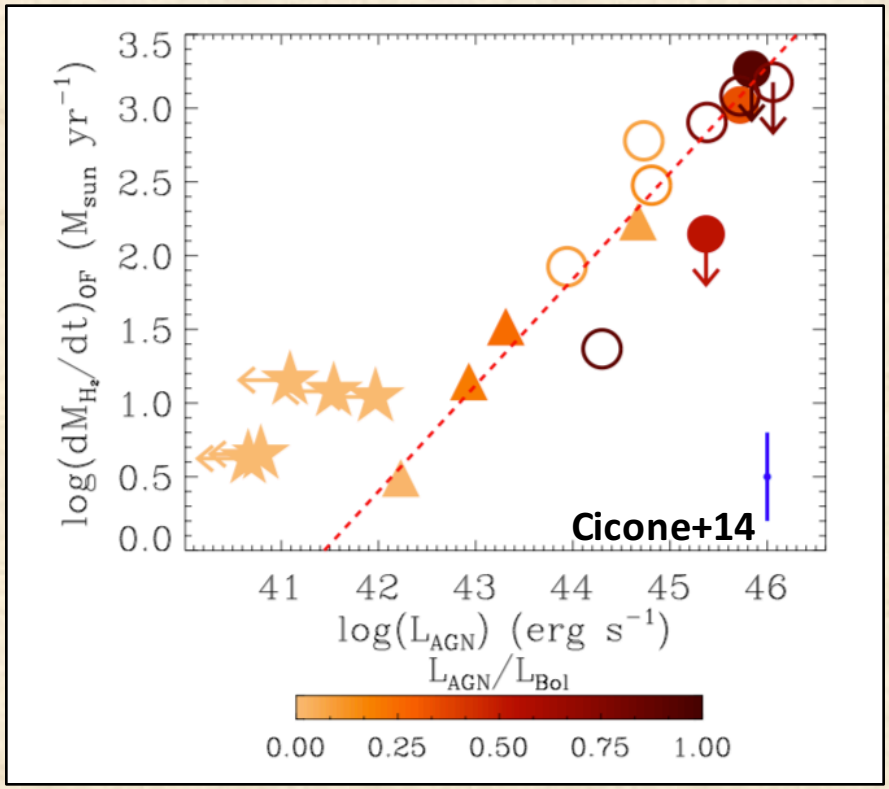
1) z~0.1
2) z~2.5
3) z~6



Galactic Outflows at z~0.1

Goal:
Characterizing in detail and with "large" statistics the properties and scaling relations of molecular outflows dependence on SF, AGN luminosity, stellar mass

Why:
previous studies have low statistics



z~0.1 z~2.5 z~6

Galactic Outflows at z~0.1

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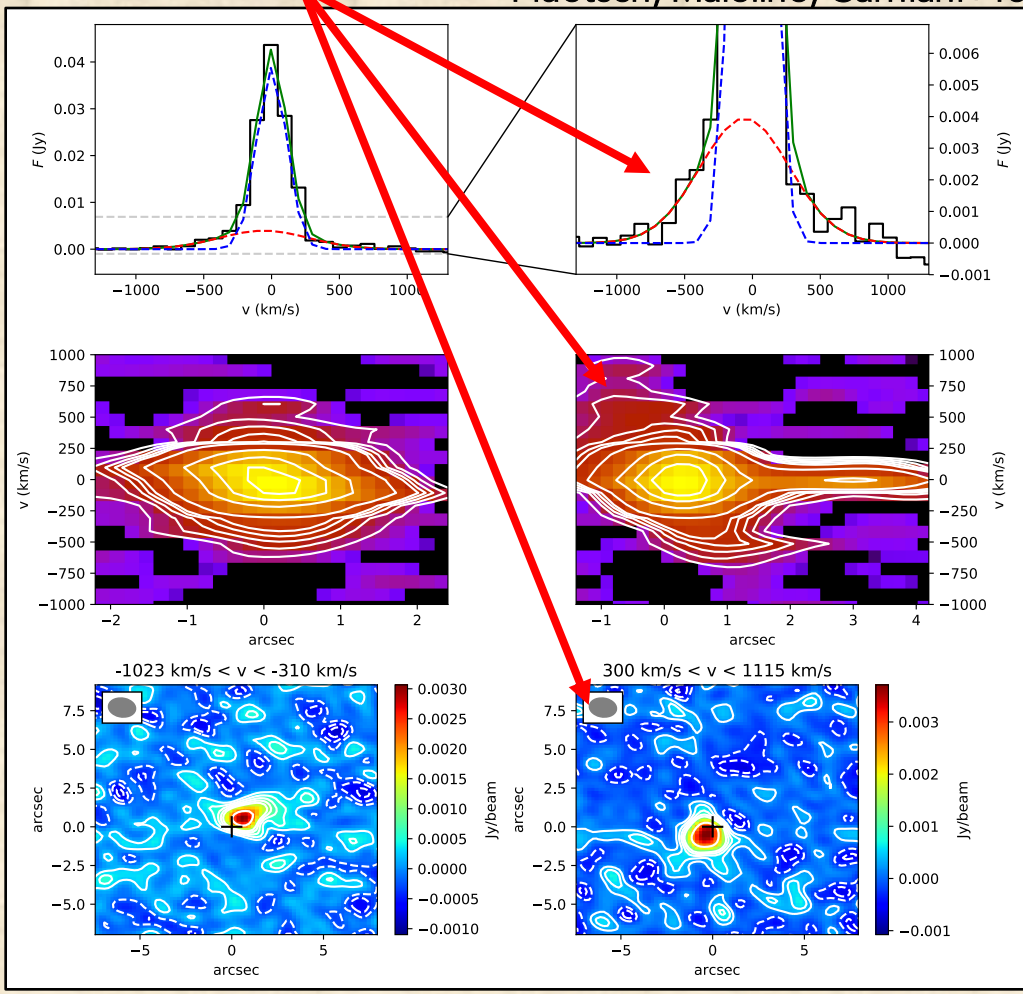
Characterizing in detail and with "large" statistics the properties and scaling relations of molecular outflows dependence on SF, AGN luminosity, stellar mass

outflow

Fluetsch; Maiolino; Carniani+18



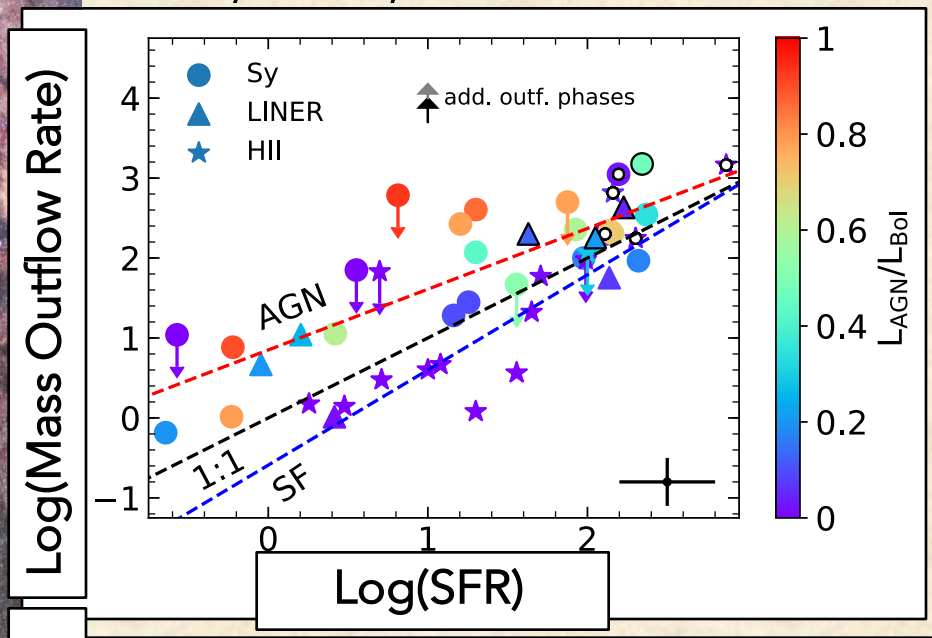
Sample:

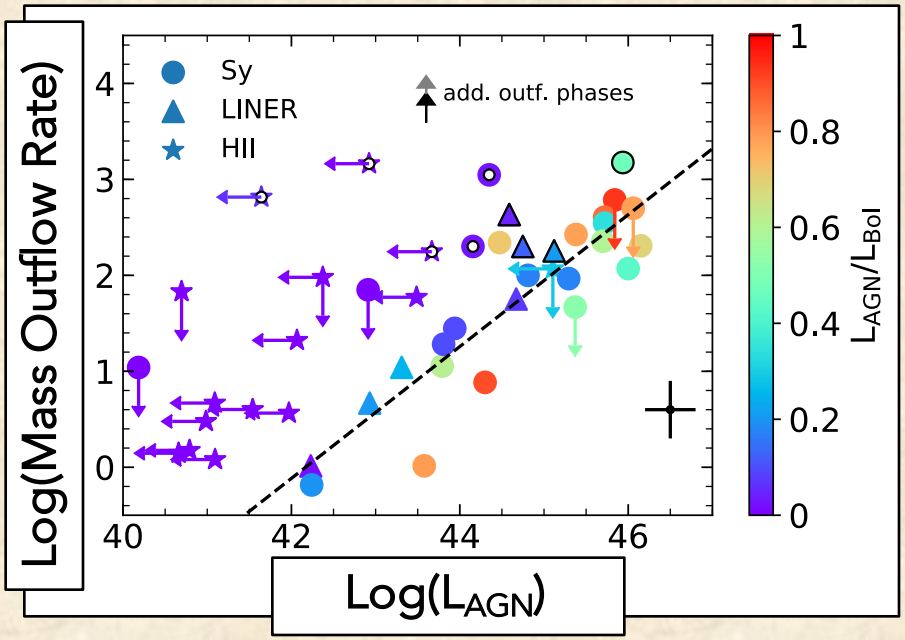
- low-J CO lines 45 galaxies (literature & ALMA archive)
-
- $z < 0.2$
  $5\ M_\odot/yr < SFR < 750\ M_\odot/yr$
-
- $10^{10} M_\odot < M_\star < 10^{12.2} M_\odot$

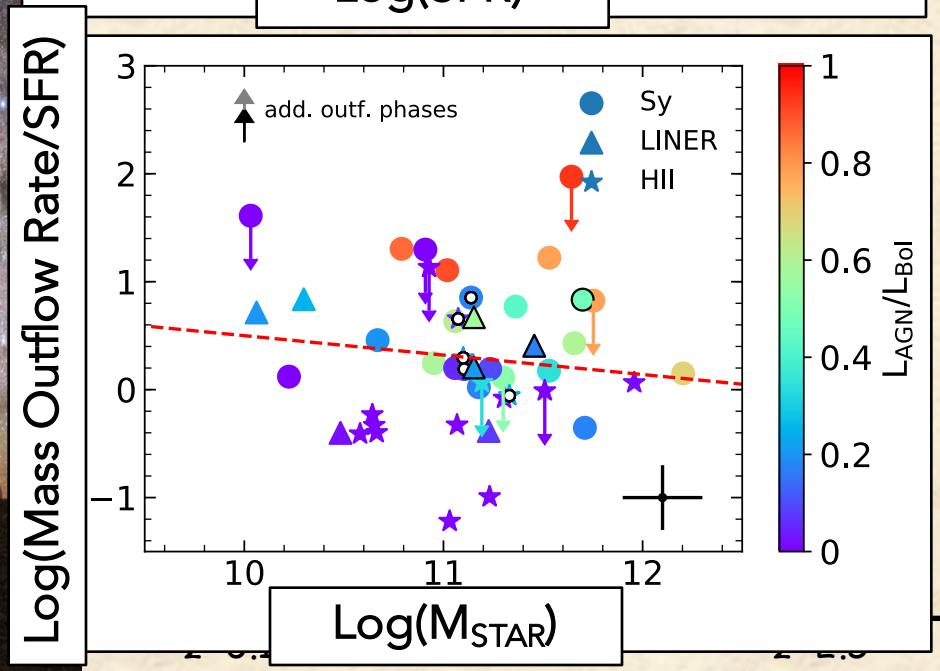
z~0.1 z~2.5 z~6

Galactic Outflows at z~0.1

Fluetsch; Maiolino; Carniani+18







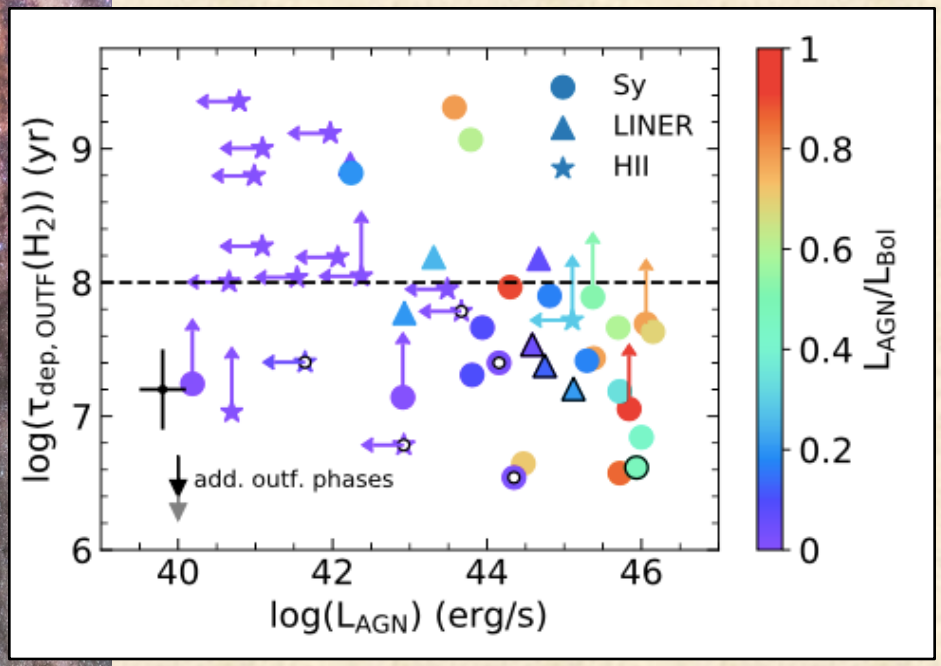
- Mass outflow rate depends on the star-formation, AGN activity, and stellar mass.
- Larger scatter than previously by Cicone+14 in a smaller sample

z~6

Galactic Outflows at z~0.1 (feedback?)

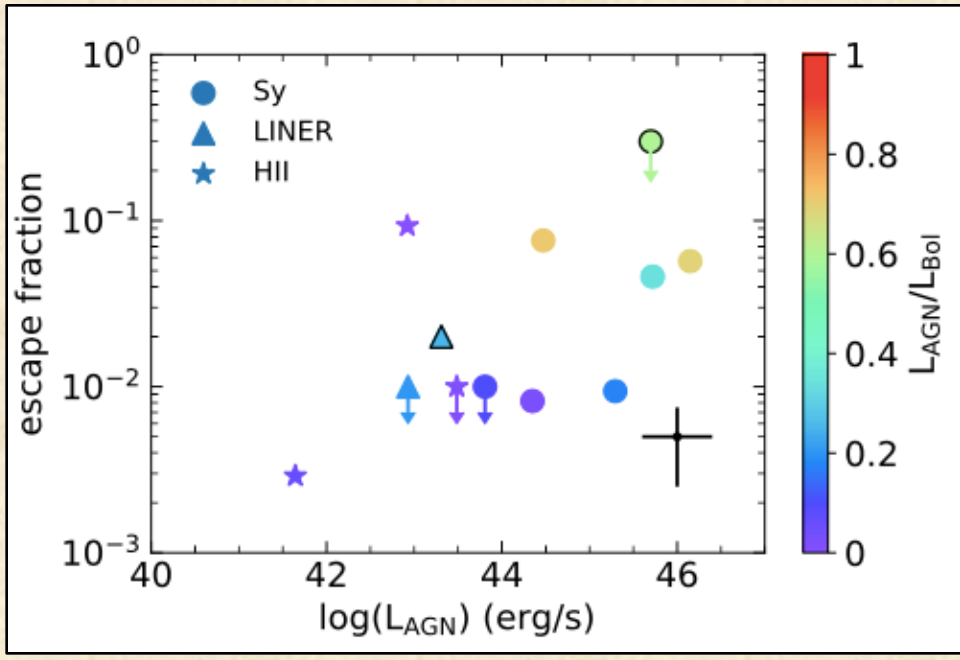
outflow depletion timescale

$\tau_{\rm dep} = M_{\rm mol}/\dot{\rm M}_{\rm outflow}$



depletion time scale is $>10^7$ yr

fraction of the molecular outflow that escapes the galaxy



only 2% of the gas escapes the galaxy

AGN-driven outflows are capable of removing the gas from the central regions, but unlikely to clean the entire galaxy from its gas content.

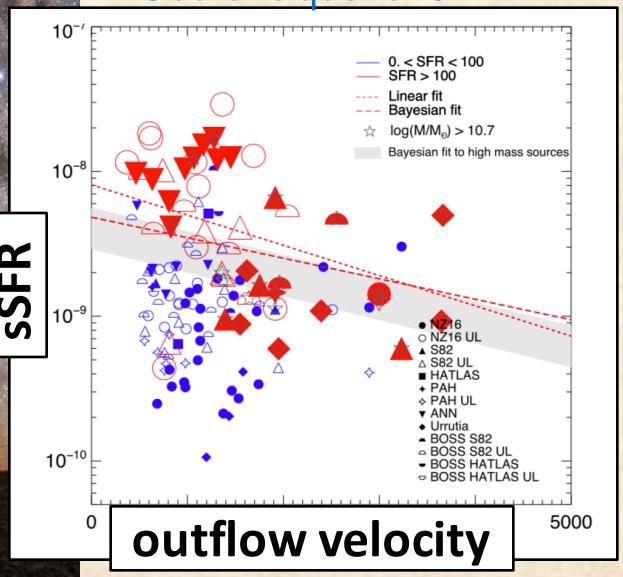
Evidence for AGN feedback

- QSO lifetime much shorter than timescale needed for feedback effects to manifest
- Delayed AGN feedback
- Mixture of multiple mechanisms that regulate BH and galaxy growth

"The long-term negative and/or positive impact on star formation by AGN-driven outflows is an ongoing challenge, with many apparently contradictory results (Harrison+18)

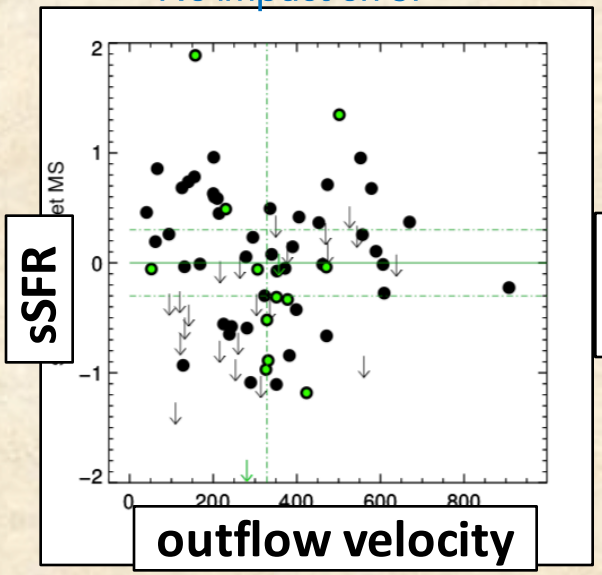
Wylezalek

Outflows quench SF



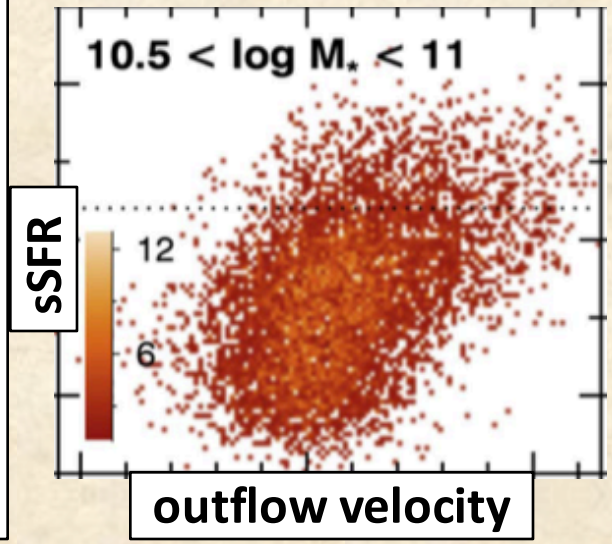
Wylezalek+16

No impact on SF



Balmaverde+15

Outfloww trigger SF



Woo+17

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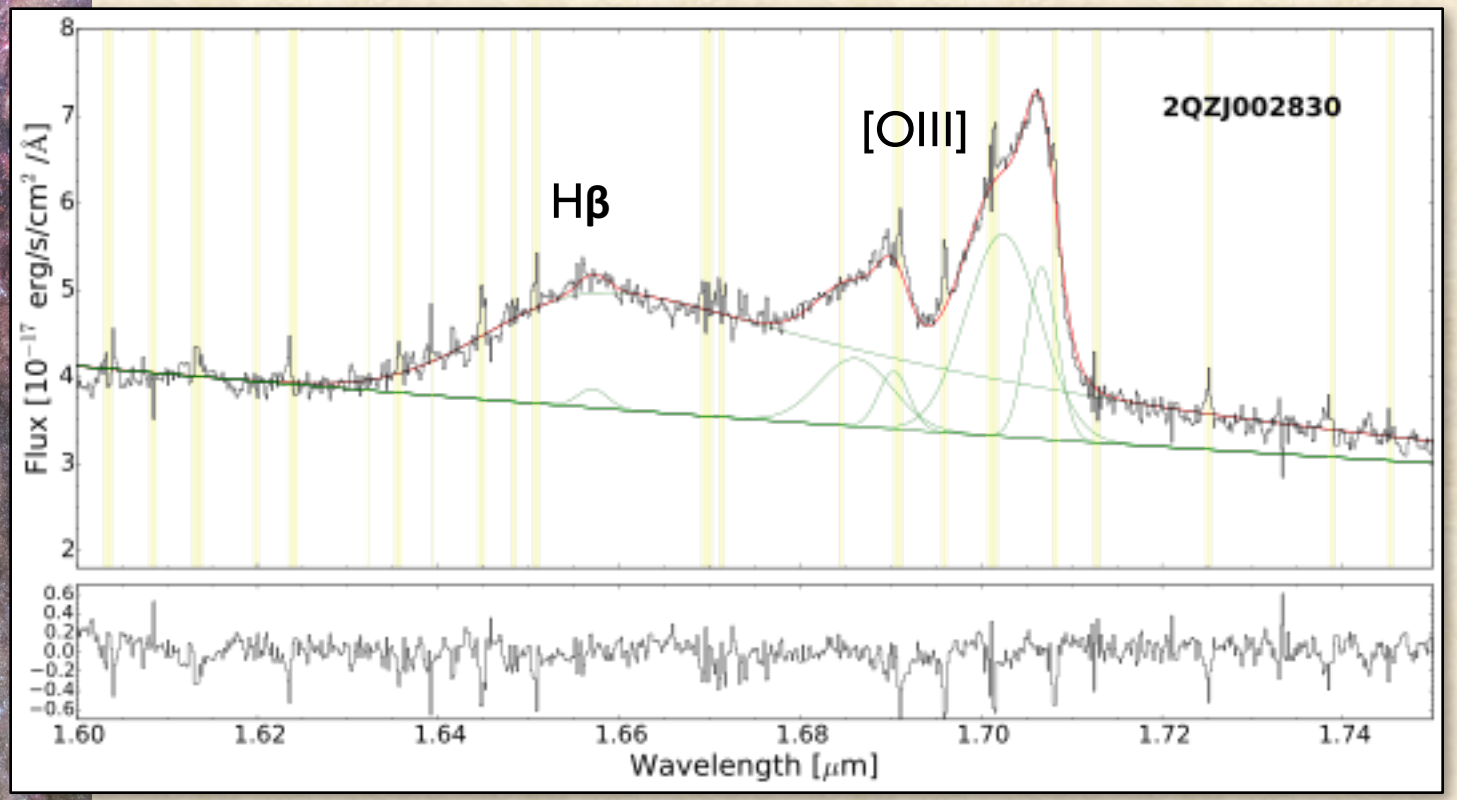
investigate thoroughly individual, pre-selected targets

Ionised Outflows at z~2

At high-z quasar-driven outflows primarily traced in the ionized phase
(e.g. Carniani+15,16, Brusa+15 Cresci+15, Harrison+16)



Sample:

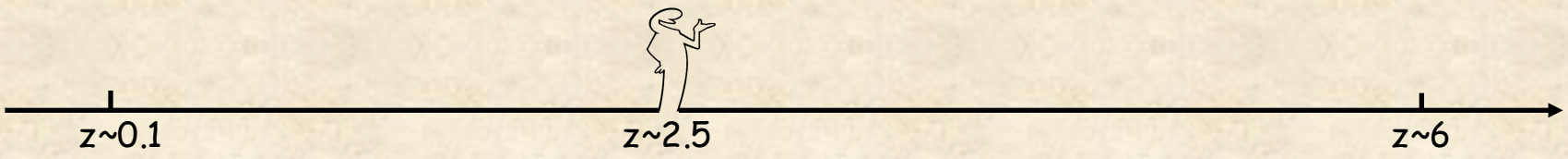
QSOs at z= 1.5-2.5

$L_{AGN} \approx 2\text{-}3 \times 10^{47}$ erg/s

Broad [OIII] (FWHM >1000 km/s)

Deep SINFONI H-band observations (6h on target)

Seeing limited resolution (0.5")



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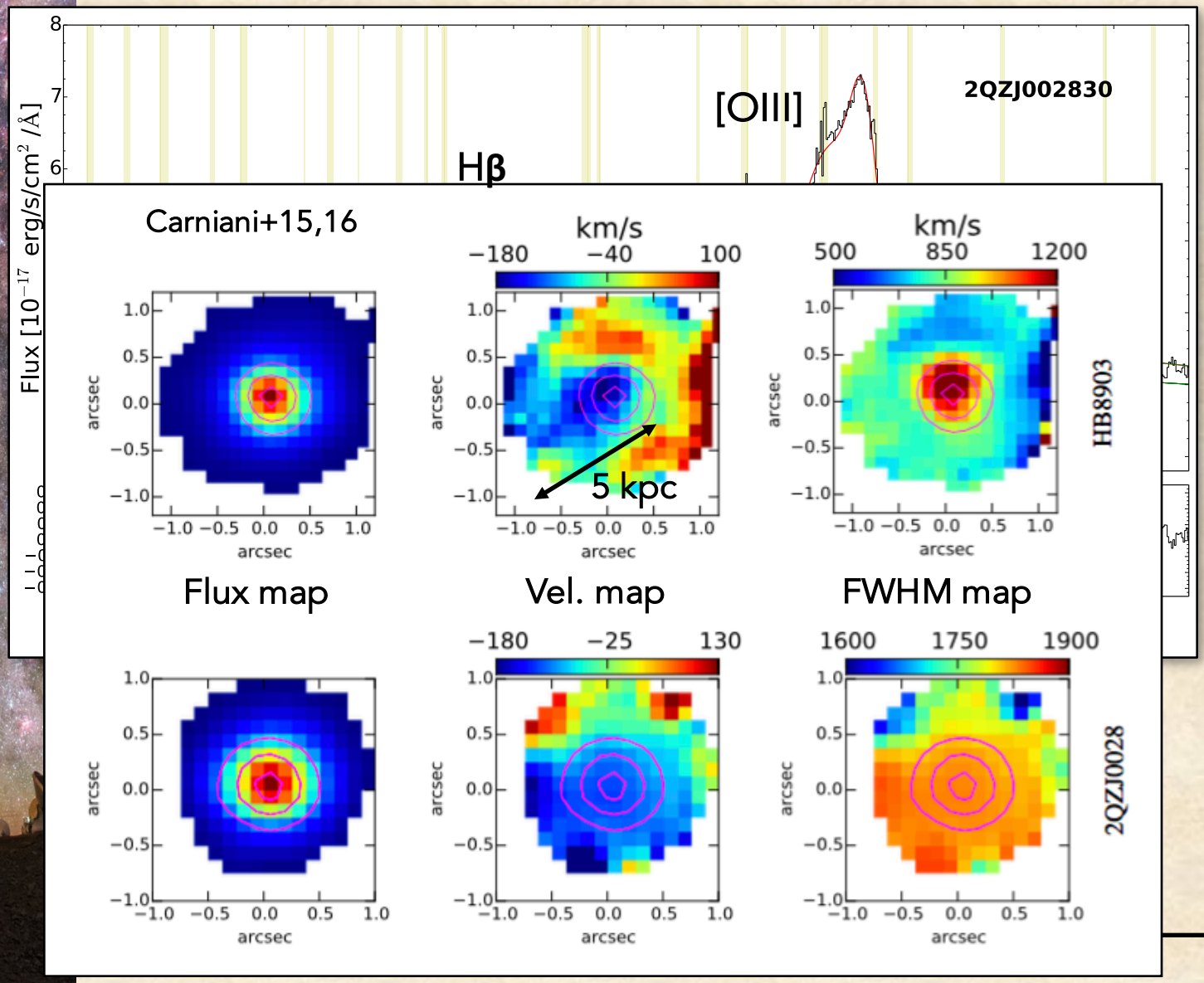

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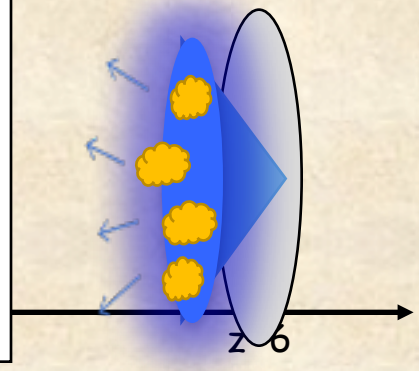
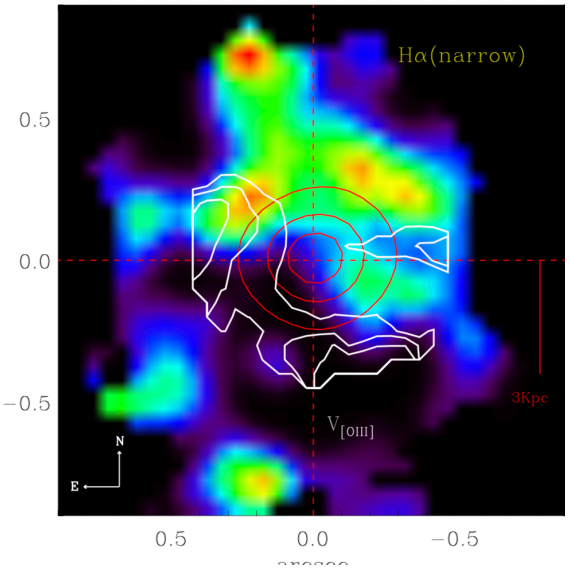
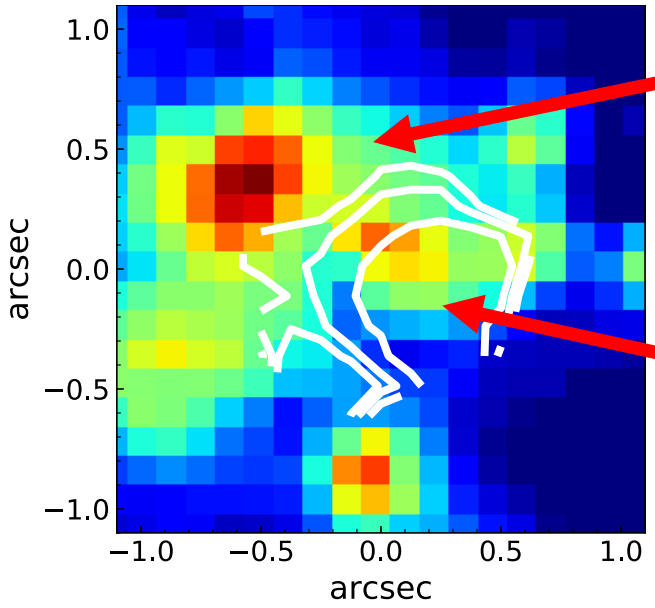


AGN feedback

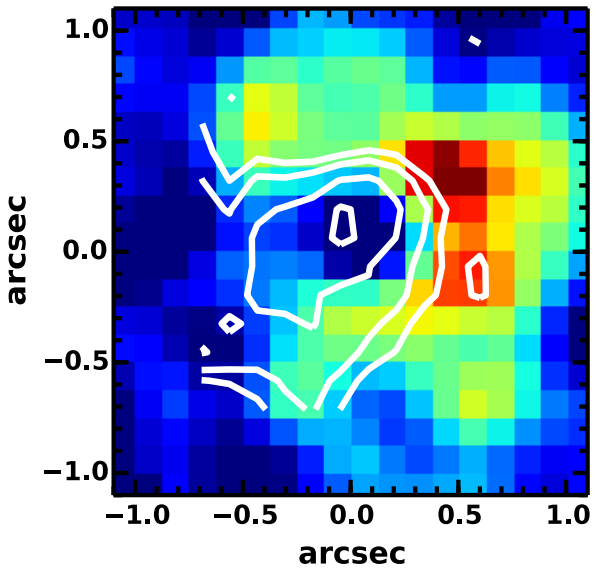
Cano+Diaz+12, Carniani+15,+16, Cresci+15, Brusa+18

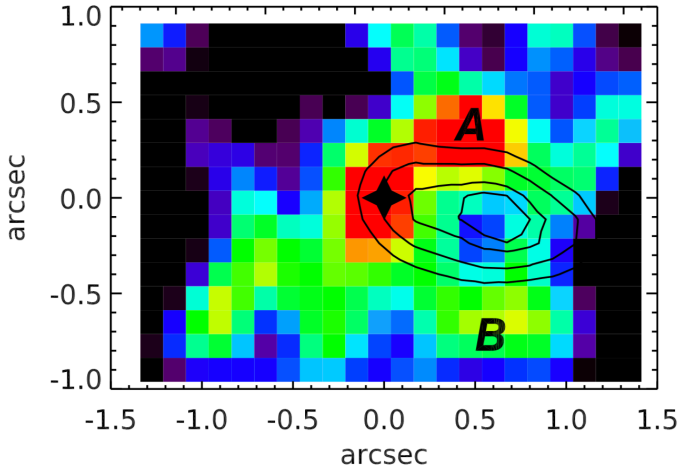




Star formation (Hα/[OIII] narrow component)

Outflow ([OIII] blue wing contours)





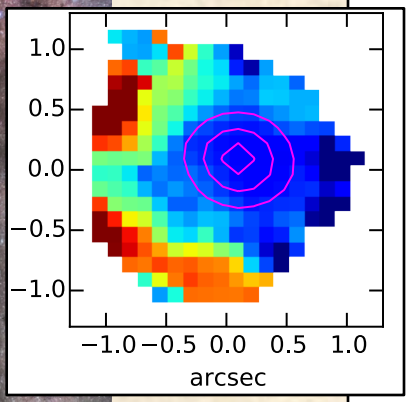
Narrow Ha emission tracing star formation is anti-correlated with fast outflow

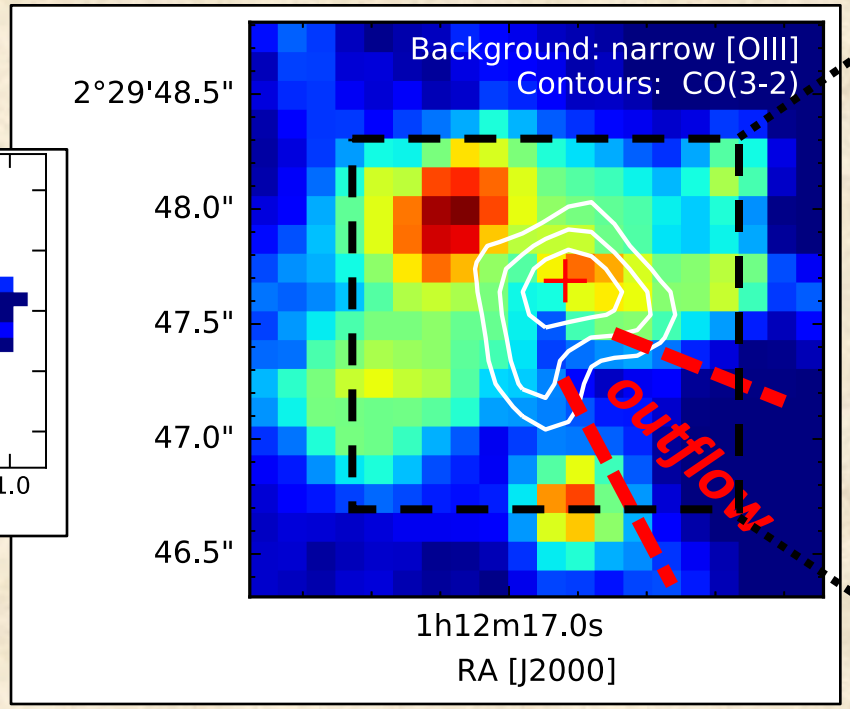
z~6

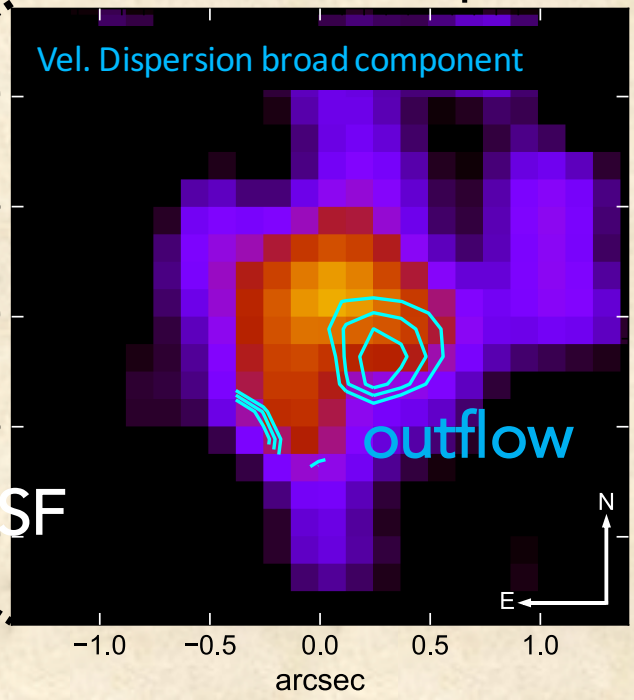
ALMA Follow-up

Carniani+16,+17

CO(3-2) flux map

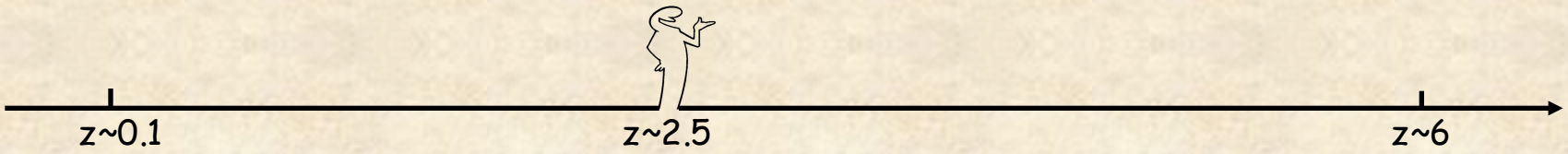




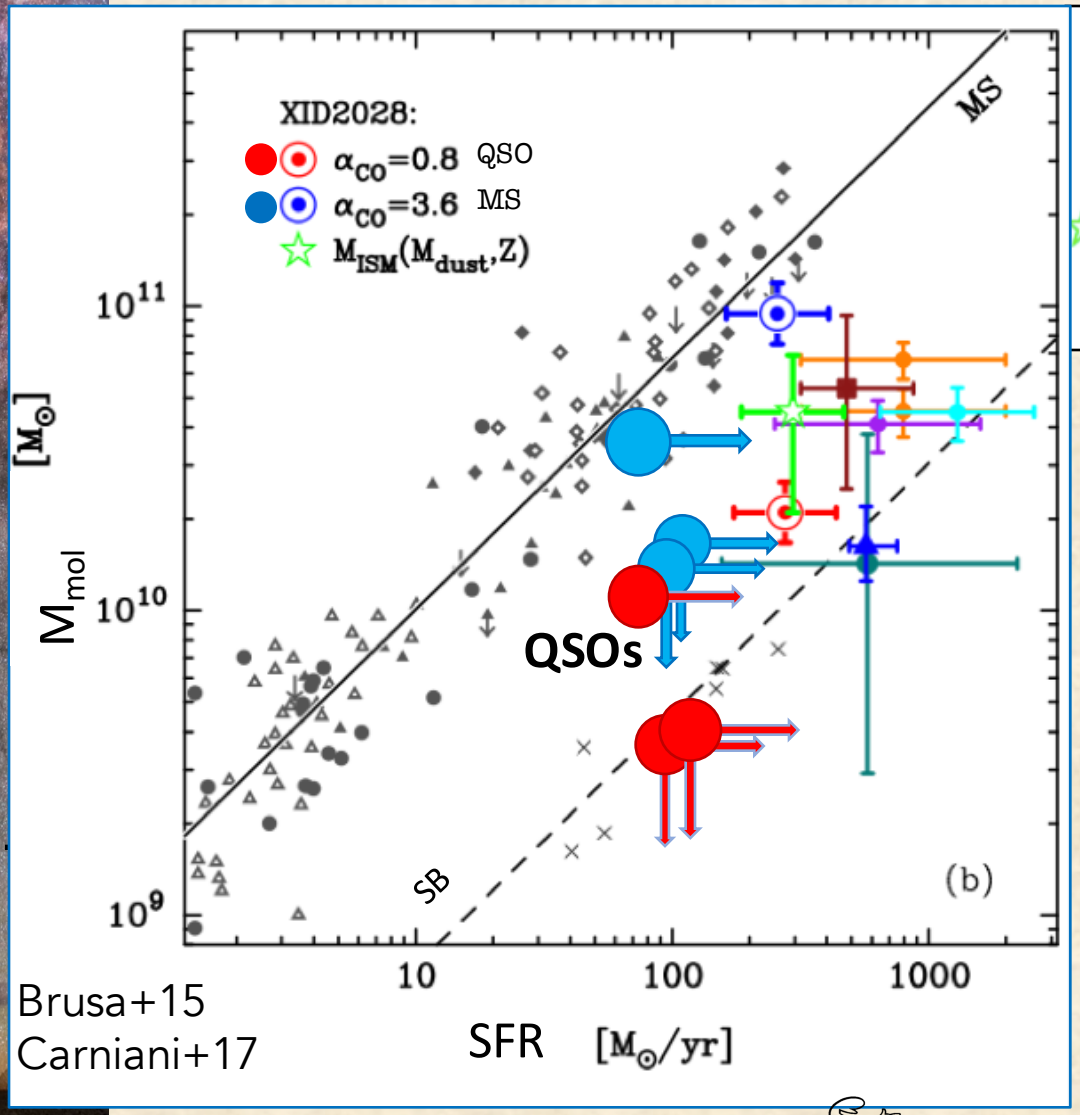


CO(3-2) emission is co-spatial to the SF region

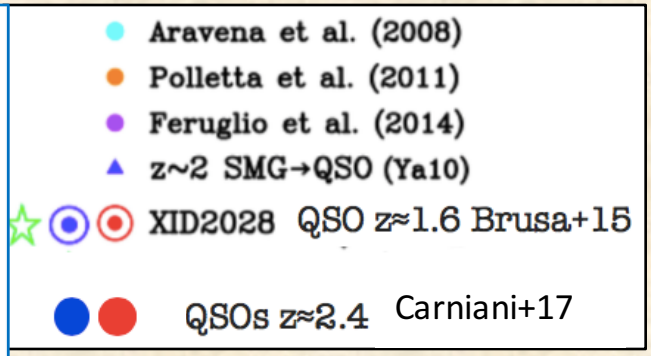
CO emission fainter in the outflow region



Cold Molecular Gas in AGN hosts



Brusa+15
Carniani+17



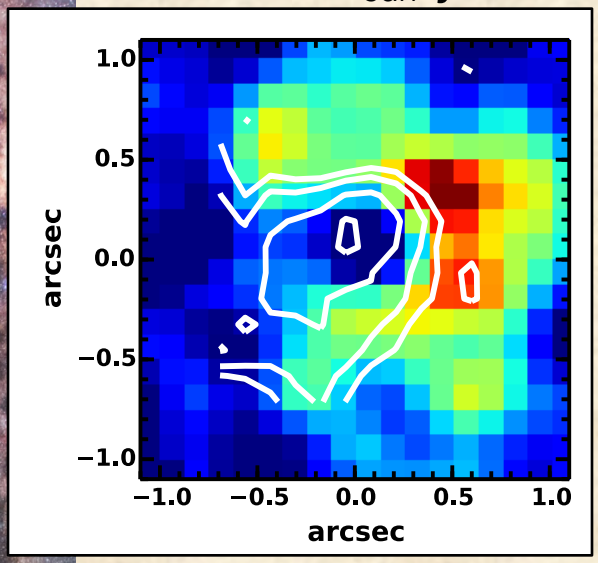
Low M_{mol} in AGN host galaxies (Carniani+17, Kakkad+17, Brusa+18)

evidence of AGN feedback?

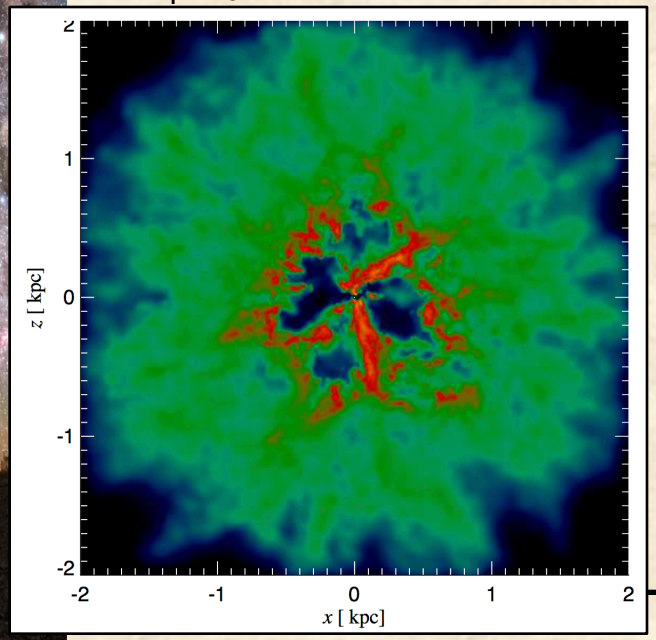
z~0.1 z~2.5 z~6

Negative Feedback?

SFR~100M_{sun}/yr

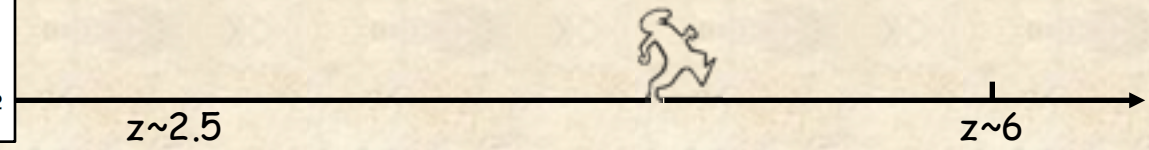


map Σ_{SFR} (Zubovas+17)



Observations of limited amount of star forming AGNs suggests that:

- gas removal may affects only a limited region of the host galaxy
- limited direct impact of AGN outflows on SF in hosts (e.g. Roos+15, Hartwig+17)
- positive feedback (Cresci+15, Maiolino+17)



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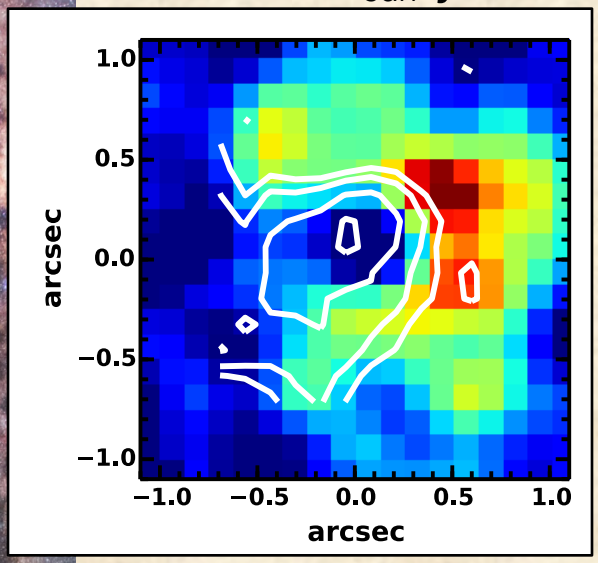

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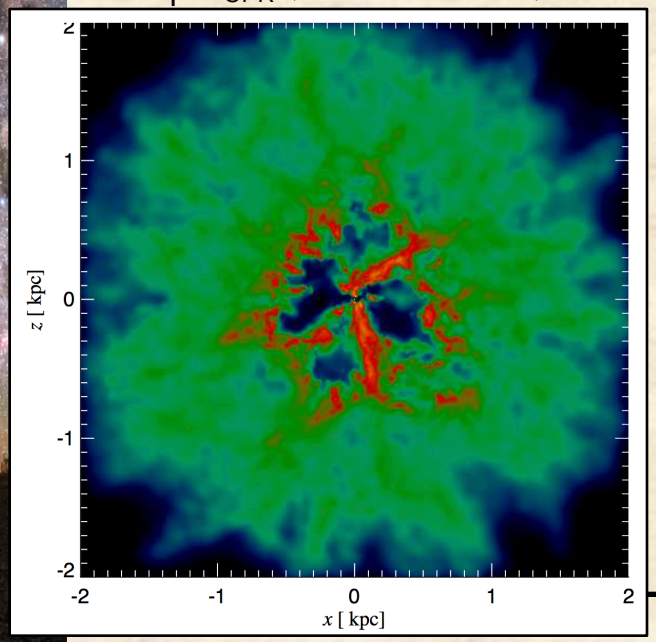

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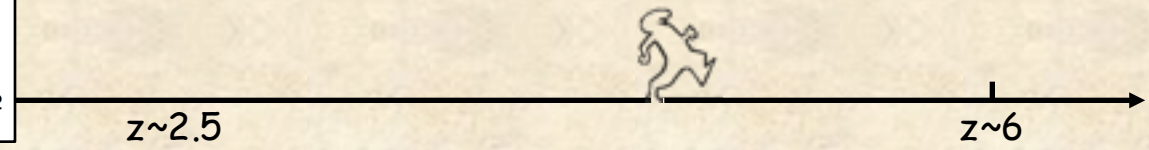
And at higher redshift?

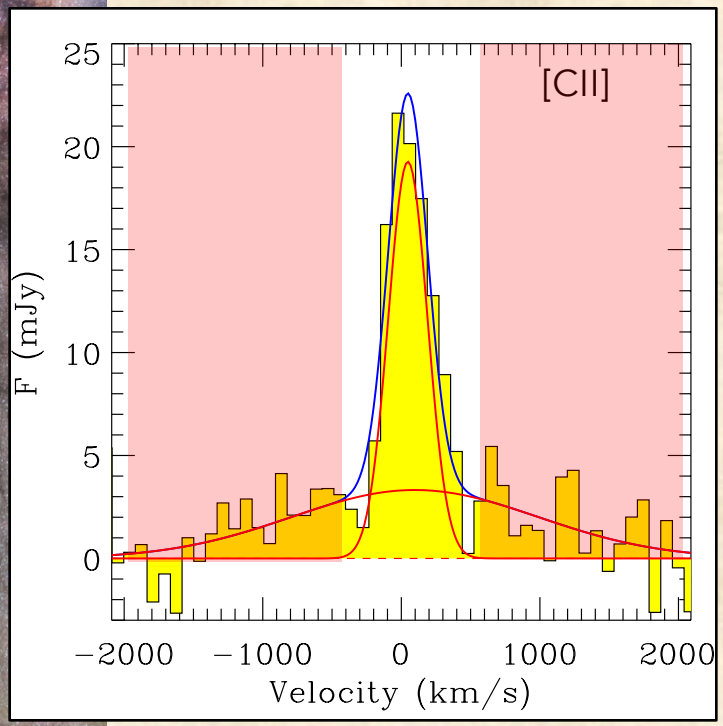
Observations of quiescent, old and massive systems at z~2 (Cimatti+04, Saracco+05, Glazebrook+04), implies the quenching process must have occurred at z~5–6

Detecting the cold component of QSO-driven outflows (and feedback) at z~6 can, paradoxically, be easier than at lower redshifts

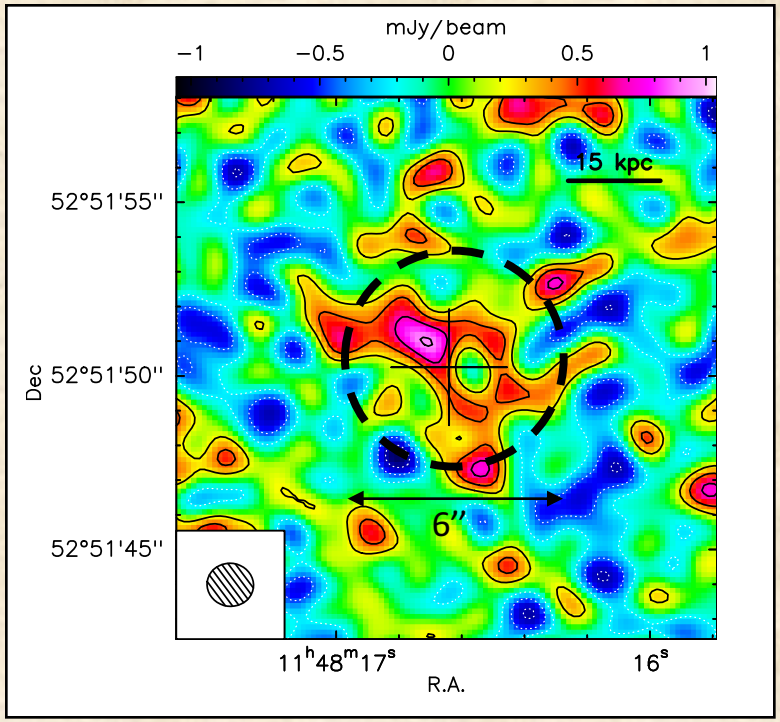


Extreme QSO-driven outflow at z~6

Maiolino+12 and Cicone+14 report the first detection of a massive quasar-driven outflow at z>6.



Flux Map of [CII] wings



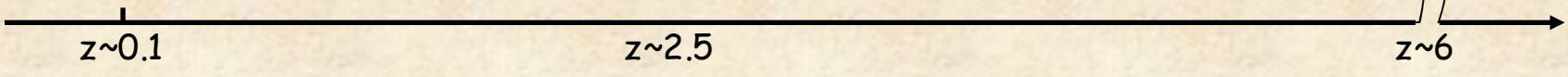
[CII] @ z=6.4189
SDSS J1148+5251
SFR=1000$M_\odot$/yr
$L_{bol} = 10^{47}$ erg/s

Outflow :

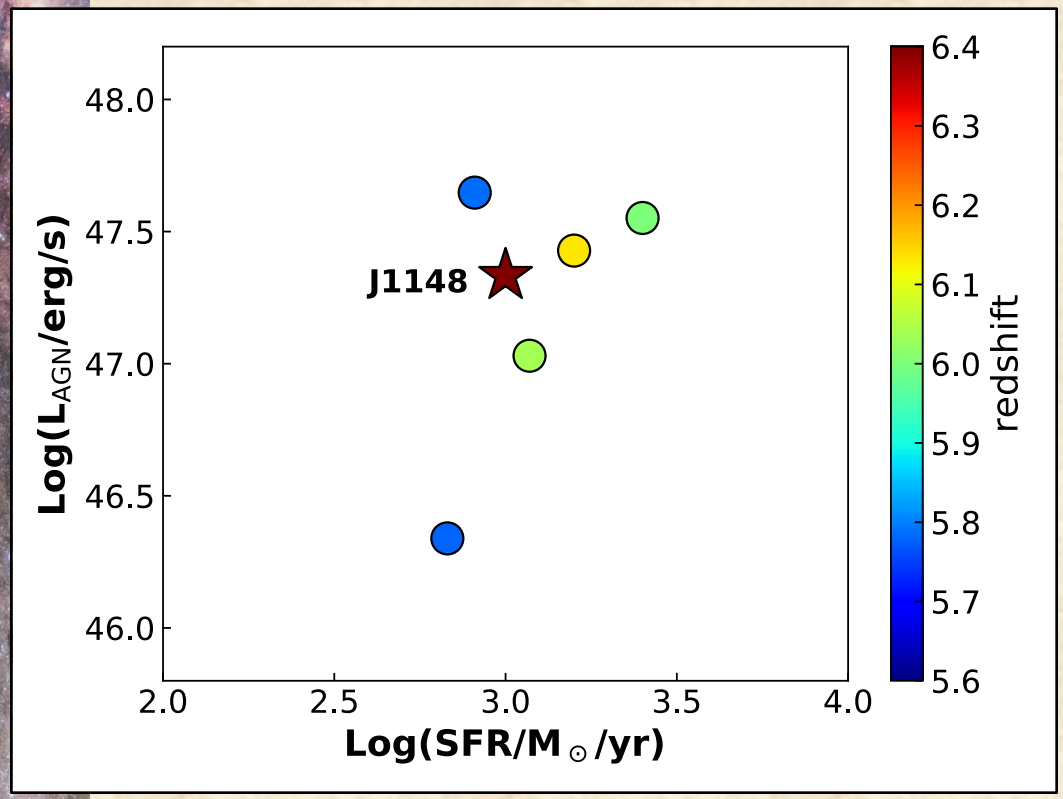
- Multi-clumps
- >30 kpc
- v~1400 km/s
- Depletion time scale $<10^7$ yr

- Can potentially clean the whole galaxy of its gas content in only ~10 Myr

Maiolino+12
Cicone+15



QSO feedback at z~6 with ALMA



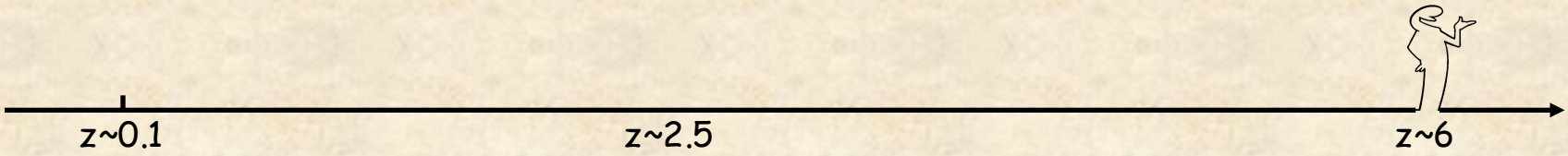
Carniani+18 (in prep.)

Sample:

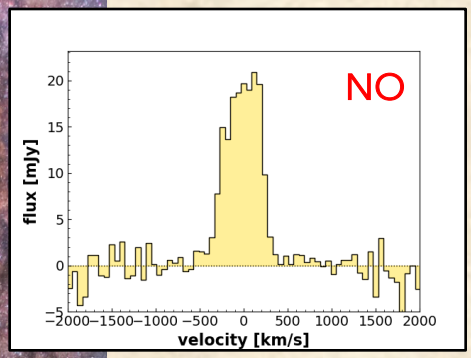
- 5 QSOs at 5.7<z<6.1 with properties similar to those of SDSS J1148+5251

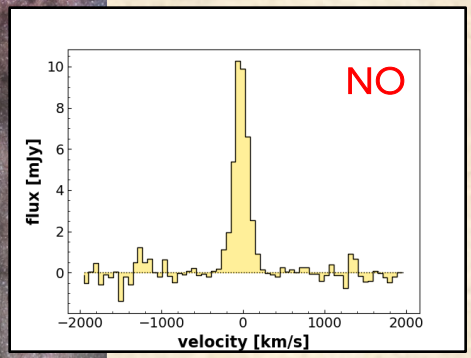
Observations:

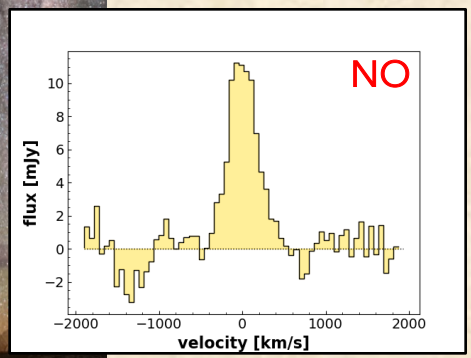
- ACA + semi-compact 12m array configuration -> improve the sensitivity to large scale emission up to 25”
- exposure time of 1-2h for 12m array and ~5-6h for ACA -> sensitivities similar or better than that reached in SDSS J1148+5251 observations



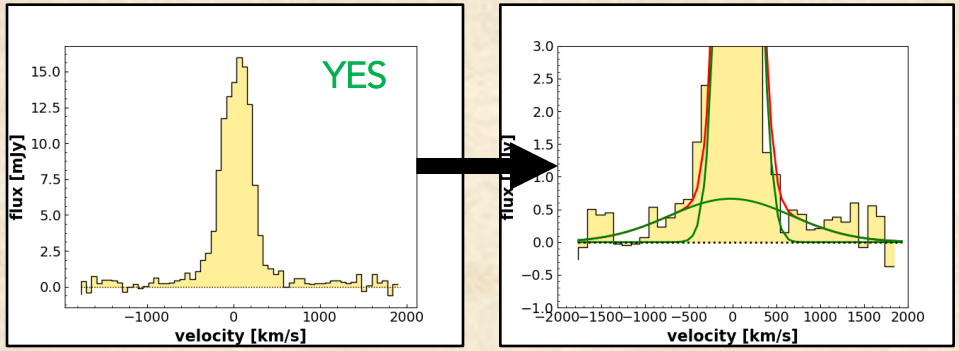
[CII] emission in QSO z~6

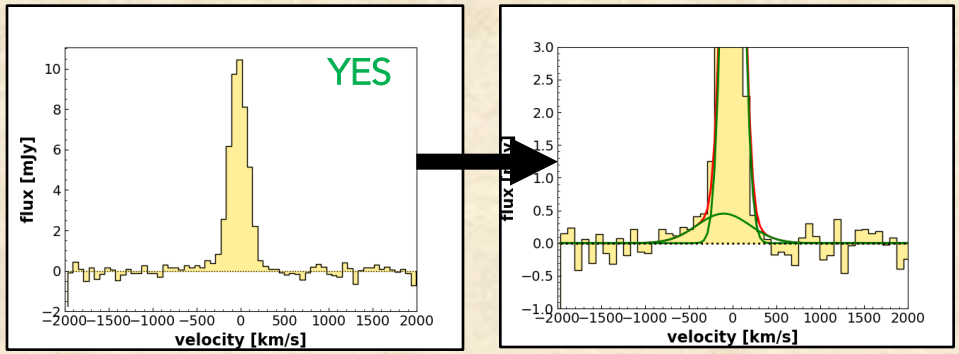






Faint broad components detected in only 2 QSOs

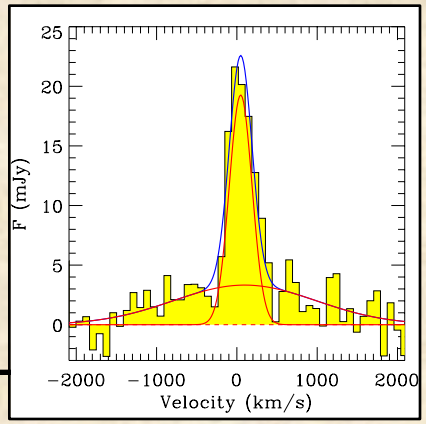




Sensitivity Issue???

It is crucial to perform a stacking analysis to investigate the the properties of massive, cold outflows traced by broad [CII] wing (Bischetti's Talk)

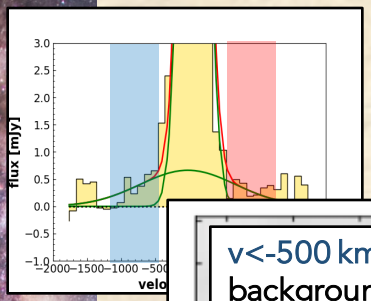
J1148 (Maiolino+12)

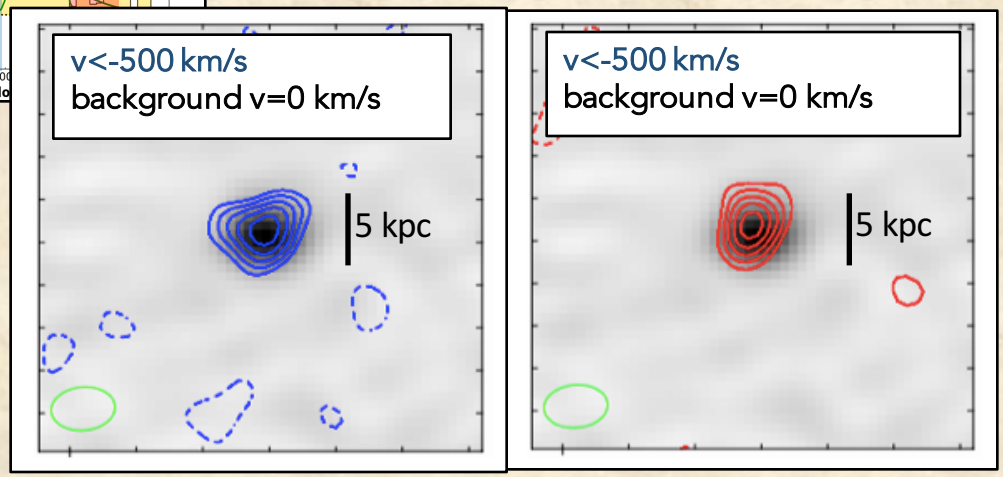


z~0.1

z~2.5

[CII] emission in QSO z~6





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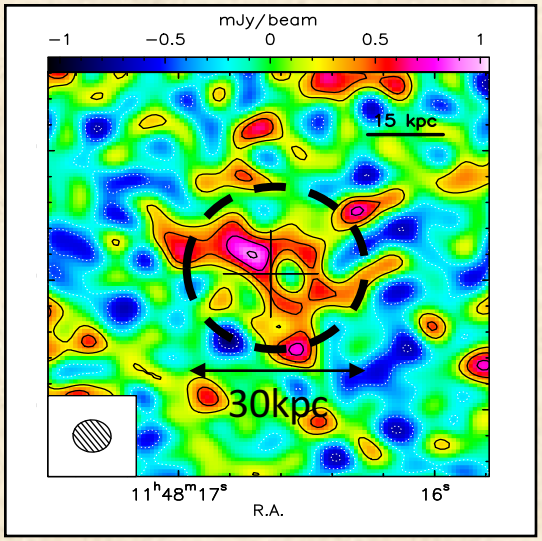
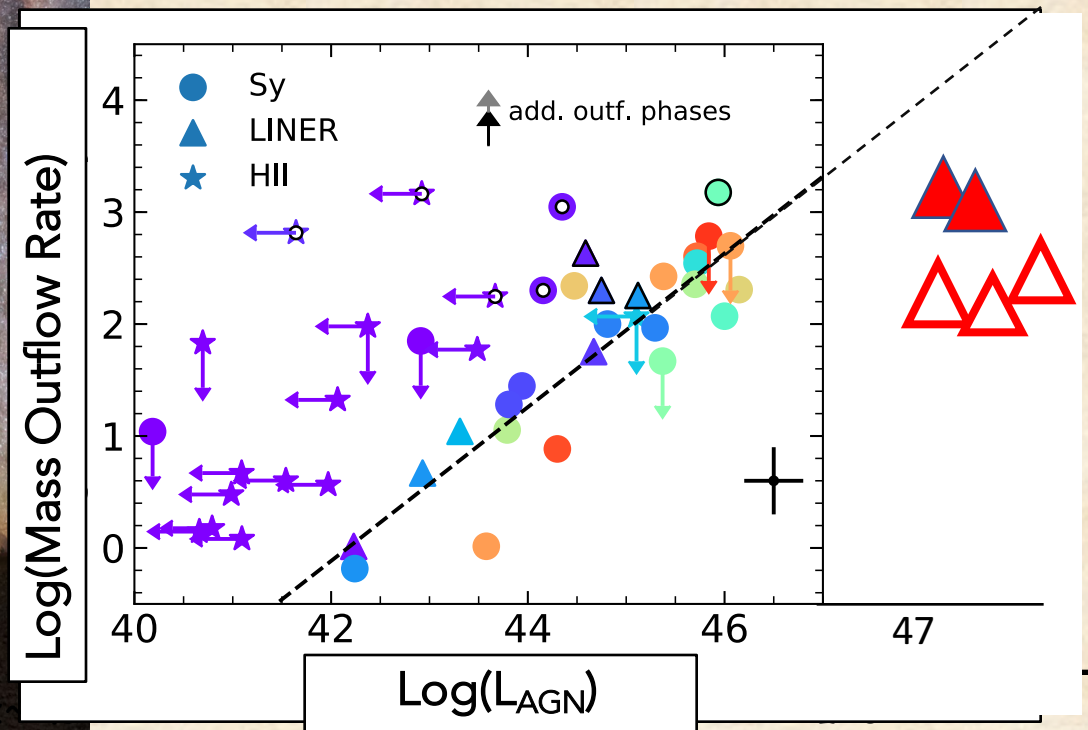
J1148(Cicone+15)





QSO-driven outflows may not be as effective as expected in removing gas out of their host galaxies in the early Universe.

Conclusion

- Depletion time longer than QSO lifetime
- Star-formation is suppressed in the region affected by outflow processes
- Low molecular gas content in AGN host galaxy (Feedback?)
- QSO-driven outflows may not be as effective as expected in removing gas

additional mechanisms must be in place to suppress star formation in early galaxies.