

Fast outflows quenching star formation at high redshift

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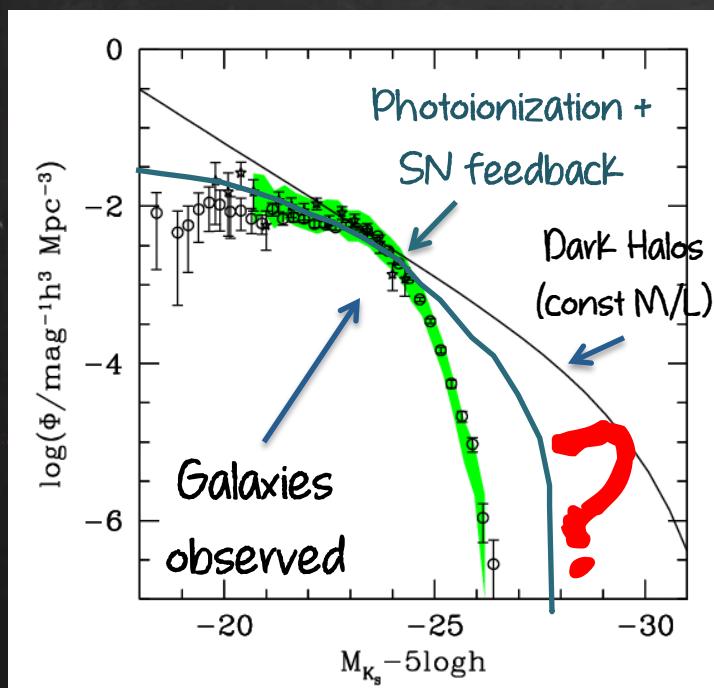
Cavendish Laboratory, University of Cambridge

Kavli Institute for Cosmology, University of Cambridge

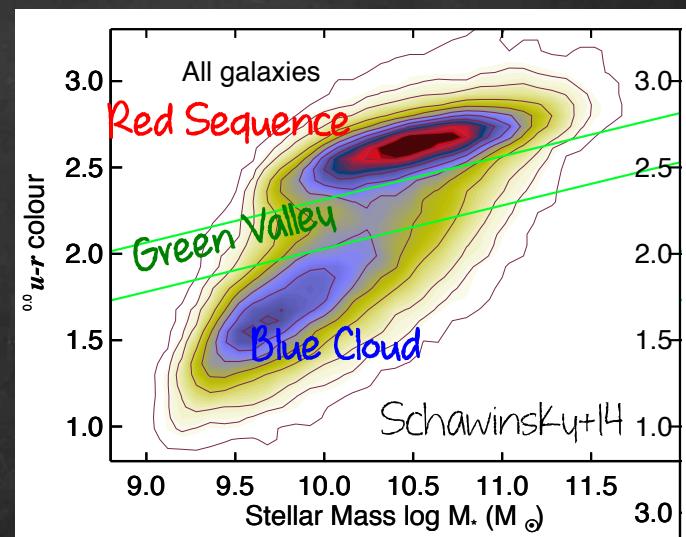
A. Marconi, R. Maiolino, B. Balmaverde, M. Brusa, M. Cano-Díaz, C. Ciccone, A. Comastri,
G. Cresci, F. Fiore, C. Feruglio, F. La Franca, V. Manieri, F. Mannucci, T. Nagao, H. Netzer, E. Piconcelli, G. Risaliti,
M. Salvati, R. Schneider O. Shemmer

Three Key Questions

- ✓ Why did galaxies during their evolution stop forming stars?
- ✓ What are the mechanisms leading the transition from gas rich, star-forming, galaxies, to passive spheroids, deprived of most of their gas? ?
- ✓ Why black holes in galactic nuclei have masses proportional to spheroid masses?



Courtesy of C.Lacey



✓ Why black holes in galactic nuclei have masses proportional to spheroid masses?

M_{BH} – σ relation

AGN feedback

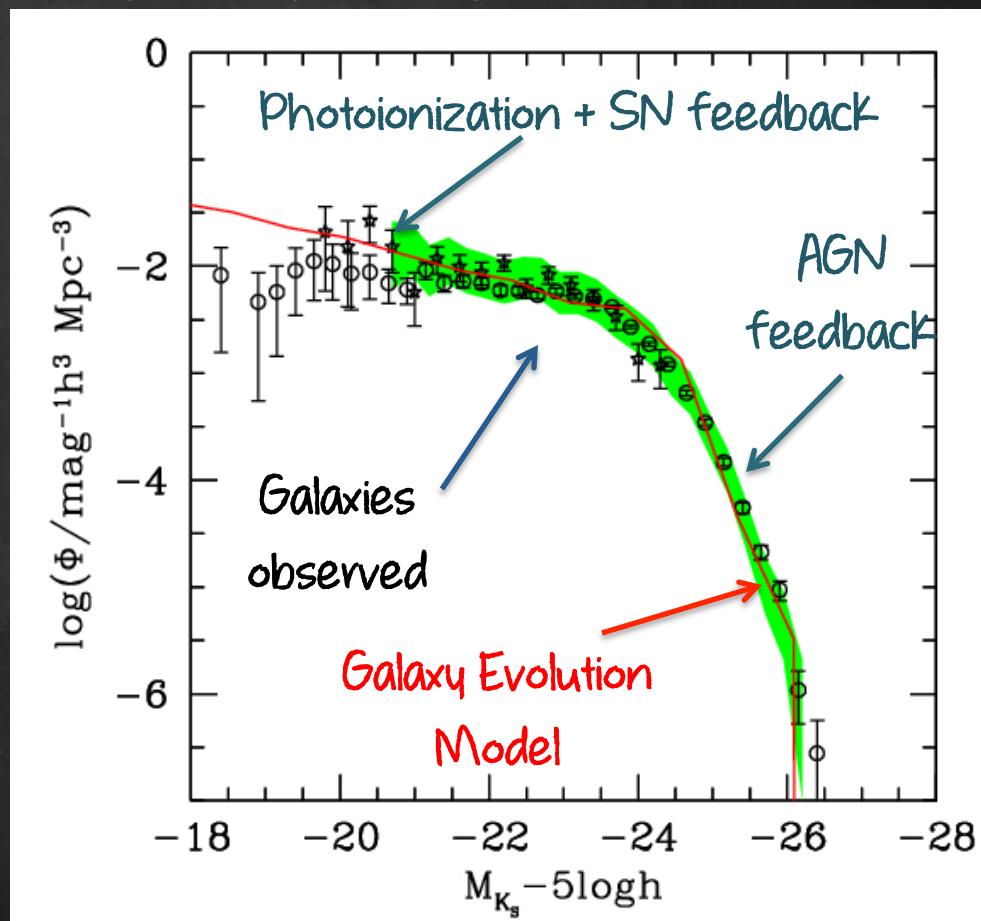
During BH growth AGN can release significant amount of energy compared to galaxy gravitational binding energy;

AGN feedback can sweep away gas in host galaxy quenching star formation, and BH growth (e.g. Fabian+12)

- ◆ Small galaxies → Stellar (SN) feedback
- ◆ Massive galaxies → AGN feedback

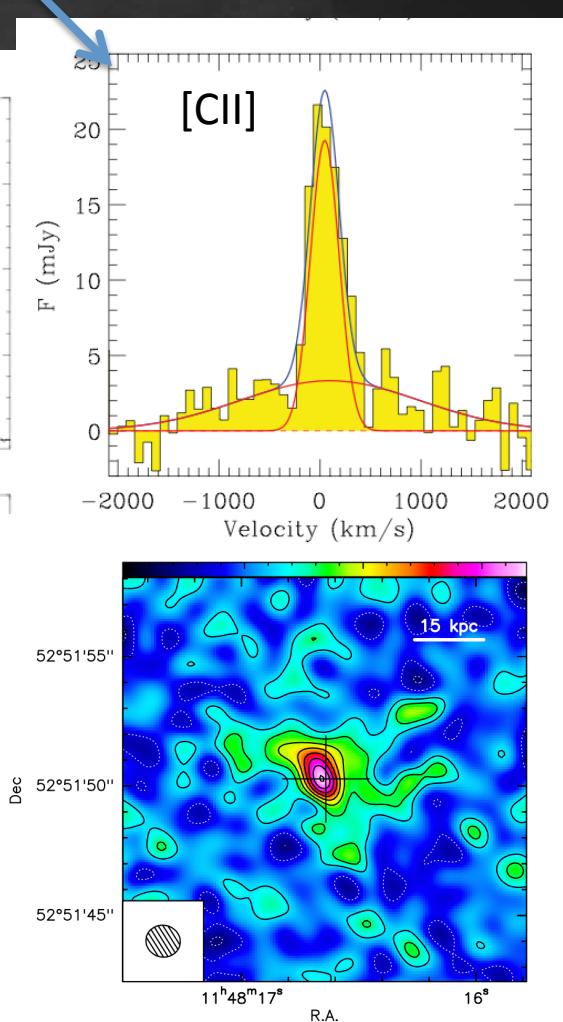
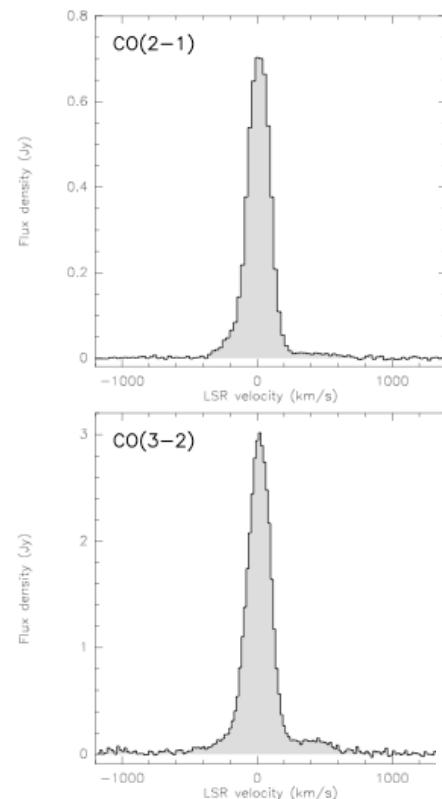
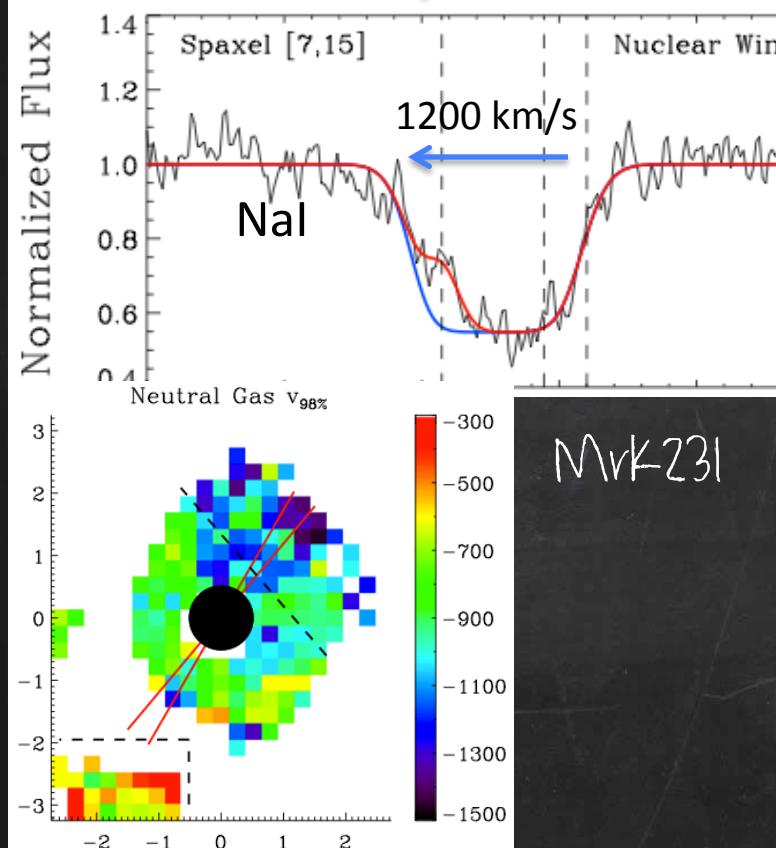
Two kinds of feedback:

- Quasar mode: High L/L_{edd} radiative feedback, short time scale.
- Radio Mode (maintenance): low L/L_{edd} kinetic feedback (jets) long time scale (heating the halo → preventing massive re-accretion of gas



AGN-driven Outflows

Neutral, molecular and ionised gas



e.g. Rupke+11,13, Spoon+11, Muller-Sanchez+11, Maiolino+12, Cicone+15, Cresci+15, Brusa+15, Perna+15, Feruglio+15...

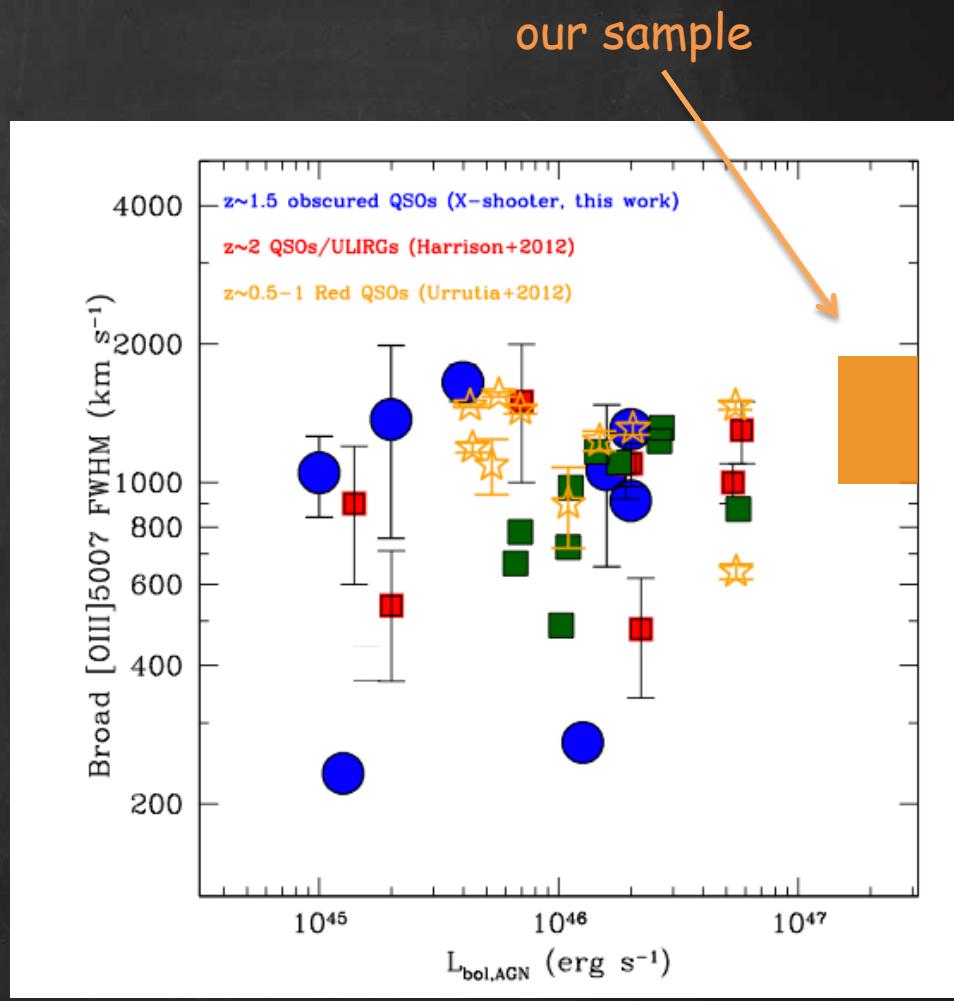
J1148+5251



Evidence for Negative Feedback??

Quasars at $z \sim 2.5$

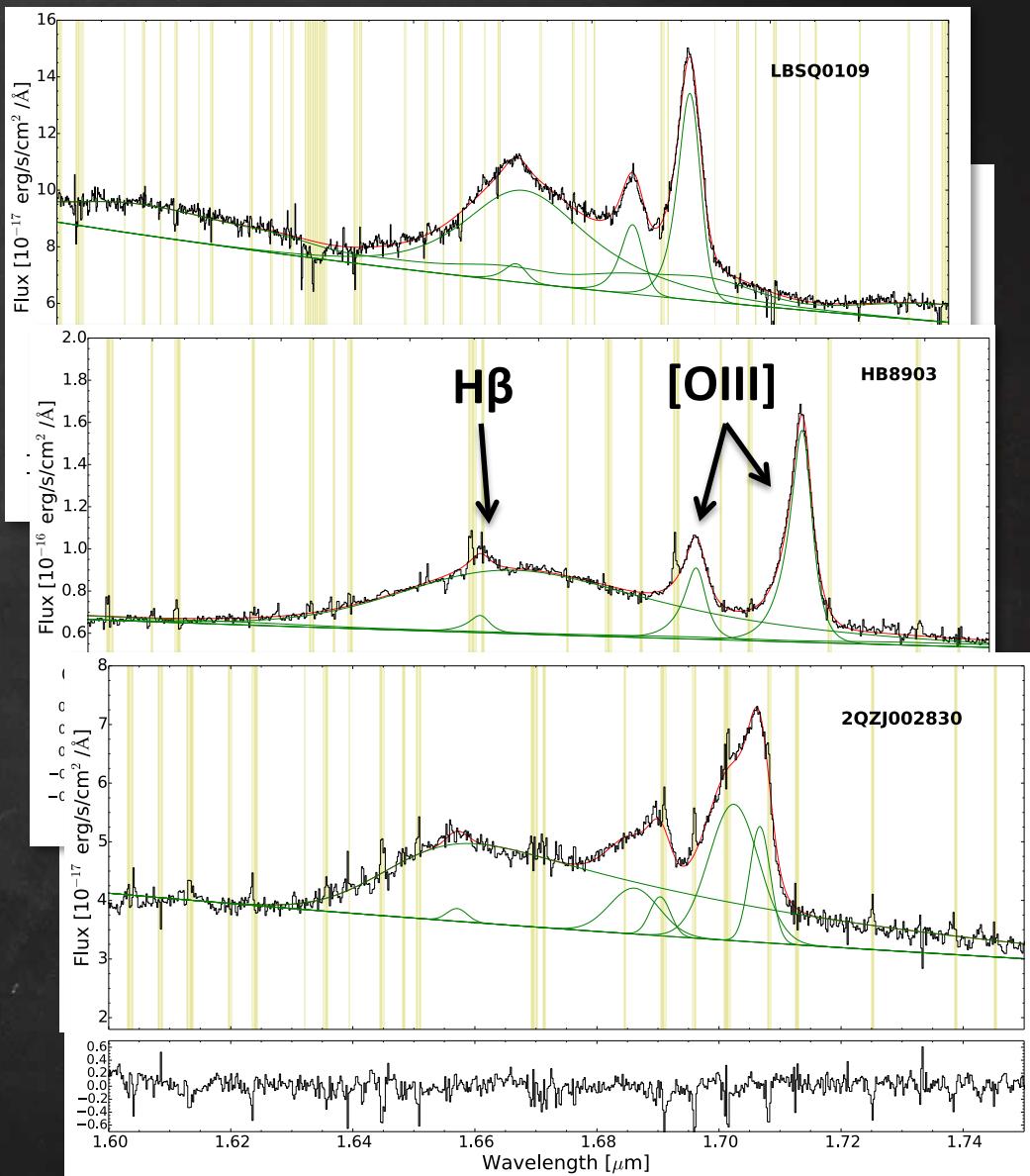
- A sample of 6 QSOs at redshift $z = 2.3-2.5$
- $L_{\text{AGN}} \approx 2-3 \times 10^{47} \text{ erg/s}$
- Broad [OIII]
 - ($\text{FWHM} > 1000 \text{ km/s}$)
- Deep SINFONI H-band observations
- Seeing limited resolution ($0.5''$)



Brusa+15

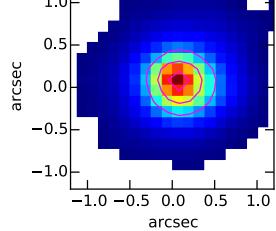
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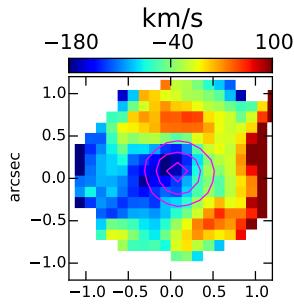


Kinematic Analysis

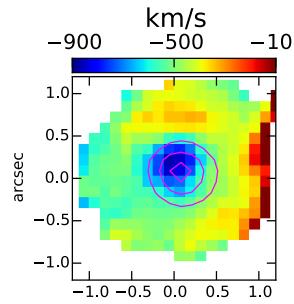
Flux



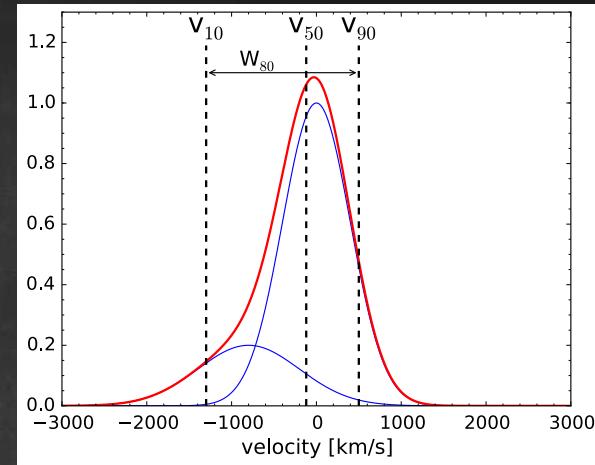
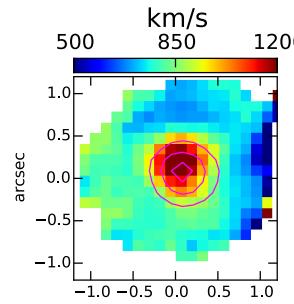
v_{50}



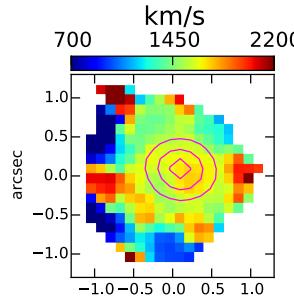
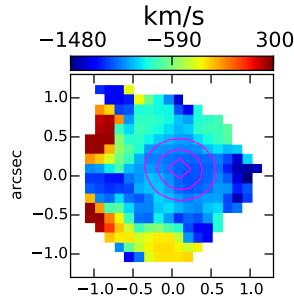
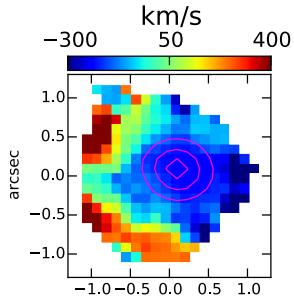
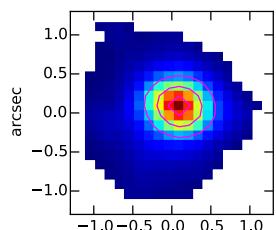
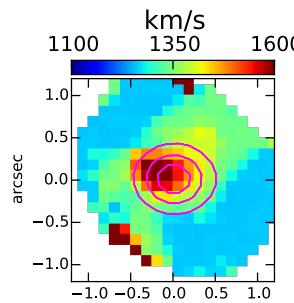
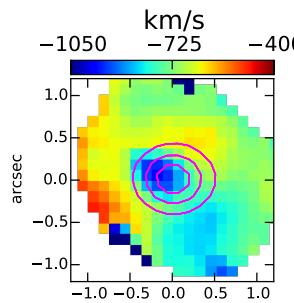
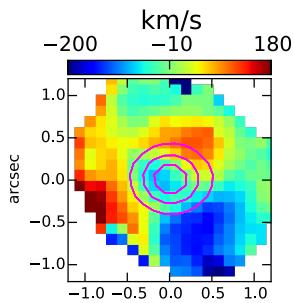
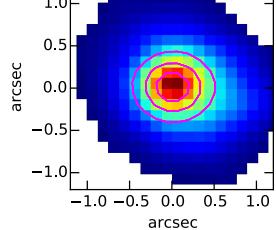
v_{10}



Velocity
Dispersion



Spatially resolved
[OIII] kinematical
maps for 5 objects



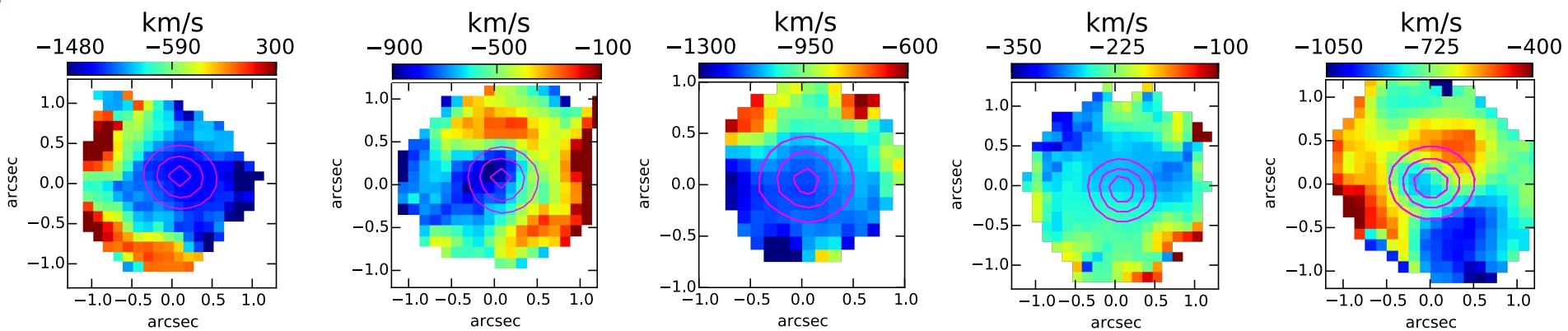
Carniani+15a

Carniani+15a

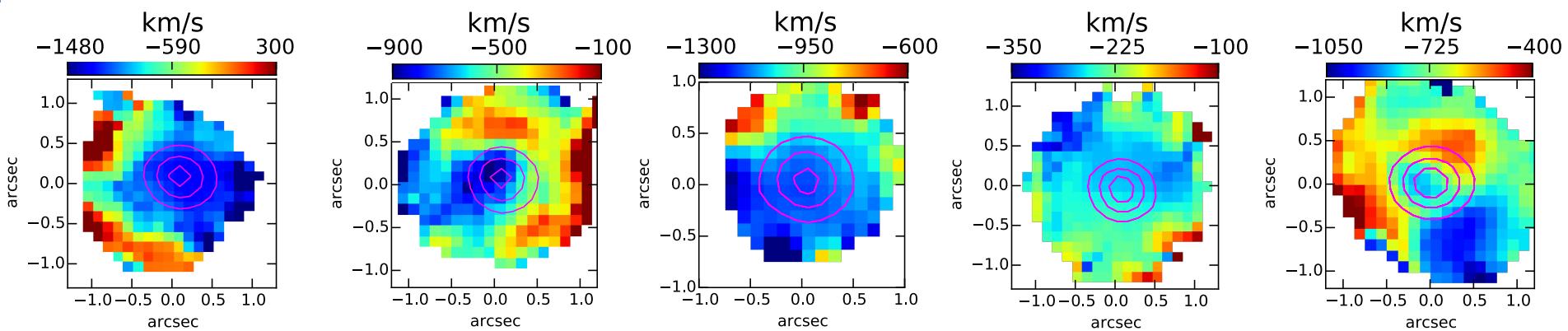
Velocity dispersion
up to 900 km/s

Outflow velocities
> 500 km/s

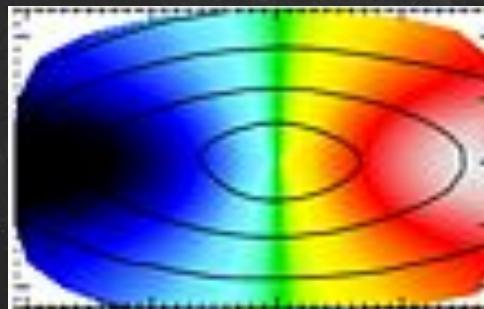
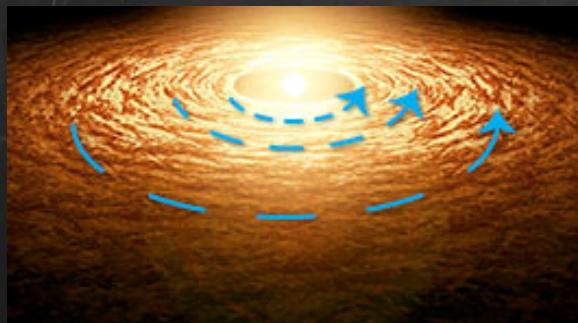
Ionised Outflows



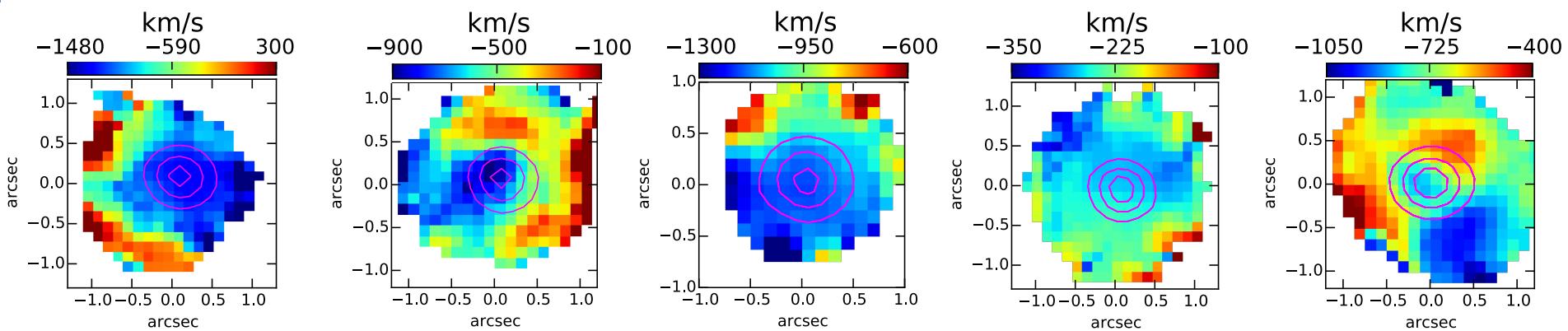
Ionised Outflows



Rotating gas disk



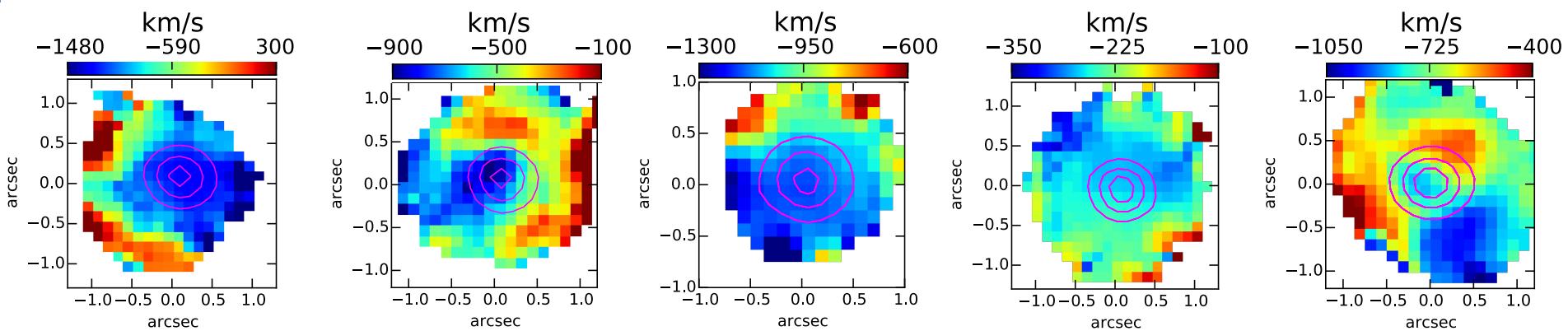
Ionised Outflows



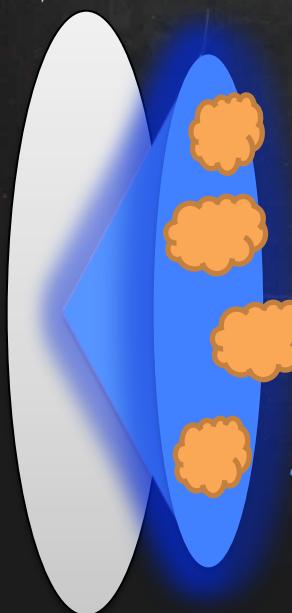
Toy model



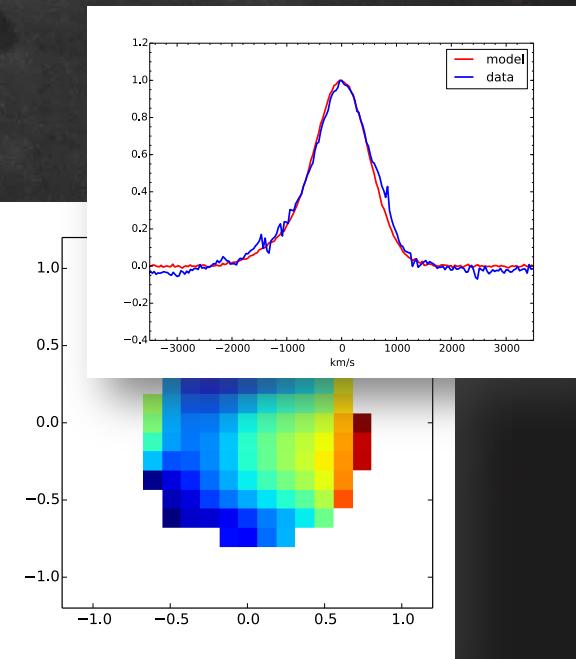
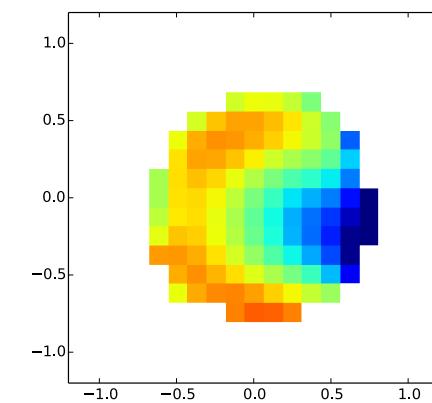
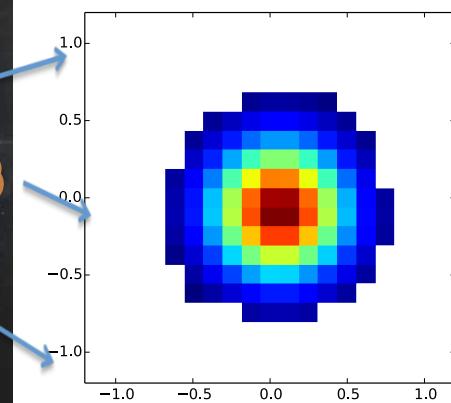
Ionised Outflows



Toy model

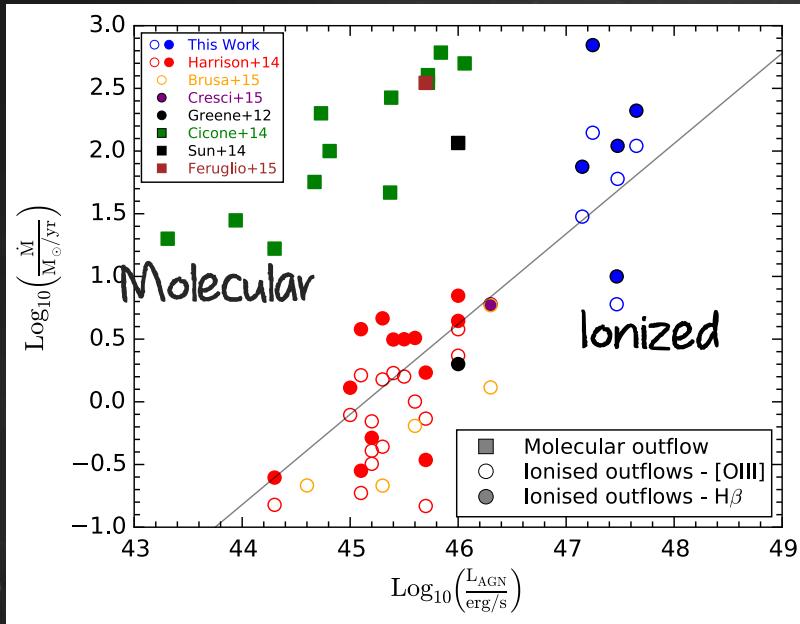


Velocity maps confirm the
existence of outflows

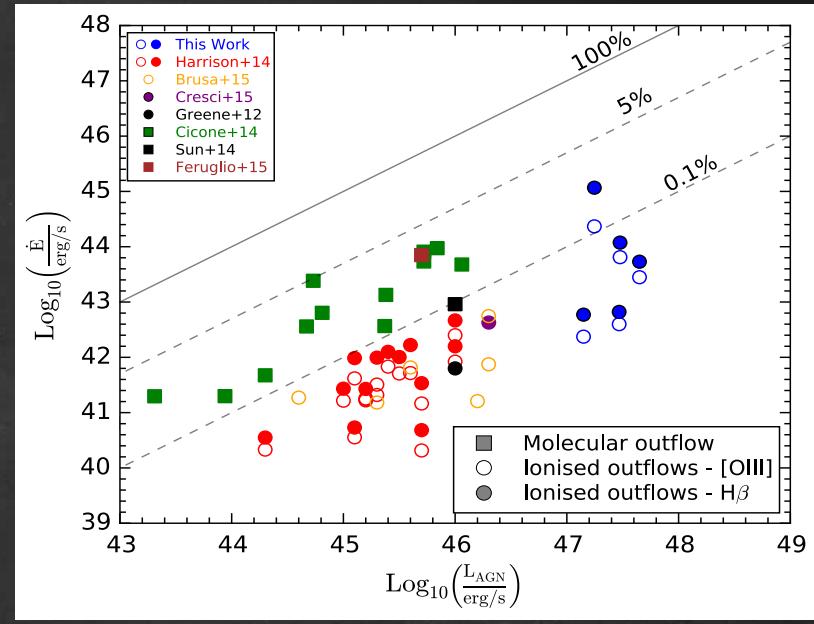
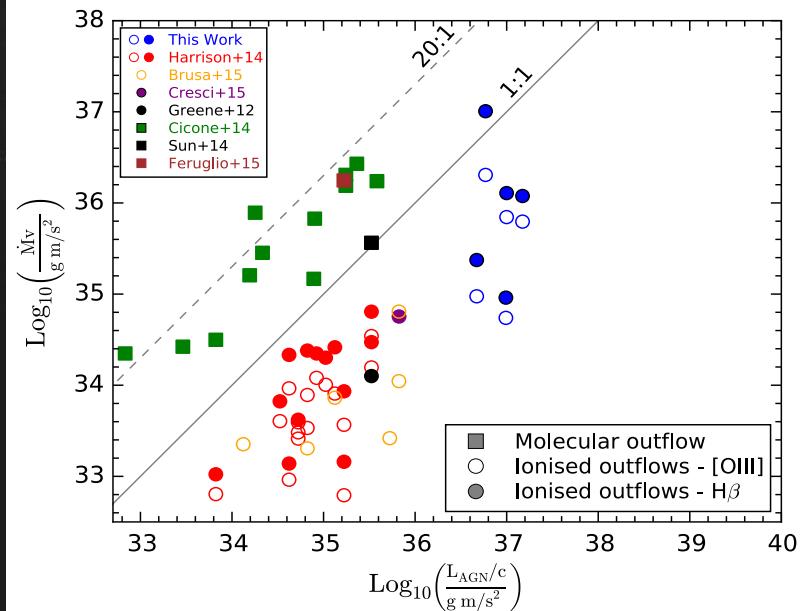


Ionised Outflows Vs Molecular Outflows

Outflow rate



Momentum rate

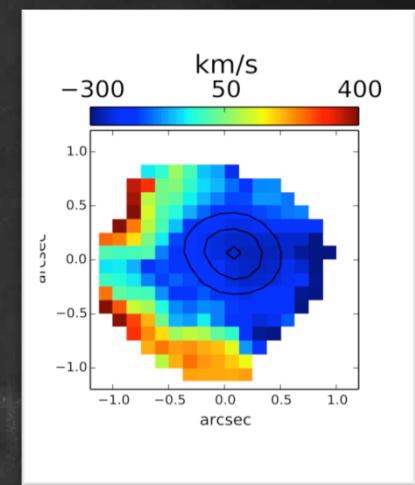
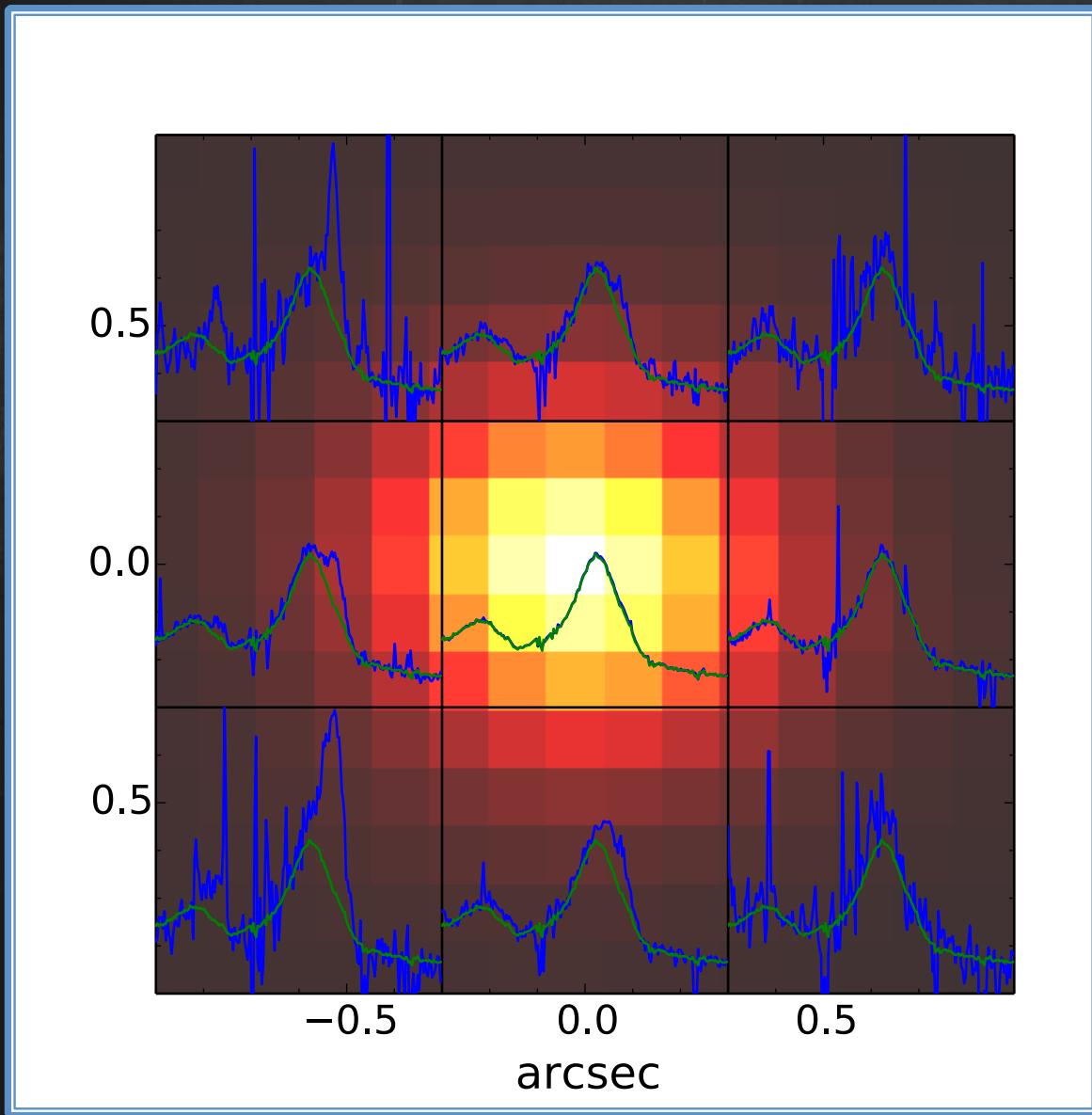


$$M = 8 \times 10^7 M_\odot \left(\frac{C}{10[\text{O}/\text{H}]} \right) \left(\frac{L_{[\text{OIII}]}}{10^{44} \text{ erg/s}} \right) \left(\frac{\langle n_e \rangle}{500 \text{ cm}^{-3}} \right)^{-1} \quad T_e = 10^4 \text{ K}$$

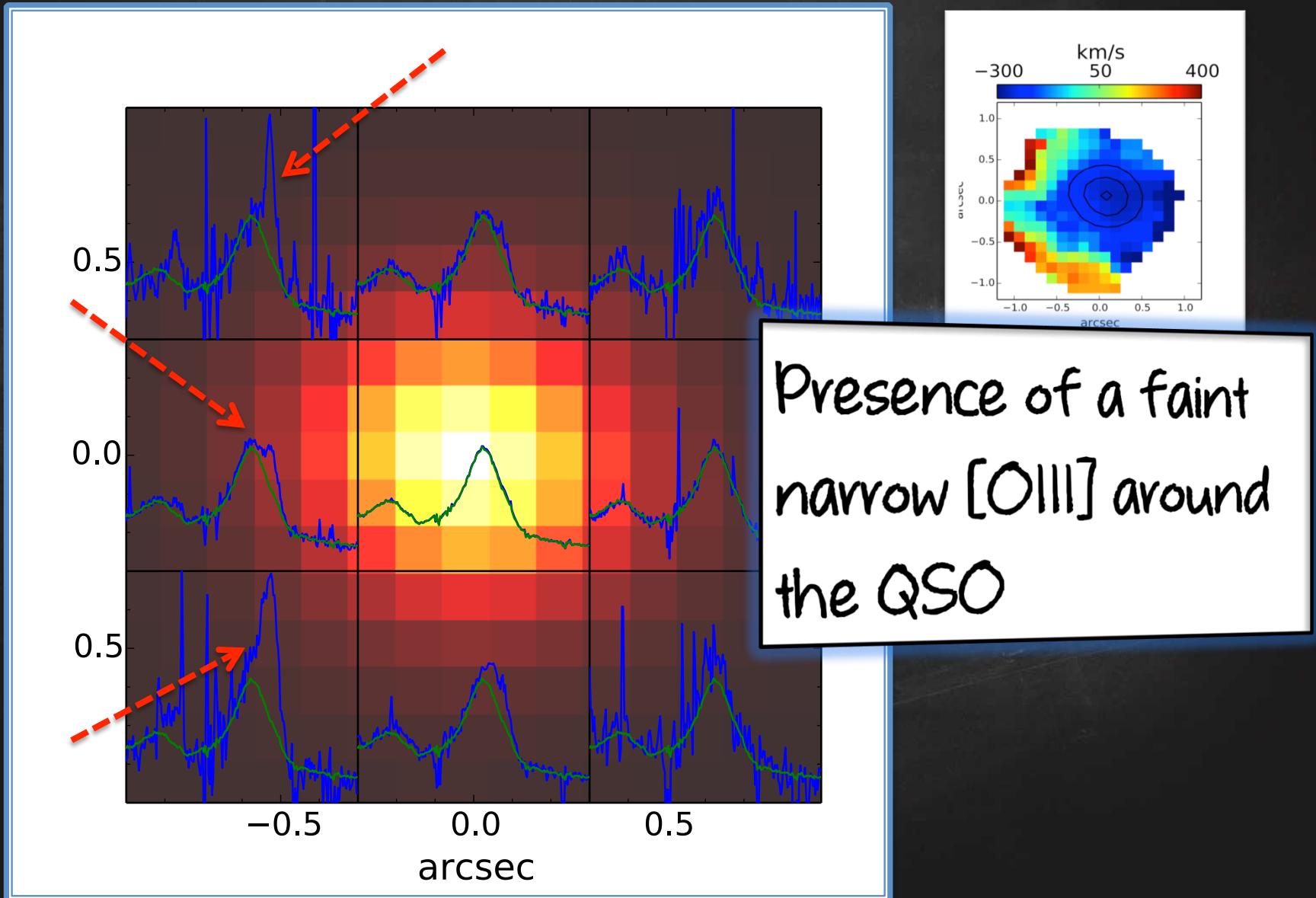
$$\dot{M} \simeq \frac{M_{\text{out}} v_{\text{out}}}{R_{\text{out}}}$$

Physical properties of outflows
-> only the ionized gas is traced

Faint Narrow [OIII]



Faint Narrow [OIII]



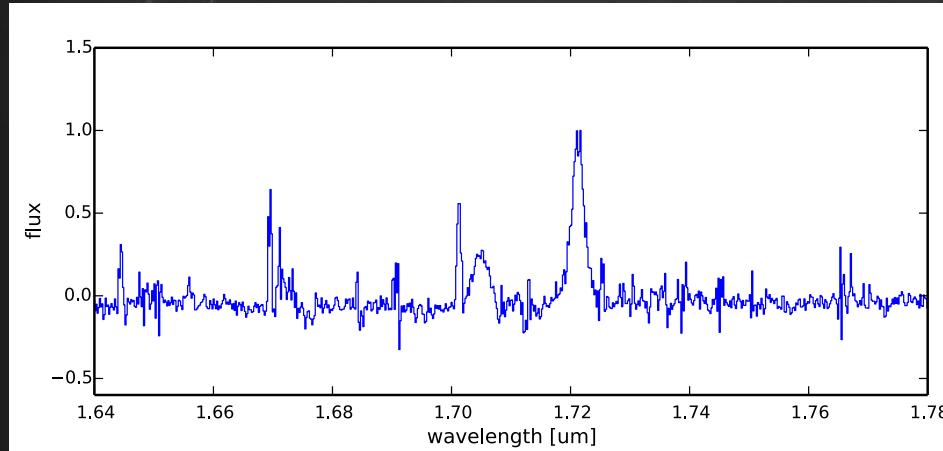
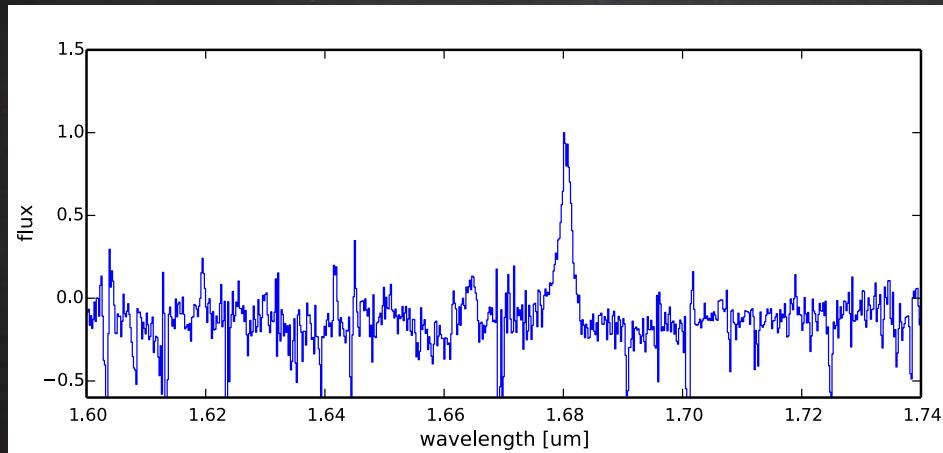
Faint Narrow [OIII]

Subtract broad (> 1000 km/s) [OIII] component \rightarrow Outflows

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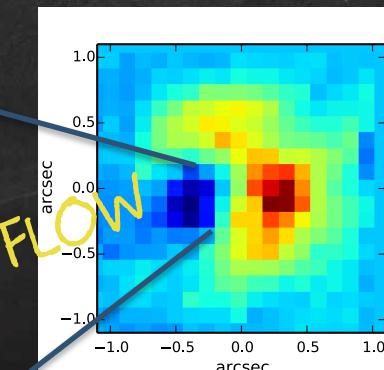
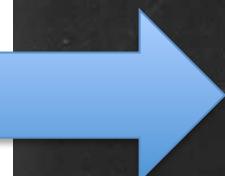
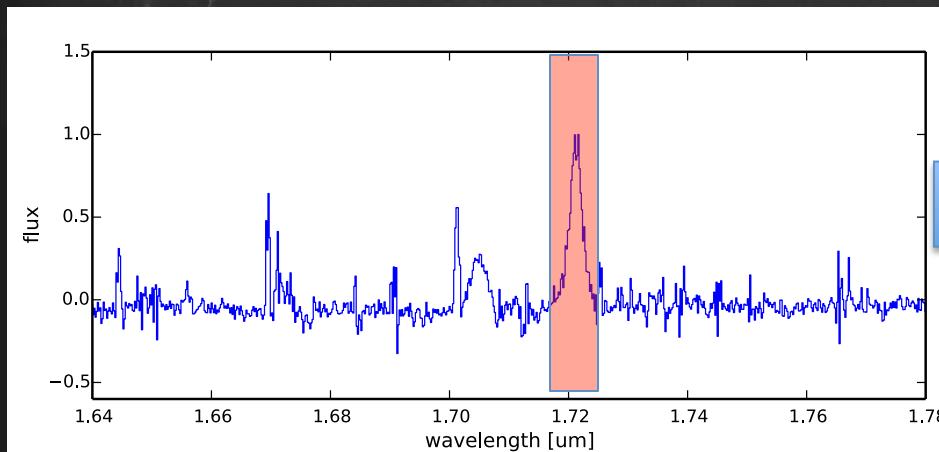
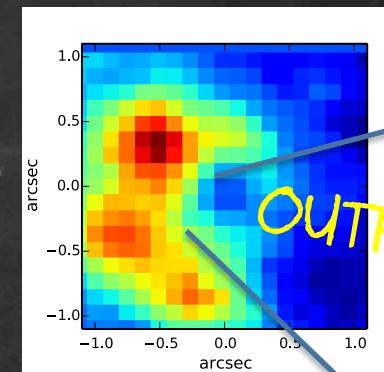
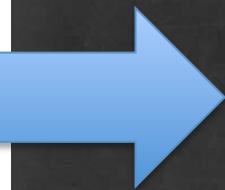
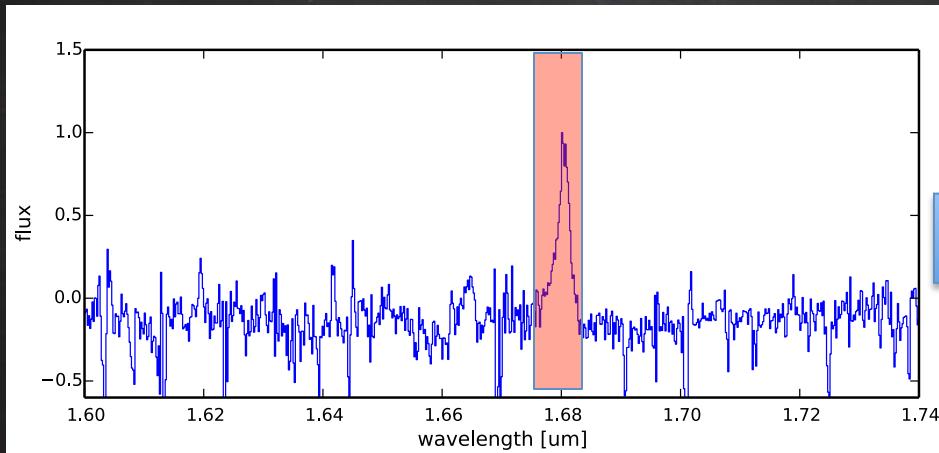
Faint narrow (~ 150 km/s) [OIII] component



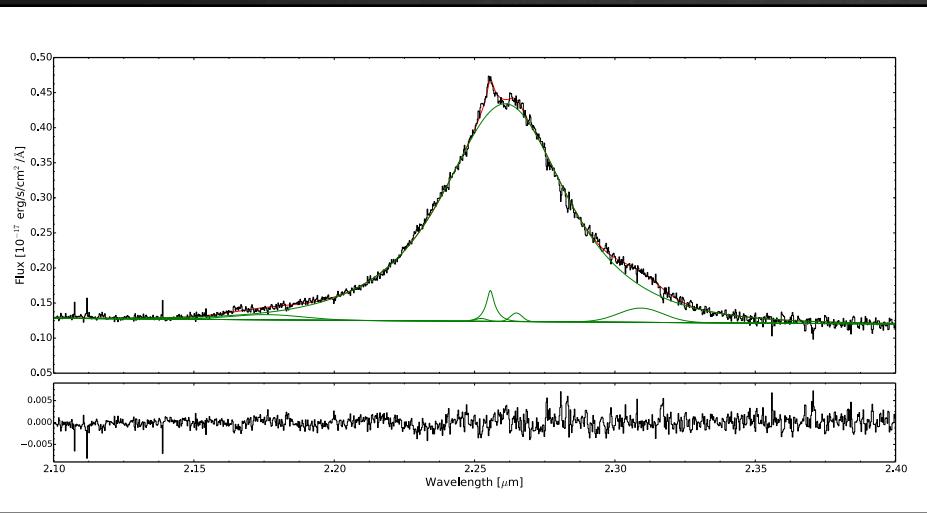
Faint Narrow [OIII]

Subtract broad (> 1000 km/s) [OIII] component \rightarrow Outflows

Faint narrow (~ 150 km/s) [OIII] component \rightarrow Star formation ??



Origin of the Narrow [OIII] ?

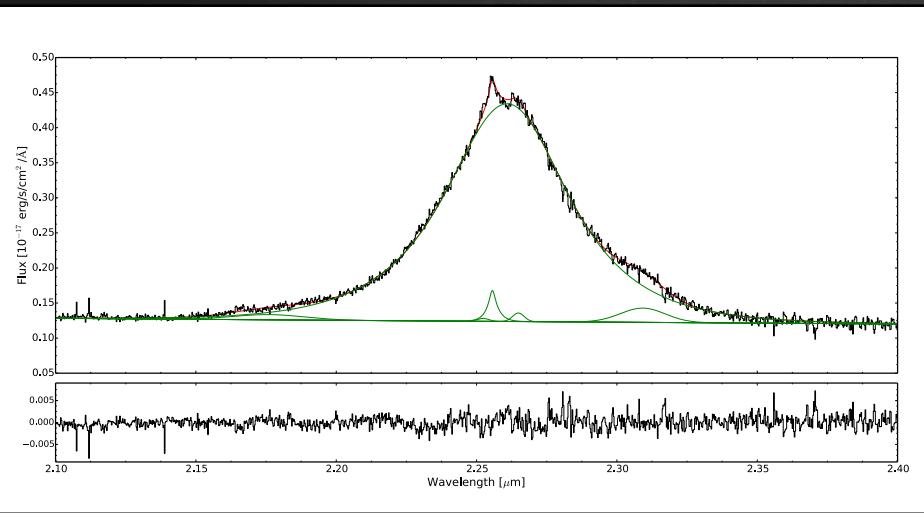


K-band observations targeting H α

SINFONI@ VLT

Seeing limited resolution (0.6'')

Origin of the Narrow [OIII] ?



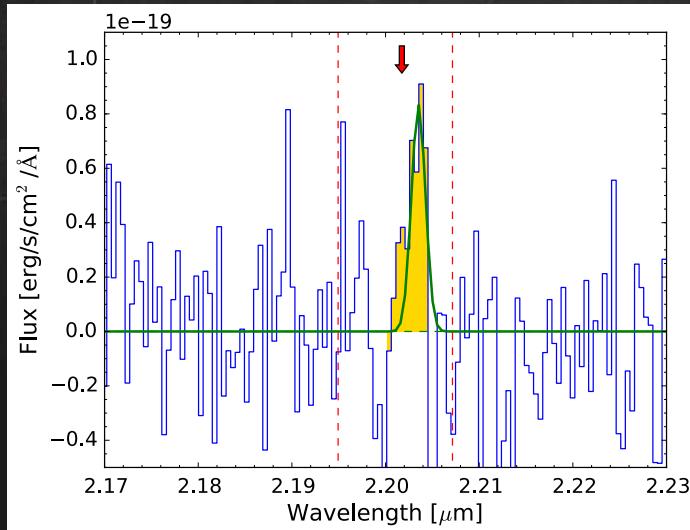
K-band observations targeting Ha

SINFONI@ VLT

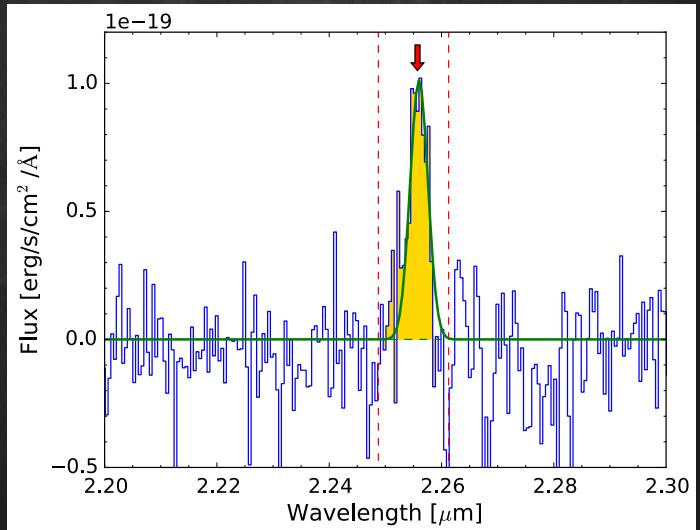
Seeing limited resolution (0.6'')

Subtract Ha broad and outflow components

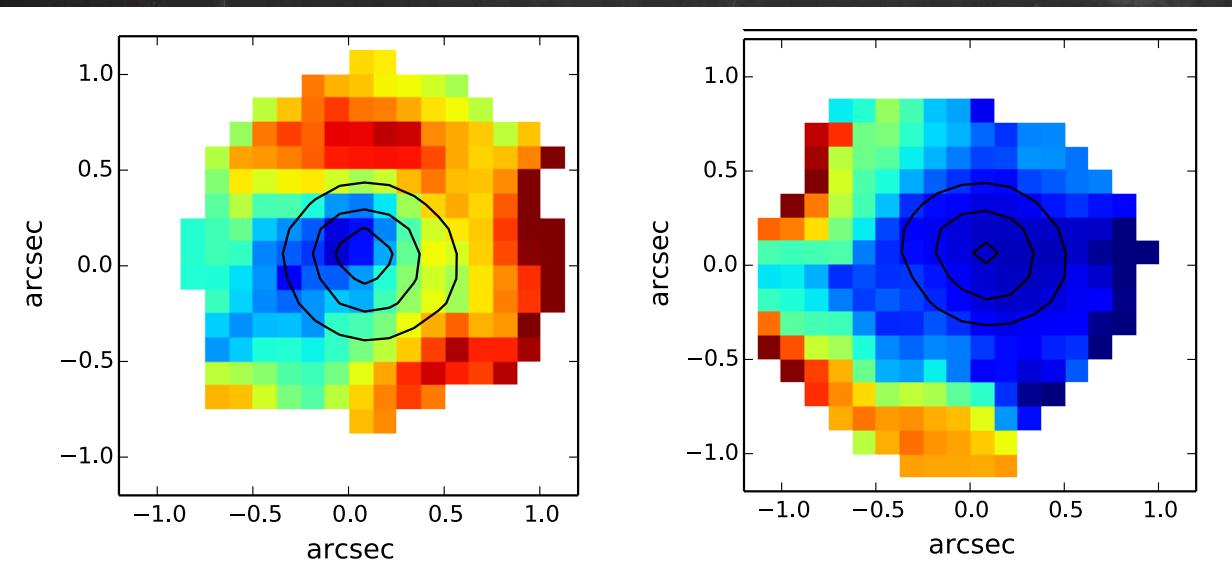
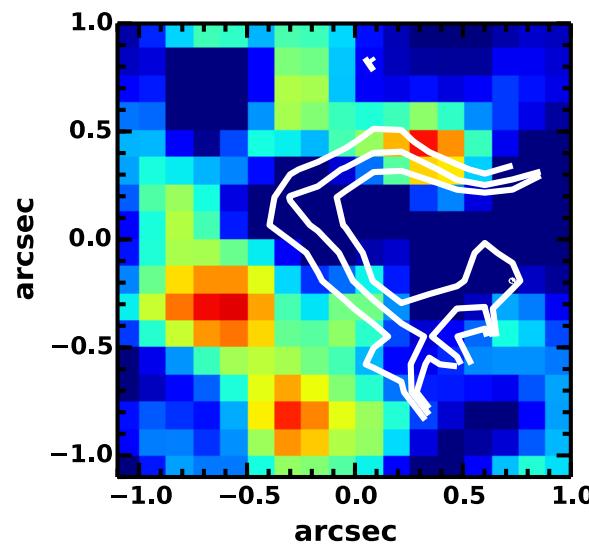
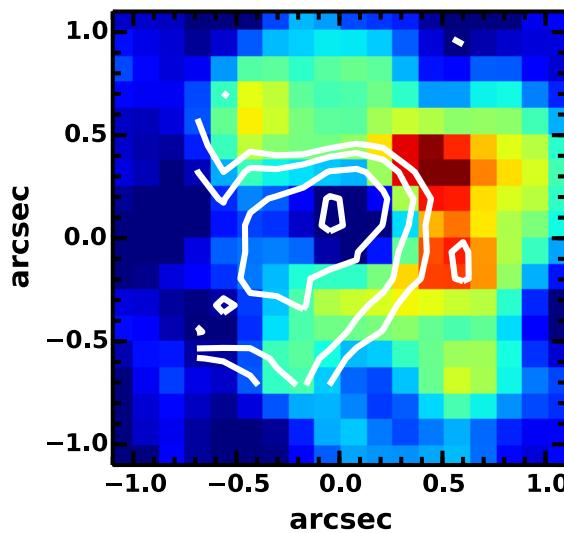
[OIII]_{SF}-Ha redshift



[OIII]_{SF}-Ha redshift



Origin of the Narrow [OIII] ?

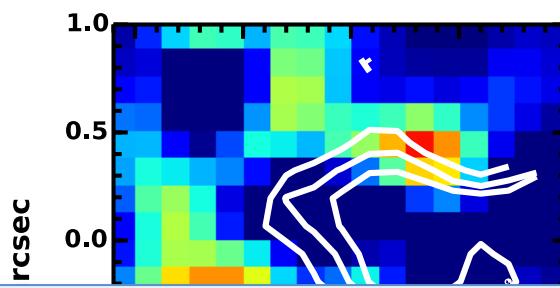
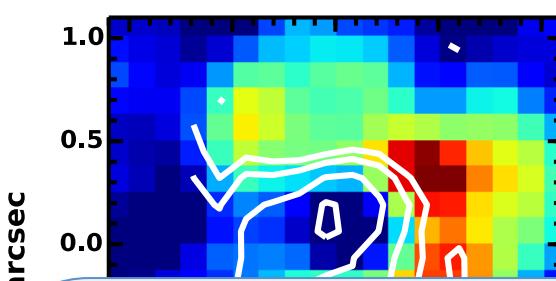


no [NII], upper limit on [NII]/H_a excludes AGN excitation



STAR FORMATION!

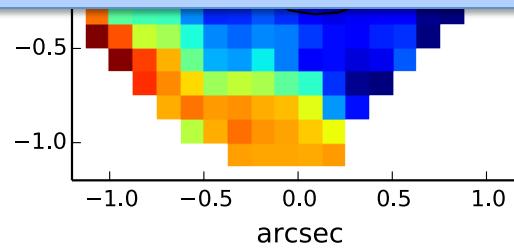
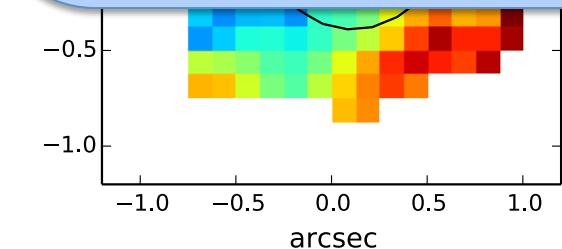
Origin of the Narrow [OIII] ?



Narrow H α /[OIII] emission traces star formation
and is anti-correlated with the presence of fast outflows!

Fast outflows “quench” star formation,

feedback revealed!



Conclusion

- ✓ Ionized gas outflows sweep away gas in quasar host galaxies
- ✓ Star Formation is suppressed in the region affected by outflow processes
- ✓ Feedback mechanisms do not significantly suppress star formation over the whole galaxy

$SFR \approx 50-100 M_{\odot}/yr$

