Cold OUtflows Ruffling the AGn Environment

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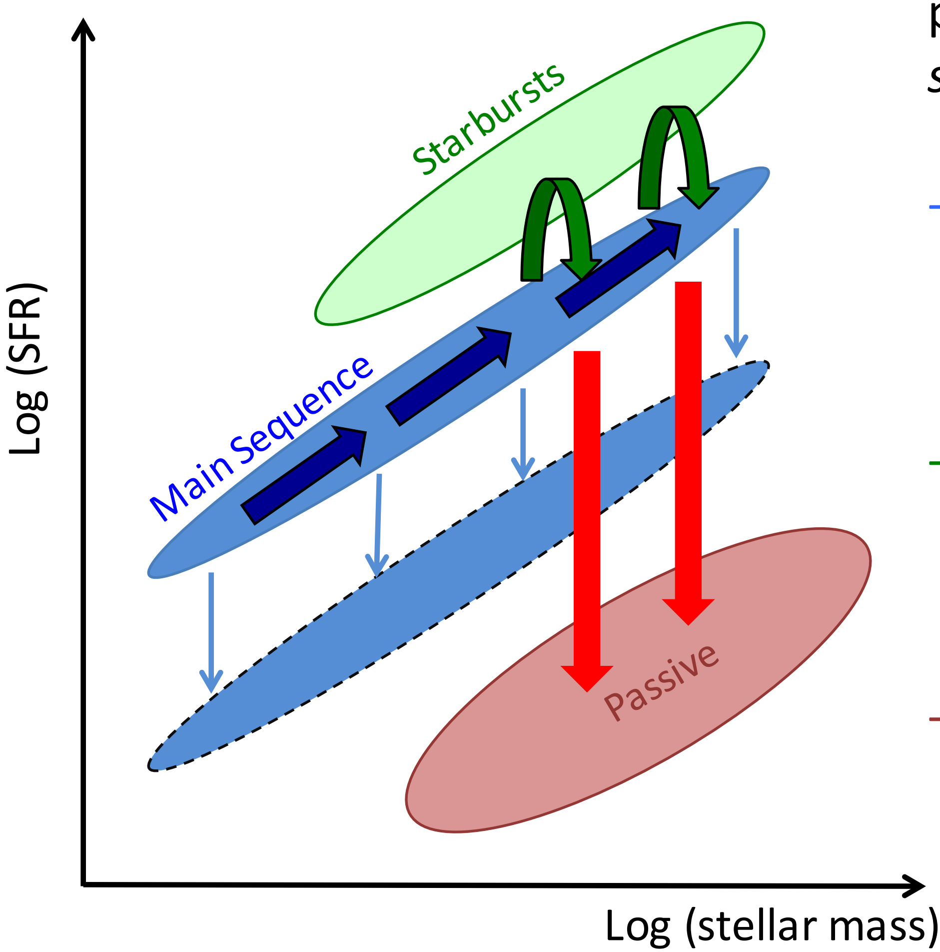
@ INAF OABrera

The galaxy population



cartoon by S. Lilly

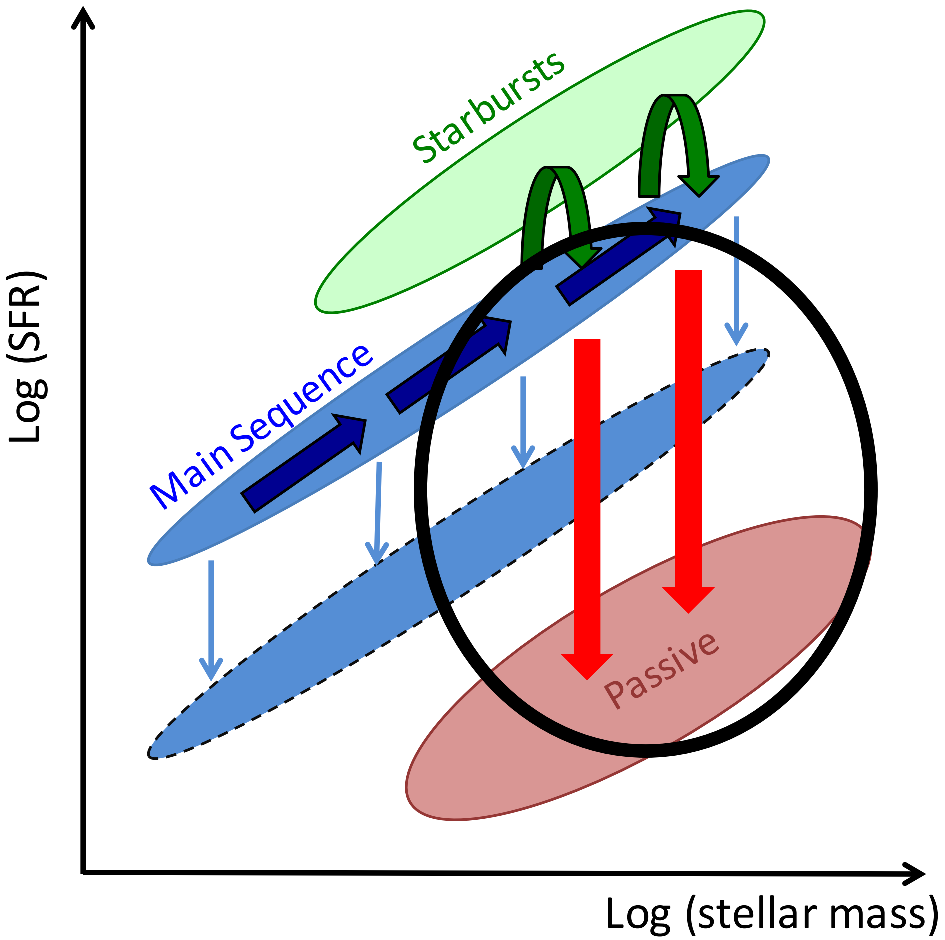
A simple cartoon to visualize a complex process. What we know from *optical surveys*:

- Most star-forming galaxies follow a tight correlation between SFR and M_*, the "main sequence" (up to z~2)

- Only a few % outliers lie above the main sequence, the "starbursts" (inc. ULIRGs, LIRGs, mergers)

- Passive galaxies observed up to z~2.5 in which star formation was suppressed early and rapidly

What suppresses star formation in massive galaxies?



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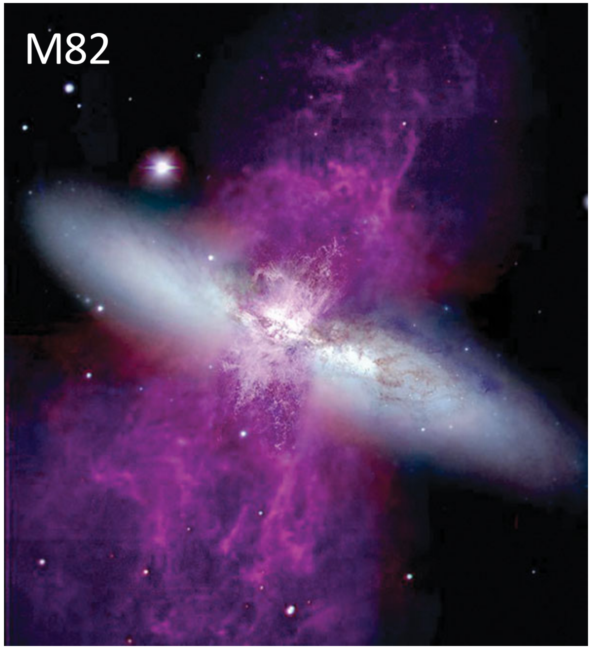
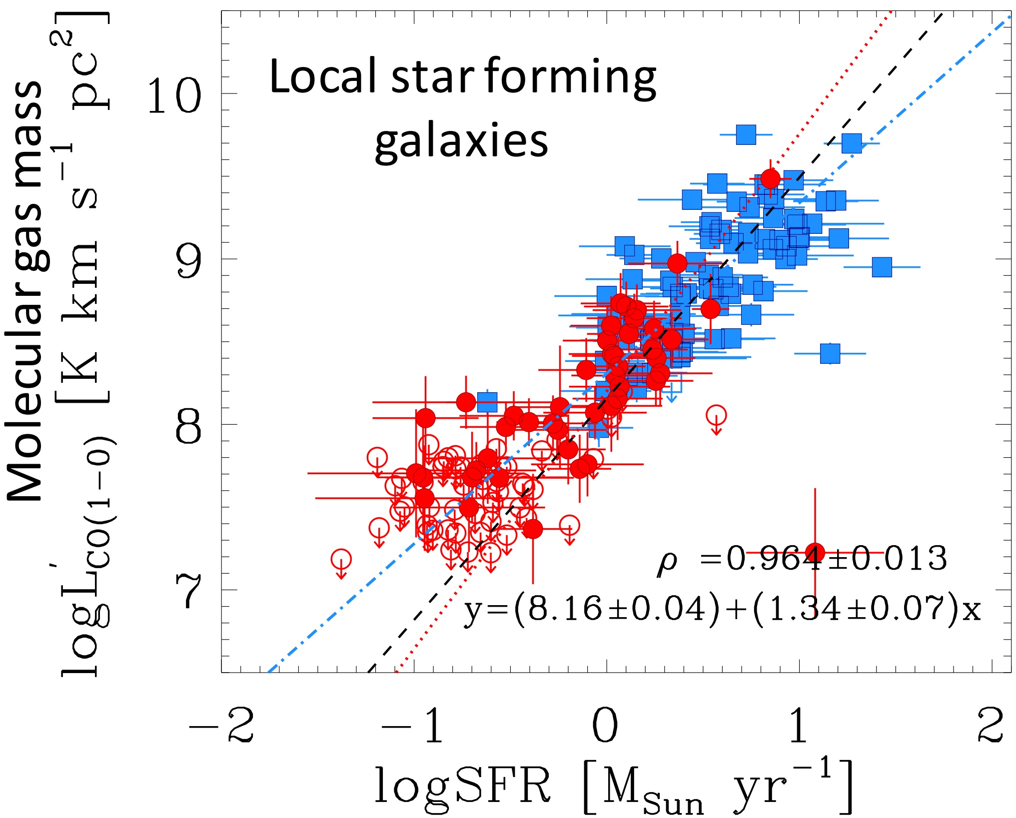


Galactic outflows can affect availability of gas *as well as* its physical conditions (n, T, Z) -> what is the effect on star formation (negative feedback)?

The importance of molecular gas



Cicone+17

H_2 is the primary ingredient for star formation

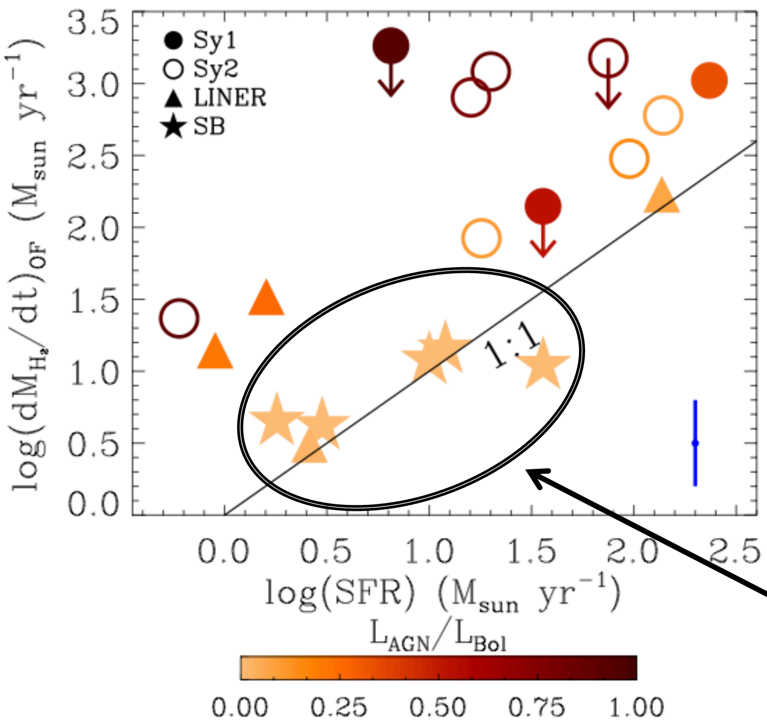
H_2 distribution follows closely that of newly formed stars

Molecular gas and SFR tightly correlated in star forming galaxies (fundamental scaling relation)

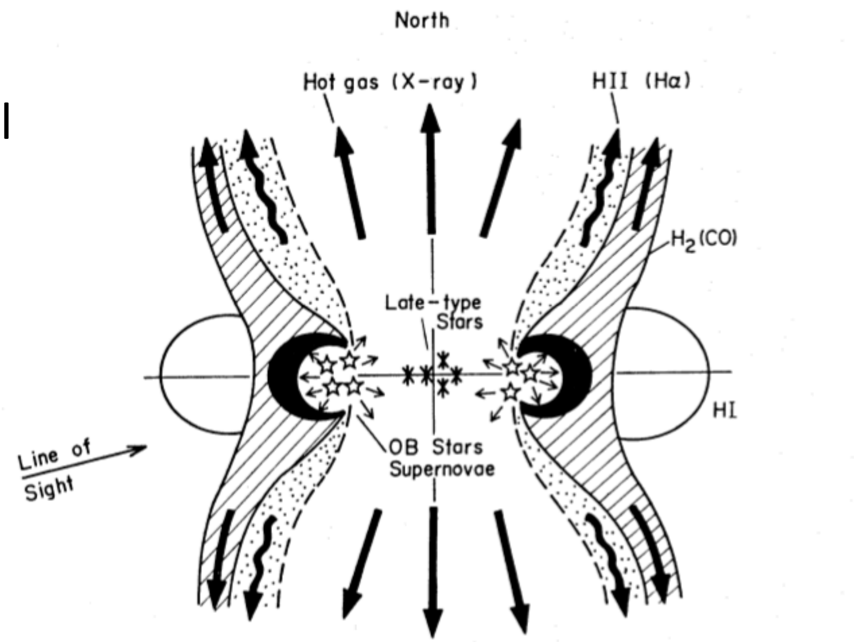
Hence any mechanism *affecting the properties of H_2 will necessarily affect the capability of a galaxy to form stars -> role of H_2 outflows*

Star formation-driven outflows

Star formation *alone* can drive powerful and massive molecular outflows



Cicone+14



Nakai+87

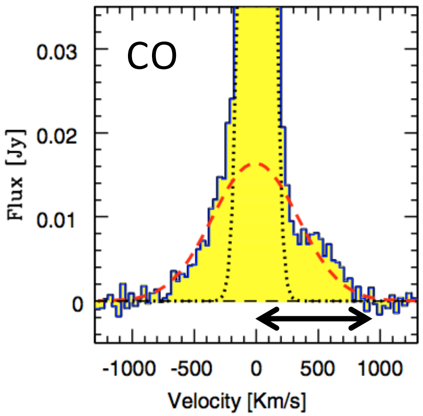
The SN-driven outflow in M82

Molecular outflows driven uniquely by star formation: $dM_{out}/dt \sim SFR$

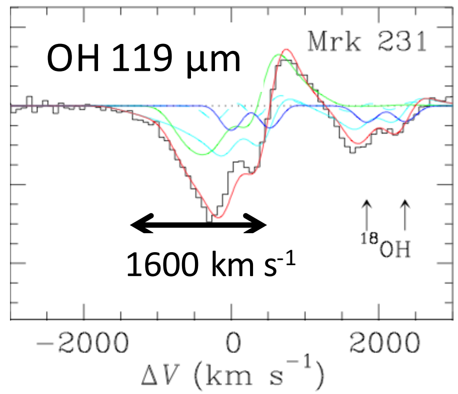
Max outflow velocity ~ 100-200 km/s

Molecular outflows in local AGN hosts

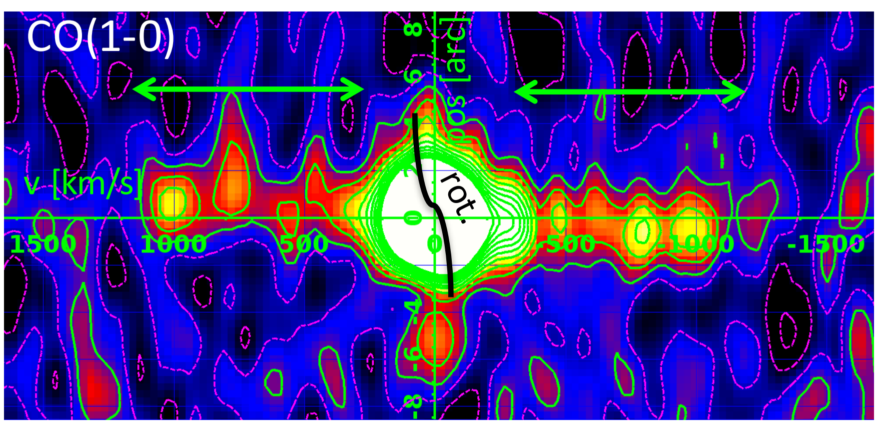
Tracing radiative-mode AGN feedback…



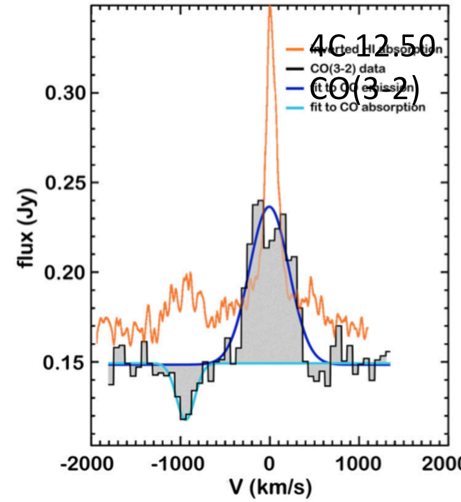
Feruglio+10



Gonzalez-Alfonso+14



..but can be also jet-driven!



Dasyra+ Combes12

Large masses of cold H_2 gas outflowing at v ~ 1000 km/s detected in AGN host galaxies on scales of a few kpc

$dM_{out}/dt >> SFR$

Cicone+14

[Rapidly expanding field, Aalto+12,15,16,Alatalo+11,15, Cicone+12, Combes+13, Dasyra+12,14,15,16, Feruglio+13a,b,15, Fiore+17, Fischer+10, Garcia-Burillo+14, Morganti+13,+15, Sun+14, Tadhunter+14, Emonts+14, Tunnard+15, Lindberg+15, Sturm+11, Stone+16, Spoon+13, Zschaechner+16, Carniani+17, Veilleux+13,+17,Gonzalez-Alfonso+17]

Quasar-mode feedback at high-z

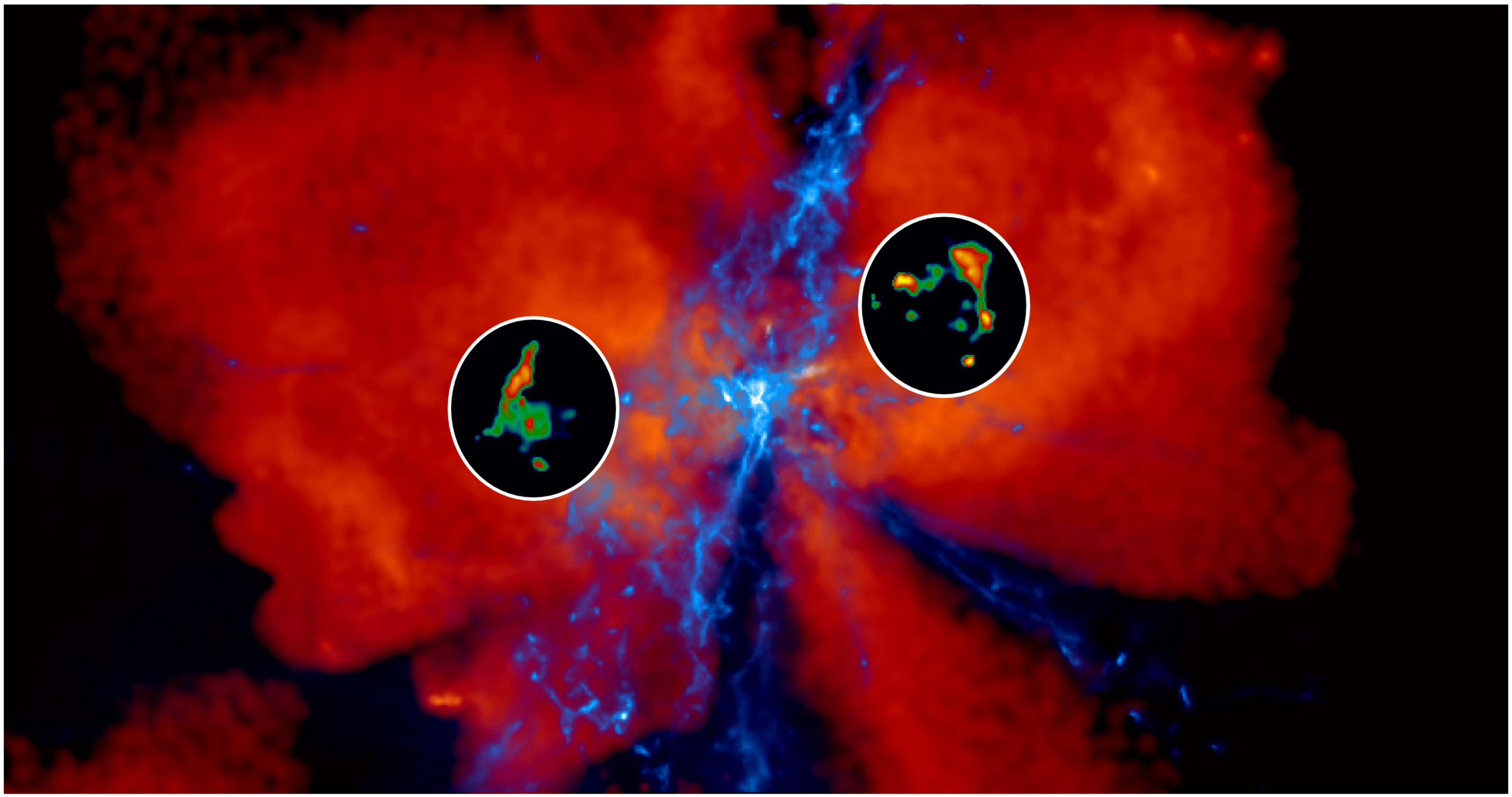
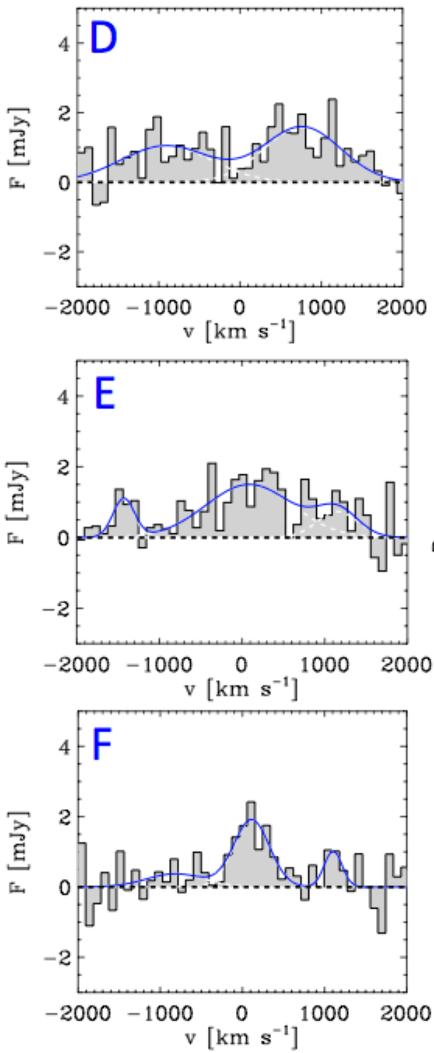


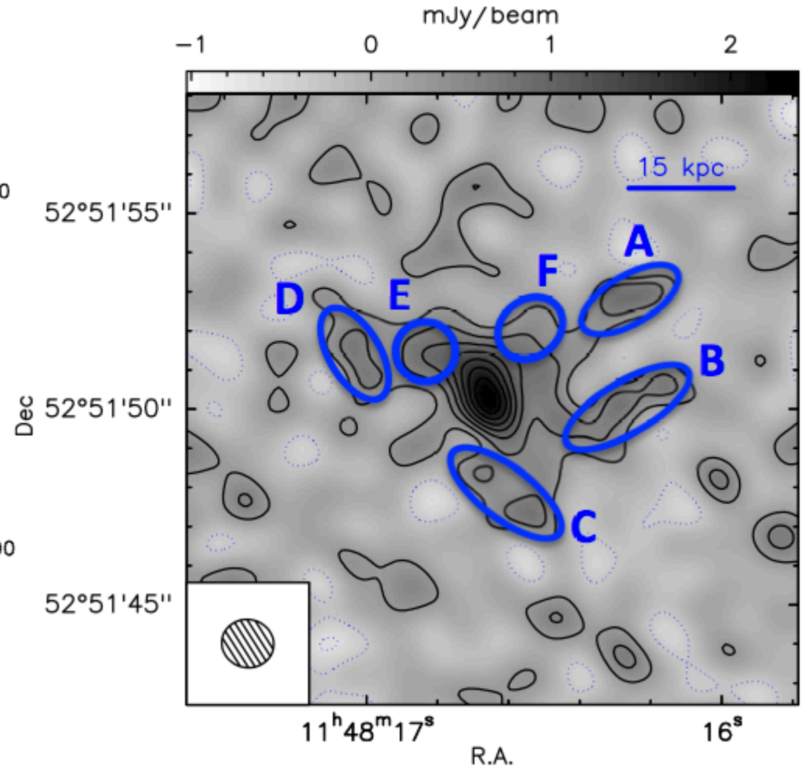
Image & simulations by T. Costa, D. Sijacki & M. Haehnelt 2015

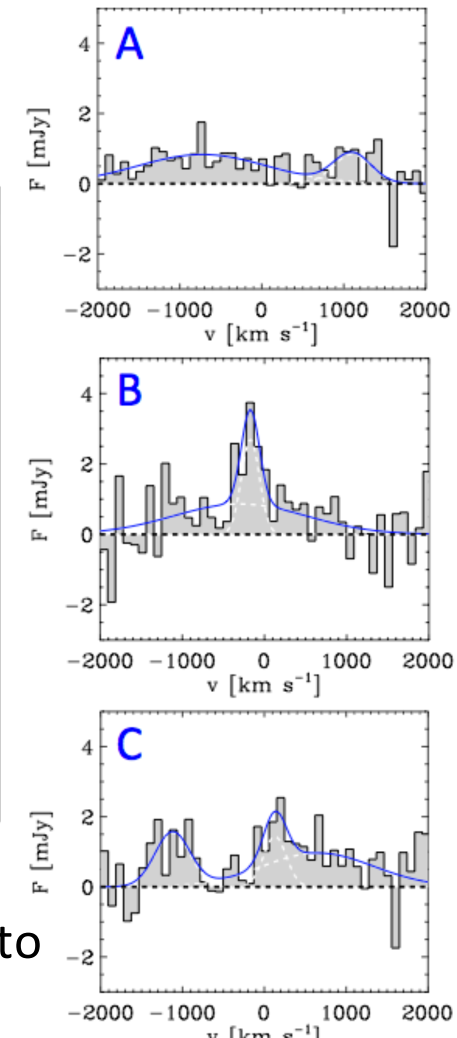
High-z quasars: fast and *synchronous* growth of SMBHs and their host galaxies. Feedback mechanisms expected to be important!

Massive outflow in a z~6 quasar



[CII] in SDSS J1148+5251 at z=6.4



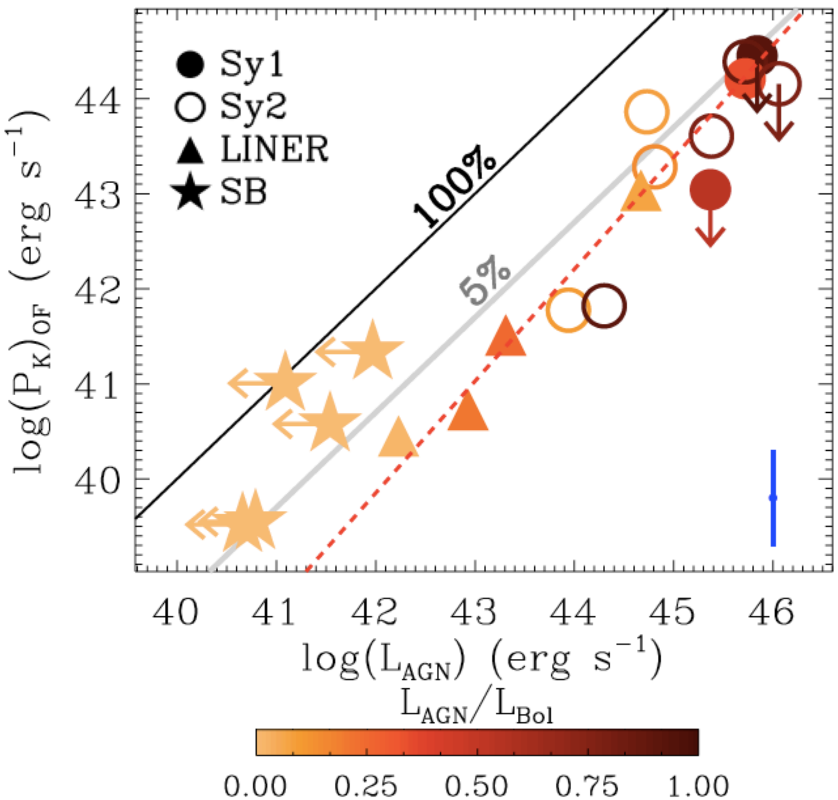


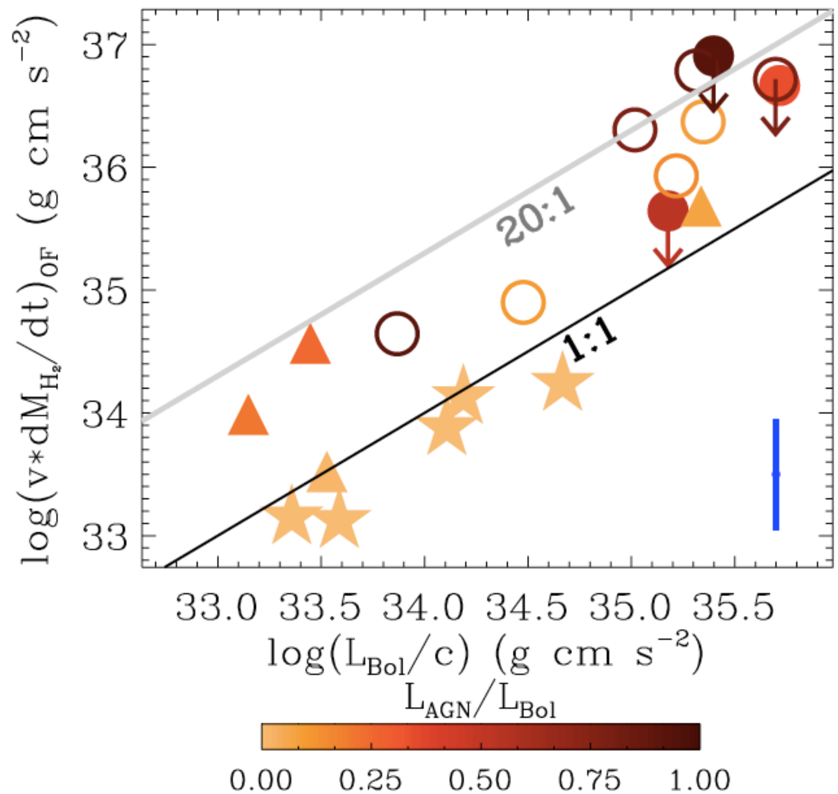
Outflowing clumps detected up to R= 30 kpc

Cicone+15, Maiolino+12

More high-z molecular outflow detections: Carniani+17, Feruglio+17

Molecular outflows and radiative-mode AGN feedback





Measurements of outflow kinetic power and momentum rate show ***good agreement with models of radiative-mode AGN feedback***

Cicone+14

The COURAGE project

Yoshida+16

2 meanings:

- "Cold OUtflows Ruffling the AGn Environment"

- COURAGE
  (and strength) !!!

Main themes:

1. The physical properties of cold outflows

2. The outflow acceleration mechanism (from pc to kpc scales)

3. AGN feedback in the early Universe

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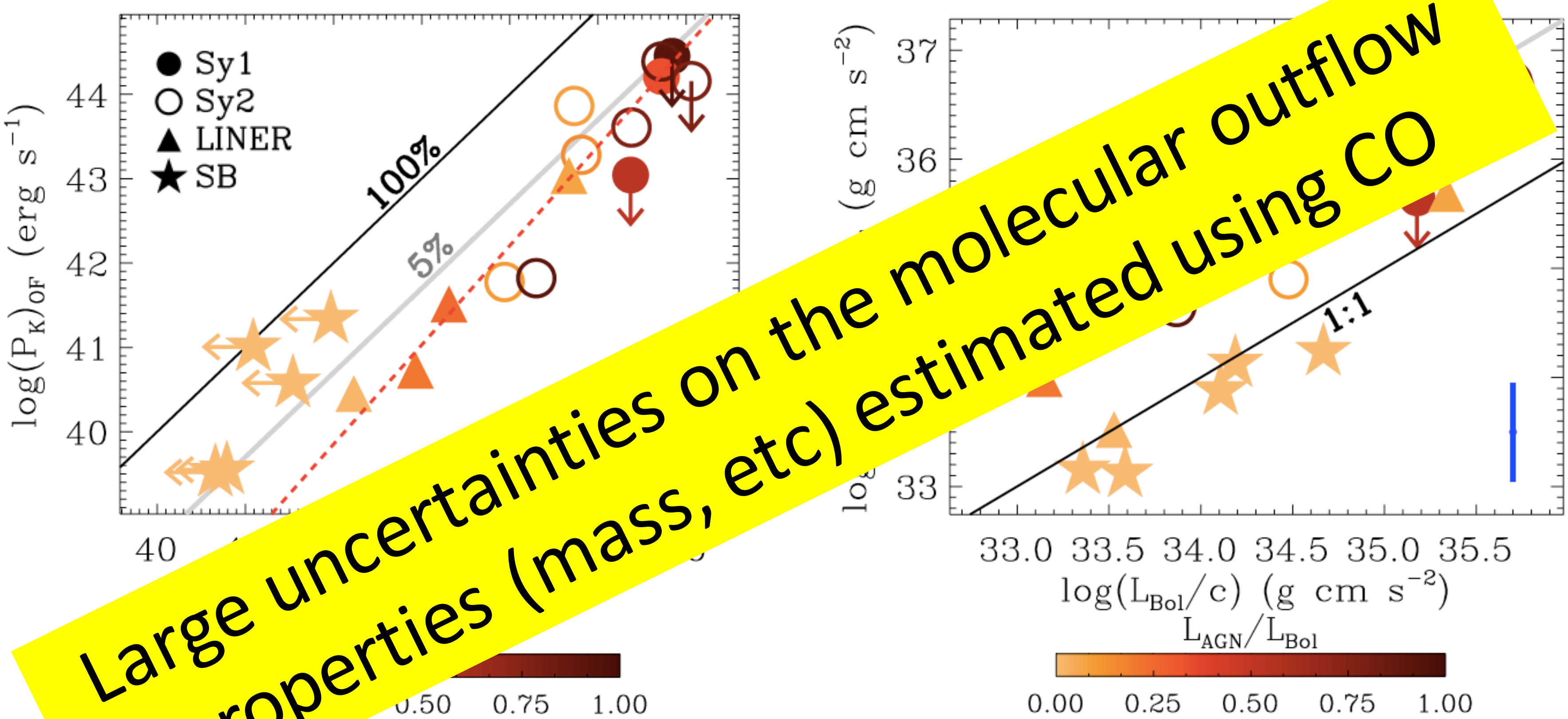
Molecular outflows and radiative-mode AGN feedback



Large uncertainties on the molecular outflow properties (mass, etc) estimated using CO

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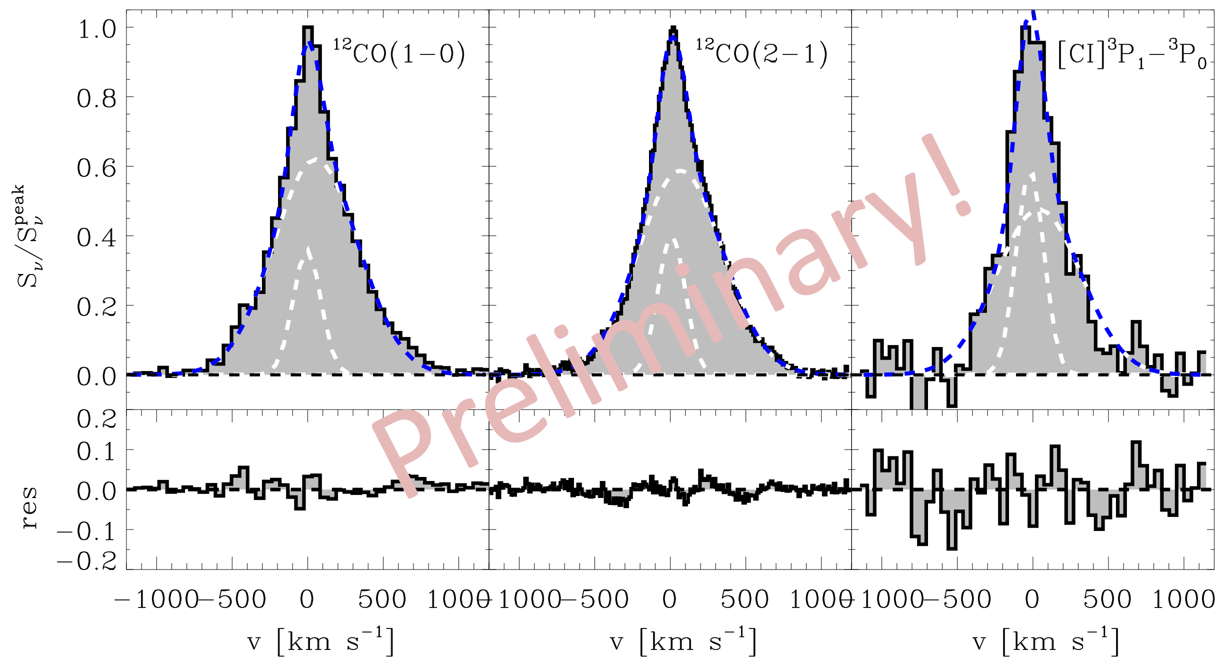
Cicone+14

The Carbon method

Aim: test the capability of the $[CI]^3P_1$-$^3P_0$ line to probe H_2 in outflow. Why?

1) Atomic carbon (CI) is fully concomitant with H_2
2) [CI] lines are optically thin -> straightforward estimate of M_{H2}
3) [CI] lines can be observed from z~0 to z>6
4) [CI] can probe CO-dark H_2 gas



$M_{mol} = \alpha_{CO(1-0)} L'_{12CO(1-0)}$

$\alpha_{CO(1-0)}^{TOT}$ = 1.83 +- 0.09

$\alpha_{CO(1-0)}^{NARROW}$ = 3.3 +- 0.3

$\alpha_{CO(1-0)}^{BROAD}$ = 1.55 +- 0.10

Cicone+ in prep

Molecular outflows ruffling AGNs

- Can expel large masses of H_2 gas "out" of the host galaxy in a very short time (a few Myr) with v >1000 km/s -> How good are our mass estimates based on CO?
- Properties of the outflows consistent with models of radiative-mode AGN feedback -> What is the link with hot nuclear winds?
- Extend by several 10s of kpc. So far most extended outflow detection *allowed by data*: R~30 kpc @ z=6.4. How common at high z?

Preliminary results indicate that CO traces outflows better than "quiescent" gas (because $\boldsymbol{\alpha}_{\mathbf{CO(1\text{-}0)}}$ is lower for the broad than for the narrow component)

-> Carbon method is promising, but CO is a worthy adversary!