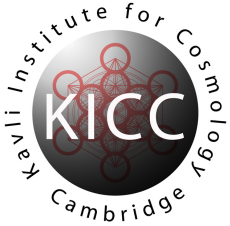
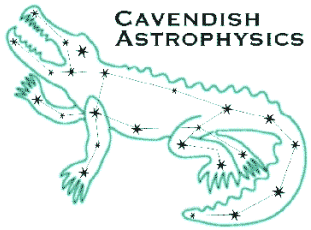
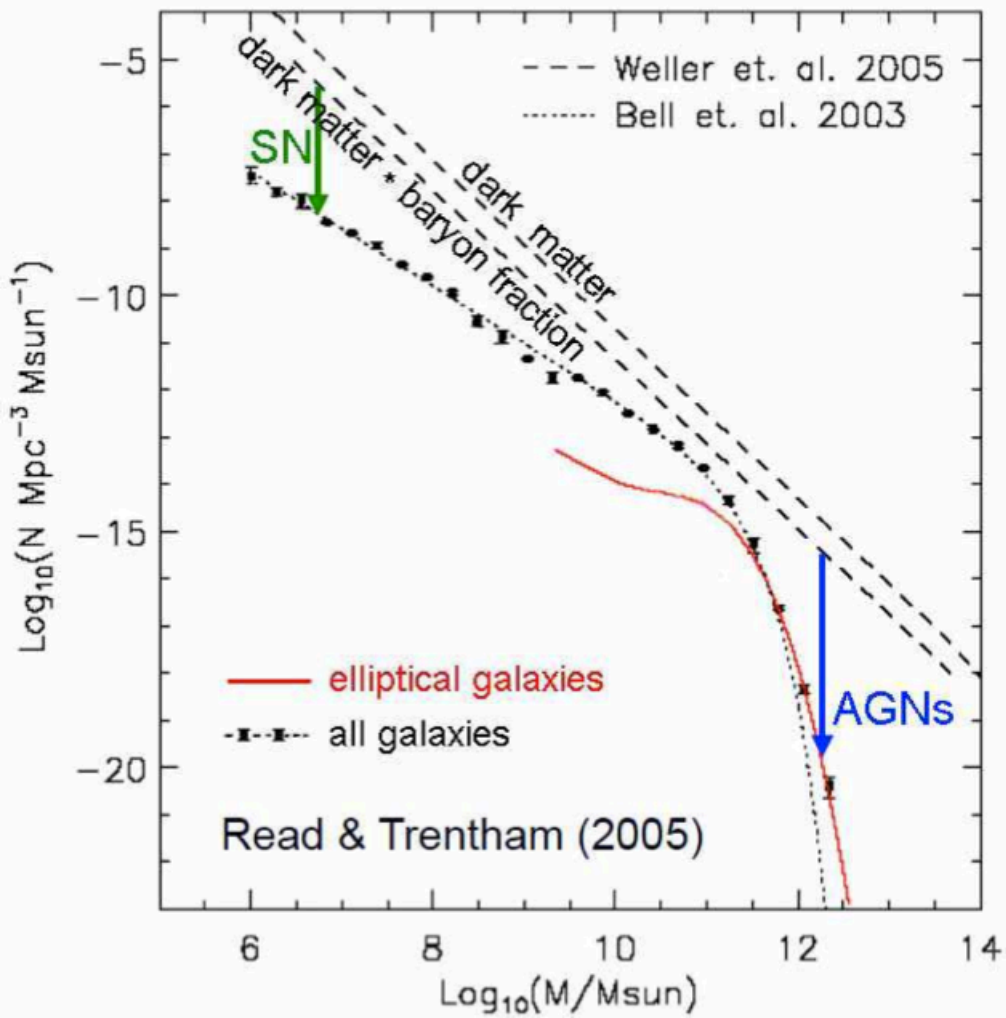
Observational evidence for AGN feedback throughout the cosmic epochs

Roberto Maiolino





The need for (negative) feedback



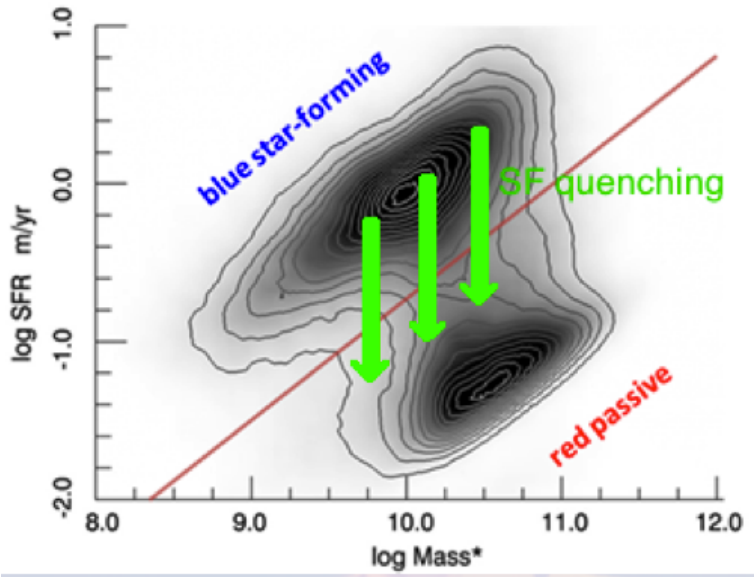
Theoretical expectations:

SNe feedback:

removes baryons from galaxies and reduce SF efficiency in low mass galaxies

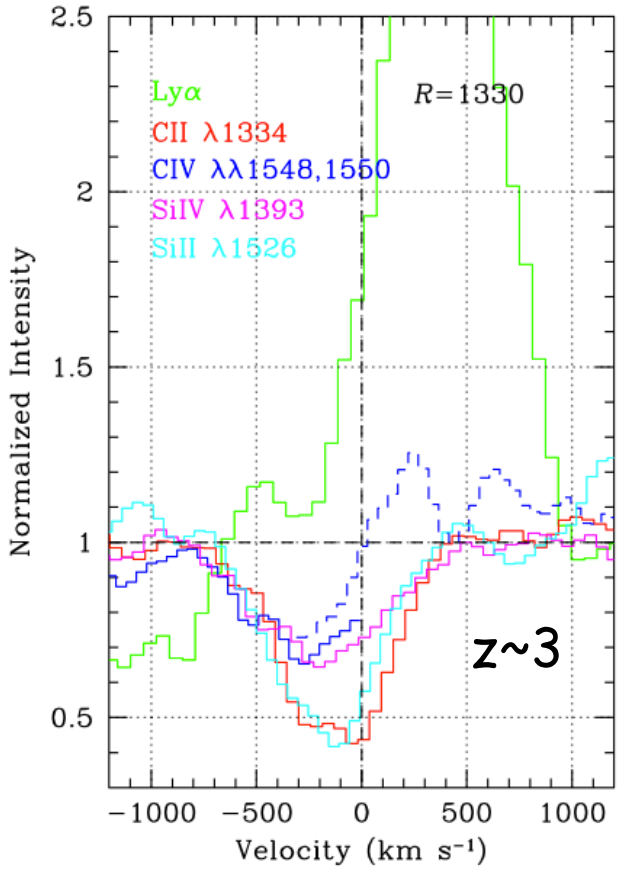
AGN feedback:

- prevents overgrowth of massive galaxies
- invoked for the M_{BH}-M_{star} relation
- explains red-and-dead properties of local ellipticals



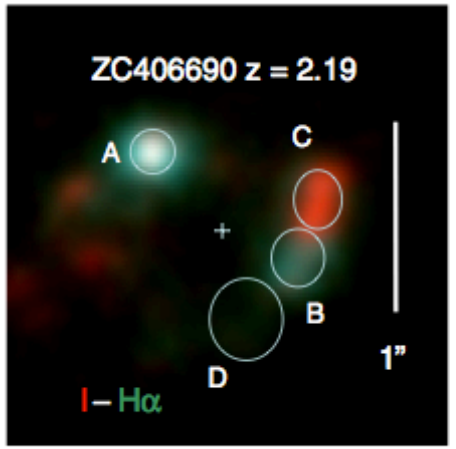
Observational evidence for (SN feedback) in local and distant (z~2-3) star forming galaxies

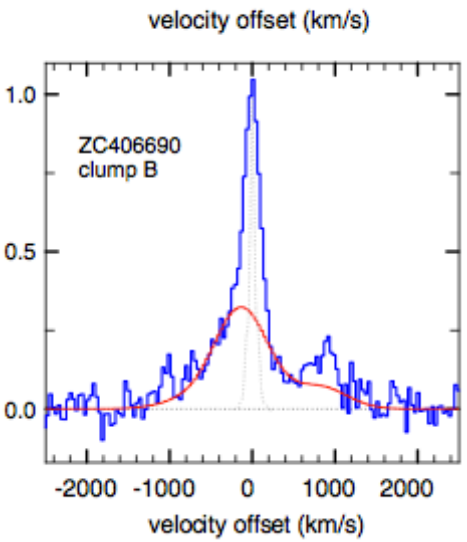
Locally



Steidel+10
Bradshaw+13
Diamond-Stanic+12

z~2

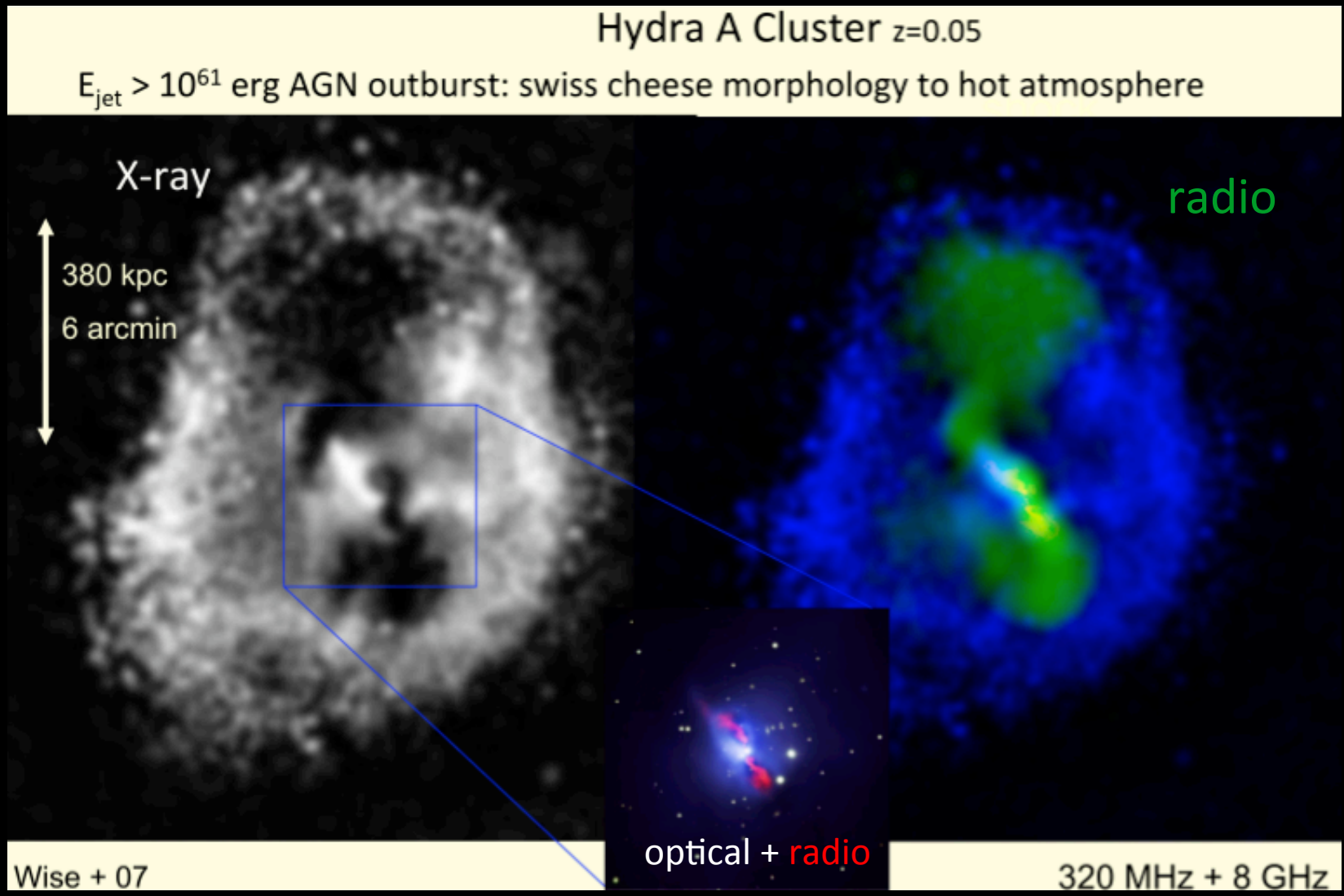




Genzel+11
Newman+12

Outflow load factor $\frac{\dot{M}}{SFR}$ ~ 1-2

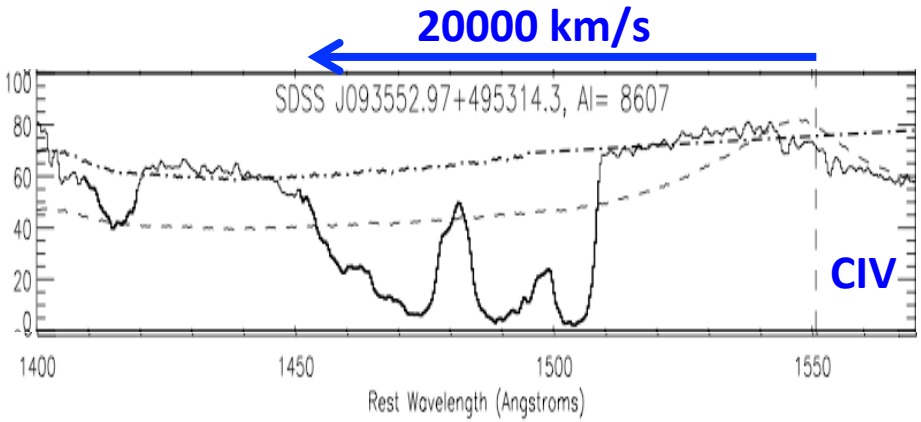
Evidence for radio-mode AGN feedback in LOCAL galaxies (maintenance mode)

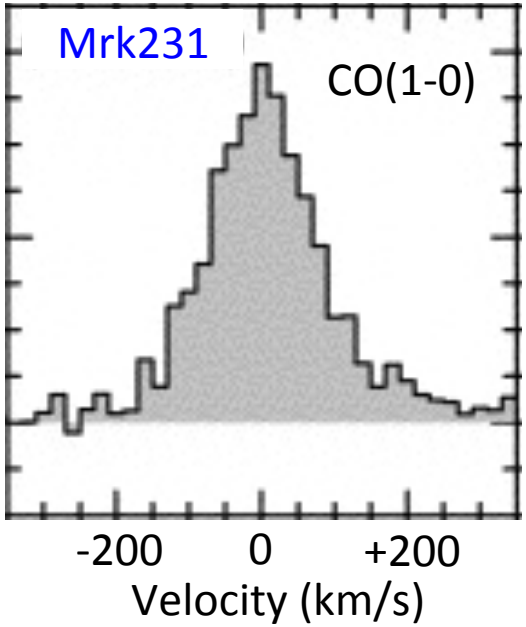


Observational evidence for "quasar-mode" feedback: early misconceptions

"BAL winds are nuclear
-> not affecting the galaxy
on large scales"

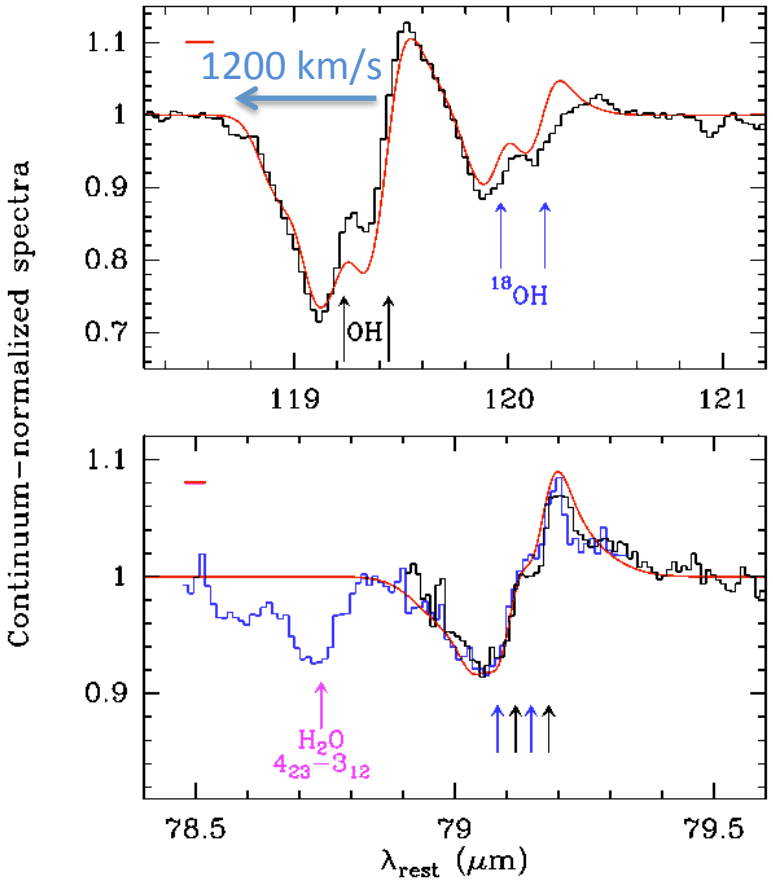
"(molecular) gas in quasar hosts is in regular rotation, quiescent unaffected by the quasar"



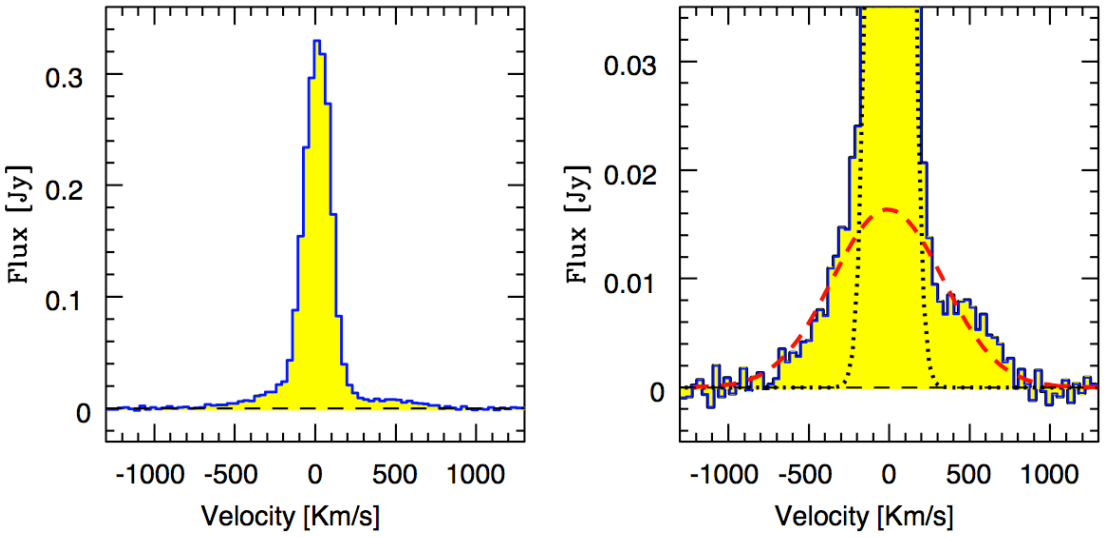


First evidence of quasar-mode feedback in local quasars achieved only recently

OH P-Cygni profiles

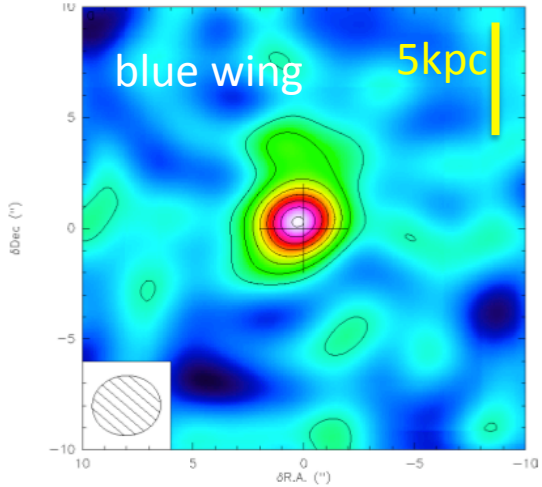


CO(1-0) high velocity wings



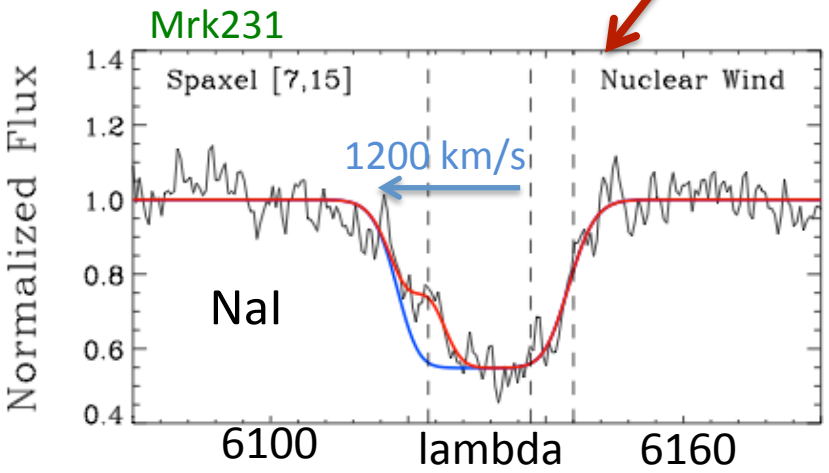
Fischer+10
Sturm+11

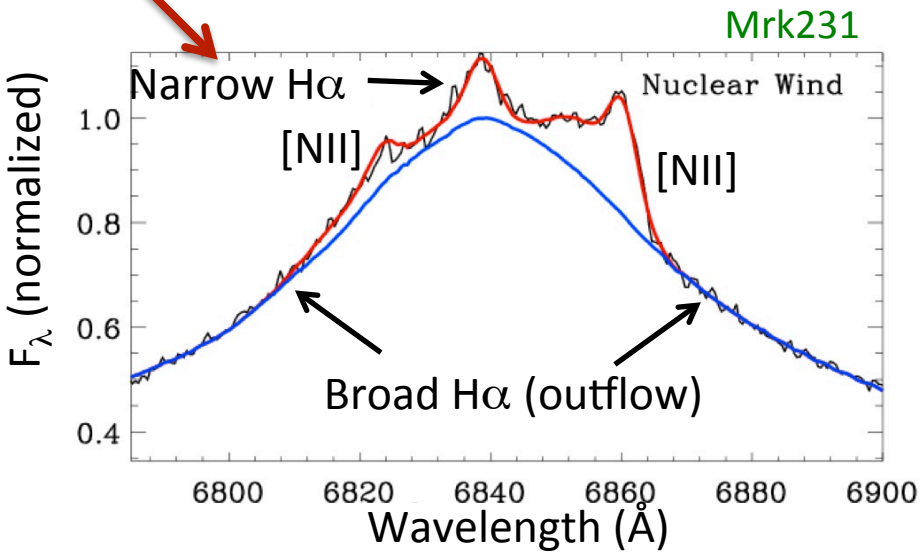
Feruglio+10,13

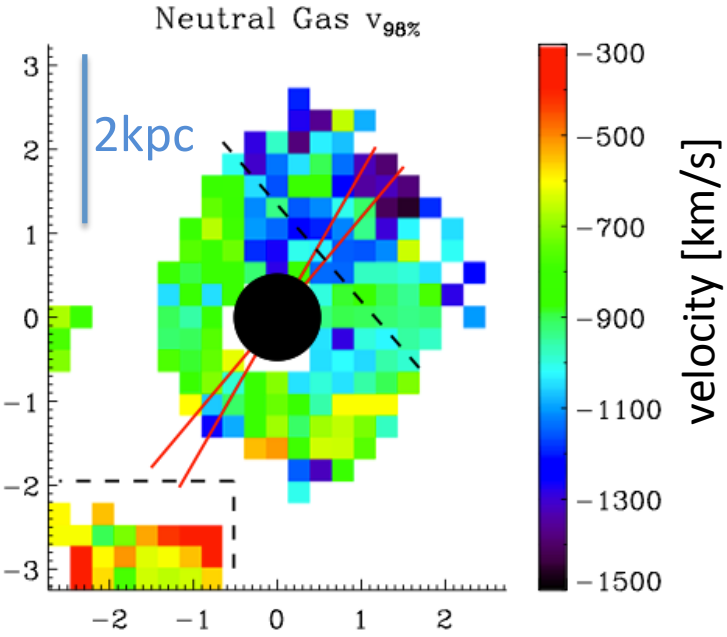


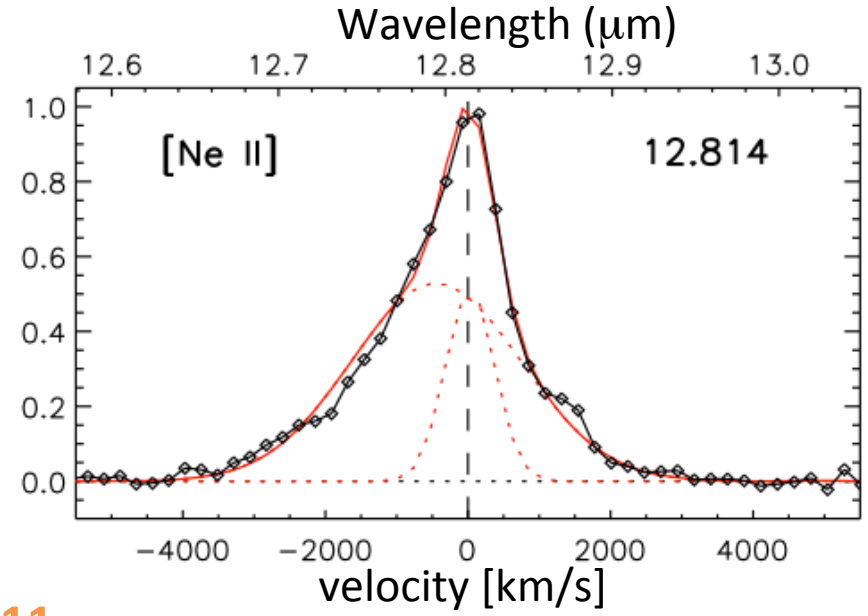
Massive molecular outflows (~1000 $M_\odot$/yr)
Extended on kpc scales

Massive outflows detected also in the atomic neutral and ionized component



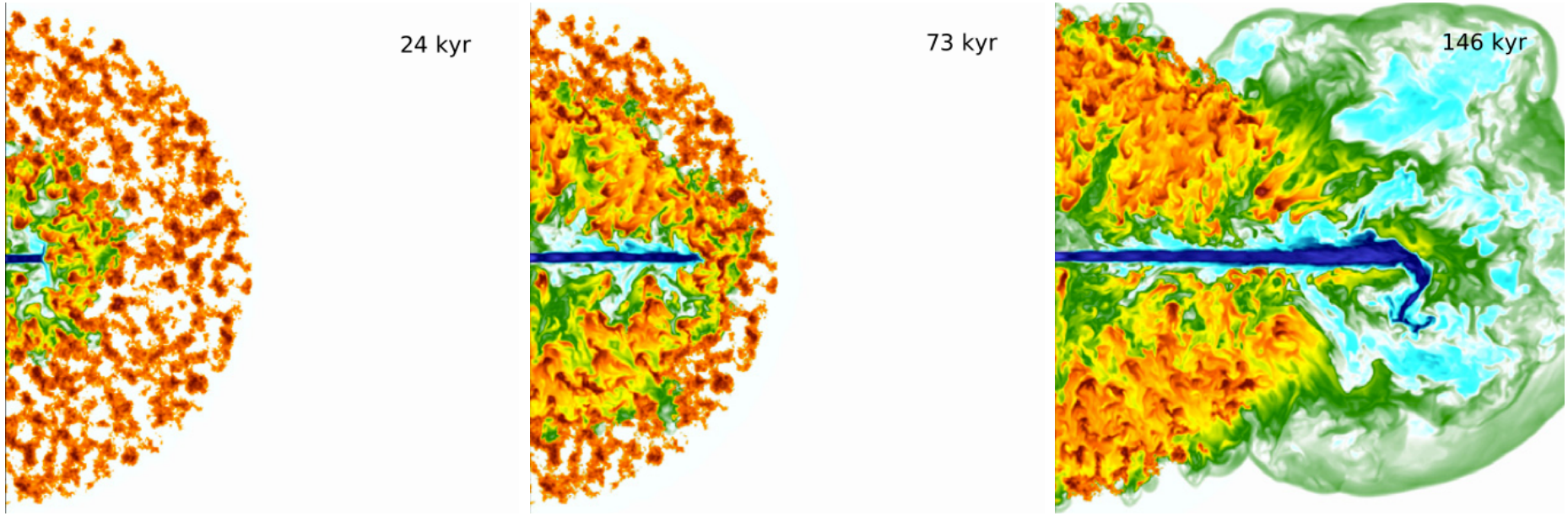






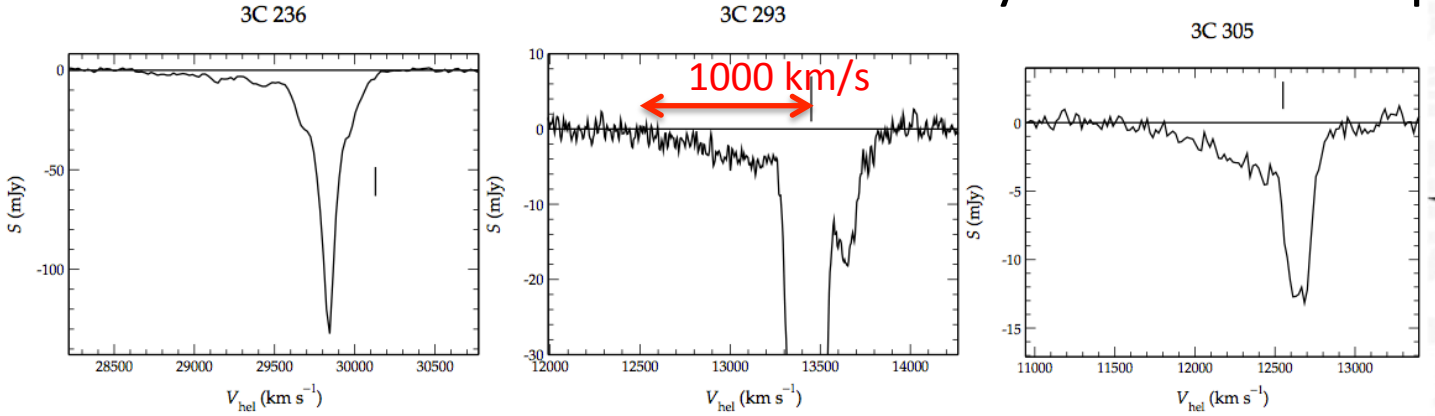
Rupke+11,13, Spoon+11, Muller-Sanchez+11

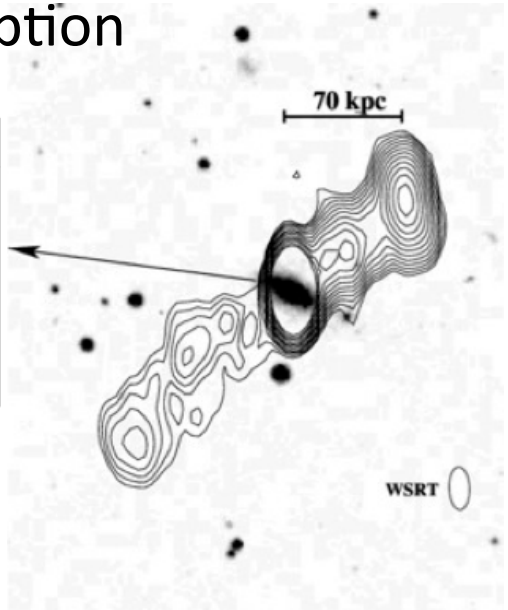
"Quasar-feedback" phase driven by jets?



Wagner & Bicknell 2011, 2012

Jet-driven atomic outflow traced by 21cm HI absorption

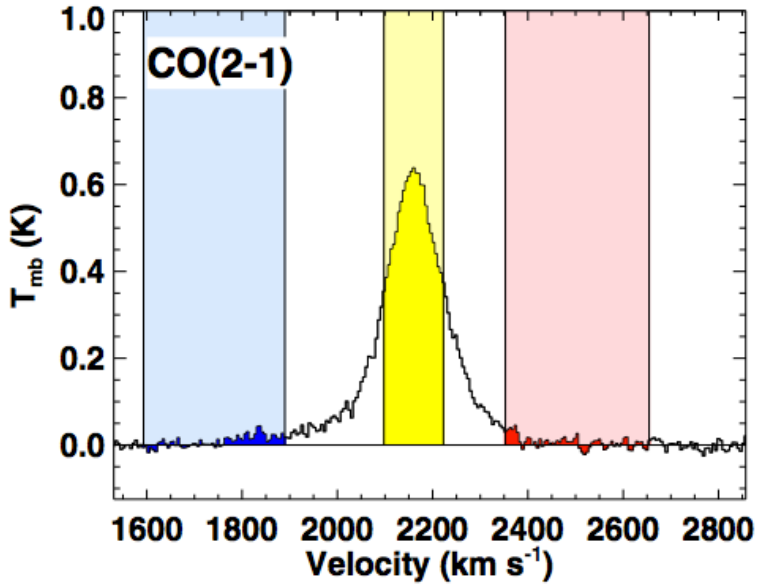


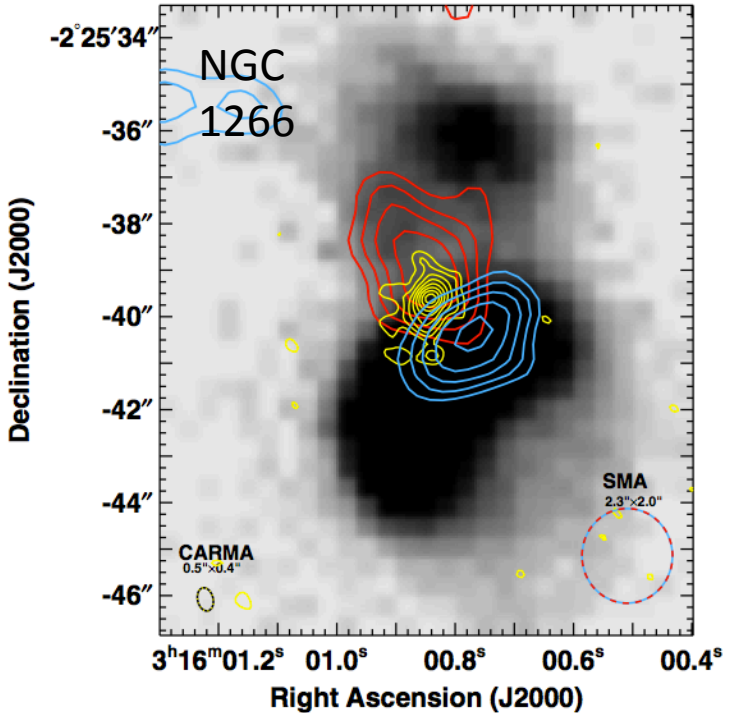


Morganti+03,05, Emonts+03

Jet-driven molecular outflow traced by CO broad wings

Alatalo+11

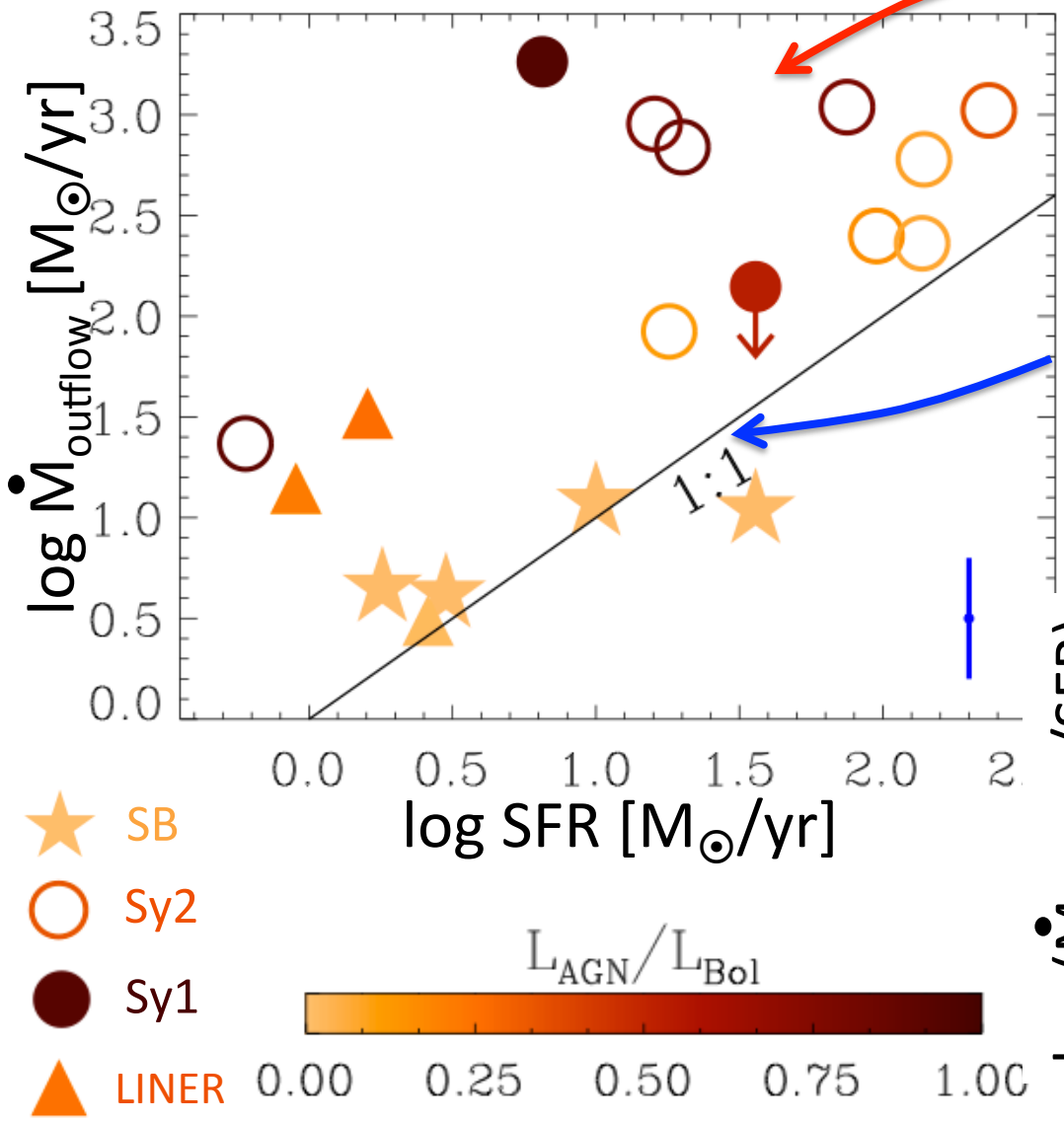


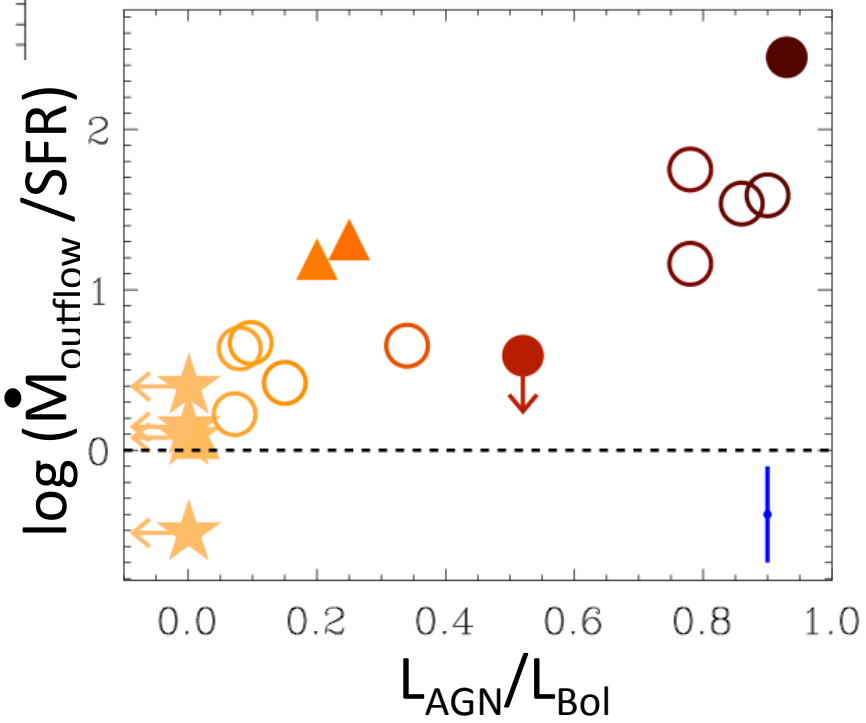


More CO observations (IRAM, Carma,…+ALMA ongoing)

AGN-dominated gals. deviate from the starburst 1:1 relation with extra outflow boost by a factor of 5-100!

Starburst-driven outflow rate ~ SFR as required by feedback models



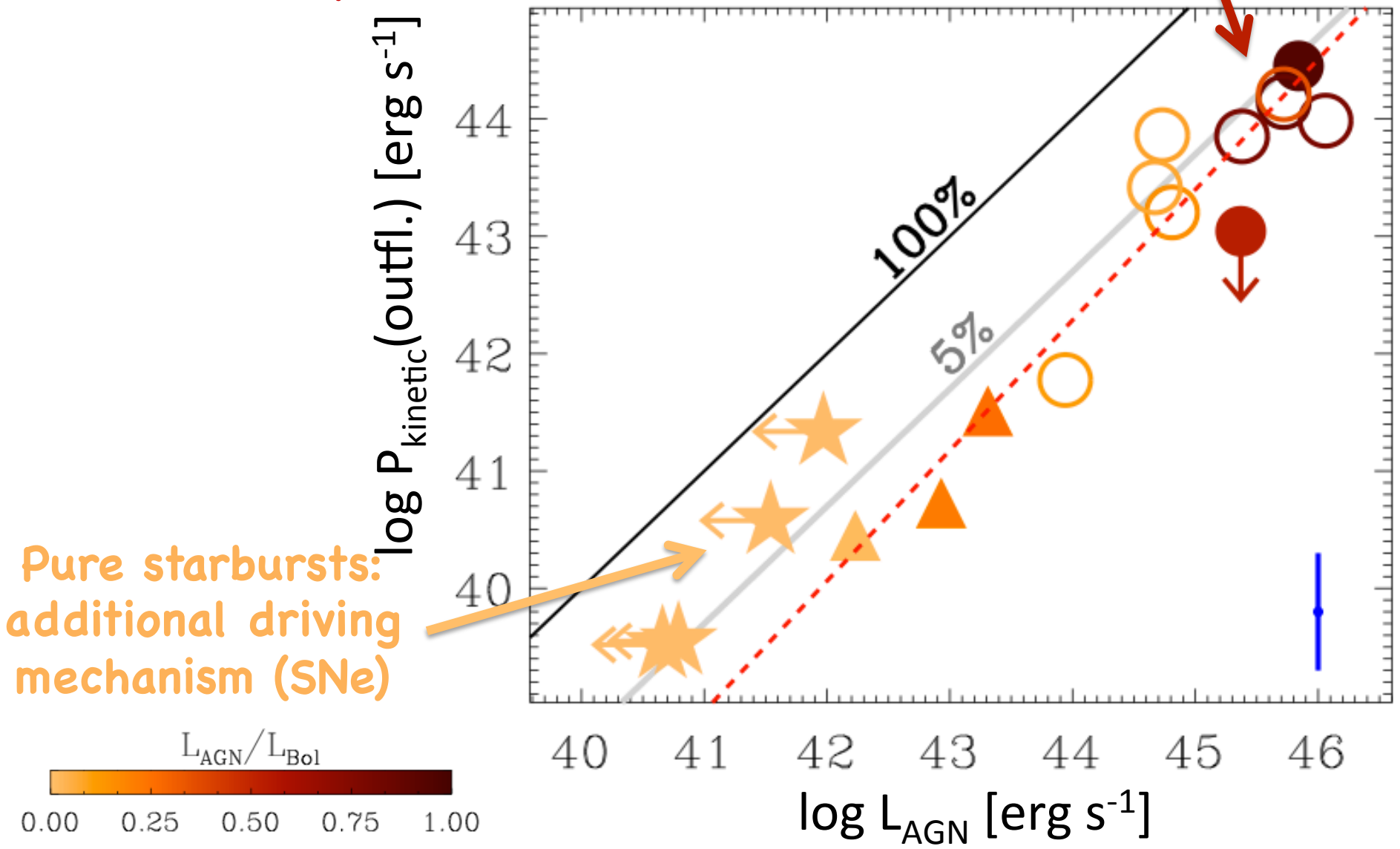


Cicone+13

Outflow kinetic power (in powerful AGNs)

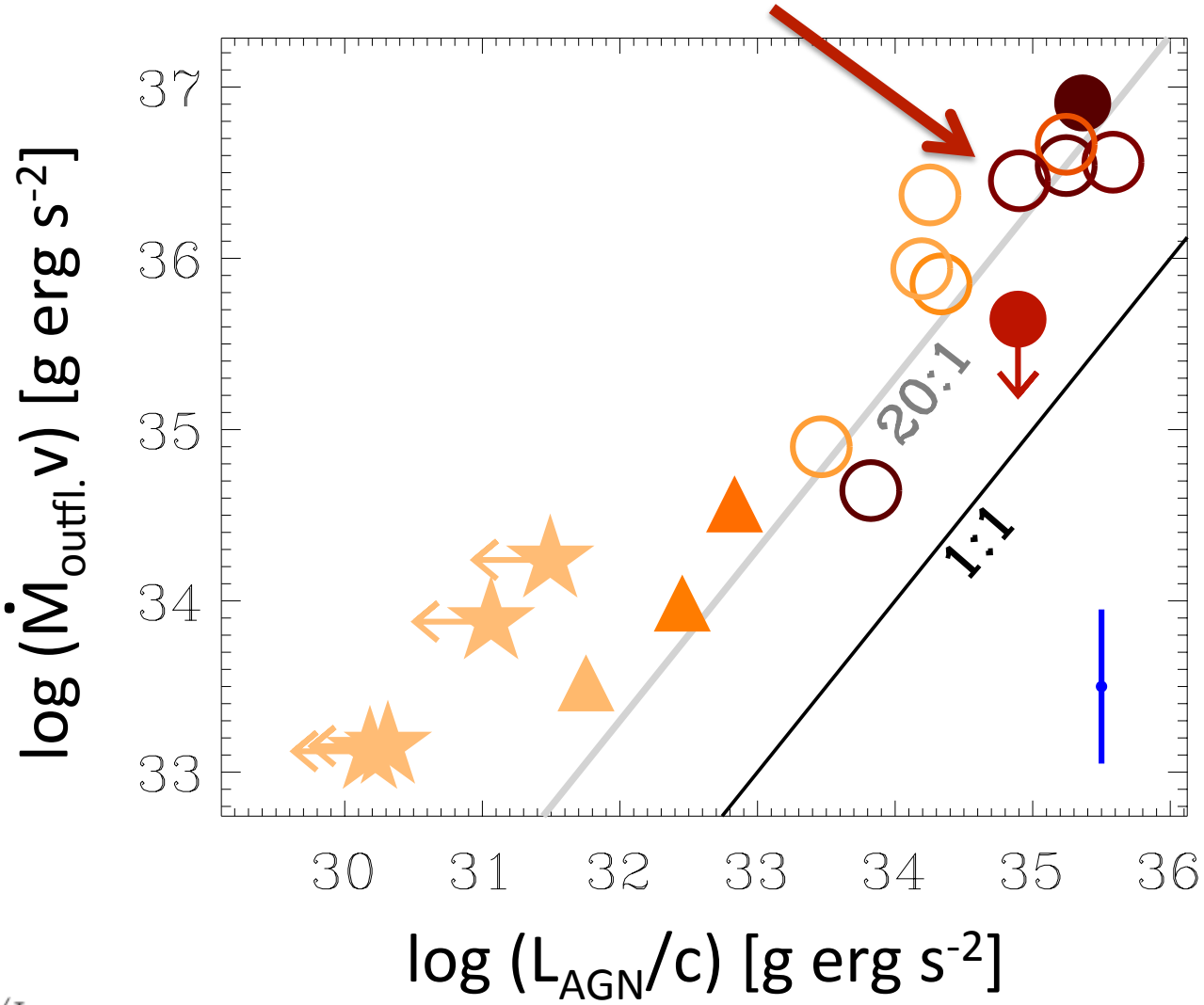
$P_K \sim 0.05\ L_{AGN}$

as predicted by models (King's talk)

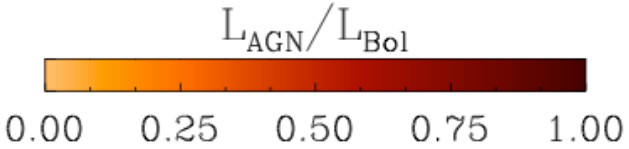


Pure starbursts: additional driving mechanism (SNe)

Outflow momentum ~ 20 L_{AGN}/c as expected by models (King's talk)

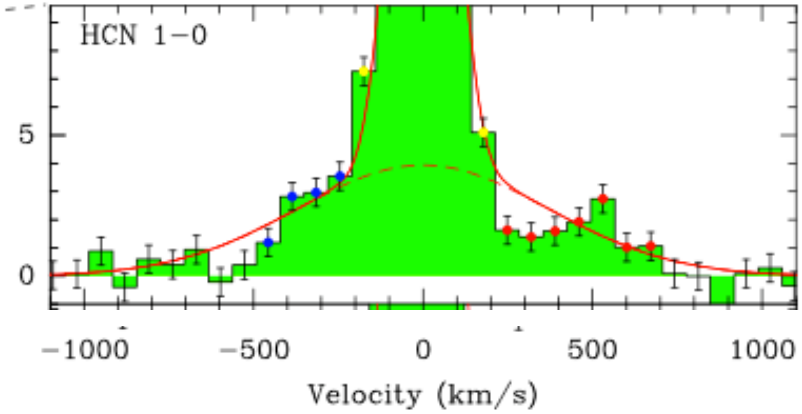


Cicone+13



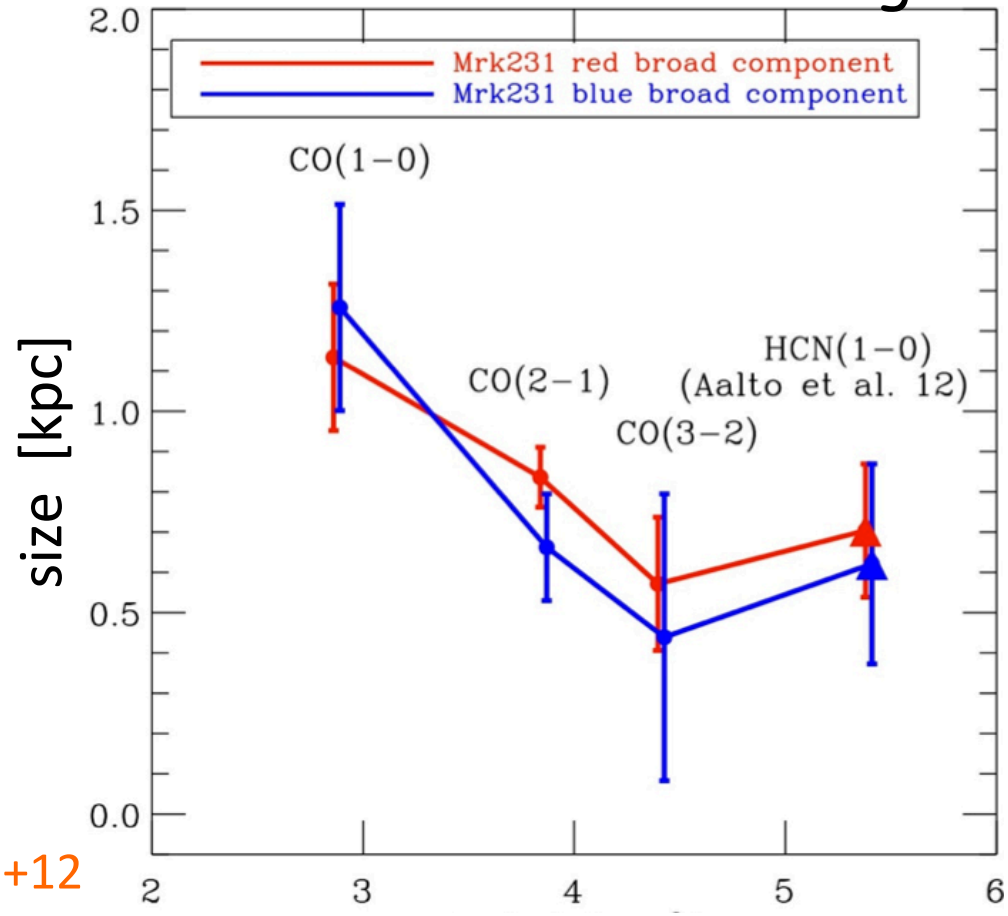
Investigating the physics gas of quasar-driven outflows

HCN wings:
dense gas in the outflow



Aalto+12

Diffuse molecular gas
more extended than dense gas

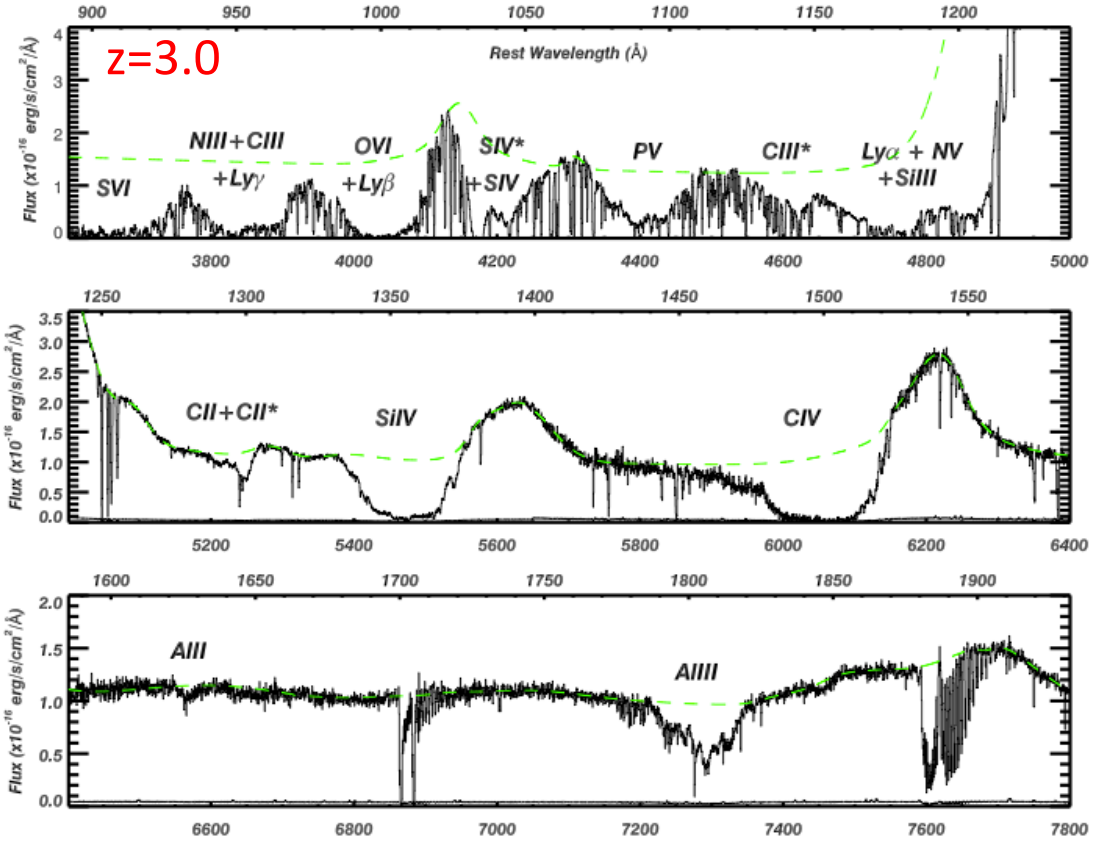


Cicone+12
Feruglio+13

AGN feedback at high redshift

To explain the local red-and-dead massive galaxies (age 10 Gyr) the strongest feedback effect should occur at high redshift (z~1-2)…

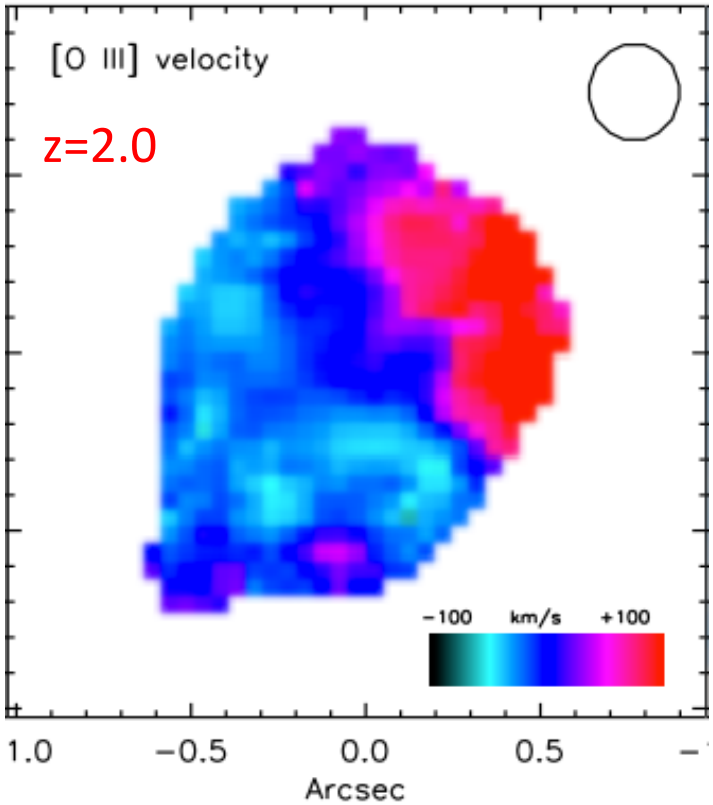
BAL QSO's are probably the best example… disregarded until recently (Arav's talk)



Bourget et al. 2012, 2013

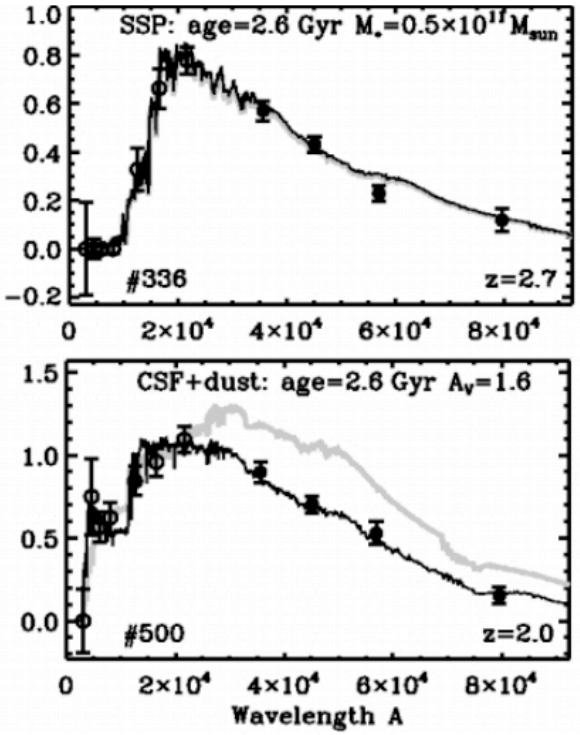
R ~ 300-2,000 pc
V = 8000 km/s
$P_K > 10^{46}$ erg/s ~ 5% L_{AGN}

[OIII]5007 velocity maps of high-z AGNs

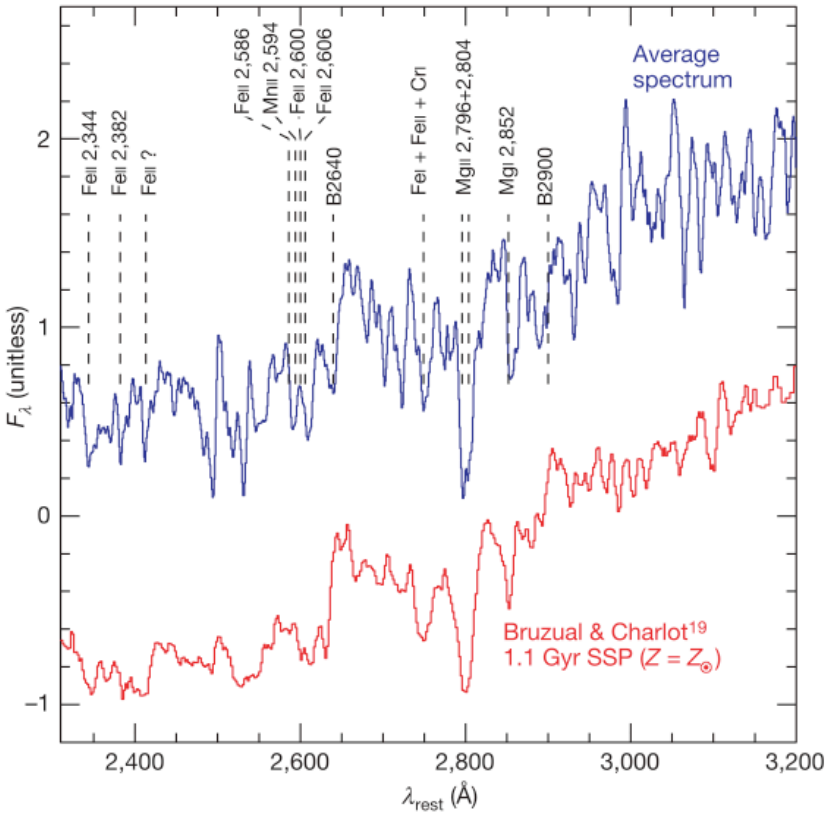


Alexander+10

Massive passive and old (age ~2-3 Gyr) galaxies have been discovered at z~2.5 (age of the Universe ~3 Gyr !)



Kriek+06, Labbe+05, Saracco+05, Cimatti+04



➔ Quasar feedback quenching star formation must already be **in place at z~6** (close to the re-ionization epoch, age of the Universe less than 1 Gyr) in a fraction of very massive galaxies

Massive quasar outflow detected at z=6.4

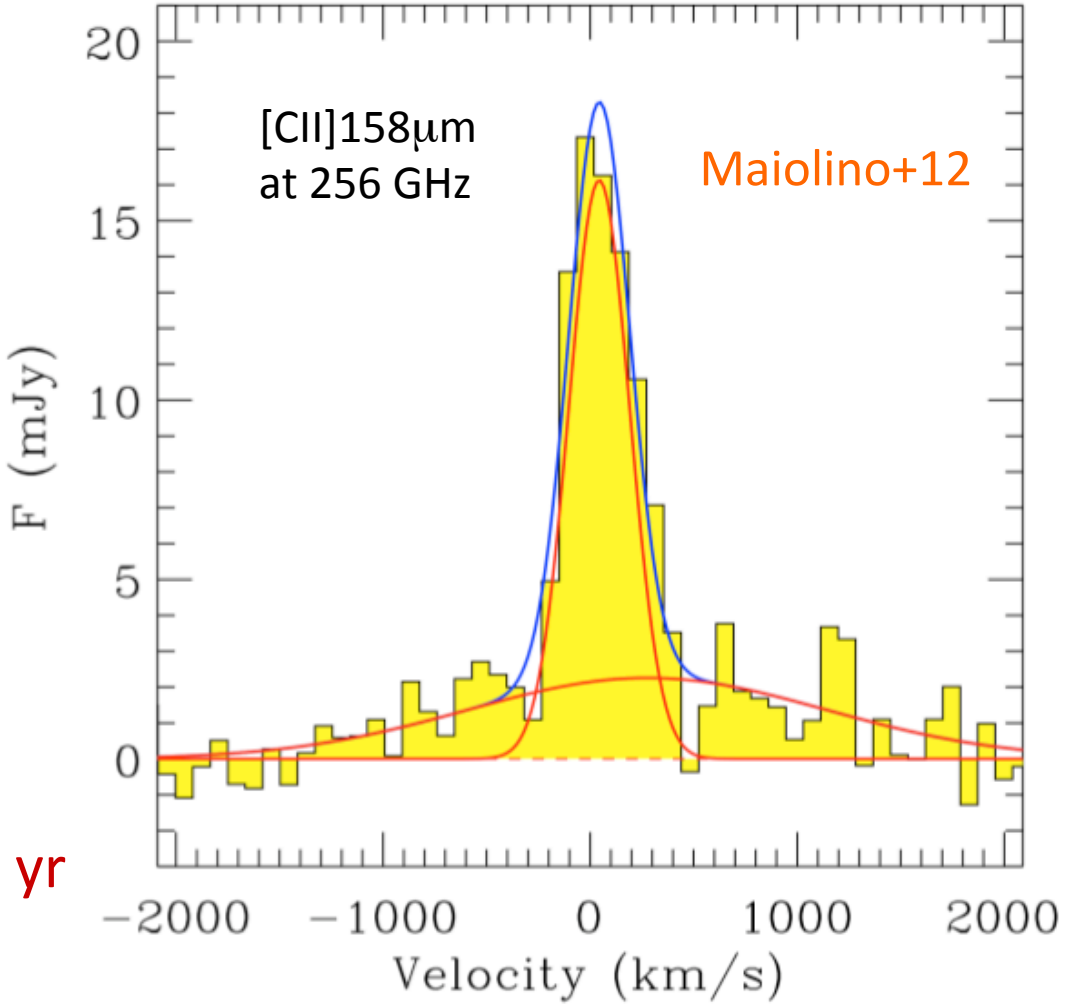
Broad wings
tracing outflow
with v~1300 km/s

Size: ~16 kpc !

$\dot{M}_{outflow} > 3500\ M_\odot/yr$

Depletion timescale < 10^7 yr

α-enhancement
in massive spheroids



Efficient quenching of
star formation in the early Universe

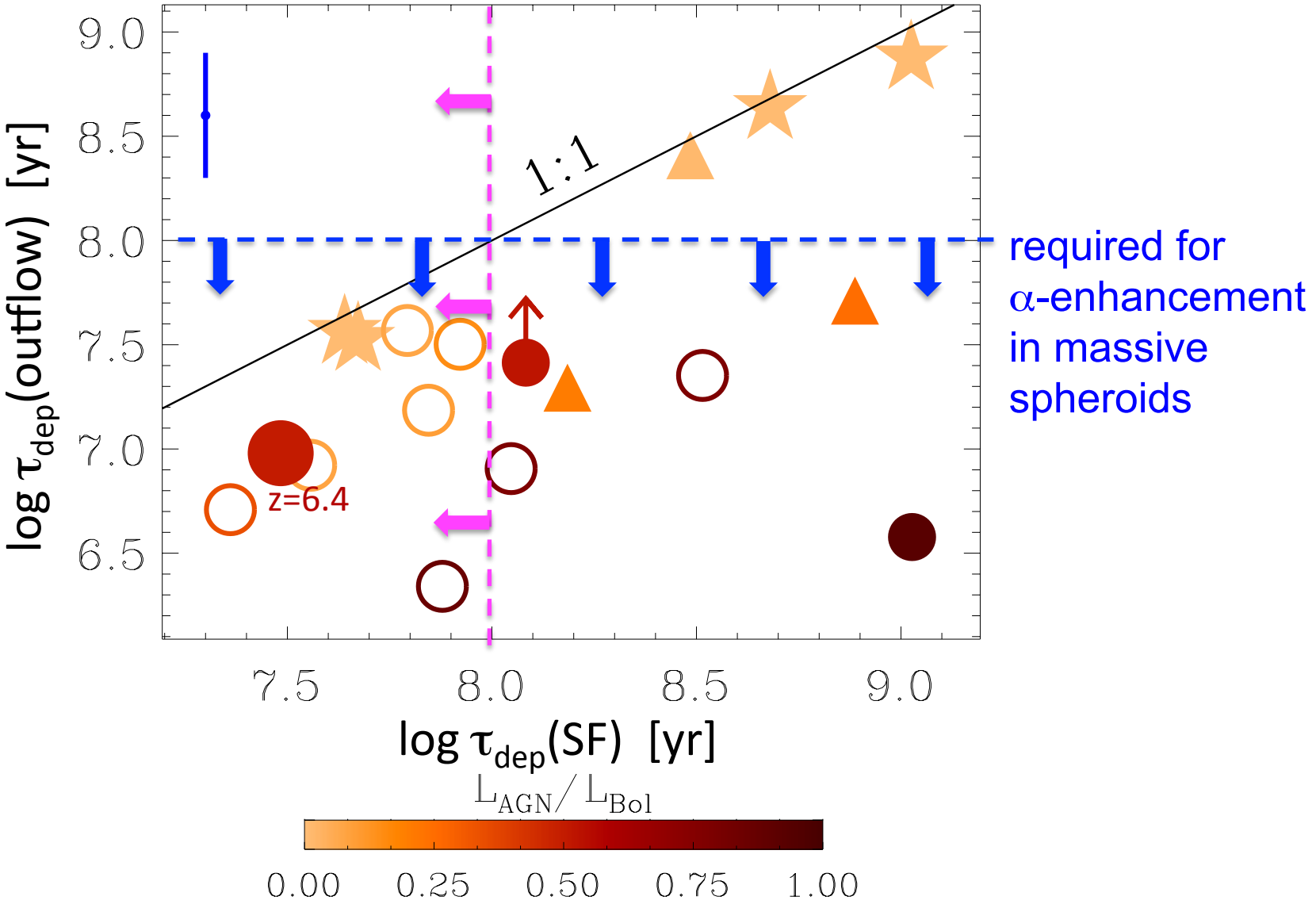
Implications for the re-ionization of the Universe

Most of the reionization ascribe[...] to *small* [...]stems
(escape fraction f_{esc} ~1 tha[...]ks to SN [...] [...]ning [...] ISM)
In *massive* system f[...] [...]e)

Let AGNs to do the "dirty job" and make the Universe shine!

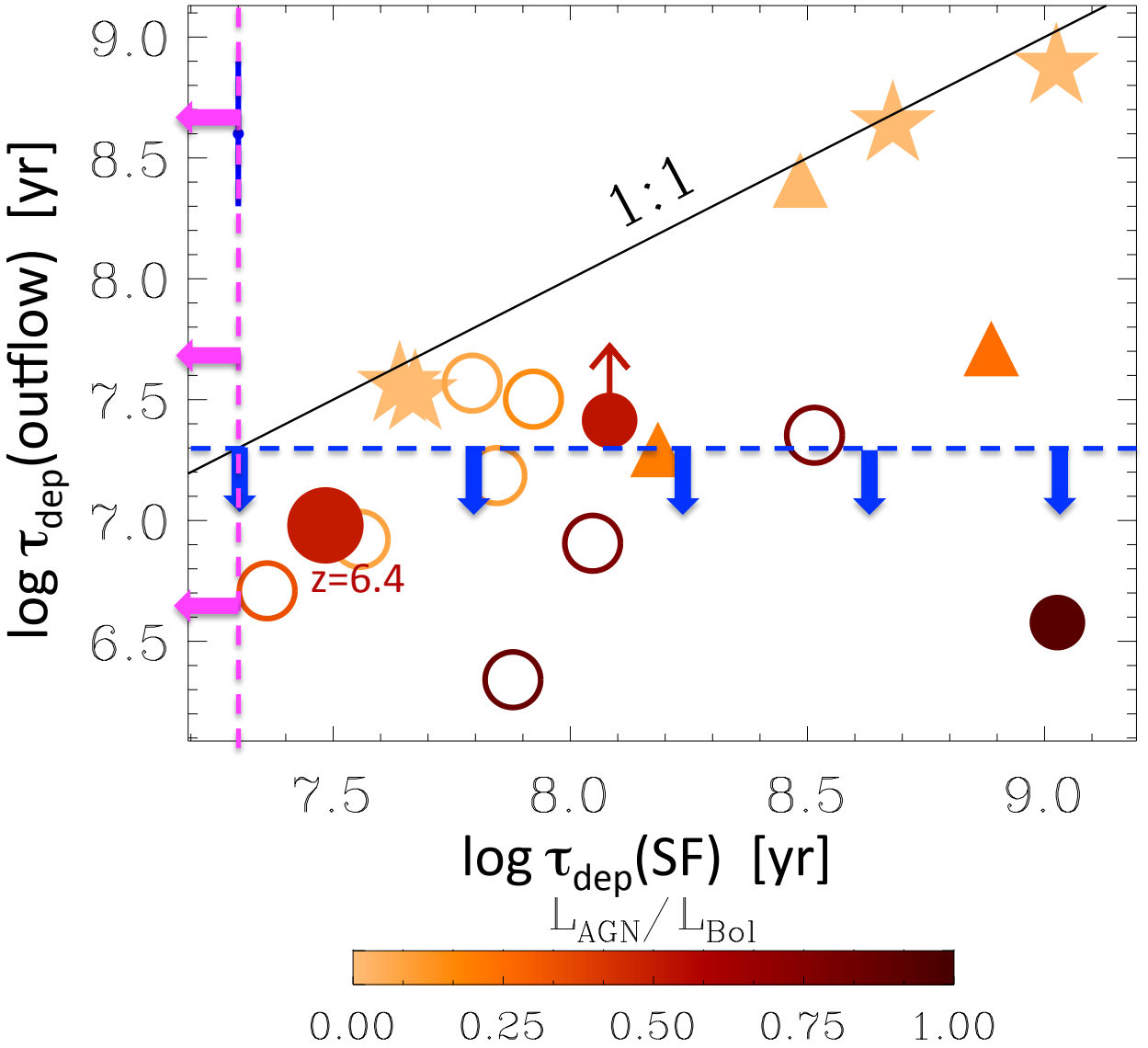
AGN fe[...]back E[...]ective in expelling the ISM
and drastically increase f_{esc} (~1)
in *massive* systems

Depletion timescale due to AGN-driven outflow much shorter than depletion due to Star Formation



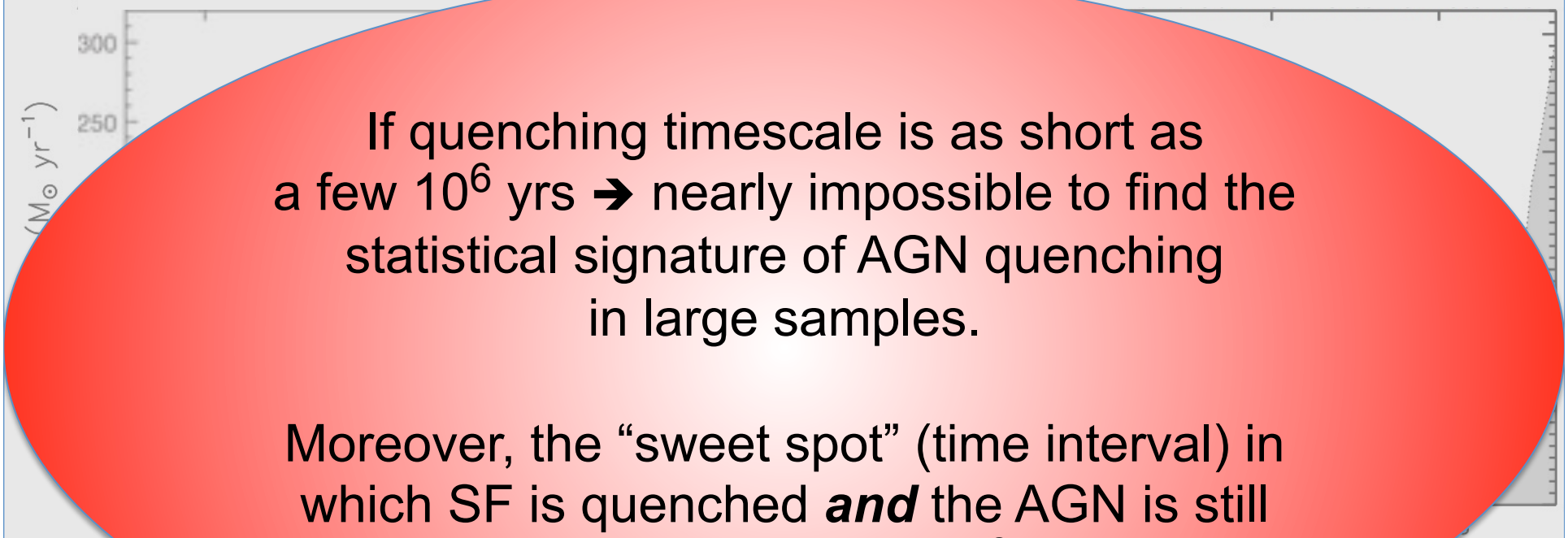
required for α-enhancement in massive spheroids

Depletion timescale due to AGN-driven outflow much shorter than depletion due to Star Formation



required by quenching timescale in post-starbursts at z~0.5-1

Direct evidence for star formation quenching?



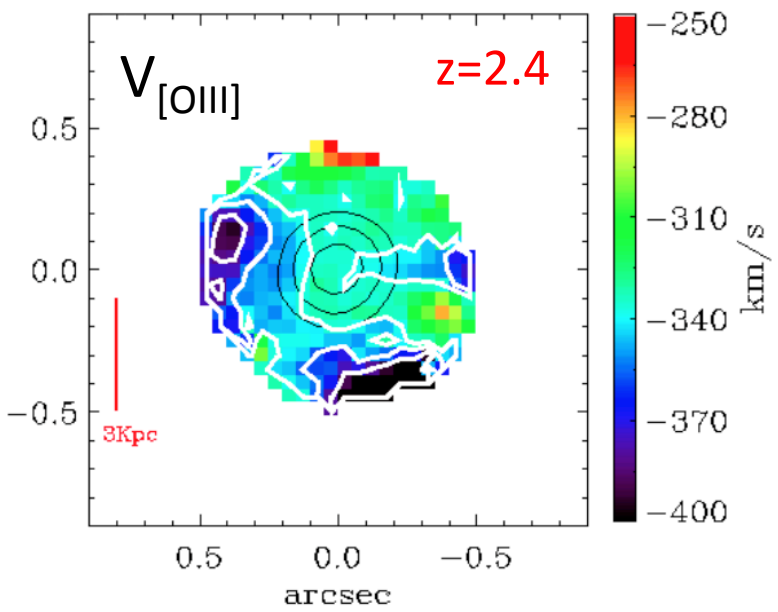
If quenching timescale is as short as a few 10^6 yrs ➔ nearly impossible to find the statistical signature of AGN quenching in large samples.

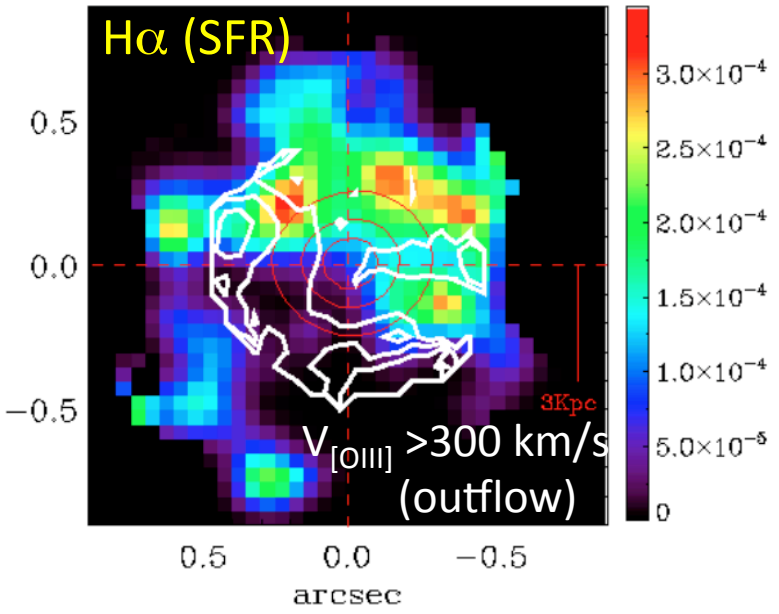
Moreover, the "sweet spot" (time interval) in which SF is quenched ***and*** the AGN is still active is actually << 10^6 yrs.

Page+12
Farra

+ several timescale issues in Lutz's talk

Better strategy:
investigate thoroughly individual, pre-selected targets





Cano Diaz et al. 2012

evidence of quasar-driven outflow
quenching star formation at z=2.4

Positive Quasar Feedback: the third mode of galaxy formation?

AGN feedback and triggering of star formation in galaxies

W. Ishibashi* and A. C. Fabian

Outflows of stars due to quasar feedback

Kastytis Zubovas[1], Sergei Nayakshin[1], Sergey Sazonov[2,3] and Rashid Sunyaev[3,2]

Jet-induced star formation in gas-rich galaxies

V. Gaibler[1,2]*, S. Khochfar[2], M. Krause[2,3] and J. Silk[4,5]

UNLEASHING POSITIVE FEEDBACK: LINKING THE RATES OF STAR FORMATION AND SUPERMASSIVE BLACK HOLE ACCRETION IN DISTANT GALAXIES

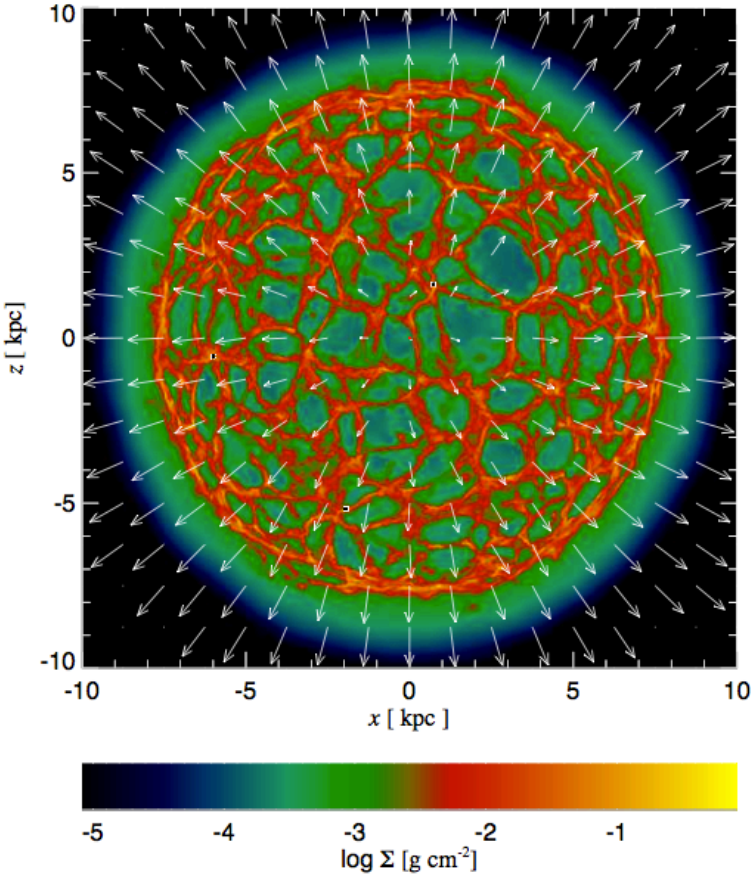
JOSEPH SILK

Quasar feedback: accelerated star formation and chaotic accretion

Sergei Nayakshin and Kastytis Zubovas

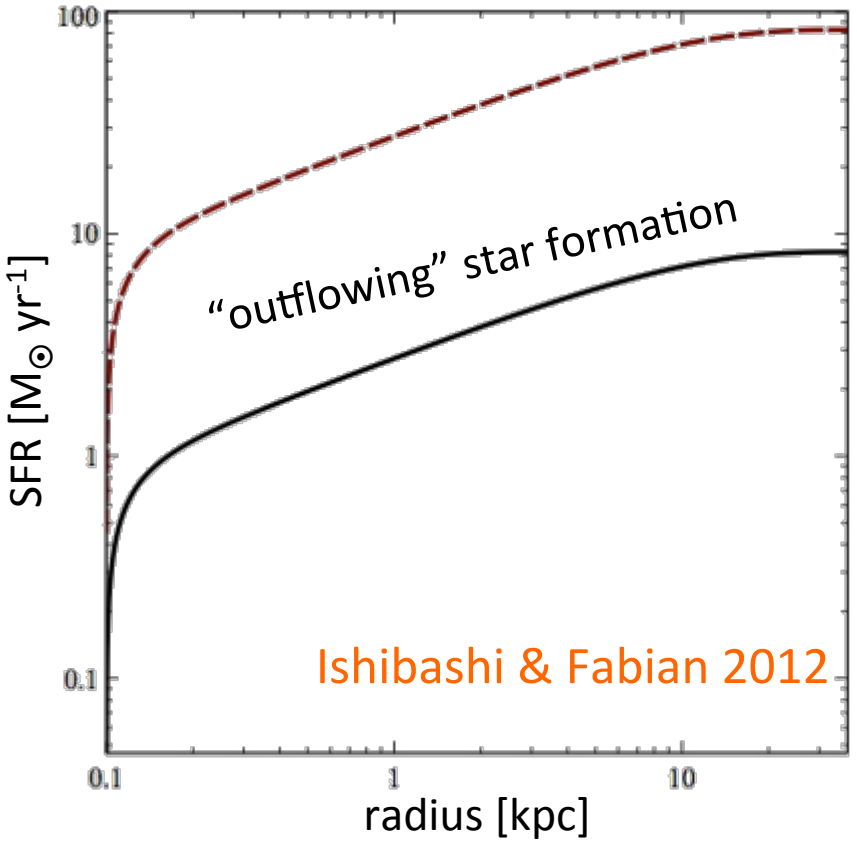
AGN outflows trigger starbursts in gas-rich galaxies

Kastytis Zubovas[1,2], Sergei Nayakshin[1], Andrew King[1], Mark Wilkinson[1]



Outflowing gas is unstable and may undergo star formation

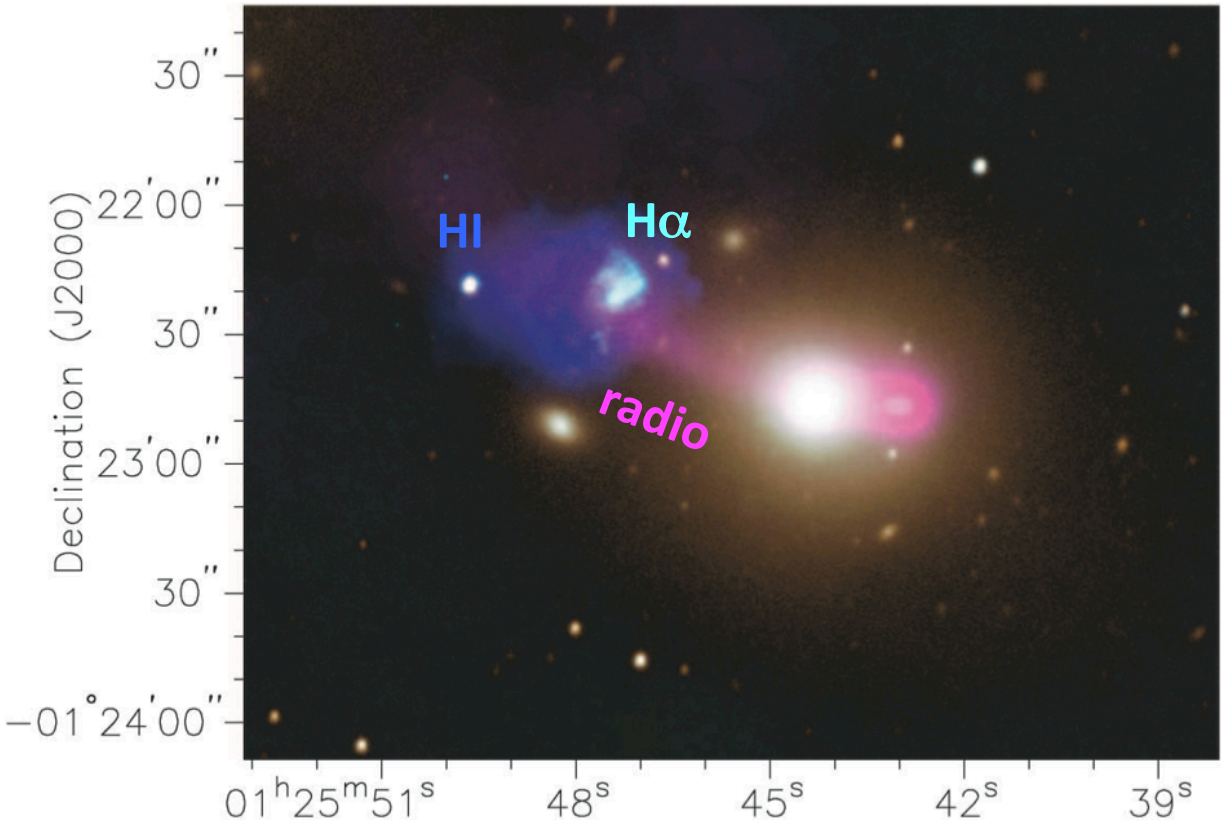
Zubovas et al. 2013



Dynamical and morphological implications for the "triggered" stellar population in massive galaxies

Silk & Norman 2010, Silk & Nusser 2011, Gaibler et al. 2012

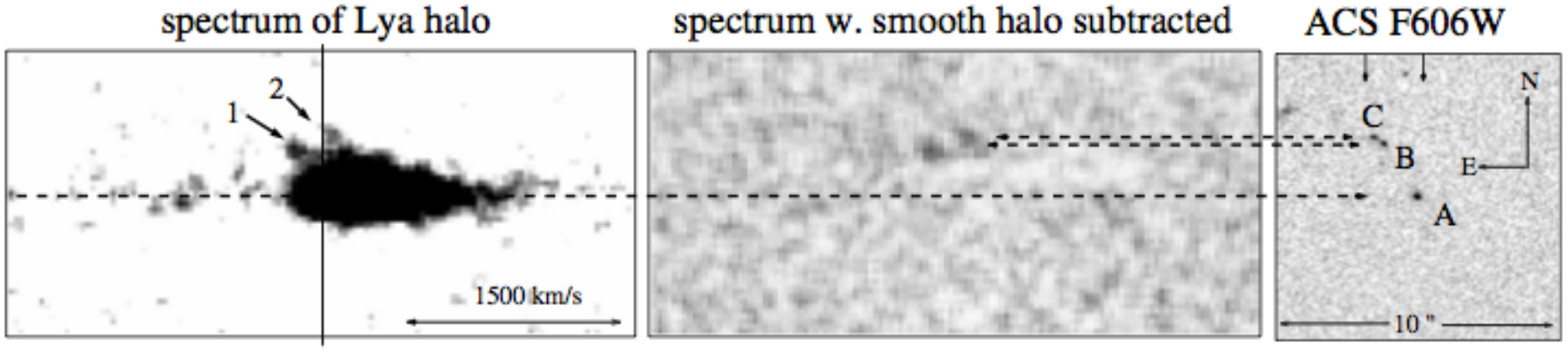
Observational evidence for AGN positive feedback?



Croft+06

Rauch+13

A z=3.045 Lyα emitting halo hosting a QSO and a possible candidate for AGN-triggered star-formation *



Summary and Outlook

- Negative AGN Feedback:
  revealed by multiple observational techniques.

  Entering the phase of characterizing the detailed feedback physics and tracing feedback at different epochs

- Positive AGN Feedback:
  new avenue, yet to be observationally explored.