Giant Outflows in Powerful Radio Galaxies:

Evidence for AGN feedback in high-z galaxies – and beyond

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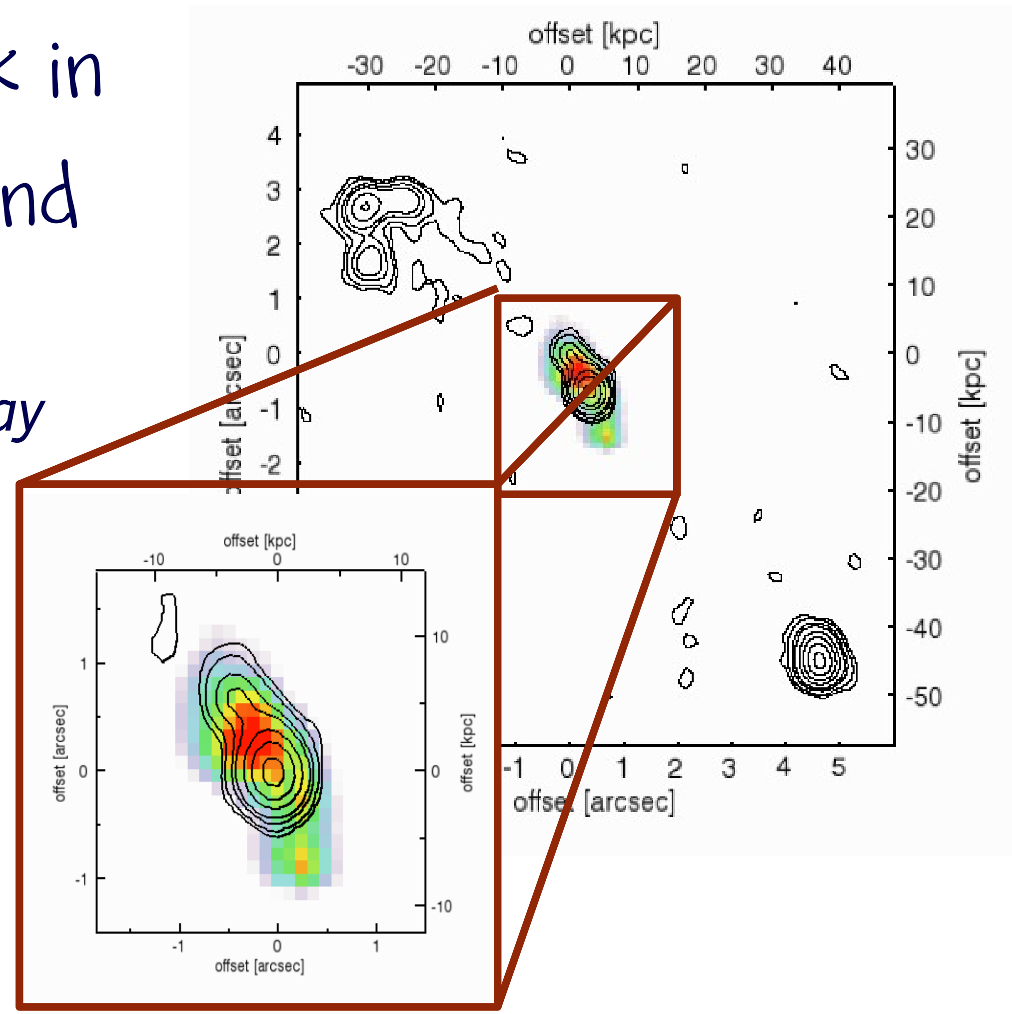

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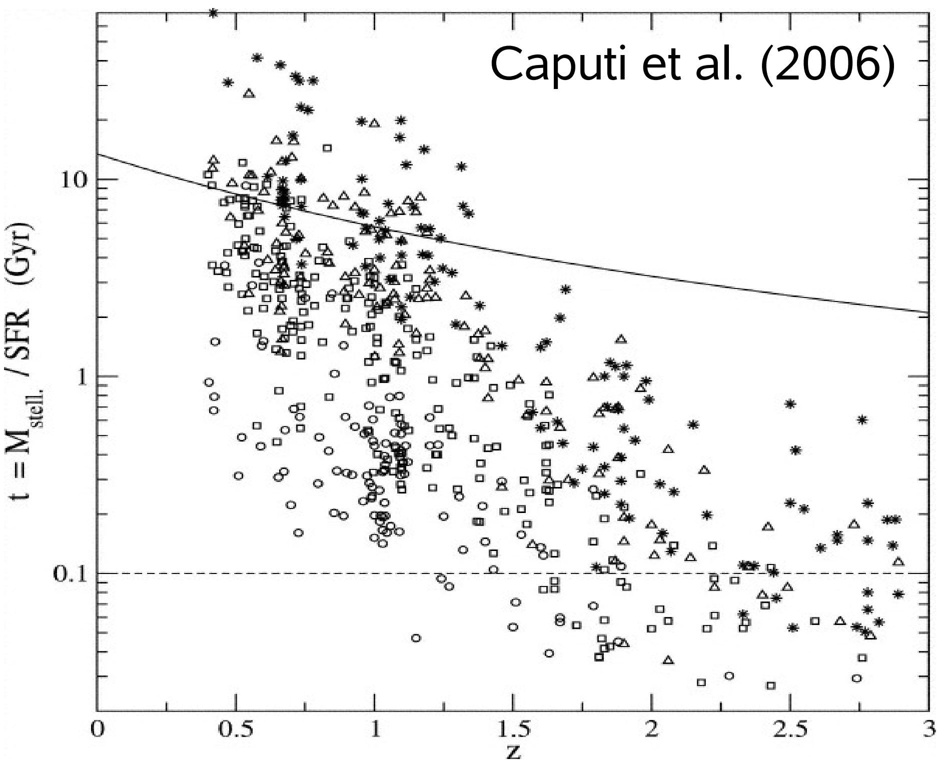
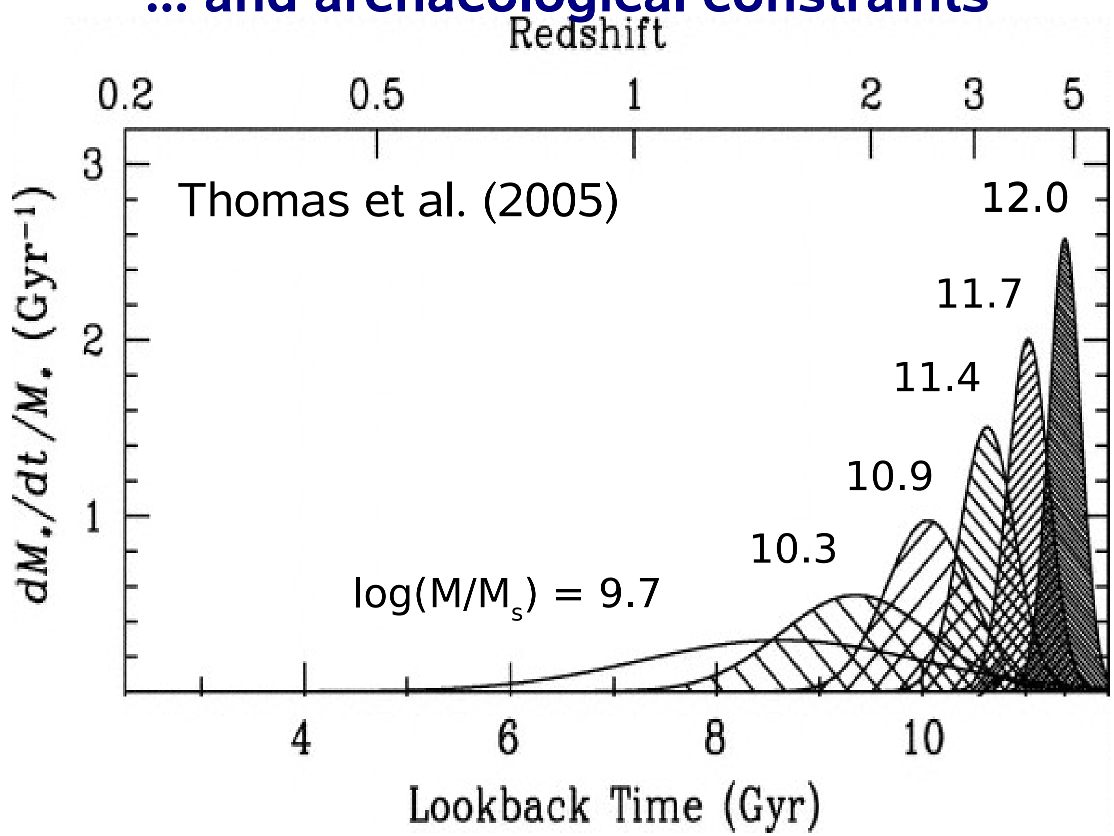
z~2: Cosmic "prime" of (massive) galaxy evolution and AGN activity

Direct observations ...

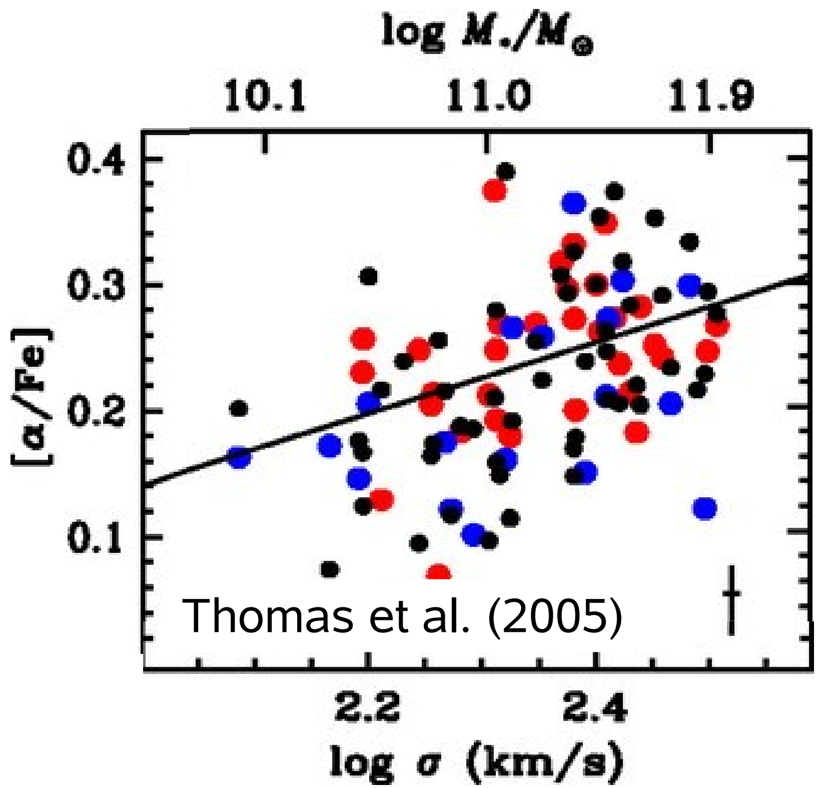


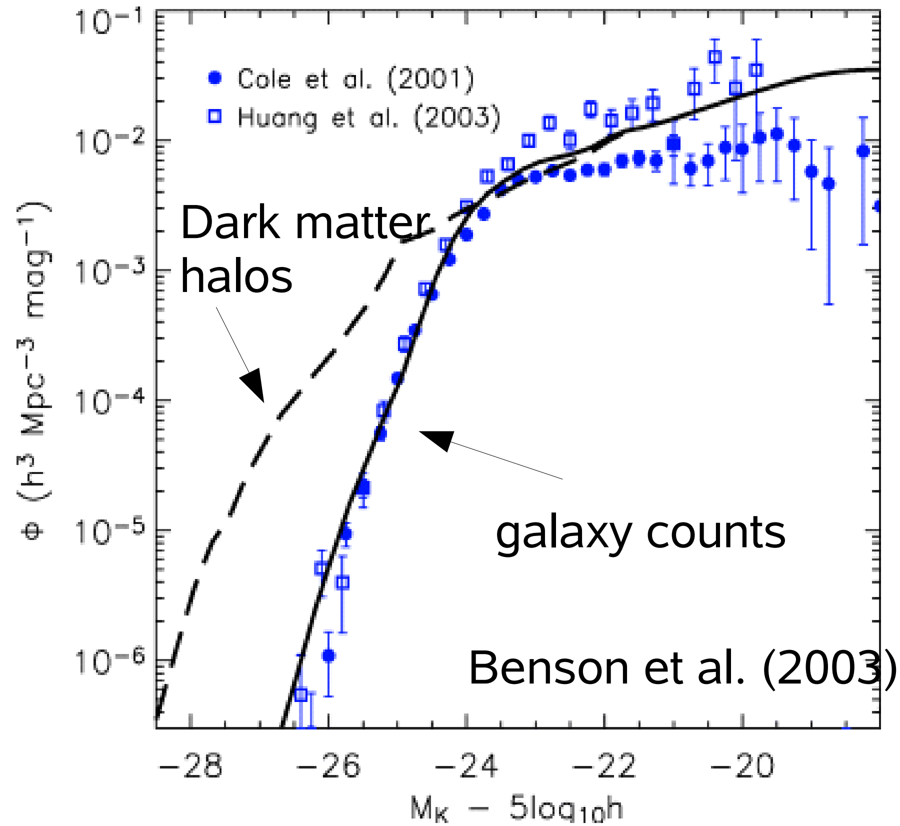
... and archaeological constraints



Short, intense starbursts in very gas-rich (several 10^{10} M_s in cold gas) massive galaxies
... and not much star-formation activity ever since

Today massive galaxies are “old, red, and dead”





Relative metal enrichment : “starburst clock”
SF truncated before gas was consumed

Deficit in massive galaxies:
Inefficient star formation

Today massive galaxies are “old, red, and dead”

Two roles for AGN feedback

“Quenching Phase” at high redshift

terminates major phase of galaxy growth “prematurely”

“Maintenance Phase” ever after

suppresses further gas accretion over cosmological timescales (e.g., Joanna's talk)

Different host properties

e.g., gas-rich versus gas-poor galaxies

Search for AGN winds in HzRGs?

(1) they are ***massive***

(2) they are ***strong starbursts near the end of their formation epoch***

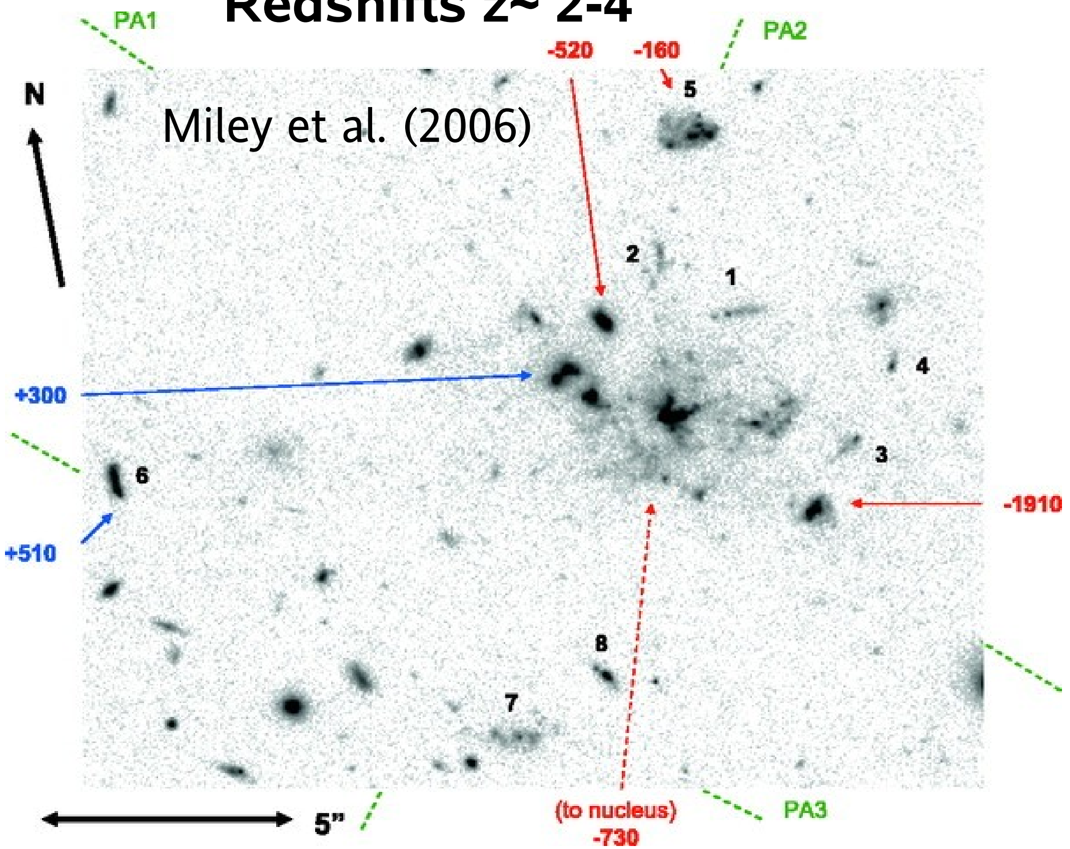
(3) they have ***particularly strong radio sources***

(4) they have ***extreme kinematics over well extended areas (~50 kpc)***

(5) (some) have ***dense environments***

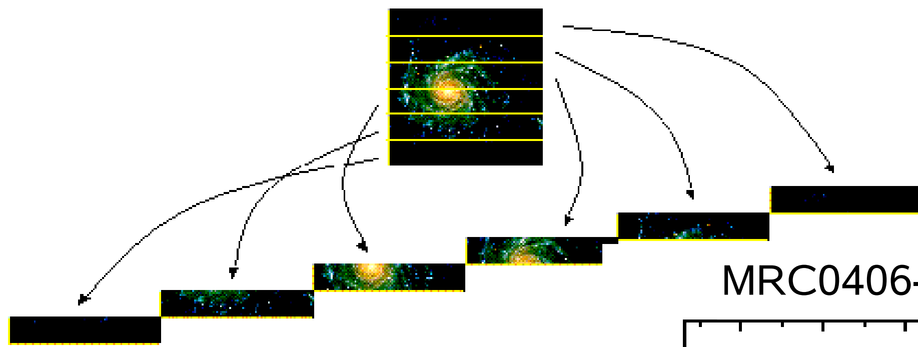
ideal targets to search for AGN-driven winds!!

Redshifts z~ 2-4

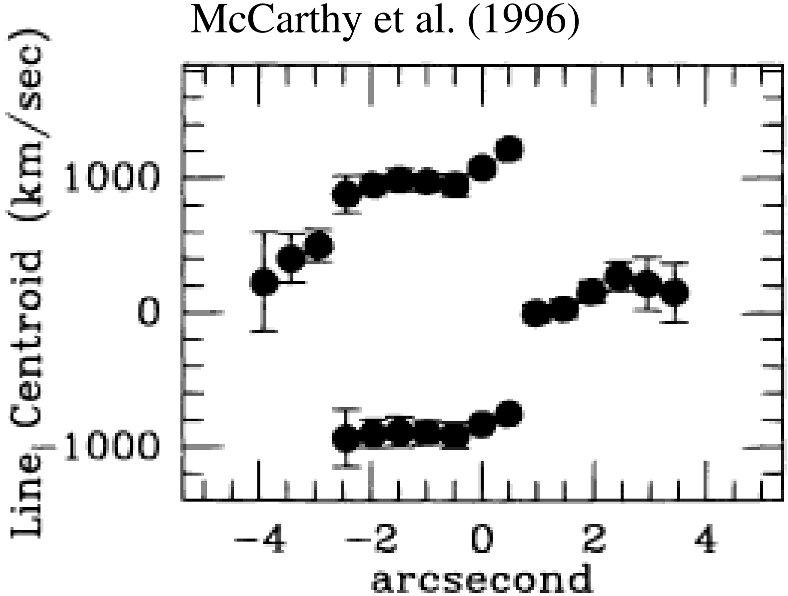


From longslits to integral-field spectroscopy

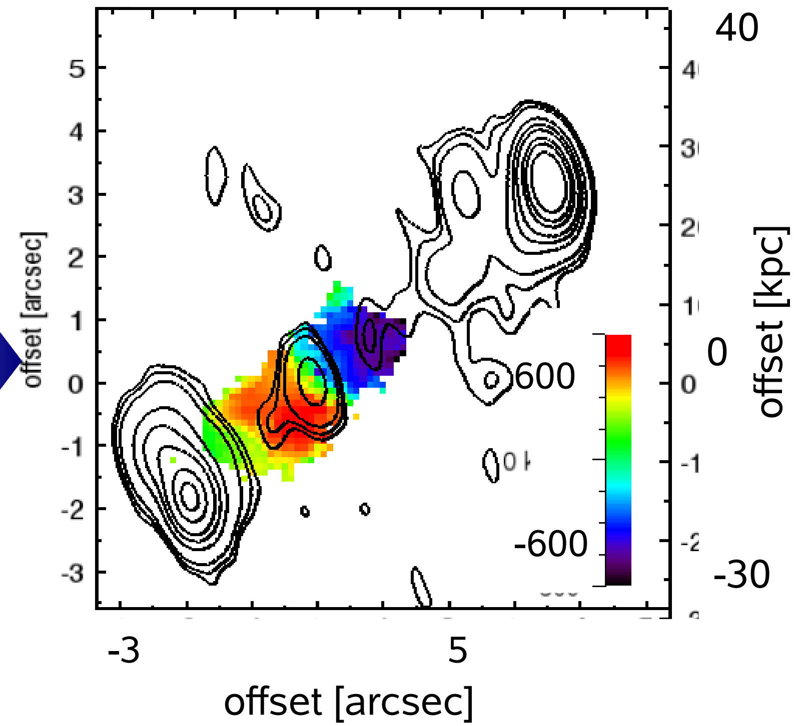
Gas kinematics in HzRGs across a 2-dimensional surface



McCarthy et al. (1996)



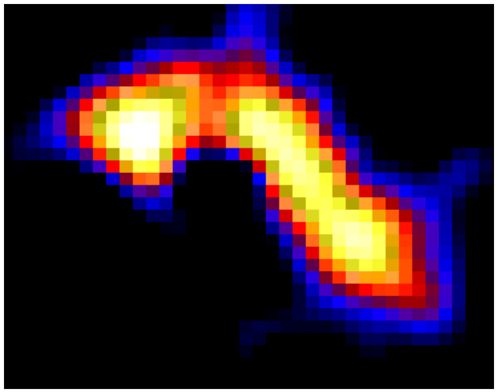
MRC0406-244, z=2.42



Tadhunter et al. (1991), McCarthy et al. (1996), Villar-Martin et al. (1999), Baum et al. (2000), ...

AGN-driven winds in HzRGs

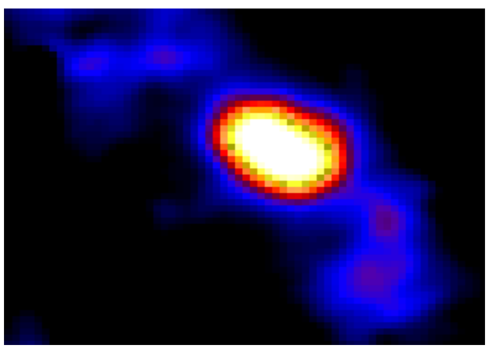
Nesvadba et al. (2006, 2007, 2008, and more in prep.)

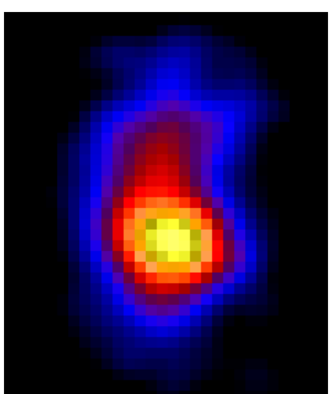


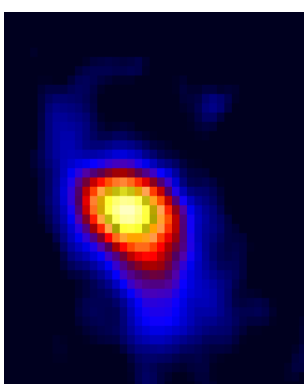
ongoing VLT/SINFONI program:
~30 HzRGs with NIR IFU spectroscopy at z=1.5 – 4
rest-frame optical lines: Hα, Hβ, [OI],[OII],[OIII],[SII], [NII]...

extended emission line regions in all galaxies
with extended radio jets

outflows of 10^{10} M_s in ionized gas







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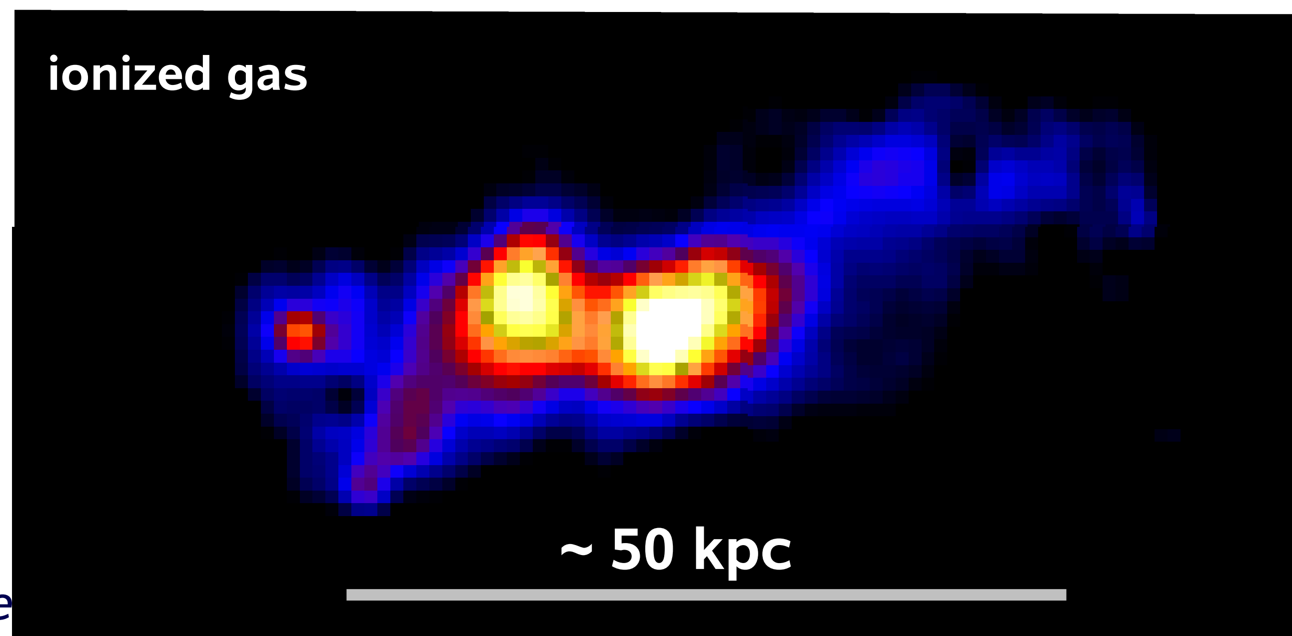
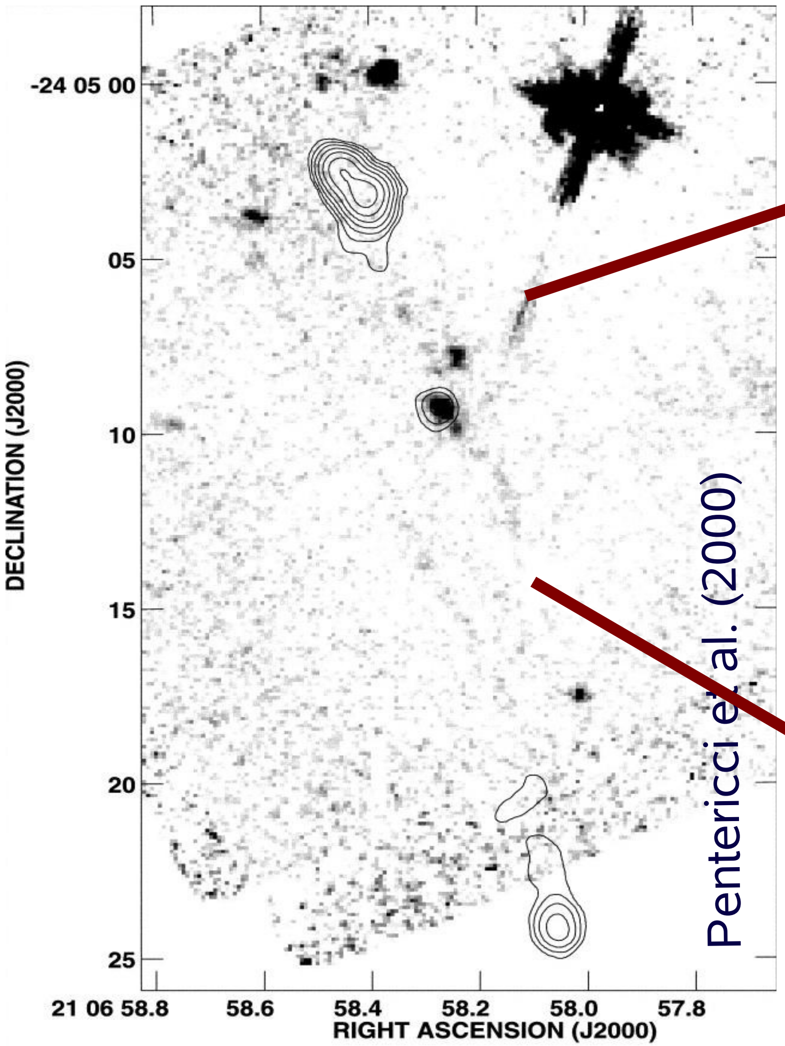


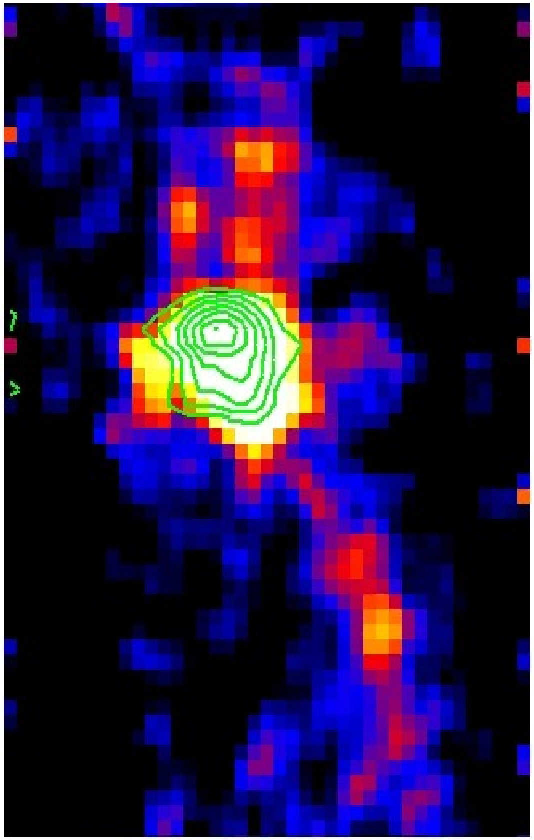
(1) Morphologies

Continuum & Line Emission

Nesvadba et al. (2007), A&A 475,145
Nesvadba et al., (2008), A&A 491,407



Hα emission line morphology

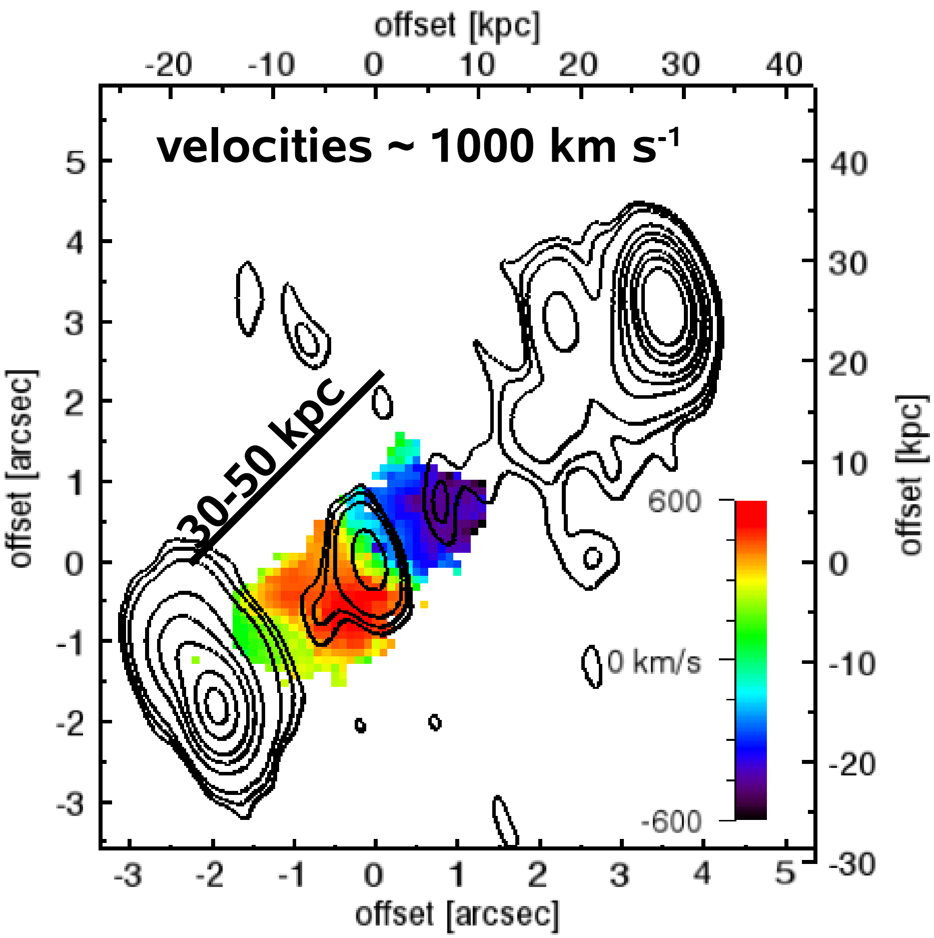


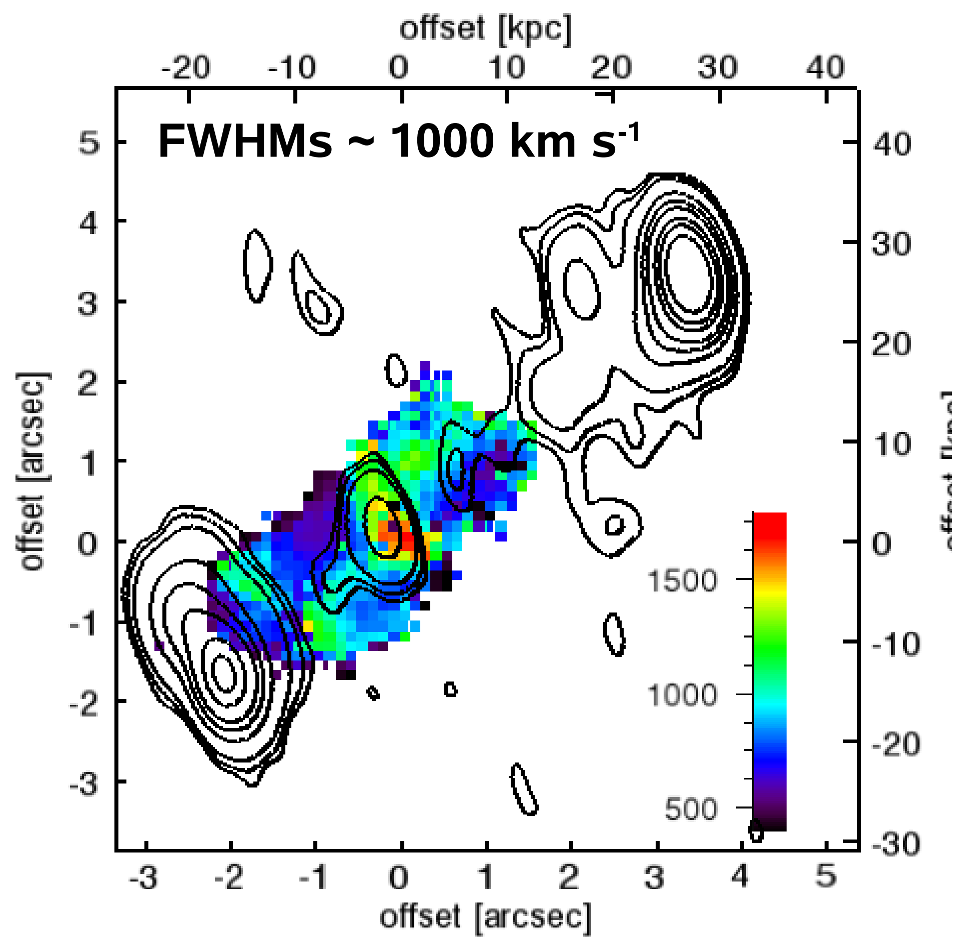
Line emission dominates broad-band photometry ! ***Continuum compact.***

(2) Gas kinematics in the nebulosities

[OIII]5007 velocity dispersions and line widths Nesvadba et al. (2008)

MRC0406-244, z=2.42





Evidence for jet-driven outflows

Nesvadba et al. (2008),
Nesvadba et al. (2009), in prep.

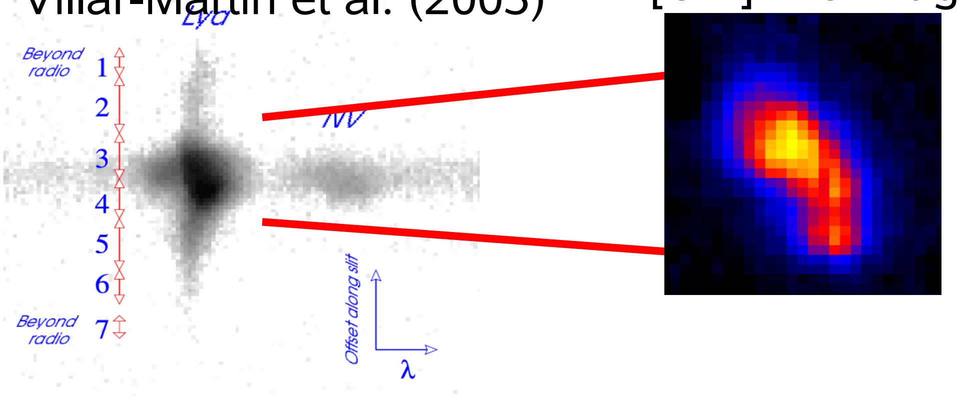
Correspondence between the radio and line emission

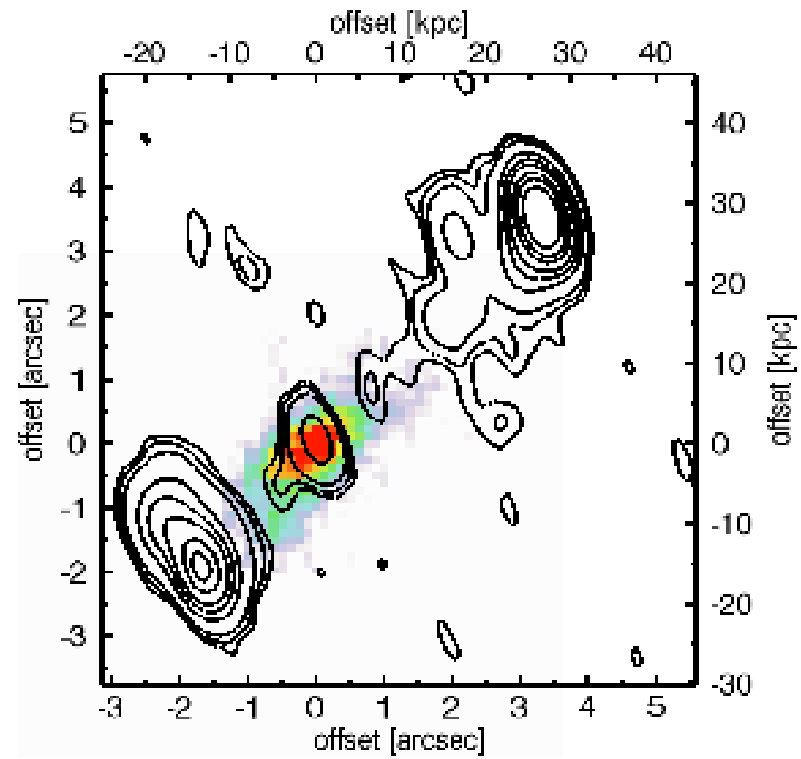
(1) Geometry:

alignment with jet axis & size of emission line region

Villar-Martin et al. (2003)

[OIII] line image





Evidence for jet-driven outflows

Nesvadba et al. (2007), Nesvadba et al. (2008)

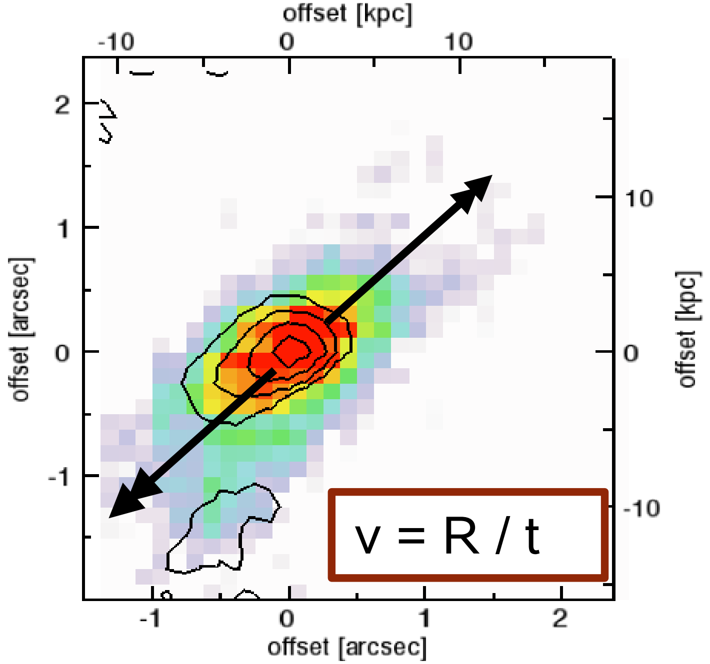
Correspondence between the kinematics and the jet properties

AGN lifetimes ~ $10^{7\text{-}8}$ yrs
Martini 2004

(2) Time scales:

jets / outflows with similar t_{dyn}

t_{dyn} = few x 10^7 yrs



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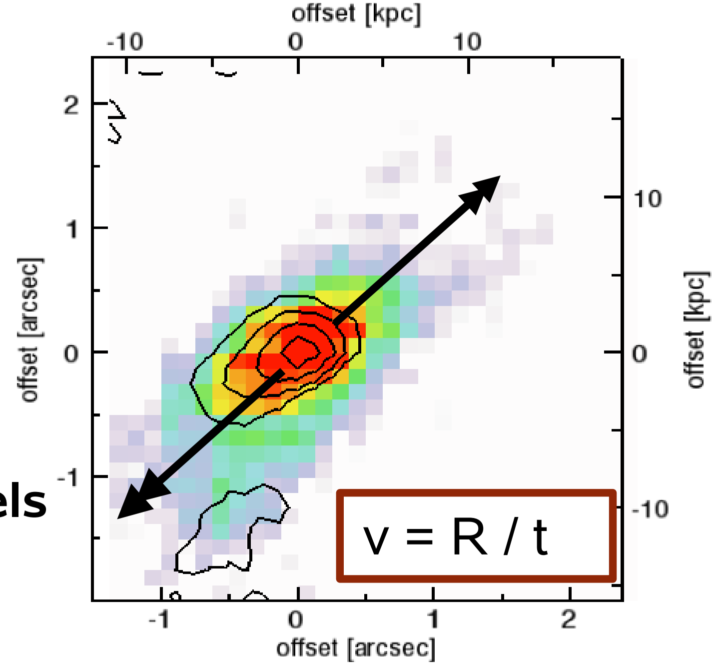
$$t_{dyn} = \text{few} \times 10^7 \text{ yrs}$$



~ galaxy evolution models

"coupling efficiency"
$\eta \sim 0.1$

(3) Energies:

jets can provide 10^{46} erg s^{-1},

$$E_{tot,jet} \approx 10^{60-61} \text{ erg}$$

(e.g., Bicknell et al. 1997, Wan et al. 2000,

Birzan et al. 2004)

e.g., for swept-up bubbles:
(Dyson & Williams, 1980)

$$v_{shell} = 235\, [dE/dt]_{44}^{1/5}\, n_0^{1/5}\, t_7^{-2/5} \text{ km s}^{-1}$$

$$E_{tot} \approx 10^{59-60} \text{ erg in } 10^7 \text{ yrs}$$

Nicole Nesvadba – AGN Feedback in HzRGs

Alternative Scenarios?

Nesvadba et al. (2007)
Nesvadba et al. (2008)

"What you see is just rotation"

virial mass estimate:

$$M = v^2 R / G \sim 10^{14\text{-}15} M_s$$

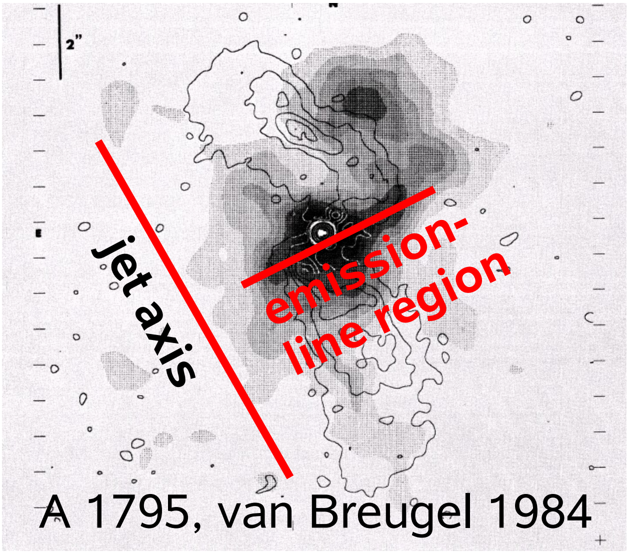
within R~20 kpc

$M_{cluster}$ (~ 1 Mpc) ~ 10^{14} M_s
(e.g., Venemans et al. 2007)

"These are inflows"

analogy with cooling-flow clusters: flow perpendicular to jet axis

also: radio polarization suggests blueshifted bubble associated with near jet (Nesvadba et al. 2008)



A 1795, van Breugel 1984

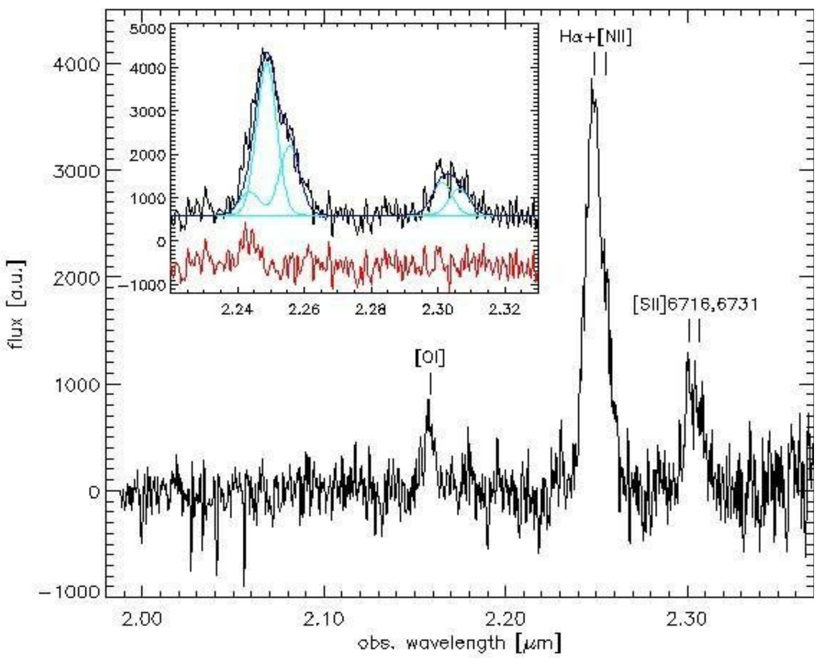
Impact on the host galaxy

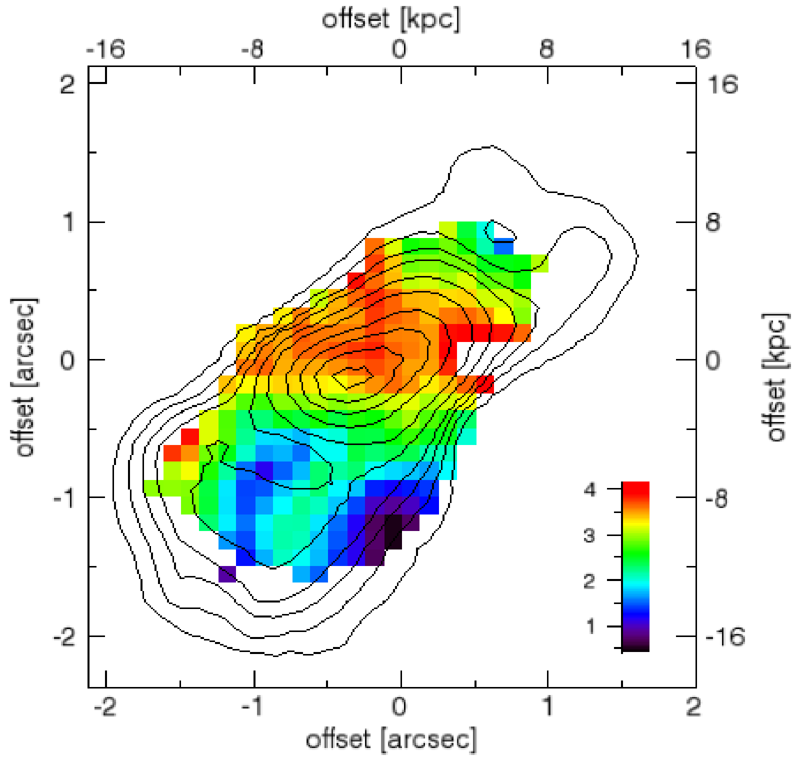
Ionized gas masses

Nesvadba et al. (2008)

$M_{H\alpha} = L_{H\alpha}\, m_p / (h\nu_{H\alpha}\, \alpha_{eff}^{H\alpha}\, n_e)$ → $M \sim$ few x $10^{10}\ M_\odot$

MRC0406-244, z=2.4





[SII]$\lambda\lambda$6716,6731: $\rho \approx$ few x 100 cm^{-3}

Balmer decrement Hα / Hβ,
$A_V \sim 1 - 4$ mag

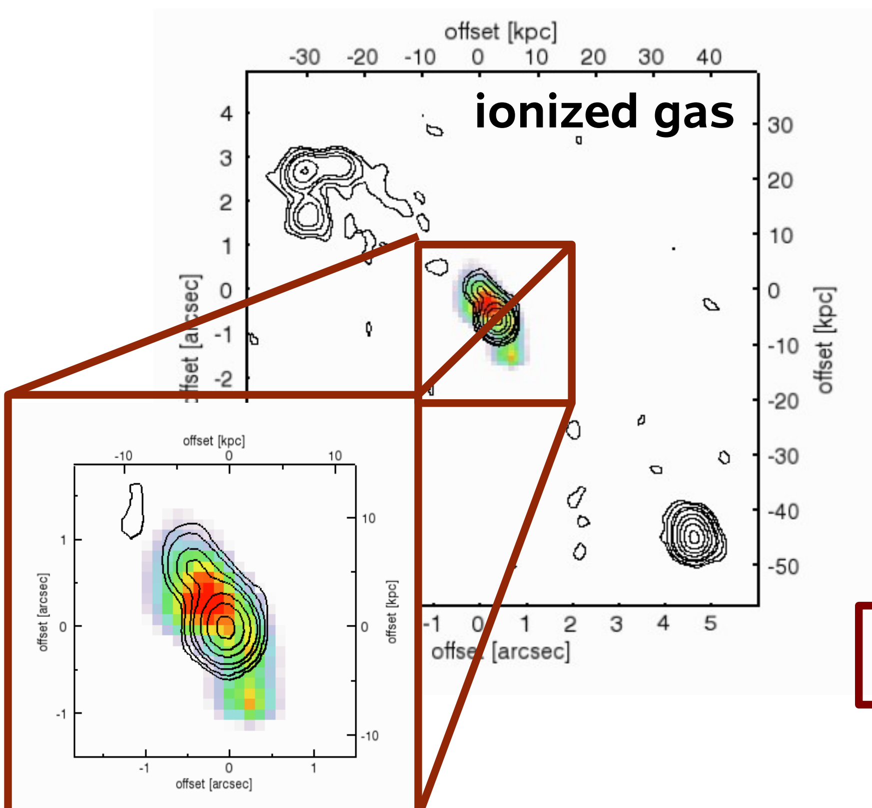
Impact on the host galaxy

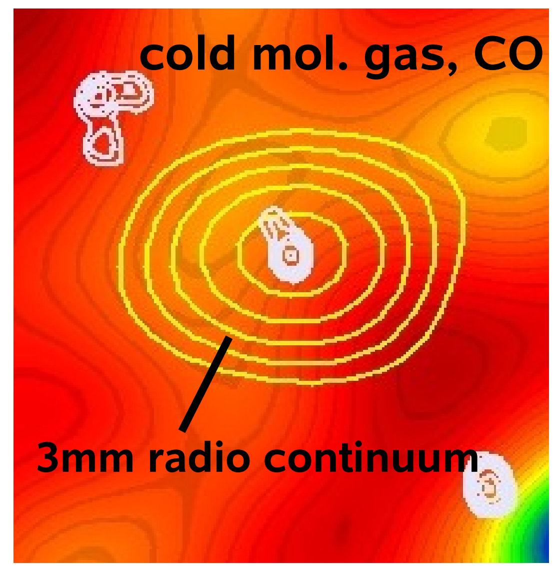
Nesvadba et al. (2009), in prep.

Cold molecular gas – CO studies at IRAM PdBI

(Kinematic) requirements for gas removal

$E \geq E_{bind}$ $\sim 10^{59\text{-}60}$ erg $v \geq v_{esc} \sim 700$ km s^{-1} $M \sim M_{ISM} \leq$ few x 10^{11} $M_{\odot}$





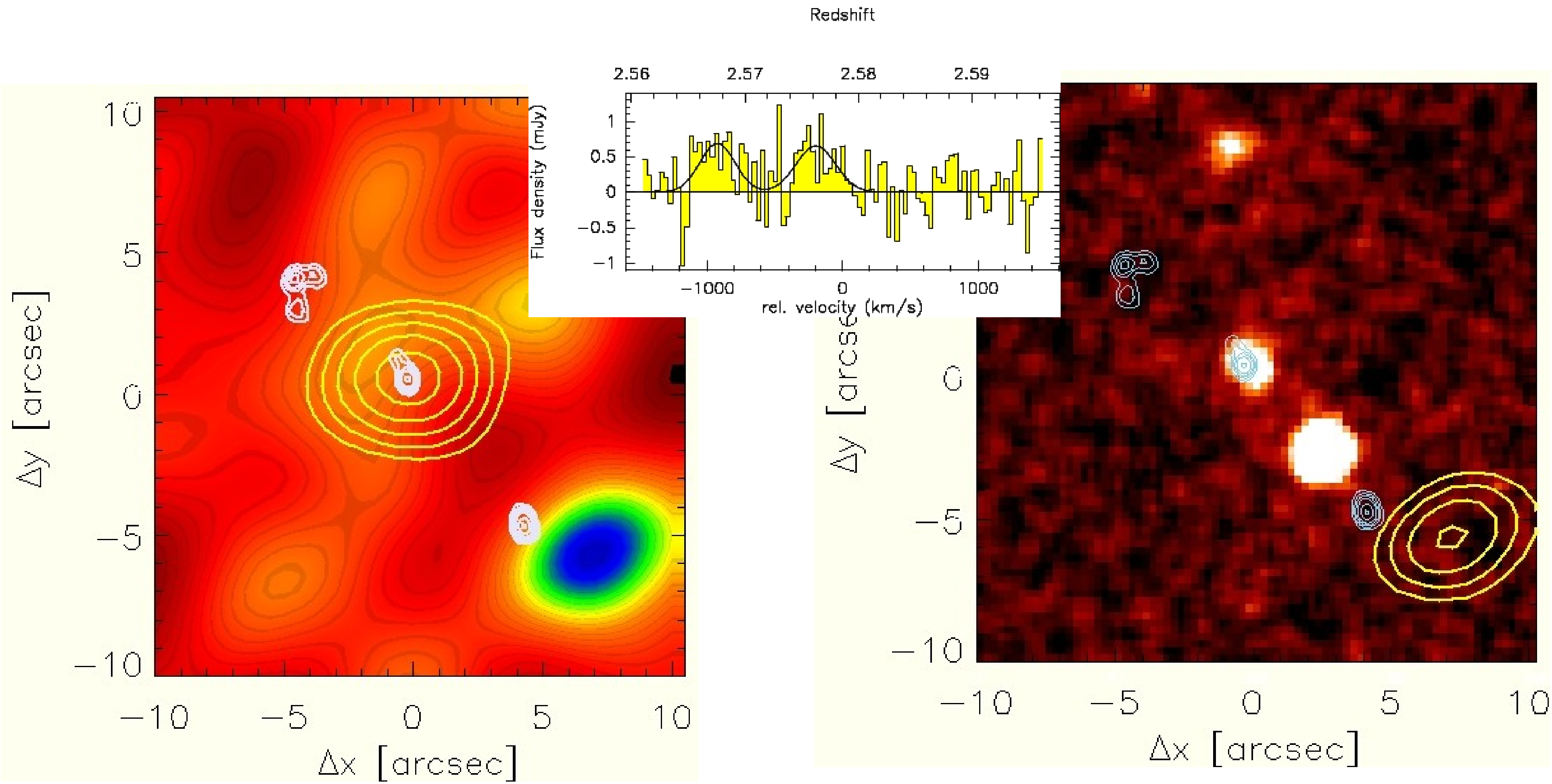
$M_{ion} \sim$ few $x10^{10}$ M_s $M_{mol.} < 10^{10}$ M_s

... normal high-z SF galaxies: $\sim 10^{-3}$

efficient heating of the cold molecular ISM?

Impact on the (cluster) environment?

Nesvadba et al. (2009), MNRAS 395L, 16



$M_{mol} \sim 2\text{x}10^{10}\ M_s$

z~2 submillimeter galaxies

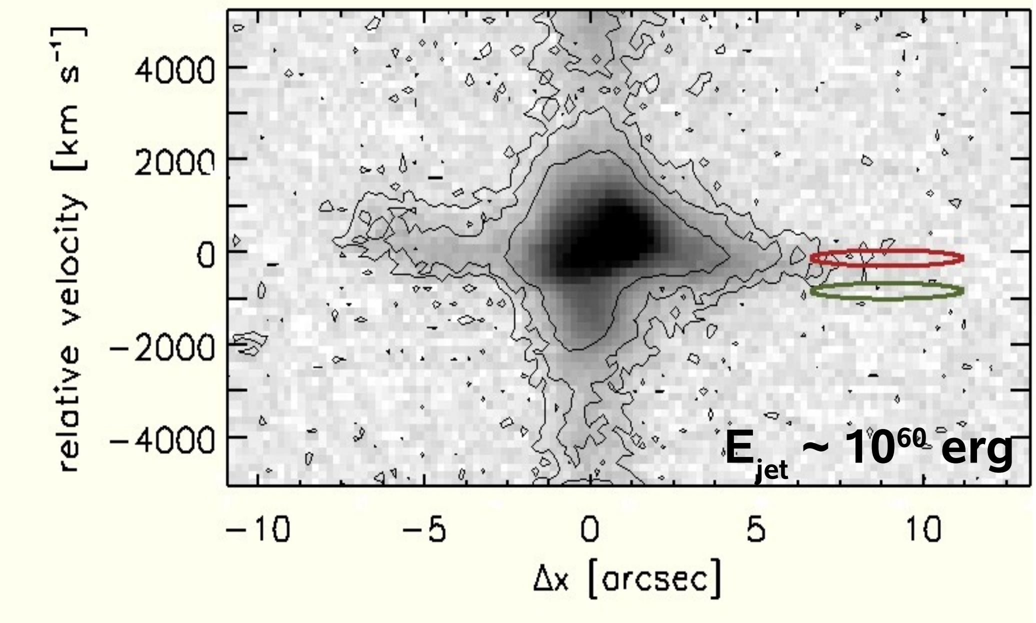
$M_{stellar} < 3\text{x}10^{9}\ M_s$,

rest-UV to MIR

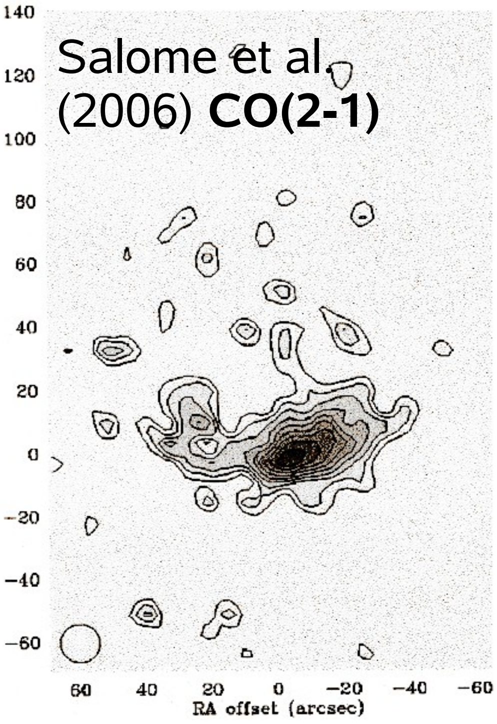
Pre-heating of the intracluster medium?

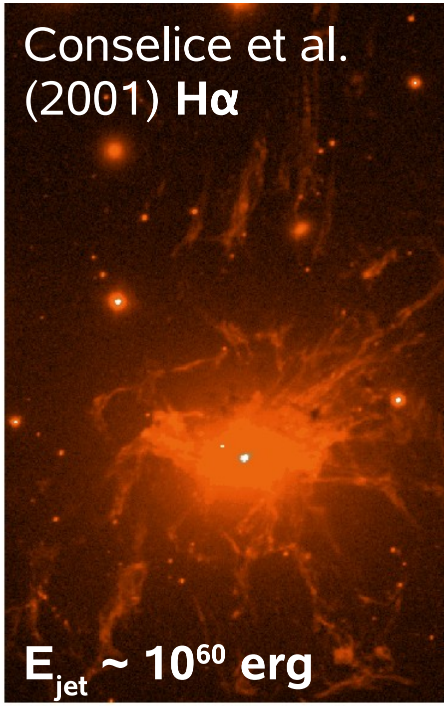
Nesvadba et al. (2009), MNRAS 395L, 16

TXS0828+193 SW1/2, z~2.6



Perseus cluster, z~0





molecular filaments in the ICM?

early pre-heating necessary to explain entropy content of massive low-z clusters
(Nath et al. 2002, McCarthy et al. 2008)

HzRGs: "Smoking gun" of AGN winds at high-z

Jet-driven AGN winds during the "Quasar Era"

- ✔ **Geometry, timescales, energy: driven by the radio jet**
- ✔ **may heat/remove ISM of a massive galaxy & quench the strongest starbursts at high-z**
- ✔ **observational constraints at low-z are fulfilled**
- ✔ **possible role for pre-heating the ICM**