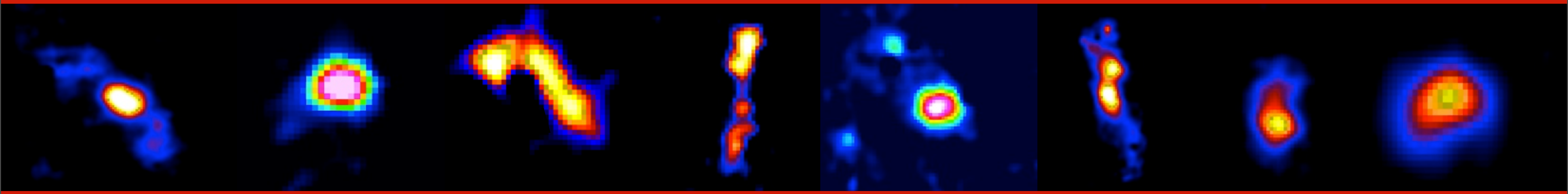
# AGN Feedback in High Redshift Radio Galaxies

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## Collaborators


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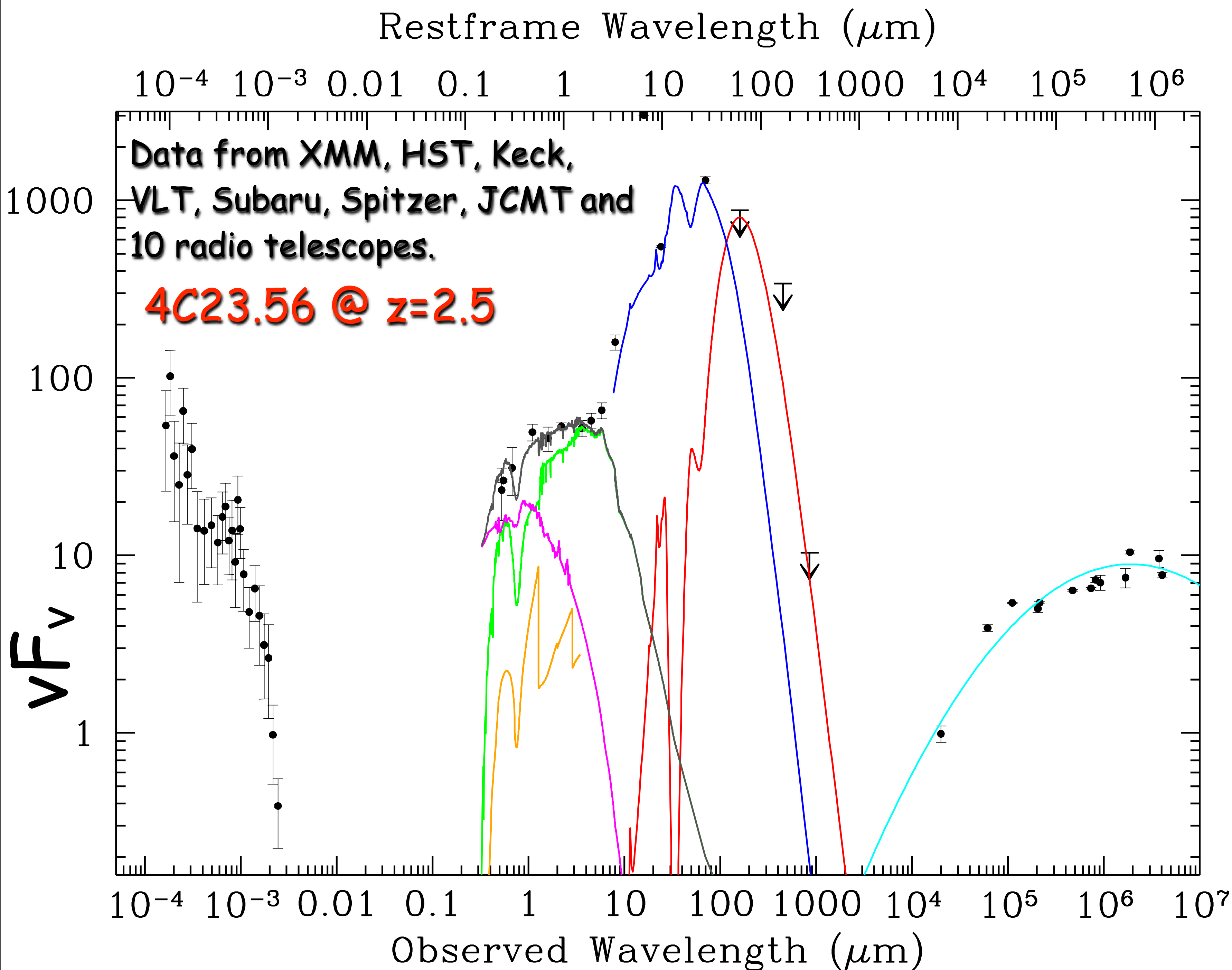
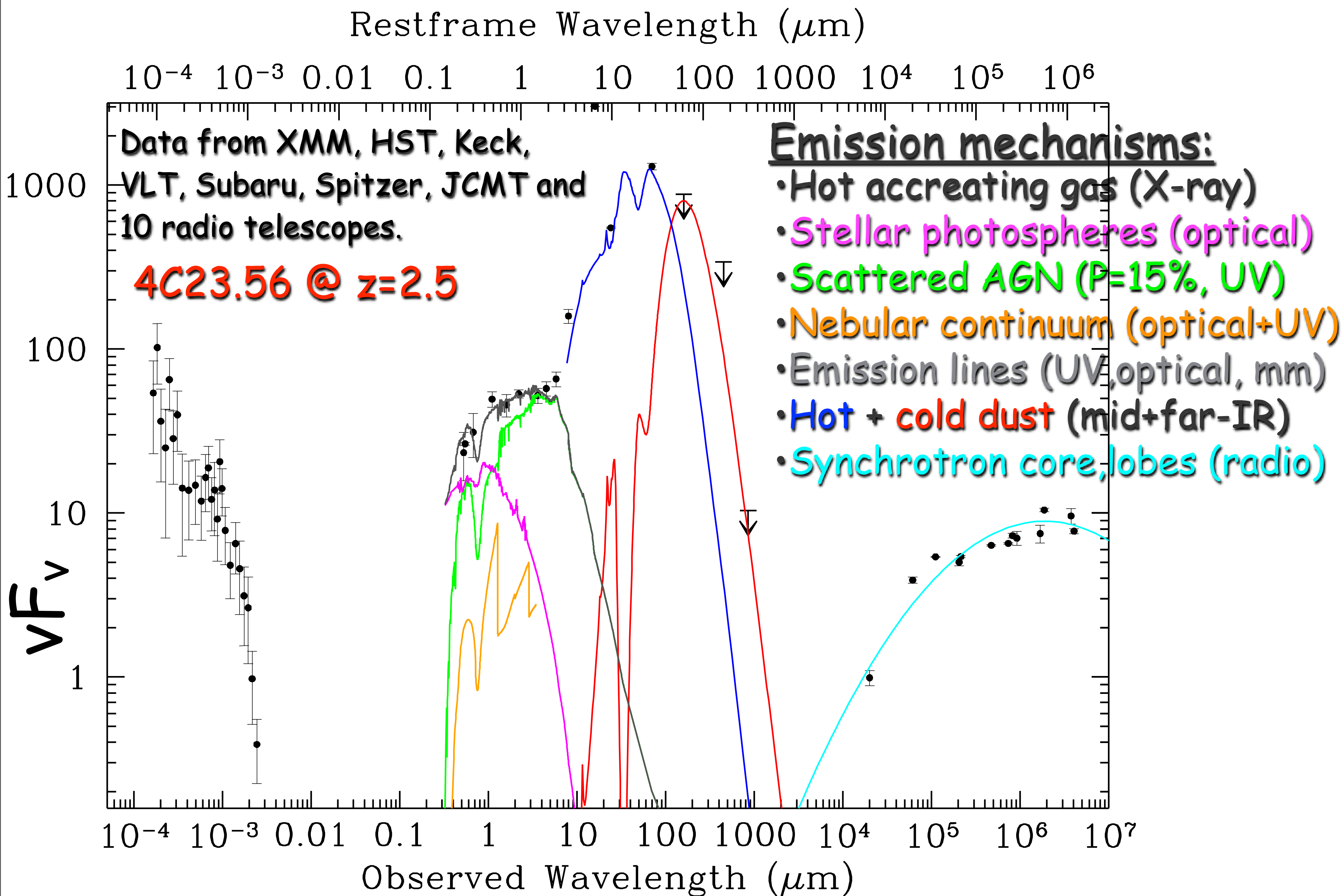
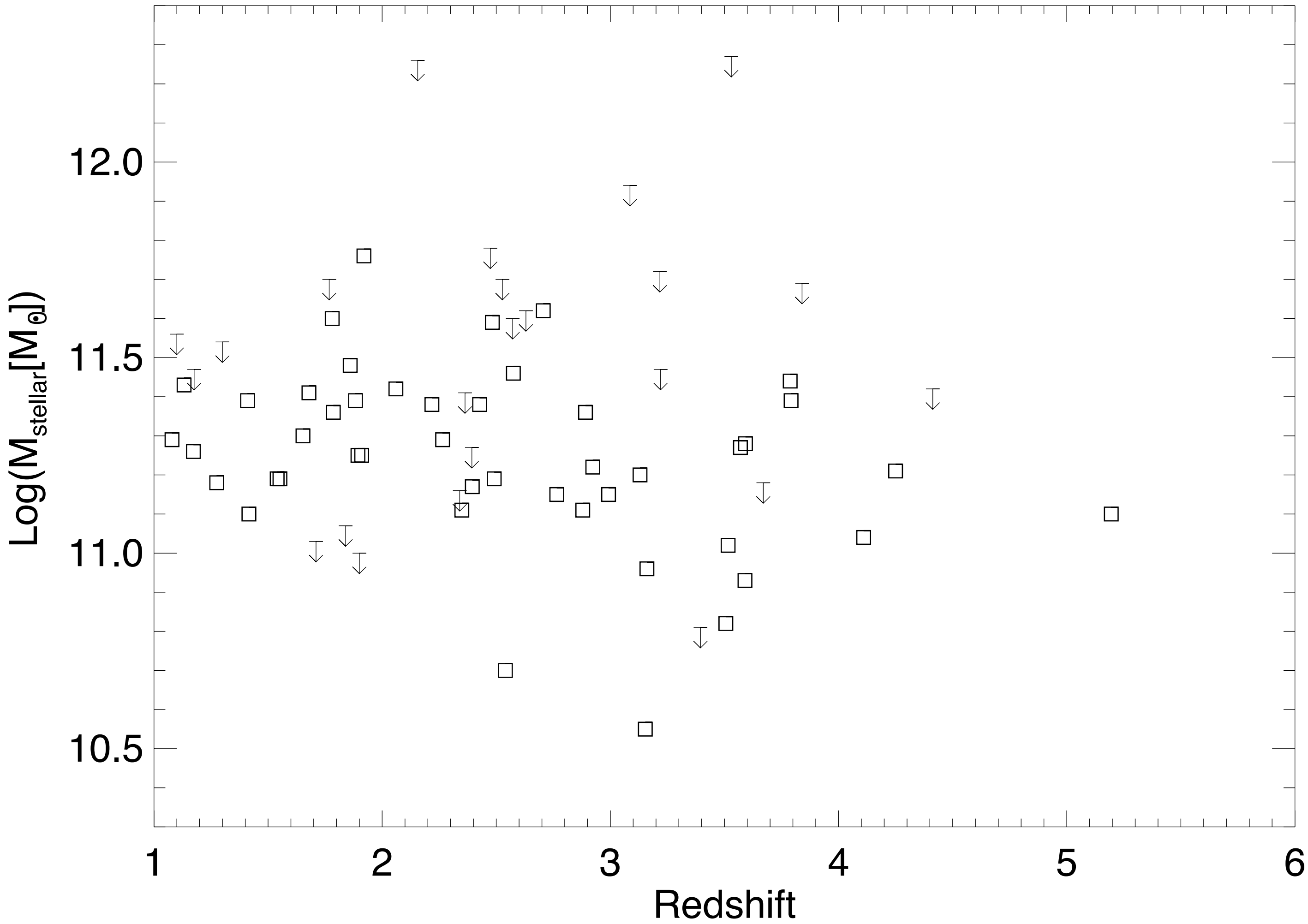
# AGN and stellar emission in radio galaxies



# AGN and stellar emission in radio galaxies



# Radio galaxies have massive hosts across cosmic time...

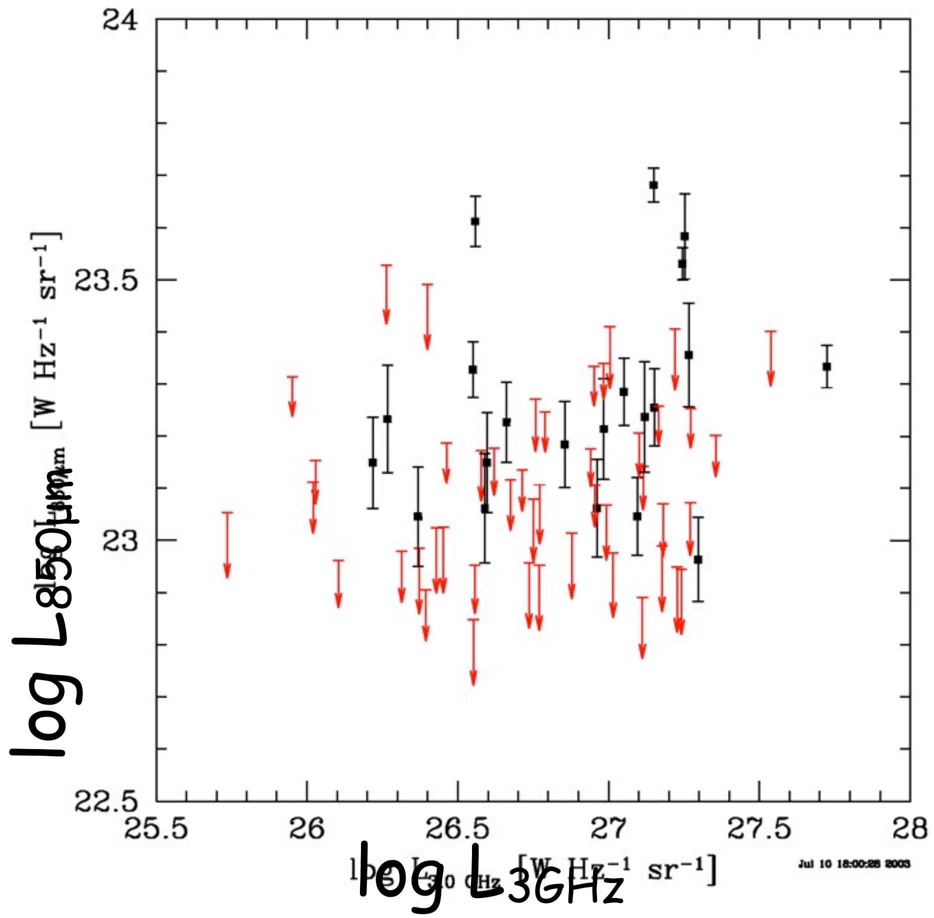


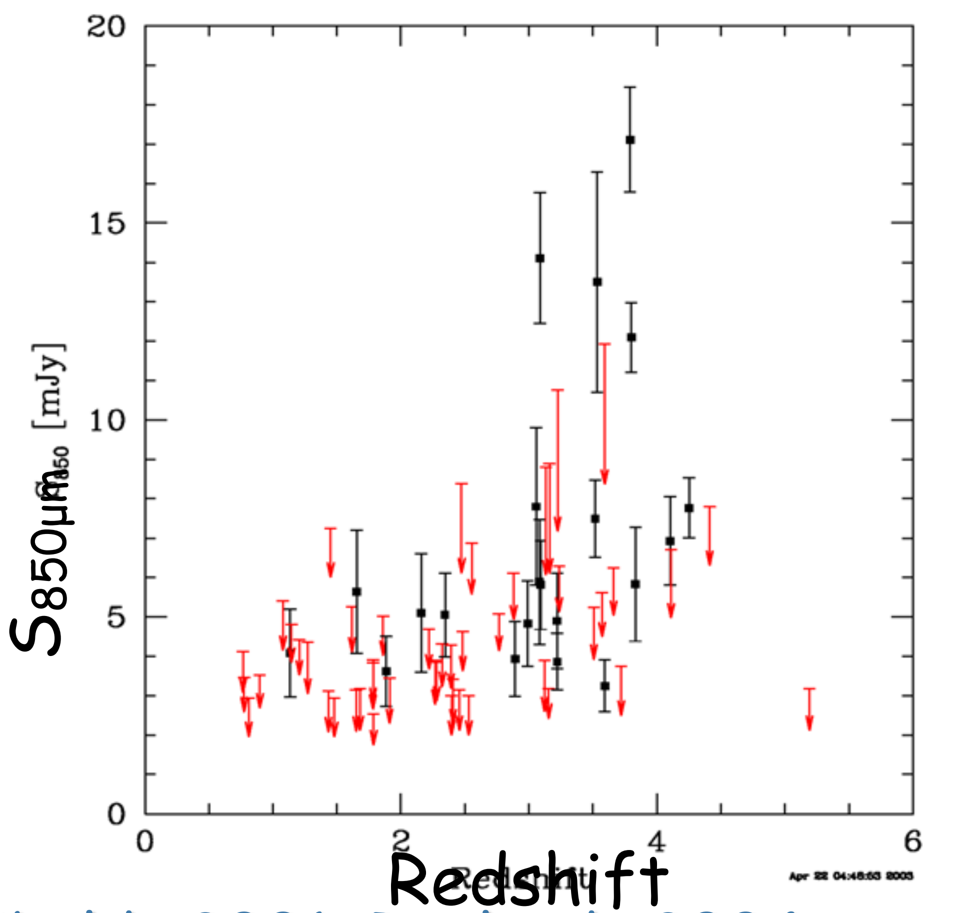

Advantage of type II AGN:

host galaxy is not dominated by AGN

# ... but also high SFR, especially at z>3

- $S_{850\mu m}$ → SFR increase with redshift at least until z~4.
- $L_{FIR} \sim 10^{13}\ L_{Sun}$ → SFR ~ 1500 $M_{Sun}$/yr.
- Needs Herschel to better isolate AGN from stellar far-IR.



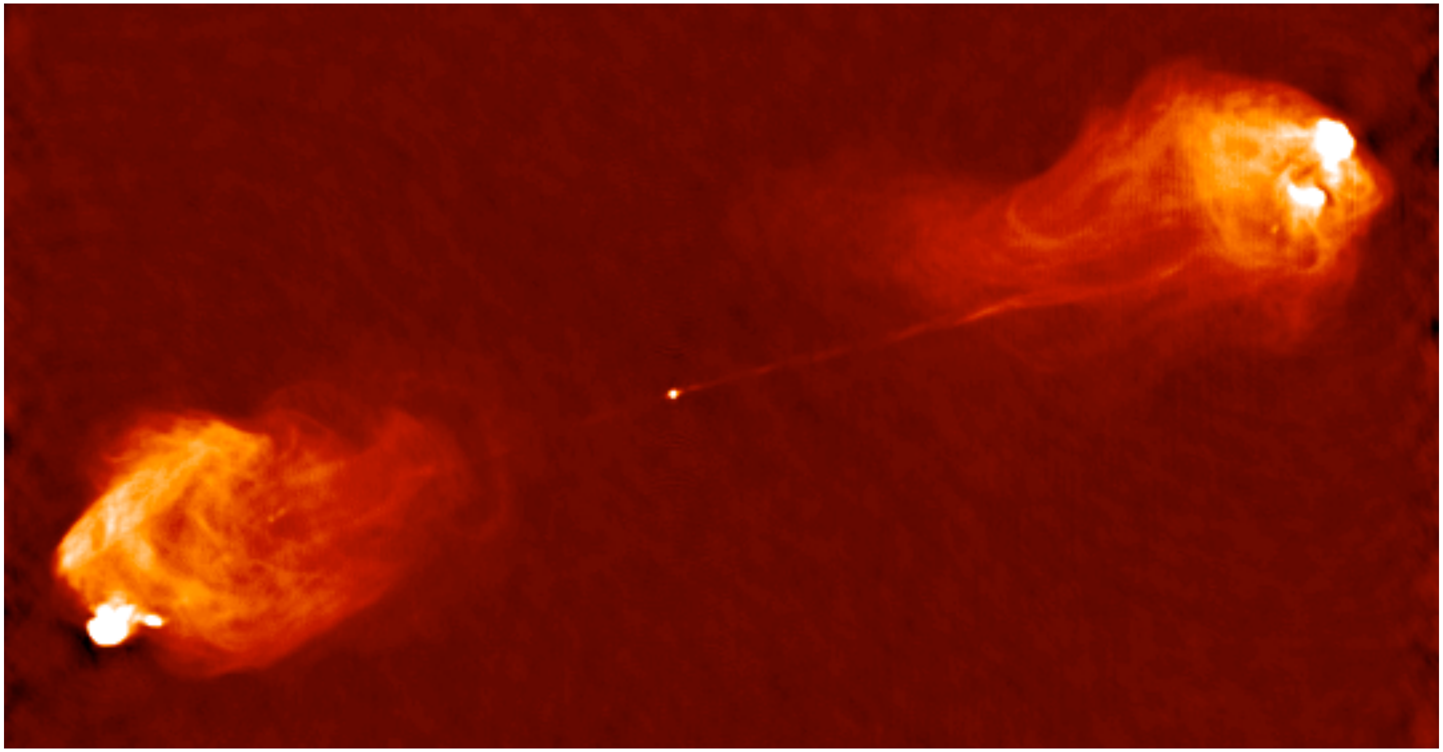

Archibald+ 2001, Reuland+ 2004

# Why radio galaxies are ideal laboratories to study AGN feedback

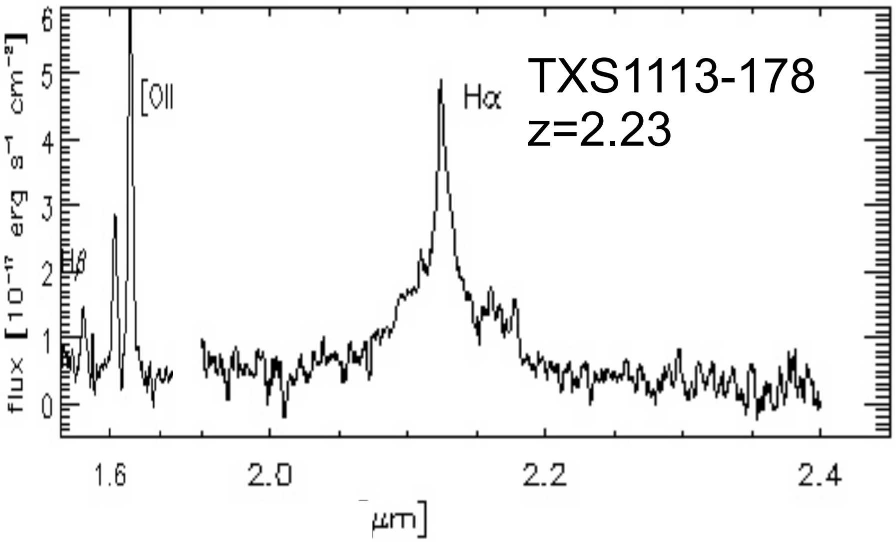
They have already accumulated most of their stellar mass, but are still forming stars at z>3.

→

Needs a strong feedback process to stop them growing for good: powerful radio source.

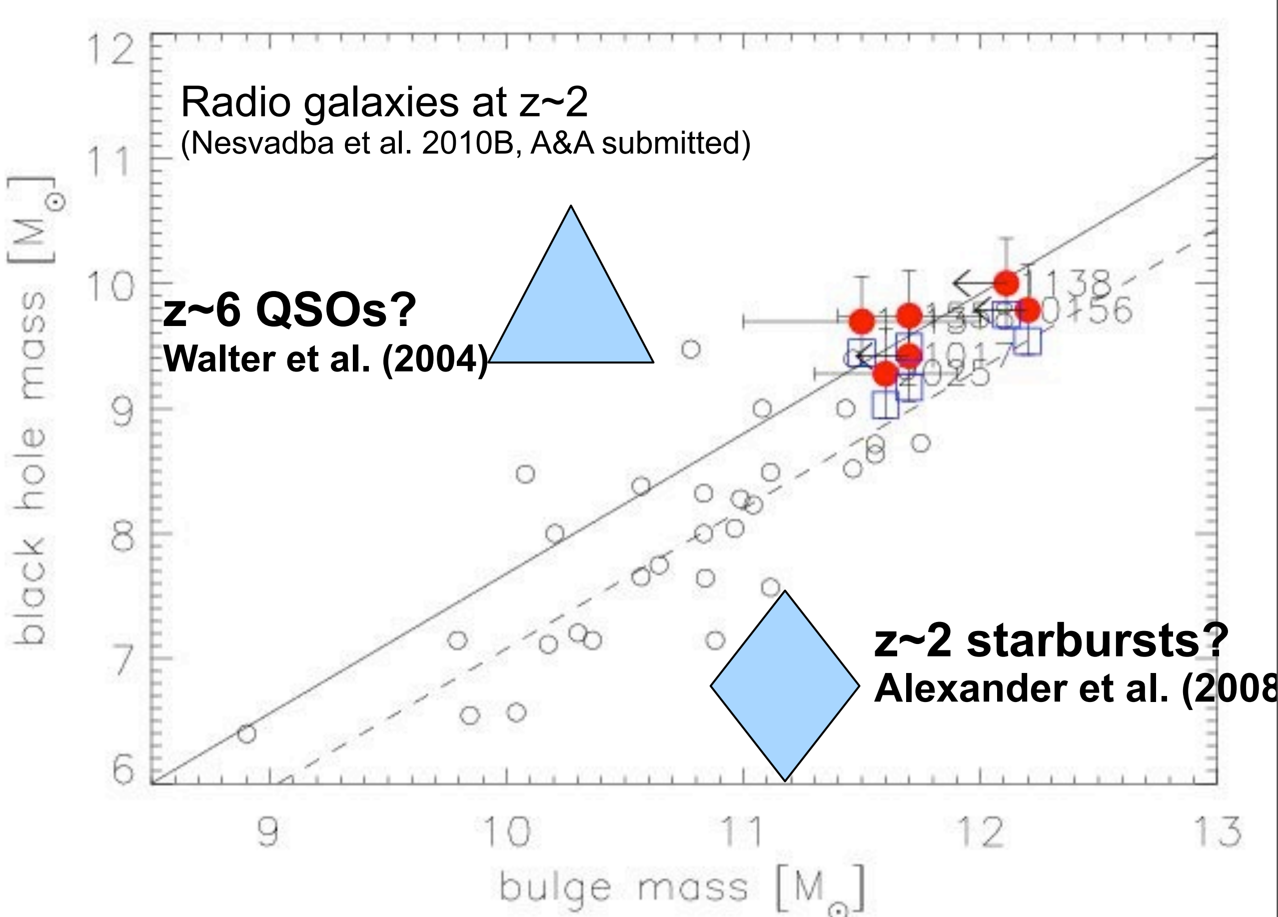


# Black hole masses & Eddington ratios



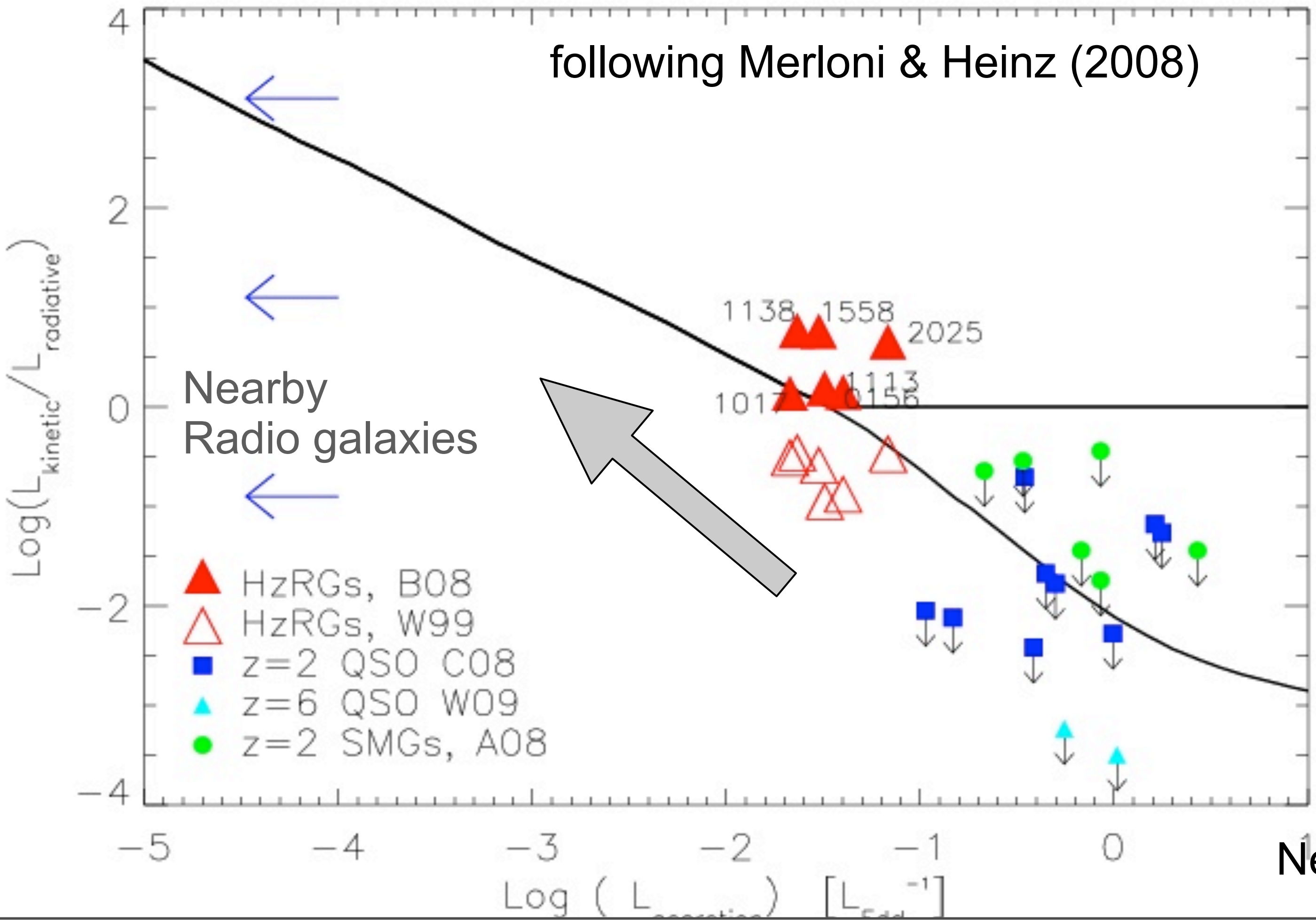

• BLR are usually completely obscured in type II AGN.
• 20% of z>2 RGs show nuclear broad-line regions in our IFU data.

• $M_{BH}$ a few $10^9$ $M_{Sun}$ (higher inclination may half $M_{BH}$)
• Appears slightly offset from local $M_{bulge}$ - $M_{BH}$ relation.
• Bolometric luminosity at few % Eddington, lower than other populations with similar $M_{BH}$
→ nearing end of active growth phase?



# Transiting objects from "Quasar" to "Radio" mode?

- Calculate $L_{kin}$ using Willott et al 1999 (▲) and Bîrzan et al 2008 (△) relations.
- Transition from "Quasar" to "Radio" mode marks the end of the phase of active growth.
- **Cfr. miniquasars:** transition from radiatively efficient to inefficient accretion at few % Eddington.




Nesvadba et al. (2010b)

# “ The Cocoon model ”

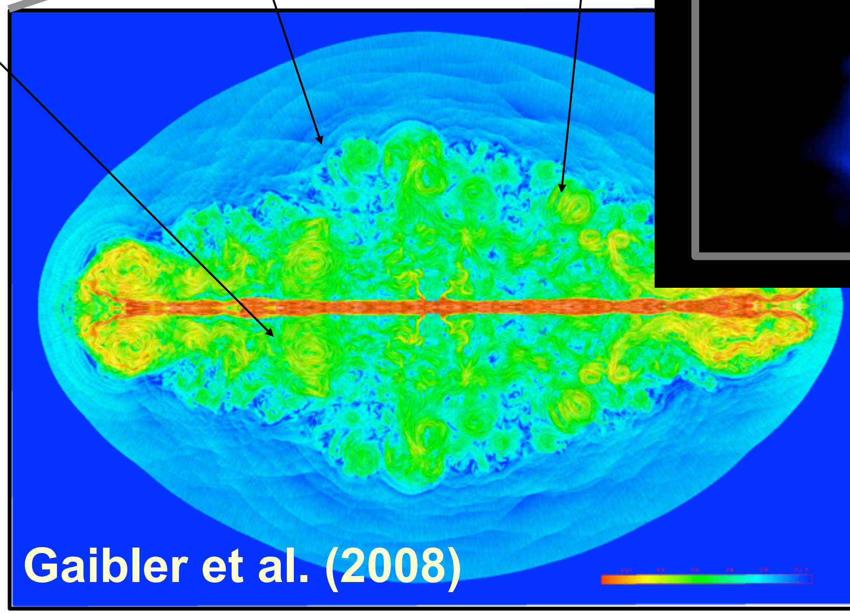
## Fairly good (basic) understanding of how jets may work

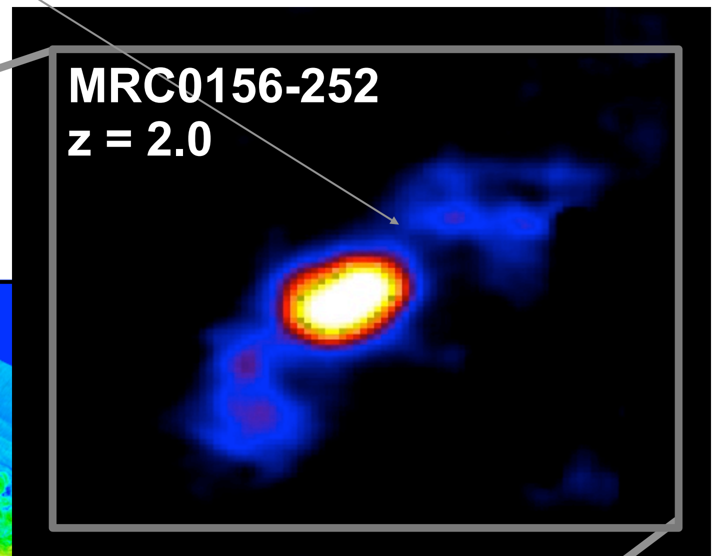
**radio jet** mechanical power → ***inflates*** → **“cocoon”** hot overpres-surized gas, X-ray → ***accelerates*** → **embedded cold/ warm clouds** molecular, atomic, T~10-$10^4$ K → ????

**In agreement with hydro models of radio jets**
(e.g. Sutherland & Bicknell 2007, Krause 2007)

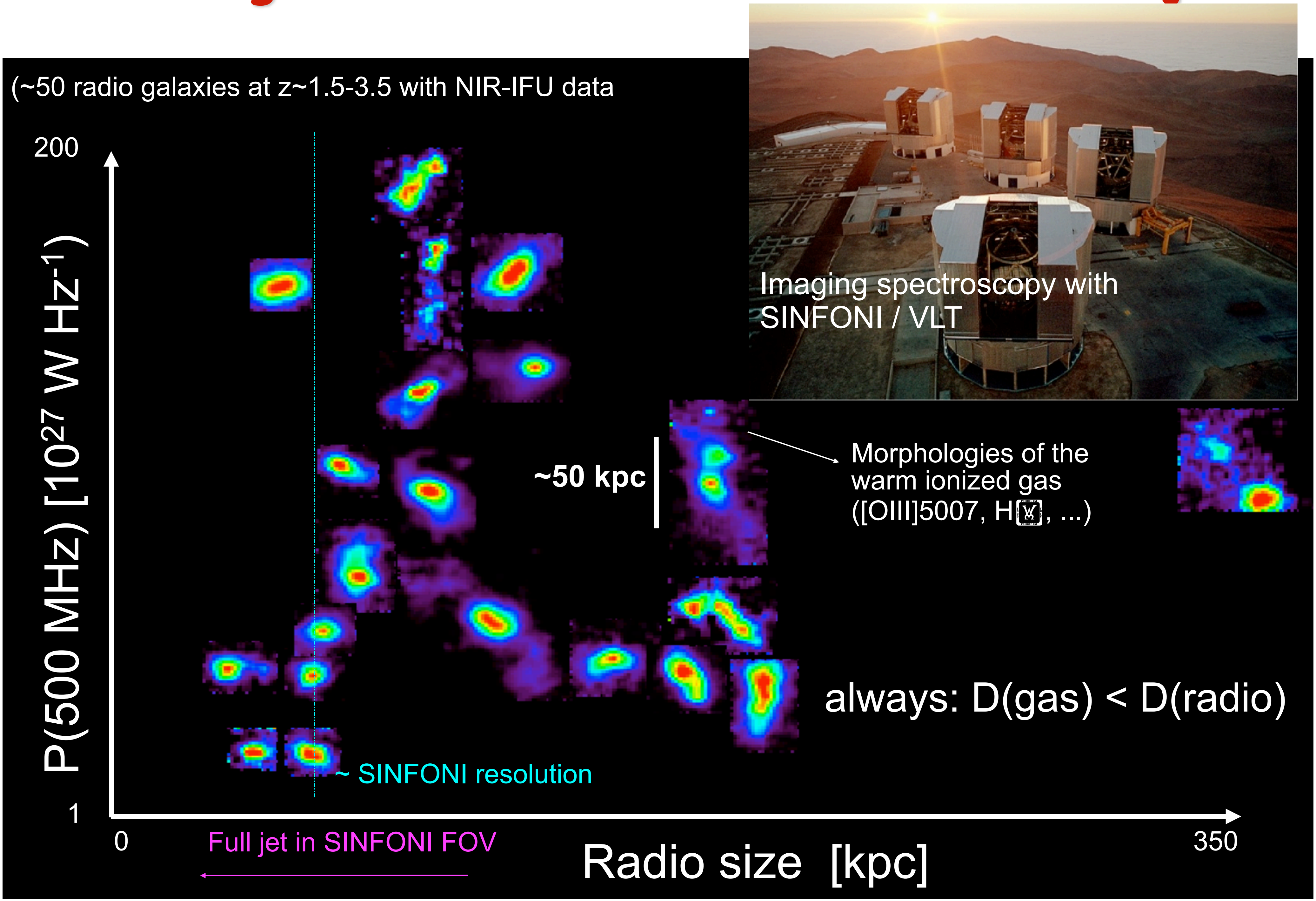
**strongest interactions w/ young radio sources**
(e.g., Holt et al. 2008)

**dissipation times of gas kinetic energy ~ jet lifetime**
(Nesvadba et al. 2010a)



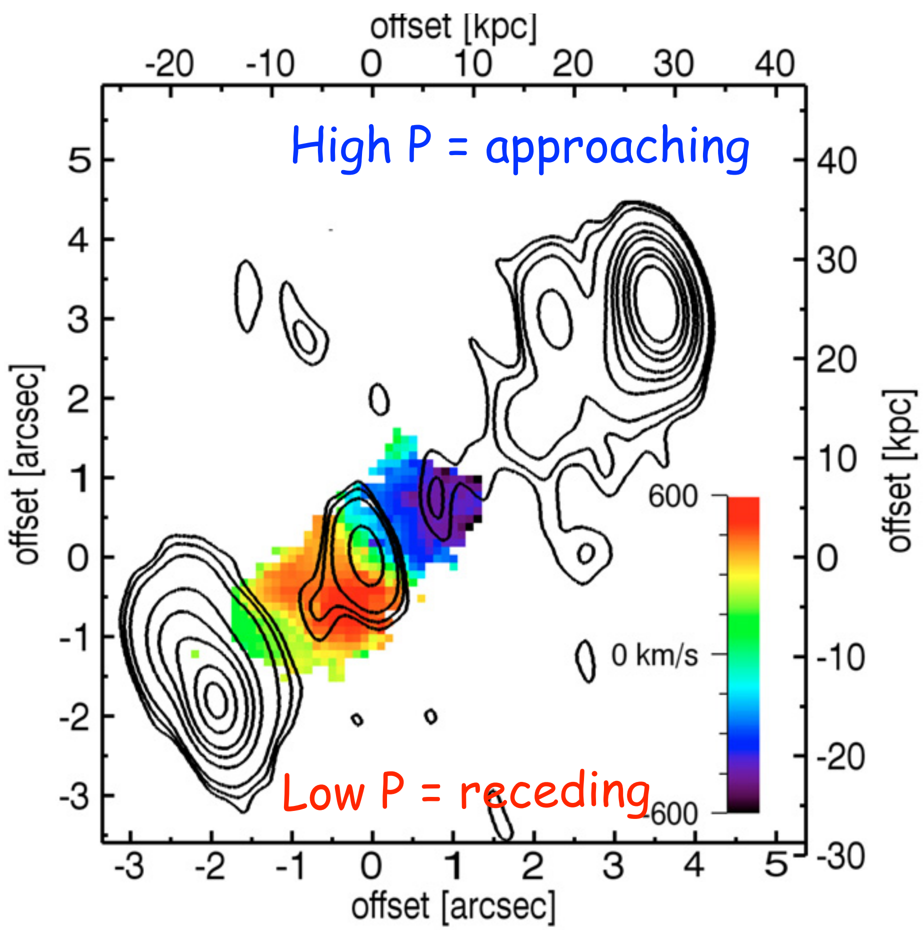



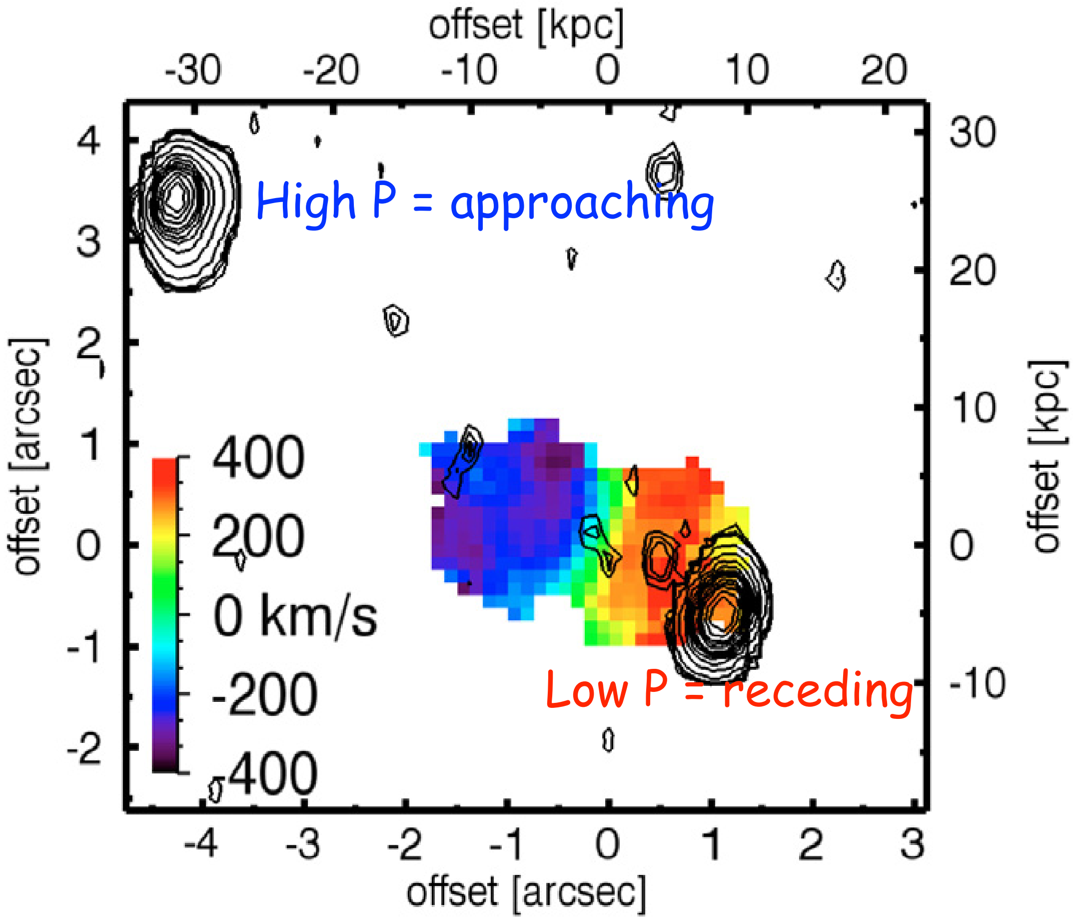
# Ionised gas halos with sizes similar to radio jets



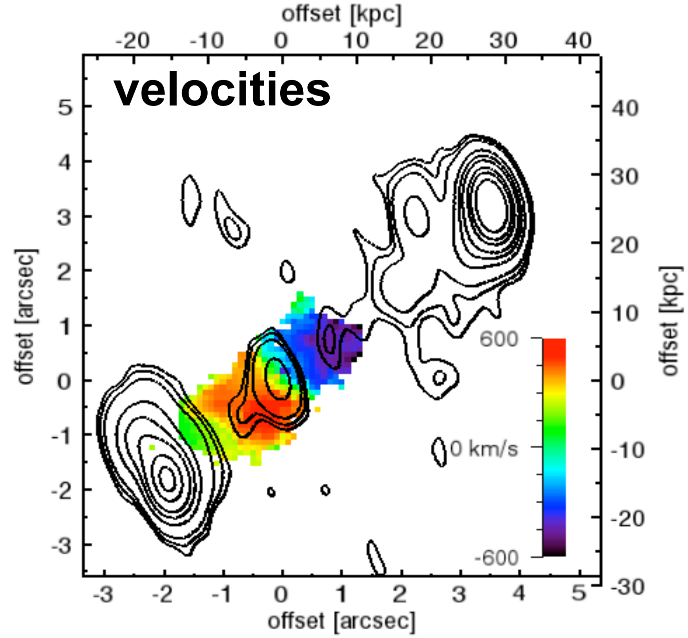
# Are these really outflows?

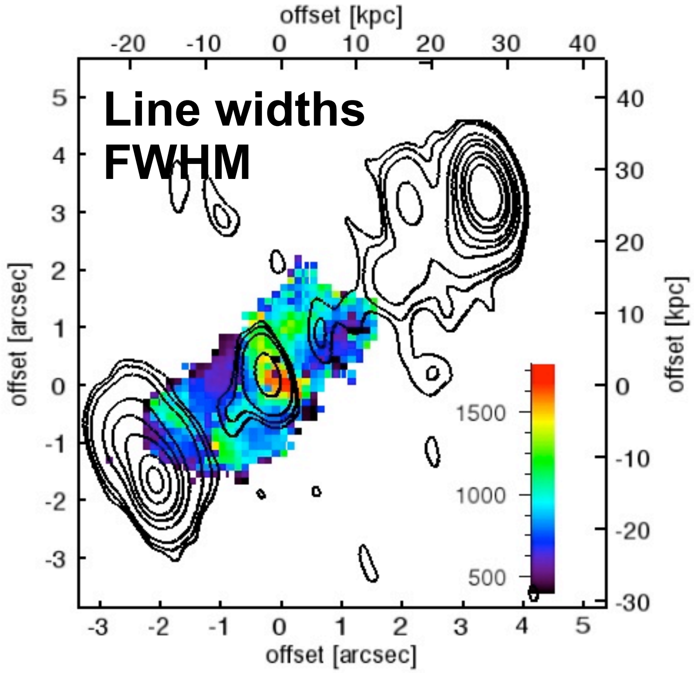
- Laing-Garrington effect: most depolarised radio lobe is receding as it passer through longer line-of sight.
- Consistently indicate bipolar outflows with velocity offsets ~ 1000 km/s and V~1000 km/s.



# Energetics and other constraints




## Characteristic: blue / redshifted bubbles

- velocity offset 1000 km $s^{-1}$ (>> rotation)
- Line widths ~ 1000 km $s^{-1}$

## Gas extends along jet axis to R >> $R_{stars}$

- only extended gas where extended radio sources
- aligned with radio source

## $M_{gas,ion}$ ~ $10^{10}$ $M_{sun}$ ~ $M_{gas, mol}$

- Hα flux, extinction, electron densities measured
- starburst galaxies: $M_{mol}$ / $M_{ion}$ ~ $10^{2-3}$

## $E_{kin,gas}$ ~ $10^{59-60}$ erg

- ~ binding energy of a massive host galaxy
- 0.1 - 0.2 % of the rest-mass energy equivalent of the SMBH
- 1-10% of the jet power

## $T_{outflow}$ few x $10^7$ yrs ~ AGN lifetime

- > characteristic time of a starburst ~ $10^8$ yrs

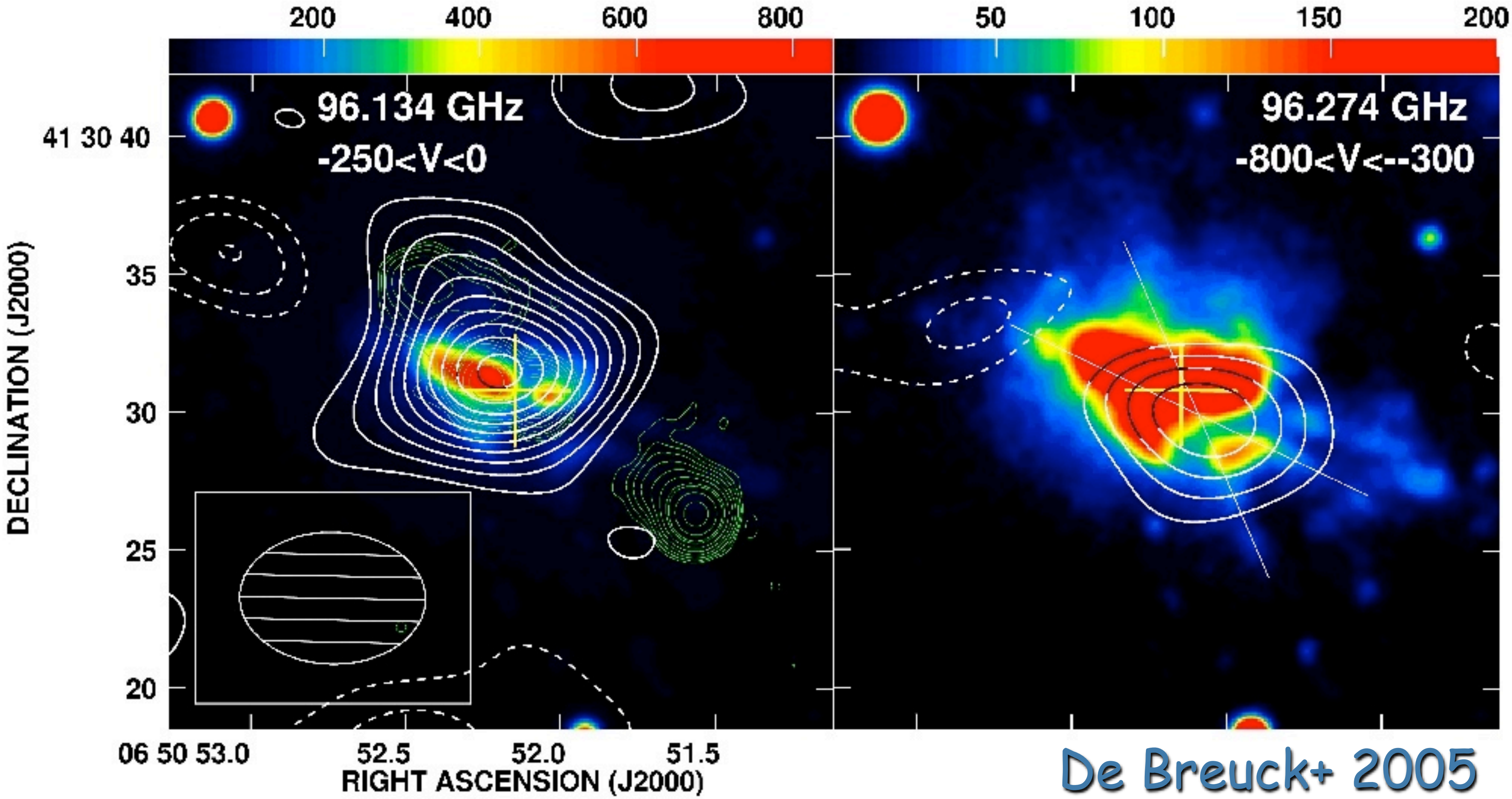
**Expected characteristics of AGN-driven winds quenching intense starbursts in massive high-z galaxies**

How about molecular (CO) gas, thought to be the main tracer of the ISM?

| Name | CO transition | z | $S_{850\mu m}$ [mJy] | $\Delta V_{CO}$ [km/s] | $S_{CO}\,\Delta V$ [Jy km/s] | $M(H_2)$ [$10^{10}$ $M_{Sun}$] |
|---|---|---|---|---|---|---|
| MG2037-0011 | 3-2 | 1.51 | - | TBD | faint det. | TBD |
| MRC0156-252 | 3-2 | 2.02 | - | TBD | TBD | TBD |
| TN J2254+1857 | 3-2 | 2.15 | - | - | offset det. | 0.6(offset) |
| 53W002 | 3-2 | 2.39 | <4.5 | 420 | 1.2± 0.2 | 1.2 |
| 3C257 | 3-2 | 2.47 | 5.4 | - | non det | - |
| USS0828+193 | 3-2 | 2.57 | - | - | offset det. | (offset) |
| B3 J2330+3927 | 4-3 | 3.09 | 14 | 500 | 1.3± 0.3 | 7 |
| WN J1123+3141 | 4-3 | 3.22 | 4.9 | - | non det | - |
| TN J0205+2242 | 4-3 | 3.51 | <5.2 | - | non det | - |
| TN J0121+1320 | 4-3 | 3.52 | 8 | 700 | 1.2± 0.4 | 3 |
| 6C 1909+72 | 4-3 | 3.54 | 13 | 530 | 1.6± 0.3 | 4.5 |
| MG2144+1928 | 4-3 | 3.59 | 2.3 | TBD | detected | TBD |
| 4C 60.07 | 4-3, 1-0 | 3.79 | 11 | >1000 | 2.5± 0.4 | 8 |
| 4C 41.17 | 4-3, 1-0 | 3.80 | 11 | 1000 | 1.8± 0.2 | 5.4 |
| TN J0924-2201 | 1-0, 5-4 | 5.20 | <3.2 | 200-400 | 2.1± 0.2 | ~10 |

# CO emission in 4C41.17 (z=3.8)

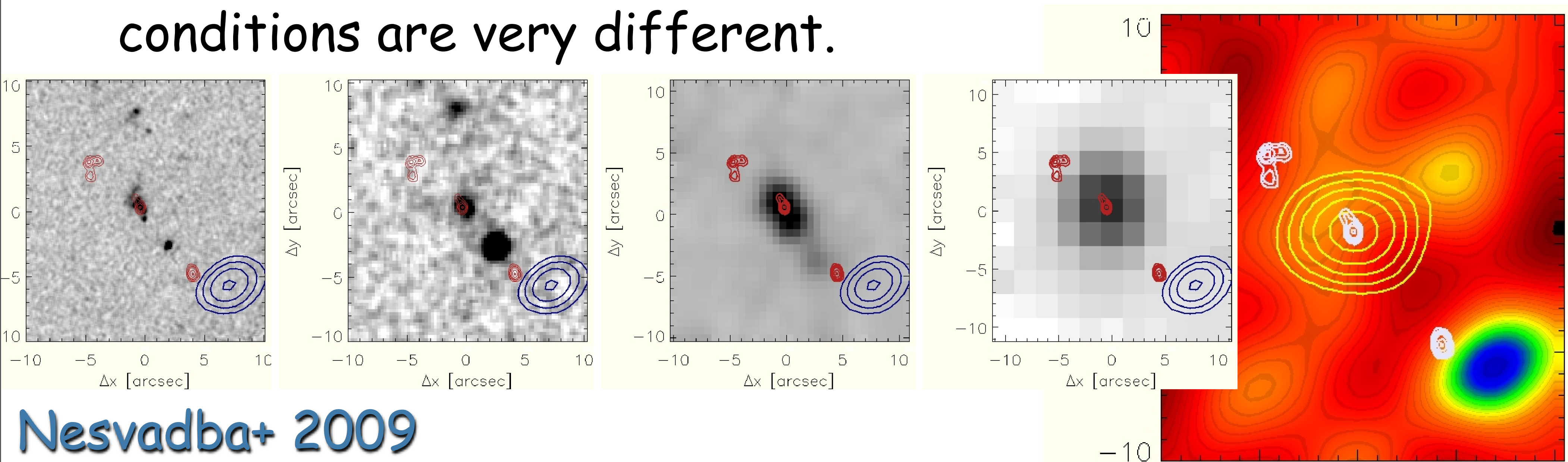
- CO is in 2 components with $M(H_2) \approx 3\times10^{10}\ M_{Sun}$.
- Each component coincident with a dark lane in Ly$\alpha$.
- Not detected in CO(1-0) with VLA $\rightarrow$ $n(H_2) \geq 10^3 cm^{-3}$.




De Breuck+ 2005

# CO in the halo of USS 0828+193 (z=2.6)

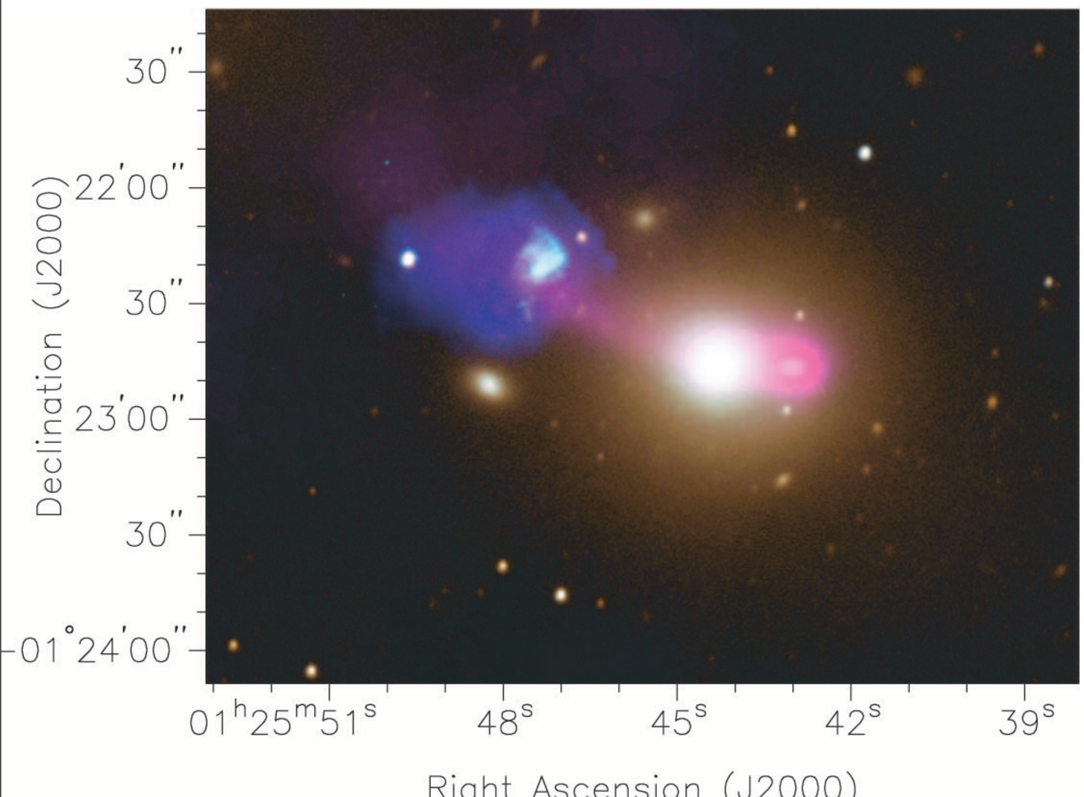
- No CO at position of radio core and host galaxy.
- 8σ detection in 2 velocity components SW1/2 detected 80 kpc from radio core, just beyond radio lobe.
- No indication for old stars or star-formation in SW1/2.
- Related to Lya absorbers in the haloes?
- Cloud collapse and excitation by the nearby radio jet?
- Similar to diffuse CO in low z clusters, but ambient conditions are very different.

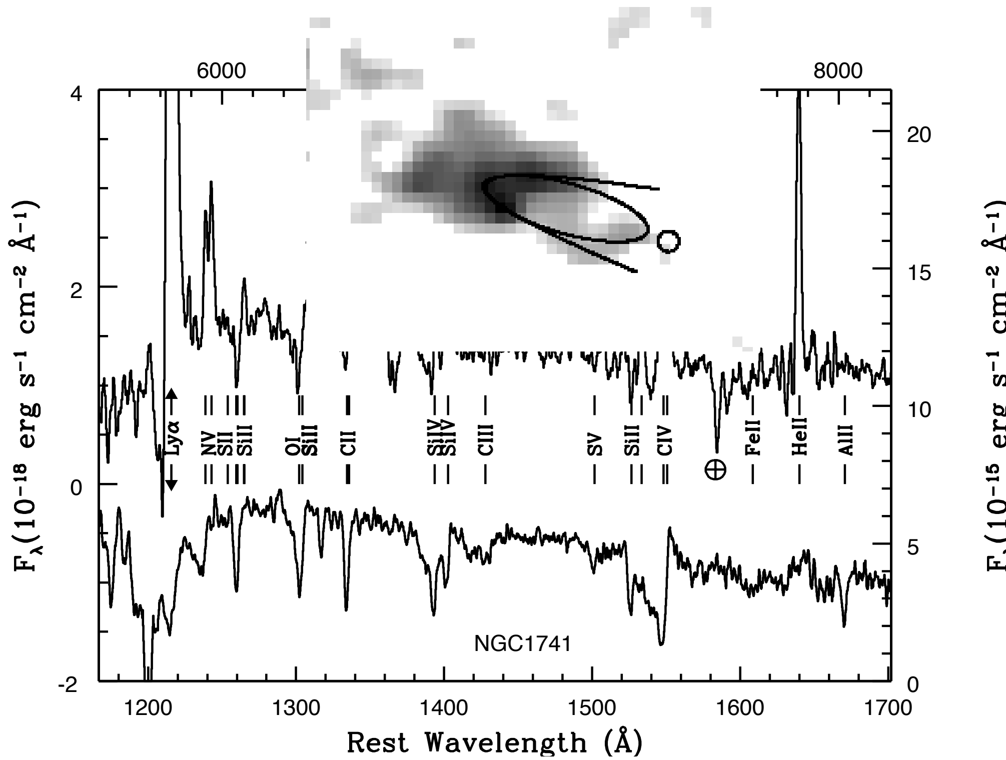



Nesvadba+ 2009

# The occasional positive feedback: jet-induced star formation

- Increased star formation along the radio jets.
- Strong evidence at low z in Minkowski's object (Croft + 2004).
- At z=3.8 in 4C41.17 (Dey + 1997, Bicknell + 2000).
- Predicted from hydrodynamic simulations (Fragile + 2004).
- Total mass of stars formed ~$10^9$ $M_{sun}$, mostly negligible.



# Summary

- High z radio galaxies have massive host galaxies, and are close to the $M_{BH}$-$M_{bulge}$ relation ⇒ need strong feedback process to stop accretion: powerful radio AGN.
- They are on the critical point between "quasar" and "radio" mode.
- VLT/SINFONI observations of 50 HzRGs show bipolar outflows aligned with radio source & sizes up to 50 kpc ~ radio source.
- Outflow kinetic energies close to the binding energy of the host.
- Ionised gas mass similar or greater than CO mass.
- We have found a CO component within the halo of a z=2.8 RG, along the radio jet direction, but without star formation.
- Feedback is predominantly negative, though occasional positive feedback may occur in the form of jet-induced star formation.