High redshift radio galaxies and SMBH evolution

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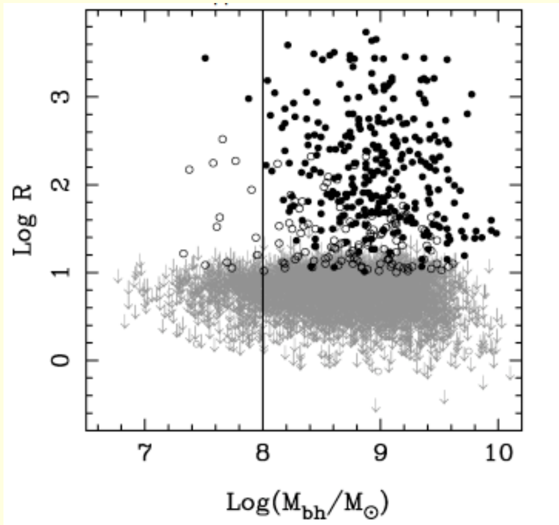
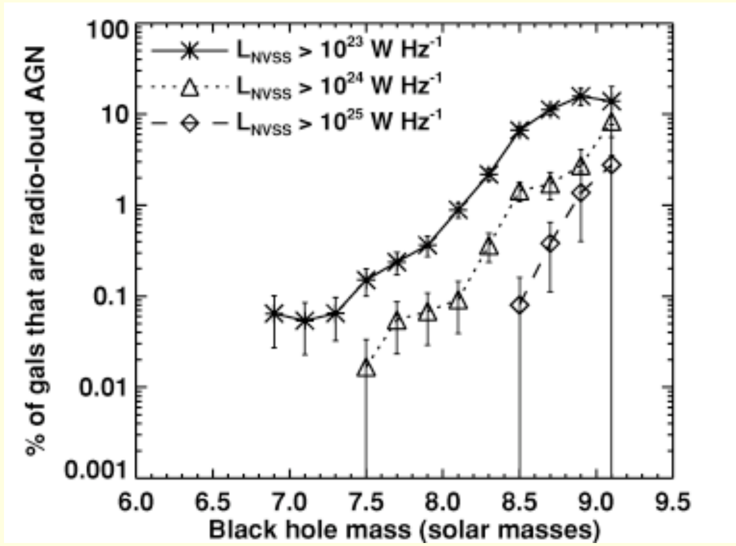
Outline - what did we learn in the last 10 years?

- Radio galaxies contain really big black holes.
- There is no obvious “redshift cutoff” in the number densities of steep spectrum radio sources.
- Some high-z radio galaxies are forming a lot of stars.
- Radio jets can both drive strong shocks into the ISM (negative feedback for star formation?) and form stars (positive feedback for star formation?).
- High-z radio galaxies are not alone - radio quiet and radio intermediate type-2 quasars are common at high redshifts.
- Radio astronomers were right about massive galaxies forming at high-z!

Black hole mass and radio-loudness

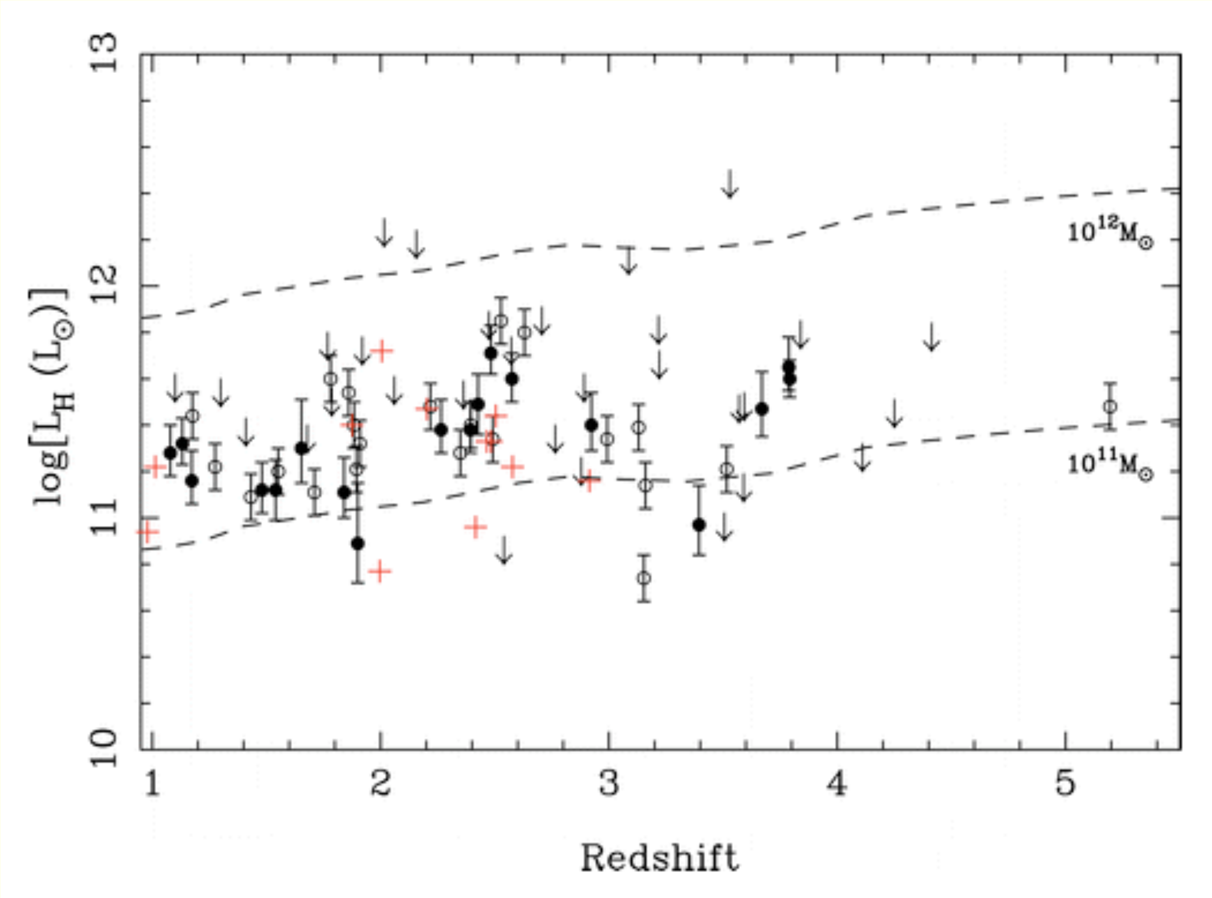
- Laor et al., Lacy et al., McClure & Jarvis: quasars
- Best et al 2005: SDSS galaxies





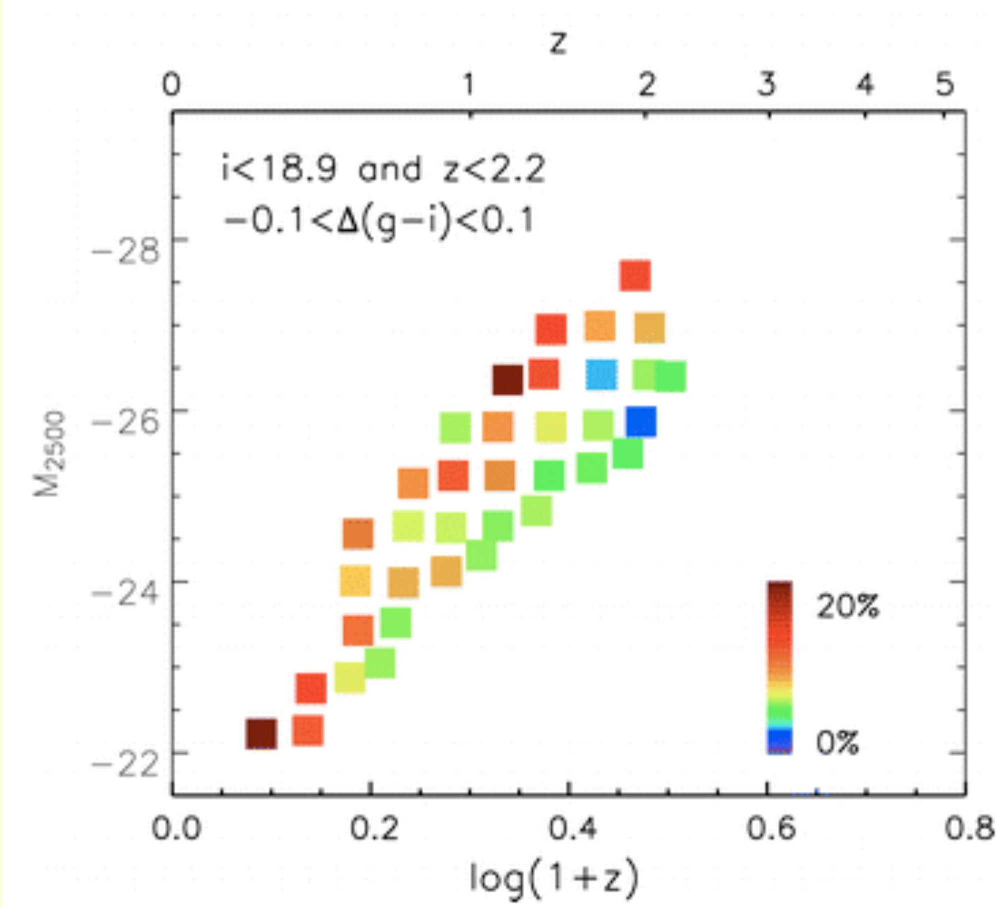
Stellar masses/populations and the K-z relation

- Rest-frame near-IR luminosity of high-z radio galaxies are high (e.g. Seymour et al 2007).
- Similar to submm galaxies (red crosses)

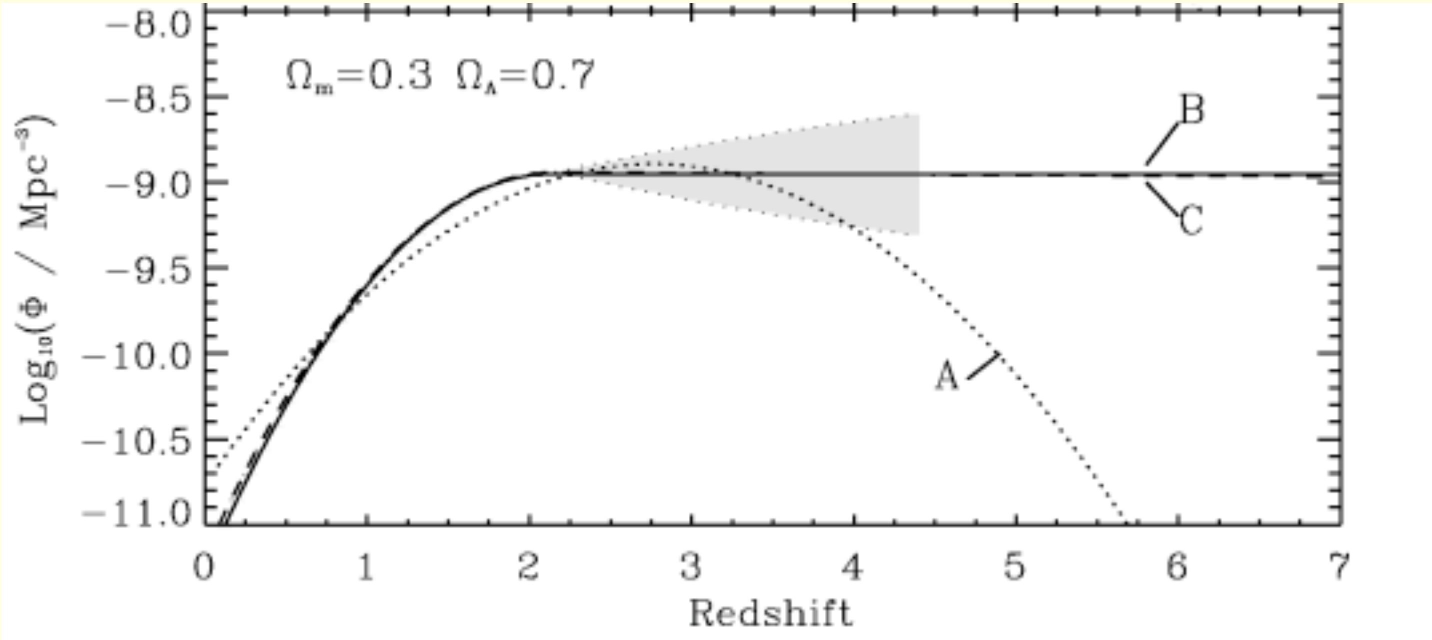


Fraction of radio-loud quasars

- Jiang et al (2007) found that, at fixed optical luminosity, RL quasar fraction in SDSS is a strong function of redshift.
- Consistent with the idea that radio galaxies/quasars are the end points of massive galaxy evolution.
- But also could be explained by radio-loud hosts being relatively dustier at high-z



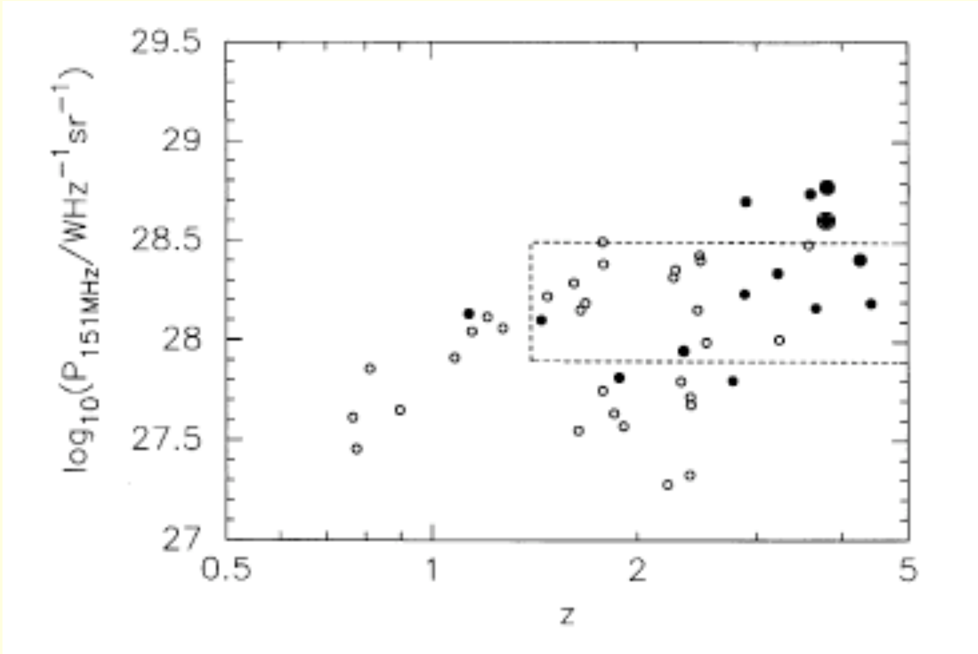
Number density evolution of high-redshift radio galaxies



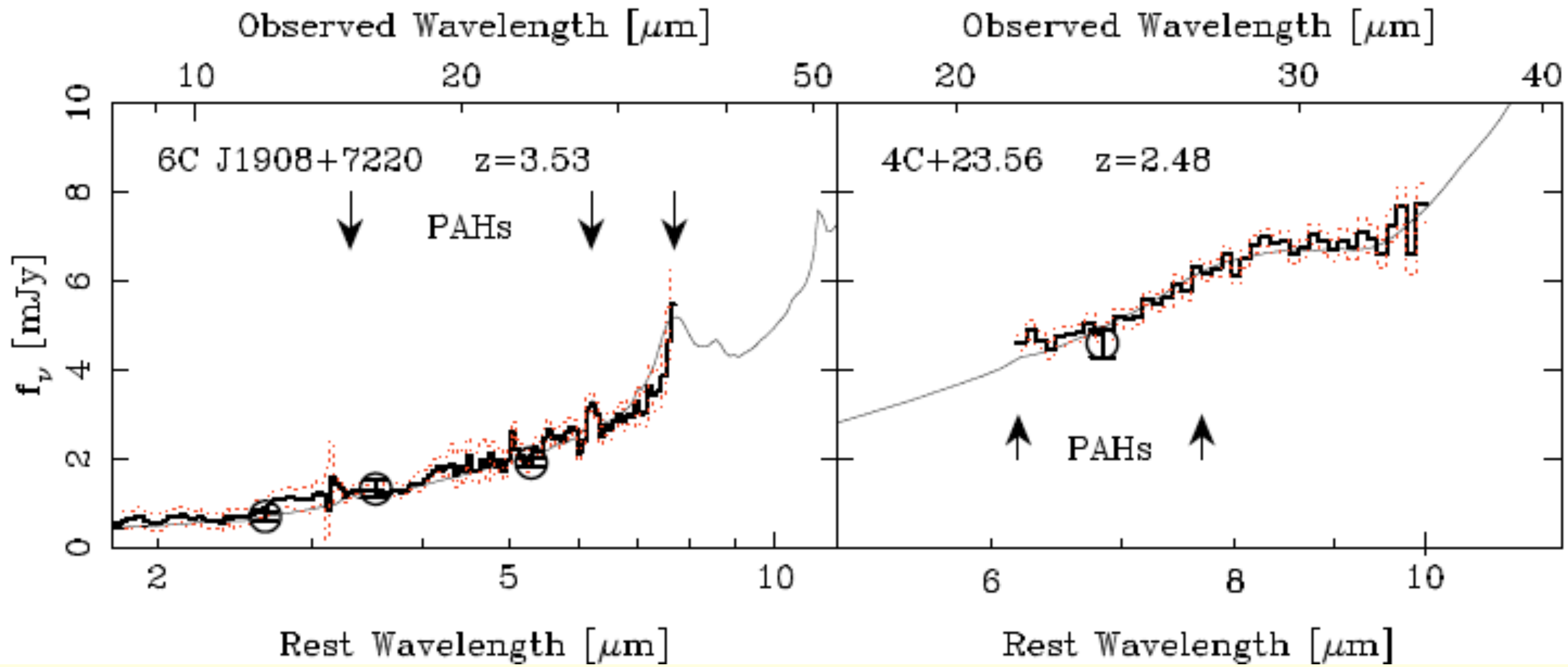
- Jarvis et al. (2001) found no evidence for a decline in the space density of radio galaxies at z>3.

Star formation in HzRGs - Submm continuum

- Many HzRGs are detected in the submm, with ULIRG-like luminosities (closed symbols).
- But many lack such extreme SFRs



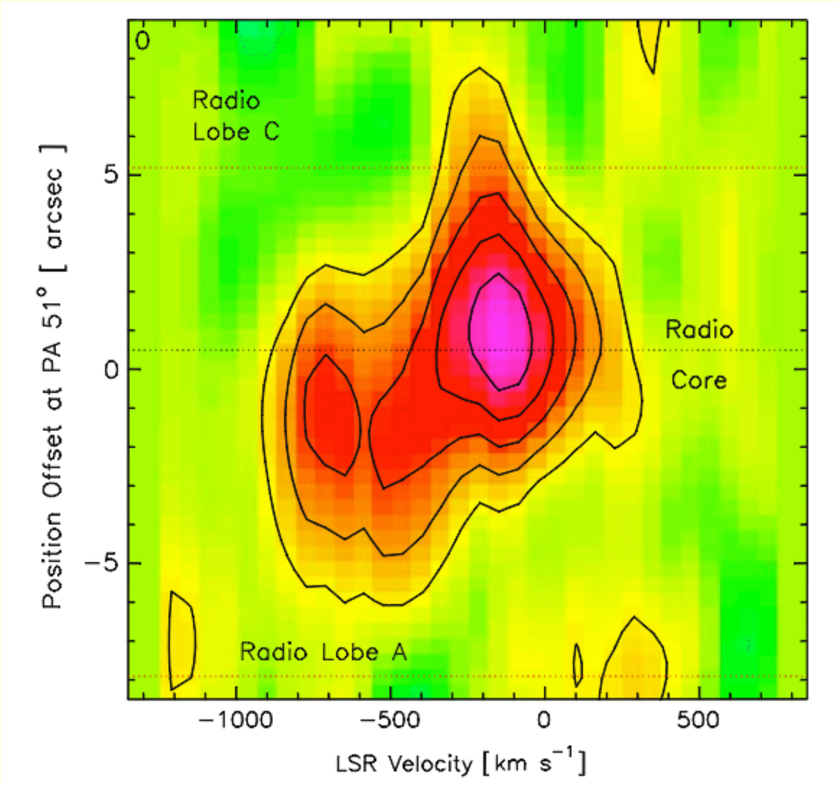
IRS spectra of HzRGs



Seymour et al. 2008

CO detections of HzRGs

- Seven HzRGs galaxies have been detected in CO, including the z=5.2 object TN J0924-2201 (Klamer et al. 2005).
- Inferred H_2 masses (from intensities) are ~$10^{10\text{-}11}$Msun.
- Dynamical masses with e.g. ALMA.



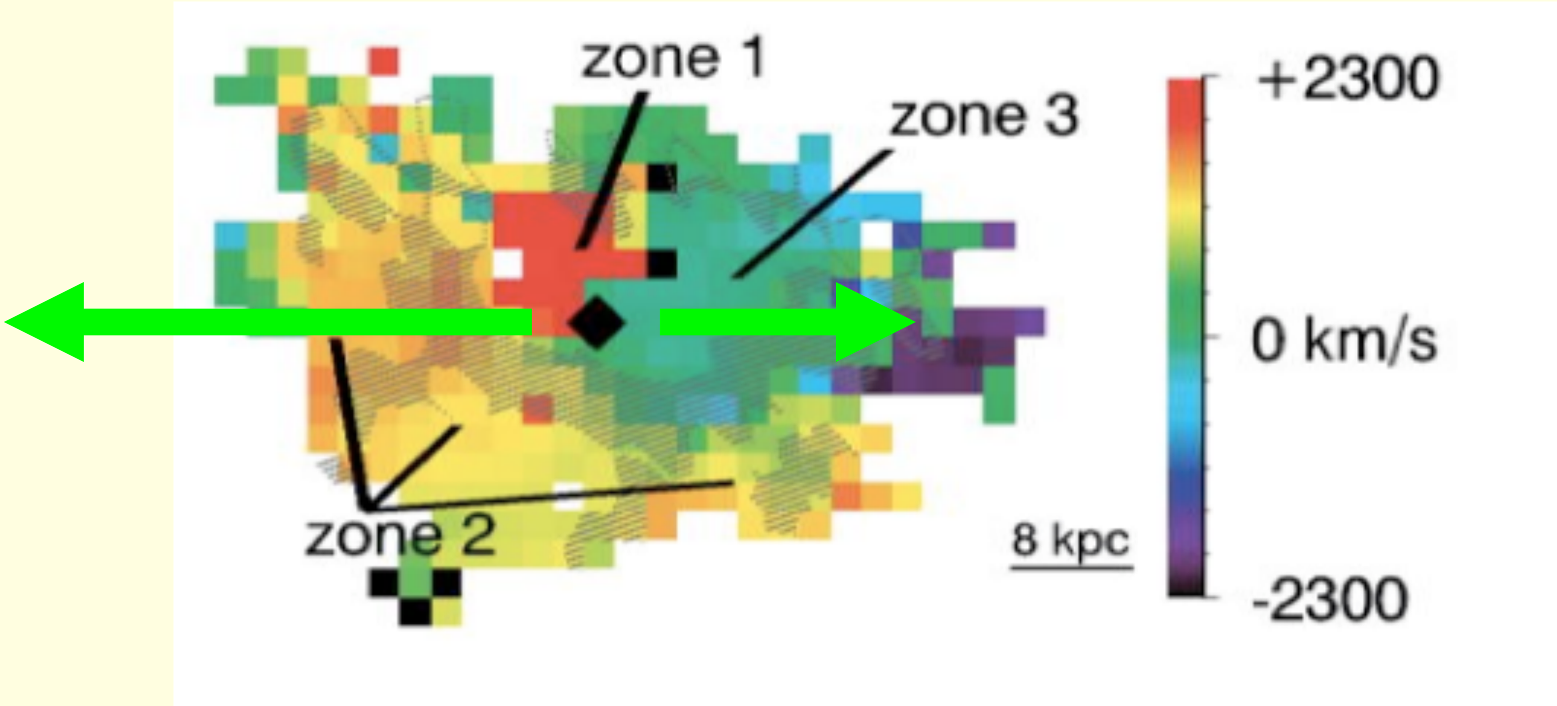
4C41.17 in CO 4-3 PdB; de Breuck et al. 2005.

Feedback - and whatever happened to the "alignment effect"?

- Radio jets of FRIIs propagate strong bow shocks into the ISM and ICM.
- Lateral shocks are weaker, but cover 4π.
- High-z radio galaxies fall into the "blast wave" class of feedback models, with powerful shocks being driven into the IGM.
- Radio-optical alignments in high-z radio galaxies were a major topic of study in the 1990s. Relevant to feedback:
  - Aligned emission line regions probably due to shocks
  - Aligned continuum a mixture of scattered quasar light and possibly jet-induced star formation, enhanced by selection effects.

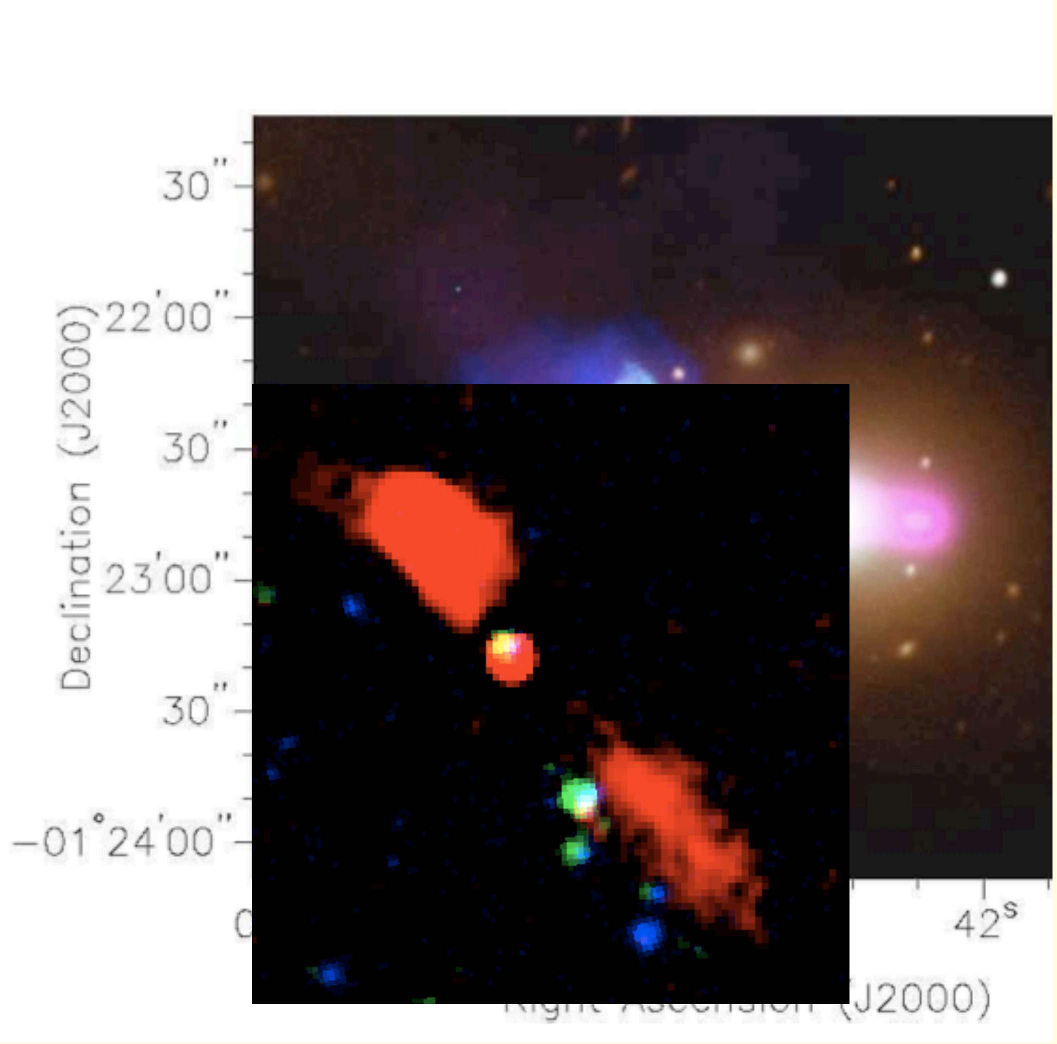
Negative feedback

MRC1138-262, Nevsadba et al. 2006



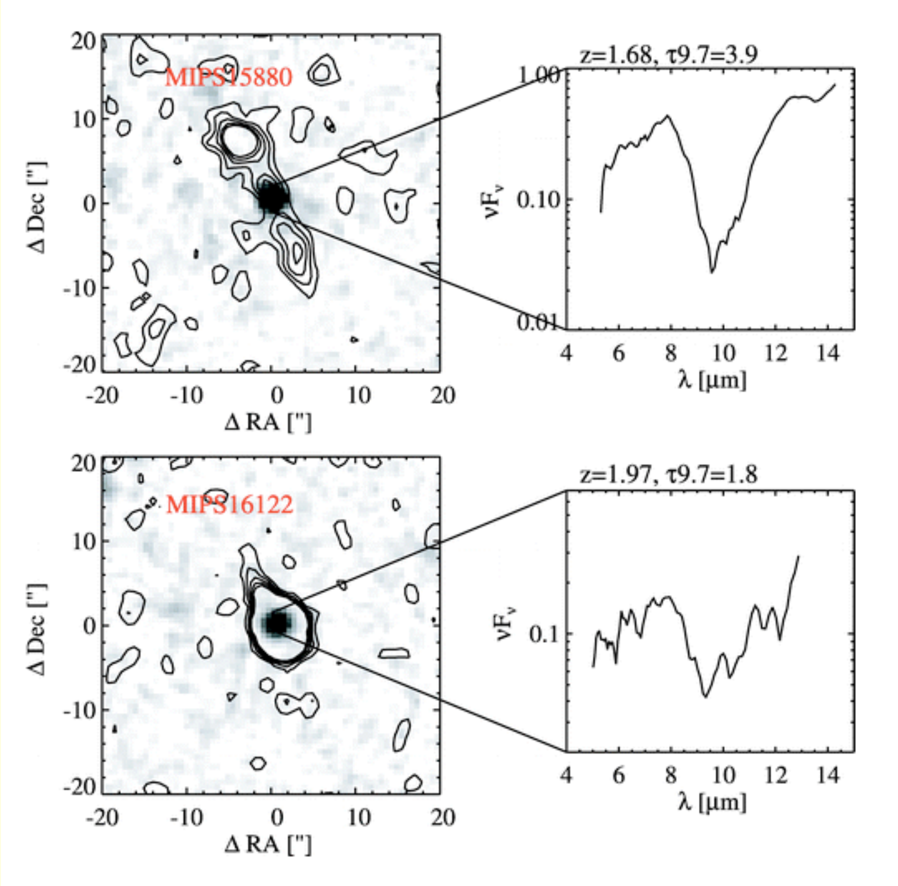
Positive feedback

- Jet-induced star formation really seems to happen (e.g. Minkowski's object; Croft et al 2006)
- Other low-z candidates being found (e.g. Sajina et al. in prep.)
- All in lower-luminosity radio galaxies - 4C41.17 is only really good candidate at high-z/high luminosity.



IR-selected high-z radiogalaxies

- ~40% of z~2 IR-selected galaxies with strong silicate absorption are radio-loud (Sajina et al. 2007).
- Strong silicate absorption is not seen in any low-z radio galaxies.



What high-z radio galaxies do and don't tell us about feedback

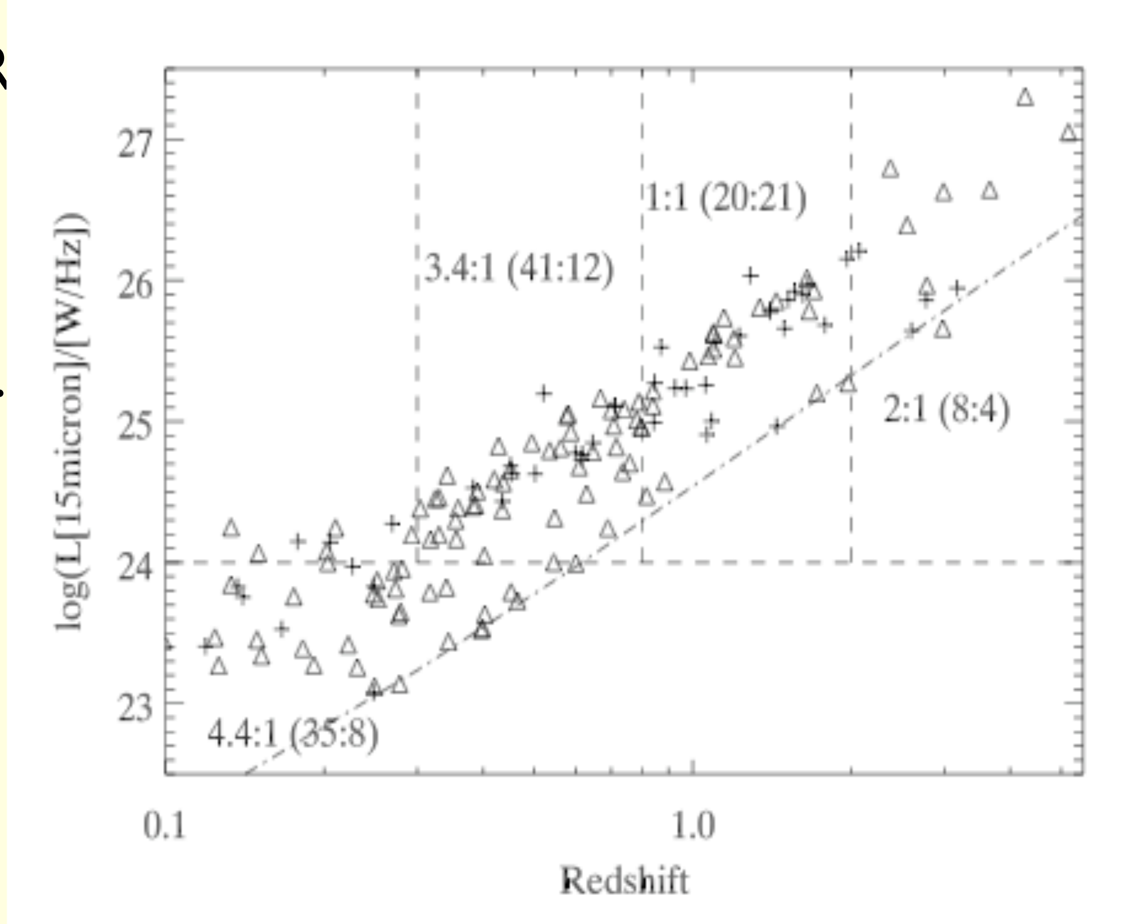
- No doubt that the kinetic power in the jets o luminous high-z galaxy jets can provide negative feedback for star formation if they can:
  - Couple effectively to the ISM
  - Have lateral shocks powerful enough to heat the ISM away from the jet axis
- But such objects are very rare (~10^{-9}Mpc^{-3}). Even if AGN duty cycle is only ~1% not enough of them to account for all massive ellipticals today (~10^{-4}Mpc^{-3}) (though could be enough to affect rich clusters).

HzRGs and feedback-2

- What about lower-luminosity sources (~FRI/FRII divide)?
- Much more common, most gEs could have been one of these at some point.
- But these often seem to be *forming* stars through JISF. At high-z, many still seem to have dense, dusty ISMs.
- Could jets inhibit accretion of gas onto the host by forming stars in the IGM, perhaps enhanced by less violent "radio mode" feedback at later epochs??

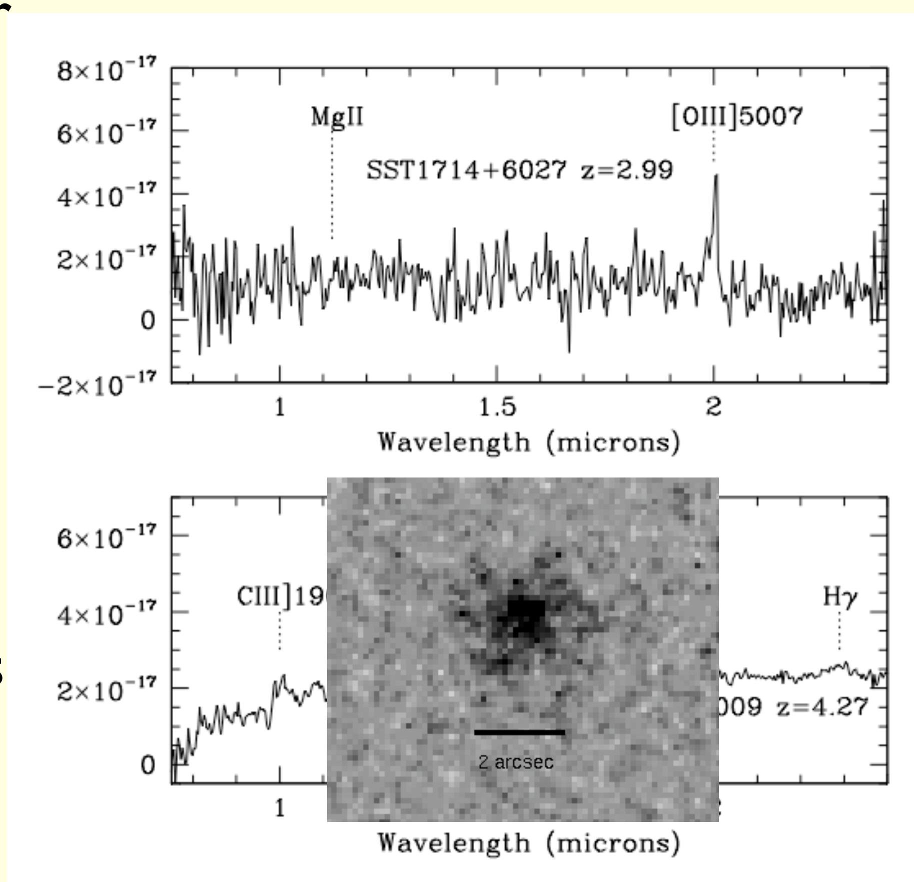
High-z radio galaxies are not alone

- Radio-intermediate IR bright obscured quasars exist (Martinez-Sansigre et al. 2005; Donley et al. 2005)
- Radio-quiet obscured quasars also common at high-z (Lacy et al. 2007).



IR-selected obscured quasars

- Some objects very similar to HzRGs with optically-bright host galaxies, and only narrow lines in the rest-frame optical.
- Others more like dust-reddened type-1 quasars, some with BAL-like outflows.
- Typical radio luminosities of high-z/high luminosity objects are around FRI/FRII divide.

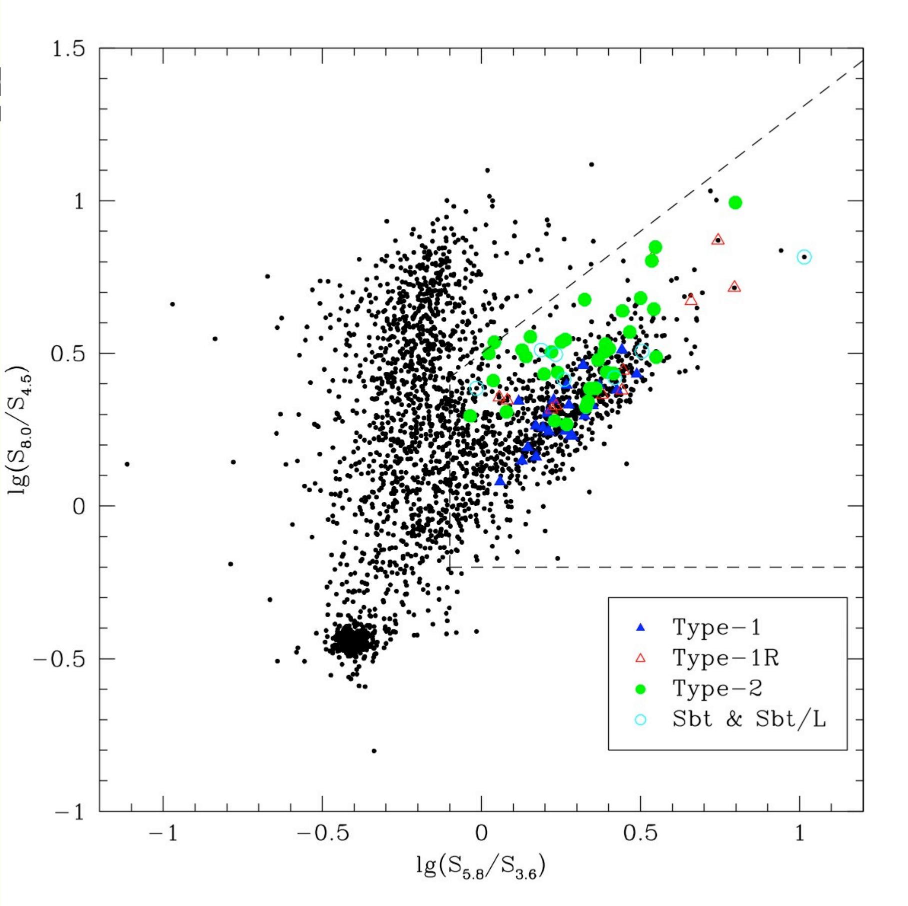


Summary

- HzRGs, along with z~6 quasars, show that at least some $\sim 10^9$ solar mass SMBHs in place at $z>3$.
- Stellar luminosities consistent with massive host galaxies surrounding the black holes.
- Number densities of HzRGs do not show an obvious cutoff at $z>2.5$, same may be true for radio-quiet obscured quasars.
  - But radio-loud quasar fraction is a strong function of redshift.
- The jets of HzRGs could either suppress or enhance star formation in their hosts.
  - AGN feedback processes may be more complicated and subtle than “blast wave” models.
  - Unclear if jets or winds dominate in the majority of quasars.

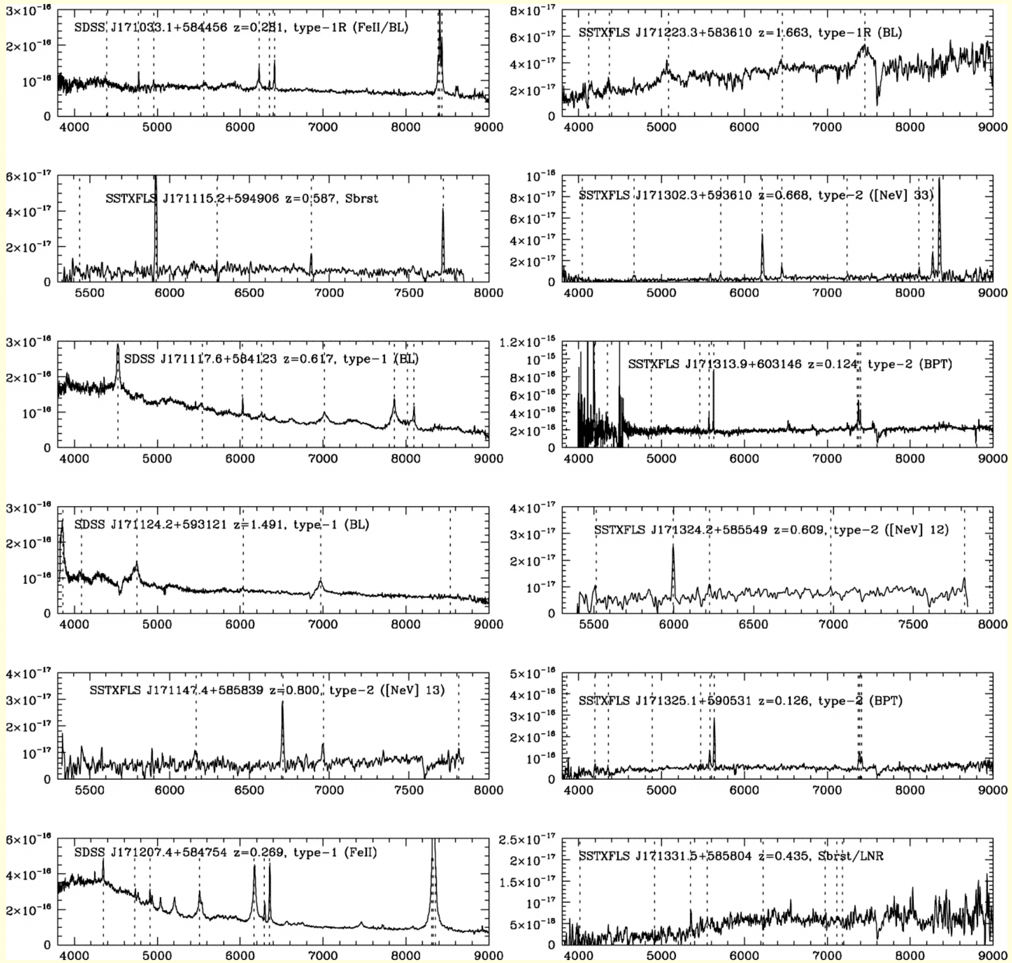
Mid-infrared selection of AGN

- Rely on hot mid-IR continuum to pick out bright AGN and quasars.
- Finds both obscured and unobscured objects.

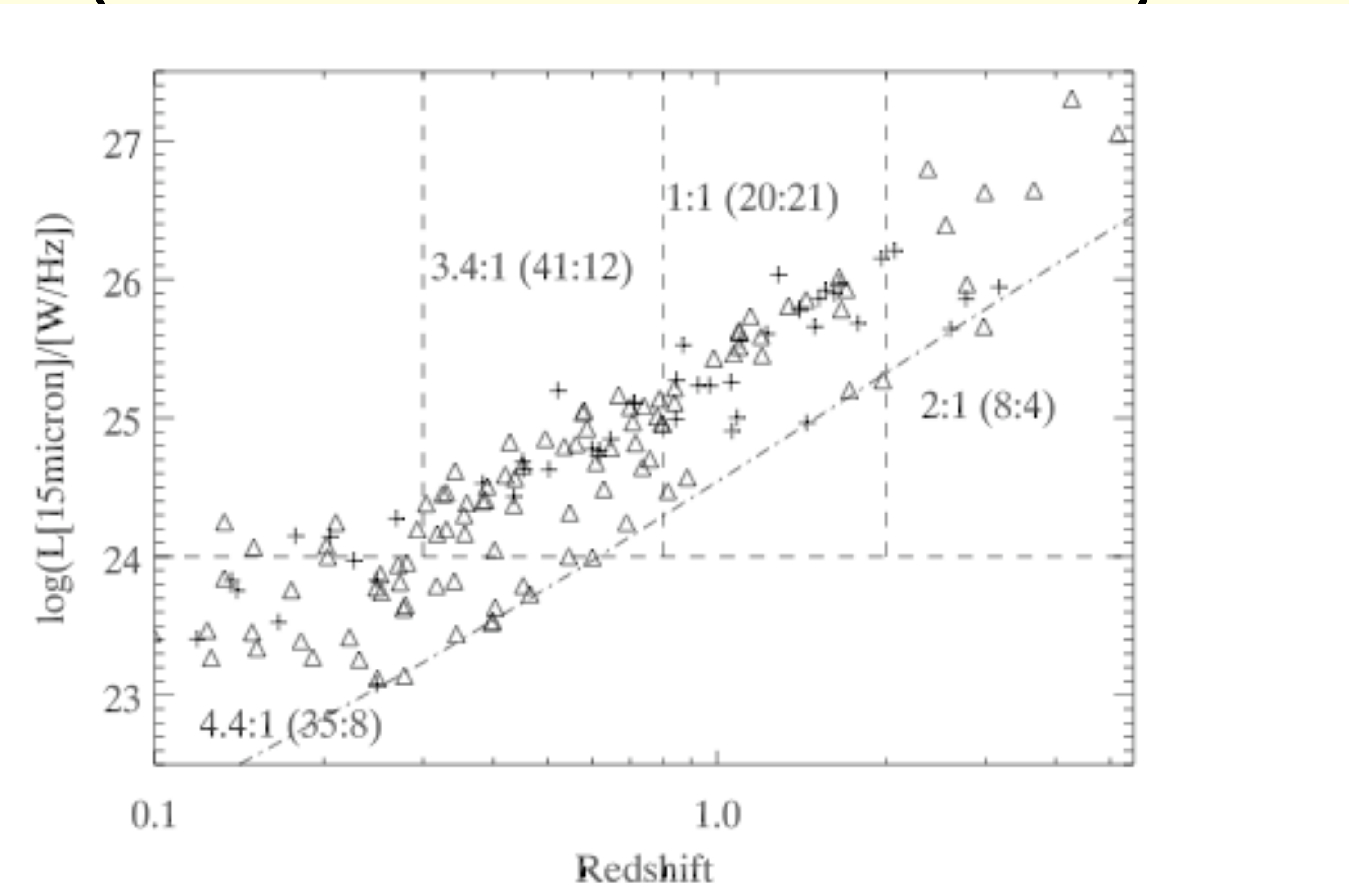


Spectroscopy

- Follow up with optical/IR spectroscopy.
- Classify as:
  - type-1 (normal quasar)
  - type-2 (high-ionization narrow lines only)
  - red type-1 (1R)
  - starburst/LINER

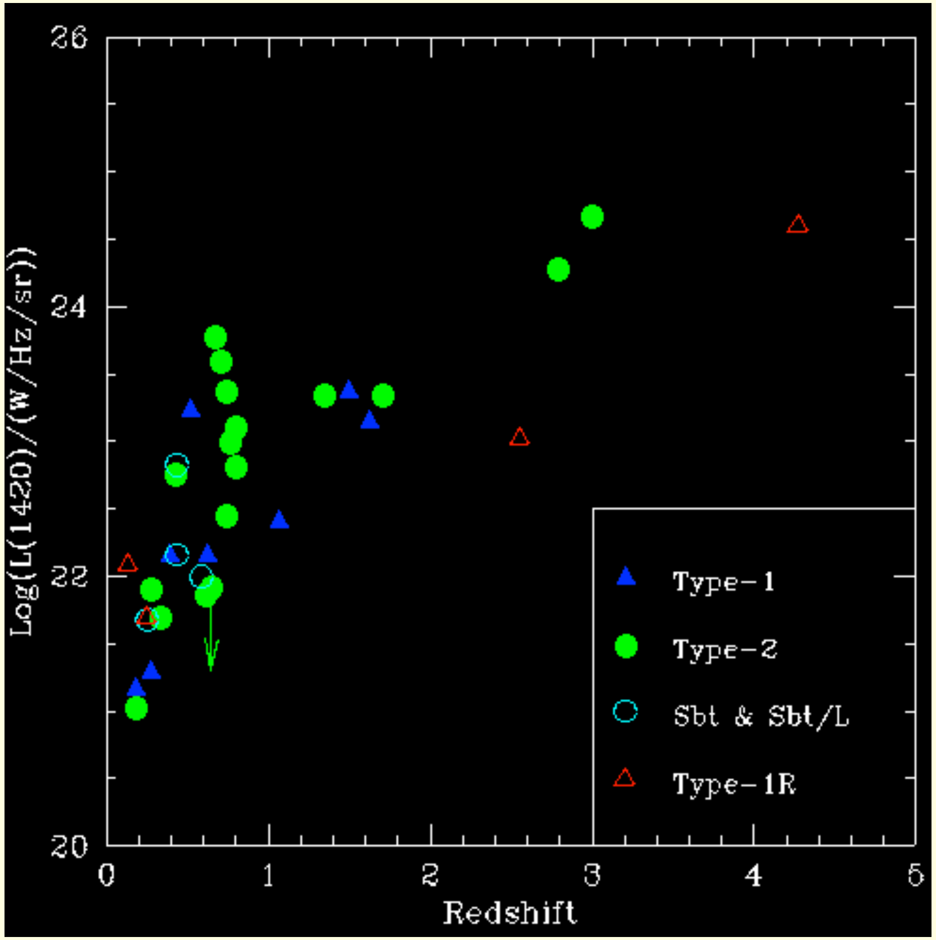


Statistics (obscured:unobscured)



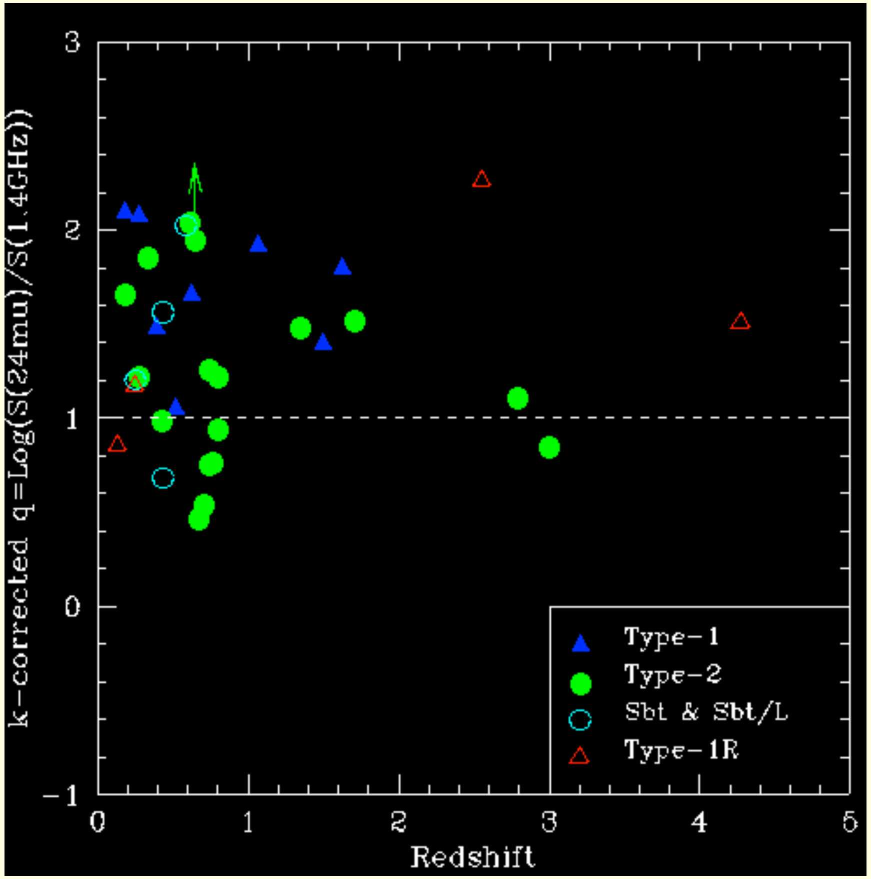
Radio properties

- Spitzer FLS has deep (0.1mJy) surveys at 1420MHz with the VLA (Condon et al. 2003) and 610MHz with the GMRT (Garn et al. 2007).
- Most luminous/highest-z radio sources are close to the radio-loud/radio quiet divide in luminosity at $10^{24.5}$



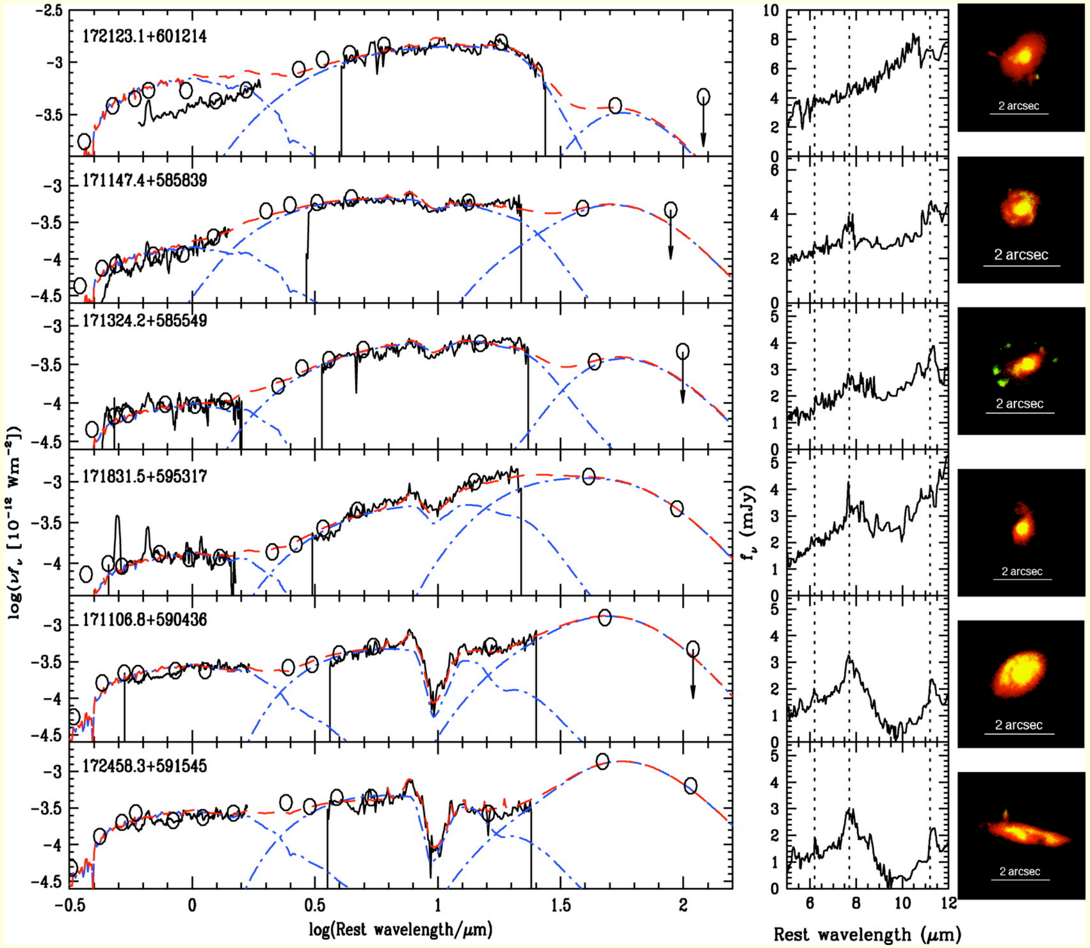
Radio-IR

- Dashed line is starburst correlation, many objects (especially type-1s) radio-weaker (cf. de Vries et al. 2007).



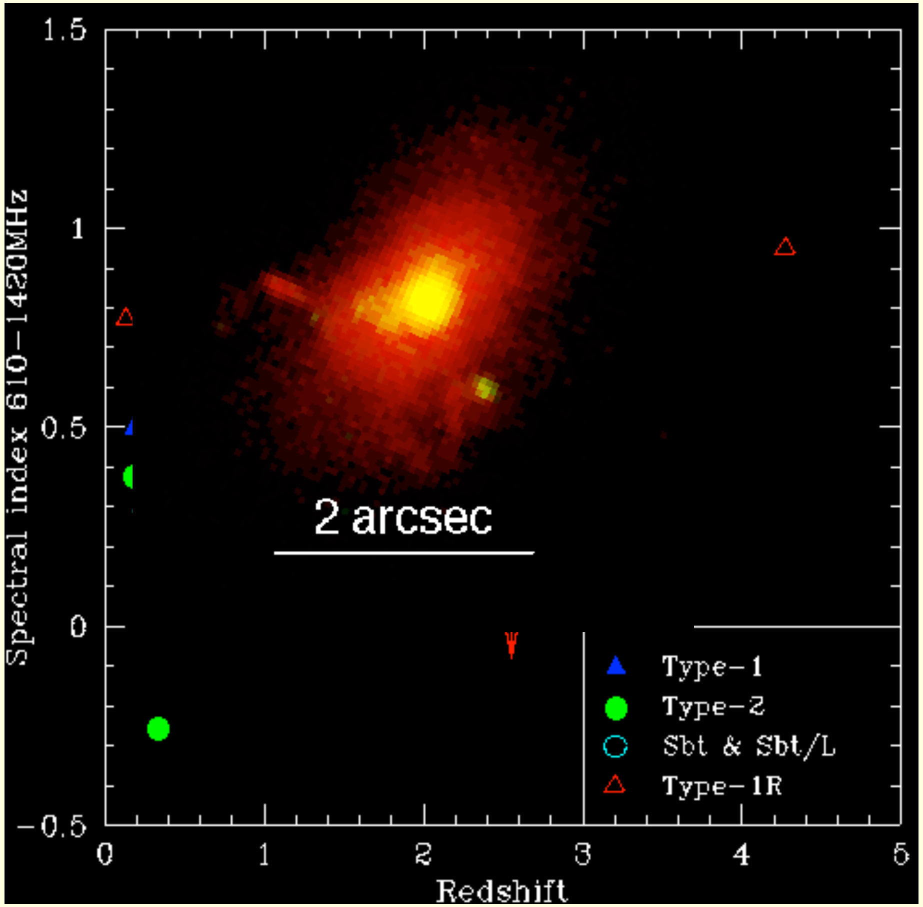
Obscured quasars

- Radio data are consistent with Spitzer and HST, showing that z~0.5 type-2 quasars have a wide range of star formation rates.
- Edge-on galaxies particularly highly-obscured - implies obscuration by host rather than AGN torus in these cases.



Spectral indices

- Most objects have steep spectra.
- Some type-2s have flat spectra (GPSs?; cf Martinez-Sansigre et al. 2006).
- Some starbursts also fairly flat (absorption?).
- No obvious tendency for high-z objects to have steeper spectra.



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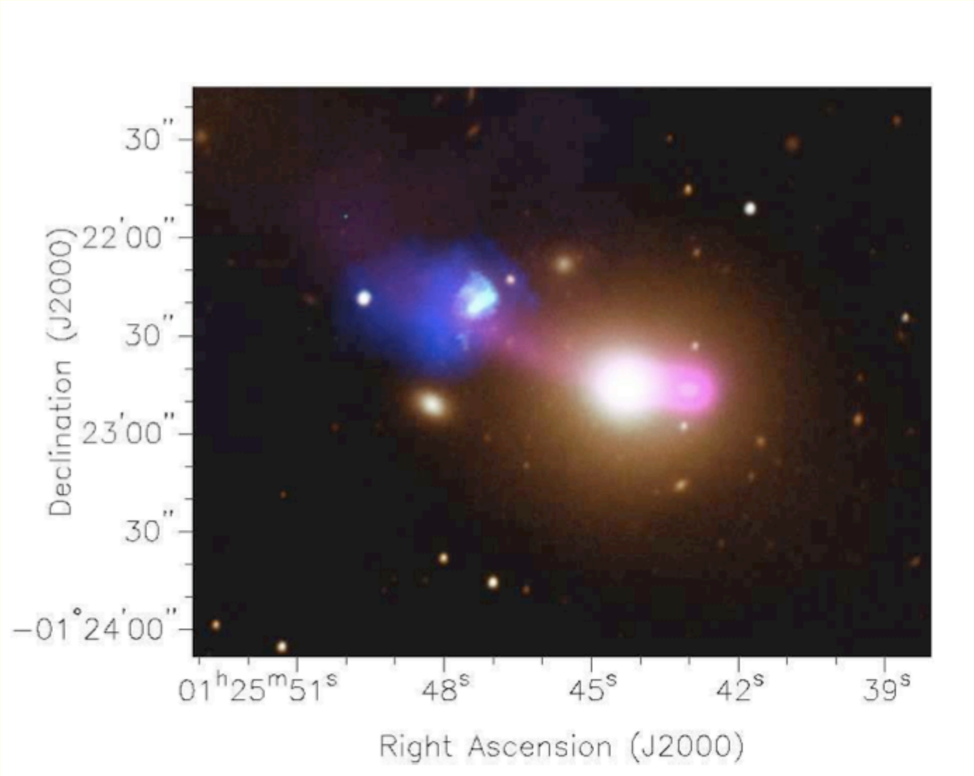
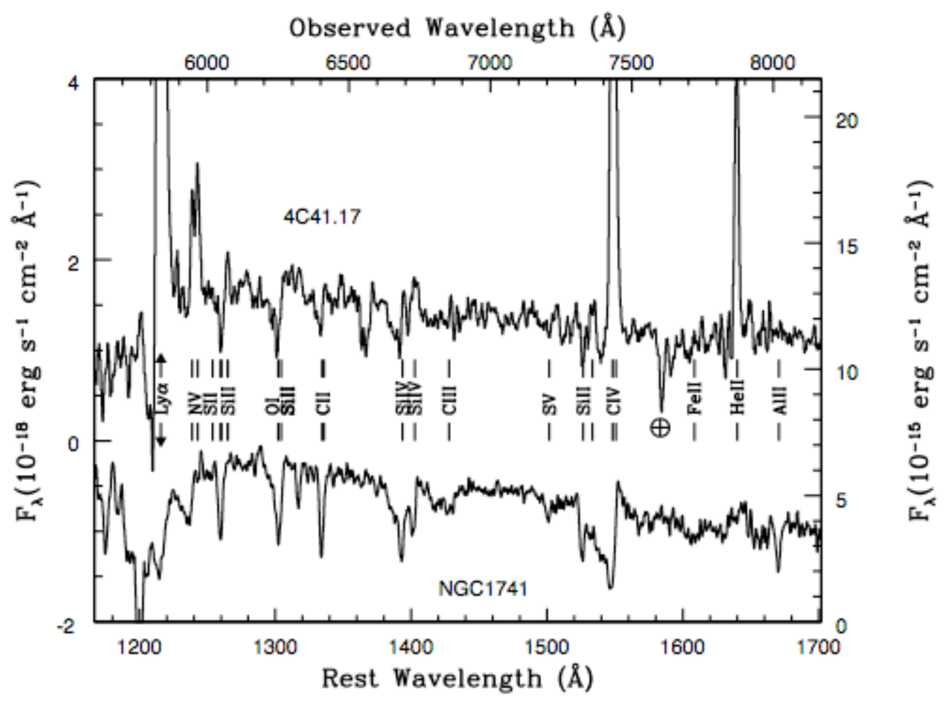


4C41.17 (Dey et al. 1997)

- z=3.8; very radio-luminous; also powerful far-IR source.
- Dey et al. claim SV and SiIV wings are from stellar photospheres.
- Also other interstellar lines typical of starbursts.



New JISF candidate from Spitzer FLS (Sajina et al. in prep.)

- Radio galaxy is at z=0.22
- Composite star-forming /AGN galaxy also at z=0.22 (cf. 3C356??)
- Getting redshifts for other 24mu sources…