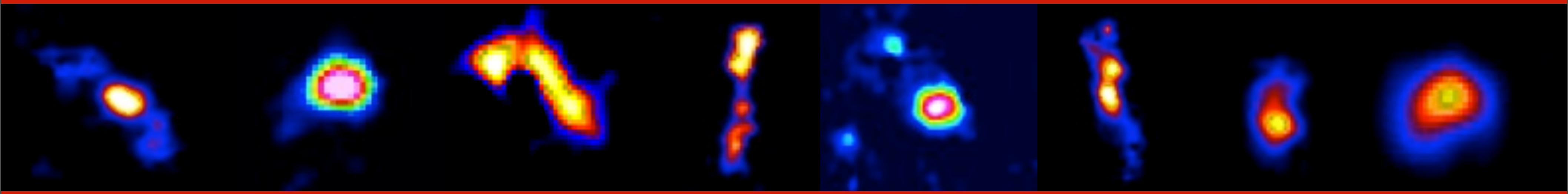
Stars, Dust and Feedback in High Redshift Radio Galaxies



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Collaborators

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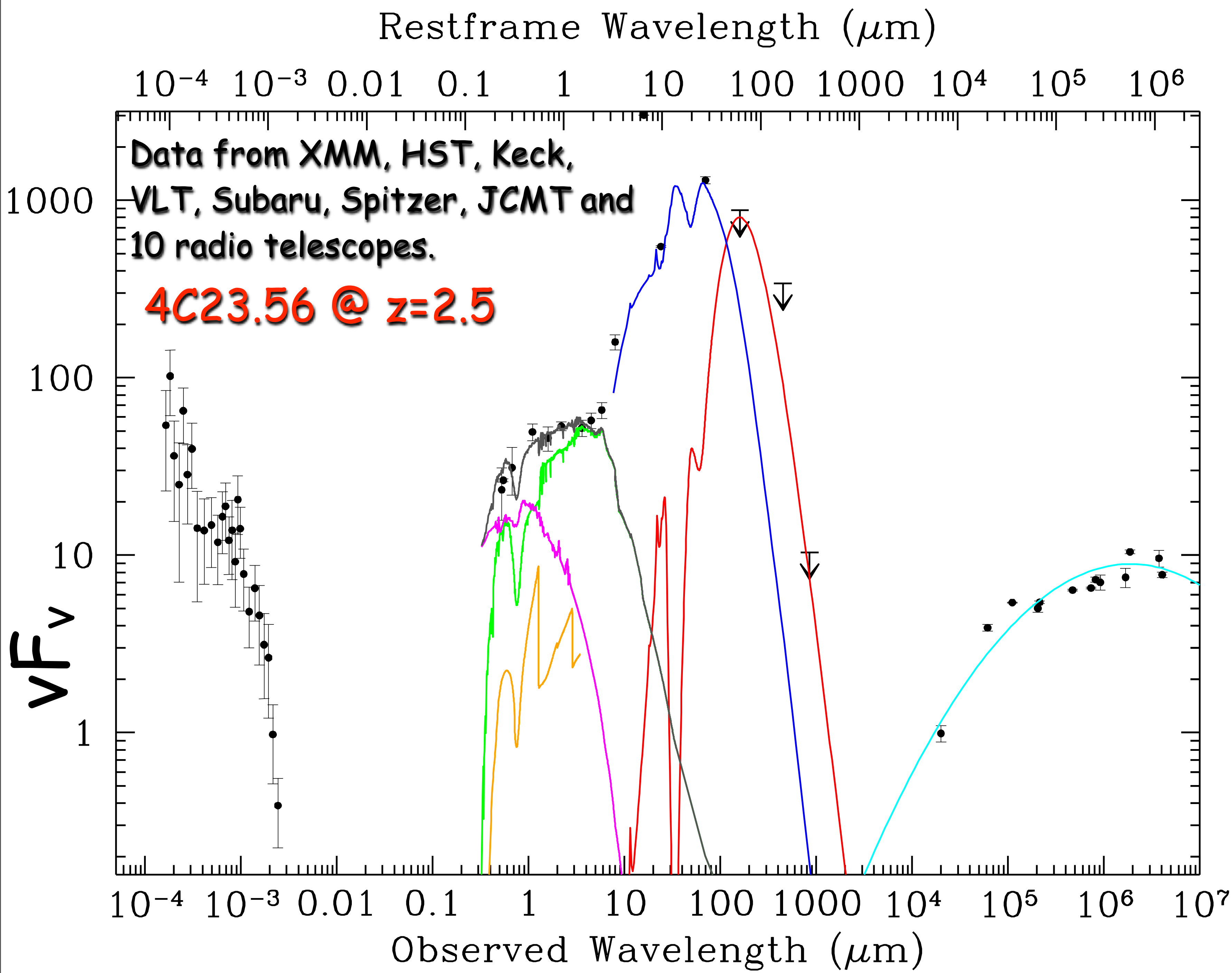
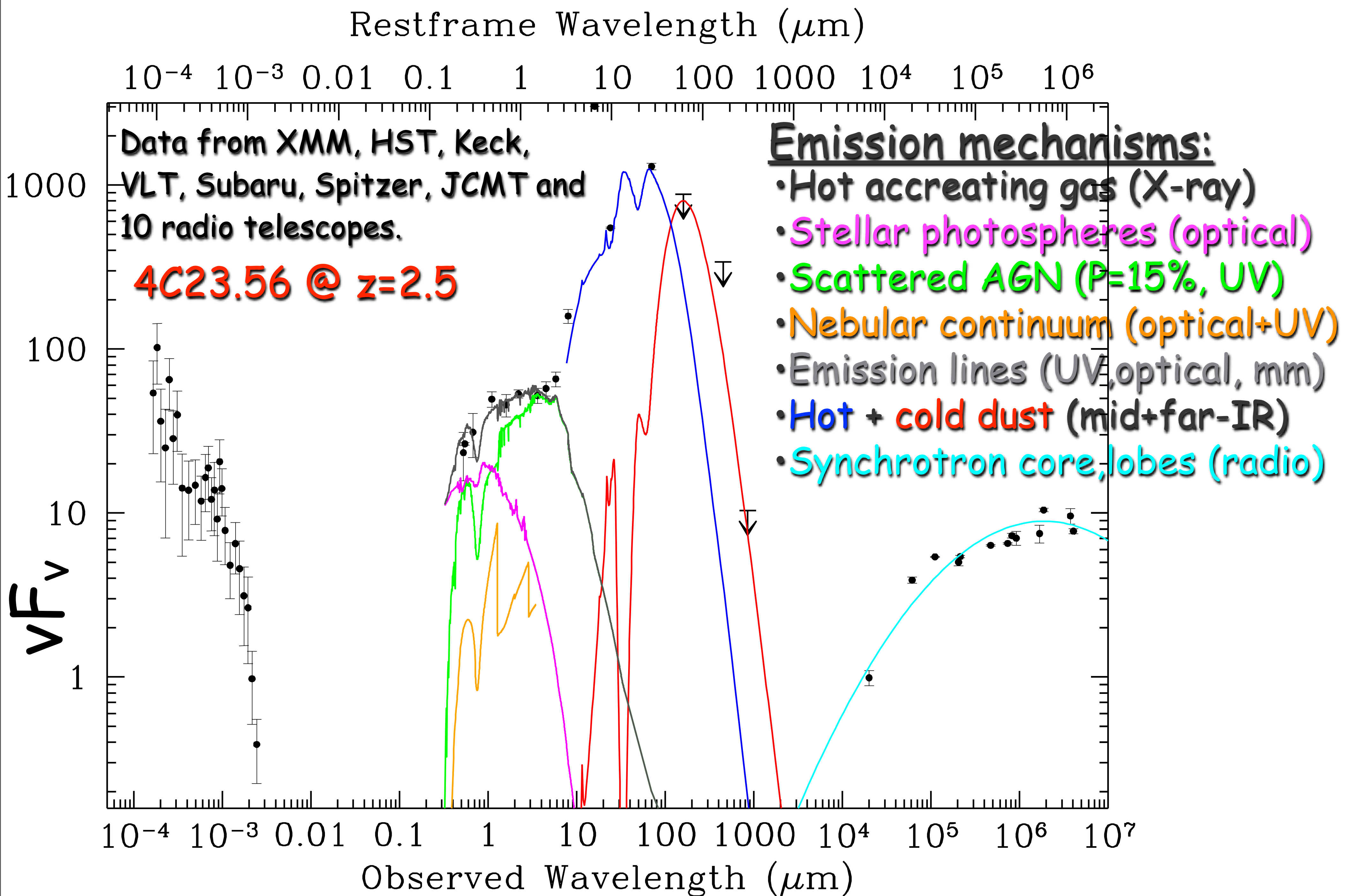
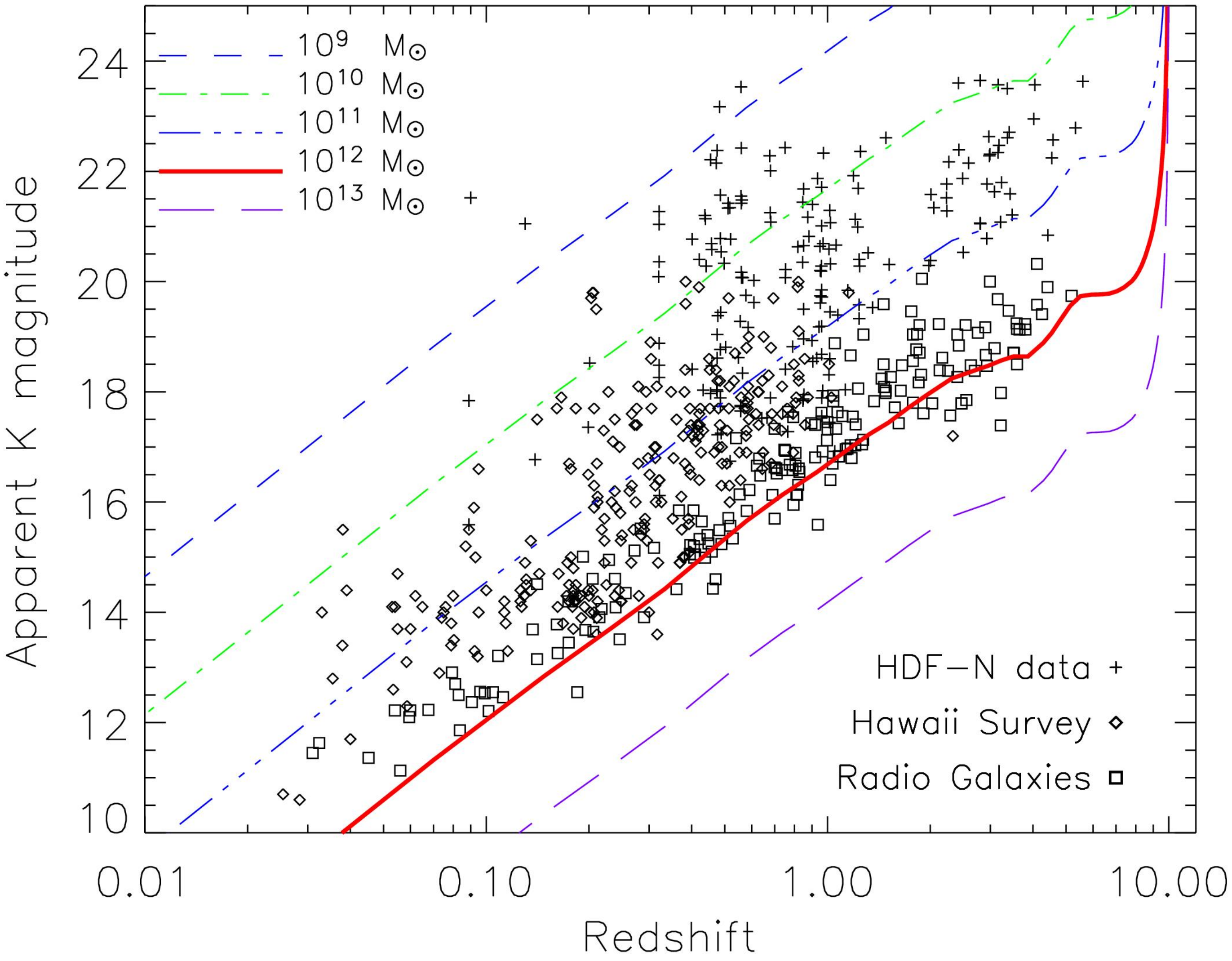
AGN and stellar emission in radio galaxies



AGN and stellar emission in radio galaxies



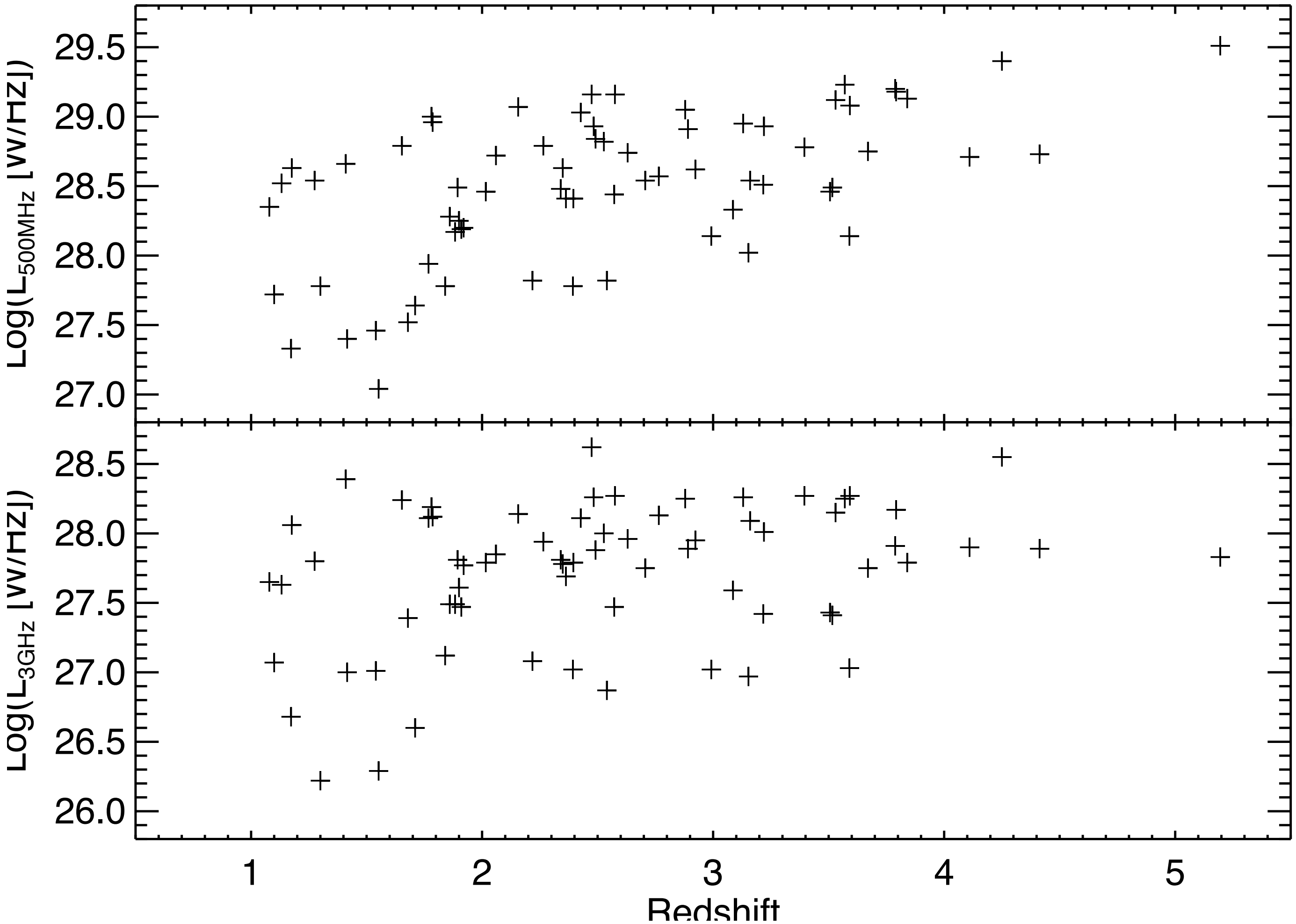
Stellar masses of HzRGs pre-Spitzer



- Remarkably tight correlation between observed K-band magnitude and redshift.
- Suggests masses up to 10^{12} M_{Sun}.
- Large k-corrections.
- AGN contributions.

Rocca-Volmerange et al 2004

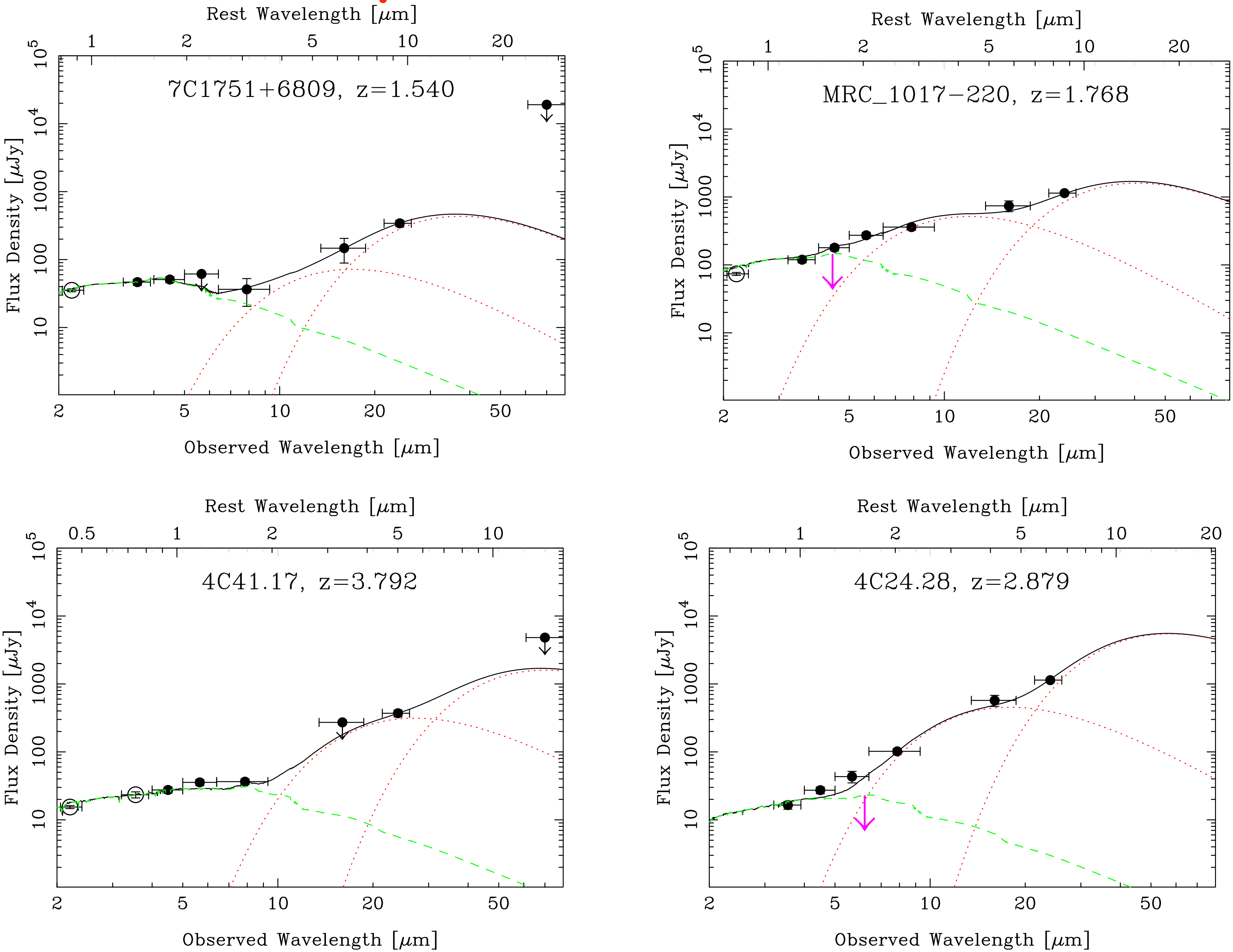
Spitzer sample of 70 radio galaxies



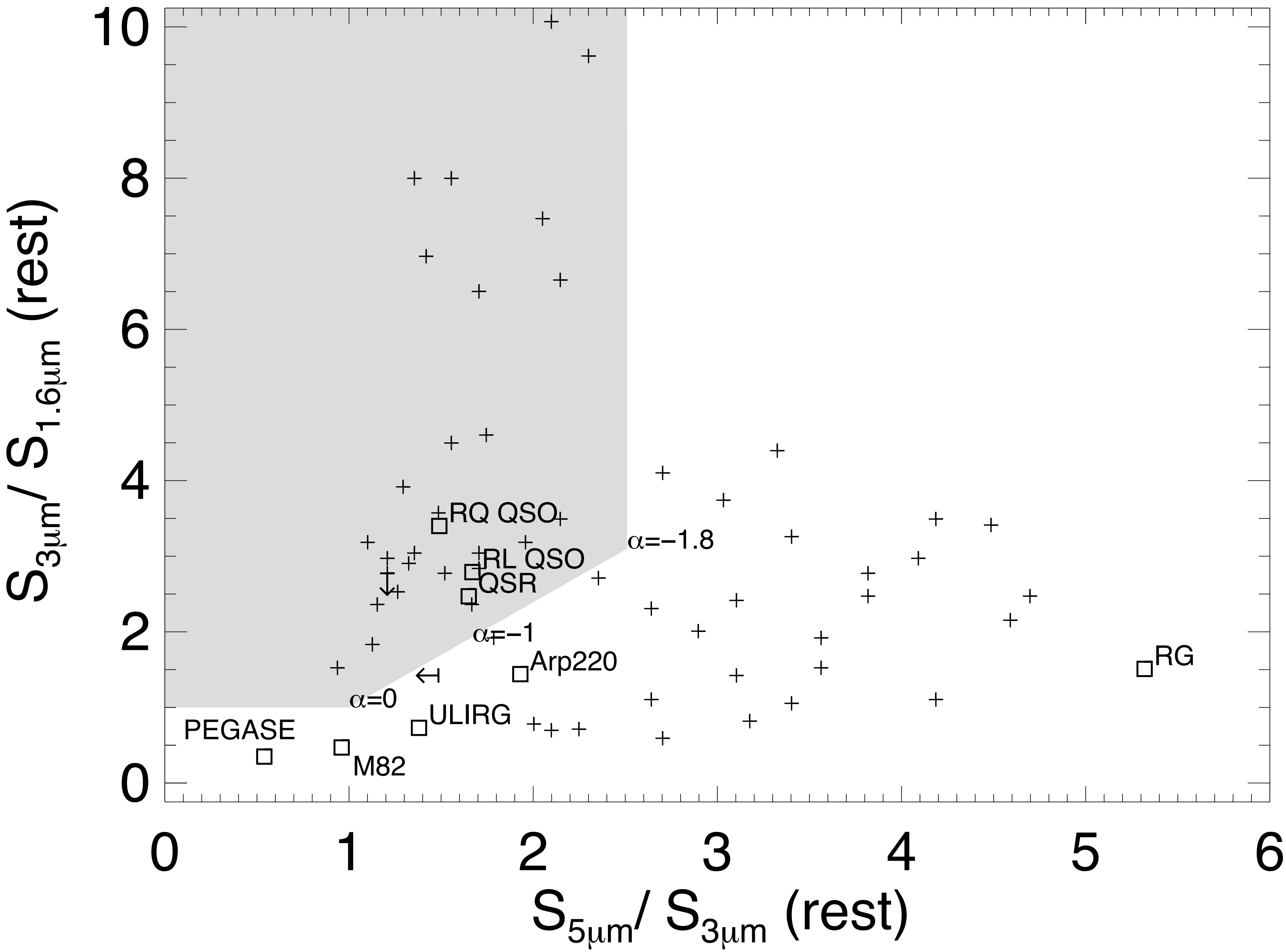
- Selected on mostly isotropic 500 MHz luminosity (midpoint VLSS & NVSS).
- Uniform coverage 1<z<5.
- Maximum amount of supporting data.
- Observed with IRAC, IRS & MIPS.

Full 3.6, 4.5, 5.8, 8.0, 16 and 24 μm photometry on all 70 targets.
Herschel 70/100, 160, 200, 350 and 500 μm (see N. Seymour's talk)

Examples of mid-IR SEDs

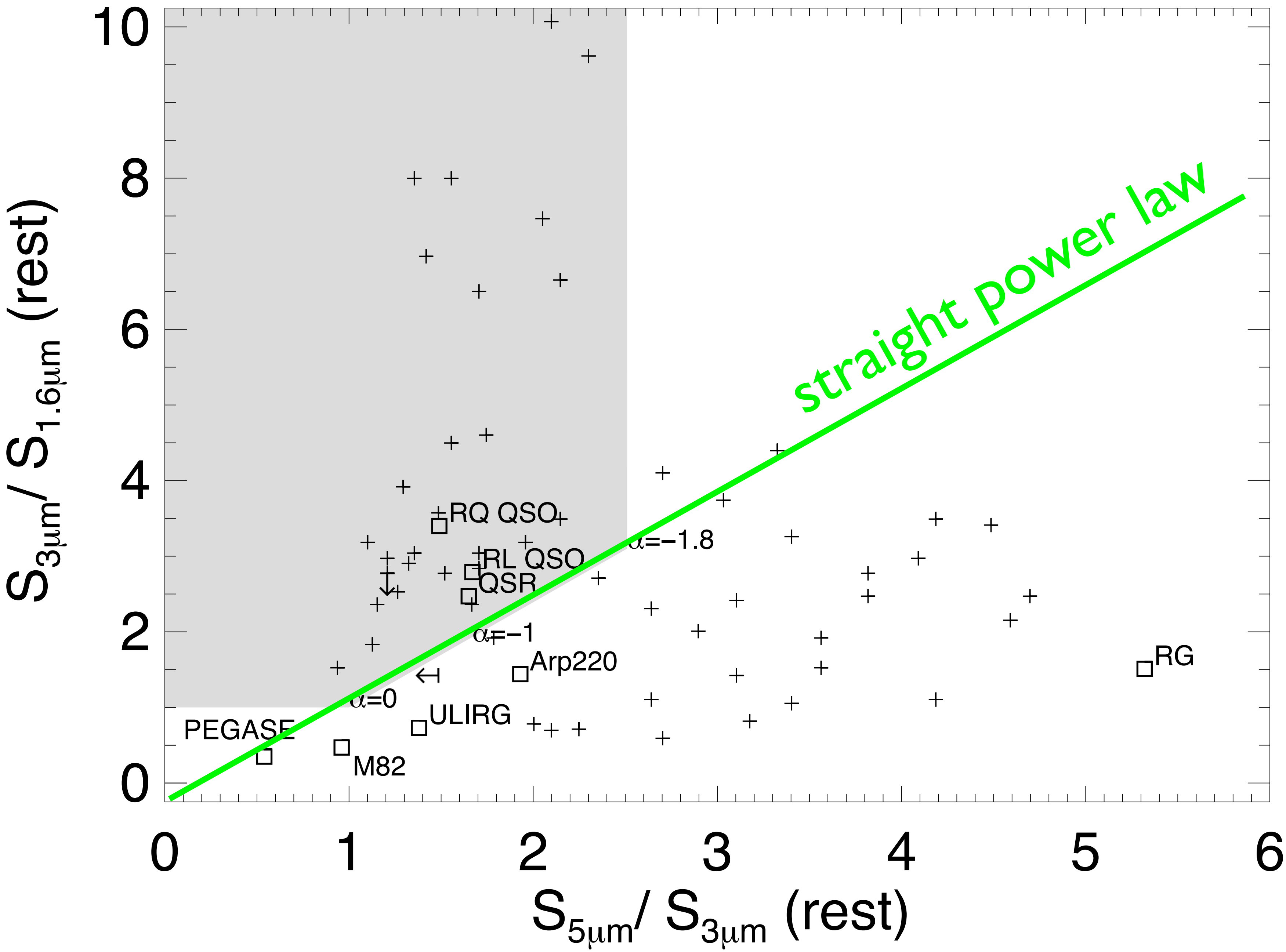


Identifying dust-dominated SEDs



Restframe color criterion to allow uniform selection at 1<z<5.

Identifying dust-dominated SEDs



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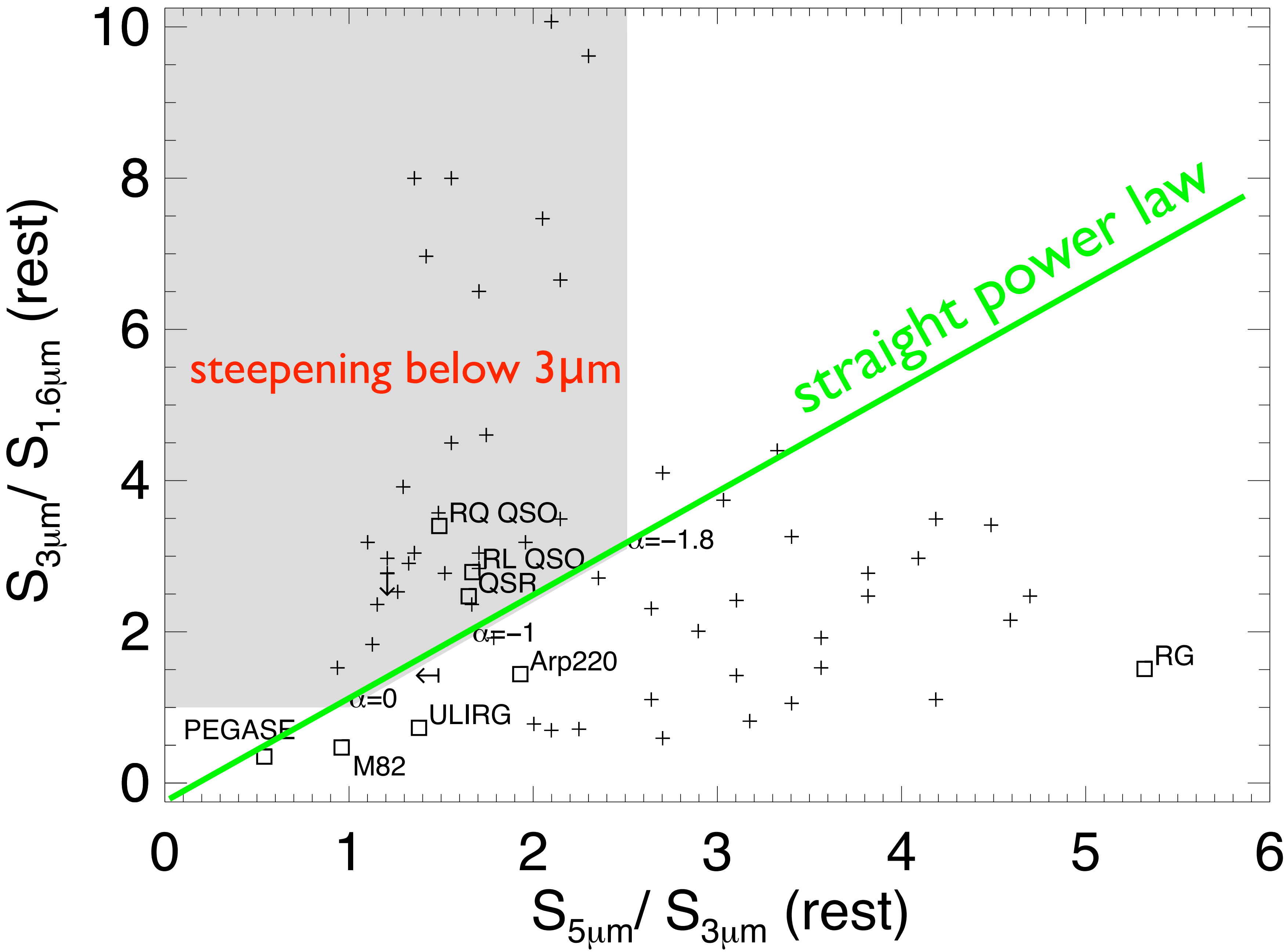

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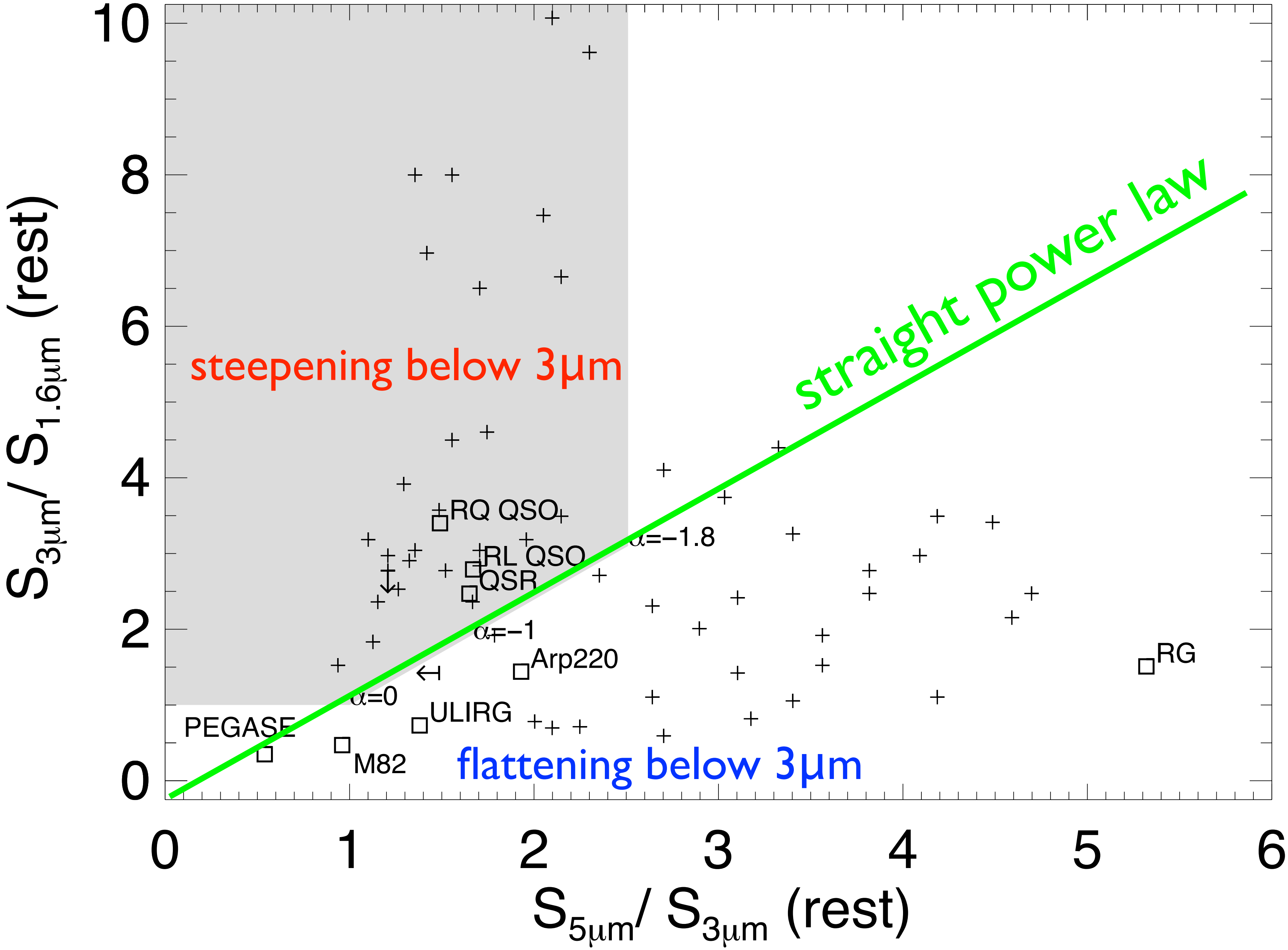

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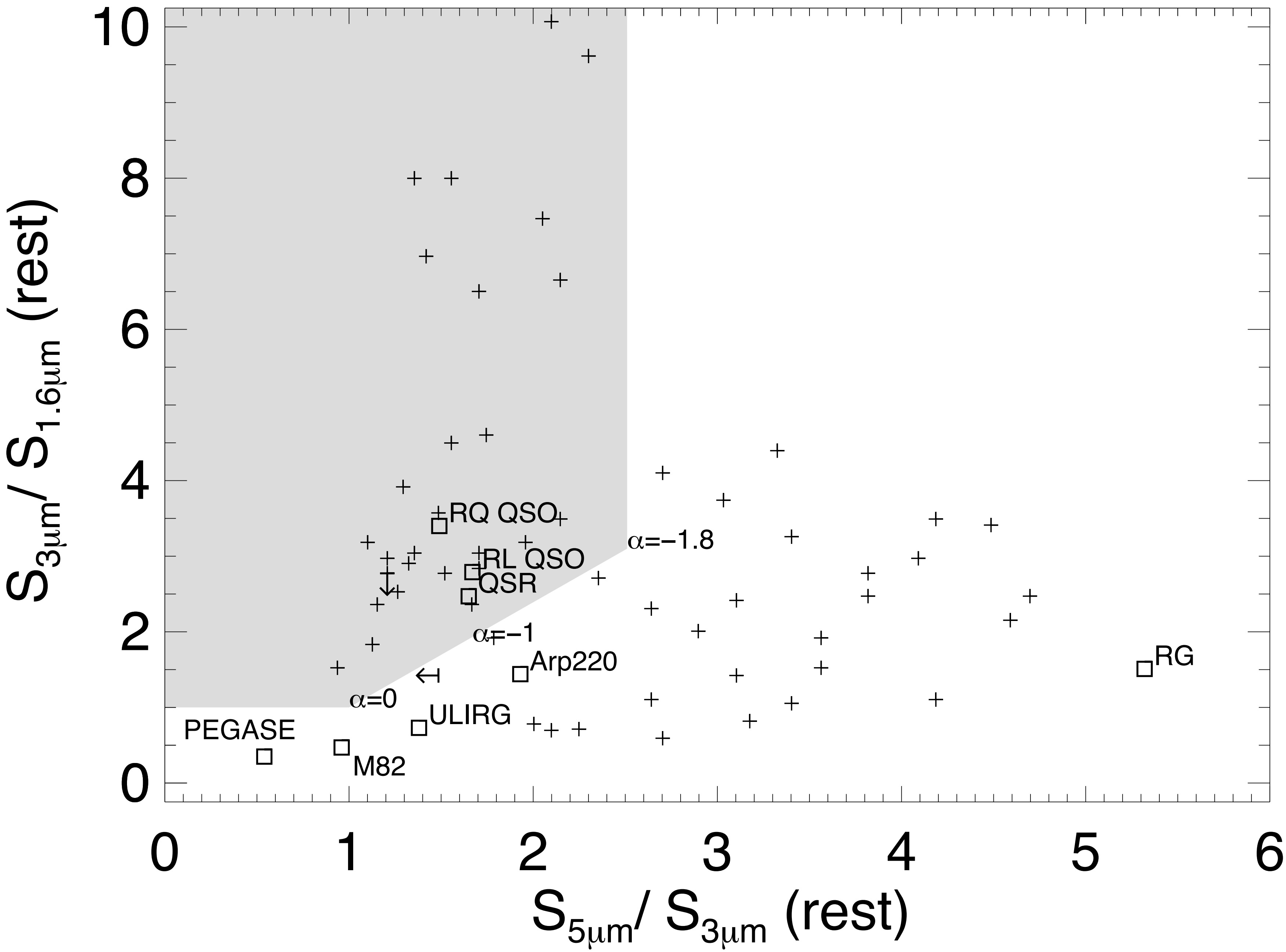

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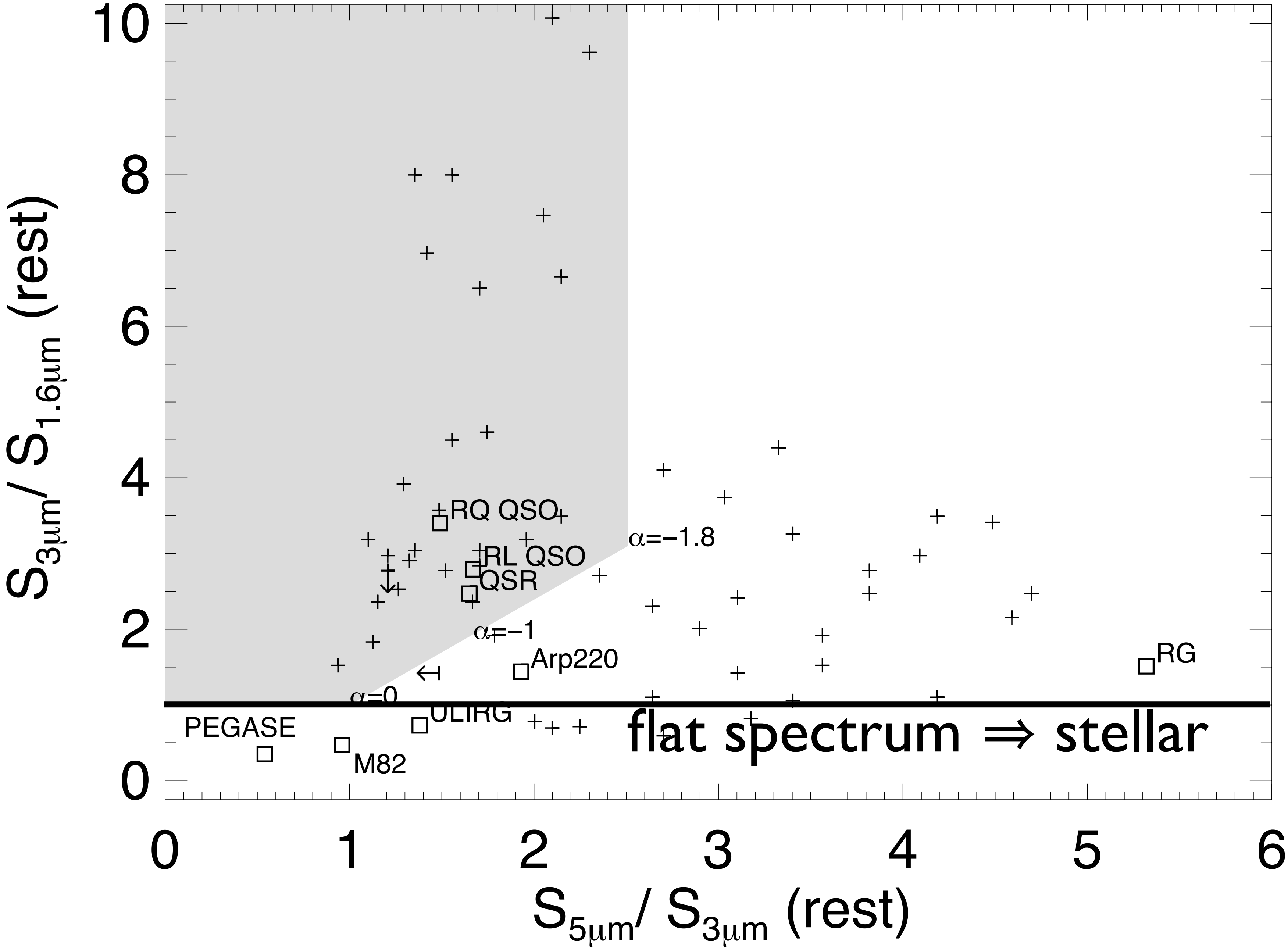
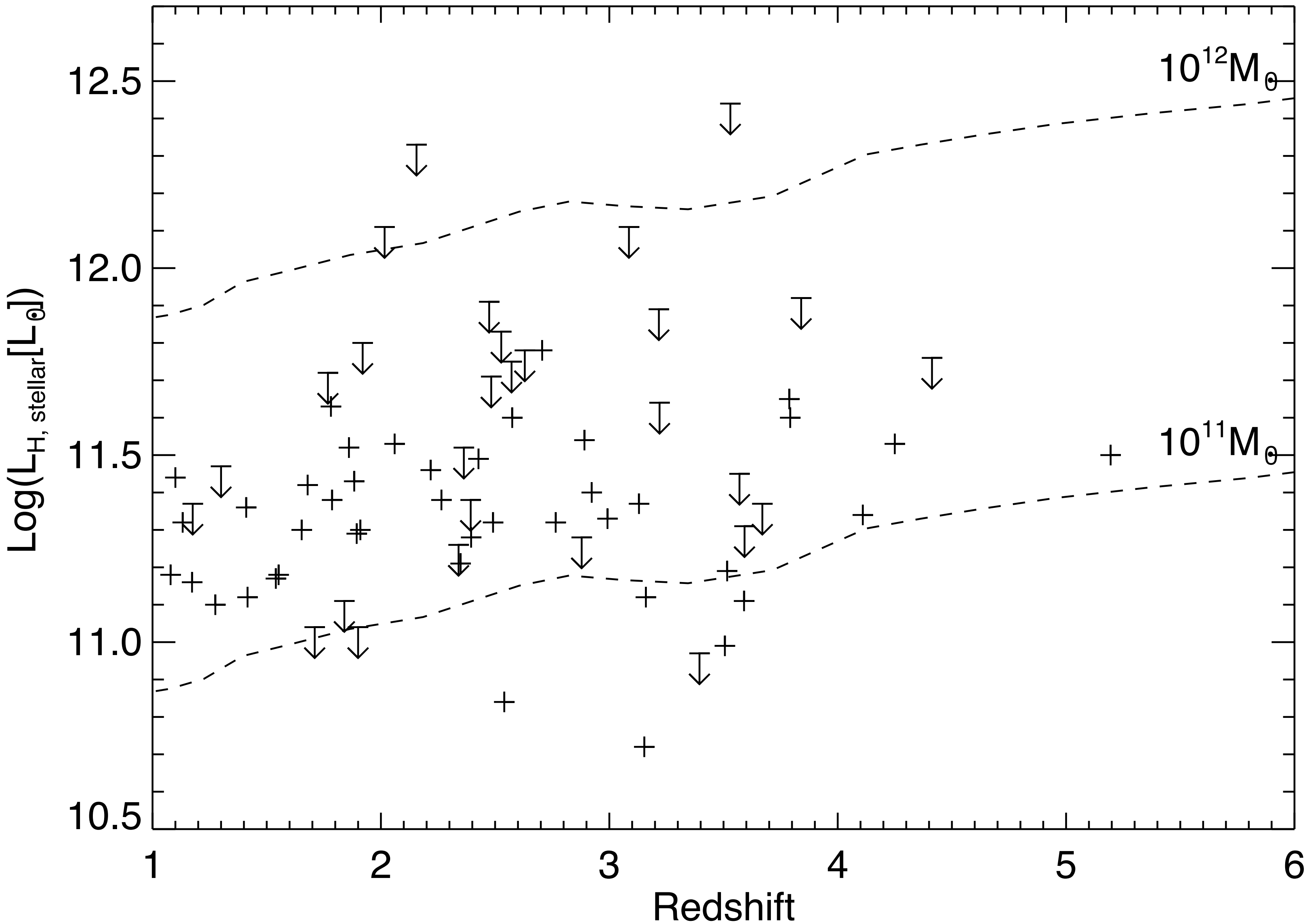


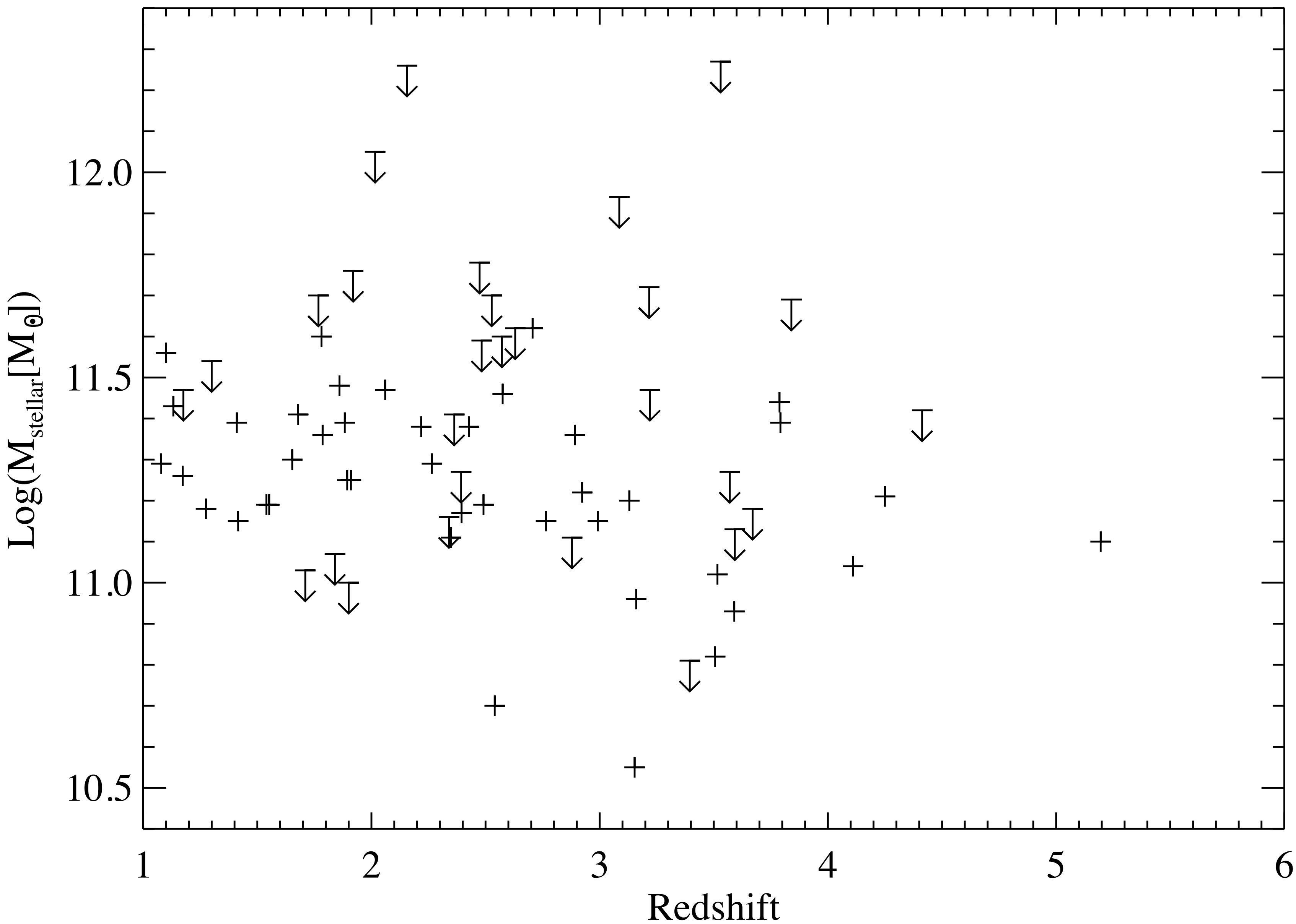
Restframe color criterion to allow uniform selection at 1<z<5.

Restframe H-z diagram



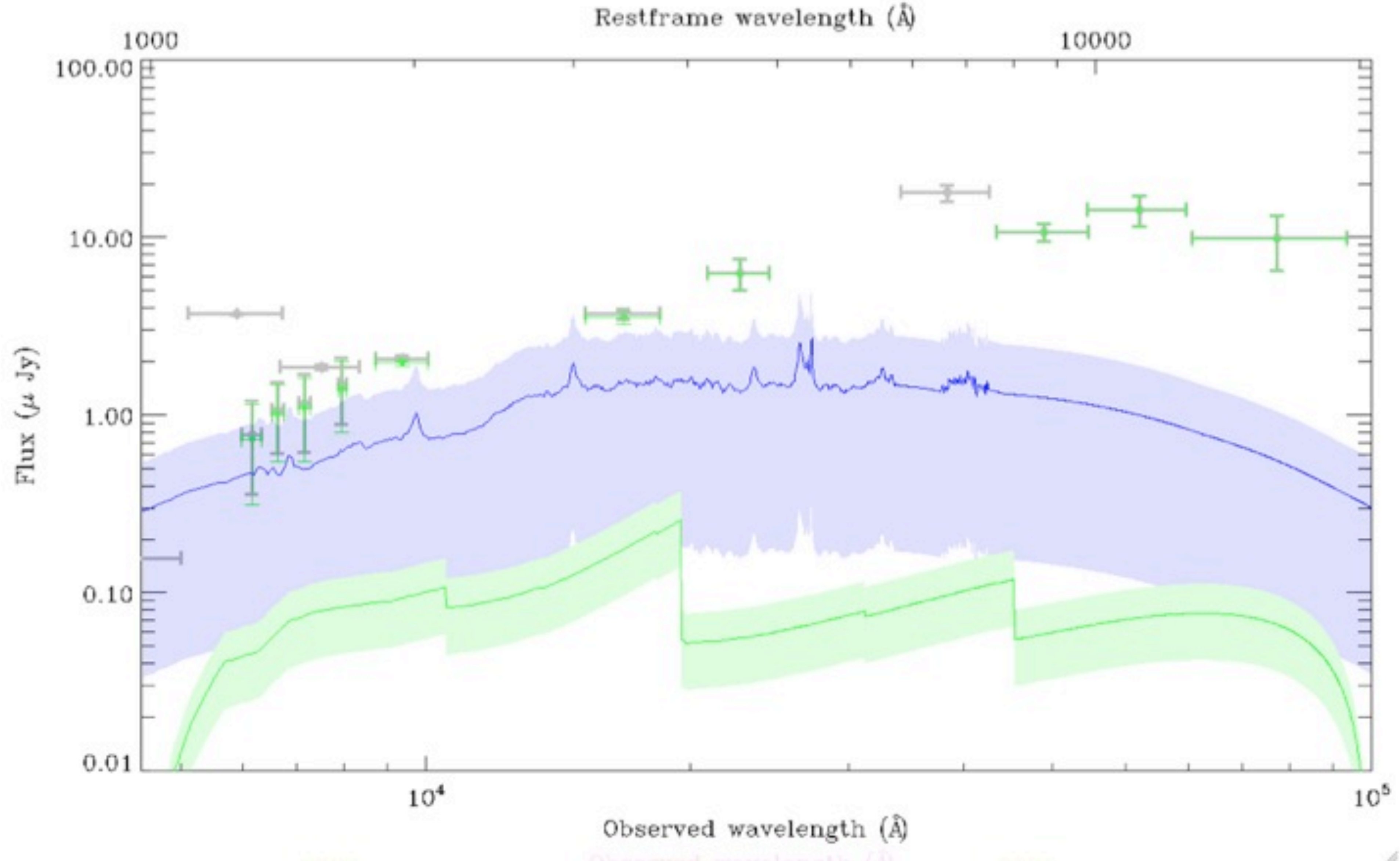
- Majority of RGs have masses of order 2-3x10^{11} M_{sun}
- Suggestion of lower mass at z>3?

Stellar mass evolution?



- Factor of 2 decrease in stellar mass at z>3?

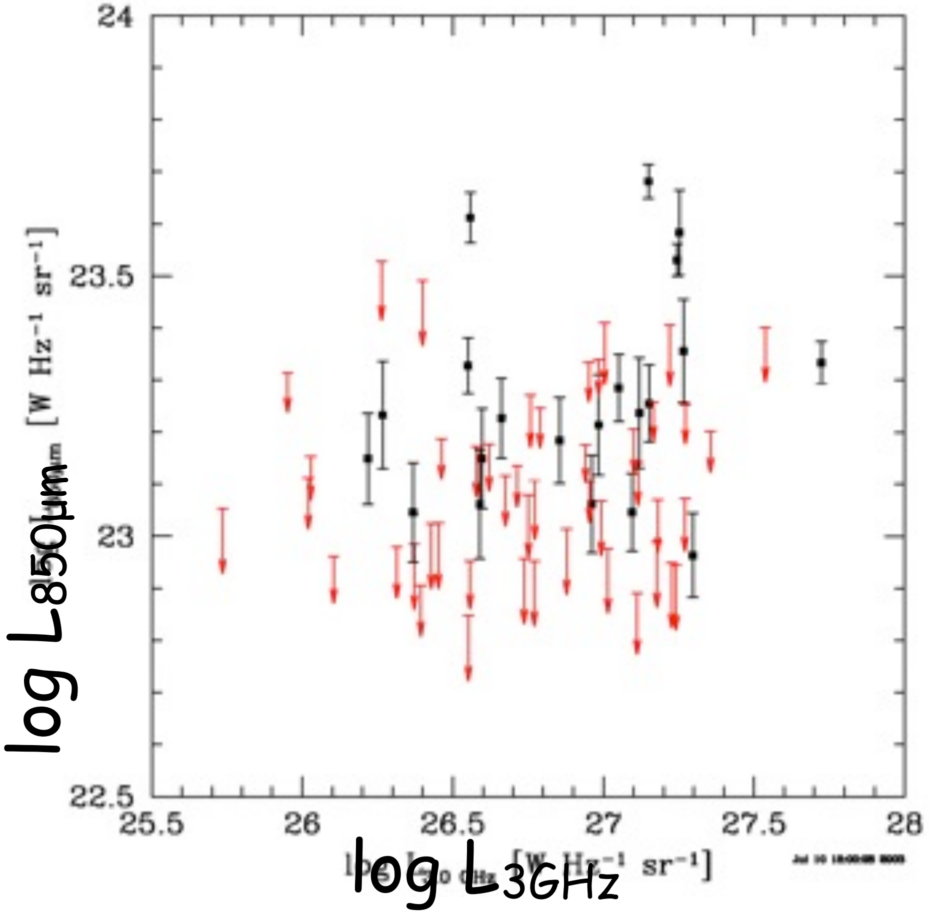
More elaborate SED decompositions

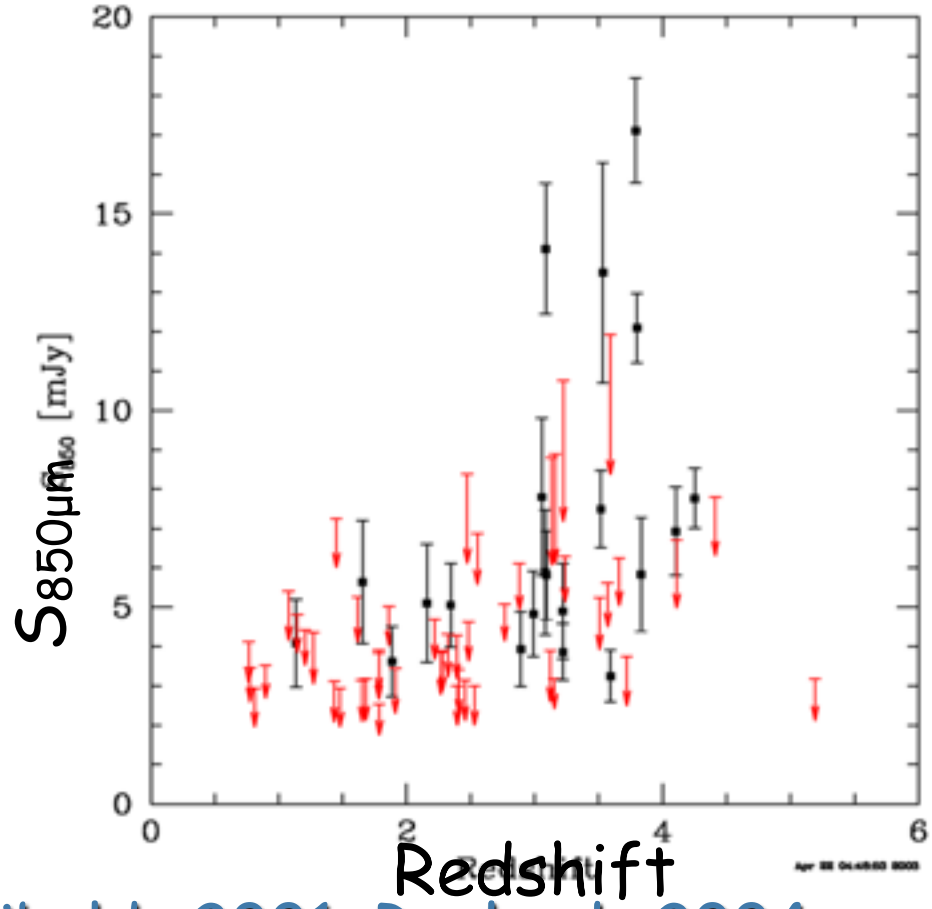


- Correct for scattered QSO, nebular continuum, em. lines.
- PhD work of Guillaume Drouart (ESO/IAP).

Indications for higher SFR at z>3

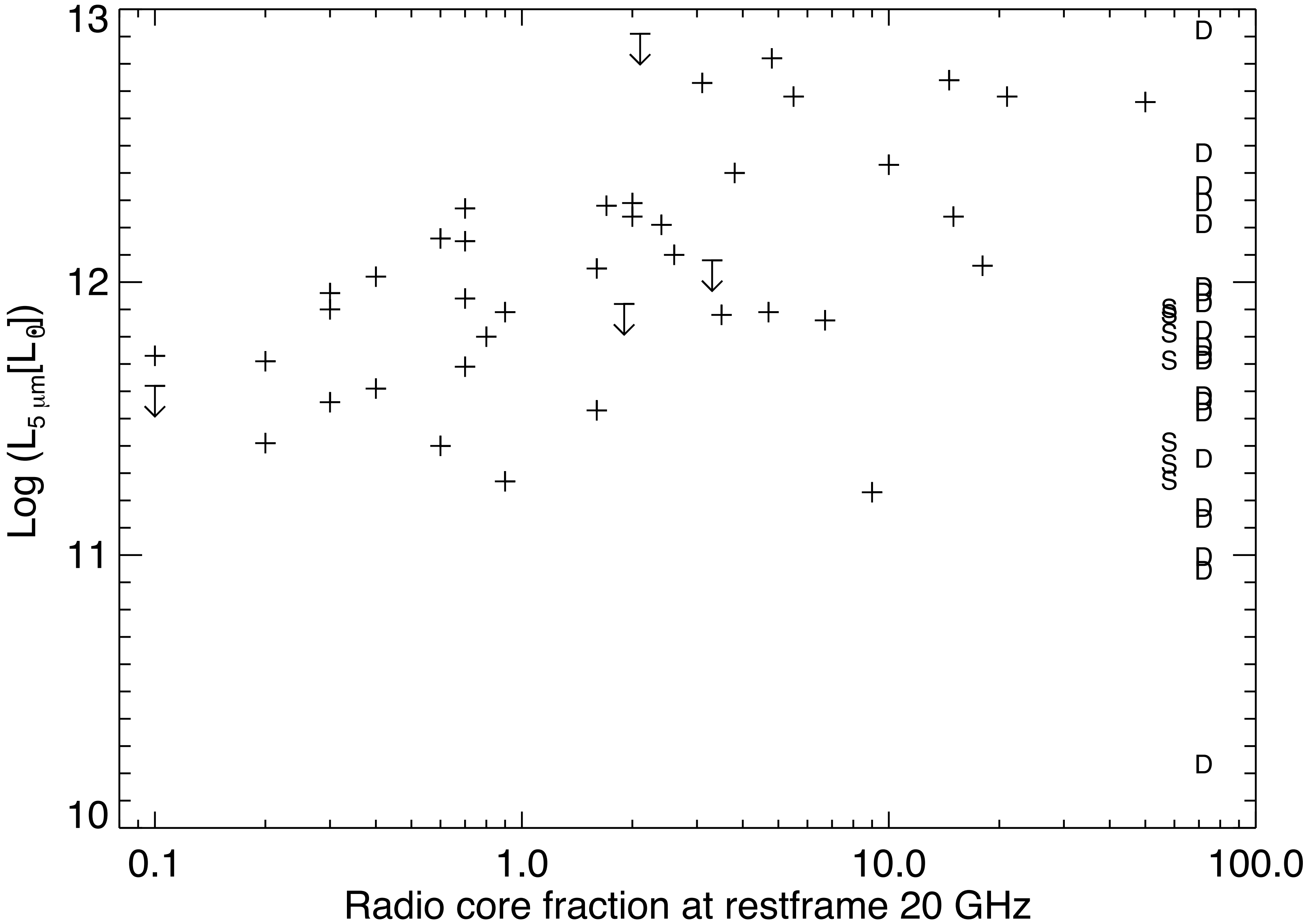
- $S_{850\mu m} \rightarrow$ SFR increase with redshift at least until z~4.
- $L_{FIR} \sim 10^{13}\ L_{Sun} \rightarrow$ SFR ~ 1500 M_{Sun}/yr.
- Needs Herschel to better isolate AGN from stellar far-IR.





Archibald+ 2001, Reuland+ 2004

Orientation effects on hot dust emission



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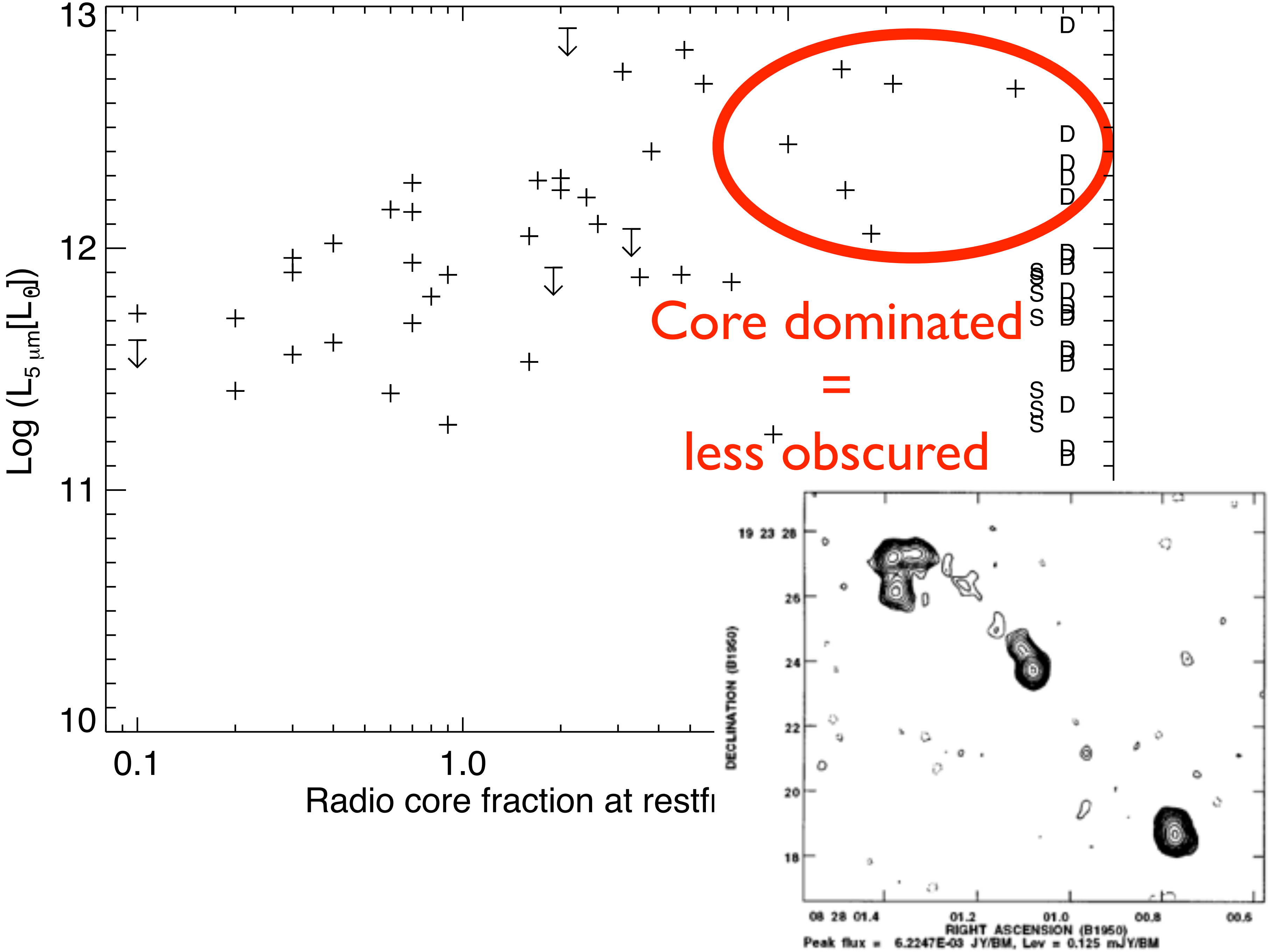
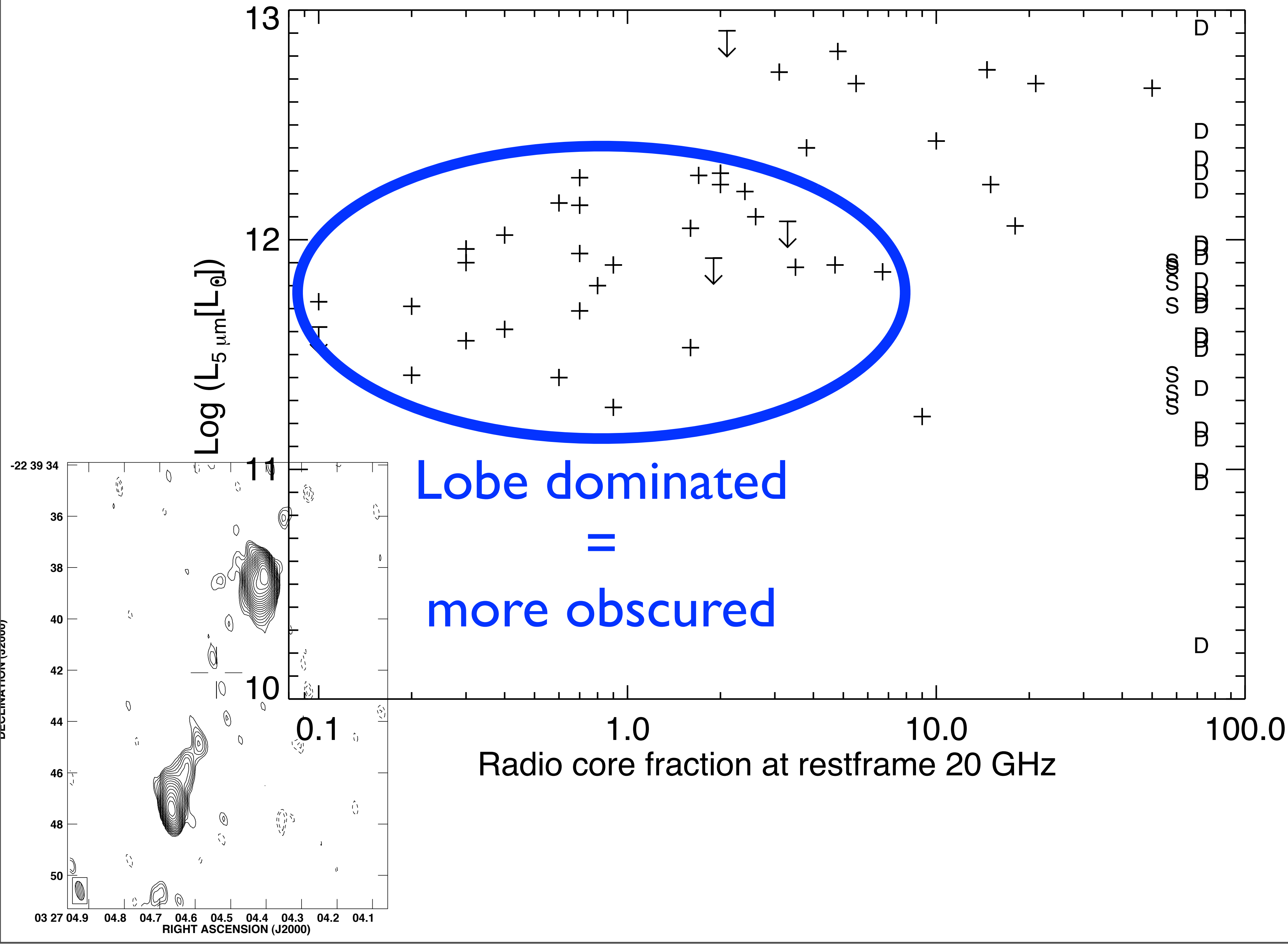
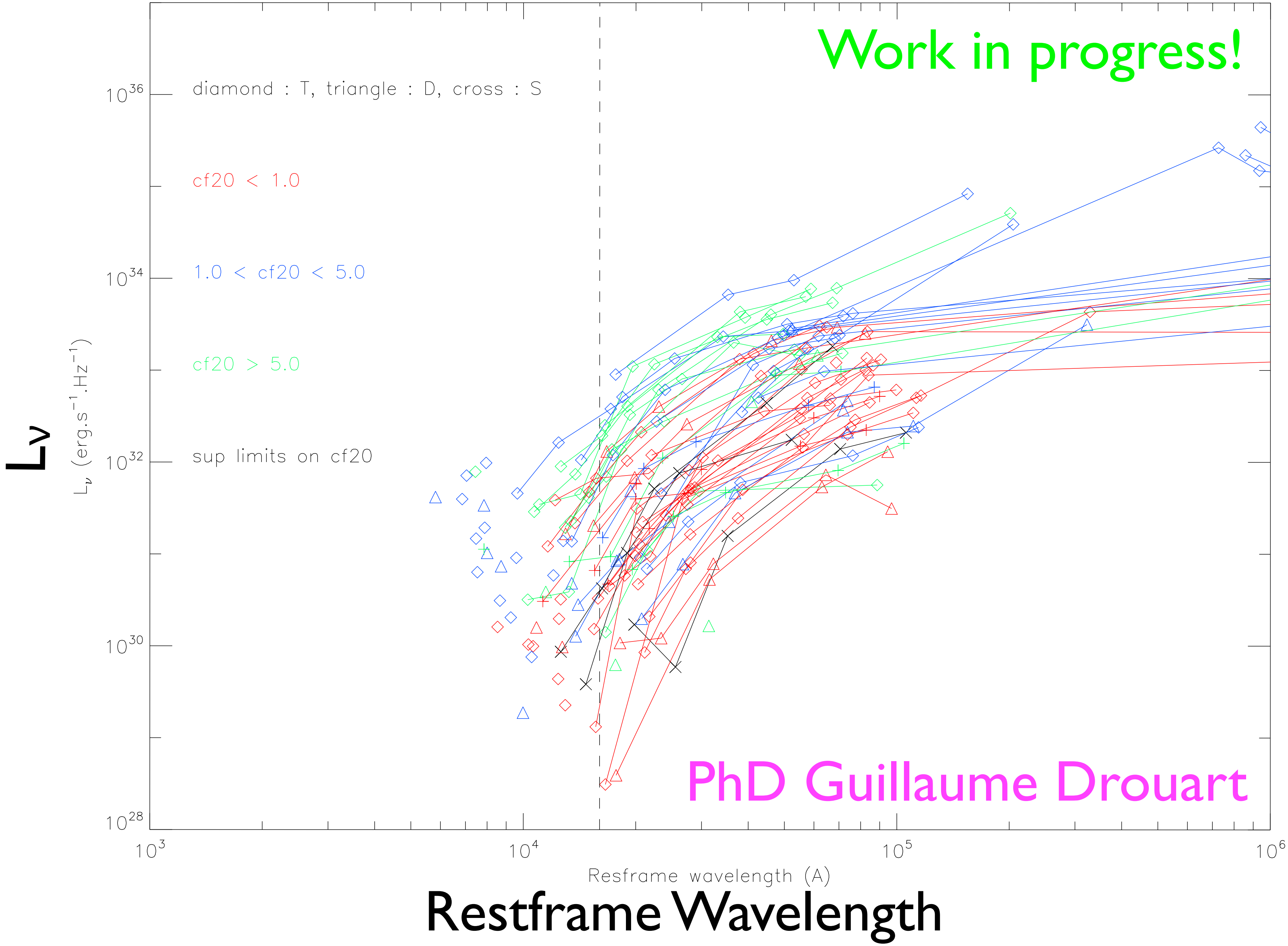


Orientation effects on hot dust emission

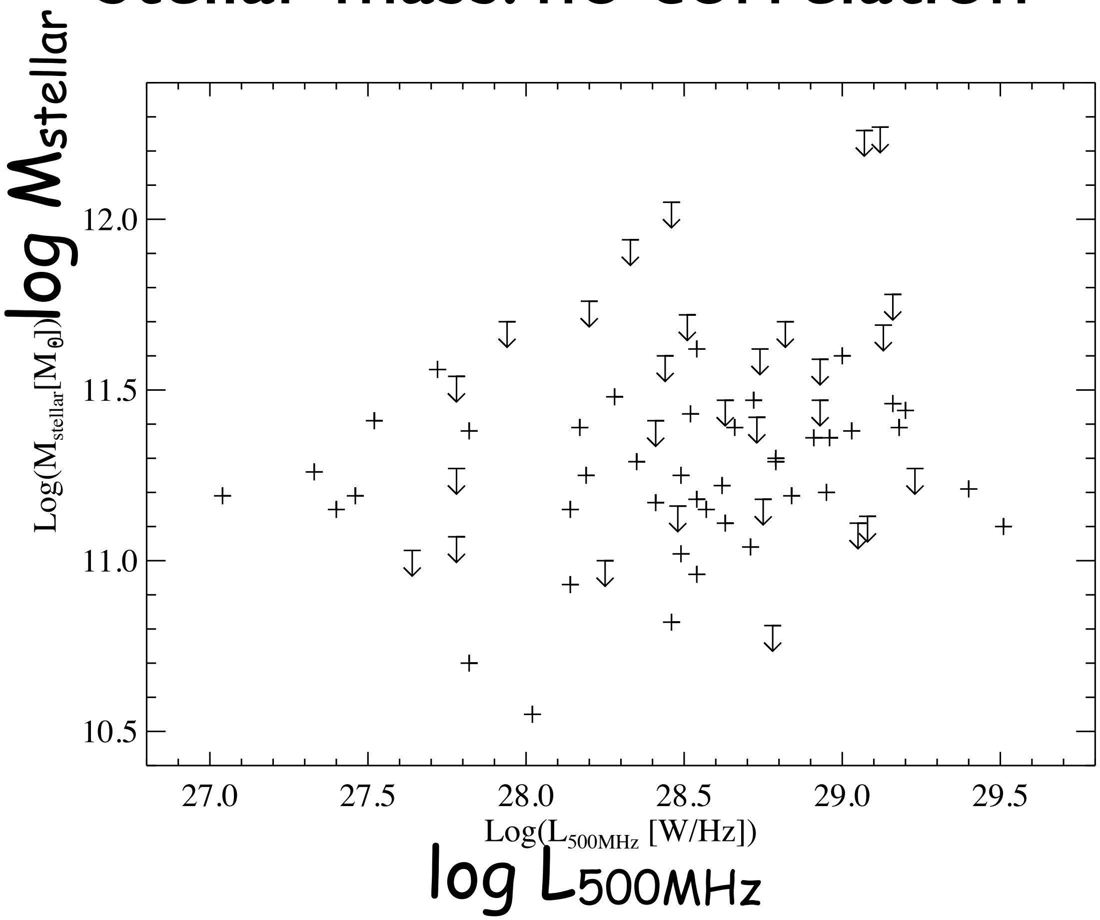


Tdust / extinction correlated with orientation?

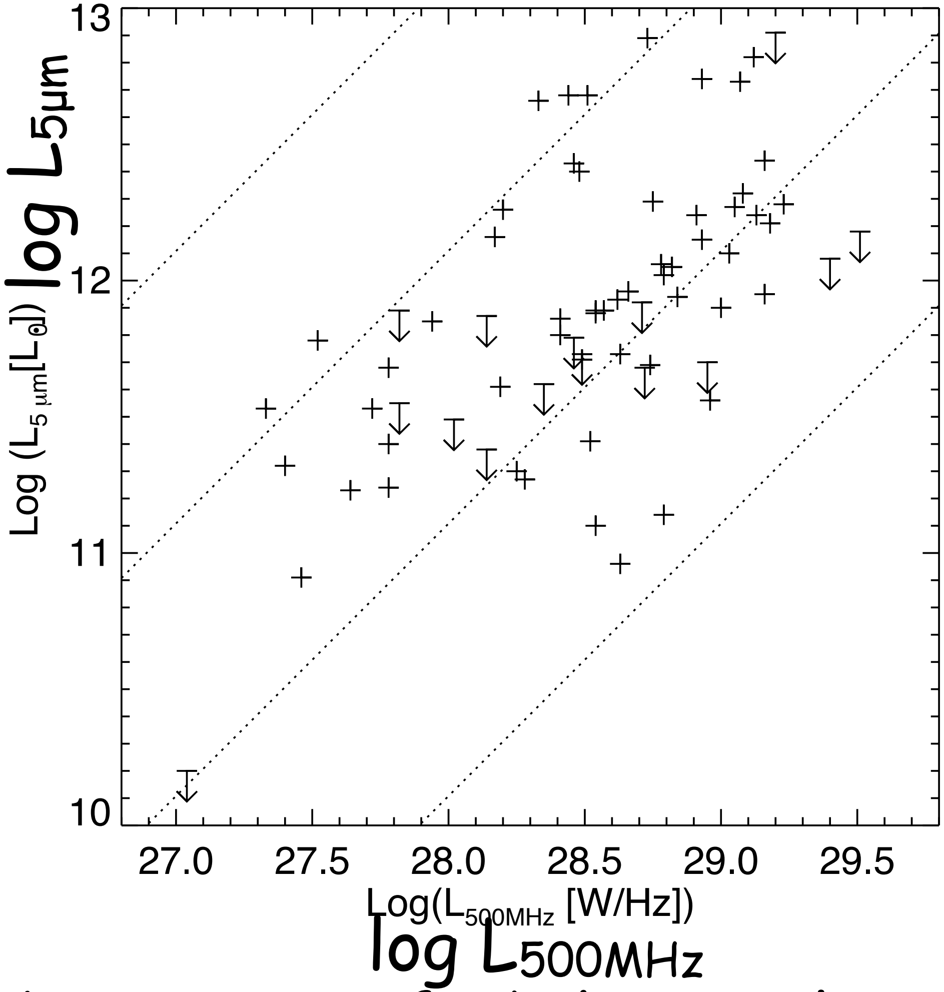


Radio luminosity as a measure of AGN power

Stellar mass: no correlation



AGN heated dust



- Radio source seems not to care about mass of it's host galaxy.
- Despite orientation effects, hot dust strongly correlated.
- Suggests variations in Eddington accretion rate on SMBH may drive both radio source and hot dust emission.

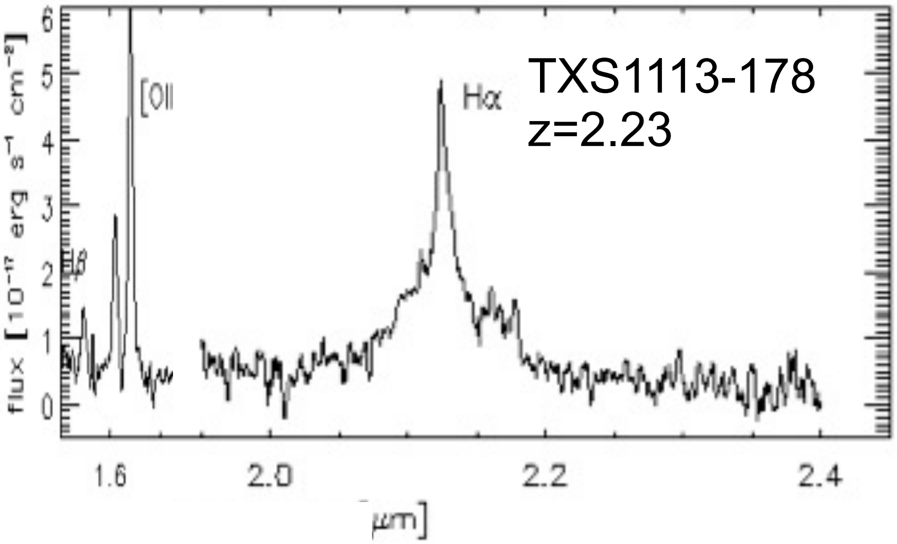
Why radio galaxies are ideal laboratories to study AGN feedback

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.

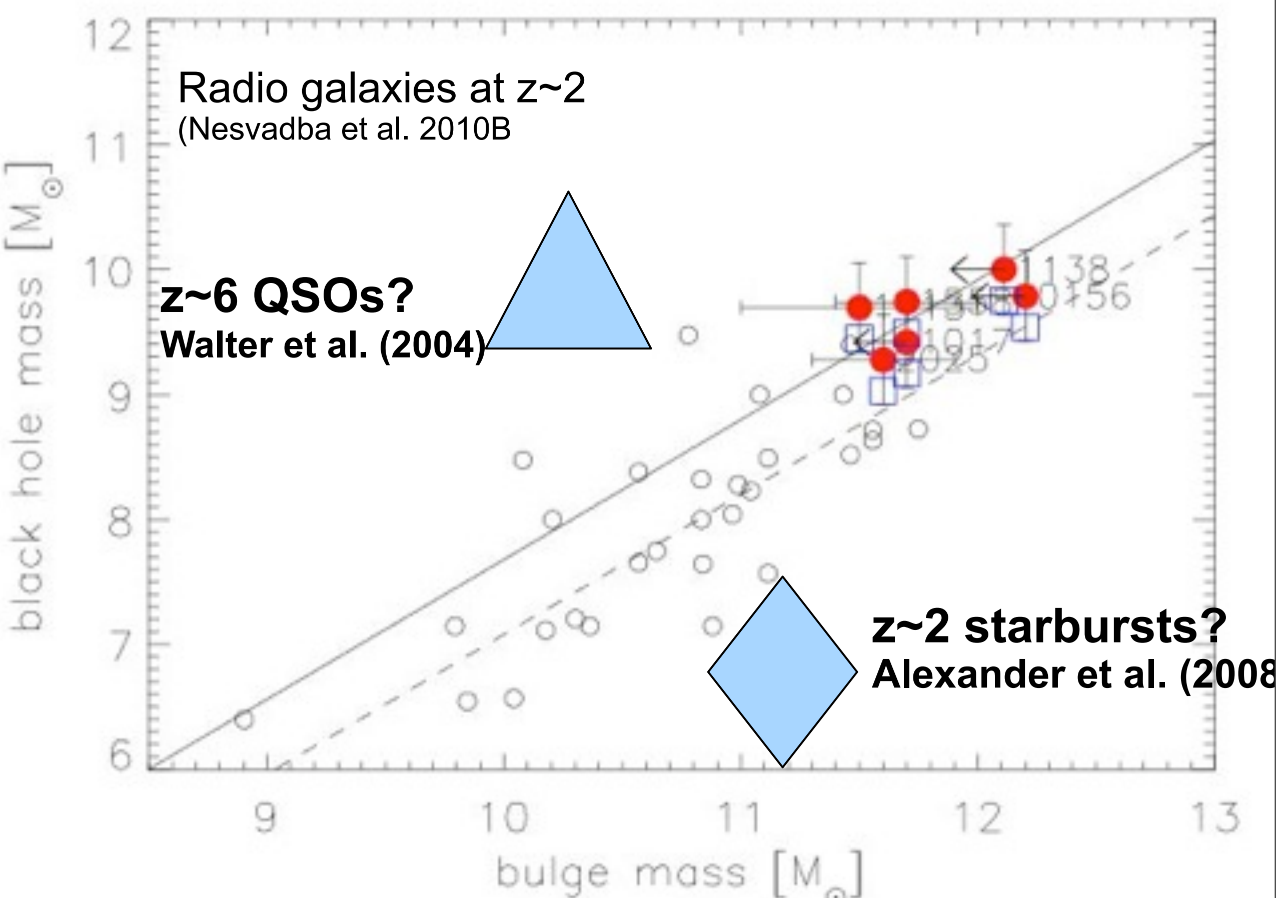
• 20% of z>2 RGs show nuclear broad-line regions in our IFU data.

• M_{BH} a few 10^9 M_{Sun} (higher inclination may half M_{BH})

• Appears slightly offset from local M_{bulge} - M_{BH} relation.

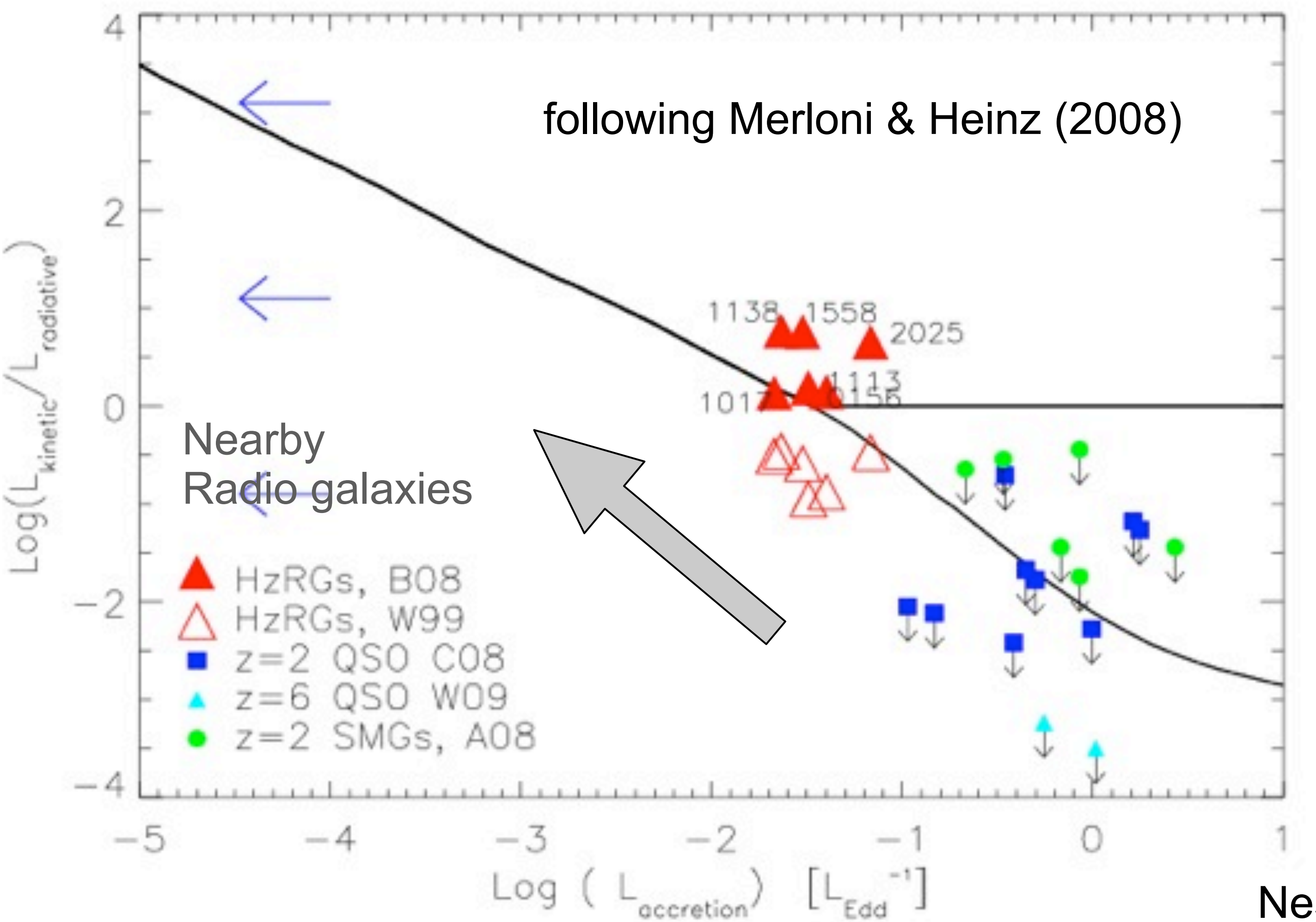
• Bolometric luminosity at few % Eddington, lower than other populations with similar M_{BH}

→ 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 feedback marks the end of the phase of active growth.



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*** →

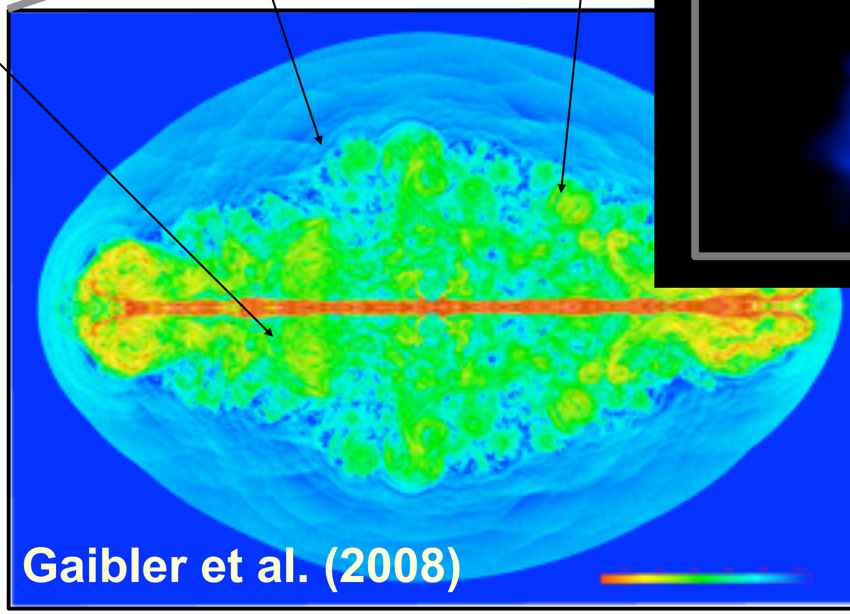
embedded cold/ warm clouds
molecular, atomic, T~10-10^4 K

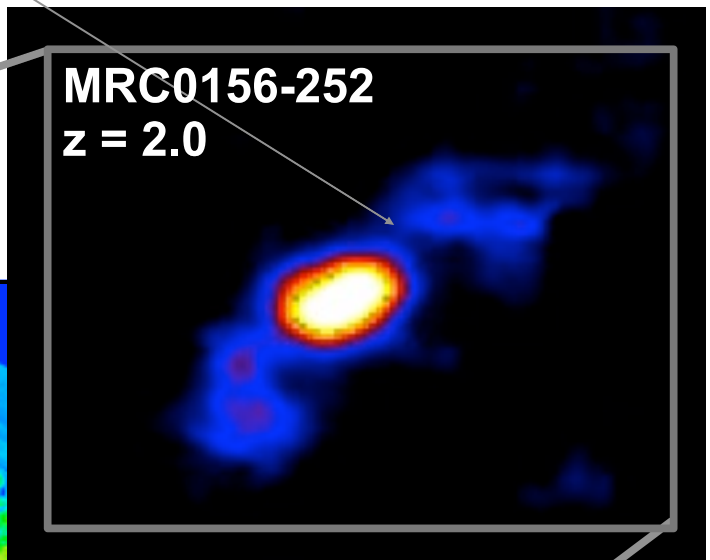
→ ????

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

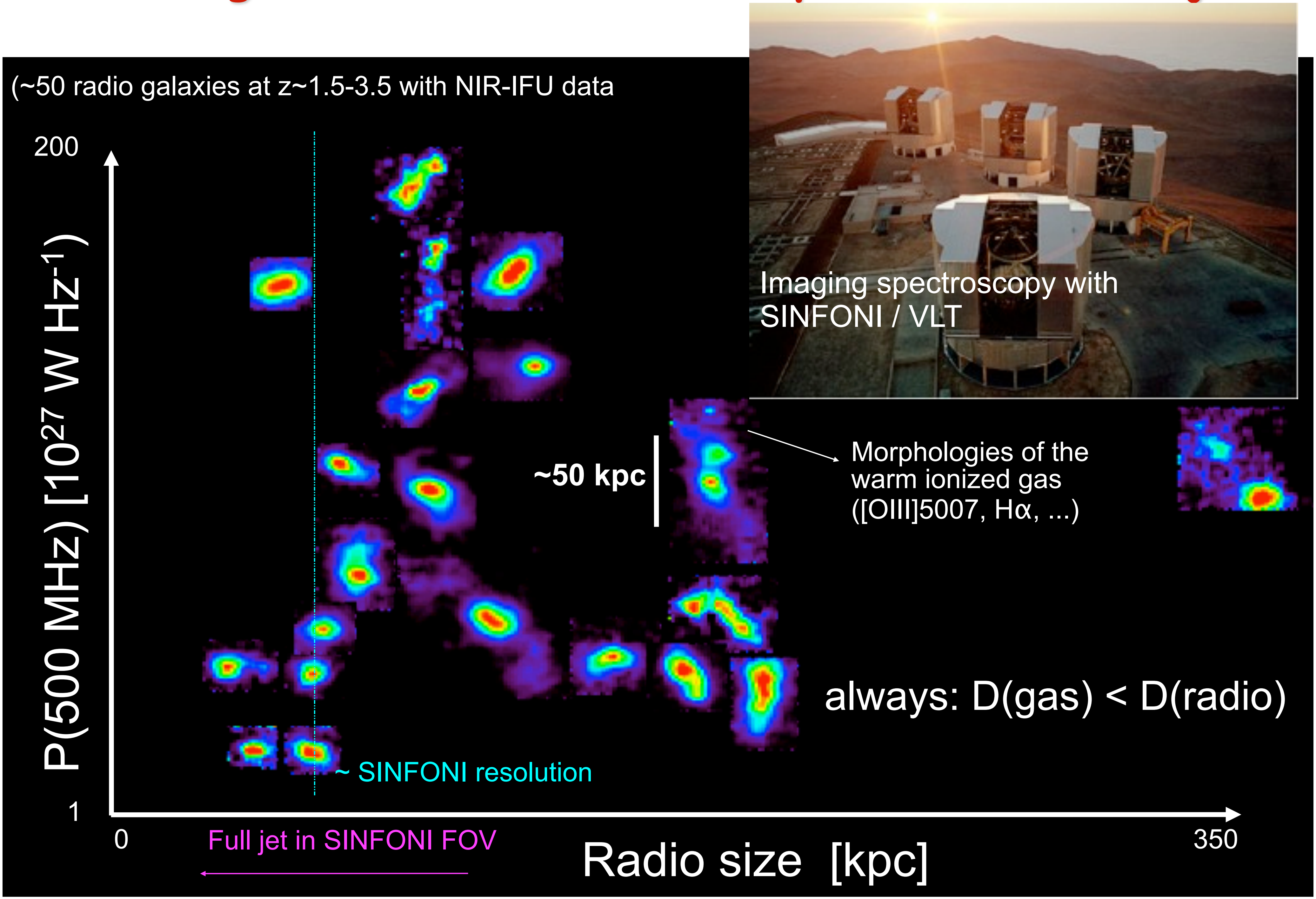
strongest interactions w/ young radio sources
(e.g., Holt et al. 2008)

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



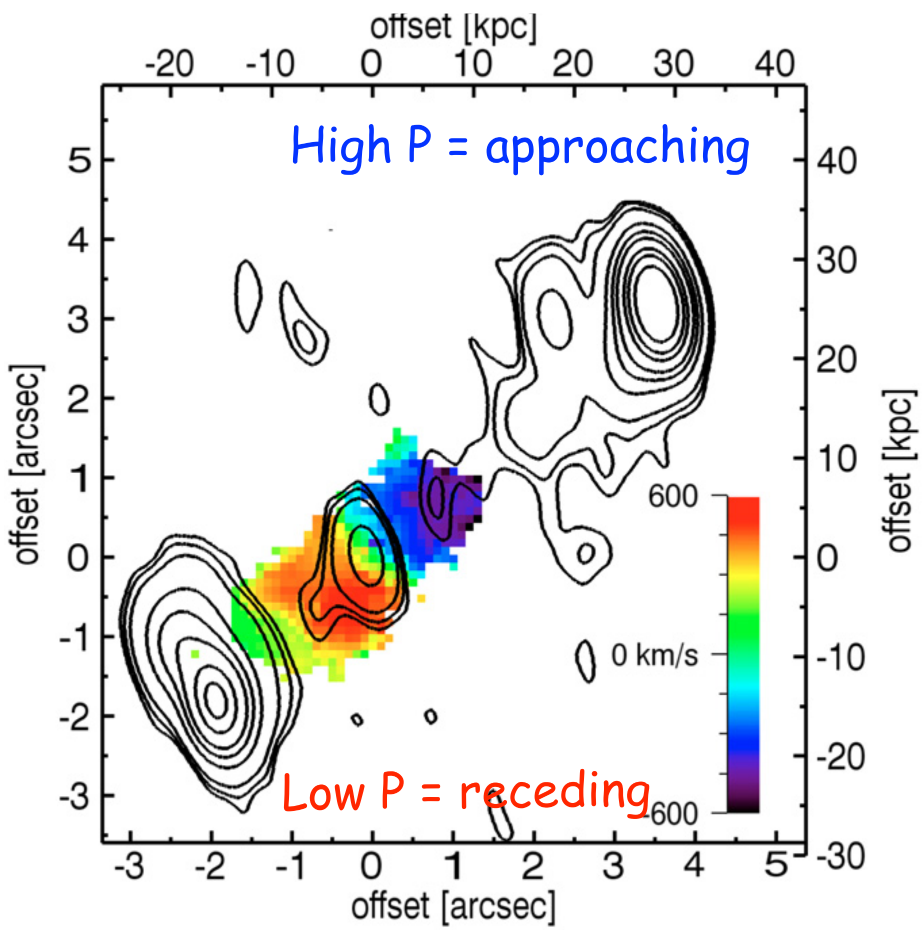


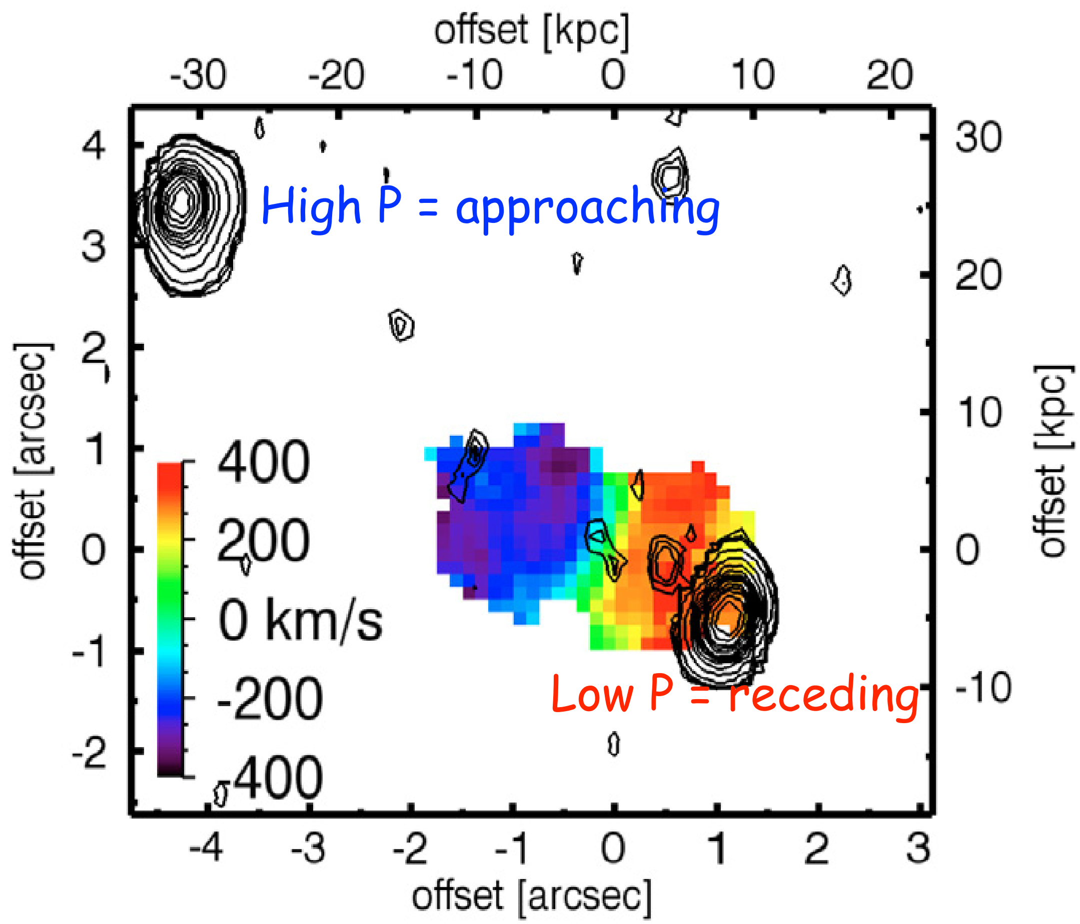
Ionized gas halos with sizes comparable to radio jets



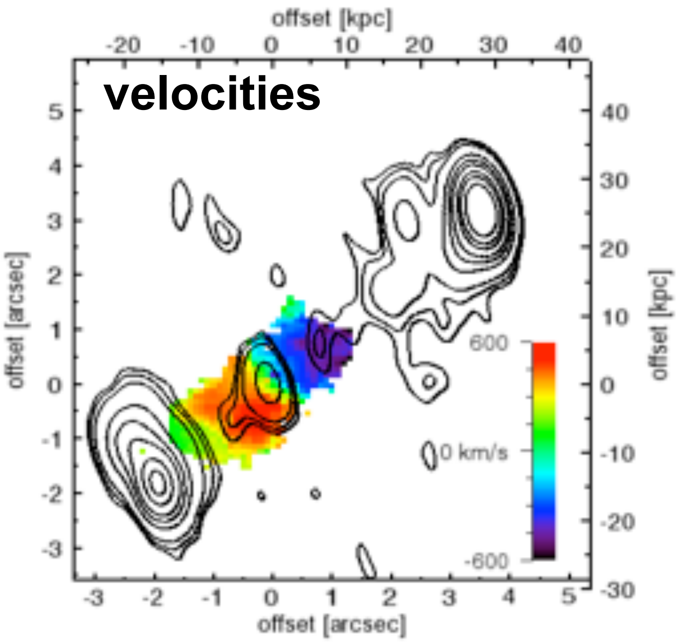
Are these really outflows?

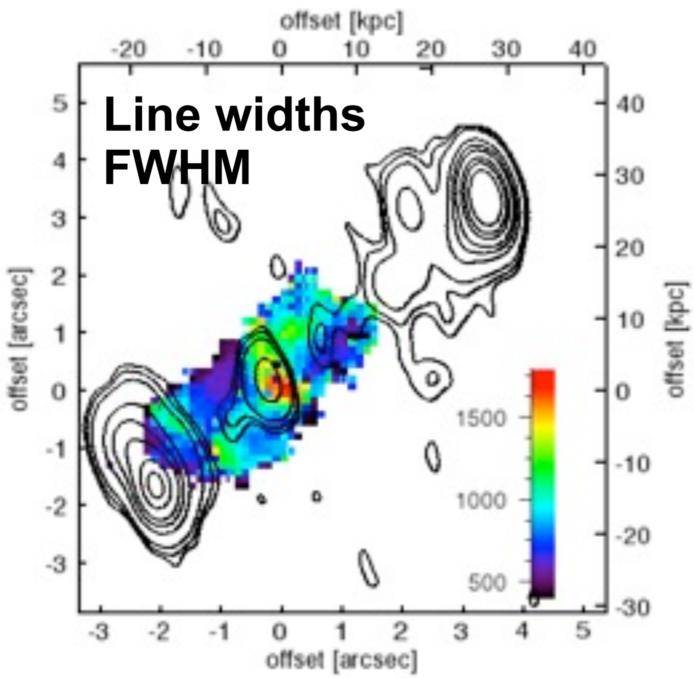
- Laing-Garrington effect: most depolarised radio lobe is receding as it passes through longer line-of sight.
- Consistently indicate bipolar outflows with velocity offsets ~ 1000 km/s and V~1000 km/s (too large for rotation).





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

Summary

- High z radio galaxies have a mix of AGN and stellar emission over a large range of wavelengths.
- They have massive host galaxies, 2-3x10^{11} M_{Sun}, with tentative evidence for lower masses at z>3.
- There is a gradual change from unobscured (type 1) to obscured (type 2) AGN, as seen from radio core fraction and hot dust emission.
- Radio power and hot dust emission are strongly correlated, suggesting that Eddington accretion rate drives both of them.
- HzRG have M_{BH} close to the M_{BH}-M_{bulge} relation ⇒ need strong feedback process to stop accretion: powerful radio AGN.
- 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.