Hercules A (z=0.154): HST and JVLA image

The 2Jy Sample
of southern radio galaxies

An infrared perspective on powerful radio galaxies in the local universe

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Why study radio galaxies in the infrared?

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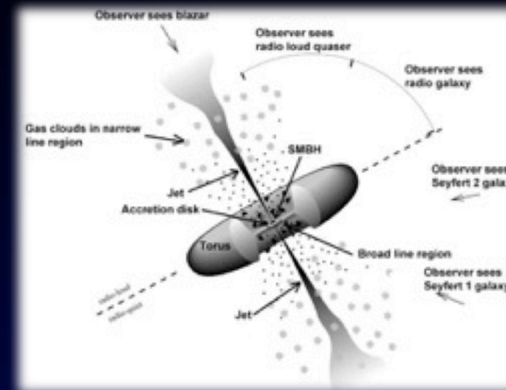
Testing unification schemes

- Less obscuration
- Isotropic emission



Star formation

- Dust heating mechanism
- Mid-infrared spectral diagnostics
- Galaxy evolution

Dust and cool ISM masses

- AGN triggering
- Mergers

The 2Jy infrared sample

The 2Jy Sample
of southern radio galaxies

- 46 steep spectrum selected radio galaxies + quasars
- Radio flux limited $S_{2.7Ghz}$>2Jy
- delta<+10 degrees: ideal for ALMA
- Intermediate redshifts: 0.05<z<0.7
- Optical classifications:
  - 43% Narrow Line (NLRG)
  - 33% Broad Line (BLRG/Q)
  - 24% Weak Line (WLRG) - i.e. 76% are strong line (SLRG)

Observational campaigns:

- Radio: VLA, ATCA
- Optical: ESO, VLT, Gemini
- Near infrared: UKIRT, SOFI/NTT
- Sub-mm: APEX - LABOCA
- X-ray: Chandra/XMM
- Infrared: Spitzer MIPS & IRS, Herschel DDT

High mid- to far-IR detection rates:

- 24μm - 100%
- 70μm - 90%
- 100μm - 100%
- 160μm - 89%

http://2jy.extragalactic.info/

Spectral Energy Distributions

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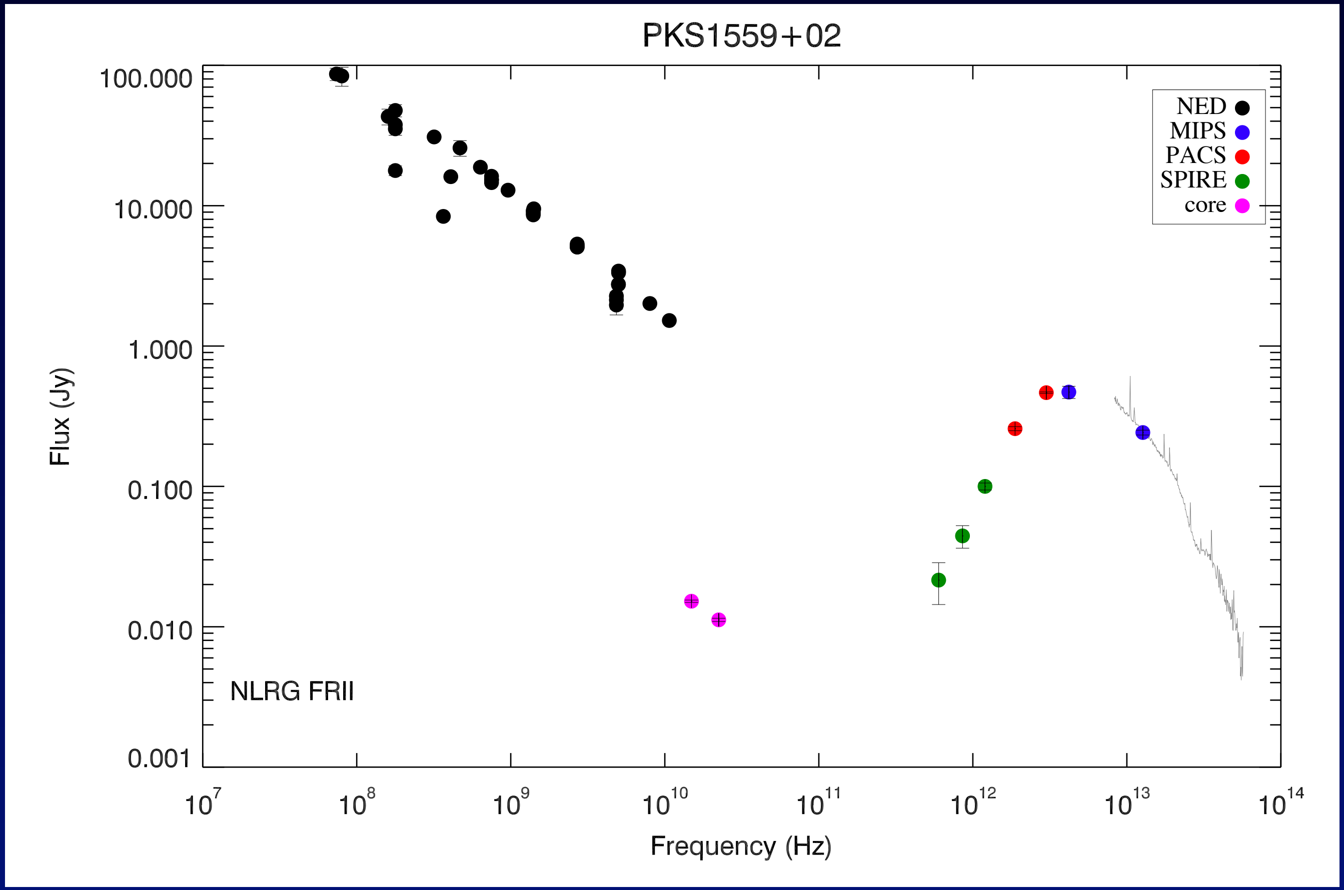
- Herschel data has been vital for completing the infrared SED
- Principally we are looking for the signatures of thermal infrared emission from dust – reprocessing the light from the AGN or star formation
- Steep spectrum (radio) emission is on larger scales compared to infrared



Importance of accounting for the non-thermal infrared emission

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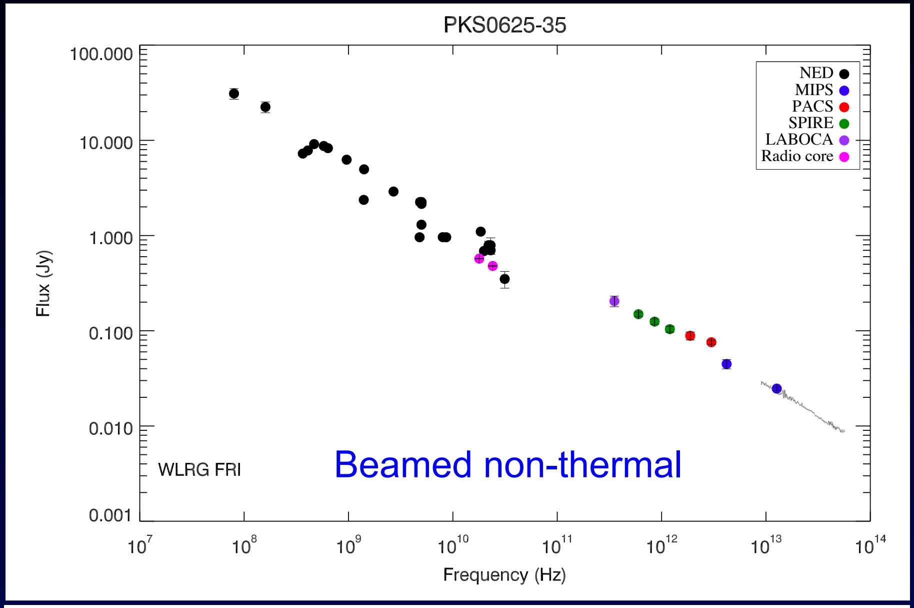

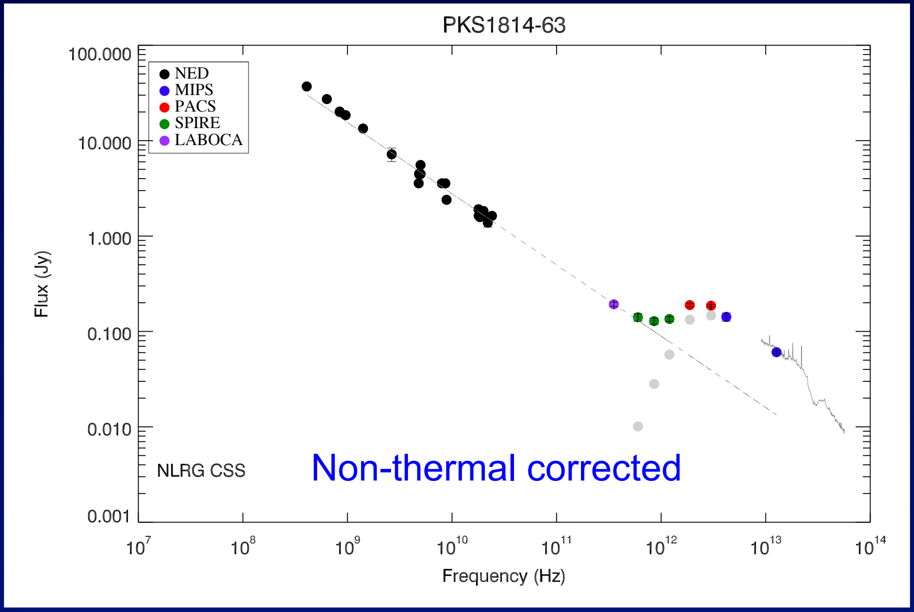

- Contamination of far-IR by beamed core emission significant in:
  - FRI 83 %
  - FRII 18 %
- Contamination by steep spectrum radio lobe emission inside infrared beam significant in:
  - FRII + CSS 15 %
- The latter can be corrected in most cases

Testing unified schemes I

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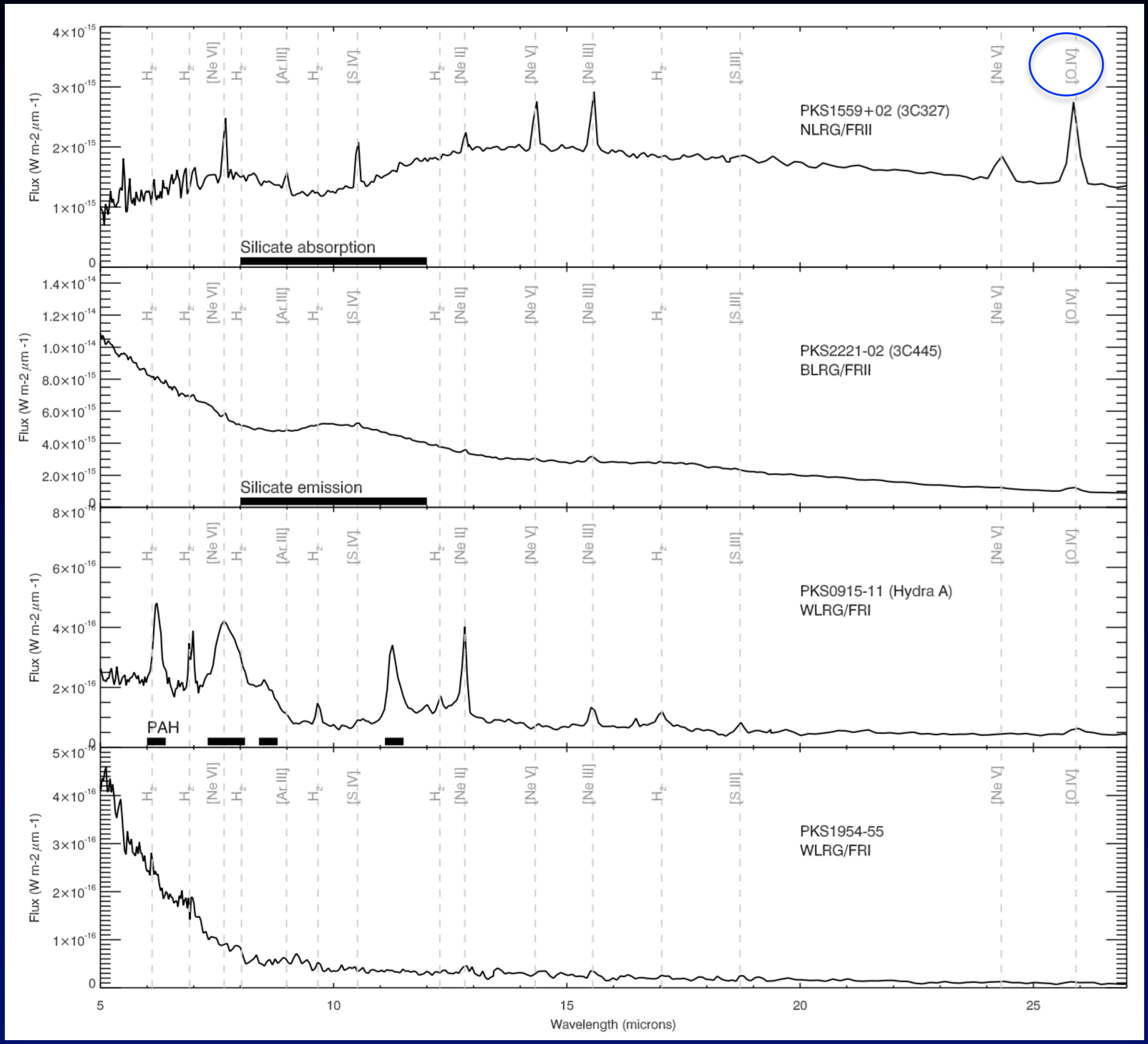
- Spitzer IRS Spectra shows differences between BLRG/Q and NLRG - silicate features
- ➢ In line with orientation based unification



NLRG: strong mid-IR emission lines. 10μm silicate absorption

BLRG/Q: 10μm silicate emission

WLRG: Strong PAH from star formation

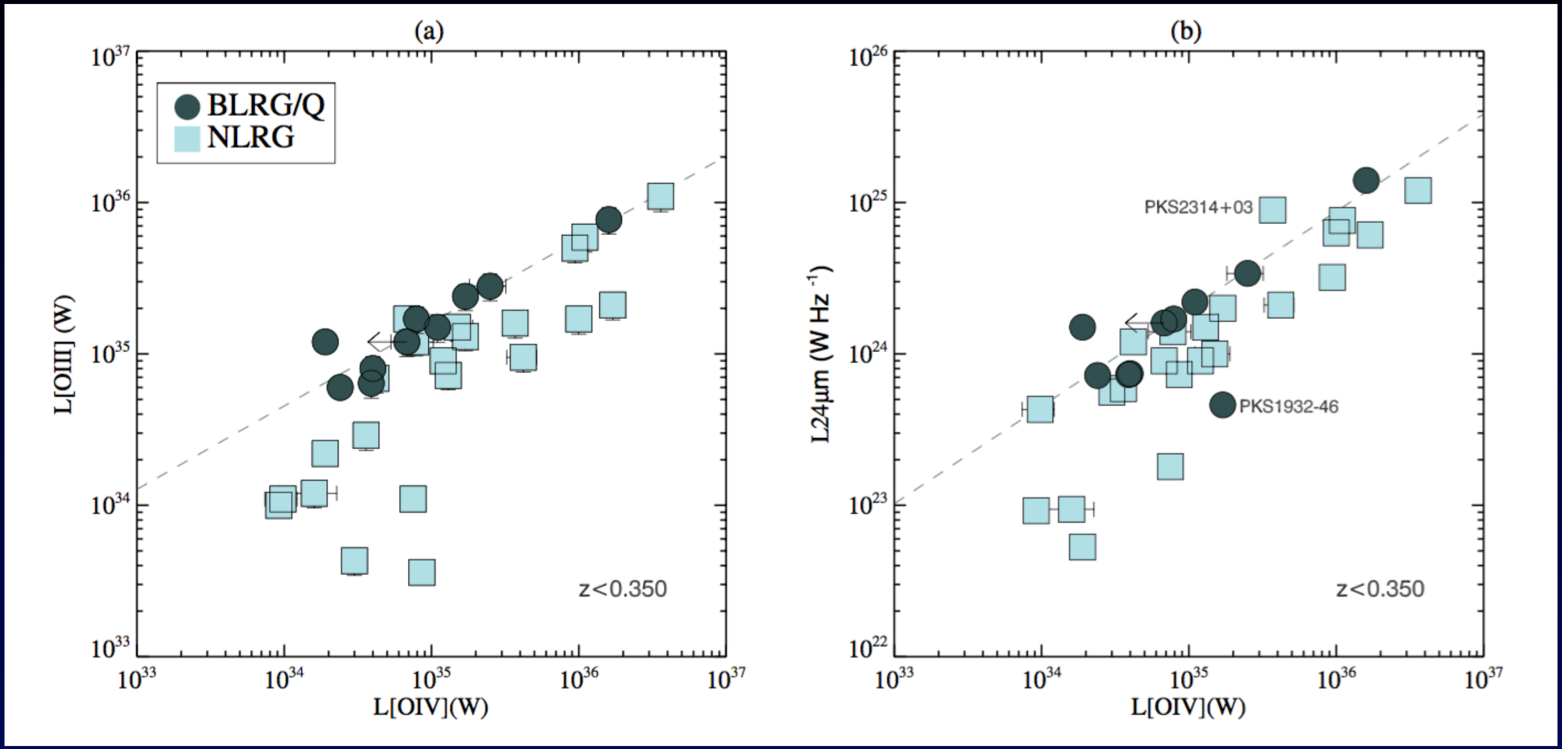
WLRG: steep upturn at the blue end originating from the stellar continuum in the host galaxy

- The mid-IR spectral line [OIV] λ25.89 μm is a good candidate for an AGN power indicator
- ➢ High ionization potential (Eion = 54.9 eV)
- ➢ Long wavelength - less likely to suffer from the effects of dust extinction

Dicken et al. 2012, 2014

Testing unified schemes II

The 2Jy Sample
of southern radio galaxies



The samples are limited to objects with z < 0.350 due to the requirement that the [OIV] line fall in the redshift range of *Spitzer*/ IRS

- BLRG/Q show tight correlation between L[OIV] and AGN power indicators L[OIII] (left) and L24 μm (right)
- NLRG show anisotropy both for optical [OIII] and L24μm
- A factor of ~2.3 attenuation in the NLRG relative to BLRG/Q for [OIII] and 24μm
- Implies AV ~ 0.8 visual extinction for [OIII] compared to AV ~ 20–100 at 24μm, depending on extinction law

Dicken et al. 2014

Dust heating mechanism

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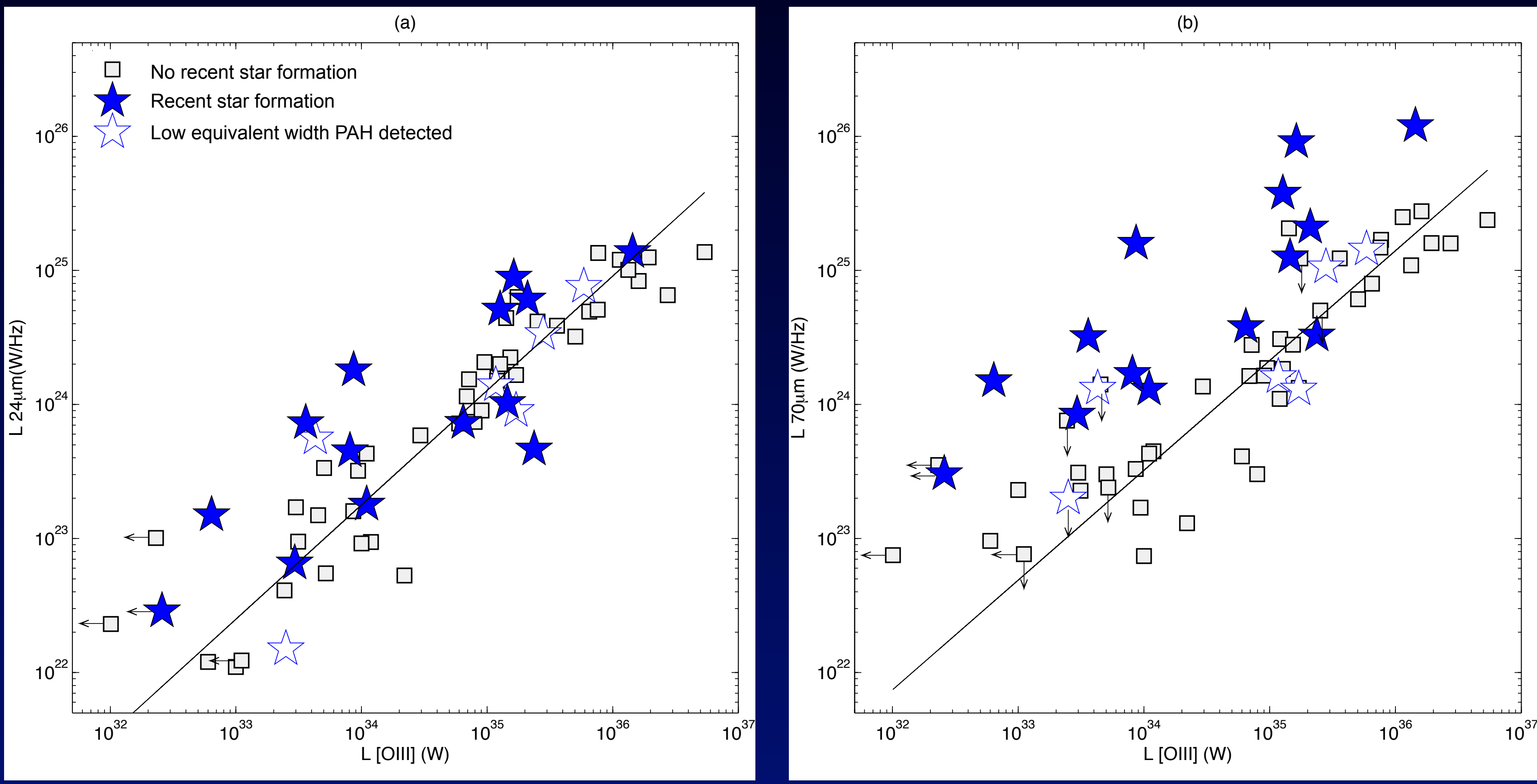
- Slope of the correlation for 24µm and 70µm with L[OIII] the same
  - Points towards common origin
- Objects with recent star formation lie above the correlation at 70µm
  - But slope remains the same



Results for 2Jy and 3CR FRII radio galaxies (Dicken et al. 2012)

Dust heating mechanism

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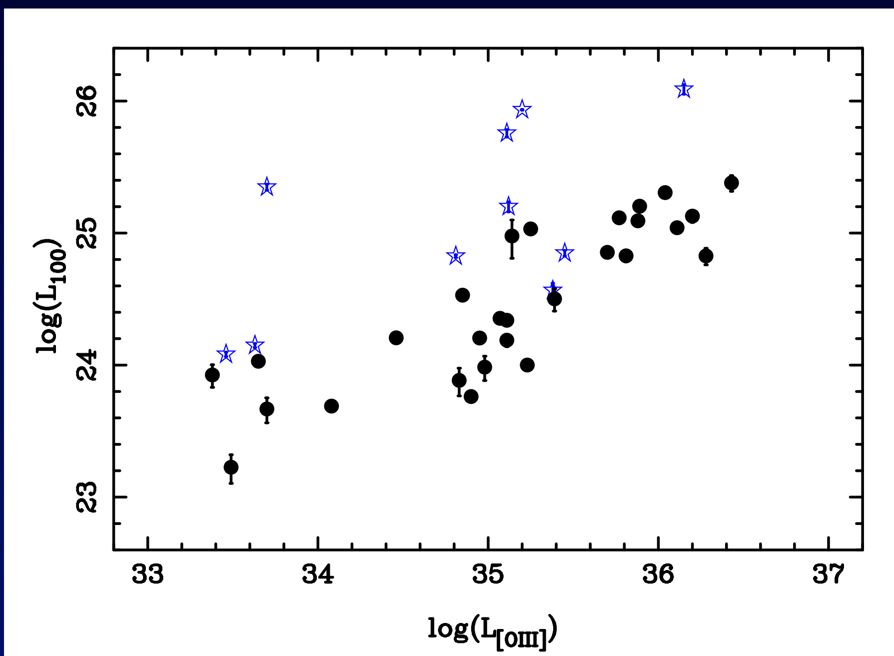
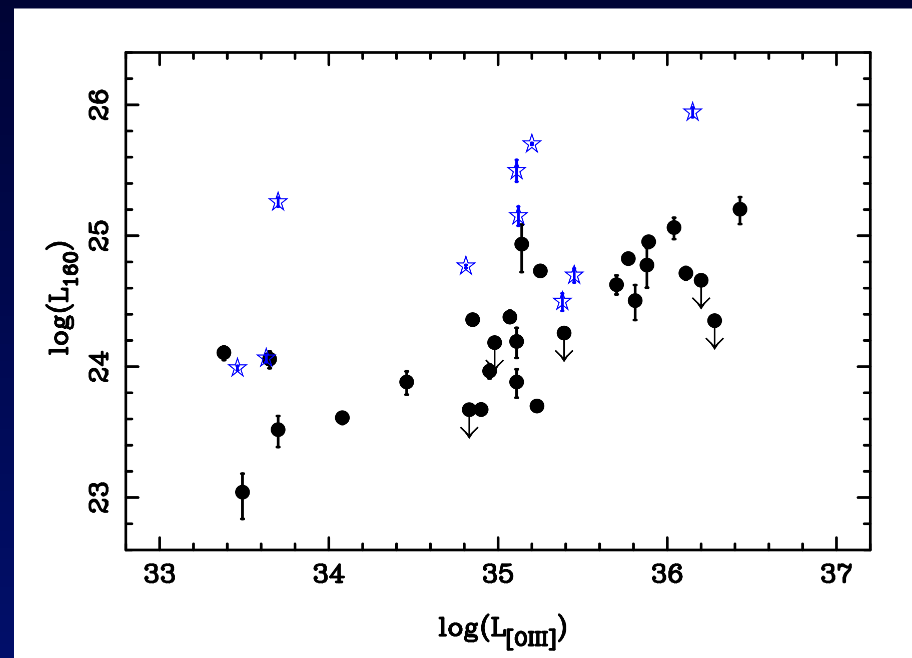
- Repeating experiment at Herschel wavelengths shows results hold out to 160μm

L100μm vs. L[OIII]



L160μm vs. L[OIII]



Showing 2Jy sample only - K-corrected far-infrared luminosities

Merger signatures

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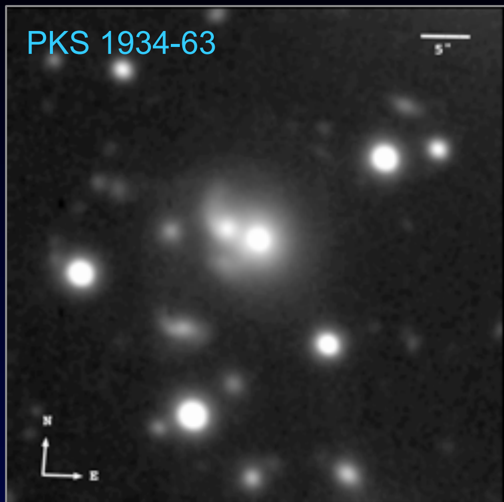
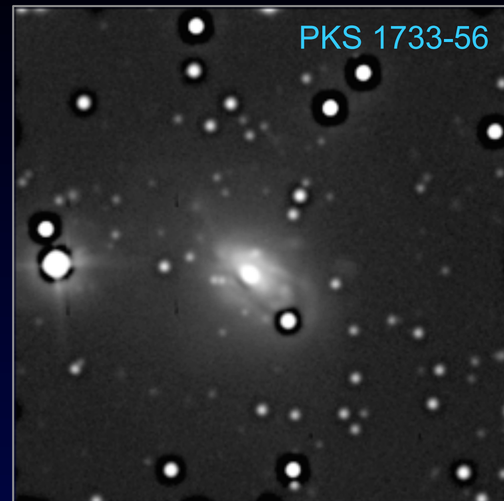
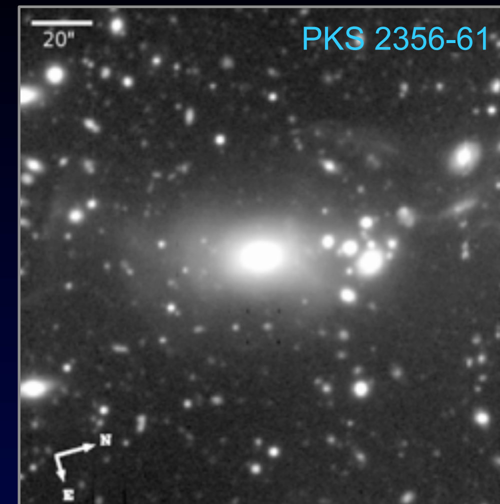


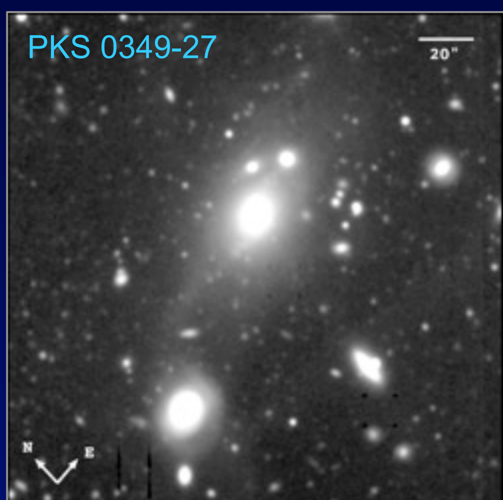


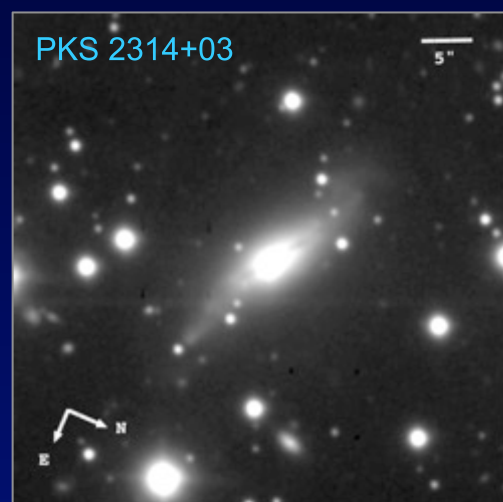


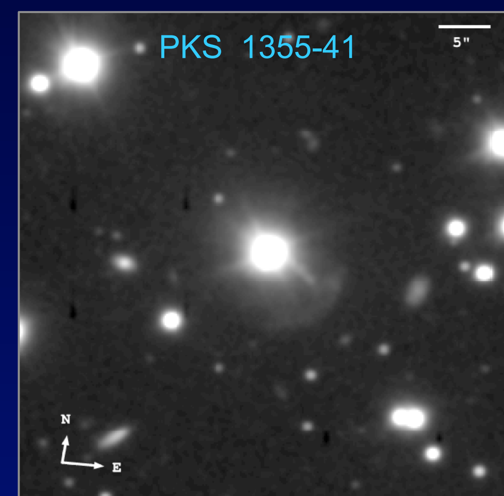
Pre-coalescence
Tidal tails, bridges

Coalescence
Distorted morphologies , dust lanes

Post-coalescence
Fans and shells







- 95% of the 2Jy SLRG show evidence for tidal features (Ramos Almeida et al. 2011, 2012)
- Important in context of mergers and AGN triggering - but what kind of mergers are these?

Star formation in major gas-rich mergers?

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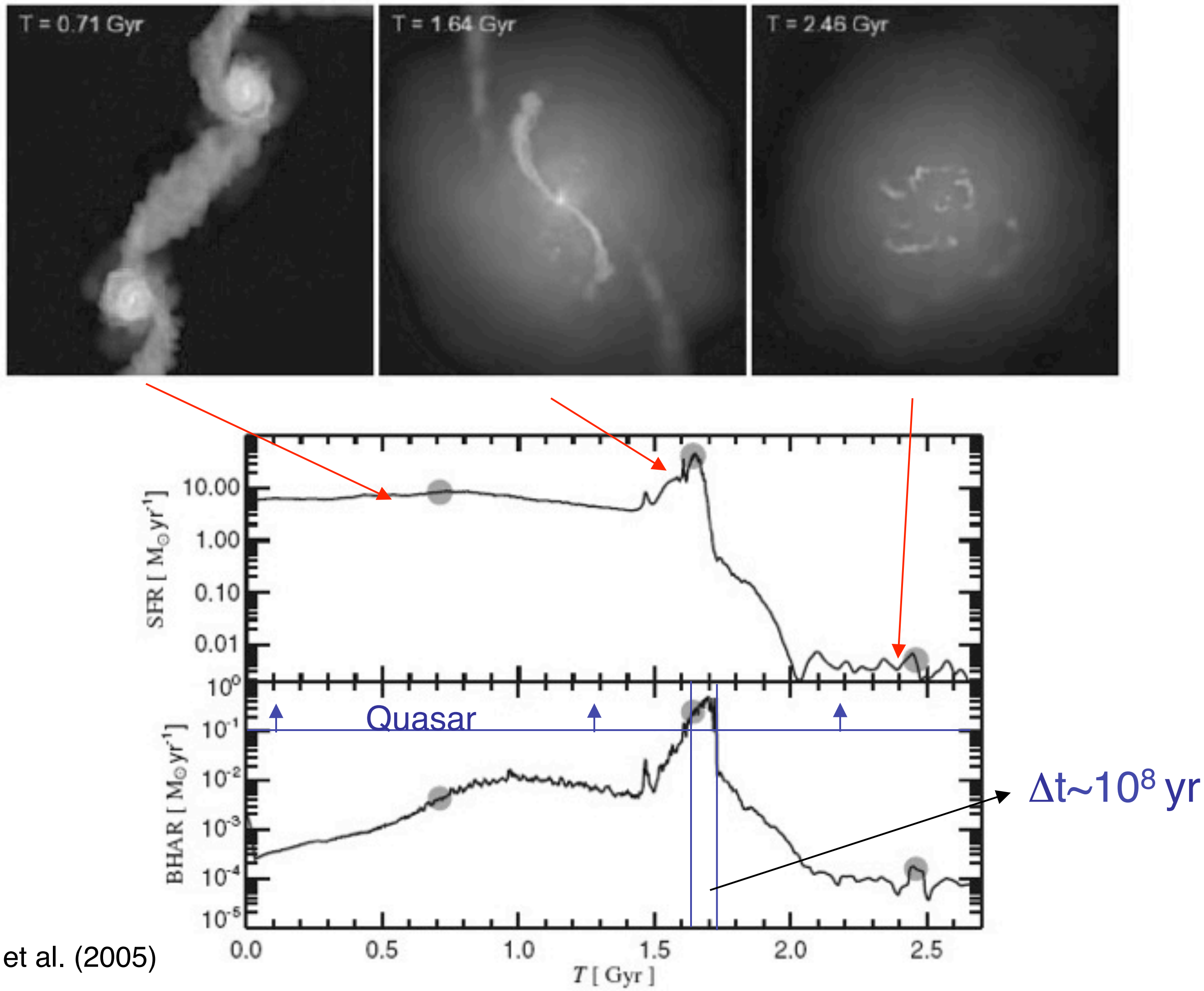

Springel et al. (2005)

- If radio galaxies triggered at peak of major merger we might expect to see ULIRG like star formation rates

70μm derived star formation rates

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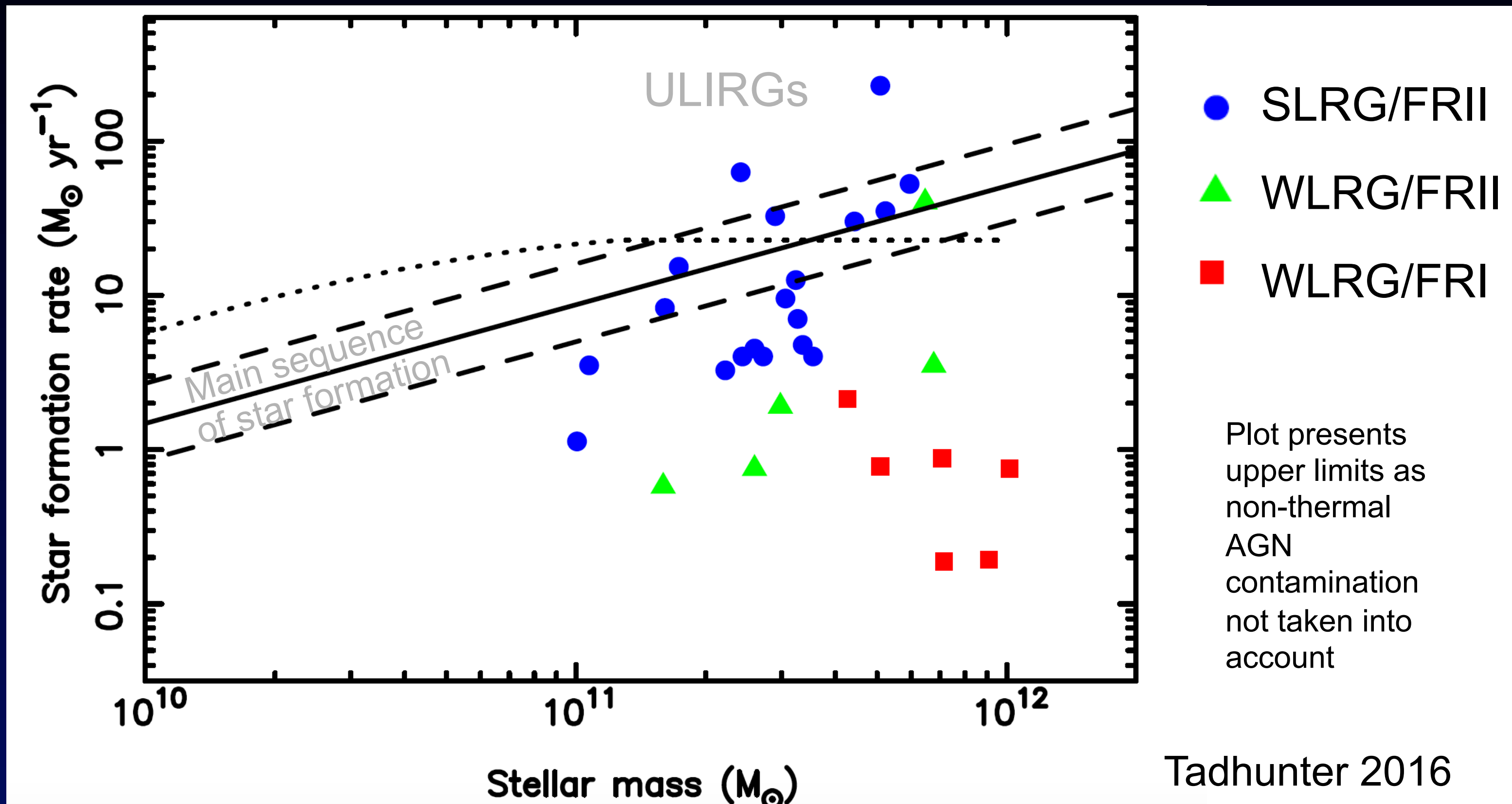

- Upper limiting star formation rates in radio galaxies typically low (0.1 – 30 $M_\odot\ yr^{-1}$)
- WLRG have lower Star formation rates than SLRG
- Unlikely that the majority of powerful radio galaxies are triggered at the peaks of *major, gas-rich* mergers

Dust masses I

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Back of the envelope calculation for quasar triggering

- Define quasar to have L_{bol}>10^{38} W
- Black hole must accrete >0.2 $M_\odot$ yr^{-1} to maintain activity (η=0.1)
- Typical quasar lifetimes: ~10^6 - 10^8 yr

➔ Mass accreted by black hole over lifetime: ~$2x10^5$ - $2x10^7$ $M_\odot$

- But, on the basis of the black hole mass/host galaxy correlations, for every 1 $M_\odot$ accreted by the black hole, ~500 $M_\odot$ stars must be formed in the bulge of the host galaxy

➔ Total gas reservoir for a particular quasar triggering event is ~ 10^8-10^{10} M_{sun}

➔ For quasar lifetime of ~10^7yr and M_{gas}/M_d=150 we predict dust mass:
~ $7x10^6$ $M_\odot$ or $\log10(M_d/M_\odot)$ ~ 6.8

Dust masses from Herschel data

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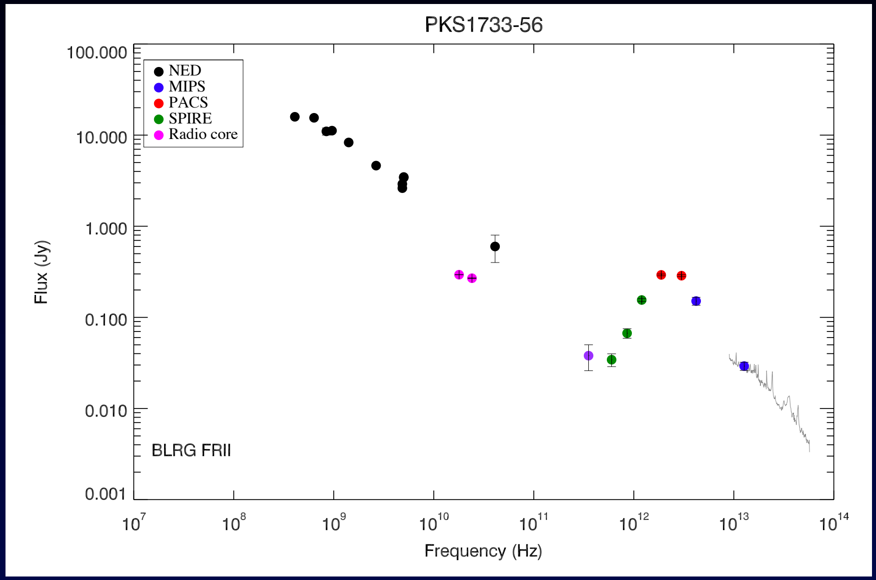
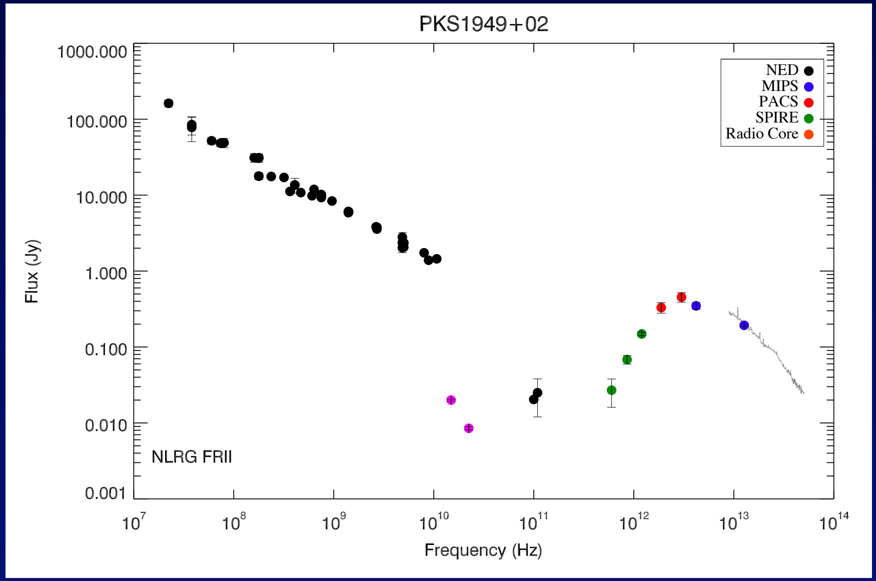
- Assume a single temperature modified BB fit
- Fits to SEDs and colour-colour plots (objects with SPIRE data) ➔ β~1.2
- Determine dust temperatures (T_d) for non-SPIRE objects from 160/100 colour and β=1.2
- Dust masses follow from:

$$M_d = \frac{S_\nu D^2}{\kappa_\nu^m B(\nu, T_d)}$$





Dust masses II

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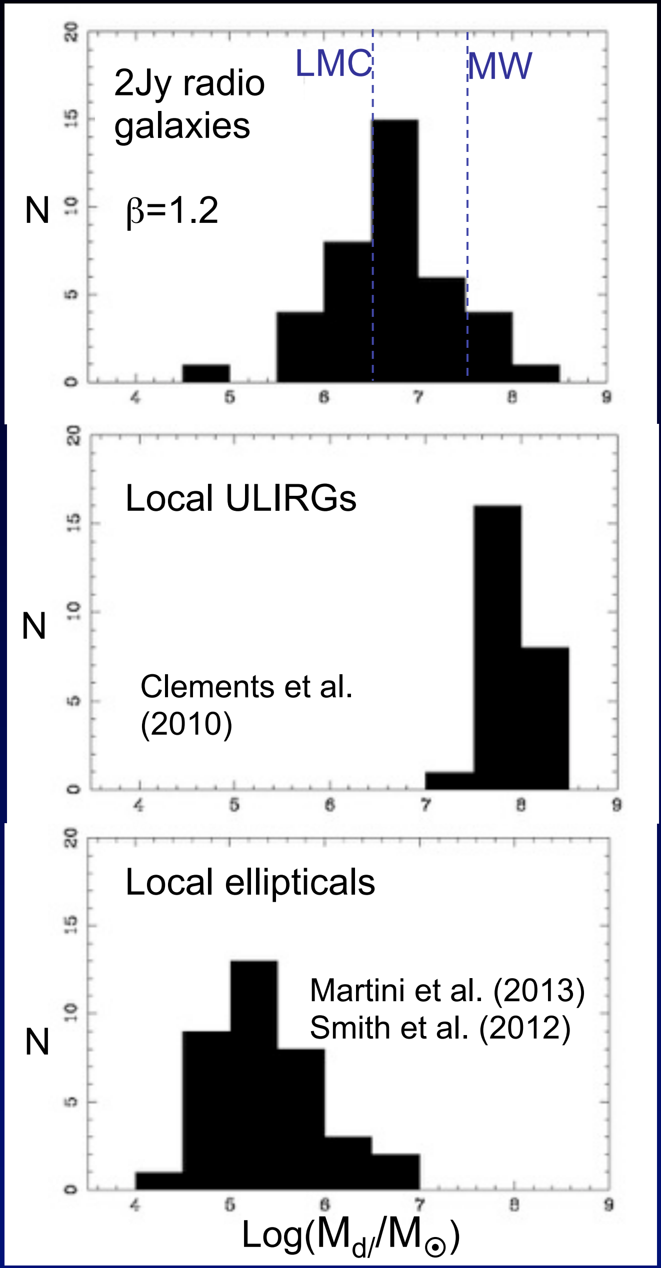
<u>Median dust masses</u>

	$\log_{10}(M_d/M_\odot)$
Radio Galaxies:	6.8
Local ULIRGs:	7.8
Local Ellipticals:	5.2
Prediction:	6.8

- Radio galaxy dust masses lie between ULIRGs and local ellipticals - although some RG are ULIRGs
- A minor merger with a gas-rich companion (~2xLMC) provides sufficient cool gas to sustain quasar-like activity for ~10^7 yr
- Such reservoirs detected in most of the powerful radio-loud AGN



Tadhunter et al. 2014

Future prospects: ALMA

Molecular gas masses - comparison with dust masses

- does quasar triggering require a large reservoir of cool gas?

Molecular gas distribution and kinematics:

- to what extent does quasar triggering depend on the distribution and kinematics of the gas?

Summary

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- Important to account for non-thermal contamination, especially in CSS and WLRG
- Far-IR results consistent with orientation-based unified schemes, with some evidence for mild anisotropy in [OIII] and 24 micron continuum
- AGN heating of far-IR dust may be significant → far-IR not a “clean” SFR indicator
- Upper limiting SFR are relatively modest in most cases (~1 – 30 M_sun yr-1)
- Dust masses are also relatively modest
- Consistent with scenario in which the majority of local radio AGN triggered in minor or modest mergers (with ~15% triggered in more major mergers)