The dust masses of powerful radio galaxies: clues to the triggering of their activity

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The 2Jy 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)
  - 72% FRII sources, 13% FRI sources, and 15% CSS/GPS

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

http://2jy.extragalactic.info/

2Jy infrared studies

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Previous Infrared Studies

- **Spitzer** MIPS photometry and IRS spectroscopy (5-70 microns):
  - Allowed investigation of the origin of the infrared emission from dust
  - We found powerful starburst are not generally associated with powerful radio galaxies

New Infrared and Sub-mm data

- **Herschel** PAC and SPIRE photometry (70 – 500 microns)
  - Allows us to probe the dust mass content of powerful radio galaxies
  - Most of the mass of dust is cold – sampled at Herschel wavelengths

- **APEX - LABOCA** (850 microns)
  - Allows us to disentangle the non-thermal emission from the radio galaxies on the thermal emission from dust

Deepest and highest detection rate of any far-infrared study of radio galaxies

- **High mid- to far-IR detection rates**:
  - 24μm - 100%
  - 70μm - 90%
  - 100μm - 100%
  - 160μm - 89%

Data

2Jy SED examples

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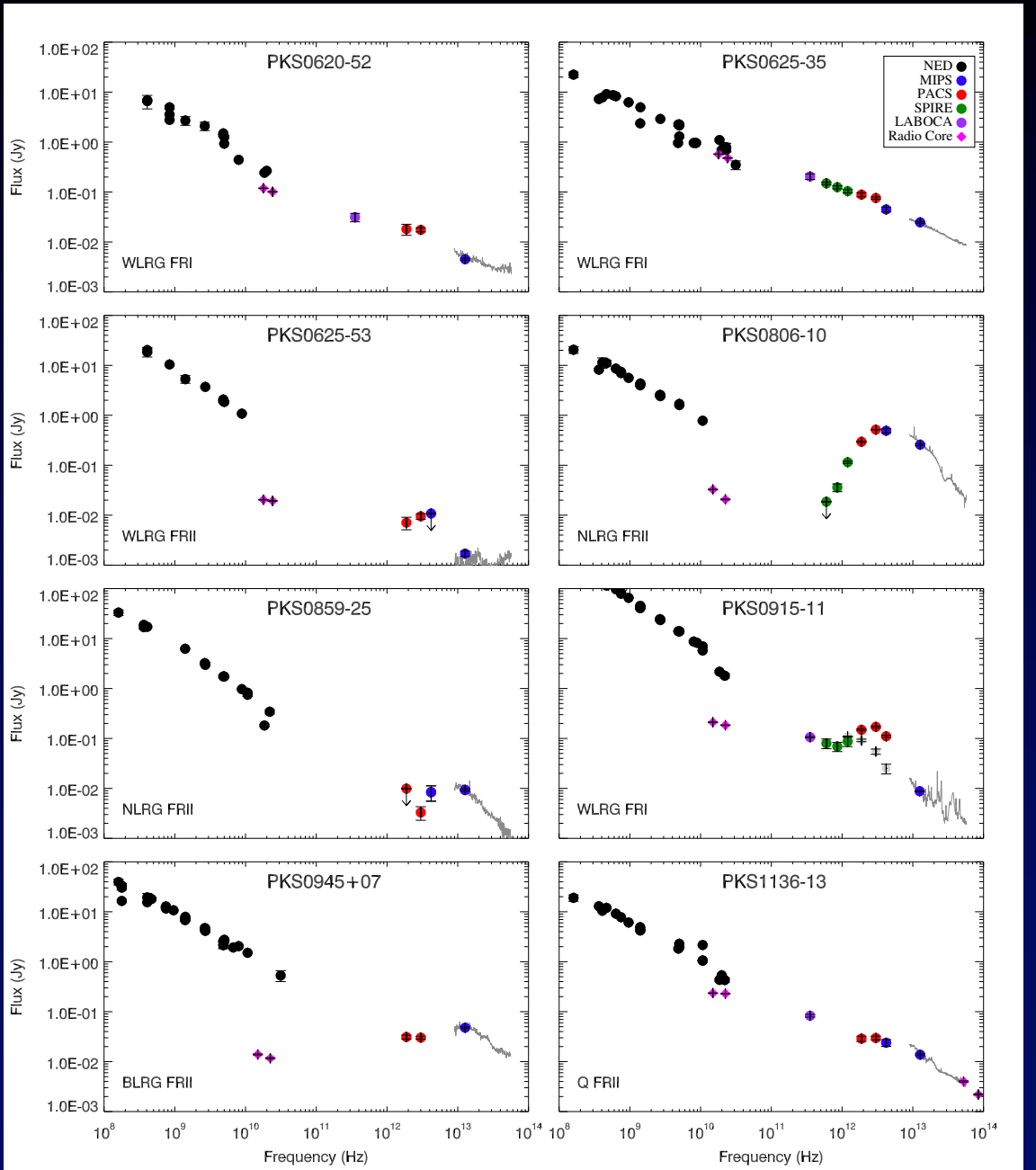
of southern radio galaxies

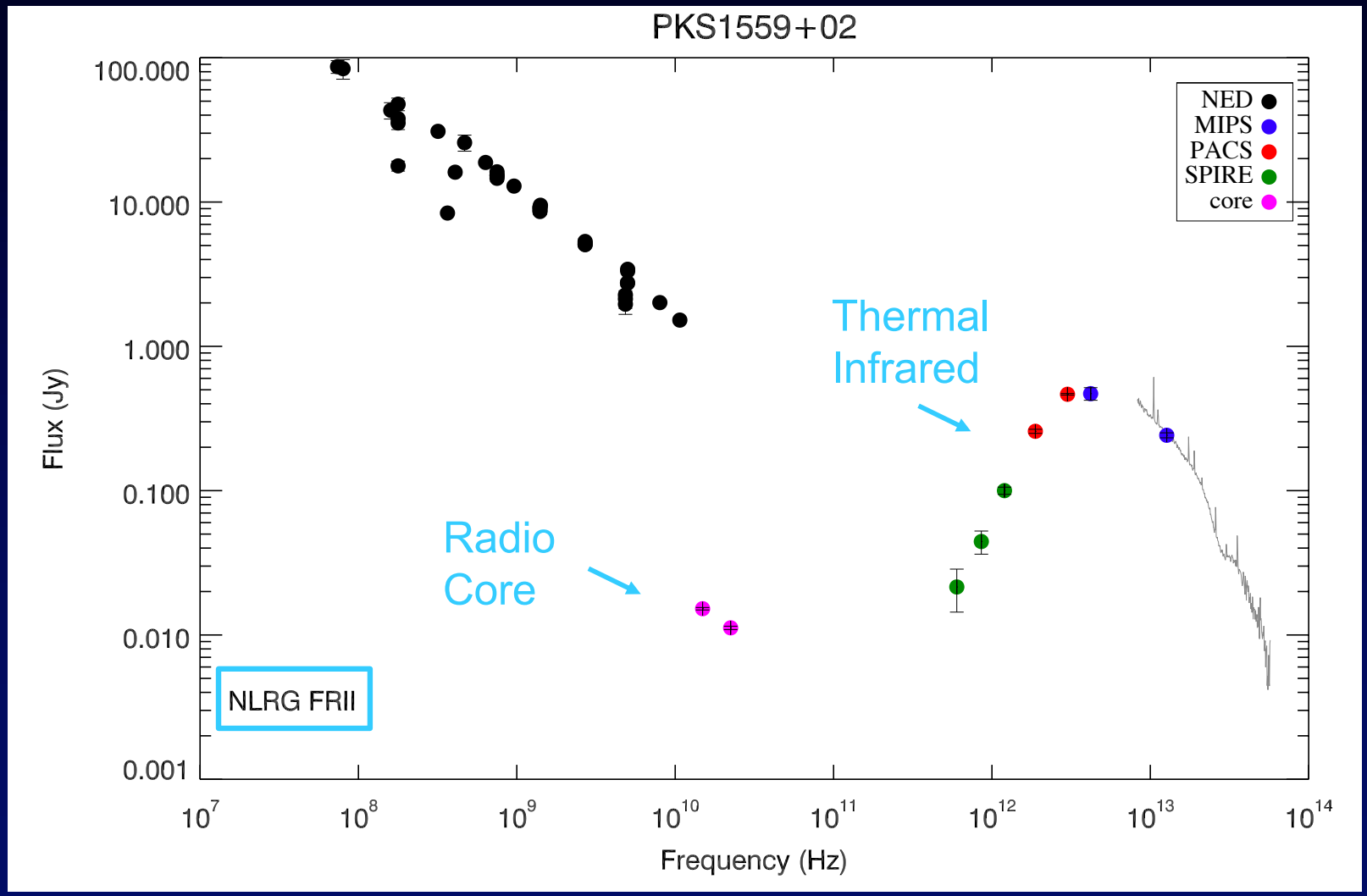
- Example SEDs of 2Jy powerful radio galaxies
- The SEDs show a variety features in the infrared revealing the nature the radio sources – strong-line, weak-line, FRI vs. FRII



2Jy SED examples

The 2Jy Sample
of southern radio galaxies

- Principally we are looking for the signatures of thermal infrared emission from dust – reprocessing the light from the AGN or star formation
- SED's with strong thermal signatures from dust



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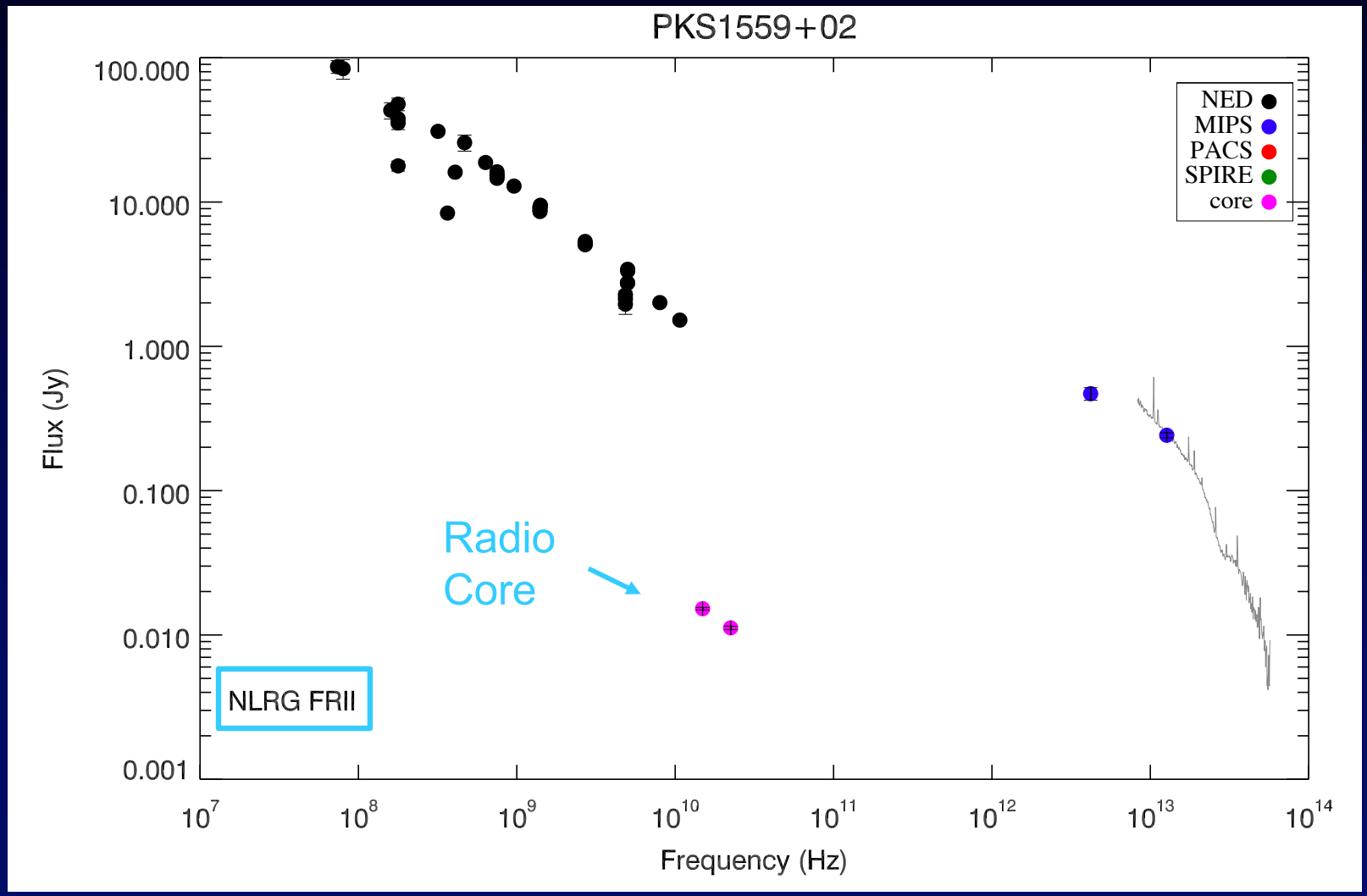

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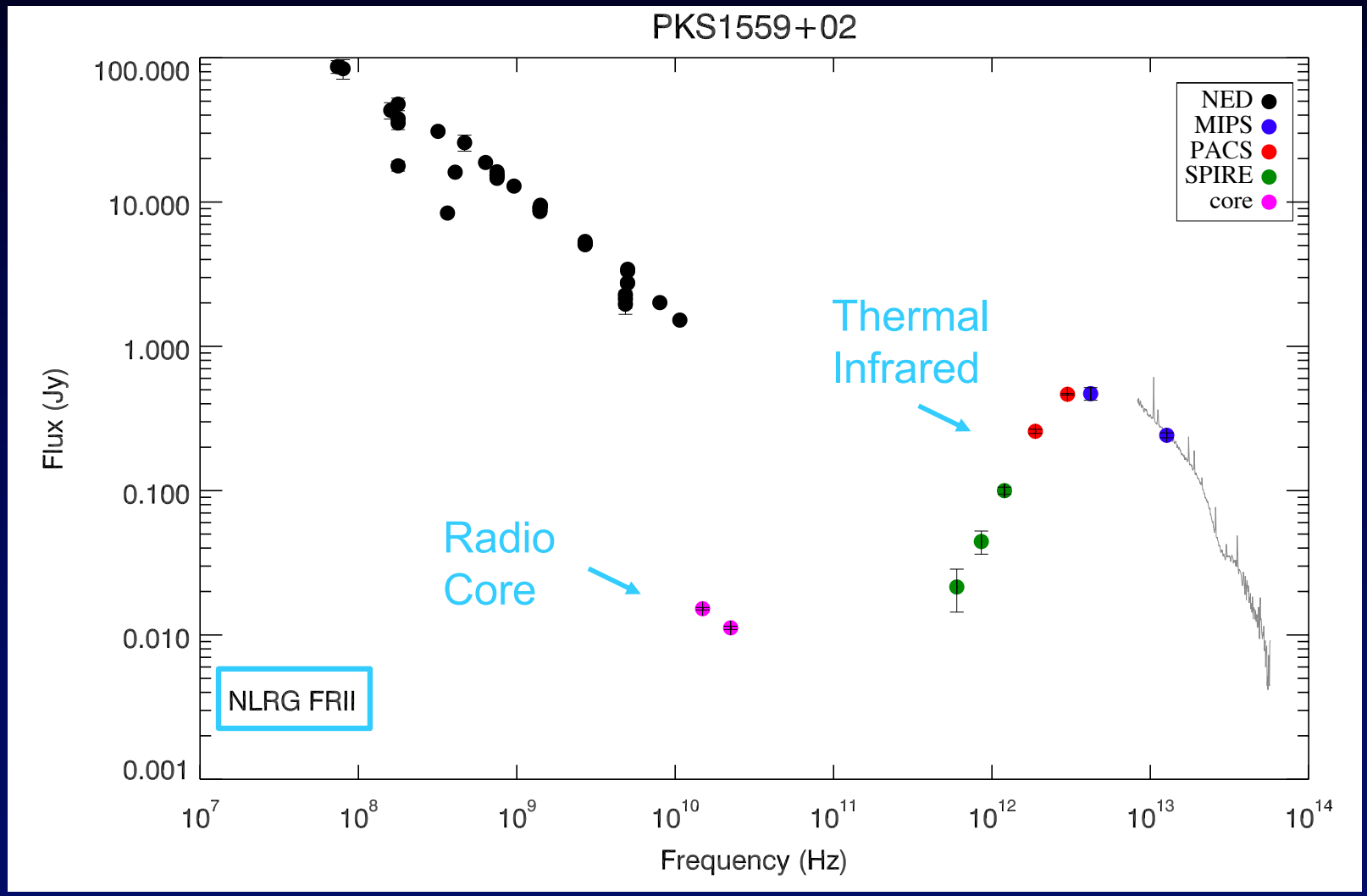

2Jy SED examples

The 2Jy Sample
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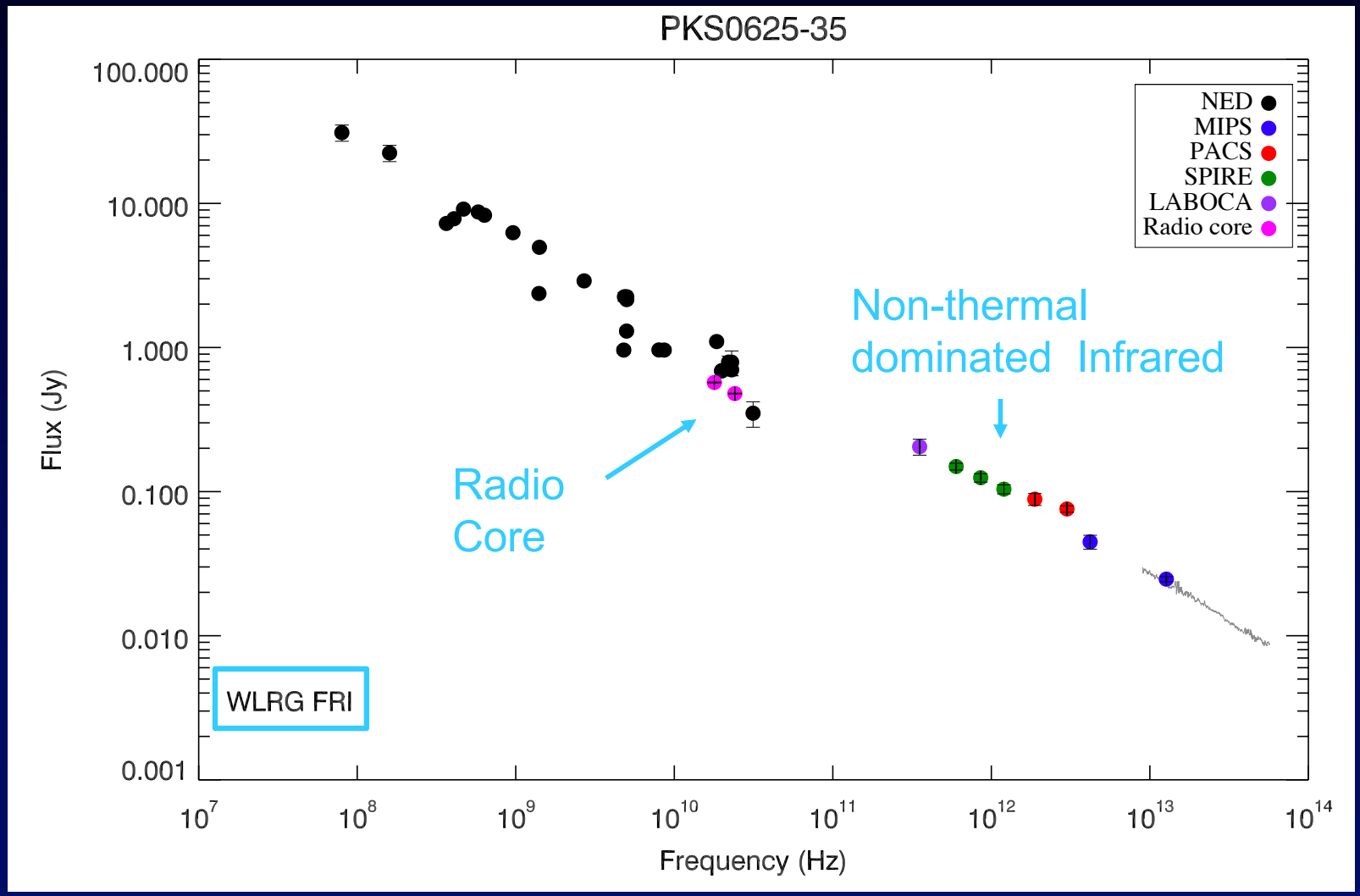
- SED's with flat spectrums, core dominated



2Jy SED examples

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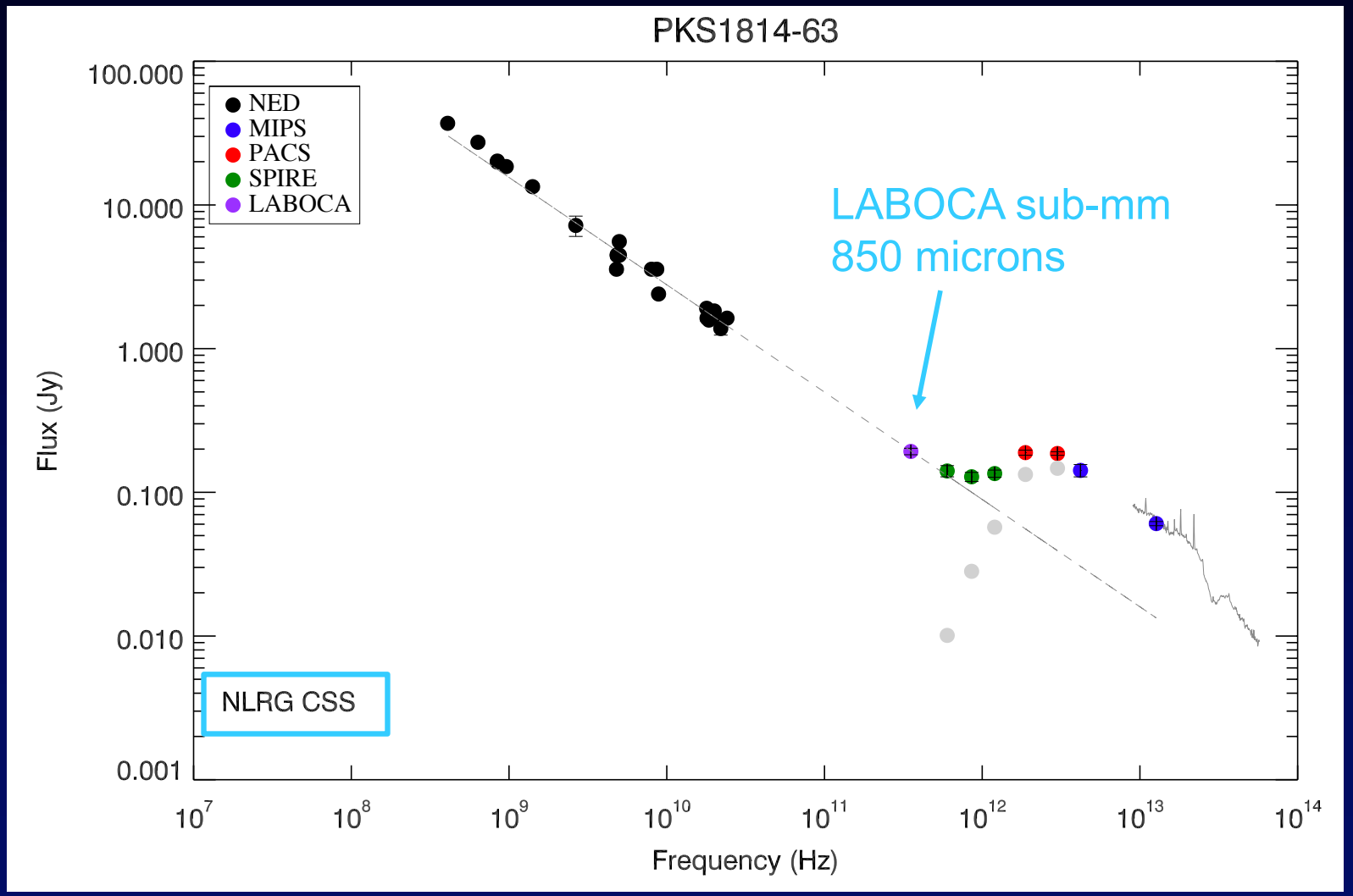
of southern radio galaxies

- SED's with non-thermal contamination of the far-infrared signature
- LABOCA data important for gauging the long wavelength contamination



Importance of accounting for the non-thermal infrared emission

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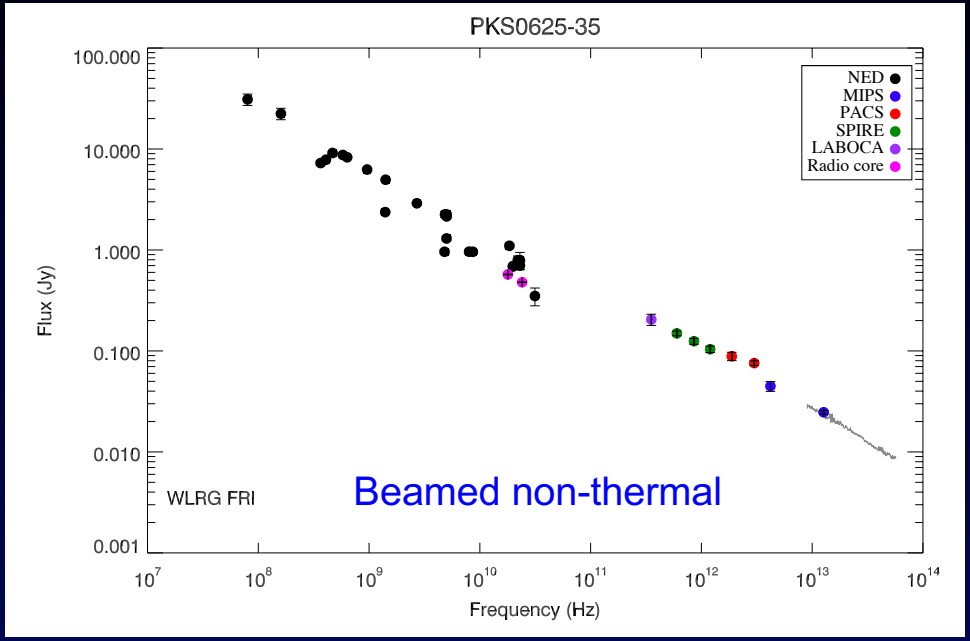

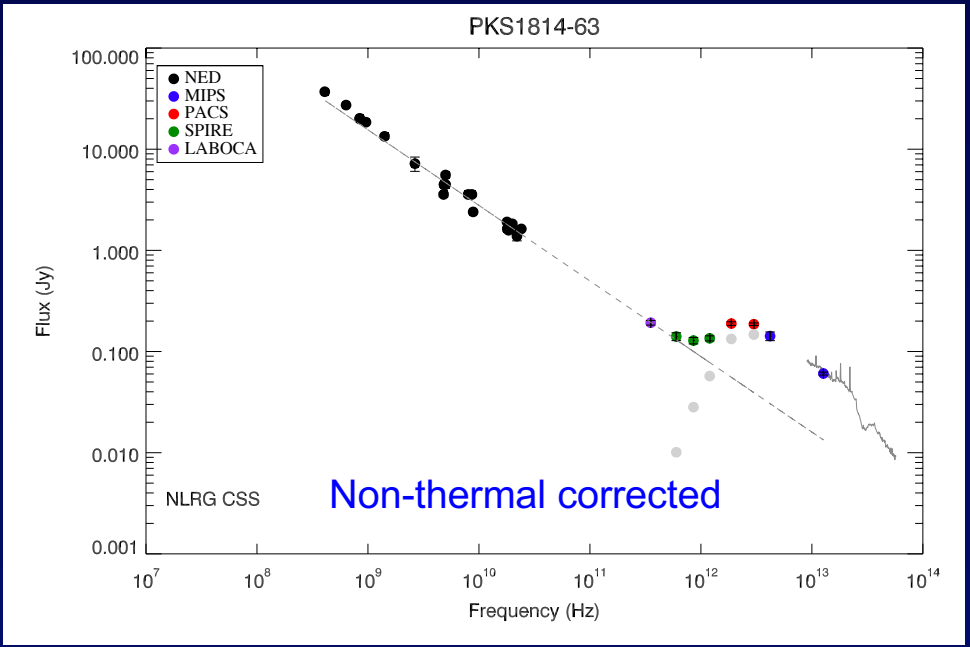

- Contamination of far-IR by beamed core emission significant in:
  - FRI 83 %
  - FRII 18 %
- Contamination by steep spectrum radio lobe emission inside infrared beam significant in:
  - FRII + CSS 15 %
- The latter can be corrected in most cases

Confused sources

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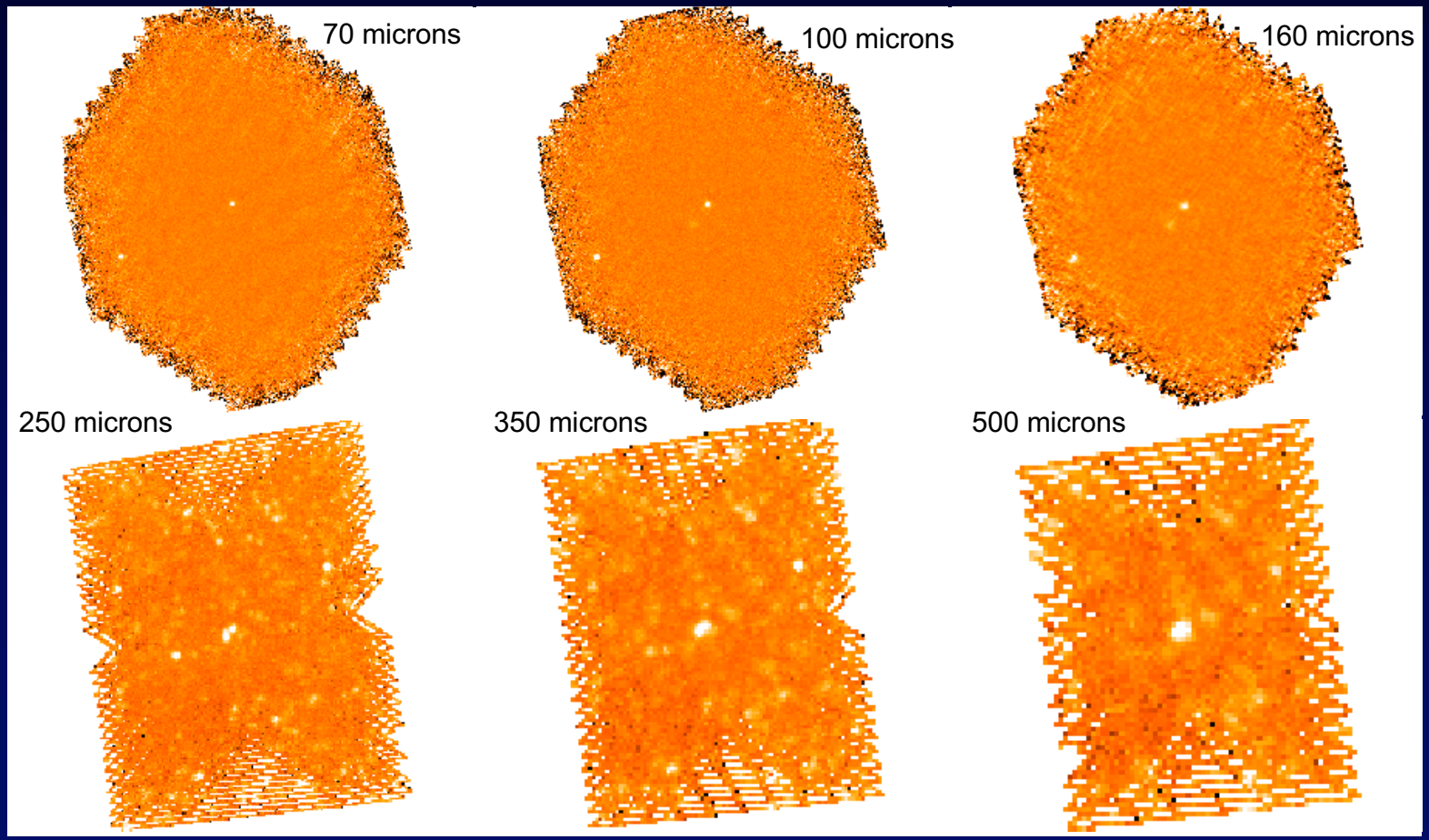
of southern radio galaxies

- Need to be be aware of the potential for confused sources, inside the telescope beam at long wavelength.
- This is not a bias that is unique to radio galaxies but can effect all studies of galaxies that use long wavelength results (stacked results) at intermediate to high redshifts



Of the 19 objects observed with SPIRE (250-500 microns) we identify contamination of the measured flux of 3 objects (17 \%) at 250\micron and 4 objects (22 \%) at 350 and 500\micron

Science

Dust masses from Herschel data

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of southern radio galaxies

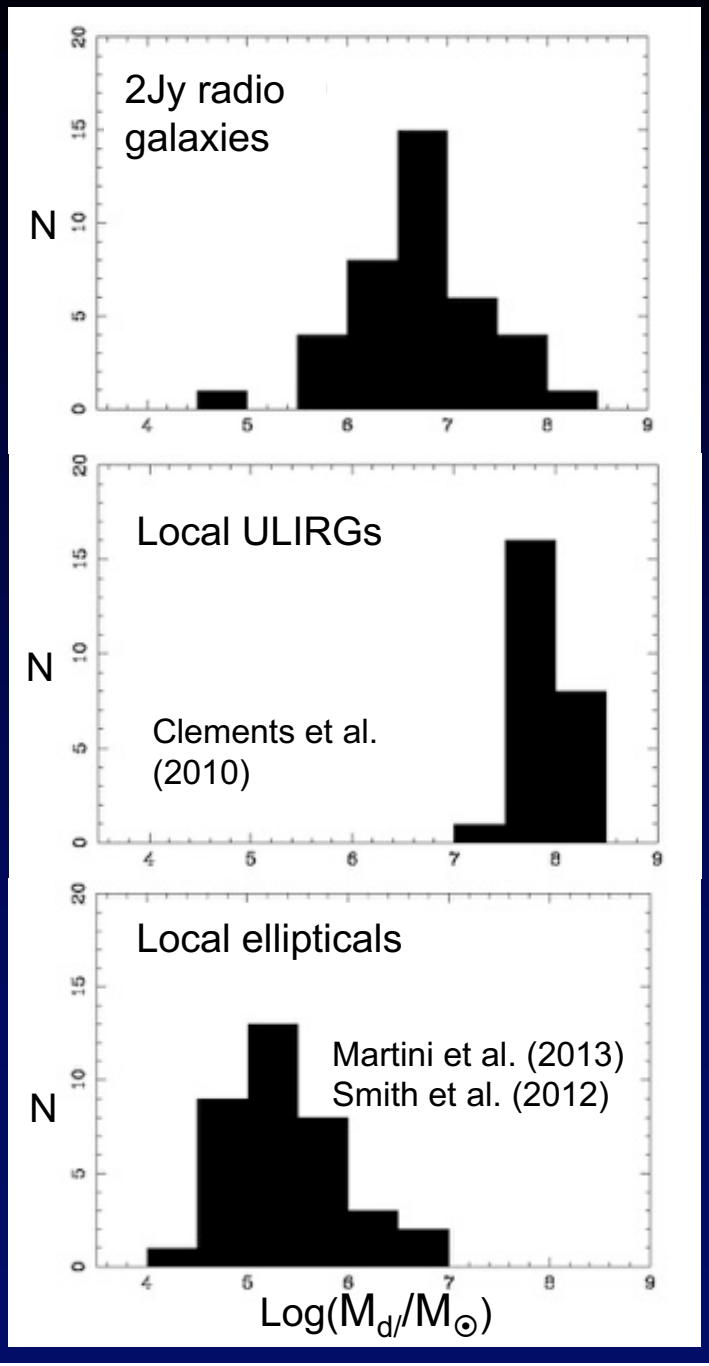
- **Initial results from the Herschel data were published in Tadhunter et al. 2014**
- **Determined dust temperatures (T_d) from single temperature modified BB fit using 160/100 colour and assuming β=1.2**
- **Dust masses follow from:**

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

- **Results showed that radio galaxy dust masses lay somewhere between that of local elliptical and ULIRGs**

Median dust masses

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



Dust masses from Herschel data

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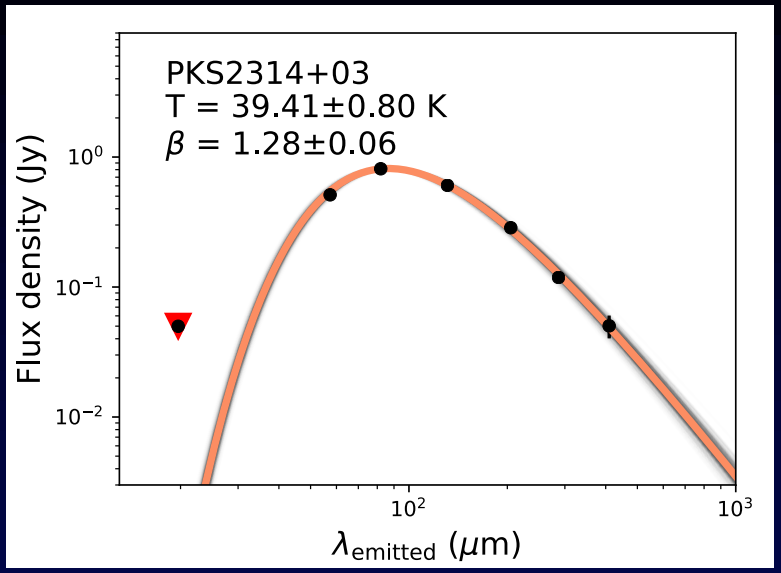
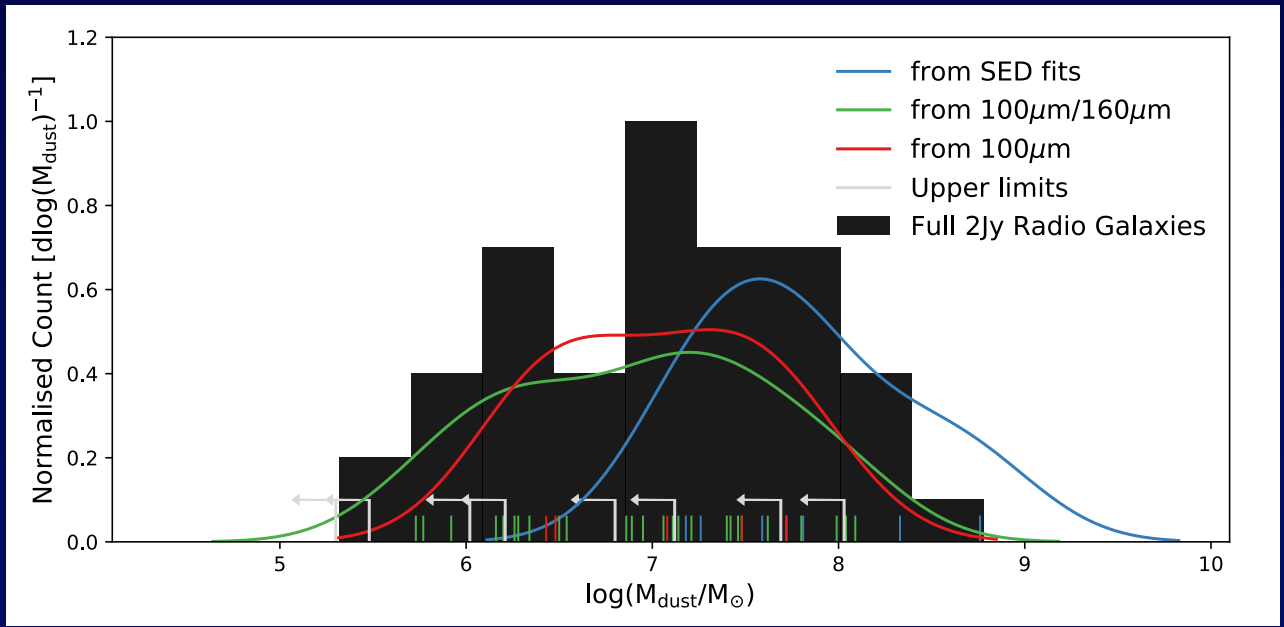
- Caveat with 2014 results for dust masses is the single temperature black body fit and the assumption of the the beta index.
- In order to be certain of the dust mass for comparison with other studies and objects we returned to the dust mass calculation
- This time we fit the far-infrared SED in multiple ways (single multiple black bodies) and carefully consider the beta index
- For objects with SPIRE data - 19 of the 46 objects
- Results show agreement with previous dust mass estimates



Example of a single component fit to the 2Jy data



Fits and plots courtesy of Manu Bernhard (University of Sheffield)

Dust masses from Herschel data

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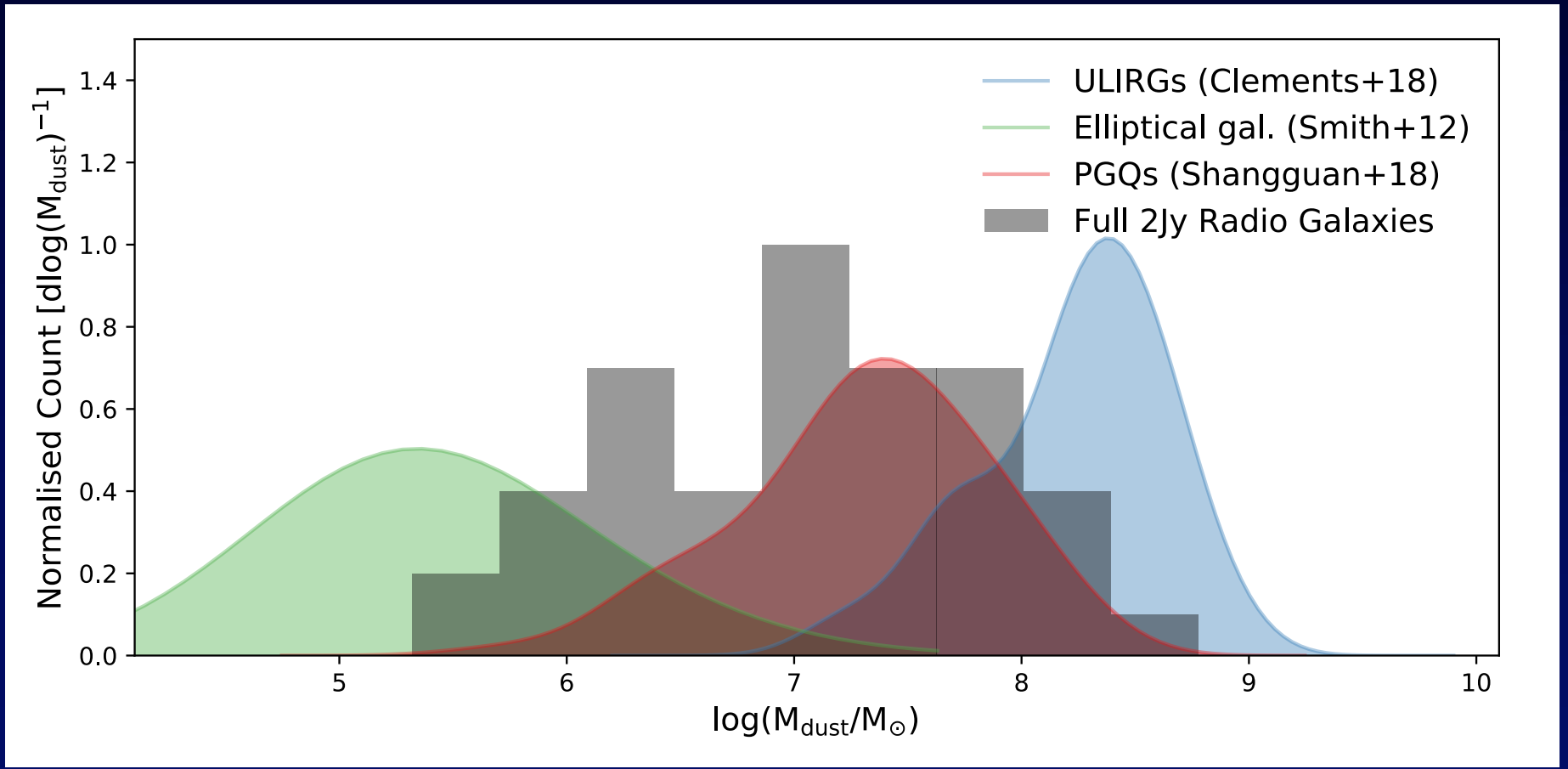
- Now confident about the dust masses derived in 2014 we can return to the dust mass comparison - adding PG quasars
- Radio galaxy dust masses lie between ULIRGs and local ellipticals - although some RG are ULIRGs



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Merger signatures in powerful radio galaxies

The 2Jy Sample
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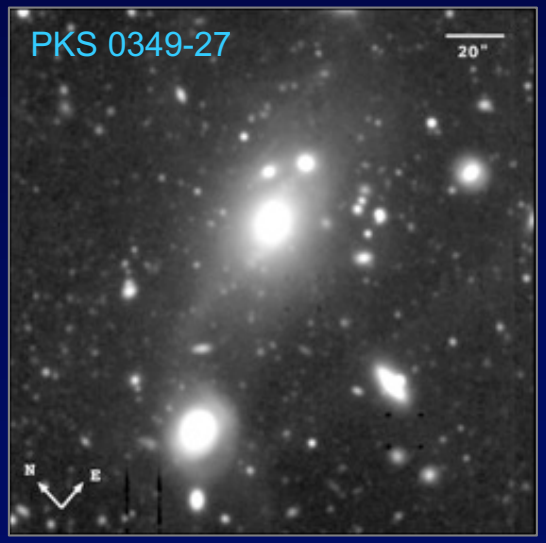
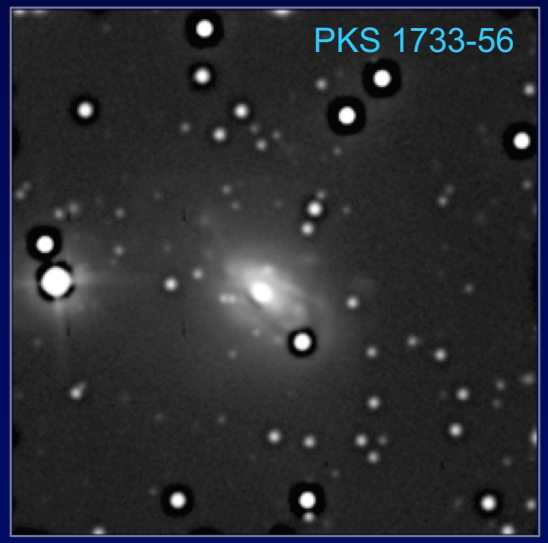
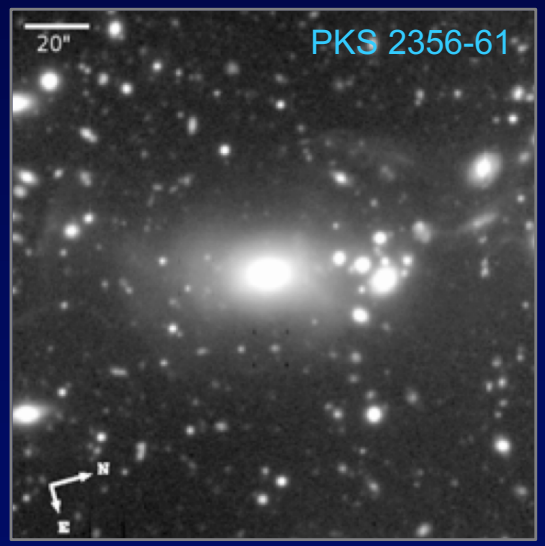
- GEMINI deep optical survey of the 2Jy sample
  - 95% of the 2Jy SLRG show evidence for tidal features (Ramos Almeida 2011, 2012)
- But what kind of mergers are these?
  - Pre-coalescence
  - Coalescence
  - And Post-coalescence
- So powerful radio galaxies not found at peak of major gas rich mergers



Pre-coalescence
Tidal tails, bridges



Coalescence
Distorted morphologies , dust lanes



Post-coalescence
Fans and shells

70μm derived star formation rates

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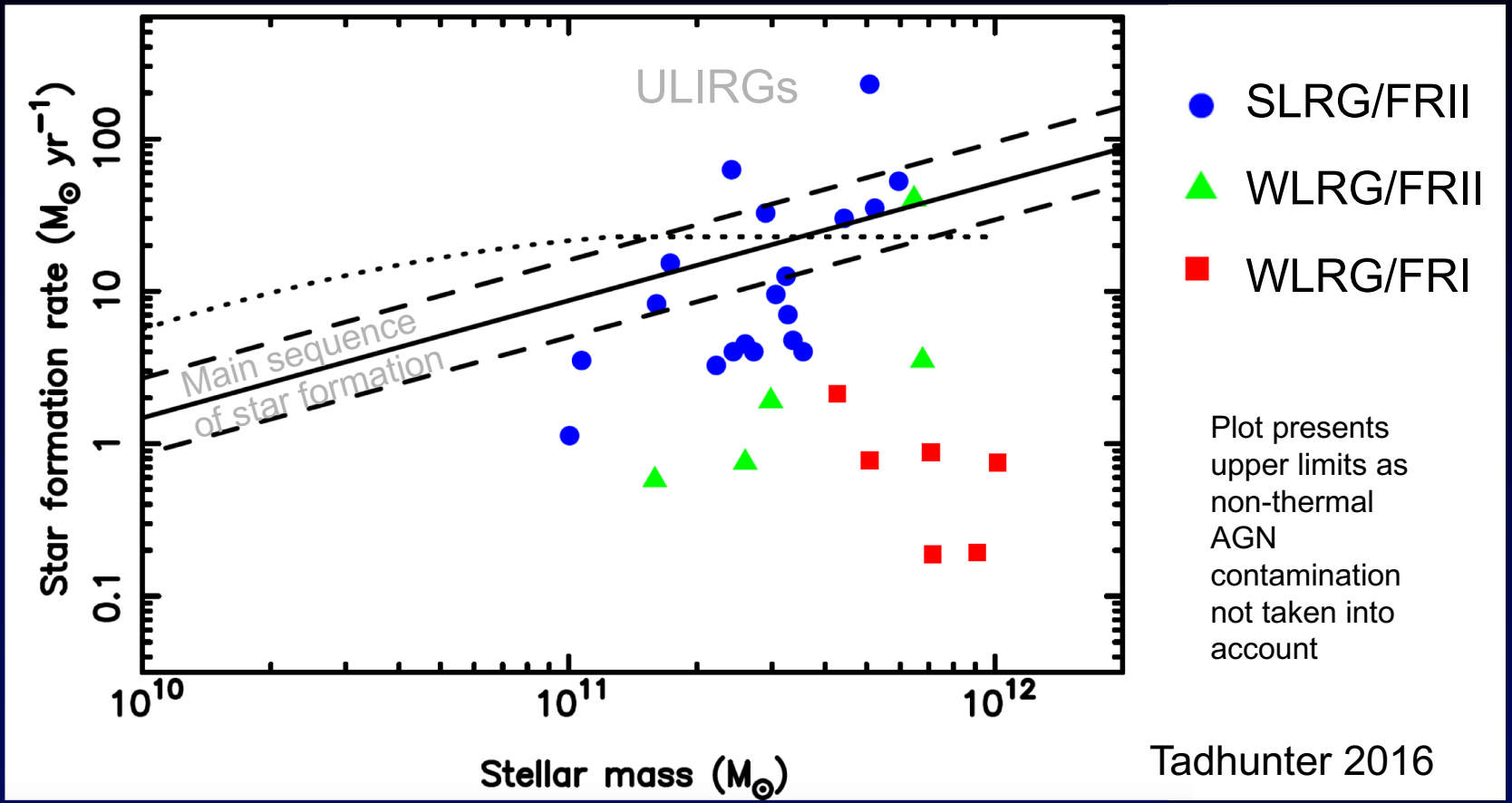

- **Star formation rate upper limits in radio galaxies typically low (0.1 – 30 $M_\odot$ yr^{-1})**
- **Again consistent with the idea that the majority of powerful radio galaxies are not triggered at the peaks of major, gas-rich mergers**

Dust masses from Herschel data

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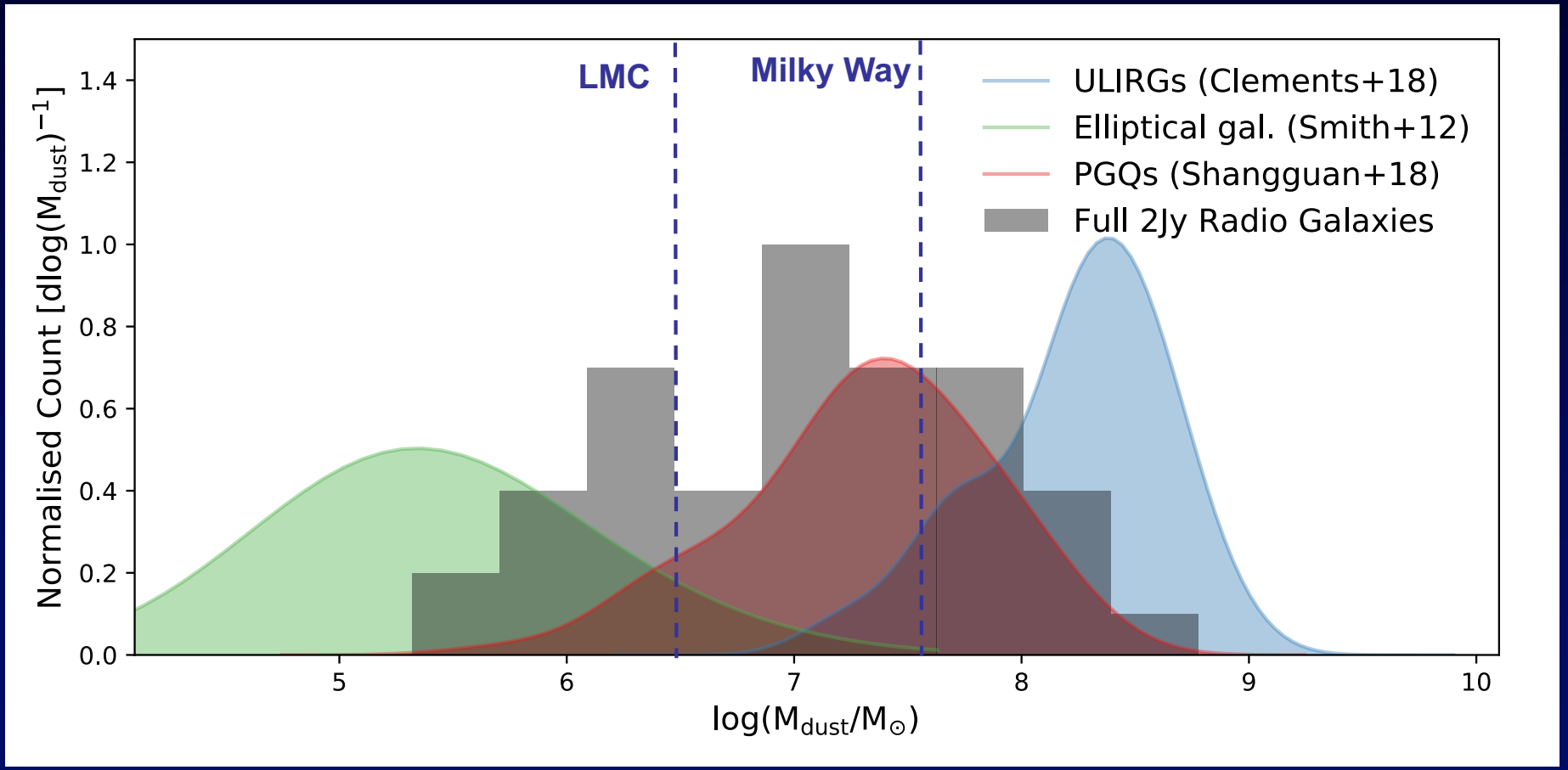
- A minor merger with a gas-rich companion (~2xLMC) provides sufficient cool gas to sustain quasar-like activity for ~10^7 yr
- Such reservoirs detected in most of the powerful radio-loud AGN



Dust mass and the AGN

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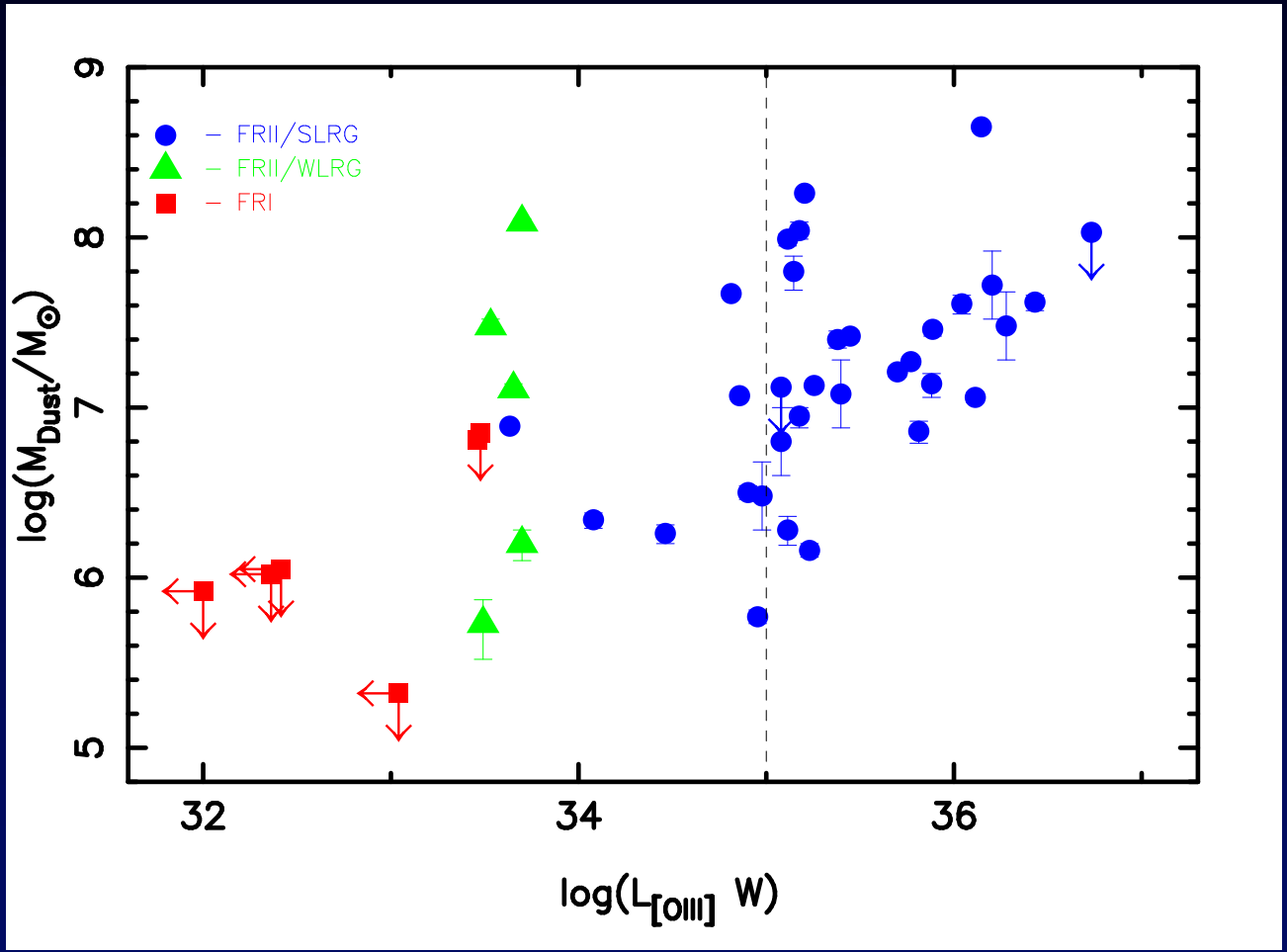
- Plotting dust mass against [OIII] luminosity – AGN power indicator
- For strong line radio (FRII) galaxies there appears to be a correlation between AGN power
- This indicates the AGN is “aware” of the global dust content of the galaxy for these powerful radio objects



Summary

- Deep Multi-wavelength data sets are important for interpreting far-infrared emission (tracers of AGN and star formation)
  - In radio sources in particular to account for non-thermal contamination
  - And generally to account for blended sources – important at high-z
- Dust mass estimates for radio galaxies put them somewhere between elliptical galaxies and ULIRGs
- All the evidence points away from the idea that powerful radio galaxies are triggered at the peak of major gas rich mergers
- Dust masses found in radio galaxies are equivalent to low mass galaxies (2xLMC) – indicates minor mergers are sufficient to trigger and fuel the AGN