The Far-Infrared-Radio Correlation and SEDs of Massive Star-Forming Galaxies Over the Last 10 Billion Years

N. Bourne, L. Dunne, S.J. Maddox
University of Nottingham, UK

R.J. Ivison
University of Edinburgh, UK

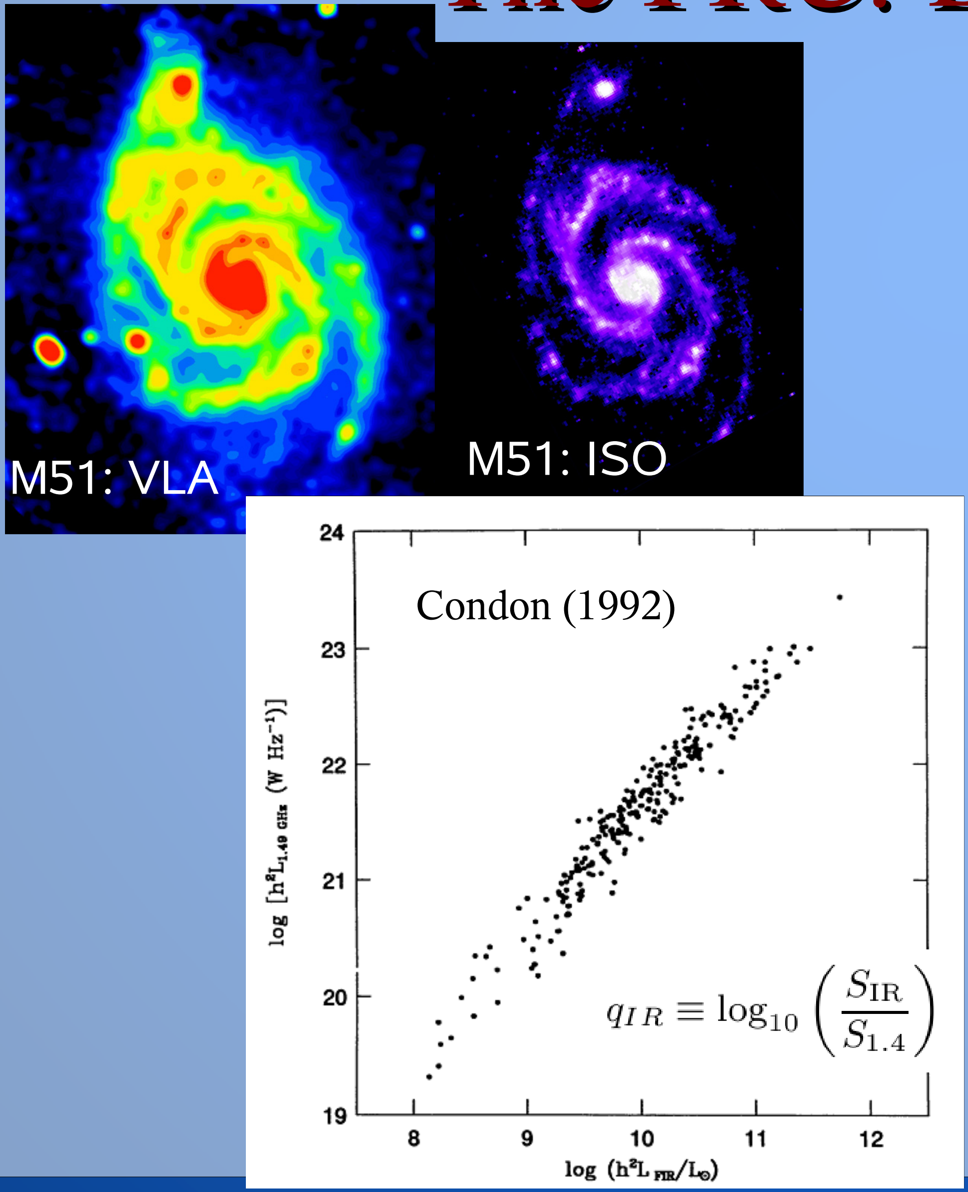
M. Dickinson
NOAO, Tucson, USA

D. Frayer
Spitzer Science Center, California Institute of Technology, USA

Summary

- Background to the FIR-Radio Correlation
- My work:
  - Sample selection
  - Stacking technique
  - Corrections and considerations
- Results and discussion:
  - Radio properties
  - IR Spectral Energy Distributions
  - K-corrections
  - FRC evolution
- Conclusions

The FRC: Background



- Helou, Soifer & Rowan-Robinson (1985):
  - large IRAS sample revealed universality and tightness of the FIR/radio correlation in disks of spiral galaxies and starburst nuclei
- Later shown to hold over 5 orders of magnitude for local galaxies (e.g. Yun, Reddy & Condon 2001)

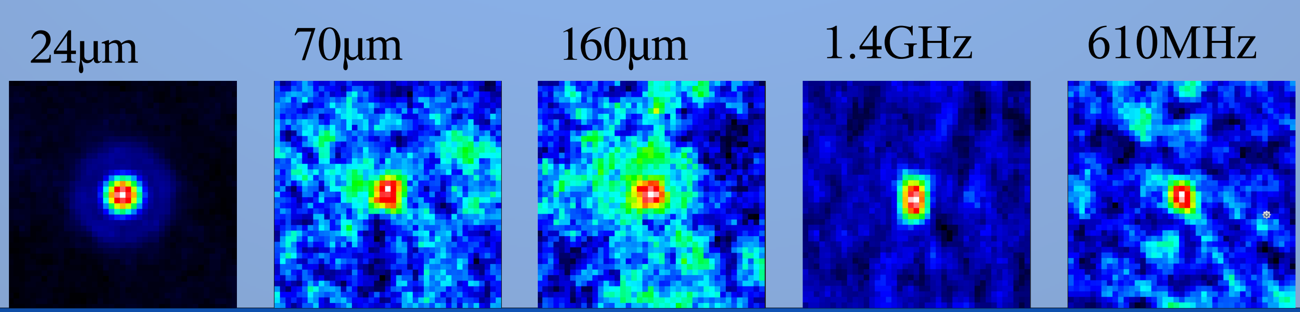
The FRC: Open Questions

- How to explain the tight correlation between thermal dust emission and non-thermal radio?
- “Conspiracy Theories”

- What does the FRC tell us about star-formation in high redshift galaxies?

Data and Method

- 3500 IRAC-selected galaxies in the ECDFS
- Photo-z's from COMBO-17 and EAZY
- FIR imaging from Spitzer MIPS (FIDEL survey) at 24, 70, 160μm
- Radio imaging at 1.4GHz (VLA) and 610MHz (GMRT)
- Stacking in bins of redshift to trace properties of the 'typical' galaxies in the sample



Clustering, Confusion and Background Subtraction

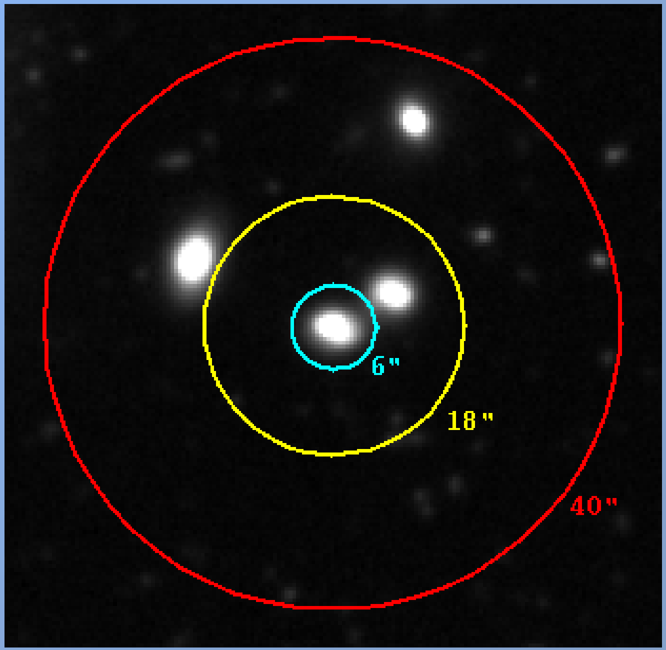
Poor resolution of MIPS imaging + Clustered nature of massive galaxies → Confusion!

- Average fractional confusion flux from a background source:

$$F = n_E \int W_{D,E}(\theta) e^{-\theta^2/2\sigma^2} 2\pi\theta d\theta$$

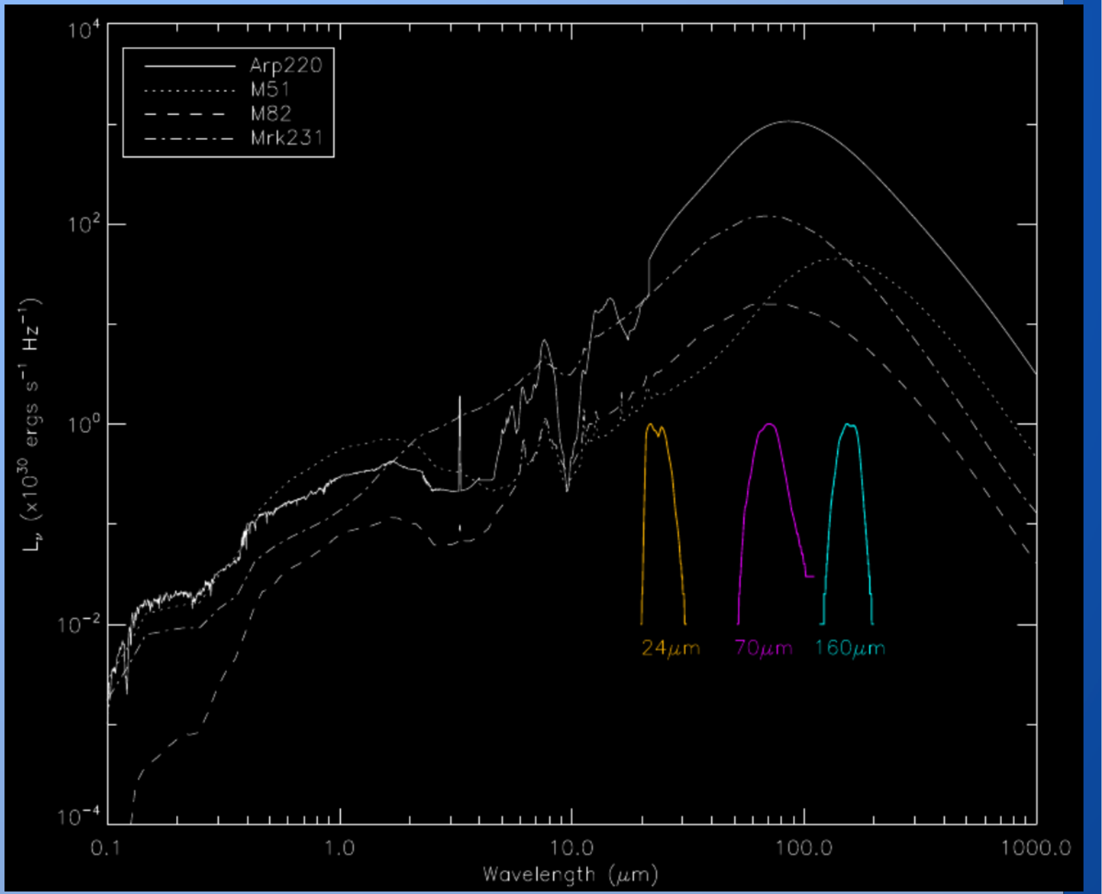
- Modified Landy & Szalay (1993) estimator for correlation function:

$$W_{D,E}(\theta) = \frac{DE - 2\,DR - RR}{RR}$$



K-corrections

- Predicting rest-frame fluxes so that we can compare high and low z
- Radio: simple power law, 2 data points → spectral index
- FIR: complicated SED profile, must try different SED templates and predict behaviour as f(z)



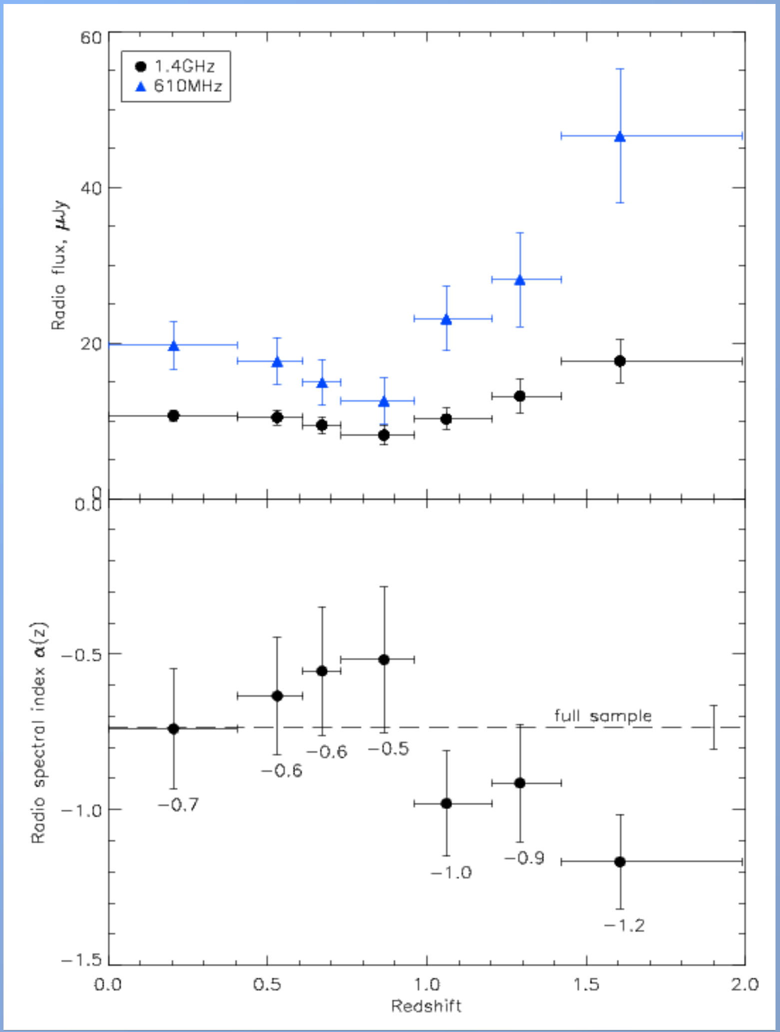
Results: Stacked Radio Fluxes

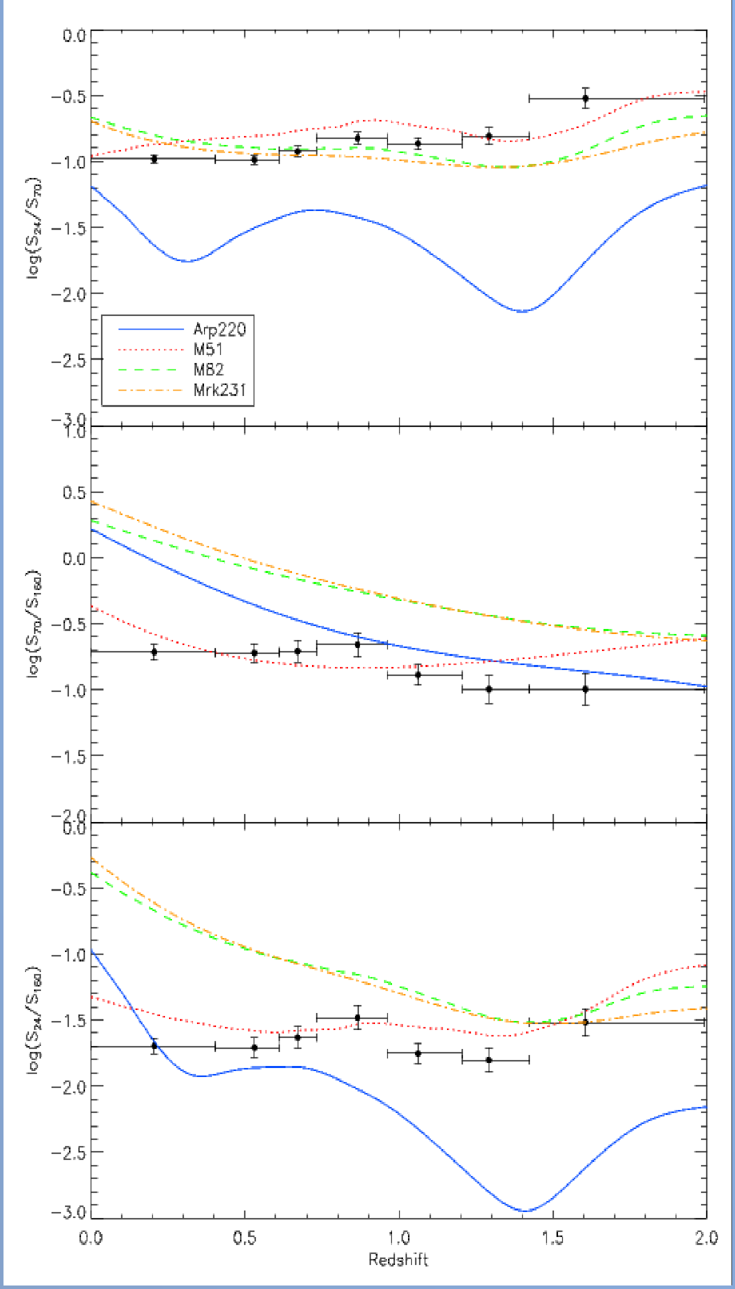
- Empirically determine spectral index and k-corr.
- Evolution of spectral index?
- Increasing radio luminosities with redshift

Bin	$L_{1.4}$, $W Hz^{-1}$	$SFR_{1.4}$, $M_{\odot} yr^{-1}$
ZB0	$(1.26 \pm 0.08) \times 10^{21}$	1.51 ± 0.10
ZB1	$(1.13 \pm 0.10) \times 10^{22}$	13.6 ± 1.2
ZB2	$(1.84 \pm 0.21) \times 10^{22}$	22.1 ± 2.5
ZB3	$(3.00 \pm 0.46) \times 10^{22}$	36.0 ± 5.5
ZB4	$(6.24 \pm 0.84) \times 10^{22}$	75 ± 10
ZB5	$(1.32 \pm 0.22) \times 10^{23}$	158 ± 26
ZB6	$(3.03 \pm 0.47) \times 10^{23}$	364 ± 56

(SFR estimate - Condon 1992)

$$S_{\nu} \propto \nu^{\alpha}$$





Results: FIR SEDs

- Need to use an SED template for k-corrections
- Normal spiral SED best match
- Implies cold dust temperatures and moderate total IR luminosities
- See increasing L_{IR} with z

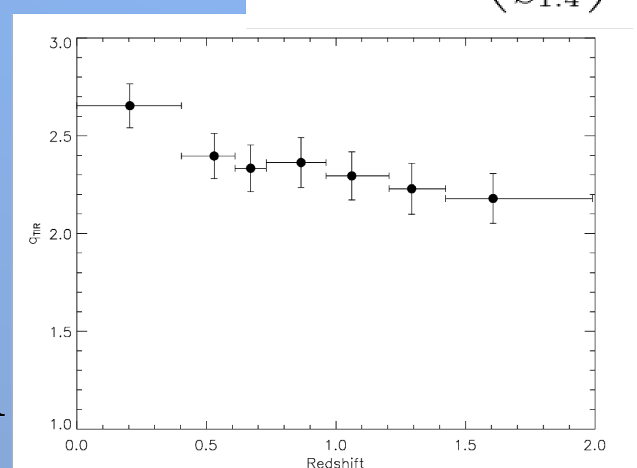
Bin	L_{TIR}, $L_\odot$	q_{TIR}
ZB0	$(0.56 \pm 0.14) \times 10^9$	2.7 ± 0.1
ZB1	$(2.8 \pm 0.7) \times 10^{10}$	2.4 ± 0.1
ZB2	$(3.9 \pm 1.0) \times 10^{10}$	2.3 ± 0.1
ZB3	$(6.8 \pm 1.7) \times 10^{10}$	2.4 ± 0.1
ZB4	$(1.21 \pm 0.30) \times 10^{11}$	2.3 ± 0.1
ZB5	$(2.19 \pm 0.55) \times 10^{11}$	2.2 ± 0.1
ZB6	$(4.49 \pm 1.1) \times 10^{11}$	2.2 ± 0.1

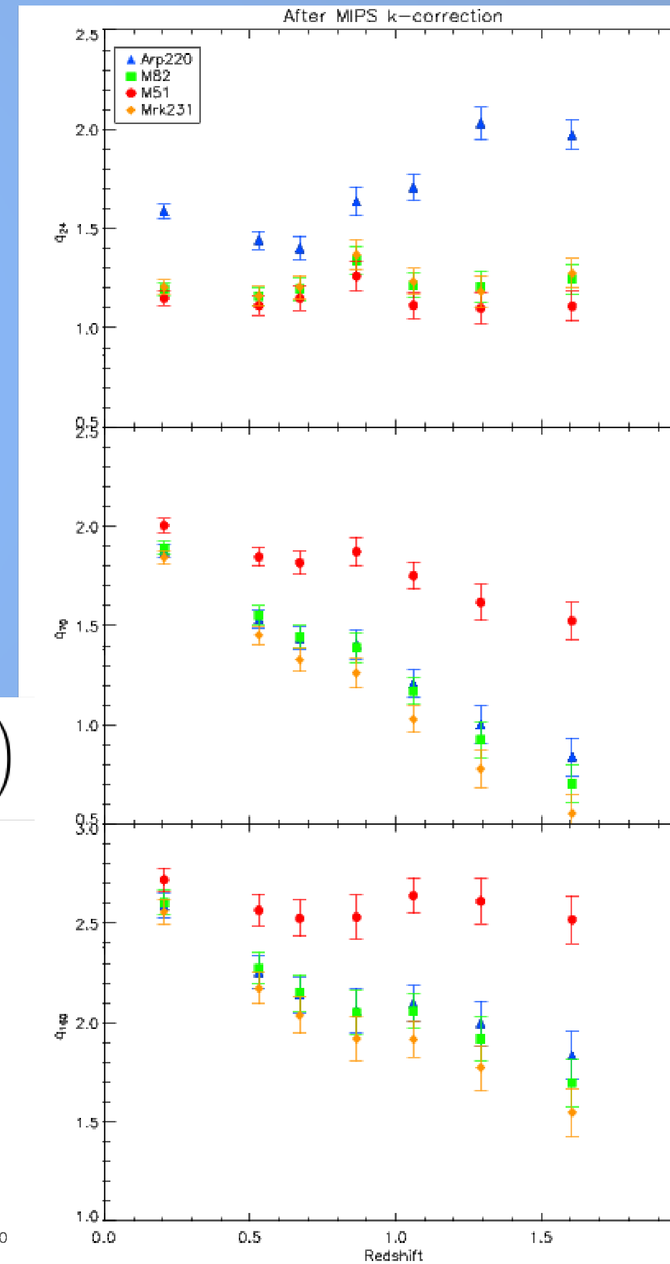
(L_{TIR} conversion – Dale & Helou 1985)

Implications for FRC

- Assuming M51 template (red points) we see no evidence for evolution in q_{24} or q_{160}
- What about q_{70}? Is this due to the SED shape?
- Plotting integrated q_{IR} depends on accuracy of all bands

$$q_{IR} \equiv \log_{10}\left(\frac{S_{IR}}{S_{1.4}}\right)$$





Conclusions

- Stacked FIR and radio images of an IRAC-selected sample as a function of z between 0-2
- Properties of the sample do evolve (radio spectrum, IR & radio luminosities)...
- But cold-dust dominated SEDs throughout
- Do not believe there is evidence for evolution in the FRC, although 70μm fluxes seem less reliable as a tracer than expected