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

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Summary

- Rationale
  - Aims
  - Context
- This work
  - Sample selection
  - Stacking technique
  - Data analysis considerations
- Results and discussion:
  - Radio properties
  - IR Spectral Energy Distributions
  - K-corrections
  - FRC evolution
- Conclusions

Rationale

- The question:

"Does the FIR-Radio Correlation persist to high redshift?"

- ...is addressed by a lot of recent/ongoing research, e.g.
  - Appleton et al. 2004
  - Frayer et al. 2006
  - Ibar et al. 2008
  - Garn et al. 2009
  - Seymour et al. 2009
  - Sargent et al. 2010

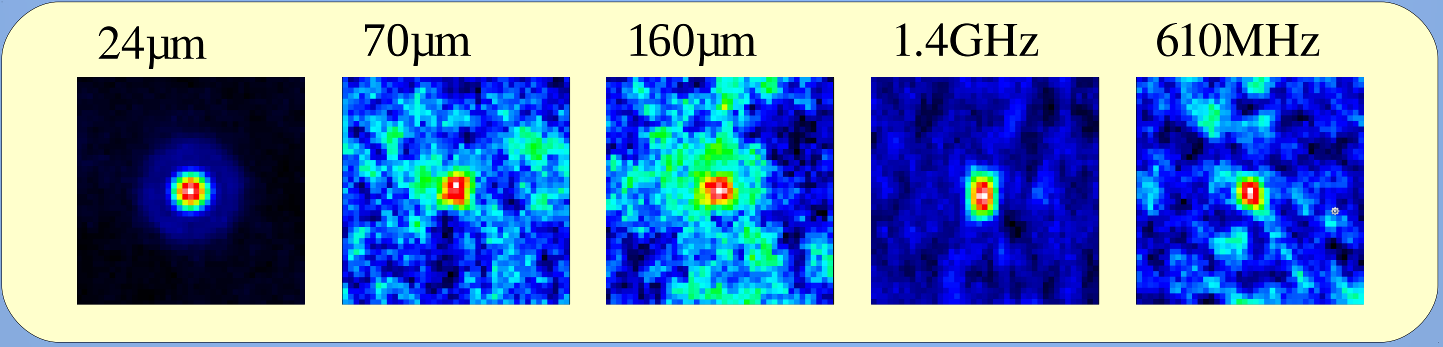
  etc etc ...
- But so far all of these studies have focused on samples selected by flux in the FIR and/or radio bands
- In this study, we want to address the question for a more general sample of massive galaxies selected in the NIR

Sampling and Stacking

- The sample:
  - 3500 IRAC (3.6+4.5μm) selected galaxies in the ECDFS
  - Photo-z's from COMBO-17 and EAZY (Damen et al 2009)
- Stacking into:
  - FIR imaging from Spitzer (FIDEL survey) at 24, 70, 160μm
  - Radio imaging at 1.4GHz (VLA) and 610MHz (GMRT)
- Median-stacking in bins of redshift to trace properties of the 'typical' galaxies in the sample
- Measure FIR-Radio Correlation (FRC) using log ratio of stacked (corrected) fluxes in each bin (i.e. q)

Data Analysis

- We can measure point-source fluxes in the stacked images:



- But in the MIPS data in particular, we must consider these two important effects:
  - Confusion
  - K-corrections

Clustering, Confusion and Background Subtraction

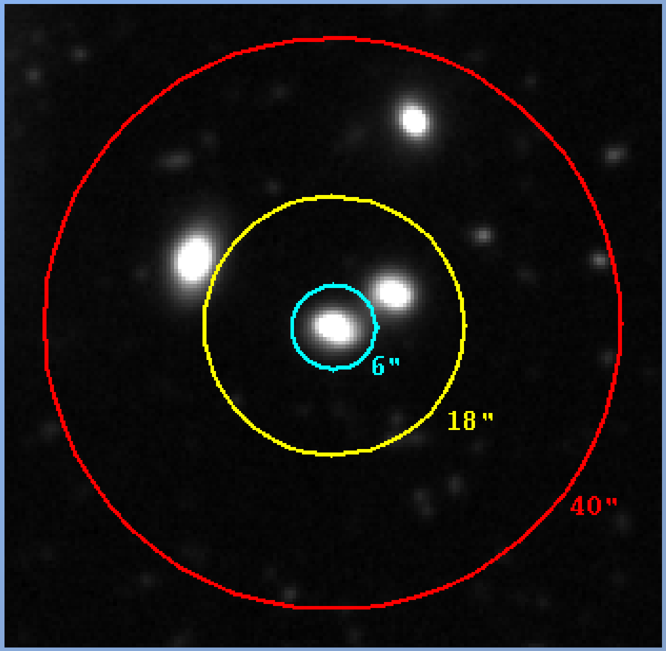
Poor resolution of MIPS imaging + Clustered nature of massive galaxies → Confusion!

- Average fractional confusion flux from a background source:

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

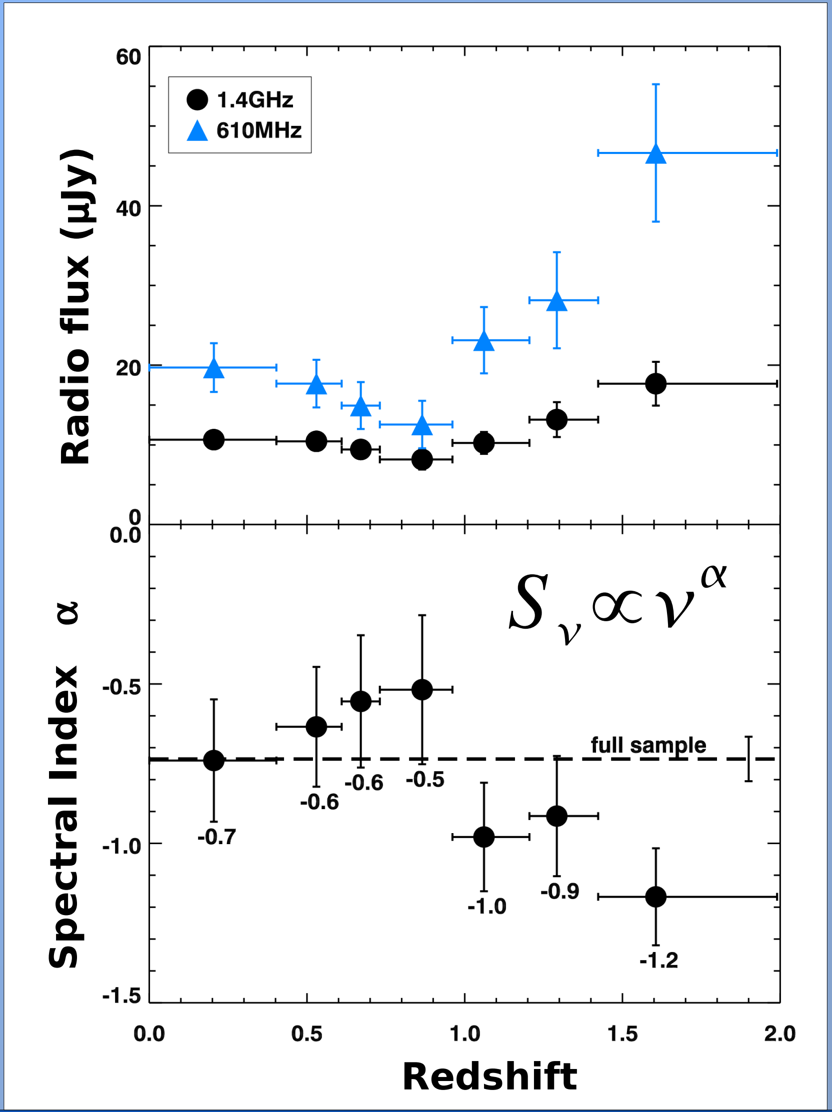
- Modified Landy & Szalay (1993) estimator for correlation function:

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



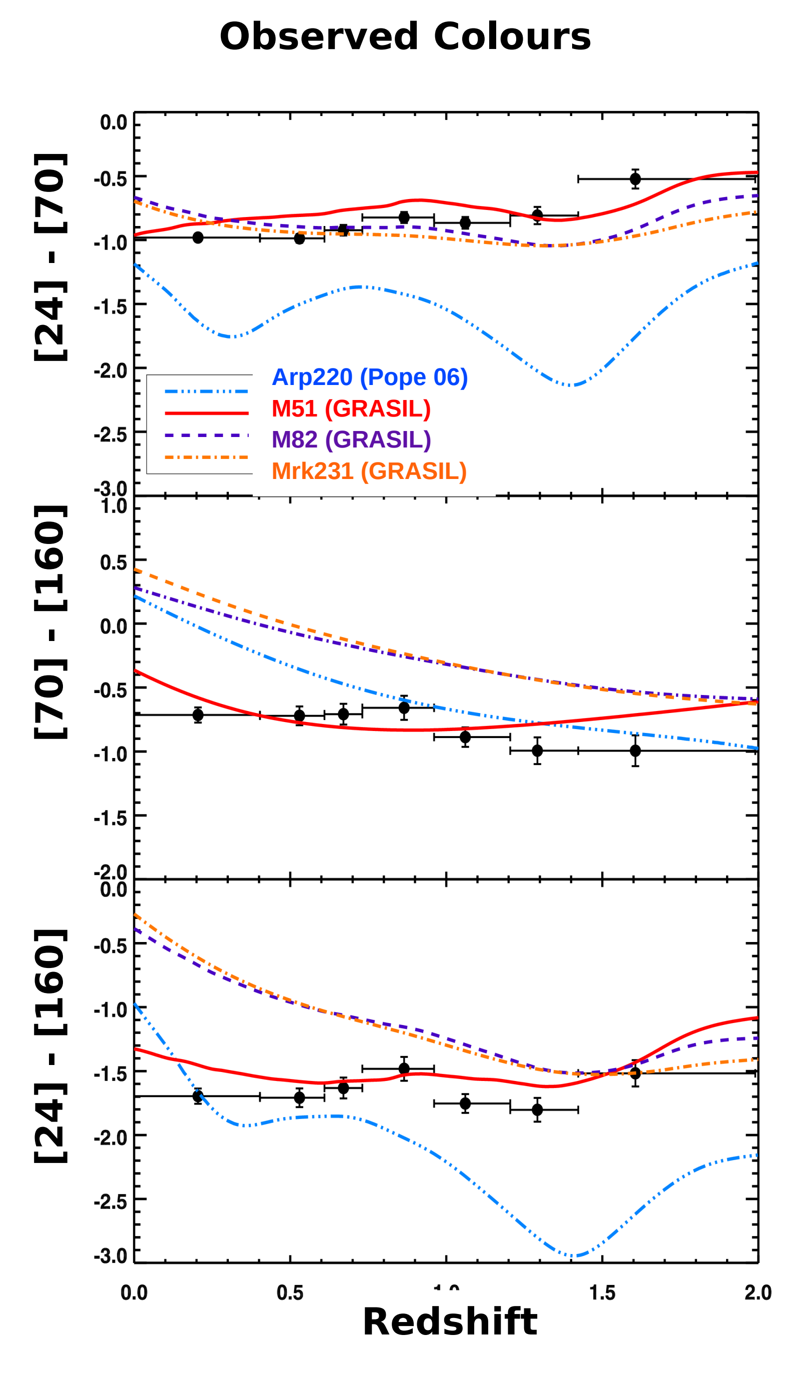
Results: Stacked Radio Fluxes

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



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

(SFR estimate - Condon 1992)



Results: FIR SEDs

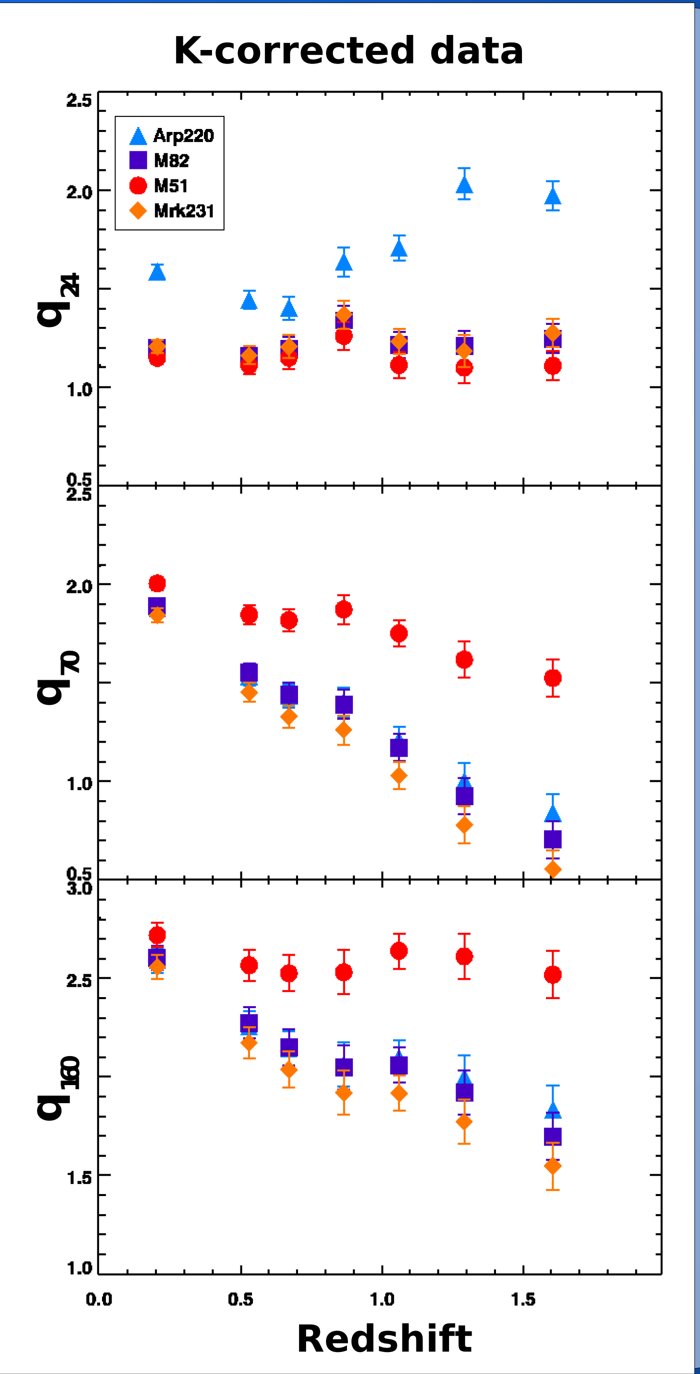
- Need to use an SED template for k-corrections
- Normal spiral SED best match
- Implies cold dust temperatures and moderate total IR luminosities
- See increasing L_{IR} with z

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

(L_{TIR} conversion – Dale & Helou 2002)

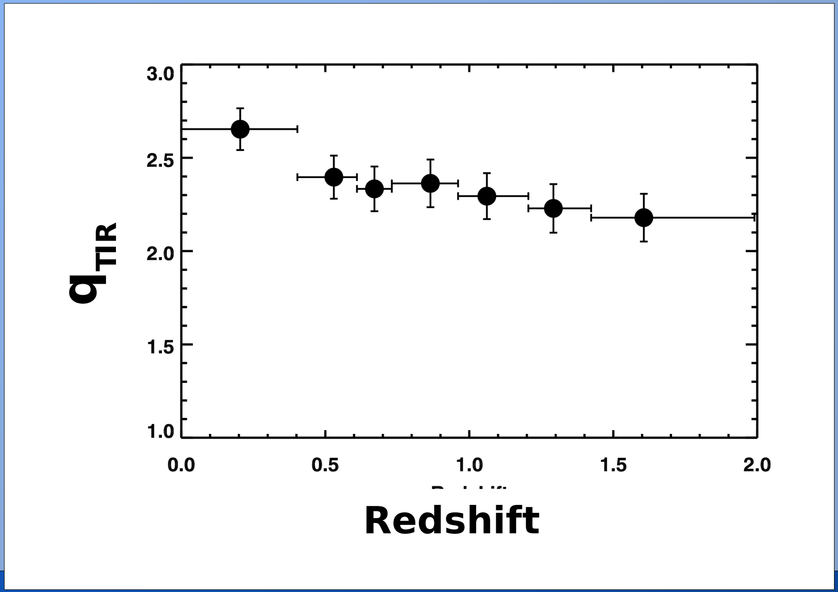
Implications for FRC

- Assuming M51 template (red points) we see no evidence for evolution in q_{24} or q_{160}
- Bump in q_{24} at z≈0.9: 12.7μm PAH or 12.8μm [NeII] (Brandl et al 2006)
- What about q_{70}? Is this due to a steepening 20-70μm slope?
- This spectral range is influenced by contribution from VSGs (e.g. Desert et al. 1990)



In Context

- Lack of evolution in q_{24} echoes other results in the literature, e.g. Appleton et al (2004) & Ibar et al (2008)
- Seymour et al (2009) also find a decreasing q_{70} not accounted for by k-correction
- Using estimated TIR luminosities, we can plot q_{TIR}
  - This depends on the accuracy of all k-corrections
- However these results seem to be comparable with recent results from Ivison et al (2010) and Sargent et al (2010)



In Context

- Our MIPS colours imply cold dust temperatures
- But cold dust temperatures have been observed in many high-z galaxies selected in the sub-mm and FIR bands
  - e.g. Chapman et al. (2005), Pope et al. (2006, 2008), Symeonidis et al. (2009)
- This sample probes a different population to other studies of the FRC – the IRAC selected sample is characterised by lower SFR and lower L_{IR}

Conclusions

- Stacked FIR and radio images of a NIR-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