The Far-Infrared – Radio Correlation in Galaxies at High Redshifts

Plan

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- A brief summary of the FIR-Radio correlation in the literature
- My own work – aims and methodology
- My results so far
- Implications of my results
- What I plan to do next

The FIR-Radio Correlation

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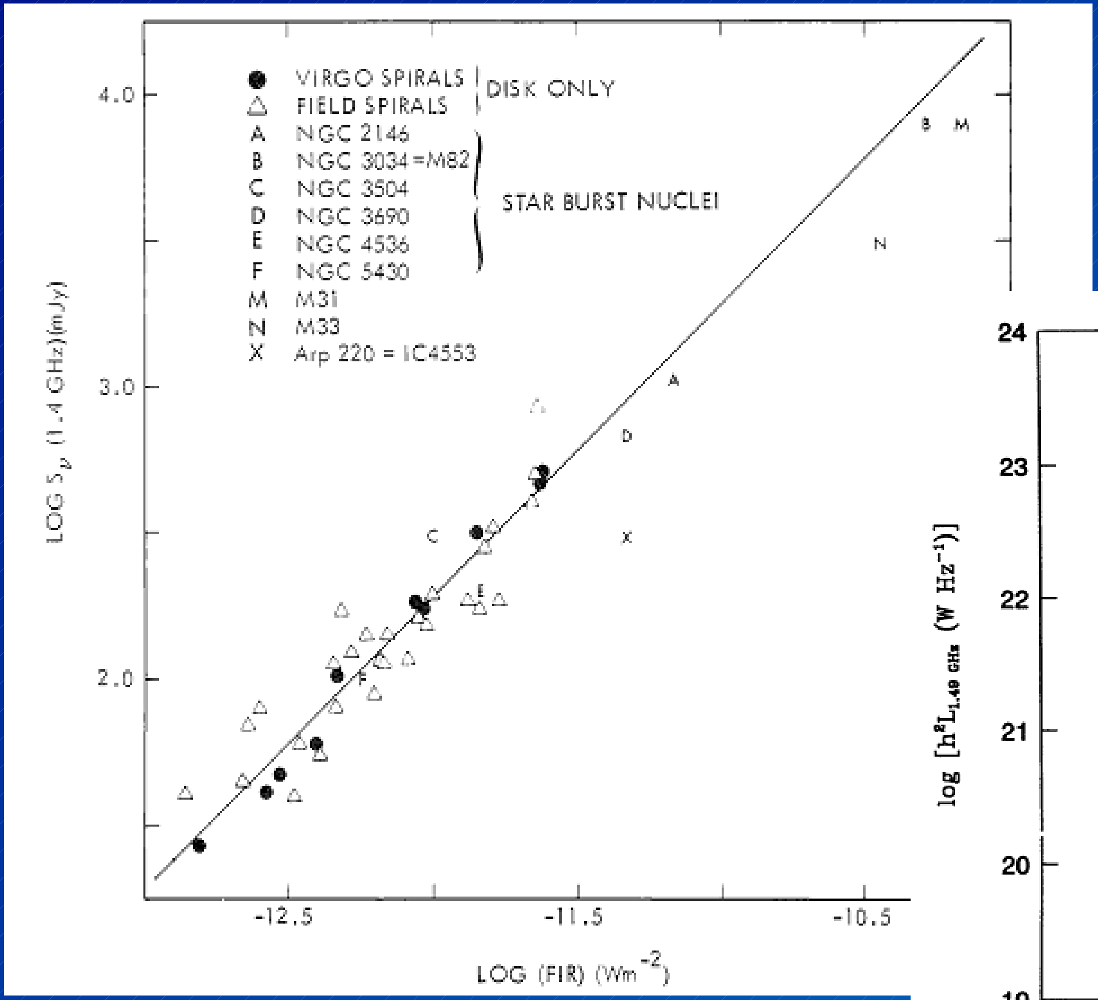
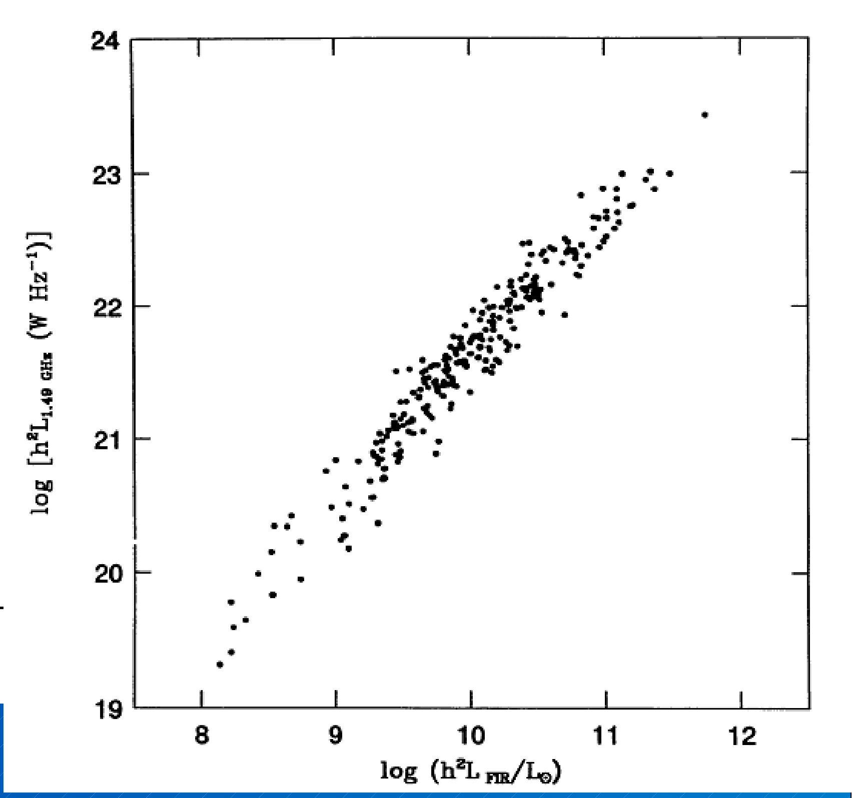
- Ven der Kruit (1971): correlation between mid-infrared and radio luminosities of Seyfert nuclei
- Van der Kruit (1973); Condon (1982); Rickard and Harvey (1984): correlation exists for ordinary spirals too
- Helou, Soifer, Rowan-Robinson (1985): large IRAS sample revealed universality and tightness of the correlation in disks of spiral galaxies and nuclei of starbursts
- Link with star formation…

The FIR-Radio Correlation





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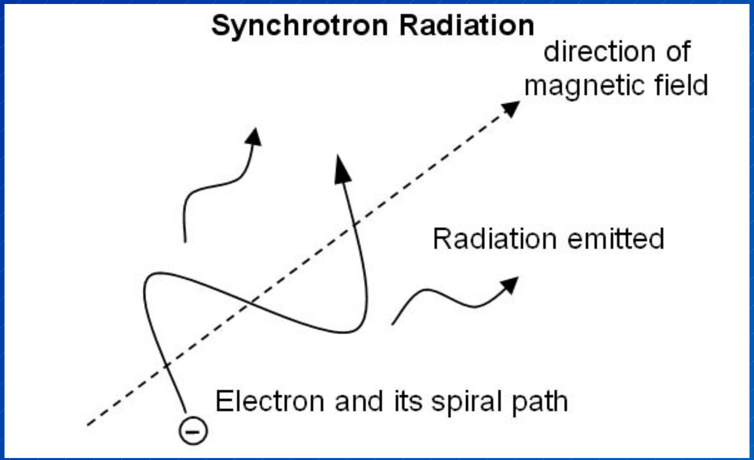
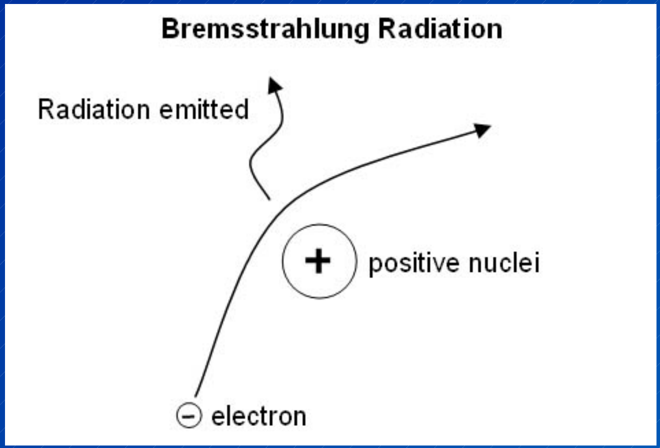
Radio non-thermal emission mechanisms



- Synchrotron radiation
  - Relativistic electrons
  - Accelerated in SNR
  - Magnetic fields in SNR



- Free-free emission

Figures credit: http://www.jeffstanger.net/Astronomy/emissionprocesses.html

Radio non-thermal emission mechanisms

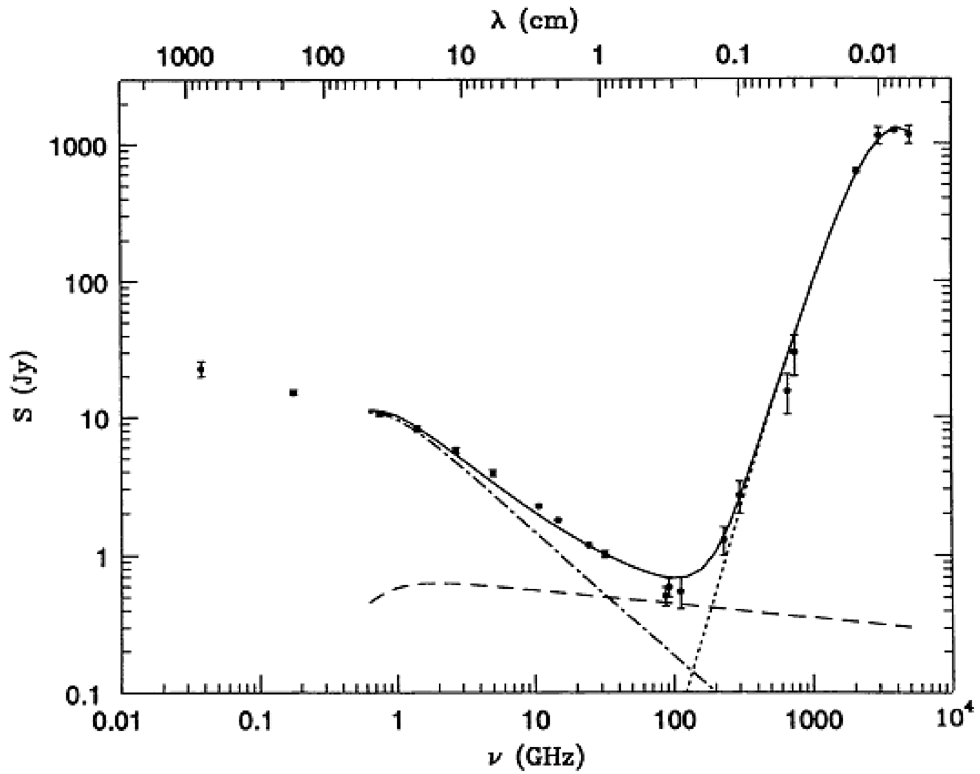


Figure 1 The observed radio/FIR spectrum of M82 (Klein et al 1988, Carlstrom & Kronberg 1991) is the sum (*solid line*) of synchrotron (*dot-dash line*), free-free (*dashed line*), and dust (*dotted line*) components. The H II regions in this bright starburst galaxy start to become opaque below $\nu \sim 1$ GHz, reducing both the free-free and synchrotron flux densities. The free-free component is largest only in the poorly observed frequency range 30–200 GHz. Thermal reradiation from $T \sim 45$ K dust with opacity proportional to $\nu^{1.5}$ swamps the radio emission at higher frequencies. Lower abscissa: frequency (GHz). Upper abscissa: wavelength (cm). Ordinate: flux density (Jy).

- Synchrotron dominates
- Diffuse emission from relativistic electrons with lifetimes ~10 y

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Far-infrared thermal emission mechanism

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- Dust both scatters and absorbs UV radiation from hot, massive stars ($>5M_{\odot}$)
- Absorbed starlight is reradiated as a blackbody spectrum peaking in the FIR
- Massive stars are short-lived so FIR emission implies recent/ongoing star formation
- Therefore FIR luminosity is a good tracer of star-formation rate

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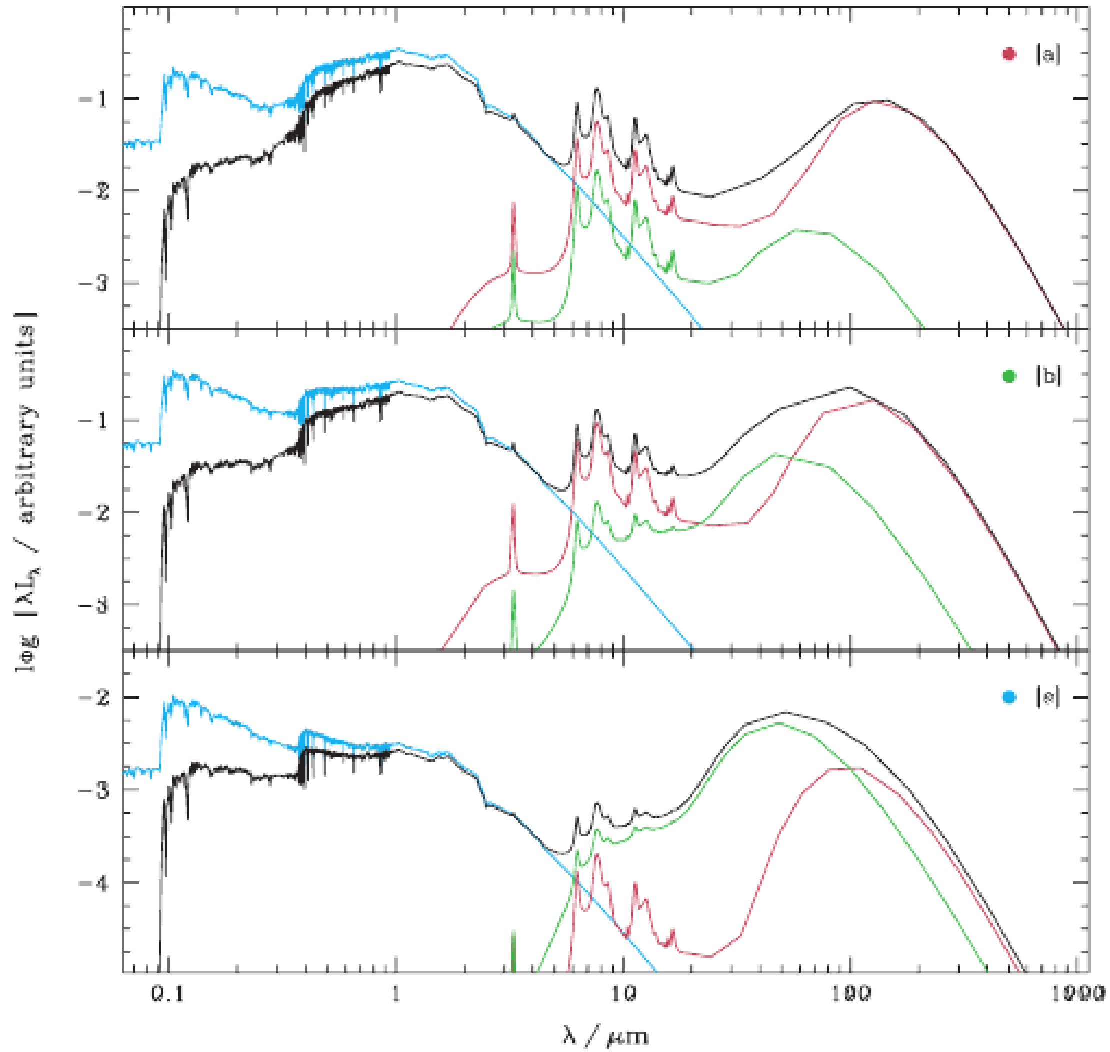

Figure 5. Examples of spectral energy distributions obtained by combining the infrared models of Table 1 with attenuated stellar population spectra corresponding to the same contributions by dust in stellar birth clouds ($1 - f_{\mu}$) and in the ambient ISM (f_{μ}) to the total energy L_{d}^{tot} absorbed and reradiated by dust (Section 2.3). (a) Quiescent star-forming galaxy spectrum combined with the 'cold' infrared model of Table 1; (b) normal star-forming galaxy spectrum combined with the 'standard' infrared model of Table 1; (c) starburst galaxy spectrum combined with the 'hot' infrared model of Table 1 (see text for details about the parameters of the stellar population models). Each panel shows the unattenuated stellar spectrum (blue line), the emission by dust in stellar birth clouds (green line), the emission by dust in the ambient ISM (red line) and the total emission from the galaxy, corresponding to the sum of the attenuated stellar spectrum and the total infrared emission (black line).

– *Figure from Da Cunha et al. (2008) MNRAS 388, 1595*

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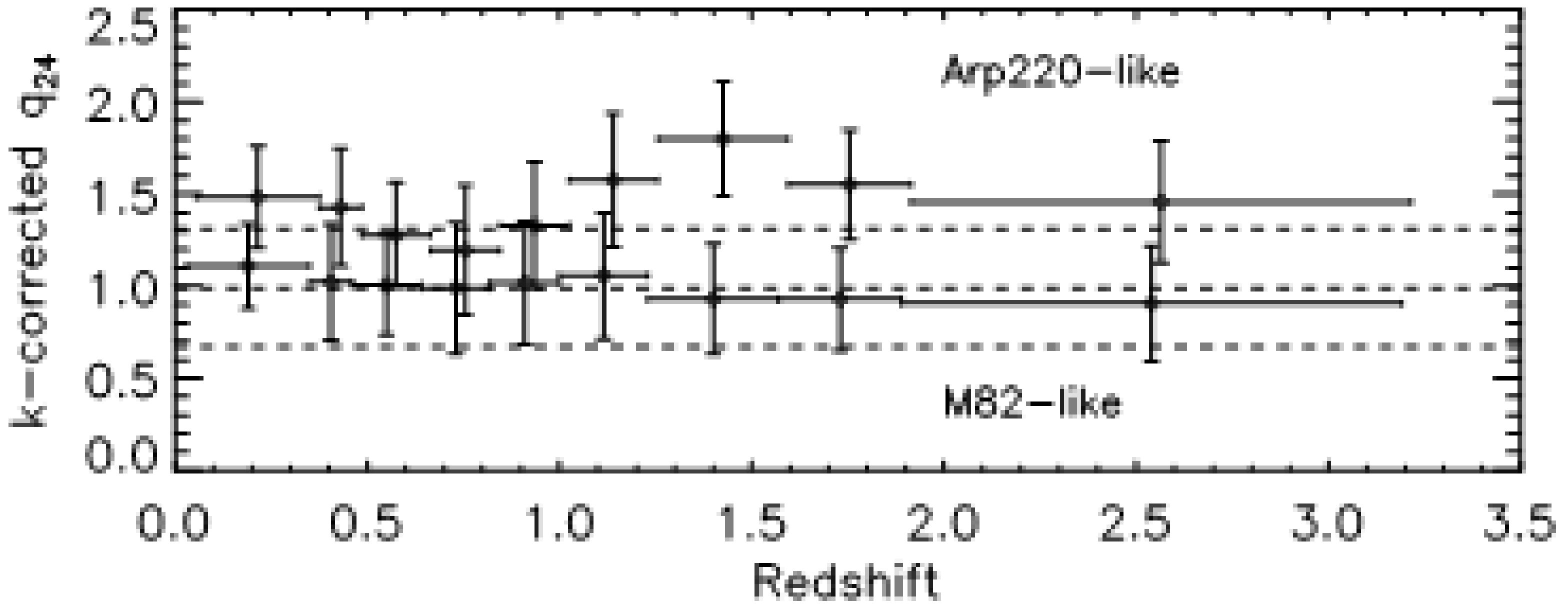
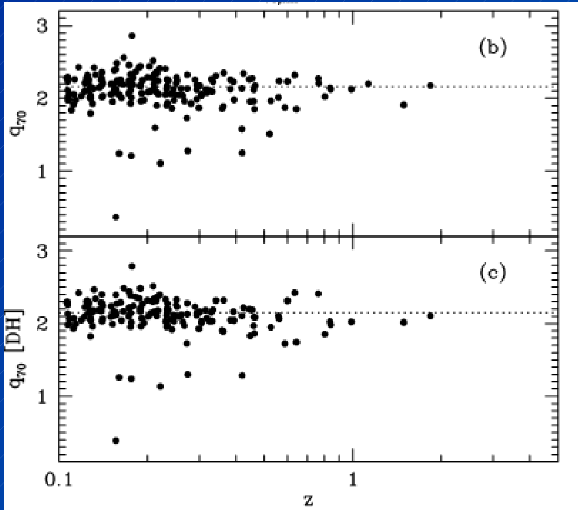
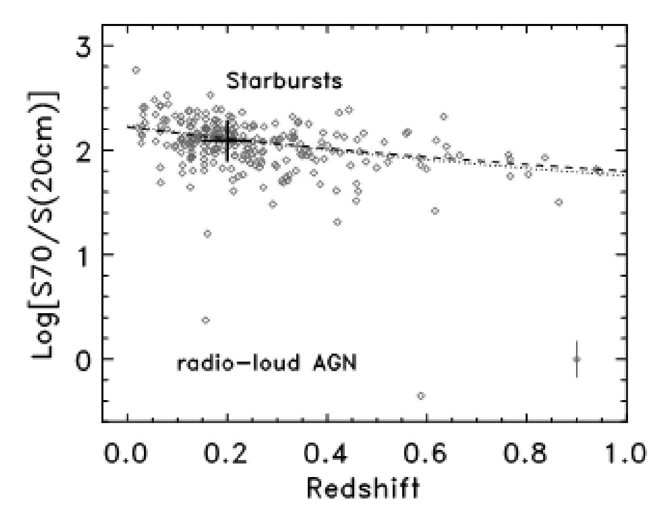


Ibar et al. (2008) MNRAS 386, 953

- E.g. Appleton et al. (2004); Frayer et al. (2006)





- Correlation could remain roughly constant, but might be evolving

Extending the correlation to the high redshift universe

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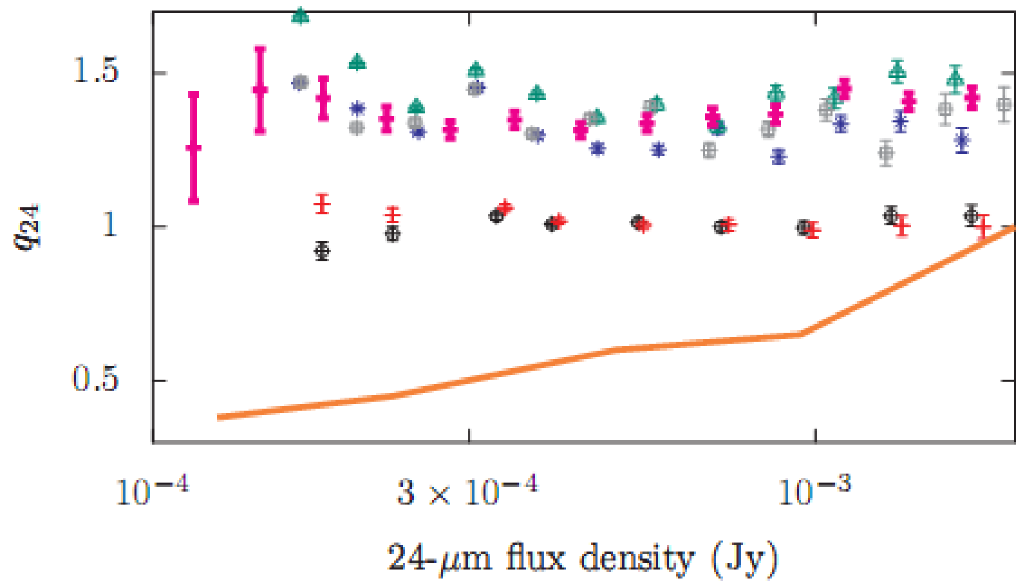

Figure 11. A comparison of all of the stacking results discussed in this work, using data shifted to 1.4 GHz where appropriate through the use of Equation 4 and $\alpha = 0.8$. The stacking results from this work are given by thin data points with error bars, with the VLA xFLS image (black circles), GMRT xFLS image (red upright crosses), GMRT ELAIS-N1 image (blue stars), GMRT ELAIS-N2 image (green triangles), and GMRT Lockman Hole image (grey squares) being shown, along with results from the Boyle et al. (2007) ATCA CDFS image (thick pink points; 'all-source' data) and the Beswick et al. (2008) MERLIN+VLA HDF-N image (thick orange solid line). All error bars represent the error on the median value of radio flux density.

My Research

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- Aim to understand the evolution of the correlation over redshifts $0<z<2$
- Stacking NIR-selected sources in 3 Spitzer MIPS bands and 2 radio bands
- Hope to constrain the SEDs of the galaxies in order to reduce uncertainty in the FIR fluxes
- Additional BLAST data at 250-500μm will help to constrain the shape of the dust peak

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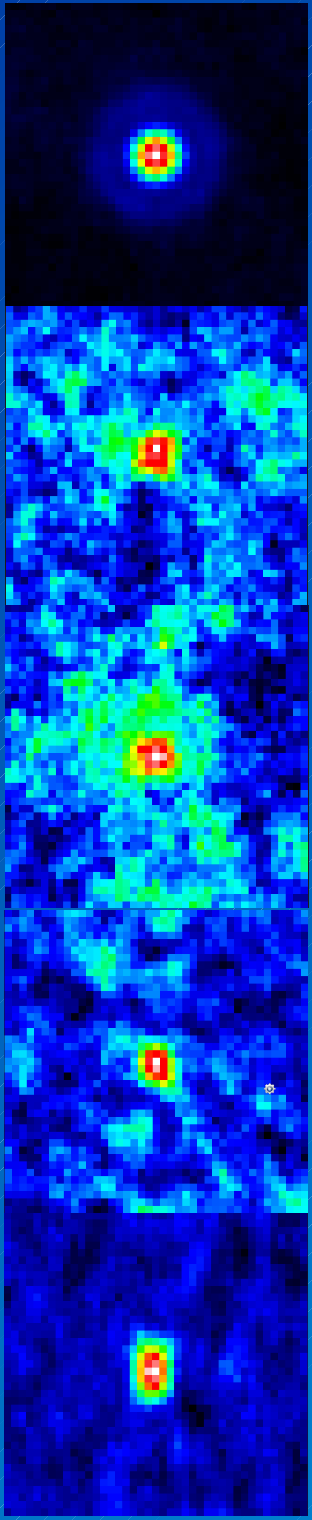
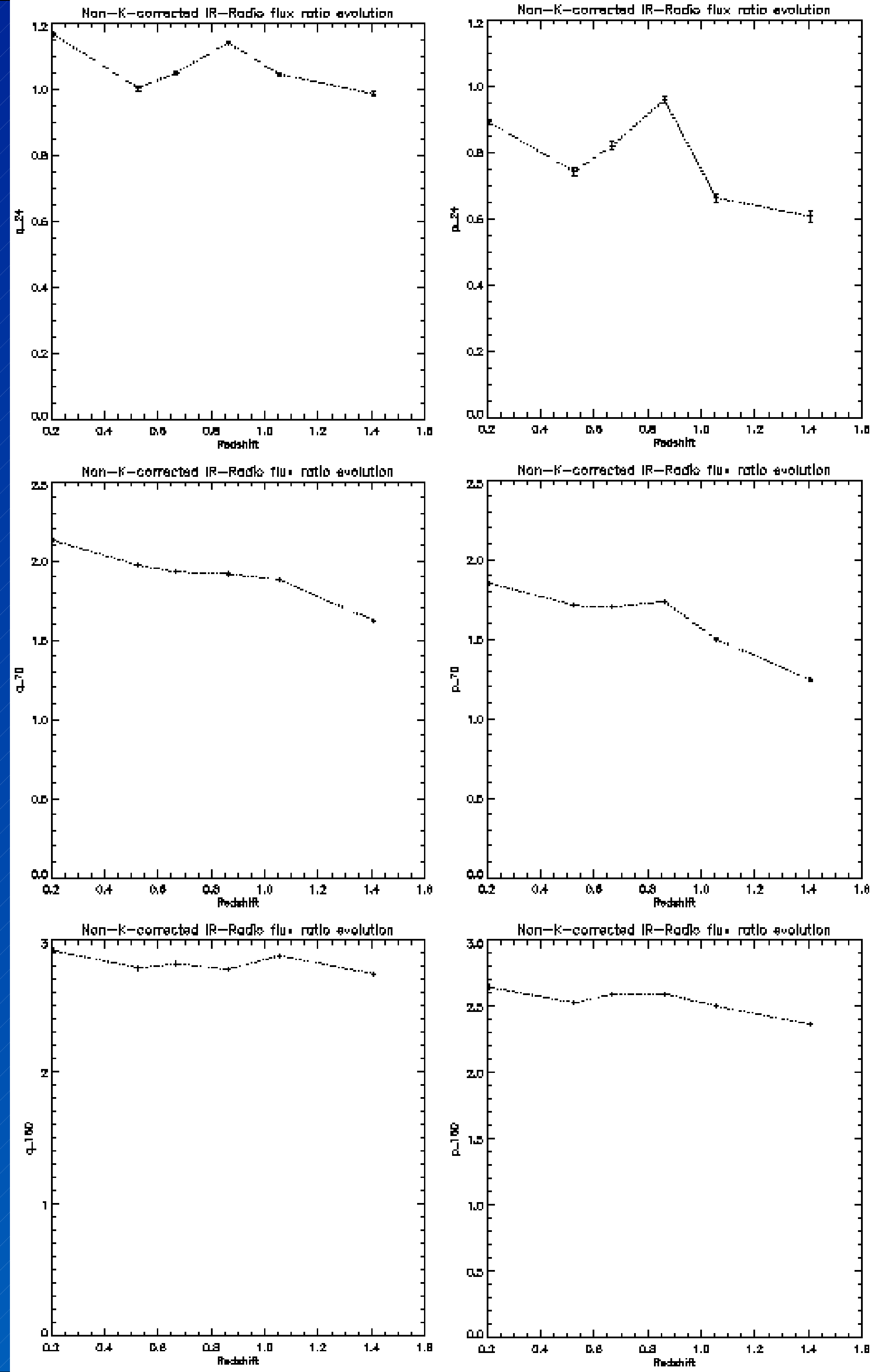
Stacking technique

- 3,500 galaxies selected in the NIR
  - This selection favours high stellar mass but is relatively unbiased towards population, star formation rate, and dust content
  - X-ray detected AGN are removed
  - Photometric redshifts from COMBO-17
- Objects are divided into redshift bins and stacked in 24, 70, 160μm, 610MHz, and 1.4GHz maps
- Fluxes measured in apertures in 24μm image; and using corrected peak pixel flux in other bands



Results

- Median q-value in each redshift bin, for each MIPS and radio band
- Before k-correction:
  - Evolution may be a real effect
  - Could result from slope of SED



K-corrections

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- As you observe objects at higher redshifts, you are sampling the SED in an increasingly bluer band
- In the FIR, the window is shifted further into the MIR, away from the dust peak
- You have to correct for the difference between the redshifted flux observed by your filter and what would be observed if it were not redshifted
- This ensures that at different redshifts you are comparing like with like
- So in order to interpret the data correctly you need to have good knowledge of the shape of the SED

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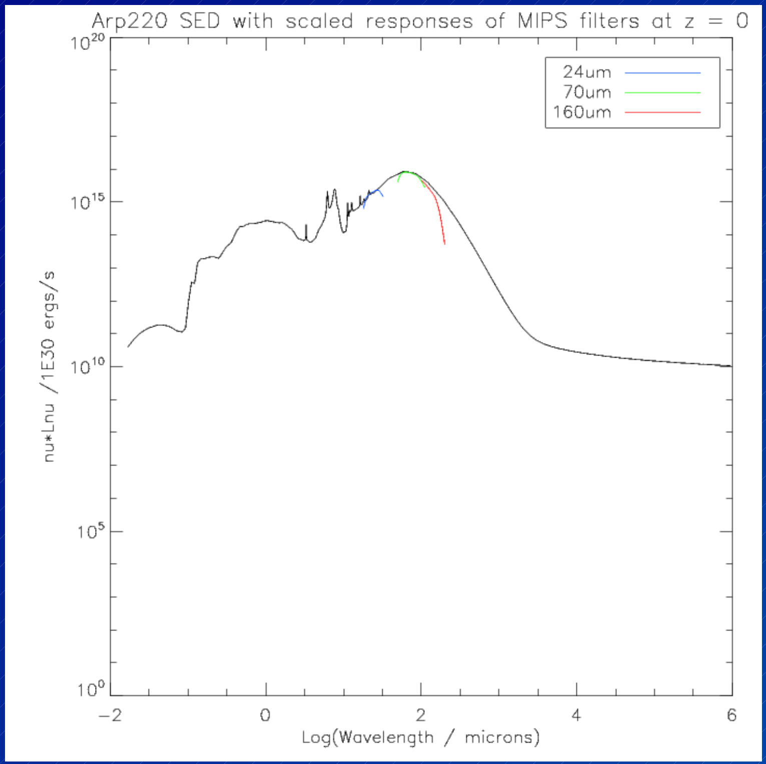

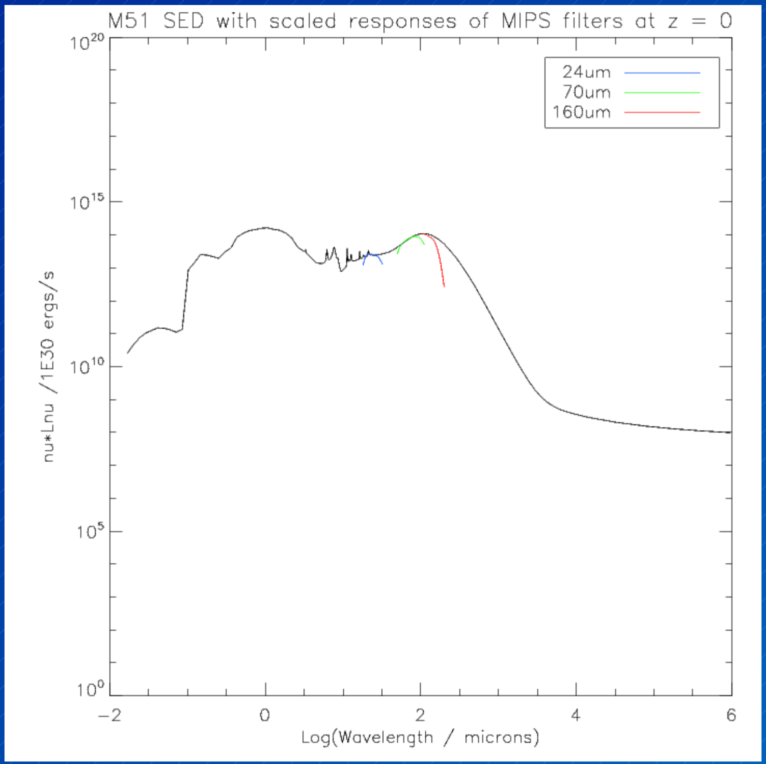

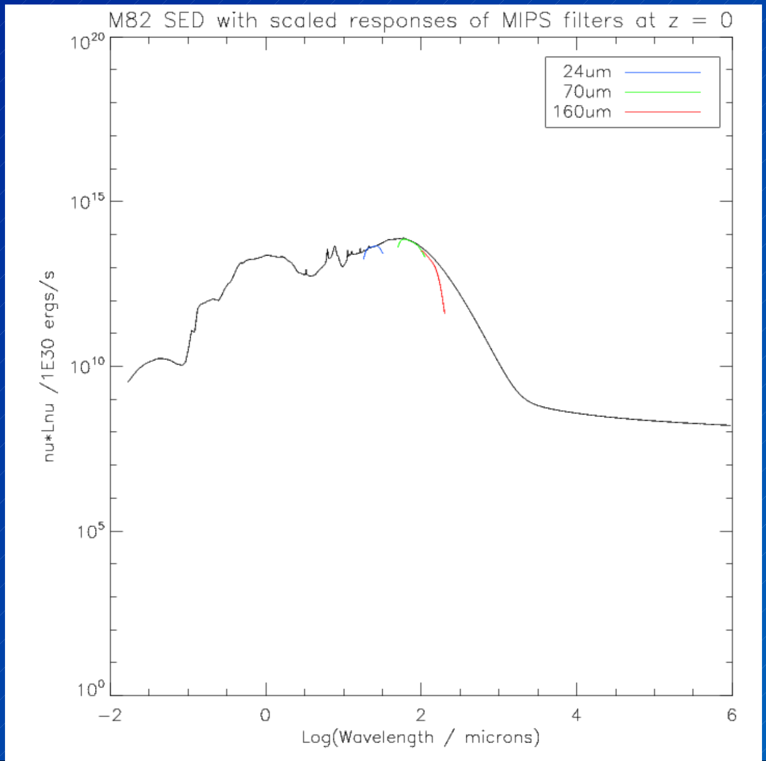

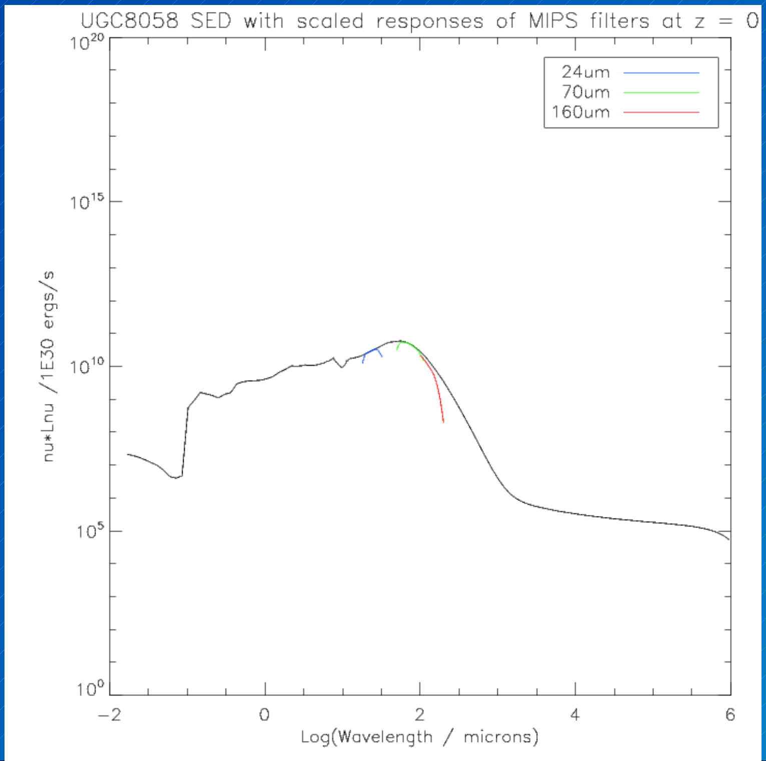

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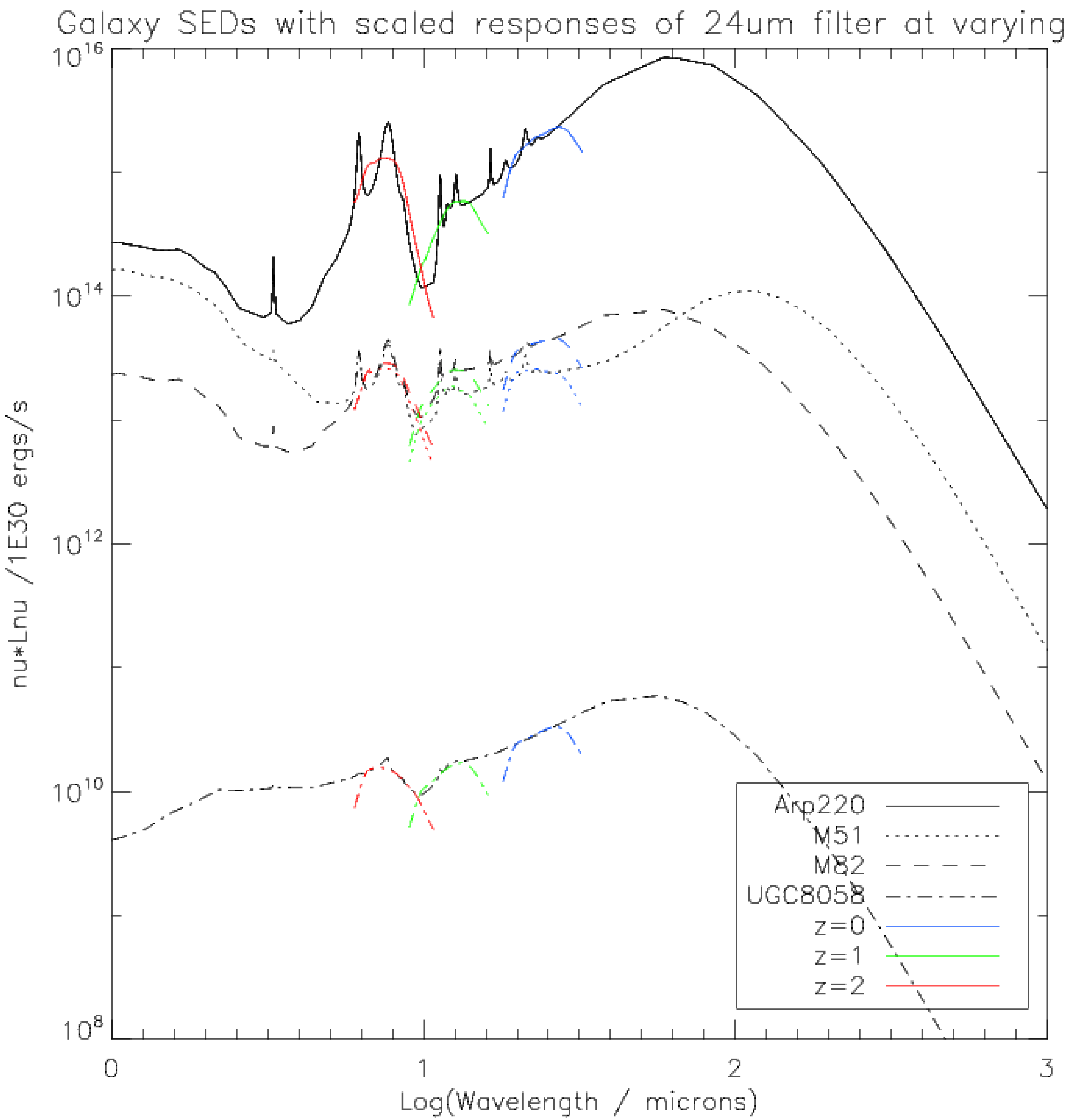

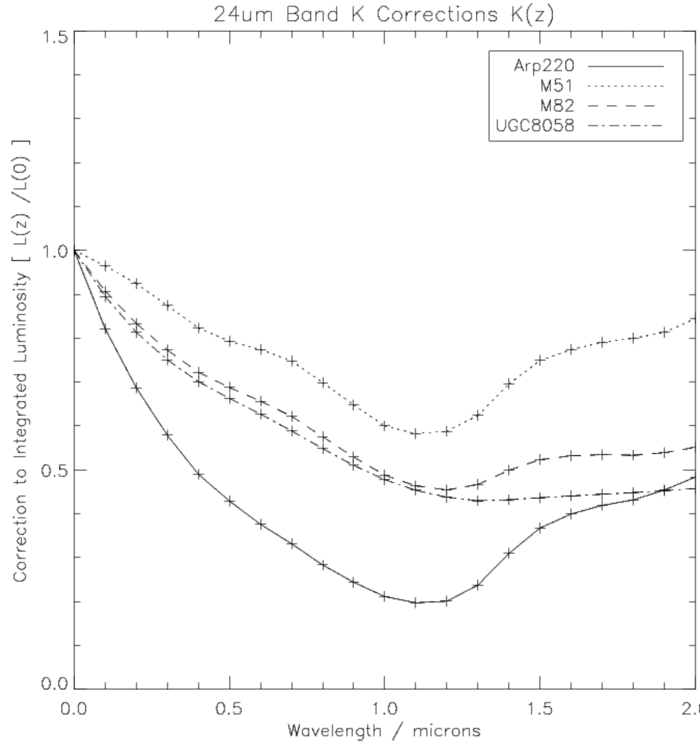

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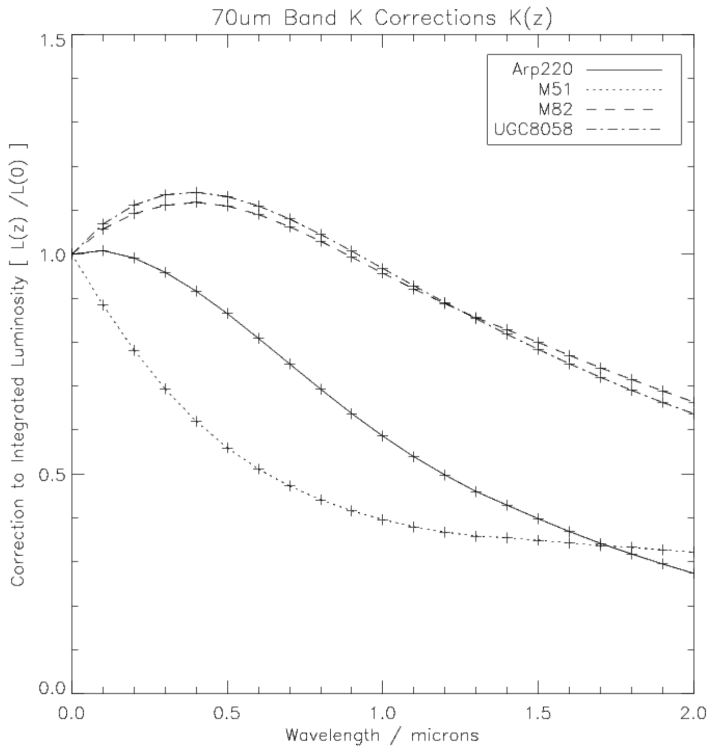

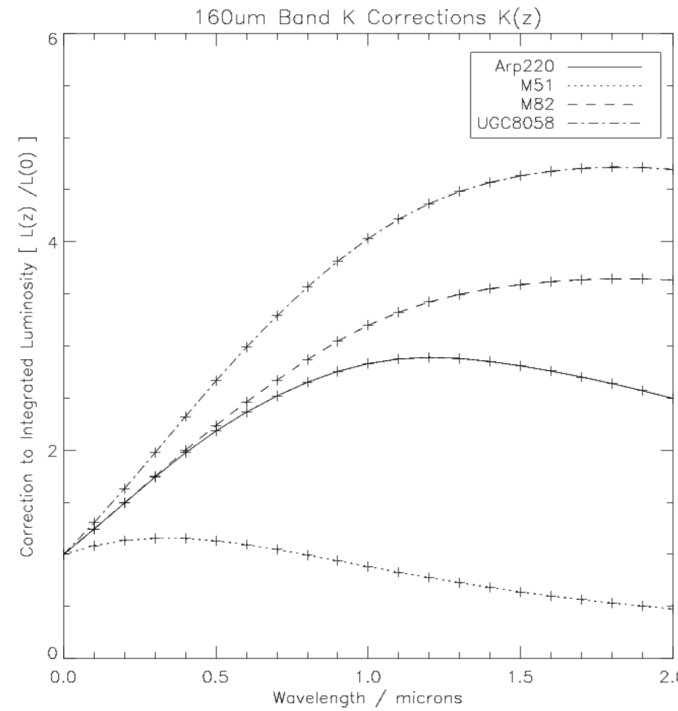

K-corrected Results

- Choice of SED has a significant impact
- Any interpretation of a trend must be taken with a large pinch of salt
  - ...until the SED has been more fully studied

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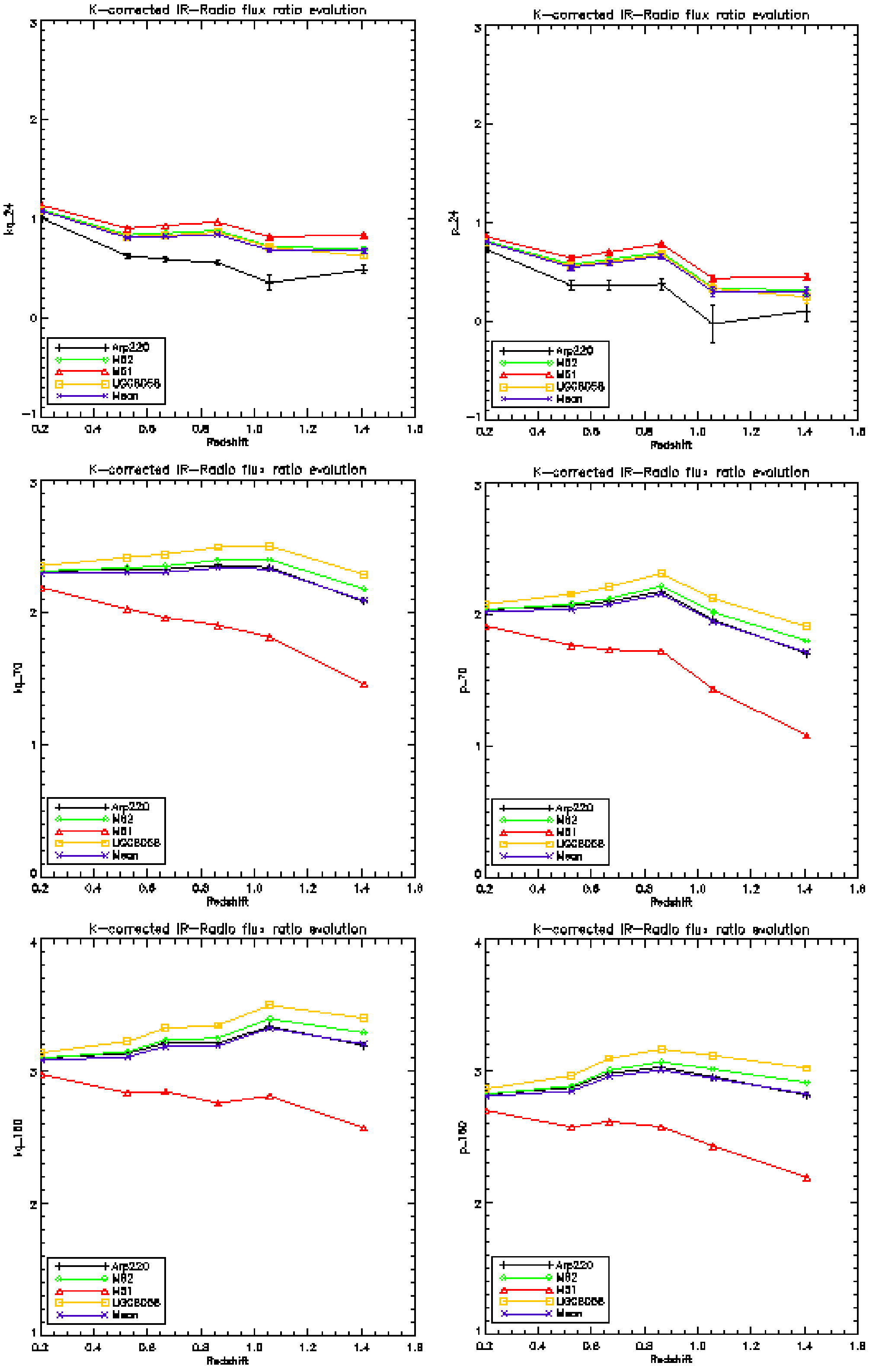
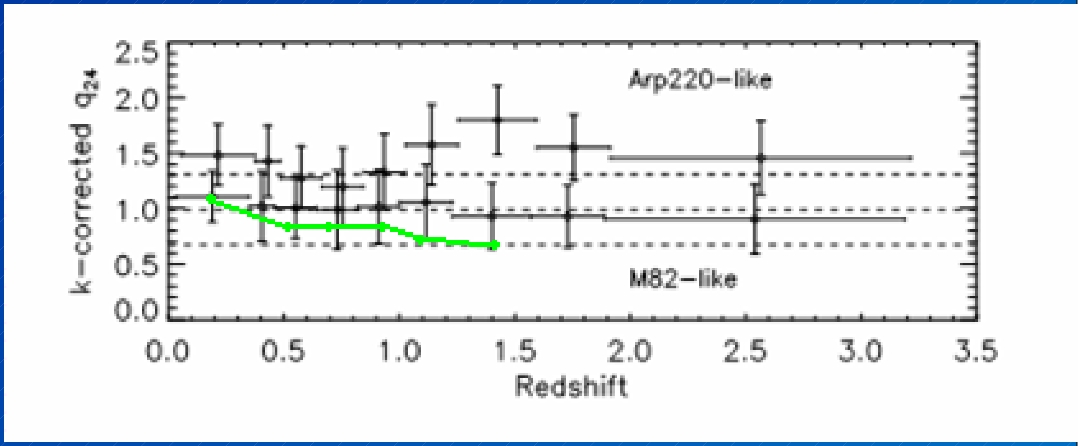
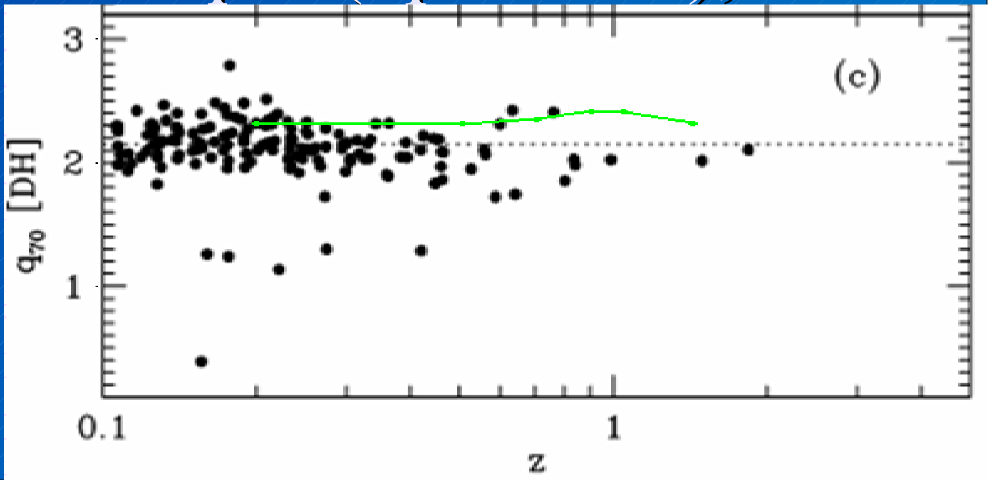


Context of my results

- M82-like K-correction often used
- Under this assumption my results show a decline in q24, unlike Ibar et al. (2008), but not inconsistent



- …and a roughly constant q70 (up to z=1), similar to Appleton et al. (2004)



Future Work

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- A more detailed breakdown of my sample
- With additional data from BLAST I will be able to study stacked SEDs to get more reliable k-corrections
- This would provide a better knowledge of the dust temperatures and star formation rates in these galaxies
- Compare the correlation of integrated IR luminosity to radio

Summary

- FIR and radio fluxes of galaxies are remarkably tightly correlated over a wide range of galaxy types, with different star-formation rates, dust composition and temperature, etc
- If it is unchanged at high redshifts this implies similarity between galaxies in the early and late universe
- Detection of any evolution is as yet uncertain and requires understanding of the SED

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