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Investigations of dust heating in M81, M83 and NGC 2403 with Herschel and Spitzer

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Abstract. We use Herschel Space Observatory and Spitzer Space Telescope 70-500 μm data along with ground-based optical and near-infrared data to understand how dust heating in the nearby face-on spiral galaxies M81, M83, and NGC 2403 is affected by the starlight from all stars and by the radiation from star-forming regions. We find that 70/160 μm flux density ratios tend to be more strongly influenced by star-forming regions. However, the 250/350 and 350/500 μm micron flux density ratios are more strongly affected by the light from the total stellar populations, suggesting that the dust emission at >250 μm originates predominantly from a component that is colder than the dust seen at <160 μm and that is relatively unaffected by star formation activity. We conclude by discussing the implications of this for modelling the spectral energy distributions of both nearby and more distant galaxies and for using far-infrared dust emission to trace star formation.

Keywords. galaxies: ISM, infrared: general

1. Introduction

After the completion of the all-sky surveys by the Infrared Astronomical Satellite, astronomers have found conflicting evidence for the heating sources of the dust producing far-infrared emission in nearby galaxies. Some authors claimed that the dust was heated primarily by star formation (e.g. Devereux & Young 1990; Buat & Xu 1996) while others indicated that evolved stellar populations could heat the dust (e.g. Sauvage & Thuan 1992; Walterbos & Greenawalt 1996). This issue has become more important since the launch of the *Herschel* Space Observatory (Pilbratt *et al.* 2010). *Herschel* has been able to produce high signal-to-noise >200 μm images of both nearby and more distant galaxies, so it will be highly sensitive to colder dust that may have been missed by telescopes primarily observing at shorter wavelengths.

Several papers have been published on the sources of the heating for the dust emitting at *Herschel* wavelengths (e.g. Bendo *et al.* 2010, Rowan-Robinson *et al.* 2010, Boquien *et al.* 2011). We will focus on the results from Bendo *et al.* (2011) on the spiral galaxies M81, M83, and NGC 2403. Their analysis was based on comparing the infrared surface brightness ratios to Hα emission (used as a tracer of star formation) and 1.6 μm emission (used as a tracer of the emission from the total stellar population). The infrared surface brightness ratios depend on dust heating, so they will appear correlated with the emission tracing the dust heating sources.

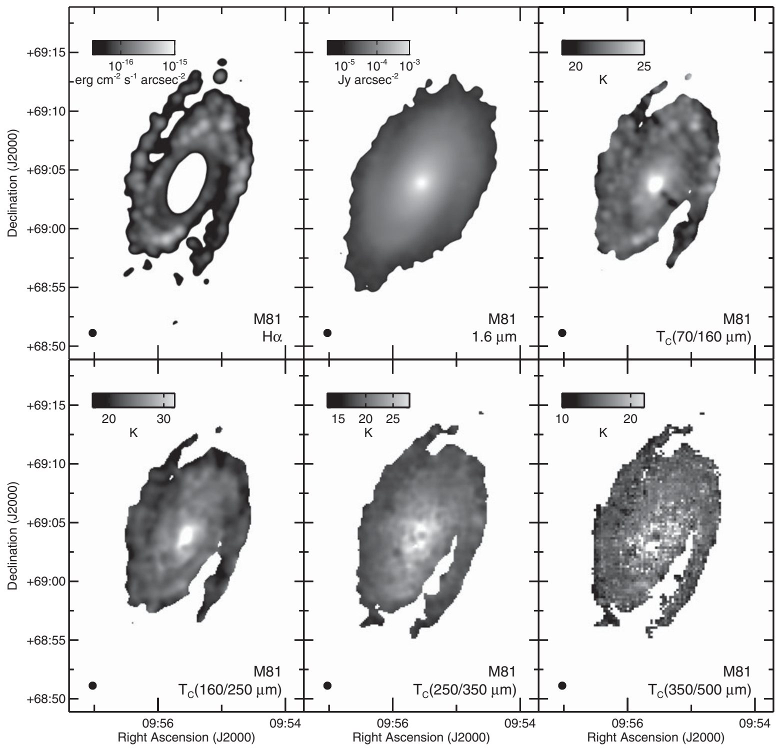

Figure 1. The colour temperature maps of M81 and Hα and 1.6 μm images at the same resolution. The 70 μm data are from *Spitzer*, the 160-500 μm data are from *Herschel*, the Hα data are from Boselli & Gavazzi (2002), and the 1.6 μm data are from Garrett *et al.* (2003). The colour temperatures are only shown for visualisation purposes; the quantitative analysis was performed on surface brightness ratios. All of these maps were created from data where the point spread function (PSF) was matched to the PSF of the 500 μm data, which has a FWHM of 36″ (shown by the circles in the lower left corner of each panel). Pixels where the signal was not detected at the 5σ level in either the single band shown (in the case of the Hα and 1.6 μm images) or in both bands (in the case of the colour temperature maps) were left blank (white). Each map is $30' \times 20'$, and north is up and east is left in each panel. See Bendo *et al.* (2011) for information on the creation of the colour temperature maps.

2. Results

Figures 1–3 show the data that were used in this comparison. Each galaxy yields similar but slightly different results. Details on the analysis, including quantitative analyses based on rebinned versions of these maps, are given by Bendo *et al.* (2011); we present a summarized version of the results here.

M81 has infrared surface brightness ratios that vary mostly as a function of the 1.6 μm emission, which mainly depends on galactocentric radius. Except in the outer disc in the 70/160 μm ratio map, very little local dust heating is seen. These results suggest that most of the dust seen at 160-500 μm as well as some of the dust seen at 70 μm is primarily heated by the total stellar population, including the evolved stellar population in the bulge.

In M83, both the star formation and the total stellar population trace the grand design spiral pattern of the galaxy, and so it is difficult to determine whether the infrared surface brightness ratios depend more on either the Hα or the 1.6 μm emission. To disentangle the relative contributions of star-forming regions and the total stellar populations to dust

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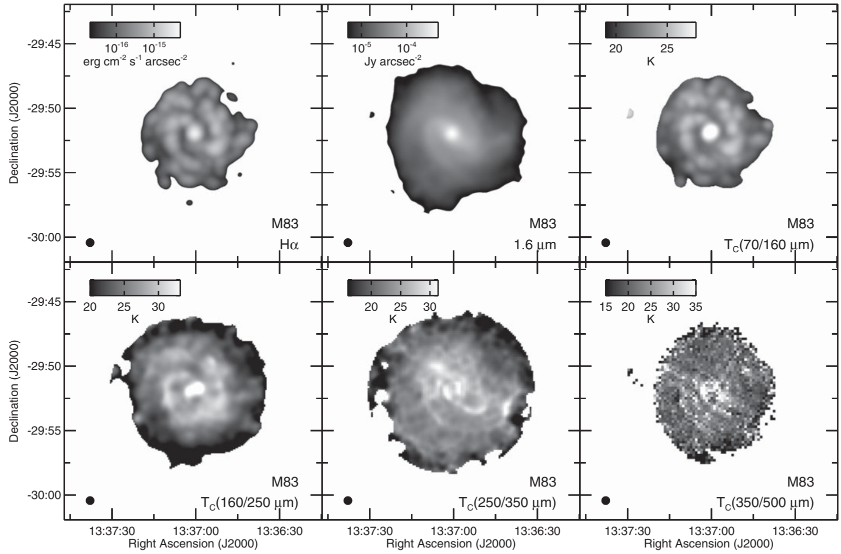

Figure 2. The colour temperature maps of M83 and Hα and 1.6 μm images at the same resolution. The data sources are the same as for Figure 1 except that the 70 μm data are from *Herschel* and the Hα data are from Meurer *et al.* (2006). Each map is $20' \times 20'$. See the caption of Figure 1 for additional information about the layout.

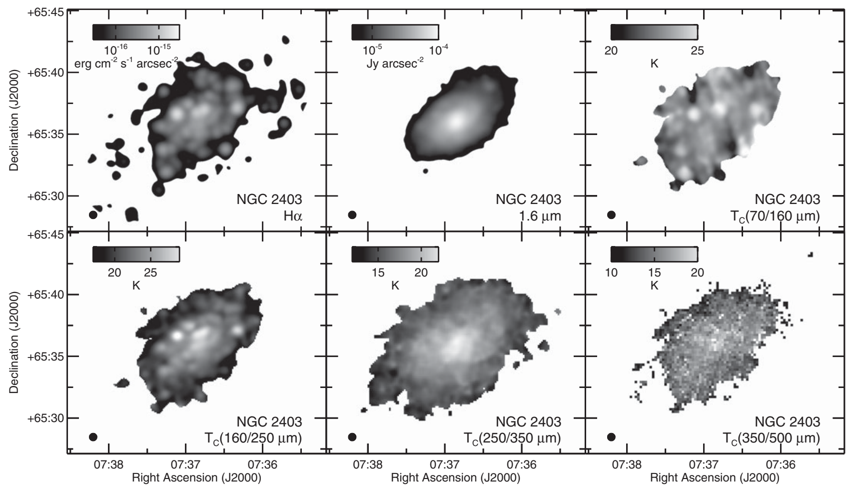

Figure 3. The colour temperature maps of NGC 2403 and Hα and 1.6 μm images at the same resolution. The data sources are the same as for Figure 1. Each map is $21' \times 18'$. See the caption of Figure 1 for additional information about the layout.

heating as traced by any pair of wavelengths λ_1 and λ_2, we fit the data with

$$\ln\left(\frac{I_\nu(\lambda_1)}{I_\nu(\lambda_2)}\right) = \alpha \ln(I(\mathrm{H}\alpha) + A_1 I_\nu(1.6\,\mu\mathrm{m})) + A_2 \tag{2.1}$$

and then examined the ratio of the $I(\mathrm{H}\alpha)$ and $A_1 I_\nu(1.6\ \mu\mathrm{m})$ terms. We found that the the 70/160 and 160/250 μm ratios primarily depend upon the Hα intensity while the 250/350 and 350/500 μm ratios primarily depend upon the 1.6 μm surface brightness. This suggests that the emission from M83 at >250 μm originates from dust heated by the total stellar population.

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NGC 2403 shows notable differences in the dust heating as a function of wavelength. The 70/160 and 160/250 μm images show that the dust emission is clearly heated locally by the star-forming regions seen in the Hα image. However, the 250/350 and 350/500 μm ratios are more strongly correlated with the 1.6 μm emission, again suggesting that the dust seen at >250 μm is heated by the total stellar population.

3. Discussion

Overall, these results show that dust emission in these three nearby spiral galaxies can be divided into a component that primarily emits at <160 μm that is heated by star-forming regions and a component that primarily emits at >250 μm that is primarily heated by the total stellar population, including evolved stars in the bulge and discs of these galaxies. This is generally consistent with the expectations from radiative transfer and dust emission models (e.g. Draine *et al.* 2007; Popescu *et al.* 2011). Despite this, the dust emission in individual wave bands between 70-500 μm observed from these galaxies is still correlated with Hα and other star formation tracers. This has also been found for >100 μm emission observed from other nearby galaxies as well (Boquien *et al.* 2010, 2011; Calzetti *et al.* 2010; Verley *et al.* 2010). These relations could arise even if the dust is not directly heated by the star-forming regions if the dust mass is correlated with star formation through the Schmidt law (e.g. Kennicutt 1998).

This has multiple implications. First of all, dust models and templates need to be adjusted to not only account for this very cold dust component but also to replicate the change in the colour variations as a function of wavlength. Dust extinction corrections that depend upon using infrared fluxes to estimate corrections need to account for dust heating by evolved stellar populations. Finally, far-infrared dust emission should be used cautiously as a star formation tracer, as dust emission may be related to star formation through the Schmidt law rather than through dust heating.

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