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

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Abstract

We use Spitzer Space Telescope and Herschel Space Observatory mid- and far-infrared 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 surface brightness ratios tend to be more strongly influenced by star forming regions. However, the 250/350 and 350/500 μm surface brightness 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.

Introduction

The goals of the analysis here are to understand dust heating sources in nearby spiral galaxies. We want to determine whether the dust seen at 70-500 μm is heated by star formation or the total stellar population. This follows up recent contradictory results from Herschel early science on the relation of dust to star formation. Boquien et al. (2010, A&A, 518, L70) and Verley et al. (2010, A&A, 518, L68) demonstrated that the 100-250 μm flux densities of star forming regions in M33 can be correlated with other tracers of star formation. However, Bendo et al. (2010, A&A, 518, L65) inferred that the dust emitting at >160 μm in M81 was heated by the total stellar population, including evolved stars in the disc and bulge.

Conclusions

- Emission at <160 μm in these galaxies generally originates from dust heated by star forming regions, although it is possible for evolved stars (such as the bulge stars in the central 3 kpc of M81) to heat the dust that emits at 70 μm.

- Emission observed at >250 μm in these galaxies originates from dust primarily heated by the total stellar population, including evolved stars in the galaxies' bulges and discs.

- The correlation between far-infrared emission measured in individual wave bands and other star formation tracers may be the result of the Schmidt law (relating star formation to the gas available to fuel it) and not a result of the dust being directly heated by star forming regions.

- Dust emission models and extragalactic SED templates need to be redesigned to take into account dust components that are largely unaffected by star forming regions.
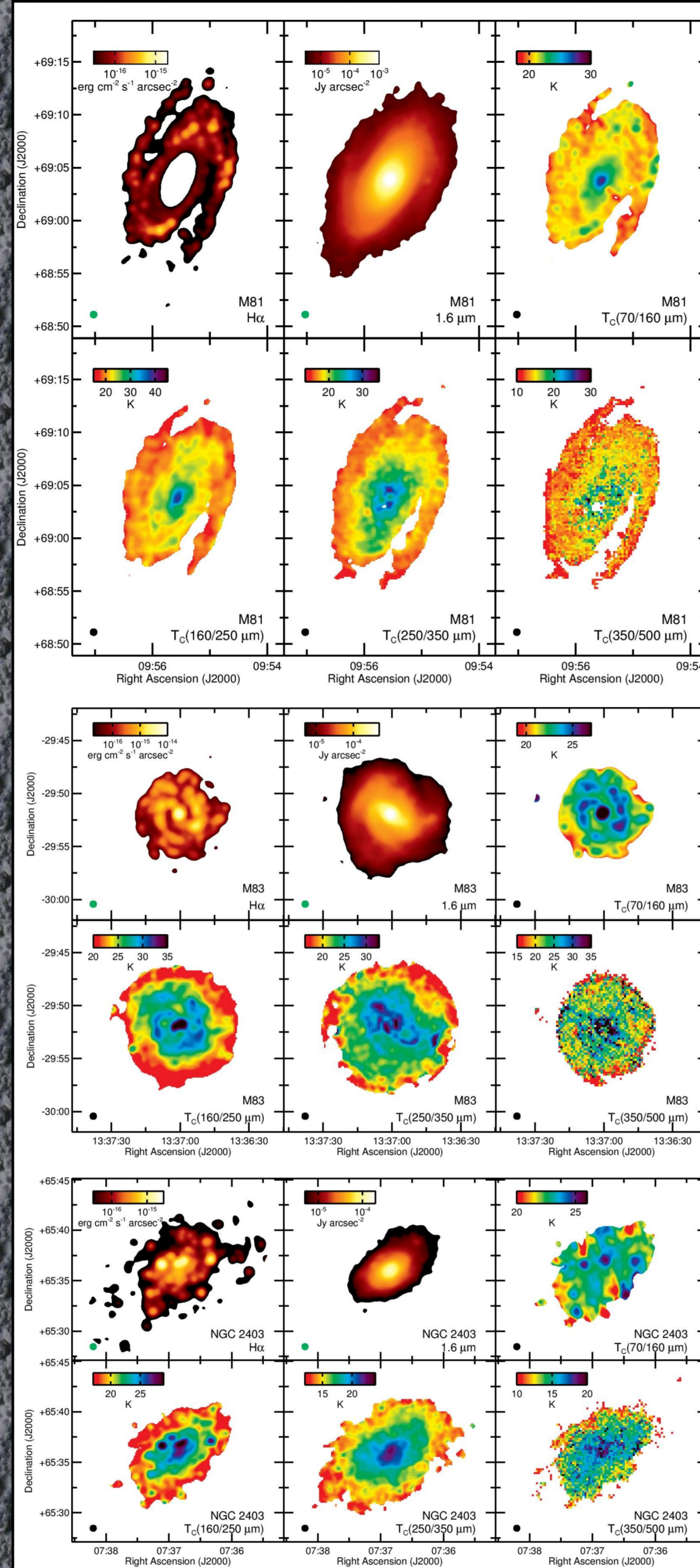

These figures show the Hα and 1.6 μm emission as well as 70/160, 160/250, 250/350, and 350/500 μm colour temperatures for each of the galaxies. The PSFs have all been matched to the PSF of the 500 μm data, which has a FWHM of 36" (shown by the circles at the bottom of each map). The 70/160 μm colour temperatures correspond well to features such as spiral arms in the Hα images, while the 250/350 and 350/500 μm structures correspond to the stellar structures seen in the 1.6 μm images as well as the overall radial gradient seen in the total stellar surface brightness. The 160/250 μm colour temperatures tend to trace structures seen in both the Hα and 1.6 μm images.
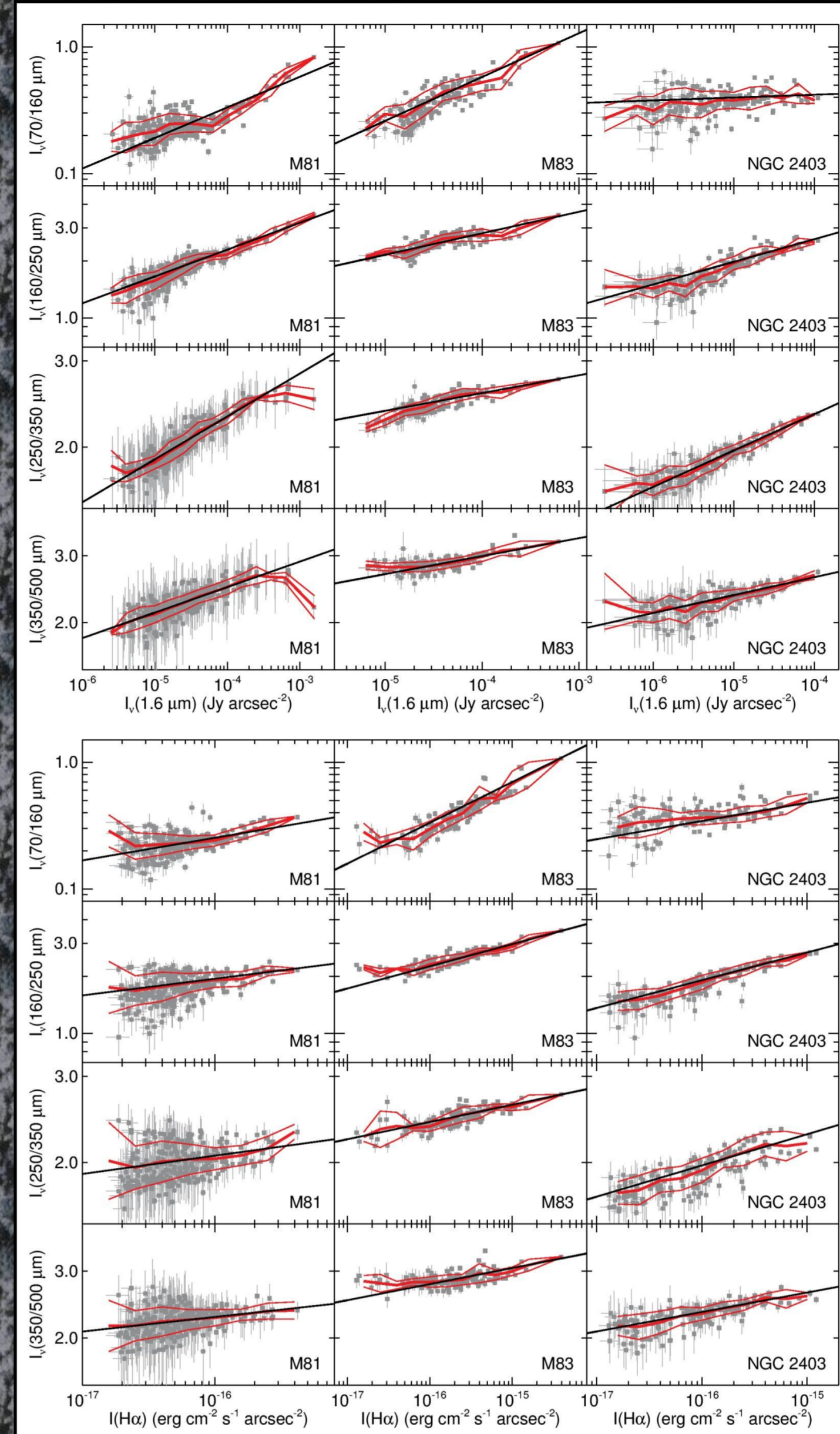
The above figures show variations in infrared surface brightness ratios as functions of the 1.6 μm surface brightness and Hα intensities for 36" square subregions within the data shown in the images to the left (where all of the PSFs match the PSF of the 500 μm data, which has a FWHM of 36"). The red lines show the mean and standard deviations of the relations at periodic intervals in the data, while the black lines show the best fit lines.

The 70/160 μm surface brightness ratios show a stronger correlation with Hα intensity, while the 250/350 and 350/500 μm surface brightness ratios show a stronger correlation with 1.6 μm surface brightness. The 160/250 μm ratios for subregions in M83 and NGC 2403 tend to show almost equally good correlations with either Hα or 1.6 μm emission, but the 160/250 μm ratios for subregions in M81 are much more closely correlated with the 1.6 μm surface brightness. This shows that emission at <160 μm mostly originates from dust heated by star forming regions, while emission at >250 μm originates from dust heated by the total stellar populations within galaxies, including evolved stars in the galaxies' bulges and discs.

Also note that, in the top plot, the nucleus of M81 (the point with the highest 1.6 μm surface brightness) deviates from the best fit lines because the AGN produces significant synchrotron emission at submillimetre wavelengths.
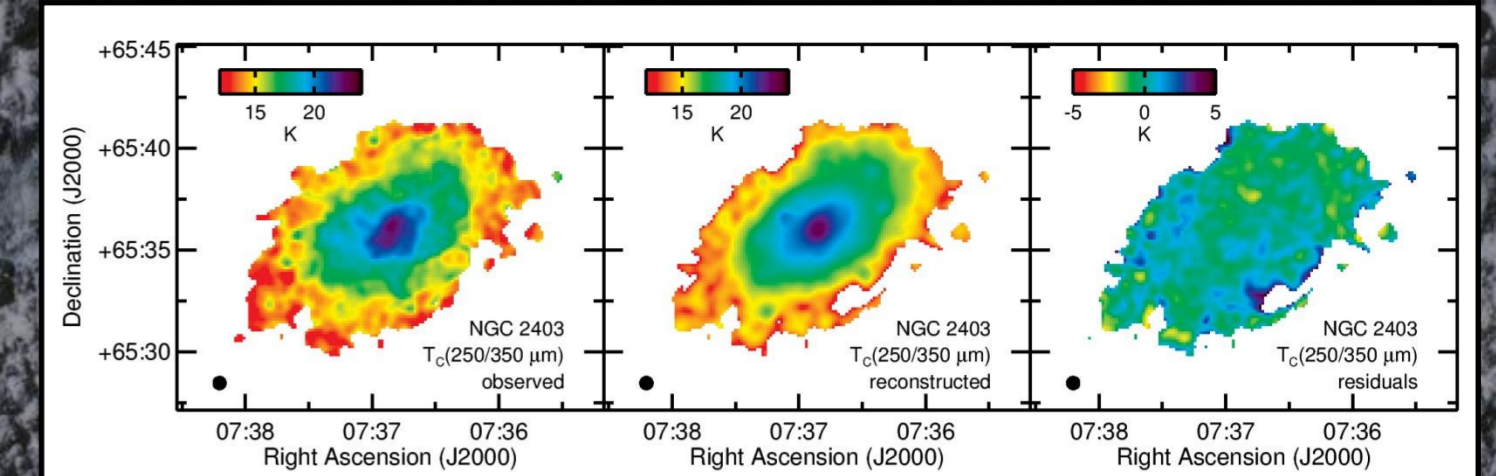
As an alternate method for determining the relative contribution of star forming regions and the total stellar population to dust heating, we fit the function

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

to the data. This is a variant on the Stefan-Boltzmann law. The images above show an example of an observed colour temperature map, a reconstructed colour temperature map based on the best fitting function of Hα and 1.6 μm emission, and the residuals between the observed and reconstructed map. The images below show, for the dust emission in a pair of wave bands, the relative fraction of dust heating from star formation, as given by

$$\frac{E_{SF}}{E_{Total}} = \frac{I(H\alpha)}{I(H\alpha) + A_1 I_\nu(1.6\mu m)}.$$

At short wavelengths, star forming regions dominate dust heating (in regions shown in blue below), but at longer wavelengths, the total stellar population dominates dust heating (shown in red below).