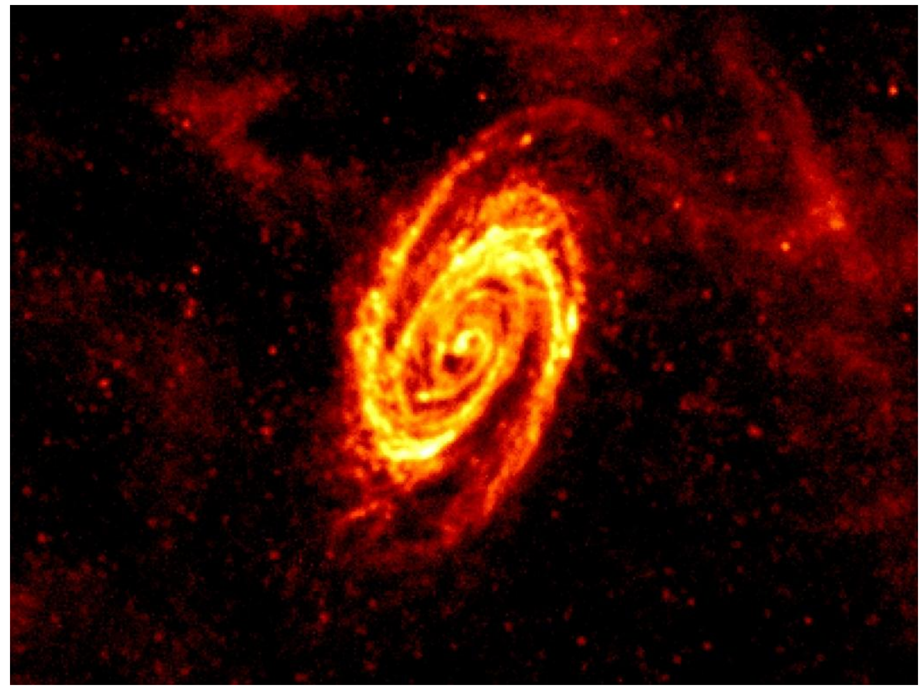
Investigations of dust heating in M81, M83 and NGC 2403 with Herschel and Spitzer



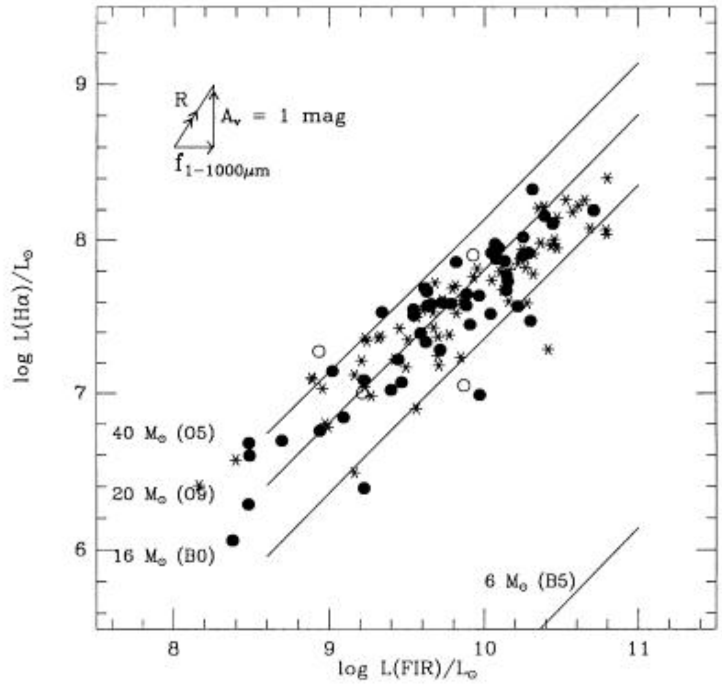
George J. Bendo
Very Nearby Galaxies Survey

Goals

The overall goals of this research are to empirically identify the heating sources for the dust observed at 70-500 μm.

Conflicting results on the nature of dust heating in spiral galaxies have been published since the completion of the IRAS surveys.

Using Herschel data, we can obtain high S/N data on the Rayleigh-Jeans side of the dust SEDs for the first time, allowing us to study the coldest dust in nearby galaxies.



Devereux & Young 1990, ApJ, 350, L25

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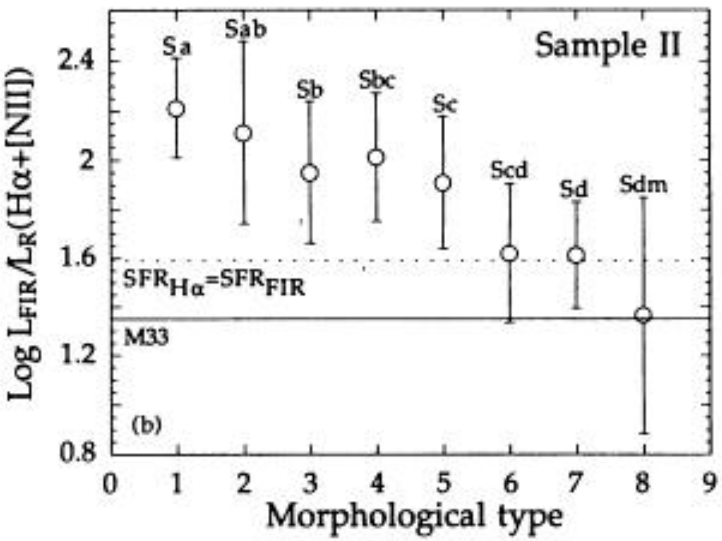

Sauvage & Thuan
1992, ApJ, 396, L69

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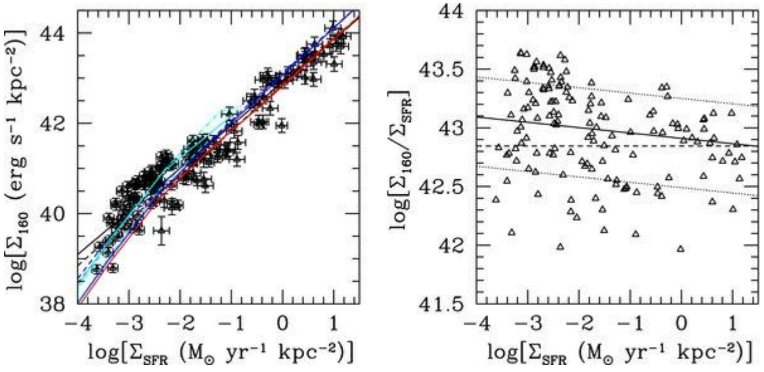
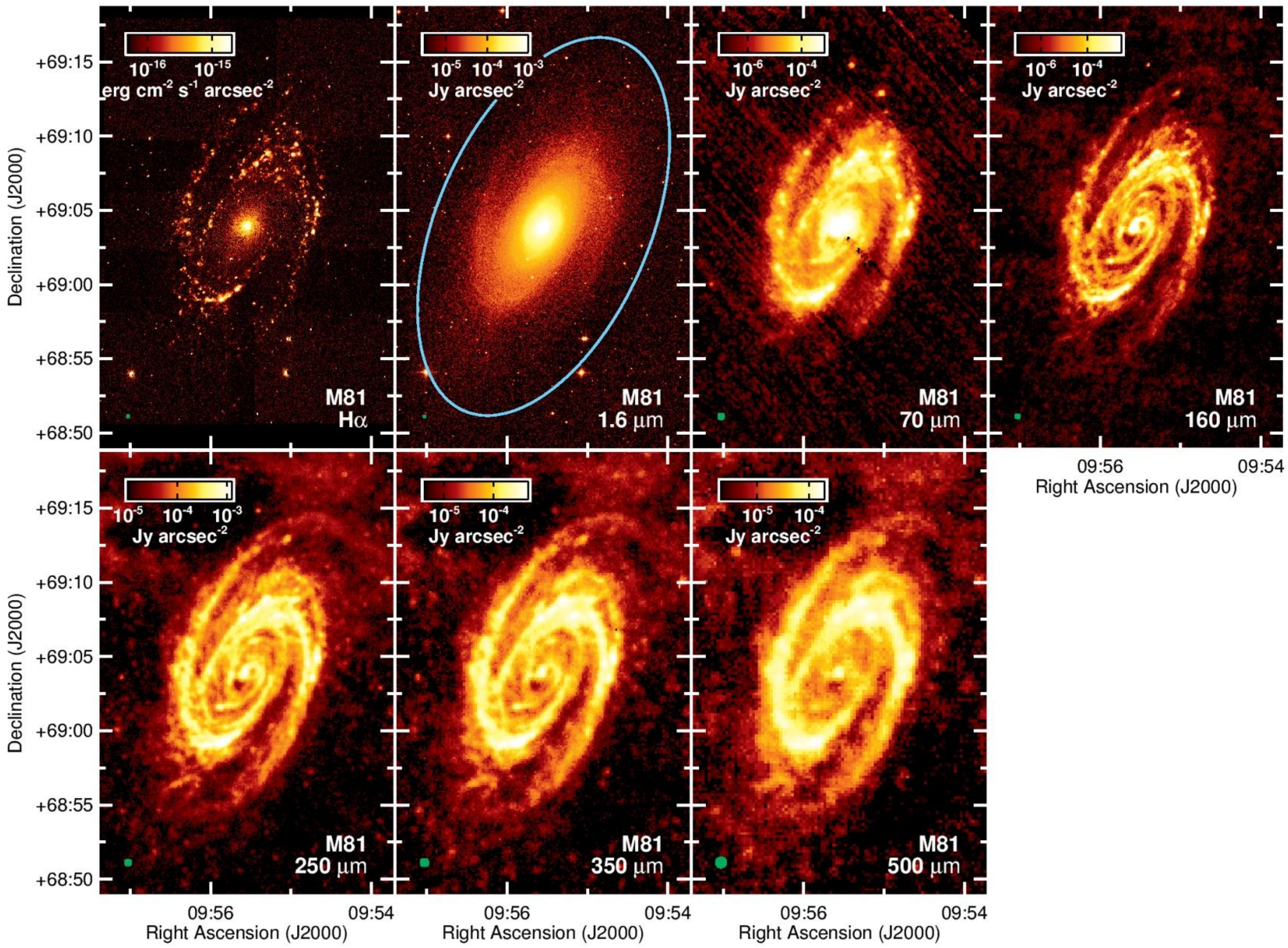
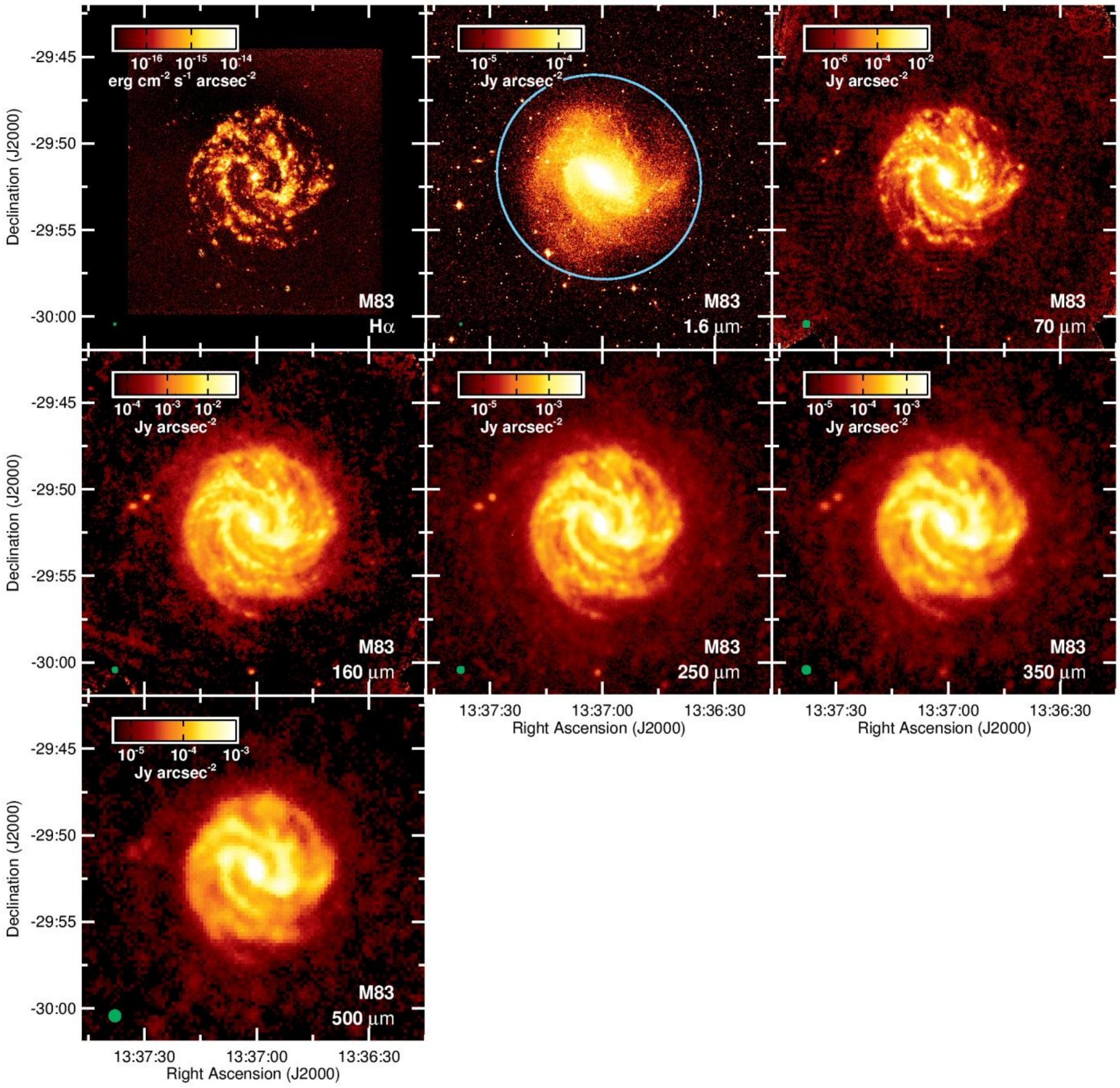


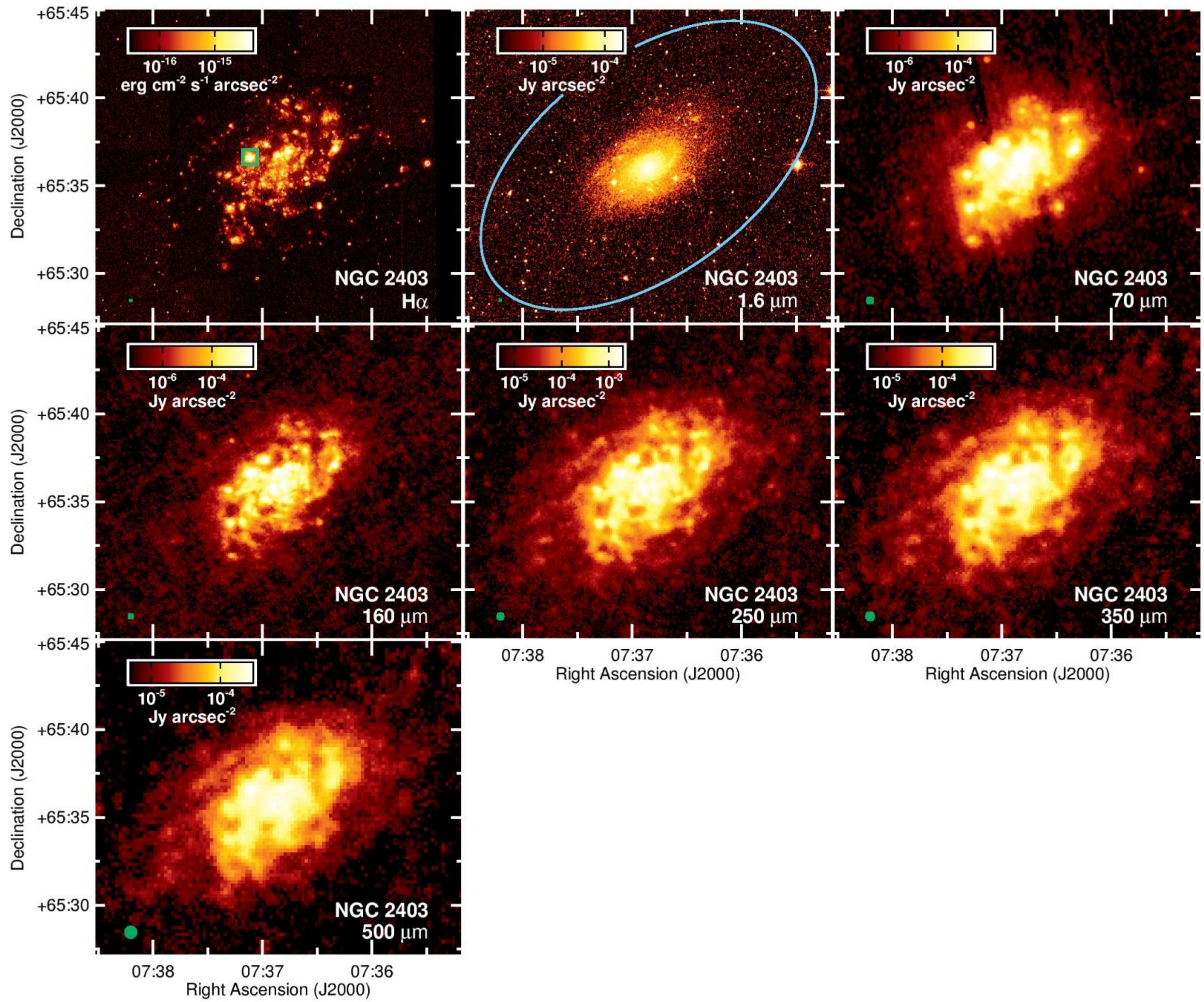
Calzetti et al.
2010, ApJ, 714, 1256



M81 Hα
erg cm-2 s-1 arcsec-2
M81 1.6 µm
M81 70 µm
M81 160 µm
M81 250 µm
M81 350 µm
M81 500 µm
Jy arcsec-2
Declination (J2000)
Right Ascension (J2000)
+69:15
+69:10
+69:05
+69:00
+68:55
+68:50
09:56
09:54



10-16 10-15 10-14
erg cm-2 s-1 arcsec-2
M83
Hα
10-5 10-4
Jy arcsec-2
M83
1.6 μm
10-6 10-4 10-2
Jy arcsec-2
M83
70 μm
10-4 10-3 10-2
Jy arcsec-2
M83
160 μm
10-5 10-3
Jy arcsec-2
M83
250 μm
10-5 10-4 10-3
Jy arcsec-2
M83
350 μm
10-5 10-4 10-3
Jy arcsec-2
M83
500 μm
Declination (J2000)
-29:45
-29:50
-29:55
-30:00
13:37:30
13:37:00
13:36:30
Right Ascension (J2000)



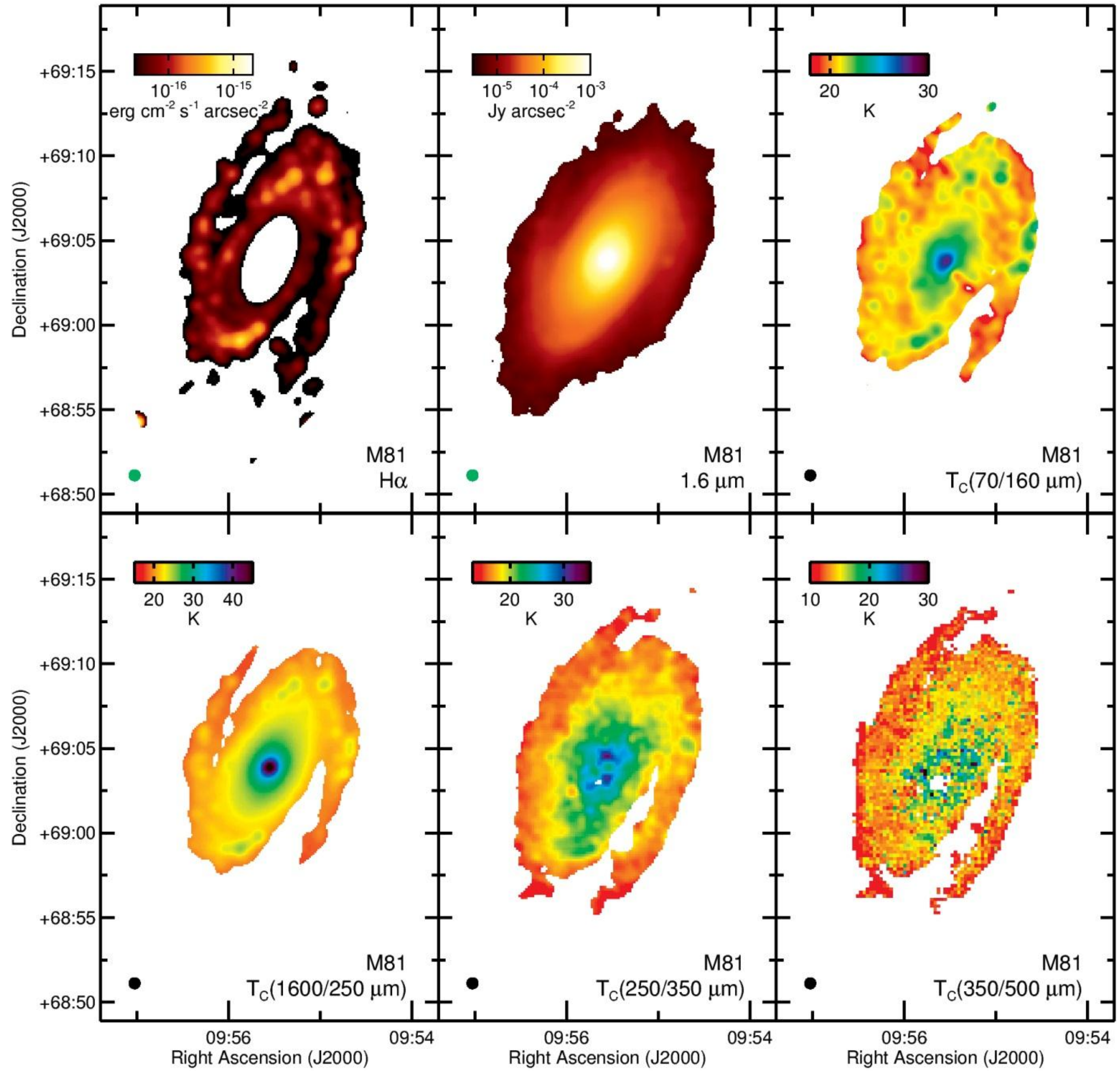
NGC 2403 Hα
erg cm-2 s-1 arcsec-2
NGC 2403 1.6 μm
NGC 2403 70 μm
NGC 2403 160 μm
NGC 2403 250 μm
NGC 2403 350 μm
NGC 2403 500 μm
Jy arcsec-2
Declination (J2000)
Right Ascension (J2000)

Infrared Surface Brightness Ratios

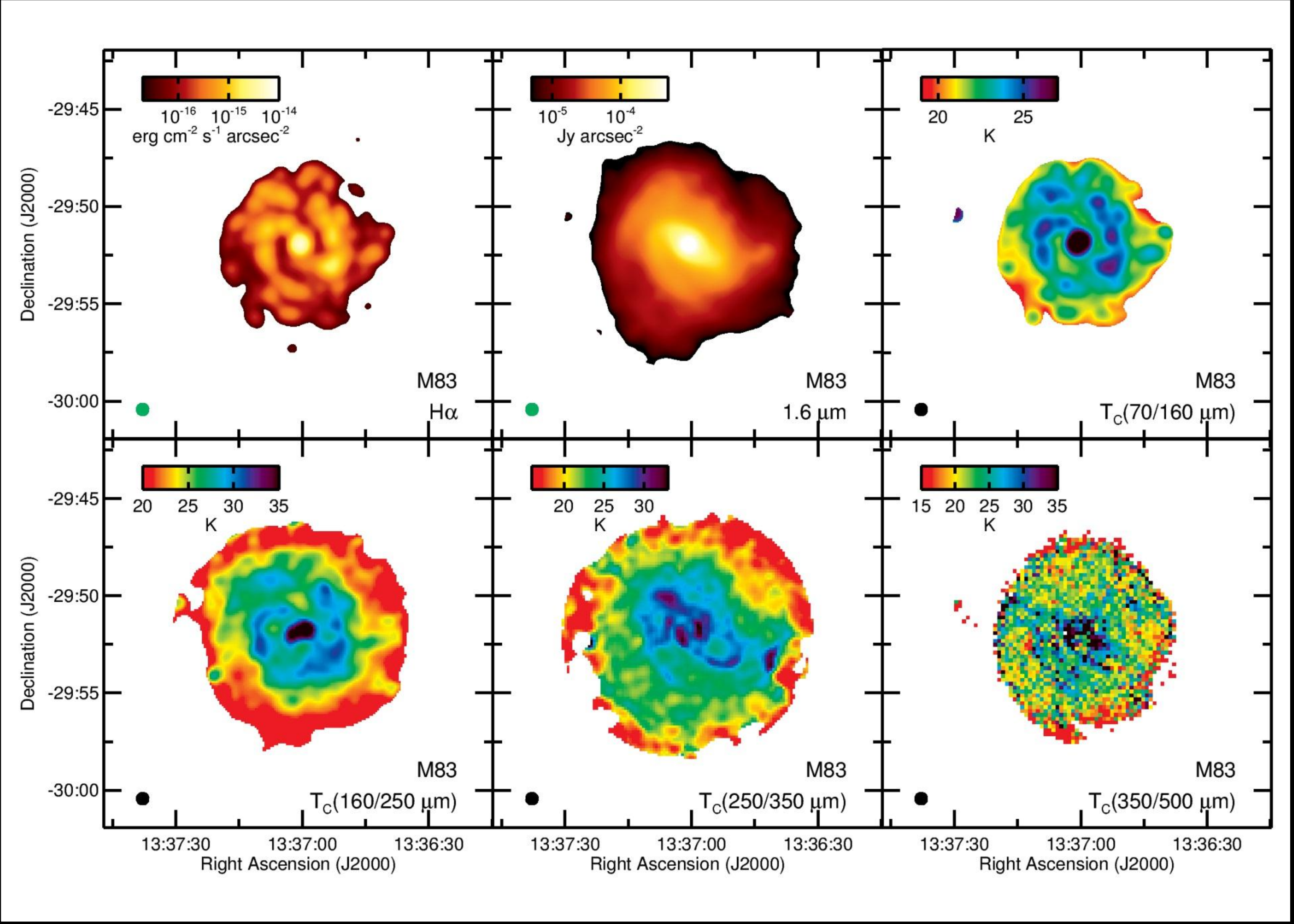
Most other people have compared dust emission in single wave bands to star formation, but if a relation is found, it is unclear how the dust is associated with star formation:

- The dust could be heated by the star formation.
- The dust surface density could be correlated with star formation through the Schmidt law.

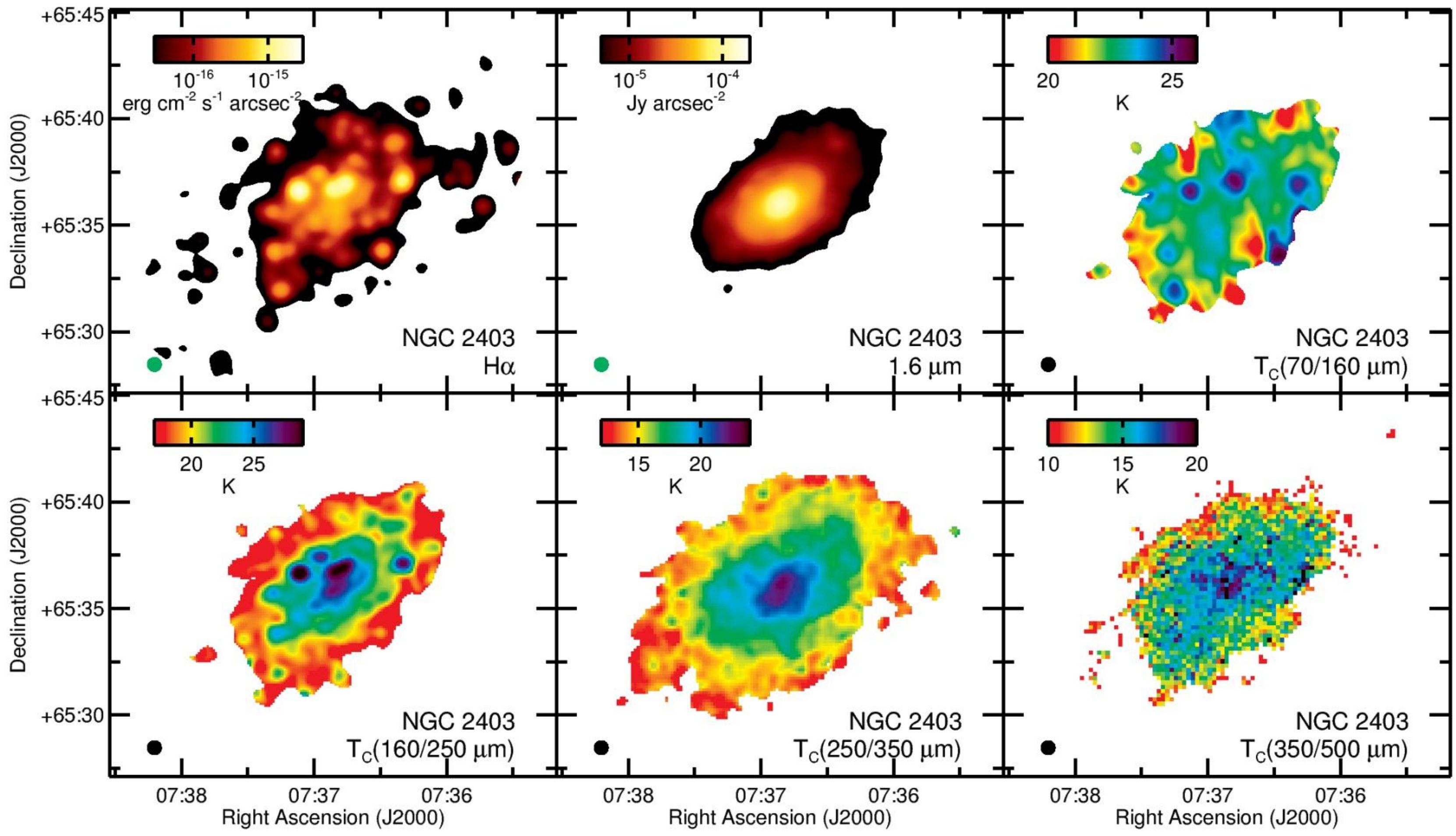
To understand the sources of dust heating for the cold dust, we used 70/160 μm, 160/250 μm, 250/350 μm, and 350/500 μm surface brightness ratios, which are related to dust heating but which are physically independent of dust mass.



+69:15
+69:10
+69:05
+69:00
+68:55
+68:50
Declination (J2000)
10-16 10-15
erg cm-2 s-1 arcsec-2
M81
Hα
10-5 10-4 10-3
Jy arcsec-2
M81
1.6 μm
20 30
K
M81
TC(70/160 μm)
20 30 40
K
M81
TC(1600/250 μm)
20 30
K
M81
TC(250/350 μm)
10 20 30
K
M81
TC(350/500 μm)
09:56
09:54
Right Ascension (J2000)



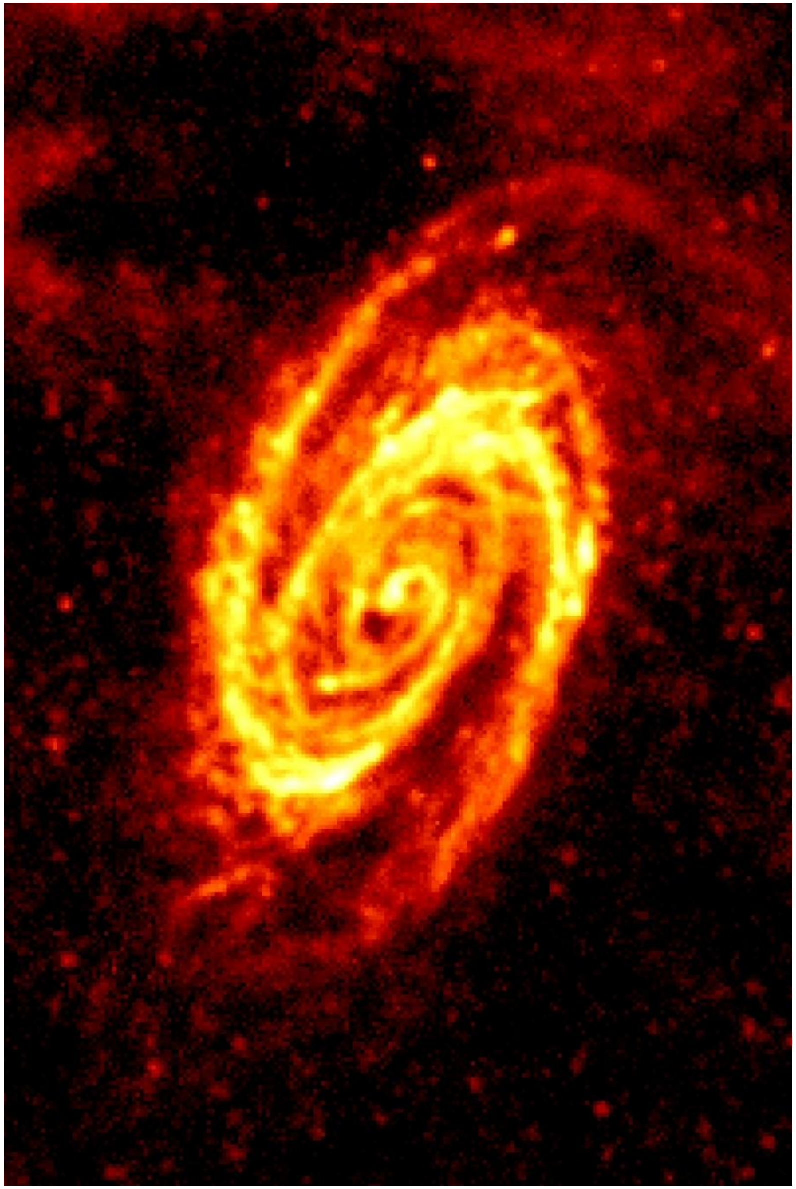
erg cm-2 s-1 arcsec-2
10-16 10-15 10-14
Jy arcsec-2
10-5 10-4
K
20 25
20 25 30 35
20 25 30
15 20 25 30 35
-29:45
-29:50
-29:55
-30:00
Declination (J2000)
M83
Hα
1.6 µm
TC(70/160 µm)
TC(160/250 µm)
TC(250/350 µm)
TC(350/500 µm)
13:37:30
13:37:00
13:36:30
Right Ascension (J2000)



10^-16 10^-15
erg cm^-2 s^-1 arcsec^-2
NGC 2403
Hα
10^-5 10^-4
Jy arcsec^-2
NGC 2403
1.6 µm
20 25
K
NGC 2403
T_C(70/160 µm)
20 25
K
NGC 2403
T_C(160/250 µm)
15 20
K
NGC 2403
T_C(250/350 µm)
10 15 20
K
NGC 2403
T_C(350/500 µm)
+65:45
+65:40
+65:35
+65:30
Declination (J2000)
07:38 07:37 07:36
Right Ascension (J2000)

Binning Analysis

For a quantitative look at these surface brightness, we matched the point spread functions of the data and then rebinned the data into individual resolution elements.



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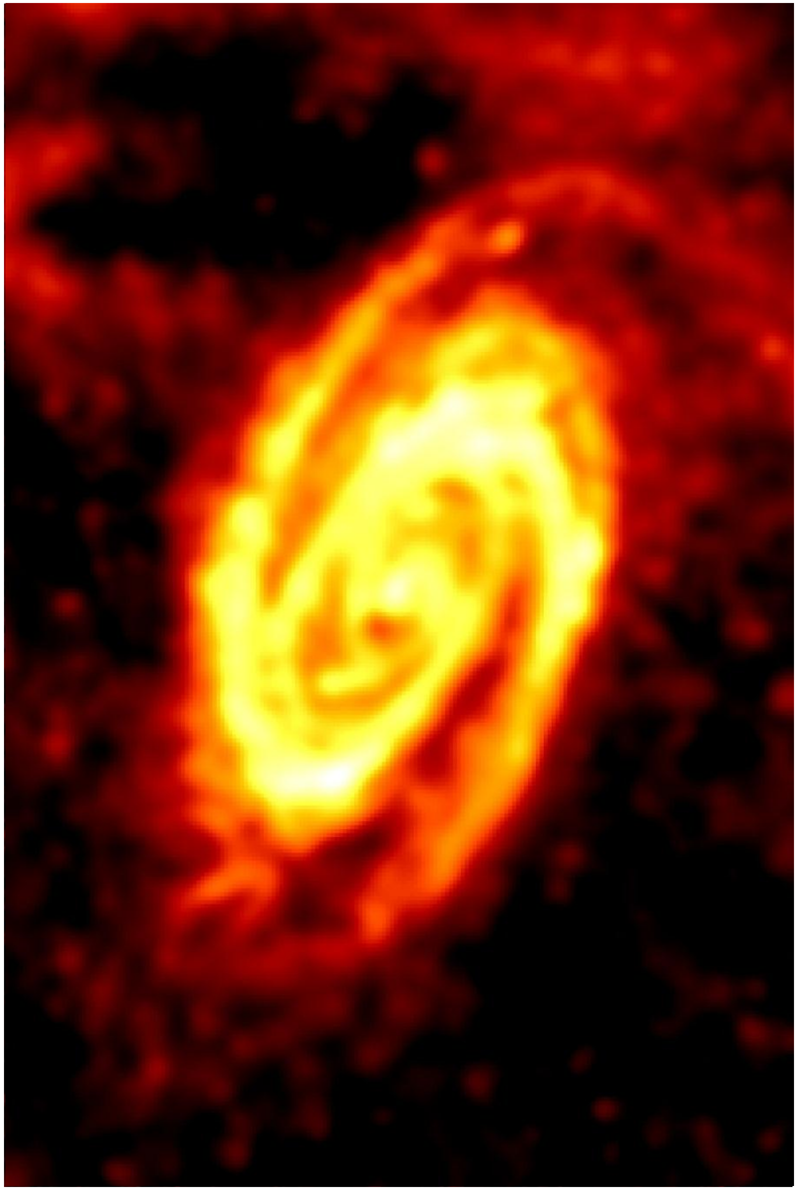

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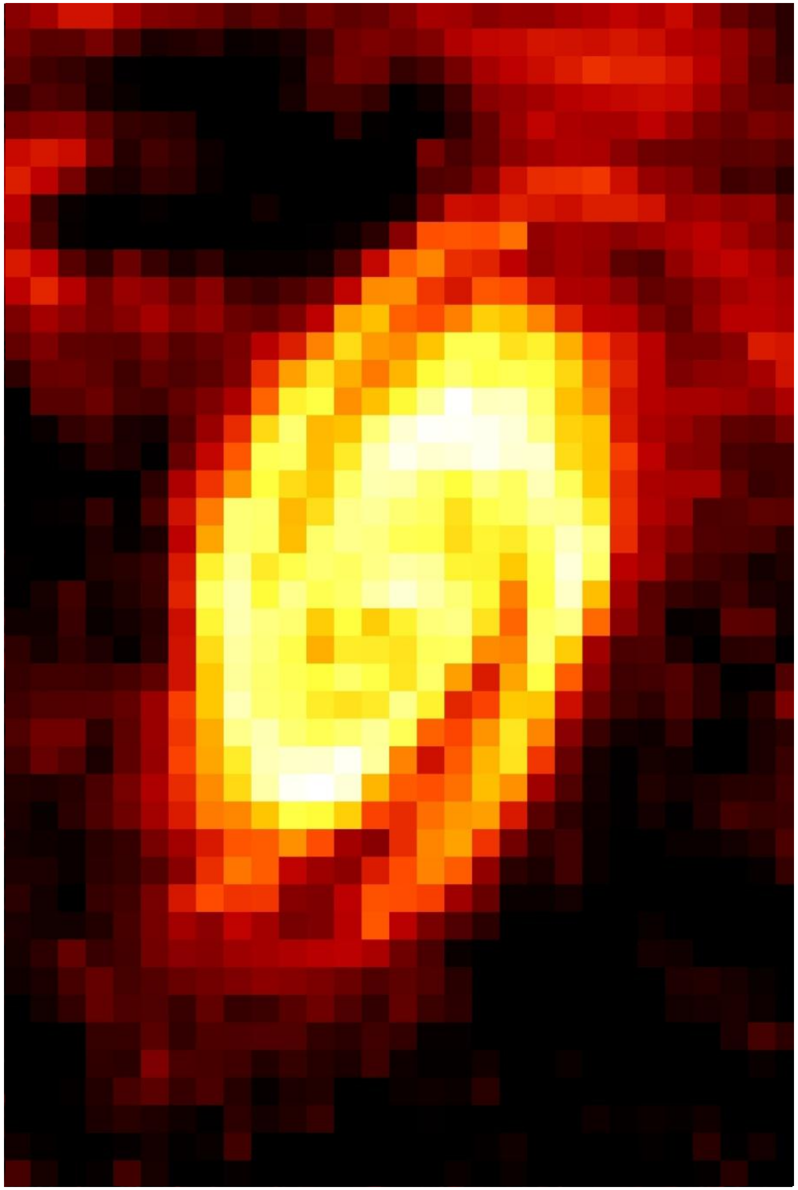
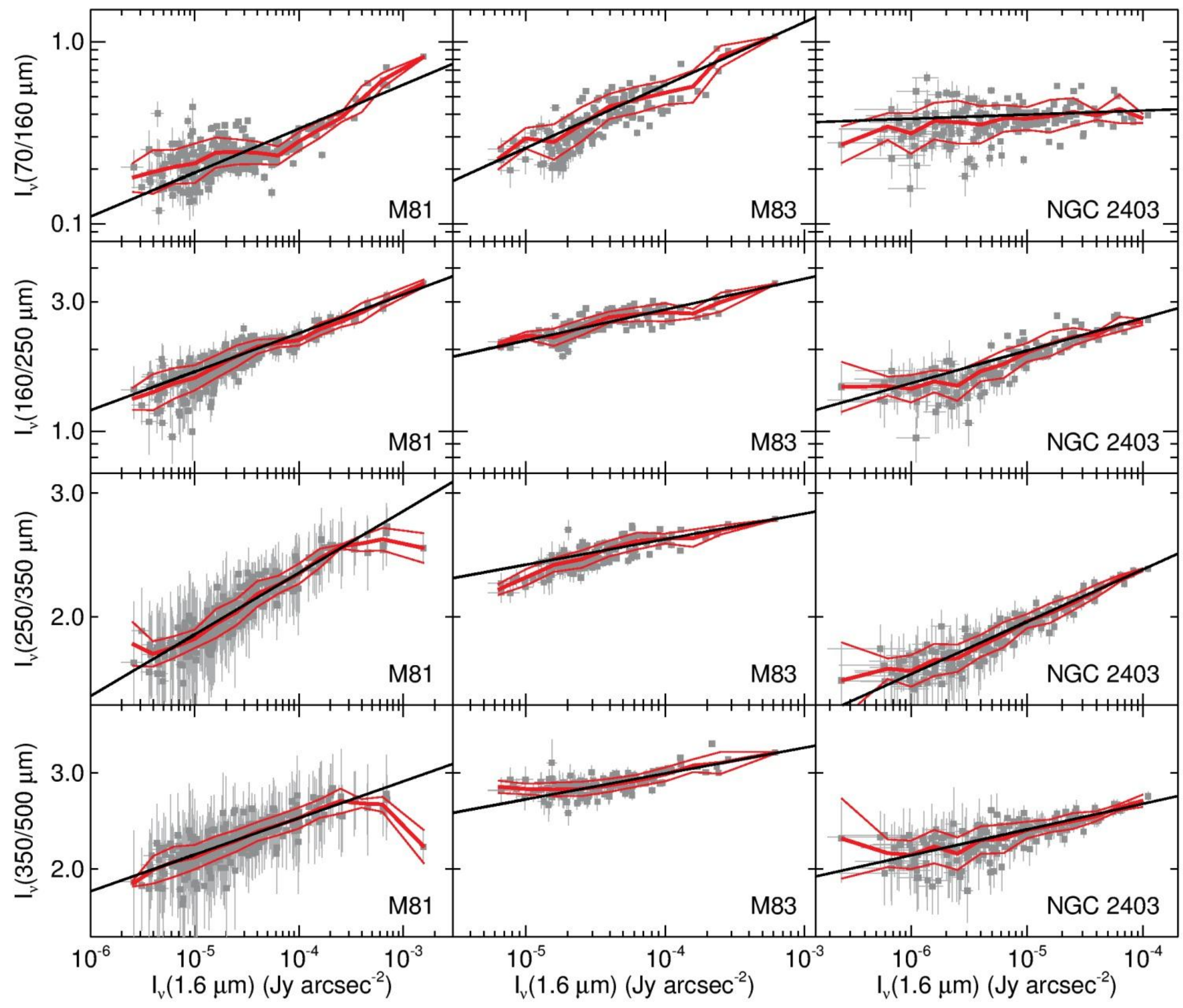
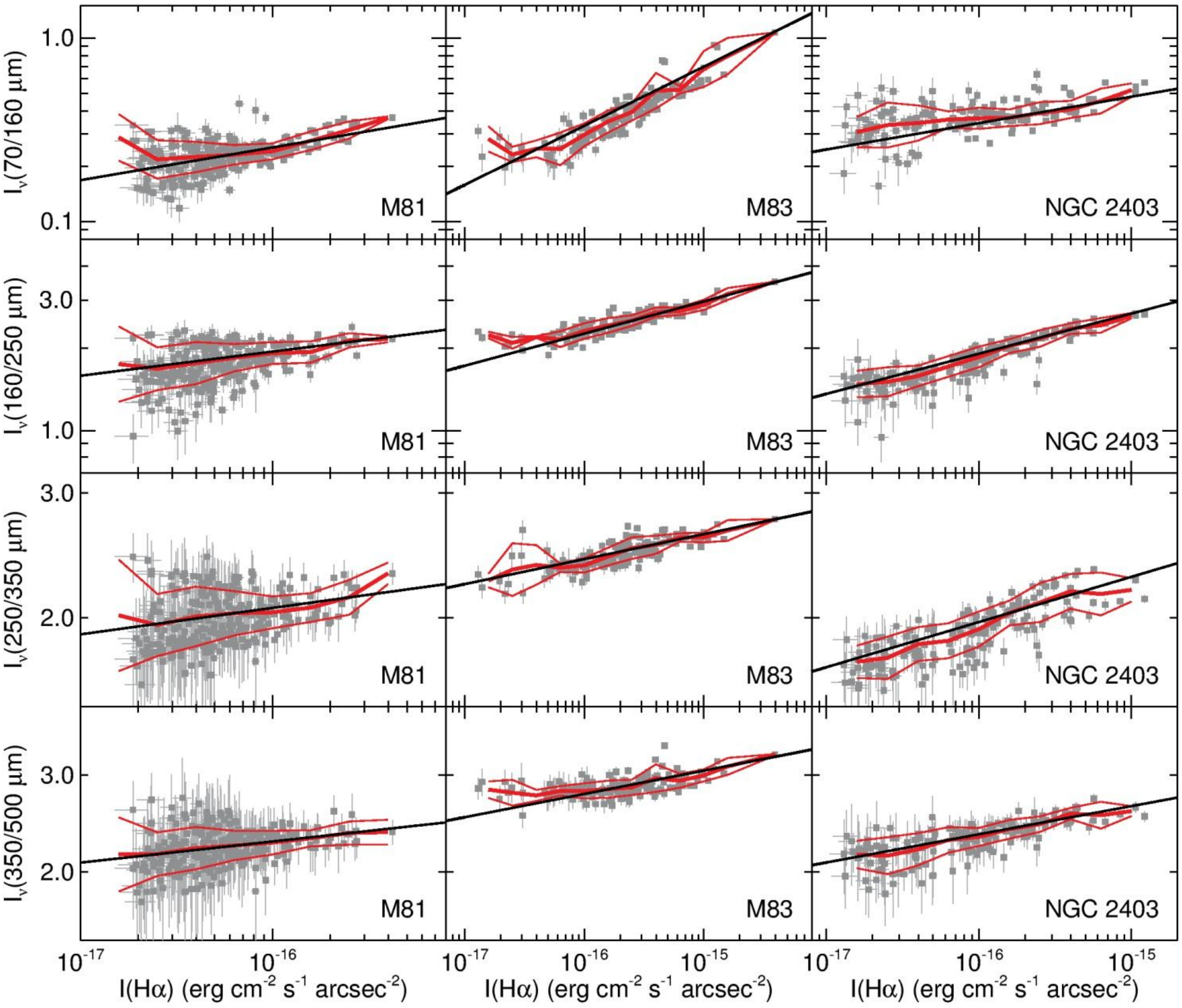




I_ν(70/160 μm)
I_ν(160/250 μm)
I_ν(250/350 μm)
I_ν(350/500 μm)
M81
M83
NGC 2403
I_ν(1.6 μm) (Jy arcsec^{-2})

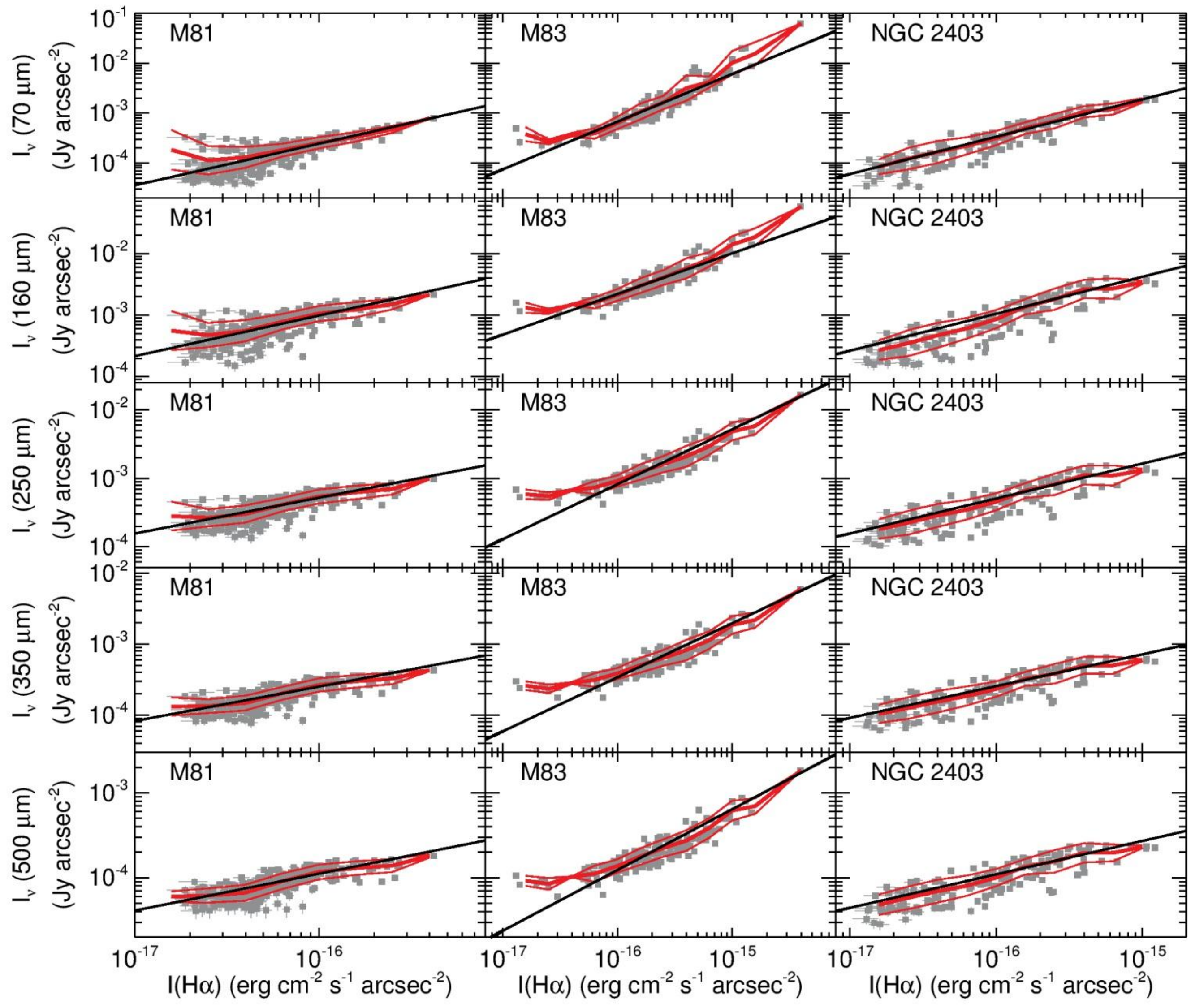


I_ν(70/160 μm)
I_ν(160/250 μm)
I_ν(250/350 μm)
I_ν(350/500 μm)
M81
M83
NGC 2403
I(Hα) (erg cm^{-2} s^{-1} arcsec^{-2})

- The 70/160 μm ratios are more closely correlated with Hα emission, which indicates that the dust seen at <160 μm is primarily heated by star forming regions.

- The 250/350 and 350/500 μm ratios are more strongly correlated with 1.6 μm emission, suggesting that the total stellar population (young and old stars) are responsible for heating the dust.

- Despite this, the Hα emission still appears correlated with infrared surface brightnesses traced in any single wave band between 70 and 500 μm, which may only be possible if the dust surface density is correlated to star formation through the Schmidt Law.



M81
M83
NGC 2403
I_ν (70 µm) (Jy arcsec^{-2})
I_ν (160 µm) (Jy arcsec^{-2})
I_ν (250 µm) (Jy arcsec^{-2})
I_ν (350 µm) (Jy arcsec^{-2})
I_ν (500 µm) (Jy arcsec^{-2})
I(Hα) (erg cm^{-2} s^{-1} arcsec^{-2})

Simultaneous Fits of Hα and 1.6 μm Emission to the Data

Some of the correlations are so similar in strength that it is difficult to gauge which correlation is more significant. To get around this problem, we fit a function based on the Stefan-Boltzmann law:

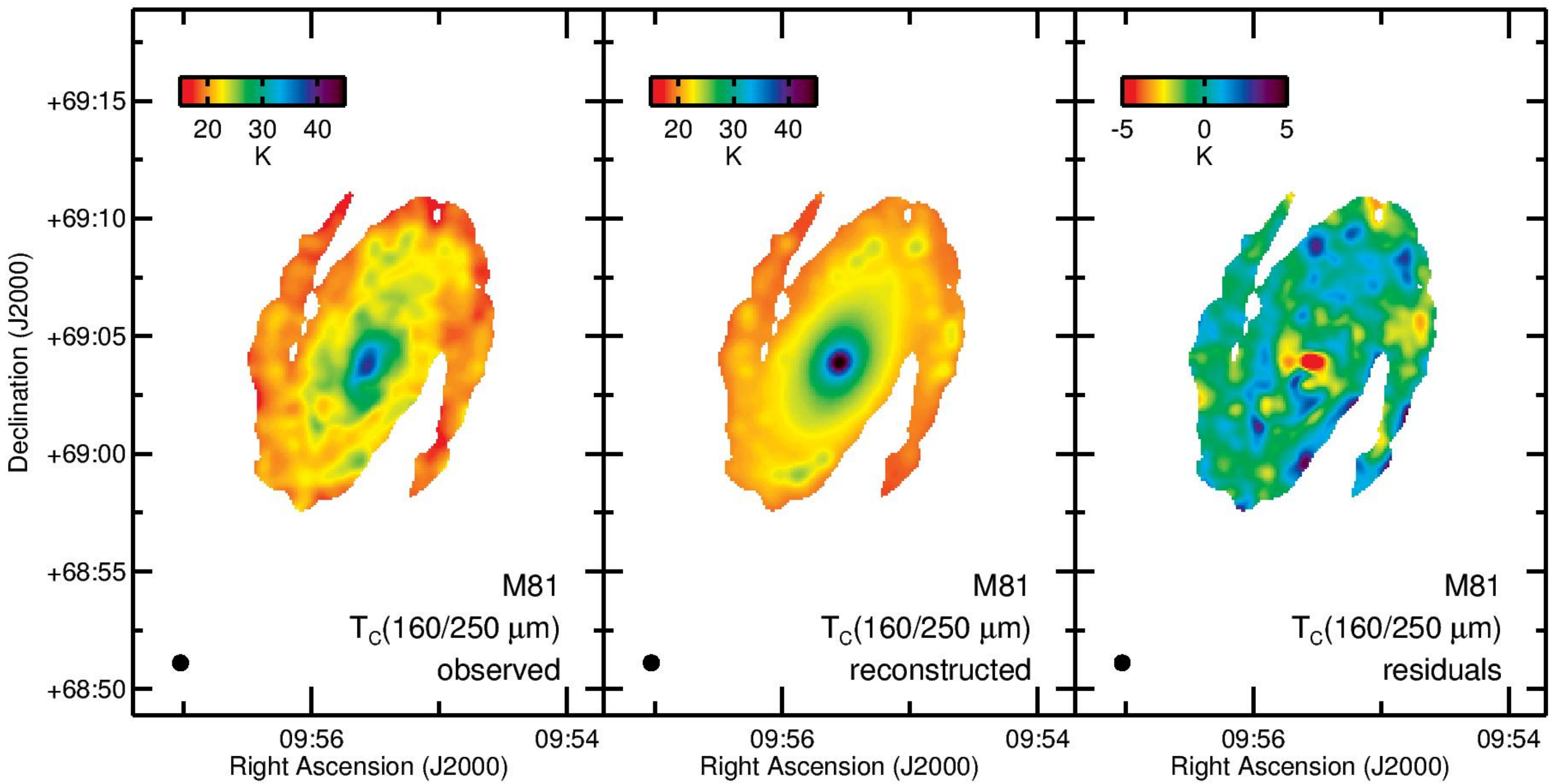
$$C_0 T^{4+\beta} = C_1 I(\mathrm{H\alpha}) + C_2 I_\nu(1.6\mu\mathrm{m})$$

$$C_0' \left(\frac{f_{\nu(\lambda_1)}}{f_{\nu(\lambda_2)}}\right)^{1/\alpha} = C_1' I(\mathrm{H\alpha}) + C_2' I_\nu(1.6\mu\mathrm{m})$$

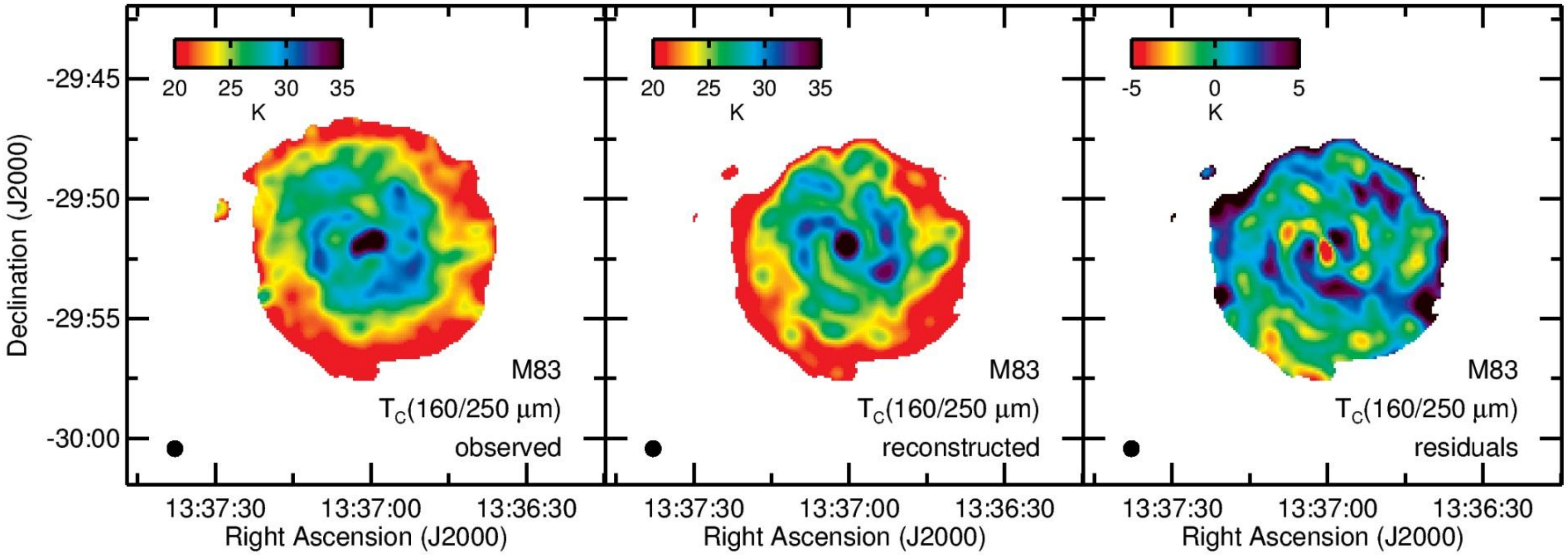
$$\ln\left(\frac{f_{\nu(\lambda_1)}}{f_{\nu(\lambda_2)}}\right) = \alpha \ln\big(I(\mathrm{H\alpha}) + A_1 I_\nu(1.6\mu\mathrm{m})\big) + A_2$$

This equation is an oversimplistic treatment of the dust emission, but it does allow us to take an empirical approach to measuring the relative contributions of star forming regions and the total stellar population to dust heating.

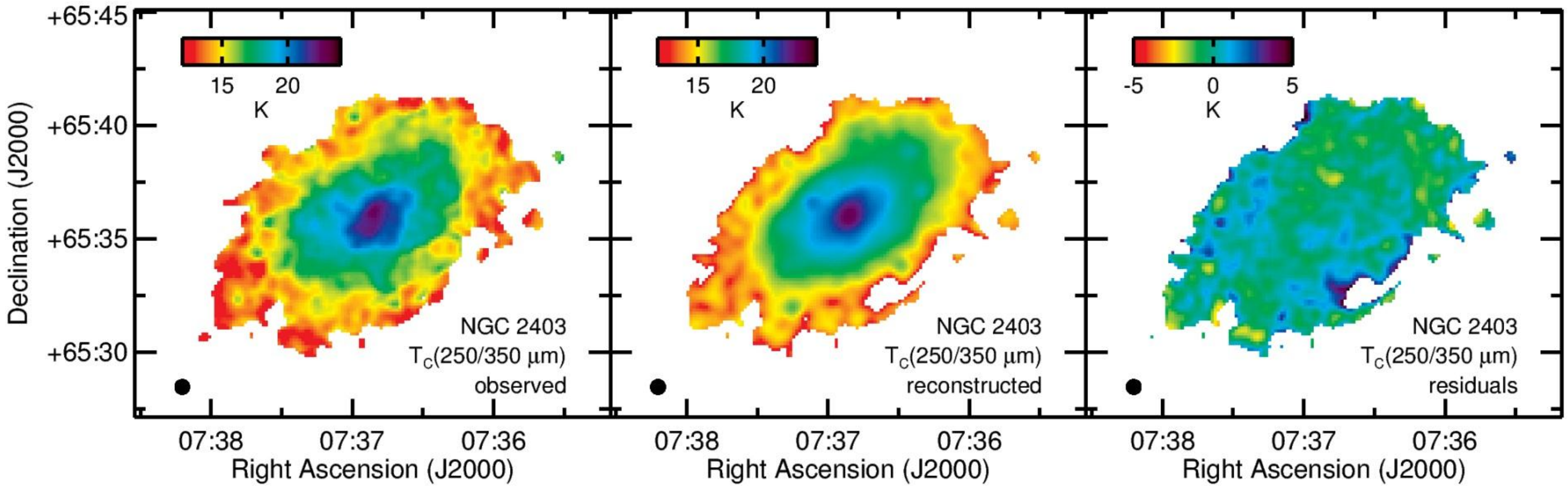
Additionally, the equation can be used to reconstruct colour temperature maps using Hα and 1.6 μm images. This worked so well that even the co-authors on my last paper did not notice when I replaced one of the observed colour temperature map with a reconstructed map earlier in this talk.

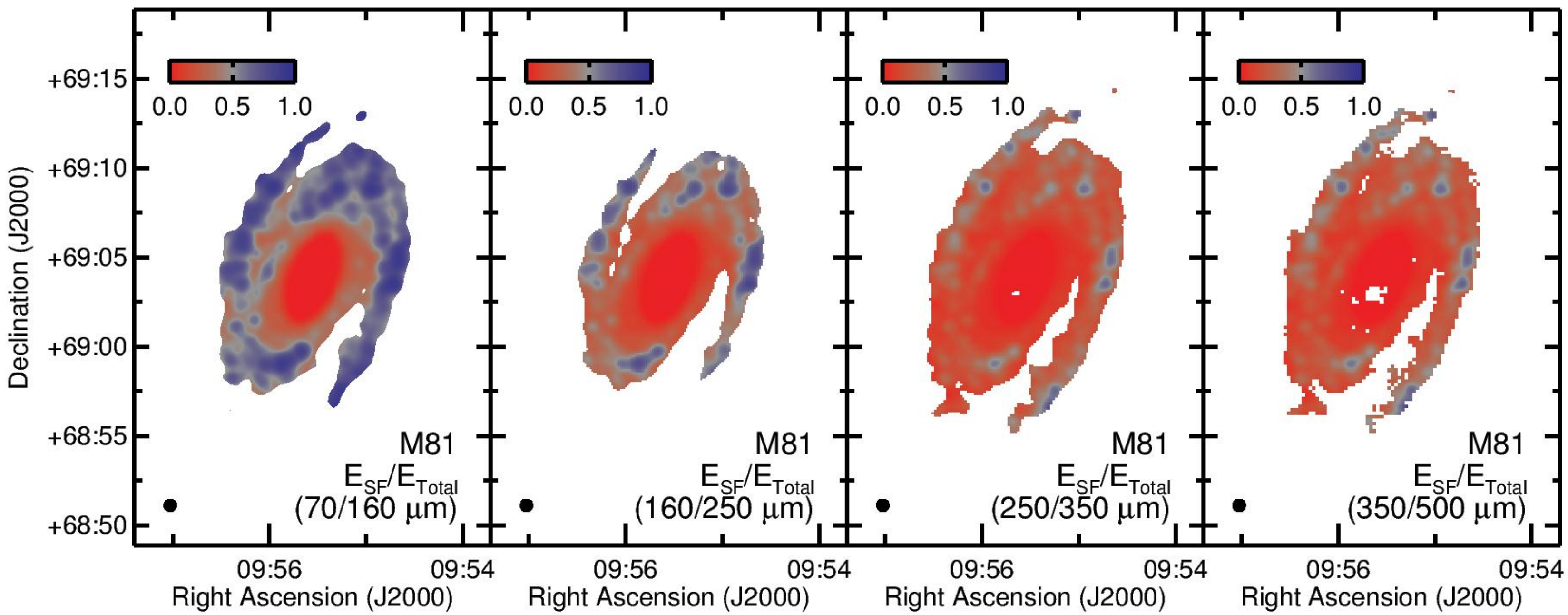


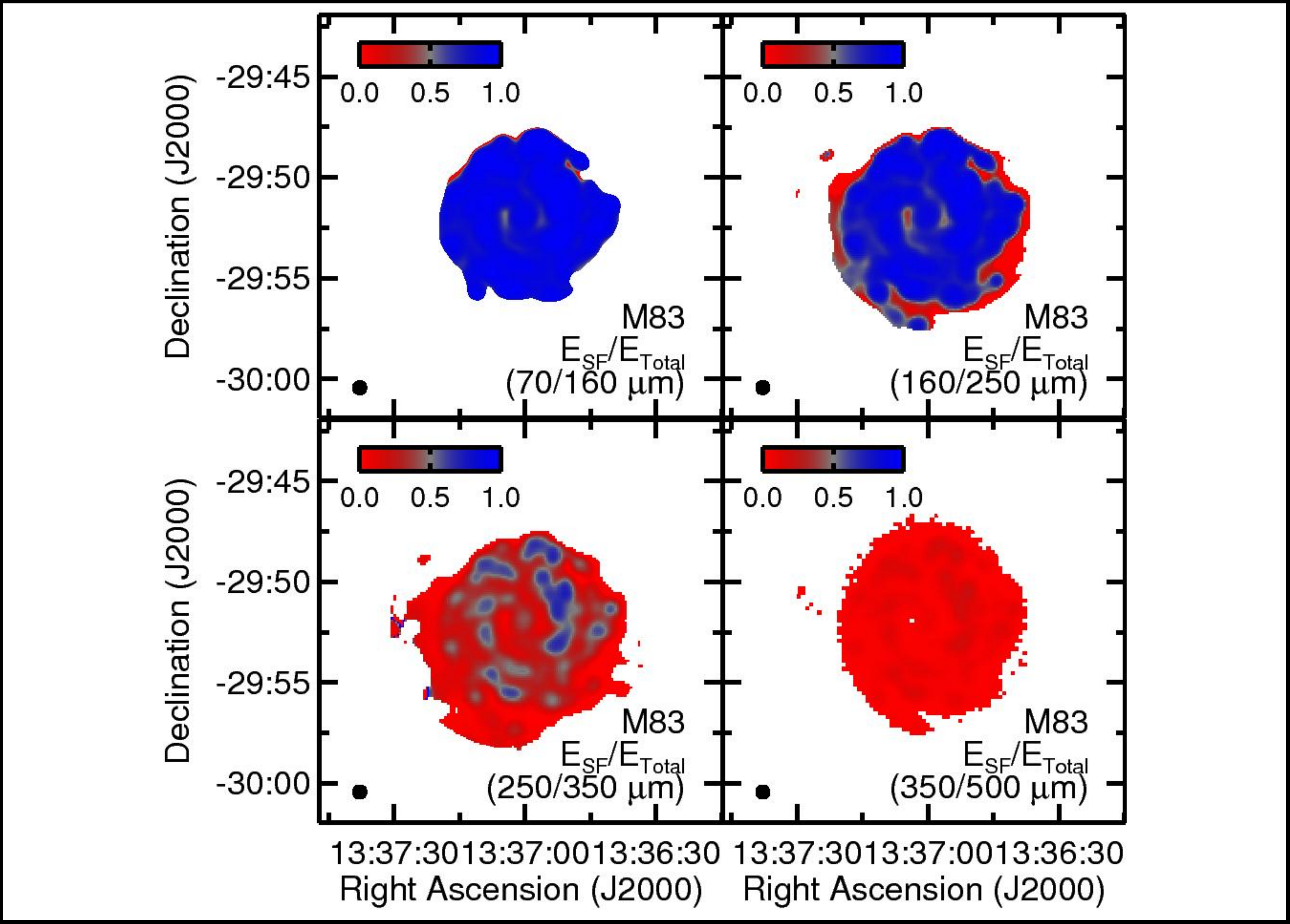
20 30 40
K
-5 0 5
K
+69:15
+69:10
+69:05
+69:00
+68:55
+68:50
Declination (J2000)
M81
T_C(160/250 μm)
observed
M81
T_C(160/250 μm)
reconstructed
M81
T_C(160/250 μm)
residuals
09:56
09:54
Right Ascension (J2000)



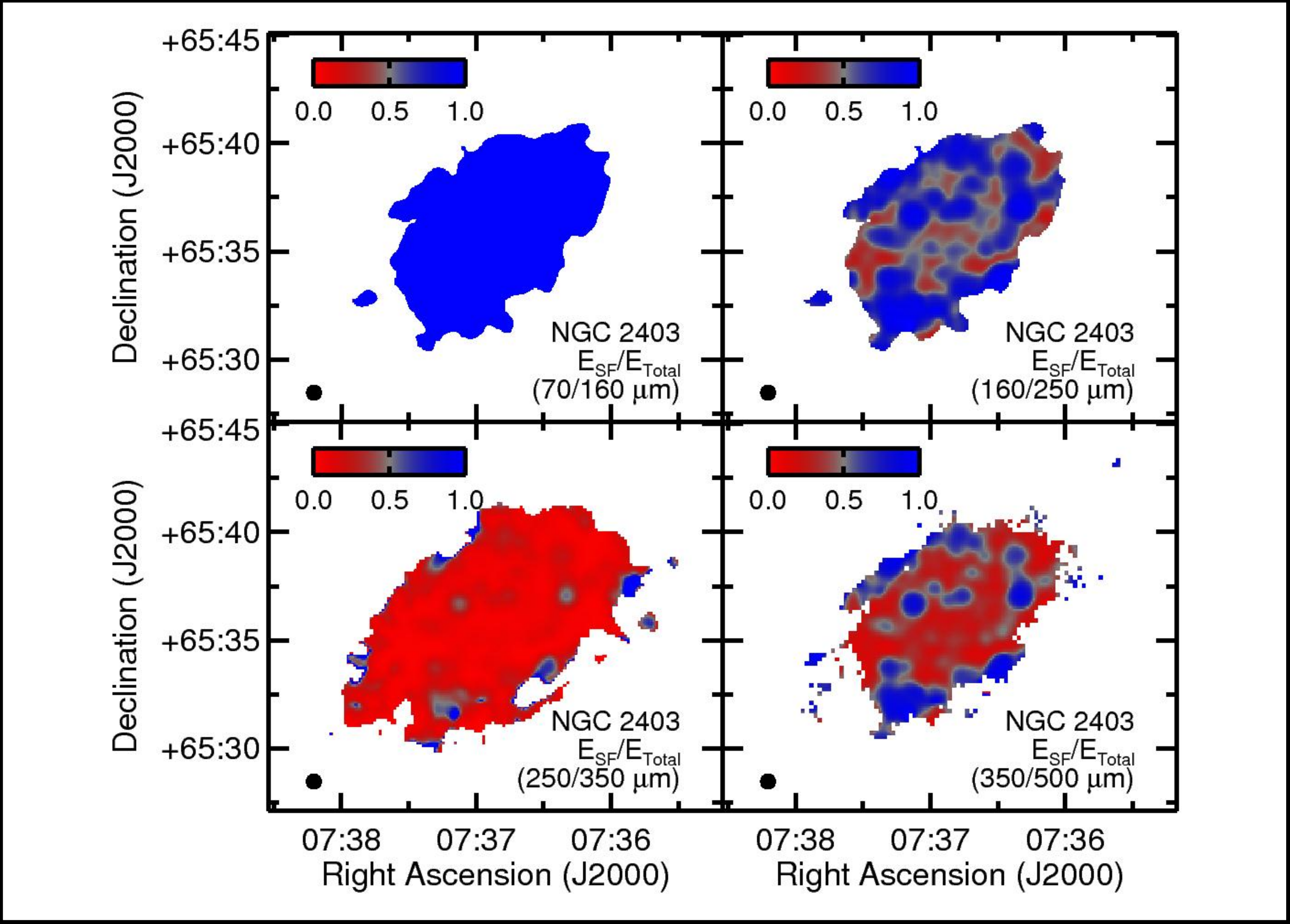
-29:45
-29:50
-29:55
-30:00
Declination (J2000)
20 25 30 35
K
M83
T$_C$(160/250 μm)
observed
13:37:30 13:37:00 13:36:30
Right Ascension (J2000)
20 25 30 35
K
M83
T$_C$(160/250 μm)
reconstructed
13:37:30 13:37:00 13:36:30
Right Ascension (J2000)
-5 0 5
K
M83
T$_C$(160/250 μm)
residuals
13:37:30 13:37:00 13:36:30
Right Ascension (J2000)


+65:45
+65:40
+65:35
+65:30
Declination (J2000)
15
20
K
NGC 2403
T_C(250/350 μm)
observed
07:38
07:37
07:36
Right Ascension (J2000)
15
20
K
NGC 2403
T_C(250/350 μm)
reconstructed
07:38
07:37
07:36
Right Ascension (J2000)
-5
0
5
K
NGC 2403
T_C(250/350 μm)
residuals
07:38
07:37
07:36
Right Ascension (J2000)


0.0 0.5 1.0
+69:15
+69:10
+69:05
+69:00
+68:55
+68:50
Declination (J2000)
M81
E_{SF}/E_{Total}
(70/160 μm)
M81
E_{SF}/E_{Total}
(160/250 μm)
M81
E_{SF}/E_{Total}
(250/350 μm)
M81
E_{SF}/E_{Total}
(350/500 μm)
09:56 09:54
Right Ascension (J2000)



0.0 0.5 1.0
-29:45
-29:50
-29:55
-30:00
Declination (J2000)
M83
E_SF/E_Total
(70/160 μm)
(160/250 μm)
(250/350 μm)
(350/500 μm)
13:37:30 13:37:00 13:36:30
Right Ascension (J2000)

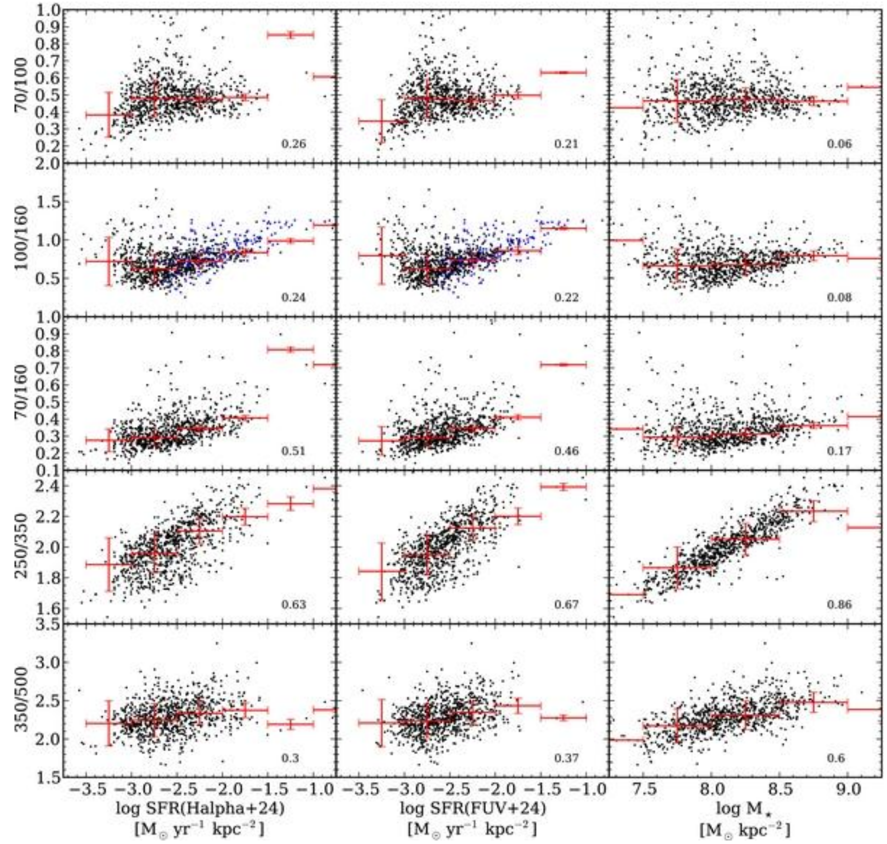


+65:45
+65:40
+65:35
+65:30
Declination (J2000)
0.0 0.5 1.0
NGC 2403
E_SF/E_Total
(70/160 μm)
(160/250 μm)
(250/350 μm)
(350/500 μm)
07:38 07:37 07:36
Right Ascension (J2000)

Other Herschel Results

Initial results on M33 implied that 100-250 μm dust emission was correlated with star formation, but very recent results show dust heating phenomena similar to what we have seen in M81, M83, and NGC 2403.

Results from SED template fitting to sources detected by HerMES imply that these sources also include dust heated by evolved stars.



Boquien et al., 2011, AJ, 142, 111

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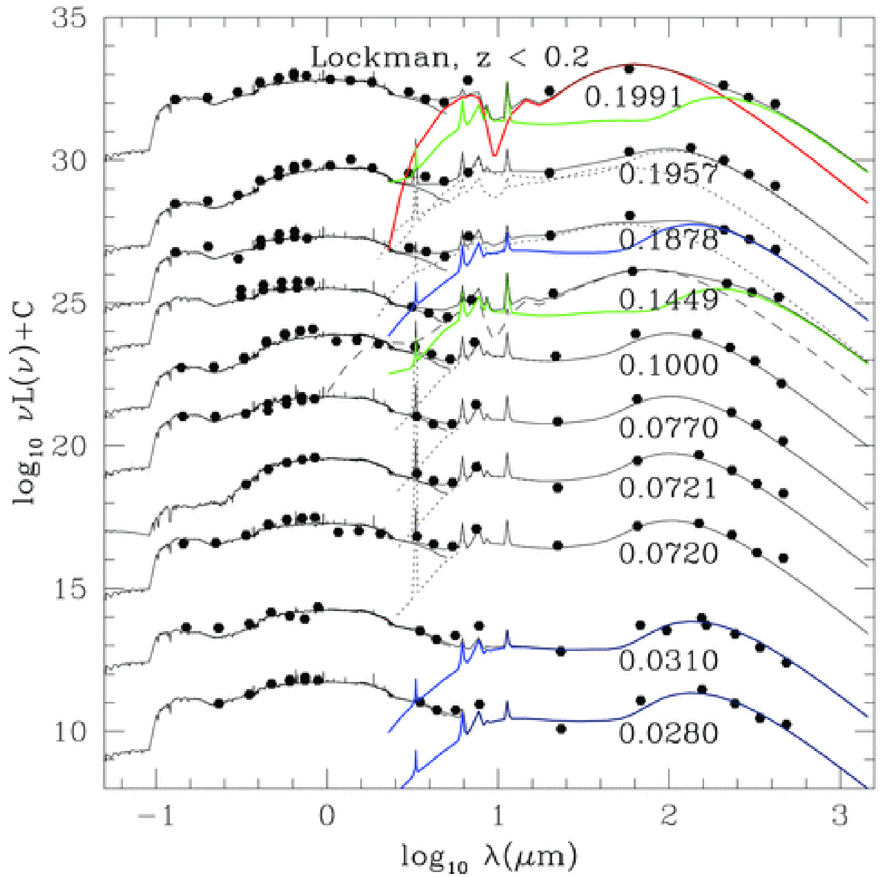

Rowan-Robinson et al., 2010, 409, 2

Conclusions

- The 70/160 μm color temperatures appear more strongly linked to star formation.
- The 250/350, and 350/500 μm colors all appear most strongly correlated with the total stellar emission at 1.6 μm.
- Far-infrared emission should be used cautiously as a star formation tracer.
- Dust models and SED templates need to account for a dust component heated by evolved stars that is seen primarily at >250 μm. Fitting dust emission between 70-500 μm with a single thermal component is not appropriate.

This work was accepted for publication last Wednesday!
Bendo et al., 2011, astro-ph/1109.0237