# The Identification of Dust Heating Mechanisms Using Infrared Surface Brightness Ratios

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## Science Goal

The overall goal of this work is to empirically identify the heating sources for the dust seen in the far-infrared:

- Identifying this properly is needed to calculate accurate dust masses.
- The analysis results can also be used to guide SED modelling.
- If the dust is not heated by star forming regions, this has an impact on using far-infrared emission as a star formation tracer.

## Analysis Overview

The analysis is based on comparing variations in infrared surface brightness ratios to heating sources.

- Emission in a single band can be correlated to star formation as the result of either temperature or mass variations.
- The ratios of infrared surface brightnesses can only depend on temperature and will only be related to the heating source.

The sample consists of 24 face-on spiral galaxies from three samples:

- 3 galaxies from the VNGS.
- 11 galaxies from the HRS.
- 10 galaxies from KINGFISH.

# Analysis Overview

The following data are used:

- 160/250 and 250/350 μm ratios used to trace dust heating.
- Hα and 24 μm emission are combined to trace star formation (as extinction-corrected Hα).
- 3.6 μm data is used as a tracer of the total stellar population.

The analysis is broken into three parts

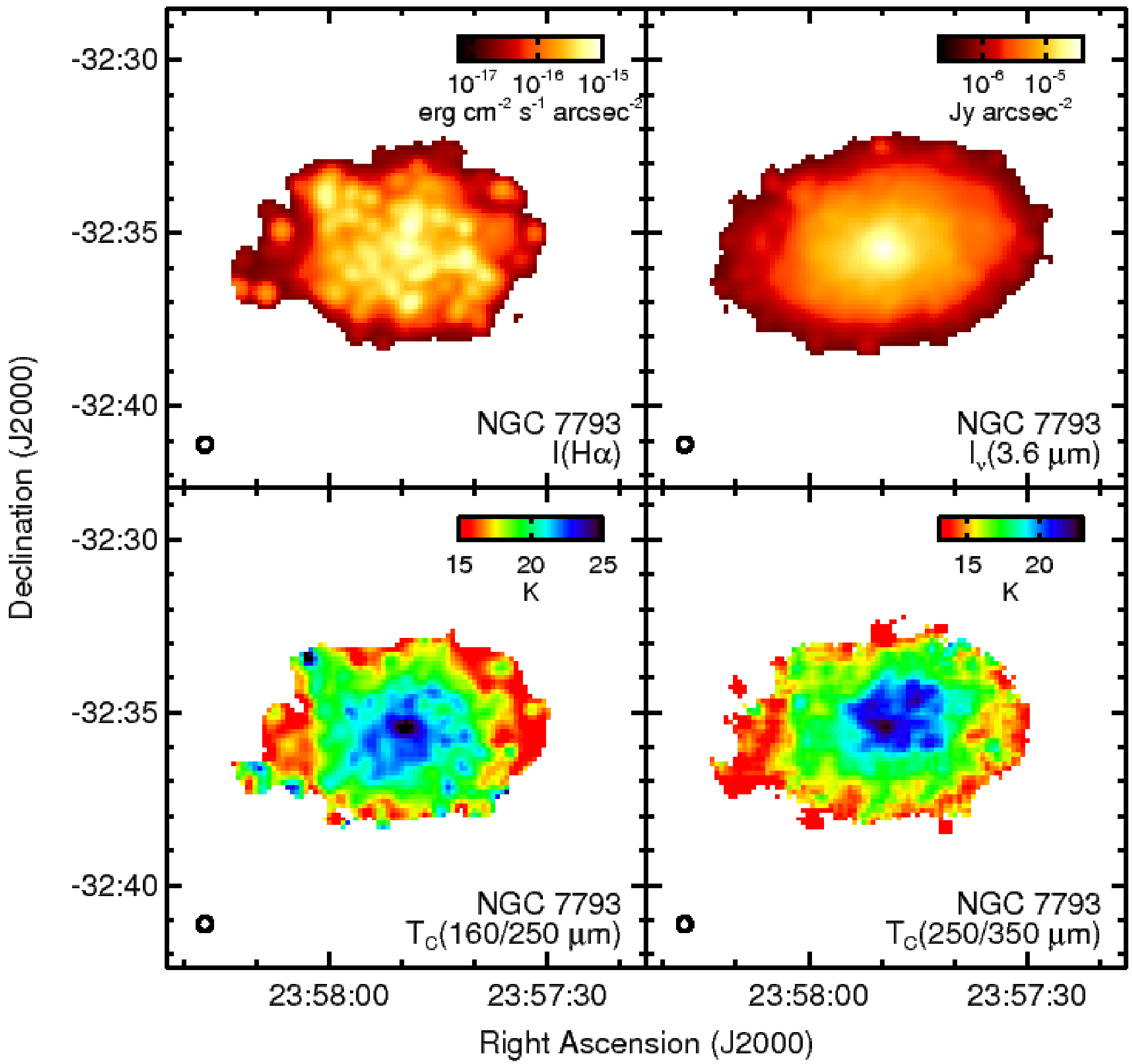
- Qualitative analysis of maps.
- Correlation of infrared surface brightness ratios to dust heating sources in binned data.
- Decomposition of surface brightness ratio maps into Hα and 3.6 μm components.

## Emission at ≥160 μm Linked to Total Stellar Population

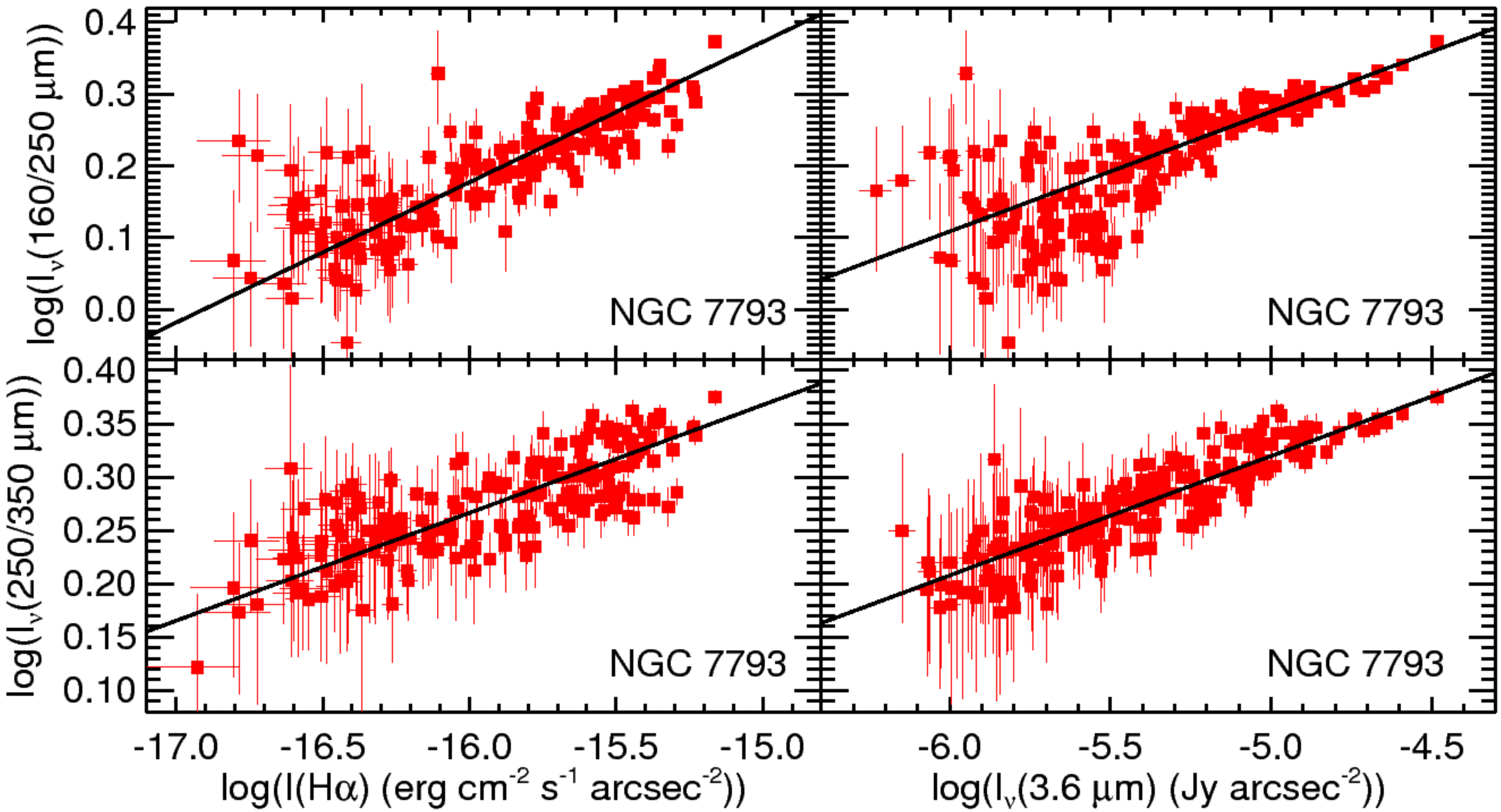
Example galaxies:

- M33 (Boquien et al. 2011, AJ, 142, 111; see also George Ford's upcoming paper)
- M81
- NGC 3621
- NGC 3631 (possible)
- NGC 3953 (possible)
- NGC 4548
- NGC 4725
- NGC 7793 (although 160 μm emission is mixed)

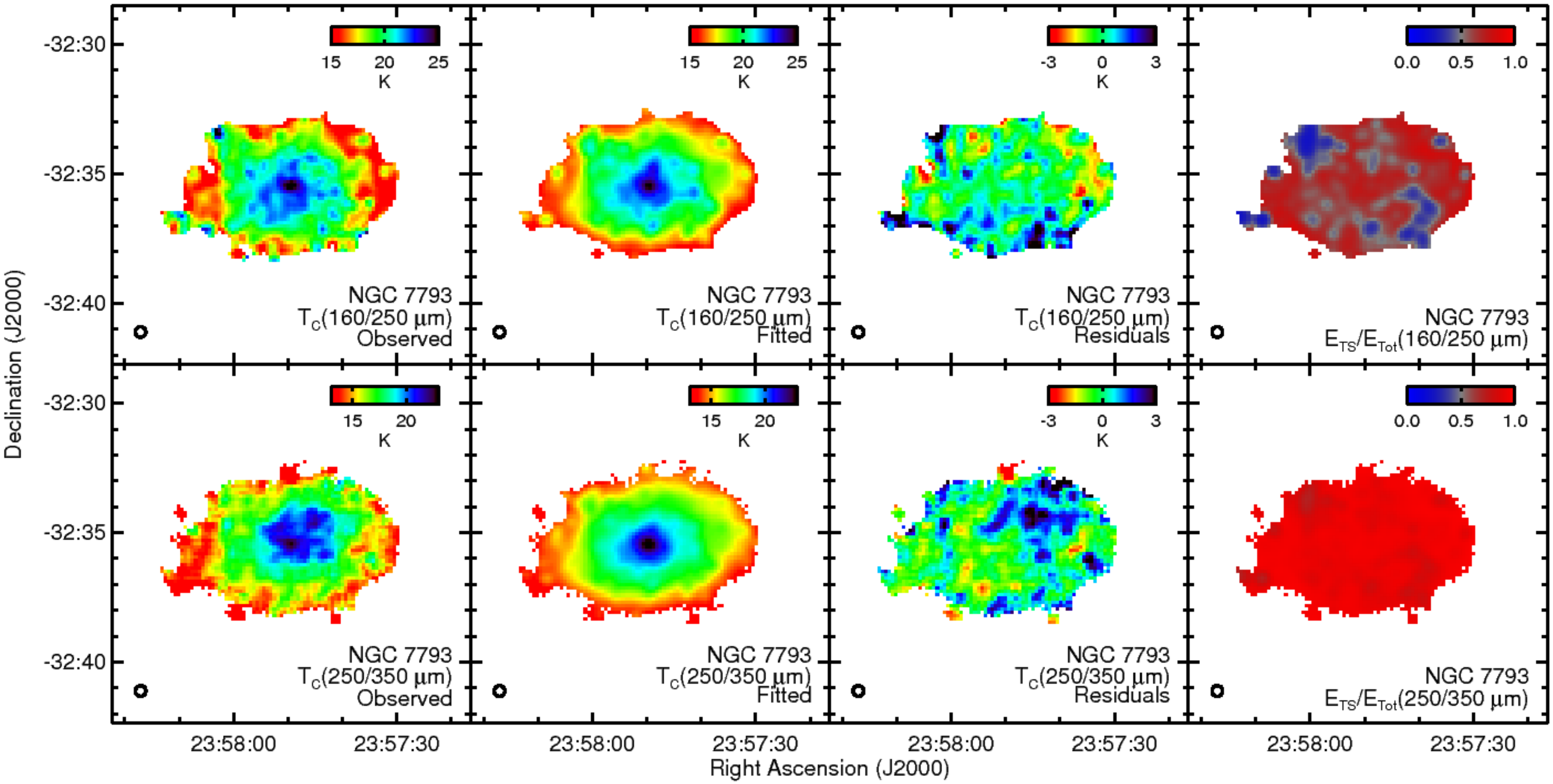
Dust heating by the total stellar population seems more common in early-type spiral galaxies.



-32:30
-32:35
-32:40
Declination (J2000)
10-17 10-16 10-15
erg cm-2 s-1 arcsec-2
NGC 7793
I(Hα)
10-6 10-5
Jy arcsec-2
NGC 7793
Iν(3.6 μm)
15 20 25
K
NGC 7793
TC(160/250 μm)
15 20
K
NGC 7793
TC(250/350 μm)
23:58:00
23:57:30
Right Ascension (J2000)



log(I_ν(160/250 μm))
0.4
0.3
0.2
0.1
0.0
NGC 7793
NGC 7793
log(I_ν(250/350 μm))
0.40
0.35
0.30
0.25
0.20
0.15
0.10
NGC 7793
NGC 7793
-17.0
-16.5
-16.0
-15.5
-15.0
log(I(Hα) (erg cm^-2 s^-1 arcsec^-2))
-6.0
-5.5
-5.0
-4.5
log(I_ν(3.6 μm) (Jy arcsec^-2))

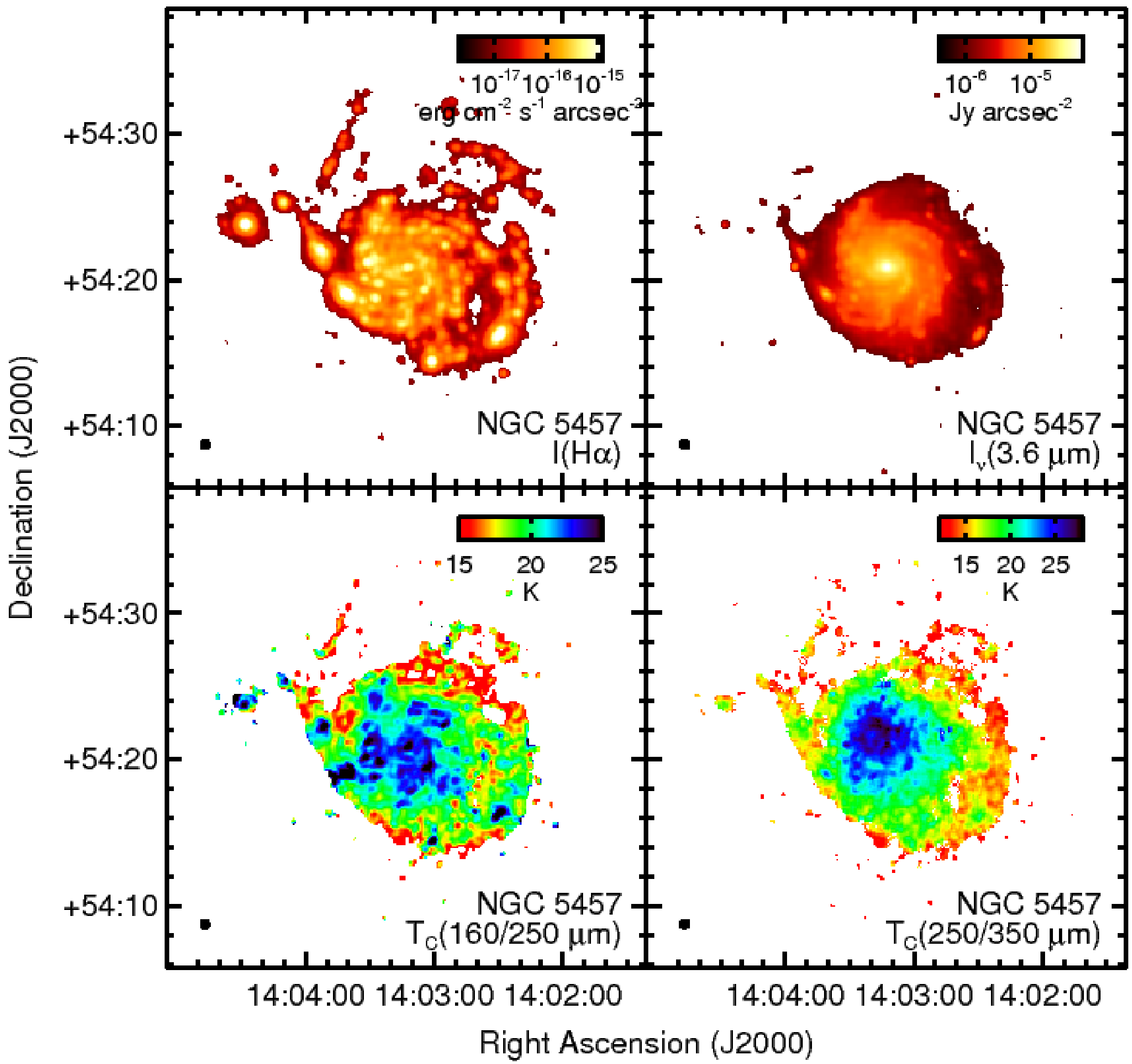


Declination (J2000)
Right Ascension (J2000)
-32:30
-32:35
-32:40
23:58:00
23:57:30
15 20 25 K
-3 0 3 K
0.0 0.5 1.0
15 20 K
NGC 7793
T$_C$(160/250 μm) Observed
T$_C$(160/250 μm) Fitted
T$_C$(160/250 μm) Residuals
E$_{TS}$/E$_{Tot}$(160/250 μm)
T$_C$(250/350 μm) Observed
T$_C$(250/350 μm) Fitted
T$_C$(250/350 μm) Residuals
E$_{TS}$/E$_{Tot}$(250/350 μm)

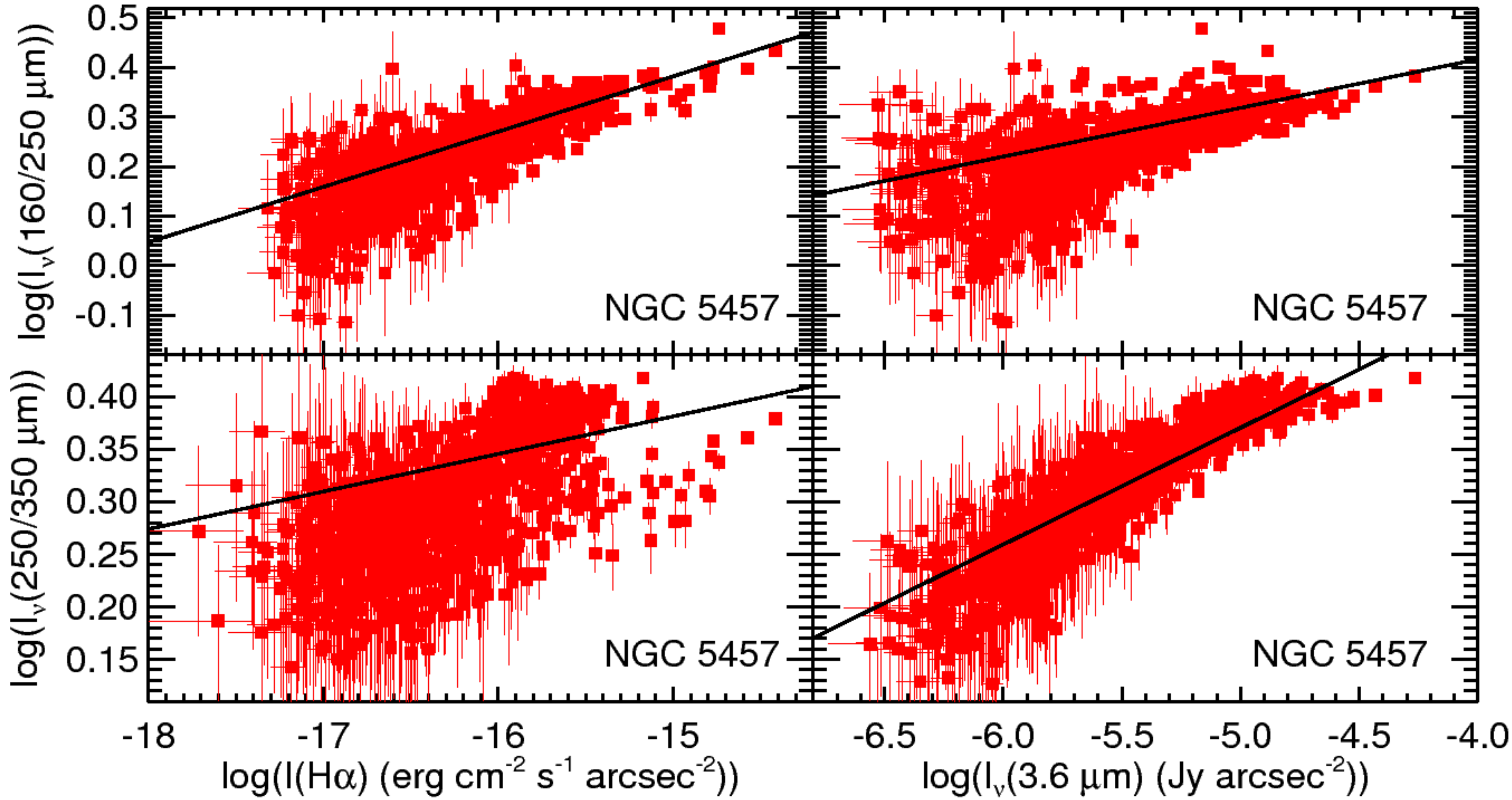
# Emission at ≤ 160 μm Linked to Star Formation, at ≥250 μm Linked to Total Stellar Population

Example galaxies:

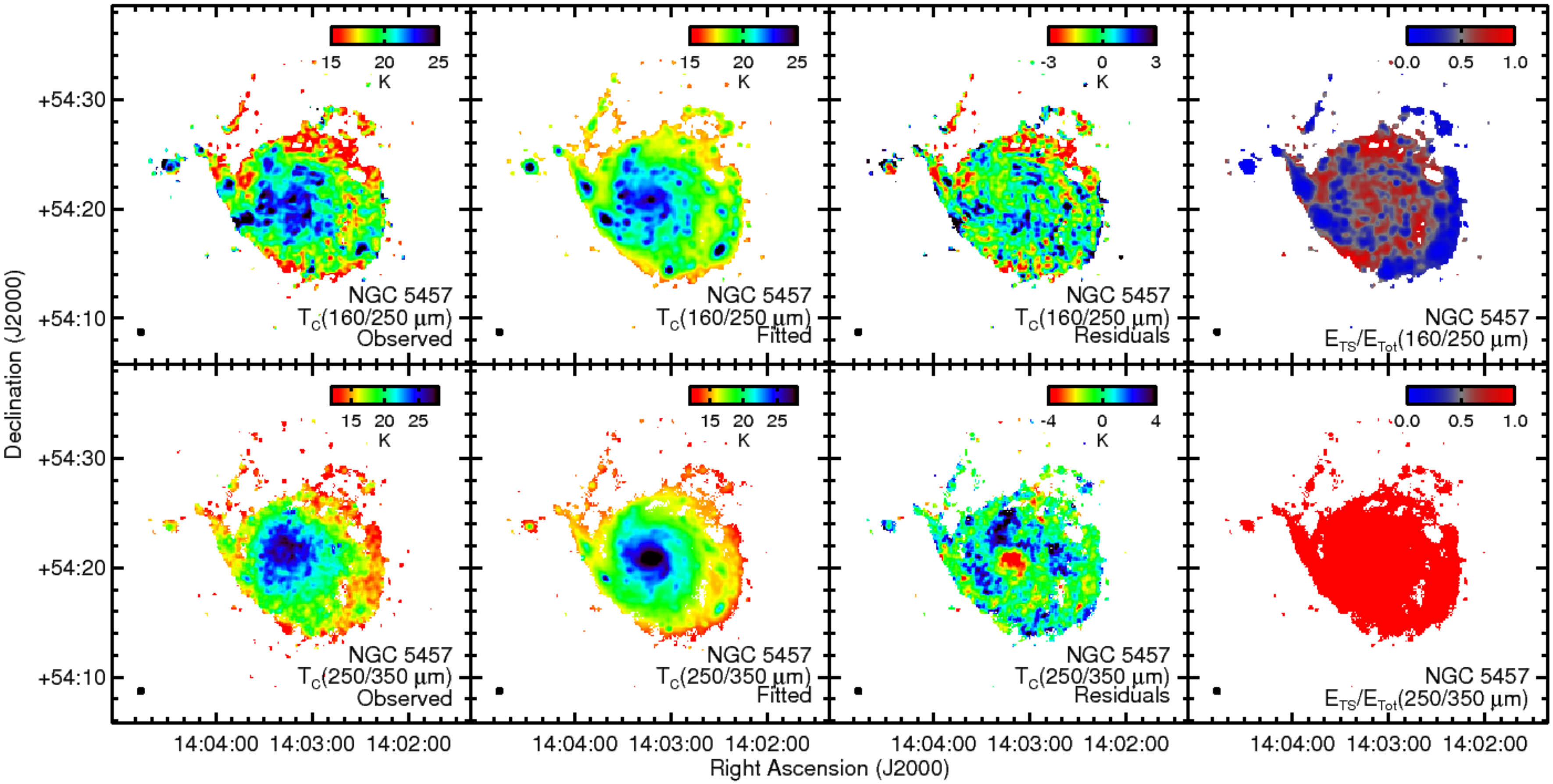
- NGC 628
- NGC 2403
- NGC 3938 (possible)
- NGC 4736 (although dust heating at 160 μm is mixed)
- NGC 5236 (possible)
- NGC 5457
- NGC 6946 (although something strange happens in the 250/350 μm maps)



10^-17 10^-16 10^-15
erg cm^-2 s^-1 arcsec^-2
NGC 5457
I(Hα)
10^-6 10^-5
Jy arcsec^-2
NGC 5457
Iν(3.6 μm)
15 20 25
K
NGC 5457
TC(160/250 μm)
15 20 25
K
NGC 5457
TC(250/350 μm)
+54:30
+54:20
+54:10
Declination (J2000)
14:04:00 14:03:00 14:02:00
Right Ascension (J2000)



log(I_ν(160/250 μm))
log(I_ν(250/350 μm))
NGC 5457
NGC 5457
NGC 5457
NGC 5457
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0.40
0.35
0.30
0.25
0.20
0.15
-18
-17
-16
-15
-6.5
-6.0
-5.5
-5.0
-4.5
-4.0
log(I(Hα) (erg cm^-2 s^-1 arcsec^-2))
log(I_ν(3.6 μm) (Jy arcsec^-2))



15 20 25
K
NGC 5457
T_C(160/250 μm)
Observed
NGC 5457
T_C(160/250 μm)
Fitted
-3 0 3
K
NGC 5457
T_C(160/250 μm)
Residuals
0.0 0.5 1.0
NGC 5457
E_TS/E_Tot(160/250 μm)
NGC 5457
T_C(250/350 μm)
Observed
NGC 5457
T_C(250/350 μm)
Fitted
-4 0 4
K
NGC 5457
T_C(250/350 μm)
Residuals
NGC 5457
E_TS/E_Tot(250/350 μm)
Declination (J2000)
+54:30
+54:20
+54:10
14:04:00 14:03:00 14:02:00
Right Ascension (J2000)

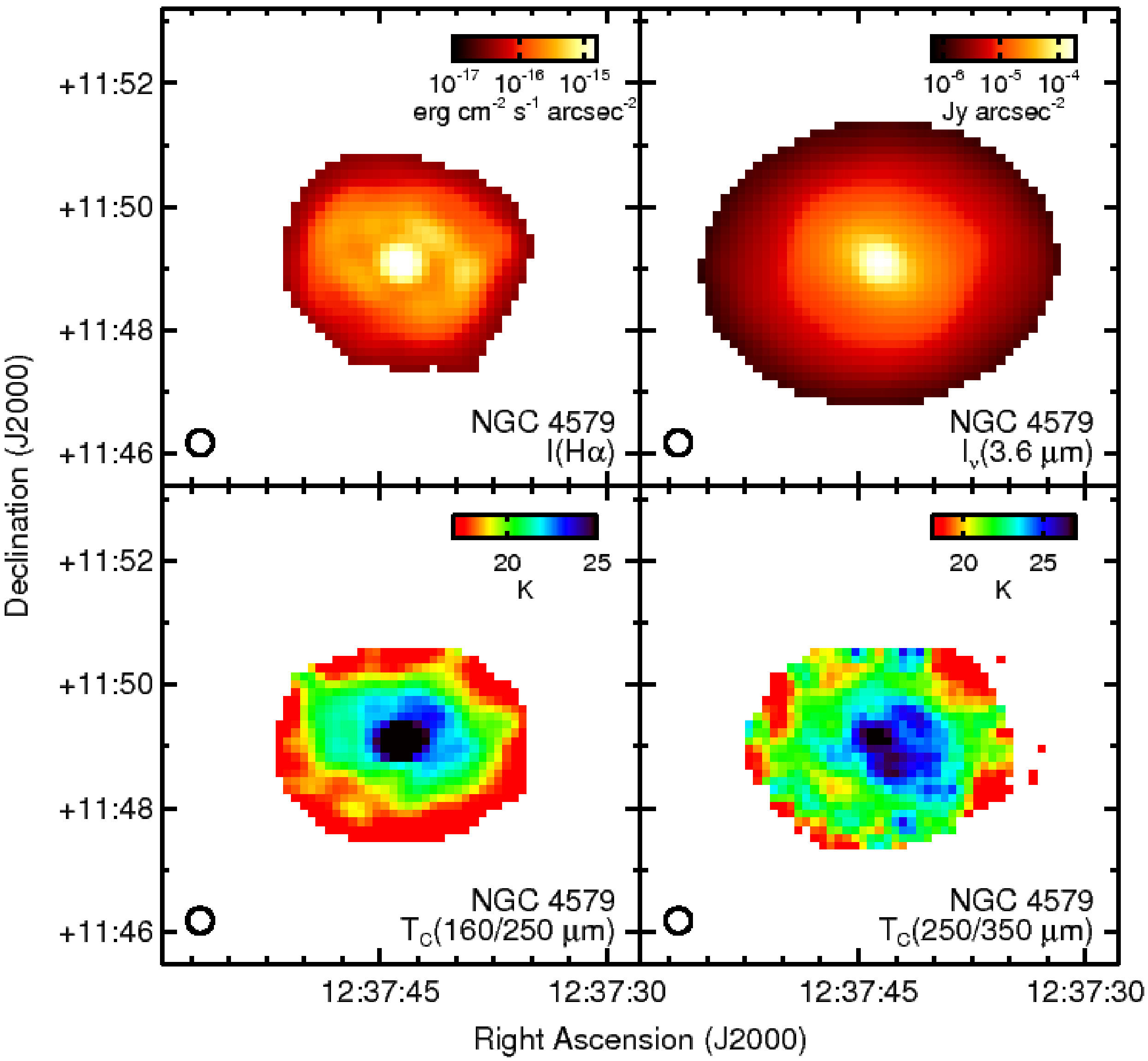
# No Dominant Heating Source for Dust Seen at 160-350 µm

Example galaxies:

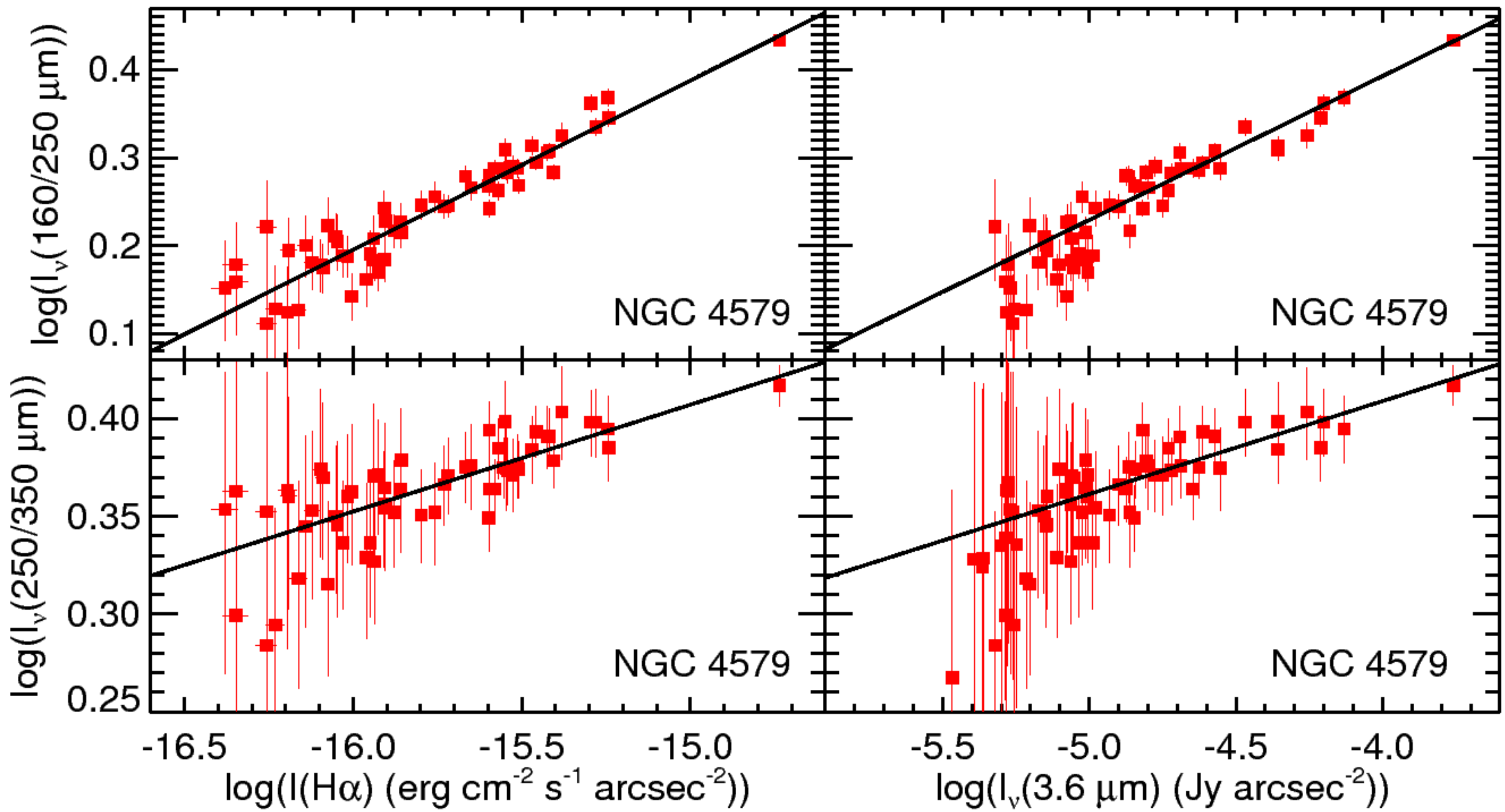
- NGC 3184
- NGC 4579

This can appear in one of two ways:

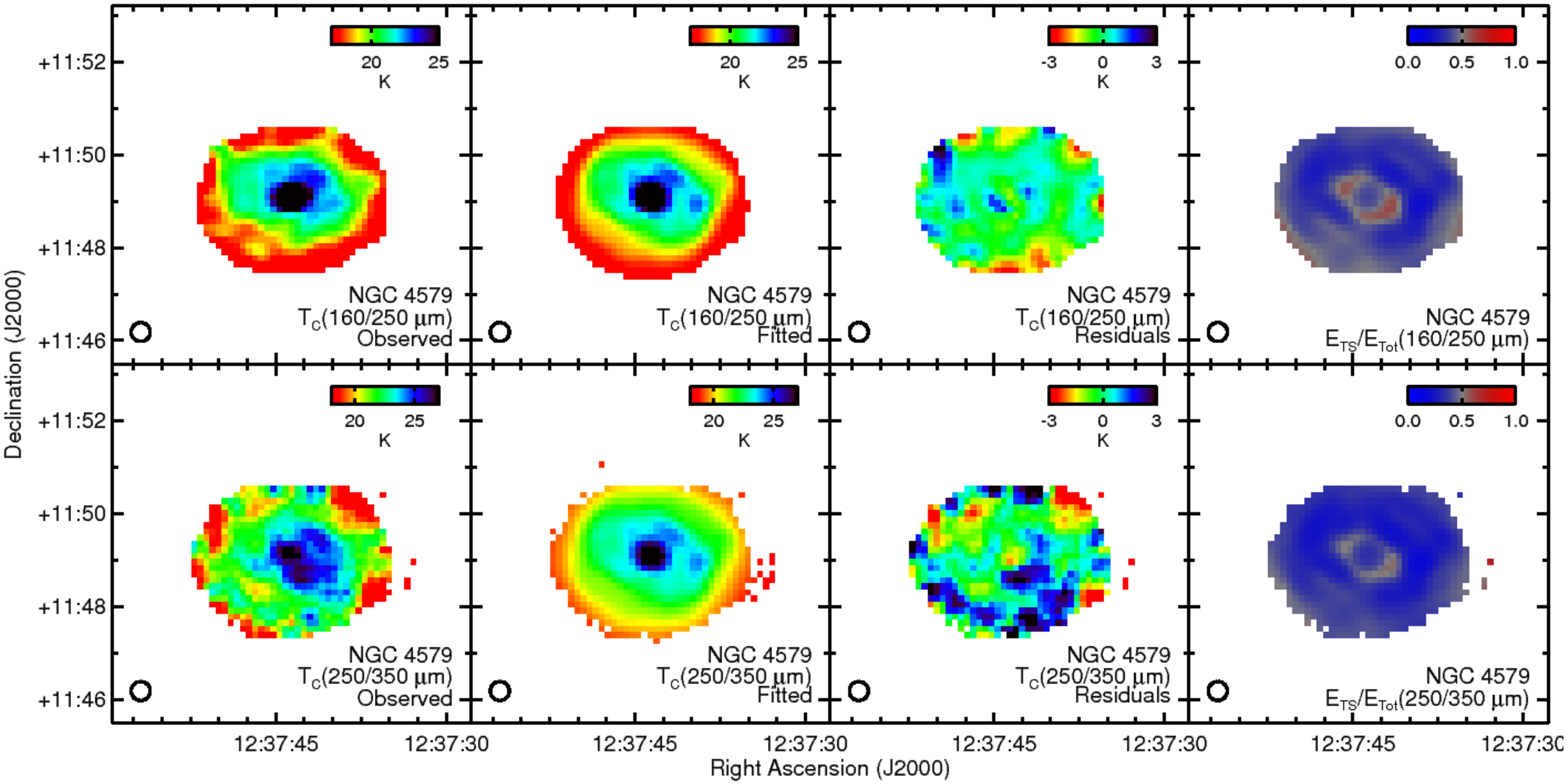
- The colour temperature structures do not look like emission traced by either heating source.
- The structures traced by both heating sources look indistinct from each other.



10^-17 10^-16 10^-15
erg cm^-2 s^-1 arcsec^-2
NGC 4579
I(Hα)
10^-6 10^-5 10^-4
Jy arcsec^-2
NGC 4579
I_ν(3.6 μm)
20 25
K
NGC 4579
T_C(160/250 μm)
20 25
K
NGC 4579
T_C(250/350 μm)
+11:52
+11:50
+11:48
+11:46
Declination (J2000)
12:37:45
12:37:30
Right Ascension (J2000)



log(I_ν(160/250 μm))
0.4
0.3
0.2
0.1
NGC 4579
NGC 4579
log(I_ν(250/350 μm))
0.40
0.35
0.30
0.25
NGC 4579
NGC 4579
-16.5
-16.0
-15.5
-15.0
log(I(Hα) (erg cm^-2 s^-1 arcsec^-2))
-5.5
-5.0
-4.5
-4.0
log(I_ν(3.6 μm) (Jy arcsec^-2))



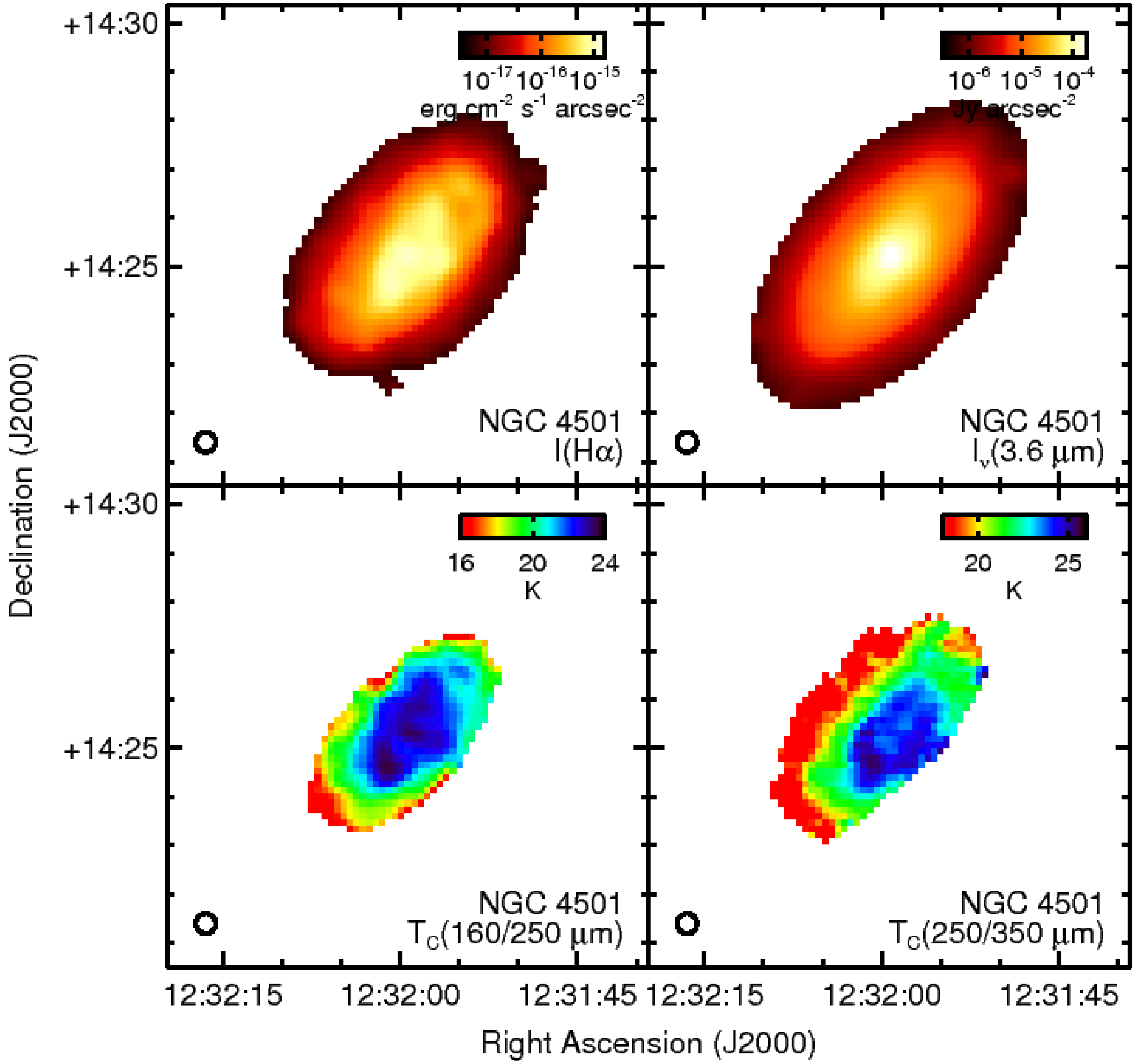
NGC 4579
$T_C$(160/250 μm)
Observed
Fitted
Residuals
$E_{TS}/E_{Tot}$(160/250 μm)
$T_C$(250/350 μm)
$E_{TS}/E_{Tot}$(250/350 μm)
K
Declination (J2000)
Right Ascension (J2000)
+11:52
+11:50
+11:48
+11:46
12:37:45
12:37:30

# Emission at ≤250 μm Linked to Star Forming Regions

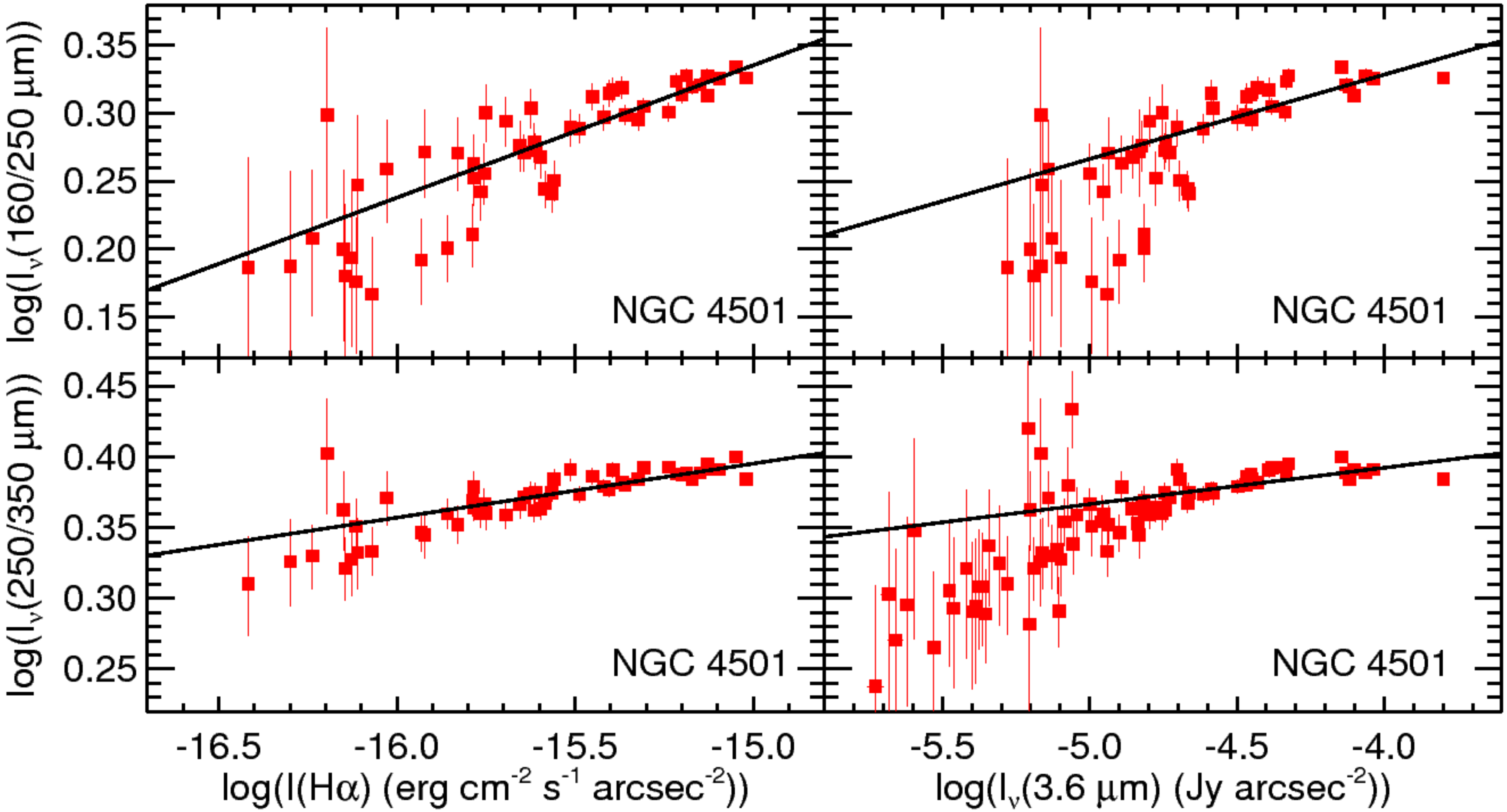
Example galaxies:

- NGC 891 (see Hughes et al., 2014, A&A, 565, 4)
- NGC 925 (possible)
- NGC 4254
- NGC 4303
- NGC 4321 (possible)
- NGC 4501
- NGC 5055 (although dust heating at ≥250 μm is mixed)
- NGC 5364

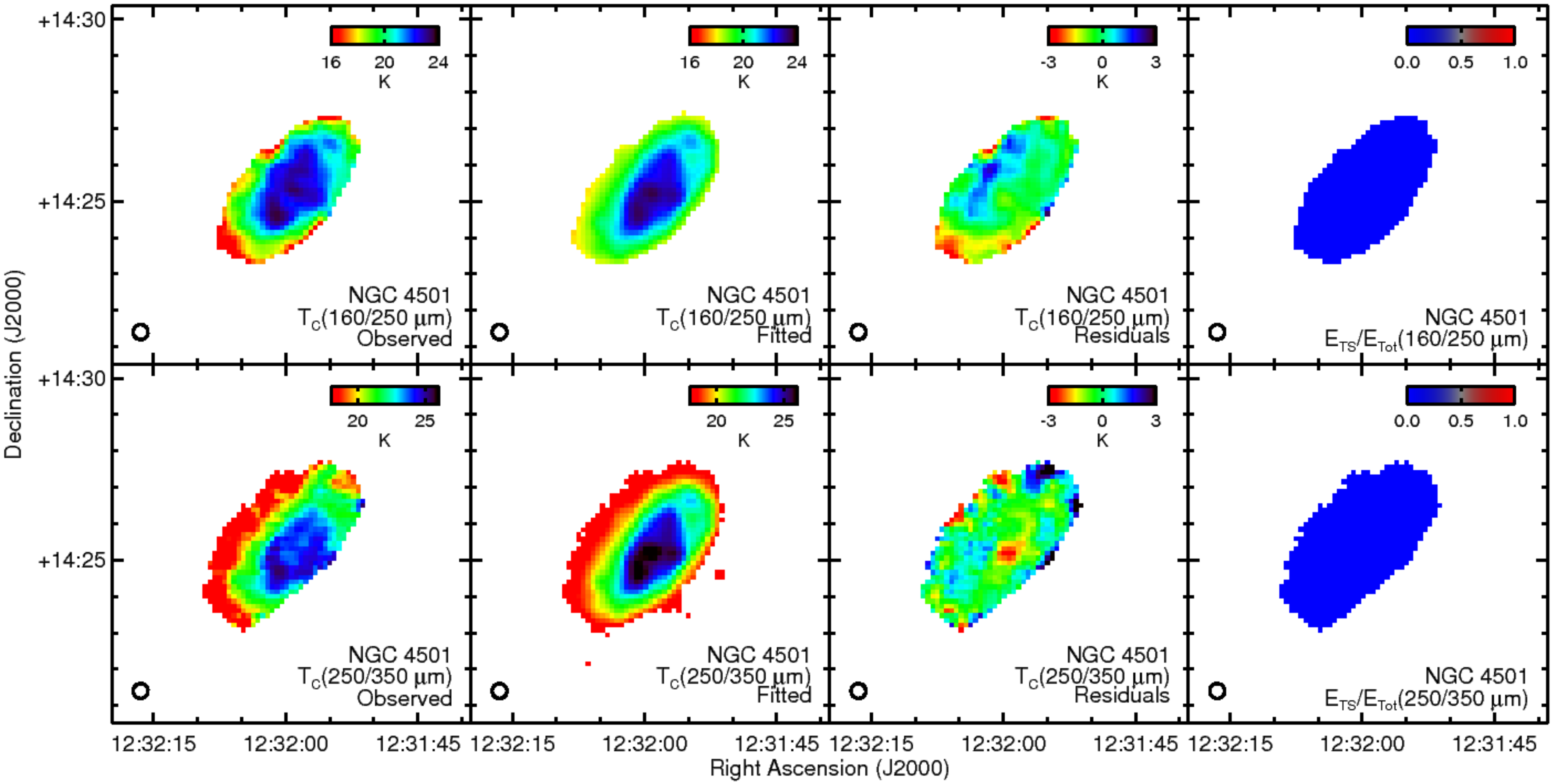
This appears in many (but not all) of the Virgo Cluster galaxies, although a couple of the Virgo Cluster galaxies are distinctly different.



+14:30
+14:25
Declination (J2000)
Right Ascension (J2000)
12:32:15
12:32:00
12:31:45
10^-17 10^-16 10^-15
erg cm^-2 s^-1 arcsec^-2
NGC 4501
I(Hα)
10^-6 10^-5 10^-4
Jy arcsec^-2
NGC 4501
I_ν(3.6 μm)
16 20 24
K
NGC 4501
T_C(160/250 μm)
20 25
K
NGC 4501
T_C(250/350 μm)



log(I_ν(160/250 μm))
log(I_ν(250/350 μm))
0.35
0.30
0.25
0.20
0.15
0.45
0.40
0.35
0.30
0.25
NGC 4501
NGC 4501
NGC 4501
NGC 4501
-16.5
-16.0
-15.5
-15.0
-5.5
-5.0
-4.5
-4.0
log(I(Hα) (erg cm^-2 s^-1 arcsec^-2))
log(I_ν(3.6 μm) (Jy arcsec^-2))



+14:30
+14:25
Declination (J2000)
16 20 24
K
NGC 4501
T_C(160/250 μm)
Observed
16 20 24
K
NGC 4501
T_C(160/250 μm)
Fitted
-3 0 3
K
NGC 4501
T_C(160/250 μm)
Residuals
0.0 0.5 1.0
NGC 4501
E_TS/E_Tot(160/250 μm)
20 25
K
NGC 4501
T_C(250/350 μm)
Observed
20 25
K
NGC 4501
T_C(250/350 μm)
Fitted
-3 0 3
K
NGC 4501
T_C(250/350 μm)
Residuals
0.0 0.5 1.0
NGC 4501
E_TS/E_Tot(250/350 μm)
12:32:15 12:32:00 12:31:45
Right Ascension (J2000)

## Caveats

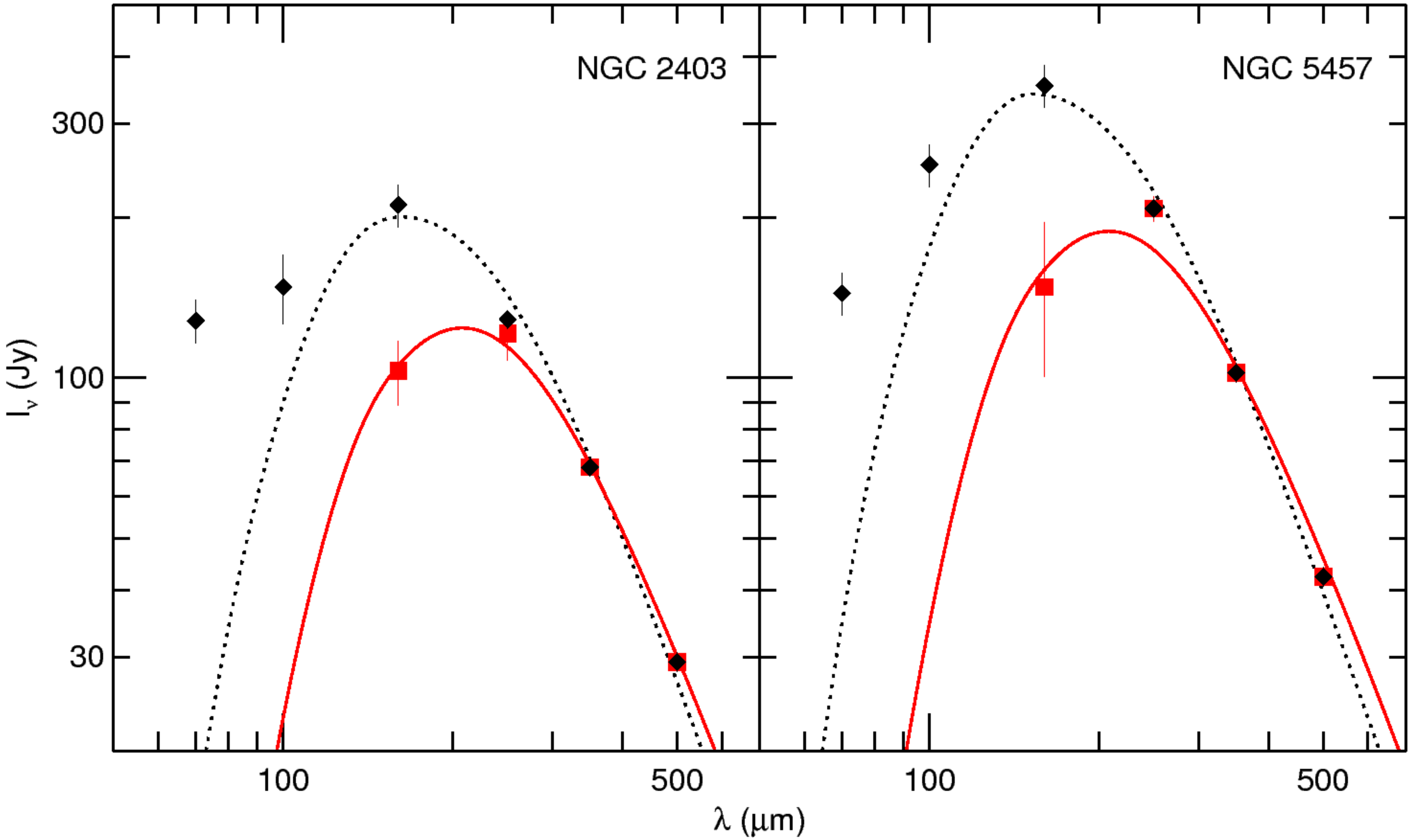
- The analysis relies upon the assumption that dust heating is local (ie that starlight does not travel further than 24”).
- The inferred contribution of star forming regions to dust heating depends on the star formation tracer.
- The nonlinear fitting in the decomposition analysis does not always seem stable.

# Implications for SED Fitting

Current SED fits appear to do one of the following:

- Assume that all of the emission longwards of a given wavelength (eg $\geq$100 μm) originate from a single thermal component and fit a single modified blackbody or model to the data.
- Fit infrared flux densities with separate components for dust heated by star forming regions and dust heated by the diffuse ISRF and ignore using any other data as clues for the heating sources.
- Fit a complex model to the data but do not track the association of emission in a given wave band with any specific heating source.

Results from the image decomposition analysis can be used to separate SEDs into different components. More ideally, it would be appropriate to develop models that replicate the colours accurately.



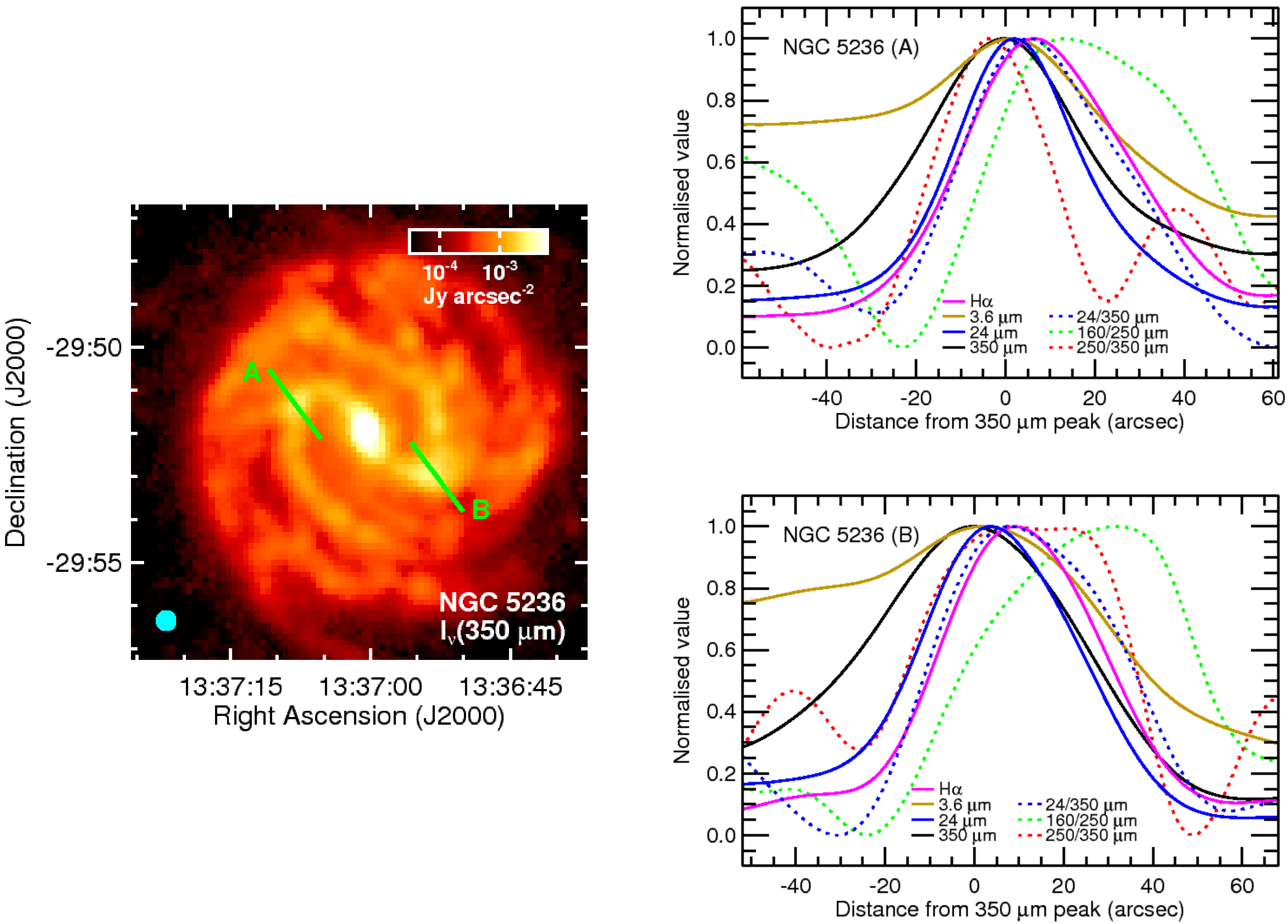
NGC 2403
NGC 5457
300
100
30
$I_\nu$ (Jy)
100
500
100
500
λ (μm)

## Bonus Result #1

As mentioned earlier, it is not always the case that dust heated in one resolution element is heated by stars within that resolution element.

In some grand-design spiral galaxies, enhanced colour temperatures are seen in locations offset from the star forming regions in the spiral arms.  This could be caused by one of two phenomena:

- Light from star forming regions propagating asymemtrically from spiral arms.
- Dust being heated by intermediate age (10-100 Myr) stellar population.



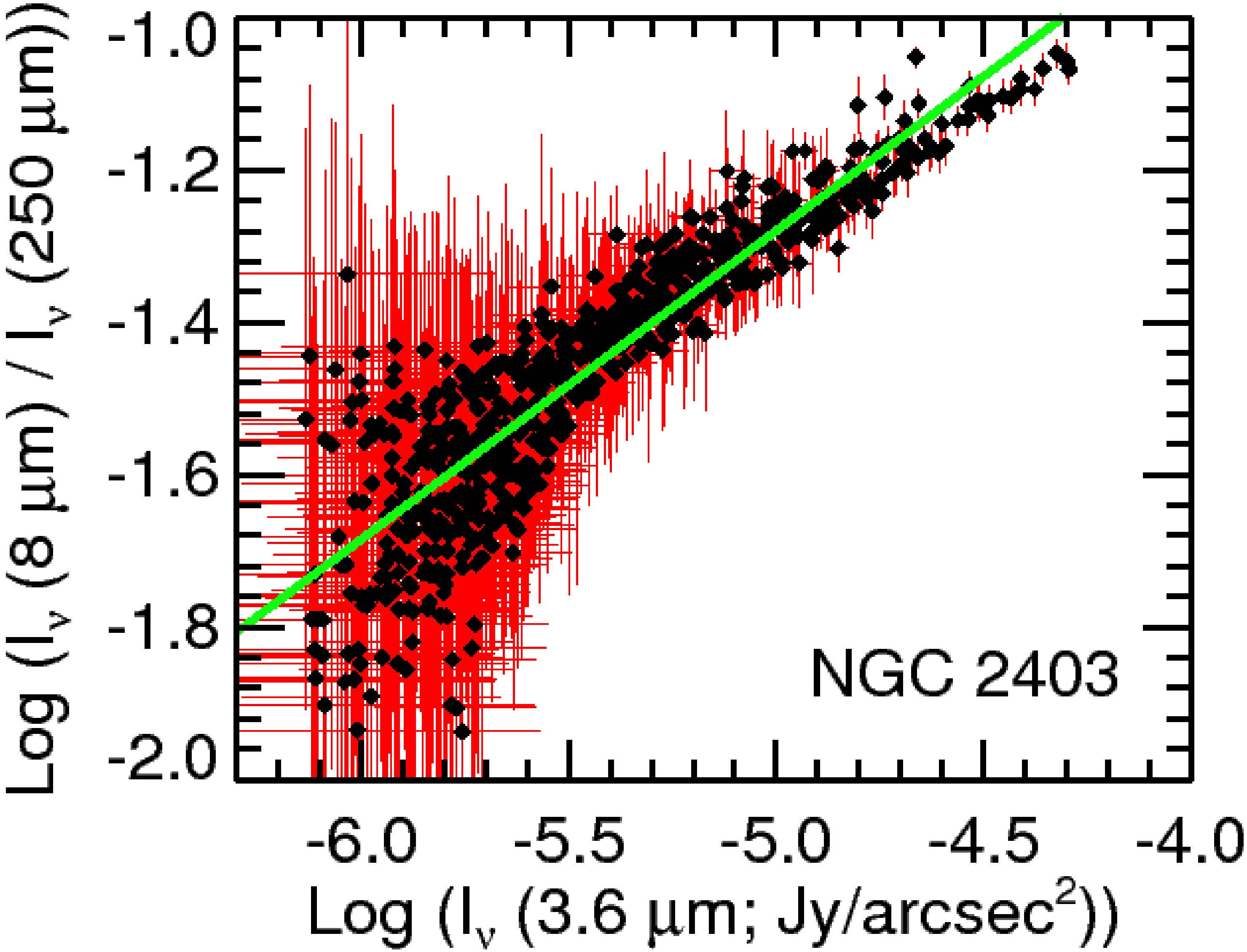
10^-4 10^-3
Jy arcsec^-2
A
B
NGC 5236
I_ν(350 μm)
-29:50
-29:55
Declination (J2000)
13:37:15 13:37:00 13:36:45
Right Ascension (J2000)
NGC 5236 (A)
NGC 5236 (B)
Normalised value
Distance from 350 μm peak (arcsec)
Hα
3.6 μm
24 μm
350 μm
24/350 μm
160/250 μm
250/350 μm

# Bonus Result #2

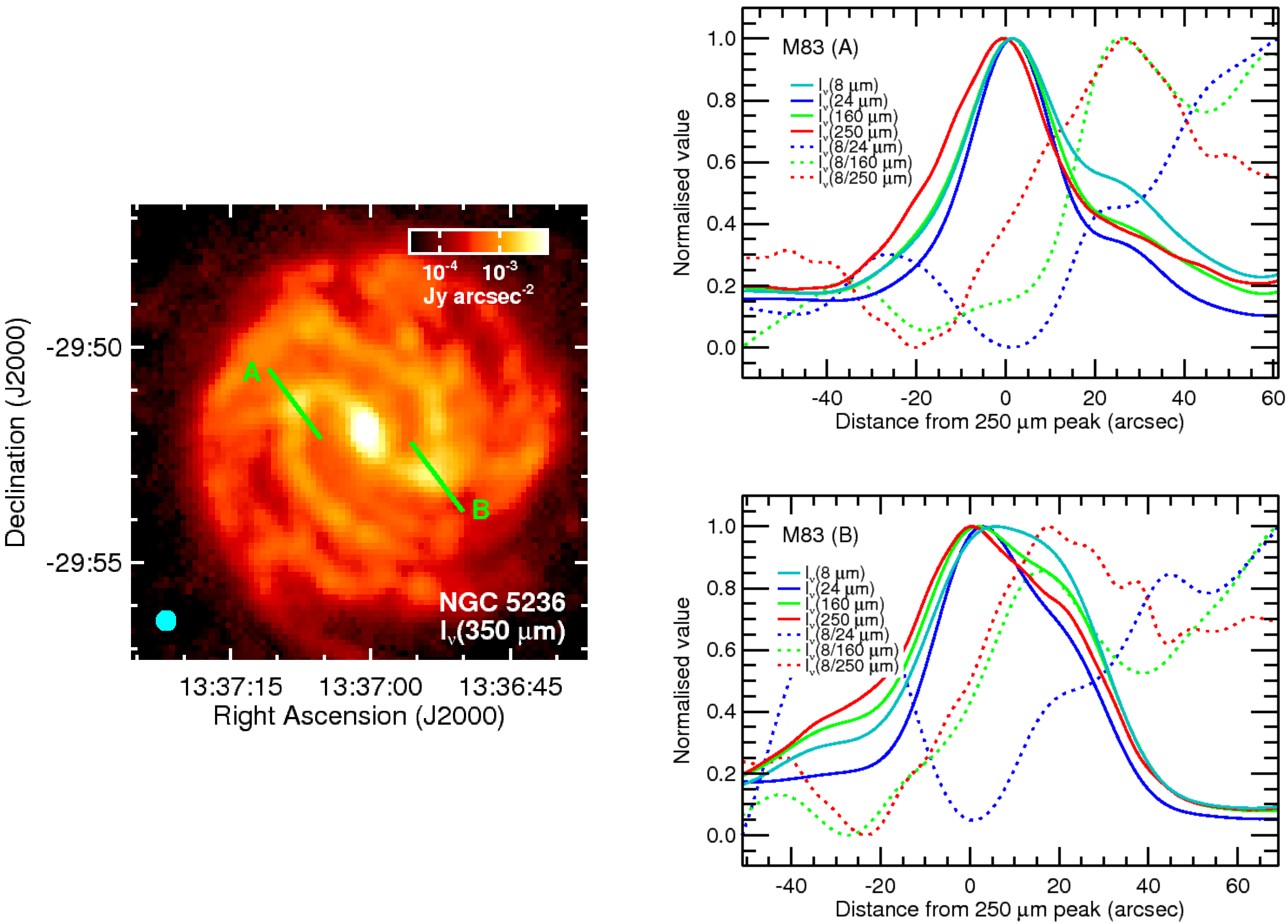
Andrew Jones (MSc student at the University of Manchester) recently completed work on studying the association of PAH emission with cold dust emission in M83 and NGC 2403.

In NGC 2403, the PAHs are strongly linked with emission at 250 µm and appear excited by the diffuse ISRF.

In M83, the PAHs are strongly linked with emission at 160 µm and appear excited in regions offset from the galaxy's spiral arms.



NGC 2403
Log ($I_\nu$ (8 μm) / $I_\nu$ (250 μm))
Log ($I_\nu$ (3.6 μm; Jy/arcsec$^2$))
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-6.0
-5.5
-5.0
-4.5
-4.0


10-4 10-3
Jy arcsec-2
A
B
NGC 5236
Iν(350 μm)
Declination (J2000)
-29:50
-29:55
13:37:15
13:37:00
13:36:45
Right Ascension (J2000)
M83 (A)
Iν(8 μm)
Iν(24 μm)
Iν(160 μm)
Iν(250 μm)
Iν(8/24 μm)
Iν(8/160 μm)
Iν(8/250 μm)
Normalised value
Distance from 250 μm peak (arcsec)
M83 (B)
Iν(8 μm)
Iν(24 μm)
Iν(160 μm)
Iν(250 μm)
Iν(8/24 μm)
Iν(8/160 μm)
Iν(8/250 μm)
Normalised value
Distance from 250 μm peak (arcsec)