Energy Sources of the Far IR Emission of M33


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M33 Properties

- Distance 840 kpc = 2.7 Mlyr (1" ~ 4 pc)
- Also known as NGC 598
- Late type spiral: SA(s)cd
- Nearly face-on i=56°
- Low metallicity
- Bright nucleus with small bulge
- No supermassive black hole

Infrared Spectral Energy Distribution
M33 Observations

- Multiple overlapping Spitzer medium rate MIPS observations created maps at 24 μm (6" resolution), 70 μm (18" res), and 160 μm (40" res.)

- Combined data with Hα (CWBST at Kitt Peak), 6 cm radio continuum (VLA & WSRT, 10" res), near infrared K-band (2MASS), the B band (Bok 2.3m at Kitt Peak).

- Convolved images of Hα and 24μm to the MIPS 70μm resolution (18") and cropped all images to a common field of view (38' x 44') for comparison.
M33 in Six Bands – HII regions

- The Hα, 24, and 70 µm (as well as 6cm radio) maps all show distinct spiral arms with nearly no bulge traced by bright HII regions.

- The 160 µm map has smoother structure, so individual HII regions contribute less at 160µm (160 res is 40" not 18")
The near IR traces older stellar population in broad arms and small bulge, with diffuse emission across galactic disk.

Optical blue image is dominated by broad spiral arm emission.

Both Hα and 24 µm trace star-formation in HII region, but Hα has slight dust attenuation (compare NE arm below NGC 604).
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Infrared vs Radio 6cm

- Based on IR radio correlation, can 'subtract' 6 cm radio map from a 24 µm image to compare infrared and compact free-free emission.

- Used IRAF script to 'subtract' (originally designed to find SNe) by taking FWHM of Gaussian fits to identical objects (IR & radio) and subtracting the image after applying an appropriate scaling factor.

- Five bright HII regions were used to align the images.

Fig. 4.—The 6 cm radio map from Devereux et al. (1997) is on the left. Subtraction of the 6 cm radio data from the 24 μm map produces the image on the right. North is up, and east is to the left. Both the 24 μm and 6 cm data were convolved to the 70 μm resolution of 18″ before subtraction.
24μm - 6cm Remarks

- After 'subtraction' diffuse residual at 24μm nearly completely goes away (except false structure from dark noise in radio continuum image near the center of the galaxy).

- Since 24μm seems to be just a broadened image of the 6cm radio continuum map, the 24μm map must originate primarily from compact HII regions that cause the free-free radio emission.

- As the 24μm and 70μm images have similar structure, the 70μm also probably originates mostly from compact HII regions.

- At 160μm, the compact structure is broadened, so some emission must originate from HII regions but other emission also come from other regions at 160μm.
To look at diffuse emission, a Fourier transform was performed which was used to filter out high (spatial) frequency changes from compact structure.

Structures smaller than five 160\(\mu\)m pixels were suppressed (~300 pc)
Diffuse Emission Results

- Hα, 24, and 70 µm look very similar implying that even diffuse radiation at these wavelengths is dominated by the same ionizing stars.

- To test whether the 160 µm cold diffuse dust is been heated by the diffuse interstellar radiation field, they compared the Fourier high-frequency filtered K (cool stars) and B bands (hot non-ionizing stars) to the 160 µm continuum. The diffuse B band is a poor fit, while the diffuse K band (cool stars) is a better fit as it displays the large central concentration and the NE-SW bar. However, the fit is not perfect so there can be other components.

- The 160 µm diffuse radiation was then compared to a diffuse radio continuum map at 17.4cm, which had similar morphological properties.
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17.4 cm radio continuum

160 μm Fourier-filtered contour map

Fig. 6.—Contour maps of the 17.4 cm data taken from (a) Fig. 1 of Buczilowski (1988) and the (b) 160 μm Fourier-filtered image scaled to the same size.
Diffuse 160µm Remarks

- Both the diffuse 160 µm and 17.4 cm (1.72 GHz) radio continuum map (made after subtraction of 24 unrelated sources, Buczilowski et al. 1988) show a similar smooth contours around the nuclear region with an elongation along a NE-SW bar.

- At 17.4 cm, the thermal radio continuum emission is estimated to be only ~15% of total radio continuum emission. Most radio maps have compact structures dominate as interferometry measurements suppress low spatial frequencies. Therefore the 17.4 cm map is from diffuse nonthermal radiation.

- They conclude the diffuse 160µm from cold dust is heated by both cool stars, and some mechanism for non-thermal emission (e.g., direct cosmic ray heating of interstellar grains, acceleration of radio-emitting e⁻ that heat the dust).
Conclusions

- Three new Spitzer MIPS maps of M33 at 24µm, 70µm, and 160µm give new info on sources of FIR emission.

- By comparing the 24 µm and 70 µm emission with Hα, K band, and 6cm radio, can conclude that dust heating at 24 µm and 70 µm is from hot ionizing stars in HII regions, and even diffuse emission is heated by hot ionizing stars.

- While the high spatial frequency 160 µm is well correlated with HII regions, there is a 160 µm diffuse emission from cold dust that has a similar spatial distribution to diffuse nonthermal radio continuum and a slightly worse fit to cool stars (near IR, K band).
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