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Global Properties of the Nearby Spiral M101

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M101 (NGC 5457) is a classic Sc I spiral galaxy located sufficiently nearby, 6.8 Mpc, (Aaronson, Mould and Huchra 1980) that its structure can be studied even with the coarse angular resolution of IRAS. This work addresses the global infrared properties of M101 including the radial dependence of its infrared emission.

IRAS pointed observations were combined to construct maps of M101 at 12, 25, 60 and 100 micron. The processing included subtraction of a linear baseline from each detector stream to remove residual electronic offsets and zodiacal emission (Rice et al. 1986). The emission from the galaxy was integrated using a circular area of 28' diameter to obtain the integrated fluxes of M101 presented in Table 1. The flux densities include small color correction factors derived by fitting an intrinsic source spectrum consisting of the sum of Planck functions at two temperatures times an emissivity proportional to frequency. The best fit temperatures are 200 K and 31 K.

Table 1. Global Properties of M101

A. Observations[1]		B. Derived Properties	
$f_\nu(12)$	9 ± 2 Jy	F(IR)[2]	5.74E-12 W m^{-2}
$f_\nu(25)$	12 ± 2 Jy	L(12-100 um)	1.3E10 L_o
$f_\nu(60)$	95 ± 15 Jy	IR/B[3]	0.40
$f_\nu(100)$	260 ± 40 Jy	L(0.15-100 um)	1.0E11 L_o

Notes: 1)Color-corrected values measured in a 28' diameter aperture; 2)flux between 40 and 120 micron as defined by Helou et al. 1985; 3) see text.

A spectrum of the galaxy from the UV to the far-infrared is presented in Fig. 1. The UV data are from Code and Welch (1982), the visible results from Okamura et al. (1976) and the near IR from Elmegreen (1980) and all have been corrected for reddening (A_V=0.17 mag) within our galaxy. In making Figure 1 a geometric correction factor was applied to the data to account for the

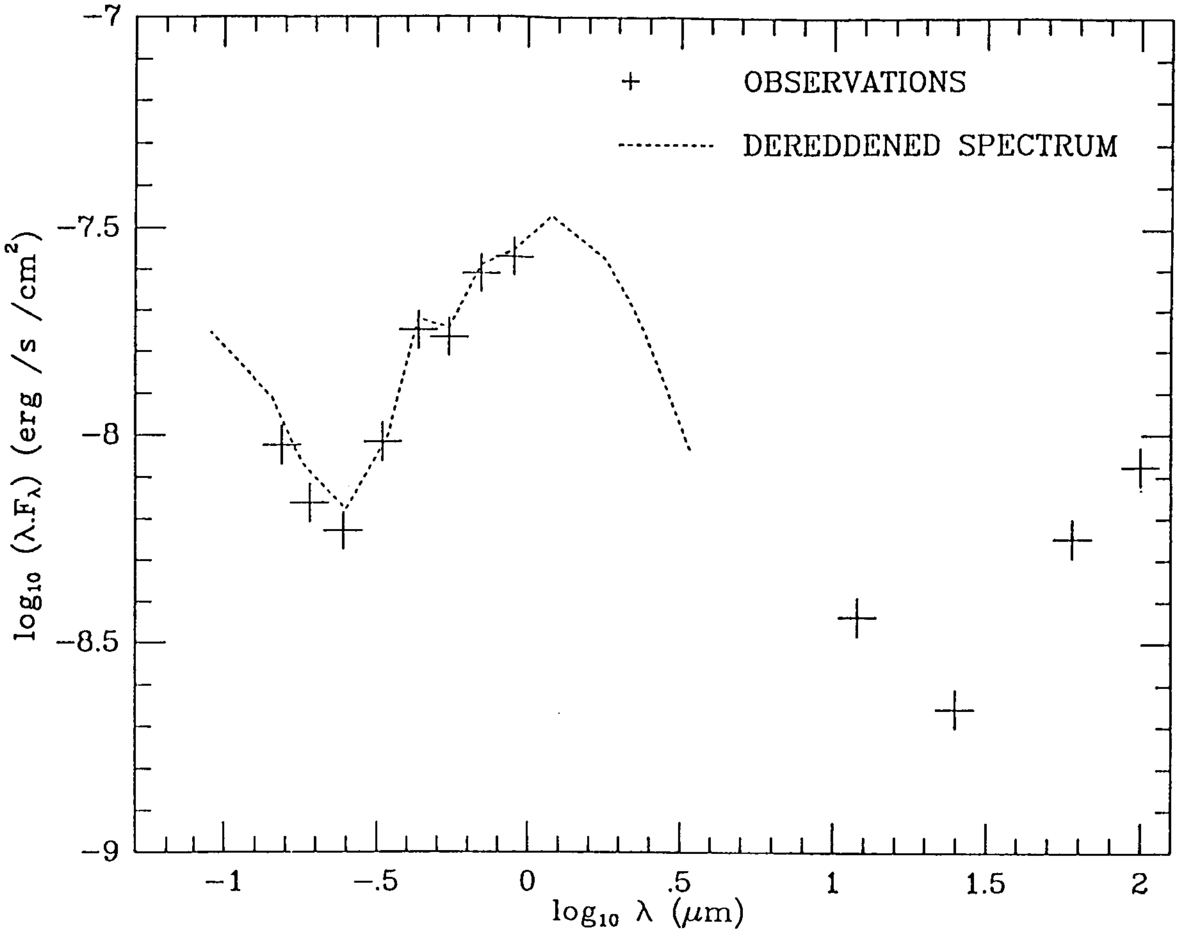

Figure 1. Spectral energy distribution of M101 from UV to far infrared wavelengths.

fact that observations at the various wavelengths were obtained with different sized apertures. This factor was based on extending an exponential disk at each wavelength to infinite radius.

The determination of the radial dependence of the infrared emission is complicated by the fact that the size of the galaxy (~10') is comparable to the resolution of the IRAS detectors (about 0.75'x4.5' at 12 and 25 micron, 1.5'x4.5' at 60 micron and 3'x5' at 100 micron) and because a number of giant HII regions are bright at these wavelengths. The following procedure was invoked to separate these two components. Data from scans which crossed the galaxy in the same direction were fitted to a model consisting of an axisymmetric exponential disk of amplitude I and scale length h convolved with the detector response; data from the vicinity of the HII regions were excluded. Fits were made in the scan direction at a number of different position angles and the results averaged. Table 2 lists the properties of the M101 disk.

Table 2. The M101 Disk

Wavelength (μm)	Disk Amplitude (MJy/sr)	Scale Length (')	(kpc)	Integrated Model (D>>28')(Jy)
12	3.1	3.0±0.2	5.9±0.4	14
25	3.4	3.2±0.2	6.3±0.4	18
60	18	3.4±0.4	6.7±0.8	110
100	45	3.4±0.5	6.7±1.0	280
CO		3.6[1]		
Visual Light		2.2-2.6		

Notes: 1) Solomon et al. 1982.

Figure 2 shows a 25 micron map of M101 before and after subtraction of exponential disks. While the fitting procedure is not yet perfect, as evidenced by the negative parts of the maps, the procedure enables one to detect five of the major HII regions in the galaxy, N5447, N5455, N5461, N5462 and N5471. Even preliminary estimates of the brightnesses of the HII regions allow one to state that the emission from M101 is dominated its disk. The influence of the major optical HII regions is negligible at 12 and 25 micron and less than 20% of the total at 60 and 100 micron.

Overall Properties

M101 is similar to other spirals detected by IRAS with an infrared luminosity and 12/25 and 60/100 micron colors consistent with those of a galaxy with modest amounts of star formation (Helou, this conference). A number of authors have used the IR to blue luminosity ratio, defined as $\nu f_\nu(80)/\nu f_\nu(B)$ where $f_\nu(80)$ is the average of the 60 and 100 micron flux densities, as a measure of infrared activity. M101 has an IR/blue ratio of 0.4, similar to that inferred for our own galaxy and close to the median for spirals detected by IRAS (Soifer et al. 1984).

Origin of the Infrared Emission

M101 is an average spiral galaxy and it is therefore important to understand the nature of its infrared emission mechanism and to distinguish it from the more luminous infrared galaxies. We argue that much of the infrared emission from M101 originates in the neutral medium, and not in the ionized component.

First, the ratio of 12 to 25 micron flux densities (Table 3) implies a temperature of 200 K and, as shown by the scale lengths in Table 2, is roughly constant across the face of the galaxy. This emission accounts for approximately 25% of the 12-100 micron luminosity of the galaxy. The existence of large amounts of hot, 200 K, material outside of HII regions cannot be accounted for within the context of equilibrium heating of grains in the interstellar radiation field of the galaxy. Further, the lack of a radial temperature gradient runs counter to the expectation that, for equilibrium heating of dust, the temperature in the disk should decrease as the radiation field falls off with increasing radius.

Table 3. M101 Colors

	M101 Disk	Galactic Cirrus
$\log(f_\nu(12)/f_\nu(25))$	-0.12	-0.2 to 0.1[1]
$\log(f_\nu(25)/f_\nu(60))$	-0.92	-0.65 ± 0.05[2]
$\log(f_\nu(60)/f_\nu(100))$	-0.34	-0.81 ± 0.02[2]

Notes: 1) Boulanger *et al.* 1985; 2) Weiland *et al.* 1986.

A solution to this problem may be found in the similarity of the 12/25 micron color of the M101 disk to that of the hot cirrus found within our own galaxy (Boulanger, Baud and van Albada 1985; Weiland *et al.* 1986). The warm Galactic cirrus has been attributed to small (<10 Angstrom) grains, possibly polyaromatic hydrocarbons (Puget, Leger and Boulanger 1985) transiently heated by the absorption of single UV photons. In this process the maximum temperature reached by a grain is independent of the intensity of the radiation field; the intensity of emergent spectrum, but not its shape, depends on the input intensity. We suggest that the existence of large amounts of 12 and 25 micron emission in the disk of M101 is due to the existence of such small, stochastically heated grains.

The poorer spatial resolution of the 60 and 100 micron maps makes it harder to separate the disk component from the HII regions. The 60/100 micron color of the disk is considerably hotter than that seen toward typical Galactic cirrus and may partially be due to unresolved HII regions. However, not all of the infrared emission can originate in HII regions. On the basis of a catalog of 21 cm continuum observations of HII regions in M101 and the integrated intensity of the galaxy at 2.8 cm (Klein and Emerson 1981), Viallefond (1986) has estimated that about 100 mJy of the 21 cm emission from M101 is thermal. From this one calculate that the infrared excess (IRE) of this disk exceeds 16, far higher than for typical HII regions with values of 5 (Myers *et al.* 1986). Such a high IRE suggests that predominantly non-ionizing photons, from A or later type stars and not from OB stars, dominate the heating of the disk.

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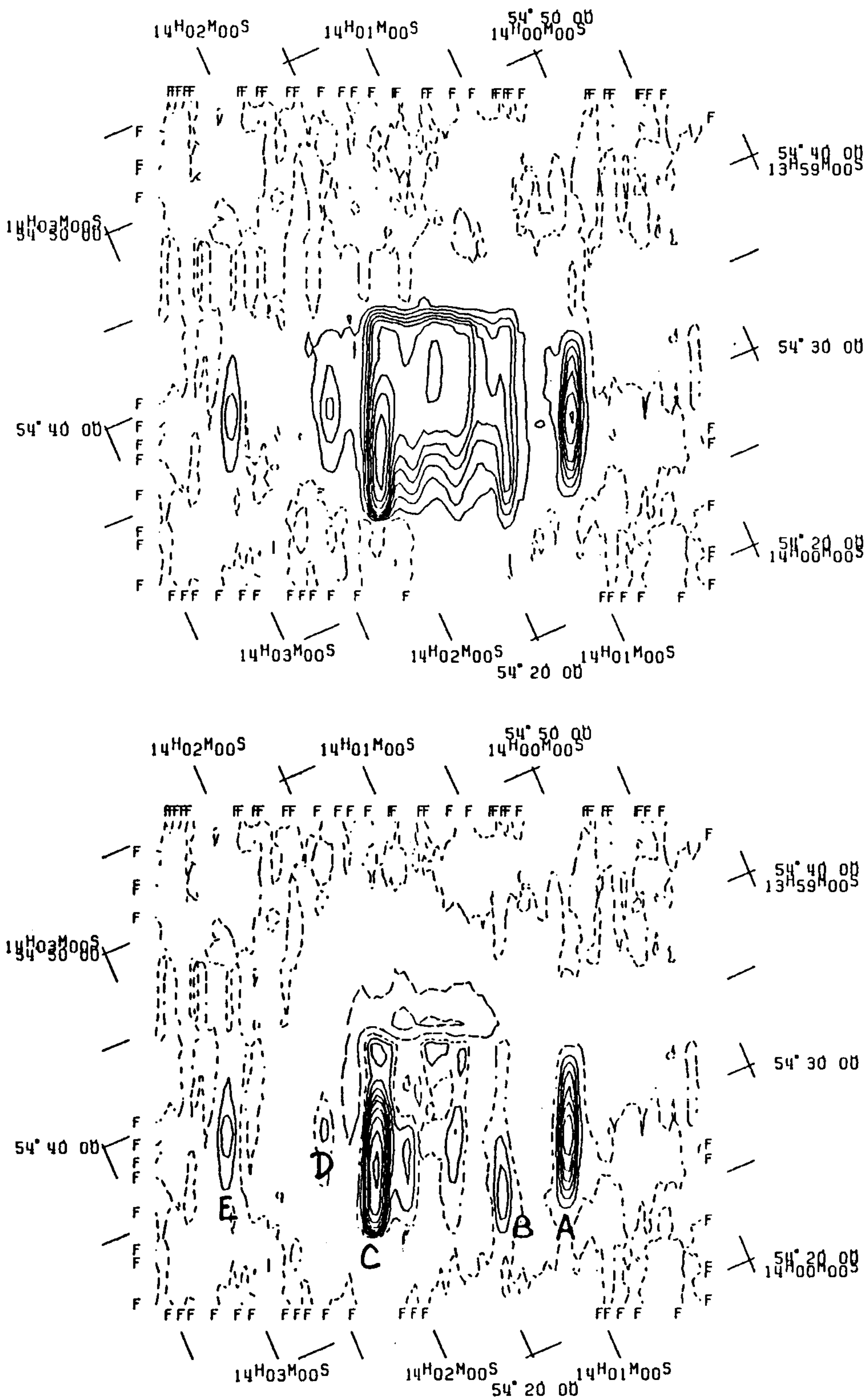

Figure 2: a) 25 micron map of M101; b) 25 micron map after subtraction of an exponential disk (dashed contours are negative). The HII regions N5447, N5455, N5461, N5462 and N5471 are marked with letters a–e.

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