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Far Infrared Mapping of the Galaxies M 51 and M 101 with ISOPHOT *

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Abstract. We present far infrared (FIR) images of the two nearby galaxies M 51 and M 101 at 60, 100, and at 175 mum. These images resolve the spiral arms of the galaxies and a number of giant H II regions embedded therein.

Key words: individual galaxies: M 51, M 101 – star formation – dust

1. Introduction

Using pointed IRAS data, Rice et al. (1988) presented a catalogue of FIR images for large galaxies. A comparison with optical maps showed that the FIR brightness profiles are similar to those observed in the UV and in the blue, indicating a rather constant dust temperature over the disk. The angular resolution of IRAS was not appropriate for detailed studies. Structures such as spiral arms and star-forming regions could hardly be distinguished. Using a maximum correlation method image construction, Rice (1993) produced maps with higher angular resolution ($\sim 50''$at 60 μm), including M 51 and M 101. The results are, however, very sensitive to the steering parameters of the program and deliver no reliable photometry. A 170 μm map for M 51 with higher angular resolution has been presented by Smith (1982).

With its considerably better angular resolution, combined with higher sensitivity, we mapped with ISOPHOT five archetypes of disk galaxies, in order to study in detail the distribution and heating of dust, star formation, and the influence of structural properties of the different morphological types on them. Since ISOPHOT reaches wavelengths far beyond the IRAS range we included mapping at a wavelength of 175 μm, which is essential for deriving the total luminosity of the galaxies. In this paper (Letter I), we present the data for two of these galaxies, M 51 which is of the morphological type Sbc and the archetype of a spiral galaxy, and M 101 of type Sc which is well known for its numerous and bright star forming regions. In a second letter (Hippelein et al. 1996, Letter II henceforth) we will present a first analysis of these unique data.

2. Observations and data reduction

The observations were performed in the PI Guaranteed Time during the revolutions 165, 172, and 174 (May 1996) using the ISOPHOT C100 and C200 detectors in the AOT mode P32. The instrument is described in detail in Lemke et al. (1996). Mapping was done in three filters, at 60 μm (FWHM 24 μm), at 100 μm (width 44 μm), and at 175 μm (width 90 μm). We have chosen the observing mode P32 which is a combination of spacecraft pointing and chopper motion and gives well sampled maps of relatively large sources. For the 3×3 pixel array C100, we used an oversampling factor of 2/3, which provides a sampling of $23''$ in the cross-scan direction and of $15''$ in the scan direction by chopping. For C200, i.e. the 2×2 pixel array, we used an oversampling factor of 1, providing a sampling of $93''$ in the cross-scan direction, while in the scan direction we chopped with $31''$. The integration time per raster point was 12 sec in all cases.

The data reduction was done with the ISOPHOT interactive analysis software package, PIA Version 4.9.2. We applied a linearity correction for the detector pixels and an

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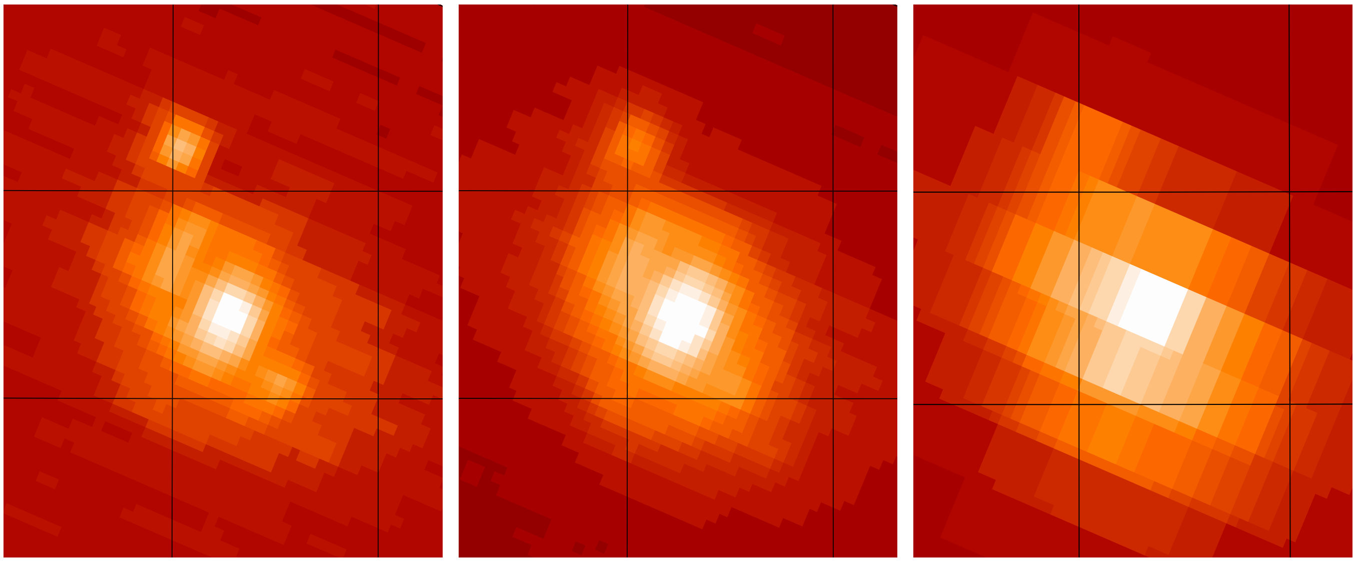

Fig. 1. Surface brightness raw maps of M 51 at 60 μm, 100μm, and at 175μm (upper row). Grid mesh size is $30^s \times 5'.0$, i.e. 6 mm arcmin^{-1}. the galaxy center is at $13^h29^m52^s$ $+47^0 12'.0$ (2000). The highest contours are at 250, 650, and 350 MJy sr^{-1}, and the background levels at 20, 20, and 6 MJy sr^{-1} for 60, 100, and 175 μm, respectively.

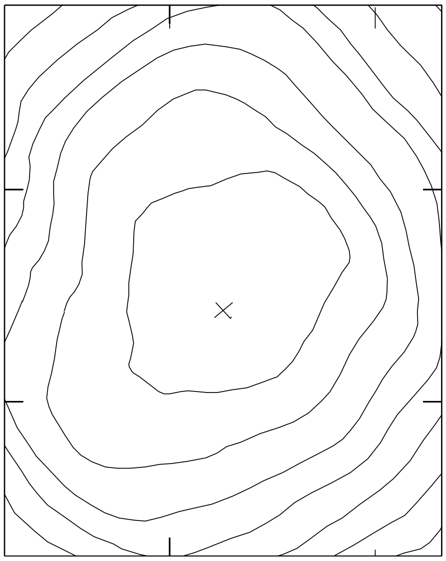

Fig. 2. The IRAS 100 μm raw map (Rice et al. 1988) for the same area. In this map, the isophotes decrease from 360 MJy sr^{-1} logarithmically by factors of 2.

actual responsivity correction from measurements of the ISOPHOT Fine Calibration Source (FCS) made at the beginning and end of each object measurement. In fact, the responsivity was different from the default one, but very stable within a few percent. Cosmic ray glitches were removed too, using the implemented deglitching algorithm. Note that the detectors yield a stream of signal values at each raster/chopper position and not just an integrated one; therefore, the deglitching can be performed well for each pixel independent of neighbouring pixels.

The flux calibration was performed using actual calibration data derived from astronomical standard sources under similar instrumental conditions during the revolutions between 095 and 180, i.e. better data than the standard calibration data of PIA V4.9.2. For the absolute flux calibration we adopt an error of 30%. Within one single map, however, the relative error is much smaller (see below). Pointing of the telescope is accurate to within 5″, the NS orientation is determined to better than 1^0.

To construct the final maps we used the mapping procedure implemented in PIA which accounts for the roll angle, i.e. the orientation of the arrays, and uses a simple gridding algorithm to handle the oversampling. For easy comparison of the C200 maps with the C100 maps we split the 30×30″map pixels into 15×15″pixels.

The formal errors and their propagation during the reduction steps result in an uncertainty for the surface brightness in the range of 5 MJy sr^{-1} which has to be compared with the signal values between 50 and 200 MJy sr^{-1} in the brighter regions of the maps.

3. Results

Figure 1 shows the color prints of the surface brightness maps of M 51 taken at 60 μm, 100 μm, and at 175 μm. They clearly show substructures such as the central bar, which are not indicated in the IRAS map (Fig. 2). Note the two bright lobes 2′ to the NE and SW from the center which are also prominent in the CO maps, but have no bright counterpart in the optical (see Letter II). They indicate large amounts of gas and dust in these areas and

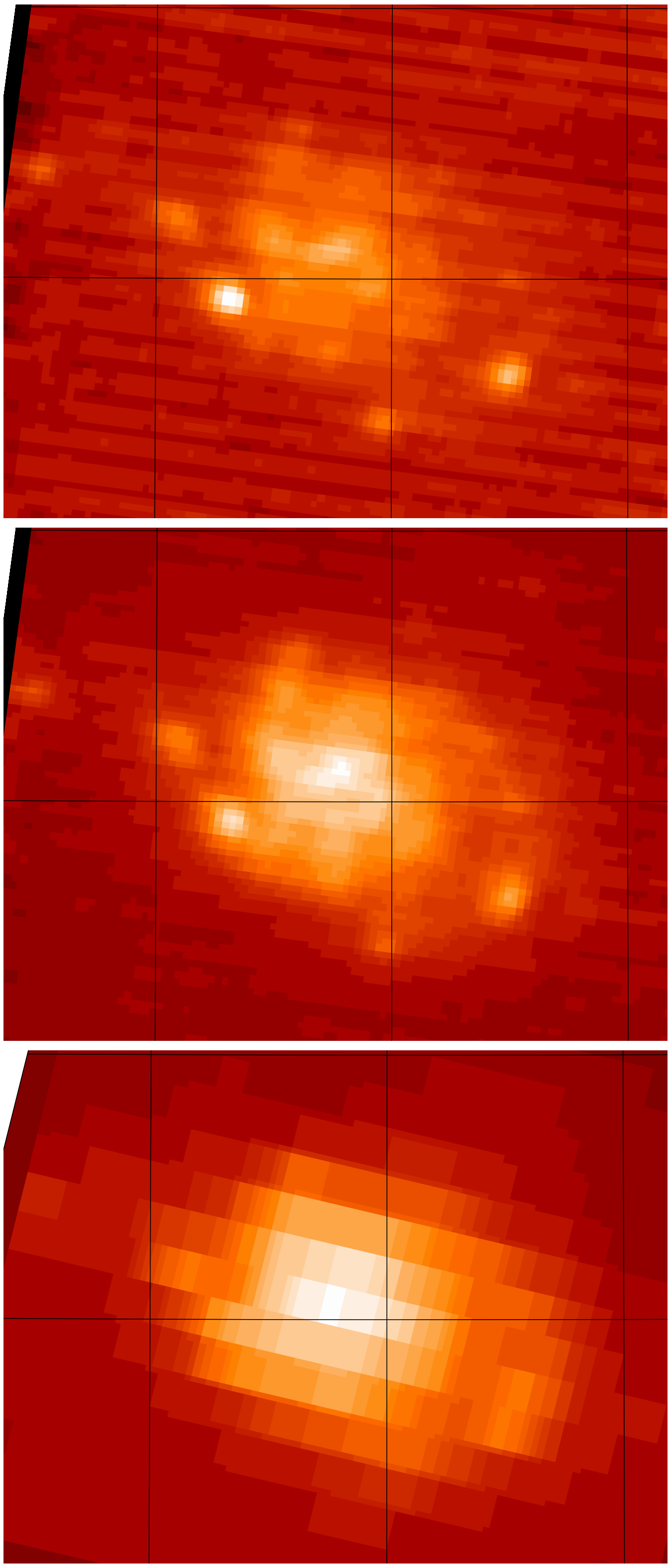

Fig. 3. Surface brightness maps of M 101 at 60 μm (top), at 100μm (center), and at 175 μm. Grid mesh size is $1^m \times 10'$, i.e. 3.5 mm arcmin^{-1}. The highest contours are at 100, 190, and 130 MJy sr^{-1}, and the background levels at 17, 15, and 6 MJy sr^{-1} for 60, 100 and 175 μm, respectively.

Table 1. Total flux densities in Jy.

	60μm	100μm ISO	175μm	60μm IRAS	100μm IRAS
M51	192.	736.	512.	108.7	292.1
M101	161.	595.	536.	88.0	252.8

their symmetry suggests that they are produced by tidal interaction with NGC 5195.

Figure 3 shows the color prints of the surface brightness maps of M 101 for the same wavelengths. Here one can trace the spiral arms out to a radial distance of 10′ and distinguish easily more than a dozen bright spots, mostly star forming regions. Most impressive is the dominant H II region (NGC 5461) about 6′ SE from the galaxy center which at 60 μm is even brighter than the galaxy center.

The total flux densities for M 51 and M 101 are given in Table 1, together with the IRAS values tabulated by Rice et al. (1988). As can be seen our total fluxes for both M 51 and M 101 are about a factor of two higher than those measured by IRAS; the reason for this discrepancy is not yet quite understood. One reason could be that for offsets $>40''$ the point spread function for the C100 and C200 arrays is considerably higher than expected, thus dispersing the signal of point sources into the underlying galaxy signal and enhancing the total flux by almost 60%. This explanation would match with the fact that for unresolved sources the agreement between ISO and IRAS fluxes is much better (see Letter II).

Concerning the 175 μm flux density for M 51 our value is in reasonable agreement with the 170 μm value by Smith (1982).

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