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Dust Distribution in the Spiral Galaxy M51

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Abstract. We present the analysis of far-infrared imaging of the nearby grand design spiral galaxy M51. Being close enough for the spiral structure to be resolved, it is possible to determine the dust temperature and distribution as a function of galactocentric radius. Using Spitzer/MIPS data at 70 μm and 160 μm in concert with a deep 350 μm image taken with the Submillimeter High Angular Resolution Camera (SHARC-II) at the Caltech Submillimeter Observatory (CSO), we have mapped the dust emission. Additional SCUBA 850 μm data help determine the overall dust spectrum. We derive the nuclear and spiral arm dust mass and temperatures (30 K in the nucleus, 25 K in the disk) and measure the emissivity index ($\beta = 1.3$).

1. Introduction

M51 (NGC5194/5195) is a unique galaxy inasmuch as it is a face-on grand-design spiral, early in a minor merger with a well-defined tidal arm, and is close enough to permit far-infrared observations at high enough spatial resolution to distinguish between the nucleus, arms, and interarm regions. We have therefore combined new 350 μm images with other far-infrared and submillimeter data to study the distribution and physical parameters of cool dust in this galaxy.

2. Observations with Spitzer/MIPS and JCMT/SCUBA

M51 was observed by Spitzer as a part of the SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy project(Kennicutt et al. 2003). SINGS is designed to be a comprehensive imaging and spectroscopic study of 75 nearby galaxies which can then be combined with observations at visible, near-infrared, ultraviolet, and radio wavelengths. With the addition of submillimeter data, the SINGS observations of M51 will provide definitive constraints on the physical conditions of star formation and the ISM properties of this galaxy. The resulting maps at 70 μm and 160 μm have angular resolutions of $\simeq 21''$ and $\simeq 47''$ and integration times of 80 s and 16 s per pixel, respectively, and are regridded at $3''$. The 160 μm image is shown in Figure 1.

We processed archival SCUBA images of M51 at 850 μm (Figure 1). The angular resolution is $\simeq 15''$, and due to the chopped mode of observing, much extended structure at scales $> 60''$ is lost. The exponential disk reported by Meijerink et al. (2005) from their analysis of this data is not evident.

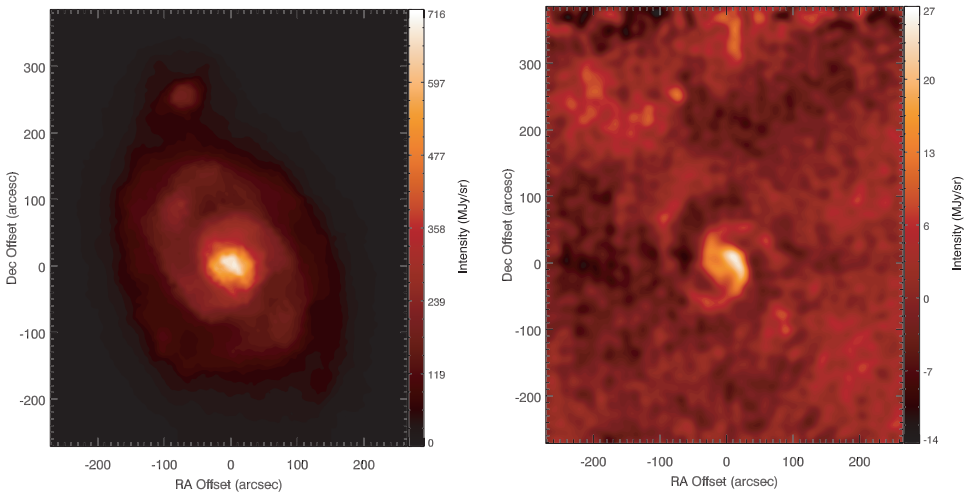

Figure 1. Spitzer/MIPS 160 μm image of M51 (Left) and JCMT/SCUBA 850 μm image (Right).

3. Observations with CSO/SHARC-II

SHARC-II is the largest bolometer array camera in use for astrophysics (Dowell et al. 2003). It features a 12×32 array of detectors optimized for operation at a wavelength of 350 μm with background-limited sensitivity, operating at the CSO on Mauna Kea. It achieves a sensitivity of $< 1\,\mathrm{Jy}/\sqrt{\mathrm{Hz}}$ in good weather. Because of its large number of pixels, SHARC-II can subtract atmospheric emission without chopping: all positions on the sky are viewed by many detectors at slightly different times with a high degree of redundancy. This introduces a self-consistent self-calibration of all pixels compared with all others and preserves extended structures.

We observed M51 during observing runs in 2003 February and May, 2004 January and March, when the weather was slightly poorer than required for our primary projects. The atmospheric opacity was around $\tau_{350\,\mu\mathrm{m}} \sim 1.5$ during the ~ 1 hr per night that M51 was observed. Maps were made at varying areas to reconstruct extended emission. The images were reduced using the CRUSH reduction package, v.1.45, which implements an iteratively self-consistent least-squares algorithm to solve for atmospheric emission, instrumental effects, and the (comparatively weak) celestial emission. The final image, shown in Figure 2, has been regridded and smoothed to $\simeq 10''$ resolution. The flux sensitivity (1 s) is of order 10 mJy/beam over the central 15 arcmin^2 and 30 mJy/beam over the central 52 arcmin^2; higher noise level regions are not shown.

4. Structure of Dust Emission

The four dust maps of M51 at wavelengths near the peak of dust emission were combined to determine the spatial structure of physical parameters of the dust. A greybody thermal emission spectrum was fit to the four bands, resulting in maps of temperature, mass, and emissivity index (β). The temperature image,

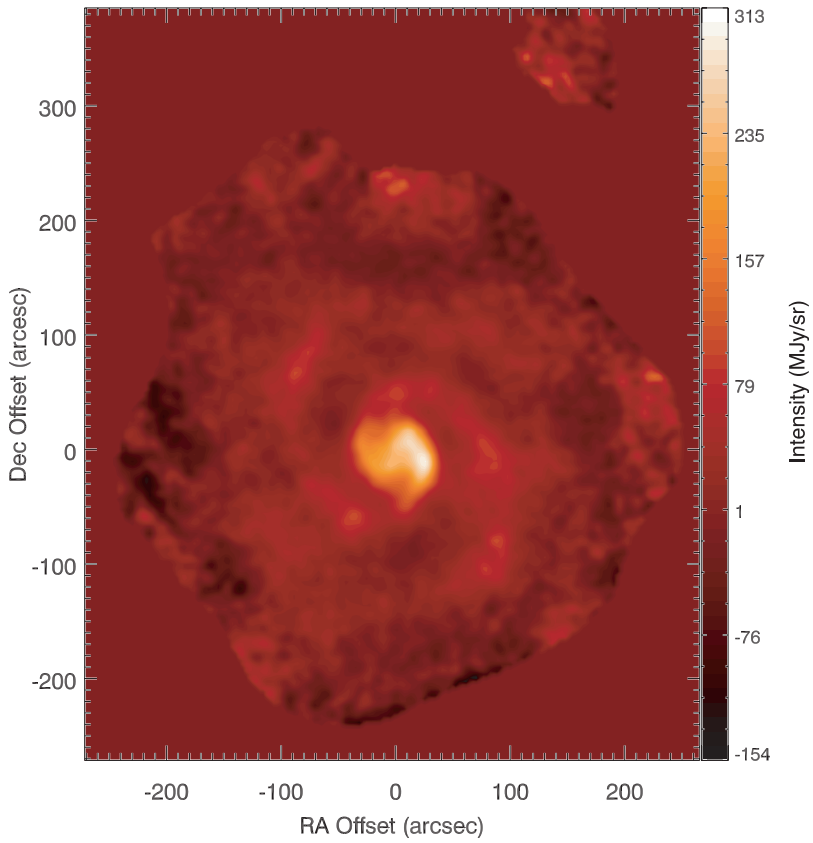

Figure 2. 350 μm image of M51 from CSO/SHARC-II.

demonstrating that the companion is significantly warmer than the overall spiral galaxy, is shown in Figure 3, whereas the mass image demonstrates that the vast bulk of the dust is broadly distributed throughout the disk.

From this fitting, we derive the mean parameters of the galaxy's cool dust Figure 4. The mean temperature is 25 ± 3 K, with some portions of the system much warmer – the inner 3 kpc region has a temperature of 31 K. This result matches the central temperature measured by Hippelein et al. (1996), whereas the companion temperature is clearly higher than their result of 32 K. The derived emissivity index averaged across the galaxy as $\beta = 1.3 \pm 0.8$. Furthermore, the radial profiles in mass and temperature show the signature of an exponential disk, the central bulge, and the inner spiral arms.

5. Conclusion

We have derived a well-defined high-resolution image of a galaxy in derived physical parameters of dust (temperature, mass, and spectral index β). This is a major step forward in the study of cool dust in galaxies, and relies on both Spitzer and large ground-based submillimeter telescopes being used in concert.

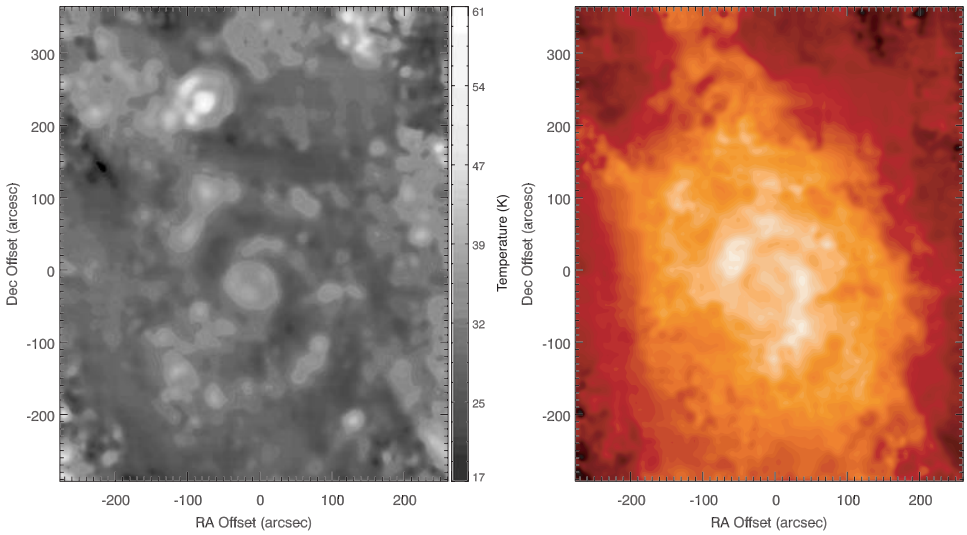

Figure 3. Derived images of M51 in temperature (Left) and mass (Right).

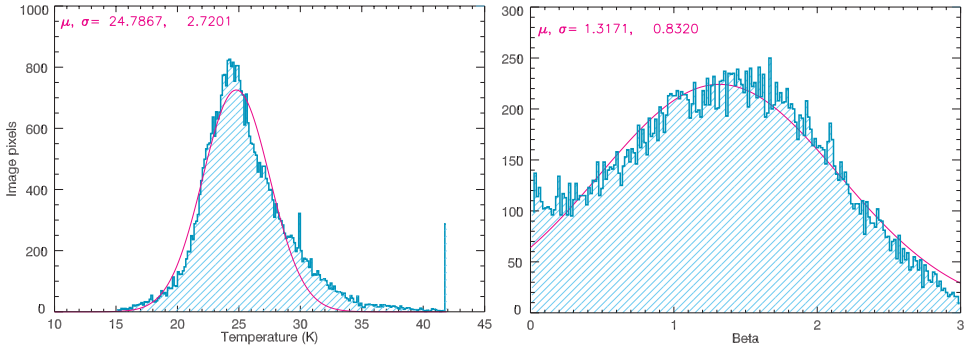

Figure 4. Histograms of temperature and emissivity index β.

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