Dust in NGC 1569: Evidence for an enhancement of very small grains

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Abstract

We have mapped the dwarf galaxy NGC 1569 at 450 μm, 850 μm with SCUBA at the James Clerk Maxwell Telescope and at 1200μm with the bolometer array at the IRAM 30m telescope. We model the infrared-to-millimetre spectrum, including data from IRAS at 12, 25, 60 and 100 μm, using the model of Désert et al. (1990). The data can be fit by a combination of big and very small grains exposed to a strong radiation field assuming that the abundance of very small grains is enhanced with respect to the solar neighbourhood value. The abundance of Polyaromatic Hydrocarbons (PAHs) is negligible. We interpret this as big grains being destroyed in the turbulent interstellar medium and the insufficient shielding due to the low metallicity. The gas-to-dust mass ratio derived with these observations is about 10 $\times$ higher than in the solar neighbourhood.

1 Dust in dwarf galaxies

Dwarf galaxies are known to possess low metallicities and therefore, since dust is made mainly from metals, a low dust abundance. Not only the dust amount, but also the overall dust properties of dwarf galaxies are different from those of spiral galaxies as indicated by their different IRAS colours (Melisse & Israel 1994). So far, however, neither the dust abundance nor its composition is very well known in dwarfs. In order to estimate the dust mass of a galaxy, (sub)mm data is essential in order to constrain the contribution of cold dust which can dominate the total dust mass. This data has not been available for many galaxies and it is especially scarce for faint dwarf galaxies.

Therefore, we have mapped NGC 1569 at submillimetre and millimetre wavelengths in order to approach the following questions: (i) How much dust is there and what is the gas-to-dust mass ratio? Due to their low metallicity, the gas-to-dust mass ratio is expected to be much higher than in spirals but the exact relation between the two quantities remains to be observationally determined. (ii) What are the dust properties?

NGC 1569 (Arp 210; VII Zw 16) is a nearby dwarf irregular galaxy at a distance of 2.2 Mpc. NGC 1569 is presently in the aftermath of a massive burst of star formation (Israel 1988, Israel & De Bruyn 1988; Waller 1991). Although a small galaxy, NGC 1569 contains two extremely compact luminous star clusters A and B (Ables, 1971; Arp & Sandage 1985; Prada, Greve & McKeith 1994) with bolometric luminosities of order 10^8 $L_\odot$ located in a deep HI minimum.

2 Observations and maps

The observations at 1200μm were carried out at the IRAM 30m telescope at Pico Velata with the 19-channel bolometer of the Max-Planck-Institut für Radioastronomie (MPIfR). The 850 and

"Dwarf Galaxies and their Environment"; Bad Honnef, Germany, 23-27 January 2001; Eds. K.S. de Boer, R.-J.Dettmar, U. Klein; Shaker Verlag

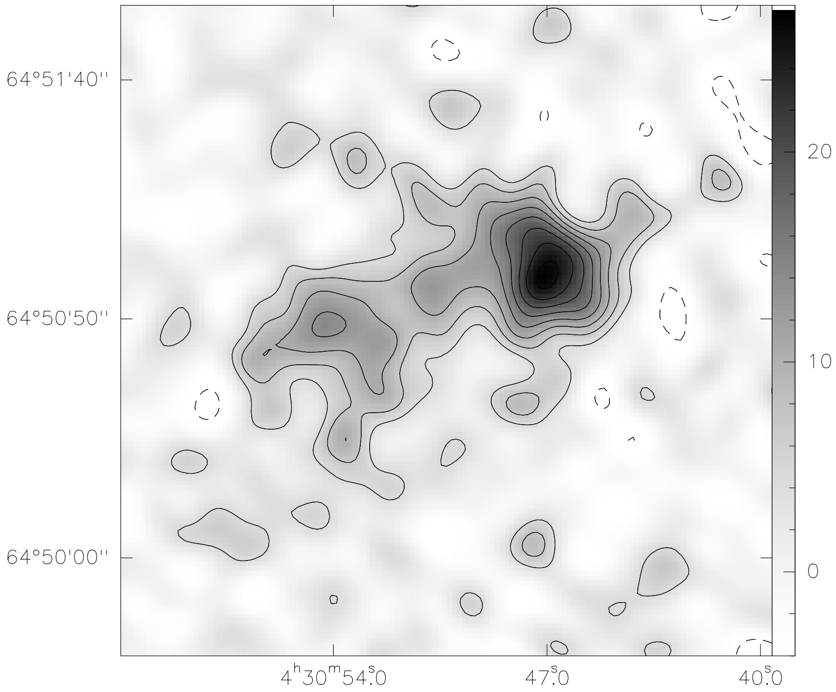

Figure 1: Map of NGC 1569 at 1200μm. The resolution is 13$''$ and the contours start at -5, 5 mJy/beam (2 σ) and increase by 3 mJy/beam. The coordinates are given in the J2000 coordinate system.

450 μm observations were made with the SCUBA camera at the James Clerk Maxwell Telescope (JCMT). Both wavelengths were observed simultaneously in jiggle mode. The observations and data reduction will be described in more detail in Lisenfeld et al. (2001). In Fig. 1 we display the resulting map at 1200μm.

At 850 μm and 1200μm the total fluxes derived from the maps have to be corrected for the contribution of CO(3–2) and CO(2–1) line emission and thermal free-free emission. The contribution of CO line emission at 1200μm and 850 μm can be estimated with the help of the CO observation of Greve et al. (1996) and is found to be small, about 2 and 10 mJy, respectively. Free-free emission, on the other hand, is still significant at these wavelengths. We have used an estimate by Wilding (1990) from radio maps at 1.5, 5, 8.4 and 15 GHz. He derives a total thermal radio flux at 1 GHz of 100 mJy, in good agreement with the value of 97 mJy estimated by Israel & de Bruyn (1988) from reddening-corrected Hα measurements. Scaling this emission as $\nu^{-0.1}$ we derive a considerable thermal radio emission of 58 mJy (56 mJy) at 1200μm (850 μm).

3 The Dust Emission Spectrum

The dust emission and extinction in our Galaxy can be modelled by 3 components (e.g. Désert, Boulanger & Puget 1990, hereafter DBP90): (i) Big grains with a power-law size distribution. These grains are in equilibrium with the radiation field and their emission, S_λ, can be described by a modified black-body curve, following from the Kirchhoff-law, $F_\lambda = B(\lambda, T) k_\lambda$ where $B(\lambda, T)$ is the Planck function, λ the wavelength, T the temperature and k_λ the extinction coefficient. (ii) Polyaromatic hydrocarbons (PAHs) responsible for the mid-infrared continuum emission and for the spectral line emission. (iii) Very small grains (VSGs), with sizes of a few nm, whose heat capacity is very low so that they can be heated to very high temperature ($T \approx 1000$ K) by a single photon. They cool down very quickly so that their temperature cannot be described by a single

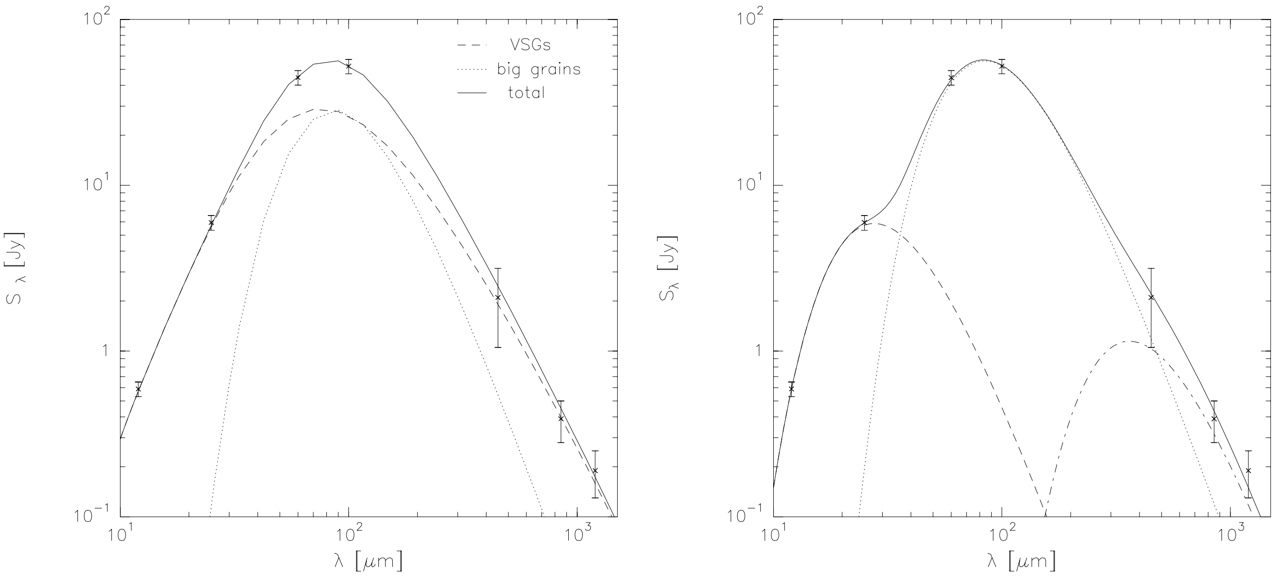

Figure 2: **Left:** The infrared–(sub)mm spectrum of NGC 1569. The crosses are the measured fluxes densities (by us and from IRAS); the flux densities at 850 μm and 1200μm are correct for the contribution of CO and free-free emission as described in the text. The lines represent the fit with the dust model of DBP90. **Right:** The result of a three-temperature fit to the spectrum of NGC 1569. The temperatures of the various components are 105 K (dashed line) 34.5 K (dotted line) and 8 K (dashed-dotted line).

value but by a temperature distribution. Their emission spectrum is broader than that of the big grains.

The dust emission spectrum from 12μm to 1200μm of NGC 1569, shown in Figure 2, provides important clues to the origin of the emission and on the relative contribution of the 3 above described components. Flux-densities shortwards of 100μm define a slope less steep than expected for a modified black-body curve; in particular the 12μm and 25μm flux-densities are much higher than expected for a such a curve. The rise in intensity between 12 and 25 μm is steep enough to preclude any significant emission contributed by PAH's, as the broadband spectrum of these *decreases* with wavelength. At the long-wavelength end, the corrected (sub)mm flux-densities are roughly proportional to λ^{-3}, i.e. proportional to a modified blackbody emission with a wavelength dependence $\beta = 1$, typical for small dust grains.

In order to interpret the dust emission spectrum of NGC 1569 more quantitatively, we have fitted it with the model of DBP90. In this model the dust is described by the three components (PAHs, VSGs and big grains) presented above immersed in a radiation field which can be varied. We tested different radiation fields and allowed for different relative contributions of the 3 components. We can achieve a good fit for dust immersed in a local interstellar radiation field scaled up by a factor of 60. The abundance of PAHs is found to be negligible whereas the abundance of VSGs is increased by a factors of about 7 relative to the Galactic abundance assumed in the model of DBP90. In this way both the mid-infrared and the submillimetre/millimetre spectrum can be fitted. In order to fit the far-infrared data points, a contribution of large grains is necessary. In Fig.2 (left) we show the results for this fit.

The fact that we can fit the dust emission of NGC 1569 with a model in which the dust is immersed in a radiation field 60 times higher than the local one is consistent with independent information showing that the UV radiation field in NGC 1569 is about 2 orders of magnitude higher than in the solar neighbourhood (Israel 1988).

The above model describes the data well, but it is certainly, given the large amount of free parameters (temperature, dust-size distribution etc.), not unique. In particular, one could try to explain the high flux densities in the submillimetre and millimetre regime by cold dust. In order to test this, we fit a model only consisting of big grains but allowing for 3 different temperature components.

In Fig. 2 (right) we show the result. The data can be fit very satisfactorily, which is no surprise given the large number of free parameters. The temperature of the coolest component which is necessary to fit the relatively high (sub)mm emission is however very low, only 8 K. A large fraction of the dust would have to be at such low temperatures in order to explain the emission at 850 μm and 1200μm. This is very unlikely, given the high radiation field of this galaxy which indicates that the dust temperature should be a factor of $100^{1/5} = 2.5$ (for $\beta = 1$) to $100^{1/6} = 2.1$ (for $\beta = 2$) higher than for the solar neighbourhood. The dust temperature in the solar neighbourhood has been estimated to be 10 K for silicates and 18 K for graphite (Mathis et al. 1983) which would imply a minimum dust temperature of 20 K in NGC 1569. A similar conclusion can be drawn when considering nearby spiral galaxies: The dust temperature of the coolest component obtained by fits to their FIR-mm spectrum is typically 15 K - 20 K (e.g. NGC 891, Alton et al. 1998, Israel, van der Werf & Tilanus 1999; M51, Guélin et al. 1995, NGC 3627, Sievers et al. 1994). The coldest dust component in a galaxy with a very high radiation field as in NGC 1569 should therefore by warmer than this.

4 Dust mass and gas-to-dust mass ratio

From our observations we can derive the total dust mass by adopting the model of DBP90. We find a dust mass of 3×10^4 $M_\odot$, the contribution of big grains being dominant with 2×10^4 $M_\odot$. With a total HI mass of $M(\mathrm{H\,I}) = 3.2 \times 10^7$ $M_\odot$ (Stil & Israel, in preparation) within a radius of 60 " – basically comprising all the dust emission – and $M(\mathrm{H_2}) = 0.35$ $M(\mathrm{H\,I})$ (Israel 1997), and $M(\mathrm{He}) = 0.35 M_{\mathrm{gas}}$, we derive a total gas-to-dust mass ratio $M_{\mathrm{gas}}/M_{\mathrm{d}} \approx 2000$, significantly (about 10 – 15 times) higher than the solar neighbourhood ratio. This ratio is in good agreement with results by Lisenfeld & Ferrara (1998) who predict it to be about an order of magnitude higher than in the solar neighbourhood for metallicities 12+log(O/H) = 9.0 and 8.16 in the Milky Way and NGC 1569 respectively.

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