Dust in Dwarfs and Low Surface Brightness Galaxies

J. L. Hinz, M. J. Rieke, G. H. Rieke, P. S. Smith, K. Misselt, M. Blaylock, and K. D. Gordon

University of Arizona, 933 N. Cherry Ave., Tucson, AZ 85721

Abstract. We describe Spitzer images of a sample of dwarf and low surface brightness galaxies, using the high sensitivity and spatial resolution to explore the morphologies of dust in these galaxies. For the starbursting dwarf UGC 10445, we present a complete infrared spectral energy distribution and modeling of its individual dust components. We find that its diffuse cold (T=19 K) dust component extends beyond its near-infrared disk and speculate that the most plausible source of heating is ultraviolet photons from starforming complexes. We find that the mass of T=19 K dust in UGC 10445 is surprisingly large, with a lower limit of 3×10^6M_☉. We explore the implications of having such a high dust content on the nature and evolution of the galaxy.

1. Introduction

Low surface brightness galaxies (LSBGs) have been assumed to have little to no dust. Their low metallicities imply that their dust to gas ratios should be systematically lower than in their high surface brightness counterparts (Bell et al. 2000). IRAS detected only two LSBGs, a further indication that dust is less important in these galaxies; this was reinforced by observations in which multiple distant galaxies are seen through LSB disks (O’Neil et al. 1997; Holwerda et al. 2005). Likewise, dust has been assumed to be an unimportant component of dwarf galaxies. Dwarfs also have low metallicities, and an explanation for this is the loss of metals and dust due to hot galaxian winds driven by supernovae (Mac Low & Ferrara 1999), where the smaller gravitational potential well of dwarfs allows for the escape of most of the metals and dust (Hogg et al. 2005).

However, infrared (IR) and millimeter observations have shown that dust in dwarfs can be retained, with up to 80% of the total dust mass comprised of a cold component (Galliano et al. 2003; 2005; Madden et al. 2005). The cold dust, much like the H I gas, has been shown in some cases to spread beyond the optical extent (Tuffs & Popescu 2005). Building on early Spitzer observations of dwarf galaxies (Rosenberg et al. 2006), we present IRAC and MIPS observations of a sample of dwarfs and LSBGs, concentrating on results regarding dust in one dwarf galaxy.

2. Observations and Data Reduction

The observations described here are from a guaranteed time observer program (P.I.D. 62; M. Rieke, P.I.). IRAC images and MIPS photometry mode data were obtained for all galaxies in the sample (see Table 1). IRAC images were reduced
with the standard Spitzer Science Center data pipeline; MIPS data were reduced using the Data Analysis Tool (DAT; Gordon et al. 2005).

MIPS images of two example LSBGs are shown in Figure 1. These galaxies appear to have detections at all three wavelengths, implying that some dust must be present. We find that, in general for our sample, galaxies displaying extended emission at 24 µm, indicating active star formation, also tend to have detections at the other MIPS wavelengths. However, those LSBGs with no detection or only point-like emission at 24 µm do not appear to have detectable emission at 70 and 160 µm. The galaxies with little or no detection at 24 µm are generally the large diffuse spirals such as Malin 1 as opposed to more compact structures such as UGC 6879.

Table 1. LSBG and Dwarf Sample.

| Galaxy      | Morphological Type | Distance [km s⁻¹] |
|-------------|--------------------|-------------------|
| UGC 5675    | Sm                 | 1102              |
| UGC 6151    | Sm                 | 1331              |
| UGC 6614    | (R)SA(r)a          | 6351              |
| UGC 6879    | SAB(r)d            | 2383              |
| UGC 9024    | S                  | 2323              |
| UGC 10445   | SBc                | 963               |
| Malin 1     | S                  | 24750             |

The closest and brightest of our sample, the starbursting dwarf UGC 10445, has the most easily accessible ancillary data, and we present more detailed results for this galaxy alone. We used circular apertures to calculate flux densities at IRAC and MIPS wavelengths for UGC 10445 and combined these with H and K-band photometry (de Jong & van der Kruit 1994), IRAS fluxes, and a 170 µm flux from the ISO Serendipity Survey (Stickel et al. 2004) to produce the spectral energy distribution (SED) shown in Fig. 2.

Figure 1. MIPS images of UGC 6614 (left) and UGC 6879 (right) at 24, 70, and 160 µm. North is up and east is to the left. The field of view is ~ 3′ × 3′.

The 160 µm emission for UGC 10445 (see Fig. 2) remains well above background longer and extends out further than all the other wavelengths presented. This extended emission is not the result of resolution differences: all wavelengths are convolved with a kernel that transforms images to the 160 µm resolution.

3. Modeling

We model the emission by dust in UGC 10445, as represented by the SED in Fig. 2, with a modified Planck function three-component dust model: a PAH
component, a warm silicate component \((T=50 \text{K})\), and a cool silicate component \((19 \text{K})\). We estimate the dust masses to be \(\sim 2 \times 10^3 M_\odot\) for the warm component and \(\sim 3 \times 10^6 M_\odot\) for the \(T=19\text{K}\) material. This value is a lower limit to the cool dust mass, as we are not sensitive to dust colder than \(19\text{K}\).

Figure 2. SED for the dwarf galaxy UGC 10445 with a three-component dust model fit (left). Azimuthally averaged radial profiles for UGC 10445 (right).

Popescu et al. (2002) propose that cold dust in galaxies is heated by the diffuse nonionizing ultraviolet (UV) radiation produced by young stars, with a small contribution from the optical radiation produced by old stars. Although there is little UV flux past \(1.5\) for UGC 10445, the flux needed to heat the dust grains to \(T=19\text{K}\) is not large. A simple \(\nu F_\nu\) comparison of FUV and \(160 \mu\text{m}\) luminosities indicates that the quantities are approximately equal for the galaxy. Dust providing a modest level of visual extinction would have sufficient optical depth in the UV to power the cold dust emission through absorption of diffuse UV radiation.

Using a value of the \(\text{H}I\) mass from the literature (Lee et al. 2002), the \(\text{H}I\) gas mass to dust mass ratio of UGC 10445 is 500, which has implications for the history of the galaxy. If we take the yield in heavy elements through stellar processes to be 0.002 (Kuzio de Naray et al. 2004), the rotation velocity to be \(65 \text{km s}^{-1}\) (Lee et al. 2002), and assume that 50\% of the metals are retained in the gravitational well of the galaxy (Garnett 2002), it follows that at least \(3 \times 10^9 M_\odot\) of stars must have formed to produce the \(3 \times 10^6 M_\odot\) of dust observed at \(160 \mu\text{m}\). If the near-IR output is from the old stellar population left from this long duration star formation, we can calculate a \(K\)-band stellar mass-to-light \((M/L_\ast,K)\) ratio and retrieve the mass of stars necessary to create the total dust mass. We select a \(M/L_\ast,K\) of 0.33 (Bell & de Jong 2001) which, using the \(K\)-band magnitude (de Jong & van der Kruij 1994), leads to a total stellar mass of \(3.9 \times 10^9 M_\odot\). The current star formation rate (e.g., van Zee 2000) would require \(\geq 26 \text{Gyr}\) to form this mass of stars. Therefore, the current star formation rate of UGC 10445 must be below the typical star forming rate over its lifetime.
4. Summary

Based on the observations of LSBGs and dwarfs in the sample, our preliminary conclusions are that large diffuse LSBGs such as Malin 1 contain no cool dust detectable by Spitzer, while LSBGs or dwarfs with modest amounts of star formation visible at 24 µm have corresponding emission at 160 µm. One explanation for this is that dust in the outer reaches of the galaxies may have to be heated by UV photons escaping from H II regions before being detectable. Additionally, surprisingly large amounts of dust (T=19 K) are shown to exist in at least one dwarf galaxy (UGC 10445) with an extended, diffuse cool dust component reaching out beyond its near-IR disk.

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