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DUST, ATOMIC, AND MOLECULAR GAS IN THE NEAREST PRIMITIVE ENVIRONMENT

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Abstract. We present ongoing work studying the dust and gas in the Small Magellanic Cloud (SMC). This work is part of the *Spitzer* Survey of the Small Magellanic Cloud, S^3MC. We combine new IRAC and MIPS observations of the SMC with existing far infrared (FIR) observations from DIRBE, IRAS, and ISO to construct a complete picture of the infrared spectral energy distribution (SED). We compare the FIR SED of the SMC to the SEDs of other nearby galaxies as measured by DIRBE. Although reasonably bright (in a normalized sense) at long wavelengths, the SMC is dimmer than other galaxies at intermediate ($\sim 5 - 50$ μm) wavelengths, presumably a result of the relative deficiency of small grains in the SMC. We also compare the FIR emission to the distribution of atomic and molecular gas as traced by HI and CO millimeter wave emission. The emissivity of atomic hydrogen in the SMC is extremely low, implying a very low dust to gas ratio. Despite this, there is evidence for a substantial "hidden" reservoir of molecular gas near the CO emission — enough to imply a CO-to-H_2 conversion factor $\sim 15 - 35$ times the Galactic value. This observation is at odds with CO studies of giant molecular clouds (GMCs) in the SMC and other nearby low metallicity systems, which find that GMC properties (including the virial parameter) are not strong functions of environment. As such, this may be evidence that the excess H_2 exists in an envelope of CO-free H_2 that lies outside the molecular gas.

1. Introduction

The Small Magellanic Cloud (SMC) is the nearest actively star forming low metallicity galaxy. Consequently it represents perhaps the best site to study ongoing star formation under "extreme" conditions. To investigate the effects of environment on star formation we have imaged the SMC in all seven IRAC and MIPS bands. This project, the *Spitzer* Survey of the Small Magellanic Cloud (S^3MC, PI: Alberto Bolatto), is a small proposal that covers most regions of active star formation in the SMC as well as the quiescent, gas rich wing and the N83 star forming region at its tip. Several other submissions also present the first results from S^3MC — please see contributions by Bolatto, Sandstrom, Simon, and Stanimirović. In this contribution we discuss preliminary results comparing the infrared emission from the SMC to that from other galaxies and with the gas content of the galaxy.

We defer an in depth discussion of observing strategy and calibration to a paper in preparation. In brief: we subtract a contribution from the Galactic foreground and one from zodiacal light from each data set (the former is very important at long wavelengths, the latter at shorter/intermediate wavelengths). We compare the data to DIRBE, trusting that data to be correctly calibrated, and find overall photometric consistency with one exception: we find it necessary to adjust the 160 μm data downward slightly (subtracting a constant 6 MJy ster^{-1} offset from the map) to achieve photometric consistency with the DIRBE (and ISO) results (the adjustment is too large to be due merely to C+ line contamination).

2. The Average Infrared SED

The left hand side of Figure 1 shows the average infrared SED of the SMC bar, from the tail stellar continuum measured by DIRBE and IRAC to the peak of the FIR emission due to large grains. Particularly at long wavelengths, the agreement among the data sets is quite good. At shorter wavelengths there are some differences between the IRAC and DIRBE data. These are a result of imperfect zodiacal light subtraction for both data sets and the fact that the processing of the IRAC data is ongoing. Considering only the IRAC points one can see an excess at in the IRAC 8μm band (the fourth point), a sign that although emission from the 7.7 μm aromatic features is dim in the low metallicity SMC, it is still present.

The right hand side of Figure 1 shows the SMC SED from DIRBE along with the SEDs of several nearby galaxies (those nearby and bright enough to be picked out by DIRBE). All galaxies have been normalized to the same value in the 2.2 μm DIRBE band (so fluxes are relative to the stellar continuum). Several features are worth noting: (1) all galaxies except the starburst M 82 (which is much smaller than a single DIRBE pixel) show the same (largely unextinguished) normalized stellar continuum; (2) the SMC shows a FIR peak comparable to that in M 33, slightly depressed relative to that in the LMC and notable higher than the quiescent M 31; (3) although the SMC resembles M 33 and the LMC at longer wavelengths it resembles M 31 at intermediate wavelengths — perhaps a sign of the deficiency of small grains in the SMC; (4) the FIR peak of the SMC comes at somewhat shorter wavelengths than that of M 33 or M 31 (i.e. the 60 micron flux is higher relative to the 100 micron flux). The dust in the SMC is hot and deficient in small grains compared to that found in other galaxies.

3. Emissivity and the Dust to Gas Ratio

We fit a single modified black body spectrum to the combination of IRAS, MIPS, and ISO data and compare the derived opacity to the HI column. If the dust is optically thin, then the opacity is a measure of the dust mass along the line of sight. Figure 2 shows that the average emissivity for the SMC is $\tau_{250}/N(HI) \sim 4 \times 10^{-27}$ cm^2, much lower than the average value of $\tau_{250}/N(HI) \sim 1 \times 10^{-25}$

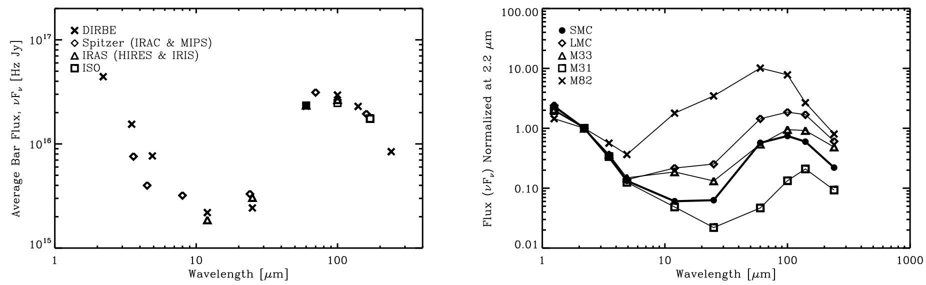

Figure 1. (left) The infrared SED of the SMC bar from DIRBE, IRAC, IRAS, MIPS, and ISO. (right) The infrared SED of the SMC and four nearby galaxies — the LMC, M 31, M 33, and M 82 — derived from DIRBE.

cm^2 found for Galactic diffuse gas (Boulanger et al. 1996). This has been seen before, by Bot et al. (2004) and Stanimirović et al. (2000). This lower emissivity implies that the dust to gas ratio in the SMC is $\sim$ 20 times lower than the Galactic value.

4. FIR Emission and The CO-to-H_2 Conversion Factor

Figure 2 shows that lines of sight associated with CO emission (Mizuno et al. 2001) show a higher emissivity than those without CO. Lines of sight with CO emission have an average emissivity of $\tau_{250}/N(HI) \sim 8 \times 10^{-27}$ cm^2 about twice the overall average. We use these data to infer the column of H_2 associated with the CO emission(Israel 1997). We assume that: (1) the dust to gas ratio and dust properties are constant within the SMC; and (2) the emission is not dominated by cold dust to which we are not sensitive. The implied CO-to-H_2 conversion factor is $3 - 7 \times 10^{21}$ cm^{-2} (K km $s^{-1})^{-1}$, or 15 – 35 times the Galactic value. This value is also several higher than the conversion factor derived using virial methods and CO emission (Blitz et al. 2006, and references therein). The difference between conversion factor derived from the FIR and from GMC properties suggests that the H_2 contributing to the FIR may not be directly associated with the CO — it may lie in an envelope of warm, CO-free molecular gas around the CO emitting region.

5. Conclusions

We find several signatures of the SMC's "primitive" properties in the infrared emission: a deficit in emission at intermediate wavelengths, implying a dearth of small grains; a low emissivity, implying a low dust to gas ratio; and FIR excesses in lines of sight near CO emission, implying a CO-to-H_2 conversion factor many times the Galactic value. We are currently working to take full advantage of *Spitzer*'s high spatial resolution to examine relationships between the gas and dust on small ($\sim$ 10 – 50 pc) spatial scales. In an upcoming paper we will present an in depth, multiwavelength comparison between the dust and gas in the SMC.

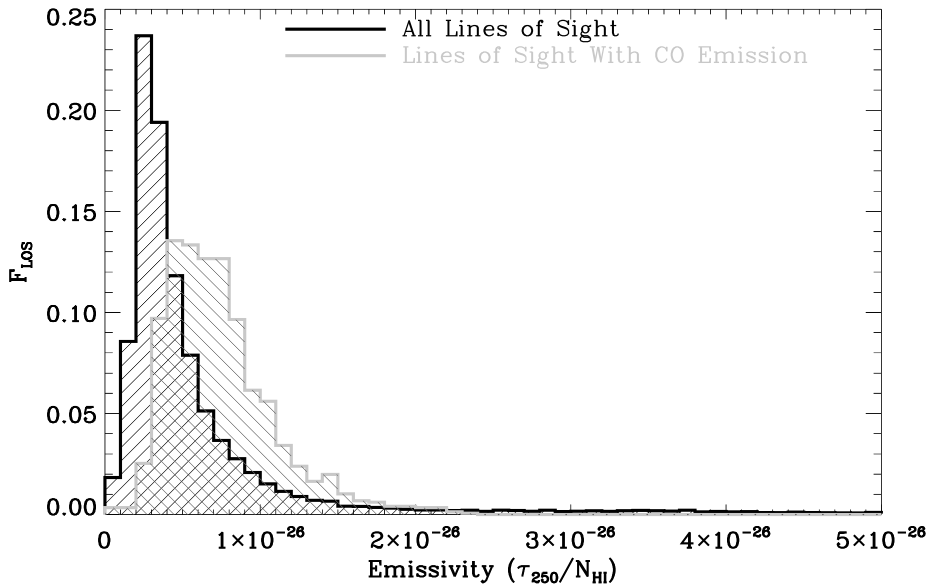

Figure 2. Two histograms show emissivity (optical depth of dust at 250 μm per HI column) along lines of sight towards the SMC. The black histogram shows the distribution of emissivities for all lines of sight, while the light gray histogram shows the distribution of lines of sight associated with CO emission.

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References

Blitz, L., Fukui, Y., Kawamura, A., Leroy, A., & Rosolowsky, E. 2006, in Protostars and Planets V, in press

Bot, C., Boulanger, F., Lagache, G., Cambrésy, L., & Egret, D. 2004, A&A, 423, 567

Boulanger, F., Abergel, A., Bernard, J.-P., Burton, W. B., Desert, F.-X., Hartmann, D., Lagache, G., & Puget, J.-L. 1996, A&A, 312, 256

Israel, F. P. 1997, A&A, 328, 471

Mizuno, N., Rubio, M., Mizuno, A., Yamaguchi, R., Onishi, T., & Fukui, Y. 2001, PASJ, 53, L45

Stanimirovic, S., Staveley-Smith, L., van der Hulst, J. M., Bontekoe, T. R., Kester, D. J. M., & Jones, P. A. 2000, MNRAS, 315, 791

Stanimirović, S., Staveley-Smith, L., & Jones, P. A. 2004, ApJ, 604, 176