DUST IN THE SMALL MAGELLANIC CLOUD

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Abstract.
We discuss simultaneous dust model fits to our extinction and polarization data for the Small Magellanic Cloud (SMC) using existing dust models. Dust model fits to the wavelength dependent *polarization* are possible for stars with small λ_{max}. They generally imply size distributions which are narrower and have smaller average sizes compared to those in the Galaxy. The best fits for the *extinction* curves are obtained with a power law size distribution. The typical, monotonic SMC extinction curve can be well fit with graphite and silicate grains if a small fraction of the SMC carbon is locked up in the grains. Amorphous carbon and silicate grains also fit the data well.

1. Introduction

The Magellanic Clouds are the nearest external galaxies. The Small Magellanic Cloud (SMC) is characterized by a small dust content which makes any study of the grains in its interstellar medium (ISM) difficult. The SMC average gas-to-dust ratio [N(H)/E(B-V)] is about 10 times that of the Galaxy (Bouchet et al. 1985), consistent with its small metallicity (e.g., Wheeler, Sneden & Truran 1989 and references therein). The most reddened stars have color excesses, E(B-V), less than 0.40^{mag} (Bouchet et al. 1985). Galactic foreground color excesses can be as large as 0.09^{mag} (Schwering 1988). While the shape of the infrared (IR) extinction is similar to that of the Galaxy ($R=A_V/E_{B-V}$ = 2.7, Bouchet et al. 1985), the ultraviolet (UV) extinction is very different from either that for the Galaxy or that for the Large Magellanic Cloud (LMC). It is roughly linear

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up to $9\mu m^{-1}$ and does not show the 2175Å bump (Prevot et al. 1984). This has often been referred to as the SMC 'typical' extinction curve. However, the SMC star AZV 456 (AZV = Azzopardi & Vigneau 1982) shows an extinction and a gas-to-dust ratio (Lequeux et al. 1984) similar to the average values in the Galaxy.

2. Polarization Data for the SMC

In an effort to determine the dust properties in the SMC more accurately, Magalhães et al. (1989, 1995=M95) have for the first time obtained multicolor polarimetric data for a number of reddened SMC stars. Their data suggest that stars with the 'typical' SMC extinction, i.e., with no UV bump, have λ_{max} smaller than the average for the Galaxy. This is the case for AZV 211 and 398. The indication is that the size distribution of the grains and not only the carbon abundance may distinguish the dust in the SMC as compared to the Galaxy. The one star with a 'Galactic' extinction curve, AZV 456, has a λ_{max} similar that the Galactic average, although the extinction and polarization curves of AZV 456 differ in detail from those in the Galaxy (M95). Details of that polarization data, as well as new UV extinction data, are given in M95.

This work aims at studying the physical properties of the dust in the SMC by introducing some innovative modifications to existing dust models and applying these models to *simultaneous* fits of the new wavelength dependent polarization data and existing extinction data. The details are presented by Rodrigues, Magalhães and Coyne (1995, R95).

3. Dust Model Fits

We have considered two shapes for the grains: spheres and cylinders. The cross sections for spherical particles have been calculated using Mie theory (e.g., Bohren & Huffman 1983), while the infinite cylinder cross sections were calculated using the formulae in Lind & Greenberg (1966) for homogeneous grains and in Shah (1970) for coated grains. Those cross sections are a good approximation to spheroids and finite cylinders (e.g., Greenberg 1968; Wolff, Clayton & Meade 1993).

Our approach was to first fit the polarization curve with a size distribution of polarizing particles. Then, the extinction is fit with additional components of spherical particles.

In the context of the MRN model (Mathis, Rumpl and Nordsieck 1977), that originally fit the Galactic extinction only, these polarizing particles are silicate cylinders (Mathis 1979, 1986). The fit to the polarization then determines the minimum and maximum size of the cylindrical particles, a_p^{sil} and a_+^{sil} respectively. From a minimum grain radius, a_-^{sil}, until the intermediate radius, a_p^{sil}, the grains were assumed to be spherical (or not aligned). We introduce two innovations (R95). First, we attempt to fit simultaneously the polarization and the extinction since the combination of shapes might be expected to affect the extinction as well as the polarization. Secondly, we introduce *volume* continuity as an alternative to *size* continuity to the size distribution describing both the spherical and the elongated silicates. That is, we employ the same shape for the size distributions of both populations, but the normalization constants of the distributions are not assumed to be the same. Specifically, we have calculated them in such a way that the **volume** distribution is continuous, i.e., the boundary condition is such that the total volume occupied by the spherical and by the cylindrical grains of size a_p^{sil} must be equal. We have also considered amorphous carbon as an alternative to graphite.

We have also performed fits using the model of Greenberg and collaborators (Hong & Greenberg 1980; Chlewicki & Greenberg 1990; hereafter, CG), in which the polarizing particles have a silicate core an an organic refractory mantle. In this model, the other components are bare silicate particles and graphite particles. For the polarization fits, we have also considered the model of Duley, Jones & Williams (1989).

The interested reader is referred to R95 for various details of the simultaneous fit to extinction and polarization.

4. Summary of the Results

From the polarization fits, we find that stars with polarization curves that have small λ_{max} and normal polarization width can be better fit than those with normal λ_{max} and narrow width. Figure 1 shows fits to the polarization data of AZV 398. Stars with 'Galactic' λ_{max} show polarization curves which are too narrow to be adequately fit by the models.

The 'typical' SMC extinction curve can be fit using the MRN silicate-graphite model. If carbon is in an amorphous form, good results can still be obtained without the assumption of a small amount of carbon in grains. Figure 2 illustrates these points for AZV 398, where 'C' stands for the carbon depletion.

In general, the SMC extinction and polarization data are best fit using distributions which are narrower and shifted to smaller sizes relative to the Galaxy. The implications of the above results in terms of the dust in the SMC environment are discussed in detail by R95.

Acknowledgments. AMM is thankful to the organizers for the financial support to attend this conference. This work has been supported by NASA Grant NAG 5 1463. It has been also partially supported by FAPESP (CVR: 89/3091-6; AMM: 89/1670-9, 92/3345-0 and 94/0033-3) and CNPq (AMM: 301558/79-5). The programs have been run at the Department of Astronomy, Instituto Astronômico e Geofísico, Universidade de São Paulo. AMM and CVR would like to acknowledge the hospitality provided by Dr. A. Code, Space Astronomy Lab and Astronomy Department, University of Wisconsin, where this research was partly done.

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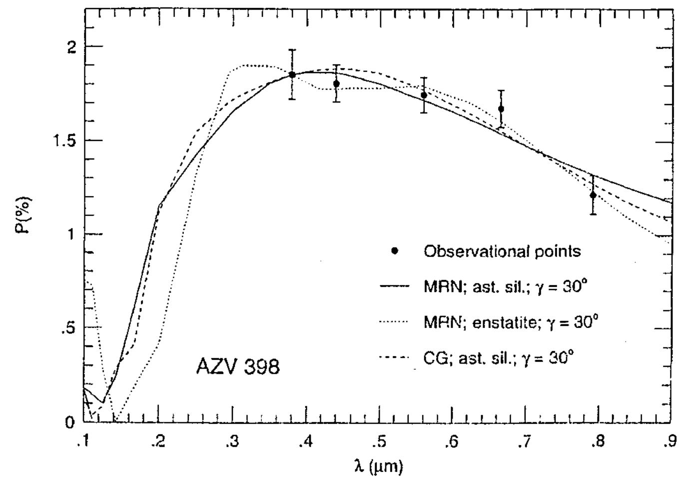

Figure 1. Fits to the polarization data of AZV398 using the MRN and CG models. The size distribution parameters used in the models are: $a_p^{sil} = 0.037\mu$m and $a_+^{sil} = 0.172\mu$m (**solid line**); $a_p^{sil} = 0.045\mu$m and $a_+^{sil} = 0.186\mu$m (**dotted line**) and $a_c = 0.039\mu$m and $a_i = 0.061\mu$m (**dashed line**). In these two figures, γ is the angle between the magnetic field and the plane of the sky.

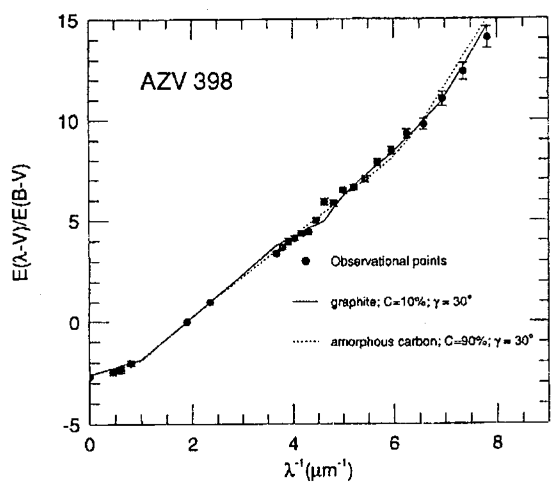

Figure 2. Fits to the extinction data of AZV 398 using the MRN model with spherical carbon and silicate particles and cylindrical silicate particles with sizes provided by the polarization fits. The maximum size of the spherical silicate particles have been constrained by the distribution of cylindrical particles as explained in sec. 4. The size distribution parameters used in the models fits are: $a_-^{sil} = 0.0008\mu$m , $a_p^{sil} = 0.061\mu$m , $a_+^{sil} = 0.099\mu$m , $a_-^{car} = 0.071\mu$m and $a_+^{car} = 0.156\mu$m (**solid line**) and $a_-^{sil} = 0.023\mu$m , $a_p^{sil} = 0.045\mu$m , $a_+^{sil} = 0.186\mu$m , $a_-^{car} = 0.013\mu$m and $a_+^{car} = 0.034\mu$m (**dotted line**).

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