Dust Production in Metal-Poor Local Group Galaxies

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ABSTRACT

Observations with the Infrared Spectrograph on the *Spitzer Space Telescope* reveal several dependencies of mass loss and dust production in evolved stars on metallicity. As the metallicity decreases, the fraction of naked stars increases, and the SiO absorption in the naked stars grows weaker. Among the oxygen-rich stars with circumstellar dust, the amount of dust decreases as metallicity decreases. The amount of dust produced by carbon stars, on the other hand, does not appear to depend on metallicity. As metallicity decreases, a larger fraction of stars on the asymptotic giant branch become carbon rich, which means that metal-poor galaxies should have more carbon-rich dust and less oxygen-rich dust injected into the interstellar medium.

Subject headings: dust, extinction — circumstellar matter — infrared: stars — stars: carbon

1. Introduction

The sensitivity of the Infrared Spectrograph (IRS) (Houck et al. 2004) on the *Spitzer Space Telescope* (Werner et al. 2004) has made it possible to survey the dust produced by evolved stars in nearby Local Group galaxies. These observations allow us to trace how the mass loss and dust production vary as a function of metallicity. These nearby galaxies can serve as proxies for high-redshift galaxies where *Spitzer* cannot resolve the separate dust-producing components.

Several *Spitzer* programs have obtained spectra of evolved stars and the dust they produce in the Large Magellanic Cloud (LMC), the Small Magellanic Cloud (SMC), and other Local Group galaxies such as the Sagittarius dwarf spheroidal (dSph) and the Fornax dSph. Table 1 gives the distances and metallicities of these systems.

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Table 1: Targeted Local Group galaxies

Galaxy	Distance (kpc)	[Fe/H]
LMC	50	−0.3
SMC	60	−0.6
Sgr dSph	24	uncertain
For dSph	142	−1.0

Sloan et al. (2008b) reviewed the five programs which concentrated on the Magellanic Clouds, describing the composition of the samples and the resulting papers, as of mid 2007. The stars in these samples are mostly supergiants or on the asymptotic giant branch (AGB). Carbon-rich AGB stars have dominated the samples in most of the papers published so far. Sloan et al. (2008a) make the first comparison of the oxygen-rich sample in the Galaxy, LMC, and SMC, based on the IRS Guaranteed Time Observation (GTO) program known as the MC_DUST program (Program ID 200). This contribution concentrates on the results of that paper.

2. Naked stars

Table 2: Fraction of naked oxygen-rich stars

	Period (days)		
Sample	≤ 250	250–700	> 700
Galaxy	2 of 106	5 of 269	0 of 11
LMC	2 of 3	2 of 9	0 of 8
SMC	1 of 1	6 of 7	0 of 1

A naked star is one with no circumstellar dust apparent in its infrared spectrum, or more properly, not enough dust excess to identify the chemical nature of the dust. Table 2 shows that as the sample grows more metal-poor, the fraction of naked evolved stars increases. The comparison sample from the Galaxy is based on the sample of AGB stars defined by Sloan & Price (1995, 1998) from observations of the Low-Resolution Spectrometer (LRS) on the *Infrared Astronomical Satellite*.

Table 3: SiO band strengths

Sample	W (μm)
SWS M giants	0.35±0.11
IRS M giants	0.28±0.06
LMC	0.26±0.11
SMC	0.16±0.08

SiO gas produces an absorption feature at 8 μm in the spectra of most late-type giants. SiO is a building block of silicate dust, and its relative strength indicates how much dust the stars could produce. Table 3 compares the equivalent widths of the SiO bands in the LMC and SMC samples to two Galactic samples. The SWS sample consists of the targets studied by Heras et al. (2002). These spectra were observed by the Short Wavelength Spectrometer (SWS) aboard the *Infrared Space Observatory*. The IRS sample is from a Cycle 4 IRS GTO program to study M giants (Sloan et al. 2008d). The samples show a clear dependence with metallicity, with weaker SiO absorption in more metal-poor samples.

3. Oxygen-rich dust

The sources showing oxygen-rich dust also reveal dependencies on metallicity. The comparison sample for the MC_DUST data again is the Galactic AGB sample observed by the LRS.

The Galactic sample reveals a wide range of oxygen-rich dust emission, including low-contrast emission from amorphous alumina dust and higher-contrast emission from amorphous silicates (Sloan & Price 1995). The LMC sample, on the other hand, shows few sources with alumina dust. The distribution of dust types in the LMC sample resembles the distribution in Galactic supergiants examined by Sloan & Price (1998), but only two of the dusty LMC objects are supergiants. The SMC sample includes only two sources showing dust emission in the 10–12 μm range, too few for a meaningful comparison.

Another test of dust content is to examine the contrast of dust to stellar emission in the mid infrared. Taking the ratio of the two quantities between 7.7 and 14.0 μm defines a dust emission contrast (DEC). Figure 1 plots the DEC for oxygen-rich variables with known periods in the MC_DUST and Galactic samples. In the Galactic sample, the amount of dust generally increases as the pulsation period increases. Few short-period variables in either the LMC or SMC show much dust, but for periods between 250 and 700 days, most LMC sources show some dust, though

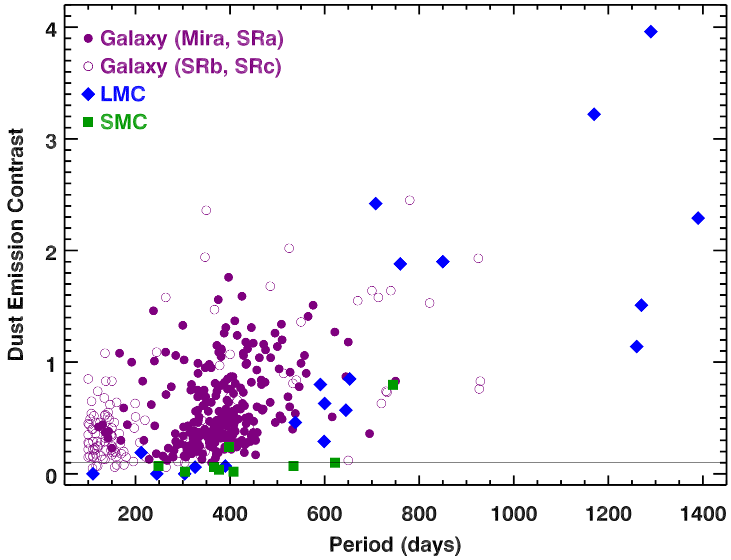

Fig. 1.— Dust emission contrast as a function of pulsation period for the MC_DUST sample of Magellanic stars and a Galactic sample observed by the LRS. The horizontal line separates naked from dusty stars.

less than Galactic sources, while most SMC sources remain naked. Above 700 days, the LMC sample contains several stars with a great deal of dust. The two LMC sources with periods close to 800 days are supergiants, and the two with DEC $>$ 3 are suspected super-AGB sources. All four of these sources are probably young and may be more metal-rich than typical LMC sources. For periods $<$ 700 days, dust content clearly declines with metallicity.

4. Carbon-rich dust

Carbon stars show several dependencies on metallicity (Sloan et al. 2006; Zijlstra et al. 2006; Lagadec et al. 2007; Leisenring et al. 2008). The contributions to the dust from SiC and MgS both drop as the samples grow more metal-poor. Galactic carbon stars show absorption bands from both C_2H_2 and HCN, but HCN absorption is absent in the Magellanic samples (Matsuura et al. 2006). The C_2H_2 absorption increases in more metal-poor samples.

The majority of these studies used the Manchester method to quantify the amount of dust and gas in the carbon stars. The key quantity is the [6.4]$-$[9.3] color, which is determined from two narrow wavelength regions mostly free from molecular absorption or dust emission. Groenewegen et al. (2007) applied radiative transfer models to many of the Magellanic carbon stars and showed that the [6.4]$-$[9.3] color tracks the mass-loss rate. Since the models assumed the same gas-to-dust ratio (200) in both the SMC and LMC and this quantity is unknown, Sloan et al. (2008a) noted that it is more reasonable to state that the [6.4]−[9.3] color tracks the *dust* mass-loss rate. It serves as an easily observable proxy for the amount of amorphous carbon around the star, which is useful because amorphous carbon shows no readily identifiable spectral features, just a smooth opacity in the infrared which falls roughly as $1/\lambda^2$.

Matsuura et al. (2007) have applied the Manchester method to five carbon stars in the Fornax dSph, which is even more metal poor than the SMC. They find that the Fornax carbon stars follow and extend the metallicity trends observed in the Magellanic Clouds. Lagadec et al. (2008) have observed several carbon stars with strong SiC features in the Sagittarius dSph. The metallicity of the sample is unclear from previous work, but the IRS sample shows how the trends established in the Magellanic Clouds can now be used as a diagnostic. Lagadec et al. (2008) conclude that their sample is more metal-rich than typical Galactic carbon stars.

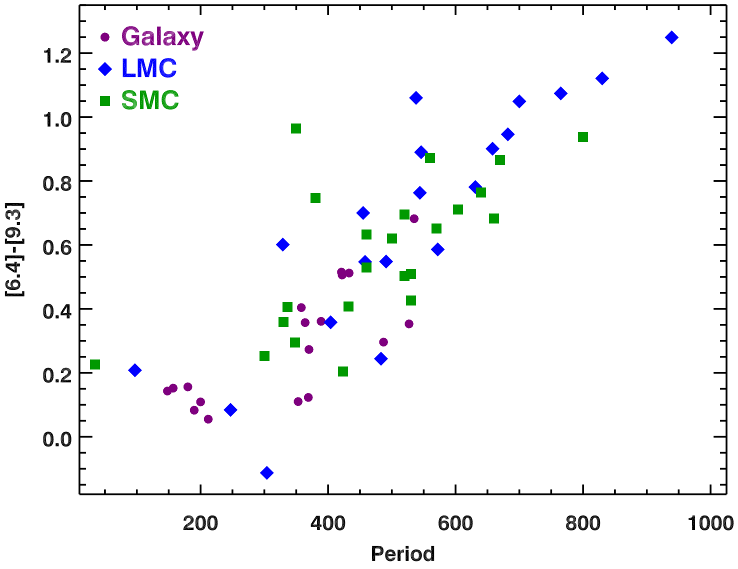

Fig. 2.— [6.4]−[9.3] color as a function of pulsation period for Magellanic and Galactic carbon stars (Sloan et al. 2006; Zijlstra et al. 2006; Lagadec et al. 2007; Sloan et al. 2008a). The [6.4−[9.3] color is a good indicator of the amount of amorphous carbon around a star. The Galactic, LMC, and SMC samples show the same dependency of carbon-rich dust content as a function of period despite their differences in initial metallicity.

Figure 2 compares the carbon stars in the Magellanic and Galactic samples of Sloan et al. (2006), Zijlstra et al. (2006), Lagadec et al. (2007), and Sloan et al. (2008a) by plotting the [6.4]−[9.3] color as a function of pulsation period. The amount of carbon-rich dust clearly depends on pulsation period. More significantly, the Galactic, LMC, and SMC samples appear to follow the same relation, despite their differences in initial metallicity.

5. Comments

Using the IRS on *Spitzer* to study the mass-loss and dust-production processes in nearby Local Group galaxies has revealed two important trends. First, the amount of oxygen-rich dust produced by evolved stars decreases as metallicity decreases. Second, the amount of carbon-rich dust does not vary appreciably with metallicity. It is well established that the fraction of AGB stars which become carbon stars increases as metallicity drops, both observationally (Blanco et al. 1978, 1980) and theoretically (Renzini & Voli 1981). Thus, as we examine galaxies of lower and lower metallicity, we should expect the contributions of silicates and alumina to interstellar dust to decline while amorphous carbon increases.

The 2175 Å bump seen in ultraviolet extinction curves is largely absent in the SMC (e.g. Gordon & Clayton 1998). The strength of the 2175 Å bump should depend on the amount of carbonaceous dust in the interstellar medium, raising the question of whether the observed deficit in metal-poor systems arises from lower production rates of carbon-rich dust or higher destruction rates. The IRS observations of evolved stars in the Local Group may have answered this question, since the amount of carbon-rich dust appears to *increase*, not decrease, as metallicity drops. The absence of sturdier silicate grains in metal-poor systems should result in harsher UV radiation fields, which in turn will lead to shorter lifetimes for more fragile carbon-rich dust grains.

The decreasing amount of silicate dust in more metal-poor samples raises the issue of what drives the mass loss from oxygen-rich stars. Woitke (2006) recently examined the mass-loss and dust-production processes in both oxygen-rich and carbon-rich stars. He found that the opacity of carbon-rich dust is sufficient to drive the mass loss through radiation pressure on the grains and coupling with the gas, but all known oxygen-rich dust species are too transparent for the same mechanism to work in oxygen-rich stars. The mechanism responsible for mass loss from oxygen-rich stars remains unclear.

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