The Magellanic System: Stars, Gas, and Galaxies
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The global gas and dust budget of the Large Magellanic Cloud: AGB stars and supernovae, and impact on the ISM

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Abstract. AGB stars are regarded as one of the important sources of dust and gas for the interstellar medium (ISM) within galaxies. Recent observations from the *Spitzer Space Telescope* enable us to study the mid-infrared dust excess of AGB stars in two nearby galaxies, the Large and Small Magellanic Clouds (LMC and SMC). Using mid-infrared spectra, together with the photometric databases from the SAGE and S^{3}MC programmes, we establish a colour selection of carbon-rich AGB stars with relatively high mass-loss rates. We also established a mass-loss rate versus colour relation for carbon-rich AGB stars, valid for stars with relatively high mass-loss rates ($> 1 \times 10^{-6}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ in gas). In the LMC, we found that the gas mass-loss rate is $6.6 \times 10^{-3}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$, if the gas-to-dust ratio of these AGB candidates is 200. AGB stars are one of the most important sources of dust in the LMC, and the dominant source of gas outside of the bar region. Supernovae are the most important gas source in the LMC bar and around 30 Dor.

Keywords. Magellanic Clouds, stars: AGB and post-AGB, stars: mass-loss, dust, extinction, galaxies: ISM, supernovae: general, stars: carbon

1. Introduction

The interstellar medium (ISM) of a galaxy is one of the most important factors driving its evolution. The composition of the ISM determines the characteristics of the next generation of stars. Simultaneously, it is continuously being renewed and enriched by stellar ejecta. The enrichment occurs when stars die, either exploding as supernovae (SNe) or experiencing intense mass loss in a super-wind. Super-winds occur both in low and intermediate mass stars during the asymptotic giant branch (AGB) phase (main sequence masses in the range $1{-}8\,\mathrm{M}_\odot$), and in more massive red supergiants. The origin of the gas and dust in the ISM is less well understood beyond our Galaxy, due to the limitation of the sensitivity.

The current rate of ISM enrichment by dust and gas depends on the total stellar population, the initial mass function and star-forming history (e.g. Salpeter 1955). Type II SNe are expected to dominate the enrichment in the early phases of galaxy evolution (Maeder 1992), up to 100 Myr. It takes more than 100 Myr for the first intermediate-mass stars to evolve onto the AGB (Vassiliadis & Wood 1993). Thus, dust and gas enrichment from AGB stars occurs later than from high-mass stars. Different galaxies, at different stages of this process, may be expected to show differences in gas-to-dust ratios, dust content, and, in consequence, ISM dust extinction curves, as well as the overall spectral distribution of galaxies.

In our Galaxy, the major dust sources are presumed to be AGB stars and SNe (Gehrz 1989). Some other sources, such as Wolf-Rayet stars and novae, also contribute dust to the

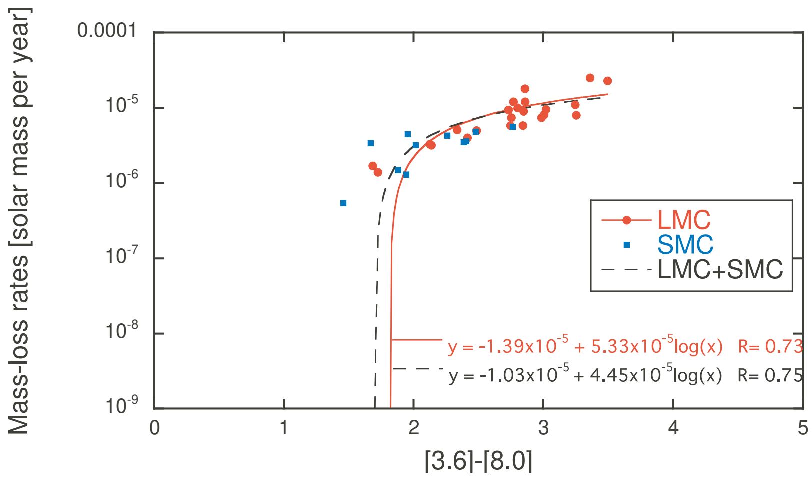

Figure 1. Gas mass-loss rates for LMC and SMC carbon stars from Groenewegen et al. (2007) are plotted as a function of [3.6] − [8.0] colours extracted from SAGE (Meixner et al. 2006). A gas-to-dust ratio of 200 is adopted here. The solid (red) curve is the fit to the LMC sample only and the dashed (green) curve is the fit to the combined LMC and the SMC samples. The fits and their correlation indices (R) are given in the bottom of the figure.

ISM of the Milky Way, but the fraction is estimated to be small. The relative importance of AGB stars and SNe remains uncertain. Dwek (1998) suggests that SNe are important silicate dust sources, while carbonaceous dust grains are solely derived from carbon-rich AGB stars. Jura & Kleinmann (1989) show that AGB stars are an important gas source within our Galaxy, except in the Galactic plane where SNe appear to be more important. The dust formation efficiency in SNe remains controversial (e.g. Sugerman et al. 2006), since supernova shocks also destroy dust (Tielens et al. 1994) and since dust production before the explosion remains unclear. Using *Spitzer Space Telescope* (Werner et al. 2004), now it is possible to measure the gas and dust budget beyond our Galaxy.

2. Analysis

We have observed AGB stars (mainly carbon-rich stars) in the Small Magellanic Cloud (SMC) and the LMC (Sloan et al. 2006, 2008; Zijlstra et al. 2006; Matsuura et al. 2006; Wood et al. 2007; Lagadec et al. 2007; Leisenring et al. 2008); there are also independent spectral surveys of these galaxies by Buchanan et al. (2006). All spectroscopic data are from the Infrared Spectrograph (IRS; Houck et al. 2004) on-board Spitzer. A complete LMC photometric survey using Spitzer was recently published by SAGE (Meixner et al. 2006) and a survey of the main part of the SMC was published by S^{3}MC (Bolatto et al. 2007). Combining these data, we obtain a census of the mass-losing stars, and compare AGB stars with other dust and gas sources in the LMC.

We derive observational mass-loss rate versus colour relations by adopting mass-loss rates estimated for carbon-rich AGB stars in the Magellanic Clouds from Groenewegen et al. (2007). Fig.1 shows the mass-loss rates as a function of [3.6]−[8.0] colour. Throughout this paper, we assume a gas-to-dust ratio of 200 for carbon-rich AGB stars, in order to convert the measured dust mass to a gas mass-loss rate (c.f. Matsuura et al. 2007).

To estimate the integrated mass-loss rates from carbon-rich AGB stars, it is essential to find a classification scheme that will separate carbon- from oxygen-rich stars. In particular, oxygen-rich AGB stars and red supergiants (RSGs) follow different mass-loss rate vs colour relations from carbon-rich stars and their dust contents will be very different.

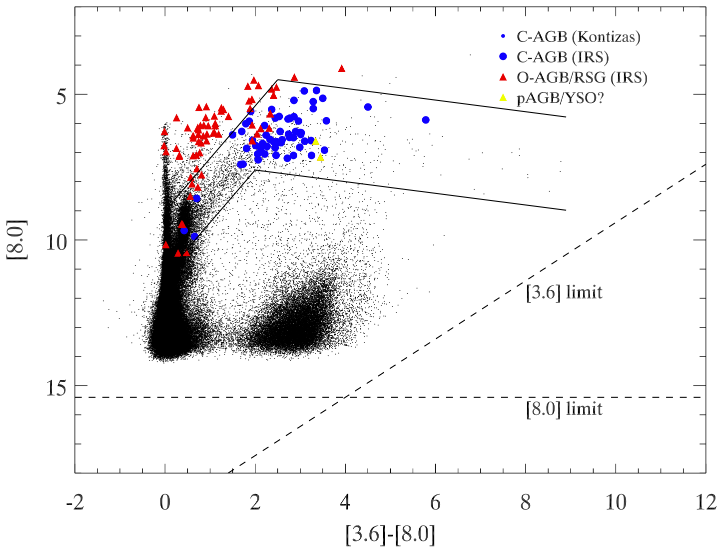

Figure 2. [3.6] − [8.0] vs [8.0] colour-magnitude diagram. Spectroscopically known oxygen-rich and carbon-rich AGB stars are plotted. Selection criteria to extract carbon-rich AGB candidates are indicated by the solid lines. The sensitivity limits quoted by Meixner et al. (2006) for the final data products are indicated by the dashed lines.

Table 1. Gas and dust injected into the ISM of the LMC

Sources	Gas mass (10^{-6} $M_{\odot}$ yr^{-1})	Dust mass (10^{-6} $M_{\odot}$ yr^{-1})	Chemical type
AGB stars			
Carbon-rich	6600	33	C-rich
Oxygen-rich	>1000	>0.4	O-rich
Type II SNe	20000−40000	0.1−130	both O- and C-rich
WR stars	60		(C-rich?)
Red supergiants	>1000	>2	O-rich

3. Discussion

Table 1 summarizes the estimated gas and dust production from various sources. AGB stars are one of the main sources of the dust enrichment for the ISM of the LMC and carbon-rich AGB stars are a major factor. Independent work by Srinivasan et al. (2008) obtained a similar gas mass-loss rate from AGB stars. The dust contribution from SNe is very uncertain. There could also be minor inputs from novae and R CrB stars. Dust evolution models show that, within our Galaxy, carbon dust originates mainly from carbon-rich AGB stars (Dwek 1998). Our work shows that dust production in the LMC follows a similar trend.

If a gas-to-dust ratio of 200 is valid for carbon-rich AGB stars, then SNe make a larger contribution to the gas in the LMC bar region. In the LMC disk, AGB stars could be the more important source of gas and dust, due to the low star formation activity in that region at recent times. Other gas and dust sources appear to present only minor contributions to the ISM enrichment.

This is in marked contrast to our Galaxy where AGB stars are estimated to be the main source, even for gas (Tielens 2005). The difference might be a consequence of the recent increase in the star forming rate (SFR; Smecker-Hane et al. 2002) in the LMC bar region, possibly due to the tidal interaction with the SMC.

The SFR is higher than the gas injection rate from SNe and AGB stars (in total $0.03{-}0.05\,\mathrm{M_{\odot}\,yr^{-1}}$). Whitney et al. (2008) estimated a SFR of $0.19\,\mathrm{M_{\odot}\,yr^{-1}}$, and Kennicutt et al. (1995) suggested a SFR of $0.26\,\mathrm{M_{\odot}\,yr^{-1}}$. These are an order of magnitude higher than the gas output from AGB candidates and SNe. This suggests that the LMC star formation depends on the large reservoir of ISM gas ($7\times10^{8}\,\mathrm{M_{\odot}}$ in H I, Westerlund 1997, and $1\times10^{8}\,\mathrm{M_{\odot}}$ in H_2, Israel 1997). Here we assume a low gas and dust inflow from the Magellanic stream. This is probably consistent with a slow increase of the metallicity in recent times (within the last few Gyrs), according to the age-and-metallicity relation (e.g. Carrera et al. 2008), as the gas feedback from stars takes Gyr to increase the metallicity.

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