Gas and dust budget of the Large Magellanic Cloud

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Abstract

Recent observations from the Spitzer Space Telescope enable us to study the mid-infrared dust excess of Asymptotic giant branch (AGB) stars in the Large Magellanic Cloud (LMC). Using mid-infrared spectra, together with photometric data from the SAGE programme, we establish a colour selection of carbon-rich AGB stars with intermediate and high mass-loss rates. We also established mass-loss rate versus colour relations for carbon-rich AGB stars. The integrated mass-loss rate over all intermediate and high mass-loss rate carbon-rich AGB candidates in the LMC is $8.5 \times 10^{-3} \, M_\odot \, \text{yr}^{-1}$. This number could be almost doubled if oxygen-rich stars are included. Gas mass-loss rate from these stars is $4\text{–}5 \times 10^{-4} \, M_\odot \, \text{yr}^{-1} \, \text{kpc}^{-2}$ in the bar and $1 \times 10^{-4} \, M_\odot \, \text{yr}^{-1} \, \text{kpc}^{-2}$ outside of the bar.

AGB stars are one of the most important dust sources in the LMC, and the dominant gas source outside of the bar. As a consequence of recent increases in the star-formation rate, supernovae are the most important gas source in the LMC bar and around 30 Dor. These differences in dust and gas sources impact on the gas-to-dust ratio and dust properties of the local ISM, because the injection from SNe could have a higher gas-to-dust ratio, resulting in a higher gas-to-dust ratio for the ISM in certain regions of the LMC.

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 superwind. 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 \, $M_\odot$), and in more massive red supergiants. The origin of the gas and dust in the ISM is less well understood beyond the 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 Salpeter55). Type II SNe are expected to dominate the enrichment in the early phases of galaxy evolution, up to 100 Myrs. It takes more than 100 Myr for the first intermediate-mass stars to evolve onto the AGB. 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 [2]). Some other sources, such as Wolf-Rayet stars and novae, also contribute dust to the ISM of the Milky Way, but the fraction is estimated to be small. The relative importance of AGB stars and SNe remains uncertain. Using Spitzer Space Telescope (Werner et al. [13]), now it is able to measure the gas and dust budget beyond our Galaxy.

![Figure 1](image1.png)

Figure 1: Gas mass-loss rates for LMC and SMC carbon stars from [3] are plotted as a function of $[3.6] - [8.0]$ colours extracted from SAGE (Meixner et al. [9]). 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.

![Figure 2](image2.png)

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. [9] for the final data product are indicated by the dashed lines.
2 Analysis

We have observed AGB stars (mainly carbon-rich stars) in the LMC and the Small Magellanic Cloud (SMC) (Sloan et al., Zijlstra et al. [11, 14]). All spectroscopic data are from the Infrared Spectrograph (IRS; Houck et al. [4]) on-board Spitzer. A complete LMC photometric survey using Spitzer was recently published by SAGE (Meixner et al. [9]) and a survey of the main part of the SMC was published by S$^3$MC (Bolatto et al. 2007 [1]). 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. [3]. Fig.1 shows the mass-loss rates as a function of [3.6]−[8.0]. 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. [7]).

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 (Fig. 2). 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.

Details of these analyses are described in Matsuura et al. [8].

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.

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 et al. [12]). The difference might be a consequence of the recent increase in the star forming rate (SFR) in the LMC bar region, possibly due to the tidal interaction with the SMC.

The SFR (0.19–0.26 $M_\odot$ yr$^{-1}$) is higher than the gas injection rate from SNe and AGB stars (in total 0.03–0.05 $M_\odot$ 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 ($7 \times 10^8 M_\odot$ in HI and $1 \times 10^8 M_\odot$ in H$_2$). 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, as the gas feedback from stars takes Gyr to increase the metallicity.
Table 1: Gas and dust injected into the ISM of the LMC

| Sources       | Gas mass \((10^{-6} M_\odot \text{yr}^{-1})\) | Dust mass \((10^{-6} M_\odot \text{yr}^{-1})\) | Dust chemical type |
|---------------|---------------------------------|---------------------------------|-------------------|
| AGB stars     |                                 |                                 |                   |
| Carbon-rich   | 8600                            | 43                             | C-rich            |
| Oxygen-rich   | >>200                           | >>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            |

‡ Dust production (or possibly destruction) in and around SNe remain uncertain.

References

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