

Global Dust Budgets of the Magellanic Clouds

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Abstract. Within galaxies, gas and dust are constantly exchanged between stars and the interstellar medium (ISM). The life-cycle of gas and dust is the key to the evolution of galaxies. Despite its importance, it has been very difficult to trace the life-cycle of gas and dust via observations. The Spitzer Space Telescope and Herschel Space Observatory have provided a great opportunity to study the life-cycle of the gas and dust in very nearby galaxies, the Magellanic Clouds. AGB stars are more important contributors to the dust budget in the Large Magellanic Cloud (LMC), while in the Small Magellanic Cloud (SMC), SNe are dominant. However, it seems that the current estimates of the total dust production from AGB stars is insufficient to account for dust present in the ISM. Other dust sources are needed, and supernovae are promising sources. Alternatively the time scale of dust lifetime itself needs some revisions, potentially because they could be unevenly distributed in the ISM or clumps.

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

1. Introduction

Stars and the interstellar medium (ISM) undergo a constant exchange of gas and dust. At the end of stellar evolution, low- and intermediate-mass stars lose their mass through stellar winds during the asymptotic giant branch (AGB) phase. The outflow from AGB stars contain newly synthesised elements in the stellar interiors. Some elements turn into dust grains around AGB stars, so that these stars feed elements and dust into the ISM. It is well accepted that AGB stars form some dust, but it is still unclear how important their contribution is to ISM dust.

High-mass stars end their life as core-collapse supernovae (SNe), and elements synthesised in the stellar interiors are injected into the ISM instantly. The role of SNe on ISM dust is largely unknown. SNe generate high energy shocks propagating across the ISM, and they destroy the dust that already exists in the ISM (Jones *et al.* 1994). SNe destruction rate dictate the life-time of dust in the ISM. Recently, observations found that dust grains should have formed in the SNe; while the SN ejecta expands, adiabatic cooling reduces the temperature of the ejecta, providing potentially an ideal site for dust condensation (Kozasa *et al.* 1989). It is not clear how much dust can form in the aftermath of these explosive events (Gall *et al.* 2011). Hence, the net effect of SNe on ISM dust is largely unknown.

Here, we report on the current understanding of stellar dust contributions to ISM dust, using the Spitzer Space Telescope and Herschel Space Observatory's observations of the Magellanic Clouds. This work focuses on two major dust sources, AGB stars and SNe, as contributions from other dust sources (novae and red-supergiants) seem to be relatively minor dust sources (Gehrz *et al.* 1989; Matsuura *et al.* 2009).

2. AGB dust

Using the Spitzer Space Telescope (Werner *et al.* 2004), we obtained the census of dust-embedded AGB stars beyond the Milky Way. The data we used include the photometric surveys of the Magellanic Clouds (MCs; Meixner *et al.* 2006; Gordon *et al.* 2011) and spectroscopic studies of selected AGB stars in these galaxies (Zijlstra *et al.* 2006; Sloan *et al.* 2006; Buchanan *et al.* 2006; Lagadec *et al.* 2007; Kemper *et al.* 2010).

From the AGB census, we estimate the total dust production from the overall AGB star population, and compare their dust input with the dust mass present in the ISM. We estimated the integrated dust mass-loss rate of AGB stars to be $8 \times 10^{-5} M_{\odot} \text{ yr}^{-1}$ and $7 \times 10^{-6} M_{\odot} \text{ yr}^{-1}$, in the Large and Small Magellanic Clouds (LMC and SMC), respectively. In the ISM, dust grains are destroyed by SN shocks and the lifetimes of dust in the ISM is predominantly determined by SN rate in the galaxy. We estimate the dust life time to be between $5\text{--}8 \times 10^8$ and $11\text{--}17 \times 10^8$ yrs in the LMC and the SMC, respectively (Matsuura *et al.* submitted). The product of the integrated dust mass-loss rates and the dust lifetime gives the equilibrium dust mass in the Magellanic Clouds, which are $4 \times 10^4\text{--}1 \times 10^6 M_{\odot}$ and $1\text{--}2 \times 10^4 M_{\odot}$. In contrast, the ISM dust masses in the Magellanic Clouds are $2 \times 10^6 M_{\odot}$ and $3 \times 10^5 M_{\odot}$, respectively (Matsuura *et al.* 2009; Leroy *et al.* 2007). In the Magellanic Clouds, AGB stars are one of the important dust sources. However, it seems that the current estimates of the total dust production from AGB stars is insufficient to account for dust present in the ISM.

Other dust sources are needed, alternatively the time scale of dust lifetime itself needs some revisions, potentially because they could be unevenly distributed in the ISM or clumps.

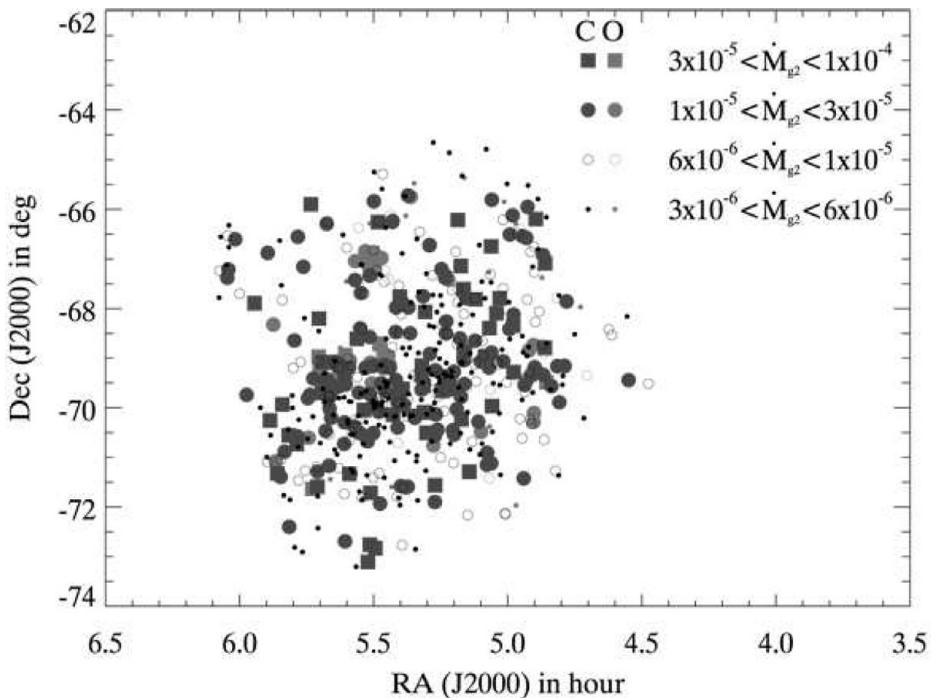


Figure 1. Spatial distribution of LMC AGB stars and their mass-loss rates.

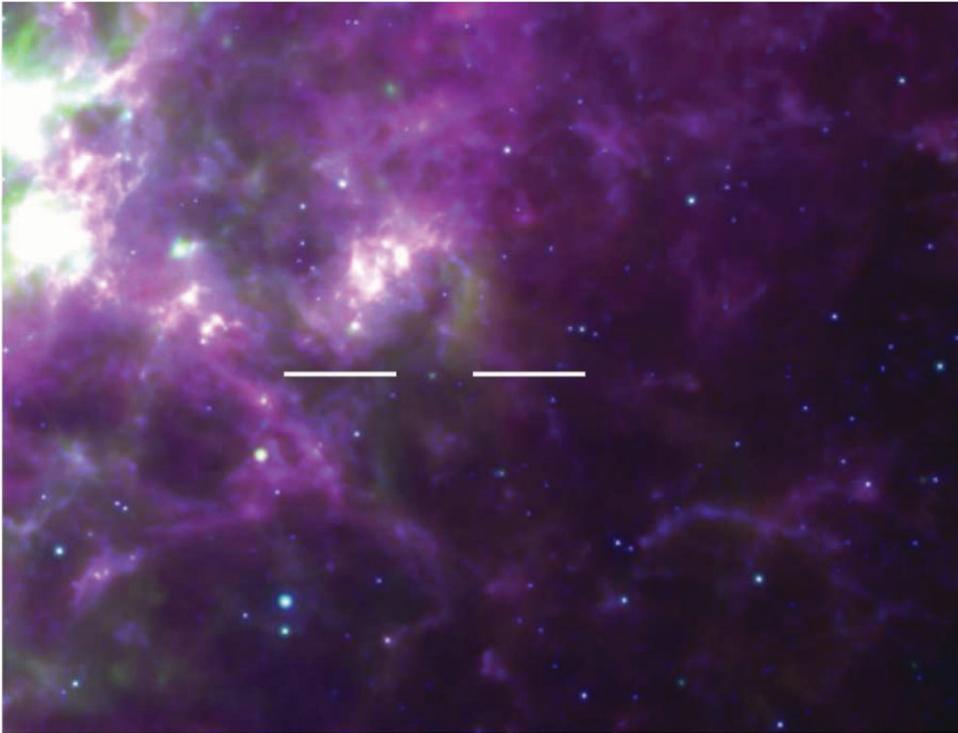


Figure 2. Infrared image of SN 1987A.

3. SN dust

In the last decade, dust formation in SN ejecta have been highlighted in recent papers but the reported dust mass in SNe had found a wide range between 10^{-6} to nearly $1 M_{\odot}$ (Gall *et al.* 2011). This requires more samples to measure more precisely.

We have detected the SN 1987A in far-infrared and submillimeter wavelengths, using the Herschel Magellanic Survey, the HERITAGE (Meixner *et al.* 2010). The estimated dust mass was between $0.4\text{--}0.7 M_{\odot}$, and the dust came from the ejecta.

Gomez *et al.* (2012) further investigated dust in Crab Nebula, finding about $0.2 M_{\odot}$. Herschel investigations consistently find cold and large dust grains formed in SN remnants.

Recent submillimeter survey of distant galaxies have found many of them have a significant dust content (e.g. Bertoldi *et al.* 2003; Smith *et al.* 2012). Theory have predicted approximately $0.1\text{--}1.0 M_{\odot}$ of mass required to explain dust found in high-redshift ($z > 6$) galaxies (Morgan & Edmunds 2003; Nozawa *et al.* 2003; Dwek & Cherchneff 2011). Our discovery of a large dust mass reservoir in SN 1987A fulfill the theoretical prediction, opening a venue to explain dust in high-redshift galaxies with SNe.

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