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Chemical Evolution of Mn in Three Dwarf Spheroidal Galaxies

Men-Quan Liu[1,2,*] & Jie Zhang[1]
[1]*Institute of Theoretical Physics, China West Normal University, Nanchong 637009, China.*
[2]*Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China.*
[*]*e-mail: liumq@shao.ac.cn*

Abstract. Based on an improved model, more reasonable nucleosynthesis and explosion rate of SNeIa and CCSNe, we studied Mn evolution for three local dwarf spheroidal galaxies (dSphs), considering the detailed SNe yield and explosion rates for different types of progenitors. The results can explain the main observation of Mn abundance for tens stars in those dSphs, and give some constraints to the nucleosynthesis and explosion ratio of different types of supernovae and Star Formation Rates (SFR) in those dSphs.

Key words. Elementary particles—nuclear reactions, nucleosynthesis, abundances—supernovae: general.

1. Introduction

Dwarf spheroidal galaxies (dSphs) in the local Universe can be studied in detail star by star since their distances from the Milky Way are not too far (Tolstoy *et al.* 2009). DART (dwarf galaxy abundance and radial-velocity team) survey have obtained many accurate spectrum for the bright stars in those galaxies (Helmi *et al.* 2006), including some low abundant elements, such as some iron-peak element. Recently, North *et al.* (2012) reported their new results of Mn abundance of several tens stars in dSphs Fonax, Sculptor, Sextans and Carina. This work makes significant improvement on the sample number of the local dSphs. The progress also provides a likelihood to test the theoretical models, both the explosive nucleosynthesis of supernovae and the evolution of dSphs in the local group.

Here, we report a newly improved model, using more reasonable nucleosynthesis and explosion rate of SNe to explain the recent observations of Mn for three dSphs: Fornax, Sculptor and Sextans.

2. Improvement in our method

Iron-peak elements are thought to be produced by supernovae, both type Ia supernovae (SNeIa) and core-collapse supernovae (CCSNe). However, the explosion mechanism of both SNeIa and CCSNe still have many uncertainties (Janka 2012; Röpke *et al*. 2011). As to the nucleosynthesis of SNe, the detailed and systematic SNeIa nucleosynthesis is still lacking (Iwamoto *et al*. 1999; Travaglio *et al*. 2005; Hillebrandt & Röpke 2010), so we have to adopt interpolation for other metallicities. The yield of CCSNe is strongly dependant on the mass of the progenitor. The most popular and cited results are provided by Woosley & Weaver (1995). But they only included the mass range from 11 to $40M_{\odot}$. Here we consider the mass range from 8 to $100M_{\odot}$ and divided them into 13 different sections, employing 12 progenitor models to represent all CCSNe.

Although many authors investigated the chemical evolution of dSphs, they mainly considered the elements with atomic number less than iron because there was only a few data of iron-peak elements at that time. Here we investigate Mn evolution in three local dSphs: Fornax, Sculptor and Sextans based on the newly improvement data provided by North *et al*. (2012). A new model proposed by Qian & Wasserburg (2012) is employed and we also make some improvement to their model. In Qian & Wasserburg's model, the evolution of Fe in a homogeneous system of condensed gas is governed by the following equations:

$$\frac{\mathrm{d}M_{\mathrm{Fe}}}{\mathrm{d}t} = P_{\mathrm{Fe}}(t) - \frac{M_{\mathrm{Fe}}(t)}{M_{\mathrm{g}}(t)}[\psi(t) + F_{\mathrm{out}}(t)], \tag{1}$$

where t is the time that begins from the formation of galaxy, M_{Fe} and M_{g} are the masses of Fe and gas in the system at time t, respectively. $P_{\mathrm{Fe}}(t) = \lambda_{\mathrm{Fe}} X_{\mathrm{Fe}}^{\odot} M_{\mathrm{g}}(t)$ is the net rate of Fe product by all sources in the system. For simplicity, λ_{Fe} is assumed as a constant, i.e., Qian & Wasserburg (2012) ignored the concrete contribution of different types of supernovae and the time delay between the birth and death of supernovae progenitors. $X_{\mathrm{Fe}}^{\odot}$ is the mass fraction of Fe in the Sun. $\psi(t) = \lambda_{*} M_{\mathrm{g}}(t)$ is SFR, where λ_{*} is a constant. $F_{\mathrm{out}}(t)$ is the rate of gas outflow.

Considering the concrete contribution from different types of supernovae and the time delay between the birth and death of supernovae progenitors, the evolution equation of Fe is

$$\frac{\mathrm{d}M_{\mathrm{Fe}}}{\mathrm{d}t} = P'_{\mathrm{Fe}}(t) - \frac{M_{\mathrm{Fe}}(t)}{M_{\mathrm{g}}(t)}[\psi(t) + F_{\mathrm{out}}(t)], \tag{2}$$

Note that equation (2) is similar to equation (1), but $P_{\mathrm{Fe}(t)}$ has been substituted by $P'_{\mathrm{Fe}(t)}$. In equation (2), $P'_{\mathrm{Fe}(t)} = R_{\mathrm{SNeIa}}(t) y_{\mathrm{Ia}}^{\mathrm{Fe}}(t) + R_{\mathrm{CCSNe}}(t) y_{\mathrm{CC}}^{\mathrm{Fe}}(t)$, where $R_{\mathrm{SNeIa}}(t)$ and $R_{\mathrm{CCSNe}}(t)$ are the explosion rates for SNeIa and CCSNe at time t, respectively. $R_{\mathrm{SNe}}(t) \propto \psi(t - \tau)$, where τ is the time delay. $y_{\mathrm{Ia}}^{\mathrm{Fe}}(t)$ and $y_{\mathrm{CC}}^{\mathrm{Fe}}(t)$ are the yields of Fe for SNeIa and CCSNe, respectively. When SFRs of North *et al.* (2012). are used, $\psi(t)$ is substituted by $\psi'(t)$. Similarly, we obtain the evolution equation of Mn.

3. Results and discussion

The results are shown in Fig. 1. We find that the theoretical curves of all these three local dSphs are the same: they go down at the initial stage and rise with some

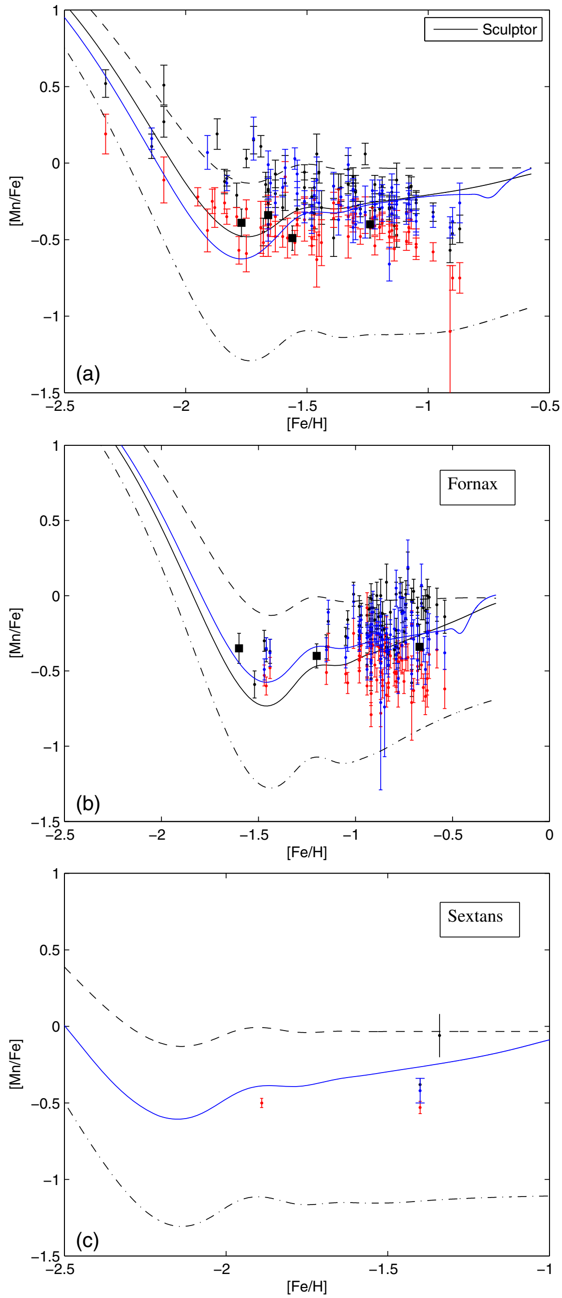

Figure 1. [Mn/Fe] vs. [Fe/H] for the three dSphs. The black, red and blue dots denote the observational data of Mn I line of $\lambda = 5407$ Å, 5420 Å and 5516 Å, respectively (data is taken from North *et al.* (2012), and the error bars of [Fe/H] are ignored). The black squares denote the observational data from Shetrone *et al.* (2003). The dashed, dot-dashed and solid curves (blue for SFR of North *et al.* (2012) and black for SFR of Qian & Wasserburg (2012)) are the results corresponding to the contribution of SNeIa, CCSNe and both of them respectively. The initial abundance of both Mn and Fe are assumed to be zero.

oscillation after the minimal point. Comparing with the previous research by Cescutti *et al*. (2008), we find that their curves go up at the initial stage, which is inverse with ours. We think it is caused by the initial condition. Usually only the stars whose mass $<100M_\odot$ are included in the calculation. On the one hand, a small amount of hyper-massive stars ($>100M_\odot$) exist and explode before the smaller ones according to Salpeter's law. So the initial [Mn/Fe] calculation should consider the relic of these hyper-massive stars. According to the theoretical estimate, their [Mn/Fe] are very smaller, so is the initial [Mn/Fe]. On the other hand, a number of these hyper-massive stars are too small to influence the galaxies. We assume that the abundance of Mn and Fe are zero. Using the definition, $[\mathrm{Mn/Fe}]_{\mathrm{initial}} = 1.96$. That is why it goes down. Comparing with the observation, there is a downward trend initially, especially for Sculptor. We also find that the [Mn/Fe] curves from SNeIa are generally higher than the observation, while the cases reverse for CCSNe. The actual abundance of Mn in the stars contributed from both these types of SNe. Because the number of massive stars becomes less and less at high metallicity in the dSphs, the nucleosynthesis of Mn is dominated by SNeIa at that time. That is why the solid curves approach the dashed line at large [Fe/H]. Comparing the theoretical results with the observed data in these different galaxies. We find the theory can explain most distribution of Mn abundance in the dSphs. In Sculptor, the solid curve can pass the centre of data as $[\mathrm{Fe/H}] \leq -1.3$ but it is larger than the centre of data as $[\mathrm{Fe/H}] > -1.3$; in Fornax, the solid curve can pass through most of the data as $[\mathrm{Fe/H}] > -1.3$, but it is a little lower than the data $[\mathrm{Fe/H}] \leq -1.3$; in Sextans, the curve accords with the data well but only a few stars have been observed.

The results show that our model can be used to fit the most of the observed data of these galaxies. However, there still are some uncertainties in the theory.

(i) *Metal-independent* [*Mn/Fe*]. The previous works have ever assumed the yield of Mn should be directly proportional to the meltallicity (i. e., $y_{\mathrm{Mn}}(z) \propto (\frac{Z}{Z_\odot})^{0.65}$). This is because the previous authors adopted the yield of 11–40$M_\odot$ CCSNe whose Mn abundance are generally high to fit the observational data. Only if the yield of Mn is quite low in the low metallicity progenitors they can attain reasonable results. We, however, find this assumption is not necessary because both the yield of $8.8M_\odot$ and $50M_\odot$ SNe models are quite low comparatively.

(ii) *The role of SNeIa*. The results of North*et al*. (2012) indicated the contribution of SNeIa is less than that of CCSNe, especially when [Fe/H] is low. We find SNeIa is very important no matter the metallicity is high or low. The contribution of SNeIa is almost equivalent to that of CCSNe in the low metallicity case; it becomes dominant in high metallicity case.

(iii) *Source of Mn*. There maybe some other sources of Mn and Fe except the typical supernovae discussed in this paper, such as the hypernovae and the SNeIa which progenitor are two degenerate white dwarfs.

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