CHEMICAL EVOLUTION OF THE MAGELLANIC CLOUDS

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Abstract

Analytical models for the chemical evolution of the Magellanic Clouds are developed assuming infall, non-selective galactic winds and burst-like modes of star formation represented by discontinuous variations in the star formation rate per unit gas mass. Chemical yields and time delays are taken to be the same as in the solar neighbourhood. We find adequate agreement with age-metallicity relations and element:element ratios within their substantial uncertainties, whereas our LMC model turns out to give an excellent fit to the anomalous Galactic halo stars discovered by Nissen & Schuster [9]. It also gives an enhanced SNIa/SNII ratio compared to the solar neighbourhood, due to the assumption that the SFR has declined in the past 1 to 2 Gyr.

1 Introduction

The Magellanic Clouds qualify only marginally as dwarf galaxies, but they can be studied in much more detail than others. Compared to the solar neighbourhood, they exhibit a number of special features:

- The stellar population has a major component under 3 Gyr old, at least in the LMC.
- They are probably losing gas, e.g. in the Magellanic Stream.
- Abundance ratios like O/Fe differ from the solar neighbourhood at the same Fe/H. This could be an effect of IMF, SFR, bursting and/or metal-enhanced winds. However, it seems that the differences have been exaggerated.
- A relatively high ratio of SNIa/SNII in the LMC.

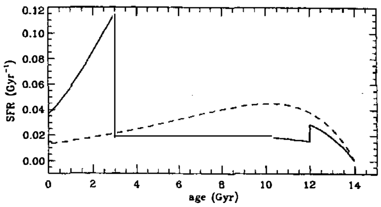

Figure 1: SFR history of the LMC according to our model. The full curve shows the bursting model and the broken-line curve shows the corresponding smooth model.

Previous chemical evolution models have been the following:

- Russell & Dopita [13] assuming steep IMF, inflow, no galactic wind, smooth SFR.
- Tsujimoto *et al.* [14] assuming steep IMF, inflow, smooth and bursting models.
- Pilyugin [12] assuming normal IMF, no inflow, homogeneous and metal-enhanced winds, bursting SFR.

We are critical of these models because the steep IMF and metal-enhanced wind assumptions are motivated by a low O/Fe ratio found in F-K supergiants. But other α-elements have solar ratios to Fe, while Galactic supergiants show the same apparent Fe deficiency, [Fe/O] $\simeq -0.2$, e.g. [8], and other data including those from H II regions, PN and SNR give [Fe/O] $\simeq 0$ [7]. We conclude that the [O/Fe] from supergiants should be shifted upwards by 0.2 dex.

2 Our models

Our models are analytical, similar to those previously put forward for our own Galaxy [10] using instantaneous recycling and delayed production approximations and assume identical yields and time delays as in the solar neighbourhood. In the Clouds we assume longer star formation timescales, inflow according to a simple prescription and homogeneous outflow reducing effective yields, and we consider both smooth and bursting models. In the bursting models we assume the transition probability for gas to change into stars to change discontinuously from a modest value like 0.1 Gyr^{-1} for the first 1.5 Gyr or so, to a low value over the next 9 Gyr followed by a high value near 0.4 Gyr^{-1} in the last 3 to 4 Gyr, these parameters being slightly different in the two Clouds. Fig 1 shows the resulting star formation history assumed for the LMC.

3 Comparison with observations

Fig 2 shows results from our LMC model compared to α-element abundances measured in planetary nebulae [4]; the bursting model is clearly favoured by these data as well as by the lack of known clusters with ages between 3 and 8 Gyr [5]. Fig 3 shows our age-metallicity relation for the SMC, designed to fit cluster metallicities from Da Costa 1991 [2]; these again favour a bursting model, but more recent results by Da Costa & Hadzidimitriou [3] are more ambiguous.

Fig 4 shows a selection of our results for element:element ratios. After shifting the LMC supergiant data for [O/Fe] upwards by 0.2 dex and those for [Si/Fe] downwards by 0.1 dex in the light of average data for Galactic supergiants, the fit is adequate within a substantial scatter,

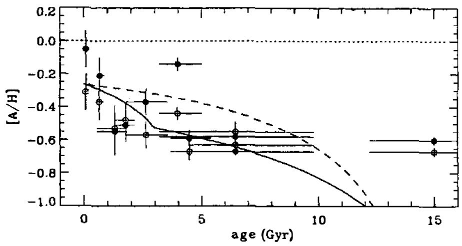

Figure 2: Age-abundance relation for α-elements in the LMC. Curves are as in Fig 1. Data are from [4]; open circles show oxygen whereas filled circles give the average of Ne, S and Ar.

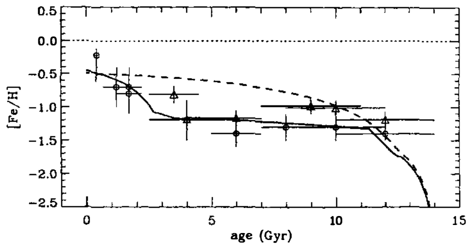

Figure 3: Age-metallicity relation for the SMC. Circles are from [2], triangles from [3].

part of which is probably spurious. Our model curves are supposed to represent evolution with time, whereas the supergiants are all young. However, it is interesting that our model gives an excellent fit to the ratios in the anomalous Galactic halo stars of Nissen & Schuster [9] (without applying any fudge factor!), and this applies also to Y and Ba which are not shown for lack of space. Thus the anomalous stars could well have been accreted from a satellite galaxy resembling the LMC. Full details including discussion of neutron capture elements are given in [11].

4 Relative supernova rates

In models with a steepened IMF, the total SNIa/SNII ratio is enhanced with respect to the solar neighbourhood which may be representative of Sbc galaxies. This effect is absent from our model, but the *current* rate ratio is enhanced according to the assumed decline in SFR in the past 1 to 2 Gyr (taking the SNIa lifetime to be $\Delta = 1.3$ Gyr):

$$\frac{R_{\mathrm{SNIa}}(T)}{R_{\mathrm{SNII}}(T)} \propto \frac{\dot{s}(T-\Delta)}{\dot{s}(T)}. \tag{1}$$

This ratio in our models is 1.2 for the Milky Way, 1.8 for the LMC and 1.5 for the SMC, giving an enhancement of a factor 1.5 in the SNIa/SNII ratio for the LMC compared to the Galaxy, where that ratio has been estimated at 0.11 to 0.25 [15]. In Sdm-Im galaxies, there is an estimate of 0.3 [1], while in the LMC itself a ratio between 0.25 and 1 has been found from X-ray observations of SNR [6]. Our LMC model is in fair agreement with these estimates, but the prediction is sensitive to the star formation history assumed; we suggest that high SNIa/SNII ratios generically indicate an SFR that has declined over the past 1 to 2 Gyr.

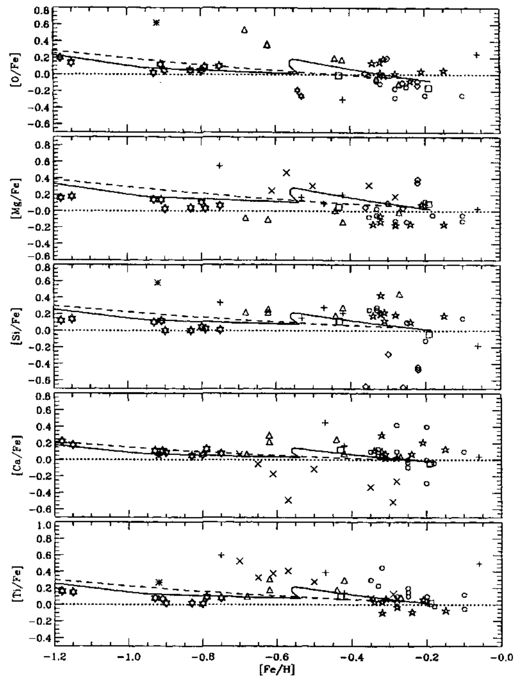

Figure 4: α/Fe ratios as a function of [Fe/H] in the LMC. The large 6-pointed stars show anomalous Galactic halo stars from [9], while the other symbols represent LMC supergiants from various literature sources with [O/Fe] shifted upwards by 0.2 dex and [Si/Fe] downwards by 0.1 dex.

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