MASS LOSS AND $\Delta Y/\Delta Z$ RATIO

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SUMMARY

The $\Delta Y/\Delta Z$ abundance ratio is studied taking into account mass loss from intermediate and massive stars, and the Y_Z vs. Z relation of Peimbert and Serrano (1980a).

INTRODUCTION

The most recent determinations of helium to heavy element enrichment ratio $\Delta Y/\Delta Z$, and yield of heavy elements Y_Z have been discussed by Serrano and Peimbert (1980a), and Peimbert and Serrano (1980) respectively. Mean values of $\Delta Y/\Delta Z=3\pm1$ and $Y_Z=0.007$ can be assumed as indicative estimates for the solar vicinity. Furthermore, while the abundance ratio $\Delta Y/\Delta Z$ does not vary significantly among different objects (main sequence F,G,K, stars, supergiant stars, planetary nebulae, globular clusters, extragalactic HII regions, Magellanic Clouds, dwarf spheroidal galaxies), Y_Z is found to increase with the mean metallicity of the galaxy. The linear relationship, $Y_Z=0.6\ Z+0.002$ is proposed by Peimbert and Serrano (1980a). Theoretical values of $\Delta Y/\Delta Z$ and Y_Z calculated with usual assumptions for the mass ejected at the end of a star's life in form of helium and heavy elements, and for the initial mass function, turned out to be substantially smaller and higher respectively ($0.3\lesssim\Delta Y/\Delta Z\lesssim1$; $Y_Z=0.019$) than the observational ones (Hacyan et al., 1976; Gingold, 1977; Arnett, 1978; Mallik, 1980). The incorporation of mass loss by stellar wind in evolutionary studies of massive stars lowered the amount of heavy elements ejected by these stars for any reasonable assumption for the initial mass function (Chiosi and Caimmi, 1979). This fact would decrease Y_Z and increase $\Delta Y/\Delta Z$ without changing significantly the helium production. However, recent studies on the helium ejection by planetary nebulae (Peimbert and Serrano, 1980b), helium enrichment due to mixing in double shell stars (Gingold, 1977), and hot bottom burning in intermediate mass stars undergoing mass loss by stellar wind (Renzini and Voli, 1980) brought further improvements to this

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problem. The effects of contributions of newly synthesized helium, stellar mass loss, and different choices for the initial mass function on $\Delta Y/\Delta Z$ have been discussed in some detail by Serrano and Peimbert (1980a) using a simple model of chemical evolution of the solar neighbourhood. While the observational $\Delta Y/\Delta Z$ and Y_Z values could be easily fitted, their simple model failed in reproducing other important properties of the solar vicinity, like the metallicity distribution in G dwarf stars, and the metal abundance of young stars. On the contrary, models that succesfully reproduced the overall properties of the solar vicinity (Chiosi, 1977, 1980; Chiosi and Matteucci, 1980a), but made standard assumptions for the chemical enrichment per stellar generation, were unable to fit the observed $\Delta Y/\Delta Z$ and Y_Z. In this paper, several new developments are taken into account, which might remove the above difficulties. The main novelty is in that the effect of metal content Z on mass loss by stellar wind from massive stars (Chiosi et al., 1980), and the Y_Z vs. Z relation of Peimbert and Serrano (1980a) are taken into account in the calculation of Y_Z. Furthermore, the results of Arnett (1978) and Renzini and Voli (1980) for the amounts of helium and heavy elements synthesized and ejected by stars at the end of their life, are used to update the calculation of element yields.

CHEMICAL EVOLUTION COEFFICIENTS

In the matrix formalism developped by Talbot and Arnett (1973), the yield Y_i of an element i, defined as the ratio of the fractionary mass of a newly synthesized element to the fractionary mass of matter locked forever in long lived stars or stellar remnants, is written as

$$Y_i = \Sigma_{i\neq j}\, q_{ij}\, X_j/(1-\Sigma_{ij}\, q_{ij}\, X_j) \ , \qquad (1)$$

where

$$q_{ij} = \int_m Q_{ij}(m)\ \Phi(m)\ dm \qquad (2)$$

is the production matrix per stellar generation, $\Phi(m)$ is the initial mass function, and X_j denotes the mass abundance of an element j. The matrix element $Q_{ij}(m)$ specifies the fraction of mass of a star of mass m, initially present in form of elements j, which is eventually ejected in form of elements i. The procedure for deriving the production matrix $Q_{ij}(m)$ rests on the formalism of Talbot and Arnett (1973) but incorporates the results of Renzini and Voli (1980) for low and intermediate mass stars ($1\lesssim m\lesssim 8$), the nucleosynthesis of Arnett (1978), and finally the results of Chiosi et al. (1978, 1980) for massive stars suffering mass loss by stellar wind, in the way discussed by Chiosi and Caimmi (1979). A detailed description of the production matrix $Q_{ij}(m)$ incorporating the above sources of data is given elsewhere (Chiosi and Matteucci, 1980b). Since all non zero features of the matrix $Q_{ij}(m)$ are found at $m\gtrsim 1\ m_{\odot}$, the initial mass function $\Phi(m)$ has been normalized by specifying the fraction ζ of mass of the initial mass function that corresponds to stars more massive than 1 $m_\odot$. Furthermore, as helium production mostly occurs in the range of intermediate mass stars for any reasonable initial mass function, whereas the bulk of heavy elements is ejected by massive stars ($m>10\ m_\odot$), in order to study separately helium and metal productions we have adopted a two zone $\Phi(m)$. Accordingly the initial mass function is written as

$$A\int_{m_1}^{m_2} m^{-\mu_1}dm = \zeta_1 \ , \qquad m_1 \leq m \leq m_2 \tag{3}$$

$$B\int_{m_2}^{m_n} m^{-\mu_2}dm = \zeta_2 \ , \qquad m_2 \leq m \leq m_n \ , \tag{4}$$

together with the supplementary conditions

$$A\ m_2^{-\mu_1} = B\ m_2^{-\mu_2} \tag{5}$$

$$\zeta_1 + \zeta_2 = \zeta \tag{6}$$

$$\zeta_1/\zeta_2 = \eta \ . \tag{7}$$

The lower and upper limits of integration, are $m_1=1\ m_\odot$ and $m_n=100\ m_\odot$, respectively. A preliminary analysis (reported in Chiosi and Matteucci, 1980b) was performed to see how our results would have been affected by different choices for μ_1, μ_2 and m_2. This gave $\mu_1=1.3$, $\mu_2=1.7$ and $m_2= 10\ m_\odot$ as the best candidates. With this choice for μ_1, μ_2 and m_2, the initial mass function we have used is similar to the one proposed by Tinsley (1980). With the above values for μ_1, μ_2 and m_2, the ratio ζ_1/ζ_2 is about 3, which together with conditions (6) and (5) fixes the values of ζ_1, ζ_2, A and B once ζ is given. From current data we estimate that ζ is in the range 0.20 to 0.50 (Pagel, 1980); in the following three values of ζ will be explored. Let us denote by q^*_{ij} the matrix elements q_{ij} per stellar generation divided by the normalization constants of the initial mass function. By doing this, the matrix elements q^*_{ij} become independent of ζ. Table 1 summarizes the values of the numerator and denominator summations of eq. (1), indicated by p^*_i and f^* respectively, for two cases of mass loss from massive stars, and initial metallicity Z of the stellar models. The cases of mass loss are indicated by the parameter α of Chiosi's et al. (1978, 1980) notation. With the yield definition (eq. 1), the data of Table 1, and the normalization constants A and B (calculated for various ζ) we may derive the yields of helium and heavy elements. In the framework of the classical simple model of galactic evolution (Pagel, 1980), we may identify the yield ratio Y_{He}/Y_Z

Table 1 (Normalized q^*_{ij})

$\dot{M}$	$1 \leq m \leq 10$			$10 < m \leq 100$			Z
	p^*_{He}	p^*_Z	f^*	p^*_{He}	p^*_Z	f^*	
0	0.0406	0.0285	1.17	0.031	0.037	0.25	0.020
α=0.83	0.0406	0.0285	1.17	0.027	0.019	0.23	0.020
α=0.90	0.0406	0.0285	1.17	0.026	0.015	0.22	0.02
α=0.83	0.0406	0.0285	1.17	0.030	0.025	0.25	0.001
α=0.90	0.0406	0.0285	1.17	0.029	0.021	0.24	0.001

with the abundance ratio ΔY/ΔZ. Our numerical results show that ΔY/ΔZ increases with the mean rate of mass loss from massive stars, independently of ζ. In fact no matter of what ζ is used, ΔY/ΔZ rises from 1.1 to about 2 as the mass loss parameter α increases from 0. to 0.9. This result confirms the previous analysis of Chiosi and Caimmi (1979).
Comparing the yield of metals Y_Z for the Galaxy and SMC (Peimbert and Serrano, 1980a) we may write

$$\frac{Y_{ZS}}{Y_{ZG}} = \frac{B_S p^*_{ZS}}{1-A_S f^*_{AS} - B_S f^*_{BS}} \cdot \frac{1-A_G f^*_{AG} - B_G f^*_{BG}}{B_G p^*_{ZG}} \quad , \tag{8}$$

where S and G stand for SMC and Galaxy respectively. From relations (3) and (4) one obtains

$$\frac{A}{B} = \frac{\zeta_1}{\zeta_2}\,\frac{1-\mu_1}{1-\mu_2}\,\frac{[m_n^{1-\mu_2} - m_2^{1-\mu_2}]}{[m_2^{1-\mu_1} - m_1^{1-\mu_1}]} \quad . \tag{9}$$

This ratio is known for the Galaxy if μ_1, μ_2, m_2, m_n and ζ are given. If one assumes that the slopes μ_1 and μ_2 are the same in the Galaxy (solar vicinity) and SMC, the system of eqs. (8) and (9) can be solved and ζ_1 and ζ_2 for SMC calculated. From Peimbert's and Serrano's (1980a) relation, we estimate that $Y_{ZS}/Y_{ZG} \simeq 0.5$. Table 2 summarizes the results obtained for several combinations of ζ, and mass loss from massive stars. From these data we see that ζ in SMC is about half of the corresponding galactic value. Although this result is mainly due to the adoption of the Y_Z vs. Z relation of Peimbert and Serrano (1980a), mass loss by stellar wind from massive stars is needed to keep Y_Z close to the observational value. If the chemical properties of SMC may be thought of as indicative of those in early stages of the galaxy evolution, it reasonably follows that ζ increases with the mean metallicity, thus making the initial mass function vary with time.

Table 2

Galaxy			SMC			SMC		
			$\dot{M}$ (α=0.83)			$\dot{M}$ (α=0.90)		
ζ	ζ_1	ζ_2	ζ	ζ_1	ζ_2	ζ	ζ_1	ζ_2
0.24	0.18	0.06	0.10	0.07	0.03	0.12	0.09	0.03
0.35	0.26	0.09	0.16	0.12	0.04	0.19	0.14	0.05
0.50	0.37	0.13	0.25	0.19	0.06	0.31	0.23	0.08

CHEMICAL EVOLUTION OF THE SOLAR VICINITY, AND ΔY/ΔZ RATIO

The results of the above section have been used in the chemical evolution model of the galactic disk described by Chiosi and Matteucci (1980a). The main properties of that model consist in the combined effect of concentration of star formation in the highest density region of the galactic disk, and accumulation of primordial gas flowing in from outside at suitable rate. The competition between gas inflow and gas consump tion by star formation gives a non monotonic time dependence of the star formation rate, which starts low, rises to a maximum, and then decreases to the present day value. The time scale of disk formation was found to be in the range 3 to 4×10^9 ys.

The main results of model computations under the new yields and $\zeta(Z)$ relation, are reported in Table 3. All these models have been calculated with the same parameters as far as inflow and star formation rate is concerned, namely $\tau=3\times10^9$ ys, $\kappa=2$ and $\nu=2.7$ in the notation of Chiosi and Matteucci (1980a). The fraction ζ of the initial mass function above 1 $m_\odot$ is let increase with Z as indicated in Table 2, until it reaches the present day value that is reported in Table 3. As expected, both the metal yield Y_Z and abundance Z increase with ζ, the same holds for the Helium abundance. Moreover, Y_Z varies with the average rate of mass loss from massive stars. The ΔY/ΔZ ratio is always at least a factor of two larger than in standard computations, in good agreement with the observational estimates. This agreement might even be better if one takes into account that the observational metal enrichment Z is mostly derived from measurements of carbon and oxygen abundances in HII regions. Therefore, this experimental quantity should be compared with the theoretical ΔY/ΔCO abundance ratio (reported in Table 3) rather than with ΔY/ΔZ. The two cases of Table 3 indicated by $\zeta=0.35$, $\alpha=0.83$ and $\alpha=0.90$ probably encompass the observational situation, succesfully reproducing all major constraints on the chemical evolution of the solar vicinity.

Table 3 (Model Results)

ζ	$\dot{M}$	Z	He^+	ΔY/ΔZ	ΔY/ΔCO	σ_g	$\dot{\sigma}_*$	Y_Z
0.24	α=0.83	0.009	0.216	1.75	1.94	9.0	2.3	0.007
0.24	α=0.90	0.007	0.216	2.18	2.45	8.9	2.1	0.005
0.35	α=0.83	0.015	0.226	1.72	2.70	9.7	2.5	0.011
0.35	α=0.90	0.012	0.226	2.17	2.45	9.8	2.6	0.006
0.50	α=0.83	0.024	0.238	1.58	2.25	10.8	2.5	0.019
0.50	α=0.90	0.019	0.239	2.06	2.44	11.0	3.5	0.011

σ_g : surface mass density of gas in $M_\odot/pc^2$

$\dot{\sigma}_*$: rate of star formation in $M_\odot/pc^2/10^9$ ys

For all model the time scale of disk formation is 3 10^9 ys.

+ : initial He=0.200

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DISCUSSION

GOLDBERG: Can you say a little more about why you expect $\dot{M}$ to decrease with decreasing Z ?

CHIOSI: Very preliminary observational analyses of wind characteristics in OB stars of SMC indicate that the wind structure may be different in these stars compared with their galactic countepart (Hutchings 1980). From this work one may also infer that the rates of mass loss are lower than in galactic stars. A quantitative estimate is however still missing. In addition to this, if one supposes the wind to be driven by radiation pressure, as SMC is less metal rich than the galaxy one might perhaps infer that owing to the lower Z a lower abundance of absorbing ions is at disposal. The dependency of K in the force multiplier on the ion abundance was discussed by Castor et al. (1975). In the computations of stellar models with mass loss by radiation pressure we assumed the mass loss rate given by Castor et al. (1975), but we took into account the metallicity dependence. This results into a lower rate of mass loss per given initial mass (let me remind you that the star luminosity does not depend too much on Z). The relation between initial mass and mass of the core shown here is obtained from those numerical models. Finally it is worth pointing out that also adopting a relationship for the rate of mass loss like those which depend on luminosity, radius and mass and assuming that the proportionality constant is the same , a lower mass loss rate would result due to the fact that low metal stars have smaller radii.

HENRICHS: In your calculations of the Helium-core mass as a function of initial mass depending on Z you calculated this relation over a wide range of Z while keeping the value of α constant (α being the force multiplier exponent in Castor et al.'s theory). Don't you expect that α will depend on Z over such a large range? And are your final results sensitive to your assumption of a constant value of α = 0.9?

MATTEUCCI: In Castor et al's. formulation there is no explicit dependence of α on Z.