Revista Mexicana de Astronomía y Astrofísica, **44**, 341–354 (2008)

THE HELIUM AND HEAVY ELEMENTS ENRICHMENT OF THE GALACTIC DISK

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Received 2008 June 23; accepted 2008 July 18

RESUMEN

Presentamos modelos de evolución química para el disco de nuestra galaxia. También presentamos una nueva determinación de X, Y, y Z para M17, una región H II de nuestra galaxia rica en elementos pesados. Comparamos nuestros modelos del disco galáctico con las abundancias de las regiones H II. El valor predicho por nuestro modelo para $\Delta Y/\Delta O$ es muy similar al valor que obtenemos por medio de las observaciones de M17 y la abundancia primordial de helio, Y_p. A partir de M17 y Y_p obtenemos que $\Delta Y/\Delta Z = 1.97 \pm 0.41$, resultado que concuerda con dos determinaciones de $\Delta Y/\Delta Z$, obtenidas a partir de observaciones de estrellas enanas K de la vecindad solar, que corresponden a 2.1 ± 0.4 y 2.1 ± 0.9 respectivamente. Nuestros modelos ajustan razonablemente bien el valor de O/H con el que se formó el Sol.

ABSTRACT

We present chemical evolution models for the Galactic disk. We also present a new determination of X, Y, and Z for M17 a Galactic metal-rich H II region. We compare our models for the Galactic disk with the Galactic H II regions abundances. The $\Delta Y/\Delta O$ ratio predicted from the Galactic chemical evolution model is in very good agreement with the $\Delta Y/\Delta O$ value derived from M17 and the primordial helium abundance, Y_p, taking into account the presence of temperature variations in this H II region. From the M17 observations we obtain that $\Delta Y/\Delta Z = 1.97 \pm 0.41$, in excellent agreement with two $\Delta Y/\Delta Z$ determinations derived from K dwarf stars of the solar vicinity that amount to 2.1 ± 0.4 and 2.1 ± 0.9 respectively. We also compare our models with the solar abundances. The solar and Orion nebula O/H values are in good agreement with our chemical evolution model.

Key Words: galaxies: abundances — galaxies: evolution — H II regions — ISM: abundances — ISM: individual (M17, Orion nebula) — Sun: abundances

1. INTRODUCTION

The main purpose of this work is to study the evolution of the helium abundance with respect to the heavy elements as a function of time and position in the Galactic disk. For this purpose we will use the Galactic chemical evolution model by Carigi et al. (2005) that has been successful in explaining: the observed O/H and C/H abundance gradients in the interstellar medium, ISM, the present gaseous distribution in the Galactic disk, the current star formation rate, the stellar mass as a function of the Galactic radius, and most of chemical properties of the solar vicinity.

To have useful observational constraints we need accurate X, Y, and Z determinations or at least $\Delta Y/\Delta Z$ determinations to compare the models with observations. In this paper we recompute the X, Y, and Z values for the H II region M17, the best Galactic H II region for which it is possible to compute an accurate enough Y value. For this purpose, we make use of the best observations available and the new He I atomic data needed for the helium abundance determination. We also compare the chemical evolution model with the $\Delta Y/\Delta Z$ determination derived from K dwarf stars of the solar vicinity with metal-

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licities similar or higher than solar by Jiménez et al. (2003) and Casagrande et al. (2007).

We also compare our model with the initial solar O/H value and with the Orion O/H value. The initial solar O/H value is representative of the ISM, 4.5 Gyr ago when the Sun was formed, and the Orion nebula O/H value is representative of the present day ISM.

The model together with the primordial helium determination is also used to provide an equation between the Y enrichment and the O enrichment of the ISM. This equation can be used to provide the initial Y values for those stars for which we can derive their initial oxygen abundances. These initial Y values provide meaningful initial abundances for a set of stellar evolutionary models with different heavy element content.

We adopt the usual notation X, Y, and Z to represent the hydrogen, helium and heavy elements abundances by mass, respectively. Based on our models we study the increase of helium, ΔY, as a function of the increase of C, O, Fe, and Z by mass.

In § 2 we discuss the general properties of the chemical evolution models, we discuss inflow models for the Galaxy with two sets of stellar yields and present the chemical abundances for the disk at 5 galactocentric distances. For the two models discussed we present the increase of helium by mass ΔY, relative to the increase of carbon, oxygen, iron and heavy elements by mass, ΔC, ΔO, ΔFe, and ΔZ. We also discuss the evolution of the Y and O abundances for our models, and present an equation that predicts for the Galaxy the Y enrichment as a function of the O enrichment of the ISM. In § 3 we present a new determination of the helium abundance for the metal rich H II region M17; this abundance is compared with our Galactic chemical evolution models.

In § 4 we compare abundances for the Orion nebula with those of B stars of the Orion association. In § 5 we discuss the absolute calibration of the O/H ratio in the local ISM. This ratio is one of the most important observational constraints for Galactic chemical evolution models. The absolute calibration of the O/H ratio is obtained based on the Orion nebula and the solar abundances. In § 6 we compare the solar initial helium abundance, inferred from the standard solar models by Bahcall et al. (2006), with our Galactic chemical evolution models considering the time since the Sun was formed and the presence of gravitational settling and diffusion. The conclusions are presented in § 7.

Throughout this paper we will use the primordial helium abundance by mass, Y_p, derived by Peimbert, Luridiana, & Peimbert (2007) based on direct helium abundance determinations of metal poor extragalactic H II, regions that amounts to 0.2477 ± 0.0029. This result is in excellent agreement with the Y_p determination by Dunkley et al. (2008), that amounts to 0.2484 ± 0.0003. This determination is based on the $\Omega_b h^2$ value derived from WMAP observations, the assumption of standard big-bang nucleosynthesis, and the neutron lifetime, τ_n, of 885.7 ± 0.8 s obtained by Arzumanov et al. (2000). Following Mathews, Kajino, & Shima (2005) the value of Y_p derived from WMAP is revised downwards to 0.2468 ± 0.0003 by adopting the $\tau_n = 878.5 \pm 0.8$ s derived by Serebrov et al. (2005), and to 0.2475 ± 0.0006 by adopting for τ_n the new world average that amounts to 881.9 ± 1.6 s, average that includes the results by Arzumanov et al. (2000) and Serebrov et al. (2005).

2. CHEMICAL EVOLUTION MODELS

2.1. *Model Parameters*

We present chemical evolution models for the Galactic disk using the CHEMO code (Carigi 1994) that considers the lifetime of each star until it leaves the main sequence. The models have been built to reproduce the present gas mass distribution and the present-day O/H values for each galactocentric distance. The values were obtained from observations of H II regions in the Galaxy (Esteban et al. 2005). Specifically, the characteristics of the models are:

(i) An inside-outside scenario with primordial infalls but without any type of outflows. The infall rate as a function of time and galactocentric distance r is given by $INFALL(r,t) = A(r)e^{-t/\tau_{\rm halo}} + B(r)e^{-(t-1{\rm Gyr})/\tau_{\rm disk}}$, where the formation timescales are $\tau_{\rm halo} = 0.5$ Gyr and $\tau_{\rm disk} = 6 + (r/r_\odot - 1)8$ Gyr. We assume the location of the solar vicinity is $r_\odot = 8$ kpc. The constants $A(r)$ and $B(r)$ are chosen to match, first, the present-day mass density of the halo and disk components in the solar vicinity, 10 and 40 $M_\odot$ pc^{-2}, respectively, and second, to reproduce the radial profile total mass in the Galaxy, $M_{\rm tot}(r) = 50e^{-(r-8)/3.5}$ (Fenner & Gibson 2003).

(ii) 13 Gyr as the age of the models, the time elapsed since the beginning of the formation of the Galaxy.

(iii) The Initial Mass Function (IMF) proposed by Kroupa, Tout, & Gilmore (1993), in the mass interval given by $0.01 < m/M_\odot < M_{\rm up}$, with $M_{\rm up} = 80$ and 60 $M_\odot$. This IMF is a three power-law approximation, given by IMF $\propto m^{-\alpha}$ with $\alpha = -1.3$

for 0.01–0.5 $M_\odot$, $\alpha = -2.2$ for 0.5–1.0 $M_\odot$, and $\alpha = -2.7$ for 0.5-$M_{\rm up}$.

Note that our models were computed assuming an IMF with $M_{\rm low} = 0.01\ M_\odot$. Kroupa et al. (1993) truncated their IMF at 0.08 $M_\odot$ because they considered only stars, but in our work we are assuming a non negligible amount of substellar objects ($0.01 < m/M_\odot < 0.08$). In models with $M_{\rm up} = 60\ M_\odot$, the mass of objects with $m < 0.08\ M_\odot$ is $\approx 12\%$ of the total $M_{\rm stars}$, that includes stars and remnants; this percentage is practically independent of $M_{\rm up}$. Even at present, the fraction of mass in substellar objects is unknown and we consider that our predicted percentage might be realistic.

Due to the uncertainties in the current $M_{\rm gas}(r)$, $M_{\rm stars}(r)$, and SFR(r) values we cannot discriminate between chemical evolution models assuming $M_{\rm low} = 0.01\ M_\odot$ and $M_{\rm low} = 0.08\ M_\odot$. The first ones predict smaller fractions of massive stars and LIMS per single stellar generation. Therefore $M_{\rm low} = 0.01\ M_\odot$ models with Galaxy formation scenario, Galactic age, and stellar yields identical to those of $M_{\rm low} = 0.08\ M_\odot$ models require a higher SFR to match the present-day O/H(r) values. The $M_{\rm low} = 0.01\ M_\odot$ model with a more efficient SFR predicts a lower $M_{\rm gas}$ and similar chemical abundances. Such a model, with higher SFR and lower $M_{\rm gas}$, is also able to reproduce the observational constraints (Carigi 1996).

(iv) A star formation rate that depends on time and galactocentric distance, varying from almost constant and low (at large r values) to bursting and high (at short r values). This SFR has been represented by the following relation $SFR(r,t) = \nu M_{\rm gas}^{1.4}(r,t)\ (M_{\rm gas} + M_{\rm stars})^{0.4}(r,t)$, in order to reproduce the current O/H gradient and the gas mass distribution of the Galactic disk (Carigi 1996), where ν is a constant in time and space that is chosen in order to reproduce the present-day radial distribution of the gas surface mass density. A ν value of 0.016 is required when the high-wind yields and $M_{\rm up} = 80\ M_\odot$ are adopted, the best model of Carigi et al. (2005), while ν values of 0.015 and 0.010 are required when the low-wind yields with $M_{\rm up} = 60$ and $M_{up} = 80\ M_\odot$ are adopted, respectively.

(v) Two sets of stellar yields. Since the main difference between these sets is the assumed mass-loss rate due to stellar winds by massive stars with $Z = 0.02$, we will call them high-wind yields (HWY) and low-wind yields (LWY), see Figure 1.

The HWY set is the one considered in the best model (model 1) of Carigi et al. (2005). The HWY set includes: (A) For massive stars (MS), those with

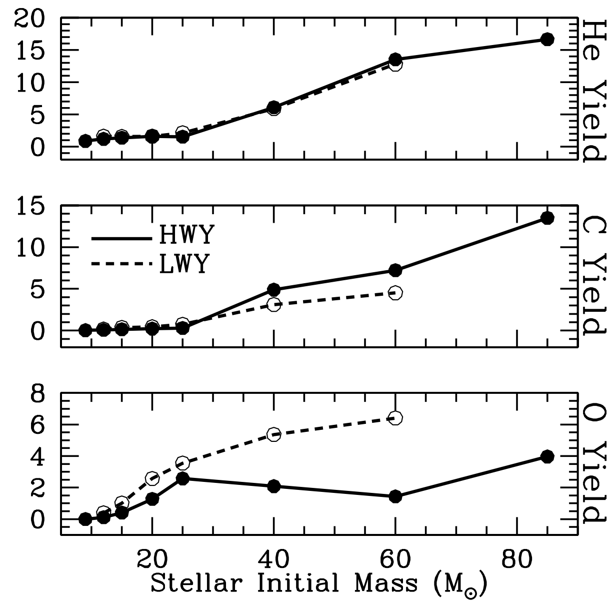

Fig. 1. Newly formed mass of a given element by massive stars, in $M_\odot$, ejected to the ISM. The initial heavy elements of the stars amount to $Z = 0.02$. Continuous lines: high wind yields by Maeder (1992), dashed lines: low wind yields by Hirschi et al. (2005).

$8 < m/M_\odot < 80$, the following yields by: (a) Chieffi & Limongi (2002) for $Z = 0.00$; (b) Meynet & Maeder (2002) for $Z = 10^{-5}$ and $Z = 0.004$; (c) Maeder (1992) for $Z = 0.02$ (high mass-loss rate yields presented in his Table 6); (d) Woosley & Weaver (1995) only for the Fe yields (Models B, for 12 to 30 $M_\odot$; Models C, for 35 to 40 $M_\odot$; while for $m > 40\ M_\odot$, we extrapolated the $m = 40\ M_\odot$ Fe yields). (B) For low and intermediate mass stars (LIMS), those with $0.8 \le m/M_\odot \le 8$, we have used the yields by Marigo, Bressan, & Chiosi (1996, 1998) and Portinari, Chiosi, & Bressan (1998) from $Z = 0.004$ to $Z = 0.02$. (C) For Type Ia SNe we have used the yields by Thielemann, Nomoto, & Hashimoto (1993). We have assumed also that 5% of the stars with initial masses between 3 and 16 $M_\odot$ are binary systems which explode as SNIa.

In the LWY set we have updated the yields of massive stars only for $Z \sim 0$ and $Z = 0.02$ assuming the yields by Hirschi (2007) and Hirschi, Meynet, & Maeder (2005) respectively. The rest of the stellar yields are those included in the high wind set.

The main differences between the LWY set and the HWY set are due to the contribution of massive stars at $Z = 0.02$. Therefore in Figure 1 we compare the He, C, and O yields for $Z = 0.02$. The main difference between the HWY and the LWY models

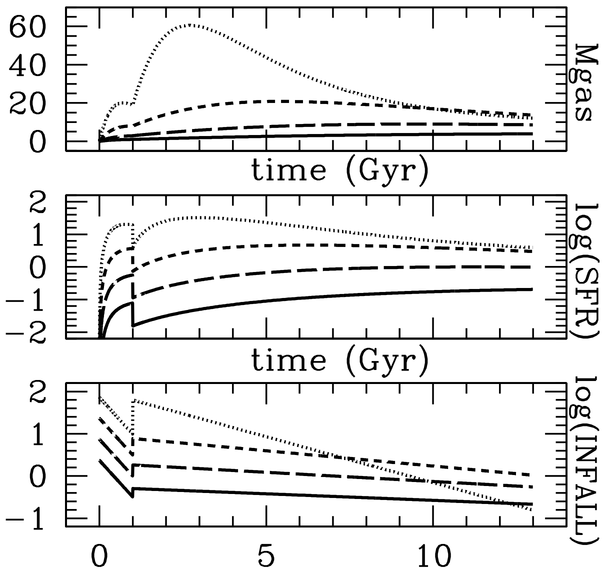

Fig. 2. Evolution of some common properties for all models of the Galactic disk: gas mass surface density ($M_\odot$ pc^{-2}), star formation rate and infall rates ($M_\odot$ pc^{-2} Gyr^{-1}), at four galactocentric distances, 16, 12, 8, and 4 kpc (continuous, long-dashed, short-dashed, and dotted lines, respectively).

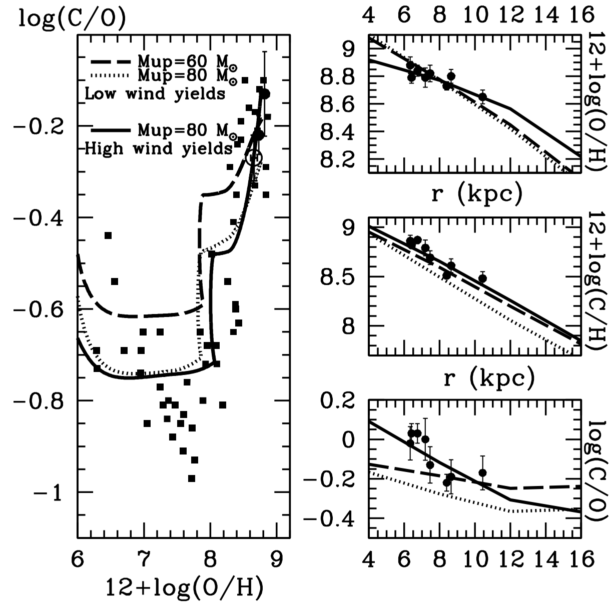

Fig. 3. Chemical evolution models for the Galactic disk and the solar vicinity (r = 8 kpc). The left panel shows the C/O evolution in the ISM of the solar vicinity with O/H. The right panels show the present-day ISM abundance ratios as a function of galactocentric distance. Continuous lines: high wind yields with $M_{\rm up}$ = 80 $M_\odot$ by Carigi et al. (2005), dashed and dotted lines: low wind yields with $M_{\rm up}$ = 60 and 80 $M_\odot$, respectively (this paper). *Filled circles*: H II regions, gas plus dust values; the gaseous values from Esteban et al. (2005) have been corrected for the dust fraction. *Filled squares*: Dwarf stars from Akerman et al. (2004). *Open circle*: Solar value from Asplund, Grevesse, & Sauval (2005).

is due to the stellar yields assumed for massive stars at high Z. The HWY assume a relatively high mass-loss rate for massive stars with $Z = 0.02$ (yields by Maeder 1992), while the LWY assume a relatively low mass-loss rate for massive stars with $Z = 0.02$ (yields by Hirschi et al. 2005). These difference between a high and a low mass-loss rate produces opposite differences in the C and O yields (see Figure 1), the reasons are the following: (a) a high mass-loss rate produces a high loss of C and consequently a high C yield, and (b) since C is needed to produce O, the high loss of C reduces the O yield.

Since the solar vicinity and the Galactic disk contain stars and H II regions of a broad range of metallicities, our Galaxy is a proper laboratory to study the $\Delta Y/\Delta X_i$ behavior at high Z values and to try to observationally test the predictions of the HWY models and the LWY models.

2.2. *Results*

The models presented in this paper reproduce the present stellar and gas mass distributions in the Galactic disk, the current star formation rate as a function of the Galactic radius, the O/H gradient evolution inferred from PNe, the SN rates, the distribution of G-dwarf stars as a function of [Fe/H], the infall rate, and the evolution of [X$_i$/Fe] vs [Fe/H]. See Allen, Carigi, & Peimbert (1998), Carigi (1994), Carigi (1996), Carigi (2000).

In Figure 2 we present some of those model properties, like gas mass surface density, star formation rate, and infall rate for four galactocentric distances: 16, 12, 8, and 4 kpc. Infall rate follows the inside-outside scenario, the inner parts of the Galaxy are formed faster than the outer parts. Since gas mass comes from infall, mainly, $M_{\rm gas}$ reflects the inside-outside scenario and the SFR shows similar behavior as the gas mass, due to the SFR being proportional to the gas mass.

In Figure 3 we show O and C gradients in the Galactic disk and the evolution of the C/O-O/H relation in the solar vicinity predicted by three models that combine different yields and IMF $M_{\rm up}$ values. Models that assume LWY fail to reproduce the C/O gradient and the C/O values for halo stars or disk stars. The LWY model with $M_{\rm up}$ = 60 $M_\odot$ reproduces poorly the C/O gradient and the C/O values in disk stars, and predicts C/O values for halo stars higher than observed. The LWY model with $M_{\rm up} = 80\ M_\odot$ does not reproduce at all the C/O gradient, matches partially the C/O values of disk stars, and explains the observed C/O values for halo stars. The HWY model with $M_{\rm up} = 80\ M_\odot$ reproduces successfully the C/O Galactic gradient and the C/O values in the solar vicinity.

Based on Figure 3 we conclude that the LWY model with $M_{\rm up} = 60\ M_\odot$ reproduces the main behavior of C/O vs O/H in the solar vicinity but cannot reproduce the C/O Galactic gradient. On the other hand, the HWY model reproduces very well the C/O vs O/H relation in the solar vicinity and the C/O Galactic gradient. Since the LWY model with $M_{\rm up} = 80\ M_\odot$ produces the poorest fit to the C/O and C/H observed values it will not be considered further.

Gibson et al. (2006) considering the O yields by Arnett (1991), that are lower than those by Maeder (1992) for MS with $m < 30\ M_\odot$, reproduce the [O/Mg] values present in the Galactic Bulge. With the same yields Gibson (1997) explains the [O/Fe] values in the intracluster medium and predicts a small increase in the C/O evolution at late times for a massive elliptical Galaxy. By adopting the Arnett (1991) yields in our model we may obtain flatter C/O gradients and might not be able to reach the C/O values observed in the H II regions and dwarf stars of the solar vicinity. The yields by Arnett (1991) do not consider stellar winds. Chiappini, Matteucci, & Ballero (2005) using LWY studied the C and O evolution in the solar vicinity and the Galactic disk; they reproduce also the C/O vs O/H behavior in the solar vicinity, but they predict flatter C/O gradients than the observed ones and they cannot match the high C/O values shown by the metal rich stars in the solar neighborhood.

Recently, McWilliam et al. (2007) suggested that the strong metallicity-dependent yields for massive stars by Maeder (1992) can explain the O/Mg vs O-Mg/H and the O/Fe vs Fe/H relations in the Galactic bulge and in the solar vicinity, in agreement with our results that favor the HWY model over the LWY model. The HWY model includes low O yields at high Z and therefore explains: (a) the small O increase in the solar vicinity from the time the Sun was formed until the present, and (b) the flattening of the O gradient in the direction of the Galactic center. Massive stars with high Z values have strong winds, lose a considerable amount of C and produce high C yields. With this C lost, the stars keep a small amount of C needed to produce O and consequently their O yields are low. Therefore the C yields for massive stars are important at high metallicities, while their O yields are more important at low metallicities, as has been shown previously by Akerman et al. (2004) and Carigi et al. (2005). By adding our previous results (Akerman et al. 2004; Carigi et al. 2005) to those of McWilliam et al. (2007) and of this paper we insist that the stellar winds with a high mass loss rate are essential to reproduce the high C/O values observed in the disk stars of the solar vicinity.

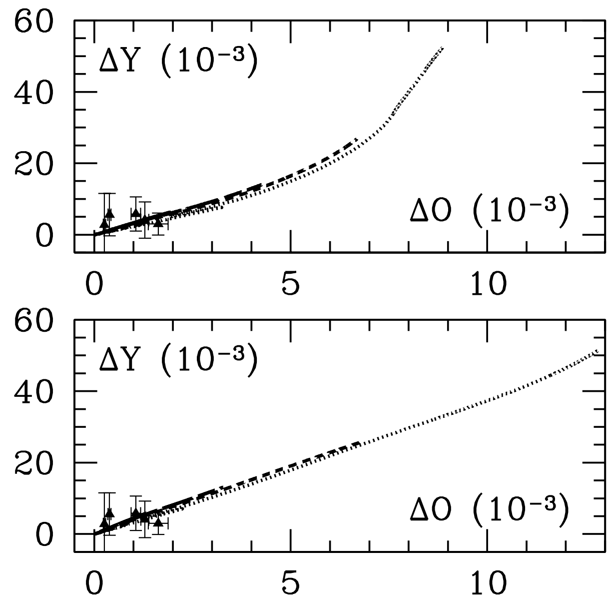

Fig. 4. Evolution of Helium vs Oxygen for the Galactic disk at four galactocentric distances, 16, 12, 8, and 4 kpc (continuous, long-dashed, short-dashed, and dotted lines, respectively). Upper panel: The chemical evolution model assumes $M_{\rm up} = 80\ M_\odot$ and high wind yields. Lower panel: The chemical evolution model assumes $M_{\rm up} = 60\ M_\odot$ and low wind yields. See Table 1. Low metallicity H II regions from Peimbert et al. (2007) (*filled triangles*) and adopting $Y_p = 0.2477$.

In the upper panel of Figure 4 we present the evolution of the model that assumes HWY and $M_{\rm up} = 80\ M_\odot$ at different Galactocentric radii (4, 8, 12, and 16 kpc) that correspond to different final metallicities ($Z = 0.028$, 0.016, 0.009, and 0.004, respectively). The $\Delta Y/\Delta$O increase at O $> 4 \times 10^{-3}$ present in Figure 4 is due to the lower O yields for massive stars with $Z = 0.02$. In the upper half of Table 1 we show the present-day O values and the $\Delta Y/\Delta X_i$ values for each galactocentric radius. We note that $\Delta Y/\Delta Z$ increases slightly with Z for large r values or low O values, while $\Delta Y/\Delta Z$ increases significantly with Z for short r values or high O values.

TABLE 1

PRESENT DAY VALUES FROM THE GALACTIC DISK MODELS

Galactocentric distance	$O(t_{\rm final})(10^{-3})$	$\Delta Y/\Delta C$	$\Delta Y/\Delta$O	$\Delta Y/\Delta$Fe	$\Delta Y/\Delta Z$
High wind yields and $M_{\rm up} = 80\ M_\odot$					
4	8.89	6.38	5.91	14.11	1.85
8	6.68	7.01	4.01	18.36	1.67
12	4.26	8.89	3.29	21.60	1.62
16	1.95	10.05	3.23	25.28	1.65
Low wind yields and $M_{\rm up} = 60\ M_\odot$					
4	12.81	7.13	4.06	14.13	1.67
8	6.78	7.73	3.79	18.36	1.67
12	3.28	9.44	3.99	21.52	1.78
16	1.34	10.18	4.39	26.11	1.90

In the lower panel of Figure 4 we show the results for the model with LWY and $M_{\rm up} = 60\ M_\odot$. This model does not predict an increasing $\Delta Y/\Delta$O value with increasing O for high O values. In the lower half of Table 1 we show the present-day O values and the $\Delta Y/\Delta X_i$ values for each galactocentric radius. With the LWY model we find higher final O values for lower r values because the O yields are higher than than those of the HWY model at high Z. Even if the HWY and LWY yields are identical for low Z, we get lower final O values for higher r values for the LWY model because it does not include stars with $m > 60\ M_\odot$. The increase or decrease of O is reflected on the $\Delta Y/\Delta$O and $\Delta Y/\Delta Z$ values because the final Y values are nearly independent of the models.

The helium to oxygen mass ratio, $\Delta Y/\Delta$O, is an important constraint in the study of the chemical evolution of galaxies. We have studied the variation of $\Delta Y/\Delta$O as O increases in the HWY and LWY evolution models (see Figure 4). For the HWY model, the model that fits the C/O gradient, we have found the following relations between Y and O:

$$Y = Y_p + \Delta Y = Y_p + (3.3 \pm 0.7)\ \mathrm{O}, \qquad (1)$$

for $\mathrm{O} < 4.3 \times 10^{-3}$, and

$$Y = Y_p + (3.3 \pm 0.7)\ \mathrm{O} + (0.016 \pm 0.003)\ (\mathrm{O}/4.3 \times 10^{-3} - 1)^2, \qquad (2)$$

for $4.3 \times 10^{-3} < \mathrm{O} < 9 \times 10^{-3}$.

For the LWY model with $M_{\rm up} = 60\ M_\odot$ we have found the following relation between Y and O:

$$Y = Y_p + (4.0 \pm 0.7)\ \mathrm{O}, \qquad (3)$$

for $0 < \mathrm{O} < 11 \times 10^{-3}$.

Jiménez et al. (2003) from a set of isochrones and observations of nearby K dwarf stars found that $\Delta Y/\Delta Z = 2.1 \pm 0.4$. Casagrande et al. (2007) found also that $\Delta Y/\Delta Z = 2.1 \pm 0.9$ from the newly computed set of Padova isochrones and observations of nearby K dwarf stars. These observational results are in very good agreement with the models presented in Table 1.

Assuming yields with a low mass-loss rate due to stellar winds (similar to that considered by Hirschi 2007), and yields without mass loss due to stellar winds by Woosley & Weaver (1995), Chiappini, Matteucci, & Meynet (2003) find for the solar vicinity $\Delta Y/\Delta Z \sim 2.4$ and 1.5, respectively.

Since stellar winds change significantly the C and O yields, but not the Y yields, we are interested to quantify the evolution of the Y contribution due to massive stars and due to low and intermediate mass stars at different metallicities. For that reason we show in Figure 5 the cumulative percentage of Y for four galactocentric distances due to MS and LIMS obtained from the HWY model, our successful model for the Galactic disk.

The fraction of helium in the ISM due to MS and and to LIMS depends strongly on time, but not on galactocentric radius or Z. At present about half of the ΔY in the ISM has been produced by MS and half by LIMS.

The strong dependency on time of the ΔY contribution is due to the lifetime of the stars. The ΔY contribution of LIMS decreases less than 5% from 4 to 16 kpc due mainly to the star formation history. In the inside-outside scenario the SFR at 4 kpc is more intense and it is also higher at earlier times than at larger distances (see the middle panel in Fig-

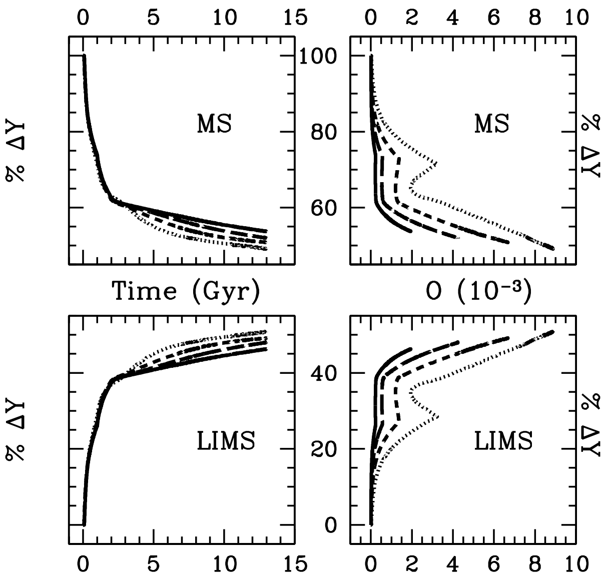

Fig. 5. Cumulative percentage of He as a function of time and oxygen in the ISM, produced and ejected by massive stars (MS) and low and intermediate mass stars (LIMS) at four galactocentric distances on the Galactic disk (lines as Figure 2). The model assumes $M_{\rm up} = 80\ M_\odot$ and high mass loss due to stellar winds, the HWY model.

ure 2); therefore the big number of LIMS formed in the first Gyrs at 4 kpc enrich the gas at later times. This fact produces the O dilution that can be seen in the right hand side panels of Figure 5, just after the model at 4 kpc reaches the value of $\mathrm{O} = 3\times10^{-3}$ for the first time.

3. THE HELIUM AND OXYGEN ABUNDANCES OF M17, A HIGH METALLICITY GALACTIC H II REGION

We will compare the predictions of the HWY and the LWY models with observations of Y and O in the Galactic disk. At present the best H II region in the Galaxy to derive the Y and O abundances is M17. The reason is that the correction for the presence of neutral helium in the abundance determination is smallest for M17 compared to other well observed Galactic H II regions. This is due to the high ionization degree of M17 (Peimbert, Torres-Peimbert, & Ruiz 1992; Esteban et al. 1999; García-Rojas et al. 2007). Due to the large amount of neutral helium present in the other well observed Galactic H II regions, the error in the Y determination is at least two times larger than the error for M17; therefore the Y determinations for the other Galactic H II regions will not be considered in this paper.

To determine very accurate He/H values of a given H II region we need to consider its ionization structure. For objects of low degree of ionization it is necessary to consider the presence of He^0 inside the H^+ zone, while for objects of high degree of ionization it is necessary to consider the possible presence of a He^{++} zone inside the H^+ zone. Peimbert et al. (1992), hereafter PTR, found for M17 an upper limit of $N(\mathrm{He}^{++})/N(\mathrm{H}^+)$ of 8×10^{-5} a negligible amount; alternatively they found differences with position of the $N(\mathrm{He}^+)/N(\mathrm{H}^+)$ ratio correlated with the sulphur ionization structure, a result that implies that M17 is ionization bounded and the presence of a small but non negligible amount of He^0 inside the H^+ zone. Therefore for this object the helium abundance is given by

$$\frac{N(\mathrm{He})}{N(\mathrm{H})} = \frac{N(\mathrm{He}^0) + N(\mathrm{He}^+)}{N(\mathrm{H}^+)}. \tag{4}$$

To minimize the effect of the correction for neutral helium we took into account only regions M17-1, M17-2, and M17-3 (from now on M17-123), which show the highest degree of ionization of the observed regions by PTR, Esteban et al. (1999), and García-Rojas et al. (2007), as well as the highest accuracy in the line intensity determinations by PTR. Following PTR we will assume that He is neutral in the regions where S is once ionized, that is

$$\frac{N(\mathrm{He}^0)}{N(\mathrm{He})} = \frac{N(\mathrm{S}^+)}{N(\mathrm{S})}, \tag{5}$$

therefore

$$\begin{aligned}\frac{N(\mathrm{He})}{N(\mathrm{H})} &= \mathrm{ICF(He)} \times \frac{N(\mathrm{He}^+)}{N(\mathrm{H}^+)} \\ &= \left[1 + \frac{N(\mathrm{S}^+)}{N(\mathrm{S}) - N(\mathrm{S}^+)}\right] \times \frac{N(\mathrm{He}^+)}{N(\mathrm{H}^+)}. \end{aligned} \tag{6}$$

To estimate the ICF(He) value we recomputed the $N(\mathrm{S}^+)/N(\mathrm{S})$ ratios derived by PTR taking into account that the [S II] $\lambda\lambda$ 4069 + 4076 lines are blended with the O II $\lambda\lambda$ 4069 and 4076 lines. The correction diminishes the [S II] electron temperatures from about 12 000 K to about 7700 K (García-Rojas et al. 2007), the lower temperatures increase the N $(\mathrm{S}^+)/N(\mathrm{S})$ ratios, and the average ICF(He) for M17-123 amounts to 1.035.

To obtain the $N(\mathrm{He}^+)/N(\mathrm{H}^+)$ value for M17-123 we decided to recompute the determinations by PTR based on their line intensities and the new helium recombination coefficients by Porter et al. (2005), with the interpolation formula provided by Porter,

TABLE 2

HE I LINE INTENSITIES RELATIVE TO Hβ FOR M17-123

He I Line	I
3889	0.1738 ± 0.0086
4026	0.0240 ± 0.0012
4471	0.0508 ± 0.0013
4922	0.0127 ± 0.0010
5876	0.1549 ± 0.0038
6678	0.0395 ± 0.0010
7065	0.0499 ± 0.0025
7281	0.0064 ± 0.0007

Ferland, & MacAdam (2007). In addition we used the hydrogen recombination coefficients by Storey & Hummer (1995), and the collisional contribution to the He I lines by Sawey & Berrington (1993) and Kingdon & Ferland (1995). The optical depth effects in the triplet lines were estimated from the computations by Benjamin, Skillman, & Smits (2002). At the temperatures present in M17 the collisional excitation of the hydrogen lines is negligible and was not taken into account.

To determine the $N(\mathrm{He}^+)/N(\mathrm{H}^+)$ value we took into account the following He I lines $\lambda\lambda$ 3889, 4026, 4471, 4922, 5876, 6678, and 7065. We corrected the 4922 line intensity by considering that it was blended with the [Fe III] 4924 line and that the contribution of the Fe line amounted to 5% of the total line intensity (Esteban et al. 1999; García-Rojas et al. 2007). The M17-123 line intensities adopted are presented in Table 2.

We did not correct the H and He line intensities for underlying absorption; the reasons are the following: (a) the average observed equivalent width in emission of H(β), $EW_{\rm em}$(Hβ), amounts to 668 Å; (b) the predicted $EW_{\rm em}$(Hβ) for $T_e = 7000$ K amounts to about 2000 Å (Aller 1984); therefore about 1/3 of the continuum is due to the nebular contribution and 2/3 to the dust scattered light from OB stars, and consequently the underlying stellar absorption only affects two thirds of the observed continuum; (c) considering the nebular contribution to the observations and based on the models by González Delgado et al. (1999, 2005) for a model with an age of 2 Myr, as well as the observations by Leone & Lanzafame (1998) for λ 7065, (since λ 7065 was not included in the models by González Delgado et al. 1999, 2005), we estimated that the $EW_{\rm ab}$ of the $\lambda\lambda$ 3889, 4026, 4471, 4922, 5876, 6678, and 7065 lines amount to 0.4, 0.4, 0.4, 0.1, 0.1, 0.2 Å respectively, an almost negligible amount considering the large $EW_{\rm em}$ observed values (see Table 4 in Peimbert et al. 1992); (d) the weighted increase in the helium line intensities amounts to about 0.7%, again an almost negligible amount; (e) the Balmer lines also show underlying absorption and the average correction to the line intensities amounts to about 0.5%, again a negligible amount that cancels to a first approximation the underlying correction effect on the He/H line ratios.

To determine the helium physical conditions of the nebula simultaneously with the $N(\mathrm{He}^+)/N(\mathrm{H}^+)$ value we used the maximum likelihood implementation presented by Peimbert, Peimbert, & Luridiana (2002). This implementation requires as inputs: (a) the oxygen temperatures, T[O III] and T[O II], and the oxygen ionization degree that provide us with the following restriction

$$T[\mathrm{O\ II} + \mathrm{O\ III}] = \frac{N(\mathrm{O}^+)T[\mathrm{O\ II}] + N(\mathrm{O}^{++})T[\mathrm{O\ III}]}{N(\mathrm{O}^+) + N(\mathrm{O}^{++})}, \tag{7}$$

and (b) a large set of helium to hydrogen line intensity ratios. In addition an estimate of the electron density, n, in the region where the He lines originate is not required but it is useful. This implementation can determine the conditions of the H II regions either with the restriction of uniform temperature, or relaxing this restriction.

From PTR we adopted T[O III] $= 8200 \pm 200$ K. From the I(3727/7325) ratios for M17-123 by PTR and for M17-3 by Esteban et al. (1999), after correcting the λ 7325 Å lines for the recombination contribution (Liu et al. 2000), we obtained 8100 ± 1300 K and 9900 ± 1300 K respectively. Therefore we adopted for T[O II] a value of 9000 ± 1000 K. From the T[O III] and T[O II] values and the observations by PTR we find that $N(\mathrm{O}^+)/N(\mathrm{H}^+) = 0.12$ and $N(\mathrm{O}^{++})/N(\mathrm{H}^+) = 0.88$. Finally from the previous results and equation (7) we obtained that T[O II + O III] $= 8300 \pm 200$ K.

To estimate the electron density we used three determinations: the n[S II] for M17-123 by PTR that amounts to 720 ± 250 cm^{-3}, the n[O II] for M17-3 by Esteban et al. (1999) that amounts to 790 ± 250 cm^{-3}, and the n[Cl III] for M17-123 that we estimated from the observed $I(5518)/I(5538)$ ratios by PTR and the atomic physics parameters by Keenan et al. (2000) that amounts to 650 ± 450 cm^{-3}. From the average of these three determinations we adopted a value of $n = 740 \pm 250$ cm^{-3} for M17-123.

By using as inputs for the maximum likelihood method T[O II+O III] $= 8300 \pm 200$ K, $n = 740 \pm$

TABLE 3

PHYSICAL CONDITIONS AND CHEMICAL ABUNDANCES IN M17

Parameter	$t^2 = 0.000$	$t^2 = 0.036 \pm 0.013$
T[O II + O III]	8300±200	8300±200
n	691±246	744±247
τ_{3889}	9.5±0.8	11.0±0.9
$N(\mathrm{He}^+)/N(\mathrm{H}^+)$	0.1014±0.0014	0.0982±0.0019
ICF(He)	1.035±0.010	1.035±0.010
N(He)/N(H)	0.1049±0.0017	0.1016±0.0022
Y	0.2926±0.0034	0.2837±0.0044
ΔY	0.0403±0.0044[a]	0.0360±0.0053[b]
O	0.00446±0.00045	0.00811±0.00081
$\Delta Y/\Delta O$	9.04±1.35[a]	4.44±0.79[b]
Z	0.0101±0.0015	0.0183±0.0027
$\Delta Y/\Delta Z$	4.00±0.75[a]	1.97±0.41[b]

[a]We adopted $Y_p = 0.2523 \pm 0.0027$ for $t^2 = 0.000$ from Peimbert et al. (2007).

[b]We adopted $Y_p = 0.2477 \pm 0.0029$ for $t^2 \neq 0.000$ from Peimbert et al. (2007).

250 cm^{-3}, and the helium line intensities presented in Table 2 we obtain for M17-123 the n, τ_{3889}, and $N(\mathrm{He}^+)/N(\mathrm{H}^+)$ values presented in Table 3. The results for M17-123 are presented in Table 3 for $t^2 = 0.000$ (constant temperature over the observed volume) and for $t^2 \neq 0.000$ (the temperature variations method). Without the restriction of uniform temperature the maximum likelihood of the temperature fluctuation parameter amounts to $t^2 = 0.036 \pm 0.013$. This t^2 value is in good agreement with those for M17 derived by PTR, Esteban et al. (1999), and García-Rojas et al. (2007) that are in the 0.033 to 0.045 range; these values were determined with two different methods: (a) combining the temperature derived from the ratio of the Balmer continuum to the Balmer line intensities with the temperature derived from $I(4363)/I(5007)$ [O III] ratio, and (b) combining the O II recombination line intensities with the λ 5007 [O III] line intensities.

From the mean values of $N(\mathrm{He}^+)/N(\mathrm{H}^+)$ given in Table 3 and the ICF(He) given by equation (6) we obtain N(He)/N(H) ratios for M17-123 of 0.1049 and 0.1016 for $t^2 = 0.000$ and $t^2 = 0.036$ respectively. These values are similar to, but more precise than, those derived by PTR for M17-123, that amount to 0.106 and 0.100 for $t^2 = 0.000$ and $t^2 = 0.040$ respectively.

We obtained the $\Delta Y/\Delta$O and the $\Delta Y/\Delta Z$ values presented in Table 3 based on the Y_p determinations by Peimbert et al. (2007). The O abundance presented in Table 3 includes both the gaseous and the dust contribution and corresponds to the average of the values derived by PTR, Esteban et al. (1999), and García-Rojas et al. (2007); these three values are in excellent agreement.

M17 is located at a galactocentric distance of 6.75 kpc, under the assumption that the Sun is located at a galactocentric distance of 8 kpc (Dias et al. 2002). In Figure 6 we have plotted the $\Delta Y/\Delta$O value for $t^2 = 0.036$. From this figure it can be noted that this value is in good agreement, at about the one σ level, with the Galactic chemical evolution model based on the HWY set, and that the O value corresponds to the prediction by the models for a galactocentric distance of 6.75 kpc (see also Table 4); alternatively the M17 $\Delta Y/\Delta O$ value for $t^2 = 0.000$ is considerably higher, by more than 3σ, than the value predicted by the HWY model. Similarly in Figure 6 we compare the M17 results with the LWY model; again, the values for $t^2 = 0.036$ are in good agreement with the Galactic chemical evolution model while the values for $t^2 = 0.000$ are not. Furthermore, from Table 4 it is also found that the $t^2 = 0.036$ value for $\Delta Y/\Delta Z$ is within one σ of the model predictions, while the $t^2 = 0.000$ value for $\Delta Y/\Delta Z$ is about 3σ away form the model predictions.

With the present accuracy of the $\Delta Y/\Delta$O and $\Delta Y/\Delta Z$ determinations in Galactic H II regions it is not possible to distinguish between the HWY and the LWY models.

TABLE 4

PRESENT DAY VALUES FROM THE GALACTIC DISK MODELS FOR $R = 6.75$ KPC

Model	$\mathrm{O}(t_{\rm final})(10^{-3})$	$\Delta Y/\Delta C$	$\Delta Y/\Delta \mathrm{O}$	$\Delta Y/\Delta \mathrm{Fe}$	$\Delta Y/\Delta Z$
HWY $M_{\rm up} = 80\ M_\odot$	7.16	6.54	4.47	17.04	1.70
LWY $M_{\rm up} = 60\ M_\odot$	8.28	7.26	3.73	17.04	1.62

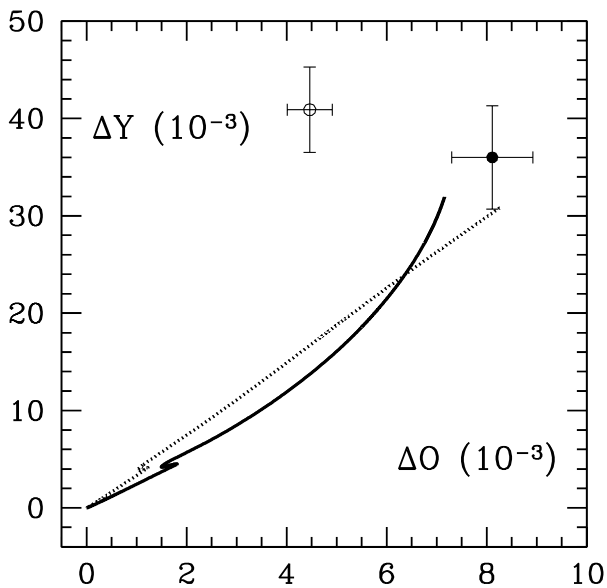

Fig. 6. Predicted evolution of He vs Oxygen for $r = 6.75$ kpc. Continuous line: model assumes $M_{\rm up} = 80\ M_\odot$ and high wind yield. Dotted line: model assumes $M_{\rm up} = 60\ M_\odot$ and low wind yield. M17 H II region at $r = 6.75$ kpc (*filled circle*, $t^2 \neq 0.000$) (*open circle*, $t^2 = 0.00$).

4. COMPARISON OF STELLAR AND NEBULAR ABUNDANCES IN ORION

To test the nebular abundances derived with different t^2 values for the Orion nebula we decided to compare them with those derived for B star abundances of the Orion association. Cunha, Hubeny, & Lanz (2006) obtained 12 + log O/H = 8.70 ± 0.09 from 11 B stars, while Lanz et al. (2008) obtained 12 + log Ar/H = 6.66 ± 0.06 from 10 B stars. These results are in excellent agreement with the nebular abundances derived by Esteban et al. (2004) for $t^2 \neq 0.00$ which amount to 8.73 ± 0.03 and 6.62 ± 0.05 for O and Ar respectively. Alternatively the values derived for $t^2 = 0.00$ amount to 8.59 ± 0.03 and 6.50 ± 0.05 for O and Ar respectively, values that are about 1σ and 3σ smaller than those derived from B stars.

5. ABSOLUTE CALIBRATION OF THE O ABUNDANCE IN THE SOLAR VICINITY

The abundances predicted by chemical evolution models are often compared with abundances in stars and in H II region. The most popular comparisons are made with the solar and the Orion nebula abundances. The comparisons among the models, the Sun, and the Orion nebula are based on the absolute abundances; therefore it is necessary to estimate not only the statistical errors but also the systematic ones in the observational determinations.

We will start by considering the solar O/H abundance. What we want from the Sun is the O/H value when it was formed, the so called initial value, and to keep in mind that it is representative of the ISM 4.5 Gyr ago when the Sun was formed. We have also to consider that the photospheric and the interior solar abundances might be different due to diffusion and gravitational settling.

In Table 5 we present the most popular O/H photospheric determinations of the last fifty years; the quoted values and the errors are the original ones published by the authors. By looking at the differences among the different determinations it is clear that for many determinations the errors probably represent only the statistical errors, and that systematic errors have not been taken into account; in short, that the total errors have been underestimated. The determinations by Asplund et al. (2005) and by Allende Prieto (2007) are qualitatively different from the previous five because they are based on 3D models, while the others are based on 1D models. The last two determinations included in Table 5, those by Caffau et al. (2008) and Centeno & Socas-Navarro (2008), indicate that the possibility of a further revision of the solar abundance is still open.

The abundances inferred from interior models of the Sun, which are based on stereosismological data, are in disagreement with the 3D photospheric models and predict heavy element abundances about 0.2 dex higher than the 3D photospheric ones (e. g. Basu & Antia 2008, and references therein).

To compare with our models we will use as the low O/H value the 3D photospheric determination

TABLE 5

12 + LOG(O/H)

		Orion nebula[b]		
Solar photosphere[a]	Year	$t^2 \neq 0.00$	$t^2 = 0.00$	Year
8.96	1960[(1)]	8.79±0.12	...	1969[(11)]
8.77±0.05	1968[(2)]	8.75±0.10	8.52±0.10	1977[(12)]
8.84±0.07	1976[(3)]	...	8.49±0.08	1992[(13)]
8.93±0.035	1989[(4)]	8.72±0.07	8.55±0.07	1998[(14)]
8.83±0.06	1998[(5)]	...	8.51±0.08	2000[(15)]
8.736±0.078	2001[(6)]	...	8.49±0.06	2003[(16)]
8.66±0.05	2005[(7)]	8.73±0.03	8.59±0.03	2004[(17)]
8.65±0.03	2007[(8)]			
8.86±0.07	2008[(9)]			
8.76±0.07	2008[(10)]			

[a](1) Goldberg, Muller, & Aller (1960). (2) Lambert (1968). (3) Ross & Aller (1976). (4) Anders & Grevesse (1989). (5) Grevesse & Sauval (1998). (6) Holweger (2001). (7) Asplund et al. (2005). (8) Allende Prieto (2007). (9) Centeno & Socas-Navarro (2008). (10) Caffau et al. (2008).

[b](11) Peimbert & Costero (1969). (12) Peimbert & Torres-Peimbert (1977). (13) Osterbrock, Tran, & Veilleux (1992). (14) Esteban et al. (1998), this value includes the fraction of O tied up in dust grains that amounts to 0.08 dex. (15) Deharveng et al. (2000). (16) Pilyugin (2003). (17) Esteban et al. (2004), this value includes the fraction of O tied up in dust grains that amounts to 0.08 dex.

by Asplund et al. (2005) and as the high O/H value the 1D photospheric determination by Grevesse & Sauval (1998), which is in good agreement with the helioseismic determination. The next step is to have reliable stellar interior models to determine the initial O/H value. For this purpose we will use the models by Bahcall et al. (2006) presented in Table 6.

The models by Bahcall et al. (2006) indicate that the photospheric values of Z and Y do not represent the initial values, due to diffusion and gravitational settling. By assuming that the O/Z ratio is not affected by these processes the initial O/H values correspond to 12 + log O/H = 8.70 and to 8.89 for the AGS05 and the GS98 surface abundances respectively. To obtain the present day ISM value we have to consider that the Sun was formed 4.5 Gyr ago and according to the Galactic chemical evolution model by Carigi et al. (2005) the O/H ratio in the ISM has increased by 0.13 dex since the Sun was formed. Therefore, our determinations of the present day ISM 12 + O/H values based on the AGS05 and the GS98 abundances amount to 8.83 and 9.02 respectively.

In Table 5 we also present the most popular O/H determinations for the Orion nebula including the errors presented in the original papers. The predictions from the solar abundances and the chemical evolution models have to be compared with the total abundances in the nebula that have to include gas and dust. With the exception of the determinations by Esteban et al. (1998, 2004) that take into account the dust fraction, all the other determinations only include the gaseous content. The other difference is that there are two possible sets of values: (a) those that assume constant temperature over the observed value given by the 4363/5007 ratio of [O III], the $t^2 = 0.00$ case, where t^2 is the mean square temperature variation (Peimbert 1967), or (b) those based on the O II recombination lines, that are in agreement with those derived from the 5007/Hβ ratio taking into account the presence of temperature variations over the observed volume, and consequently, that $t^2 \neq 0.00$.

Esteban et al. (2004) obtain for the Orion nebula that 12 + O/H = 8.73 for $t^2 \neq 0.00$, a value that includes the dust correction. By taking into account the presence of the O/H Galactic abundance gradient that amounts to -0.044 dex kpc^{-1} (Esteban et al. 2005) we obtain a value of 12 + O/H = 8.75 for the local ISM. This value is smaller than the values estimated for the local ISM based on: the solar pho-

TABLE 6

STANDARD SOLAR MODELS[a]

Values	GS98	AGS05
initial X	0.70866	0.72594
initial Y	0.27250	0.26001
initial Z	0.01884	0.01405
initial O	0.00879	0.00582
initial O/H	8.89	8.70
initial $\Delta Y/\Delta Z$	1.32	0.88
initial $\Delta Y/\Delta$O	2.82	2.11
surface X	0.7410	0.7586
surface Y[b]	0.2420 ± 0.0072	0.2285 ± 0.0067
surface Z	0.0170	0.0122
surface O/H[b]	8.83 ± 0.17	8.66 ± 0.17

[a]Standard solar models by Bahcall et al. (2006). The GS98 and AGS05 columns correspond to models with the heavy element abundances derived from photospheric observations by Grevesse & Sauval (1998) and by Asplund et al. (2005) respectively.

[b]The errors are the conservative ones adopted by Bahcall et al. (2006).

tospheric abundances by AGS05 and the GS98, the standard solar models by Bahcall et al. (2006), and the chemical evolution of the Galaxy that amount to 8.83 and 9.02 respectively. Similarly, from the results by Esteban et al. (2004) for the Orion nebula for $t^2 = 0.00$ and the observed Galactic gradient, we obtain that 12 + O/H = 8.51 for the local ISM. From the previous discussion it follows that the best agreement for the derived O/H ISM value is given by the $t^2 \neq 0.00$ result from Orion and the AGS0 result from the Sun. From these two determinations we recommend for the present day local ISM the value $12 + \log \mathrm{O/H} = 8.79 \pm 0.08$.

From the previous discussion it follows that the best agreement between the solar and the Orion nebula abundances is obtained for the high nebular abundances, that are derived from the $t^2 \neq 0.00$ values and that include the fraction of atoms tied up in dust grains, and the AGS05 solar value.

6. THE SOLAR HELIUM ABUNDANCE

We also want to compare our Galactic chemical evolution model with the helium abundance when the Sun was formed, the initial Y value. Basu & Antia (2004), based on seismic data, have derived the Y value in the solar convective envelope, which amounts to 0.2485 ± 0.0034. To derive the initial value we need a model of the solar interior that takes into account helium and heavy element diffusion and that agrees with the helium abundance of the envelope.

Again we have at our disposal the solar interior models by Bahcall et al. (2006) presented in Table 6. The GS98 model agrees with the Y value in the envelope derived by Basu & Antia (2004), but not with the O/H value in the envelope derived by Asplund et al. (2005). On the other hand the AGS05 model agrees with the O/H value in the envelope derived by Asplund et al. (2005) but not with the Y value derived by Basu & Antia (2004). Based on the discussion of the previous section we conclude that the Orion nebula O/H value agrees with the O/H value predicted by the Galactic chemical evolution model and the photospheric value by Asplund et al. (2005), and not with the photospheric value by Grevesse & Sauval (1998). The discrepancy between the photospheric abundances by Asplund et al. (2005) and the Y value derived from helioseimological data is a very important open problem. An excellent review discussing this issue has been presented by Basu & Antia (2008).

Bahcall et al. (2006) present the initial Y, Z, and O solar values for their standard solar models, see Table 6. By adopting the Y_p value by Peimbert et al. (2007) for $t^2 \neq 0.00$ it is also possible to obtain the $\Delta Y/\Delta Z$ and the $\Delta Y/\Delta$O values for the GS98 and the AGS05 standard solar models. The values so derived are in fair agreement with the predictions of the HWY and LWY Galactic chemical evolution models. To try to make a more rigorous comparison between the solar interior and Galactic chemical evolution models it is necessary to estimate the errors in the initial solar values by Bahcall et al. (2006), a task which is beyond the scope of this paper.

7. CONCLUSIONS

Based on the HWY model we find the following equation to estimate the initial helium abundance with which stars form in the Galactic disk

$$Y = Y_p + (3.3 \pm 0.7)\ \mathrm{O},$$

for $\mathrm{O} < 4.3 \times 10^{-3}$, and

$$Y = Y_p + (3.3 \pm 0.7)\ \mathrm{O} + (0.016 \pm 0.003)(\mathrm{O}/4.3 \times 10^{-3} - 1)^2,$$

for $4.3 \times 10^{-3} < \mathrm{O} < 9 \times 10^{-3}$.

The increase of ΔFe$/\Delta Z$ has to be taken into account in order to determine the $\Delta Y/\Delta Z$ value based on the [Fe/H] abundances of stars in the solar vicinity.

High mass loss rates due to stellar winds should be adopted in the evolutionary stellar models for massive stars of high metallicity, because only the Galactic chemical evolution models with HWY can reproduce simultaneously the O/H and C/O Galactic gradients, the C/O versus O relation in the solar vicinity, and the $\Delta Y/\Delta$O value in the inner Galactic disk.

Based on the O/H value of the Orion nebula and the solar photospheric value together with a chemical evolution model of the Galaxy we recommend for the present day local ISM a value of 12 + log O/H = 8.79 ± 0.08, where both the gaseous and the dust components of O are taken into account.

By comparing the O/H value of the Orion nebula with the solar value we find that the nebular ratio derived using O recombination lines, that is equivalent to the use of the forbidden O lines under the adoption of a $t^2 \neq 0.00$, is in considerably better agreement with the initial solar value than the Orion nebula value derived adopting $t^2 = 0.00$.

The stellar O/H and Ar/H abundance ratios derived by Cunha et al. (2006) and Lanz et al. (2008) for B stars of the Orion association are in excellent agreement with the nebular abundance ratios derived from the $t^2 \neq 0.00$ values for the Orion nebula.

The $\Delta Y/\Delta Z = 1.97 \pm 0.41$ value derived from observations of M17 for $t^2 = 0.036$ is in very good agreement with the 2.1 ± 0.4 and the 2.1 ± 0.9 values derived by Jiménez et al. (2003) and Casagrande et al. (2007) from K dwarf stars of the solar vicinity. On the other hand, the value $\Delta Y/\Delta Z = 4.00 \pm 0.75$ derived from observations of M17 for $t^2 = 0.000$ is not.

Both Galactic chemical evolution models with the HWY set and the LWY set are in agreement with the observed $\Delta Y/\Delta Z$ for $t^2 = 0.036$ but not with the $\Delta Y/\Delta Z$ for $t^2 = 0.000$. Higher accuracy determinations of $\Delta Y/\Delta Z$ for high metallicity objects are needed to discriminate between the HWY model and the LWY model predictions.

We are grateful to Brad Gibson and Antonio Peimbert for several fruitful discussions. We are also grateful to the anonymous referee for some excellent suggestions. This work was partly supported by the Conacyt grants 46904 and 60354.

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