The Evolution of Oxygen and Magnesium in the bulge and Disk of the Milky Way

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ABSTRACT

We show that the strong decline in the [O/Mg] ratio with metallicity in the Galactic bulge is remarkably similar to that seen in the disk, supporting the idea of a metallicity dependent decline in the yield ratio of O/Mg from massive stars, consistent with the suggestion by McWilliam & Rich (2004) relating the decline in bulge oxygen abundances at high metallicity with the Wolf-Rayet phenomenon.

We modify our existing models for the chemical evolution of the Galactic bulge and the solar neighborhood with the inclusion of theoretical oxygen yields from massive stars that decline with increasing metallicity, due to mass loss by stellar winds. Our results significantly improves the agreement between predicted and observed [O/Mg] ratios in the bulge and disk above solar metallicity; although zero-point normalization problems remain to be resolved.

The result here confirms our earlier conclusion that the bulge formed rapidly, based on the over-abundances of elements produced by massive stars. We also provide an explanation for the long-standing difference between [Mg/Fe] and [O/Fe] trends in the solar vicinity.

Subject headings:

1. Introduction

Oxygen and magnesium are so-called alpha elements, thought to be produced in the cores of massive stars during the hydrostatic phase. They are among the elements most easily understood because their synthesis is restricted to well processes in the cores of massive stars and they are thought to be unaffected by the complications of explosive nucleosynthesis (e.g. WW95); thus, one might expect that O and Mg abundances should vary in lock-step in all, or most situations. O and Mg are particularly interesting as probes of massive stars, and the star formation rate in chemically evolving stellar systems. A classic example of this is the paper by Matteucci and Brocato (1990) that predicted enhancements of alpha elements in the Galactic bulge and giant elliptical galaxies, relative to the solar neighborhood, due to the high star formation rate expected in the bulge and ellipticals. Matteucci and Brocato (1990) also predicted deficiencies of alpha elements in galaxies thought to have low star-formation rates, such as the LMC. The simple reason for this was that in high SFR systems high metallicites are reached before Type Ia supernovae can inject significant amounts of Fe to the ISM; thus, the alpha/Fe ratios remain at the high levels expected to be produced by core-collapse, Type II, supernovae.

Early observational confirmation of the predictions of Matteucci and Brocato (1990) came from McWilliam & Rich (1994) for the bulge and Shetrone, Côté, & Sargent (2001) for dwarf spheroidal galaxies. These early results have been verified and improved upon by many others for the bulge, including McWilliam & Rich (2004), Fulbright, McWilliam & Rich (2006, 2007, henceforth FMR), Zoccali et al. (2006), Lecureur et al. (2007) and also for dwarf galaxies (e.g. Hill 1997; Geisler et al. 2005; Venn et al. 2004; Tolstoy et al. 2003; McWilliam & Smecker-Hane 2005).

While McWilliam & Rich (1994) found alpha enhancements in Galactic bulge stars, a curiosity was that not all alpha elements were enhanced. McWilliam & Rich (1994) proposed that a bulge IMF skewed toward massive stars could explain this selective alpha enhancement, based on the mass-dependent yields of WW95, that indicated relatively greater production of Mg than Ca and Si from higher mass Type II SNe. McWilliam & Rich (2004) found a steeply declining [O/Fe] ratio in the bulge stars with a slope almost consistent with no production of O above [Fe/H] > -0.5. They suggested O yield decline due to winds from massive stars, related to the WR phenomen. Later FMR noted the apparent discord between nearly flat, enhanced, [Mg/Fe] and yet declining, although enhanced, [O/Fe] in the bulge above [Fe/H] $\sim$ -1.0; again, they suggested that declining metallicity dependent O yields related to the WR phenomenon. More recently, Lecureur et al. (2007) also found a decreasing trend for [O/Mg] in the bulge stars, and suggested a difference in the stellar yields of O and Mg from massive stars.

This observed difference between Mg and O trends could potentially lead to a conflict in the estimated star formation rate and formation timescale of the bulge: if the steeper decline of [O/Fe], compared to [Mg/Fe], with inceasing metallicity is due to the addition of Fe from Type Ia SNe, then a lower SFR and longer bulge formation timescale would be indicated from O than for Mg. If the different decline rates for O and Mg are due to the supernova yields it is necessary to understand them in a consistent picture of nucleosynthesis and chemical evolution.

Different slopes in the [Mg/Fe] and [O/Fe] ratios are visible in metal rich stars in the solar vicinity, where the [Mg/Fe] seems to reach a plateau for [Fe/H] > 0, whereas the [O/Fe] ratio continues to decrease (see Edvardsson et al.1993; Bensby et al. 2005). This trend also suggests the effect of strongly metal dependent O yields in metal rich massive stars.

Stellar yields can be affected by mass loss in massive stars. Maeder(1992) computed the wind contributions in He, C, N, O and Ne in stars in the mass range 1-120$\odot$ and for metallicities Z=0.001 and Z=0.02. He found that at high Z (metallicities solar and over) large amounts of He and C are ejected into the interstellar medium before being turned into heavier elements. This makes low O but large C and He. The same effect is not seen at low metallicities and therefore the nucleosynthesis production very much depends on the initial stellar metallicity. This is due to the assumed mass loss rate in massive stars which is supposed to depend on the radiation pressure mechanism, as originally proposed by Lucy & Solomon (1970), and therefore on the stellar metallicity. The effect of mass loss on stellar yields as a function of metallicity is particularly strong for initial stellar masses $> 25 - 30 M_{\odot}$, those which will become Wolf-Rayet (WR) stars and eventually explode as Type Ib/c supernovae. By means of these stellar models Maeder was able to reproduce the number statistics of WR and O-type stars in nearby galaxies with various metallicities; however, it is now apparent that there wass some good luck involved in this, because Maeder's originally adopted mass-loss rates, which are today considered quite high, made up for the neglect of rotation in his models.

Later, Langer & Henkel (1995) also computed He and CNO isotope yields for stars in the mass range $15 \leq M/M_{\odot} \leq 50$ losing mass. They also found drastic differences relative to models without mass mass loss for the yields of oxygen in metal-rich stars more massive than $30 M_{\odot}$.

More recently, Meynet & Maeder (2002, 2003, 2005) have computed a grid of models for stars with masses $> 20 M_{\odot}$ including rotation and metallicity dependendent mass loss. The effect of metallicity dependenent mass loss in decreasing the O production in massive stars was confirmed, although they employed significantly lower mass loss rates, based on work by Vink et al. (2000) and Nugis & Lamers (2000). The new and improved mass-loss rates are factors of 2 to 3 lower than previously adopted by Maeder (1992); however, with these mass-loss rates and the inclusion of rotation the models are able to reproduce the frequency of WR/O stars, the observed WN/WC ratio, and the observed ratio of type Ib/type Ic supernovae at different metallicties. In galactic chemical evolution models, the effect of the Maeder (1992) yields was studied by Prantzos, Aubert & Audouze (1996), who concluded that the mass loss in massive stars has strong effects on the production of C and O.

In summary, the effect of metallicity dependent mass loss on stellar yields appears relevant for stars with solar metallicities or larger, and therefore it should be taken into account in computing the bulge chemical evolution and the late stages of chemical evolution in the solar vicinity.

In this letter, we present new results for the chemical evolution of the galactic bulge and the solar vicinity concerning the evolution of O, Mg and Fe. We adopt detailed models developed for the bulge (Ballero et al. 2007a) and for the solar neighborhood (Chiappini et al. 1997) in which we include metallicity dependent yields for O from Woosley & Weaver (1995) up to solar metallicities and the mass loss dependent yields for O from Maeder (1992) for metallicities above solar. For the yields of Fe and Mg, which are unaffected by mass loss, we adopt those of Woosley & Weaver (1995) with corrections suggested by François et al. (2004), in order to obtain a very good fit of the solar vicinity abundance patterns. By means of these models we will predict the behavior of the [O/Mg] ratio both in the bulge and in the solar neighborhood to test whether the mass loss O yields can solve the problem.

The paper is organized as follows: in Section 2 a brief description of the chemical evolution models is given, in Section 3 the theoretical results are compared with the data and in Section 4 some conclusions are drawn.

2. Observational Evidence for Metallicity-Dependent Oxygen Yields

The difference between the trends of [Mg/Fe] and [O/Fe] seen in the Galactic bulge found by McWilliam & Rich (2004), FMR and confirmed by Lecureur et al. (2007), adds confusion to the interpretation of the evolution timescale for the bulge, because oxygen declines precipitously, while Mg changes very slowly, with metallicity. One might have expected the two abundance trends to be very similar, since O and Mg are both thought to be produced only by stars that end as Type II supernovae (e.g. WW95); however, the Galactic bulge observations clearly show that the abundances of O and Mg do not vary in lockstep. Indeed, the dissimilarity of the bulge [O/Fe] and [Mg/Fe] trends was the reason why McWilliam & Rich (2004) suggested a metallicity-dependent decline in oxygen yields, related to the Wolf-Rayet phenomenon.

Because O and Mg are produced only in the hydrostatic cores of massive stars, then if the O/Mg yield ratio declines as a function of metallicity, the same trend should be present in stellar systems, nomatter what the star formation rate, providing that the formation timescale is long enough to permit all masses of Type II SNe to occur. To test the metallicity-dependence of the O/Mg ratio in this paper we compare the abundance ratio of O/Mg seen in the Galactic bulge and the thin and thick disks. In particular we use [Mg/H] and [O/H] as metallicity indicators, rather than [Fe/H], in order to eliminate the effect of Fe from Type Ia supernovae.

The observational evidence for a decrease in the oxygen yield from Type II supernovae with increasing metallicity (relative to magnesium) is summarized in Figures 1a and 1b. In Figure 1a we show a plot of the [O/Mg] versus [Mg/H] for the bulge from FMR, Origlia & Rich (2002), Zoccali et al. (2004), and Lecureur et al. (2007), compared with points for the solar neighborhood thin and thick disks from Bensby et al. (2005). Contrary to what one might expect for two alpha-elements produced by the same stars the [O/Mg] ratio is not flat, but declines steeply for [Mg/H] values larger than -0.5 dex. The same effect is visible both in the bulge and disk stars. Note that in Figure 1b we show the same [O/Mg] ratio, but with [O/H] as the metallicity indicator. For the bulge points we employ the mean [O/H], based on [Fe/H] and a fit to the trend of [O/H] versus [Fe/H]; it was motivated to reduce the scatter in the [O/H] metallicity axis resulting from the use of only the 6300Å [O I] line for the oxygen abundances. Oxygen is useful as a metallicity indicator, despite the noise, because it contributes more than half of the total metallicity, Z. We have avoided using the recent oxygen abundances for thick disk stars by Reddy, Lambert & Allende Prieto (2006), because these were based on the high excitation O I triplet lines near 7771Å, and not the robust [O I] 6300Å indicator, because the high excitation O I lines require correction for non-LTE effects that are somewhat uncertain.

In both figures there is a clear decline in the bulge [O/Mg] ratio of ∼0.8 dex from low to high metallicity, including a markedly steeper descent above solar metallicity. It is notable, and very important, that the [O/Mg] trends for the Galactic disk closely overlap the bulge trends; and that both show the steeper decline above solar metallicity. This similarity in the evolution of the products of Type II supernovae in the disk and bulge is remarkable, because the bulge is thought to have evolved much more rapidly than the disk, based on theoretical fits to the alpha/Fe ratios (e.g. Ballero et al. 2007a; Matteucci, Romano & Molaro 1999). Thus, Figures 1a and 1b compare the composition of the bulge, formed within the initial ∼1 Gyr after the Big Bang, with the composition of disk stars formed up to the present epoch. We note that the trend with [Mg/H] as metallicity indicator is particularly important because the [Mg/Fe] ratios in the bulge are significantly higher than in the disk. Given these differences between the disk and bulge it is remarkable that the [O/Mg] trends with [Mg/H] and [O/H] follow eachother so closely. We take this as evidence that the decline in oxygen yield is intrinsic to Type II supernova and is modulated by metallicity. It is also evidence that, as generally acknowledged, O and Mg are produced only in stars with short lifetimes.

We note that Bensby, Feltzing & Lundström (2004) identified the decline in [O/Mg] versus [Mg/H] in the thin and thick disks of the Galaxy. They considered the possibility that metallicity-dependent oxygen yields from massive stars could explain the observed trend, but they dismissed this idea based on their interpretation of the oxygen yields of massive stars from models, including rotation, by Meynet & Maeder (2002). Our assesment is that while rotation does increase the core mass, the effect of decreased oxygen yields with increasing metallicity, due to mass loss, is clear in works of Meynet & Maeder (2002, 2003, 2005); the effect on the yields is particularly noticable for the most massive stars above solar metallicity (Meynet & Maeder 2005). This result holds, despite the recent decrease in adopted mass-loss rates, compared to Maeder (1992).

3. The chemical evolution models

For the chemical evolution of the Milky Way we adopted the model of Chiappini et al. (1997) with updated nucleosynthesis prescriptions as in François et al. (2004). This model is the so-called two-infall model where the halo and part of thick disk are formed during a first relatively short episode (< 2 Gyr) of accretion and star formation, whereas the thin disk formed out of a second independent infall episode which lasted much longer (8 Gyr in the solar vicinity) and formed the disk "inside-out". This model takes into account in detail the stellar lifetimes, detailed nucleosynthesis and supernovae of all types. It follows the evolution in space and time of 35 chemical species. The adopted IMF is the one from Scalo (1986) and is considered constant in space and time. The nucleosynthesis prescriptions are: for massive stars ($M > 10 M_{\odot}$) the basic yields are those from Woosley & Weaver (1995, hereafter WW95) although for some elements such as Mg we made some corrections following the suggestions of François et al. (2004). In particular, the yields from stars in the range 10-20$M_\odot$ were increased in order to fit the observed Mg absolute solar abundance. The low Mg yields is a well known problem discussed already by other authors (Thomas, Greggio & Bender, 1998). The yields for Type Ia SNe, which are assumed to originate from single-degenerate systems, are taken from Iwamoto et al. (1999). Finally the yields for low and intermediate mass stars are those from van den Hoeck & Groenewegen (1997).

The model for the bulge is that developed by Ballero et al. (2007a); exactly the same nucleosynthesis prescriptions and SN progenitor models are adopted here. The differences between the solar vicinity model and the bulge are in the timescale for the formation of the bulge which is $\tau_B = 0.1$ Gyr versus the time of formation of the solar vicinity $\tau_{SV} = 8$ Gyr, as well as in the star formation efficiencies (star formation rate per unit mass of gas) which is $\nu_B = 20Gyr^{-1}$ compared to $\nu = 1Gyr^{-1}$ for the solar vicinity. This means that the bulge is assumed to have formed extremely rapidly, during a burst of star formation. Ballero et al. (2007a) showed, in agreement with previous papers, that the initial mass function (IMF) in the bulge should be flatter than in the rest of the disk, as required by the comparison with the metallicity distribution of bulge stars. Therefore, here we adopted the best model of the Ballero et al. paper with the following IMF: $X = 0.95$ for stars with $m > 1M_\odot$ and $x = 0.33$ for stars with $m \leq 1M_\odot$. This model provided a very good fit of the stellar metallicity distribution and also a good fit of the [α/Fe] vs. [Fe/H] patterns, predicting a long α-enhanced plateau for both O and Mg, as observed, but it predicted a flatter than observed behaviour of the [O/Fe] for [Fe/H] > 0.

4. Results

In order to investigate the potential effect of mass loss on predicted O/Mg ratios we decided to update our current model with the Maeder (1992) yields that take into account the effect of mass-loss for massive stars as a function of metallicity. We used the Maeder

(1992) yields, rather than the latest results of Meynet & Maeder (2005), in order to maintain consistency with the pre-existing model employing the WW95 yields; both WW95 and Maeder (1992) models ignore the effects of rotation, but both provide similar yields near solar metallicity. In this way our calculation should show how the metallicity-dependent yields affect the current model. In Figure 2 we can see the differences between the yields of oxygen of WW95 and Maeder (1992) for two different initial stellar metallicities. The effect of the metallicity-dependent mass loss is evident in the figure, especially for stars with masses larger than $25M_{\odot}$ and with solar metallicity the O production is strongly depressed due to mass loss. In Figure 3 we show the same data as in Figure 1 where we have superimposed the theoretical predictions for the bulge and disk. As one can see in both cases the slope of the [O/Mg] ratio is very well reproduced by the Maeder yields. In particular, both the observations and our predictions indicate a sudden steepening of the slope above solar metallicity, with good agreement between the predicted and observed slopes below and above the break-point.

The model predictions have been normalized to the solar abundances as predicted by the Milky Way model which give a very good fit to the Asplund et al (2005) solar abundances. It is worth recalling that Asplund et al. (2005) found a lower O abundance than Grevesse & Sauval (1998), whereas there is little difference for the abundances of Mg and Fe. In Figure 4 we show the same plot as in Figure 3 but only for the bulge and including more data from other sources (e.g. Origlia & Rich 2002, 2004; Origlia et al. 2003, 2005; Zoccali et al. 2004, 2006); the agreement between the predicted slope adopting the Maeder yields and data is again very good. The predicted absolute values are a bit higher than the data but this depends on the normalization to the solar abundances. In Ballero et al. (2007a) where the solar abundances were those of Grevesse & Sauval (1998), the predicted [O/Mg] was lower, due to the higher O solar abundance suggested by Grevesse & Sauval relative to Asplund et al. In Figure 4 we show also the same model predictions normalized to the Grevesse & Sauval (1998) solar abundances. The important points are that the slopes and break-point in the [O/Mg] trends with metallicity, and the fact that both Milky Way results and bulge, are normalized to the same solar abundances. It is also important to note that the predicted [O/Mg] in the bulge is higher than in the Milky Way. In our models this mainly depends on the assumed IMF in the bulge which is flatter than in the solar vicinity. Such a flatter IMF seems to be unavoidable in order to reproduce the observed stellar metallicity distribution in the bulge, as extensivily discussed in Ballero et al. (2007a) and Ballero, Kroupa & Matteucci (2007b). The bulge parameters determined by Ballero et al. (2007a) for the IMF, star formation rate and infall timescale are not affected by the consideration of mass-loss dependent yields investigated here. For the IMF and star formation rate the Ballero et al. (2007a) work was entirely constrained by [O/Fe] at metallicities below solar, for which mass-loss dependent yields are not a factor. While the [O/Fe] predictions of Ballero et al (2007a) provided a better fit with in infall timescale near 0.7 Gyr^{-1}, the metallicity distribution function excluded values larger than 0.1 Gyr^{-1}. However, the metallicity-dependent oxygen yields considered here are consistent with an infall timescale near 0.1 Gyr^{-1}, in agreement the value adopted by Ballero et al. (2007a). It is also worth noting, in Figure 3, that our chemical evolution model for the solar vicinity does not predict such high [Mg/H] values as observed by Bensby et al. (2005). This is not an important fact since it may depend on many model parameters such as the present time infall rate which could have been slightly overestimated or the efficiency of star formation which could have been slightly underestimated. The important fact is that with the same nucleosynthesis prescriptions we reproduce the slope of the [O/Mg] ratio, thus supporting the original suggestion of McWilliam & Rich (2004) and FMR. It is important to consider the fact that [O/Mg] versus [Mg/H] or [O/H] plots do not contain the effects produced by the chemical enrichment of Type Ia SNe, but depend only on the different yields for O and Mg because these two elements are produced on similar timescales. On the other hand, the effect of Type Ia SN enrichment is clearly visible in the [α/Fe] versus [Fe/H] plots. In these plots the change in slope of the [O,Mg/Fe] ratios is mainly due to the time-delay with which the bulk of Fe is injected into the ISM by Type Ia SNe. This well known effect has been already extensively studied and commented in several previous papers (Matteucci & Brocato, 1990; Matteucci, Romano & Molaro, 1999, Ballero et al. 2007a). In particular, the fact that the history of star formation plays an important role in the [α/Fe] versus [Fe/H] diagrams: in the bulge, which is assumed to have suffered an intense, burst-like, star formation we expect a long plateau of enhanced-α's and a turning point occurring at [Fe/H]$\geq$ 0, as opposed to the Milky Way where the star formation proceeded much more smoothly and therefore we expect a turning point occurring at lower metallicities. The situation is even more extreme in the dwarf galaxies where the star formation has proceeded very slowly. In this case the turning point is expected at even lower metallicities thus having low [α/Fe] ratios at low [Fe/H]. The predictions for [O/Fe] versus [Fe/H] in the bulge compared with data can be seen in Figure 5, and the fit is again excellent. In Ballero et al. (2007a) this plot was also shown with the difference that the predicted [O/Fe] at high metallities was flatter and in less good agreement with the observed points.

According the Maeder (1992) prescription, and the later works of Meynet & Maeder (2002, 2003, 2005), our model clearly suggests that carbon should increase in the bulge at metallicities above solar, due to the effect of mass-loss on massive stars. We expect that the carbon enhancements could be significant, although we have not performed detailed calculations at this point. We shall investigate this qualitative prediction for the bulge composition in a forthcoming paper.

5. Conclusions

A summary of recent observational measurements of [O/Mg] versus [Mg/H] and [O/H] indicate that the [O/Mg] ratio has similar trends in the Galactic bulge and solar neighborhood, despite the vastly different formation timescales of these two systems. This similarity of abundance trends is consistent with a metallicity-dependent decline in oxygen yields, relative to Mg, from massive stars, above approximately solar metallicity, in qualitative agreement with the suggestion of McWilliam & Rich (2004) that metallilcity-dependent stellar winds, related to the Wolf-Rayet phenomenon, depleted the oxygen yields in the bulge. This observation also indicates that O and Mg are not produced in significant quantities by stars with long lifetimes.

We have extended the bulge chemical evolution model of Ballero et al. (2007ab) by including the metallicity-dependent oxygen yields of Maeder (1992) resulting from stellar winds. We find that the predicted slopes and break-points of the [O/Mg] trend with [O/H] and [Mg/H], and [O/Fe] versus [Fe/H], are very well reproduced by the enhanced model, although zero-point differences of up to ∼0.2 dex exist with observations. The inclusion of these metal-dependent O yields into the Ballero et al. (2007ab) model substantially improves the comparison between observed and predicted abundance trends. Thus, the simple inclusion of the known effects of mass-loss on the yields of massive stars is enough to explain much of the O/Mg trend in the bulge and disk.

In particular, we note that by including the Maeder (1992) metal-dependent yields we remove the previous disagreement between the IMF slope obtained by the Ballero et al. fit to the trend of [O/Fe] with [Fe/H] and the slope they found by fitting the metallicity function. Now both methods are consistent with the IMF slope adopted by Ballero et al (2007b), based on the metallicity function.

By understanding the O/Mg decline in the bulge as a result of metal-dependent winds in massive stars we have removed any apparent inconsistency between [O/Fe] and [Mg/Fe] slopes with [Fe/H] for high metallicity bulge stars; both elements are now consistent with a rapid bulge formation timescale, as suggested by Matteucci et al. (1999) and Ballero et al. (2007a).

A qualitative prediction of this work is that there should be an increase in carbon abundances for bulge stars showing the metallicity-dependent oxygen decrease; quantitative predictions will be made in a future investigation. However, for carbon the comparison between solar neighborhood and bulge will be complicated by significant sources from low and intermediate mass stars in the disk.

*** MIKE: I thought that there were R-type carbon stars found in the bulge, but I cannot find a reference. If there are, then they might be understood as being carbon enhanced through the reduction of core masses by metallicity-dependent winds here. There would not need to be an associated s-process. Anywya, if you know of a reference to R-type carbon stars in the bulge, then that woueld be very helpful.

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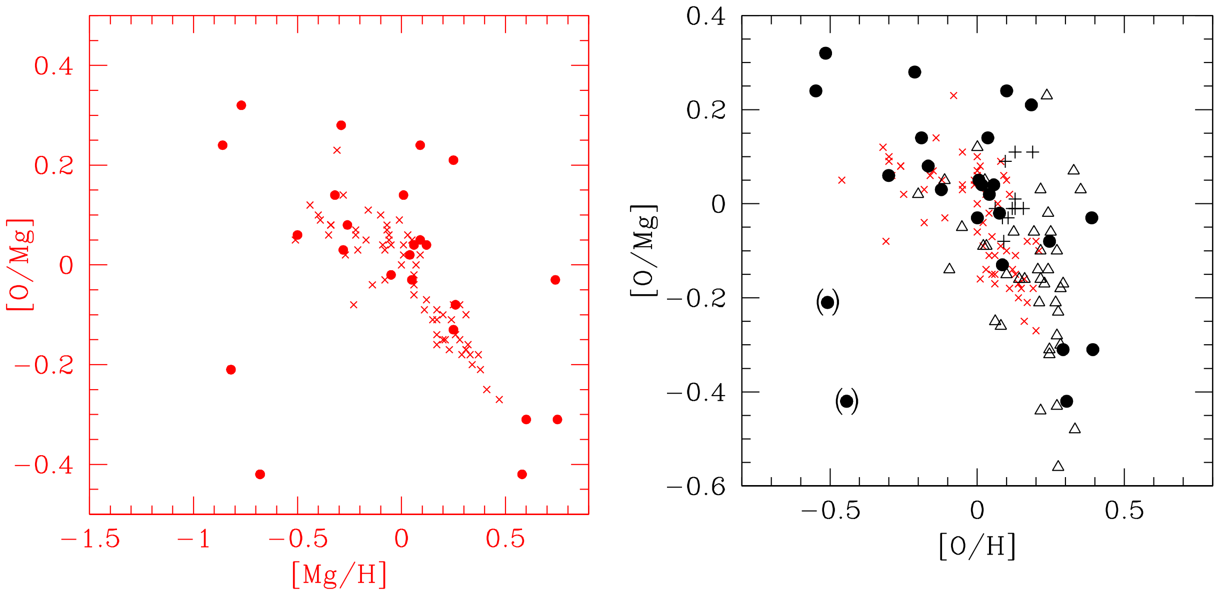

Fig. 1.— Data for the bulge (black dots) and solar vicinity stars (crosses).

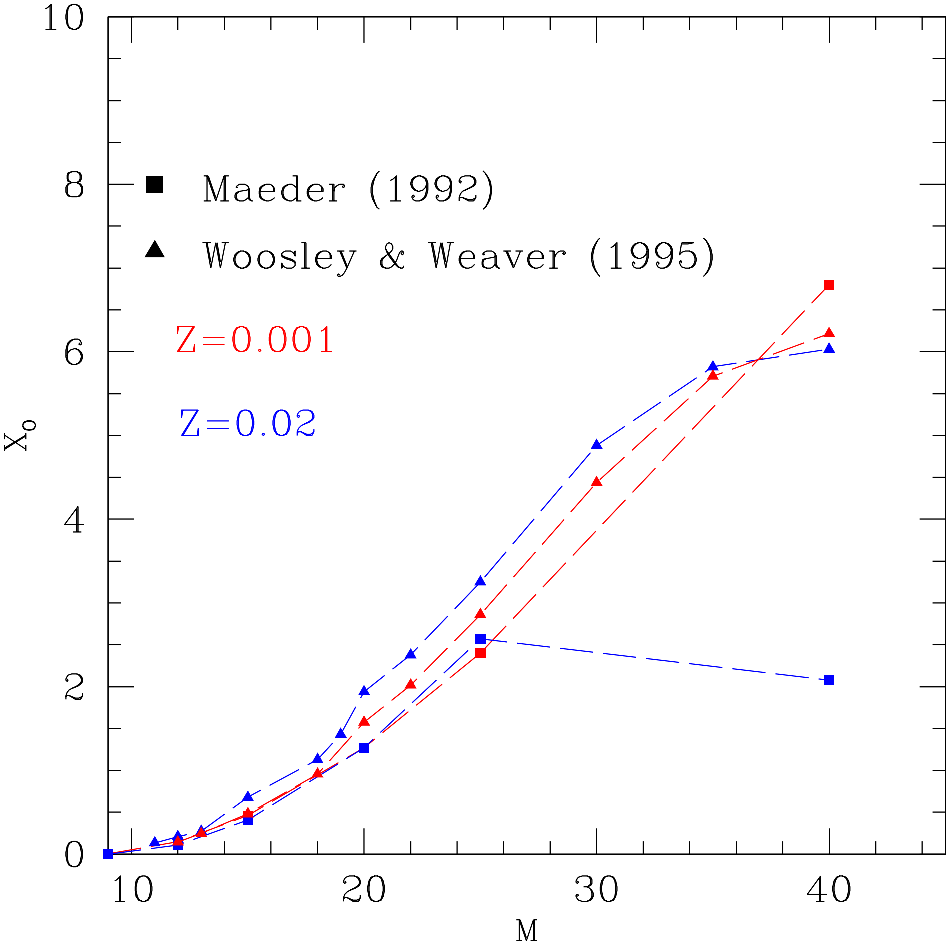

Fig. 2.— Comparison between the O yields of Maeder (1992) and WW95 for massive stars as functions of initial stellar mass.

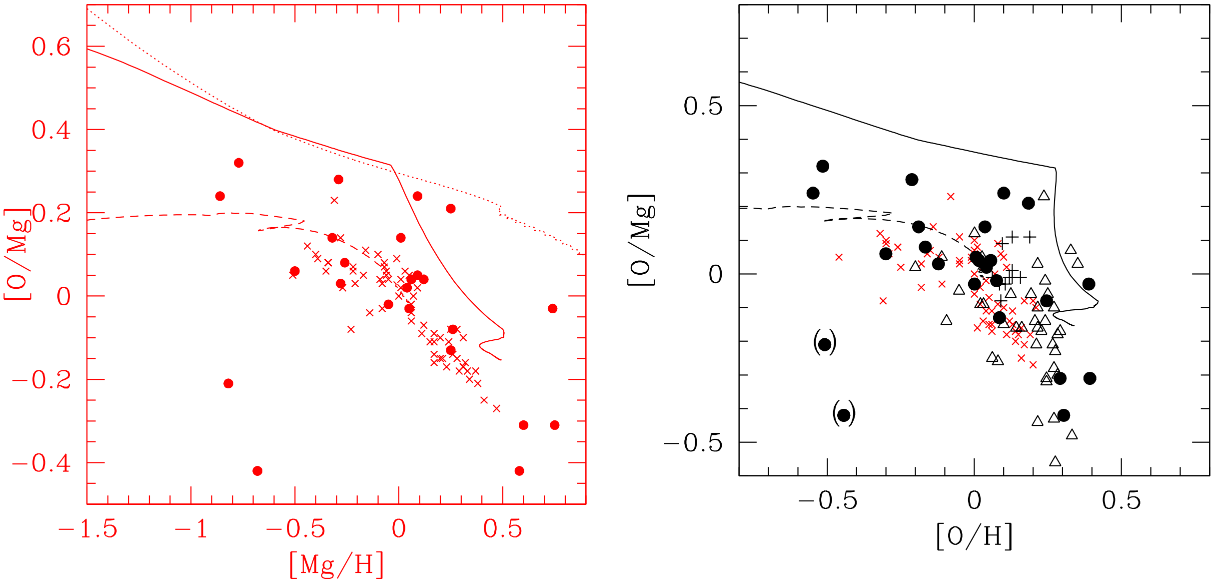

Fig. 3.— Comparison between the predicted [O/Mg] vs. [Mg/H] and [O/Mg] vs. [O/H] and the observations for the bulge and solar vicinity. The data are the same as in Fig.1. The continuous line is the prediction for the bulge when the Maeder (1992) O yields are considered for metal rich massive stars. The dotted line is the predicted [O/Mg] by Ballero et al. (2007a) by adopting the O yields as function of metallicity by WW95. Finally the dashed line represents the prediction for the solar neighbourhood when the O yields by Maeder are considered both. In all models we have normalized the abundances to the solar abundances as predicted by the Milky Way model 4.5 Gyr ago. These predicted abundances are in good agreement with recent solar abundance determination by Asplund et al. (2005).

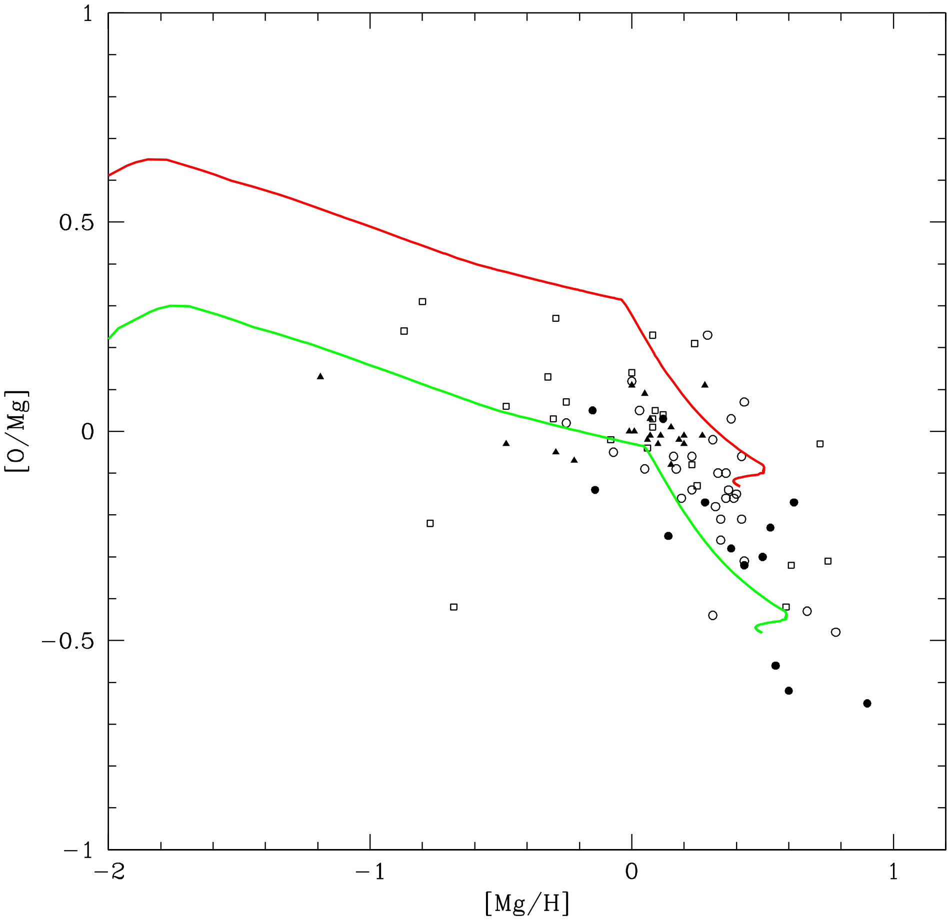

Fig. 4.— Predicted and observed [O/Mg] vs. [Mg/H] only for the bulge.The model (continuous line) is the one with Maeder's yields. The upper line refers to the apredicted bulge abundances normalized to the solar predicted values by the Milky Way model, as in the curves of Figure 3. The lower line instead refers to the predicted bulge abundances normalized Grevesse & Sauval (1998) solar abundances.The shift between the two curves is mainly due to the fact that our predicted solar abundances imply an O solar abundance in very good agreement with the one suggested by Asplund et al. (2005) which is lower than previous estimates. Data are from: triangles are the infrared data by Origlia et al. (2002), Origlia & Rich (2004), Origlia et al. (2003, 2005); the empty and filled circles are the data of Zoccali et al. (2006, low SNR and high SN, respectively); the empty squares are the data from Fulbright et al. (2007).

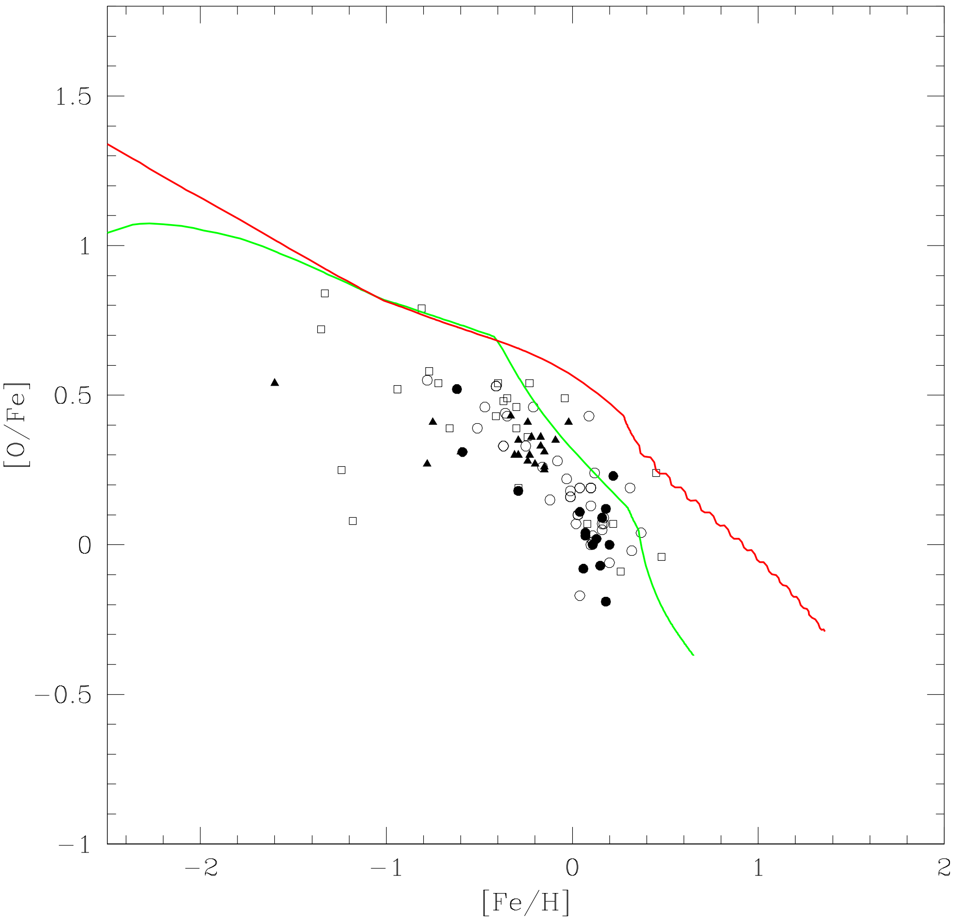

Fig. 5.— Predicted and observed [O/Fe] vs. [Fe/H].The model with Maeder's yieldsis represented by the lower green curve whereas the predictions of Ballero et al. (2007a) are represented by the red upper line.Both model predictions are normalized to the solar abundances as predicted by our Milky Way model. Data are from Origlia & Rich (2003;2004),Origlia et al. (2003, 2005) (black triangles) Zoccali et al. (2006) (empty circles, low SNR data, filled circles high SNR data), Fulbright et al. (2007) (squares).