Astron. Astrophys. 351, L49–L52 (1999)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

Metallicity distribution of bulge planetary nebulae and the [O/Fe] $\times$ [Fe/H] relation

W.J. Maciel

Universidade de São Paulo, Instituto Astronômico e Geofísico, Av. Miguel Stefano 4200, 04301-904 São Paulo SP, Brazil (maciel@iagusp.usp.br)

Received 15 October 1999 / Accepted 22 October 1999

Abstract. The O/H metallicity distribution of different samples of planetary nebulae in the bulge of the Milky Way and M31 are compared. O/H abundances are converted into [Fe/H] metallicity by the use of theoretical [O/Fe] $\times$ [Fe/H] relationships both for the bulge and the solar neighbourhood. It is found that these relationships imply an offset of [Fe/H] abundances by a factor up to 0.5 dex for bulge nebulae. Systematic errors in the O/H abundances as suggested by some recent recombination line work, ON cycling and statistical uncertainties are unable to explain the observed offset, suggesting that the adopted relationship for the bulge probably overestimates the oxygen enhancement relative to iron.

Key words: ISM: planetary nebulae: general – ISM: abundances

1. Introduction

Recent chemical evolution models usually predict different relationships between the [α-elements/Fe] and the metallicity as measured by the [Fe/H] ratio for the different phases that comprise the Galaxy, namely the disk, bulge and halo (see for example Pagel 1997). These relationships basically reflect the rate at which these elements are produced in different scenarios, being usually faster in the bulge and halo compared to the disk in the framework of an inside-out model for Galaxy formation.

Metallicities of bulge stars are poorly known compared with disk objects, as only limited samples of well measured stars are available. As a conclusion, the derived metallicity distribution and the corresponding ratios between the α-elements and metallicity are not well known. In this work, a sample of bulge planetary nebulae (PN) with relatively accurate abundances is used to shed some light on the [O/Fe] $\times$ [Fe/H] relationship adopted for the bulge. It will be shown that this relation probably exagerates the amount of oxygen produced at a given metallicity.

2. Metallicity distribution of bulge PN

Many bulge, or type V PN (Maciel 1989) are known, but only recently have accurate abundances been obtained. Recent work by Cuisinier et al. (1999) and Costa & Maciel (1999) has led to He, O, N, Ar and S abundances for about 40 bulge PN, with an uncertainty comparable to disk objects, namely up to 0.2 dex for O/H. The bulge O/H abundances are generally comparable with those of the disk, and the O/H, Ar/H and S/H ratios can be higher than the disk counterparts even though very metal rich PN are missing in the bulge. Since underabundant nebulae are also present, these results suggest that the bulge contains a mixed population, so that star formation in the bulge spans a wide time interval.

Chemical abundances of PN in the bulge of M31 have been recently studied by Jacoby & Ciardullo (1999), who have included in their analysis some results by Stasińska et al. (1998) and Richer et al. (1999). Fig. 1 shows a comparison of this sample (42 PN, top panel) with the galactic bulge objects from Ratag et al. (1997) (103 PN, lower panel, thin line) and Cuisinier et al. (1999) (30 PN, lower panel, thick line). The oxygen abundance is given in the usual notation, $\epsilon(\mathrm{O}) = \log(\mathrm{O/H}) + 12$. It can be seen that all the O/H abundance distributions are similar, peaking around 8.7 dex, and showing very few if any super metal rich objects with supersolar abundances.

In order to compare the PN metallicity distribution with the stellar distributions, it is necessary to convert the measured nebular O/H abundances into the usual [Fe/H] metallicities relative to the Sun. Direct measurements are of limited usefulness, for two main reasons. First, a very small number of planetary nebulae have measured iron lines, due to their weakness and the relatively large distances of the nebulae, so that the derived values are more uncertain than the usual O, N or Ar abundances. Second, all available measurements indicate a strong depletion usually attributed to grain formation, so that the measured Fe abundances should be considered as lower limits to the total abundances at the times of formation of the PN progenitor stars. Both these aspects are illustrated in Fig. 2, where we plot the [Fe/H] abundances against oxygen for a group of four disk planetary nebulae from Perinotto et al. (1999, squares with error bars) and one object by Pottasch & Beintema (1999, triangle with error bars). In all conversions we have used the solar iron abundance $\epsilon(\mathrm{Fe})_\odot = 7.5$ (Anders & Grevesse 1989) and average O/H error bars.

Send offprint requests to: W. J. Maciel

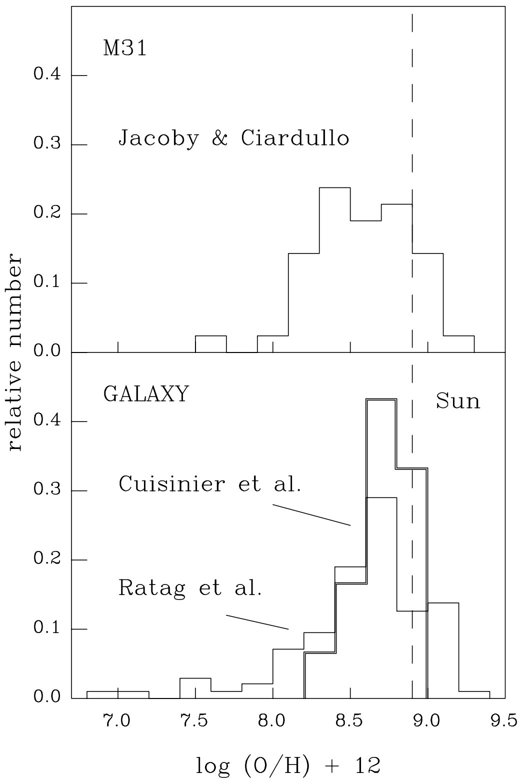

Fig. 1. Lower panel: metallicity distribution of bulge PN from Cuisinier et al. (1999, thick line) and Ratag et al. (1997, thin line). Top panel: The same for the PN in the bulge of M31 (Jacoby & Ciardullo 1999)

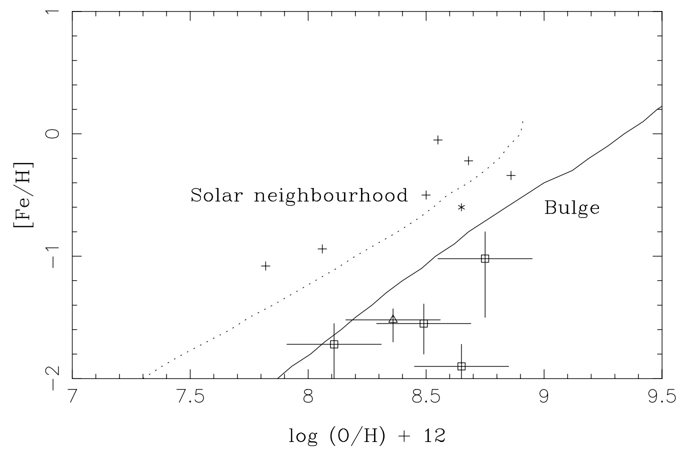

Fig. 2. [Fe/H] $\times$ log O/H + 12 relation for the galactic bulge (solid line) and solar neighbourhood (dotted line) from the [O/Fe] $\times$ [Fe/H] relations of Matteucci et al. (1999). Also shown are: Four disk PN from Perinotto et al. (1999, squares with error bars), a disk PN from Pottasch & Beintema (1999, triangle with error bars), 6 bulge giants from McWilliam & Rich (1994, crosses), and a bulge star from Barbuy (1999, asterisk).

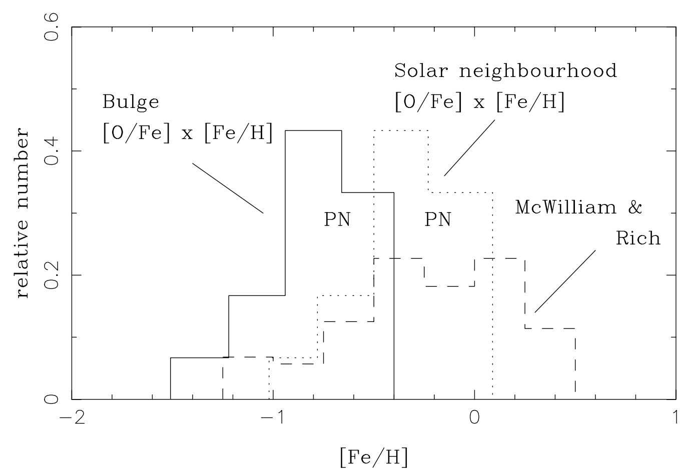

Fig. 3. Metallicity distribution of bulge PN using the [O/Fe] $\times$ [Fe/H] relations from Matteucci et al. (1999) for the bulge (solid line) and solar neighbourhood (dotted line). The dashed histogram shows the distribution of K giants from McWilliam & Rich (1994).

A better way to convert O/H abundances into [Fe/H] metallicities is to use theoretical [O/Fe] $\times$ [Fe/H] relationships, such as those recently derived by Matteucci et al. (1999) both for the solar neighbourhood and the galactic bulge. The corresponding relations are more suitably plotted in Fig. 2 using $\epsilon(\mathrm{O})_\odot = 8.9$ (Anders & Grevesse 1989) both for the bulge (solid line) and the solar neighbourhood (dotted line).

Taking into account the relations shown in Fig. 2, the O/H distribution of bulge PN from Cuisinier et al. (1999) can be converted into a [Fe/H] distribution, as shown in Fig. 3. Again the solid line corresponds to the [O/Fe] $\times$ [Fe/H] relationship for the bulge, and the dotted line was obtained using the solar neighbourhood relation shown in Fig. 2. As a comparison, the dashed histogram in Fig. 3 shows the metallicity distribution of bulge K giant stars in Baade's Window by McWilliam & Rich (1994). It can be seen that the PN metallicity distribution looks similar to the K giant distribution if the *solar neighbourhood* [O/Fe] $\times$ [Fe/H] relation is adopted, but when the *bulge* relation is taken into account the derived distribution is displaced towards lower metallicities by roughly 0.5 dex. The PN samples were carefully selected not to include disk objects (see a detailed discussion in Cuisinier et al. 1999), and their progenitor stars are clearly not massive enough to appreciably change their initial O/H composition. Therefore, the bulge PN metallicity distribution is expected to be similar to that of the K giants. This conclusion is strenghtened by the earlier measurements of Sadler et al. (1996) for Mg and by the results recently presented by Feast (2000), who has shown that the metallicity distribution of bulge Mira variables peaks around [Fe/H] $\simeq 0$, which is again higher by roughly 0.5 dex than the bulge PN shown by the solid histogram in Fig. 3. Since both classes of objects are basically the offspring of the evolution of intermediate to low mass stars, their metallicity distributions should also be similar. These objects may be located within a certain distance from the galactic centre, but, as discussed by Frogel (1999), any gradient between Baade's Window and the Centre must be small, amounting up to a few tenths of a dex.

3. Discussion

Several reasons can be considered in order to explain the discrepancy between the bulge PN distribution shown in Fig. 3 and the K giants of McWilliam & Rich (1994): (i) systematic errors in the O/H abundances of planetary nebulae, leading to mild to strong underestimates of this quantity; (ii) ON cycling in the PN progenitor stars, which would lead to a depleted O/H ratio; (iii) Statistical uncertainties due to the fact that the considered samples are relatively small and probably incomplete, and (iv) uncertainties in the adopted [O/Fe] $\times$ [Fe/H] relationships. Let us briefly consider each of these possibilities.

First, some recent work has raised the possibility that the O/H abundances of planetary nebulae may be underestimated, in view of the discrepancies between the forbidden line and recombination line values for a number of objects (Mathis & Liu 1999, Liu & Danziger 1993). In principle, that would be applied to all PN samples considered in this work, namely, the bulge PN of Ratag et al. (1997), Cuisinier et al. (1999) and the objects in the bulge of M31 of Jacoby & Ciardullo (1999). There are no detailed published (under)abundance analyses for a large number of objects, but in order to be able to explain the discrepancy shown in Fig. 3, the O/H abundances should have to be underestimated by about 0.5 dex, or a factor 3. This factor should also be applied to *disk* PN, as their abundances are derived using basically the same methods used for bulge PN. However, Cuisinier et al. (1999) have shown that their metallicity distribution for bulge PN is similar to the corresponding distribution of disk PN given by Maciel & Köppen (1994). This is confirmed by the recent (although smaller) sample of disk PN used by Maciel & Quireza (1999) to study radial abundance gradients in the galactic disk. This sample includes 128 disk PN, and an application of the solar neighbourhood [O/Fe] $\times$ [Fe/H] relationship of Matteucci et al. (1999) (dotted line in Fig. 2) produces a [Fe/H] distribution peaked at [Fe/H] $\simeq -0.3$. This is very similar to the recent G-dwarf metallicity distribution of the solar neighbourhood by Rocha-Pinto & Maciel (1996) within the usually adopted uncertainties in the PN abundances of up to 0.2 dex for oxygen. *Therefore, if we were to apply a correction factor of about 0.5 dex to the O/H abundances, the derived disk PN distribution would imply a very large number of extremely metal-rich objects, whose nature it would be very difficult to explain. Moreover, the PN distribution would peak at about 9.2 dex, which means that most disk PN would be more oxygen rich than the Sun by about a factor 2*. Even considering that the populations of PN and G-dwarfs have somewhat different ages, no known age-metallicity relation would be sufficient to explain such large overabundance (see for example the age metallicity relation by Twarog 1980 or the recent work by Rocha-Pinto et al. 1999 and references therein). As a conclusion, any underestimate of the O/H abundances in PN would have to be much lower than 0.5 dex, and could be well accommodated within an average uncertainty of 0.2 dex. Of course, this does not exclude the possibility that some *individual* nebulae may have strongly underestimated abundances, but the *average* factor is probably much lower than 0.5 dex. Further work is needed, possibly including a sizable sample of disk PN with well measured forbidden-line and recombination-line abundances.

Second, the possibility of ON cycling has often been mentioned for planetary nebulae (see for example Maciel 1992), basically due to some anticorrelation in the N/O ratio compared with He/H for disk PN. However, this phenomenon is only expected to occur in Type I PN (cf. Peimbert 1978), which are formed mainly from the higher mass progenitor stars. These objects have an excess of He/H and/or N/O, and their oxygen abundances are in fact slightly lower than the most common Type II objects (see for example Maciel 2000). However, the amount by which the O/H ratio is decreased is very small (roughly 0.1 dex), and Type I objects are explicitly excluded from the disk sample of Maciel & Quireza (1999). Regarding the bulge PN, almost all objects show no trace of He/H or N/O enrichment, so that this possibility cannot be used to explain the discrepancy shown in Fig. 3.

Third, statistical uncertainties are more difficult to analyze, since the considered samples are relatively small and may be affected by observational selection effects. However, all distributions can be understood in terms of general models for chemical evolution of the Galaxy, and the similarities of the metallicity distributions of different objects such as G-dwarfs and disk PN, or bulge PN, Mira variables and K giants fit rather nicely in the framework of galactic evolution, within the uncertainties of the derived abundances. Considering the bulge PN in particular, the similarity of the three different distributions shown in Fig. 1 is striking, even though they reflect different samples using different techniques. Small differences such as the lack of oxygen rich PN in the Cuisinier et al. (1999) sample may be explained by the smaller size of this sample. However, we are interested in very broad aspects of these distributions, and not in the detailed behaviour at a given metallicity of range of metallicities, so that it is unlikely that statistical uncertainties might produce the discrepancy shown in Fig. 3.

Fourth, we are left with the possibility that the bulge [O/Fe] $\times$ [Fe/H] relation as given by Matteucci et al. (1999) or, equivalently, the [Fe/H] $\times \log$ O/H relation given by the solid line in Fig. 2 might be responsible for all or most of the discrepancy in the metallicity distributions shown in Fig. 3. Such relation assumes a faster evolution during the bulge formation, so that at a given metallicity the [O/Fe] ratio is higher than in the solar neighbourhood. Although this is correct in principle, the present results suggest that the amount of oxygen produced has been overestimated, leading to an excess of O/H for a given metallicity. In fact, the earlier models of Matteucci & Brocato (1990) predict a lower [O/Fe] enhancement, producing a better agreement with the present results. On the other hand, there are some independent evidences that the theoretical [O/Fe] in the bulge may be overestimated. A recent analysis by Barbuy and collaborators for one star in the bulge globular cluster NGC 6528 (see for example Barbuy 1999) shows that [O/Fe] $\simeq 0.35$ for a metallicity [Fe/H] $\simeq -0.6$, so that [O/H] $\simeq -0.25$ and $\log$ O/H + 12 $\simeq 8.65$. This object is also shown in Fig. 2 (asterisk) and is closer to the dotted curve than to the bulge relation (solid line). Also, for *all* six bulge giants with measurable [OI] features in the McWilliam & Rich (1994) sample the [O/Fe] ratio is lower by 0.2–0.7 dex than predicted by the [O/Fe] $\times$ [Fe/H] relationship of Matteucci et al. (1999). These stars are also shown in Fig. 2 (crosses), and are clearly located to the left of the bulge curve, even allowing for some uncertainty in the O/H abundances. The average difference is about 0.5 dex, which is just what is needed to eliminate the offset of the bulge PN metallicity distribution shown in Fig. 3. Therefore, it can be concluded that the theoretical [O/Fe] $\times$ [Fe/H] relation for the bulge probably overestimates the oxygen enhancement relative to iron by 0.3 to 0.5 dex, at least for metallicities [Fe/H] ≥ -1.5 dex.

Acknowledgements. I am indebted to B. Barbuy, F. Matteucci, F. Cuisinier and R.D.D. Costa, for some helpful discussions. This work was partially supported by CNPq and FAPESP.

References

Anders, E., Grevesse, N., 1989, Geochim. Cosmochim. Acta 53, 197
Barbuy, B., 1999, Galaxy evolution, ed. M. Spite, F. Crifo, Kluwer (in press)
Costa, R.D.D., Maciel, W.J., 1999, Galaxy evolution, ed. M. Spite, F. Crifo, Kluwer (in press)
Cuisinier, F., Maciel, W.J., Köppen, J., Acker, A., Stenholm, B., 1999 A&A (in press)
Feast, M., 2000, Chemical evolution of the Milky Way: stars versus clusters, ed. F. Giovannelli, F. Matteucci, Kluwer (in press)
Frogel, J.A., 1999, Galaxy evolution, ed. M. Spite, F. Crifo, Kluwer (in press)
Jacoby, G.H., Ciardullo, R., 1999, ApJ 515, 169
Liu, X.-W., Danziger, J., 1993, MNRAS 263, 25
Maciel, W.J., 1989, IAU Symp. 131, ed. S. Torres-Peimbert, Kluwer, 73
Maciel, W.J., 1992, Elements and the cosmos, ed. M.G. Edmunds, R.J. Terlevich, Cambridge, 210
Maciel, W.J., 2000, Chemical evolution of the Milky Way: stars versus clusters, ed. F. Giovannelli, F. Matteucci, Kluwer (in press)
Maciel, W.J., Köppen, J., 1994, A&A 282, 436
Maciel, W.J., Quireza, C., 1999, A&A 345, 629
Mathis, J.S., Liu, X.-W., 1999, ApJ 521, 212
Matteucci, F., Brocato, E., 1990, ApJ 365, 539
Matteucci, F., Romano, D., Molaro, P., 1999, A&A 341, 458
McWilliam, A., Rich, R.M., 1994, ApJS 91, 749
Pagel, B.E.J., 1997, Nucleosynthesis and chemical evolution of galaxies, Cambridge
Peimbert, M., 1978, IAU Symp. 76, ed. Y. Terzian, Reidel, 215
Perinotto, M., Bencini, C.G., Pasquali, A., Manchado, A., Rodriguez Espinoza, J.M., Stanga, R., 1999, A&A 347, 967
Pottasch, S.R., Beintema, D.A., 1999, A&A 347, 975
Ratag, M.A., Pottasch, S.R., Dennefeld, M., Menzies, J.W. 1997, A&AS 126, 297
Richer, M.G., Stasińska, G., McCall, M.L., 1999, A&AS 135, 203
Rocha-Pinto, H.J., Maciel, W.J., 1996, MNRAS 279, 447
Rocha-Pinto, H.J., Scalo, J., Maciel, W.J., Flynn, C., ApJL (in press)
Sadler, E.M., Rich, R.M., Terndrup, D.M., 1996, AJ 112, 171
Stasińska, G., Richer, M.G., McCall, M.L., 1998, A&A 336, 667
Twarog, B.A., 1980, ApJ 242, 242