Chemical Composition of Planetary Nebulae: The Galaxy and the Magellanic Clouds

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Abstract. An analysis is made of the abundances of planetary nebulae (PN) in the Galaxy (MW), the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC). The data have been gathered by the IAG/USP group in a homogeneous procedure, involving observational techniques, data acquisition and reduction. Emphasis is placed on distance-independent correlations, which are particularly important for PN in the Galactic disk. It is shown that: (i) our abundances are comparable to the accurate abundances of nebulae with ISO data; (ii) most abundance correlations hold for all three systems, taking into account the metallicity differences between the Galaxy and the Magellanic Clouds; and (iii) there is a good general agreement of our data with the predictions of recent theoretical models for PN progenitors.

1 Introduction

Planetary nebulae (PN) are especially important for studies of the chemical evolution of the Galaxy and the Magellanic Clouds. They are the offspring of stars in a mass range of roughly 0.8 to 8 $M_\odot$, so that a relatively wide distribution of ages and population types can in principle be observed.

Chemical abundances of PN are derived for several elements, so that empirical distance-independent correlations can be determined with a reasonable degree of accuracy. These correlations can then be compared with the predictions of the nucleosynthetical processes and chemical evolution models of intermediate mass stars (see for example [15], [7], [12]) and act as constraints on these models.

In particular, it is known that there is a general metallicity difference between the Galaxy and the Magellanic Clouds, and between the LMC and SMC themselves. On the other hand, it is not clear whether the chemical evolution has proceeded differently in the Clouds as compared to the Galaxy, or the evolutionary steps were essentially the same, albeit starting from a more metal-poor gas. Some information in this respect can be obtained by the analysis of the abundances of a relatively large sample of PN in these systems.

The total number of PN in the Clouds with accurate abundances is relatively small, as compared with the population of PN in the Galactic disk and bulge (see for example [18] and [13]). Since the early nineties, the IAG/USP group launched a long term project to derive accurate abundances for PN in the Galaxy and the Magellanic Clouds, based on detailed spectroscopic observations secured both in Brazil and in Chile (see [2] for some references). In this paper, we will present a brief account of this work.

2   The Data

In a series of papers by the IAG/USP group, the chemical compositions of over two hundred planetary nebulae have been derived, including objects in four different regions: (i) the Galactic disk; (ii) the Galactic bulge; (iii) the LMC; and (iv) the SMC. The main references are [3], [6], [5], [2], [4], [1], [8], [9], [10], and [11]. All observations have been obtained using either the 1.6 m LNA telescope at Brasópolis, Brazil, or the 1.52 m ESO telescope at La Silla, Chile. At ESO a Boller and Chivens cassegrain spectrograph was used with a CCD detector at a reciprocal dispersion of about 2.5 Å/pixel. At the LNA the dispersion was of about 4.4 Å/pixel. The reductions have been made using the IRAF package. Basically, the electron densities have been determined from the [SII] 6716/6731Å lines, while for the electron temperatures we have used the [OIII] 4363/5007Å and [NII] 5754/6584Å lines. The observational techniques employed, data acquisition and reduction procedures have all been similar, as warranted by the high degree of homogeneity desirable in the analysis of the chemical composition of planetary nebulae.

3   Distance-Independent Correlations

Planetary Nebulae and HII Regions Comparing the average abundances of PN with the corresponding values for HII regions, we find that the abundances of the elements S, Ne, Ar, and O are similar both in the PN and HII regions of each system. Average values for oxygen in PN are $\epsilon(O) = \log O/H + 12 \simeq 8.65$, 8.40 and 8.16 dex for the MW, LMC and SMC, respectively. The differences for O, S, Ar and Ne are relatively small, generally under 0.2 dex, similar or smaller than the average abundance uncertainties. The main differences appear for helium and especially nitrogen, which are enriched in PN, and are dredged up in the progenitor stars. The differences amount to about 40% for He/H and 0.5 to 0.7 dex for N/H.

Correlations Involving S, Ar, Ne and O The elements S, Ar and Ne are not expected to be produced by the PN progenitor stars, as they are manufactured in the late evolutionary stages of massive stars. Therefore, S, Ar and Ne abundances as measured in planetary nebulae should reflect the interstellar composition at the time the progenitor stars were formed. Regarding the oxygen abundances, there is some evidence of a reduction in the O/H ratio in some PN due to ON cycling in their progenitor stars, so that there may be some small variations in the O/H abundances in the nebular gas relative to the pristine abundances.

The variation of the ratios S/H, Ar/H and Ne/H with O/H show a good positive correlation for all systems, with similar slopes. Our sample is not complete, so that the average abundances do not necessarily reflect the metallicities of the galaxies considered. However, the metallicity differences can be observed judging from the observed metallicity range. The Galactic nebulae extend to higher metallicities (up to $\epsilon(O) \simeq 9.2$), while the LMC objects reach $\epsilon(O) \simeq 8.8$, and

the SMC extends to even lower metallicities, namely $\epsilon(O) \simeq 7.0$. Taking into account the Galactic and MC nebulae by Stasińska et al. [18], these results are confirmed and extended, especially at lower metallicities, $\epsilon(O) < 8.0$, for which their sample is richer than ours.

Correlations Involving N An anticorrelation between N/O and O/H has been discussed by a number of people (see for example [2], [18] and Perinotto et al., this conference) and may be an evidence for the conversion of O into N in the PN progenitor stars. This scenario is basically supported by our data. The Galactic disk nebulae show a mild correlation, taking into account the majority of objects with $\epsilon(O) > 8.0$. For the Magellanic Clouds, the anticorrelation appears better defined, particularly for the SMC. In this case, our sample fits nicely the previous sample [18], especially at higher O/H ratios, that is, $\epsilon(O) > 8.0$.

Assuming that the nitrogen abundance is directly proportional to the oxygen abundance, as is the case for S, Ar and Ne, then for lower O/H ratios the N/O ratio is expected to be essentially constant. Since this ratio increases on average for lower O/H values, we have to conclude that the nitrogen abundance is enhanced, possibly at the expense of oxygen. Since the N/O $\times$ O/H anticorrelation is better defined for the Magellanic Clouds, it seems that the lower metallicities of these galaxies favour the ON-cycling as observed in planetary nebulae.

A well defined N/O v. N/H correlation is shown in Fig. 1 for Galactic (crosses), LMC (empty circles) and SMC (filled circles) nebulae. Average error bars are provided at the lower right corner. The dashed line shows the theoretical predictions of the final model for the LMC by Groenewegen and de Jong [12]. The inflection point of the line corresponds to initial stellar masses of about $2 \, M_\odot$, lower masses being associated with the left side of the plot and higher masses to the right side. As pointed out in [12], the location of PN in this diagram is a good indicator of main sequence mass of the progenitor star. We can see that our SMC sample includes basically low mass progenitors.

Correlations Involving He Another interesting correlation is a plot of N/O as a function of He/H (figure 2). For the Galaxy (crosses), a good correlation is observed. The inclusion of the LMC and SMC objects generally supports this conclusion, although the scattering increases, probably due to the different metallicities of the galaxies. The main differences occur for the SMC, for which the He/H ratio has approximately the same range as the LMC and even the Galaxy, but N/O is generally lower, at least in our sample. Since the O/H ratio is also smaller in the SMC, due to the metallicity difference, we apparently observe a smaller nitrogen enhancement in the SMC, so that the progenitor star masses are somewhat lower in this galaxy, as also suggested by Fig. 1. In other words, type I PN are probably less frequent in the SMC, in agreement with the conclusion by Stanghellini et al. [17], based on HST data, that bipolar PN are much rarer in the SMC than in the LMC or in the Galaxy (see also Shaw and Villaver, this conference). It is argued that the lower metallicity environment of
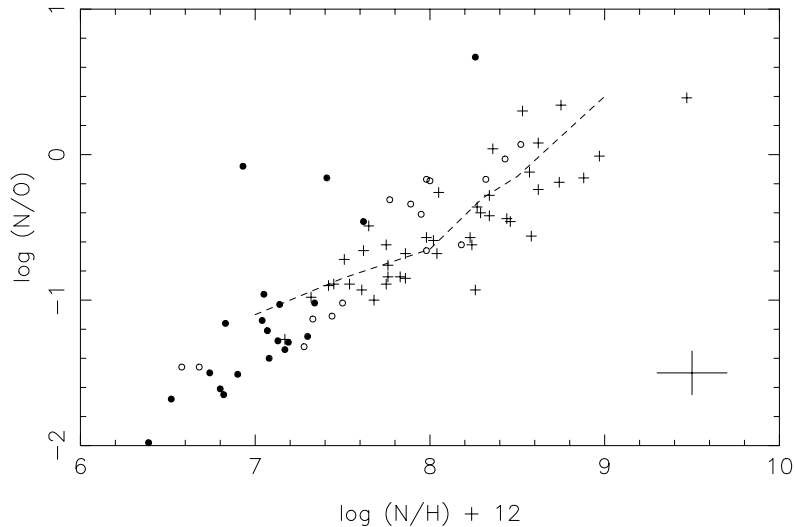
Fig. 1. Nitrogen abundances of PN in the Galaxy (crosses), LMC (empty circles) and SMC (filled circles). The dashed line shows predictions of the final model by Groenewegen and de Jong [12]. Average error bars are shown at the lower right corner.

the SMC does not favour the formation of the higher mass progenitors that give rise to Type I bipolar (or asymmetric) PN.

Recently, Marigo et al. [15] have presented abundances of Galactic PN for which ISO and IUE spectra are available, so that their abundances are presumably well determined, as all important ionization stages have been considered, making it practically unnecessary to use ionization correction factors. Also, infrared data are less dependent on the electron temperatures and their intrinsic uncertainties. These objects are included in Fig. 2 (triangles connected by dashed lines), and show a good agreement with our data, at least for the Milky Way. Another comparison of our Galactic PN with nebulae having ISO abundances can be seen in Fig. 3, where we plot our PN along with nebulae having ISO abundances from Pottasch et al. [16] (triangles connected by dashed lines). Also shown in the figure are the Sun, Orion (lozenge) and predictions of theoretical models by Marigo et al. [15] (continuous line), which consist of synthetic evolutionary models for the thermally pulsing asymptotic giant branch stars.

4   Final Remarks

Recently, Costa et al. [3] have analyzed a sample of PN located in the direction of the Galactic anticenter. It was shown that the observed radial O/H gradient tends to flatten out for large galactocentric distances, roughly $R > 10$ kpc, in agreement with previous results by Maciel and Quireza [14]. Therefore, it is interesting to investigate whether anticenter PN – which are in principle more
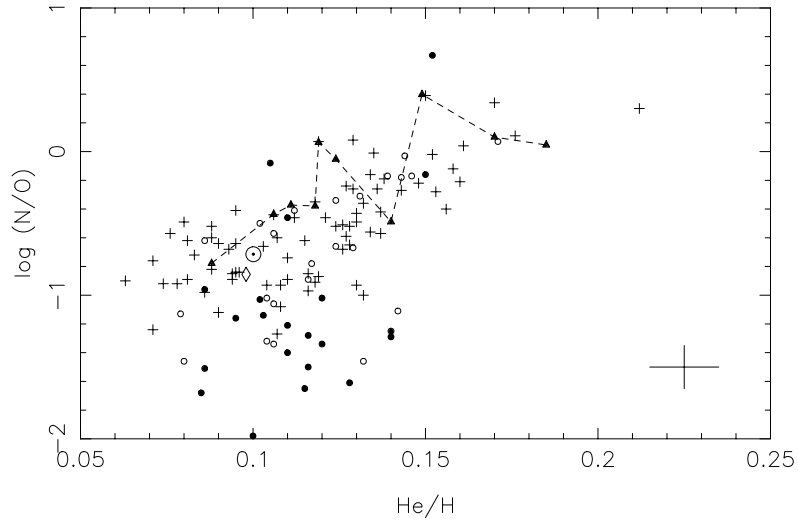
Fig. 2. The N/O v. He/H correlation for PN. Symbols are as in Fig. 1. Also included are the Sun, Orion (lozenge) and Galactic PN with ISO data from Marigo et al. [15] (triangles connected by dashed lines).
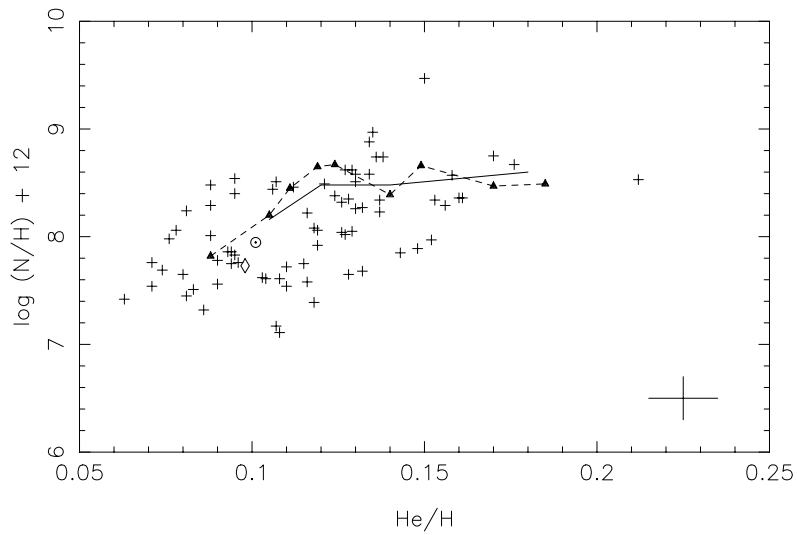

Fig. 3. The N/H v. He/H correlation for Galactic PN. Also included are the Sun, Orion (lozenge), PN with ISO data from Pottasch et al. [16] (triangles connected by dashed lines) and predictions of theoretical models by Marigo et al. [15] (continuous line).

metal poor than their inner counterparts – have abundances closer to metal poor systems, namely the LMC and SMC.

An analysis of our sample shows that all Galactic nebulae, comprising inner and outer objects, are evenly distributed along the disk, so that there is apparently no association of the outer nebulae with the lower metallicity objects of the Magellanic Clouds. However, taking into account the nebulae of the larger sample of Lago and Maciel (in preparation), which includes objects from the literature at low galactocentric distances, we conclude that a tendency can be observed, in the sense that the higher metallicity objects are preferentially located closer to the Galactic center.

Finally, it is interesting to notice that the same correlations found for PN in the Galactic disk and in the Magellanic Clouds can also be observed in the objects of the Galactic bulge, as recently shown by Escudero et al. [6].

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