Some Implications of Galactic Abundance Gradients Derived From H\textsc{ii} Regions and Planetary Nebulae

Manuel Peimbert and Leticia Carigi

Instituto de Astronomía-UNAM,
Apdo Postal 70-264, México D. F., México

Abstract. By comparing observed abundance gradients with those predicted by a chemodynamical model of the Galaxy, the following results are obtained: there is a deficiency of O/H poor PNe in the solar vicinity implying that only a fraction of intermediate mass stars produces PNe; a similar result is obtained from the observed abundance distributions of Ne/H, S/H and Ar/H; the age distributions of the stellar progenitors of type II and type III PNe show a substantial overlap, but the average age of the progenitors of type III PNe is larger than that of the progenitors of type II PNe; the S/H and the Ar/H gradients of type I PNe and H\textsc{ii} regions are similar; the flatter O/H gradient of type I PNe relative to that of H\textsc{ii} regions is probably due to the effect of temperature fluctuations on the abundance determinations; the similarity of the abundance gradients derived from H\textsc{ii} regions and PNe implies that transient phenomena are not important in shaping the present day H\textsc{ii} gradients.

1. Introduction

In trying to fit a chemodynamical model of the galaxy to the observed radial abundance gradients derived from H\textsc{ii} regions and planetary nebulae many assumptions have to be made. In this note, we discuss the effect on the assumptions of the comparison of the chemodynamical model by Allen et al. (1998) with the observations of H\textsc{ii} regions by Peimbert (1979), Shaver et al. (1983), and Vílchez & Esteban (1996) and of planetary nebulae by Maciel & Köppen (1994). H\textsc{ii} regions give us information on the present value of the abundance distributions in the interstellar medium (ISM), while PNe give us information on the abundance distributions in the ISM at the time of the formation of the progenitor stars of those elements not affected by stellar evolution. Maciel & Köppen have used the classification by Peimbert (1978), where type I PNe come from the high mass end of the intermediate mass stars (IMS) (those in the 0.83 \mbox{M}_\odot to 8.4 \mbox{M}_\odot range), and types II and III from the intermediate and low mass end of the IMS, respectively.

2. The Planetary Nebula Problem

In Figure 1a, we present the O/H distribution for all the observed PNe as predicted by the model by Allen et al. (1998) under the assumption that all IMS
produce PNe. This is compared with the observed O/H distribution by Maciel & Köppen (1994). The observed distribution shows a deficiency of O/H poor objects relative to the predicted distribution. A similar result is obtained for the Ne/H, S/H and Ar/H distributions, ruling out the possibility that O/H poor objects increase substantially their O/H ratio during their evolution. We call this deficiency of O/H poor objects the PN problem, in analogy with the G dwarf problem. It should be noted that the chemodynamical model explains the G dwarf problem and that a different solution has to be found for the PN problem.

Allen et al. (1998) suggest that only about half of the IMS produce PNe, moreover they proposed a fraction function, FF, that gives the probability that a star of a given mass will produce a PN. In Figure 1b, we present the expected O/H distribution adopting the FF proposed by Allen et al. There are other results discussed by Allen et al. that support the idea that only a fraction of IMS produce PNe: a) the scale height of PNe in the solar neighborhood, b) the estimated PNe birth rate for the solar neighborhood, c) the decrease of the PNe birthrate with $M_{bol}$ and $(B-V)_0$ in extragalactic systems, and d) the observed fraction of white dwarfs with masses in the $0.4 M_{\odot}$ to $0.55 M_{\odot}$ range that presumably did not go through the PN stage.

In Figure 2, we present the O/H cumulative function for PNe; from this figure it can also be noted that without the FF there is a deficiency of O/H poor PNe.
3. Planetary Nebula Types

Peimbert (1978, 1990) divided PNe in four types according to the mass of the progenitor in the main sequence. To estimate the mass of the progenitor of a given PN, and consequently its type, one can use its chemical composition or its dynamical properties. From models, it is trivial to divide PNe among different types; from observations it is difficult to estimate the mass of the progenitor stars of PNe.

Allen et al. (1998) defined those PNe with peculiar velocities higher than 60 km s$^{-1}$ as type III, and those with peculiar velocities lower than 60 km s$^{-1}$ as type II. From Allen et al., it follows that there is an overlap in initial masses between PNe of types II and III. The average mass of the progenitors of type II PNe is 1.29 M$_\odot$, corresponding to an average age of 3.6 Gyr, while for type III PNe, the averages correspond to 1.05 M$_\odot$ and 6.4 Gyr respectively. This division is in good agreement with the fractions of the observed PNe by Maciel & Köppen (1994), that amount to 39, 45, and 16 percent for types I, II, and III, respectively. We have adopted a solar Galactocentric distance of 8 kpc and have considered only those PNe with Galactocentric distances in the 6 to 10 kpc range. We have not estimated the incompleteness effect on the sample by Maciel and Köppen due to dust absorption in the plane of the Galaxy; this effect goes in the opposite direction to that needed to solve the PN problem, since the incompleteness is higher for type I and II than for type III PNe.

We can also divide type II and III PNe strictly by mass, adopting the FF of Allen et al. (1998) and the relative fractions of observed types by Maciel.
Table 1. Average $12 + \log(O/H)$ values for PN types divided by velocities and by abundances. The values in parenthesis correspond to the fraction of PNe in each category.

| Type II ($v < 60 \text{ km s}^{-1}$) | Model | Model x FF | Observed |
|----------------------------------|-------|------------|----------|
| Type II (high O/H)               | 8.46  | (45%)      | 8.69 (45%) |
| Type III ($v > 60 \text{ km s}^{-1}$) | 8.28  | (44%)      | 8.35 (16%)  |
| Model x FF                       | 8.58  | (47%)      | 8.66 (45%)  |
| Observed                         | 8.40  | (20%)      | 8.35 (16%)  |

& Köppen (1994). The limiting mass between both types becomes 0.97 $M_\odot$. The following averages are obtained from the chemodynamical model by Allen et al. (1998): $12 + \log(O/H) = 8.62$, and $M = 1.25 M_\odot$ for type II, while $12 + \log(O/H) = 8.20$, and $M = 0.92 M_\odot$ for type III. The average masses correspond to 4.0 Gyr for type II and to 9.5 Gyr for type III. As we saw in the previous paragraph, it is not possible to have a sharp mass boundary between types II and III based on dynamical arguments only. Neither is it possible to have a sharp mass boundary based on the observed abundances for the following reasons: a) there are observational errors in the abundance determinations, b) at a given Galactocentric distance there are PNe that originated at different Galactocentric distances, and c) probably there is a scatter in the chemical abundances present in the ISM for a given time and a given Galactocentric distance.

Using the set of Maciel & Köppen (1994), we derive average values of $12 + \log(O/H) = 8.66$ and 8.35 for types II and III respectively (see Table 1). On the other hand, we can also divide PNe types by abundances only; therefore by assuming that type III PNe comprise 16% of the objects with the lowest O/H values in the set of Maciel & Köppen, and that the rest of non type I are of type II (45%), we obtain averages of $12 + \log(O/H) = 8.28$ and 8.69 for types III and II respectively (see Table 1). The similarity of the O/H values implies that type II and type III PNe can be divided by O/H values or by dynamical properties. Also in Table 1, we present the O/H average values predicted by the model of Allen et al. (1998) for the two types of PNe, divided by velocities and by abundances, assuming that all the IMS produce PNe and that only a fraction of the IMS produce PNe. By comparing the observed values with the predicted ones, it can also be concluded that a better fit to the observations can be made with the use of the FF proposed by Allen et al. Note that in the model predictions based on abundances, the limiting mass between type I and type II PNe differs from that adopted by Allen et al.
4. Other Implications

The O/H and Ne/H gradients derived from type I PNe are considerably smaller than those derived from H\textsc{ii} regions. On the other hand, the S/H and the Ar/H gradients are similar. The difference in the O/H gradients could be due to ON cycling or to the presence of temperature fluctuations. The presence of ON cycling in PNe is controversial (e.g. Torres-Peimbert & Peimbert 1997, and references therein); Peimbert et al. (1995) argue that the low O/H values derived for type I PNe are due to the assumption of a constant temperature in the abundance determinations; taking temperature fluctuations into account, they find that ON cycling is not present in type I PNe. The presence of temperature fluctuations affects more the Ne and O than the S and Ar abundance determinations, when these abundances are derived from nebular lines. This is because the excitation energies of the O and Ne lines are higher than those of the S and Ar lines. Moreover it can be shown that the effect goes in the direction of flattening the gradients, since the higher the heavy element abundances, the lower the temperature and the higher is the effect of temperature fluctuations on the abundance determinations.

The similarity of the abundance gradients derived from H\textsc{ii} regions, PNe of type I (S and Ar), PNe of type II, and PNe of type III implies that transient phenomena are not important in shaping the present day H\textsc{ii} gradients. PNe seem to show a flattening of the abundance gradients at large Galactocentric distances similar to that of H\textsc{ii} regions (Maciel 1997, private communication), these flattenings are not explained by the model of Allen et al. (1998, see also Carigi 1996), and probably imply that gas flows are important in the outer regions of the Galaxy (see reviews by Peimbert 1995; Maciel 1997).

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