PLANETARY NEBULAE AND THE CHEMICAL EVOLUTION OF GALAXIES

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1. INTRODUCTION

Tinsley (1978) has done an excellent review that illustrates the methods and concepts that can be developed to assess the effects of planetary nebulae (PN) on the long-term history of the galaxy. Tinsley concluded that research in PN could put constraints on the past rate of star formation and provide information on chemical enrichment by low mass stars.

In fact, the relationship between PN and chemical evolution of galaxies is twofold; one aspect of this relationship is the constraints produced by studies of PN on the fundamental parameters of chemical evolution: accretion of gas in galaxies, yields of primary and secondary elements, the initial mass function (IMF) and the variations in time and location of the stellar formation rate (SFR). On the other hand, chemical evolutionary models of galaxies, based on independent evidence, can clarify and put constraints on our theoretical understanding of the mixing and ejection processes in the stars precursors of PN. In this review some recent examples of this twofold relationship are illustrated.

2. MASSES OF THE PROGENITORS

PN are of interest to study the chemical evolution of galaxies and to test theories of nucleosynthesis. Firstly, because the initial mass of the stars that produce them is relatively low (1 to 5 $M_{\odot}$) and this means high numbers, long stellar lifetimes and, hence, information on the conditions of star formation (abundances, IMF, SFR) long ago. Secondly, because PN are produced in the final stages of the active stellar lifetime and their abundances reflect not only the composition at the time and place of birth, but also show the effect of newly synthesized material . In this sense, they contribute to the enrichment of chemical abundances in the interstellar medium. For both reasons, the fundamental parameters that affect models of chemical evolution are the nebular abundances and masses as a function of the initial mass of the star (see e.g. Iben and Truran 1978; Renzini and Voli 1981; Iben and Renzini 1982,

D. R. Flower (ed.), Planetary Nebulae, 463–472.

and references therein).

The number of objects for which a crude estimate of their masses at the zero age main sequence can be made is very small (see Méndez and Niemela 1981; Peimbert and Serrano 1980; Calvet and Peimbert 1982); binary central stars, as in NGC 3132 and 2346, or probable members of a cluster, as NGC 2818, are rare to find. Moreover, the known masses happen to be very similar (about 2.4 $M_{\odot}$). Hence, in order to estimate the dependance on initial stellar mass, statistical arguments must be used.

1.1 TYPE I PN: THOSE WITH MASSIVE PROGENITORS

Greig (1971) has classified PN into two main groups according to their morphology. Cudworth (1974) finds that the kinematics of these groups correspond to stars of 1 and 1.5 $M_{\odot}$, respectively. On the other hand, Peimbert (1978) has divided PN into four groups, according to their He and N abundances and to their kinematics (see also Peimbert's review in this Symposium).

From a review of the best observed PN, Peimbert and Serrano (1980) suggest that Peimbert's Type I PN are more massive than Types II and III and that the dividing line between them corresponds to objects of $\sim$ 2.4 $M_{\odot}$. In Figure 1, a comparison is shown between He/H and N/O

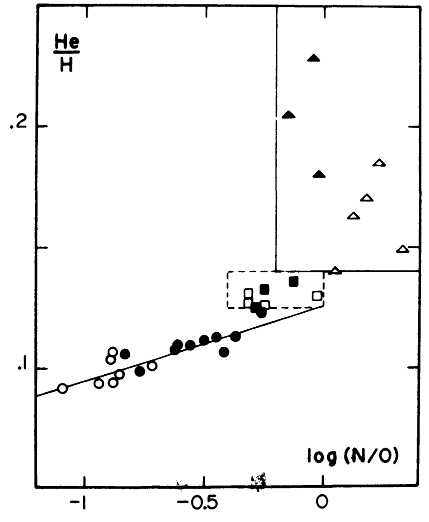

Fig. 1. Comparison of N(He)/N(H) and N(N)/N(O) ratios. Full and open symbols represent PN in the direction of the galactic center and galactic anticenter respectively. Triangles are Type I, squares are Type I-II and circles are Types II or III. The solid line is the least squares solution for PN of Types II and III.

abundance ratios. There is a clear separation between Type I PN and the rest. The three objects of known initial stellar mass mentioned above are all of Type I-II. This suggests that stars more massive than $\sim 2.4\ M_\odot$ give rise to Type I PN with large overabundances of He and N, while stars with mass smaller than $2.4\ M_\odot$ would give rise to PN Types II and III. According to Peimbert and Serrano, the fraction of Type I PN is the 10 to 30% range.

A knowledge of the fraction of Type I PN and of the lower mass limit for their formation can be combined with the stellar birthrate to estimate stars of the various types of PN. Adopting Serrano's (1978) IMF and a fraction of 20%, Peimbert and Serrano find that stars in the 2.4 to $4.6\ M_\odot$ range produce PN of Type I, while stars in the 1 to $2.4\ M_\odot$ range produce PN of Types II and III. The upper limit of $4.6\ M_\odot$ should correspond to the minimum mass, M_W, required to produce a degenerate carbon-oxygen core of $1.4\ M_\odot$. Renzini and Voli (1981) obtained similar values of M_W if the parameter η in the Reimer's (1975) formula for the mass loss rate is 1/3. It is also similar to the value obtained by van den Heuvel (1975). However, Romanishin and Angel (1980) have obtained, from counts of faint blue objects in open clusters, that M_W is probably $\sim 7\ M_\odot$. Such a value would imply a higher η and either a fraction of Type I PN higher than 20%, or that stars of $\sim 1\ M_\odot$ very seldom become PN (see, however, Renzini 1981).

1.2. THE ENVELOPE MASSES

It is well known that the electron densities derived from forbidden lines are usually higher than those derived from the flux in Hβ. Thus, lower and upper bounds for the envelope mass can be derived by assuming either extreme density fluctuations or the density indicated by the Hβ flux, respectively. Taking the filling factor found by Torres-Peimbert and Peimbert (1977) and interpolating between the two limits to the mass, Peimbert (1981) has obtained a mean envelope mass for PN of $0.09\ M_\odot$ using the Cahn and Kaler (1971) distance scale, and of $0.25\ M_\odot$ using the Cudworth (1974) distance scale. On the other hand, using the IMF mentioned above, Serrano and Peimbert (1981a) obtained average nebular masses of $0.6\ M_\odot$ and $0.33\ M_\odot$ for Renzini and Voli's cases A and B, respectively. Agreement between theory and observations would favor Renzini and Voli's case B and Cudworth's distance scale. Thus, it appears that Wood and Cahn (1977) have overestimated the luminosity at which a star of a given mass give rise to a PN.

2. ABUNDANCE GRADIENTS

Several authors have obtained abundance gradients from PN (D'Odorico *et al.* 1976, Aller 1976, Torres-Peimbert and Peimbert 1977, Barker 1978). Peimbert and Serrano (1980) used a large sample of the best observed PN and obtained He, N and O abundances as a function of galactocentric distance, as shown in Figure 2. For Type II and III PN there is a correlation between abundance and position for the three elements. Moreover, PN

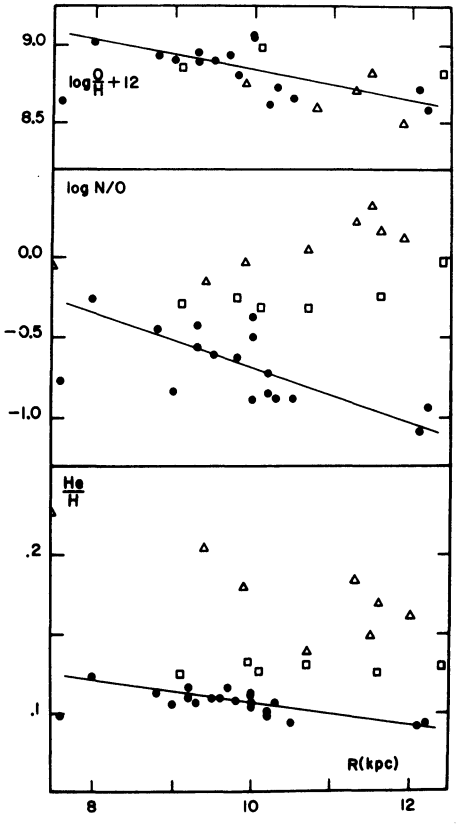

Fig. 2. Abundance ratios of O/H, N/O and He/H compared to the galactocentric distance. A value $R_{\odot}$= 10 kpc was adopted. Symbols as in Figure 1. Lines are least square solutions to PN of Types II and III, without NGC 5307.

of Type I also show a good fit to the gradient of O/H defined by those of Types II and III. On the contrary, N/H and He/H values in PN of Type I do not show any correlation with position.

This difference arises, as Renzini and Voli pointed out, because the first dredge-up dominates in less massive stars, giving rise to relatively small He and N surface enhancements, while the third dredge-up dominates for stars with M> 2.5 $M_{\odot}$, resulting in much higher He and N enhancements at the surface.

Notice, however, that the observed slope Δ(He/H)/Δ(N/O) in Figure 1 for Types II and III PN is ∿ 0.03, while models of stellar evolution predict a very high slope in this mass range (see e.g. Renzini and Voli's Figure 10). This indicates that mixing of N into the envelope has been underestimated for low mass stars (see Iben and Renzini 1982).

Pagel (1978) has shown that in an exponential disk the yield of primary elements, p, is proportional to the gradient of heavy elements. Assuming that O is a constant fraction of the heavy elements abundance, Z, Peimbert and Serrano (1980) obtained, from the gradient of O/H apparent in Figure 2, a yield p= 0.008. This value of p is intermediate between that of metal poor galaxies, p= 0.003, and those of galactic H II regions, p= 0.01, or of the metal rich galaxy M83 (p= 0.014). This fact led Peimbert and Serrano (1982) to suggest that p increases with metallicity and that this is due to a decrease of the amount of low mass stars ($M < 1\ M_\odot$) with Z.

It must be mentioned, however, that Kaler (1980) does not find evidence for a galactic gradient of O/H in PN. He divides PN into age groups and finds that the mean O/H for each group increases with decreasing age, revealing the oxygen enrichment of the galaxy from the formation of the early halo to the present.

3. HELIUM PRODUCTION

A long standing problem in the chemical evolution of galaxies has been the observed helium to heavy elements enrichment ratio by mass, $\Delta Y/\Delta Z = 3\pm1$ (Serrano and Peimbert 1981a, and references therein). Hacyan *et al.* (1976) produce chemical evolution models of the solar neighborhood without being able to fit $\Delta Y/\Delta Z$ and p at the same time.

Helium production is considerably increased when PN and their progenitor stars are taken into account. In Figure 3, He production of a

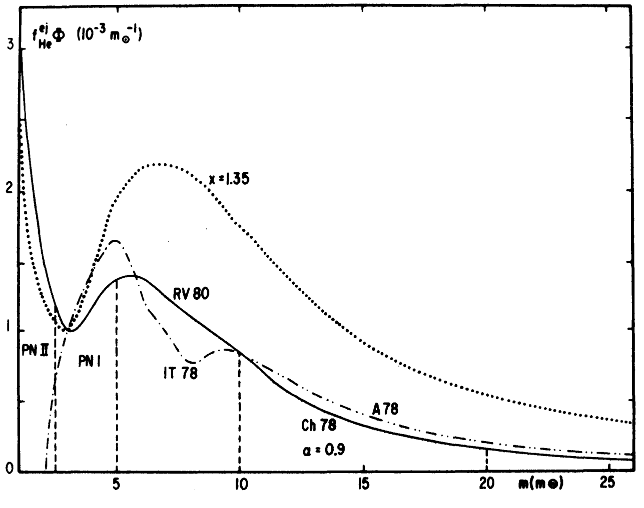

Fig. 3. Weighted fraction of the mass of the star contributing to the He production, per unit stellar mass.

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TABLE 1

$\Delta Y/\Delta Z$ FOR DIFFERENT ASSUMPTIONS ABOUT MASS LOSS

Models adopted for mass loss		Properties at G= 0.1		Maximum
Intermediate mass stars	Massive stars (α)	ΔY	$t(10^9\ y)$	$\Delta Y/\Delta Z$
RV80 (Std.)	0.9	0.032	12.19	3.06
"	0.8	0.032	"	2.28
"	0.0	0.031	"	1.01
IT78	0.9	0.026	12.22	2.47
no	0.9	0.013	"	1.23

RV80= Renzini and Voli 1980; IT78= Iben and Truran 1978; α of Chiosi *et al.* 1978.

generation of stars is shown. In is clear from this figure (taken from Serrano and Peimbert 1981a) that intermediate mass stars contribute with 2/3 of the newly formed He ejected per generation of stars. PN of Type I contribute with 1/6 of the total He production, the same as those of Type II. In Table 1, $\Delta Y/\Delta Z$ is shown for different assumptions about mass loss in intermediate and in massive stars. Chiosi and Matteucci (1982) have also constructed detailed models of the chemical evolution of the solar neighborhood in which $\Delta Y/\Delta Z$ is consistent with the observed value. It must be stressed that not only the third dredge-up but also envelope burning (as in Renzini and Voli 1981) is necessary to account for the observed $\Delta Y/\Delta Z$.

4. CARBON PRODUCTION

Observed C abundance in PN seem to agree with the predictions of evolution models of intermediate mass stars (Figure 4). Exceptions are the halo PN, and two Type I PN. The halo PN seem to have larger C/O values than those predicted by stellar models of metal poor stars (Peimbert 1981; Torres-Peimbert et al. 1981). The opposite effect is shown by the type I PN NGC 6853 and, particularly, NGC 6302 (not shown in Fig. 4); these planetaries have relatively low C abundance but high He/H.

From Figure 4 it would seem that models with envelope burning ($\alpha \neq 0$) produce abundances nearer to the observed ones than models without it. If case B is preferred, as other arguments suggest, then models with higher mass loss rates reproduce better the observed abundances. PN of Types II and III have lower He abundances than the models, but this is probably due to the model initial abundances.

A further evidence in this direction comes from a comparison of the C/O values produced by models with varying α and the observed C/O $\sim$ 0.58 in the solar neighborhood. As it is shown in Figure 5 and Table 2, there

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TABLE 2

MODEL C/O FOR DIFFERENT VALUES OF α

α = ℓ/Hp	C/O*
0	0.95
1	0.95
1.5	0.71
2	0.53

* Total C/O ratio by number. The contribution of C(>8)/O is 0.25 in these units.

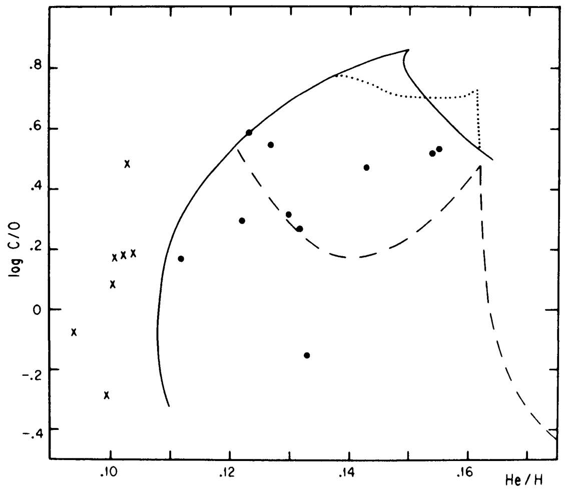

Fig. 4. Model surface abundances at the time of PN ejection (from Renzini and Voli 1981) are represented for a model with α= 0 and case A by a continuous line. Also shown models with α= 2 represented by dashed and dotted lines for cases A and B respectively. Case B corresponds to lower mass planetaries and α measures the importance of envelope burning. Observed points for PN of Types II and III (X) are taken from Peimbert 1981, and those of Type I PN(.) from Peimbert and Torres-Peimbert (1982).

is galactic overproduction of C unless envelope burning is effective,i.e. α >2 (Serrano and Peimbert 1981b). Moreover, as shown in Table 3, the lower mass limit for PN I formation is consistent with the discussion in §1, only if α >2.

5. NITROGEN PRODUCTION

To study the galactic enrichment of N it is necessary to know which stars are responsible for it and if the production is due to primary or secondary mechanisms.

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TABLE 3

MINIMUM MASS REQUIRED TO PRODUCE PLANETARY NEBULAE OF TYPE I*

$\alpha = \ell/H_p$	m_{min} ($M_\odot$)
0	...
1	7.4
1.5	4.3
2	3.4

*From models by Renzini and Voli (1981)

PN of Types II and III show moderate production while PN of Type I show much larger overabundances of N (Peimbert 1978). Primary production of N, if present, should be easiest to achieve in PN of Type I. However, Serrano and Peimbert (1982) have shown that the N/O vs O/H diagram for external galaxies can only be explained if N is mainly a secondary product of the low mass stars (nevertheless, for a different interpretation, see Edmunds and Pagel, 1978).

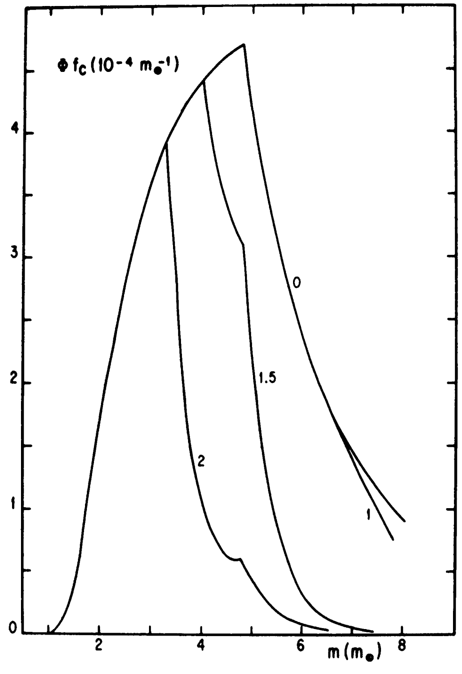

Fig. 5. Weighted fraction of the newly formed carbon, $f_c\Phi$, as a function of initial stellar mass. The area under the curve gives the fraction of an average stellar mass, in a generation of stars, which is ejected as newly formed carbon, in the $1 \leqslant m/M_\odot \leqslant 8$ range, $\langle f_c(1\text{-}8)\rangle$.

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KWOK: A more realistic value for η is 2.5, rather than 0.3.
The fact that mass-loss from AGB stars is the major contributor to the ISM was recognized by Woolf as early as 1971.

SERRANO: I would agree that η should be larger than 0.3, but smaller than 2.5. Regarding mass-loss from AGB stars, the current (unsolved) problem is to determine the composition of the mass which is lost in order to compare with the observed abundances in the ISM.