Rev. Mexicana Astron. Astrof., 5, 9-18 (1980).

ON THE HELIUM AND NITROGEN ENRICHMENT OF THE INTERSTELLAR MEDIUM BY PLANETARY NEBULAE

M. Peimbert and A. Serrano

Instituto de Astronomía
Universidad Nacional Autónoma de México
Received 1979 June 11

RESUMEN

Se analizan los diversos tipos de nebulosas planetarias, NP, para estudiar la contribución al enriquecimiento del medio interestelar, en helio y elementos pesados, debida a estrellas de poca masa. A partir de observaciones de NP en la Galaxia y en las Nubes de Magallanes se encuentra que las NP de Tipo I constituyen aproximadamente el 20% del total de NP. Las NP de Tipo II sirven como traza de gradientes de composición química a lo largo del disco de la Galaxia. Las NP de Tipo I enriquecen el medio interestelar con helio producido por ellas mientras que las NP de Tipo II muestran el cociente de He/H con el que se formaron. Se presenta evidencia en favor de una mayor masa para las NP de Tipo I que para las de Tipo II; esta evidencia indica que la frontera entre los dos tipos se encuentra aproximadamente en 2.4 $M_\odot$.

ABSTRACT

To study the contribution from stars in the $1 < M/M_\odot < 5$ range to the enrichment of the interstellar medium a discussion of the various types of planetary nebulae (PN) is made. From observations of PN in the Galaxy and in the Magellanic Clouds it is found that PN of Type I comprise about 20% of the total number of PN. Type II PN delineate well defined abundance gradients across the galactic disk. Type I PN enrich significantly the interstellar medium with freshly made helium while Type II PN present the He/H abundance ratios with which they were formed. Evidence is presented that suggests that Type I PN are more massive than Type II PN and that the dividing line between them corresponds to objects of $\sim 2.4\ M_\odot$.

Key words: **ABUNDANCES – ABUNDANCE GRADIENTS – PLANETARY NEBULAE.**

I. INTRODUCTION

Low mass stars eject a considerable fraction of their masses into the interstellar medium before becoming white dwarfs. Part of this process can be studied in the planetary nebulae stage of stellar evolution. PN show significant differences in their He, N and O abundances (e.g. D'Odorico *et al.* 1976; Aller 1976; Torres-Peimbert and Peimbert 1977; Barker 1978; Kaler 1979). Peimbert (1978*a*) argues that for most PN, particularly those of Type II, the He and O enrichment due to their evolution has not been considerable and that the differences are related to the gradients present in the interstellar medium at the time of formation of the progenitor stars. Alternatively, Kaler *et al.* (1978; see also Kaler 1978, 1979) have proposed that the He enrichment in a substantial fraction of PN is due to the second dredge-up episode. It is the purpose of this paper to study the enrichment of the ISM by PN and in particular, to study the relative importance that abundance gradients and the second dredge-up episode have on the observed He/H abundance ratios.

II. TYPES OF PLANETARY NEBULAE

Peimbert (1978*a*) has divided PN into four types according to their chemical composition. In order of decreasing helium and heavy element abundances the types are: I) He and N rich, II) intermediate, III) high velocity and IV) halo population. In what follows we will define the various types.

Type I present $N(He)/N(H) \geqslant 0.14$, or $\log N/O > 0.0$ for those objects without a He/H determination. Type I-II present $0.140 > N(He)/N(H) \geqslant 0.125$. Types II and III present $N(He)/N(H) < 0.125$ and $\log N/O < -0.2$; Type II PN are intermediate population

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System

1980RMxAA...5....9P

objects with a distance to the galactic plane, z, smaller than 1 kpc and a peculiar radial velocity, v_{PR}, smaller than 60 kms^{-1} while Type III PN are population II objects with a z larger than 1 kpc or a v_{PR} larger than 60 km s^{-1}. In many cases it is difficult to place an object as Type II or Type III because the distances to most PN are only poorly known; for optically thin PN the difference between the two most widely used distance scales, those of Cahn and Kaler (1971) and Cudworth (1974), is of about 1.5 and each of these scales only provides a statistical distance since they are based on the assumption that the root mean square mass is the same for all PN. Type IV PN are extreme population II objects that belong to the halo, a discussion of them is given elsewhere (Torres-Peimbert and Peimbert 1979).

Kaler (1979) has compiled a list of 98 objects with determinations of one or more of the following abundance ratios: He/H, N/H, O/H and N/O. To this list we will add M3-35 and IC 4997 (see Tables 1 and 2) and subtract M1-67 and NGC 6857 which are H II regions and not PN (Pişmiş and Recillas-Cruz 1979; Chopinet and Lortet-Zuckermann 1976; Bridle and Kesteven 1970). The accuracy of the abundance determinations varies considerably from object to object and extreme care should be taken to analyze the data.

From the available data we have listed in Table 1 *all* the objects with $N(He)/N(H) \geqslant 0.125$. The He/H, N/O and O/H abundance ratios are average values derived from the sources of column 7 giving equal weight to all determinations and adopting a mean square temperature fluctuation, t^2, equal to 0.035. Determinations based on the same observational data often yield slightly different results, due to different weighting procedures, and were considered as independent. The heavy element abundance by mass, Z, was computed under the assumption that it is proportional to oxygen and that O constitutes 45% of Z (Peimbert and Torres-Peimbert 1974). R, z and r represent the galactocentric distance, the distance perpendicular to the galactic plane and the radius of the object respectively; to derive these values we adopted the Cudworth (1974) distance scale, $R_{\odot} = 10$ kpc and the angular sizes in the catalogue of Perek and Kohoutek (1967). To derive the velocities with respect to the local standard of rest, v_{LSR}, we adopted the solar motion determined by Woolley *et al.* (1970) and the observed radial velocities compiled by Acker (1978). The peculiar radial velocity, v_{PR}, was obtained from v_{LSR} and the rotation curve by Burton (1971, equation 7).

In Table 1 we have included two bulge PN, it is not clear if the helium excess corresponds to a higher He/H abundance ratio in the region of the bulge where they were formed or if they have produced it themselves.

In Table 2 we present the best observed planetary nebulae of Types II and III of the solar neighborhood that were chosen considering the following criteria: a) projected galactocentric distance between 7 and 13 kpc excluding H4-1 which is a Type IV PN; b) known angular diameter, to be able to estimate the distance; c) $\log T_{*} > 4.65$, to exclude those objects with a substantial amount of neutral helium and thus without accurate He/H ratios; d) objects whose relevant line intensities come from Torres-Peimbert and Peimbert (1977) and show a semicolon were excluded; and e) errors in their N(He)/N(H) ratio smaller than 0.012 according to Kaler (1979). By comparing different abundance determinations it is estimated that the nominal accuracy in the N/O ratio is about 0.1 dex. The columns were derived in a similar fashion to those of Table 1. The He/H abundance ratios by Kaler (1979) of NGC 3211 and NGC 4361 were not taken into account due to a misprint in the first case and to the very large differences with the results by Torres-Peimbert and Peimbert (1977) and Barker (1978) in the second case. Kaler (1979) has suggested that the usual formula to derive the N/O abundance ratio does not apply to objects with a very high degree of ionization, those with $N(He^{++})/N(He) \geqslant 0.50$. Consequently we do not present N/O ratios for these objects.

It should be emphasized that, unlike Table 2 where we present only the best observed PN with $N(He)/N(H) < 0.125$, in Table 1 we present *all* the known objects with $N(He)/N(H) \geqslant 0.125$ and note that most of these objects have observations of low accuracy and should be observed again. Nevertheless we consider that the He-N overabundances for Type I PN in Table 1 are significant in defining them as a group.

III. ABUNDANCE GRADIENTS AND THE YIELD OF PRIMARY ELEMENTS

In Figure 1 we have plotted the He/H versus N/O abundance ratios given in Tables 1 and 2. No tight correlation is present for Type I PN between N/O and He/H. In this figure there is a very tight correlation for PN of Types II and III. Moreover, II and III PN with low N/O and He/H ratios are in the anticenter's direction while those with high N/O and He/H are in the center's direction. From this figure we conclude that two different effects are needed to explain the N/O versus He/H behaviour in PN; one for PN of Types II and III and another for PN of Type I.

In Figure 2 we have plotted the He/H abundance ratio versus the radius of the shell with the idea of checking the existence of a possible systematic effect in the abundance determinations or an increase of the He/H abundance ratio with radius. No such effects were found. This implies that Type II PN do not become

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System

1980RMxAA...5....9P

TABLE 1

PLANETARY NEBULAE OF TYPES I AND I-II

Object	He/H	log(N/O)	12+log(O/H)	Y	Z	Type	Source	R (kpc)	z (kpc)	V_{LSR} (km s^{-1})	V_{PR} (km s^{-1})	r (pc)
NGC 6445	.228	-0.04	....	....	....	I	1,2	7.5	+ .36	+ 28	+ 16	.21
NGC 6302	.205	-0.15	....	....	....	I	2,3,4	9.4	+ .01	- 32	- 29	.07
PB -6	.185	+0.23	8.72	.421	.011	I	2,5	11.3	+ .62	....	....	.19
NGC 7293	.180	-0.02	8.75	.414	.011	I	6	9.9	- .18	- 20	- 21	.44
Hu 1-2	.170	+0.17	....	....	....	I	2	11.6	-1.01	+ 19	+ 61	.08
Me 2-2	.163	+0.12	8.49	.392	.007	I	7	11.9	+ .70	-145	- 97	.15
NGC 2440	.149	+0.33	8.82	.368	.014	I	2,5	11.5	+ .10	+ 47	+ 14	.18
M2 -27	.144	+0.12	....	....	....	Bulge	8	....	....	+190	....	...
NGC 2818	.140	+0.05	8.60	.356	.009	I	5,9	10.7	+ .39	- 2	- 21	.28
NGC 6309	....	+0.26	....	....	....	I	2,10	6.9	+ .75	- 36	- 54	.11
M 1-80	....	+0.25	....	....	....	I	2	15.3	+ .31	- 52	+ 50	.17
Cn 2-1	.137	-0.23	....	....	....	Bulge	8	....	....	-262	....	...
NGC 6741	.136	-0.13	....	....	....	I-II:	2	6.1	- .28	+ 55	- 27	.11
NGC 6853	.133	-0.25	....	....	....	I-II:	2	9.8	- .02	- 41	- 46	.31
NGC 650	.131	-0.32	....	....	....	I-II	2	10.7	- .19	- 23	- 8	.37
NGC 2371	.130	-0.03	8.81	.337	.015	I-II	2,5	12.4	+ .88	+ 12	+ 3	.27
NGC 3132	.127	-0.32	8.98	.337	.022	I-II	2,5	10.1	- .35	- 15	- 17	.22
NGC 2346	.126	-0.25	....	....	....	I-II:	2,11,12	11.6	+ .12	+ 29	+ 4	.26
NGC 5315	.125	-0.29	8.85	.328	.016	I-II:	2,5	9.1	- .12	- 33	- 12	.02

(1) Aller *et al.* 1973; (2) Kaler 1976, 1978, 1979; (3) Aller and Czyzak 1978; (4) Danziger *et al.* 1973; (5) Torres-Peimbert and Peimbert 1977; (6) Hawley 1978; (7) Barker 1978; (8) Webster 1976; (9) Dufour and Hack 1977; (10) Perinotto 1974; (11) Kaler *et al.* 1976; (12) Méndez 1978.

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System

TABLE 2

BEST OBSERVED PLANETARY NEBULAE OF TYPES II AND III

Object	He/H	log N/O	12+log(O/H)	Y	Z	Source	R (kpc)	z (kpc)	V_{LSR} (km s^{-1})	V_{PR} (km s^{-1})	r (pc)
NGC 6803	.123	-0.26	9.02	.322	.024	1,2,3	8.0	+ .25	+ 27	+ 10	.05
IC 4997	.117	....	....	....	....	3	9.2	+ .33	- 51	- 71	.007
NGC 3211	.117	....	8.93	.312	.020	2	9.7	.32	- 27	- 19	.13
NGC 4361	.117	....	....	....	....	2	9.7	.97	+ 10	+ 3	.28
NGC 7009	.113	-0.45	8.93	.305	.020	2,3	8.8	- 1.10	- 38	- 57	.13
NGC 7027	.113	-0.37	9.04	.303	.026	2,3	10.0	- .03	+ 20	+ 19	.016
NGC 6884	.112	-0.50	9.06	.301	.027	2,3	10.0	+ .36	- 24	- 25	.045
NGC 3918	.110	-0.61	8.90	.300	.019	2,3	9.5	+ .11	- 17	- 4	.05
NGC 6720	.110	-0.56	8.89	.300	.019	2,3,4	9.3	+ .45	- 7	- 25	.22
M 3-35	.110	....	....	....	....	5	9.6	+ .07	-150	-161	.019
IC 2501	.108	-0.62	8.90	.296	.019	2,3	9.8	- .20	+ 24	+ 29	.010
NGC 6572	.107	-0.42	8.95	.293	.022	2,3	9.3	+ .19	+ 6	- 6	.028
NGC 3242	.107	-0.88	8.72	.296	.013	2,3	10.3	+ .88	- 4	- 12	.16
NGC 6210	.106	-0.84	8.90	.292	.019	3,5,6	9.0	+ 1.08	- 21	- 37	.07
NGC 6826	.104	-0.89	....	....	....	3	10.0	+ .49	+ 7	+ 7	.14
NGC 7026	.101	-0.72	....	....	....	3	10.2	+ .01	- 31	- 26	.08
NGC 5307	.099	-0.77	8.64	.281	.011	2,3	7.6	+ .94	+ 41	+ 99	.16
IC 2448	.098	-0.85	8.61	.279	.010	2,3	10.2	+ 1.54	- 32	- 38	.13
NGC 1535	.094	-0.94	8.58	.271	.010	2,3	12.2	- 2.06	- 20	- 39	.14
NGC 7662	.094	-0.88	8.65	.270	.011	2,3	10.5	- .44	- 7	+ 6	.07
IC 3568	.092	-1.09	8.71	.265	.013	1,5	12.1	+ 2.23	- 36	+ 1	.17

(1) Peimbert and Torres-Peimbert 1971a; (2) Torres-Peimbert and Peimbert 1977; (3) Kaler 1978, 1979; (4) Hawley and Miller 1977; (5) Barker 1978; (6) Danziger 1975.

1980RMxAA...5....9P

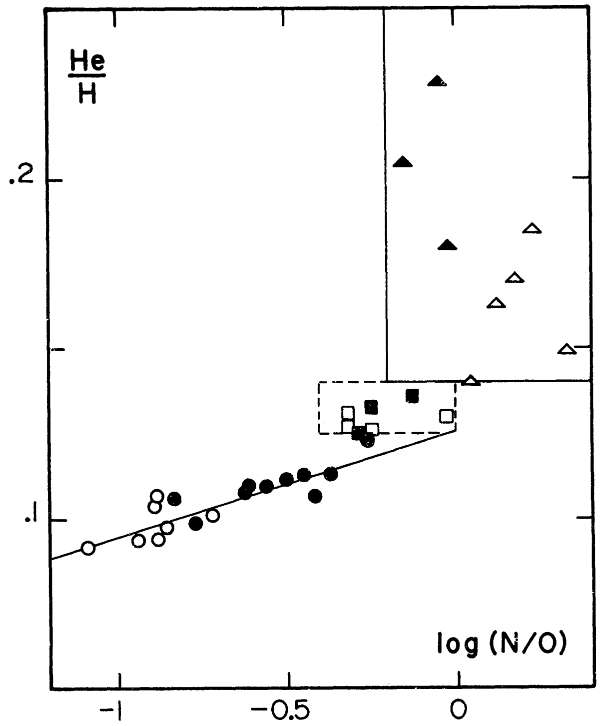

Fig. 1. Comparison of N(He)/N(H) and N(N)/N(O) ratios. Full and open symbols represent PN in the direction of the galactic center and galactic anticenter respectively. Triangles are Type I, squares are Type I-II and circles are Types II or III. The solid line is the least squares solution for PN of Types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

Type I and that the initial conditions of both Types are different.

In Figure 3, we have plotted O/H, N/H and He/H versus galactocentric distance. Significative gradients are present in the three abundance ratios for PN of Type II. Abundance gradients derived from PN had been reported before in the literature (D'Odorico *et al.* 1976; Aller 1976; Torres-Peimbert and Peimbert 1977; Barker 1978), our results are more precise than previous determinations because the sample in Table 2 is larger and includes only the best observed objects available in the literature. In Table 3 we present the logarithmic gradients together with the standard deviation and the correlation coefficient. NGC 5307 is a clearcut Type III PN that deviates considerably from the correlations in the three plots and that maybe should be excluded. The gradients with NGC 5307 included are in excellent agreement with those by Torres-Peimbert and Peimbert (1977) (which also include NGC 5307).

The abundances of the Orion nebula, assumed to be located at R = 10.4 kpc, are: log He = 11.00, log O = 8.75, and log N = 7.76 (Peimbert and Torres-Peimbert 1977); which in the case of He and O are in excellent agreement with those in Table 3 and indicate that Type II PN have not enriched their envelopes with freshly produced He and O. N is up by a factor of three to four which indicates that PN have produced some N in agreement with a previous result by Peimbert and Torres-Peimbert (1971*b*). The He and O gradients are in excellent agreement with those reported by Peimbert (1978*b*) for H II regions and with the O gradient by Talent and Dufour (1979). The O/H values and gradient present in Type I PN are in very good agreement with those of Type II PN while their He/H ratios are very different (see Figure 3); this indicates that Type I PN have not enriched their envelopes with freshly made O and that the He/H enrichment in PN of Type I is not related to their locations at birth but to some other stellar property.

The high values and similar correlation coefficients for the He, O and N abundance gradients of Type II PN are due to their galactocentric distance and not to their original mass. For He and O the gradient corresponds to the interstellar medium gradient, while for N it is a combination of the gradient present in the interstellar medium plus a secondary production whose mechanism, for the mass range comprised by PN of Types II and III, is essentially independent of the stellar mass.

By performing a linear fit to the data in Table 2, instead of an exponential one, it is found that O/H = 0 at R = 15.47 kpc, in very good agreement with the H II region's value of R = 15.77 kpc (Peimbert 1978*b*). This result and the logarithmic abundance gradients in

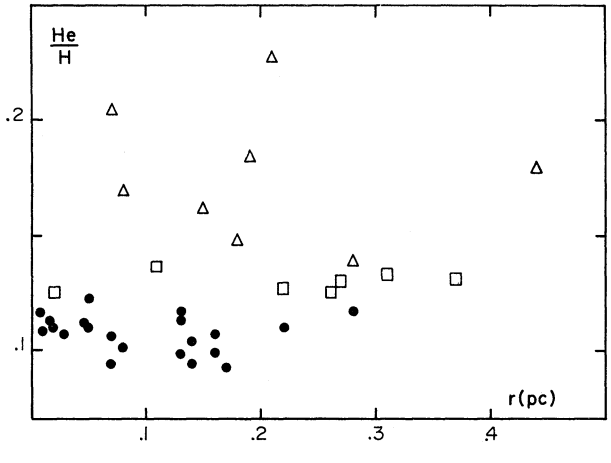

Fig. 2. Comparison of PN helium abundances with nebular radii. Triangles are Type I, squares Type I-II and circles are Types II or III.

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System

1980RMxAA...5....9P

TABLE 3

GALACTIC ABUNDANCES AND GRADIENTS EVALUATED AT R = 10 kpc

X	log(X)*	$\frac{d}{dR}$ log(X) (kpc^{-1})	Correlation coefficient r	t^2 (10^{-2})	Number of objects	Sample
He	11.02 ± .01	−0.019 ± .006	−.59	3.5	21	1
	11.03 .01	−0.029 ± .005	−.81	3.5	20	2
	....	−0.008 ± .008	....	0.0	11	3
O	8.83 ± .04	−0.056 ± .032	−.42	3.5	16	1
	8.84 ± .03	−0.099 ± .028	−.70	3.5	15	2
	8.67 ± .03	−0.044 ± .028	−.39	0.0	16	1
	8.68 ± .03	−0.078 ± .026	−.64	0.0	15	2
	....	−0.059 ± .017	....	0.0	11	3
N/O	−0.71 ± .05	−0.12 ± .04	−.61	3.5	17	1
	−0.69 ± .04	−0.17 ± .04	−.75	3.5	16	2
N	8.17 ± .10	−0.18 ± .08	−.51	3.5	15	1
	8.21 ± .08	−0.27 ± .08	−.71	3.5	14	2
	7.96 ± .08	−0.16 ± .07	−.56	0.0	15	1
		−0.08 ± .02	....	0.0	11	3

* with log H = 12.00.

(1) PN in Table 2; (2) PN in Table 2 without NGC 5307; (3) galactic H II Regions (Talent and Dufour 1979).

Table 3 are based on the Cudworth (1974) distance scale; the distance scale by Cahn and Kaler (1971) would have produced larger gradients and a smaller value for the distance at which O/H becomes zero.

In Table 3 we have also computed the O/H gradient under the assumption of no temperature variations along the line of sight, $t^2 = 0.00$.

Pagel (1978) has derived the yield of primary elements, p, from H II regions of the solar neighborhood based on the following assumptions: a) the simple model of chemical evolution; b) a constant yield over the history of the galactic disk; c) a constant surface density of the gas for the galactocentric distances of interest, and d) a total density proportional to exp($-\alpha$ R), where α is equal to 0.28 kpc^{-1} for the exponential disc radius of Schmidt's (1965) model (Serrano 1978).

These assumptions imply that

$$p = \frac{1}{\alpha} \frac{\Delta Z}{\Delta R} . \qquad (1)$$

From equation (1) and Table 3, we have also derived the yield of primary elements corresponding to PN of Type II. The results are given in Table 4 where again we have assumed that the amount of mass in the form of O constitutes 45% of Z. The considerably smaller yields derived under the assumption of $t^2 = 0.00$ are due to: a) the O/H values are smaller than for $t^2 = 0.035$, and b) the presence of a positive gradient in the electron temperature that reduces the effect of temperature variations along the line of sight for objects at larger galactocentric distances.

TABLE 4

YIELD OF PRIMARY ELEMENTS

t^2 (10^{-2})	p (10^{-3})	Sample
3.5	8±4	1
3.5	14±4	2
0.0	4±3	1
0.0	8±3	2

(1) PN in Table 2; (2) PN in Table 2 without NGC 5307.

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System

1980RMxAA...5....9P

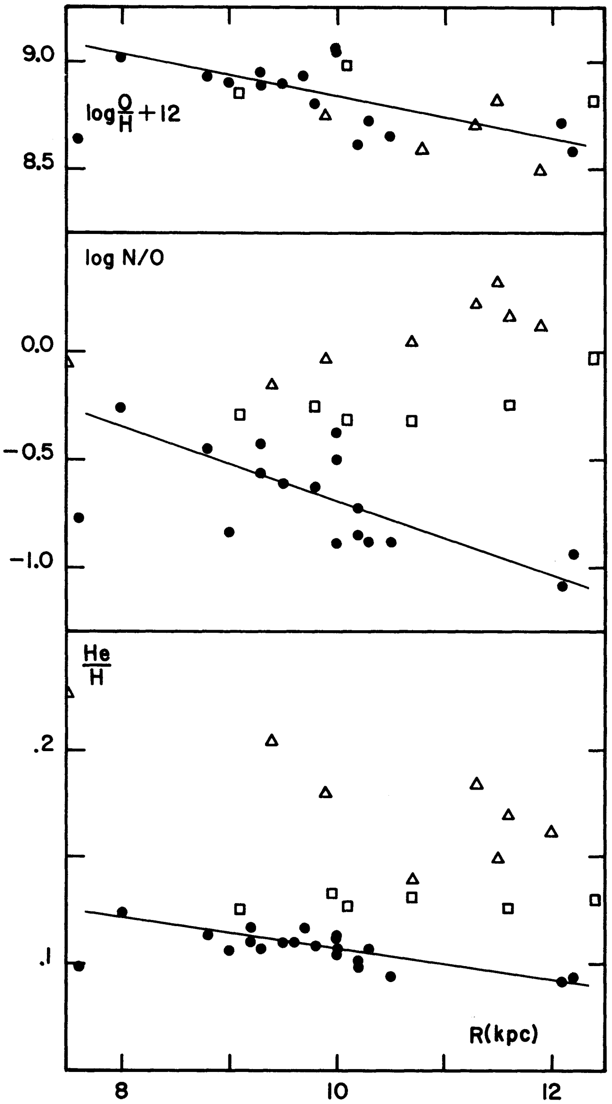

Fig. 3. Abundance ratios of O/H, N/O and He/H compared to the galactocentric distance. A value $R_{\odot}$ = 10 kpc was adopted. Symbols as in Figure 2. Lines are least square solutions to PN of Types II and III, without NGC 5307.

IV. NITROGEN ENRICHMENT AND THE ΔY/ΔZ RATIO DERIVED FROM PN OF TYPES II AND III

We decided to study the abundance correlations of PN of Types II and III that do not depend on distance and the results are given in Table 5, where the errors indicate the standard deviation.

An extrapolation of the He/H versus N/O relation in Table 5 (see also Figure 1) to a pregalactic helium abundance of $Y_P = 0.23$ yields log N/O = −1.65 which is very close to the primary N/O ratio suggested by Lequeux *et al.* (1979) based on irregular and blue compact galaxies.

A relationship of the type $[N/O] = \beta[O/H]$ (where the square brackets denote the usual logarithmic difference) with $\beta = 1$ is predicted by simple models of chemical evolution with instant recycling approximation assuming nitrogen to be of secondary origin (Talbot and Arnett 1973). The result $\beta = 1.24 \pm 0.22$ indicates that PN of Types II and III are producing nitrogen by a secondary process in agreement with the higher value found for PN than for H II regions; this N enrichment could have been produced during the first ascent up the giant branch (Iben 1964, 1967*a*; Torres-Peimbert and Peimbert 1971). From the He and O abundances and assuming that there is no enrichment of these elements in the PN envelopes it is found that $Y = 0.254 + 2.2\ Z$ (Table 5), this result is similar to that derived from H II regions (Lequeux *et al.* 1979). The result for $t^2 = 0.00$ is also presented in Table 5.

A thorough discussion of the ΔY/ΔZ ratios and the p values derived from observations of PN and other objects is presented elsewhere (Serrano and Peimbert 1980).

V. HELIUM ENRICHMENT AND THE FRACTION OF PN OF TYPE I

Kaler *et al.* (1978) (see also Kaler 1978, 1979) have proposed that the relatively high He/H and N/O values as well as the positive correlation between them observed

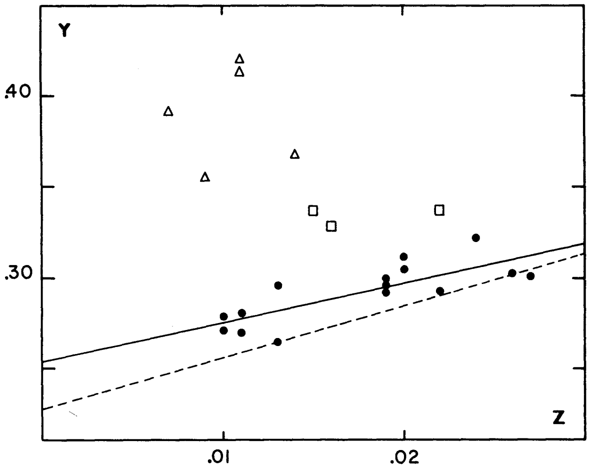

Fig. 4. Comparison of helium and heavy element abundances. Symbols as in Figure 2. The solid line is the least squares solution of slope 2.2 for the PN of Types II and III; the broken line is the least squares solution for galactic and extragalactic H II regions by Lequeux *et al.* (1979).

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System

TABLE 5

ABUNDANCE CORRELATIONS FROM PN OF TYPES II AND III

Relationship	Correlation coefficient r	t^2 (10^{-2})	Number of objects
He/H = .126 ± .003 + (.031 ± .004)log(N/O)	.87	3.5	17
log(N/O) = −11.59 ± 1.95 + (1.24 ± 0.22)[log(O/H) + 12]	.84	3.5	15
log(N/O) = −13.66 ± 2.41 + (1.50 ± 0.28)[log(O/H) + 12]	.83	0.0	15
Y = 0.254 ± .009 + (2.20 ± 0.46)Z	.79	3.5	16
Y = 0.249 ± .010 + (3.63 ± 0.76)Z	.79	0.0	16

in PN is due to the second dredge-up episode, a process predicted to occur in objects with masses larger than 3 $M_\odot$ (Iben 1972; Iben and Truran 1978). This suggestion might apply to a small fraction of PN, those of Type I, but it does not apply to the large majority of PN, those of Types II and III. There are four reasons why it does not apply to those of Type II: a) the absolute value of the He/H abundance ratio of H II regions and Type II PN of the solar neighborhood are very similar (see §III); b) the substantial spread in the He/H and N/H values is strongly correlated with galactocentric distance (see §III); c) most PN progenitors have masses smaller than 3 $M_\odot$ (see below), and d) the second dredge-up episode predicts that Δ(He/H) = 0.19 [N/O] (Kaler *et al.* 1978) while from PN of Type II we found Δ(He/H) = 0.03 [N/O] (Table 5), a difference of a factor of six on the slope.

To be able to compare the theoretical predictions of helium enrichment with the observations, it is necessary to estimate the initial masses of the PN progenitors. Osterbrock (1973) obtains a mean distance $\langle z \rangle$ perpendicular to the galactic plane for PN of Type II of 150 pc while Alloin *et al.* (1976) obtain $\langle z \rangle$ = 130 pc from the Cahn and Kaler (1971) distance scale and $\langle z \rangle$ = 190 pc from the Cudworth (1974) distance scale; these values correspond to an average mass on the main sequence of 1.4 to 1.5 $M_\odot$ for the stellar progenitors of PN. This average mass, the steepness of the IMF (Serrano 1978) and the fact that low mass stars seldom become PN (van den Bergh 1973; Alloin *et al.* 1976) imply that most PN progenitors have masses smaller than 3 $M_\odot$. It is of great importance to determine the fraction of PN of Type I and the masses associated with these objects to try to find out if they correspond to more massive progenitor stars than those of PN of Type II. If that were the case, the possibility that the He enrichment in Type I PN were due to the second dredge-up mechanism would be strengthened.

There are three objects in Table 1 for which a crude estimate of their masses at the zero age main sequence can be made: NGC 3132, NGC 2346 and NGC 2818.

Since the classification of HD 87892 as an A-type star (Evans 1964), this object, located in the center of NGC 3132, is no longer considered to be the ionizing source of the PN. Méndez (1975) proposed a binary nature for HD 87892 and computed the physical parameters of the optically fainter component responsible for the PN ionization. Kohoutek and Laustsen (1977) discovered a faint companion which they claim is probably associated to HD 87892 (see also Méndez *et al.* 1978). The projected separation between both components is of about 1500 AU which implies that their binary nature has not affected their individual evolution. Méndez (1978) has estimated that the brighter companion is an A2 V star, with $T_{eff} \approx 9500$°K, log g $\approx$ 4.0 and $M/M_\odot = 2.4 \pm 0.7$, starting to evolve off the main sequence. The Ca II equivalent width of HD 87892 (Méndez 1978) implies a T_{eff} = 9200°K (Rodgers 1971), which is not in contradiction with the temperature inferred from the Balmer discontinuity (Stickland 1971); by adopting this temperature, log g = 4.00 and the models by Iben (1967*b*) we estimate a mass of 2.1±0.3 $M_\odot$ for this object. By considering the time that it takes a star to travel from the main sequence to the PN phase we estimate that the PN nucleus had an initial mass on the main sequence of about 2.5 $M_\odot$ (Iben 1967*b*, 1974).

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System

Lutz (1977) has classified the central star in NGC 2346 as A2 V. Unlike HD 87892 we do not know how long has this star been on the main sequence. By assuming that the A2 V star has an unseen companion which has produced the PN shell and its ionization, and considering that we only have an upper limit for the age of the A2 V star we can only estimate a lower limit of about 2.5 $M_\odot$ for the PN progenitor (Iben 1967*b*, 1974). It should be mentioned that Méndez (1978) has given arguments suggesting that the A star is a foreground horizontal-branch object.

NGC 2818 apparently is a member of the open cluster with the same name, the cluster has a main sequence turn-off at about A5 or $(B-V)_0 = 0.15 \pm 0.04$ (Tifft *et al.* 1972) which combined with the temperature calibration by Code *et al.* (1976) and the models by Iben (1967*b*) corresponds to a turn-off mass of 1.8 ± 0.3 $M_\odot$; again by considering the time that it takes a star to travel from the main sequence to the PN phase a mass of 2.1 $M_\odot$ is estimated for the PN progenitor (Iben 1967*b*, 1974).

NGC 3132, NGC 2346 and NGC 2818, are mild examples of He-N enrichment, under the hypothesis that the more massive objects would show a higher He-N enrichment, the lower mass limit for this process to occur would be around 2.4 $M_\odot$, the average of the three mass determinations.

To explain the observed He/H abundance ratios in Type I PN the efficiency of helium production by the second dredge-up mechanism has to be higher than that proposed by Kaler *et al.* (1978), since according to them the He/H ratios of NGC 2818, NGC 2346 and NGC 3132 correspond to masses in the 5-7 $M_\odot$ range, masses which are considerably higher than those derived here.

Other mechanisms not associated with a high mass might be responsible for the Type I phenomenon, in this respect it should be noted that Me 2-2 and Hu 1-2 show high v_{PR} values possibly indicating a low mass for the PN progenitors, nevertheless a smaller distance for Hu 1-2 and a larger one for Me 2-2 would reduce the v_{PR} values considerably.

To estimate the fraction of Type I PN we have subtracted from the sample in §II 5 bulge PN and 15 objects with $\log T_* < 4.65$, which reduces the number of PN in the sample to 78. From Table 1 the number of Type I PN is 10 and the number of Type I-II PN is 7 which amount to fractions of 13% and 9% respectively. Webster (1978), based on previous work (Webster 1976; Osmer 1976; Dufour and Killen 1977), presented a review on PN in the Magellanic Clouds; from this review, it is found that 5 out of 19 PN are of Type I which amounts to a fraction of 26% There are several selection effects difficult to evalute. PN of Types I and II are still very bright at sizes of 0.4 pc (see Figure 2) and their velocities of expansion are similar (Wilson 1950), therefore it can be concluded that the lifetimes of PN of Types I and II are also similar; NGC 6302 seems to be an exception since it shows a relatively large velocity of expansion (Minkowski and Johnson 1967). If Type I objects are really more massive than other types of PN, then dust absorption in the galactic plane would produce a selection effect against finding Type I objects in the Galaxy; this effect would not apply to PN in the Magellanic Clouds. Alternatively, due to their higher masses. Type I PN would become optically thin in a later phase making them, on the average, brighter than PN of other types.

Considering the size of the samples and the selection effects it is estimated that the fraction of Type I PN is in the 10 to 30% range.

An estimate of the mass range for the progenitor stars of the various types of PN can be made under the following assumptions: a) the fraction of stars that produce Type I PN is 20%; b) Type I PN correspond to the most massive PN progenitors with a lower mass limit of approximately 2.4 $M_\odot$ in the main sequence; c) stars with main sequence masses smaller than 1 $M_\odot$ seldom become PN (van den Bergh 1973; Alloin *et al.* 1976); d) The IMF by Serrano (1978) with the high-mass portion and the low-mass portion merging at 1.5 $M_\odot$. These assumptions imply that stars in the 2.4 to 4.6 $M_\odot$ range produce PN of Type I and stars in the 1 to 2.4 $M_\odot$ range produce PN of Types II and III.

VI. CONCLUSIONS

The very large He/H and N/O ratios derived for PN of Type I and their lack of correlation with galactocentric distance (see Table 1 and Figure 3) cannot be attributed to the abundance gradients present in the Galaxy nor to observational errors; these objects indeed show an excess of He and N with respect to Type II PN and H II regions located at similar galactocentric distances. This excess is probably produced by the stellar evolution of the parent star and might be associated to the second dredge-up mechanism.

The He/H and O/H abundance ratios of Type II PN are similar to those of H II regions at comparable galactocentric distances. This result implies that PN have not enriched appreciably their envelopes with freshly made He and O and that they can be used to study the yield of primary elements and the $\Delta Y/\Delta Z$ ratio.

Type I-II PN comprise: a) objects that show a mild case of helium enrichment, produced by the progenitor star that should be classified as Type I, and b) Type II objects that have been misclassified due to observational errors. In past photographic work weak lines have

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System

been systematically overestimated, this effect yields higher He/H ratios and higher electron temperatures which in turn produce spuriously large N^+/O^+ and N/O ratios. Type I-II PN should be reclassified based on better observations.

The yield of primary elements and the $\Delta Y/\Delta Z$ ratio derived from Type II PN as well as the contribution of Type I PN to the helium enrichment of the interstellar medium have been used elsewhere in models of galactic chemical evolution (Serrano and Peimbert 1980).

REFERENCES

Acker, A. 1978, *Astr. and Ap. Suppl.*, **33**, 367.

Aller, L.H. 1976, *Pub. A.S.P.*, **88**, 574.

Aller, L.H., and Czyzak, S.J. 1978, *Proc. Natl. Acad. Sci.*, **75**, 1.

Aller, L.H., Czyzak, S.J., Craine, E., and Kaler, J.B. 1973, *Ap. J.*, **182**, 509.

Alloin, D., Cruz-González, C., and Peimbert, M. 1976, *Ap. J.*, **205**, 74.

Barker, T. 1978, *Ap. J.*, **220**, 193.

Bridle, A.H., and Kesteven, M.J.L. 1970, *A.J.*, **75**, 902.

Burton, W.B. 1971, *Astr. and Ap.*, **10**, 76.

Cahn, J.H., and Kaler, J.B. 1971, *Ap. J. Suppl.*, **22**, 319.

Chopinet, M., and Lortet-Zuckermann, M.C. 1976, *Astr. and Ap. Suppl.*, **25**, 179.

Code, A.D., Davis, J., Bless, R.C., and Hanbury Brown, R. 1976, *Ap. J.*, **203**, 417.

Cudworth, K.M. 1974, *A.J.*, **79**, 1384.

Danziger, I.J. 1975, *Astr. and Ap.*, **38**, 475.

Danziger, I.J., Frogel, J.A., and Persson, S.E. 1973, *Ap. J. (Letters)*, **184**, L29.

D'Odorico, S., Peimbert, M., and Sabbadin, F. 1976, *Astr. and Ap.*, **47**, 341.

Dufour, R.J., and Hack, E.C. 1978, in *Planetary Nebulae: Observations and Theory*, IAU *Symp.* No. 76, ed. Y. Terzian, (Dordrecht: D. Reidel), p. 66.

Dufour, R.J., and Killen, R.M. 1977, *Ap. J.*, **211**, 68.

Evans, D.S. 1964, *M.N.A.S.S.A.*, **23**, 84.

Hawley, S.A. 1978, *Pub. A.S.P.*, **90**, 370.

Hawley, S.A., and Miller, J.S. 1977, *Ap. J.*, **212**, 94.

Iben, I., Jr. 1964, *Ap. J.*, **140**, 1631.

Iben, I., Jr. 1967*a*, *Ap. J.*, **147**, 624.

Iben, I., Jr. 1967*b*, *Ann. Rev. Astr. and Ap.*, **5**, 571.

Iben, I., Jr. 1972, *Ap. J.*, **178**, 433.

Iben, I., Jr. 1974, *Ann. Rev. Astr. and Ap.*, **12**, 215.

Iben, I., Jr. and Truran, J.W. 1978, *Ap. J.*, **220**, 980.

Kaler, J.B. 1976, *Ap. J.*, **210**, 113.

Kaler, J.B. 1978, *Ap. J.*, **226**, 947.

Kaler, J.B. 1979, *Ap. J.*, **228**, 163.

Kaler, J.B., Aller, L.H., and Czyzak, S.J. 1976, *Ap. J.*, **203**, 636.

Kaler, J.B., Iben, I., Jr., and Becker, S.A. 1978, *Ap. J. (Letters)*, **224**, L63.

Kohoutek, L., and Laustsen, S. 1977, *Astr. and Ap.*, **61**, 761.

Lequeux, J., Peimbert, M., Rayo, J.F., Serrano, A., and Torres-Peimbert, S. 1979, *Astr. and Ap.*, **80**, 155.

Lutz, J.H. 1977, *Astr. and Ap.*, **60**, 93.

Méndez, R.H. 1975, *Ap. J.*, **199**, 411.

Méndez, R.H. 1978, *M.N.R.A.S.*, **185**, 647.

Méndez, R.H., Niemela, V.S., and Lee, P. 1978, *M.N.R.A.S.*, **184**, 351.

Minkowski, R., and Johnson, H.M. 1967, *Ap. J.*, **148**, 659.

Osmer, P.S. 1976, *Ap. J.*, **203**, 352.

Osterbrock, D.E. 1973, *Mém. Soc. Roy, Sci. Liège*, 6° serie, **5**, 391.

Pagel, B.E.J. 1978, paper presented at Fourth European Regional Meeting in Astronomy, Uppsala.

Peimbert, M. 1978*a*, in *Planetary Nebulae: Observations and Theory*, IAU *Symp.* No. 76, ed. Y. Terzian (Dordrecht: D. Reidel) p. 215.

Peimbert, M. 1979, *in The Large-Scale Characteristics of the Galaxy*, IAU *Symp.* No. 84, ed. W.B. Burton (Dordrecht: D. Reidel) p. 307.

Peimbert, M., and Torres-Peimbert, S. 1971*a*, *Bol. Obs. Tonantzintla y Tacubaya*, **6**, 21.

Peimbert, M., and Torres-Peimbert, S. 1971*b*, *Ap. J.*, **168**, 413.

Peimbert, M., and Torres-Peimbert, S. 1974, *Ap. J.*, **193**, 327.

Peimbert, M., and Torres-Peimbert, S. 1977, *M.N.R.A.S.*, **179**, 217.

Perek, L., and Kohoutek, L. 1967, *Catalog of Galactic Planetary Nebulae*, (Prague: Czechoslovak Acad. of Sci.).

Perinotto, M. 1974, *Astr. and Ap.*, **35**, 293.

Pişmiş, P., and Recillas-Cruz, E. 1979, *Rev. Mexicana Astron. Astrof.*, **4**, 271.

Rodgers, A.W. 1971, *Ap. J.*, **165**, 581.

Schmidt, M. 1965, in *Galactic Structure*, ed. A. Blaauw and M. Schmidt (Chicago: University of Chicago Press), p. 513.

Serrano, A. 1978, Ph. D. Thesis, University of Sussex.

Serrano, A., and Peimbert, M. 1980, in preparation.

Stickland, D.J. 1971, *M.N.R.A.S.*, **153**, 501.

Talbot, R.J., and Arnett, W.D. 1973, *Ap. J.*, **186**, 51.

Talent, D.L., and Dufour, R.J. 1979, *Ap. J.*, **233**, 888.

Tifft, W.G., Connolly, L.P., and Webb, D.F. 1972, *M.N.R.A.S.*, **158**, 47.

Torres-Peimbert, S., and Peimbert, M. 1971, *Bol. Obs. Tonantzintla y Tacubaya*, **6**, 101.

Torres-Peimbert, S., and Peimbert, M. 1977, *Rev. Mexicana Astron. Astrof.*, **2**, 181.

Torres-Peimbert, S., and Peimbert, M. 1979, *Rev. Mexicana Astron. Astrof.*, **4**, 341.

van den Bergh, S. 1973, in *Variable Stars in Globular Clusters and in Related Systems*, ed. J.D. Fernie (Dordrecht: D. Reidel), p. 26.

Webster, B.L. 1976, *M.N.R.A.S.*, **174**, 513.

Webster, B.L. 1978, in *Planetary Nebulae: Observations and Theory*, IAU *Symp. No.* 76, ed. Y. Terzian (Dordrecht: D. Reidel) p. 11.

Wilson, O.C. 1950, *Ap. J.*, **111**, 279.

Woolley, R., Epps, E.A., Penston, M.J., and Pocock, S.B. 1970, *Royal Obs. Ann.*, No. 5.

Manuel Peimbert and Alfonso Serrano: Instituto de Astronomía, UNAM, Apdo. Postal 70-264, México 20, D.F., México.

© Universidad Nacional Autónoma de México • Provided by the NASA Astrophysics Data System