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GALACTIC ABUNDANCE GRADIENTS FROM PLANETARY NEBULAE

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RESUMO. Considerando uma amostra de 40 nebulosas planetárias de tipo II, com abundâncias e distâncias conhecidas, estudam se os gradientes radiais de He/H, O/H, N/H, N/O, S/H e C/H. São detectados gradientes radiais de He/H e O/H, elementos para os quais são mais confiáveis as determinações de abundâncias.

ABSTRACT. Radial and vertical gradients of He/H, O/H, N/H, N/O, S/H and C/H are studied, considering a sample of 40 type II galactic planetary nebulae, with known abundances and distances. Radial gradients have been detected for He/H and O/H, for which reliable abundance determinations are available.

Key words; planetary nebulae - abundances - gradients

I. INTRODUCTION

The problem of the chemical abundance gradients in spiral galaxies derived from H II regions has been treated by Searle (1971); Benvenuti et al. (1973); Shields (1974); Rodríguez et al. (1974); Smith (1975); Peimbert (1975), and Peimbert and Torres-Peimbert (1976). Diffuse nebulae are among the youngest component of the Galaxy, and a negative radial gradient was detected in the studies of Peimbert, Torres-Peimbert and Rayo (1978); Hawley (1978), and Talent and Dufour (1979).

Another attempt to detect the presence of abundance gradients across the Galaxy has been made on the basis of planetary nebulae (PN) by D'Odorico et al. (1976); Aller (1976); Torres-Peimbert and Peimbert (1977); Kaler (1978,

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1979, 1980, 1981a, 1983); Barker (1978); Peimbert and Serrano (1980), and Faúndez-Abans and Maciel (1984).

Galactic temperature gradients are known to exist both for high-density and low-density H II regions (Churchwell and Walmsley 1975; Garay and Rodríguez 1983; Wink et al. 1983; Azcárate et al. 1984), being usually associated with the observed abundance gradients.

Recently, temperature gradients similar to the observed in H II regions have been detected from a sample of type II planetary nebulae (Maciel and Faúndez-Abans 1984a,b) having distances determined by the mass-radius relation (Maciel and Pottasch 1980; Maciel 1984).

The purpose of the present paper is to investigate the behaviour of the heavy-element abundances in planetary nebulae across the Galaxy, using the classification scheme proposed by Peimbert (1978) and a sample of PN from the homogeneous catalogue of distances by Maciel (1984). Both radial and vertical gradients are considered, and a comparison is made with previous estimates of the abundance gradients.

II. CLASSIFICATION OF PLANETARY NEBULAE

The subsystem of PN comprises a mixture of different populations, so that a detailed classification scheme is necessary in order to investigate the existence of galactic gradients. The classification criteria devised by Kaler (1970, 1980) are not particularly suitable for the study of abundance gradients across the Galaxy, as they are broad enough to include objects with very different properties. Therefore, we decided to adopt the classification criteria proposed by Peimbert (1978; see also Peimbert and Serrano 1980; Peimbert and Torres-Peimbert 1983; Peimbert 1983).

The main characteristics of the classification scheme are shown in table 1. Here, Z is the average height from the galactic plane, $|\Delta V|$ is the peculiar radial velocity, and $\bar{M}$ is the mass of the progenitor star. The LSR velocities are from Schneider et al. (1983), and the adopted rotation curves are from Burton and Gordon (1978) ($R<R_o$ = 10 Kpc) and Blitz et al. (1980) ($R>R_o$). There are four types of PN: type I (He, N-rich); type II (intermediate population); type III (high velocity) and type IV (halo objects). Type II PN are probably more suitable to study the presence of abundance gradients, since their chemical abundances are less affected by the progenitor star evolution than type I objects. In addition, their orbits are nearly circular, and they are located at galactocentric distances similar to those of their birthplaces. Therefore, type II PN are probably good indicators of chemical abundance gradients across the Galaxy.

TABLE 1. Planetary nebulae classification criteria

TYPE I	TYPE II	TYPE III	TYPE IV
He/H ≥0.125	He/H< 0.125	|ΔV|> 60 Km/s	Belong to the halo
log(N/O)≥ -0.3	log(N/O)< -0.3	|Z|> 800 pc	population
Filamentary structure	|Z|< 1000 pc	Not belong to the	$\bar{M}\sim$ 0.8 - 1 $M_\odot$
Strong forbidden lines	|ΔV|< 60 Km/s	halo	He/H~ 0.10
Location on the diagrams	Location on the diagrams	$\bar{M}\sim$ 1 - 1.2 $M_\odot$	log(O/H)~-4.3,-3.7
He/H x log(N/O)	He/H x log(N/O)	He/H~ 0.11	log(C/O)~1.0
log(O/H) x log(N/O)	log(O/H) x log(N/O)	log(O/H)~-3.4	log(Ne/O)~-1.6,+0.1
Class B (Greig)	$\bar{M}\sim$ 1.2 - 2.4 $M_\odot$	log(N/O)~ -0.4	log(S/O)~ -2.6
$\bar{M}\sim$ 2.4 - 8 $M_\odot$	Intermediate population	log(Ne/O)~ -0.6	log(Ar/O)~ -3.4
Population I objects	I objects		log(C+N)/O~ 1.1
log(O/H)~ -3.2	log(O/H)~ -3.3		
log(C/O)~ -0.3,+0.4	log(C/O)~ -0.4, +0.4		
log(N/O)~ +0.2	log(Ne/O)~ ∓0.6		
log(Ne/O)~ -0.7	log(Ar/O)~ -2.1		
log(C+N)/O~ 0.45	log(S/O)~ -1.6		
	log(C+N)/O~ 0.25		

III. THE DATA

(a) Abundances

In order to select the relative abundance of the galactic planetaries, we have used only recently published data on the different elements. We have studied the He/H, O/H, N/H, N/O, S/H and C/H ratios based on the works of Aller and Czyzak (1983); Peimbert and Torres-Peimbert (1983); French (1983); Barker (1983), and Kaler (1979, 1980, 1981b). From the catalogue of distances (Maciel 1984) we classified 53 objects as type II. The best data refer to the ratios He/H (40 objects) and O/H (35 objects), which are shown in table 2. We have selected the nebulae having at least two abundance determinations not very different from each other, in order to minimize errors. Exceptions to this are some objects with one measurement by Aller and Czyzak (1983).

(b) Distances

The distances were determined by a statistical method based on a relationship between the nebular ionized mass and radius (Maciel and Pottasch 1980; Maciel 1984). In a few cases, the catalogue provides distance limits only, so that distances from Acker (1978, 1980) and Daub (1982) were adopted. Besides He/H (colum 6) and O/H (column 9) abundances, table 2 shows the name of the nebula (column 1); the PK number (column 2); the distance to the Sun (column 3) the height from the galactic plane (column 4), and the distance to the galactic centre projected on the galactic plane (column 5). In column 3, the letters 'A' and 'D' stand for Acker (1978, 1980) and Daub (1982), respectively.

TABLE 2. Type II nebulae

Name	P-K	d(pc)	Z(pc)	R(Kpc)	He/H	log(O/H)+12
NGC 40	120 +09 1	839	144	10.44	-----	8.78
NGC 1535	206 -40 1	1627	-1058	11.12	0.096	8.61
NGC 2022	196 -10 1	2163	- 410	12.05	0.107	8.29
NGC 2371-2	189 +19 1	1459	495	11.36	-----	8.86
NGC 2392	197 +17 1	1149	344	11.05	0.092	8.50
NGC 2792	265 +04 1	1754	125	10.28	0.116	----
NGC 3211	286 -04 1	2543	- 216	9.60	0.117	8.82
NGC 3242	261 +32 1	787	418	10.13	0.105	8.66
NGC 3918	294 +04 1	923	76	9.65	0.109	8.81
NGC 5882	327 +10 1	1573	276	8.73	0.116	----
NGC 6210	043 +37 1	1311	803	9.27	0.116	8.70
NGC 6309	009 +14 1	2053	525	8.05	0.112	8.98
NGC 6543	096 +29 1	668	332	10.08	0.112	8.75
NGC 6572	034 +11 1	814	167	9.36	0.122	8.95
NGC 6720	063 +13 1	679	164	9.72	0.114	8.79
NGC 6790	037 -06 1	1513	- 168	8.86	0.105	8.60
NGC 6818	025 -17 1	1459	- 448	8.77	0.109	8.74
NGC 6826	083 +12 1	687	149	9.95	0.110	8.38
NGC 6884	082 +07 1	1709	211	9.91	0.117	8.66
NGC 6886	060 -07 2	2759	- 372	8.96	0.120	----
NGC 6891	054 -12 1	2149	- 451	8.93	0.118	----
NGC 7009	037 -34 1	871	- 494	9.44	0.114	8.68
NGC 7026	089 +00 1	891	6	10.02	0.113	8.79
NGC 7027	084 -03 1	724	- 44	9.96	0.111	8.91
NGC 7354	107 +02 1	838	34	10.29	0.118	----
NGC 7662	106 -17 1	797	- 241	10.24	0.117	8.57
IC 351	159 -15 1	3006	- 788	12.75	0.100	8.48
IC 418	215 -24 1	750	- 308	10.57	0.093	8.64
IC 1747	130 +01 1	946	23	10.64	0.112	8.75
IC 2003	161 -14 1	2429	- 625	12.24	0.095	8.62
IC 2165	221 -12 1	1856	- 399	11.42	0.105	8.39
IC 2501	281 -05 1	832^{D}	- 82	9.88	0.108	8.87
IC 4593	025 +40 1	2424	1582	8.38	0.122	----
IC 5117	089 -05 1	1000^{D}	- 90	10.05	0.110	8.61
IC 5217	100 -05 1	2837	- 267	10.88	0.100	8.70
Hb-12	111 -02 1	2300^{A}	- 115	11.06	0.105	8.40
Hu 1-1	119 -06 1	6040^{D}	- 712	13.98	0.094	----
Hu 2-1	051 +09 1	1180^{D}	199	9.32	0.104	8.48
J 320	190 -17 1	4068	-1242	13.83	0.107	8.32
J 900	194 +02 1	2080	94	12.02	0.098	8.50
M 1-1	130 -11 1	2900^{D}	- 590	12.03	0.117	8.30
M 1-74	052 -04 1	2500^{A}	- 175	8.70	0.105	8.71

A : Distance from Acker (1978, 1980)

D : Distance from Daub (1982)

IV. RESULTS AND DISCUSSION

A controversy clearly exists on whether planetaries could be good indicators of abundance gradients across the Galaxy (see for example Kaler 1983). In a series of papers, Kaler argues that radial gradients may be a reflection of the vertical gradients, and that radial gradients could not be detected from galactic planetaries. On the other hand, D'Odorico et al. (1976) Torres-Peimbert and Peimbert (1977), Peimbert and Serrano (1980) and others found radial gradients in He/H, N/O and O/H from a small sample of objects. In this work, we attempt to make a contribution to this problem by considering a larger and more homogeneous set of planetaries than considered by Peimbert and co-workers, and more refined a classification scheme than used by Kaler.

(a) Radial gradients

Figure 1 shows the He/H ratio plotted against R for type II planetary nebulae. The least squares straight line shown implies a gradient d(He/H)/dR= -0.004 Kpc^{-1}, with a standard deviation $\sigma = 0.006$ and correlation coefficient r= -0.66. This corresponds to d log(He/H)/dR= -0.018 Kpc^{-1}, with a similar correlation coefficient. The nebulae M1-1 and J 320 were excluded from this calculation, as they strongly deviate from the average behaviour of the nebulae. If they are included, a slight deviation from the quoted values would occur.

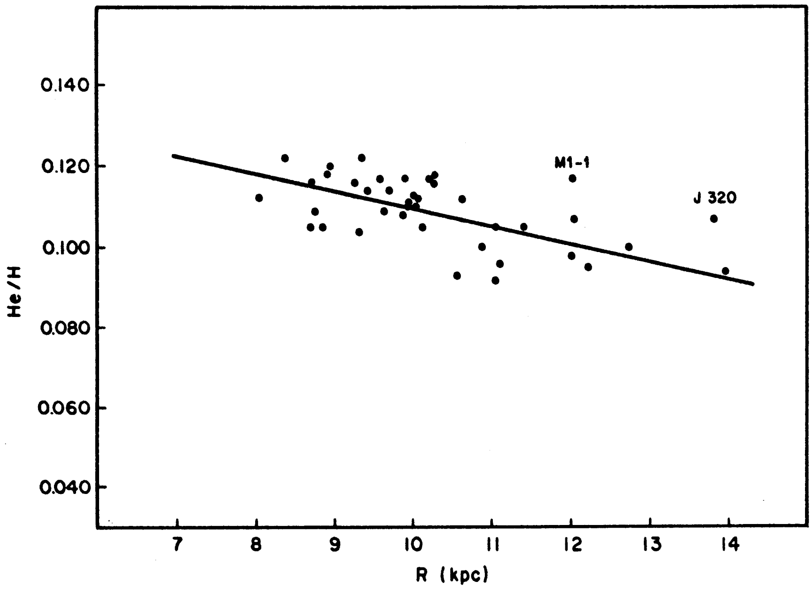

FIGURE 1. He/H ratio as a function of the galactocentric distance for type II nebulae.

The obtained gradient agrees with previous results for PN and H II regions as well (table 3). However, the present results are probably more reliable, which can be seen by the correlation coefficient and the larger sample considered. A similar situation occurs for O/H, as can be seen in figure 2. The least squares line shown implies a gradient d log(O/H)/dR= -0.094 Kpc^{-1}, with a standard deviation σ= 0.15 and correlation coefficient r= -0.63. Although the scatter is higher than in the previous case, the correlation coefficient is still better than in other calculations (table 3). The observed gradient lies between the calculations by Peimbert and co-workers and the values derived for the H II regions.

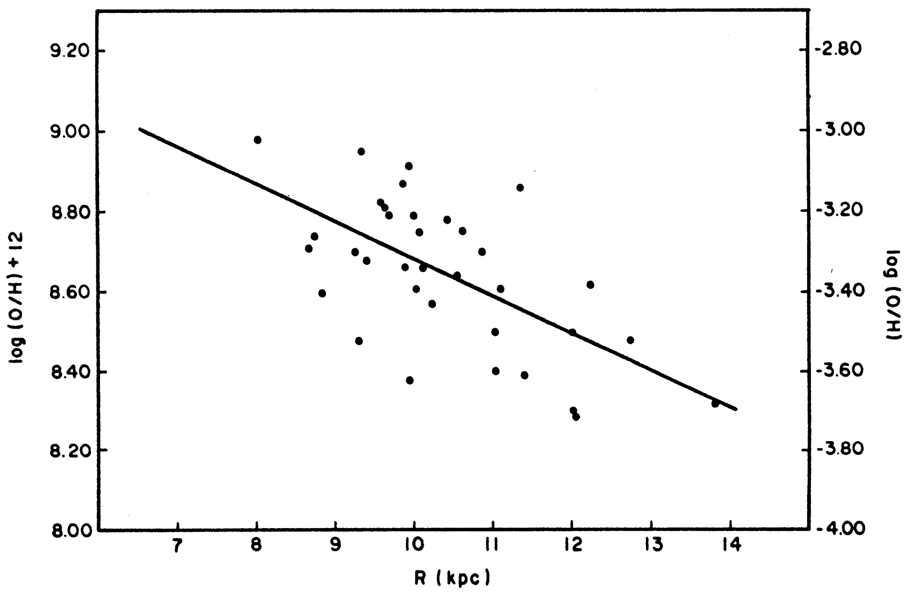

FIGURE 2. O/H ratio as a function of the galactocentric distance for type II nebulae.

As far as nitrogen abundances are concerned, no clear-cut gradients have been detected. However, the application of the selection criteria mentioned previously would reduce the sample of PN to about 10 objects, which we do not consider as significant as in the previous cases. Our results seem to be compatible with the gradients derived by Torres-Peimbert and Peimbert (1977) and Peimbert and Serrano (1980) for N/H and N/O, although not much can be said presently.

A similar situation occurs for S and C, for which the available data is extremely meagre. A gradient seems to exist for S/H and C/H, but further observations would be necessary in order to decide whether the effect is real. The detection of carbon gradients is further complicated by the contribution due to the evolution of the central star (see for example Kaler 1981b; French 1983).

TABLE 3

Ratio(X)	$\frac{d \log(X)}{d R}$ (Kpc^{-1})	Correlation coefficient	Number of objects	Reference
He/H	-0.02	-----	--	1
	-0.02	-----	--	2
	-0.019	-0.59	21	3
	-0.021	-0.45	19	4
	-0.018	-0.66	38	5
O/H	-0.06	-----	--	1
	-0.13	-----	--	2
	-0.056	-0.42	16	3
	-0.024	-0.28	20	4
	-0.094	-0.63	35	5

References:

1 : Torres-Peimbert and Peimbert (1977)
2 : Peimbert et al. (1978)
3 : Peimbert and Serrano (1980)
4 : Faúndez-Abans and Maciel (1984)
5 : this work

(b) Vertical gradients

No vertical gradients for He/H was detected from the sample of table 2, and a weak gradient may be found from the O/H data. In fact, the existence of such gradients seems to be less clear than the radial gradients. In addition, it is more difficult to detect vertical gradients using type II nebulae, since the classification criteria require $|Z| < 1000$ pc, thus limiting the region where such gradients could be detected (see also Maciel and Faúndez-Abans 1984a). In this respect, it is interesting to notice that vertical gradients of N/H and N/O have been detected using a small sample of nebulae with individual distances by Faúndez-Abans and Maciel (1984).

V. CONCLUSIONS

The main conclusions of the present study may be summarized as follows:

(a) Radial gradients of He/H and O/H are detected from a sample of galactic type II planetary nebulae. The results are displayed in table 3, where a comparison is made with previous estimates. On the other hand, no such gradients are apparent in nebulae of types I, III and IV, although the number of objects with reliable abundances and distances is now small.

(b) No vertical gradients are observed for He/H and O/H. This may be a consequence of the condition that $|Z| < 1000$ pc for type II PN.

(c) The similarity between the gradients of He/H and O/H derived from H II regions and type II PN suggests that the PN abundances are good indicators of the abundances at the time of formation of the progenitor stars (see the discussion by Maciel and Faúndez-Abans 1984a; Peimbert 1978, 1983). The observed gradients are probably real, and not a reflection of any vertical gradient.

(d) No clear-cut gradients could be derived for N/O and N/H, since reliable data for a statistically large number of objects is lacking. However, our results are compatible with earlier determinations by Peimbert and co-workers.

(e) The S/H and C/H ratios seem to present a radial gradient similar to the observed for He/H and O/H. However, the available abundances are less reliable than in the case of He and O, so that the results are uncertain. Furthermore, the analysis of any gradient in the C/H ratio is complicated by the contribution of the central stars.

(f) The main results of this paper are not strongly dependent on the adopted distance scale. In fact, essentially the same results would be obtained considering the distance scale by Daub (1982).

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