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VERTICAL ABUNDANCE GRADIENTS OF PLANETARY NEBULAE

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RESUMEN

Se examinó la existencia de gradientes verticales de abundancia usando nebulosas planetarias galácticas. Para esto se consideró una muestra grande, conteniendo sobre 90 NP de los tipos I, II, III y IV de Peimbert, las cuales tienen abundancias y distancias confiables. Se encontró que las NP de tipo II del disco no muestran un gradiente medible, mientras que las NP de tipos II, III y IV en conjunto muestran gradientes verticales de O/H, S/H, Ne/H y Ar/H compatibles con las variaciones conocidas de las abundancias de elementos pesados perpendicularmente al plano galáctico.

ABSTRACT

The existence of vertical abundance gradients from galactic planetary nebulae is examined. A large sample containing over 90 NP of Peimbert types I, II, III and IV is considered, for which reliable abundances and distances are available. It is found that the disk type II PN show no measurable gradients, while PN of types II, III, and IV taken together present vertical gradients of O/H, S/H, Ne/H, and Ar/H compatible with the known variations of heavy element abundances perpendicular to the galactic plane.

Key words: **ABUNDANCES – GALACTIC DISTRIBUTION – NEBULAE-PLANETARY**

I. INTRODUCTION

The observed increase in the abundances of heavy elements as the distance z to the galactic plane decreases is a well known fact, which is directly linked to the population concept (see for example Mihalas and Binney 1981; Mould 1982; Sandage 1986). From the analysis of subgroups of stars with differing metallicities, average estimates can be obtained for the vertical composition gradient close to the galactic plane, d[Fe/H]/dz, which range from -0.2 kpc^{-1} to -0.8 kpc^{-1} (Mihalas and Binney 1981; Mould 1982).

The role played by planetary nebulae (PN) in this respect is not very clear, as these objects comprise different population types, regarding their space distribution, kinematics, and chemical composition (cf. Peimbert 1978). A recent discussion (Maciel 1988) includes 4-6 different types of PN, ranging from the type I nebulae, which are disk objects of the old population I, to the halo (type IV) and centre (type V) objects, both belonging to the extreme population II. Intermediate types are the disk type II nebulae, which may be further subdivided into subtypes IIa and IIb according to their N abundance (Faúndez-Abans and Maciel 1987*a*), and the high-velocity type III nebulae, probably of the intermediate population II.

In a series of recent papers (Maciel and Faúndez-Abans 1985,1986; Faúndez-Abans and Maciel 1986*a*, *b*, 1987*b*), it is shown that type II PN present radial gradients of most heavy elements for which measurements are available, especially those that are not strongly produced by the central star, suggesting that the gradients reflect the interstellar conditions at the time the central star formation.

The detection of possible vertical gradients from such a sample of PN is much more difficult, as the type II nebulae are restricted to $|z| \lesssim 1$ kpc. Earlier attempts suggested a marginal gradient for nitrogen (cf. Faúndez-Abans and Maciel 1986*b*), although a small sample was then considered. Kaler (1983 and references therein) summarizes the work done during several years, and gives a discussion on vertical gradients from planetary nebulae, collecting evidences in favour of gradients of He/H, N/O, and O/H. It is pointed out that the first two elements may be affected by enrichment processes of the stellar progenitors, which contribute to confuse the determination of the gradient.

In the present work, a large sample of PN is used to investigate the presence of galactic vertical gradients of He/H, O/H, N/H, C/H, S/H, Ne/H, and Ar/H. The type II objects that present radial gradients in temperatures

TABLE 1

ABUNDANCES OF TYPE I PLANETARY NEBULAE

Name	PK	d (pc)	Z (pc)	He/H	log (X/H) + 12					
					O	N	S	C	Ne	Ar
NGC 2346	215 + 03 1	1478	93	0.133	8.45	8.11	6.18	...	7.78	6.54
NGC 2440	234 + 02 1	1062	45	0.156	8.68	8.80	6.60	8.54	8.03	6.71
NGC 2818	261 + 08 1	2260	338	0.143	8.69	8.63	...	...	...	...
NGC 3132	272 + 12 1	1079	232	0.126	8.78	8.30	...	...	...	...
NGC 5315	309 − 04 2	694 D	− 54	0.154	8.60	...	7.34	8.99	...	...
NGC 6153	341 + 05 1	1047	99	0.130	9.00	9.30	7.57	8.90	8.40	7.00
NGC 6302	349 + 01 1	415	8	0.180	8.78	8.93	6.79	9.08	7.99	6.90
NGC 6445	008 + 03 1	1030	70	0.206	8.71	8.70	...	...	...	...
NGC 6741	033 − 02 1	1668	− 78	0.139	8.90	8.94	6.92	8.63	8.23	6.70
NGC 6778	034 − 06 1	2159	−252	0.155	8.43	8.56	7.18	9.00	8.40	6.43
NGC 6803	046 − 04 1	2513	−181	0.130	8.77	8.50	7.11	8.73	8.30	6.86
NGC 6853	060 − 03 1	400	− 26	0.133	8.75	8.52	...	8.61	8.23	...
NGC 6881	074 + 02 1	1697	62	0.151	...	...	...	...	...	...
NGC 6894	069 − 02 1	1504	− 69	...	8.46	...	...	...	...	...
NGC 7008	093 + 05 2	908	87	0.140	...	...	...	...	...	...
NGC 7293	036 − 57 1	180	−151	0.180	8.52	8.40	...	...	...	...
IC 4406	319 + 15 1	1674	454	0.141	8.76	...	...	...	...	...
IC 4997	058 + 10 1	1210 D	−230	0.130	8.04	7.28	...	7.74	7.48	...
Hu 1-2	086 − 08 1	2177	−334	0.168	8.11	8.51	6.48	8.57	7.83	6.20
Me 2-2	100 − 08 1	2800 A	−426	0.163	8.23	8.13	6.30	...	7.61	...
Mz-3	331 − 01 1	1024	− 18	0.180	...	...	...	...	...	...
M 1-8	210 + 01 1	3534	118	0.127	8.81	...	...	...	...	...
M 1-17	228 + 05 1	5787	541	...	8.45	...	...	...	...	...
M 1-41	006 − 02 1	1390	− 54	0.160	...	...	...	...	...	...
M 2-55	116 + 08 1	1878	279	0.157	...	...	...	...	...	...
PB-4	275 − 04 1	2909	−212	0.140	8.42	...	...	...	...	...
PB-6	278 + 05 1	3960	344	0.185	8.38	...	...	...	...	...
Vy 1-1	118 − 08 1	1900 A	−287	0.139	8.35	...	...	7.81	...	...
Vy 2-2	045 − 02 1	1900 A	− 90	0.143	7.85	...	...	...	...	...
Ym29	205 + 14 1	247 D	60	0.132	8.53	8.34	6.66	...	8.22	...

TABLE 2

ABUNDANCES OF TYPE III PLANETARY NEBULAE

Name	PK	d (pc)	Z (pc)	He/H	log (X/H) + 12					
					O	N	S	C	Ne	Ar
NGC 6439	011 + 05 1	3751	385	...	8.35	...	...	...	...	...
NGC 6567	011 − 00 2	2084	− 23	0.117	8.46	7.32	6.60	...	7.54	...
NGC 6644	008 − 07 2	2800 A	− 357	0.116	8.40	7.48	6.12	8.32	7.78	...
NGC 6807	042 − 06 1	5547	− 669	0.103	8.37	...	...	...	...	...
NGC 6833	082 + 11 1	1160 D	228	0.107	8.18	7.45	6.45	7.96	7.67	...
IC 4732	010 − 06 1	3391	− 383	0.104	8.08	...	...	...	...	...
IC 4846	027 − 09 1	2800 A	− 460	0.089	8.56	7.68	6.84	8.09	7.90	6.11
A 50	078 + 18 1	2807	901	0.089	...	...	...	...	...	...
Hb-8	003 − 17 1	5341	−1572	...	8.31	...	...	...	...	...
Me 2-1	342 + 27 1	4022	1859	0.102	8.78	8.15	7.15	8.81	8.18	6.41
M 2-9	010 + 18 2	3291	1020	0.080	8.72	...	...	...	...	...
M 2-50	097 − 02 1	4800 A	− 206	0.080	8.45	7.49	...	...	7.55	...
Sn-1	013 + 32 1	5400 A	2920	0.084	8.59	7.25	7.12	...	7.96	...
Vy 1-2	053 + 24 1	4702	1917	0.097	8.79	8.03	6.98	8.23	8.19	...

TABLE 3

ABUNDANCES OF TYPE IV PLANETARY NEBULAE

Name	PK	d (pc)	Z (pc)	He/H	log (X/H) + 12 O	N	S	C	Ne	Ar
Ha 4-1	049 + 88 1	9580 A	9575	0.106	8.34	8.50	5.20	9.30	6.70	5.30
DDM 1	061 + 41 1	12000 B	7936	0.104	8.10	7.40	6.46	<7.10	7.32	5.80
K 648	065 − 27 1	9345	− 4289	0.100	7.66	6.50	5.15	8.73	6.70	4.26
BB 1	108 − 76 1	16100 A	−15622	0.114	7.88	8.50	5.70	9.09	7.72	4.59

and abundances are treated first, followed by the discussion of the remaining PN types.

II. THE DATA

The chemical composition of type II PN has been given by Faúndez-Abans and Maciel (1986*a*, 1987*b*). For the remaining types, the abundances are given in Table 1 (type I), Table 2 (type III), and Table 3 (type IV). All abundances have been taken from published data by Pottasch (1984), Aller and Czyzak (1983), Barker (1983, 1978), French (1983, 1981), Kaler (1981, 1980, 1978), Peimbert and Serrano (1980), Peimbert and Torres-Peimbert (1983), Natta, Pottasch, and Preite-Martinez (1980), Barker and Cudworth (1984), and Clegg, Peimbert, and Torres-Peimbert (1987). A careful comparison of all recent data has been made, and only the most reliable abundances have been taken into account (for details see Maciel and Faúndez-Abans 1985; Faúndez-Abans and Maciel 1986*a*).

The adopted distances are basically from the distance scale developed by Maciel (1984), except for a few cases where distances by Acker (1978, 1980), Daub (1982) and Barker and Cudworth (1984) were used. These are marked with the letters A, D and B in Tables 1-3.

III. ABUNDANCE GRADIENTS PERPENDICULAR TO THE GALACTIC PLANE

Planetary nebulae of type II, which define a fairly accurate *radial* abundance gradient, do not seem to present any *vertical* gradient for the heavy elements considered here. As an example, Figure 1 shows the oxygen abundance relative to H as a function of $|z|$, which can be considered as representative of all elements. Similar plots using z instead of $|z|$ lead to the same conclusion, showing that no differences are detected between the north and south galactic hemispheres.

This negative result can be understood considering that any existing gradient is expected to be small, so that both (1) the restriction to $|z| \lesssim 1$ kpc and (2) the uncertainties in the determined abundances (which can reach $\Delta \log N \cong 0.2$ or higher, in a few cases) will combine to mask the gradients from type II PN. As a conclusion, any information concerning vertical gradients should be based on a larger sample, including the remaining PN types. Type V, or galactic centre objects, should probably not be included, as they are limited to the galactic centre, in contrast to the wider distribution of the remaining types.

Figures 2-8 show the plots of the heavy element abundances relative to H as function of $|z|$. Four types of PN are shown, namely, type I (crosses), type II (dots), type III (open circles), and type IV (squares). It can be seen from the figures that a decrease occurs in the abun-

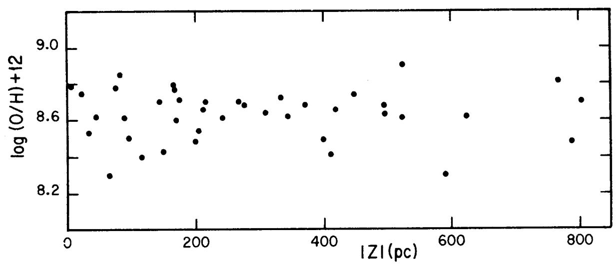

Fig. 1. Oxygen abundance relative to H for type II PN as a function of the distance to the galactic plane.

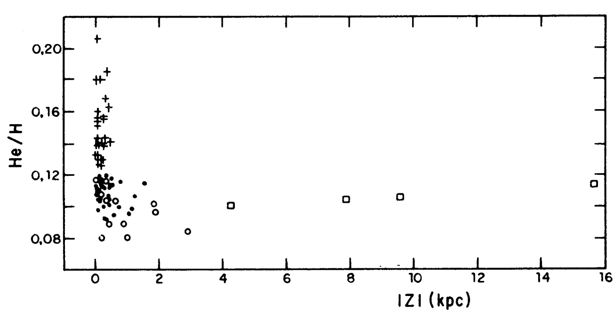

Fig. 2. Helium abundance relative to H as a function of the distance to the galactic plane for PN of type I (crosses), type II (dots), type III (open circles), and type IV (squares).

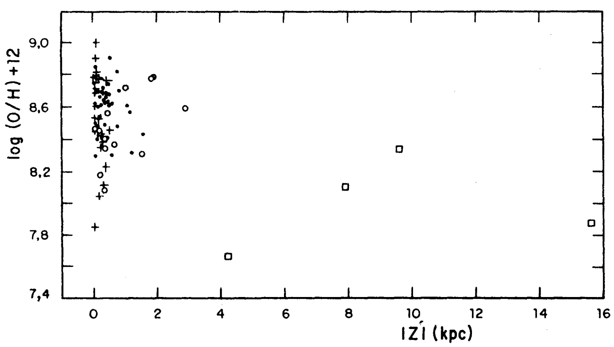

Fig. 3. The same as Figure 2 for oxygen.

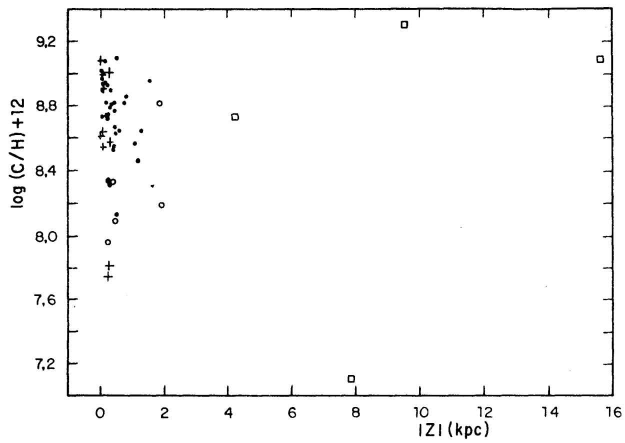

Fig. 6. The same as Figure 2 for carbon.

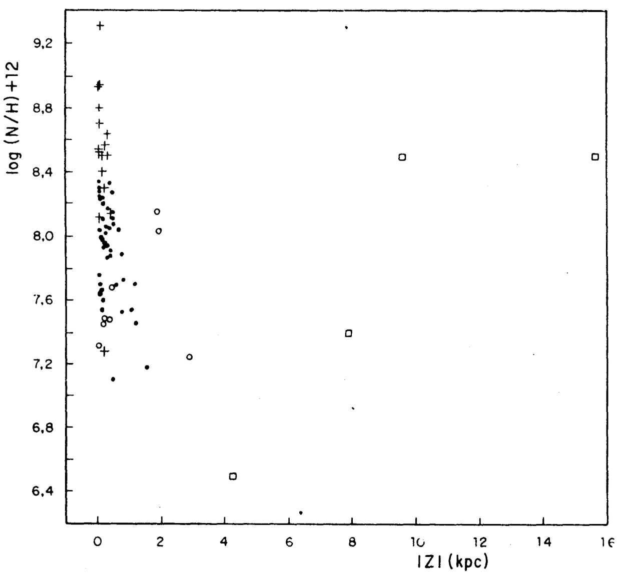

Fig. 4. The same as Figure 2 for nitrogen.

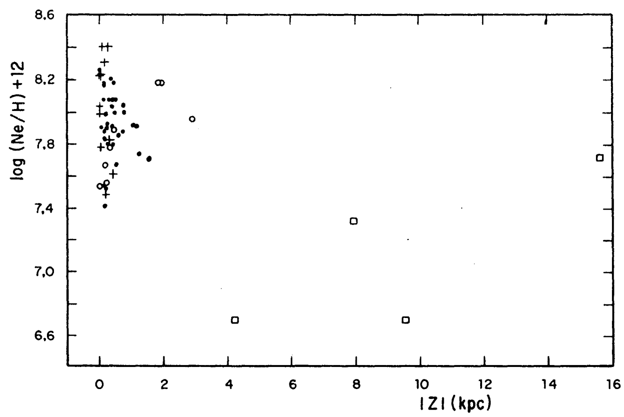

Fig. 7. The same as Figure 2 for neon.

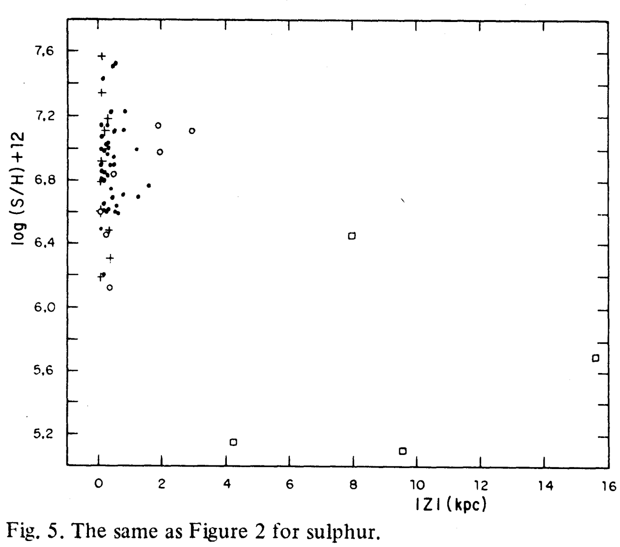

Fig. 5. The same as Figure 2 for sulphur.

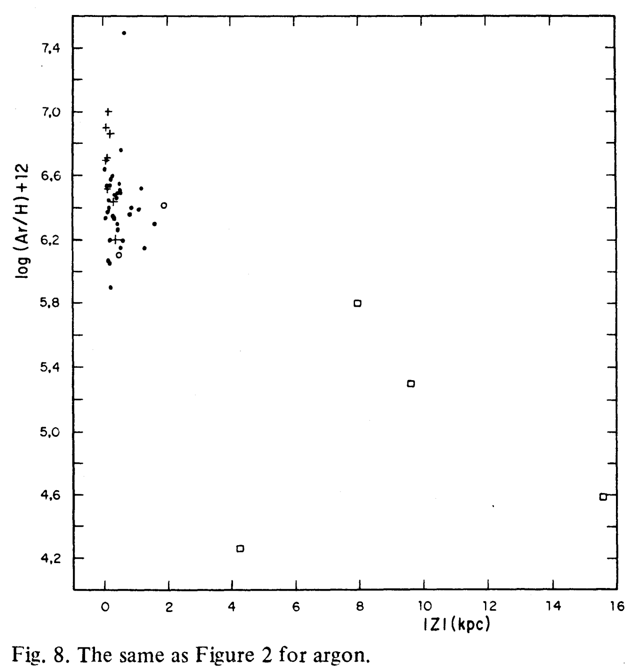

Fig. 8. The same as Figure 2 for argon.

dances of O/H, S/H, Ne/H, and Ar/H as the distance to the plane increases, when all four types are taken into account. This result shows clearly the chemical composition differences between the galactic halo and disk, specially if one considers that these elements are not significantly produced by the intermediate mass stars that give origin to the planetary nebulae. On the other hand, the possibly "contaminated" elements N an C, which can be produced by dredge-up processes (Iben and Renzini 1983; Clegg *et al.* 1987), show no clear variations from halo to disk. This result becomes more evident if the type I PN are excluded, as they present a particularly strong enrichment of He and N (and possibly C).

Excluding the halo nebulae, Figure 4 suggests some decrease in the N abundance close to the galactic plane, as already suggested by Faúndez-Abans and Maciel (1986*b*), and in agreement with the results by Kaler (1983). The He/H ratio shows a steep decrease in the first 2 kpc from the plane, where PN of types I, II, and III are considered, in agreement with Kaler (1983). However, if the He-rich type I PN are removed, all remaining types (II, III, and IV) present a uniform helium abundance up to 16 kpc from the galactic plane.

The halo-disk abundance variations relative to H are more prominent for the elements O, S, Ne, and Ar (Figures 3, 5, 7 and 8). The existence of an O/H gradient has already been established earlier (Kaler 1983). However, the available data are not accurate enough for a good determination of the vertical gradient to be made. A very rough estimate can be attempted from Figures 3, 5, 7 and 8, amounting to

$$\frac{d \log (X/H)}{d\,|z|} \lesssim -0.1 \text{ kpc}^{-1} \quad ,$$

corresponding to a scale height of about 4 kpc, if a simple exponential distribution is adopted for the heavy element abundance X/H. The equality sign in the above equation applies roughly to the large range halo-disk variations, while the upper limit is associated with the nebulae closer to the galactic disk. The latter is close to the upper metallicity limit given in §I, so that the present results are compatible with the known variations perpendicular to the galactic disk derived from abundance analysis in stars.

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