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Abundances of non-type I planetary nebulae in the LMC*

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Abstract. Spectroscopic observations, plasma diagnostics and chemical composition of 15 non-type I planetary nebulae in the Large Magellanic Cloud are reported. Abundances of He, O, N, S, and Ar are determined and compared with recently obtained data for nebulae both in the Magellanic Clouds and in the Galaxy.

Key words: planetary nebulae: general – Magellanic Clouds – galaxies: abundances

1. Introduction

In the last decade, a large effort has been made to derive chemical abundances for planetary nebulae (PNe)in the Large Magellanic Cloud (LMC, Aller et al. 1987; Monk et al. 1988; Henry et al. 1989). The comparison of these results reveals a considerable spread in the abundances, in particular in the case of helium, for which the derived abundances may differ by a factor of 2. Differences even larger are also observed for oxygen, a key tracer element in the study of the chemical evolution of the Magellanic Clouds.

In order to better determine the abundances in the LMC, we have carried out an observational programme to obtain the chemical composition of a sample of planetary nebulae in that galaxy. In a previous paper (Freitas Pacheco et al. 1992, hereafter Paper I) we reported oxygen abundances for 8 type I planetary nebulae and we have shown that the average abundance is consistent with values reported in the literature for other young objects in the LMC. These type I nebulae are supposed to have originated from stars near the high mass bracket of intermediate mass stars, and their abundances are comparable to that observed in the interstellar medium (ISM). In fact, for those elements not affected by the dredge-up episodes in the progenitor stars, namely, S, and Ar, the average abundances in type I nebulae are in agreement with those observed in the local ISM.

In the present paper, we report spectroscopic observations of 15 non-type I PNe in the LMC, as well as their physical properties and chemical abundances. These objects are expected to be older on the average than type I objects (the average age of the bulk planetary nebulae in the LMC is about 3.5 Gyr, according to Meatheringham et al. 1988), and, consequently, indications of some evolutionary changes in the abundances may be expected, following the trend observed in the galactic nebulae (Maciel 1992; Freitas Pacheco 1993). As already stressed in Paper I, we emphasize that in order to obtain the same enrichment factor of the N/O ratio with respect to the ISM both for the LMC and the Galaxy (Peimbert & Torres-Peimbert 1983), we consider as non-type I objects those with $N/O < 0.30$ and/or $He/H < 0.125$, to compensate for the lower metallicity of the LMC.

2. Observations

The observations were carried out at the 1.6m telescope of the National Astrophysical Observatory (LNA, Brasópolis, Brazil), using a Boller & Chivens Cassegrain spectrograph and a CCD detector. One single grating was used for all measurements, allowing a reciprocal dispersion of about 4.4 Å/pixel and a spectral coverage of 4600 Å centered on HeIλ5876. Typical exposure times were 900 to 1200 seconds, increasing the number of exposures for weaker objects. Details of the data reduction procedure

Table 1. Log of the observations

Name	α (1975)	δ (1975)	Date
SMP6	4 48 05	-72 30.9	1990 Nov. 15
SMP13	5 00 20	-70 30.5	1991 Dec. 03
SMP15	5 01 07	-70 15.0	1991 Dec. 03
SMP19	5 04 00	-70 15.6	1991 Dec. 06
SMP23	5 06 11	-67 47.8	1991 Dec. 03
SMP32	5 09 52	-70 51.1	1990 Oct. 24
SMP35	5 10 42	-65 31.3	1991 Dec. 03
SMP36	5 10 44	-68 37.6	1991 Oct. 27
SMP50	5 20 50	-67 07.3	1991 Oct. 28
SMP58	5 24 35	-70 06.4	1991 Dec. 04
SMP71	5 30 51	-70 45.8	1991 Oct. 28
SMP84	5 37 10	-71 54.2	1991 Dec. 04
SMP97	6 10 30	-67 56.1	1991 Dec. 05
SMP98	6 18 12	-73 12.1	1991 Dec. 05
SMP99	6 19 24	-71 35.6	1991 Dec. 05

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* Based on observations made at the National Laboratory for Astrophysics - Brasópolis - Brazil

Table 2. Line intensities for the nebulae

SMP	6	13		15		19		23		32		35		36	
Ion	$I = I_c$	I	I_c	I	I_c	I	I_c	I	I_c	I	I_c	I	I_c	I	I_c
Hγ λ4340	47.0	45.0:	52.0:	37.0	40.4	35.9	47.0	-	-	-	-	-	-	-	-
[OIII]λ4363	30.5	13.2:	15.2:	11.4	12.4	16.7	21.9	-	-	-	-	-	-	-	-
HeIIλ4686	51.8	36.4	38.1	25.8	26.5	31.0	33.8	-	-	79.5	80.7	15.8	15.3	48.1	55.4
Hβ λ4861	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
[OIII]λ5007*	1419	1444	1394	1686	1651	1864	1746	1256	1221	1481	1468	1688	1665	2202	1978
HeIIλ5411	2.3	3.2	2.8	2.3	2.1	4.3	3.4	-	-	9.0	8.7	2.2	2.1	-	-
[NII]λ5754	-	0.62	0.51	1.4	1.2	4.6	3.2	1.1:	0.93:	1.3	1.2	1.6	1.5	7.2	3.9
HeIλ5876	11.7	15.4	12.3	14.4	12.6	17.9	11.8	18.4	15.3	10.0	9.3	14.7	13.5	25.9	13.0
[OI]λ6300	8.8	6.9	5.1	13.0	10.9	24.9	14.3	1.9	1.5	7.5	6.8	8.8	7.8	22.6	9.0
[SIII]λ6312	1.7	2.0	1.5	2.1	1.8	4.3	2.5	1.2	0.94	3.6	3.2	1.7	1.5	6.2	2.5
Hα λ6563	280	402	285	350	285	540	285	377	285	313	280	326	285	818	286
[NII]λ6584*	45.5	25.2	17.9	74.4	60.6	243	128	11.2	8.5	47.9	42.8	70.3	61.4	159	55.4
HeIλ6678	2.3	4.3	3.0	4.3	3.5	4.8	2.5	6.0	4.5	2.4	2.1	3.9	3.4	-	-
[SII]λ6724*	8.3	6.3	4.4	13.9	11.2	52.5	26.5	4.0	3.0	13.4	11.9	9.3	8.0	12.3	4.0
[ArV]λ7005	-	-	-	-	-	3.9	1.8	-	-	-	-	-	-	5.9	1.7
HeIλ7065	5.1	6.0	3.9	7.6	5.9	8.4	3.9	11.0	7.8	2.3	2.0	3.9	3.3	30.2	8.4
[ArIII]λ7135	8.8	11.9	7.8	19.7	15.3	26.9	12.2	14.1	10.0	11.5	10.1	8.6	7.3	34.4	9.3
[OII]λ7325*	12.4	8.0	5.1	19.6	15.0	34.8	15.1	7.1	4.9	8.2	7.1	6.2	5.2	69.3	17.4
R(SII)	0.51	0.48		0.58		0.64		0.60		0.63		0.75		1.0	
E(B-V)	0.00	0.30		0.18		0.56		0.24		0.10		0.12		0.92	

* summed over the doublet

Table 2. (continued)

SMP	50		58		71		84		97		98		99	
Ion	I	I_c	I	I_c	I	I_c	I	I_c	I	I_c	I	I_c	I	I_c
Hγ λ4340	38.4	47.6	-	-	14.7:	20.5:	-	-	46.3	49.7	38.1	50.7	37.0	44.3
[OIII]λ4363	8.9	10.9	-	-	14.2:	19.5:	-	-	14.0	15.0	14.8	19.4	11.5	13.6
HeIIλ4686	16.1	17.2	-	-	46.7	51.9	-	-	69.8	71.4	-	-	22.4	23.7
Hβ λ4861	100	100	100	100	100	100	100	100	100	100	100	100	100	100
[OIII]λ5007*	1575	1496	1029	926	1700	1569	979	955	1328	1305	2043	1908	2010	1926
HeIIλ5411	1.3	1.1	-	-	-	-	-	-	5.6	5.2	-	-	1.8	1.5
[NII]λ5754	.93:	0.69:	2.6	1.4	3.2:	2.0:	0.8	0.7	-	-	4.5	3.0	2.2	1.7
HeIλ5876	19.5	14.0	38.8	19.7	19.9	11.9	15.3	13.0	5.7	5.1	18.9	12.2	13.4	10.2
[OI]λ6300	4.2	2.7	5.9	2.4	24.7	12.4	0.4	0.3	2.6	2.2	25.2	14.0	12.2	8.4
[SIII]λ6312	1.5	0.96	3.3	1.3	6.0	3.0	0.4	0.3	1.5	1.3	9.3	5.1	1.6	1.1
Hα λ6563	474	285	807	286	627	286	364	285	338	285	560	285	433	285
[NII]λ6584*	21.4	12.9	41.3	14.6	203	92.4	8.1	6.3	7.8	6.6	82.6	42.0	185	121
HeIλ6678	5.0	2.9	13.2	4.4	6.8	3.0	5.0	3.8	2.7	2.2	14.5	7.1	4.6	2.9
[SII]λ6724*	4.6	2.7	5.1	1.7	29.0	12.5	1.3	1.0	4.2	3.5	15.9	7.7	13.3	8.5
[ArV]λ7005	-	-	-	-	8.1	3.2	-	-	3.1	2.5	-	-	-	-
HeIλ7065	7.3	3.9	37.0	10.5	12.4	4.8	9.3	6.9	-	-	22.4	9.9	7.7	4.6
[ArIII]λ7135	6.3	3.4	23.6	6.5	23.0	8.7	9.5	7.0	8.8	7.1	27.4	11.8	14.3	8.5
[OII]λ7325*	4.7	2.4	39.8	10.1	35.2	12.5	4.8	3.5	4.4	3.5	34.7	14.3	14.1	8.1
R(SII)	0.66		0.80		0.50		1.0		0.80		0.68		0.63	
E(B-V)	0.45		0.91		0.69		0.21		0.15		0.59		0.37	

* summed over the doublet

can be found in Paper I. The log of the observations is given in Table 1, where we used the designation by Sanduleak et al. (1978).

The line intensities relative to Hβ [I(Hβ) = 100] are given in Table 2, which lists both the measured value (I) and the intensities corrected for the interstellar extinction (I_0). Typical errors in the relative intensities are about 15% for lines stronger than 10 and about 30% for weaker lines. The derived colour excess, also given in Table 2, was based on the Balmer ratio (Hα/Hβ), assuming case B.

3. Physical conditions

The electron temperature and density were estimated from the following line intensity ratios

$$\mathrm{R(OIII)} = \frac{\lambda 4363}{\lambda 5007} \; ; \; \mathrm{R(NII)} = \frac{\lambda 5754}{\lambda 6584} \; ; \; \mathrm{R(SII)} = \frac{\lambda 6716}{\lambda 6730}$$

The resulting values are shown in Table 3. The comparison of our temperature values with those obtained by other authors (Monk et al. 1988 - MBC88; Meatherigham & Dopita 1991 - MD91; Henry et al. 1989 - HLB89) indicates, in general, a quite good agreement. In the case of SMP6, the temperature we found (T(OIII)$\simeq$17800 K) is considerably higher than other determinations reported in the literature. We adopted the value given by Aller et al. (1987- AKMGMS87), which is intermediate between our determination and the others. For 5 nebulae (SMP23, SMP32, SMP35, SMP36, SMP58) our T(OIII) determination is uncertain, since the intensity of the line [OIII]λ4363 is quite weak. For those objects, we adopted the values obtained by other studies, as indicated in Table 3.

The determination of the ionic abundances was performed using a three level atom model including radiative transitions, collisional excitation and de-excitation in the solution of the statistical equilibrium equations. The relevant atomic data are from Mendoza (1983). The ionization correction factors (icf) used to derive the elemental abundances are the same as in Paper I (references therein). The helium abundance was derived following the procedure by Freitas Pacheco & Costa (1992), taking into account optical depth effects as well as collisional excitations (see also Paper I). The resulting elemental abundances are given in Table 4, using the notation ϵ(X)=log(X/H)+12.

Table 3. Physical properties

Object	T(OIII)	T(NII)	n_e (cm^{-3})
SMP6	14560 (1)	-	1.2×10^4
SMP13	13000:	13200	1.4×10^4
SMP15	11400	11700	6.8×10^3
SMP19	13900	13320	6.1×10^3
SMP23	12300 (2)	-	7.0×10^3
SMP32	15900 (3)	14100	6.7×10^3
SMP35	15700 (4)	13500	3.7×10^3
SMP36	14500 (2)	-	1.3×10^3
SMP50	11350	-	4.5×10^3
SMP58	13250 (2)	-	2.9×10^3
SMP71	-	12200:	1.2×10^4
SMP84	14000 (5)	-	4.9×10^2
SMP97	13500	-	2.9×10^3
SMP98	12800	-	4.8×10^3
SMP99	11200	10200	5.5×10^3

Notes:
(1) AKMGMS87; (2) MBC88; (3) MD91; (4) HLB89; (5) VDMB92

Table 4. Elemental abundances

Object	He/H	ϵ(O)	ϵ(N)	ϵ(S)	ϵ(Ar)
SMP6	0.117	8.40	7.62	6.67	5.97
SMP13	0.116	8.41	7.52	7.00	5.91
SMP15	0.106	8.66	7.60	6.80	6.33
SMP19	0.106	8.50	7.93	6.86	6.11
SMP23	0.106	8.28	6.94	6.72	5.93
SMP32	0.129	8.46	7.79	6.85	6.10
SMP35	0.102	8.23	7.73	6.60	5.67
SMP36	0.142	8.55	7.44	6.60	6.00
SMP50	0.104	8.52	7.50	7.12	5.56
SMP58	0.132	8.14	6.68	6.38	5.75
SMP71	0.124	8.64	7.98	7.05	6.10
SMP84	0.080	8.04	6.58	5.95	5.67
SMP97	0.104	8.60	7.28	6.88	6.09
SMP98	0.079	8.46	7.33	7.14	5.99
SMP99	0.086	8.80	8.18	6.88	6.12
Average	0.109 ±0.018	8.45 ±0.20	7.47 ±0.44	6.77 ±0.31	5.95 ± 0.21

4. Discussion

The average He abundance for non-type I planetary nebulae in the LMC compares quite well with the average values found in their galactic counterparts. It also agrees with the results recently reported by Dopita (1991). The average N abundance derived from our data is about 0.2 dex lower than that given by Barlow (1991) and 0.24 dex higher than the value obtained by Dopita (1991). Since this element is affected by the nucleosynthesis of the star, introducing consequently a larger spread in the observed values, the results of these different studies cannot be considered inconsistent.

The average oxygen abundances for non-type I PNe in the LMC is similar to that found for type I objects (see Paper I), but displaying a larger spread (cf. Table 5). Our average value agrees quite well with that by Barlow (1991). Under 'non-type I' planetaries all objects are included whose progenitors had masses M$\leq$2.4 M$_\odot$ and therefore we should expect a large spread in the corresponding ages. In fact, in the range 7.7 < ϵ(O) < 8.8, sulphur and argon abundances correlates with oxygen, reflecting the gradual enrichment of the ISM. In Paper I, using the derived S/O and Ar/O ratios in type I PNe, we estimated that the relative

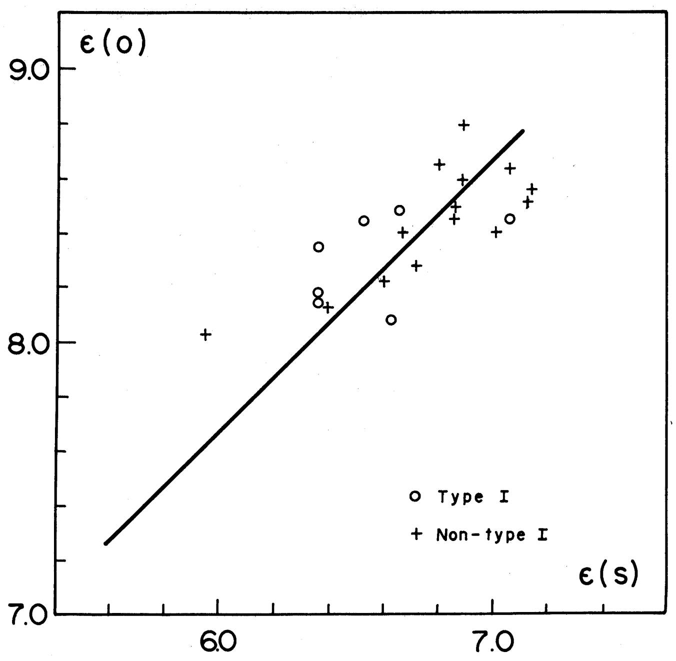

Fig. 1. Oxygen abundance as a function of the sulphur abundance for the objects of our sample. The solid line is the expected variation if r=0.70, where r is the ratio of type II supernovae to the total number of supernovae (see text)

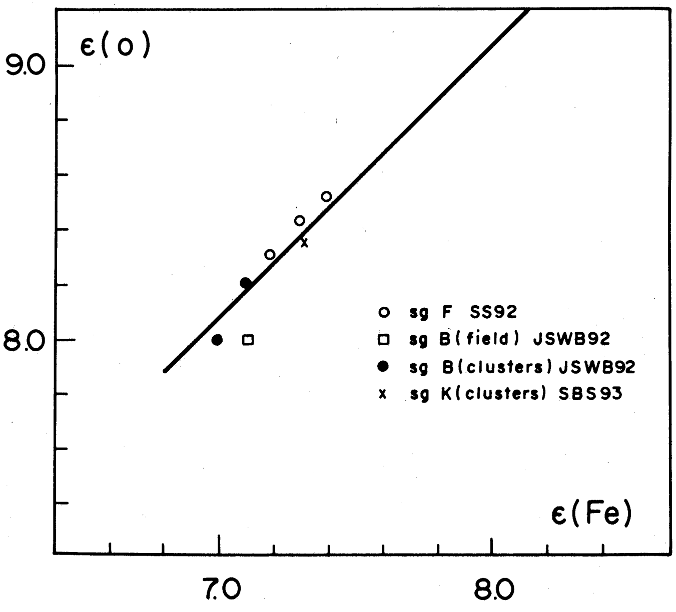

Fig. 2. Oxygen abundance derived for supergiants in the LMC as a function of their iron content. The solid line represents the expected variation for r=0.70, as Fig. 1

number of type II supernovae with respect to the total number of supernova events which occurred in the LMC is r=0.62. If we consider a sample including both type I (Paper I) and non-type I planetary nebulae (present study), we derived a slightly higher value for the relative number of type II supernovae which occurred in the LMC, namely, r=0.70 .

Table 5. Oxygen abundances in the LMC

Object	ϵ(O)	source
Type I PNe	8.33 ±0.13	Paper I
Non-type I PNe	8.42 ±0.25	this work
Non-type I PNe	8.30 ±0.06	Dopita (1991)
Type I PNe	8.41 ±0.20	Barlow (1991)
Non-type I PNe	8.41 ±0.18	Barlow (1991)
HII regions	8.38	Dufour (1984)
'Young objects'	8.35	Russell & Dopita (1992)

In Fig. 1 we show the oxygen abundance as a function of the sulphur abundance, including both planetary types. The solid line is the expected variation, if the relative number of type II supernovae remained constant and equal to r=0.70 . We see that, in spite of the scatter of the data points (the correlation coefficient for this sample is 0.60), the enrichment of the ISM is consistent with a constant ratio between type II and type I supernovae, at least in the range $8.0 < \epsilon(O) < 8.8$. Two main differences, with respect to the chemical enrichment of the galactic disk may be noticed: the first, already discussed in Paper I, concerns the fact that the relative number of type I supernovae which occurred in the LMC is almost twice that of the Galaxy; secondly, in our Galaxy the chemical evolution of the disk occurred with a varying r, as the [O/Fe]×[Fe/H] diagram suggests (Freitas Pacheco 1993), whereas in the LMC a constant ratio is suggested as we have seen. More recently new data on LMC supergiants have been obtained by different groups. In Fig. 2 we plot the oxygen abundance derived for supergiants in the LMC as a function of their iron content. The solid line represents again the expected variation for r=0.70 . The consistency of these new data points with our expectations gives further support to our chemical enrichment scenario, concerning the role of supernovae.

5. Conclusions

From the present results, oxygen, sulphur, and argon are on the average deficient by a factor 4 with respect to the solar values. For non-type I PNe sulphur and argon correlate with oxygen in the range $7.5 < \epsilon(O) < 8.8$, as we would expect for a gradual enrichment of the local ISM. In agreement with the conclusions of Paper I, this enrichment is consistent with a relative contribution of type Ia supernovae larger than that in the Galaxy. A similar conclusion was also reached recently by Nomoto & Tsujimoto (1992). Moreover, the enrichment in the range of O abundances studied is consistent with a constant r, different from what we observe in the chemical evolution of the galactic disk. Recent data on LMC supergiants support our scenario.

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