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IUE OBSERVATIONS OF THE HALO PLANETARY NEBULA BB-1: THE C, O AND Ne ABUNDANCES

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RESUMEN

Presentamos nuevas observaciones con el satélite IUE en alta y baja dispersión de la nebulosa planetaria del halo BB-1 (PN G108.4 -76.1). Hemos determinado que el valor de C/H es 5.1×10^{-4}. Este objeto está entre las nebulosas planetarias con los cocientes más altos de C/O y Ne/O; su cociente Ne/O es 10 veces mayor que el solar. El enriquecimiento extremo de C y Ne impone condiciones muy estrictas sobre los modelos de evolución estelar de estrellas de baja masa.

ABSTRACT

We present new high and low dispersion IUE observations of the halo planetary nebula BB-1 (PN G108.4 -76.1). We have determined the C/H value to be 5.1×10^{-4}. This object is among the PNe with the highest C/O and Ne/O ratios; its Ne/O ratio is 10 times higher than solar. The extreme enrichment of C and Ne imposes strong constraints on stellar evolution models of low-mass stars.

Key words: **ISM: ABUNDANCES — PLANETARY NEBULAE: GENERAL**

1. INTRODUCTION

Halo stars are expected to have low mass and extreme metal deficiency. The study of halo PNe can provide information about the ejection process of the nebular material, the evolution of Population II stars and the abundances of elements in the early chemical history of the Galaxy. Determinations of the chemical composition of the nebular material allow us to derive the initial chemical composition of the elements that do not change during nuclear processes in intermediate mass stars – such is expected to be the case for Ar, S, and Si. While from the study of the elements altered by stellar nucleosynthesis, like N and C, we can understand better the different evolutionary episodes within the progenitor star (Peimbert 1992; Renzini 1989).

The known sample of extreme Population II PN is limited to H4-1, BB-1, K 648, M2-29 and GJJC-1 and there are other 5 objects identified as belonging to the thick galactic disk. There are several abundance studies on BB-1 in the literature (Barker 1980; Torres-Peimbert et al. 1981, 1990; Peña et al. 1991, hereinafter PTPR91) and there has been a considerable effort to determine the chemical abundances of all halo PNe (e.g., Peña et al. 1989, 1990, 1991; Torres-Peimbert et al. 1990). Several of the extreme halo PN are underabundant in S and Ar relative to solar values by about two orders of magnitude and underabundant in O and Ne by about one order of magnitude. Two possibilities have been discussed in the literature to explain the different underabundances: a) that the enrichment of O and Ne in the interstellar medium has proceeded faster than that of Ar and S; and b) that the O and Ne excesses relative to Ar and S were produced by their progenitors

[1] Guest observer International Ultraviolet Satellite

(Peimbert 1973, 1981, 1992; Hawley & Miller 1978; Torres-Peimbert & Peimbert 1979; Barker 1980, 1983; Clegg et al. 1987; Clegg 1989; Torres-Peimbert et al. 1990).

BB-1 has an apparent diameter or 1.35" (Zijlstra et al. 1989), a radial velocity = +196 ± 10 km s^{-1} (Boeshaar & Bond 1977); a distance of 22.5 kpc has been assigned to it (Hawley & Miller 1978), while a distance of 10.8 kpc has been calculated assuming an ionized mass of 0.018 $M_\odot$ (Torres-Peimbert et al. 1990). PTPR91 found for this object the following values: log F(Hβ) = −12.66, C(Hβ) = 0.23, T_e(O III) = 14 500±700 K, N_e(S II) = 3 000 cm^{-3} (very uncertain), N_e(O II) = 3 500 cm^{-3}, N_e(rms) = 1 280 cm^{-3} (from radio data); we derive here a value of N_e(rms) = 3 500 cm^{-3} from the Hβ flux.

2. OBSERVATIONS

Previous to this work there were IUE exposures available for this object, however the C lines were saturated on them. Therefore new IUE observations were carried out in August 1991. A deep spectrum displaying the faint lines can be found in Feibelman et al. (1988). We obtained the following low dispersion SWP exposures: 45331 (25 min), 45332 (25), 45338 (30), 45339 (25), 45340 (30), 45341 (30), 45345 (60), 45346 (20), 45347 (20), 45368 (25); high dispersion SWP exposures: SWP 45367 (120), 45369 (175), 45386 (150), 45371 (330); and low dispersion LWP exposures: 23697 (120), 23699 (200). In all cases the large aperture was used, which includes the whole object.

All the spectra were analyzed, including the archival ones, using the Goddard RDAF facility. We derive the following mean observed flux values for the emission lines: F(C IV λ1549) = 549 ± 53.8, F(He II λ1640) = 50.0 ± 13.6, F(C III λ1909) = 366.4 ± 51.5, F(C II λ2327) = 24.5 ± 3.5, F(Ne IV λ2424) = 16.9 ± 3.4, F(Mg I? λ2852) = 8.7 ± 3.4, and F(He I λ3190) = 50.0 ± 10 (in units of 10^{-14} erg cm^{-2} s^{-1}). From the high dispersion spectra we obtain the following ratios: F(λ 1548)/F(λ 1550) = 1.89 ± 0.01, and F(λ 1907)/F(λ 1909) = 1.55 ± 0.05. The C III 1907/1909 ratio is at the low density limit, yielding a value of the density N_e < 3000 cm^{-3}.

The adopted UV line strengths are presented in Table 1, where f(λ) is the reddening function from Seaton (1979), F(λ) is the observed flux and I(λ) is the dereddened flux. The UV line fluxes relative to Hβ were obtained from the emission line ratios relative to F(λ1640), where I(1640)/I(4686) = 7.07 (Seaton 1978) was assumed, and were dereddened by C(Hβ) = 0.23.

TABLE 1
UV MEAN LINE INTENSITIES[a]

λ	ion	f(λ)	log F(λ)/F(1640)[b]	log I(λ)/I(Hβ)
1549	C IV	1.184	+1.04	+1.31
1640	He II	1.136	+0.00	+0.26
1909	C III]	1.229	+0.86	+1.14
2327	C II]	1.351	−0.31	+0.00
2424	[Ne IV]	1.116	−0.47	−0.21
2852	Mg I ?	0.608	−0.76	−0.62
3190	He I	0.430	+0.00	+0.10

[a] where f(λ) is the reddening correction from Seaton (1979), F(λ)/F(1640) is the observed ratio and I(λ)/I(Hβ) is the intrinsic ratio

3. IONIC ABUNDANCES AND TOTAL ABUNDANCES

To derive the ionic abundances we used the UV line fluxes presented above and the optical line fluxes, reddening, electron density and temperature from PTPR91. In Table 2 we present the ionic abundances for T_e = 14500 K and N_e = 3000 cm^{-3}, except for the case of C IV λ1549 for which we assumed T_e = 15380 K as predicted by the model (section 4), and atomic parameters from Mendoza (1983); we also include the ionic abundances of C and Ne derived from the optical lines. The errors listed correspond to an error of 700 K in the temperature.

We obtain higher ionic abundances for C^{+2} from the $\lambda4267$ recombination lines than from the collisionally excited $\lambda1909$ UV line. This effect is present in other PNe, such as NGC 4361, but it is not as large for BB-1. There has been a long standing controversy in the literature about the validity of the C^{+2} abundances derived from $\lambda4267$. If the line is only produced by recombination, and the atomic data are correct, then the difference would imply temperature variations over the observed volume. The temperature fluctuations could be due to shock waves or chemical inhomogeneities (see Torres-Peimbert et al. 1990). The sum of the ionic abundances gives a total carbon abundance of $C/H = 5.1 \times 10^{-4}$ from UV lines, and $= 1.47 \times 10^{-3}$ from recombination lines . In either case, this is an unusually high value for any galactic PN. From the line intensities ratio of $\lambda1909/\lambda1662$ we have determined a value of $C^{+2}/O^{+2} \geq 4.8$; this limit depends very weakly on the temperature and is consistent with that derived from $\lambda1909/\lambda5007$ of $C^{+2}/O^{+2} = 7.8$.

TABLE 2

IONIC ABUNDANCES FROM UV LINES

ion	line	abundance
C^{+}	2327	$2.14 \pm 0.55 \times 10^{-5}$
C^{+2}	1909	$2.95 \pm 0.94 \times 10^{-4}$
	4267	$1.23 \pm 0.03 \times 10^{-3}$
C^{+3}	1549	$1.91 \pm 0.61 \times 10^{-4}$
	4650	$2.24 \pm 0.08 \times 10^{-4}$
Ne^{+2}	3869	$4.57 \pm 0.74 \times 10^{-5}$
Ne^{+3}	2424	$1.62 \pm 0.56 \times 10^{-5}$
C	UV lines	$5.07 \pm 0.85 \times 10^{-4}$
C	optical lines	$1.47 \pm 0.04 \times 10^{-3}$
Ne	$Ne^{+2} + Ne^{+3}$	$6.91 \pm 0.68 \times 10^{-5}$

A total Ne/H ratio of 7.57×10^{-5} has been calculated from $Ne^{+3} + Ne^{+2}$ corrected for the i_{cf} derived from the model below.

If the $\lambda2852$ line is due to collisional excitation of the resonance line of Mg I, then it would correspond to a Mg^0/H^+ abundance of $1.5 \times 10^{-6}\Omega$, where Ω is the collision strength for the transition. For any reasonable value of Ω it is inconsistent with the lack of the Mg II λ 2798 line; for which we can place an upper limit of $0.1\times$ I(Hβ). Aldrovandi (1980) fitted several model nebulae to BB-1 and predicted an intensity ratio I(Mg II $\lambda2798$)/I(Hβ) ≈ 2.0 for $Mg/H = 2 \times 10^{-6}$. Furthermore, this line cannot be Ar IV $\lambda2854+68$, since from the optical lines of 4711,4740 and 7170,7236 we predict a ratio of the transauroral line I($\lambda2854+68$)/I(Hβ) < 0.001.

4. MODEL COMPUTATIONS AND STELLAR PARAMETERS

We have computed ionization structure models to fit the observed parameters of the nebula. The models were computed for an envelope of homogeneous density, $N_H = 3000$ cm^{-3}, filling factor = 1.0 and He/H =0.10, log C/H = 8.78, log N/H = 7.94, log O/H = 7.68, log Ne/H = 7.76, log Mg/H = 5.80, log Si/H = 5.80, log S/H = 5.80, and log Ar/H = 4.74. The input stellar atmospheres were from Clegg & Middlemass (1987) for He/H = 0.10; they correspond to high effective temperature and high gravity objects. In Table 3 we present the comparison between the observed quantities and the parameters of our best fit. This model corresponds to the case of $T_* = 100\,000$ K, log g = 5.5, and $R_* = 0.07\ R_\odot$, corresponding to a star of $L_{bol} = 380\ L_\odot$. In order to fit the line intensities the model was assumed to be material bounded. From the optical continuum we derive the unreddened magnitude of the central star to be $V_0 > 17.2$, corresponding to $M_V > 2.0$ for a distance of 10.8 kpc, consistent with the adopted model.

Our model temperature derived for O^{+2} is 14 600 K, and is similar for most once- and twice- ionized species, the model predicts higher temperatures for C^{+3}, and other highly ionized species. The i_{cf} predicted by the models for O, N, and Ne are in general agreement with the empirical determinations (PTPR91). In general the fit is satisfactory in reproducing the line ratios for He, C, O, N, and Ne. However the Hβ emissivity predicted is greater than observed by a factor of 2.6.

TABLE 3
COMPARISON WITH MODEL NEBULA

parameter	observed	T100g5.5
He I 4471	−1.34	−1.46
He II 4686	−0.59	−0.53
C II 2327	+0.00	+0.08
C III 1909	+1.14	+1.36
C IV 1549	+1.31	+0.84
N II 6584	−0.51	−0.47
O II 3727	−0.88	−1.26
O III 5007	+0.50	+0.50
Ne III 3869	+0.22	+0.26
Ne IV 2424	−0.21	−0.19
E(Hβ)	5.2 +33	1.5 +34
$M_{ionized}$ ($M_\odot$)	0.025	0.060
$R_{ionized}$ (pc)	0.037	0.052

In Table 4 we present an overview of the chemical abundances of the extreme population PNe (adapted from PTPR91). The objects are listed in increasing order of O/H. The C/H values listed were derived from collisionally excited lines in the UV, except for H4-1 and K648 where they were derived from optical recombinations. As noted before, BB-1 has the highest values of C/O, N/O, and Ne/O of the sample, much higher than solar, while its Ar/O is one fourth solar. No other objects in the sample exhibit the same behavior.

TABLE 4
COMPARISON WITH HALO PN[a]

	He	O	C/O	N/O	Ne/O	S/O	Ar/O	refs.[b]
M2-29	10.97	7.3	...	−0.3	−0.6	−1.4	−2.0	1
BB-1	11.02	7.7	+1.0	+0.2	+0.2	−1.9	−3.0	1,2
K648	11.02	7.7	+1.0	−1.2	−1.0	−2.5	−3.4	3,4,5
NGC4361	11.02	7.8	+0.5	<−0.4	−0.2	...	−1.9	6
NGC2242	11.00	8.0	+0.4	−0.3	−0.2	...	−2.1	6
DDDM-1	11.00	8.1	<−1.0	−0.7	−0.7	−1.6	−2.3	7
PRMG-1	10.96	8.1	<−0.8	...	−0.6	...	−2.3	8,9
H4-1	10.99	8.4	+0.9	+0.1	−1.7	−3.2	−3.7	3,4
PRTM-1	11.03	8.4	<−0.8	<0.4	−0.5	...	−2.0	9
GJJC-1	...	>10.0	...	...	+0.0	...	...	10,11
Sun	10.99	8.9	−0.4	−0.9	−0.8	−1.7	−2.4	12

[a] He and O given in 12 + log N(X)/N(H), other elements are log N(X)/N(O)
[b] References: 1. PTPR91, 2. this work, 3. Barker 1980, 4. Torres-Peimbert & Peimbert 1979, 5. Adams 1984, 6. Torres-Peimbert et al. 1990, 7. Clegg et al. 1987, 8. Peña et al. 1989, 10. Peña et al. 1990, 10. Peimbert 1992, 11. Gillet et al. 1989, 12. Grevesse & Anders 1989

5. CONCLUSIONS

From new IUE observations, optical data, and ionization structure models of BB-1 we have obtained the following stellar parameters: $T_* = 100\,000$ ($\pm$ 10 000) K, log g = 5.5, $R_* = 0.07\ R_\odot$, and $L_{bol} \approx 380\ L_\odot$.

We have obtained the following nebular abundances: $C_{coll}/H = 5.1 \times 10^{-4}$, $C_{rec}/H = 1.5 \times 10^{-3}$ and Ne/H $= 7.6 \times 10^{-5}$. There is a discrepancy between the recombination and the collisional carbon abundance, probably due to chemical inhomogeities in the nebula. BB-1 is one of the PNe with the highest C/O and Ne/O values; while it has very low S/H and Ar/H values. It is important to derive an accurate Mg/H abundance to try to find out if it also shows a magnesium enrichment.

It has been argued that the excesses in O and Ne relative to S and Ar in BB-1 and GJJC-1 have been produced by their progenitor stars (Peimbert 1992) in disagreement with current evolutionary models of low-mass stars.

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REFERENCES

Adams, S., Seaton, M.J., Howarth, I.D., Aurrière, M, & Walsh, J.R. 1984, MNRAS, 207, 471
Aldrovandi, S.M.V. 1980, ApSSc, 71, 393
Barker, T. 1980, ApJ, 237, 428
Barker, T. 1983, ApJ, 270, 641
Boeshaar, G.O., & Bond, H.E. 1977, ApJ, 213, 421
Clegg, R.E.S. 1989, in IAU Symp. 131, Planetary Nebulae, ed. S. Torres-Peimbert, (Kluwer: Dordrecht), 139
Clegg, R.E.S. & Middlemass, D. 1987, MNRAS, 228, 759
Clegg, R.E.S., Peimbert, M., & Torres-Peimbert, S. 1987, MNRAS, 224, 761
Feibelman, W.A., Oliversen, N.A., Nichols-Bohlin, J., & Garhart, M.P. 1988, NASA Reference Publication 1203
Gillett, F.C., Jacoby, G.H., Joyce, R.R., Cohen, J.G., Neugebauer, G., Soifer, B.T., Najakima, T., & Matthews, K. 1989, ApJ, 338, 862
Grevesse, N. & Anders, E. 1989, in Cosmic Abundances of Matter, ed. J. Waddigton (New York: American Institute of Physics), 1
Hawley, S.A., & Miller, J.S. 1978, ApJ, 220, 609
Mendoza, C. 1983 in IAU Symp. 103, Planetary Nebulae, ed. D.R. Flower, (Dordrecht: Reidel), 143
Peimbert, M. 1973, Mem. Soc. R. Sci. Liege, Ser 6, 5, 307
——. 1981, in Physical Processes in Red Giants, eds. I. Iben Jr. & A. Renzini (Dordrecht: Reidel), 409
——. 1992, in Elements and the Cosmos, eds. M.G. Edmunds & R.J. Terlevich, (Cambridge: University Press), 196
Peña, M., Ruiz, M.T., Maza, J., & González, L.E. 1989, RMexAA, 17, 25
Peña, M., Ruiz, M.T., Torres-Peimbert, S., & Maza, J. 1990, A&A, 237, 454
Peña, M., Torres-Peimbert, S., & Ruiz, M.T. 1991, PASP, 103, 865
Renzini, A. 1989, in IAU Symp. 131, Planetary Nebulae, ed. S. Torres-Peimbert (Kluwer, Dordrecht), 391
Seaton, M.J. 1979, MNRAS, 187, 73p
Seaton, M.J. 1978, MNRAS, 185, 5p
Schneider, S.E., Terzian, Y., Purgathofer, A., & Perinotto, M. 1983, ApJSS, 52, 399
Torres-Peimbert, S., & Peimbert, M. 1979, RMexAA, 4, 341
Torres-Peimbert, S., Peimbert, M., & Peña, M. 1990, A&A, 233, 540
Torres-Peimbert, S., Rayo, J., & Peimbert, M. 1981, RMexAA, 233, 540
Zijlstra, A.A., Pottasch, S.R., & Bignell, C. 1989, A&AS, 79, 329

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