

ULTRAVIOLET OBSERVATIONS OF PLANETARY NEBULAE. NGC 6572, NGC 5315 AND BD+30°3639

S. Torres-Peimbert¹ and M. Peña

Instituto de Astronomía
Universidad Nacional Autónoma de México

RESUMEN

Presentamos observaciones hechas con el satélite *IUE* para 3 nebulosas planetarias. Hemos calculado la composición química de NGC 6572 y obtuvimos $\log C = -3.60$, $\log N = -3.67$, $\log O = -3.27$ y $\log Ne = -3.8$. En el caso de NGC 5315 y BD+30°3639, las estrellas centrales son del tipo Wolf-Rayet de carbón y la contribución estelar en el UV es importante. Por esto, en estas nebulosas solamente determinamos la abundancia de carbono; obtuvimos $\log C = -3.01$ y > -3.27 , respectivamente.

ABSTRACT

We present *IUE* observations of three planetary nebulae. We have obtained the chemical composition of NGC 6572 to be $\log C = -3.60$, $\log N = -3.67$, $\log O = -3.27$, and $\log Ne = -3.8$. For NGC 5315 and BD+30°3639, the stellar WR contribution in the UV is very significant, and for these nebulae we are only able to derive the carbon abundance. We found $\log C = -3.01$ and > -3.27 , respectively.

Key words: ABUNDANCES – NEBULAE-PLANETARY – ULTRAVIOLET-SPECTRA

I. INTRODUCTION

This paper is part of a series of publications of *IUE* observations of planetary nebulae of high surface brightness (Torres-Peimbert, Peimbert, and Daltabuit 1980; Torres-Peimbert, Peña, and Daltabuit 1981; Peña and Torres-Peimbert 1981). These nebulae were selected for observation because they have well determined physical parameters derived from optical observations by Peimbert and Torres-Peimbert (1971 = PTP71), and Torres-Peimbert and Peimbert (1977 = TPP77).

In this work we have used the same data reduction method as Peña and Torres-Peimbert (1981) for NGC 7662. For the short wavelength exposures presented here, the error in the ITF was corrected with the 3 Agency 4th File Method (Casatella, Holm, Ponz, and Schiffer 1980). We have applied the mean *IUE* calibration curve given in Bohlin, Holm, Savage, Snijders, and Sparks (1980).

In §II we present observations and derived quantities for NGC 6572; in §III the data obtained for NGC 5315; §IV contains data for BD+30°3639 and in §V we discuss the results and present a summary.

II. NGC 6572

a) Observations

We have obtained the following *IUE* low dispersion, large aperture exposures: SWP 3200 (12 min), SWP 3201 (18 min), LWR 2783 (12 min) and LWR 2784 (12 min), for NGC 6572.

The measured fluxes for each exposure are tabulated in Table 1. Data marked with colon are very uncertain. We also list intrinsic fluxes, $I(\lambda)$ relative to $I(H\beta)$.

Our measurements are higher by about 11% than those obtained by Flower and Penn (1981). We have more serious discrepancies with the measurements carried out by Boggess, Feibelman, and McCracken (1981), for the short wavelength exposures.

In Figure 1 we present a composite spectrum of the object. Clearly, the lines $\lambda 1240$ of N IV, $\lambda 1371$ of O V and $\lambda 1549$ of C IV show P Cygni profiles, indicating stellar contributions.

The central star has been classified as Of+WR by Aller (1976). The ultraviolet continuum of this object has been compared with spectra of WR stars by Nussbaumer *et al.* (1979); it does not show characteristic WR emission. So we have assumed that the lines that do not show P Cygni profiles are nebular lines.

Furthermore, in NGC 6572 the He II lines are probably of stellar origin and it is not possible to derive from these lines the reddening value. TPP77 derive

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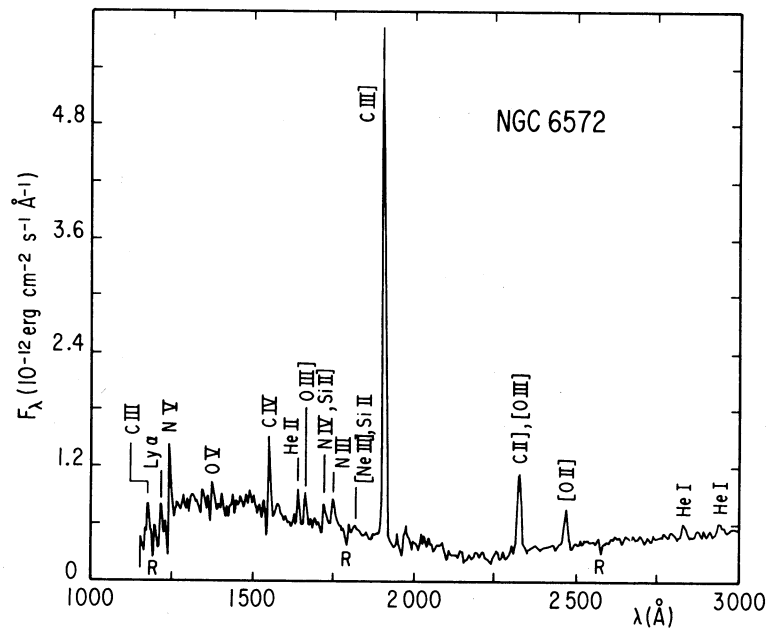


Fig. 1. Composite calibrated spectrum of NGC 6572. The exposures SWP 3200 and LWR 2784 have been joined at λ 1950 Å.

TABLE 1
OBSERVED AND INTRINSIC LINE FLUXES OF NGC 6572

λ	Ion	Notes ^a	$F(\lambda)^b$				$I(\lambda)^c$
			SWP 3201	SWP 3200	LWR 2784	LWR 2783	
1176	C III		17.0	20.0	...	...	7.5
1216	H I	g	29.5	28.7	...	...	...
1240	N V	p	59.9	46.9	...	...	17.9
1371	O V	p	22.8	17.6	...	...	5.2
1549	C IV	p	71.3	67.7	...	...	13.6
1640	He II		23.5	33.8	...	...	6.1
1663	O III]		27.9	30.3	...	...	5.5
1718	N IV+Si II]		12.6	16.9	...	...	3.0
1747	N III		28.6	26.7	...	...	5.1
1820	[Ne III]+Si II		10.7	4.0	...	...	2.0
1909	C III]		> 543.3	> 592.6	505.4	471.0	119.0
2252	He II		...	...	10.7:	4.1:	2.9:
2282	[N III]		...	...	6.4:	9.2:	1.6:
2297	C III		...	...	4.1:	13.2:	3.2:
2326	C II]+[O III]		...	...	119.4	95.8	27.4
2470	[O II]		...	...	53.8	52.8	8.8
2800	Mg II		...	...	<10.0	<8.1	<1.1
2830	He I		...	...	19.0	16.9	2.1
2946	He I		...	...	24.1	6.1	2.4
3188	He I		...	...	51.3	36.1	4.0

a. Notes: g = geocoronal; p = P Cygni profile.
b. In units of 10^{-13} erg cm^{-2} s^{-1} .
c. $I(\lambda)$ relative to $\text{H}\beta$, where $I(\text{H}\beta) = 100$; assuming $C(\text{H}\beta) = 0.44$.

$\lambda(H\beta) = 0.32$ from the Balmer decrement; Kaler (1976) reports $C(H\beta) = 0.41$ from comparison of radio emission and $H\beta$, while Pottasch *et al.* (1977) give $C(H\beta) = 0.44$ from their *ANIS* satellite narrow-band photometry at $\lambda 1500$ – 3300 Å. From our observations we derive $\lambda(H\beta) = 0.40 \pm 0.10$ from the shape of the $\lambda 2200$ feature; from the $I(2470)/I(7320+30)$ ratio of [O II] we derive $\lambda(H\beta) = 0.53$, and from $I(1663)/I(5007)$ ratio of [O III], assuming $T_e = 9200^\circ\text{K}$, we derive $C(H\beta) = 0.40$. We have adopted $C(H\beta) = 0.44$ for our reductions, and we calculate the intrinsic flux on Table 1 as

$$\log I(\lambda)/I(H\beta) = \log F(\lambda)/F(H\beta) + C(H\beta) f(\lambda),$$

where we have assumed $F(H\beta) = 1.74 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ as given by PTP71, and the reddening law, $f(\lambda)$, from Seaton (1979).

b) Physical Parameters and Ionic Abundances

For the analysis presented we have used the optical measurements from TPP77 and PTP71.

Aller and Walker (1970) have derived $\log N_e = 4.0$ from forbidden lines of [C I III]; Feibelman *et al.* (1980) have found, from $\lambda\lambda 1909/1907$ of C III], $\log N_e = 4.5$; and TPP77 give $\log N_e = 4.3$ from forbidden lines and $\log N_e(\text{rms}) = 4.0$. To reduce our data we have adopted $\log N_e = 4.3$.

We have assumed $T_e(\text{N II}) = 11500^\circ\text{K}$, as representative of the zone of low stage of ionization (C^+ , O^+ and N^+), and $T_e(\text{O III}) = 9200^\circ\text{K}$ of the high ionization zone; these values have been taken from TPP77. The line intensity at $\lambda 4267$ of C II has been taken from Aller and Lzyzak (1979).

We have assumed in this work that there are no spatial temperature fluctuations, that is, $t^2 = 0.0$. The calculated ionic abundances are listed in Table 2. As expected, the C^{++} results from $\lambda 1909$ are very sensitive to the adopted temperature. We have computed models for this nebula that predict C^{++} in an intermediate zone

between O^{++} and N^+ , but where the temperature is closer to $T_e(\text{O}^{++})$.

The nitrogen total abundance was obtained by adding the abundances of N^+ , N^{++} and N^{3+} . We have assumed that there is no N^{4+} in this nebula.

For oxygen total abundance, we assumed that there is no O^{3+} , since we do not detect $\lambda 1402$, and there seems to be no nebular He II present; so we added O^+ from $\lambda 3737$ and O^{++} from $\lambda 1663$.

In the case of neon, we only have the optical line at $\lambda 3869$ of Ne^{++} and we have calculated the Ne abundance as given by

$$\frac{N(\text{Ne})}{N(\text{H})} = \frac{N(\text{Ne}^{++})}{N(\text{O}^{++})} \frac{N(\text{O})}{N(\text{H})}.$$

For the case of this nebula this approximation appears valid. The models we have calculated for this object predict that we are underestimating the Ne abundance by less than 30%.

The total abundances derived are presented in Table 3.

TABLE 2
IONIC ABUNDANCES OF NGC 6572

Ion	λ	$\log N(X^{+m})/N(\text{H}^+)$
C^+	2326	-4.73
C^{++}	1909	-3.23
C^{++}	4267	-3.36
C^{3+}	2297	-3.92 ^a
C^{3+}	1176	-3.74 ^a
N^+	6584	-4.94
N^{++}	1747	-3.76
N^{3+}	1487	-4.70
O^+	3727	-4.46
O^{++}	5007	-3.32
O^{++}	1661	-3.28
Ne^{++}	3869	-3.91

a. Effective recombination coefficients from Storey (1981).

TABLE 3

TOTAL ABUNDANCES BY NUMBER AND REDDENING OF NGC 6572

Author	$\log \text{O}/\text{H}$	$\log \text{C}/\text{O}$	$\log \text{N}/\text{O}$	$\log \text{Ne}/\text{O}$	$C(H\beta)$
this work	-3.27	+0.13	-0.40	-0.53	0.44
this work	-3.38	+0.12	-0.42	-0.46	0.32
TPP77	-3.05	+0.3	-0.46	-0.63	0.32
Flower and Penn 1981	-3.28	+0.04	...	...	0.48
Kaler 1981	...	-0.06	...	...	0.31
sun ^a	-3.17	-0.26	-0.77	-0.79	...

a. Bertsch, Fichtel and Reames (1972); Withbroe (1971).

c) Discussion

For this nebula, the total abundances obtained show an apparent carbon enrichment of the nebula relative to solar abundances. The C/O ratio is slightly higher than that by Flower and Penn (1981) because they did not consider the existence C^{3+} in the nebula. By contrast, most of the difference with TPP71 is due to their estimated ionization correction factor of C^{3+} which is too large. For a discussion of carbon determination see Peña and Torres-Peimbert (1981).

Although the total abundances are sensitive to the adopted reddening, the abundance ratios are relatively insensitive to it, as can be seen in Table 3, where we list the abundances for a lower reddening value.

Almost all the carbon in the nebula is in the form of C^{++} , as can be seen in Table 2. The C^+ ionic abundance is obtained from $\lambda 1909$ and is strongly dependent on the electron temperature. A difference in T_e of $\pm 500^\circ K$

changes the ionic estimate by a factor of 1.6. On the other hand, $\lambda 4267$ is a weak line and its measurement is uncertain. Nevertheless, both results are compatible, which gives us confidence in our calculations.

III. NGC 5315

a) Observations

For this nebula we have the low dispersion exposures, at large aperture: SWP 1915 (30 min), SWP 3193 (30 min), LWR 2750 (30 min) and LWR 1779 (35 min).

The UV spectrum shows many features due to the WR emission from the central star. In Figures 2 and 3 we present short and long wavelength spectra of this object and comparative WR type spectra given by Nussbaumer *et al.* (1979). The nucleus of this nebula has been classified as WC6 by Smith and Aller (1969). The UV

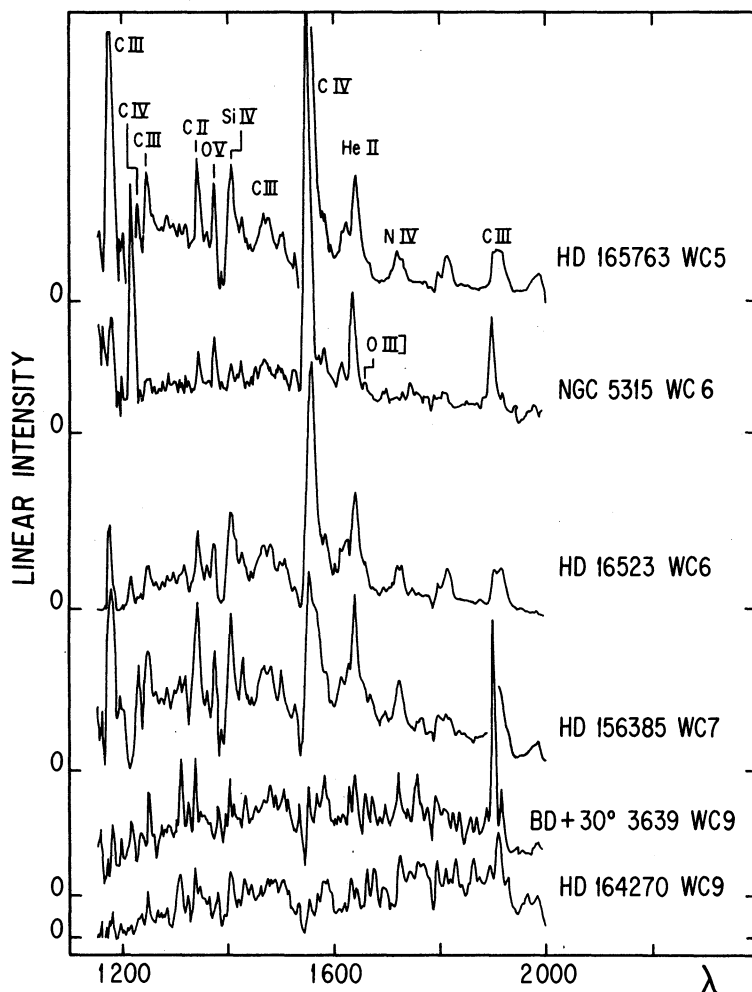


Fig. 2. IUE short wavelength calibrated spectra of NGC 5315 and BD+30°3639. Some WR type spectra from Nussbaumer *et al.* (1979) are included for comparison. For NGC 5315 the lines $\lambda\lambda 1909$ and 1549 are out of range in this figure.

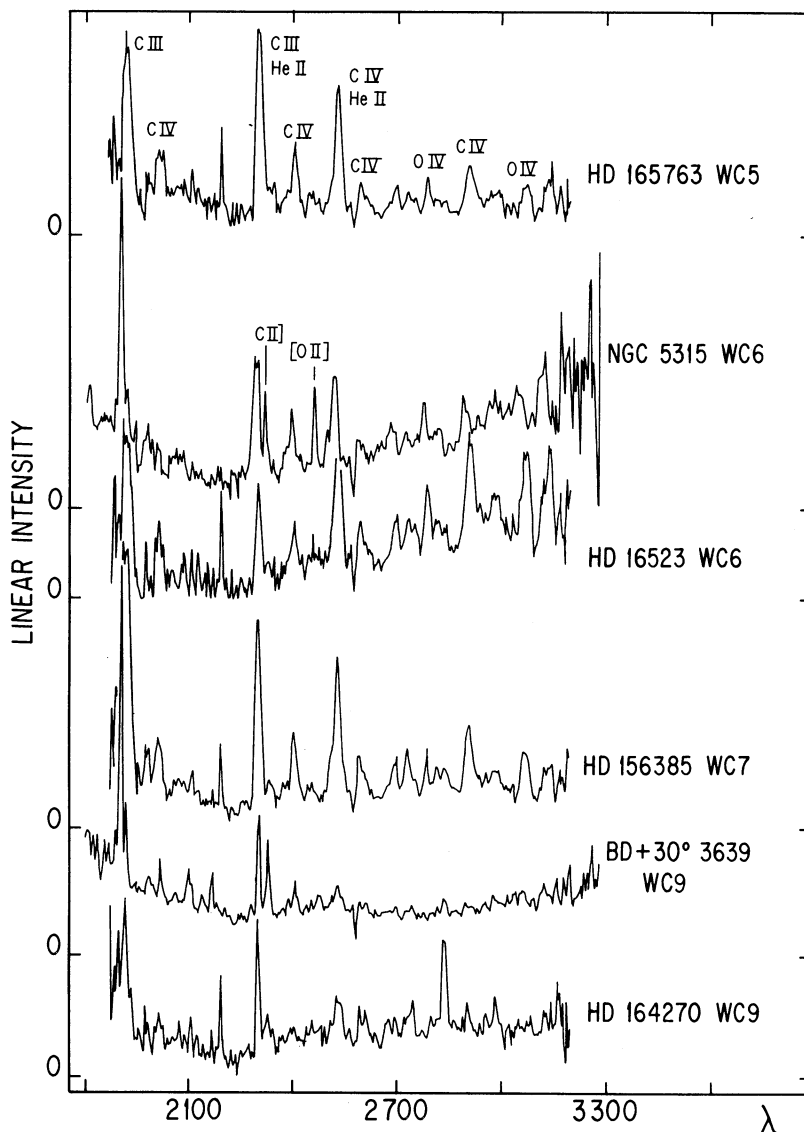


Fig. 3. IUE calibrated long wavelength spectra of NGC 5315 and BD+30° 3639. The WR spectra are from Nussbaumer *et al.* 1979.

spectrum agrees with this classification. For many lines it is not possible with our low dispersion exposures to separate the stellar contribution from the nebular emission. The only lines that are of nebular origin in the JV spectrum, are $\lambda 2326$ of C II] and $\lambda 2470$ of [O II]; while $\lambda 1909$ of C III] and $\lambda 1549$ of C IV are contaminated by circumstellar emission.

In Table 4 we present the measured and the intrinsic fluxes for these lines.

We have used the $I(2470)/I(7320 + 30)$ ratio of O II] for obtaining the reddening, $C(H\beta)$. By adjusting the observed ratio with the theoretical value (Flower 1980) we have obtained $C(H\beta) = 0.50$. This value agrees with $C(H\beta) = 0.6$ of TPP77 and $C(H\beta) = 0.55$ of Kaler (1976). We have adopted $C(H\beta) = 0.50$ and

$F(H\beta) = 3.8 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ (TPP77) for our calculations.

b) Ionic Abundances

To obtain ionic abundances we have adopted $N_e = 1.4 \times 10^4 \text{ cm}^{-3}$, $T_e = 10900^\circ\text{K}$ for the low ionization zone (C^+ , O^+), and $T_e = 9000^\circ\text{K}$ for the higher ionized species (C^{++}); these data are from TPP77.

From the ratio $I(5007)/I(1663)$ of [O III] and the adopted reddening we derived $T_e = 9500^\circ\text{K}$, in agreement with the temperature given above. We have adopted 9000°K because the $\lambda 1663$ line is very weak and probably is distorted by the wide stellar emission $\lambda 1640$ of He II.

TABLE 4
OBSERVED AND INTRINSIC FLUXES OF NEBULAR LINES IN
NGC 5315

λ	Ion	$F(\lambda)^a$				$I(\lambda)^b$
		SWP 1915	SWP 3193	LWR 1779	LWR 2750	
1549	C IV	193.0	183.0	...	...	198.0
1663	O III]	1.9	4.1	...	...	3.9
1909	C III]	21.0	28.0	31.0	...	33.7
2326	C II]	...	...	7.8	11.0	13.9
2470	[O II]	...	...	11.0	14.0	12.3

a. In units of 10^{-13} erg cm $^{-2}$ s $^{-1}$.
b. Relative to H β , where $I(\text{H}\beta) = 100$, $C(\text{H}\beta) = 0.50$.

We have derived the abundance of C $^+$ from $\lambda 2326$. For the case of $\lambda 1909$ we have assumed that only the narrow emission is of nebular origin; it corresponds to two thirds of the total emission. From this, we derive the C $^{++}$ abundance listed in Table 5. For $\lambda 1549$ we

half of the $\lambda 1549$ line intensity is of nebular origin. We have adopted this last criterion to derive the C 3 abundance. The result is listed in Table 5, where we also include ionic abundance of O $^+$ and O $^{++}$ from optical data. We have assumed that there is no O $^{3+}$ in the nebula.

In Table 8 we present total abundances of C and O for this nebula and the results are discussed in §V.

TABLE 5
IONIC ABUNDANCES OF NGC 5315

Ion	λ	$\log N(X^{+m})/N(H^+)$
C $^+$	2326	-4.89
C $^{++}$	1909	-3.95 ^a
C $^{3+}$	1550	-3.07 ^b
O $^+$	3727	-4.42
O $^{++}$	1663	-3.31
O $^{++}$	5007	-3.44

a. Assuming that 0.67 of the line intensity is nebular.
b. Assuming that 0.5 of the line intensity is nebular.

derive a C $^{3+}$ abundance of 1.7×10^{-3} relative to H $^+$. This is an upper limit since this line is also formed in the circumstellar envelope. On the other hand, our models predict C $^{3+}/C^{++} = 0.365$, which would yield C $^{3+}$ abundance of 4.1×10^{-5} . Furthermore, from the comparison in Figure 2, we can see that in NGC 5315 at least one

IV. BD+30°3639

a) Observations

We have obtained the following low resolution $I(U)$ spectra: SWP 1895 (12 min), SWP 1896 (4 min), LWR 1759 (12 min) and LWR 1760 (4 min). In all cases the aperture was centered on the star.

In Figures 2 and 3 we present the short and long wavelength spectra, respectively. The characteristic W1 features are clearly present. The central star has been classified optically as WC9 (see Aller 1976). The UV spectrum agrees with this classification.

Almost all the expected nebular lines appear widened or blended with circumstellar emission features, and thus it is not possible to use them to calculate physical parameters in the nebula.

TABLE 6
OBSERVED AND INTRINSIC FLUXES OF NEBULAR LINES OF BD+30°3639

λ	Ion	$F(\lambda)^a$				$I(\lambda)^b$
		SWP 1895	SWP 1896	LWR 1759	LWR 1760	
1909	C III]	44.2	32.2	...	...	154.0
2326	C II]	...	...	> 15.9	19.7	78.1
2470	[O II]	...	...	> 4.8	5.0	14.1

a. In units of 10^{-12} erg cm $^{-2}$ s $^{-1}$.
b. Relative to H β , where $I(\text{H}\beta) = 100$, $C(\text{H}\beta) = 0.44$.

In Table 6 we present the measured fluxes for the lines that we have considered nebular, namely, the lines $\lambda 2470$ of [O II] and $\lambda 2326$ of C II; and, although probably blended, we have included $\lambda 1909$.

The intrinsic fluxes were calculated adopting $F(\text{H}\beta) = 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ and $C(\text{H}\beta) = 0.44$ given by PTP77. The reddening value agrees with our $I(2470)/I(7320+30)$ ratio. Pottasch *et al.* (1977) have reported $C(\text{H}\beta) = 0.35$ for this nebula.

b) Physical Parameters and Ionic Abundances

We have calculated the abundance of C^+ using the $\lambda 2326$ intensity and assuming $T_e(\text{C II}) = T_e(\text{N II}) = 8200^\circ \text{K}$, and $N_e(\text{FL}) = 10^4 \text{ cm}^{-3}$ from TPP77.

From the comparison of the spectrum of BD+30° 3639 with other WC stars in Figure 2, it can be seen that there is significant nebular emission in $\lambda 1909$. We have computed C^{++} assuming that one half of the $\lambda 1909$ line intensity is of nebular origin. The results are presented in Table 7.

TABLE 7

IONIC ABUNDANCES OF BD+30° 3639

Ion	λ	$\log N(\text{X}^{+m})/N(\text{H}^+)$
C^+	2326	-3.27
C^{++}	1909	$< -2.94^a$
O^+	3727	-3.72
O^{++}	5007	< -5

a. We have assumed that 0.5 of the line intensity is of nebular origin.

For the carbon abundance, we have obtained a lower limit by assuming that only C^+ is present. This value is given in Table 8. If we were to adopt C^{++} abundances as derived previously, we would obtain $\log \text{C/O} = 0.94$.

TABLE 8

TOTAL ABUNDANCES BY NUMBER OF NGC 5315 AND BD+30° 3639

	Author	$\log \text{O/H}$	$\log \text{C/O}$
NGC 5315	this work	-3.40	+0.39
	TPP77	-3.15	...
BD+30° 3639	this work	-3.72	$\geq +0.44$
	TPP77	-3.02	...

V. CONCLUSIONS

We have derived C, N and O abundances for NGC 6572, and C abundance for NGC 5315 and BD+30° 3639. In the three cases we find the ratio $\text{C/O} > 1$. We have compared these results with the prediction by Becker and Iben (1980) for the surface abundance of stars during the giant branch evolution. We find that the comparison of C/O versus He/H for NGC 6572 and NGC 5315 agrees within the errors, with the prediction for stars of 2.5 and 3 M_\odot , respectively, after the phase of 3rd dredge-up.

The derived N/O ratio in NGC 6572 is 12% larger than the predicted value of Becker and Iben, but still can be considered compatible.

We have not done an analogous comparison for BD+30° 3639 because we have no information about its He abundance.

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REFERENCES

- Aller, L.H. 1976, *Mém. Soc. Roy. Sci. Liège*, 6e. Serie, IX, 271.
 Aller, L.H. and Czyzak, S.J. 1979, *Ap. and Space Sci.*, 62, 397.
 Aller, L.H. and Walker, M.F. 1970, *Ap. J.*, 161, 917.
 Becker, S.A. and Iben, I., Jr. 1980, *Ap. J.*, 237, 111.
 Bertsch, D.L., Fichtel, C.E., and Reames, D.V. 1972, *Ap. J.*, 171, 169.
 Boggess, A., Feibelman, W.A. and Mc Cracken, C.W. 1981, in *The Universe in Ultraviolet Wavelengths. The First Two Years of IUE*, NASA CP-2171, ed. R.D. Chapman, p. 663.
 Bohlin, R.C., Holm, A.V., Savage, B.D., Snijders, M.A.J., and Sparks, W.M. 1980, *Astr. and Ap.*, 85, 1.
 Cassatella, A., Holm, A., Ponz, D., and Schiffer, F.H. 1980, *NASA IUE Newsletter*, No. 8.
 Feibelman, W.A., Boggess, A., Hobbs, R.W., and Mc Cracken, C.W. 1980, *Ap. J.*, 241, 725.
 Flower, D.R. 1980, *M.N.R.A.S.*, 193, 511.
 Flower, D.R. and Penn, C.J. 1981, *M.N.R.A.S.*, 194, 13p.
 Kaler, J.B. 1976, *Ap. J. Suppl.*, 31, 517.
 Kaler, J.B. 1981, *Ap. J.*, 249, 201.
 Nussbaumer, H., Schmutz, W., Smith, L.J., Willis, A.J., and Wilson, R. 1979, in *The First Year of IUE*, ed. A.J. Willis (University College: London), p. 259.
 Peña, M. and Torres-Peimbert, S. 1981, *Rev. Mexicana Astron. Astrof.*, 6, 309.
 Peimbert, M. and Torres-Peimbert, S. 1971, *Bol. Obs. Tonantzintla y Tacubaya*, 6, 21, (PTP71).
 Pottasch, S.R., Wesselius, P.R., Wu, C.-C., and van Duinen, R.J. 1977, *Astr. and Ap.*, 54, 435.
 Seaton, M.J. 1979, *M.N.R.A.S.*, 187, 73p.
 Storey, P.J. 1981, *M.N.R.A.S.*, 195, 27 p.
 Smith, L.F. and Aller, L.H. 1969, *Ap. J.*, 157, 1245.
 Torres-Peimbert, S. and Peimbert, M. 1977, *Rev. Mexicana Astron. Astrof.*, 2, 181, (TPP77).
 Torres-Peimbert, S., Peimbert, M. and Daltabuit, E. 1980, *Ap. J.*, 238, 502.

Torres-Peimbert, S., Peña, M. and Daltabuit, E. 1981, in *The Universe in Ultraviolet Wavelengths. The First Two Years of IUE* NASA CP-2171, ed. R.D. Chapman, p. 641.

Withbroe, G.L. 1971, in *The Menzel Symposium, NBS Special Publ. 353*, ed. K.B. Gebbie, p. 127.

DISCUSSION

Mendoza, C.: ¿Porqué las abundancias de N y C de la nebulosa no son iguales que las de la estrella central?

Torres-Peimbert: Es posible que la nebulosa represente la capa más externa que ya ha sido arrojada al medio y que la estrella haya sufrido cambios posteriores, o bien que mediante la pérdida de la capa externa se hayan descubierto zonas más internas.

Cersósimo: ¿Es posible que el carbono que se observa esté localizado a cierta distancia de la estrella formando una región de carbono ionizado como ocurre en las regiones C II?

Torres-Peimbert: Si lo es, por esto es importante complementar este estudio con modelos de estructura de ionización. En caso de NGC 6572 y NGC 5315 no afectará nuestros resultados ya que el C⁺ no es dominante.

Niemela: La estrella dentro de NGC 6572 parece muy interesante.

Torres-Peimbert: Efectivamente, en el catálogo de Perek-Kohoutek se encuentra listada como WN6, aunque más tarde Aller (1976) la clasificó Of + WR.

Miriam Peña and Silvia Torres-Peimbert: Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México, D.F. México.