Rev. Mexicana Astron. Astrof., 6, 301-308 (1981)

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

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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.

1. Guest investigator of the International Ultraviolet Explorer Program operated by NASA.

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(λ) relative to I(Hβ).

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 Mc Cracken (1981), for the short wavelength exposures.

In Figure 1 we present a composite spectrum of the object. Clearly, the lines λ1240 of N IV, λ1371of O V and λ1549 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

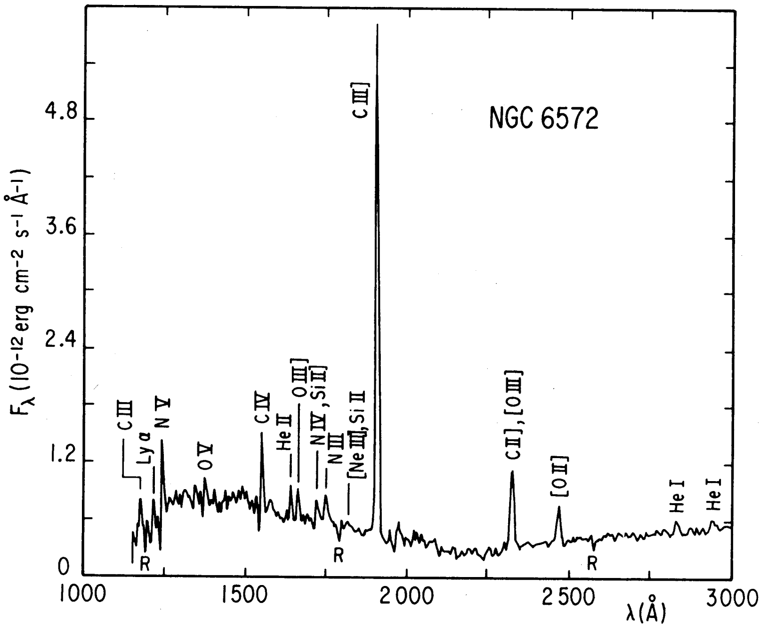


Fig. 1. Composite calibrated spectrum of NGC 6572. The exposures SWP 3200 and LWR 2784 have been joined at λ1950 A.

TABLE 1

OBSERVED AND INTRINSIC LINE FLUXES OF NGC 6572

λ	Ion	Notes[a]	F(λ)[b]				I(λ)[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	[OII]		...	...	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(λ) relative to Hβ, where I(Hβ) = 100; assuming C(Hβ) = 0.44.

:(Hβ) = 0.32 from the Balmer decrement; Kaler (1976) eports C(Hβ) = 0.41 from comparison of radio emission nd Hβ, while Pottasch *et al.* (1977) give C(Hβ) = 0.44 rom their *ANS* satellite narrow-band photometry at λ1500-3300 A. From our observations we derive :(Hβ) = 0.40±0.10 from the shape of the λ2200 feature; rom the I(2470)/I(7320+30) ratio of [O II] we derive :(Hβ) = 0.53, and from I(1663)/I(5007) ratio of [O III], ssuming T_e = 9200°K, we derive C(Hβ) = 0.40. We have dopted C(Hβ) = 0.44 for our reductions, and we cal- :ulate the intrinsic flux on Table 1 as

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

/here we have assumed F(Hβ) = 1.74×10^{-10} erg cm^{-2} $^{-1}$ as given by PTP71, and the reddening law, f(λ), from ;eaton (1979).

b) *Physical Parameters and Ionic Abundances*

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

Aller and Walker (1970) have derived log N_e = 4.0 rom forbidden lines of [Cl III]; Feibelman *et al.* (1980) ave found, from λλ1909/1907 of C III], log N_e = 4.5; nd TPP77 give log N_e = 4.3 from forbidden lines and og N_e(rms) = 4.0. To reduce our data we have adopted og N_e = 4.3.

We have assumed T_e(N II) = 11500°K, as represen- ative of the zone of low stage of ionization (C^+, O^+ and N^+), and T_e(O III) = 9200°K of the high ionization one; these values have been taken from TPP77. The line ntensity at λ4267 of C II has been taken from Aller and :zyzak (1979).

We have assumed in this work that there are no patial temperature fluctuations, that is, t^2 = 0.0. The alculated ionic abundances are listed in Table 2. As xpected, the C^{++} results from λ1909 are very sensitive o the adopted temperature. We have computed models or this nebula that predict C^{++} in an intermediate zone between O^{++} and N^+, but where the temperature is closer to $T_e(O^{++})$.

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 λ1402, and there seems to be no nebular He II present; so we added O^+ from λ3737 and O^{++} from λ1663.

In the case of neon, we only have the optical line at λ3869 of Ne^{++} and we have calculated the Ne abundance as given by

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

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(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 O/H	log C/O	log N/O	log Ne/O	C(Hβ)
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 λ1909 and is strongly dependent on the electron temperature. A difference in T_e of ±500°K changes the ionic estimate by a factor of 1.6. On the other hand, λ4267 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

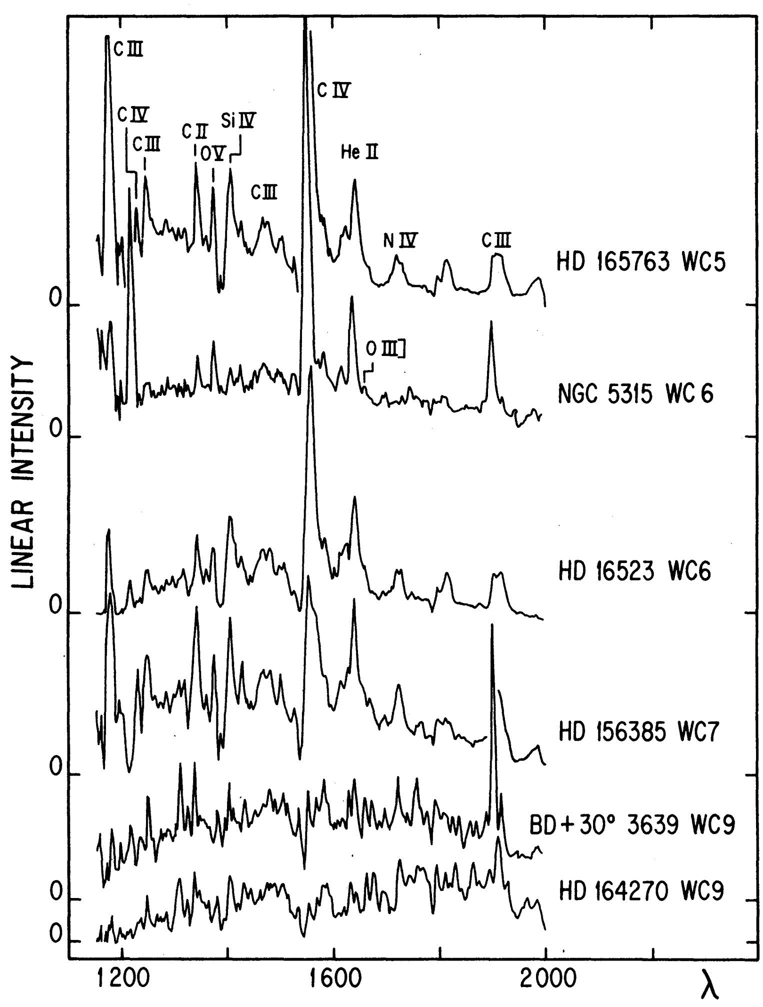
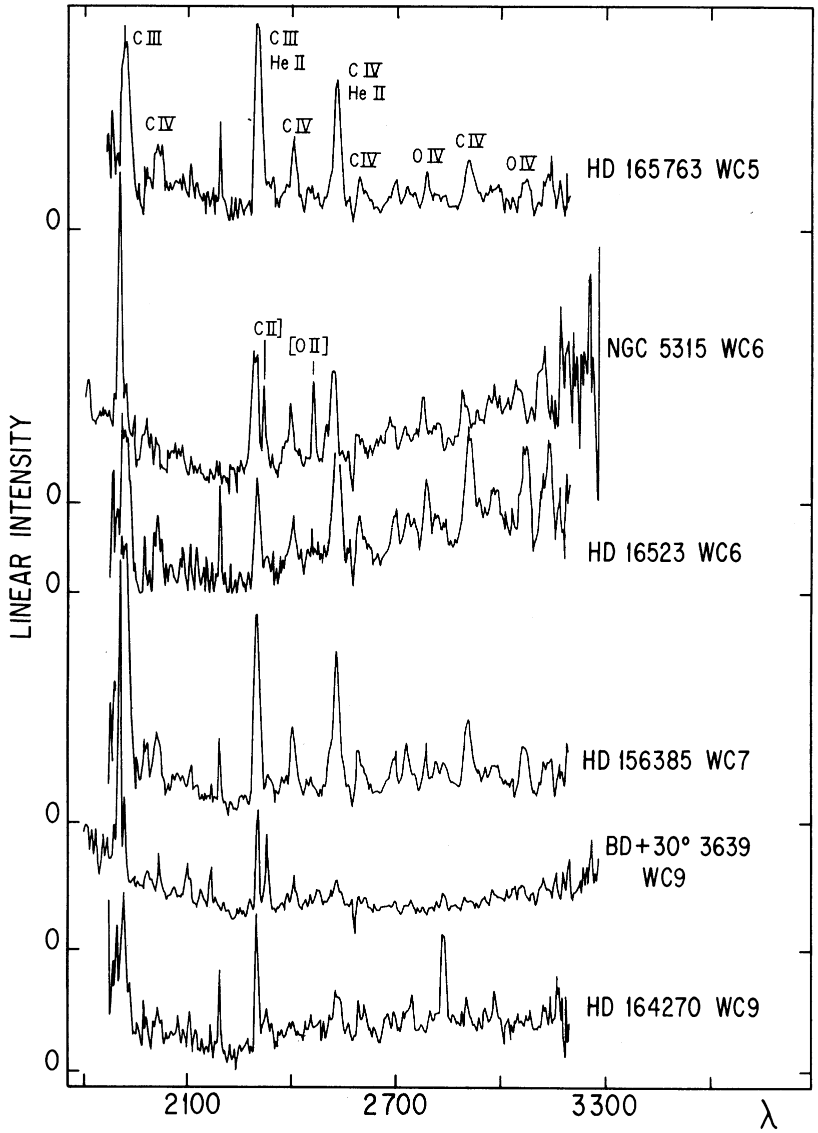


Fig. 2. *IUE* short wavelength calibrated spectra of NGC 5315 and BD+30° 3639. Some WR type spectra from Nussbaumer *et al.* (1979) are included for comparison. For NGC 5315 the lines λλ1909 and 1549 are out of range in this figure.



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

pectrum agrees with this classification. For many lines t is not possible with our low dispersion exposures to eparate the stellar contribution from the nebular ·mission. The only lines that are of nebular origin in the JV spectrum, are λ2326 of C II] and λ2470 of [O II]; vhile λ1909 of C III] and λ1549 of C IV are contamiıated by circumstellar emission.

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

We have used the I(2470)/I(7320 + 30) ratio of O II] for obtaining the reddening, C(Hβ). By adjusting he observed ratio with the theoretical value (Flower 980) we have obtained C(Hβ) = 0.50. This value agrees ⁄ith C(Hβ) = 0.6 of TPP77 and C(Hβ) = 0.55 of Kaler 1976). We have adopted C(Hβ) = 0.50 and F(Hβ) = 3.8 × 10^{-11} erg cm^{-2} s^{-1} (TPP77) for our calculations.

b) *Ionic Abundances*

To obtain ionic abundances we have adopted N_e = 1.4 × 10^4 cm^{-3}, T_e = 10900°K for the low ionization zone (C^+, O^+), and T_e = 9000°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°K, in agreement with the temperature given above. We have adopted 9000°K because the λ1663 line is very weak and probably is distorted by the wide stellar emission λ1640 of He II.

TABLE 4

OBSERVED AND INTRINSIC FLUXES OF NEBULAR LINES IN NGC 5315

λ	Ion	F(λ)[a]				I(λ)[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 Hβ, where I(Hβ) = 100, C(Hβ) = 0.50.

We have derived the abundance of C^+ from λ2326. For the case of λ1909 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 λ1549 we 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 half of the λ1549 line intensity is of nebular origin. W have adopted this last criterion to derive the C abundance. The result is listed in Table 5, where we als include ionic abundance of O^+ and O^{++} from optic data. We have assumed that there is no O^{3+} in th nebula.

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.

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

IV. BD+30° 3639

a) *Observations*

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

In Figures 2 and 3 we present the short and lon wavelength spectra, respectively. The characteristics W features are clearly present. The central star has bee classified optically as WC9 (see Aller 1976). The U spectrum agrees with this classification.

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

TABLE 6

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

λ	Ion	F(λ)[a]				I(λ)[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 Hβ, where I(Hβ) = 100, C(Hβ) = 0.44.

In Table 6 we present the measured fluxes for the lines that we have considered nebular, namely, the lines λ2470 of [O II] and λ2326 of C II]; and, although probably blended, we have included λ1909.

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

b) *Physical Parameters and Ionic Abundances*

We have calculated the abundance of C^+ using the λ2326 intensity and assuming T_e(C II) = T_e(N II) = 8200° K, and $N_e(FL) = 10^4$ 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 λ1909. We have computed C^{++} assuming that one half of the λ1909 line intensity is of nebular origin. The results are presented in Table 7.

TABLE 7

IONIC ABUNDANCES OF BD+30° 3639

Ion	λ	$\log N(X^{+m})/N(H^+)$
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 C/O = 0.94.

TABLE 8

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

	Author	log O/H	log C/O
NGC 5315	this work	−3.40	+0.39
	TPP77	−3.15	. . .
BD+30° 3639	this work	−3.72	⩾+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 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.

We are grateful to M. Peimbert for fruitful discussions. We acknowledge the collaboration of E. Daltabuit in the data acquisition and reduction. This is contribution No. 16 of Instituto de Astronomía, UNAM.

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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-Pembert: 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.

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