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A SPECTROPHOTOMETRIC STUDY OF THE PLANETARY NEBULA N66 IN THE LARGE MAGELLANIC CLOUD

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RESUMEN

Presentamos datos espectrofotométricos de la nebulosa planetaria N66 de la Nube Mayor de Magallanes. Las observaciones se combinan con datos ultravioleta y modelos de estructura de ionización, para obtener la composición química y las condiciones físicas de la nebulosa, así como algunas características de la estrella central. En N66 se obtiene log O/H = 8.26±0.05, log N/H = 8.17±0.05 y log C/H = 7.45±0.10. El cociente N/O es 4 veces mayor que el del conjunto de nebulosas planetarias de la NMM, mientras que el C y el O son subabundantes con respecto a las regiones H II de la NMM; N66 parece ser una nebulosa planetaria de tipo I, cuyas abundancias de C, N y O han sido afectadas por los procesos nucleares de la estrella progenitora. A partir del mejor modelo de estructura de ionización obtenido, derivamos para la estrella central una temperatura efectiva de 90000 K, una luminosidad de 9400 $L_\odot$ y una masa de 0.64 $M_\odot$. Estos parámetros estelares no concuerdan con estimaciones hechas por otros autores.

ABSTRACT

We present spectrophotometric data of the LMC planetary nebula N66. Combining these observations with IUE data and ionization structure models, we derive the chemical composition of the nebula and parameters of the central star. The abundances derived are log O/H = 8.26±0.05, log N/H = 8.17±0.05 and log C/H = 7.45±0.10. The N/O ratio is a factor of 4 larger than in the bulk of the LMC planetary nebulae, while the C and O appear underabundant relative to the LMC-H II regions. N66 seems to be a type I planetary nebula, where the C, N and O abundances were affected by nuclear processes in the precursor star. From the best ionization structure model, constructed with a NLTE stellar energy distribution model, we derived an effective temperature of 90000 K, a luminosity of 9400 $L_\odot$ and a mass of 0.64 $M_\odot$ for the central star. These stellar parameters are in disagreement with previous estimates.

Key words: **GALAXIES-MAGELLANIC CLOUDS – NEBULAE-PLANETARY – SPECTROPHOTOMETRY**

I. INTRODUCTION

N66 (also known as WS35 and SMP83 in the catalogs of Westerlund and Smith 1964; Sanduleak, MacConnell and Phillip 1978, respectively), is one of the most highly excited planetary nebulae in the LMC. Dopita, Ford and Webster (1985) have found an [O III] λ5007 line splitting with an extraordinary expansion velocity of 85 km s^{-1}, suggesting a bipolar morphology.

The spectrum shows very intense high ionization stage emission lines, as well as neutral ion lines. From the strength of the high ionization emission lines, such as He II λ4686 and [Ne V] λ3426, Dopita *et al.* (1985) have deduced a large stellar effective temperature and a mass of 1.2 to 1.3 $M_\odot$ for the central star. This is one of the largest masses suggested for the nucleus of a planetary nebula.

From speckle interferometry at [O III] λ5007, Wood, Bessell and Dopita (1988) measured a nebular angular diameter of 0.32″ and, combining this data with the Hβ flux, they derived a lower limit for the nebular ionized mass of 0.07 $M_\odot$. Alternatively, Barlow (1987) has deduced an angular diameter of 1.23″ and an ionized mass of 0.48 $M_\odot$. Recently, Monk, Barlow and Clegg (1988), have derived the chemical composition of N66 and they classify it as a type I LMC-PN.

Due to the striking features of N66, we considered of great interest to make a detailed spectrophotometric study of it, to obtain nebular and stellar characterstics of this remarkable planetary nebula.

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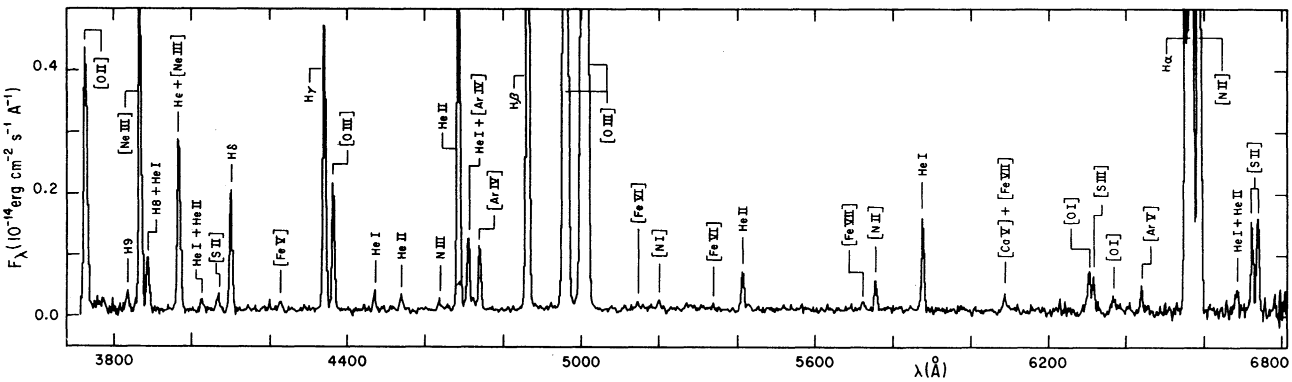

Fig. 1. Optical spectrogram of N66. The most important lines are indicated.

II. OBSERVATIONAL DATA

a) *Visible Spectrum*

Spectrophotometric data have been obtained with the CTIO 4-m telescope equipped with an R-C spectrograph and a 2D-Frutti detector in January, 1985. The spectral range between 3700 A and 7100 A was covered at 4 A resolution; we used a slit of 2″ x 50″ in size, and the aperture for extraction of the data was 2″ x 2.5″. Two exposures were obtained: one of 600s and the other of 120s, with a neutral filter of 2.5 mag in order to cover the intensity range from the strong [O III] lines to the weaker features. The sky was subtracted using parts of the slit that showed no evidence of emission. Three flux standards as well as a He-Ne-Ar lamp were used in order to calibrate the spectra in flux and wavelength. The data reduction was performed at the CTIO La Serena Computing Facilities.

Figure 1 shows selected details of the spectrum. The optical spectral features of N66 correspond to a very high excitation planetary nebula. Collisionally excited lines of [Ne IV], [Fe VII], and [Ar V] are clearly detected. Unfortunately we did not obtain the [Ne V] $\lambda\lambda$ 3346, 3426 lines that would have been helpful in assessing the excitation level of N66. However, Dopita *et al.* (1985) measured the [Ne V] λ3426 line to be twice as intense as Hβ. On the other hand, N66 also shows neutral ion emission lines like [O I] λ6300 and [N I] λ5200. Strong [Fe V], [Fe VI] and [Fe VII] emission lines are present, as in the LMC planetary nebula WS25 (Aller and Czyzak 1983).

In our galaxy, the extraordinary planetary NGC 6302 shows a similar spectrum and comparable dynamics.

b) *Ultraviolet Spectrum*

UV data are needed to derive the C abundance by mean of the strong C IV λ1550 and C III] λ1909 doublets. Some other high excitation *UV* emission lines, such as NV λ1240, O IV] λ1403 and others, are also helpful in determining chemical abundances and physical conditions.

The fluxes of the *UV* lines, between 1200 A and 2000 A, have been measured from the merged IUE spectrum of SWP 19905 (183 min exposure time). This spectrum (from the observing program of R.E.S. Clegg in 1983) was obtained from the IUE Data Bank, and the data reduction was performed with the IUE Regional Data Analysis Facilities. The *UV* spectrum is plotted in Figure 2.

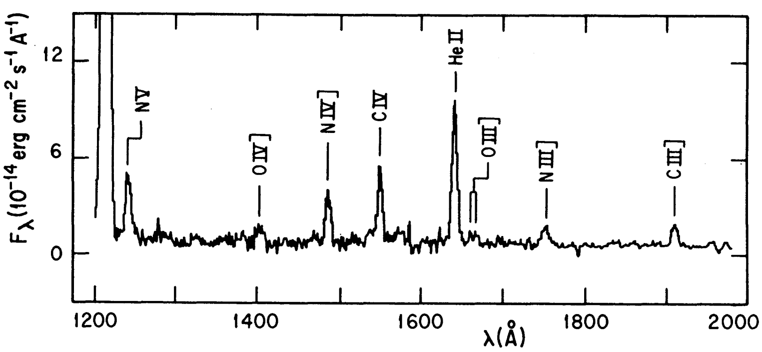

Fig. 2. Ultraviolet spectrum of N66. It corresponds to image SWP 19905, from the IUE Data Bank.

III. REDDENING AND PHYSICAL CONDITIONS

In Tables 1 and 2 we present the observed fluxes, F(λ), and the emission line intensities, I(λ), relative to Hβ, corrected for interstellar extinction. The logarithmic reddening correction, C(Hβ) = 0.18, was derived by fitting the observed Balmer decrement to the theoretical one computed by Hummer and Storey (1987), for case B. We have assumed an electron temperature of T_e = 16250 K and a density of log n_e = 3.3. A similar extinction parameter can be deduced from the He II λλ1640/4686 intensity ratio based on the IUE observations of N66 (Barlow 1987). We have dereddened the observations in the visible with the reddening function

TABLE 1

OBSERVED FLUXES AND DEREDDENED LINE INTENSITIES[a]

λ	id	log F (λ)/F (Hβ)	f (λ)	log I (λ)/I(Hβ)
3727	[O II]	−0.07	.255	−0.02
3835	H_9	−1.18	.228	−1.14
3869	[Ne III]	−0.04	.223	0.00
3889	H_8 + He I	−0.84	.217	−0.80
3967	H_7 + [Ne III]	−0.40	.202	−0.36
4026	He I + He II	−1.51:	.187	−1.48:
4068 + 76	[S II]	−1.39	.178	−1.36
4102	Hδ	−0.61	.172	−0.58
4227	[Fe V]	−1.61:	.142	−1.59:
4340	Hγ	−0.35	.125	−0.32
4363	[O III]	−0.71	.124	−0.67
4472	He I	−1.55:	.078	−1.53:
4540	He II	−1.56:	.073	−1.55:
4638	N III	−1.71:	.045	−1.70:
4686	He II	−0.17	.042	−0.16
4711 + 15	[Ar IV] + Ne IV]	−0.93	.039	−0.92
4725	[Ne IV]	−1.75:	.035	−1.74:
4740	[Ar IV]	−1.05	.031	−1.04
4861	Hβ	0.00	.000	0.00
4959	[O III]	0.49	−.022	0.49
5007	[O III]	0.97	−.033	0.96
5146	[Fe VI]	−2.17::	−.065	−2.18::
5200	[NI]	−1.92:	−.073	−1.93:
5338	[Fe VI]	−2.14:	−.105	−2.16:
5412	He II	−1.30	−.120	−1.32
5428	[Fe VI]	−1.99:	−.123	−2.01:
5723	[Fe VII]	−1.89:	−.180	−1.92:
5755	[N II]	−1.47	−.185	−1.50
5876	He I	−1.03	−.208	−1.07
6087	[Ca V]	−1.71:	−.250	1.75:
6300	[O I]	−1.37	−.284	−1.42
6312	[S III]	−1.50	−.286	−1.55
6375	[O I]	−1.71:	−.292	−1.76:
6438	[Ar V]	−1.74:	−.303	−1.79:
6548	[N II]	−0.26	−.321	−0.32
6563	Hα	0.50	−.322	0.44
6584	[N II]	0.21	−.325	0.15
6678	He I	−1.56:	−.339	−1.62:
6717	[S II]	−1.13	−.343	−1.19
6731	[S II]	−1.00	−.344	−1.06
7007	[Ar V]	−1.40	−.375	−1.47
7065	He I	−1.36	−.382	−1.43

a) The estimated errors are: less than 10% if log I (λ)/I(Hβ) ⩾−1.0, about 20% if −1.1 > log I (λ)/I(Hβ) > −1.5., 50% or greater for those marked with a colon.

TABLE 2

UV LINE INTENSITIES[a]

λ_o	id	F (λ) (10^{-14} erg cm^{-2} s^{-1})	f (λ) Galaxy	f (λ) LMC	log I(λ)/I(Hβ)
1240	N V	39.1	1.63	2.76	0.65
1383	S IV	6.2	1.34	2.21	−0.23
1404	O IV] + S IV + Si IV	11.8	1.31	2.18	0.05
1488	N IV]	24.9	1.23	1.96	0.34
1550	C IV	39.2	1.18	1.86	0.53
1574	Ne V	6.4	1.17	1.80	−0.27
1640	He II	72.1	1.14	1.63	0.76
1665	O III]	7.9	1.13	1.61	−0.20
1754	N III]	13.6	1.12	1.57	0.03
1884	Si III]	2.0	1.19	1.43	−0.80
1909	C III]	13.0[b]	1.23	1.41	−0.01

a) We have used $C(H\beta)_{Gal} = 0.09$, $C(H\beta)_{LMC} = 0.09$ and log F (Hβ) = −12.66 (Webster 1969) to derive dereddened line intensities.

b) Slightly saturated.

of Seaton (1979). We assumed that, in the optical region of the spectrum, the extinction law in the LMC is the same as in our galaxy.

The *UV* lines were dereddened by assuming that the total logarithmic reddening correction is C(Hβ) = 0.18, where C(Hβ) = 0.09 is due to foreground galactic extinction and C(Hβ) = 0.09, due to extinction within the LMC. The galactic extinction towards N66 has been estimated from the data of Burstein and Heiles (1982) who found $E(B-V) = 0.06$ in this direction. The reddening law of Nandy *et al.* (1981) was used for the LMC.

The relevant references to the atomic parameters to derive physical conditions and the chemical composition are from the compilation of Mendoza (1983).

The conventional diagnostic line ratios have been analyzed. From these, we derived T(O III) = 16250±300 K, T(N II) = 11600±500 K and log n_e(S II) = 3.29±0.08. The errors correspond to the uncertainty in the line fluxes. To derive the density sensitive [Ar IV] λλ4711/4740 intensity ratio, we have subtracted the contribution of the [Ne IV] λ4715 and the He I λ4713 emission lines to that of [Ar IV] λ4711; we have assumed that, under the physical conditions of N66, log [Ne IV] λλ 4711/4725 = −0.21 and log He I λλ4713/4471 = −0.86. From this, a logarithmic value of 0.07 is derived for the [Ar IV] ratio, which corresponds to log n_e = 3.62±0.10. This value for the density seems to indicate that N66 is centrally condensed. An electron density of log n_e = 3.44, was derived by Barlow (1987) from the [O II] λλ 3727/3729 intensity ratio.

IV. CHEMICAL ABUNDANCES

a) *Heavy Elements*

To derive ionic abundances, we have adopted a three-temperature zone model. We used T_e(N II) for the calculations of N^+, O^+, S^+ and S^{++} abundances. T_e(O III) has been used for He^+, C^{++}, N^{++}, O^{++}, Ne^{++} and A^{3+}; and for the higher ionization stages, we have used the electron temperature predicted by the best ionization structure model calculated for N66 (see § V).

The resulting ionic abundances are presented in Table 3, where we also tabulated the adopted T_e for each ion. The errors in the ionic abundances include the errors introduced by the line intensities in the electron temperature and in the relative emissivities of the ion relative to the Balmer lines.

TABLE 3

IONIC ABUNDANCES

ion	Adopted T_e	12 + log $N(X^{+m})/N(H^+)$
He^+	16,250	10.76 ± .02
He^{++}	19,000	10.77 ± .03
C^{++}	16,250	7.08 ± .07
C^{3+}	19,000	6.95 ± .07
N^+	11,600	7.26 ± .04
N^{++}	16,250	7.66 ± .07
N^{3+}	19,000	7.61 ± .06
N^{4+}	19,800	7.47 ± .10
O^+	11,600	7.36 ± .04
O^{++}	16,250	7.90 ± .03
O^{3+}	19,000	7.90 ± .10
Ne^{++}	16,250	7.31 ± .05
Ne^{3+}	18,000	6.75 ± .15
S^+	11,600	5.47 ± .05
S^{++}	11,600	6.49 ± .08
A^{3+}	16,250	5.80 ± .05
A^{4+}	19,000	5.25 ± .08

TABLE 4

TOTAL ABUNDANCES

		12 + log N(X)/N(H)					
Element	i_{cf}	i_{cf} method	Observed ΣX^{+m}	Model Input	Adopted Value	Monk *et al.*	Average of PN in LMC
He	1.00	11.07	11.07	11.07	11.07 ± .03	10.97	10.94
C	1.48[a]	7.49	–	7.45	7.45 ± .10	–	–
N	7.94	8.16	8.17	8.16	8.17 ± .05	8.36	7.81
O	2.00	8.31	8.26	8.26	8.26 ± .05	8.51	8.49
Ne	2.63	7.67	–	7.60	7.60 ± .10	7.76	7.64
S	1.45	6.69	–	6.69	6.69 ± .20	–	–
Ar	1.4[b]	6.08	–	–	6.08 ± .10	5.82	5.9

a) i_{cf} extracted from model.
b) By assuming that $N(Ar^{++}) = 0.5\ N(Ar^{3+})$. See text.

Total abundances can be obtained from the derived ionic concentrations and some standard formulae for ionization correction factor i_{cf} (e.g., Peimbert and Torres-Peimbert 1977; Barker 1983). We have used Barker's expression in deriving the O, N, Ne and S abundances. Abundances for O and N can be also derived by adding the ionic concentrations of all the available ions. The results are presented in Table 4.

The C abundance was derived from:

$$N(C)/N(H) = 1.43\ [N(C^{+}) + N\ \ N(C^{++})]/N(H^{+}) \ ,$$

where the i_{cf} was obtained from the ionization structure model.

The formula used for the Ar abundance was:

$$N(Ar)/N(H) = [1.5\ N(Ar^{3+}) + N(Ar^{4+})]\ /\ N(H^{+}) \ ,$$

where we have considered that $N(Ar^{++})/N(H^{+}) = 0.5\ N(Ar^{3+})/N(H^{+})$; this is the mean value derived by Aller and Czyzak (1983) and Aller *et al.* (1987) for some PN of the LMC with ionization conditions similar to those of N66.

b) *Helium Abundance*

The He^{+}/H^{+} abundance was calculated using three different He I lines (see Table 5). We have taken into account the contribution to the observed He I line intensities resulting from the collisional excitation of the 2^3S state of the He I. According to the discussion of Peimbert and Torres-Peimbert (PTP, 1987*a,b*), in N66 the He I λ4471, λ5876, λ6678, and λ7065 are enhanced by factors of 1.098, 1.210, 1.071 and 2.019 respectively due to collisional effects. Slightly greater correction factors (7% – 17%) are obtained by using the correction formulae of Clegg (1987), who does not include the photoionization effect of the He I 2^3S level, nor other possible sources of depopulation of this level, therefore Clegg's correction factors can be considered as upper limits to the actual ones.

TABLE 5

He^{+} ABUNDANCE

	He^{+}/H^{+}		
line	no coll	PTP[a]	Clegg[b]
4471	.064	.059	.054
5876	.071	.059	.050
6678	.060	.056	.053

a) Adopting PTP correction.
b) Adopting Clegg correction.

We have adopted the He^{+}/H^{+} abundance by taking the average of the abundances from the He I λ4471, λ5876 and λ6678 lines, as modified with the PTP corrections. We have not considered the λ7065 line which appears enhanced by a factor of 1.6, due to self-absorption effects.

In Table 4, we present total abundances for He, C, N, O, Ne, Ar and S derived with the i_{cf} and other methods. The differences among the different methods are small and the adopted values are presented in column 6. The errors include the uncertainties in the ionic abundances. For comparison we have also included the chemical composition derived by Monk *et al.* (1988) for N66 and for the bulk of the LMC planetary nebulae. The differences in the chemical abundances of N66 derived by Monk *et al.* and the values presented here, can be accounted on the differences in the adopted T_e. We derived T_e = 16250 K, while Monk *et al.* adopted T_e = 15000 K.

V. THE CENTRAL STAR

To determine the effective temperature of the central star, we used the Stoy energy-balance method, as developed by Preite-Martinez and Pottasch (1983). According to this method the dereddened intensities of the collisionally excited lines, and values for the electron temperature and the density are needed.

The dereddened line intensities of Tables 1 and 2, give $\rho = 32.54$ (ρ is the ratio between the flux of the collisionally excited lines and Hβ). In order to take into account some important unobserved collisionally excited lines (He I λ10800, [Ne V] λλ3346, 3426, [S III]λλ 9069, 9532, some IR lines, etc.), a contribution of ρ = 8.05 was added. This contribution is consistent with the observed lines and the model predictions. The value of ρ = 40.59 corresponds to a black body energy distribution with effective temperature of 109000 K, 110000 K and 98000 K for cases I, II and III of Preite-Martinez and Pottasch (1983). If we take the NLTE stellar energy distributions of Clegg and Middlemass (1987), we find that models with $T_{eff} \sim 90000$ K and log g $\sim$ 5.0 are adequate for the derived ρ.

Consequently, we have calculated a grid of nebular ionization structure models using NLTE central stars with effective temperatures ranging from 80000 K to 110000 K and log g ranging from 4.5 to 5.5. The NLTE stellar energy distributions were taken from the models with He/H = 0.10 calculated by Clegg and Middlemass (1987). This He/H ratio is in agreement with recent determinations of the He/H ratio in central stars of galactic planetary nebulae by Méndez *et al.* (1988). The stellar radius was calculated in order to fit the He II λ4686 line emission. We have used the code described by Peña (1986).

It was found that no filled uniform density distribution could reproduce adequately the observed electron temperatures and line intensities, and a model with an inner zone and an outer thin shell was adopted. This is in agreement with the [O III] λ5007 complex line profile found by Dopita *et al.* (1985), where besides the bipolar morphology, a multiple component structure is suggested. Moreover, it was necessary to assume that the nebula is density bounded, in order to adjust the low ionization line intensities. In this sense, N66 appears as an optically thin nebula, with a complex density distribution.

In Table 6 we present three ionization structure models calculated for central stars with effective temperatures of 80000 K, 90000 K, and 100000 K, respectively. The line intensities and the physical conditions predicted by the models are compared with the observations. We also included the stellar radius and the stellar luminosity derived in each case. From the stellar luminosity and the effective temperature we have interpolated values for the stellar mass from the evolutionary tracks calculated by Schönberner (1979, 1983).

In Table 6 it can be seen that the 100000 K model predicts electron temperatures and line intensities relative to Hβ that are too high, while both models with effective temperature of 80000 K and 90000 K fit the most important line intensities within 15 per cent. The 90000 K model reproduces better the higher excitation lines O IV] λ1403, N V λ1240, and C IV λ1550; although the 80000 K model fits better the intermediate excitation lines [O III] λ5007 and C III] λ1909. On the other hand, from the derived stellar radii and masses, we calculated a gravity of log g = 4.9 for the 80000 K star and of log g = 5.0 for the 90000 K star. The 90000 K star has a more consistent set of parameters; consequently, we adopted its parameters as those of the central star of N66.

The main discrepancies of the model predictions with observations are:

1) The low intensity predicted for the N V λ1240 emission line. A stellar effective temperature greater than 10^5 K would be necessary to reproduce the observed intensity, but such models predict a much higher electron temperature and line intensities (see Table 6). Moreover, the N V λ1240 line could be enhanced by stellar emission in which case the discrepancy might not be significant.

2) The C III] λ1909 is predicted approximately 50% higher and C IV λ1550, 30% lower than observed; moreover, the possible presence of a small amount of dust would reduce the C IV resonant lines, increasing the discrepancy (Hummer and Kunasz 1980). However, the total flux in both lines is similar to the observed value.

3) The model fails to predict a low T_e for the outer zone where the [N II] lines are emitted. The observed T(N II) depends on the weak [N II] λ5755 line, nevertheless an increase of a factor of 2 is needed to raise the temperature to the model prediction values. We consider that the line intensity has been measured with better accuracy compared to this discrepancy.

4) The spherically symmetric optically thin model could not reproduce the line intensities of the neutral species. N66 must be optically thick in some directions and optically thin in other directions in order to explain the observations; this is in agreement with the bipolar morphology found by Dopita *et al.* (1985).

VI. DISCUSSION AND CONCLUSIONS

By comparing the chemical composition derived for N66 (Table 4) with the bulk of the LMC-PN (Monk *et al.* 1988), it is found that N66 is a type I planetary nebula in the LMC, as defined by Peimbert and Torres-Peimbert (1983). The nitrogen to oxygen ratio is 0.8, while the He abundance is 35 per cent larger than in the bulk of LMC-PN, nevertheless He is not as enhanced as in the extreme type I LMC-PN P7 and P9 (Aller *et al.* 1987). He abundances of 0.133 and 0.152 are derived for P7 and P9 from Aller *et al.* data, after correction for collisional effects.

In N66 the C, N and O abundances follow the pattern of P7 and P9 in the sense that the O and C appear underabundant, by 0.21 dex and 0.45 dex, respectively, relative to LMC-H II regions (Dufour, Shields and Talbot 1982),

TABLE 6

OBSERVATIONAL AND PREDICTED LINE INTENSITIES[a]

			NLTE Models[b]		
ion	λ_o	I_o	80,000 log g = 4.5	90,000 log g = 4.9	100,000 log g = 5.0
He I	5876	8	7	7	7
He I	4471	3	3	3	3
He II	4686	72	76	76	77
He II	1640	578	576	578	580
C III]	1909	102	143	162	197
C IV	1549	331	239	251	251
[N II]	6583	141	139	140	265
[N II]	5755	3	5	5	14
N III]	1746	107	209	239	286
N IV]	1488	217	243	250	236
N V	1240	437	251	288	310
[O II]	3727	95	74	68	117
[O III]	5007	933	1020	1100	1250
[O III]	4363	21	24	26	33
O III]	1663	64	85	92	110
O IV]	1403	109	95	102	98
[Ne III]	3869	100	103	101	106
[S II]	6717	6	3	3	7
[S II]	6731	9	5	6	10
[S III]	6312	3	6	7	9
T_e(O III)		16250	16540	16740	17300
T_e(N II)		11900	15900	16200	16600
$r_{central\ part}$ (pc)		–	.13	.13	.13
r_{shell} (pc)		–	.27	.29	.29
n_H (cm^{-3})		1900	2000	2000	2000
log $L_*/L_\odot$		–	3.85	3.97	3.78
$R_*/R_\odot$		–	0.44	0.40	0.26
$M_*/M_\odot$		–	0.63	0.64	0.62

a) Relative to I(Hβ) = 100.0.
b) Model atmospheres from Clegg and Middlemass (1987).

while N is enhanced by 1.16 dex; however, the sum of C, O and N abundances is the same as in H II regions, indicating that O and C have been converted into N as a result of the CNO cycle. The Ne, S and Ar abundances are similar to LMC-PN and H II regions and much smaller than in our galaxy.

By means of an ionization structure model fitting the observations, we have derived an effective temperature of 90000 K, a luminosity of 9400 $L_\odot$, a radius of 0.4 $R_\odot$ and a mass of 0.64 $M_\odot$ for the central star of N66. Dopita *et al.* (1985) have suggested a much higher temperature and mass ($T_{eff} > 120000$ K and $M > 1.2\ M_\odot$), based on the high ionization degree of N66. The latter suggestions are in disagreement with the ionization structure models presented here and with the effective temperature derived from the Stoy energy-balance method.

A further argument against the high mass suggestion, is that a very massive central star would evolve so rapidly that the changes in stellar luminosity would be apparent in a few years, and changes in the nebular spectrum would be detected within a couple of decades. No evidence of spectral variations is found between the observations reported here and new spectral data obtained by us in August, 1987; moreover, the [O III] λ5007 and [O II] λ3727 line fluxes, relative to Hβ, measured by Webster (1969) agree within the errors with the present ones. However, the observations should be repeated in several years.

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