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ON THE PLANETARY NEBULA NGC 3918

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RESUMEN

Se han obtenido espectrogramas *IUE* de alta dispersión con diferentes tiempos de exposición. Se midieron y se analizaron las intensidades de las líneas de emisión. Las densidades derivadas a partir de los distintos iones confirman que la nebulosa no tiene variaciones sistemáticas de densidad. Las líneas de [Mg V] excitadas colisionalmente son intensas, en cambio las líneas resonantes de Mg II, λλ2795 y 2803 no aparecen en emisión. Se derivaron abundancias iónicas y se calcula un valor de la reducción del magnesio en la componente gaseosa de las partes externas de la nebulosa.

Se midió la velocidad de expansión de los distintos iones en los espectros de longitud de onda larga, y se encontró que la velocidad de expansión aumenta con una disminución del grado de ionización. Se derivó la distribución espacial de velocidades y se obtuvo que ésta es compatible con los modelos hidrodinámicos de expansión en el vacío. Se derivó para la nebulosa una edad cinemática de 3100 años. Se midió la dependencia con la longitud de onda de la asimetría entre las componentes roja y azul de las líneas. Se analiza una posible interpretación de esta dependencia.

ABSTRACT

We have obtained for this nebula high dispersion *IUE* spectra in the short and long wavelength ranges and with different exposure times. We have measured the emission line intensities and analyzed them. The density derived from different ions confirm that the nebula has no systematic density variations. The collisionally excited lines of [Mg V] λλ2783 and 2928 are present, but no measurable Mg II λλ2795 and 2803 appear in emission. We derived ionic abundances and a value for the depletion of magnesium in the gaseous component of the external parts of the nebula.

From the long wavelength exposures we have measured the expansion velocity for different ions, and we find an increasing expansion velocity with decreasing ionization degree. We have obtained the velocity field and we find that it is compatible with predictions, in the literature, for a nebula under isothermal expansion into vacuum. We derive for the object a kinematical age of ∿ 3100 years. A wavelength dependence of the asymmetry of the blue and red components of the lines is measured. We analyze a possible interpretation for this dependence.

Key words: NEBULAE – PLANETARY

I. INTRODUCTION

NGC 3918 has also been designated as PK 294 + 4°1 in the Perek and Kohoutek (1967) catalogue, and is He2-74 from the southern survey by Henize (1967). Its apparent diameter is of 19″ according to Westerlund and Henize (1967) who describe it as 'bipolar with ansae that extend 15″ from the center', while according to Evans and Thackeray (1950) it is a simple disk with very slight equatorial structure of 13″ diameter. The nebula has a high surface brightness and has been studied in great detail at *UV*, optical, infrared and radio wavelengths.

Its distance and extinction have been calculated by several authors. Milne and Aller (1975) from 5 GHz observations derived a distance of 1770 pc and a logarithmic reddening corrections at Hβ of C = 0.33; Torres-Peimbert and Peimbert (1977) from optical observations derived d = 1300 pc and C(Hβ) = 0.30; from *uv* data, Torres-Peimbert, Peña, and Daltabuit (1981, hereinafter TPPD) find C(Hβ) = 0.40 while Clegg *et al.* (1984) from *uv* and optical data find d = 1500 pc and C(Hβ) = 0.43. From these data we have adopted a distance of 1500 pc and an extinction of C(Hβ) = 0.40.

The nebula shows a wide range of excitation. Lines of Mg^{+4} and N^{+4} are present as well as those of O^{0} and N^{0}. TPPD obtained *IUE* low dispersion observations and computed ionization structure models; which combined with the previous study by Torres-Peimbert and Peimbert (1977) based on optical data allowed them to obtain physical conditions and the chemical composition of the nebula. They derived N_e(rms) = 5000 cm^{-3}, N_e(FL) = 5000 cm^{-3}, and found three temperature zones T(N II) = 8900 K, T(O III) = 12100 K, and T(Ne IV) = 13800 K. The abundances derived for this nebula are He/H = 0.112, log C/H = 8.98, log N/H = 8.39, log O/H = 8.78 and log Ne/H = 8.16. They also conclude that the observations are best fitted with an exciting star of $T_* = 150000$ K, and $L_* = 4 \times 10^3 L_\odot$. They found that low excitation lines

1. *IUE* guest observer.

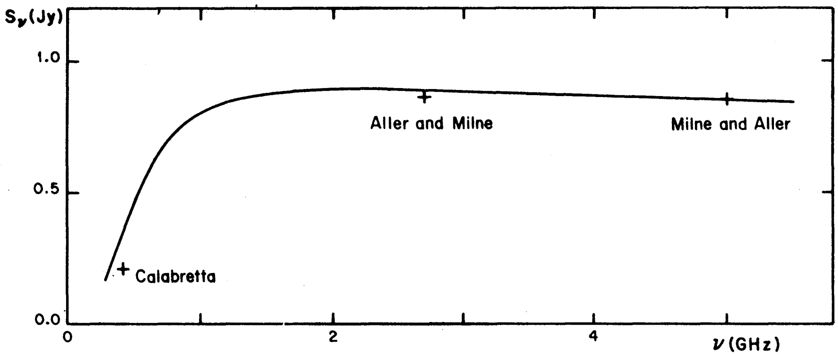

Fig. 1. Radio observations at 408 MHz (Calabretta 1982), at 2.7 MHz (Aller and Milne 1972) and at 5.0 GHz (Milne and Aller 1975). The solid line is the predicted radio continuum of a source of T_e = 12 000°K and emission measure of 1.43 × 10^6 cm^{-6} pc.

are weaker than predictions from spherically symmetric models. TPPD argued that the nebula is density bound.

Infrared data show that it has emission peaking at 37μ that decreases sharply to either side indicating the presence of dust at 200° K (Moseley 1980). More recent *IRAS* observations confirm this maximum (Pottasch 1984). The dust is probably responsible for the absorption of resonance *uv* lines (Peña and Torres-Peimbert 1983). Radio observations have been made by Milne and Aller (1975), Aller and Milne (1972), and Calabretta (1982) at 5, 2.7, and 0.408 GHz. We fitted the detected continuum with the free-free emission expected from a

TABLE 1

SHORT WAVELENGTH OBSERVATIONS

		IUE FLUX (10^{-2} counts s^{-1})							
		SWP 21762	SWP 21763	SWP 21764	SWP 21765	SWP 21766	SWP 21767	SWP 21768	
Ion	λ	150 min	60 min	120 min	20 min	15 min	20 min	30 min	log I (λ) / I (Hβ) [a]
H I	1215.6	97	83	81	...	...	...	...	− 0.67
N V	1238.7	59	46	63	...	...	...	...	− 0.89
N V	1242.6	28	35	37	...	...	...	...	− 1.12
C III d.r.	1247.3	15:	...	...	...	...	...	...	− 1.48:
O IV]	1399.7	32	...	42	...	...	...	...	− 1.31
O IV]	1401.0	109	131	105	150:	...	94:	98:	− 0.78
O IV]	1404.6	69	91	50	...	...	62:	60:	− 0.94
O IV]	1407.2	44	...	30	...	...	29:	24:	− 1.15
N IV]	1483.1	120	142	129	100	...	140	134	− 0.74
N IV]	1486.4	76	89	78	89	...	51:	72:	− 0.95
C IV	1548.0	>829	>1350	>952	1736	1529	1557	1464	+ 0.34
C IV	1550.7	>705	849	>733	827	849	820	844	+ 0.07
Ne IV	1601.3	44	38	33	...	...	...	...	− 1. 35
?	1605.7	...	...	26	...	...	...	...	− 1.45:
He II	1640.2	>856	>1610	>969	2055	1797	1922	1873	+ 0.28
O III]	1660.6	65	76	51	...	...	56:	47:	− 1.22
O III]	1666.1	180	178	168	92	...	140	175	− 0.79
N IV d.r	1718.6	13:	...	...	...	...	...	...	− 1.96:
N III]	1748.5	28	...	35	...	...	...	...	− 1.67
N III]	1749.5	132	110	130	108	...	149	130	− 1.07
N III]	1752.1	73	72	66	111:	...	85:	64	− 1.32
N III]	1753.8	33	...	40	...	...	...	...	− 1.61
Si III]	1882.4	58	47	67	...	...	...	65:	− 1.48
Si III]	1891.9	48	47	49	...	...	...	46:	− 1.56
C III]	1906.5	>963	>2083	>1048	3370	3217	3212	>3189	+ 0.26
C III]	1908.5	>747	>1635	> 827	2623	2396	2470	>2457	+ 0.15
C III d.r.	1923.1	20	...	...	...	...	...	...	− 1.96:

[a]. Intrinsic intensities already corrected for reddening with C(Hβ) = 0.40; we have adopted F(Hβ) = 9.3 × 10^{-10} erg cm^{-2} s^{-1}, I(4686)/I(Hβ) = 0.44, and I(1640)/I(4686) = 4.33.

plane parallel source of $T_e = 12000$ K of 18″ of apparent diameter and emission measure of 1.4×10^6 cm^{-6} pc (see Figure 1).

In Section II we describe the high dispersion *IUE* observations obtained; in Section III we present the line diagnostics and chemical abundances; in Section IV we discuss the line structure and velocity field of this object. Our conclusions are presented in Section V.

II. OBSERVATIONS

We have obtained a series of *IUE* high dispersion spectra with different exposure times in both short and long wavelength cameras for this nebula, in order to examine in detail the emission lines of different intensities. The line measurements for each exposure are presented in Tables 1 and 2 in *IUE* counts per unit time.

TABLE 2

LONG WAVELENGTH OBSERVATIONS

		IUE FLUX (10^{-2} counts s^{-1})				
Ion	λ	LWP 2407 180 min	LWP 2409 60 min	LWP 2410 30 min	LWP 2411 15 min	log I(λ)/I(Hβ)[a]
C III]	1906.7	> 587	557	632	440	0.57
C III]	1908.7	> 474	490	569	545	0.48
C III d.r.	2297.0	78	74	...	...	– 1.22
He II	2306.1	38	28::	...	...	– 1.54
[O III]	2320.9	75	116	...	...	– 1.19
C II]	2325.3	259	206	...	...	– 0.82
C II]	2326.8	132	163	...	...	– 1.02
C II]	2328.1	38	...	...	...	– 1.62
He II	2385.4	87	120	...	...	–1.35
[Ne IV]	2421.7	> 1 200	1 350	1 460	1 410	– 0.31
[Ne IV]	2424.3	> 1 100	1 360	1 390	1 290	– 0.34
[O II]	2470.3	217	323	...	...	– 1.19
He II	2511.3	253	281	363	321	– 1.20
?	2590.0	28:	...	...	...	– 2.40:
?	2628.3	11::	...	...	...	– 2.83::
He I He I	2677.0 2677.8 }	42:	...	...	...	– 2.30:
?	2678.7	16:	...	...	...	– 2.73:
He II	2733.3	> 746	744	808	836	– 1.07
He I	2764.0	19	...	...	...	– 2.68
[Mg V]	2782.9	> 399	449	396	411	– 1.36
?	2809.8	30:	...	...	...	– 2.56:
O III	2818.8	85	92:	...	...	– 2.06
He I	2829.0	80	103:	...	...	– 2.02
O III	2836.2	> 834	817	886	841	– 1.06
[Ar IV]	2853.8	241	217	133:	287	– 1.56
[Ar IV]	2868.2	79	102	...	...	– 2.02
[Mg V]	2928.3	104	110	...	...	– 1.93
He I	2945.0	78	...	...	...	– 2.05
O III	3023.3	171	165	...	...	– 1.59
O III	3024.6	44	74:	...	...	– 2.16
O III	3035.5	36:	...	...	...	– 2.23:
O III	3043.8	18:	...	...	...	– 2.53:
O III	3047.4	> 627	680	828	938	– 0.86
O III	3121.9	91	114:	...	...	– 1.54
O III	3132.8	> 1 060	> 2 300	> 2 080	> 1 810	> – 0.17
He I	3203.0	298	287	365	...	– 0.78

a. Intrinsic intensities already correct for reddening with C(Hβ) = 0.40; we have adopted F(Hβ) = 9.3×10^{-10} erg cm^{-2} s^{-1}, I(4686)/I(Hβ) = 0.44 and I(2733)/I(4686) = 0.19.

The errors in each measured line are relatively high; but there is general agreement between exposures within a factor of 0.97 ± 0.15. The mean *IUE* fluxes reported here are systematically brighter than those of the 120 min high dispersion exposure SWP 3215 (Peña and Torres-Peimbert 1983) by a factor of 1.2 ± 0.20. This difference in fluxes from the two epochs probably stems from the doubling in sampling that took place in November 1981, rather than from a difference in sensitivity, since the reports by Sonneborn (1984) indicate a loss of sensitivity of only ∿ 1% per year in the SWP camera.

To convert to absolute fluxes we have adopted the calibration curve by Casatella, Ponz, and Selvelli (1983) for the SWP exposures; while for the long wavelength region we have used the calibration curve for the LWP camera by Casatella and Harris (1983) and the calibration factors given for the LWR camera by Casatella, Ponz, and Selvelli (1983). We have verified the applicability of the latter to our LWP material by comparing with line intensities from low dispersion spectra from TPPD and by checking the He II recombination line ratios. The agreement is better than a factor of 1.2. To obtain dereddened fluxes we have used the extinction law by Seaton (1979) and have applied a reddening correction at Hβ of C = 0.40.

III. PHYSICAL CONDITIONS AND CHEMICAL COMPOSITION

a) *Density and Temperature Determinations*

In Table 3 we present density dependent intensity ratios obtained from data of Tables 1 and 2, as well as from other authors. All data are compatible with a rather homogeneous nebula with a mean density of 5000 (± 1500) cm^{-3} and a temperature of 10^4 °K, which confirm the results by Peña and Torres-Peimbert (1983) showing no systematic density variations with ionization potential. The comparison of the density obtained from collisionally excited lines with the rms density from Hβ flux (Torres-Peimbert and Peimbert 1977) indicates a filling factor near unity for NGC 3918.

From our measure of [Ne IV] λλ1602, 2422 line intensities we derived T(Ne IV) = 14000 ± 1000 K, where the uncertainties in temperature correspond to uncertainties in line intensity. This result is in agreement with the previous measurements of TPPD which indicate that there is a decreasing temperature with decreasing ionization degree.

TABLE 3

DENSITY DEPENDENT LINE RATIOS

		log Ne		
Ion	Ratio	This paper	Peña and Torres-Peimbert (1983)	Clegg *et al.* (1984)
O IV	1401/1405	3.93 ± .06	3.7	⩾ 3.85
N IV	1483/1486	< 4.0	⩽ 4.0	< 4.00
Si III	1883/1892	⩽ 4.0	4.0	3.54
N III	1752/1749	⩾ 4.0	⩾ 4.0	...
C III	1907/1909	3.83 ± .05	3.7	3.76
Ne IV	2424/2421	3.73 ± .05	...	3.62
S II	6717/6731	3.68 ± .03[a]	...	3.67
O II	3727/3729	...	...	3.66
H I	rms	3.66[b]	...	...

a. From intensity values of Torres-Peimbert and Peimbert (1977).
b. From Torres-Peimbert and Peimbert (1977).

b) *Chemical Composition*

1. *Mg Abundances*. From the [Mg V] λλ2873 and 2928 line intensities and assuming an electron temperature of 13800 °K for the zone of higher degree of ionization (obtained by Torres-Peimbert *et al.* 1981) we derive a value of $Mg^{+4}/H^+ = 3.98 \times 10^{-6}$. We were not able to measure the Mg II doublet at λλ2796.4 and 2803.5; our upper limit for each line is < 0.3 *IUE* counts s^{-1} (< 1.6×10^{-13} erg cm^{-2} s^{-1}). From the observed upper limit of log I(2803)/I(Hβ) < − 2.50, we derive an abundance $Mg^+/H^+ < 1.9 \times 10^{-7}$ for an electron temperature of 8900 K (typical of the lowest ionized species). That is, we find that $Mg^+/Mg^{+4} < 1/20$. This ratio is lower by a factor of ∿ 3 than expected from our models.

The relative depletion of the Mg II 2800 features have been pointed out by several authors for the nebulae NGC 6572, NGC 7027, NGC 7662, IC 2165, and NGC 2440 (Flower and Penn 1981; Pequignot and Stasinska 1980; Harrington, Seaton, Adams and Lutz 1981; Harrington and Marionni 1981; Shields *et al.* 1981). In several instances the derived ratio is up to two orders of magnitude larger than predicted by the models.

The resonance Mg II lines are probably attenuated by internal dust absorption and by interstellar Mg II absorption.

Pequignot and Stasinska proposed that magnesium is locked up in grains in the outer part of NGC 7027 (low Mg^+) but not in the inner part (normal Mg^{+4}).

On the other hand although we could not measure any emission of Mg II 2800 lines in any of our exposures, in LWP 2407 we can barely see traces of very noisy line emission at λλ2802.3 and 2803.4 and even fainter emissions at λλ2793.1 and 2796.3; these features can also be interpreted as wide emission lines with overlying absorption at λλ2795.8 and 2802.9 of 0.8 A FWHM. In the available material these 'absorptions' cannot be measured above the noise level; however, it is interesting to point out that the absorptions are seen against the nebular continuum itself because no stellar continuum is detected at this wavelength (Clegg *et al.* 1984).

Our data could be interpreted as absorption of the Mg II resonance lines taking place in the outer layers of the nebula; although our models are consistent with a nebula optically thin to Lyman radiation (density bounded), the nebula may be surrounded by considerable additional material. The absorption could also take place in the interstellar medium. Longer exposures of NGC 3918 would clarify this problem.

2. *C, N and O Abundances from Dielectronic Recombination Lines*. Dielectronic recombination lines from several ions have been observed in planetary nebulae, specially those from C II λ1335 and C III λ2297 (Seaton 1983). Such lines permit us to derive ionic abundances almost independently of electron temperature. The atomic data for these lines have been calculated by Storey (1981) and Nussbaumer and Storey (1984).

i) C^{+3} Abundance.

From our data we have measured C III λλ2297, 1247 and 1923 lines that were not detected in the low dispersion spectra. From these intensities we obtained a mean value of log $C^{+3}/H^+ = -3.50 \pm 0.10$. The derived abundance from C IV λ 1550 is log $C^{+3}/H^+ = -3.82$ (TPPD), this indicates a reduction of a factor of 2 of the resonance line intensity, generally attributed to internal dust absorption.

The model computed by TPPD predicted a value of the resonance line a factor of 3 higher than the observations. Our results, regarding the anomaly in the resonance line doublets of C IV and N V reported by Peña and Torres-Peimbert (1983) for this object have already been presented elsewhere (Torres-Peimbert and Peña 1984).

ii) O^{+4} Abundance.

The O IV λ1342 dielectronic recombination line was not detected in our spectra. Taking our upper limit detection to be 0.15 *IUE* counts s^{-1}, which corresponds to log I(1342)/I(Hβ) < −1.85, the ionic abundance is log $O^{+4}/H^+ < -4.60$. TPPD derived from observations log O/H = −3.22 and from their models predicted for O^{+4} and higher ionization stages a relative abundance of ∿ 23%. We find from λ1342 and the oxygen abundance by TPPD that the relative O^{+4}/O abundance is < 4%.

iii) N^{+4} Abundance.

The N V ionic abundance, as derived from the faint dielectronic recombination line N IV λ1718.6, is log $N^{+4}/H^+ = -4.55$. On the other hand, the N V λ1240 resonance line intensity of log I(1240)/I(Hβ) = −0.69 gives an abundance of log $N^{+4}/H^+ = -4.74$, for $T_e = 14000$ K. So that the N V resonance line appears attenuated a factor of 1.5 instead of the factor of ∿ 6 that TPPD derived from models. We find that 11% of the nitrogen in NGC 3918 is in the form of N^{+4} while the model by TPPD predicts 25%.

IV. LINE STRUCTURE AND VELOCITY FIELD

Line doubling of the lines at the center of planetary nebulae is a common feature, these line shapes have been interpreted as resulting from the expansion of the nebular gas approximately radially outward (Wilson 1948, 1950). In planetary nebulae, ΔV, the separation of the two components within a single line vary from ion to ion. In a general way the lines of highest degree of ionization, which are located in the central part of the nebula show the smallest value of ΔV, while those from lowest stages of ionization, which are located further out in the nebula, show larger values of ΔV. This result is indicative of an increase in the expansion velocity radially outward from the central star.

In the case of NGC 3918, in the long wavelength exposures available, the lines show appreciable double structure with line splitting of the order of 0.2 to 0.4 Å.

Some lines in the short wavelength exposures also show double structure but at these wavelengths the splitting becomes < 0.2 Å and both line components appear extremely blended. With the available precision, the measurement of such line splitting becomes very uncertain; we did not attempt to deconvolve each component since our spectra were obtained through the large aperture which has its long axis along the dispersion. It would be desirable to perform these short wavelength measurements from spectra taken with the small aperture.

We measured the splitting of the lines in the long wavelength exposures and obtained the expansion velocities of the ions in the nebula. The results are presented in Table 4. We have found as in other planetary nebulae that the ions of higher ionization potential are expanding more slowly.

TABLE 4

EXPANSION VELOCITIES

Ion[a]	ΔV/2[b] (km s^{-1})
C III	19
O II	22
He I	19
C III	17
O III	14
Ar IV	12
C IV	13
He II	13
Ne IV	11
Mg V	10

a. In order of increasing ionization potential.
b. Error ± 2 km s^{-1}.

Typical line splittings can be seen in Figure 2 where we present line profiles for [Ne IV] λλ2421 and 2424. In Figure 3 we show the detailed structure for the same pair of lines. These isocontours were extracted from the geometrically and photometrically corrected image files (GPI files) by NASA. From these contours it can be seen that there is indeed a well defined splitting in those lines.

Although, as explained previously, the exposures available are not the best suited material from which to derive radial positions, we decided to search for an ex-

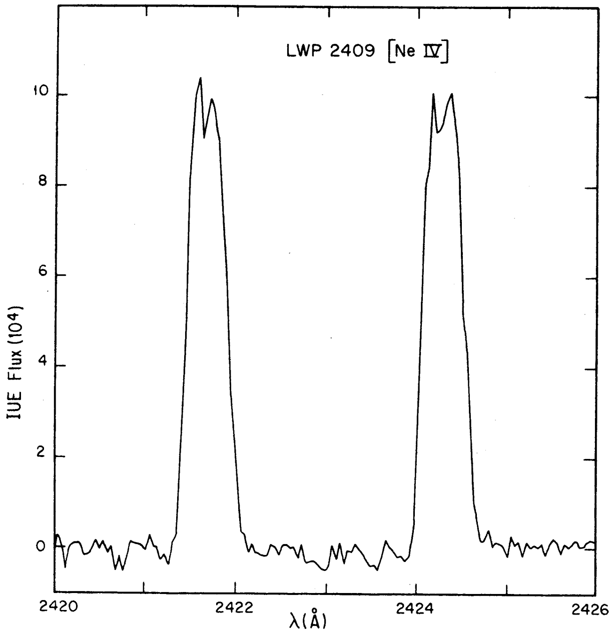

Fig. 2 [Ne IV] λλ2421 and 2424 line profiles from the LWP 2407 exposure showing the doubling of each line.

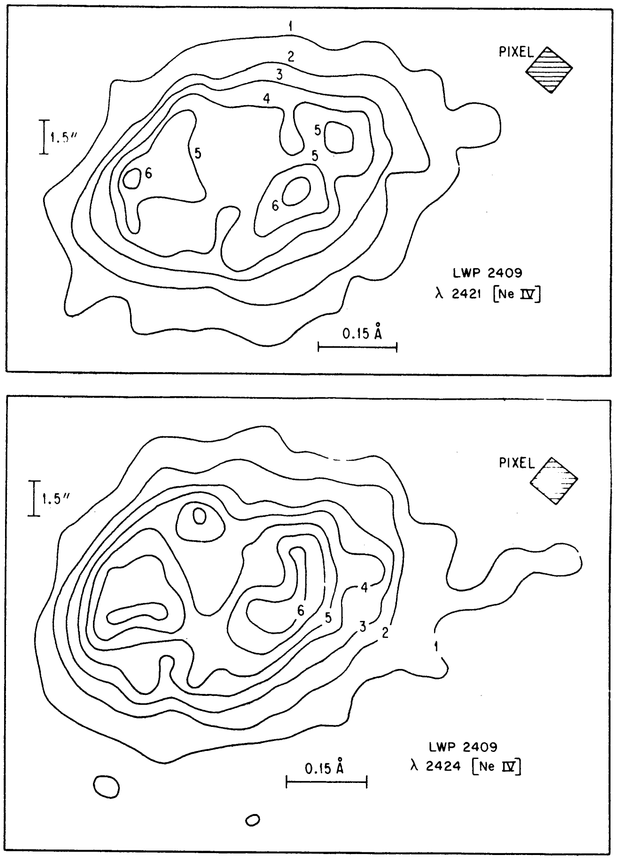

Fig. 3. [Ne IV] λλ2421 and 2424 isocontours from the geometrically and photometrically corrected image of the LWP 2407 exposure.

pansion velocity versus distance relation since a wide range of ions visible at *UV* wavelengths are present which are not otherwise observable at other wavelength range.

From the ionization structure model that best fitted the observations by TPPD we calculated the radial position of the maximum of emissivity for each line of interest. Figure 4 is a plot of expansion velocity versus radius. Hydrodynamic models of spherical nebulae in expansion into vacuum have been given by Osterbrock (1974) and Ferch and Salpeter (1975). All these models show, as expected, an increasing expansion velocity with radial distance and a similar behavior with our observations. Ferch and Salpeter have included in their calculations the effect of radiation pressure on dust grains which are coupled to the gas by drag forces. From their work we have included, for comparison in Figure 4, their model 1 with a nebular mass of $0.15\ M_\odot$ an initial expansion velocity of 10 km s^{-1} and 1000 years old, and their model 4 which has a nebular mass of $0.5\ M_\odot$, an initial velocity proportional to r, and is 3000 years old. Both models are for a gas-to-dust mass ratio of 400, and a central star of $10^4\ L_\odot$. The acceleration of the external shell is mainly due to isothermal expansion into a vacuum. We conclude from this comparison that the shapes are similar and would perhaps fit better if more realistic conditions for NGC 3918 were used.

Considering the expansion velocity, we have obtained for NGC 3918 a kinematical age given by

$$t_{kin} = 3144 \left(\frac{\phi}{18''}\right)\left(\frac{d}{1.5\ \mathrm{kpc}}\right) \Big/ \left(\frac{v}{20\ \mathrm{km\ s^{-1}}}\right) \mathrm{years},$$

which means that NGC 3918 is a very young nebula.

The global expansion properties of NGC 3918 (V_{exp} vs size) fall among the bulk of the relatively young planetary nebulae presented in the comprehensive study by Robinson, Reay, and Atherton (1982).

A slight asymmetry from the red to the blue components of [O II] λλ3727 and 3729 have been reported by Clegg *et al.* (1984) and we find the same asymmetry present in the *UV* lines.

We measured the asymmetry for each line in the LWP exposures and found that the red-to-blue intensity ratio varies systematically both with ionization potential and wavelength. These systematic effects have been measured in other planetary nebulae (cf. Doughty and Kaler 1982).

We found that for those lines that are formed near the center (Mg V, Ne IV, He II, Ar IV, and the O III flourescent lines) the mean ratio of the red to the blue component is $\langle r/b \rangle = 1.04 \pm 0.08$ while that of the less ionized species is $\langle r/b \rangle = 1.18 \pm 0.08$.

The ratio of the red to the blue component is higher at shorter wavelengths, this effect can be attributed to dust absorption within the nebula.

We have followed a similar treatment as that by

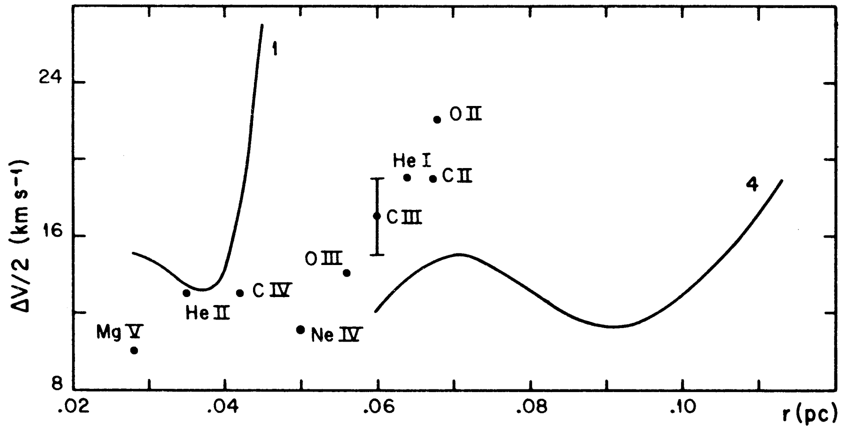

Fig. 4. Expansion velocities versus radial distance for NGC 3918. Filled circles are measurements for different ions and the solid lines are models 1 and 4 from Ferch and Salpeter (1975) at 1000 and 3000 years, respectively.

Doughty and Kaler (1982) who considered a nebular configuration that consists of two slabs expanding from the central star that produce the blue shifted and the red shifted line components. The observed red to blue emission ratio is given at any wavelength by

$$\left(\frac{r}{b}\right) = \left(\frac{r}{b}\right)_0 \frac{\tau_b}{\tau_r} \frac{1-\exp(-\tau_r)}{1-\exp(-\tau_b)} \exp(-\tau_b) \ , \qquad (1)$$

where τ_b and τ_r are the dust optical depths of the slabs that produce the red shifted and the blue shifted components, and $(r/b)_0$ is the intrinsic line emission ratio with no dust present. The ratio of intrinsic emissivities is given by the ratio of emission measures

$$\left(\frac{r}{b}\right)_0 \approx \frac{N_e^2(r)\, L_r}{N_e^2(r)\, L_b} \ ,$$

and for nebulae with constant gas-to-dust ratio

$$\left(\frac{r}{b}\right)_0 = \frac{N_e(r)\, \tau_r}{N_e(b)\, \tau_b} \ . \qquad (2)$$

In the optically thin case, equation (1) can be approximated by the second order in τ_r, τ_b

$$(r/b) \cong (r/b)_0\, [1-\tau_r/2+\tau_r^2/6]\, [1-\tau_b/2+\tau_b^2/12] \quad (3)$$

which reduces to

$$\cong (r/b)_0\, (1-\tau/2)$$

where $\tau = \tau_r + \tau_b$ is the optical depth of the whole nebula.

By assuming the wavelength dependence of the extinction by internal dust, $\tau(\lambda) = f(\lambda)\ \tau(H\beta)$, and that $(r/b)_0$ is independent of wavelength it is possible to derive the optical depth (at Hβ, for example) from the observed wavelength dependence of the asymmetry of the approaching and receding section of the nebula.

We fitted a least squares solution for equation (3) with our data and by adopting a normal extinction law (Seaton 1975).

We find $(r/b)_0 = 1.08 \pm 0.08$ and an optical depth of dust within the ionized zone

$$\tau(H\beta) = 0.08 \pm 0.04$$

From the above value it can be seen that in the case of NGC 3918 the optically thin approximation apppears to be valid. The above value of the dust optical depth is larger than that derived for the same object by Natta and Panagia (1981) who give $\tau(uv) \cong 0.04$ from far *IR* observations.

According to § 1 this nebula has an emission measure of 1.43×10^6 cm^{-6} pc and from our Table 3 we can substitute $N_e \cong 5000$ cm^{-3}, which yields an ionized hydrogen column density of 8.4×10^{20} cm^{-2}. For a normal extinction law we derive for the nebula a value of $E(B-V) = 0.012$ due to internal dust and thus obtain

$$N(HI)/E(B-V) = 7 \times 10^{22}\ \mathrm{cm^{-2}\ mag^{-1}}$$

The derived ratio is a factor of ∿ 13 larger than that of the mean interstellar medium. This result is in agreement with other measurements of internal extinction relative to hydrogen column density which have been found to be lower in planetary nebulae than in the interstellar medium (Bohlin, Marionni, and Stecher 1975).

V. CONCLUSIONS

In general, we confirm the results of Torres-Peimbert *et al.* (1981) about the characteristics of NGC 3918. It is a carbon rich PN, excited by a central star of $T_* \sim 150000$ °K and $L_* \sim 4.5 \times 10^3\ L_\odot$. The nebula has $N_e = 5000$ cm^{-3}, its filling factor is ∿ 1, and at a distance of 1.5 kpc, it has a size of 0.07 pc and a mass of 0.15 $M_\odot$.

We were able to measure several faint dielectronic recombination lines that yield temperature independent abundances of C^{+3}, N^{+4} and O^{+4} we found that the resonance lines C IV λ1550 and N V λ1240 are attenuated by factors of ∿ 2 and 1.5 respectively. These values are smaller than the model predictions by TPPD of 3 and 6.

For the case of C^{+3}, the model results and the abundance derived from the dielectronic recombination lines are consistent and both predict a reduction of the resonance lines of a factor of 2-3. On the other hand, in the case of N^{+4} we cannot reconcile the dielectronic recombination line abundance and the model that predicts a substantial fraction of the nebular nitrogen in higher stages of ionization. Furthermore we find the same effect in the case off O^{+4}.

From our observations we derived the abundance ratio $Mg^{+}/Mg^{+4} \leqslant 1/20$, while TPPD models, which are for a density bounded nebula, predict a value of 1/6; that is, we found a depletion of Mg^{+} relative to Mg^{+4} which is less extreme than the depletion observed in other nebulae. In our observations, there is the suggestion that the Mg II λ2800 line may be in absorption, instead of in emission. This absorption would take place in a surrounding tenuous external shell or in the general interstellar medium.

From our expansion velocity measurements we have calculated a kinematical age of 3150 years which is indicative of a mean mass loss rate of 4.8×10^{-5} $M_{\odot}$ year^{-1}. The nebular size and effective temperature of the central star can be located in the diagram of M_v versus age by Schoenberner and Weidemann (1983) from which it follows that the central star has a mass of ∿ 0.64 $M_{\odot}$ and $M_v = 3.3$. The central star is located at a fainter position than the bulk of the observed planetary nebulae. A change in distance a factor of 3 further away would bring it into the bulk of PN but then other characteristics like effective temperature would not fit with the observed line intensities.

The total mass of the progenitor star is likely to be greater than 0.8 $M_{\odot}$, then we may expect a substantial amount of material (∿ 0.5 $M_{\odot}$) surrounding the dense shell, ejected in a previous less intense mass loss phase like the red giant regular wind described by Renzini (1984).

From the wavelength dependence of the asymmetry of the red shifted to blue shifted components of the lines and assuming a normal reddening law we find the opacity due to dust within the ionized zone. This dust opacity is lower by a factor of ∿ 13 than that of the mean interstellar medium for its hydrogen column density.

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