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PHYSICAL CHARACTERISTICS OF TWO LOW–EXCITATION PLANETARY NEBULAE: HE 2-277 AND HE 1312

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RESUMEN

Se presentan nuevos datos espectroscópicos sobre dos nebulosas planetarias de baja excitación (He 2-277 y He 1312). He 2-277 es probablemente una planetaria de Tipo II pero tiene una deficiencia de abundancia respecto a los valores "cósmicos" de aproximadamente un factor de 3. Las distancias estimadas a He 2-277 y He 1312 son de 0.57 kpc and 1.7 kpc y las temperaturas Zanstra de las estrellas centrales son de 30400 K y 21300 K, respectivamente, consistentes con las características de baja excitación de las nebulosas.

SUMMARY

New spectroscopic data on two low-excitation planetary nebulae (He 2-277 and He 1312) are presented. He 2-277 is probably a Type II planetary but has an abundance deficiency of about a factor of three with respect to the "cosmic" values. The estimated distances to He 2-277 and He 1312 are respectively 0.57 kpc and 1.7 kpc and the Zanstra temperatures of the central stars are 30400 K and 21300 K, consistent with the low-excitation characteristics of the nebulae.

Key words: ABUNDANCES – NEBULAE-PLANETARY – SPECTROPHOTOMETRY

I. INTRODUCTION

Planetary nebulae in their early evolutionary phases are dense (and compact), displaying a low excitation spectrum. In the present paper we report new data on two of such nebulae, namely, He 2-277 (M1-26; HD 316248) and He 1312 (CPD-58°8315), considering the interest of studying the physical conditions of those objects near the epoch of their formation.

Both objects have a spectrum with emission lines due to low ionized species superimposed on a bright continuum due to the central star.

Recently Hutsemekers and Surdej (1985) presented a description of the spectral features of He 2-277. Their observations seem to indicate a net increase of the [O III] λ5007 intensity when compared with data obtained several years before. The [O III] λ5007/Hβ intensity ratio found by Vorontsov-Velyaminov *et al.* (1975) was 0.1 around 1968-70, 0.4 in 1977-78 (Kohoutek and Martin 1981) and we report presently a ratio of 0.6, as shown in §II. He 2-277 is highly reddened and has a strong infrared emission which is probably due to dust grains mixed with the ionized gas (Allen 1973). The central star of He 2-277 was observed by Kohoutek and Martin (1981) through narrow band photometry. A color temperature of 33100 K was derived from such data (Martin 1981), consistent with the low excitation characteristics of the nebula.

He 1312 is listed in the catalog of emission-line objects compiled by Wackerling (1970). Our data show a conspicuous absorption feature at λ3932 A, probably due to the K-line of Ca II, which was already reported by Sanduleak and Stephenson (1972).

In the following sections we describe our observations, derive the physical data, and discuss our results.

II. THE OBSERVATIONS

Our data consist in a set of moderate-resolution (7 A) spectrophotometry and Coudé spectroscopy with a resolution of about 0.5 A, obtained with the 1.6-m reflector of the National Laboratory for Astrophysics (LNA). The lower resolution data were obtained using a Cassegrain Boller & Chivens spectrograph with a 500-channel SIT-Vidicon detector while an intensifed Reticon was used with the Coudê spectrograph. The Vidicon data were reduced using a package which includes wavelength calibration, correction for flat-field and atmospheric extinction. Absolute fluxes were obtained through the observation, on the same nights, of standard stars (Stone and Baldwin 1983). The Reticon data were reduced similar-

TABLE 1

LINE FLUXES FOR He 2-277[a]

λ	Ion	I	Icor	λ	Ion	I	Icor
3727	[O II]	19.0	52.7	5537	[Cl III]	1.00	0.55
3970	Hε	5.2	11.5	5577	[O I]	1.5	0.81
4026	He I	0.43	0.91	5754	[N II]	10.9	5.1
4068	[S II]	1.90	3.90	5875	He I	17.7	7.7
4076	[S II]	0.68	1.39	6300	[O I]	7.5	2.5
4101	Hδ	11.0	22.0	6312	[S III]	7.0	2.3
4340	Hγ	29.9	50.4	6363	[O I]	3.4	1.1
4387	He I	0.24	0.40	6548	[N II]	143.7	41.5
4471	He I	0.93	1.5	6563	Hα	991.3	284.4
4657	[Fe III]	0.40	0.50	6583	[N II]	479.0	135.8
4701	[Fe III]	0.26	0.30	6678	He I	7.7	2.0
4713	He I	0.31	0.36	6716	[S II]	5.2	1.4
4755	[Fe III]	0.25	0.28	6730	[S II]	12.1	3.2
4861	Hβ	100.0	100.0				
4922	He I	0.67	0.63				
4959	[O III]	18.0	16.3				
5007	[O III]	60.0	52.1				
5015	He I	2.3	2.0				
5270	[Fe III]	0.77	0.53				
5517	[Cl III]	0.28	0.16				

a. log $F_{H\beta} = -11.17 \pm 0.04$ (in erg cm^{-2} s^{-1}).

ly using an adapted package developed originally at Harvard (CfA) for the "z-machine".

The Vidicon spectra were obtained at two observing runs: 18/July/85 and 9/April/86. For each object two images were obtained: one covering the interval between 3600–5900 A and another, in the range 4650–6930 A. Such a choice allows us to derive directly line intensities with respect to Hβ and relate the data on both images. In order to cover the same spectral range with the Coudé, nine images are necessary, with some overlapping to relate line ratios. The Reticon observations of He 2-277 were performed on two nights, 15/16 June/86. The Reticon data for He 1312 are not of good quality and they are not reported in this paper.

The average fluxes of the main lines in the spectrum of He 2-277 and He 1312 are given respectively in Tables 1 and 2. The typical errors in the line intensities are of the order of four percent for lines stronger than 10 ($I_{H\beta}$ = 100) and of the order of ten percent for lines weaker than 1.

The measured Hβ flux for He 2-277, i.e., log $F_{H\beta}$ = −11.17±0.04 is in excellent agreement with that obtained by Kohoutek and Martin (1981) through narrow-band photometry, namely, log $F_{H\beta}$ = −11.16±0.02. The other common lines such as Hα, Hγ, [N II] λ6585, [O III] λ5007, He I λ5876 are also in very good agreement. Inspection of Table 1 reveals that this object is quite similar to the dense and compact planetary SwSt-1 (Pacheco and Veliz 1987).

Besides the lines reported in Table 1, it is worth mentioning that Si II lines λ5041,56; λ5957,79; λ6347,71 are clearly present in our Coudé spectra. The N III λ4640 complex, also detected by Hutsemekers and Surdej (1985), is present in our data as well as the C III λ5696 transition. We suspect that both N III and C III are probably associated with the central star and not with the nebula. Hutsemekers and Surdej reported the presence of two relatively bright features at λλ4537 and 5584, which were not identified. The first one was not seen by us but the second is clearly present at λ5587. In addition, two other unidentified features seem to be present in the spectrum of He 2-277 at λ5978 and λ6046. Further data are necessary to confirm the reality of those suspected lines.

III. REDDENING AND DISTANCES

He 2-277 is near the galactic plane and close to the galactic center direction. We would expect under these circumstances that the nebula would be considerably reddened. Indeed the observed Balmer decrement indicates a color excess of $E_{B-V} = 1^m\!.15 \pm 0^m\!.24$. Radio observations of He 2-277 were reported by Milne and Aller (1975) and by Marsh, Purton, and Feldman (1976). These observations indicate that the nebula is optically thin above 2.6 GHz. In this case the radio data can be combined with the Hβ flux to derive the reddening. Milne and Aller obtained by this method $E_{B-V} = 1^m\!.12$. In fact they used a Hβ flux slightly smaller than our measured value (which, if used, gives $E_{B-V} = 0^m\!.91$) still consistent with that derived from the Balmer decrement. One should emphasize that the reddening derived from

TABLE 2

LINE FLUXES FOR He 1312[a,b]

λ	Ion	I	Icor	λ	Ion	I	Icor
3727	[O II]	32.7	50 9	5007	[O III]	150.4	141.6
4101	Hδ	23.5	31.7	5577	[O I]	6.7	5.1
4340	Hγ	43.1	54.0	5754	[N II]	11.8	8.5
4363	[O III]	6.8	8.5	5875	He I	18.2	12.7
4861	Hβ	100.0	100.0	6563	Hα	508.5	295.8
4959	[O III]	46.9	45.1	6583	[N II]	132.4	76.6

a. Vidicon data only.

b. log $F_{H\beta} = -11.49 \pm 0.06$ (in erg cm^{-2} s^{-1}).

the Balmer decrement would be in fact an upper limit if optical depth effects are present in the nebula. We adopt in our calculations the color excess derived from our data, and we give in the fourth column of Table 1 the dereddened line fluxes by such an amount. For He 1312 no radio data is available and we adopt a color excess of $E_{B-V} = 0^m.50$ derived from the Hα/Hβ ratio. Similarly, the dereddened line fluxes for this object are given in the fourth column of Table 2.

Milne and Aller (1975) using the Shklovsky method for radio fluxes derived a distance of 5 kpc to He 2-277. The Shklovsky method assumes an optically thin nebula (density bounded) and overestimates the distance for ionization bounded objects. Maciel (1984) using a mass-radius relationship which improves the Shklovsky method gives a lower limit, 1.4 kpc for the distance of He 2-277. If the gas is optically thick to the ionizing radiation and a balance is established between the ionization and recombination rates, then $M_i \propto 1/n_e$, where M_i is the mass of the ionized gas and n_e is the electron density. This situation is particularly true for the dense and young nebulae, as is the case of He 2-277 and He 1312. If we modify the Shklovsky method by taking into account the above variation of the ionized mass as the nebula expands, one obtains (Pottasch 1984)

$$D = 3\, F_{H\beta}^{-1/2} \quad \text{kpc}, \tag{1}$$

where $F_{H\beta}$ is the corrected Hβ flux in units of 10^{-11} erg cm^{-2} s^{-1}. From our data and adopted reddening, the equation (1) yields a distance of 530 pc for He 2-277 and 2.2 kpc for He 1312. Another independent distance estimate can be obtained from the empirical relationship between the absolute visual magnitude and temperature (Pacheco and Veliz 1987) namely,

$$M_V = -23.60 + 5.27 \log T\,. \tag{2}$$

As we shall see in the next sections, the temperature of He 2-277 is about 30400 K and that of He 1312 is about 21300 K. From equation (2) one obtains $M_V = +0^m.02$ for He 2-277 and $M_V = -0^m.8$ for He 1312. From our data, the visual magnitude (not corrected for reddening) of He 2-277 and He 1312 are respectively $12^m.5$ and $11^m.3$, resulting in distances of 610 pc and 1.3 kpc for the considered objects. We adopt as distances the straight averages from both methods resulting in values of 570 pc for He 2-277 and 1.7 kpc for He 1312.

IV. PHYSICAL CONDITIONS

In order to derive the electron density and temperature for He 2-277, we used the line ratios [S II] λλ

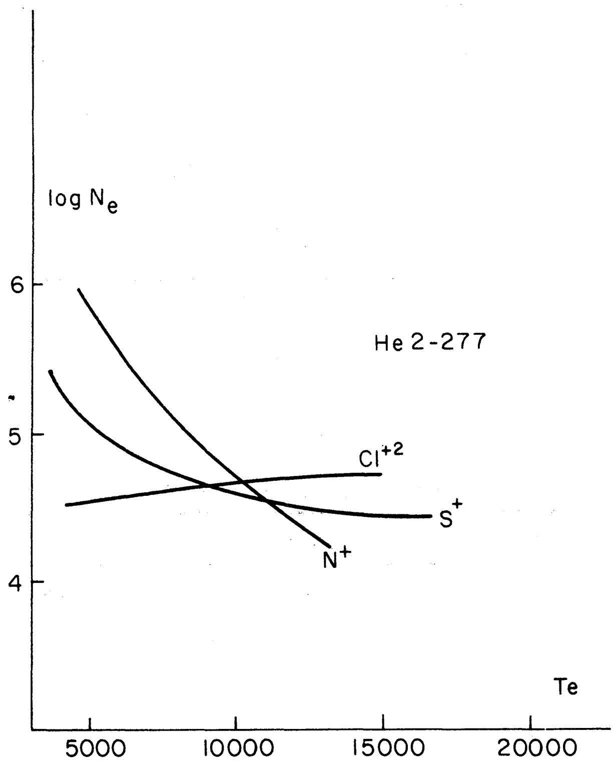

Fig. 1. Diagnostic diagram for He 2-277.

(4068,76)/(6716,30), [N II] λ5755/(6548,84) and [Cℓ II] λ5537/5517. The loci of the observed line ratio in the (log n_e – T_e) plane are shown in Figure 1. From this figure one obtains T_e = 10170 K and $n_e = 4.2 \times 10^4$ cm^{-3}. The line [O III] λ4363 is not detected on He 2-277. If we assume that I([O III] λ4363) < I(He I λ4387) we find that the ratio R([O III]) = I(λ5007)/I(λ4363) is larger than 130. In this case, with $T_e \sim 10^4$ K, such a limit implies that $n_e \lesssim 5 \times 10^4$ cm^{-3}, consistent with the results derived from other line ratios. In the case of He 1312, besides the nitrogen lines we used the ratio [O III] λ4363/(4959,5007). However, no single pair of values for the density and temperature could be found, indicating a more complex physical situation inside the nebula. If the electron temperature is in the range 8000 K $\leqslant T_e \leqslant$ 11000 K, then from our data we would expect that the density would lie in the interval $2 \times 10^5 < n_e < 3 \times 10^6$ cm^{-3}.

The ionic abundance was calculated using a three-level atom model, including collisional excitation and de-excitation and radiative transitions. In our computations we used the atomic data compiled by Mendoza (1983). No abundances were derived for He 1312 due to the uncertainties in the physical conditions.

Tables 3 and 4 give respectively the ionic and the elemental abundances for He 2-277. The ionization correction factors were taken from Mathis (1985), who calculated ionization equilibrium models for low-excitation nebulae. The ionization correction factor for helium is a difficult problem when the exciting star has a low temperature. Therefore, we give the ionic abundance only.

Our derived abundances indicate that oxygen, nitrogen, sulphur and chlorine are underabundant by a factor of three on the average with respect to the "cosmic" values, but the relative abundances with respect to oxygen are quite normal.

TABLE 3

IONIC ABUNDANCE FOR HE 2-277

Ion	Fractional Abundance	Number of Lines
S^+	8.8×10^{-7}	2
S^{+2}	4.3×10^{-6}	1
N^+	3.9×10^{-5}	2
O^+	1.2×10^{-4}	1
O^{+2}	1.8×10^{-5}	1
$Cℓ^{+2}$	6.7×10^{-8}	1
He^+	0.077	3

TABLE 4

ELEMENTAL ABUNDANCES FOR HE 2-277

Element	log [X/H] + 12	"Cosmic"
O	8.14	8.82
N	7.65	7.96
S	6.71	7.20
Cℓ	5.00	5.60

V. THE CENTRAL STARS

As we have seen both nebulae are relatively dense and we should expect that, in this case, the Lyman continuum radiation will be completely absorbed by the shell. In such a situation, the Zanstra temperature should give an acceptable estimate for the central star temperature. Using our data, we derived a Zanstra temperature T_Z(H I) = 30400 K for He 2-277 and 21300 K for He 1312. We have binned our continuum-flux data in order to simulate filter bands of about 40 A. These data points, after being corrected for the nebular continuum contribution (see, for instance, Pacheco *et al.* 1986) were compared with a black-body distribution (Figure 2). The best fitting corresponds to geometrical dilution factors of W = (1.74±0.50) × 10^{-21} for He 2-277 and

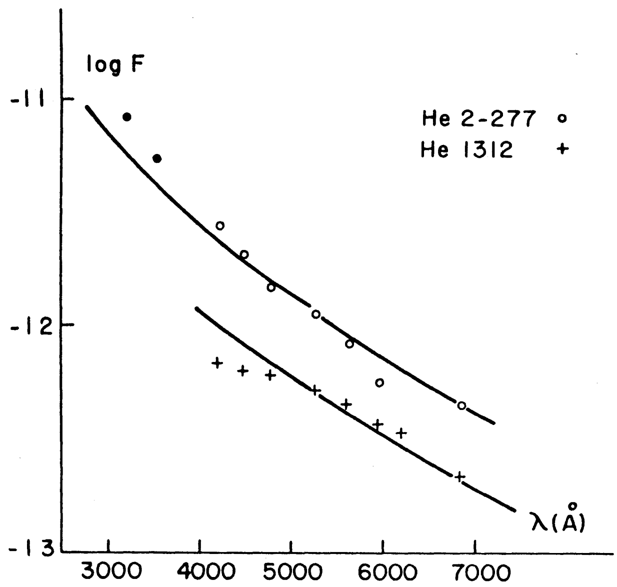

Fig. 2. Continuum fluxes for He 2-277 (open dots) and He 1312 (crosses). Filled dots are data points for He 2-277 by Martin (1981). Solid curves are black-body fits to the data.

$W = (1.38 \pm 0.20) \times 10^{-21}$ for He 1312. Our distance estimates and these last results allow us to evaluate the stellar radii as 1.0 $R_\odot$ and 2.7 $R_\odot$ for He 2-277 and He 1312 respectively.

The temperature derived for He 1312 is quite low but is consistent with the value obtained through the energy-balance method (Preite-Martinez and Pottasch 1983), namely, $T_{Stoy} = 20700$ K.

VI. DISCUSSION

He 2-277 is a relatively dense planetary nebula. The object is practically on the galactic plane and should probably be included among the Type II or intermediate population I planetaries (Peimbert 1978). However the heavy element abundances indicate an average deficiency by a factor of three with respect to "cosmic" values. A similar behaviour is observed in SwSt-1 where a deficiency by a factor of two is verified (Pacheco and Veliz 1987). These deficiencies are probably a consequence of original differences in the chemical composition of the material out of which these objects were formed.

He 1312 is denser and more compact than He 2-277. Besides that, it has a lower temperature and a larger radius. These are consistent with a picture of He 1312 being at an earlier evolutionary phase.

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