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He 2-104 revisited*

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Abstract. We report new spectroscopic observations of He 2-104 (the southern crab). The Balmer decrement indicates a reddening corresponding to a colour excess E(B-V)=1.2 mag. The main body of the ionized region has an important density stratification with values ranging from 10^3 cm^{-3} up to 6-7 $\times$ 10^6 cm^{-3}, shown by a robust correlation between density and the ionization potential of the preceding ion. The average electron temperature through that region is about 13 000 K. Our data suggests only a modest enhancement of He and N. The Stoy temperature of the hot star is of the order of 30 000 K, suggesting an early evolutionary stage for the planetary.

Key words: stars: abundances – planetary nebulae: individual: He2-104

1. Introduction

He 2-104 is an emission line object, which has extensively been studied in the last decades. Webster (1966) classified the object in her class A, considering the star as a probable planetary nebula. Allen (1973) from infrared photometry also classified He 2-104 as a compact planetary nebula with a circumstellar dust shell. Baldwin,Phillips & Terlevich (1981) considered different line ratios, trying to separate emission line objects according to their excitation level. Using such an approach, Gutiérrez-Moreno et al.(1986) concluded that He 2-104 distinguishes from planetaries and that the object is probably a symbiotic system. More recently, optical and UV spectra have been reported by Lutz et al. (1989), who performed the first quantitative analysis from these data.

CCD-images taken through narrow filters at Hα, [NII] λ658.4 nm and [SII]λ673 nm (Schwarz, Aspin & Lutz 1989) show a morphology suggesting the presence of an important bipolar flow. More recently, two other nebulae with similar morphology have been reported in the literature: BI Cru and MyCn 18 (Corradi & Schwarz 1993). These objects suggest a possible link between symbiotic system (at least for some types) and bipolar (planetary) nebulae.

In this work we present new spectroscopic observations of He 2-104, including new (faint) line intensities. The reddening was estimated from the Balmer decrement, and from our data we have obtained a new derivation of the electron temperature and densities. We have also estimated some elemental ratios, which give some insight about dredge-up effects suffered by the progenitor of the nebula.

2. Observations

As a part of an observational programme on symbiotic stars and planetary nebulae (Freitas Pacheco & Costa 1992; Costa & Freitas Pacheco 1994), we have secured spectra of He 2-104 since 1986 (Freitas Pacheco, Costa & Codina 1990). The spectroscopic observations were obtained using a Boller & Chivens spectrograph attached to the 1.6 m telescope of the National Laboratory for Astrophysics (Brazópolis - Brazil). The log of the observations is given in Table 1. The data were reduced using a standard software including wavelength calibration, flatfield and atmospheric extinction corrections, and flux calibration. The CCD data were reduced using the IRAF package and an Apollo 720 workstation. Fig. 1 shows the latest CCD spectra at different regions.

The slit of the spectrograph was always set in the WE direction and centered in the bright core. Since the data obtained with the various detectors are quite consistent, we have averaged line fluxes. The relative intensities are given in Table 2.

3. Reddening

From our data, using the ratios Hα/Hβ, Hγ/Hβ and Hδ/Hβ, we derived a colour excess E(B-V)=1.20$\pm$0.19, under the assumption that those ratios follow case B (Osterbrock 1974). This value can be converted to c=2.01$\pm$0.34 based on the relation between E(B-V) and c computed by Kaler and Lutz (1985). We assume, in our calculations, the reddening law given by Nandy

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* Based on observations made at the National Laboratory for Astrophysics - Brasópolis - Brazil

Table 1. Log of the observations

Date	Detector	Resolution	Spectral Range
1986 April 08	SIT Vidicon	9 Å	3600 - 7000
1987 July 02	Int. Reticon	9 Å	3900 - 7900
1988 March 27	Int. Reticon	4 Å	3800 - 7600
1989 May 04	Int. Reticon	9 Å	4100 - 8200
1993 May 03	GEC CCD	2 Å	3600 - 7100

Table 2. Line intensities for the nebula

Ion	I	I_0
[OII]λ3728	1.4	5.7
[FeV]λ3795	0.5	1.8
[NeIII]λ3869	40.0	132.0
[NeIII]λ3967(+H7)	19.7	57.0
[SII]λ4068	1.4	3.5
Hδ λ4101	9.3	22.5
[FeV]λ4180	0.3	0.6
Hγ λ4340	30.2	53.9
[OIII]λ4363	41.3	71.8
HeIλ4471	5.1	7.8
[ArV]λ4625	1.5	1.9
NIIIλ4640	3.9	4.9
CIIIλ4647	0.8	1.0
[FeIII]λ4657	0.3	0.37
HeIIλ4686	15.4	18.5
[FeIII]λ4701	0.14	0.16
[ArIV]λ4711	3.2	3.7
[NeIV]λ4724	3.2	3.7
[ArIV]λ4740	2.5	2.8
Hβ λ4861	100	100
[OIII]λ4959	108.5	98.3
[FeVI]λ4972	5.0	4.5
[OIII]λ5007	349.3	301.9
HeIλ5015	2.0	1.7
SiIIλ5041	2.1	1.7
[FeVI]λ5176	11.0	8.1
[ArIII]λ5191	0.6	0.4
[NI]λ5200	1.1	0.8
[FeIII]λ5270	0.4	0.27
[FeVI]λ5277	0.9	0.6
[CaV]λ5309	5.2	3.4

et al. (1975). Our derived colour excess is about 0.5 mag higher than the colour excess obtained by Lutz et al.(1989) and such a difference can be attributed to their smaller measured Hα intensity. The consistency of the corrected Balmer ratios with case B suggests that self-absorption is not very important, at least in the observed region. On the other hand, Whitelock (1987) found an important amount of circumstellar reddening corresponding to A_K=1.5 mag. This could be an indication that the distribution of dust in the system is patchy and that most of the ionized gas is not reddened by the material which surrounds the red star.

Table 2. (continued)

Ion	I	I_0
[ClIV]λ5323	0.2	0.13
[FeVI]λ5335	2.0	1.3
HeIIλ5411	2.9	1.7
[FeVI]λ5423,26	2.5	1.5
[ClIII]λ5517	0.72	0.39
[ClIII]λ5538	0.36	0.19
[OI]λ5577	0.5	0.26
[FeVI]λ5630	2.5	1.2
[FeVI]λ5677	3.7	1.8
[FeVII]λ5721	0.4	0.18
[NII]λ5754	6.3	2.8
CIVλ5801	0.7	0.3
CIVλ5812	0.2	0.09
HeIλ5876	34.4	14.1
[MnV]λ5891	0.1	0.04
[FeVII]λ6086	1.3	0.45
[OI]λ6300	3.8	1.15
[SIII]λ6312	3.5	1.05
[OI]λ6363	1.3	0.38
[ArV]λ6435	8.5:	2.3
[NII]λ6548	32.2	8.3
Hα λ6563	1235	315
[NII]λ6584	86.4	21.8
HeIλ6678	7.1	1.7
[SII]λ6716	3.6	0.84
[SII]λ6730	4.9	1.13
[ArV]λ7005	3.1	0.61
HeIλ7065	25.0	4.7
[ArIII]λ7135	11.0	2.0
[ArIV]λ7170	1.5	0.26
[OII]λ7325	8.7	1.4

In this work we adopt our reddening determination and the line corrected intensities are also given in Table 2.

4. The electron temperature and density

The usual forbidden line ratios do not allow a unique electron temperature determination since the nebula has an important density stratification. Lutz et al. (1989) have estimated the electron temperature using the ratio between the semi-forbidden line CIII]λ1909 Å(collisionally excited) and the recombination line CIIλ4267 Å. Using the results by Kaler (1986), they obtained $T_e \approx$16000 K. In fact, their estimate of the CIIλ4267 Å intensity is uncertain and the line is not seen in our CCD data (Fig. 1).

We estimated the electron temperature by using the ratio of the CIVλ1550 Åline (collisionally excited) and the recombination line CIIIλ4647 Å. The intensity ratio R=$I_{\lambda 1550}/I_{\lambda 4647}$ is given by

$$R = \frac{1.15 \cdot 10^6 t^{-1/2} e^{-9.285/t}}{\alpha_{\lambda 4647}(t)}$$

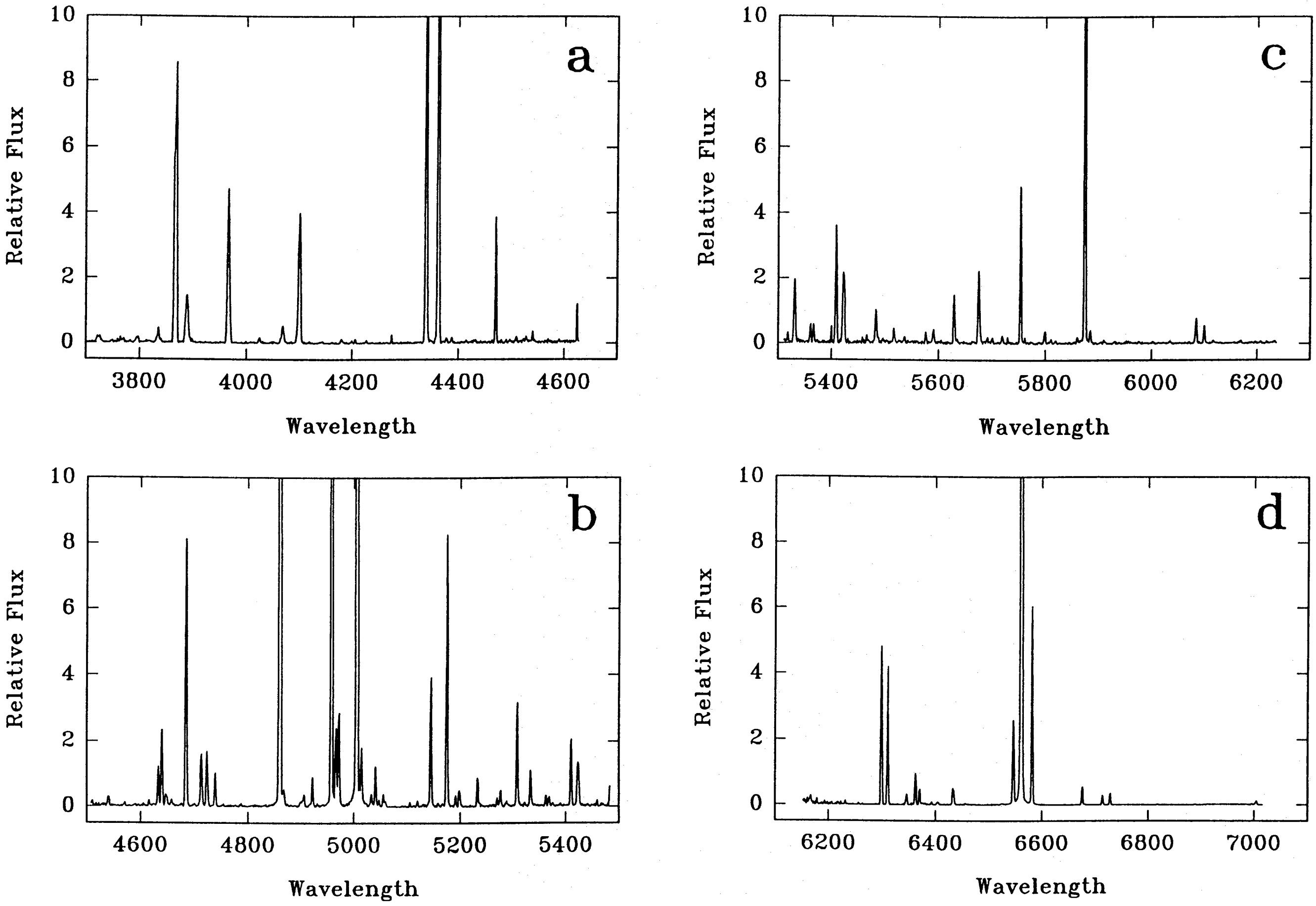

Fig. 1a-d. The spectrum of He2-104 in different spectral regions

where t=$T_e/10^4$ K and $\alpha_{\lambda 4647}(t)$ is the effective recombination coefficient of the line. Numerical factors were obtained using the collision strength given by Mendoza (1983). The effective recombination coefficient was calculated using the data by Freitas Pacheco et al. (1993)

The flux of the UV line was taken from Lutz et al., scaled to $I_{H\beta}$=100 by the following procedure: we first calculated the IUE flux of the line with respect to HeIIλ1640 Å. Then we correct for reddening using the colour excess obtained previously. The scaling to Hβ is then derived by adopting the ratio HeIIλ1640/HeIIλ4686=6.8 from a pure recombination theory, and the observed (reddening corrected) ratio HeIIλ4686/Hβ. Using our measured CIIIλ4647 Å line intensity, we obtained $T_e \approx$ 13000 K.

If we assume that the electron temperature throughout the main body of the nebula is 13000K, then from the ratio of forbidden lines we can estimate the electron density where the considered ion is dominant. Solving the statistical equilibrium equations, taking into account radiative and collisional processes, the resulting density for each considered line ratio and the corresponding ionization potential I_{eV} of the precedent ion are given in Table 3. We notice a robust correlation between the electron density and I_{eV}, indicating the presence of a density gradient through the nebula (Fig. 2). The same effect was noted by Allen (1983) for H1-36; from his Fig. 1, he claims that N_e is higher for more highly ionized species. However, the final interpretation of this correlation for He2-104 may be still more complex, as pointed out by Lutz et al. (1989). We have also estimated the average electron density from six [FeVI] line ratios, obtaining $\overline{log n_e}$=6.6, consistent with the highest value in table 3. This indicates a "saturation" of the correlation around log n_e=6.6 and, probably the maximum density at the inner edge of the nebula.

Table 3. Electron densities

Line Ratio	log n_e	I (eV)
[SII]6717/6730	3.2	10.36
[OII]3728/7324	4.0	13.60
[NII]5754/6584	5.0	14.53
[FeIII]4702/4658	5.0	16.16
[OIII]4363/5007	6.4	35.12

5. Chemical abundances

As we mentioned previously, an important density gradient exists through the main body of the nebula. Under this condition, the usual procedure to evaluate ionic abundances is not applicable. We have tried to model the nebula using the photoionization code CLOUDY (Ferland 1993). However, in spite of the large

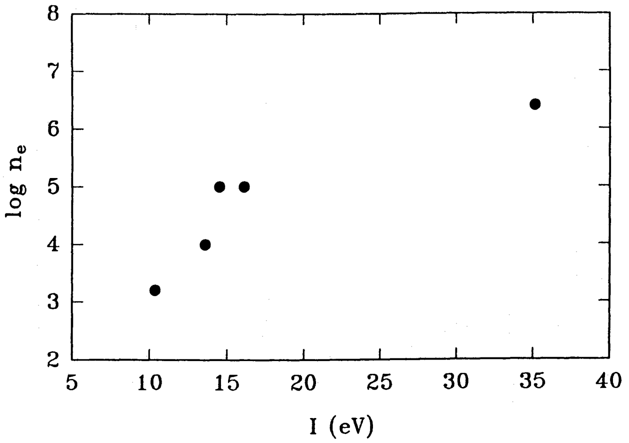

Fig. 2. Correlation between ionization potential and electron densities for the ions of Table 3

number of runs, exploring the variation of different parameters, we were not succeeded to reproduce the observed line ratios. This could be an indication that some ions may be produced by shocks in the complex velocity field of the nebula.

If He ions fill the same ionized volume as hydrogen, then using the method of Freitas Pacheco & Costa (1992) we get He^{+}=0.090 and He^{+2}=0.017, corresponding to a total helium abundance of He=0.107.

On the other hand, a rough estimate of the $\frac{N}{O}$ ratio can be obtained from the optical lines, since we would expect that N^{+} and O^{+} are dominant near in the same volume. In this case, one obtains:

$$\frac{N}{O} \approx \frac{N^{+}}{O^{+}} = 0.20$$

These values, in the diagram He vs. $\frac{N}{O}$ (Costa & Freitas Pacheco 1994), place He 2-104 consistently in the region occupied by planetaries and symbiotics. Moreover, using the UV line ratios reported by Lutz et al. (1989) corrected by our derived reddening, allow us to estimate similarly the ratio

$$\frac{N}{C} \approx \frac{N^{+2}}{C^{+2}} = 0.96$$

These ratios indicate that in the core of the progenitor a fraction of C was converted into N through the CNO cycle and dredged-up. This can be also verified through the ratio $\frac{(CNO)}{O}$=1.4, comparable to the solar value 1.6 . However, face to the structure of the nebula these values must be taken cautiously.

6. The central star

An estimate of the temperature of the central star, responsible for the ionization of the nebula, can be obtained using the Stoy method (Preite-Martinez & Pottasch 1983). We have derived $T_{Stoy} \approx 30000K$. The real temperature may be slightly higher but certainly not comparable to the values usually found in symbiotics ($\approx 10^5$ K).

If the abundance ratios are not able to shed some light into the nature of He 2-104, the temperature of the central star suggests a planetary nebula in a early evolutionary stage, whose envelope is strongly interacting with the wind emanating from the red companion. This is a situation prior to a "symbiotic" phase where the central star will reach a quite high temperature and, the outer envelope will be almost diluted into the interstellar medium.

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