

Spectrophotometric observations of two symbiotic stars

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Summary. Spectrophotometric measures of some emission lines for two objects, He2-104 and He2-106, both included in Allen's (1982) list of symbiotic stars, are presented. The symbiotic nature of He2-106 seems well established, since it has a cool component of spectral type *M*. On the other hand, no cool component has been found for He2-104. He2-106 has a very steep Balmer decrement, suggesting an optical depth at $H\alpha > 1$. The plots of the relevant ratios in Baldwin et al. (1981) diagnostic diagrams show that both objects are separated from the regions occupied in them by planetary nebulae. Their position in the $\langle \Delta E \rangle$, 3757/5007 diagram suggests a temperature of the central star somewhat lower than that accepted for normal planetaries.

Key words: spectrophotometry – symbiotic stars

1. Introduction

Symbiotic stars are complicated objects in which different physical processes exist. A discussion of their properties may be found, for example, in Boyarchuk (1982) or Sahade (1982). One of their characteristics is that they have emission line spectra, similar to those of high excitation planetary nebulae (PN), together with molecular bands corresponding to late-type stars. Different single and binary models have been proposed in the light of data (Friedjung, 1982). Single-star models present a number of problems and, in general, binary models are preferred. The most promising one, according to Plavec (1982) is that of a cool component – a red giant ascending the asymptotic branch, but not yet filling its critical lobe – and a hot star – maybe a subdwarf located in the same region of the Hertzsprung-Russell diagram as the central stars of PN – both surrounded by a nebular envelope excited by the hot component. Several authors (for example Kenyon and Webbink, 1984) propose that the hot component may be an accretion disk surrounding a low mass companion to the late-type giant, and consider that an adequate ionization mechanism to explain the intensity of $\text{He II } \lambda 4686$ – otherwise unexplained –

is the mechanical energy input into the nebula via hydromagnetic waves produced in a boundary layer near the central star.

The binary hypothesis is supported by the fact that many symbiotic stars are cataclysmic variable stars, slow novae, recurrent novae or binary systems which follow the models mentioned. But there is a group of stars which, at least at first sight, do not differ much from normal PN and, in fact, have been classified as such when just discovered. Allen (1984) has published a catalogue of symbiotic stars, preferring the variable star name, or, in general, the stellar designation. Nevertheless, we can see that there is a group of stars that retain the designation given to them in the Perek and Kohoutek (1967) catalogue of PN. The data in the optical region for all of them are scarce. Allen (1984) includes in his catalogue a set of optical spectra, ranging from $\lambda\lambda$ 3400 to 7500 Å, but most of them are not calibrated and no numerical values of the fluxes are given.

On the other hand, Baldwin, Phillips and Terlevich (BPT, 1981) have made a study of different parameters of emission line objects, in order to separate them according to the type of excitation mechanism. In their diagrams, specially in their Figs. 8 and 9, PN are clearly separated from other emission line objects, such as H II regions or emission line galaxies. One may ask: where do symbiotic stars fall in BPT diagrams? Do they occupy the same region than PN or a different one? Do BPT diagrams allow a separation between PN and symbiotic stars from their optical spectrum only? Trying to answer these questions and to increase the information on symbiotic stars, we have started a program of observation in which at least the lines used by BPT will be measured for a group of symbiotic stars. Up to the present, two objects have been observed: He2-104 and He2-106, and the results are discussed in the present paper.

2. Previous results

He2-104 and He2-106 were discovered by Henize (1964, 1967); both were studied by Webster (1966) and classified in her class A, having $N_1 \geq H\beta$, and considered probable PN. A list of some results found by different authors is given in Table 1.

Allen (1973) and Allen and Glass (1974), from their infrared studies, find that both objects have very large color indices [$(H - K) > 0.7$ mag and $(K - L) > 1.0$ mag] and estimate that the infrared excess cannot be readily accounted for by hot free-free radiation, but rather must be ascribed to reradiation from circumstellar dust clouds; on this basis, both objects are classified

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Table 1. Some previous results

Name	He2-104	He2-106	Ref.
PK designation	315+9°1	312-2°1	1
α (1950.0)	14h 08.6m	14h 10.4m	1
δ (1950.0)	-51° 12'	-63° 12'	1
Diameter	< 5"	< 10"	1
λ 5007/H β	~ 3	~ 6	2
log F(H β)	-11.80	-11.76	3,4
log F(5007)	-	-11.07	4
Flux density (5GHz)	0.015 Jy	0.070 Jy	5
Optical radius	< 2.5"	< 1.5"	5
C (radio-H β)	< 0.43	1.06	5
IR magnitude: K	6.80	5.5 (var)	6
J-H	2.04	3.6	6
H-K	1.76	1.9	6
K-L	2.06	2.1	6
Spectral type of the late component	-	M	6

- References: 1) Perek and Kohoutek, 1967
 2) Webster and Allen, 1975
 3) Perek, 1971
 4) Webster, 1969
 5) Milne, 1979
 6) Allen, 1982

by them as compact PN of type *D* (with circumstellar dust). Swings (1973) gives a list of observable permitted and forbidden lines for both objects, without quoting intensities, and establishes that He2-104 is a high excitation planetary, since its emission spectrum exhibits lines of [Ne v], [Fe vi] and [Fe vii]; he also suggests that the relative intensities of [O iii] λ 4363 and λ 5007 in such a high temperature object indicate that at least some zones of this nebula must have high electron density, of the order of 10^6 to 10^7 cm $^{-3}$. The same considerations are valid for He2-106. Sanduleak and Stephenson (1973) present observations of a list of strong emission line objects in the Southern Milky Way; they include He2-104, and establish that in their objective prism plates the object shows no continuum and that it presents a very steep Balmer decrement, probably due to reddening. Webster and Allen (1975) study these objects within a group of symbiotic stars of type *D*; they also give a list of detectable emission lines. Allen (1982) also includes them in his list of infrared observations of symbiotic stars, but Acker et al. (1982), in their Catalogue of Central Stars of True and Probable Planetary Nebulae, make no remark concerning the possible symbiotic nature of He2-104.

Radio observations have been made, among others, by Milne and Aller (1975), Milne (1979) and Calabretta (1982). The main results from Milne (1979) are quoted in Table 1; he classifies He2-106 as MP, meaning "Misclassified as PN – peculiar". Calabretta gives observations for the same object at 408 MHz (<0.08 Jy), 2.7 GHz (0.09 Jy) and 5.0 GHz (0.070 Jy). He also suggests the symbiotic character of He2-106.

Thus, He2-106 seems well established as a symbiotic star both from its general characteristics and from the presence of a cool component of type *M*. But the character of He2-104 is doubtful. In fact, Allen (1984) has taken it out of his catalogue of symbiotic stars, including it in a list of possible symbiotic objects; he states that it is a bipolar nebula of high excitation, possibly lacking a

late-type component, and resembling instead NGC 6302 (Oliver and Aller, 1969).

3. Spectrophotometric measures

The measures presented here have been made with the two-channel low-resolution Harvard spectral scanner attached to the 0.9m telescope of Cerro Tololo Inter-American Observatory. The observation procedures have been described elsewhere (Gutiérrez-Moreno et al., 1985). The atmospheric extinction used was determined by the authors, and will be published soon (Gutiérrez-Moreno et al., 1986). The emission lines were observed at peak intensities; besides, H α was scanned in order to deconvolve the blended profiles of H α itself and the two [N ii] lines at $\lambda\lambda$ 6548 and 6584 before integration. H β was also scanned and integrated, in order to get as accurate as possible H β fluxes. The scans show that the [N ii] lines do not contaminate the flux of H α at peak intensity for either of the two objects. The results of our measures are given in Table 2, with their percentage errors. The values of $F(\text{H}\alpha)/F(\text{H}\beta)$ were obtained independently from the comparison of the peak intensities and of the integrated fluxes of both lines. The results for [O i] λ 6300 must be considered upper limits, since this line is blended with [S iii] λ 6311, which has been reported as present by Webster and Allen (1975), and no attempt has been made to resolve this blend.

The logarithmic reddening corrections were obtained by the Balmer decrement method, using the reddening function $f(\lambda)$ normalized at H β , as derived from the Whitford (1958) extinction law. We attempted to fit the observed decrement to the theoretical value computed by Brocklehurst (1971) for $T_e = 10^4$ K and $N_e = 10^4$ cm $^{-3}$ for case B. The calculations were made for H α and H γ . The determination is straightforward for He2-104: we get $C_x = 0.60$, $C_y = 0.70$, and $\langle C \rangle = 0.65 \pm 0.05$, which is within what can be expected from the observational errors, but gives a Balmer decrement somewhat less steep than normal. He2-106 presents a different problem. Using the same procedure, we get $C_y = 1.24$, which is somewhat larger than the value quoted in Table 1 and obtained by Milne (1979) from comparison of H β and radio observations, and agrees well with the value 1.2, given by Kaler (1976), and obtained by the same procedure as Milne's value. Nevertheless, the calculation with H α /H β gives $C_x = 1.74$, which is not compatible with C_y and with the values just quoted. The very high value of $F(\text{H}\alpha)$ cannot be explained by recombination theory alone. In principle, it can be explained if the optical depth for H α and H γ is greater than unity. Pottasch (1960a, b) studied this problem and showed that the ratio $I(\text{H}\alpha)/I(\text{H}\beta)$ increases with the increase of optical thickness; on the other hand, if collisional

Table 2. Measured fluxes $F(\lambda)/F(\text{H}\beta)$

λ	He2-104	ϵ (%)	He2-106	ϵ (%)
3727	0.174	± 9.8	0.116	± 6.0
4340	0.378	7.1	0.318	3.1
5007	3.171	1.2	4.228	0.6
6300	0.058	5.2	0.188	2.6
6563	4.532	2.0	10.765	0.6
6584	0.408	± 12.3	0.138	± 4.6
log F(H β)	-11.76	± 0.00	-11.69	± 0.00

Table 3. Emission line intensities $\log [I(\lambda)/I(H\beta)]$

λ	He2-104	He2-106
3727	-0.56	-0.51
4340	-0.34	-0.32
5007	+0.48	+0.59
6300	-1.42	-1.11
6563	+0.44	+0.58
6584	-0.61	-1.32

excitations become important, the Balmer decrement will also be steepened (Aller, 1984). We have attempted an estimate of τ_α and of C by the use of the data given by Pottasch (1960a) in his Table 5. A good agreement between C_α and C_γ was obtained by trial and error for $\tau_\alpha = 2.9$, with $I(H\alpha)/I(H\beta) = 3.84$ and $I(H\gamma)/I(H\beta) = 0.483$, which gives $\langle C \rangle = 1.34$. Two remarks concerning this estimate are important: a) Pottasch's theory is for a static medium; if velocity gradients existed in the nebula, the results should have to be modified; b) it must be emphasized that Pottasch (1960a) states that his Table 5 is valid for electron densities below 10^5 cm^{-3} , while symbiotic stars envelopes probably have much higher densities. This makes the estimates of $\langle C \rangle$ much uncertain.

The assumption of He2-106 being optically thick seems justified by its small angular radius [$\theta < 1.5''$ according to Milne (1979)]. We may estimate the linear radius by computing the distance by means of Cudworth (1974) distance scale for optically thick nebulae; but it must be remembered that these estimates are uncertain, since assumptions valid for planetary nebulae are not necessarily valid for symbiotic stars. This is particularly true for the Cudworth distance scale, based on an assumed absolute magnitude for optically thick nebulae. Using $M_n = -2$ and $m_n(\text{pg}) = -2.5 \log I(H\beta) - 15.77$ (O'Dell, 1963) – with $I(H\beta)$ = dereddened flux in $H\beta$ – we get $d = 2.63 \text{ kpc}$, and the linear radius $R < 0.019 \text{ pc}$ according to Milne's data. The use of Maciel (1984) distance, $d = 3.5 \text{ kpc}$ (upper limit) does not change the conclusion that He2-106 is optically thick according to the criterion given by Torres-Peimbert and Peimbert (1977), that a nebula is optically thick if $R < 0.12 \text{ pc}$.

On the other hand, calculations for He2-104 using again Cudworth distance scale, give $d = 6.32 \text{ kpc}$ (against 6.3 – upper limit – given by Maciel), and with $\theta < 2.5''$, we get $R < 0.077 \text{ pc}$, which means that He2-104 is also optically thick, though no optical depth effects are noticeable in the Balmer decrement.

Table 3 gives $\log [I(\lambda)/I(H\beta)]$, where $I(\lambda)$ is the dereddened flux, obtained with the values of $\langle C \rangle$ just quoted, giving the most consistent results.

4. The BPT diagrams

With the data listed in Table 3, we have computed the logarithms of the ratios of interest for the BPT diagrams, including the corresponding ΔE values and, finally, the weighted average $\langle \Delta E \rangle$. The results are plotted in Figs. 1 to 6, which reproduce the BPT diagrams, retaining only the crosses and the vertical lines which represent the PN and the curves fitted by BPT to the H II regions from a simplified model which follows Searle (1971). We can see that in Figs. 1 to 5, He2-104 (large dot) and He2-106 (open circle)

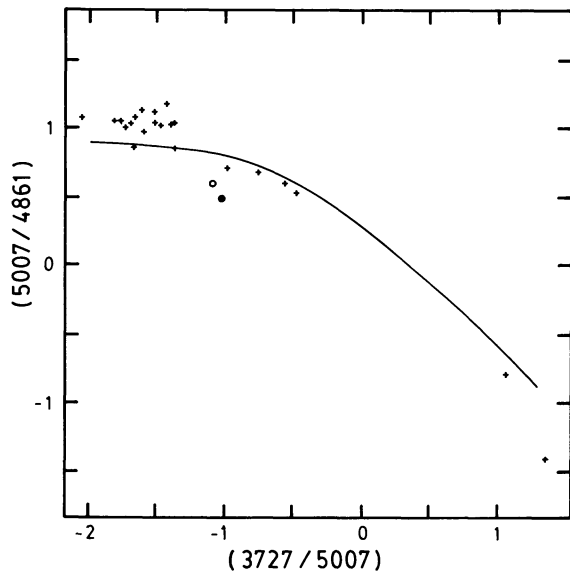


Fig. 1. Reproduction of Fig. 1 from BPT, showing the locus of H II regions, computed by BPT from a simple theoretical model; the location of PN (crosses) is indicated. He2-104 and He2-106 are represented by the large dot and the open circle, respectively. The coordinates are logarithms of the indicated intensity ratios

are clearly separated from the bulk of the points representing the PN; besides, in Fig. 6 both objects fall practically in the limit of the H II regions, far from the PN zone. Notice that a few PN used by BPT in their study are located within the zone of the H II regions. BPT establish that they may be misclassified H II regions or planetaries having unusually cool central stars.

We have analyzed the effects of a change in $\langle C \rangle$ on the location of the points in the different figures. The final results are summarized in Table 4, which gives the values of $\log [I(3727)/I(5007)]$ and $\langle \Delta E \rangle$ for the reddening constants $C = 0$, C_α , C_γ , $(C_\alpha + C_\gamma)/2$ and $\langle C \rangle$ when these two values are different. It can

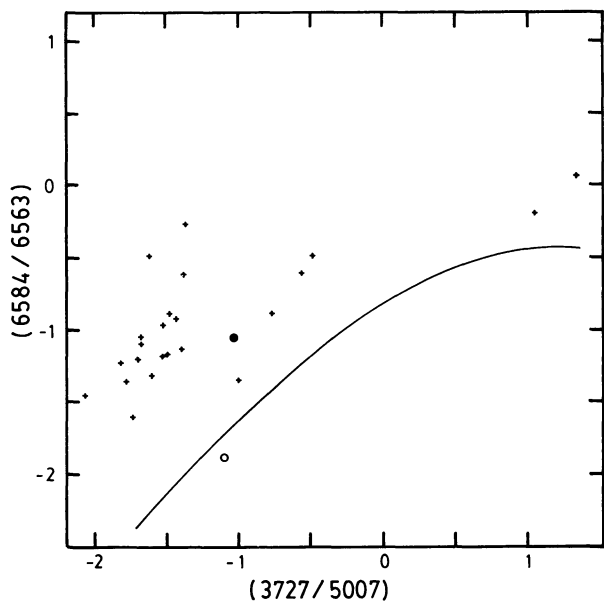


Fig. 2. The same as Fig. 1, for Fig. 3 from BPT

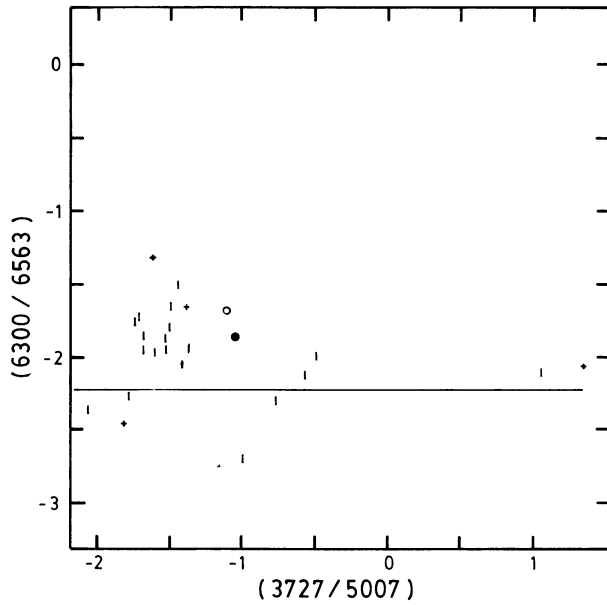


Fig. 3. The same as Fig. 1, for Fig. 4 from BPT. Vertical lines indicate upper limits. No theoretical curve for H II regions was computed, since BPT model does not predict the strength of $[\text{O I}] \lambda 6300$

be seen that the effect of a change in C is small, and does not change too much the location of the stars in the final diagram. With increasing reddening the point representing the star moves to the bottom and to the right of the plot, but always close to the position corresponding to $C = \langle C \rangle$. Thus, reddening errors do not affect the conclusions here obtained. In fact, this was already stated by BPT, who expressed that their parameters can discriminate different types of objects just as well with as without the reddening correction.

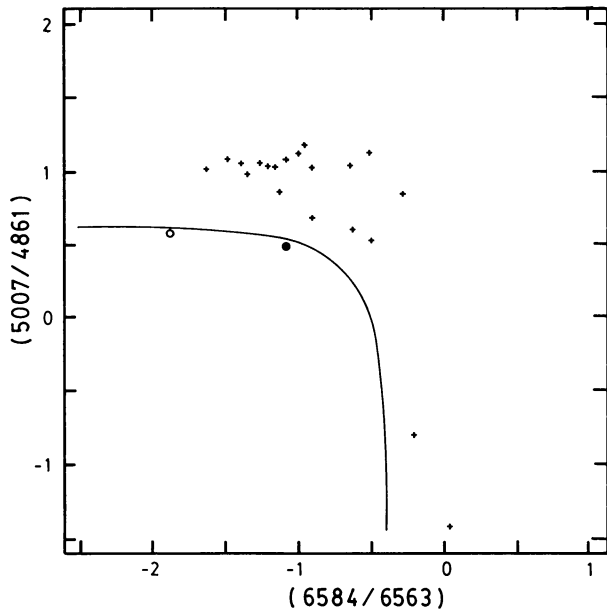


Fig. 4. The same as Fig. 1, for Fig. 5 from BPT

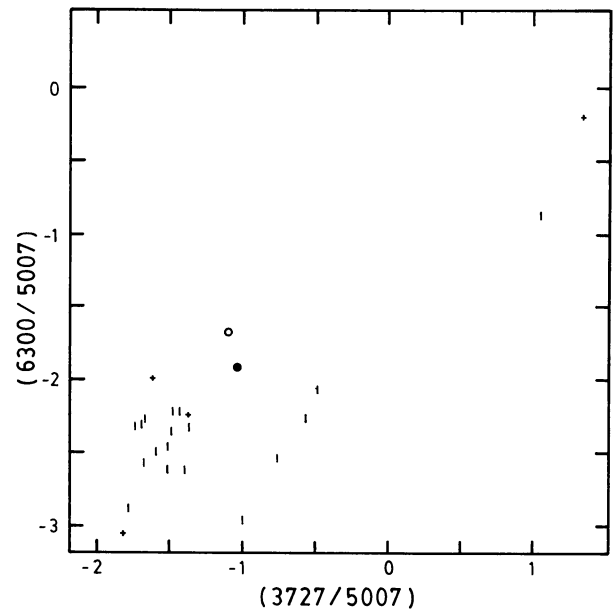


Fig. 5. The same as Fig. 3, for Fig. 6 from BPT

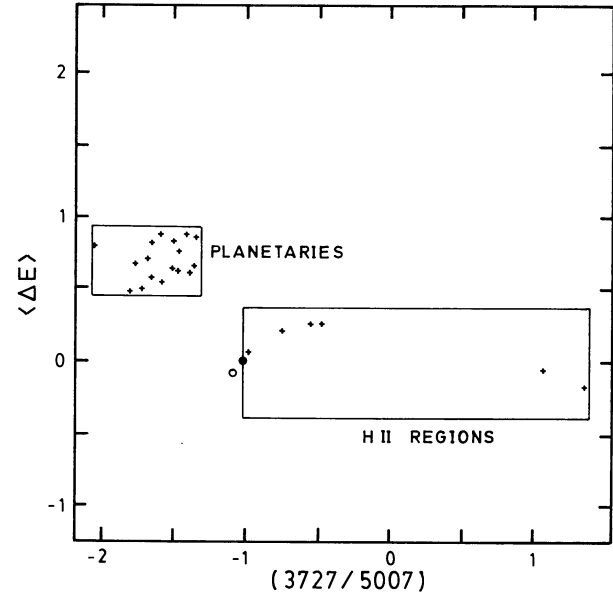


Fig. 6. Reproduction of Fig. 8 from BPT. The two objects studied here are located in the left outer edge of the H II regions zone

Table 4. Effects of reddening errors

	He2-104			He2-106		
	C	$\frac{3727}{5007}$	$\langle \Delta E \rangle$	C	$\frac{3727}{5007}$	$\langle \Delta E \rangle$
	0.00	-1.26	+0.046	0.00	-1.56	-0.020
C_α	0.60	-1.05	+0.023	1.24	-1.13	-0.063
C_γ	0.70	-1.01	+0.018	1.74	-0.96	-0.087
$(C_\alpha + C_\gamma)/2$	-	-	-	1.49	-1.05	-0.076
$\langle C \rangle$	0.65	-1.03	+0.021	1.34	-1.10	-0.068

5. Discussion

He2-104 and He2-106 are both optically thick *D*-type objects, with infrared excess due to reemission of radiation by circumstellar dust. After correcting by reddening, He2-104 shows a Balmer decrement slightly less steep than normal, similarly to NGC 6302 (Oliver and Aller, 1969), while He2-106 retains a steep decrement, which seems to imply an optical depth larger than unity (of the order of 3) for $H\alpha$. The position of both objects in BPT diagrams clearly separates them from PN, and suggests a temperature of the central stars somewhat lower than that accepted for normal planetaries, maybe a value between those of central stars of PN and those of O stars, in spite of the high excitation estimated by Swings (1973). Both objects have, in general, very similar behaviour, and He2-106 being a recognized symbiotic star, it seems possible to accept that He2-104 is also symbiotic, even though a cool component has not been detected.

We have shown that BPT diagrams have been able to segregate these two objects from PN. It is clear that two objects alone are not sufficient for accepting these results as definitive criteria to separate PN from symbiotic stars, but we intend to pursue this study further, extending it to as many certain or probable symbiotic stars as possible, to determine their general behaviour with respect to these properties and, in general, to measure and study the characteristics of their optical emission spectra.

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