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Spectroscopic observations of D-type symbiotic stars*,**

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Abstract. Observations of five D-type symbiotics are presented: three oxygen Mira (He2-38, H2-38 and H1-36) and two carbon Mira symbiotics (AS 210 and SS 38). The observations in the spectral range between 3200Å and 7400Å show the presence of several emission lines in various states of excitation. A line list is provided with their suggested identifications. Several parameters were derived for each object: interstellar reddening as determined from Balmer decrement and He II lines, temperature and electronic density, abundance ratios of Ne/O, Ar/O, Fe/Ne, N/O and He/H. We found nitrogen enrichment while for the other elements their abundances are compatible with solar, except iron which is depleted. We did not detect significant changes in the line and in the continuos spectra of the stars analyzed here, except for He2-38, which increased its degree of excitation compared to Allen's (1984) catalogue.

Key words: stars: abundances – binaries: symbiotic

1. Introduction

Symbiotic stars are divided, based on their infrared emission, into two groups : those that present dust continuum emission between 1.0 and 5.0μm and those that, in the same spectral range, exhibit a stellar spectrum. The former are classified as D-types while the later are classified as S-types. The infrared colors of the D-types indicate that dust emits radiation at T$\approx$800 - 1 000K. The differences between S(star)- and D(dust)-type were defined after several photometric surveys of emission line objects carried out in the infrared using J, H, K and L filters, (Allen & Glass, 1974, 1975). In earlier analyses of the stars V 1016 Cyg & RX Pup (Swings & Allen, 1972) and He2-104 & He2-106 (Swings(1973)), the presence of an infrared excess due to dust was already noted. Glass & Webster (1975), after observing another sample through infrared photometry, concluded that symbiotic stars which show an infrared excess should represent a small sub-class of stars. Webster & Allen (1975) observe that D-type objects have a ratio [O III]$\lambda\lambda$4959,5007Å/Hβ greater than 1.0 while S-type objects have a ratio of less than 1.0. The properties of both types were well summarized by Allen (1982) in the first IAU Colloquium devoted to symbiotic stars. It is also known that the primary component of the D-types is a Mira variable. The evolutionary status of the Mira variable was discussed by Schild (1989) who found, from a relationship between the rate of mass-loss vs period of the pulsating Mira, that the cool component is in the same evolutionary status as short-period OH/IR sources.

Symbiotic binaries are also known to have photometric and spectroscopic variations. They can be either regular or erratic depending on the nature of the phenomenon. In the first case they are related to the orbital motion while in the latter, they are due to outbursts or some unexpected variations in the giant's wind which could also account for changes in the UV/optical continuum level. Among the three types of symbiotics (D- D$'$ and S-types), the D-types are those that exhibit little variation in the absence of outbursts. This is due to the larger orbital periods of these binary systems (P$\geq$10 years).

In this work, spectroscopic observations of five D-type symbiotics (three oxygen Mira (He2-38, H2-38 and H1-36) and two carbon Mira (AS 210 and SS 38)) are reported and discussed. We concentrate our analysis on D-types since these objects, due to their large binary separation, have a lower electron density (10^6 cm^{-3} - 10^7 cm^{-3}) compared to the S-types (short orbital period 1 - 3 years, $N_e \approx 10^9$ cm^{-3}). In this way, classical techniques for plasma diagnostics e.g., reddening determinations, physical conditions in the emitting nebulae and abundance analysis can be applied to these objects.

2. Observations and reductions

Spectroscopic observations were performed using a Boller & Chivens cassegrain spectrograph at the 1.52m ESO telescope of La Silla (Chile). A UV-flooded thinned Loral Lesser CCD #39 (2048 x 2048, 15μm/pixel) detector was used giving high quantum efficiency in the blue and in the UV.

In order to achieve a better investigation of the observed objects, two gratings, with different dispersions were used. One

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** Table 2 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

Table 1. Observation log of symbiotic stars.

Star	Date	Wavelength range	Exp time (sec)
He2-38	1997 Jan 17	3110Å - 5210Å	900
			600
	1997 Jan 19	3200Å - 7065Å	600
			300
	1997 Fev 24	3530Å - 7390Å	360
			240
AS 210	1997 Fev 23	3055Å - 5055Å	600
			180
	1997 Fev 25	3530Å - 7390Å	120
			600
H2-38	1997 May 21	3538Å - 7434Å	60
			420
	1997 May 23	3110Å - 5113Å	900
			600
H1-36	1997 July 20	3533Å - 7437Å	900
			180
			60
			20
	1997 July 22	3115Å - 5118Å	900
			300
			90
SS 38	1997 May 22	3538Å - 7134Å	60
			900
	1997 May 23	3110Å - 5113Å	720
	1997 July 20	3533Å - 7437Å	900
			300
	1997 July 22	3130Å - 5133Å	2400
			900

grating with 1200 l/mm and the other with 600 l/mm. The former allows a reciprocal dispersion of 1Å pixel^{-1} with a resolution of 2Å and the latter, 1.9Å pixel^{-1} with a resolution of 4.6Å. Observations taken with the 1200 l/mm grating give a spectral coverage between ≈3100Å and ≈5100Å while those taken with the 600 l/mm grating give a coverage between 3500Å and 7400Å. All the objects in the UV-blue region were observed at very low air mass X≤1.1. The slit width was 4 arcsec. Table 1 shows the log of observations.

The data were reduced to the linear scale, i.e. wavelength versus flux, using IRAF. The data were initially treated with the help of the *ccdproc* and *onedspec* tasks of IRAF. We followed the standard procedure consisting of bias subtraction, flat-field normalization and wavelength calibration through a He-Ar lamp. Counts were corrected from atmospheric extinction and calibrated from instrumental chromactic response through observations of standard stars from Oke (1974) and from Hamuy et al (1994). In the linearized spectra, the line fluxes were measured with the *splot* task and blends were resolved using the *deblend* option. Figs. 1 and 2 show the reduced spectra of our sample. We estimate the errors in the fluxes to be about 20% for weaker lines (line fluxes ≈10 on the scale of Hβ=100) and about 10% for stronger lines.

3. The spectra

All the objects display a rich emission line spectrum. Most lines are common features of planetary nebulae and other symbiotic stars previously studied in the optical range. However, in order to identify the weaker lines - those which have not been previously reported or seen in any symbiotic system - we use the line lists provided by Kaler (1976) of planetary nebulae and diffuse nebulae, McKenna's et al (1997) identification list of RR Tel and the references therein, Andrillat & Houziaux's (1994) identification list of PU Vul and Aller's et al (1996) line list of PN NGC 6790. Table 2 shows the observed line intensities and the suggested identifications. Since different sources are consulted, quite often more than one ion can be allocated to a single spectral line. In these cases, we give all the possible identifications for example, Ne II, [Fe II] and V II may all contribute to the feature at 4232 Å. Of all the lines in the sample, 20 remain unidentified and 3 of them have already been reported in the spectra of other gaseous nebulae (Wyse 1942): 5835Å and 6041Å in the planetary nebulae NGC 7027 and 6130Å in the planetary nebulae NGC 6741. These lines are quoted as $w1$, $w2$ and $w3$ in Table 2. For H1-36, we also use the line list provided by Allen (1983).

The carbon Mira AS 210 and the oxygen Mira H1-36 are the most investigated objects of our sample. Emission line observations of AS 210 were presented by de Freitas Pacheco & Costa (1992), Gutiérrez-Moreno & Moreno (1996) and Medina-Tanco & Steiner (1995). Our spectra between 3100Å and 5100Å clearly show the Balmer decrement in emission plus the strong emission lines of He IIλ3204Å [Ne V]λ3425Å and the blend of the Bowen line of O IIIλ3340Å with [Ne V]λ3345Å. Our spectrum of AS 210 does not show the G band as was earlier reported by Wilde (1965). The spectrum has the same C_2 and CN bands as found in the carbon Mira SS 38. Between 3400Å - 7400Å many additional emission lines are seen. He IIλ4686Å is strong in our spectra. In fact, the equivalent width of He IIλ1640Å (500Å) suggests a high temperature of the ionizing source (Schmid & Nussbaumer, 1993). Comparing our line ratios with those analyzed by the previous authors, we find that AS 210 has suffered little variation. In a I(4363)/I(Hγ) vs I(5007)/I(Hβ) diagram (Fig. 8 of Gutiérrez-Moreno & Moreno (1996)), AS 210 has moved little in the last 10 years. The slope of the continuum of AS 210 does not show any significant variation either, with the exception of the spectrum of Medina-Tanco & Steiner (1995).

SS 38 is the other known Mira type carbon symbiotic in our galaxy. Schulte-Ladbeck et al (1987) classified SS 38 as C9 star. Our spectrum clearly shows the C_2 bands at 5125Å and 5636Å and the CN bands at 6925Å 7088Å and at 7259Å. The shape of the continuum has not shown any significant change relative to the spectrum in Allen's (1984) catalogue.

Previously published line fluxes of H2-38 are found in Mikolajewska et al (1997). Comparing their line ratios relative to Hβ with ours, the degree of excitation has increased in the last 12 years. Our line ratios for the most excited lines, He IIλ4686Å, [Fe VII]λ6087Å, [O III]λ5007Å and O VIλ6830Å scattered line, are twice as large as theirs. The same can be said for the H I and He II recombination lines which also has implications for

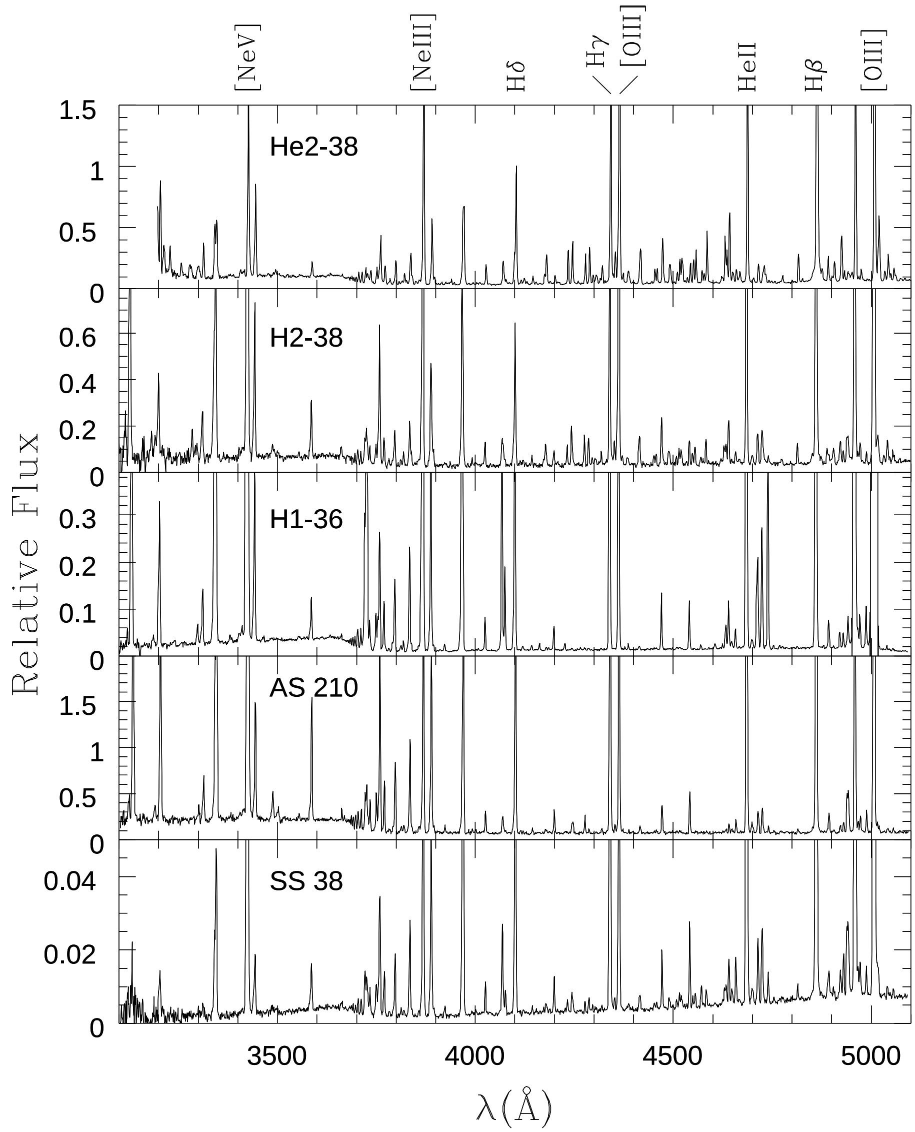

Fig. 1. Blue spectra of our sample stars. The Balmer continuum is clearly seen in emission as well as the strongest lines. [O III]λ5007Å in H1-36 is saturated.

the reddening. The observations of H2-38 presented by Medina-Tanco & Steiner (1995) use a spectral range which goes up to 10 000Å making it difficult to compare it with our data. Yet, we can see that in the spectral region near Hα, the continuum is flat in both spectra.

When comparing our data to previous observations no significant variations in the line fluxes of AS 210, H1-36 and SS 38 are found. However, our observations show the emergence of the λ6830 band in H1-36 and SS 38 which were not observed before. Although weaker, when compared with other stars, these bands are clearly seen in our spectrum. Fig. 2 shows the spectra of our sample stars in the near infrared region.

Of all our objects, He2-38 is the one that has changed most. We compute a [O III]5007/Hβ ratio of 1.1 from our observations which stands in contrast to the value of 0.2 in Allen's (1984) catalogue. In the data of de Freitas Pacheco & Costa (1992) the same ratio is 8.6. A closer inspection of Allen's (1984) spectrum also shows that other lines of high excitation [Ne V]λ3425, He IIλ4686 and [Fe VII]λ6087 are weak. This was not the first variation reported for He2-38. Webster & Allen (1975) had already realized that the N1/Hβ ratio had increased since the observations of Sanduleak & Stephenson (1972) and then returned to its value at the time of the discovery in 1965. In a diagram of Gutiérrez-Moreno & Moreno (1996), He2-38 changed its locus between 1978 and 1997 from the position occupied by the S-type symbiotics to the position of the D-types. As was said before, the major difference between the spectra published by Allen and ours, is the strength of the forbidden lines as well as the recombination lines. The degree of excitation of the ionized gas in our spectra increased, and a possible explanation relies on the change of the temperature of the ionizing source or on the variation of the mass loss rate of the Mira star in order to weaken the forbidden lines. A more complete study will be presented later, when more spectrophotometric data will be analyzed.

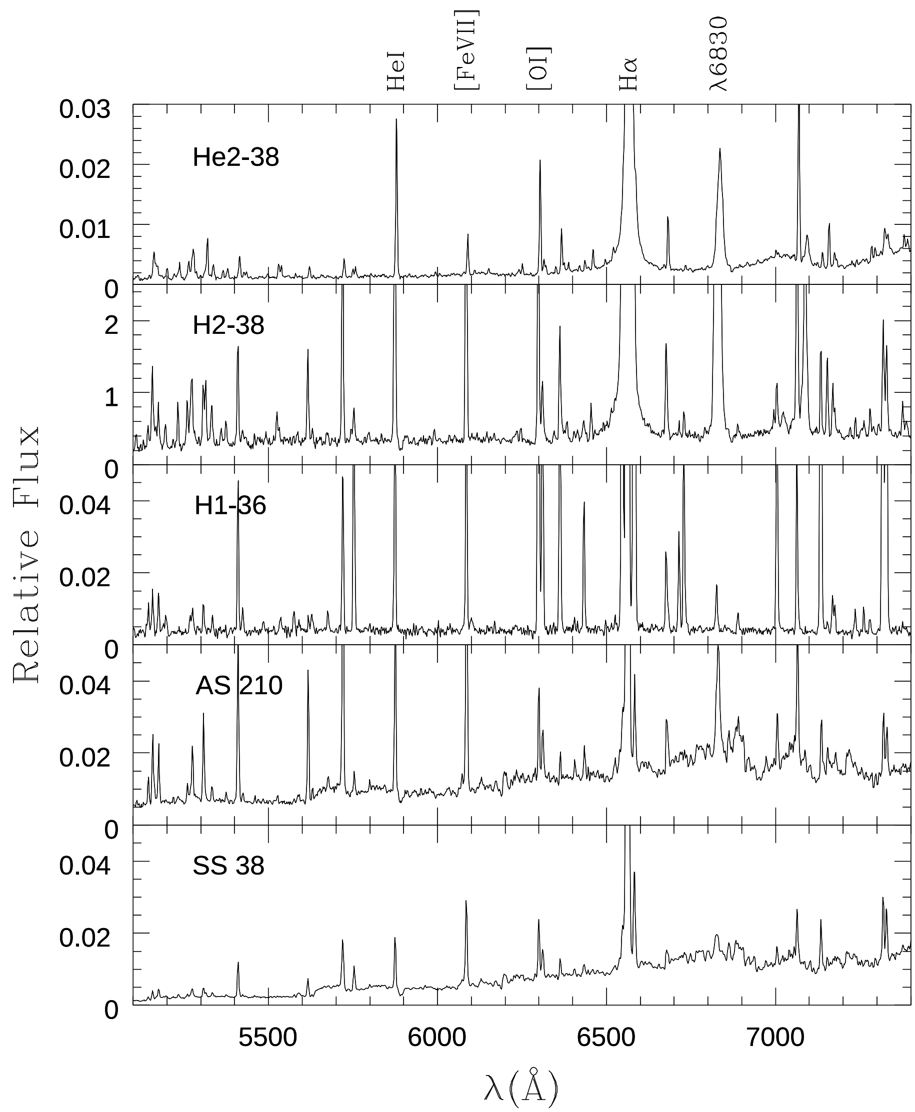

Fig. 2. Optical spectra of our sample stars. Notice the O VI scattered line at λ6830Å in H1-36 and SS 38. Also notice the C_2 and CN bands, respectively at 5626Å and at 6925Å, in the stars AS 210 and SS 38.

Table 2. E(B-V) for He2-38, AS 210, H2-38, H1-36 and SS 38.

line ratio	He2-38	AS 210	H2-38	H1-36	SS 38
$H\gamma/H\beta$	1.15	0.18	0.58	0.51	1.11
$H\delta/H\beta$	1.05	0.31	0.34	0.54	1.13
adopted Balmer decrement	1.10	0.25	0.46	0.53	1.12
$\sigma E(B\text{-}V)_{\rm Balmer}$	0.07	0.09	0.17	0.02	0.01
He II 3204/4686	0.80	0.35	0.55	0.88	1.21
adopted E(B-V)	0.95	0.30	0.51	0.71	1.17
σE(B-V)	0.21	0.07	0.06	0.25	0.06

4. Extinction

We determined the extinction parameter from H I and He II recombination lines. It was assumed that the reddening law can be represented by the standard interstellar extinction curve f(λ) (Osterbrock, 1974). For the H I lines, it was better to concentrate on higher transitions of Balmer lines, which are less affected by absorptions effects, than $H\alpha$. A check on the reddening from the Balmer lines, can be obtained from He II. For the H I and the He II lines, it was assumed that they are formed under case B conditions (Hummer & Storey, 1987) with a mean electron temperature of T_e=15 000K for the H I lines and T_e=20 000K for the He II lines and electronic density of $N_e=10^7$ cm^{-3}. For H1-36, we assumed a lower density, $N_e=10^6$ cm^{-3} The extinction parameter was derived from $H\gamma/H\beta$, $H\delta/H\beta$ and He II 3204/4686.

Table 3. Dereddened line ratios for diagnostic diagrams.

line ratio	He2-38	AS 210	H2-38	H1-36	SS 38
R(O III 4959,5007/4363)	2.03	6.00	4.26	27.4	7.7
R(O III/Ne III 4959,5007/3869)	1.61	5.40	4.00	9.4	5.6
R(Fe VII 5159/6087)	0.70	0.16	0.33	0.26	0.18
R(Fe VII 3759/6087)	3.00	1.20	0.87	1.12	1.27
R(Fe VII 4942/6087)	—	0.35	0.31	0.18	0.37
R(Fe VI 5176/5146)	0.54	1.50	1.90	1.76	2.10
R(Fe VI 5278/5146)	0.18	2.00	—	0.73	2.60
R(Fe VI 5335/5146)	0.57	0.50	—	0.53	0.89
R(Fe VI 5424/5146)	0.20	0.50	—	0.73	0.40
R(Fe VI 5677/5146)	—	0.50	0.46	0.67	—
R(Fe VI 3663/5146)	0.11	1.10	—	0.27	—
R(N II 6548,6584/5754)	—	6.20	5.40	10.0	4.6
R(S II 4068/6716,31)	—	—	2.75	5.05	—
R(O I 5577/6300,6363)	0.06	0.06	0.03	0.02	0.04

The results of the different reddening calculations are presented in Table 3 and agree reasonably well for all objects.

We can compare our derived E(B-V) values with those from earlier work.From the data of Gutiérrez-Moreno & Moreno (1996) of AS 210, the ratios Hγ/Hβ, Hδ/Hβ and He II 3204/4686 give E(B-V)=0.29 which is only slightly different from the value adopted here. Good agreement was also found for SS 38 between our data and the value of E(B-V) reported by Schulte-Ladbeck (1985) (E(B-V)=1.22). For H1-36, we found the same value of the one given in Allen (1983).

As was above mentioned, the line fluxes of H2-38 are higher in our data than previously reported. So the reddening determination from our data differs from the one by Mikolajewska et al. (1997). Since our line ratios of Hγ/Hβ and Hδ/Hβ are higher than before, the E(B-V) value is lower.

Our E(B-V) for He2-38 is slightly lower than the one derived by Mikolajewska et al (1997) and de Freitas Pacheco & Costa (1994). An even lower value for the reddening of He2-38 was found by Schulte-Ladbeck (1985) (E(B-V)=0.77) under B recombination.

5. Physical conditions

Table 4 shows the emission line ratios used for the diagnostic diagrams of the physical conditions (electronic temperature, T_e and density, N_e) and Table 5 lists the results. All the atomic data used in our calculations was taken from the compilation of Mendoza (1983). It was assumed that N_e and T_e were constant within the section of the nebulae where a given ion occurs.

The ratios R([O III]), R([O III]/[Ne III]) and those given by the R([Fe VII]) and R([Fe VI]) (Table 4), represent a high density where ionic species of O^{+2}, S^{+2}, Ne^{+2}, Ne^{+4}, Ar^{+2}, Ar^{+3}, Fe^{+5} and Fe^{+6} are dominant. The low density region are characterized by ionic species of N^{+}, S^{+} and O^{0} which is represented by the R([N II]), R([S II]) and R([O I]).

Table 4. Electron temperature and densities.

star	T_e	N_e - high	N_e - low
He2-38	12 800±1 500	$(1.8\pm0.6)\times10^{7}$	—
AS 210	13 000±1 000	$(2.5\pm0.5)\times10^{6}$	$(2.4\pm0.4)\times10^{5}$
H2-38	14 000±1 200	$(6.3\pm1.0)\times10^{6}$	$(2.8\pm0.8)\times10^{5}$
H1-36	11 200±1 000	$(7.9\pm2.0)\times10^{5}$	$(1.8\pm0.6)\times10^{5}$
SS 38	14 800±1 500	$(2.0\pm0.3)\times10^{6}$	$(2.8\pm0.8)\times10^{5}$

6. Abundances

Table 6 shows the ionic ratios in the emitting nebula. The ionic ratios, which reflect the elemental abundances most accurately were those as in Schmid & Schild (1990):

$$\frac{Ne}{O} = \frac{Ne^{+2}}{O^{+2}} \tag{1}$$

$$\frac{Ar}{O} = \frac{Ar^{+2} + Ar^{+3}}{O^{+2}} \tag{2}$$

$$\frac{Fe}{Ne} = \frac{Fe^{+5}}{Ne^{+4}} \tag{3}$$

$$\frac{N}{O} = \frac{N^{+}}{O^{+}} \tag{4}$$

For the Ne/O ratio the line fluxes of [Ne III]λ3869 and [O III]$\lambda\lambda$4363,5007 were used. For the Ar/O ratio we took the line fluxes of [Ar III]λ7136 and [Ar IV]λ4740. The Fe/Ne abundance ratio was derived from the line fluxes at [Fe VII]λ3587 and [Ne V]λ3426. The errors in the ionic abundances were estimated by taking into account the uncertainties in the measured line fluxes and the error of N_e and T_e given in Table 5. The N/O ratio was derived from the [N II]$\lambda\lambda$6584,5754/[O II]λ7320 line ratio. These lines are expected to form at smaller volumes at the outer edge of the ionized region, in the low-density region.

The abundance pattern of the symbiotics analyzed in this work do not show differences to other systems previously investigated (Schmid & Schild 1990; de Freitas Pacheco & Costa

Table 5. Relative elemental abundances for symbiotic stars, Sun and planetary nebulae.

star	Ne/O	Ar/O	Fe/Ne	Fe/O	N/O
He2-38	0.19±0.09	0.0024±0.0009	0.17±0.10	0.032±0.024	—
AS 210	0.12±0.04	0.012±0.003	0.25±0.09	0.030±0.015	0.31±0.09
H2-38	0.12±0.04	0.0042±0.0011	0.20±0.07	0.026±0.013	0.59±0.16
H1-36	0.16±0.07	0.0062±0.0021	0.10±0.05	0.016±0.011	0.25±0.08
SS 38	0.15±0.05	0.0066±0.0019	0.20±0.09	0.030±0.017	0.29±0.08
Sun[1]	0.12	0.005	0.47	0.056	0.13
PN[2]	0.25	0.006	0.02	0.050	0.42

(1) : Grevesse (1984).
(2) : Aller and Czyzak (1983)

Table 6. Helium abundance from recombinations line ratios.

line ratio	He2-38	AS 210	H2-38	H1-36	SS 38
He II 4686/Hβ	0.048	0.069	0.084	0.061	0.059
He II 4686/Hγ	0.054	0.064	0.087	0.055	0.058
He II 4686/Hδ	0.051	0.068	0.074	0.053	0.059
He II 4686/H9	0.040	0.063	0.052	0.055	0.064
He II 4686/H10	0.034	0.062	0.072	0.056	0.071
adopted y^{++}	0.045±0.008	0.065±0.008	0.074±0.009	0.056±0.009	0.062±0.011
He I 5876/He II 4686	2.28	0.37	1.61	0.55	0.34
He I 6678/He II 4686	2.15	0.58	1.76	0.65	0.57
adopted y^{+}	2.22±0.40	0.48±0.03	1.69±0.12	0.60±0.11	0.46±0.09
He/H	0.12±0.03	0.096±0.013	0.19±0.03	0.09±0.02	0.091±0.024

1992; Costa & de Freitas Pacheco, 1995; Pereira, 1995). The ratios Ne/O and Ar/O are basically solar while the ratio Fe/O seems to indicate Fe depletion which might be condensed into grains. In fact, all the stars investigated show some dust plus silicate emission (Roche et al, 1983). AS 210 and SS 38 are the two known carbon rich symbiotic Mira in our galaxy. Their abundance ratios do not show any difference compared with the oxygen Mira symbiotic. Most of the useful lines for carbon abundance determinations lie outside the optical region, in the UV range.

The ratio N/O shows enrichment in all of the stars. For AS 210, our N/O ratio agrees well with the one derived by Schmid & Nussbaumer, 1993). In this study, the authors also observed carbon enrichment from an analysis of the ultra-violet spectrum obtained with the IUE satellite. SS 38 is located near the coalsack region and is supposed to be faint at UV. However, in our spectrum, the continuum between 3200 and 3600Å is clearly observed. It's interesting to remark that SS 38 is not at the same locus in the color diagram K - [12] vs [12] - [25] as the carbon symbiotic AS 210 (Whitelock, 1987).

For H1-36, we also have the same ratio as Costa & de Freitas Pacheco (1994) within the errors considered.

6.1. Helium abundances

Helium abundances in symbiotic stars of our sample were obtained from the ratios He IIλ4686Å to Balmer lines, y^{++}, and from the ratios of He I λ5876Å and He Iλ6678Å to He IIλ4686Å, y^{+}. The emissivities of He I lines were taken from Almog & Netzer (1989) and of the He IIλ4686Å line from Hummer & Storey (1987). Table 7 gives the contribution of He^{+} and the resulting helium abundance. The results in Table 7 show that H2-38 has a larger helium abundance. SS 122 is another object which has a similarly high helium abundance (0.193 ; Pereira, 1995) although the nature of this object is unclear (S- or D-type).

Despite of having the ratio I(6678/5876) close to H1-36, a symbiotic with the lowest electronic density of our sample, the stars He2-38 and H2-38 have an anomalous He/H and their results should be regarded with caution. Their ratios He I5876,6678/He II4686 are systematically larger than the other systems. This effect was also observed for a sample of S-types symbiotics (Pereira, 1995). The most likely explanation for these differences among the stars in the present study is collisional excitation to the helium metastable state $2\,s^3S$, that rises optical depth effects which changes the recombination cascade routes. In fact, the computed τ(Hα) for stars of our sample shows that, using Netzer's (1975) results, that optical depth effects can be neglected for AS 210, SS 38 and H1-36, is moderate for He2-38 and strong for H2-38 (τ(Hα)=4.2 and 13.0, respectively for He2-38 and H2-38).

Proga et al (1994) shows another difference between S- and D-type symbiotics: The ratio I(6678)/I(5876) is ≈0.25 for the D-types and $\geq$ 0.5 for the S-types. Our data shows, after correcting for the reddening, that all the stars studied here exhibit ratios typical of D-types. The two carbon Miras show this ratio a little larger, ≈0.4.

7. Conclusions

New spectroscopic data in the ranges 3100Å - 5100Å and 3500Å - 7500Å for a sample of D-type symbiotics were obtained and investigated. All stars have never been examined in the blue region and two of them (H2-38 and SS 38) also in the optical region. For all the stars the reddening, physical conditions in the emitting gas and abundance ratios of Ar/O, Ne/O, Fe/Ne, N/O and He/H were obtained. The abundance ratios show that, in all the stars, dredge-up episodes did not affect Ar/O, Ne/O, Fe/Ne and He/H. The N/O ratio found for all the objects show strong nitrogen enrichment compared to solar, which indicates that material processed nuclearly, found in the nebulae, was emitted by the red giant's wind. Helium abundances of the systems studied here are solar, however for the stars He2-38 and H2-38, the He I lines seem to be affected by collisions.

He2-38 is the symbiotic that presented the largest variation in the line ratios when compared to Allen's (1984) catalogue. This object deserves a better investigation in order to understand its nature.

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