THE UV SPECTRUM OF THE BINARY SYSTEM SZ PSC

E. DANEZIS, E. ANTONOPOULOU, E. THEODOSSIOU

Section of Astrophysics, Astronomy and Mechanics, Department of Physics, University of Athens, Greece

and

M. MATHIOUDAKIS

Armagh Observatory, N. Ireland

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Abstract. In this paper we study the far-UV as well as the UV spectrum of the spectroscopic binary system SZ Psc in the wavelength ranges $\lambda\lambda$1235–1950 Å and $\lambda\lambda$2710–3090 Å, respectively, from spectra obtained with the International Ultraviolet Explorer (IUE). The UV spectrum of SZ Psc is mainly an emission spectrum. The short wavelength region includes emission lines formed from the low chromosphere to the transition region (e.g., Si IV, C IV, and N V) and also a deep and broad absorption line of Fe II.

The Mg II [1] resonance doublet at about λ2800 Å presents a P Cygni profile and a multiple structure with two emission and two absorption satellite components. We also present the emission measure diagram in the temperature region $4.4 < \log T_e < 5.3$.

1. Introduction

SZ Psc (= HD 219113 = BD + 1°4695: K1IV + F8IV; P = 3.97 days) is a double-lined spectroscopic binary system and an eclipsing system with an Algol-like light curve; it is a very interesting member of the RS CVn-type binary class.

SZ Psc is known that it shows strong Ca II H and K emission lines, produced by the active chromosphere of the K component (Jakate *et al.*, 1976) and shifted wave-like light variations outside eclipses (Bakos and Heard, 1958; Eaton, 1977; Antonopoulou and Williams, 1984) attributed to spot activity of the active K component.

Photoelectric spectrophotometry by Weiler (1976, 1978) and spectroscopic observations by Bopp and Talcott (1978), showed random variations in Hα. In a later work, Bopp (1981) pointed out the very unusual behaviour of the Hα line in the SZ Psc. Velocity measurements indicate that the K star was the source of the Hα emission. Bopp (1981) suggested that the Hα outburst observed from SZ Psc, with its unusual profile and temporal behaviour, can be attributed to a circumstellar ring or shell of gas around the primary component. Fernandez-Figueroa *et al.* (1986), study the appearance of the emission feature of the h and k lines of Mg II in a sample of RS CVn system (including the SZ Psc) using IUE spectra. They look for a correlation between the Mg II emission core, which is a chromospheric activity indicator and the orbital period, temperature, or gravity of each system. SZ Psc has become of singular interest because of its large chromospheric activity, its surprisingly complex light curve, the large period variation ($\mathrm{d}P/\mathrm{d}t = 6 \pm 5 \times 10^{-8}$ days day^{-1}) and the strange behaviour of the Hα feature.

The present work is a study of the far-UV $\lambda\lambda$1235–1950 Å (SWP 22958) as well as

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the UV spectrum $\lambda\lambda$2710–3090 Å (LWR 9679) of the binary system SZ Psc in order to have a better understanding of the system.

Similar work has been done for some other RS CVn systems like for UX Ari (Simon *et al.*, 1980), HR 1099 – II Peg – AR Lac (Byrne *et al.*, 1982), λ And (Baliunas *et al.*, 1984), σ Gem (Ayres *et al.*, 1984).

2. Observations – Data Reduction

This work is based on two IUE spectra. The low-resolution spectrum (SWP 22958) has been taken under a programme by Fernandez and Gimenez at VILSPA on 9 May, 1984. The estimated phase, using the ephemeris (T_0(J.D. Hel.) = 2442308.946 + + 3.9658663E) given by Hall and Kreiner (1980), is $\varphi = 0.724$.

The high-resolution spectrum ($\lambda\lambda$2710–3090 Å) has been taken under a programme by Linsky and Simon in NASA GSFC, on 10 January, 1981. The estimated phase, using the above ephemeris is $\varphi = 0.362$.

The spectra were extracted from de-archived IUE images from the World Data Center (RAL) using the IUEDR package on STARLINK (Gidding, 1983). Further analysis of the spectra was performed using the DIPSO package also available on STARLINK (Howarth and Murray, 1987).

The line identifications were performed on the basis of the multiplet tables of Moore (1968) and Kelly (1979).

The precision of the observed line position is limited by the IUE spectrum resolution (the low resolution is 5 Å and the high 0.2 Å) and by the blending due to the crowding of the lines.

3. Results and Discussion

3.1. THE FAR-UV SPECTRUM (SWP 22988)

Figure 1 gives the low-resolution spectrum of SZ Psc (SWP 22988). The dots represent the points of the Kurucz (1979) photospheric model for $T_{\text{eff}} = 6300$ K and $\log g = 4.0$, which corresponds to the hotter component (F8IV). This was the best fit for effective temperatures from 6000 to 6500 K. We did not take into account the cooler component (K1IV) because the contribution of this star in the continuum is negligible in this particular spectral region.

The far-UV spectrum of SZ Psc in the region 1235 to 1950 Å shows emission profiles for the resonance lines of N V, C IV, Si IV. The N V resonance lines at 1240 Å are blended. The same happens for the C IV resonance doublet at 1550 Å.

Emission lines of C I multiplets [2], [5], [53], [64], O I multiplets [1], [2], C II [1], Si II [1], He II [12], Al II [2], P I [1], S I [2], and Fe III multiplets [51], [52], [57], [62], [68] have been found in the far-UV spectrum ($\lambda\lambda$1235–1950 Å) of SZ Psc.

The O III unclassified emission line at λ1767 Å is present. O III unclassified emission

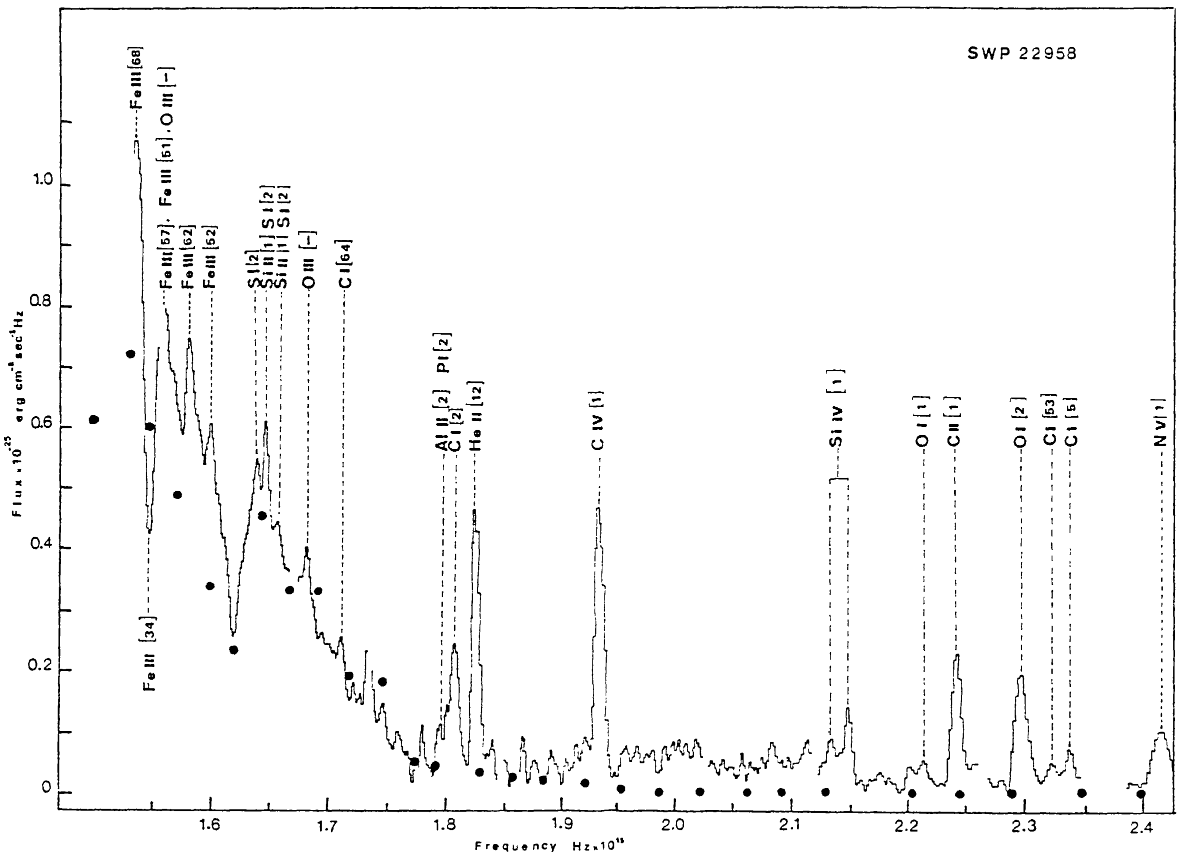

Fig. 1. Low-resolution spectrum of SZ Psc (SWP 22988). The dots represent the points of the Kurucz (1979) photospheric model.

lines at λ1784 Å and 1921 Å are possible present with the P I [1] and Fe III multiplets [51], [57], respectively (Table I).

The Si III [1] low-intensity emission line at λ1892 Å is probably present blended with the strong Fe III emission lines of multiplet [62]. Because of the low resolution (5 Å) of the available spectra, it is not possible the reliable estimation of the R.V.

The comparison of the far-UV spectrum SWP 22988 of SZ Psc with the Kurucz's model, shows the existence of a deep and broad absorption line at about 1920 Å, which coincides with a blend of two very strong lines of Fe III [34] $\lambda\lambda$1914.056 and 1926.30 Å (Figure 1).

3.1.1. *Differential Emission Measure*

We cannot determine the electron density directly from density sensitive lines since we cannot determine fluxes for these lines from the short wavelength spectrum. For a detailed description of the technique, the reader is referred to Byrne *et al.* (1987).

However, we can construct a differential emission measure diagram using the lines N V (1240 Å), C II (1335 Å), Si IV (1393 Å), C IV (1550 Å) and, therefore, cover the temperature region from 4.4 to 5.3 in the $\log T_e$. In order to calculate the emission measure we have taken the line emissivities from Raymond and Doyle (1981) assuming that $\log P_e/k = 15$ cm^{-3} K. We take the liberty to do that since the effect of pressure changes on the line emissivities is relative small. The emission measure can then be calculated using the relation

$$\mathrm{EM} = \frac{F}{4\pi\varepsilon} \times 10^{26}$$

in units of cm^{-5}, where F is the line surface flux and ε the line emissivity. The emission measure curve is presented in Figure 2. The line surface fluxes where determined by use of a radius of $R = 5.08\ R_\odot$ (Huenemoerder and Ramsey, 1984) for the K component of the system which is the most active (Strassmeier *et al.*, 1988).

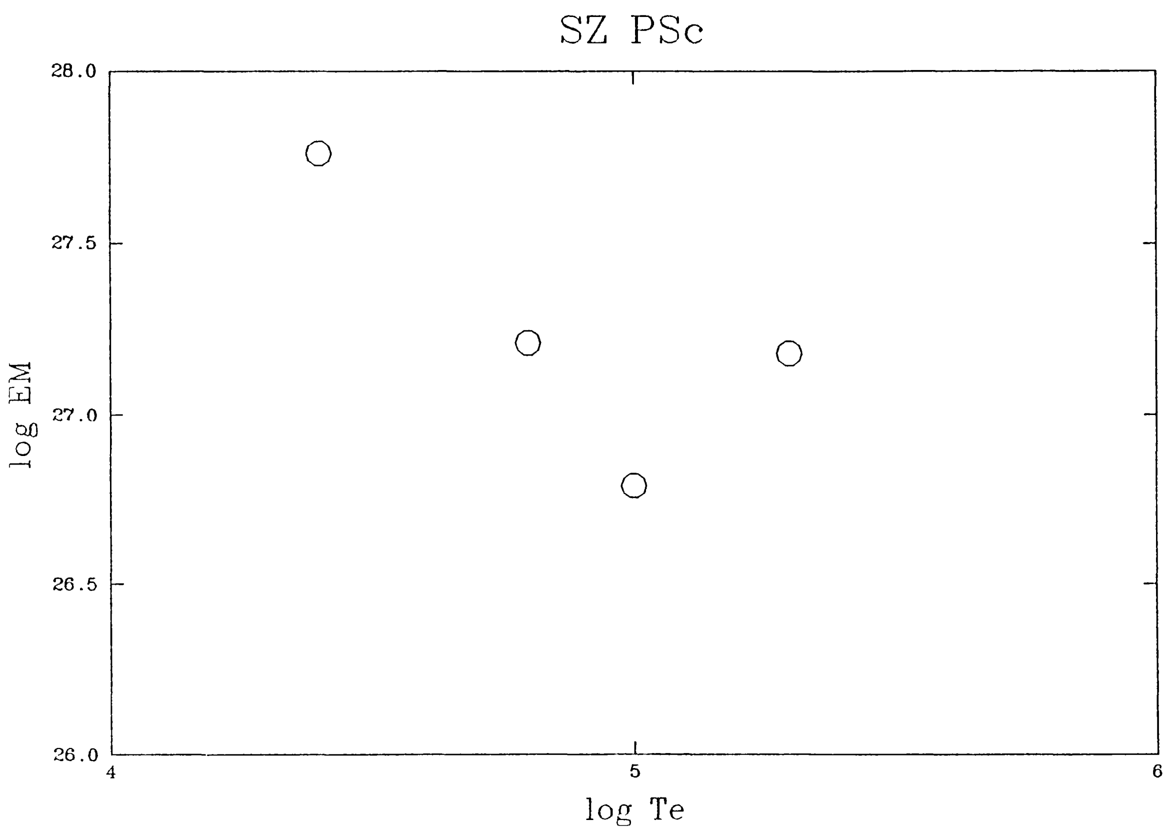

Fig. 2. Logarithmic differential emission measure diagram for SZ Psc.

3.2. The UV spectrum (LWR 9679)

The UV spectrum LWR 9679 ($\lambda\lambda$2710–3090 Å) is mainly characterised by the Mg II [1] resonance doublet.

Fe I [9] emission lines are present. The Fe I [1] emission line at λ2937 Å is present; but the Fe I [1] emission line at λ2948 Å seems to be lost in a strong absorption line coming from S III [18].

The Fe II multiplets [78], [60] emission lines at $\lambda\lambda$2948 and 2954 Å, respectively, are probably present. Unfortunately, we have not the spectral range between $\lambda\lambda$2380–2630 Å in order to take more information about the Fe II strong emission lines of multiplets [1] and [2].

Probable emission lines are S III [16] at λ2775 Å, Mg II [6] at λ2780 Å, and the unclassified line of O V at λ2781 Å.

Finally, we point out the existence of the strong emission lines of C II [13] at λ2837 Å (Table II).

TABLE I

The observed emission lines of SZ Psc in the far UV

Ion	λ_{lab} (Å)	Mult.	Int.
N V	1238.821	1	1000
N V	1242.778	1	800
C I	1280.330	5	700
C I	1288.420	53	500
O I	1302.168	2	1000
C II	1335.707	1	1000
O I	1302.168	2	1000
O I	1358.512	1	60
Si IV	1393.755	1	1000
Si IV	1402.770	1	800
C IV	1548.185	1	1000
C IV	1551.770	1	950
He II	1640.474	12	600
C I	1657.007	2	1000
Al II	1670.786	2	1000
N IV	1716.400	7	1000
C I	1751.820	64	800
O III	1767.780	–	1000
O III	1784.850	–	600
P I	1782.870	1	600
Si II	1808.012	1	150
S I	1807.310	2	550
Si II	1816.927	1	200
S I	1820.342	2	500
S I	1826.245	2	450
Fe III	1869.828	52	650
Fe III	1871.150	52	600
Fe III	1882.047	62	650
Fe III	1882.972	62	250
Fe III	1883.816	62	200
Fe III	1884.596	62	550
Fe III	1918.284	57	450
O III	1921.520	–	500
Fe III	1922.789	51	1000
Fe III	1952.640	68	700
Fe III	1953.320	68	900
Fe III	1953.480	68	650

TABLE II

The observed emission lines of SZ Psc in UV

Ion	λ_{lab} (Å)	Mult.	Int.	λ_{obs} (Å)	R.V. (km s^{-1})	FWHM
S III	2775.250	16	250	2771.560	-440 ± 22	0.9
Mg II	2779.830	6	160	2777.390	-315 ± 22	0.45
O V	2781.010	–	1000	?		
Fe I	2832.435	44	380	2832.160	-80 ± 21	0.43
C II	2836.710	13	1000	2832.980	-440 ± 21	0.43
Fe I	2936.903	1	340	2936.080	-235 ± 20	0.55
Fe II	2947.658	78	750	2944.080	-415 ± 20	0.55
Fe II	2953.774	60	550	2950.400	-390 ± 20	0.55
O III	2983.780	18	200	2980.940	-285 ± 20	0.55
Fe I	2983.569	9	320			
Fe I	3020.490	9	200			
Fe I	3020.639	9	380	3018.980		0.54
Fe I	3021.072	9	240			
Fe I	3059.085	9	320	3058.800	-27 ± 20	0.54

Table II gives the list of emission lines – except the Mg II doublet – observed in the spectrum of SZ Psc (LWR 9679). The successive columns in Table II give:

(1) The ion corresponding to the emission line.
(2) The laboratory wavelength in Å for each emission line.
(3) The multiplet number.
(4) The intensity of the line (Kelly, 1979).
(5) The observed wavelength in Å for the above emission lines.

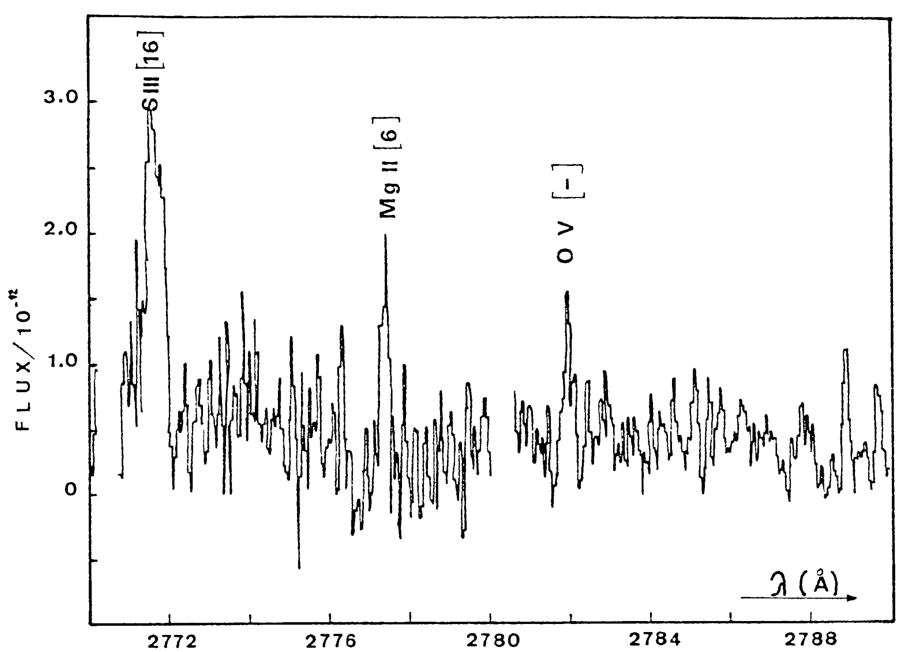

Fig. 3. A collection of spectral regions in the long wavelength spectrum (LWR 9679) of SZ Psc.

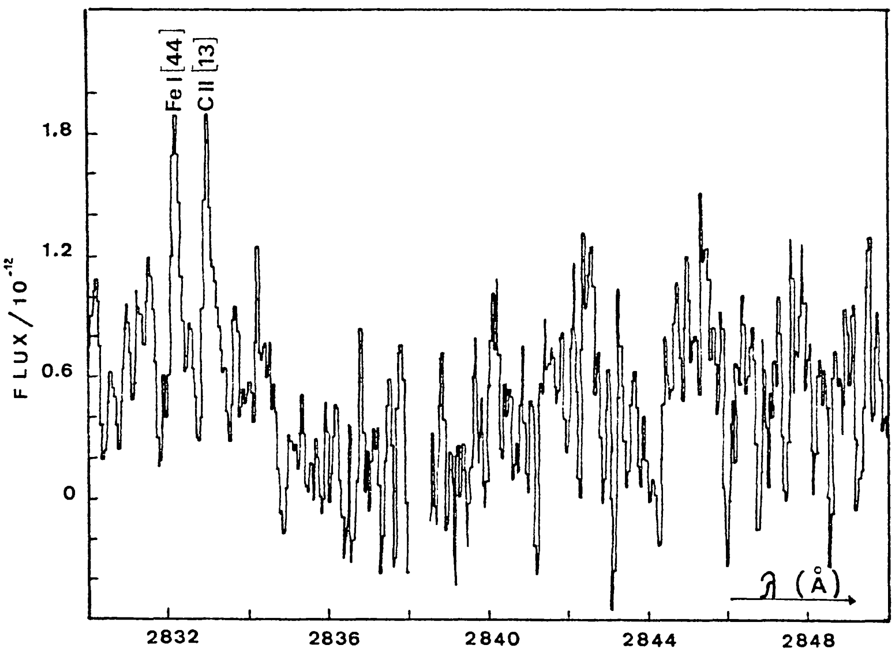

Fig. 4. Same as Figure 3.

(6) The radial velocity, measured from the emission peak.

(7) The value of FWHM/observed wavelength, multiplied by 10^4.

The UV spectrum of SZ Psc (LWR 9679) is crowded by a number of probable absorption lines. The most important of them are those placed in the red wings of two

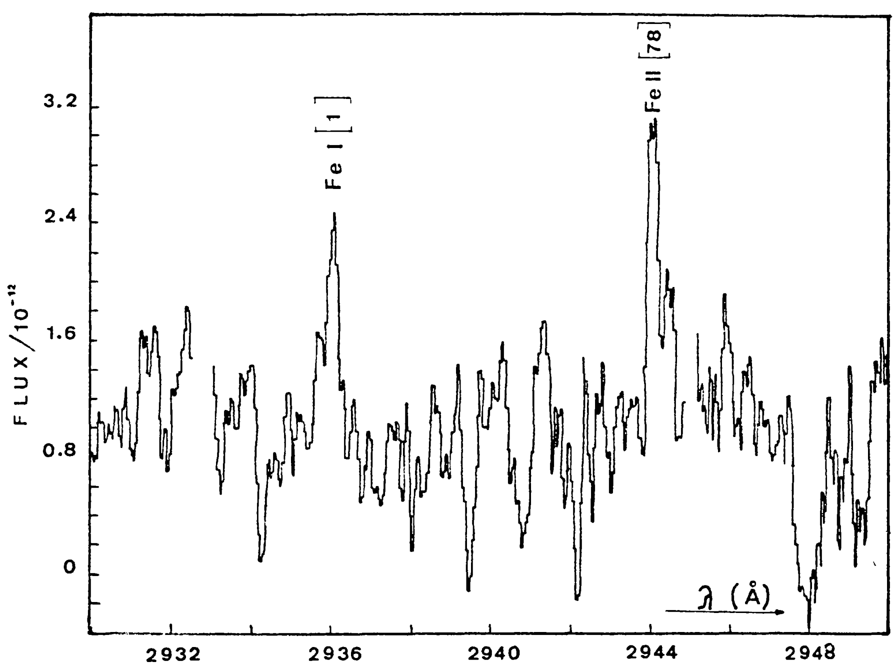

Fig. 5. Same as Figure 3.

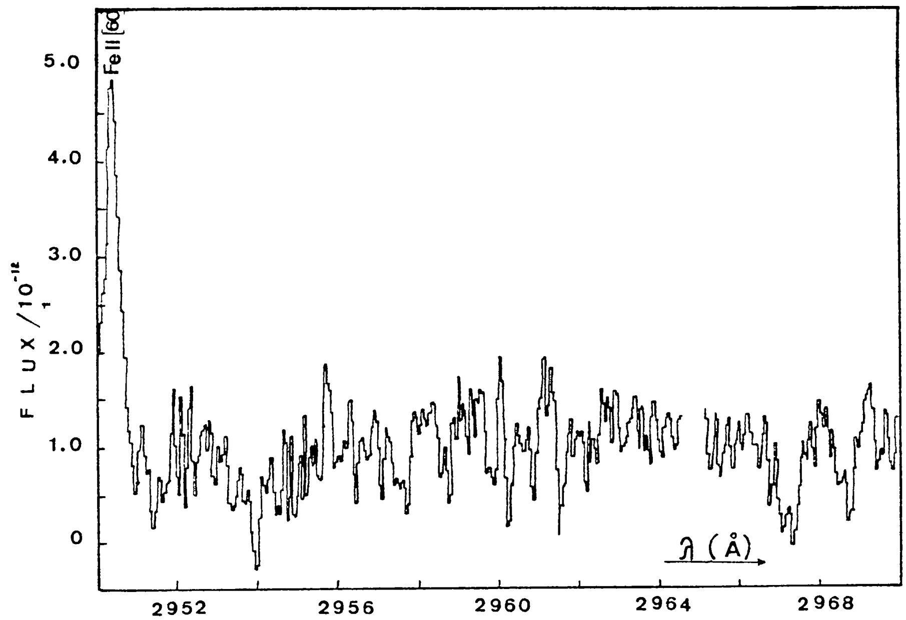

Fig. 6. Same as Figure 3.

emission lines of Fe I [9] at λλ3019 and 3059 Å, respectively. One of them at λ3059 Å coincides with the absorption line of O IV [1] at λ3063 Å.

Another possible absorption line appears at λ2872 Å which coincides with two absorption lines of Fe II multiplets [230] and [279].

We have already mentioned above the possible absorption line which coincides with the S III [18] at λ2948 Å, blended with the emission Fe I [1].

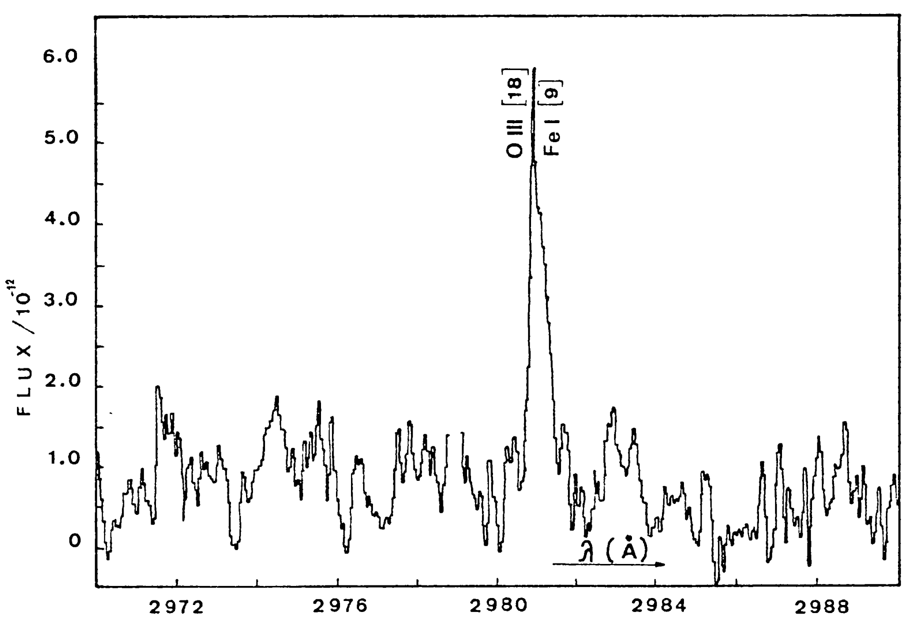

Fig. 7. Same as Figure 3.

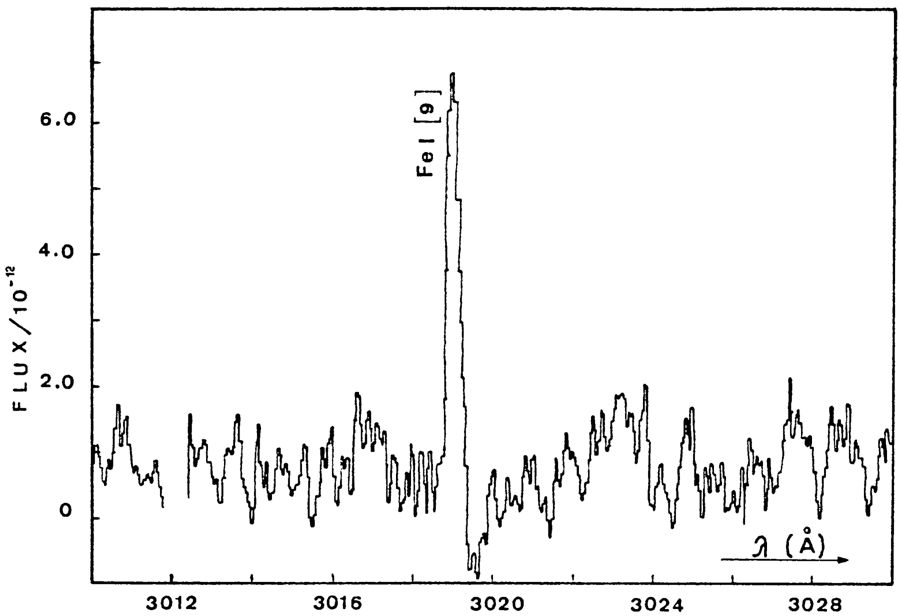

Fig. 8. Same as Figure 3.

Figures 3 to 9 show a collection of spectral regions in the long wavelength spectrum (LWR 9679) of SZ Psc, between $\lambda\lambda$2710–3090 Å. The emission lines of this spectral region, which attributed to an emission shell go from 0 eV (low-ionization potential) to 35 eV, which means that shell is extending from low to high temperatures.

In Figure 10 we give the relation between the blue edge velocities and the ionization potential of the ions (Table II), which are present in the above-mentioned emission shell.

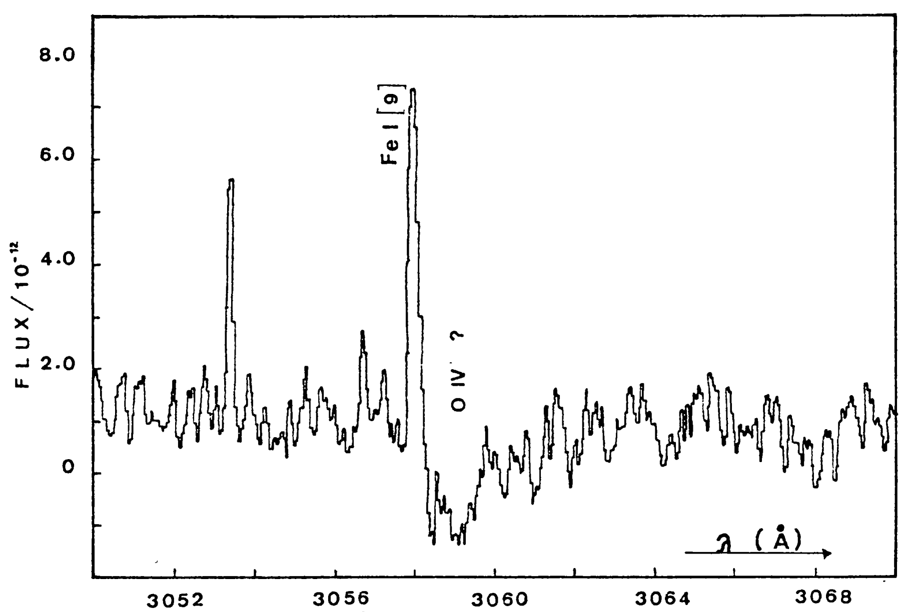

Fig. 9. Same as Figure 3.

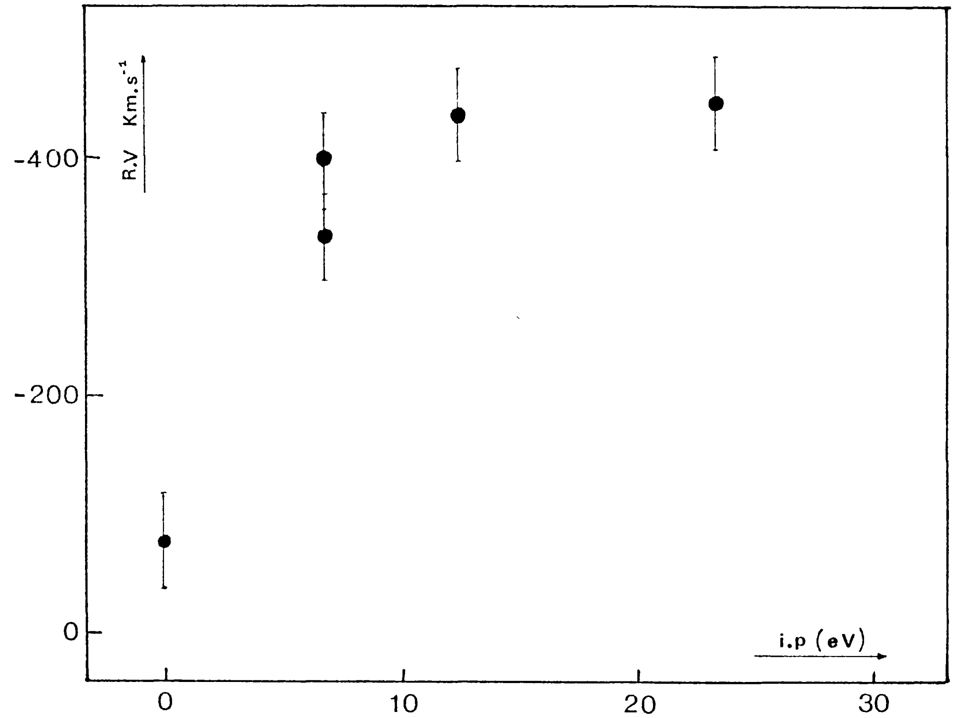

Fig. 10. Relation between the blue edge velocities and the ionization potential of the ions (Table II), which are present in the emission shell.

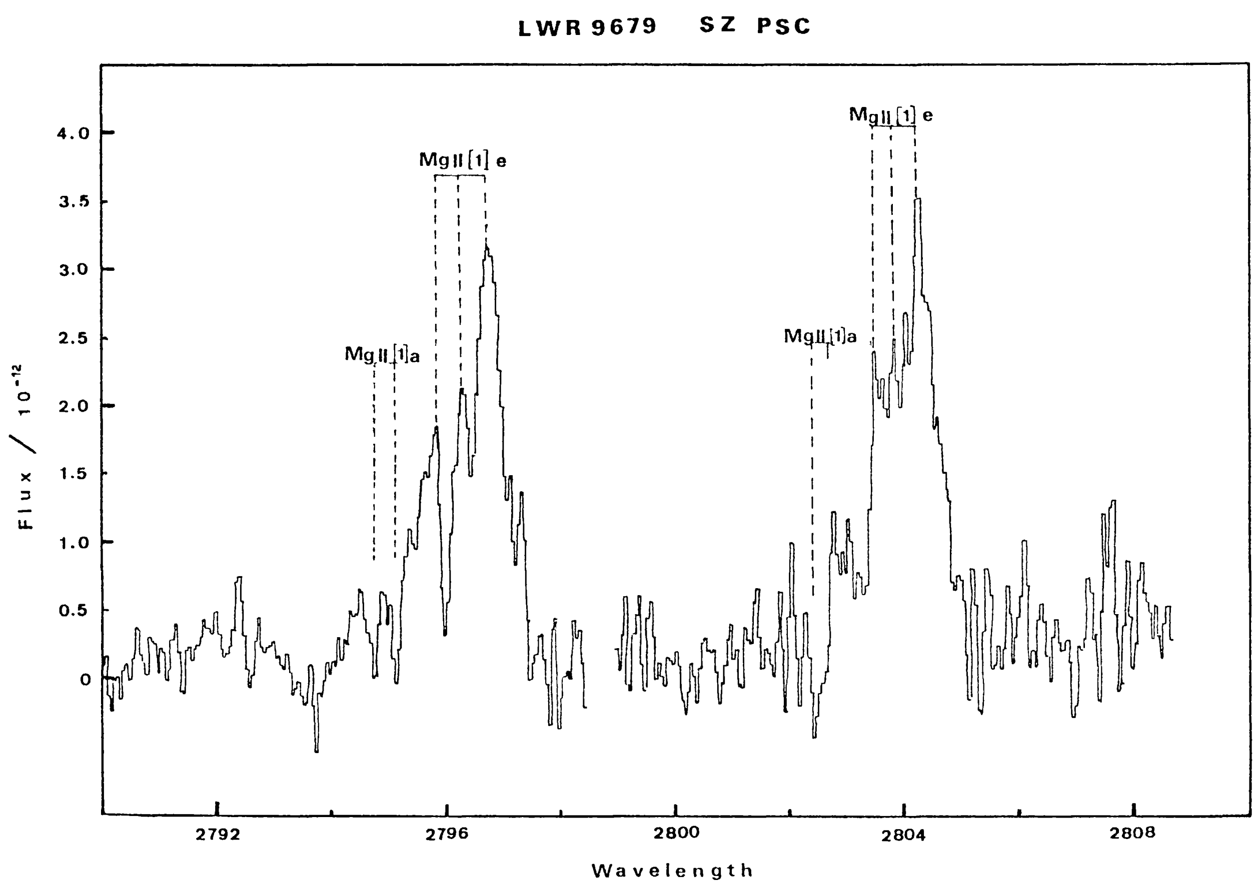

Fig. 11. Mg II [1] resonance doublet, characterized by a P Cygni profile and one absorption and two emission satellite components in the blue side of each emission line.

3.2.1. *The* Mg II *resonance doublet*

One of the most remarkable feature in the long wavelength region of the IUE spectrum of SZ Psc is the Mg II [1] resonance doublet, characterized by a P Cygni profile (Figure 11). The two emission and two absorption satellite components are present in the blue side of each emission line.

Table III describes the structure of Mg II resonance doublet. The successive columns in Table III give:

(1) The laboratory wavelength in Å.

(2) The ion.

(3) The multiplet number.

(4) The intensity of line (Kelly, 1979).

(5) The observed wavelength in Å for the emission lines and their satellite components measured from the emission peak.

(6) The radial velocities of the above lines.

(7) The observed wavelength in Å for the absorption satellite components.

(8) The radial velocities of the above lines.

TABLE III

The structure of Mg II resonance doublet of SZ Psc

Ion	λ_{lab} (Å)	Mult.	Int.	λ_{obs} (Å) e.l.	R.V. (km s^{-1}) e.l.	λ_{obs} (Å) a.l.	R.V. (km s^{-1}) a.l.
Mg II	2795.523	1	400	2796.74	$+80 \pm 20$	2795.15	-90 ± 20
				2796.29	$+30 \pm 20$	2794.74	-130 ± 20
				2795.84	-20 ± 20		
Mg II	2802.697	1	300	2804.29	$+120 \pm 20$	2802.45	-80 ± 20
				2803.84	$+70 \pm 20$	–	–
				2803.40	-25 ± 20		

4. Conclusions

The SZ Psc is a very interesting, active and variable binary system and we need a series of high-quality and high-resolution spectra in the region between λλ1200 to 3100 Å, at different orbital phases, in order to model it. Though, with the existing data we obtained a series of important information, which we summarize here:

(1) The comparison of the far-UV spectrum SWP 22988 of SZ Psc with the Kurucz's model shows the existence of a deep and broad absorption line at about 1920 Å, which coincides with a blend of two very strong lines of Fe III [34] λλ1914.056 and 1926.30 Å (Figure 1).

(2) In the spectral region λλ1700–2000 Å we pointed out emission lines of Fe III [68], [57], [62], [52].

(3) For the Mg II [1] resonance doublet we detected the existence of emission and absorption satellite components. These lines are also characterized by a P Cygni profile.

(4) In the spectral region $\lambda\lambda 2700-3100$ Å we have the indication for the existence of several emission features (e.g., Fe I [9], C II [13], S III [16]).

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