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SPECTRAL AND POLARIMETRIC STUDY OF CLOSE BINARY SYSTEMS XZ CEP AND V 448 CYG WITH A COMPOSITE SPECTRUM

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Abstract. The main parameters of the close binaries V448 Cyg and XZ Cep were determined. Computation of the chemical composition of the atmospheres of their primary components showed the existence of the hydrogen deficiency in them. The polarimetric measurements allowed to establish the sparse structure of the circumstellar envelopes.

Key words: Binaries: spectroscopy, polarimetry
Binaries: Individual: XZ Cep, V448 Cyg

XZ Cep and V448 Cyg are the representatives of the not numerous group of close binary systems, which have passed the phase of the mass exchange, and at present have the components of the similar luminosity, so one may observe the composite spectrum of the system. This allows to investigate the spectrum of the evolved star, which has lost a considerable part of its initial mass. Incidentally, such component (primary) shows a higher luminosity, despite its mass is significantly lost during the exchange process, and now is less than the mass of the other component (secondary).

Photometric, spectral and polarimetric observations show the presence of a circumstellar envelope in these systems, and allow to specify the structure of this envelope and its main parameters.

Based upon the high-dispersion spectral material obtained in 1981-1984 at the 6-meter telescope of the Special Astrophysical Observatory, the new spectral elements of the orbits of XZ Cep and V448 Cyg were obtained (Glazunova, 1985, 1986a). They are listed in Table 1. The spectral elements of XZ Cep were obtained for the first time. The star with a higher luminosity has proved to have a lower mass as compared with the companion. All the photometric elements of orbit, which were published earlier, were obtained without considering this fact. The new photometric elements of XZ Cep were obtained by Glazunova (1989). The elements and the absolute parameters of the system are listed in Table 1. Our spectral elements for V 448 Cyg are essentially different from those obtained by other authors. From the high-dispersion spectra, the nature of the significant distortion of the radial velocity curve of the secondary was found. The equivalent line widths of the primary star have proved to be much larger than those of normal stars of the same spectral type. This appears as the strong blending of the hydrogen and helium lines of the secondary star, the radial velocities of which were determined. The high dispersion of the obtained spectra allowed us to resolve these blends.

The spectral types and luminosity classes are presented in Table 1 for both components of the investigated systems (Glazunova and Karetnikov, 1985, Glazunova et al., 1986).

The spectral investigation of the primaries allowed to estimate the abundance of helium, nitrogen and carbon, by using the theoretical curves-of-growth. The overabundance of helium and nitrogen and the deficiency of carbon was found. These results as well as the place of the system's components at the Hertzsprung- Russell diagram (according to the parameters listed in Table 1, and the known age of V448 Cyg system belonging to NGC 6871 cluster, i.e. $6 \cdot 10^6$ years) allows to make a conclusion, that the exchange in both systems has started at the end of the hydrogen-burning phase in the core of initially more massive star (case AB). At present, the system XZ Cep has passed the phase of the mass exchange and is at the intermediate detached phase; V448 Cyg is at the end of the exchange phase, and the primary component continues on losing mass in the nuclear time scale (Glazunova, 1986b). The presence of such a stage is peculiar for the evolutionary AB case. The system with initial parameters: $M_{10} = 16 \cdot M_\odot$, $M_{20} = 15 \cdot M_\odot$, $A_0 = 27 R_\odot$, $P_0 = 3^d.04$, $X_0 = 0.043$is the most adequate for all the calculated models of evolution of close binary stars with the AB-case exchange. During the exchange phase, the primary components have lost about 54 and 37 per cent of their initial mass, for V448 Cyg and XZ Cep, respectively.

For the investigation, we used the values of the equivalent widths of these stars obtained from the spectral material with the dispersion $D = 9$Å/mm, as well as the values published by Glazunova and Karetnikov (1985) and Glazunova et al.(1986). The equivalent widths of all the light elements have proved to be larger than those of the standard stars of the same spectral characteristics (Peters, 1976, Wright et al., 1964), what is the main spectral peculiarity of the primary components of V448 Cyg and XZ Cep. This phenomenon is present even at such phases of an orbital period, when the influence of the circumstellar gaseous envelope is at minimum. It does not disappear after the reduction to the system of equivalent line widths of standard stars (Peters, 1976, Wright et al.,1964).

The possible interpretations of the anomalous enlargements of the equivalent widths (4-10 times) of all the light elements in the spectra of the primary components of V448 Cyg and XZ Cep are the following:

1) the atmospheres of these stars differ qualitatively from those of normal stars (eg. by the hydrogen deficiency);

2) W_λ can be enlarged due to the higher microturbulent velocities as compared with the normal stars. In order to obtain the quantitative characteristics of the considered phenomenon, we carried out the analysis of the spectra of the investigated stars by using the method of the 'model atmospheres' (Klochkova et al., 1985). We used the computer code elaborated by V.V.Tsymbal, based on the programs ATLAS6 and WIDTH6 (Kurucz, 1979). The main parameters of the components T_{eff} and log g were obtained earlier, by using the spectral type (Glazunova and Karetnikov, 1985, Glazunova et al.,1986), mass and the stellar radius (Glazunova, 1989, Ashbrook, 1942):

V448 Cyg: $T_{eff} = 20000$ K $\pm$ 300 K, $\log g = 3 \pm 0.5$

XZ Cep : $T_{eff} = 22500$ K $\pm$ 300 K, $\log g = 3 \pm 0.5$

The rotation velocities of the primary components are 130 km/s and 113 km/s for V448 Cyg and XZ Cep, respectively (Glazunova, 1986b). Therefore it was of great importance to take into account the blending while calculating the values of W_λ. The blends' components necessary for W_λ -calculations were obtained from the computations of the synthetic stellar spectra. The parameters of

the broadening of the helium lines due to the square Stark effect were taken from Barnard et al.(1974), for other lines - from Grim (1978), oscillators' strengths of the lines - from Kurucz and Peytremann (1975). For the computations, we used different values of the microturbulent velocity (5,10,15,20 km/s) and of the helium abundance (from 0.1 to 0.9), until the empiric equivalent width of each element became consistent with the calculated one. The calculations showed, that the degree of the W_λ- enlargement differs for different elements with the same helium abundance. For the majority of the calculated lines (Si III, Si IV, O II, Al III, Mg II, Fe III), the best agreement with the observed W_λ for both stars was obtained for the models with the hydrogen deficiency in the range from ε_{He} 0.4 to 0.9 (with the account of errors of the observed equivalent widths) and with the high microturbulent velocities: V = 20 km/s for V448 Cyg and 15 km/s for XZ Cep. Incidentally, in order to explain the considered anomalies in the behavior of the lines of the light elements, it was necessary to add some nitrogen overabundance (0.18 dex for V448 Cyg and 0.3 dex for XZ Cep in the model with ε_{He} = 0.9) and some carbon deficiency ($\sim$ 1 dex for both stars) to the hydrogen deficiency. We verified the presence of the hydrogen deficiency in the atmospheres of the investigated stars by computing the values of W_λ for the Balmer lines for the models with the main parameters mentioned above, and varying the hydrogen abundance. The computations were carried out by using the 'BALMER' program (Kurucz, 1979). The calculated equivalent line widths of H_β, H_γ, H_δ have proved to fit those in the spectra of both stars for the models with ε_{He} from 0.8 to 0.9 (with the account of errors the values of observed equivalent widths).

Thus, the anomalous enlargement of the lines of all the light elements in the spectra of the primary components of V448 Cyg and XZ Cep can be satisfactory explained in virtue of the assumptions on the hydrogen deficiency and microturbulent velocities in atmospheres of the investigated stars.

The results the linear polarimetry of XZ Cep in three bands are published by Saute and Martel(1979). The observed values of the parameters of polarization at maximum light they interpreted as corresponding to the interstellar polarization. The values of the intrinsic polarization obtained in the above mentioned manner allowed the authors to make a conclusion on the sparse structure of the gaseous envelope in the system.

The polarimetric investigation of V448 Cyg carried out in U, B, V, R, I - color bands is described by Shakhovskoy et al.(1992). In this work, the variability of the parameters of polarization was found for the first time in all the color bands. The amplitude of variation of the degree of polarization (P) in band U, for example, is more than 0.4 per cent (σ_p = 0.05 per cent), that of the variation of the position angle (Θ) is more than 30^0 (σ_Θ = 4.4) .The interstellar component was found as well as the constant component of the intrinsic polarization with a flat spectrum in the observed polarization. The evaluation of the Fourier harmonics of the normalized Stokes parameters allowed to find a contribution of the intrinsic polarization. It shows a spectral dependence inherent to the Be-stars. The constant component of the intrinsic polarization is probably connected with an extended disk-like optically thin scattering envelope, whereas a variable one - with the relatively dense condensations near the inner Lagrangian points of the system. The mass of the extended envelope and the mass loss rate in the system are about $1.5 \cdot 10^{-8}$ $M_\odot$ and $8.68 \cdot 10^{-7}$ $M_\odot$/yr, respectively.

Thus, the analysis of the spectral and polarimetric data on the investigated systems allows to establish the sparse structure of the circumstellar gaseous envelopes surrounding them.

Table 1. The parameters of XZ Cep and V 448 Cyg

Parameter	XZ Cep	V 448 Cyg
K_1 (km/s)	224.8 ± 7.7	246.5 ± 3.6
K_2 (km/s)	174.7 ± 4.4	96.3 ± 7.6
γ (km/s)	−4.8 ± 5.5	13.8 ± 2.5
e	0.04 ± 0.06	0.00 ± 0.02
ω_1	77^0 ± 2	-
ω_2	210^0 ± 2	-
$a_1 \sin i$	15.745 ± 0.546	22.101 ± 0.323
$a_2 \sin i$	12.204 ± 0.313	8.550 ± 0.719
$M_1 \sin^3 i$ ($M_\odot$)	14.62	7.65
$M_2 \sin^3 i$ ($M_\odot$)	18.81	19.60
Sp_1	B1.5 II	B1.2 Ib
Sp_2	B1.1 V	O8.9 V
$\log g_1$	3.26	2.92
$\log g_2$	3.9	3.99
ξ_t (km/s)	15	23
i	88.4^0 ± 0.3^0	-
r_1	0.326 ± 0.002	-
r_2	0.245 ± 0.002	-
L_1	0.54 ± 0.02	0.69
L_2	0.46 ± 0.02	0.31
M_1 ($M_\odot$)	14.20	8.14
M_2 ($M_\odot$)	18.11	20.85
R_1 ($R_\odot$)	13.0	16.7
R_2 ($R_\odot$)	9.8	7.61
M_{v1}	-4.4	-5.7
M_{v2}	-3.9	-4.8

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