VARIATIONS IN MASS TRANSFER DURING THE ACTIVITY MAXIMUM OF THE BINARY SYMBIOTIC SYSTEM CH CYGNI

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ABSTRACT. Based on the study of the variations in the radial velocities of absorption spectral lines of ionized metals Ti II and Sc II of the symbiotic star CH Cyg, it is demonstrated that variations in mass transfer between the components of the system occured on a time scale of 20 days during the activity maximum of this object in 1982.

ВАРИАЦИИ З ПЕРЕНОСЕ ВЕЩЕСТВА ВО ВРЕМЯ МАКСИМУМА АКТИВНОСТИ ДВУХЗВЕЗДНОЙ СИМБИОТИЧЕСКОЙ ЗВЕЗДЫ CH ЛЕБЕДЯ. На основании изучения изменений лучевых скоростей спектральных линий ионизированных металлов Ti II и Sc II симбиотической звезды CH Лебедя показано, что во время максимума активности объекта в 1982 г. происходили вариации в переносе массы с одной компоненты на другую на шкале времени 20 дней.

VARIÁCIE V PRENOSE HMOTY POČAS MAXIMA AKTIVITY DVOJHVIEZDNEJ SYMBIOTIC-KEJ SÚSTAVY CH CYGNI. Na základe štúdia zmien radiálnych rýchlostí absorpčných spektrálnych čiar ionizovaných kovov Ti II a Sc II symbiotickej hviezdy CH Cyg je ukázané, že v období maxima aktivity tohto objektu v roku 1982 do-

chádzalo k variáciám v prenose hmoty medzi zložkami sústavy na časovej škále 20 dní.

1. INTRODUCTION

The spectrum of CH Cyg has appearance of an M6 III star, however, at the time of an outburst, which usually lasts for several years, it displays the features of a symbiotic star. The last outburst occurred from 1977 to 1984 (Selvelli and Hack, 1985; Mikolajewski and Biernikowicz, 1985). CH Cyg reached maximum brightness in 1982: $V = 5.5^m$, B-V = 0.5, U-B = -0.4 (Chochol et al., 1984). The increase in brightness was accompanied by spectroscopic changes: an increase in the intensity of emission lines, blue continuum and the velocity gradient of the absorption components of the Balmer series (Skopal, 1986). A remarkable feature was the splitting of the lines of ionized metals, namely Ti II, Cr II, Sc II, but also He I and Mg I, into 2 components in the summer of 1981 (Chochol and Hric, 1982; Wallerstein, 1983; Skopal, 1986). This led Wallerstein (1983) to interpret the object as a shell star with two absorption envelopes. Skopal (1986) interpreted the rapid variability of the intensity and radial velocity of the R component of absorption spectral lines of ionized metals as an enhanced mass transfer from the M6 giant to the hot component in the binary system in accordance with the model suggested by Luud (1980).

The purpose of this paper is to prove that the variations in the radial velocities of object CH Cyg during the activity maximum in the autumn of 1982 agrees with the concept mentioned above, and that the variations in mass transfer occur on a time scale of 20 days.

2. OBSERVATIONAL MATERIAL AND ITS PROCESSING

The spectroscopic observations were made with the 1.22 m telescope of the Crimean Astrophysical Observatory, fitted with a grating spectrograph with dispersion 3.6 nm/mm. A total of 14 spectrograms were taken between Sept. 13 and Nov. 28, 1982. The list of observations is in Table 1.

Table 1.

Date	U.T.	J.D. 2445000+	Exp.time (min.)	Emulsion	Wavelength region (nm)
Sept. 13, 1982	$20^h \ 00^m$	226.3333	60	103aO	360 - 495
Sept. 16, 1982	$19^h \ 20^m$	229.3056	60	103aO	360 - 495
Sept. 21, 1982	$17^h \ 35^m$	234.2326	63	103aO	360 - 495
Sept. 27, 1982	$17^h \ 14^m$	240.2181	63	103aO	360 - 495
Oct. 1, 1982	$17^h \ 04^m$	244.2111	55	103aO	360 - 495

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Table 1 (cont.)

Date	U.T.	J.D. 2445000+	Exp.time (min.)	Emulsion	Wavelength region (nm)
Oct. 4, 1982	$17^h 43^m$	247.2382	65	103aO	360 - 490
Oct. 14, 1982	$17^h 32^m$	257.2306	55	103aO	360 - 495
Oct. 22, 1982	$17^h 04^m$	265.2111	46	103aO	360 - 505
Oct. 24, 1982	$16^h 50^m$	267.2014	60	103aO	360 - 505
Oct. 27, 1982	$16^h 50^m$	270.2014	50	103aO	360 - 505
Nov. 1, 1982	$16^h 30^m$	275.1875	60	103aO	360 - 505
Nov. 3, 1982	$16^h 32^m$	277.1889	43	103aO	360 - 445
Nov. 10, 1982	$16^h 40^m$	284.1944	50	103aO	375 - 500
Nov. 28, 1982	$15^h 30^m$	302.1458	50	103aO	370 - 500

The positions of the spectral lines for the purpose of studying the ra-
dial velocities were measured with the TV Abbé comparator of the Astronomical
Institute of the Slovak Academy of Sciences in Tatranská Lomnica. A detailed
description of the instrument can be found in Minarovjech's paper (1984). The
atlas of comparison lines, published in the paper by Vitrichenko and Polosu-
khina (1973), proved to be insufficient and, therefore, the comparison spec-
trum was identified according to Moore (1945) and the following comparison
lines were used (Table 2).

Table 2.

Element	Wavelength (nm)	Element	Wavelength (nm)	Element	Wavelength (nm)
Ne II, 1	369.422	Fe I, 43	404.5815	V II, 30	440.468
Ne II, 5	372.708	Fe I, 43	406.3597	Ne II,57	440.930
Fe I, 21	375.8235	Fe I, 43	414.3871	Fe I, 2	446.1654
Ne II, 1	377.716	Fe I,695	415.8798	Fe I, 2	448.2171
Fe I, 20	382.0428	Fe I, 3	420.6702	Ne I, 17	454.0376
Fe I, 4	385.6373	Fe I,693	422.7434	Ne I, 11	470.4395
Fe I, 4	388.6284	Fe I, 42	432.5765	Ne I, 16	471.5344
Fe I, 4	393.0299	Fe I, 41	438.3547	Ne I, 21	475.27313
Fe I, 43	400.5246	Ne II,57	439.194	Ne I, 14	503.77505

The stellar lines of CH Cyg were identified according to Yoo and Yama-
shita (1982). The measurements of the radial velocities are listed in Table 3.
Each entry in Table 3 is followed by the mean square error and the number of
measured lines. The radial velocities of the absorption components of the
spectral lines of Ti II and Sc II are plotted in Figures 1 and 2. As regards
the ionized elements, these lines occur most frequently. On an average, 15
- 24 lines of Ti II and 2 - 5 lines of Sc II were measured on each spectro-
gram. With the exception of the spectrogram of Sept. 27, 1982, the radial ve-
locities of both elements agree within the limits of the mean square error

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Table 3.

Element	Sept. 13	n	Sept. 16	n	Sept. 21	n	Sept. 27	n	Oct. 1	n	Oct. 4	n	Oct. 14	n
H I em	-146.9±7.2	4	-153.8±6.6	6	-202.1±9.7	4	-141.7±7.0	3	-163.9±8.0	6	-156.6±14.0	3	-146.4±5.8	6
H I abs	-15.1±1.2	8	-0.2±4.1	8	-8.5±9.2	8	-7.8±2.0	8	-25.5±4.5	12	-7.6±7.4	6	-9.9±4.5	11
He I em					-29.1	1							-34.9	1
He I abs	25.5	1	67.7	1	44.0	1	48.9	1			53.9	1	40.3	1
Mg I,3 em	-137.3	1							-154.9	1				
Mg I,3 abs							-14.0±1.8	2						
Mg I,1 em	-44.4	1	-62.5	1	-61.9	1					-52.7	1	-55.9	1
Mg II em											-149.4	1	-143.1	1
Mg II abs			7.3	1	5.4	1			-34.3	1	1.7	1	-6.8	1
Sc II abs	-27.6±3.9	4	-18.0±1.9	3	-19.6±4.1	4	-13.6±1.5	3	-34.2±8.5	2	-8.3±6.9	4	-19.5±6.4	4
Cr II em	-90.6	1	-81.2±3.3	3	-135.9	1	-80.5	1			-103.7	1		
Cr II abs			2.8	1	20.9	1	-14.2	1			-2.6	1		
Ca II em	-302.8	1	-324.7	1					-320.0	1	-343.2	1	-324.8	1
Ca II abs	-85.9±5.8	2	-81.4±6.0	2	-93.5±11.1	2	-70.7±0.8	2	-85.7±0.8	2	-81.8±1.5	2	-84.9±4.4	2
Ti II em	-144.9±27.7	3	-98.3±6.0	3	-129.4±17.6	2			-157.9	1	-111.6±9.2	5	-129.2±6.5	3
Ti II abs	-22.4±2.8	14	-18.5±2.6	20	-11.3±3.6	14	-24.4±3.6	15	-34.1±2.5	21	-7.5±2.7	13	-21.1±2.7	16
Fe I abs	-33.4±6.2	2	-24.9±2.3	3	-41.9±7.7	3	-33.7±6.8	4	-34.7	1	-62.7±10.0	4	-31.0	1
Fe II em	-75.4±7.6	6	-75.4±3.3	10	-64.8±8.3	18	-57.1±0.2	2	-83.5±6.7	8	-58.0±3.1	16	-76.8±2.5	16
[Fe II] em	-63.7±0.9	2	-54.9±7.6	3	-58.0±3.6	4			-60.7±5.3	6	-48.9±4.9	3	-62.4±3.7	3
Si II em			-121.4	1									-131.9±9.9	2
Si II abs														
V II abs	-46.8±4.3	2					-32.4	1			-29.2	1	-36.0±0.5	2
Sr II abs	-14.3	1			-18.1	1					-27.1	1		

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Table 3 (cont.)

| Element	Oct. 22	n	Oct. 24	n	Oct. 27	n	Nov. 1	n	Nov. 3	n	Nov. 10	n	Nov. 28	n
H I em	-164.7 ± 4.4	6	-140.5 ± 13.5	4	-138.6 ± 7.4	9	-151.4 ± 9.1	4	-143.5 ± 4.7	3	-162.4 ± 8.2	8	-133.7 ± 4.5	9
H I abs	-3.5 ± 4.8	10	16.2 ± 3.7	9	2.1 ± 4.3	8	-6.5 ± 5.2	10	0.3 ± 4.1	5	-18.8 ± 4.2	10	12.2 ± 5.0	10
He I em	-83.3 ± 13.3	3			-97.5	1	-16.0	1	-17.7	1	-46.3	1	-82.5 ± 4.9	2
He I abs	43.1	1	63.8		70.0	1	51.1	1					-93.9 ± 20.0	2
Mg I,3 em					-158.2	1								
Mg I,3 abs	-32.3	1			-17.9	1	-5.2	1	-20.6	1				
Mg I,1 em	-72.6	1			-57.7	1	-55.0	1	-43.4	1	-61.9	1	-68.7	1
Mg II em					-121.0	1	-113.6	1					-114.2	1
Mg II abs	4.3	1			16.1	1	11.4	1	0.0	1	-14.3	1	7.8	1
Sc II abs	-32.2 ± 5.4	3	-16.1 ± 1.5	2	-14.1 ± 2.6	3	-6.2 ± 7.4	4	-20.3 ± 5.6	3	-30.6 ± 1.4	2	-8.6 ± 6.2	5
Cr II em	-110.2	1			-97.1	1	-98.9 ± 6.9	4	-105.2 ± 4.1	3			-108.6 ± 9.2	3
Cr II abs			-20.4	1	-20.6	1	-6.4	1	-5.4 ± 0.9	2			8.8	1
Ca II em	-317.2	1			-324.1	1	-290.7 ± 35.9	2	-321.2	1			-324.2 ± 8.8	2
Ca II abs	-90.8 ± 1.7	2	-65.7 ± 4.7	2	-85.4 ± 12.4	2	-65.0 ± 8.8	2	-67.1 ± 2.3	2	-86.5 ± 1.7	2	-85.7 ± 8.6	2
Ti II em	-150.6 ± 19.0	2	-200.2	1	-151.3 ± 15.2	4	-116.2 ± 4.6	5	-114.2 ± 4.7	4	-172.8 ± 5.4	3	-131.3 ± 9.6	3
Ti II abs	-36.3 ± 2.1	16	-17.0 ± 3.3	15	-11.8 ± 1.9	16	-14.9 ± 2.8	19	-24.6 ± 2.7	18	-32.0 ± 2.5	13	-7.5 ± 3.2	24
Fe I abs	-53.2 ± 15.3	2	-23.8 ± 18.3	2	-29.9 ± 7.8	5	-13.0 ± 3.3	3	-36.5 ± 6.4	4			-26.9 ± 6.6	4
Fe II em	-71.7 ± 2.9	15	-70.6 ± 0.7	2	-67.1 ± 3.5	16	-68.9 ± 3.2	14	-64.6 ± 2.9	17	-66.0 ± 5.3	9	-80.2 ± 3.1	16
[Fe II] em	-57.7 ± 3.8	2	-62.0	1	-51.8 ± 4.3	3	-55.0 ± 5.1	4	-56.4 ± 1.4	3	-58.1 ± 3.1	3	-61.5 ± 1.9	3
Si II em	-122.1	1			-98.9	1			-73.7	1			-103.2 ± 8.8	2
Si II abs	11.2	1			45.7	1							30.5	1
V II abs			-20.9 ± 0.2	2	-22.0	1			-47.5	1	-45.1	1	-24.6	1
Sr II abs									-24.6 ± 11.2	2				
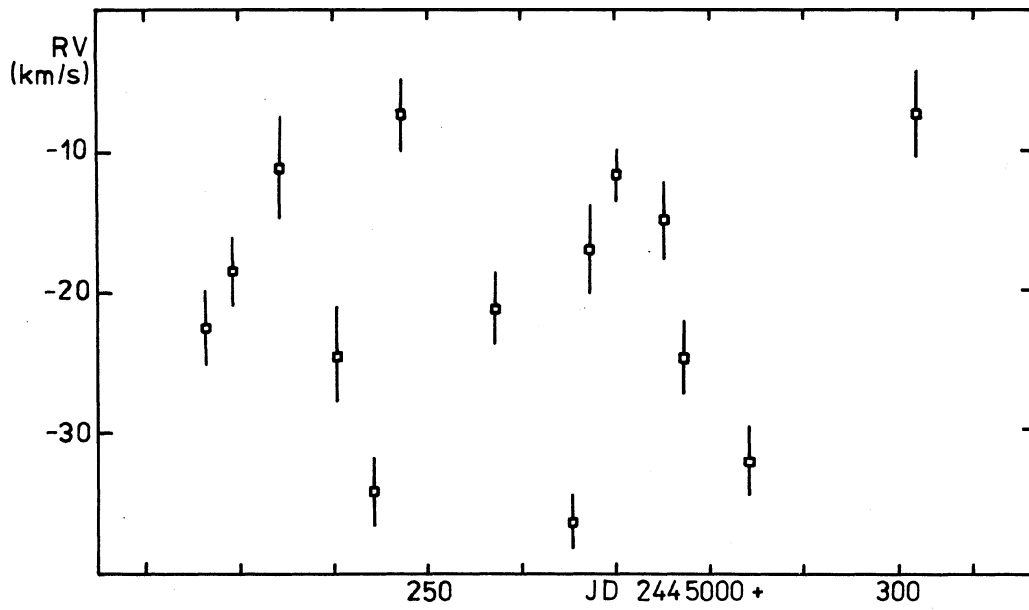
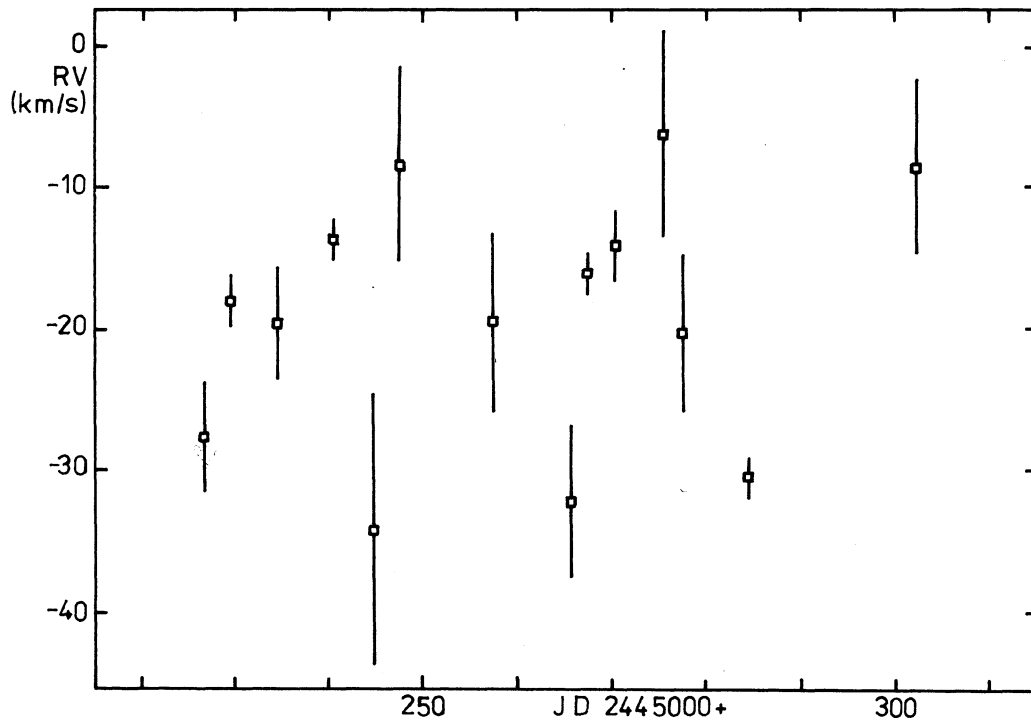Fig. 1. Radial velocities of Ti II lines in CH Cyg.

Fig. 2. Radial velocities of Sc II lines in CH Cyg.

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for n measurements.

3. INTERPRETATION

The principal feature of the observed variations of radial velocities are 4 maxima in the interval of -13.7 to -4.3 km/s and 3 minima between -38.4 and -29 km/s. The average difference between these maxima and minima is 25 km/s. The time interval between the maxima is $23^d \pm 5^d$ and between the minima $20^d \pm 1^d$. Owing to the short time period of the observations and the fact, that the observational material is not sufficiently extensive, it is not possible to decide about the regularity of radial velocity changes.

The problem of interpreting these variations in the radial velocities of ionized metals is related to the low dispersion of the spectroscopic material used. The unblended spectral lines have a halfwidth $\Delta\lambda > 0.1$ nm and their profile, even with strong lines, is determined by the instrumental profile. Lines whose difference in wavelengths $\Delta\lambda < 0.3$ nm form blends which makes it impossible to determine their radial velocities correctly. Using spectra with a dispersion of 0.85 nm/mm, Skopal (1986) proved that the absorption lines of the ionized metals split in the summer of 1981 as a result of the increased mass transfer in the CH Cyg system. The maximum difference in the radial velocities between the V component and the newly generated R component was 50 km/s, which corresponds to a difference in wavelengths $\Delta\lambda \sim 0.07$ nm. In the low-dispersion spectra, a shift of the lines towards the red end of the spectrum is observed instead of splitting. This was checked on a spectrogram with a dispersion of 0.85 nm/mm taken at the Ondřejov Observatory on Aug. 6, 1981. Since the intensities of the R and V components of absorption lines of Ti II in this high-dispersion spectrum are rougly equal, the radial velocities of the line centres correspond to the radial velocity of the lines generated by the superposition of two absorption lines in the low-dispersion spectra. In the spectrum mentioned, the radial velocity of the Ti II line centre is shifted from the V component by 28.5 km/s (Table 4). The radial velocities of the minima (-34.1, -36.3 and -32.0 km/s) measured on the low-dispersion spectrograms (Fig. 1) agree with the radial velocities of the V components of the Ti II lines on the high-dispersion spectrograms taken in 1982 (Skopal, 1986). The average of the maximum deviations of the radial velocities from these minima (25.0 km/s) corresponds to the average displacement of the line centres on the high-dispersion spectrogram. These are the reasons, why we interpret the variations in the radial velocities of the lines of ionized metals in the low-dispersion spectra in the same way as Skopal (1986), i.e. in terms of a sudden mass transfer burst from the M giant to the hot secondary component. In the observation period of Sept. 13 to Nov. 28, 1982, this phenomenom occured approximately on Sept. 21, Oct. 4, Oct. 27 and Nov. 28, 1982.

This interpretation of the observational material is based on the assumption that, in 1982, the orientation of the binary system CH Cyg relative to the observer was such that the projection of the gaseous stream from the M

Table 4.

Radial velocities of the components of Ti II lines in the spectrum of CH Cyg taken on Aug. 6, 1981.

Ti II line (nm)	RV of the V component (km/s)	RV of the R component (km/s)	RV of the centre of the line (C) (km/s)	C - V shift in RV (km/s)
429.0	-42.3	10.8	-13.8	28.5
429.4	-46.1	6.1	-16.7	29.4
430.0	-40.1	4.5	-14.7	25.4
430.8	-45.8	13.2	-13.0	32.8
431.4	-44.4	7.6	-15.5	28.9
439.5	-42.8	6.4	-14.9	27.8
440.0	-44.1	6.5	-12.7	31.4
441.8	-42.7	3.2	-20.0	22.7
444.4	-43.5	10.6	-15.6	28.0
445.0	-44.6	12.3	-17.1	27.5
446.8	-42.3	3.9	-16.0	26.3
450.1	-43.6	7.7	-12.0	31.5
453.4	-44.2	5.5	-15.2	29.0
457.2	-47.3	-0.3	-18.0	29.3
Mean	-44.1 ± 0.5	6.8 ± 1.0	-15.6 ± 0.6	28.5 ± 0.7

giant to the accretion disk of the hot component could be observed. Mikolajewski and Biernikowicz (1985) studied the radial velocities and intensities of H_β lines, as well as the decrease in brightness of CH Cyg in August to December 1984, and came to the conclusion that the end of activity was caused by the eclipse of the hot component by the cool M giant in agreement with the minimum epoch predicted from the long-period orbit of 5750 days, found by Yamashita and Maehara (1979). In the years 1981 and 1982 the orientation of the CH Cyg binary did not differ very much with a view to its long-period orbit and, therefore, the observed variations in the radial velocities in 1982 can be explained in the same way as in 1981, i.e. by an increased mass transfer between the components.

These results support Bath's concept (1984) of the oscillations of mass transfer in cataclysmic variables caused by the dynamic instabilities of the cool component.

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