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EMISSION LINES IN THE OPTICAL SPECTRA OF CH CYGNI 1991–1995

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This paper deals with the interpretation of part of a long-term observation of the symbiotic star CH Cygni performed at Haute Provence Observatory from January 1990 until March 1995. The work covers four different dates belonging to the active phase of the star from its beginning in 1991 to the decline in 1995. The Hγ and Hδ Balmer emission lines were measured together with the λ4471 He I, λ4363 [O III], λ4233 Fe II and λ4243 [Fe II] lines. The results were considered in the context of the data published for this period and compared with observations in other active and inactive phases. Conclusions about the physical conditions in the line-emitting region have been deduced without supporting a unique model of the star.

KEY WORDS Symbolic stars, spectarl observations, emission lines, CH Cyg

1 INTRODUCTION

CH Cygni is a unique object among the symbiotic stars and has been continuously monitored throughout its active and inactive phases.

A mild increase of activity was recorded between July and December 1990, accompanied by an increase of intensity of all emission lines. The activity declined toward July 1991. Further observations have confirmed the start of a new active phase with its first signs taking place already in the same year (Panov and Ivanova, 1992; Mikolajewski *et al.* 1992).

Our observations, beginning in August 1991, are attached directly to the previous ones and extend through the active period until its decline in 1995. There are unfortunately only four records covering a four year time interval, insufficient to follow the spectral changes and hence the symbiotic behaviour on the short time scales. Still, even such rare spectra make possible the study of physical properties of CH Cygni indifferent phases of its outburst and contribute to the complete set of observations performed during this time interval.

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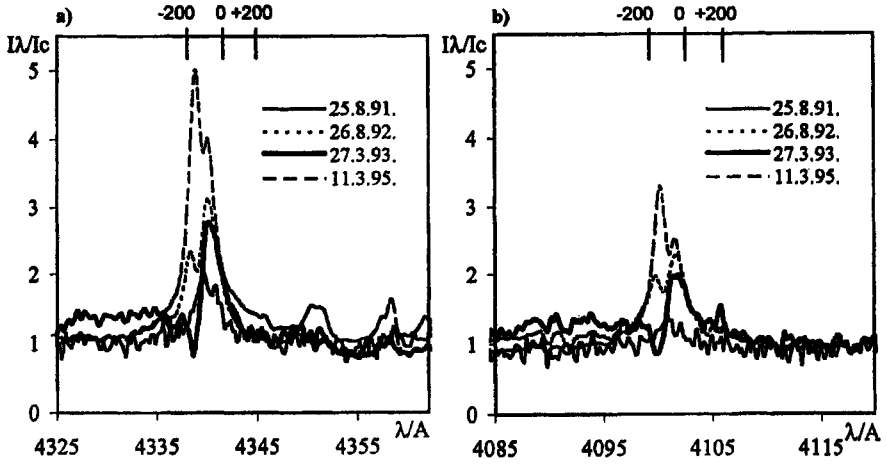

Figure 1 The profiles of: (a) Hγ and (b) Hδ in the spectra of CH Cygni from 1991 to 1995.

2 OBSERVATIONS

The spectra were taken with the spectrograph operated at a reciprocal linear dispersion of 16.5 Å mm^{-1} and attached to the Coude focus of the 152 cm reflector of the OHP. The detector and a 600 lines mm^{-1} grating yielded coverage from $\lambda\lambda$4080 to 4480Å with a resolving power of 6500 in first order. The spectra were reduced using the MIDAS reduction package.

We studied the emission lines Hγ and Hδ of the Balmer series, as well as the λ4471 He I, λ4363 [O III], λ4233 Fe II and λ4243 [Fe II] lines.

3 RESULTS AND DISCUSSION

The spectra taken at four different dates during the 1991–95 time interval give evidence of different kinds of line profiles, reflecting variable physical conditions in the line-emitting region. In each spectrum Hγ and Hδ have the same shape with a nearly constant intensity ratio throughout the observed period. Their features are in agreement with those from other reports referring to the time intervals around the dates of our spectra (Kotnik-Karuza and Jurdana-Šepić, 1999). The measured parameters of the line profiles are given in Table 1.

The profiles are double peaked, except for the one in March 1993, i.e. in the middle of the outburst, which is of P Cygni type. The blue shifted absorption has its origin in the outflowing gas merging from the accretion complex and is followed toward shorter wavelengths by widely (up to 1000 km s^{-1}) spread emission features (Figure 1).

Table 1. Observation of the Balmer Hγ and Hδ emission lines 1991–95.

Date	*JD 244 0000+*	*Line*	*Profile*	*R/V [km s^{-1}]*			*Intensity ratio*			$I_{H\gamma}/I_{H\delta}$	*FWHM* km s^{-1}	*EW* km s^{-1}	*FWZI* km s^{-1}
				V	*A*	*R*	*V/R*	*V/A*	*R/A*				
25.8.91	8494	Hγ	Double-peaked Asym.	−61.3	−3.4	+25.0	1.11	1.17	1.06	1.38	188.5	188.5	418.6
		Hδ	Double-peaked Asym.	−68.5	−7.8	+22.9	1.11	1.26	1.13		149.1	67.2	285.0
26.8.92	8861	Hγ	Double-peaked Asym. B	−146.9	−104.2	−32.3	0.74	1.12	1.51	1.36	237.6	497.2	627.8
		Hδ	Double-peaked Asym. B	−144.5	−99.2	−7.8	0.86	1.11	1.28		211.9	271.2	114.7
27.3.93	9073	Hγ	P-Cyg B shifted em.	−133.2[a]		− 17.8[e]		3.43[e]		1.38	153.3	267.9	/
		Hδ	P-Cyg B shifted em.	−144.5[a]		− 7.5[e]		2.35[e]			171.8	171.7	/
11.3.95	9787	Hγ	Double-peaked Sym.	−118.7	−61.3	−32.3	1.25	1.31	1.05	1.52	192.7	770.7	973.9
		Hδ	Double-peaked Sym.	−113.8	−53.1	−23.2	1.45	1.32	0.91		189.3	435.6	796.7

Note: *V*, *R*, and *A* stay for violet emission peak, red emission peak and absorption core, respectively;
[e]emission component of the P Cyg profile;
[a]absorption component of the P Cyg profile.

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Other profiles are double peaked with asymmetry in peak heights. The central absorption changes from spectrum to spectrum but reaches a level below the continuum in none of the three cases. If the double peaked profiles were the result of two merging emission components, the ratio of the central depression to the emission peaks should be the same for both Hγ and Hδ. The opposite observational fact (Table 1) argues in favour of the statement that the Balmer profiles are a result of an absorption feature superimposed onto a single-emission component. The idea that the self-absorption arises in a partially ionized red giant wind which is subject to accretion by the WD and results in a highly variable asymmetric accretion structure, called a transient accretion disk (Albright and Richards, 1995), has been largely accepted (Tomov *et al.*, 1996; Bode *et al.*, 1991). The transition zone where hydrogen changes from ionized to neutral is rather narrow (Schwank *et al.*, 1997). While the depth of the central reversal is determined by the density of absorbers along the line of sight and could be explained either by an enhanced mass transfer from the red giant and/or by a variable stellar separation in the highly eccentric orbit, the ratio V/R can be at least partly explained by the radial velocity of the absorbing layer in which the absorption core has been formed.

The two Balmer lines in the 1991 and 1995 spectra have $Y/R > 1$, while the same lines in the 1992 spectrum show $V/R < 1$. Both possibilities were present also during the 1977–1986 activity (Hack *et al.*, 1988). A more negative radial velocity leads to a decrease of the violet peak intensity and when the radial velocity is less negative, the red wing intensity decreases. The loose relation between radial velocity and the ratio V/R (Table 1) suggests that besides the expansional velocities of the absorbing region also the rotational velocities probably influence the line profile variations.

The line wings of the double peaked profiles from the 1991,1992 and 1995 spectrograms are asymmetric, which could be a result of asymmetry in the accretion process (Ballerau *et al.*, 1996). No definite statement can be made about the wings shape of the 1991 weak profile because the possible blue or red shifted features cannot be resolved from the background. The other two profiles, dating from 1992 and 1995, differ in the wings. Both Balmer lines taken in 1992 in the rising part of the outburst decline more steeply on the red side, while the blue-shifted emission component contaminates the violet wing. This prominent feature, also observed by Ijima *et al.* (1994), could be ascribed to a bipolar gas outflow whose receding part is obscured. The strong Balmer emission indicates a strong outflow of matter which can be due to propeller interaction of the rapidly rotating magnetic WD with the giant's wind (Mikolajewski *et al.*, 1992).

The line wings of the 1995 profiles observed during the decline of activity extend to larger velocities on the red side than on the blue side with a steeper slope on the blue side. The red asymmetry in the form of a red-shifted emission could be explained as a consequence of penetration of the accretion disc near the WD surface (Leedjarv *et al.*, 1994) in the form of high velocity infall channelled by its magnetosphere (Gullbring *et al.*, 1996). At the same time the strong line emission flux indicates an outflow of matter which can be due to propeller interaction of the rapidly rotating magnetic WD with the giant's wind. The increase of intensity could

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Table 2. Central depths ($-Rc$) of emission lines in the four spectrograms from 1991–1995.

Line	*25.8.91*	*26.8.92*	*27.3.93*	*11.3.95*
λ4233 Fe II	0.33	0.34	0.48	0.86
λ4243 [Fe II]	0.37	0.50	0.46	0.69
λ4363 [O III]	0.42	0.61	0.01	0.35
λ4471 He I	0.47	0.50	0.84	1.05

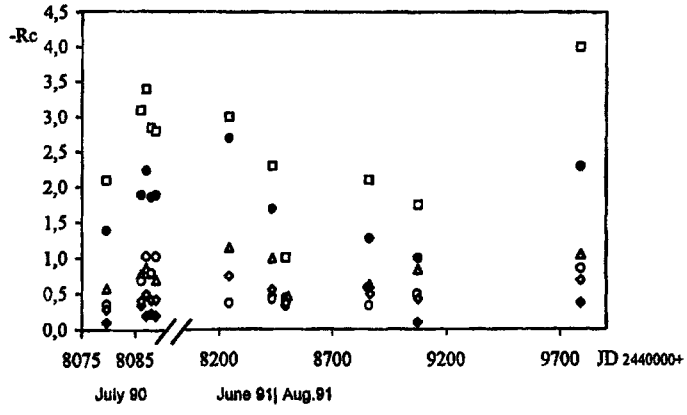

Figure 2 The variation of the central depths of the emission lines. □: Hγ; •: Hδ; △: λ4471 He I; ♦: λ4363 [O III]; ○: λ4233 Fe II; ◇: λ4243 [Fe II].

also be indicative for the thinning out of the envelope which can be regarded as a transition to the nebular phase (Panov *et al.*, 1985). The former explanation could be valid at least at the beginning of 1995, i.e. two months before our observation when remarkable signs of activity were still present (Rossi *et al.*, 1995; Viotti *et al.*, 1998).

The central depths of the Hγ and Hδ lines have been measured together with other emission lines of He I, [O III], Fe II and [Fe II] (Table 2) and in addition to the corresponding data of Hack and Aydin (1992) presented as a function of time in Figure 2. Regarding the Balmer lines, no monotonic behaviour during the 1991–95 activity has been recorded. This could be taken as an indication of erratic activity which results from the highly unstable physical conditions near the WD. The lines are less intensive relative to the corresponding values for the previous mild outburst (Hack and Aydin, 1992), except in 1995, after the decline of the active phase, when they were remarkably stronger. Other emission lines show no significant change in central depths over the 1989–1995 time interval.

The rather chaotic behaviour of the central depths of emission lines in the successive recorded dates from June 1991 to March 1995 is evident from Figure 3*a–d*:

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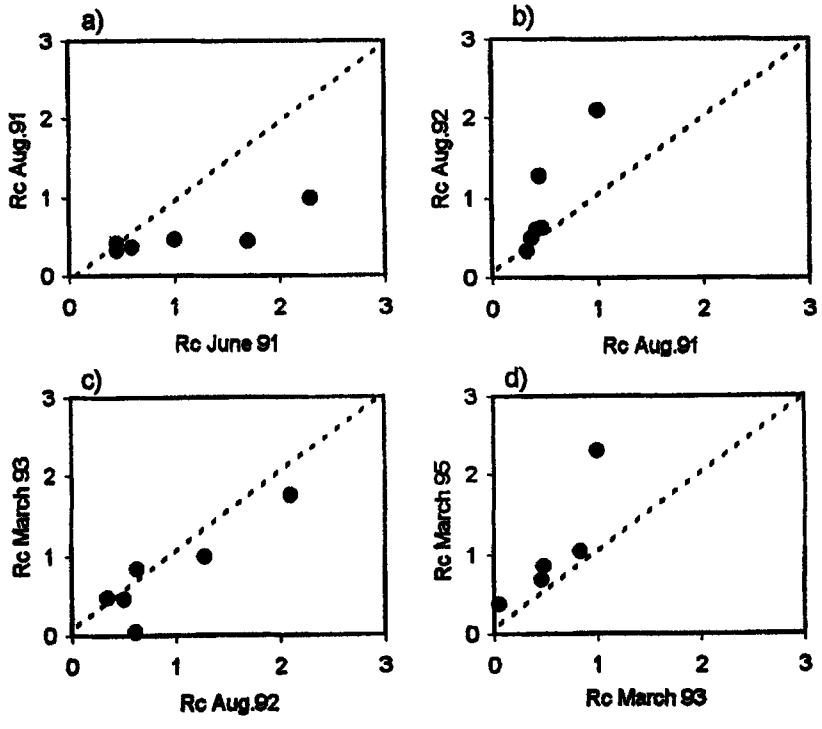

Figure 3 Comparison of the central depths of the emission lines between successive recorded dates: (a) 25 August 1991 vs. 26 June 1991; (b) 26 August 1992 vs. 25 August 1991; (c) 27 March 1993 vs. 26 August 1992; (d) 11 March 1995 vs. 27 March 1993.

there is a decrease in August 1991 relative to June 1991, then an increase in August 1992, a decrease in March 1993 and an increase in March 1995.

The measured values of full widths at half maximum (FWHM), full widths at zero intensity above the continuum (FWZI) and equivalent widths (EW) have been displayed in Table 1.

The main source of uncertainty in the determination of the widths is essentially due to the choice of the continuum level. An accurate treatment of the errors is very difficult particularly in the cases with red-shifted and blue-shifted features. The widths can be underestimated due to an overestimation of the continuum level in the case of large emissions which imply very extended wings. A rough estimation yields an error of about 10%.

It is evident from our results that all widths increase starting from 1991 toward 1995 with the exception of FWHM which decreases at the end of the observed interval. The increase of EW could be due to an increase of the outer radius of the accretion complex. At the same time, adding emitting material at large radii preferentially increases the intensity near the line centre, reducing the FWHM intensity. FWZI increases with decreasing inner radius of the accretion complex

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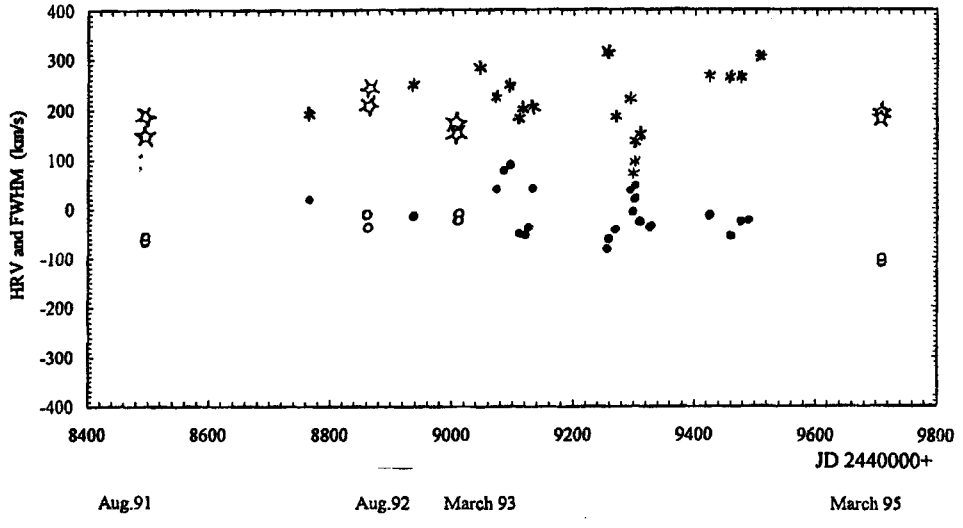

Figure 4 The radial velocities (circles) and FWHM (asterisks) of the Balmer lines in the spectra of CH Cygni from 1991 to 1995. White symbols: this work; black symbols: Leedjarv and Mikolajewski, 1995.

accompanied by an increase of rotational velocity (Murray and Chiang, 1997; Daems and Waelkens, 1997).

Our observations of radial velocities of the strongest emission peaks of the Balmer lines with their erratic variations between -7 and -120 km s^{-1} fit in with the measurements of Leedjarv v and Mikolajewski (1995) during the same time interval. The same is valid for our values of the FWHM between 150 and 250 km s^{-1} (Figure 4).

The close lying lines of [Fe II] λ4244 and Fe II λ4233 could be measured together

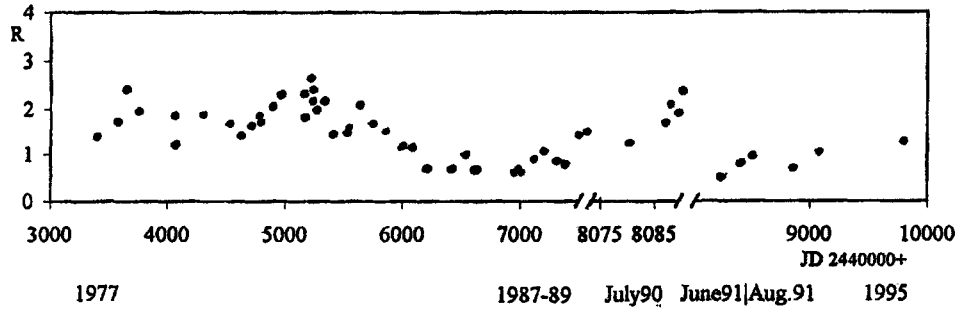

Figure 5 The ratio of the central depths (R) of λ4233 Fe II and λ4243 [Fe II] in the spectra of CH Cyg from 1988 to 1995. 1977–85: Hack *et al.*, 1986; 1987–89: Kotnik-Karuza *et al.*, 1992; 1990–91: Hack and Aydin, 1992; 1991–95: this work.

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on all spectrograms. Their intensity ratio can be used as a useful indicator of the physical properties in the emitting envelope and leads to an estimation of the density or of the radiation field, depending on the mechanism which governs the population of the higher levels relative to the metastable and ground iron levels (Viotti, 1976). In the case of CH Cygni with reasonable value of T about 10^4 K and N_e ranging between 10^5 and 10^{10} cm^{-3} (Hack *et al.*, 1986; Mikolajewska *et al.*, 1988; Hack and Aydin, 1992) our results (Table 2) suggest that the excitation mechanism in the line-formation region is coupled to the radiation field with a dilution factor of about 10^{-4}.

It is interesting that these results vary insignificantly (actually in the frames of the error) around a relatively low value throughout the 1991–95 phase compared to remarkably higher values during the strong 1977–86 and the mild 1990 outbursts (Figure 5).

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