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CH Cygni 1987-89: The inactive state as a precursor to the new outburst

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Abstract. In order to help answering the question generally posed for symbiotic stars: are the apparently inactive periods quiescent at all, or should they be regarded merely as a transition between adjacent outbursts, we tried to establish correlation between the subtle phenomena in the time evolution of the cool giant's photosphere and emission line profiles of the symbiotic star CH Cygni during the period 1987-89. Optical spectra of this star in its inactive state taken at the Haute Provence Observatory as well as the spectra of late type giant's of the same spectral type have been used. The comparison of the results obtained suggests that the time evolution of the physical parameters of CH Cyg reflect the symbiotic phenomena rather than the intrinsic variability of the cool component. The time behaviour of the Balmer emission line profiles rules out the general validity of the established models. An acceptable model valid at least for the observed period has been proposed. According to it, an envelope of variable optical thickness surrounds the hot component. The development of its inner radius, of Hα and Hβ line profiles and of the λ5007 [OIII] nebular line leads to the conclusion that the inactive state is not stationary, but is gradually evolving in time toward the new activity of the star.

Key words: stars: binaries: symbiotic — stars: CH Cygni

1. Introduction

CH Cyg, as a highly interesting object, has a remarkable place among the symbiotic stars. It has been generally accepted to be a binary consisting of a cool M6-7III late type giant and a hot component surrounded by an accretion complex formed from the cool giant's wind (Mikolajewski et al. 1990). Its irregular outbursts show a bunch of exotica like flickering, jet activity, high ionization lines, X-ray and radio emission, dust cocoon etc. (Munari et al. 1996). The outbursts, which differ from each other, have been separated by quiescent phases of different duration (Wallerstein & Cassinelli 1968; Bruch 1986; Garcia 1986; Mikolajewski et al. 1990; Bode et al. 1991; Kotnik-Karuza et al. 1992; Orio 1993; Jurdana & Kotnik-Karuza 1994; Kotnik-Karuza & Jurdana-Šepić 1997). Although some recent works have recognized the importance of quiescent phases for understanding the physical mechanisms of symbiotic stars and the nature of the outbursts, spectroscopic works dealing with the quiescent states of CH Cyg have still been rather restricted.

The fact that CH Cyg was in the extended period of inactivity before 1963 (Muciek & Mikolajewski 1989), as well as the complex behaviour of its spectroscopic and photometric parameters which is extremely difficult to interpret consistently, make each observation of this star, as a unique and unrepeatable event, an extremely important contribution to its understanding.

After its longest quiescent phase in the last few decades, CH Cyg showed signs of renewed activity in 1990 (Panov & Ivanova 1992) which represented an introduction to a new large outburst lasting from 1990-1995 (Munari et al. 1995). The results of these observations shed doubt on the models constructed in the meantime and turned again our attention to the optical spectra of this star taken at the Haute Provence Observatory in the quiescent period from June 1987 to January 1989 (Kotnik-Karuza et al. 1992).

2. Physical parameters of the cool component

In the previous work (Jurdana & Kotnik-Karuza 1994) we followed the behaviour of the excitation temperature of neutral metals in the cool giant's photosphere, which approximately equals its effective temperature and determines the physical state of the photospheric layers (Komarov et al. 1974). The observed monotonic decrease of the $T_{\rm exc}$ for each element cannot be due to the red giant's intrinsic variability since the total temperature change in the observed period exceeded 1000 K. This value

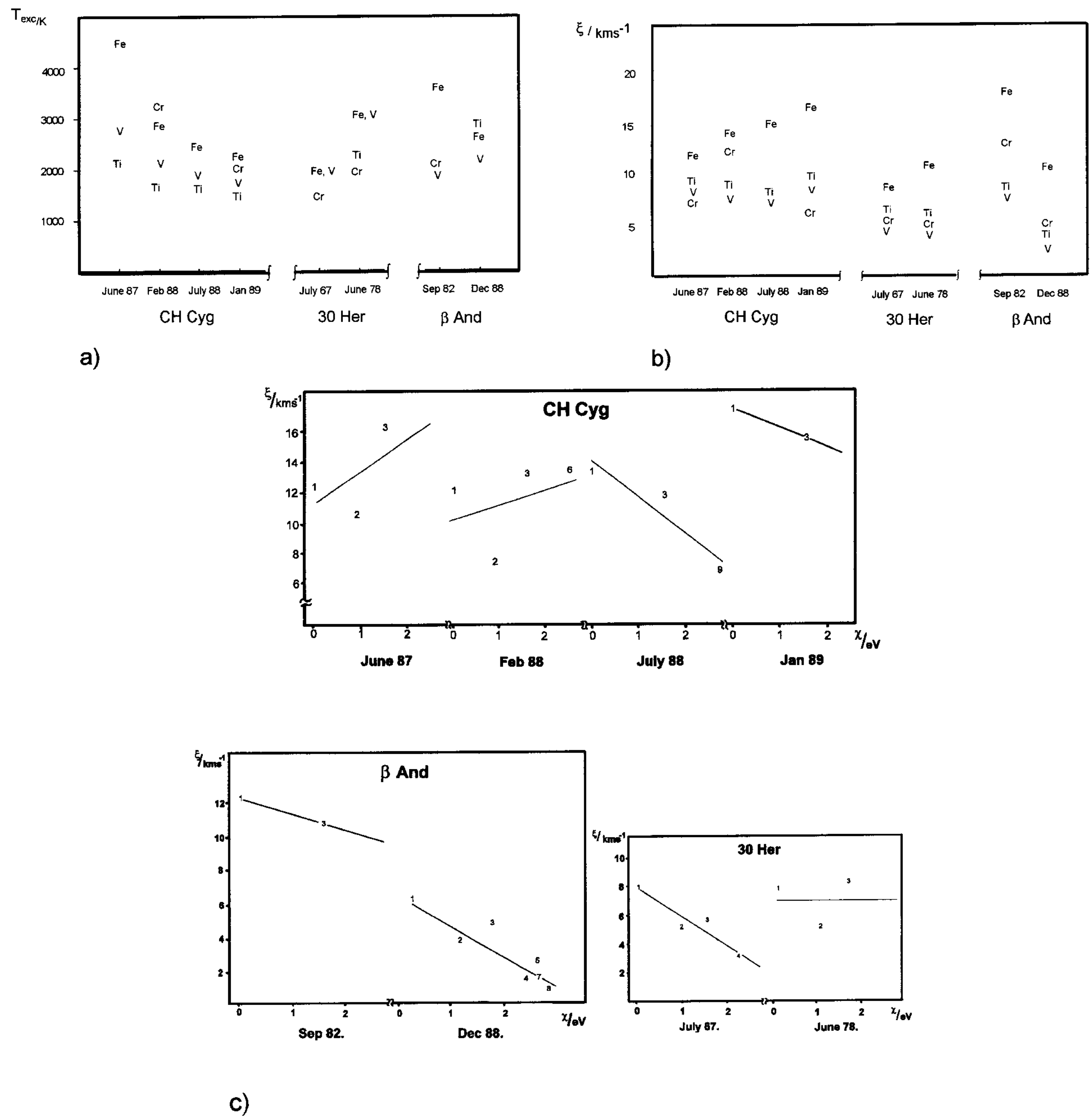

Fig. 1. Physical parameters of CH Cyg compared with the corresponding values of the late type giant's of the same spectral type 30 Her and β And at different epochs: **a)** mean values of effective temperature for neutral metals as a function of time, **b)** mean values of microturbulent velocity for neutral metals as a function of time, **c)** microturbulent velocity of a Fe I as a function of the excitation potential of the lower state

is remarkably higher compared to 420 K of intrinsic variability for the cool component of CH Cyg (Taranova 1990). This parameter for the same elements was determined for the Sr 30 Her over a ten year interval as well as for the invariable β And (Kotnik-Karuza & Jurdana-Šepić 1997). The revised and completed results of the mean values of $T_{\rm exc}$ (Fig. 1a), show remarkably higher oscillations in CH Cyg than in 30 Her and negligible small oscillations of $T_{\rm exc}$ in β And. The data for 30 Her and β And are presented in Table 1. The corresponding data for CH Cyg are taken from the previous work (Jurdana & Kotnik-Karuza 1994).

The microturbulent velocities have been well defined in the optical region during quiescence since most lines that could be measured with reasonable accuracy in these highly crowded absorption spectra were more or less saturated. In such cases the classical methods make an accurate determination of microturbulent velocities possible under the assumption that the oscillator strengths are sufficiently well known. The m icroturbulent velocities of

Table 1. Results for excitation temperature and microturbulent velocity with basic features of empirical curves of growth for 30 Her and β And

		30 Her		β And	
		July 67.	June 78.	Sep. 82.	Dec. 88.
Fe I	Part of curve of growth	DT	DT	T	T
	Slope of straight line	0.09	0.09	0.05	0.13
	Number of lines	21	18	19	64
	s	0.65246	0.74570	0.16299	2.10228
	Temperature/K	2000 ± 50	3100 ± 300	3600 ± 300	2700 ± 100
	Microturbulence/km s^{-1}	8.75 ± 2.27	10.89 ± 2.94	18.29 ± 0.92	10.69 ± 0.56
Ti I	Part of curve of growth	T	T	T	T
	Slope of straight line	-	0.09	0.05	0.11
	Number of lines	11	9	19	60
	s	-	0.33552	-	2.59940
	Temperature/K	-	2300 ± 650	-	2900 ± 300
	Microturbulence/km s^{-1}	6.38 ± 1.00*	6.06 ± 0.95	8.44 ± 0.66*	4.70 ± 0.24
V I	Part of curve of growth	DT	DT	T	DT
	Slope of straight line	0.13	0.05	0.05	0.05
	Number of lines	24	21	18	39
	s	0.74211	0.67103	0.24454	1.12170
	Temperature/K	2000 ± 150	3100 ± 600	2000 ± 400	2200 ± 100
	Microturbulence/km s^{-1}	3.80 ± 0.66	4.14 ± 1.02	8.17 ± 0.53	2.56 ± 0.39
Cr I	Part of curve of growth	T	T	T	DT
	Slope of straight line	0.05	0.05	0.05	-
	Number of lines	7	10	18	16
	s	0.54645	0.10400	0.40682	-
	Temperature/K	1500 ± 450	2000 ± 950	2100 ± 250	-
	Microturbulence/km s^{-1}	6.08 ± 1.60	5.51 ± 1.14	12.98 ± 1.09	5.18 ± 0.78*

CH Cyg, taken as mean values over different multiple groups for each of the four neutral metals, show erratic variations of about 6 km s^{-1} throughout the investigated time interval (Fig. 1b). These data compared with the results for the variable 30 Her and nonvariable β And (Table 1) confirm the general opinion that there is no clear distinction regarding this parameter between variable and non-variable stars, i.e. it is not likely that intrinsic variability would have direct effect upon stellar turbulence (Tsuji 1986). From Fig. 1b it is evident that the turbulent velocities vary from atom to atom for all investigated stars. This confirms the belief that such stratification most likely exists in the largely extended atmospheres of giant stars (Farragiana & Hack 1971).

In the four spectra taken at different times of the quiescent period we measured the dependence of the microturbulent velocity ξ on the excitation potential of the lower state χ for Fe I which rendered itself most reliable because of the greatest number of measurable lines (no fewer than 40). A surprising evidence of anomalous behaviour of the microturbulent velocity was found in CH Cyg up to February 1988: this parameter was increasing with the multiplet number. In July 1988 the dependence $\xi = f(\chi)$ common for the red giant stars has been recovered (Fig. 1c). Namely, a decrease of microturbulent velocities with increasing excitation potential of the lower state is expected because of their dependence on the height in the photosphere. This could be a consequence of their possible relationship to the granular convection in the red giant's photosphere (Tsuji 1991) and of their origin in the gradient of the velocity field along the line of sight.

It is evident from our observations that the time behaviour of the physical parameters contradicts the picture of a quiescent red giant's photosphere.

3. The Balmer emission

The general appearance of the Balmer emission lines in the quiescent phase 1987-89 has already been described (Kotnik-Karuza et al. 1992). Hα and Hβ are the most intense and easily measurable members of the series with line profiles varying in time. They are easily distinguished from the highest points of the pseudocontinuum. There are no remarkable absorption features to disturb the neighbourhood of the both Balmer lines. In order to estimate the influence of the cool star on the symbiotic spectrum a comparison with the spectra of 30 Her and β And has been made. No Balmer lines in emission were observed in their spectra (Kotnik-Karuza & Jurdana-Šepić 1997). The smooth continuum in the Hβ region in 30 Her and Hα and Hβ Balmer lines in absorption in β And suggest that these lines in the spectrum of CH Cyg are not augmented by the possible disturbance of the cool component.

The time evolution of Balmer emission line profiles normalized to the local continuum is given in Fig. 2. Their predominantly expressed double-peaked structure with asymmetry in peak heights imply that these lines could originate either in a rotating accretion disc or are a result of superposition of an absorption feature on to a single emission component. In order to test the former assumption we measured the intensity ratio of the violet and red wing of Hα and Hβ and extrapolated these results to the previous measurements of Hα (Leedjärv 1989) as shown in Fig. 3. Our values of V/R of Hα in the observed period 1987-89 did not exceed 1, which would exclude an eclipse of the hot component by the cool giant. It is true that V/R of Hβ was slightly higher than 1 in January 1989. Also the ratio V/R of Leedjärv (1989) of Hα exceeds 1 in the period JD 244 6850−244 7050, i.e. at the begining of our time interval. Anyway, the discrepancies are not bothering since none of the known models for CH Cygni predict an eclipse at that time. Unfortunately, there are no observations in the Hα and Hβ spectral region just in the time when an eclipse could have happened according to the triple star model of Hinkle et al. (1993) and with the assumption of high orbital inclination. However, there are objections to this model (Munari et al. 1996), as well as to the possibility to take an eclipse as a probe for the existence of an accretion disc in binaries with the hot component being less massive than the cool one (Robinson et al. 1994). An eclipse in the far more reliable long period orbit could not have happened at that time (Mikolajewski & Mikolajewska 1988). The different intensity and time evolution of the central depression in Hα compared to that of Hβ argues in favour of the latter explanation, which means that the compact object, most likely a white dwarf, accretes matter via the M giant's wind resulting in an accretion complex being different from a substantial accretion disc. In this picture the lines arise in an ionized region of the red giant's wind around the hot component and are then self absorbed in the neutral regions of the same wind. Bode et al. (1991) fitted the Hα line profiles during the quiescent phase: out of 8 profiles only one taken in June 1986 lent itself readily to testing the accretion disc hypothesis. This suggests that the accretion disc can be considered as a transient phenomenon associated only with outbursts of the system.

The most intriguing phenomenon in the time evolution of both lines is the appearance of an one component asymmetrical emission profile without any noticeable absorption or additional emission in July 1988. After that, a gradual decrease in intensity of Hα and Hβ toward the end of 1988 was recorded. At the beginning of 1989 the double-peaked structure was re-established. We believe that these changes in line profiles reflect the variable rate of the mass flow via stellar wind onto the hot component, which influences the optical thickness of the gas along the line of sight. The enhanced mass transfer from the cool component could be considered as a probable sign of a renewed activity. The time coincidence of intensity decrease with approach to apoastron in the long period orbit cannot be taken as the only reason of the reduced mass transfer. If this were true, typical irregular appearance of activity phases of variable duration could not be explained.

The more negative radial velocities of the single emission and central absorption of the Balmer lines by about 10 km s^{-1} with respect to the systemic velocity in our case suggest that the Balmer region is a slowly expanding shell of material ejected by the cool object.

4. The nebular λ5007 [OIII] line

This line has been present throughout the whole investigated period with decreasing intensity (Fig. 4). Its profile was complex and dramatically variable in shape. Its multiple emission components of different velocities and profiles including a rectangular form at the beginning of 1989. support the idea that the [OIII] matter consists of several inhomogenous nebular clouds. The very improbable existence of a substantial accretion disc at this time rules out bipolar flows as ejection mechanism of this matter. It is most likely supplied by the cool component due to its mass loss by stellar wind. The nebula absorbs the ionizing radiation emitted by the hot component. The diminishing intensity suggests the decline of one or both mechanisms and the persistence of the mechanism which supports the shell- expansion away from the hot star.

5. Discussion

Our observations of CH Cyg suggest that the phenomena recorded throughout its evolution phases are due to interaction between its cool and hot component well represented in the binary model with a 5700d period orbit. The complexity of spectroscopic phenomena and their changes in time reflect complex and variable conditions in both stellar atmospheres leading to the conclusion that even in the inactive phase the star has not been quiescent.

The shape and time evolution of the Balmer emission profiles do not suggest the existence of an accretion disk during the inactive state. Contrary to this, in outbursts a strong evidence of an accretion disk has been given. It means that the accretion disk in CH Cygni can be regarded as a transient phenomenon which disappears and reappears in different phases of star's evolution. This belief has been justified by simulations of Theuns & Jorissen (1993) which, apart from some discrepancies, proved to be applicable to CH Cygni. They, namely, discuss the formation of a disk in an unperturbed binary system where the primary does not fill its Roche lobe and is subject to a spherically symmetrical stellar wind around it. In the case of higher wind speeds, the gas is partly accreted by the

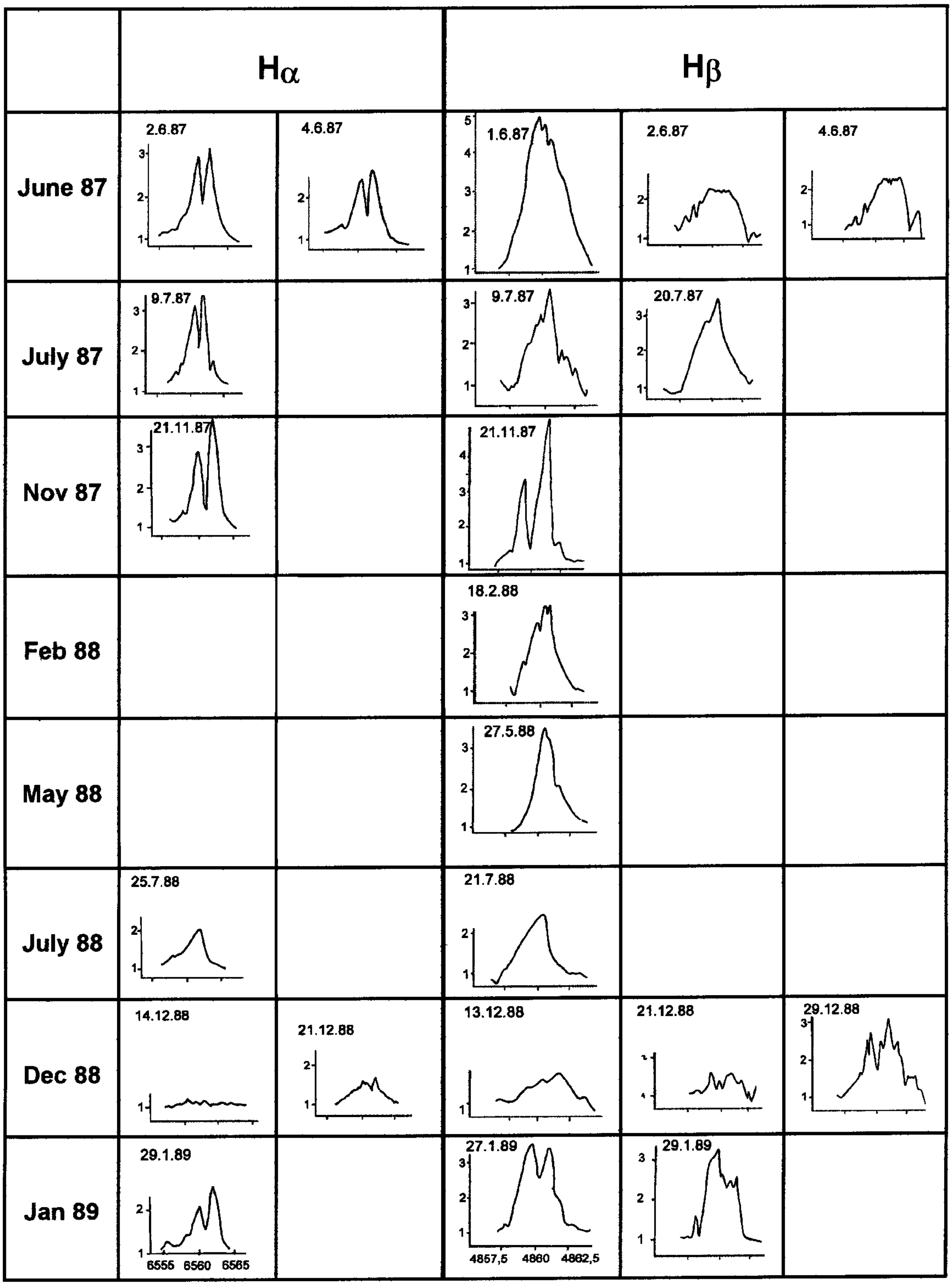

Fig. 2. Balmer emission line profiles normalized to the continuum level from June 87-Jan. 89

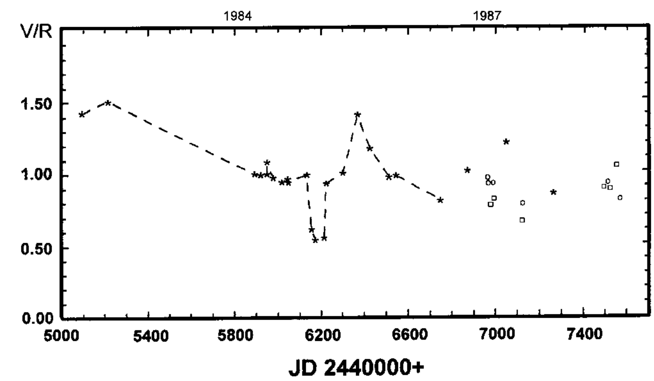

Fig. 3. The intensity ratio V/R in the double-peaked Balmer emission lines Hα (circles) Hβ (squares) -our data, Hα (asterisk) -Leedjärv 1989

secondary which is orbiting in the bubble of gas blown by the primary. The crucial question regarding the formation of an accretion disk concerns the amount of matter that can be accreted by the secondary.

The minimal value of the variable self-reversal in the double-peaked Hα and Hβ profiles observed with better resolution (Bode et al. 1991) and recognized as single line emission in our spectra would correspond to a reduced mass transfer from the red giant's atmosphere and to minimal optical thickness of the envelope around the hot companion. The assumption of an optically thick accretion disk in the Horne & Marsh model is obviously unsuitable for the quiescent period and responsible for the mismatch of the Hα and Hβ profiles taken by Bode et al. (1991) later than June 1986 with the accretion disk hypothesis (Robinson et al. 1994).

If the increase of optical thickness of the accreted matter toward the end of the observed period i.e. January 1989 were a result of an enhanced mass transfer rate, this could not have been caused by effects related to the eccentric orbit since the star was at that time far from periastron in the long period orbit (Mikolajewski et al. 1988). Variations of the mass transfer rate cannot be explained either by eccentricity of the short period orbit in the triple star model (Hinkle et al. 1993). Namely, the optical thickness of the envelope reached its minimum in July 1988, about 40 days after periastron i.e. shifted in phase only by 0.06.

On the other hand, the explanation of the gradual decrease of the excitation and effective temperature in the M giant's photosphere without influence of irradiation by the hot star in the detached binary system remains questionable.

According to the oblique rotator model in the inactive phase there is a lack of a noticeable accretion complex around the magnetic white dwarf (Tomov et al. 1996). Consequently an envelope of variable optical thickness cannot be explained by this model. Still, the main objection to the oblique rotator model follows from its prediction that this inactive phase of CH Cyg should last for several decades, necessary to accumulate enough material around the white dwarf to start a new propeller and accretor phase (Skopal et al. 1996b). The observations of a new outburst which announced itself already in 1990 contradict this prediction.

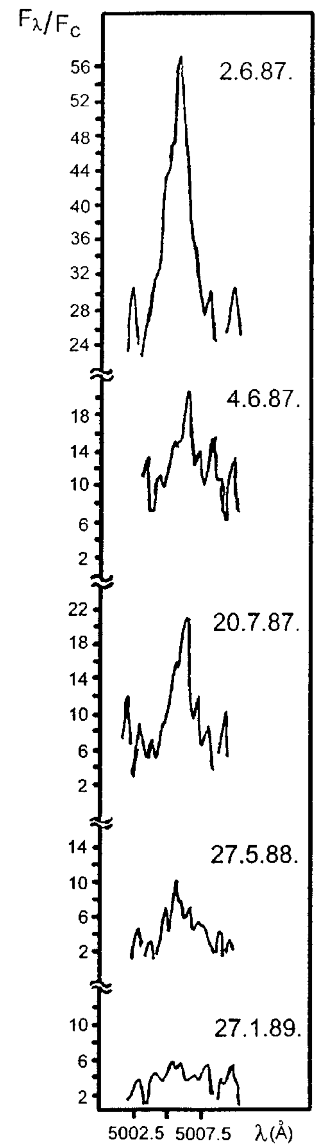

Fig. 4. Profiles of nebular λ5007 [OIII] line normalized to the continuum level at different epochs

Because of the discrepancies of our results with the triple star and oblique rotator models we are tempted to propose a model acceptable at least for the observed inactive period 1987-1989. Since the origin of Balmer emission in an accretion disk seems to be improbable, we looked for it in a rotating envelope consisting of material supplied by the stellar wind from the cool component and being ionized by UV radiation emitted by the hot star. These mechanisms determine the physical conditions in the HII region, whereas a wind from the hot component

Table 2. Inner and outer Keplerian radius of CH Cygni calculated from the Hα profiles

Date	JD 2440000+	$r_{\rm out}$ $/10^{10}$m	$r_{\rm in}$ $/10^{8}$m	Reference
05.05.82	5095	4.59	69.60	Leedjärv et al. (1994)
04.09.84	5948	4.59	0.84	Leedjärv et al. (1994)
14.11.84	6019	4.59	4.87	Leedjärv et al. (1994)
08.12.84	6043	4.59	20.88	Leedjärv et al. (1994)
25.08.85	6303	6.26	104.40	Leedjärv et al. (1994)
24.03.86	6514	4.18	20.88	Leedjärv et al. (1994)
23.04.86	6544	4.18	59.16	Leedjärv et al. (1994)
28.06.86	6610	8.37	4.39	Bode et al. (1991)
02.06.87	6948	11.63	3.50	This paper
04.06.87	6950	8.37	3.50	This paper
09.07.87	6985	14.04	3.50	This paper
21.11.87	7120	5.55	5.80	This paper
29.01.89	7555	6.78	5.50	This paper

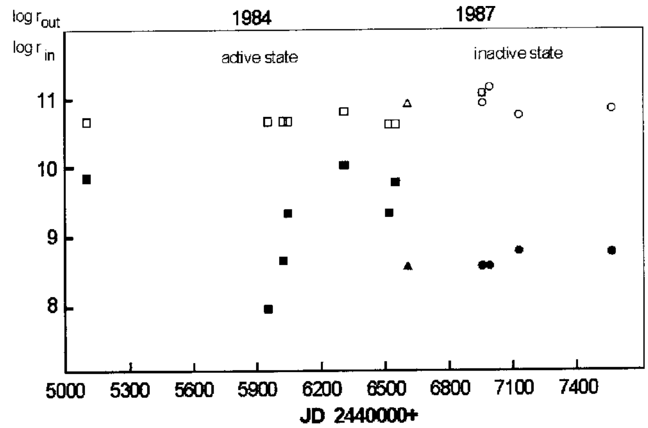

Fig. 5. Evolution of the inner (black symbols) and outer (white symbols) Keplerian radius in time derived in meters according to: our results (circles), Bode et al. (1991). (triangles) and Leedjärv et al. (1994). (squares)

as well as violent mass ejecting outbursts appear unlikely (Munari & Patat 1993). The HI region, which is influenced only by the red giant wind is responsible for the shape of the central reversal. Evident similarity of the peak-to-peak separation in the double peaked Hα profiles during the time evolution lead us to an attempt to establish a relationship beetwen these profiles and the shape of the rotating envelope. We adopted the simplest way already accepted for the description of the accretion disks (Robinson et al. 1994; Theuns & Jorissen 1993), according to which the particles in the envelope follow Keplerian trajectories, which represent curves of constant radial velocities. The double peaked emission originating from the physically longest constant radial velocity curve can be used to calculate the outer radius of the envelope. Similarly, the limits of the profile wings determine the corresponding inner radius.

We measured peak-to-peak and wing limits separation in the Hα emission profiles at different epochs and, using our data together with those of Bode et al. (1991), calculated the corresponding inner and outer radii of the Keplerian accretion complex. These results together with the data of Leedjärv et al. (1994) are given in Table 2 and Fig. 5. For the inclination of the system and the mass of the compact star we assumed the values used by Robinson et al. (1994): $i = 78°, M_{\rm C.S.} = 1\ M_{\odot}$. Nearly constant values of the inner and outer radii starting from June 1986 have been consistent with the inactivity of the hot component, though a slight increase of the inner radius in 1988 could possibly indicate a start of a process by which the infalling matter is expelled from the white dwarf.

In addition to the described influence of the hot and cool component on the shape of Balmer lines, their profiles can be affected by orbital phase, especially in cases with high inclination like CH Cygni. This dependence is expected to become larger in the case with increasing asymmetry of the Balmer region. No significant difference in the shape of the double peaked Hα profiles in the course of time, particularly in the depth of their central reversals suggests ultimately a spherical shell shape of the emitting region. This fits the model of the Strömgren sphere (Taylor & Seaquist 1984) which contains the HII region. The actual shape of this ionized envelope has been the subject of observational and theoretical research. The radio emission proved to be an important source of information since it originates exactly in the ionized portion of the red giant's wind. A model that accounts for the radio properties of the symbiotic stars (Seaquist et al. 1984) has further been developed by Taylor & Seaquist (1984) and is consistent with parameters from optical and IR data. It proves the shape of the ionization front to be determined only by the physical properties of the binary pair (mass loss rate from the cool giant, its wind velocity, separation of the components, luminosity of the ionized radiation). In the case of CH Cygni an ionization bounded region would be of an approximately spherical shape. Radio emission of CH Cygni was detected in quiescence and activity (Skopal et al. 1996b). The authors present a good fit of their radio observations during the latest outburst to the spherical shell model and even give the values of inner and outer shell radii.

Our idea of what is happening in CH Cygni in its transition between activity and inactivity, particularly during the apparently quiescent state, has been firmly supported by the already quoted calculations of Theuns & Jorissen (1993). Their three dimensional model of the flow pattern takes binary rotation and the same order of magnitude of the the wind and orbital velocity into account. The pattern differs substantially for the two values of polytropic index γ, reflecting an isothermic process for $\gamma = 1$ and adiabatic for the assumed $\gamma = 1.5$.

In both processes, adiabatic and isothermal, the gas that comes directly from the primary is compressed by the gravitational force of the accreting star toward the orbital plane. In the adiabatic case this compression heats up the gas, the pressure increases so much that the gas stream expands vertically and is not confined in a disc. Instead, it gives rise to a vortex structure in a plane perpendicular to the orbital plane.

In isothermal case the temperature and pressure are not high enough to dissipate the gas from the orbital plane and consequently, a thin, nearly Keplerian disk has been settled.

The transition from the isothermal case $\gamma = 1$ with an accretion disk to the adiabatic case $\gamma = 1.5$ without a disk reflects in this picture a variable thickness of the disk corresponding to γ varying continuously between the given values.

Since γ has been determined by the efficiency of cooling, this process will in its turn determine the formation of a disk. As an increase of cooling corresponds to an increase of density, and density is a function of mass loss rate, binary separation and the ratio of wind speed to orbital velocity, the probability of disk formation is expected to increase with an increased mass loss rate, decreased binary separation and with the wind speed of the same order of magnitude as the orbital velocity.

The disappearance of accretion disc in the transition to an inactive state is correlated with an increase of polytropic index γ above 1 which corresponds to a decreased efficiency of cooling. The decrease of density associated with a decrease of optical thickness leads to reduced self-absorption in the outlying part of the accretion complex because of the smaller number density of absorbers along the line of sight. The double peaked line profiles with $V/R < 1$ can be explained by absorption in the wind material whose radial velocity is directed predominantly toward the observer. A single line profile means that this process has achieved its minimum. It is the result of a decreased wind mass loss from the cool giant which is correlated with wind speed and binary separation. Since the physical properties of the cool giant determine how this material is lost and to what extent it interacts with the hot component, it means that the cool component ultimately determines the observable characteristics of this symbiotic star. The transient nature of the accretion disc in the detached CH Cyg system, with separation of components of about 1700 $R_\odot$ (Skopal 1995) is correlated with the variable degree of filling the red giant's tidal lobe (Iben & Tutukov 1996), which is significantly being remarkably underfilled in the inactive phase.

The question how to reconcile the complicated three dimensional transient structure around the hot component with the spherical shell model during the inactive state of the star remains open for further discussions.

6. Conclusion

Our investigations of the quiescent period 1987-1989 of CH Cyg lead to the following conclusions:

- The existing models of CH Cyg cannot be generally applied. They do not even fit consistently the observed features in a particular phase and can only partially explain some phenomena of this symbiotic star.
- The presence of an accretion disc in the system, indicated by flickering variability and jet activity during the outburst has not been confirmed in quiescence. It means that it can be regarded as a transient phenomenon associated with outbursts of the system.
- It is important to understand that the physical properties of the cool giant ultimately determine the observable characteristics of a symbiotic star. Investigations of the manner in which the physical parameters of its atmosphere depend on time should be of great interest.
- Further systematic photometric and spectroscopic observations of CH Cyg in the optical and other spectral regions are necessary to understand the symbiotic phenomenon.

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