ISSN 0351-2657
HOBUD7 22(1) 53 (1998)

OPTICAL SPECTROSCOPY AND MODELLING OF THE SYMBIOTIC STAR CH CYGNI IN THE INACTIVE STATE

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UDC 524.338.3-355-17
Conference paper
(Received December 23, 1997; accepted March 30, 1998)

Abstract. This paper contributes to the ongoing discussion on the nature of the extraordinary star CH Cygni. A review of our observations of optical spectra of CH Cygni in its inactive period 1987-1989 is given. The results are discussed in view of the existing models which are based mainly on observations of the star during outbursts. We have suggested a picture acceptable to explain at least the phenomena connected with quiescence and pointed out the importance of continuous monitoring of this star system also in the quiescent phases for the construction of a generally valid model.

Key words: symbiotic stars, spectroscopic and photometric variability, inactive phases

1. Introduction

During the last three decades CH Cygni has been the subject of detailed investigations and numerous discussions. The spectroscopic observations over a wide spectral range (Mikolajewski *et al.*, 1990, and references therein) have classified it as a symbiotic star since it showed a composite spectrum during active periods. These phases were separated by intervals of inactivity of different duration during which CH Cygni appeared as a normal M6-7 III semiregular variable. A rather small number of works were dealing with these, apparently quiescent phases (Wallerstein and Cassinelli, 1968; Bruch, 1986; Garcia, 1986; Bode *et al.*, 1991; Kotnik-Karuza *et al.*, 1992; Orio, 1993; Jurdana and Kotnik-Karuza, 1994; Kotnik-Karuza and Jurdana-Šepić, 1997). The spectacular behaviour of this star during outbursts turned the attention of observers and theorists predominantly to the phenomena associated with periods of activity. Each attempt to construct a generally valid model for CH Cygni has failed, its results beeing put into doubt by the next unpredictable event of irregular appearance. Recently, attention has been paid also to the inactive phases which have proved to be a valuable source of information for the consistent interpretation of the spectroscopic and photometric parameters of this star. Actually, each observation should be taken into account as a unique and unrepeatable event, extremely important for its understanding.

2. Observations and Results

Our observations of the high resolution optical spectra of CH Cygni taken at the Haute Provence Observatory during its longest recorded quiescent period 1987-1989 were already described (Kotnik-Karuza *et al.*, 1992). The optical region has been difficult to interpret because of the crowded, often blended absorption lines, as well as strong molecular bands which also contribute to the truncation of the continuum. On the other hand, beside these features typical for late type giants, radiation of the hot source is also present in this region, being dominant during the outbursts and offering the possibility to look for its traces in the quiescent phases. During the investigated period 1987-1989 we focused ourselves on extracting every information contained in our spectra which covered the wavelength range from 3750-6800 Å: we estimated the continuum and measured the radial velocities and relative intensities of all spectral lines (Kotnik-Karuza *et al.*, 1992). Further we determined the equivalent widths of the absorption lines and measured the emission profiles (Jurdana and Kotnik-Karuza, 1994). A comparison with the spectra of two late type giants of the same spectral type, 30 Her and β And, was performed (Kotnik-Karuza and Jurdana-Šepić, 1997). A thorough analysis of the behaviour of the molecular bands is in elaboration.

The results of this extensive work confirm the idea that CH Cygni is a binary symbiotic star consisting of a late type giant, a hot component and an ionized nebula surrounding the whole system. During the investigated inactive period the cool component with numerous absorption lines of neutral and singly ionized metals and TiO molecular bands, dominates the spectrum. These features, originating from the red M7III type star's photosphere clearly reflect its physical conditions. The emission lines, particularly some forbidden and Balmer lines, shed light on the so far poorly understood hot component. Its presence in the optical spectra of the quiet phase is, however, not so astonishing as the evidence that the physical parameters of the red giant's photosphere as well as the emission profiles were continuously changing throughout the entire two years interval. The complexity of spectroscopic phenomena and their changes in time reflect complex and variable conditions in both stellar atmospheres, which makes every attempt to establish an appropriate general model of CH Cygni an extremely difficult task.

3. Discussion

3.1. Models of CH Cygni Based on Observations during Outbursts

Different models of CH Cygni have been constructed up to now. They are based mainly on the photometric and spectroscopic observations of the star during outbursts. None of them proved to be generally valid, its assumptions being at least partly contradicted by other observations.

The binary model of CH Cygni (Yamashita and Maehara, 1979) with mass transfer between the two components: a cool component which is a well defined late type mass donating giant, contrary to the hot component the true identity of which is still questionable, has been at present almost generally accepted.

Since mass transfer seems essential for all binary models, the physical size of the giant determines how this mass is lost and to what extent it interacts with the hot component. There are two possible ways of mass transfer that are related to the nature of the hot component and both of them have been candidates in CH Cygni. Roche lobe filling giants apparently lose mass at rates exceeding $10^{-6}M_o$/yr and this is roughly the lower limit required to form a symbiotic system with an accreting main sequence star. In this case the giant transfers material tidally into an accretion disc surrounding the low mass companion. This model for CH Cygni has been recently proposed by Skopal *et al.* (1996) according to their estimates of the mass loss rate and of the mass accretion rate required to power the outburst in 1992-1994 which was observed in the radiowavelength region. However, Mikolajewski *et al.* (1987) conclude from the combination of RV data and the light curve through the eclipse that even at periastron at the highly eccentric orbit of the binary the red giant would underfill its Roche lobe by a factor of 2, which leads to the second model of possible mass transfer (Mikolajewska *et al.*, 1988). Consistent with it, a red giant underfilling its Roche lobe can only lose mass in a stellar wind at rates of the order of $10^{-7}M_o$/yr. The only few percent of this material that can be gained by the hot component, are insufficient to be accreted by a main sequence star. The hot component of the binary should be a white dwarf. Many authors (Tomov *et al.*, 1996; Leedjarv *et al.*, 1994; Mikolajewska *et al.*, 1988; Hinkle *et al.*, 1993; Mikolajewski *et al.*, 1988; Munari *et al.*, 1996) find the description of CH Cygni by this model justified, because of its long orbital period, large separation of components, large radio emission from an extended nebula etc.

The triple model was inaugurated by Hinkle *et al.* (1993) in order to explain a very regular variation in the red giant radial velocities with a short period of 756 days observed in the high resolution IR spectra. The symbiotic pair represents the short period component of the triple star and the unseen third star is probably a G-K dwarf revolving around the symbiotic binary in a long period 14.5 yr orbit. However, there are serious objections concerning this model; for example, the concept of a Roche lobe filling giant is contradicted by the observed light curve of CH Cygni. Hinkle *et al.* (1993) took the periodic spectral type variation by approximately two subclasses as a proof of the existence of a heating effect, which is expected to be pronounced in a system with an orbital period as short as 756 days. However, no traces of a detectable heating effect by the white dwarf radiation on the facing side of the M giant have been observed (Munari *et al.*, 1996). Furthermore, Mikolajewski *et al.* (1990) report that the spectral changes are not periodic, but monotonic in the sense of tracing a progressive shift from M6III to M7-8III during the last 10-20 years.

The oblique rotator model (Mikolajewski and Mikolajewska, 1988) promised a lot in the sense of giving a suitable explanation for the outburst mechanism. According to it, stellar wind interaction with a rapidly rotating magnetosphere of the white dwarf occurs via a three step accretion process:

1. inactive, characterized by accumulation of material around the magnetosphere
2. low (propeller) in which accretion of the accumulated matter onto the magnetosphere takes place
3. high (accretor) with accretion of matter on to the white dwarf surface

This approach can be questioned on several counts (Skopal *et al.*, 1996):

- existence of a strong magnetic field of the order 10^3T, as predicted by the model, has not been detected.
- 500s oscillations, supposed to reflect the rotational period of the white dwarf, observed in the U light have not been reproduced independently.
- the model cannot explain the existence of high-velocity outflow in the last outburst as well as the observed phenomena which preceded this activity phase.
- the extremely variable length of inactive phases, i.e. a very long one up to 1963 and a very short one preceding the 1990-95 outburst cannot be explained by this model either.

3.2. Our Observations in View of the Proposed Models

Our radial velocity curves of the absorption and emission lines clearly showing a phase shift between the sources of the absorption and emission lines, all except for the [OIII] nebular line (Kotnik-Karuza *et al.*, 1992), confirm the already doubtless binary model. The equivalent width measurements of the red giant's photospheric lines lead to the determination of the time evolution of some physical parameters during the "quiescent" period. A quite distinguished change of excitation temperature of some neutral metals (Fe I, Ti I,V I, Cr I) has been recorded (Figure 1).

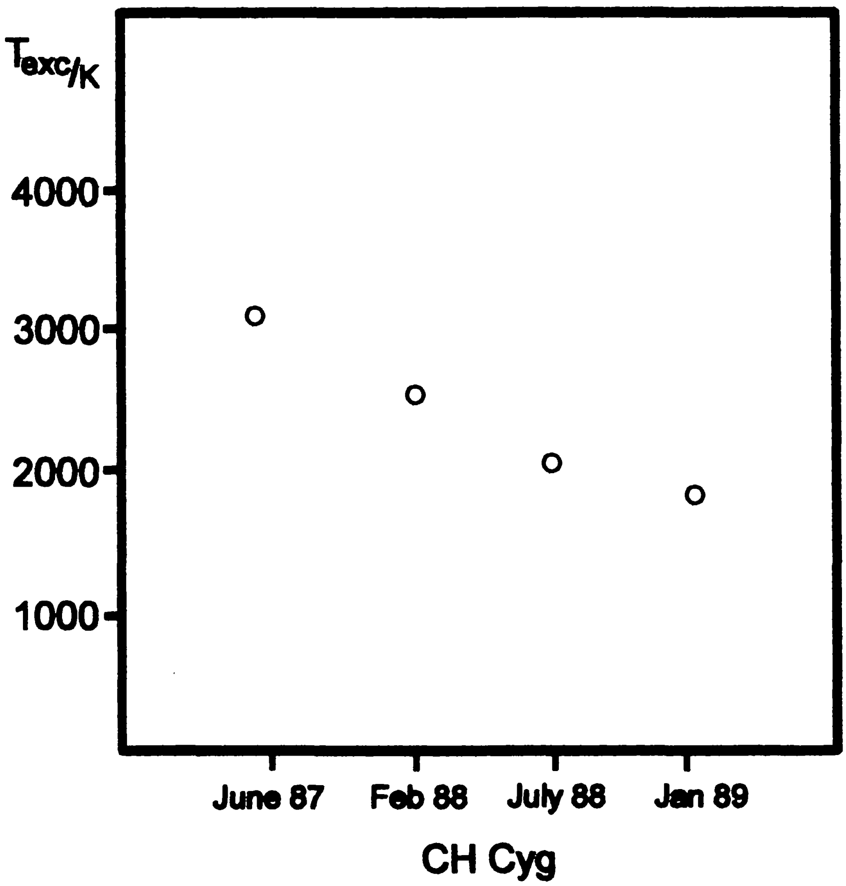

Fig. 1. Time evolution of the excitation temperature taken as mean value over some neutral metals.

This would rule out the expected quiescence and strenghten the belief that a such smooth temperature decrease could be a result of interaction in the symbiotic pair. Evidences of interaction between the two components have been naturally found in active phases. For example, X-ray emission and high ionization line radiation can be explained by a shock formed in interaction between the high velocity wind ejected by the eruptive star and the low velocity wind lost by the cool giant (Kenyon, 1986). In our case, the temperature variation in the red giant photosphere could have been caused by irradiation of the M star by the hot component.

We could easily explain this effect by the triple star model, where the components of the symbiotic pair are revolving in a short period orbit relatively close to each other, if this model was not put under doubt also by our observations of the Balmer emission. The first members of the series show double peaked profiles, the depths of their central reversals changing in time. This suggests a variable rate of the mass transfer from the red giant to the hot component, since the stellar wind supported by the giant may be changed significantly by the presence of a close satellite which modifies the characteristics of gravitational potential surfaces. That's why in the case of an eccentric orbit the additional mass transfer is expected near periastron, i. e. in general, the mass transfer is associated with a particular orbital phase. The disappearance of the central dip in July 1988 in this picture would correspond to a maximally reduced mass transfer rate which is in contradiction with periastron in the short period elliptical orbit of Hinkle *et al.* (1993) taking place at that time (Figure 2).

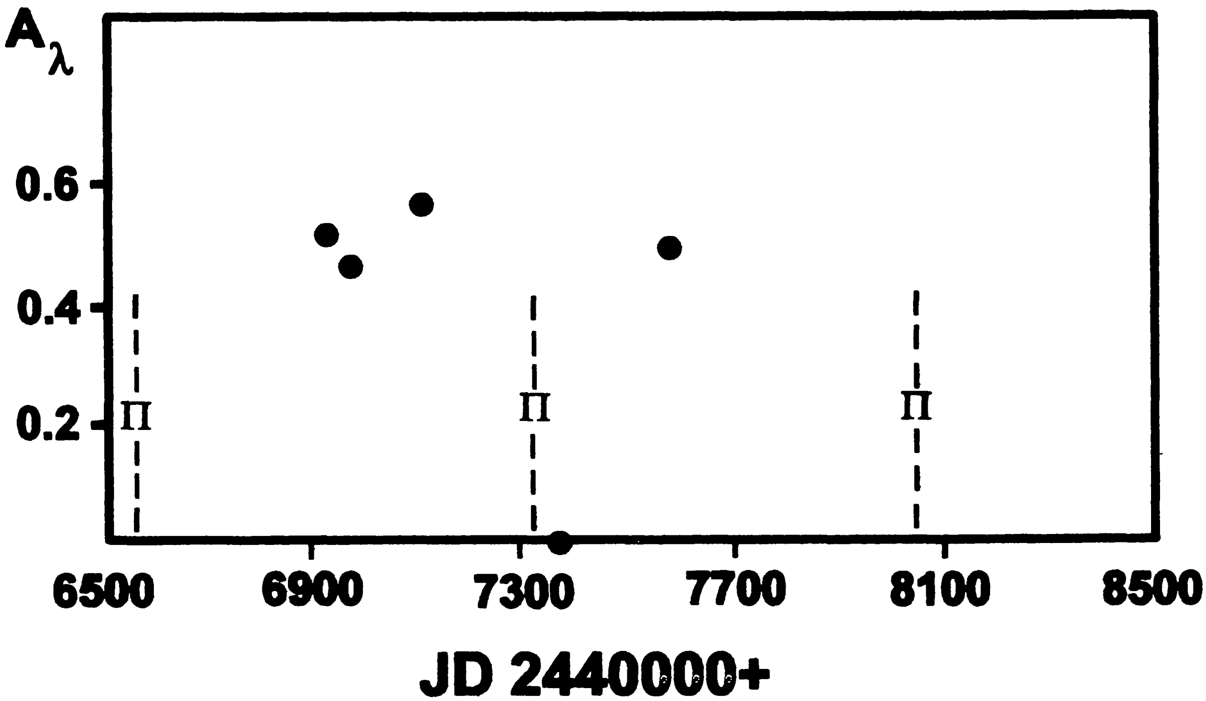

Fig. 2. Time evolution of the central reversal depth in the Hα emission profile with regard to periastrons π in the short period orbit.

The origin of the temperature decrease in our spectra thus remains questionable.

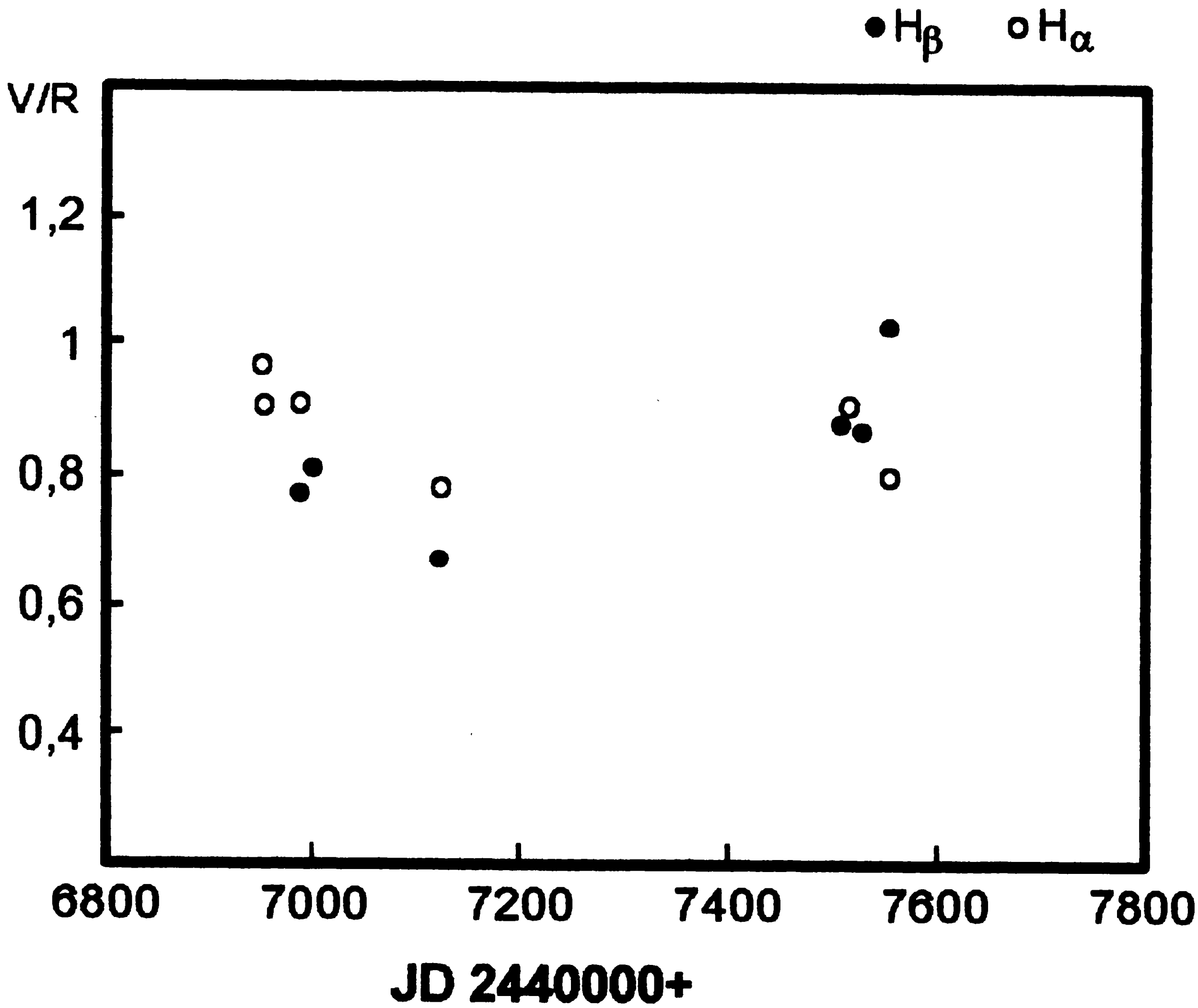

Fig. 3. Intensity ratio V/R in the double-peaked Balmer emission lines Hα (white circles), Hβ (black circles).

It is true that the observed decrease of the central reversal coincides with approach to apoastron in the long period orbit, but the orbital phase cannot be taken as the only possible reason of the reduced mass transfer. Some other mechanism must be responsible for it, otherwise the typical irregular appearance of activity phases of variable duration could not be explained. The double peaked Balmer profiles might also have their origin in an accretion disc around the hot component. The disc can be verified in the case of its eclipse by the cool giant. Our observations exclude this possibility, because the intensity ratio of the violet and red wing never exceeds the value of 1 (Figure 3) instead of becoming greater than 1 after passing the eclipse, i.e. after the disappearance of the central reversal.

Anyway, according to the theory of Robinson *et al.* (1994), the eclipse can be taken as a probe for the existence of an accretion disc only in binaries with a more massive hot component than the cool one, which is in CH Cygni certainly not the case (Mikolajewski *et al.*, 1987). There is no observational evidence of an accretion disc in the inactive period 1987-1989. Moreover, Bode *et al.* (1991), who fitted the $H\alpha$ line profiles during the period 1986-1990, found that out of 8 profiles only one taken in June 1986 was suitable for testing the accretion disc hypothesis. This leads to the conclusion that the accretion disc can be considered as a transient phenomenon associated only with outbursts of the system. In the inactive phases it is replaced by an accretion complex of variable optical thickness and complicated structure, influenced by the interactive gaseous fluxes originating from both components.

The main objection to the oblique rotator model follows from its prediction that this inactive phase of CH Cygni 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.*, 1996). The new outburst, which announced itself already toward the end of 1989 by enhanced mass transfer and reflected in the deepening of central reversals of the Balmer lines, contradicts this prediction.

4. Conclusion

A concise report of the established models of CH Cygni and the range of their validity, discussed in this paper together with our investigations in the period 1987-1989, lead to the conclusion that no model of this star describes consistently its complex behaviour. In order to remove this inconsistence, we stress the importance of further continuous observations of CH Cygni particularly in its quiescent phases, when spectral features of all its components can be identified in the optical region.

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OPTIČKA SPEKTROSKOPIJA I MODELIRANJE SVOJSTAVA SIMBIOTSKE ZVIJEZDE CH CYGNI U NEAKTIVNOM STANJU

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Izlaganje sa znanstvenog skupa
(Primljeno 23. prosinca 1997.; prihvaćeno 30. ožujka 1998.)

Sažetak. Rad predstavlja doprinos raspravi o prirodi neobične zvijezde CH Cygni. Dan je pregled opažanja optičkog dijela spektra zvijezde u neaktivoj fazi 1987-89. Rezultati se tumače u svjetlu postojećih modela konstruiranih uglavnom na temelju opažanja tokom provala. Predložena je slika podesna za objašnjenje pojava povezanih s mirnim fazama. Ukazano je na značaj kontinuiranog praćenja zvjezdanog sistema i u periodima neaktivnosti, kako bi se omogućilo konstruiranje općenito važećeg modela.

Ključne riječi: simbiotske zvijezde, spektroskopske i fotometrijske promjene, neaktivne faze