OPTICAL SPECTROSCOPY OF CH CYGNI IN 1985/86

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ABSTRACT. Some arguments for the explanation of the spectroscopic and photometric behavior of CH Cyg in terms of an eclipsing binary with P=5700 days, consisting of M6 III star and an accreting white dwarf, are presented. Physical and geometrical parameters of the system have been estimated and discussed.

1. INTRODUCTION

The last outburst of CH Cygni started in 1977. The photometric and spectroscopic behavior during the active phase was described by many authors (e.g., Mikolajewski and Biernikowicz, 1986, Hack et al., 1986 and references therein).

Recently, Mikolajewski and Biernikowicz (1985, 1986) have interpreted sudden changes in Balmer line profiles as well as a drop of the UBV brightness in mid 1984 in terms of the eclipse ingress of the Balmer emission region by the M6 giant. Taking into account relatively large amplitudes of radial velocity curves (for the orbital period of about 16 years), one should expect a very high inclination. Otherwise masses of the components would be enormous (see also Luud and Tomov, 1984). Moreover, a deep minimum in the Johnson U band observed in 1969 (JD ~2440550) coincides with the epoch of eclipse predicted from the spectroscopic ephemeris given by Yamashita and Maehara (1979). Finally, the next eventual eclipse should have happened around 1985. Unfortunately, it appeared that the rapid photometric and spectroscopic variations in mid 1984, correlated with the radio outburst and an appearance of two radio jets (Taylor et al., 1986) were not due to an eclipse.

In the following, we discuss new photometric and spectroscopic observations in the contect of an eclipse which probably occured about one year after the radio outburst.

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2. OBSERVATIONS

About 250 spectra of CH Cyg have been obtained with the Canadian Copernicus spectrograph (CCS) attached to the 90-cm Schmidt-Cassegrain telescope at the Torun Observatory (λλ 3500-5100 Å, dispersion 18 Å/mm, 1982-86) and with the Coudé spectrograph (R) of the 2-m, telescope at the Rozhen Observatory (λλ 3500-8700 Å, dispersion 9 Å/mm and 4 Å/mm - blue spectra in 1981-84; 18 Å/mm - red and blue spectra in 1981-86). Occasional UBV photometric observations have been made at Torun and Rozhen.

3. CH Cyg AFTER THE RADIO OUTBURST IN 1984

3.1. Spectral Behavior

The spectral evolution of CH Cyg from July 1984 until April 1986 has been discussed in detail by Mikolajewski and Tomov (1986), Luud et al. (1986) and Tomov et al. (1986). The main observational characteristics are summarized in Table I.

Table I
Spectral behavior of CH Cygni after drop of brightness in July 1984.

August-December 1984	- [FeII], [SII];↗[OIII], [NeIII]↗ - HI: V≥R; strong wings 2000-3000 km/s - HeII 4686 ?? - absorption features: TiII, SrII ↘ ; TiO ↗
January-February 1985	- HI ↘ ; R>V; only red wing component present - HeI ↘ - forbidden lines ↗
March-October 1985	- pure M6III absorption spectrum - very strong forbidden lines - weak, single-peaked Balmer emission lines
November-December 1985	- HI double-peaked again: V>R; - only blue wing component present - FeII (emission) ↗ ; HeI ↗
January-May 1986	- HI: variable V/R ratio and wings - HeII 4686 ?? - absorption lines of TiII present (λλ<3650)
Flickering:	- present until December 1984 - absent in August-September 1985 - present in April 1986

During November-December 1985 we observed very strong spectral changes which were reversed with respect to those seen during January-February 1985. The possible detection of the very broad (FW 600-1000 km/s) and weak HeII 4686 emission line in August-December 1984 and again in 1986 is worth to note. Finally, the absorption shell spectrum reappeared in the beginning of 1986.

3.2. H_β and H_γ Variations

After the drop of brightness in mid 1984, the double-peaked Balmer lines showed strong variability with different time scales. The appearance of the radio jets was connected with the development of broad wings (FW ~ 2500 km/s).
Figure 1 and Table II present the variations of the H_β profile.

Table II
H_β variations

JD	No. of plates	I/I_c			$I_c/\Delta I_{TiO}$	V_r[km/s]		
2446000		V	A/E	R		V	A/E	R
077-083	3	8.71	3.16	10.0	0.49	-115.0	-53.6	20.6
094	2	7.58	3.55	8.91	0.49	-125.7	-67.0	-5.9
104-110	5	4.99	3.87	6.28	0.47	-109.3	-62.1	0.0
130	1	2.57	-	2.89	0.74:	-98.5	-70.0	-26.7
177-196	5		6.95		0.25		-66.0	
199-202	3		6.24		0.32		-50.2	
213-226	4		5.37		0.38		-60.9	
272-289	3		4.82		0.30		-67.2	
311	1		3.97		0.39		-58.4	
374	1	6.71	2.17	4.65	0.46	-117.8	-49.2	28.7
400-405	2	16.5	3.07	13.1	0.46	-120.8	-49.2	18.1
423-424	2	10.2	3.0	8.26	0.65	-118.7	-51.7	16.6
439-476	7	6.19	2.41	5.03	0.81	-114.7	-51.1	9.0
487	1	2.75	1.41	3.46	1.45	-129.3	-71.1	2.0
506-508	1	9.34	2.96	12.0	1.07	-118.1	-51.4	8.9
513-522	3	19.5	4.91	14.2	0.63	-112.3	-57.3	1.6
543	1	10.1	3.75	6.98	0.67	-113.2	-54.2	4.8
sigma:		7%	10%	7%	7%		2,6 km/s	

The intensities I* related to the depth of the TiO (4955) band are independent on fluctuations of the hot continuum and provide a good measure of the absolute line intensity (see Mikolajewski and Biernikowicz, 1986 for details). The intensity I* of the central

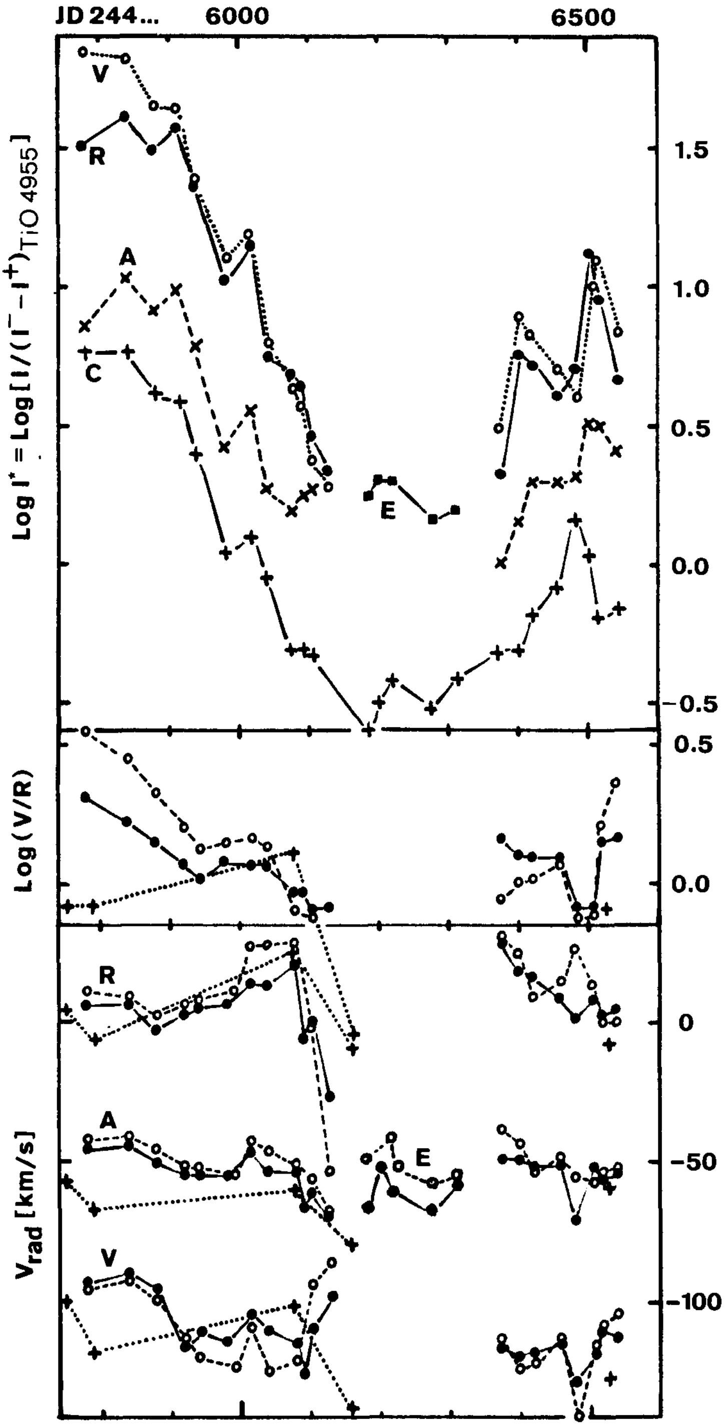
JD 244...
6000
6500
Log I* = Log[I/(I⁻ − I⁺)]TiO 4955
1.5
1.0
0.5
0.0
−0.5
V
R
A
C
E
Log(V/R)
0.5
0.0
Vrad [km/s]
0
−50
−100
R
A
V
E

Fig. 1. H_β and H_γ profile variations: (top) intensities of the red (R) and violet (V) peaks, central absorption, local continuum (C) and single profile emission observed during May-October 1985 (E) for H_β, related to the depth of the TiO λ 4955 band; (bottom) V/R ratios and radial velocities of H_β (dots) and H_γ (open circles) observed during 1985-85, and of H_β (crossed) observed during 1968-70. The JD scale for the 1968-70 data is shifted by 5700 days.

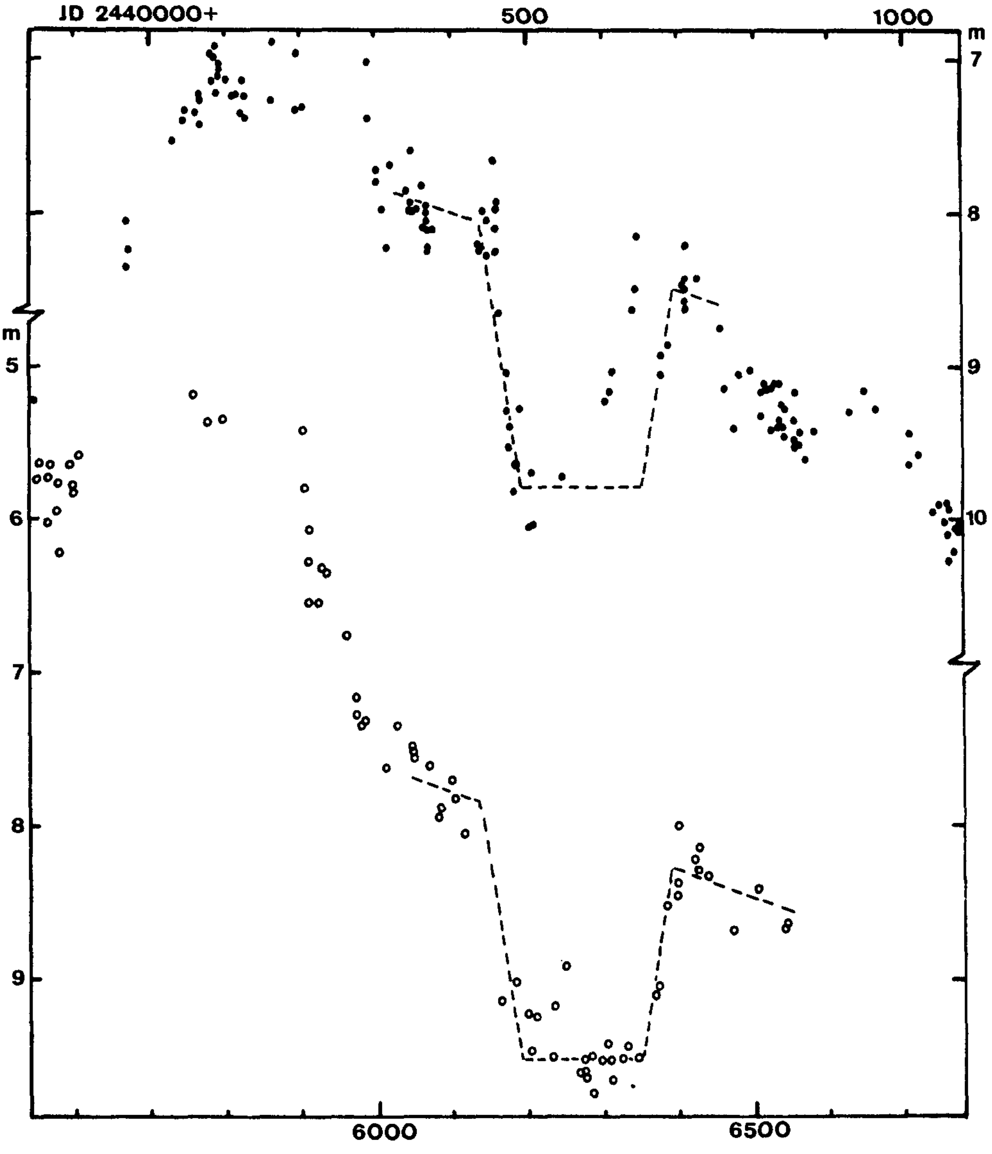
JD 2440000+
500
1000
m
7
8
9
10
m
5
6
7
8
9
6000
6500

Fig. 2. Johnson U light curves of CH Cyg observed during 1967-70 (dots) and 1983-86 (open circles). References: Luud et al. (1977), Cester (1972), Belyakina (1974), Luud et al. (1986). Panov et al. (1985), Antov (1986, Private communication), Skopal and Chochol (1986, Private communication) and present paper.

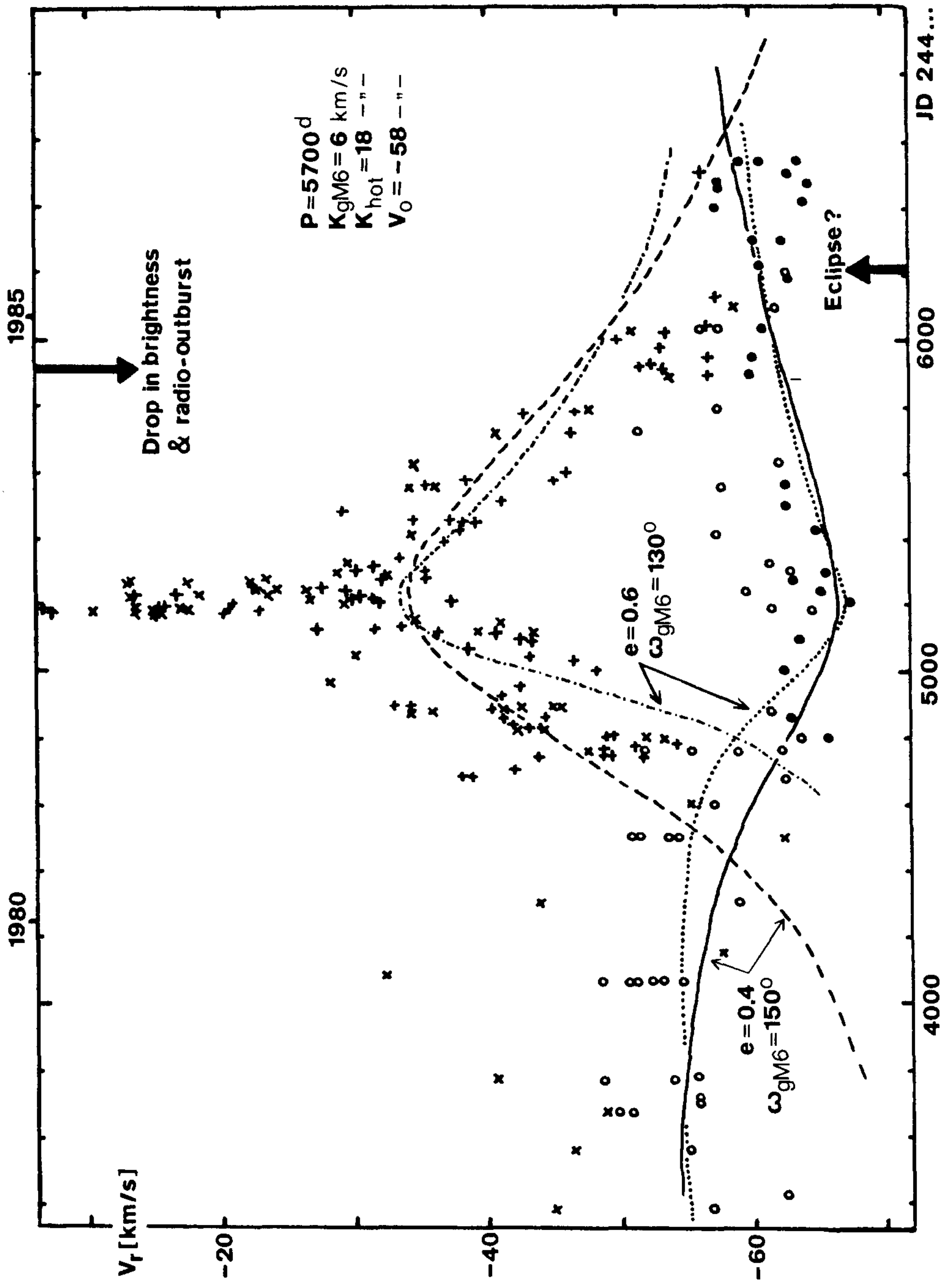
1980
1985
Drop in brightness
& radio-outburst
P=5700^d
K_gM6=6 km/s
K_hot=18 –"–
V_o=–58 –"–
e=0.6
ω_gM6=130°
e=0.4
ω_gM6=150°
Eclipse ?
JD 244...
4000
5000
6000
V_r [km/s]
-20
-40
-60

Fig. 3. CH Cyg radial velocity curves during 1977-86. Dots (CCS and R) and open circles (Hack et al., 1982, 1986; Yamashita and Maehara, 1979) correspond to 9 M6 photospheric lines. Averaged values for ionized metals (TiII, ScII, CrII, VII) are marked by = (CCS and R; also Skopal et al., 1986) and by x (Hack et al., 1982, 1986; Skopal, 1986; Chochol et al., 1986; Wallerstein, 1981, 1983; Yoo & Yamashita, 1984). Two extreme orbital solutions allowing for eclipses observed in 1969 and 1985 are also plotted.

absorption was determined only from spectra with a dispersion of 18 Å/mm. The values of the V/R peak ratio as well as radial velocities of the violet, red and absorption components of Hβ and Hγ are also plotted.

It is very interesting that the weak single line observed during March-October 1985 has nearly the same radial velocity as the absorption component observed in remaining periods. Since the absorption component is physically real (on high dispersion spectra taken before 1985, the absorption falls below the continuum level), the absence of the double-peaked profile can be explained only as disappearance of matter from which this profile originates. The radial velocity of this absorption component follows the radial velocity of ionized metals, which may reflect the orbital motion of the hot component during the active phase (Mikolajewski and Biernikowcz, 1985).

4. DISCUSSION

4.1. Minima observed in 1985 and 1969

Generally, the Hβ profile variations observed in 1985 are similar to those observed during the eclipse in VV Cephei (Kawabata et al., 1981), which can be interpreted as an eclipse of a rotating and possibly expanding disk or envelope. However, a few differences become noticeable. The most important one is that in CH Cyg, at minimum, the weak single profile is observed instead of the double one. This suggests that the eclipse in CH Cyg is total. The weak emission observed during the totality probably originates in outer parts of the envelope with a different velocity field. The radial velocity changes, similar to those observed in VV Cep, are difficult to be interpreted. This suggests a complex structure of the emission region and a significant influence of the cool giant atmosphere during the ingress and the agress phases.

The discussed Hβ profile variations were strongly correlated with a minimum observed in the UV flux (Mikolajewska, Selvelli and Hack, 1986) and in the optical continuum (Fig. 1). The very deep minimum was also detected in U light, while the V magnitude was only slightly affected. It is interesting that about 16 years ago, a similar feature appeared in the light curve (Figure 2). Besides a flare which occurred around JD 2440630, the minima have practically the same geometry (D=250 days, d=150 days). Moreover, around JD 2440300 a drop in brightness similar to that in 1984, was observed. Although the maximum U brightness during the 1967-70 outburst was by 2 mag lower than during the last outburst, the U magnitude observed before, during and after both minima was practically the same. Moreover, the minima are separated by the 5700-day period, which is very close to the spectroscopic period P=5750 days found by Yamashita and Maehara (1979).

It is striking that both minima occurred near to end of an activity phase and about 500 days after the maximum of brightness.

This behavior indicates that the activity of CH Cyg is certainly connected with the orbital positions of both components.

Unfortunately, relatively few spectroscopic data obtained during the 1967-70 outburst exist. Figure 1 also presents the changes of H_β profiles observed during the previous minimum, according to data published by Faraggiana and Hack (1971). The V/R ratios as well as the radial velocities of the R and A components display a similar behavior as during the 1985 minimum.

A gap in high-resolution data coincides with the mid minimum. Nevertheless, six objective prism spectra obtained during September-October (JD ~2440477-510) did not show any hydrogen emission lines, while strong lines were present before JD 2440449 (Jimsheleishvili, 1971). The high resolution spectrum obtained after the minimum (JD 2440719) showed again strong double-peaked H_β line.

Summarizing, the photometric and spectroscopic variations observed in 1969 and 1985 are consistent with the eclipses of a hot, active component by the cool giant. The IUE observations of the CH Cyg continuum in 1985 (Mikolajewska, Sevelli, and Hack, 1986) confirm this suggestion and may be interpreted as the eclipse of the Balmer continuum.

4.2. Parameters of the CH Cyg system

Following Luud and Tomov (1984) we have assumed that absorption lines of ionized metals reflect the orbital motion of the hot component. These lines became particularly strong in mid 1981 (Wallerstein, 1983).Figure 3 shows the radial velocity curves of both components of CH Cyg observed during 1977-1986.

Radial velocities of the M6 III star have been measured in the near - IR spectra ($\lambda\lambda$ 6700-8700 Å), and since 1985 also in the blue spectra.

The solution for a spectroscopic orbit leads to the high value of eccentricity of e=0.55 and ω(hot)=4° (Skopal et. al., 1986). After allowing for the presence of eclipses we expect that the orbital elements are within the range e=0.4, ω(hot=-30° and e=0.6, ω(hot)=50°. The passage through periastron occurred roughly on JD 2445040 and an appreciable reduction of the distance between the components caused the activity.

Fig. 3 suggest the mass ratic to be: 3 < q+M(cool)/M(hot) < 4. Assuming P=5700 days and i=90, this gives the masses M(hot)+ 1.6$M_\odot$, M(cool)=4.7 $M_\odot$ and the separation a=2500 ($R_\odot$ (Ce=-0.4, K(hot)=18, q=3), and M(hot)=0,5$M_\odot$, M(cool)=2 $M_\odot$ and a=1800 $R_\odot$ (e=0.6, K(hot)=16, q=4).

The total duration of the eclipse D and the phase of the total eclipse d (expressed in days) are related to the sizes of the components: r(cool)/$R_\odot$ =0.03 v_t(D+d), r(hot)/$R_\odot$ =0.03 v_t(D-d). Taking minimum and maximum values of the relative tangential velocity v_t for the orbital parameters given above (13.3 and 16.3 km/s, respectively) we have estimated 160 $R_\odot$ < r(cool) < 185 $R_\odot$ and 40 $R_\odot$ < r(hot) < 50 $R_\odot$. Since we have assumed i-90° and taking into account possible uncertainties in the determination of the D and d values, the above estimates should be considered as lower limits for possible dimensions. The determined size of the hot component is consistent with the dimension of the eclipsed HII region derived from IUE date (Mikolajewska et al., 1986).

4.3 Model of CH Cyg

We assume that transient accretion phenomena are responsible for the activity of CH Cyg. Our observational data suggest that it consists of a normal M6 giant ($M \sim 3\ M_{\odot}$, $r \sim 170\ R_{\odot}$) and an accretine white dwarf ($M \sim 1\ M_{\odot}$). Since even at periastron the Roche lobe size is about 2 times larger than the radius of the cool giant, accretion from the stellar wind should be expected. The total luminosity of the hot component during the active phase can be explained in terms of the mass-accretion rate $\dot{m}$ 10 $m_{\odot}^{-7}$ /yr 0.01 $\dot{m}_{krijt}$ (Mikolajewska et al. 1986). Simultaneously, the Balmer line profile variations during the 1985 minimum can be interpreted as the eclipse of a rotating disk or ring.

The possibility of an accretion disk formation from as stellar wind has been recently discussed by Livio and Warner (1984) and Livio et al. (1986). For the parameters of the CH Cyg system, one should expect that the accretion on the dwarf companion occurs via a dense accretion wake (see also Chapman, 1981). Assuming a reasonable value for the velocity of the wind, $v \sim 20$ km/s, the mass-accretion rate at periastron will be only 2-3 times higher than at apastron. This is evidently inconsistent with the observed changes of the hot component luminosity. A. possible solution of the problem can be the following. Since the M giant atmosphere is very extended, tidal interactions at periastron may lead to a substantial enhancement of the mass outflow rate. On the other hand, if a relatively cool accretion disk is formed, the development of instabilities similar to those suggested to be responsible for dwarf-nova eruptions (e.g., Smak, 1982) cannot be excluded. Assuming the mass-loss rate from the giant to be $\dot{m}_{wind} = 10^{-6}\ M_{\odot}/y$, about 2-6x110 $M_{\odot}$ can be accumulated in the disk during 10-12 y. This is sufficient to support the luminosity observed during the active phase.

Finally, it is necessary to mention that if the wind velocity is low (~20 km/s), the companion reaches the supersonic velocity only near the periastron and then a transient shock front on the accretion cone surface can develop. The presence of an accretion cone with a disk inside and an ionization shock front outside may account for the very peculiar behavior of CH Cyg.

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