THE PHOTOMETRY OF THE ACTIVE AND QUIESCENT PHASES OF CH Cyg

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ABSTRACT. New U, B, V observations of the symbiotic star CH Cyg, carried out in the years 1986 to 1988 at the Skalnaté Pleso Observatory, are presented. A marked separation of U and V magnitudes was observed during this period, together with a constant increase of the U magnitude up to 11 mag. in September 1988 and the vanishing of the rapid fluctuations of the star brightness in all filters. These changes were interpreted as a distinct decrease in the amount of accretion material around the hot component, and considered to be photometric evidence of the end of the activity phase of CH Cyg. The U, B, V observations made since 1967 are summarized and discussed. The light curves in the U and V filters best reflect the basic properties and changes of the blue continuum in the active and quiescent phases of CH Cyg.

ФОТОМЕТРИЯ АКТИВНОЙ И СПОКОЙНОЙ ФАЗЫ CH Лебедя. В роботе опубликованны новые U, B, V наблюдения симбиотической звезды CH Лебедя выполненые во время 1986 - 1988 гг. на обсерватории Skalnaté Pleso. В этом периоде наблюдалось выразительное отличие U и V магнитуды, постоянный возраст U-магнитуды до 11 маг. в сентябре 1988 и практическое исчезнение быстрых флуктуаций яркости звезды во всех фильтрах. Эти изменения интерпретируются значителным уменьшением аккреционного материала вокруг горячего компонента и считаются фотометрическим потверждением закончения фазы активности CH Лебедя. Собранны и дискутированны U, B, V наблюдения с 1967 г. Ход кривой блеска в U и V фильтрах лучше схватывает основные свойства и изменения синего континуума в фазах активности и покоя CH Лебедя.

FOTOMETRIA AKTÍVNEJ A KĽUDNEJ FÁZY CH Cyg. V práci sú prezentované nové U, B, V pozorovania symbiotickej hviezdy CH Cyg vykonané v rokoch 1986 až 1988 na Observatóriu Skalnaté Pleso. V tomto období bol pozorovaný výrazný rozdiel U a V magnitúdy, stály vzrast U magnitúdy až na 11 mag. v septembri 1988 a praktické vymizenie rýchlych fluktuácií jasnosti hviezdy vo všetkých filtroch. Tieto zmeny sú interpretované výrazným zmenšením akrečného materiálu okolo horúcej zložky a sú považované za fotometrickú evidenciu konca fázy aktivity CH Cyg. Sú zhrnuté a diskutované U, B, V pozorovania od roku 1967. Priebeh svetelnej krivky v U a V filtroch najlepšie vystihuje základné vlastnosti a zmeny modrého kontinua v aktívnych a kľudných fázach CH Cyg.

1. INTRODUCTION

The characteristic feature of typical symbiotic stars is a weak blue continuum which dominates in the shoter wavelengths of the spectrum, roughly up to 500 nm. Its presence, rapid and slow variations, as well as its strong attenuation in the quiescent phases are generally ascribed to the activity of the hot component of the interacting binary system. Nevertheless in many systems, e.g., EG And, Z And, CI Cyg, SY Mus, AR Pav, AX Per, some fluctuations of the UV continuum represent a quite convincing proof of binary motion.

The U, B, V photometry of the symbiotic star CH Cyg indicated all the mentioned properties of the blue continuum. In the active phases it displayed a sudden enhancement, the brightness of the star in the U-filter roughly equalled the brightness in the V-filter. On the contrary, the quiescent phase was characterized by the separation of both magnitudes (Fig. 1). The rapid fluctuations of the blue continuum, of the order of minutes to hours, were observed in the active phases (Slovak and Africano, 1978; Chochol et al., 1984). For the period 1982-1986 they were analysed in more detail by Skopal (1987). A minimum, which was interpreted as the eclipsing of the hot component of CH Cyg by its cool component (Mikolajewski et al., 1987), was observed on the U light curve in 1985.

The observations carried out in the optical region of the spectrum in 1930 to 1940 indicated irregular variations of the visual magnitude. The larger scatter of its values corresponded to the observations of the inner hemisphere of the cool component of CH Cyg with regard to its present binary model (Dziewulski et al., 1988). Other observations, from 1901 to 1939, indicated irregular changes in the photographic magnitude, which yielded an average cycle of 98.8 days. A long period of 4700 days was also observed in this interval (Gaposhkin, 1952). Gusev (1976) analysed the overall visual (from 1899 to 1974) and photographic light curves (from about 1935). Apart from the period of 100 days, he also found changes in the brightness with a period of about 4 years. At the beginning of 1960, the amplitudes of these variations increased markedly (up to 1.5 mag.). Gusev noted that this could be related to an increase in the activity of CH Cyg, observed by Deutsch (1964) in 1963. Similar properties are also displayed by the optical light curve of CH Cyg, compiled from the AAVSO observations made between 1949 and 1964 (Kenyon, 1986; Fig. A. 10). Later,

in the years 1967 to 1977, Luud et al. (1977) observed variations in brightness of about 1.5 mag. with a period of about 700 days in the V light curve.

The purpose of this study is to point the basic properties of the overall U and V light curve, as well as some of its peculiarities, as well as to present new U, B, V observations made in 1986 - 1988 and, on their basis, prove that the activity phase of CH Cyg has terminated.

2. OBSERVATIONS

The observations of CH Cyg in the standard U, B, V system were carried out with a single-channel photoelectric photometer installed in the Cassegrain focus of the 0.6/7.5 m telescope at the Skalnaté Pleso Observatory. HD 184 786 was used as the comparison star (S) and HD 184 960 as the check star (C). The observations were made in roughly hourly cycles: S, C, S, CH Cyg, S,..., S, CH Cyg, S, C, S. The integration time of one measurement was 10 s. The measurements were reduced to the international system and are compiled in Tab. 1. Each value represents the average of the observations made during one night. The number "n" indicates the number of individual observations per night.

TABLE 1

U, B, V OBSERVATIONS OF CH CYG IN 1986-1988

J.D.	V	B-V	U-B	N	DATE	U.T.
2446720.460	7.766	1.321	-0.050	12	1986 OCT. 16	23 02
6721.280	7.801	1.321	-0.081	19	1986 OCT. 17	18 43
6733.380	7.866	1.193	-0.084	12	1986 OCT. 29	21 07
6959.520	7.281	1.555	1.026	9	1987 JUNE 13	00 28
6978.470	7.120	1.608	1.115	10	1987 JULY 1	23 45
6983.490	7.070	1.596	1.098	13	1987 JULY 6	23 45
6984.470	7.058	1.584	1.075	17	1987 JULY 7	23 17
6998.510	7.054	1.609	1.034	8	1987 JULY 22	00 14
7038.460	7.456	1.466	0.782	10	1987 AUG. 30	23 02
7040.530	7.446	1.520	0.835	3	1987 SEPT. 2	00 43
7072.320	6.763	1.545	0.894	8	1987 OCT. 3	19 41
7073.340	6.771	1.566	0.924	25	1987 OCT. 4	20 09
7074.360	6.771	1.579	0.864	30	1987 OCT. 5	20 38
7099.210	7.137	1.462	0.586	5	1987 OCT. 30	17 02
7100.200	7.242	1.452	0.514	9	1987 OCT. 31	16 48
7161.220	6.496	1.870	1.586	10	1987 DEC. 31	17 17
7262.590	7.861	1.041	1.523	7	1988 APR. 11	02 10
7271.580	7.776	1.176	1.419	7	1988 APR. 20	01 55
7276.560	7.799	1.155	1.540	6	1988 APR. 25	01 26
7283.510	7.980	1.549	1.062	9	1988 MAY 2	00 14
7297.540	7.628	1.289	1.532	7	1988 MAY 16	00 58
7320.520	7.818	1.418	1.489	5	1988 JUNE 8	00 29
7373.540	7.502	1.839	1.512	9	1988 JULY 31	00 58
7390.350	7.399	1.744	1.664	5	1988 AUG. 6	20 24
7384.350	7.343	1.900	1.607	7	1988 AUG. 10	20 24
7385.370	7.339	1.846	1.637	4	1988 AUG. 11	20 53
7388.530	7.292	1.813	1.688	11	1988 AUG. 15	00 43
7404.320	7.431	1.823	1.644	7	1988 AUG. 30	19 41
7406.330	7.431	1.836	1.678	4	1988 SEPT. 1	19 55
7408.360	7.445	1.800	1.707	10	1988 SEPT. 3	20 39

3. RESULTS AND DISCUSSION

3.1. U, V Light Curve

Figure 1 shows the overall U and V light curve of CH Cyg since 1967. The activity phases, 1967 - 1969 and 1977 - 1987, were charscterized by a strong blue continuum. During these intervals, the colour U-V index was roughly equal to zero and in the activity maximum of 1982 - 1984 it was even negative (Figs. 1 and 2). The quiescent phase of 1970 - 1977 was characterized by the separation of both magnitudes and an increase in the values of the U-V and B-V colour indices. The maximum values of the U-V index in this period were around 2.5 mag. and of the B-V index around 1.5 mag. Since 1986, the values grew rapidly and in August to September 1988 they reached about 3.5 and 1.8 mag., respectively. Also long-term variations with a period of about 700 days were observed (Luud et al., 1977). Besides this, short increases with $\Delta U \sim 0.5\text{-}1.5$ mag., lasting from weeks to months, were indicated in July 1972 (JD 2 441 520), in May 1974 (JD 2 442 200) and October 1987 (JD 2 447 084); these are shown in Figs 1 and 2 and marked with arrows.

The variability of the V-magnitude in the interval 1967 - 1977 is periodic. Luud et al. (1977) found a period of 714 days in this interval. A new analysis of these data using the method of phase dispersion minimization (Stellingwerf, 1978) and the STEST computer program (Zverko, private communication) yielded a period of 758 days at a significance of $\Theta = 0.53$ (Fig. 3). From 1977 up to 1985 the variations in the V spectral region were affected by the strong blue continuum ($U\text{-}V \leq 0$). Since 1985 until the autumn of 1987, there was a long-term variation of the V-magnitude with an amplitude of about 1 mag. lasting approximately 1000 days (Fig. 4). The most recent observations indicate a shortening of this variation, although this conclusion requires further observations to be made. These periodic variations of the V-magnitude, observed since 1960 (Gusev, 1976; Kenyon, 1986, Fig. A. 10) are probably related to the radial pulsations of a late red giant. The observed changes of its spectral classification (Luud et al., 1982; Andrillat, 1988) could be a reflection of these pulsations. To prove this property of the red giant, the hitherto published radial velocities (140 values) of the cool component of CH Cyg were analysed using the same method as applied to the photometric observations. In the interval from 500 to 1200 days periods ranging from 650 to 855 days were thus found, however, the significance was only 0.80 - 0.85 (Fig. 3). Although this result is not unique proof of the existence of the radial pulsation of the red giant, it can at least be assumed.

The simultaneous origin of these pulsations and of the symbiotic phenomenon after 1960 (Gusev, 1976; Deutsch, 1964) enables us to conjecture that the basic cause of the erratic outbursts of CH Cyg is the dynamic instability of the red giant. Its critical equipotential surface is relatively small, roughly 200 $R_\odot$ (Skopal, 1988). Consequently, a part of the external atmosphere may "overflow" the critical equipotential as the cool giant expands and be attracted by the compact component. This process could conversely affect the very

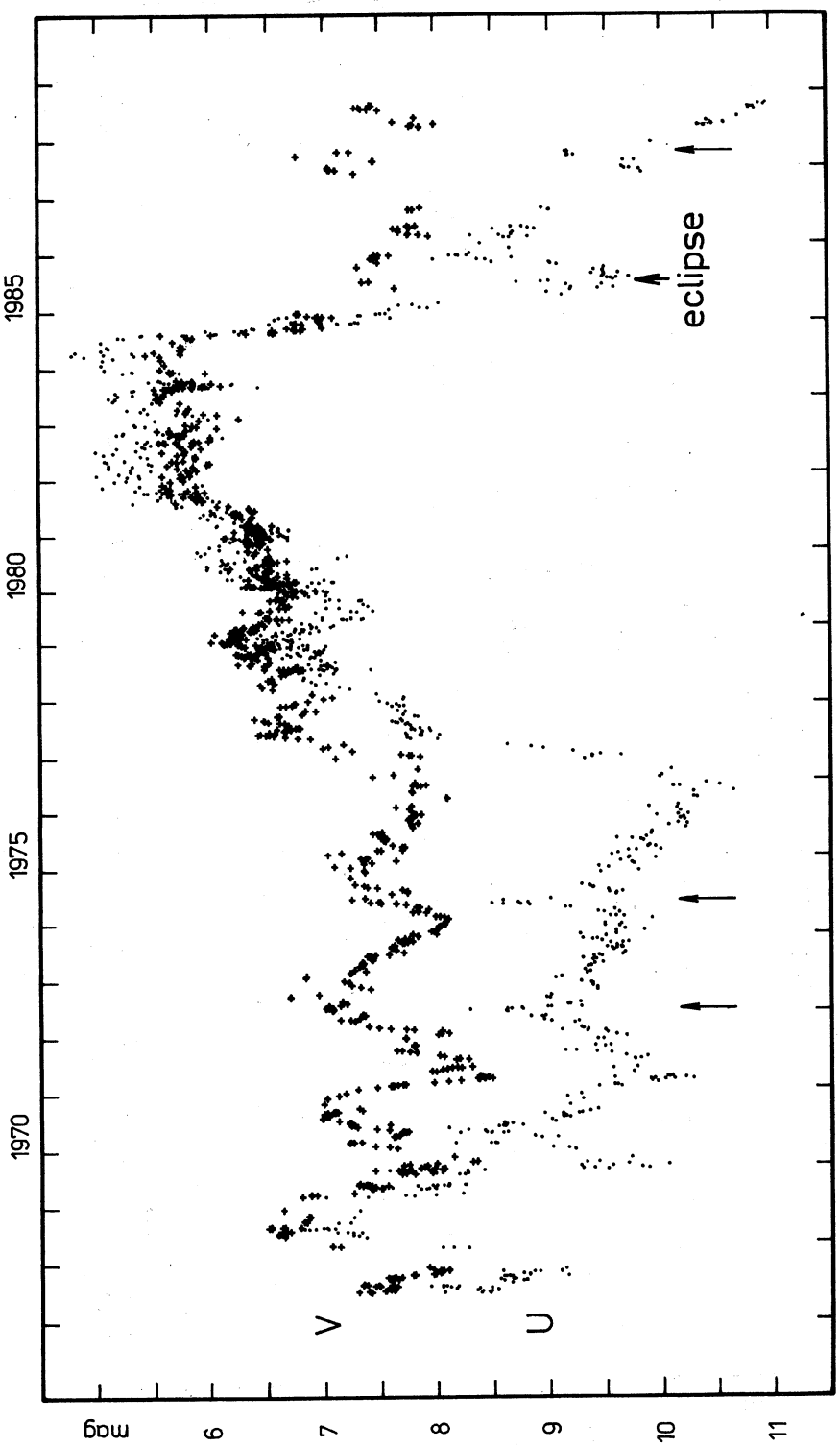

Fig. 1. U, V light curve of CH Cyg according to data published by Cester (1969), Doroshenko and Magnitsky (1982), Hopp and Witzigmann (1981), Chochol et al. (1984), Ichimura et al. (1979), Luud et al. (1977, 1982), Martel and Gravina (1985), Mikolajewski and Mikolajewska (1985), Mikolajewski and Wikierski (1986), Milone et al. (1986), Nakagiri and Yamashita (1982), Panov et al. (1985a,b), Reshetnikov and Khudyakova (1984), Skopal (1987), Taranova et al. (1982), Vennik et al. (1983, 1987) and from JD 2 446 700 this paper.

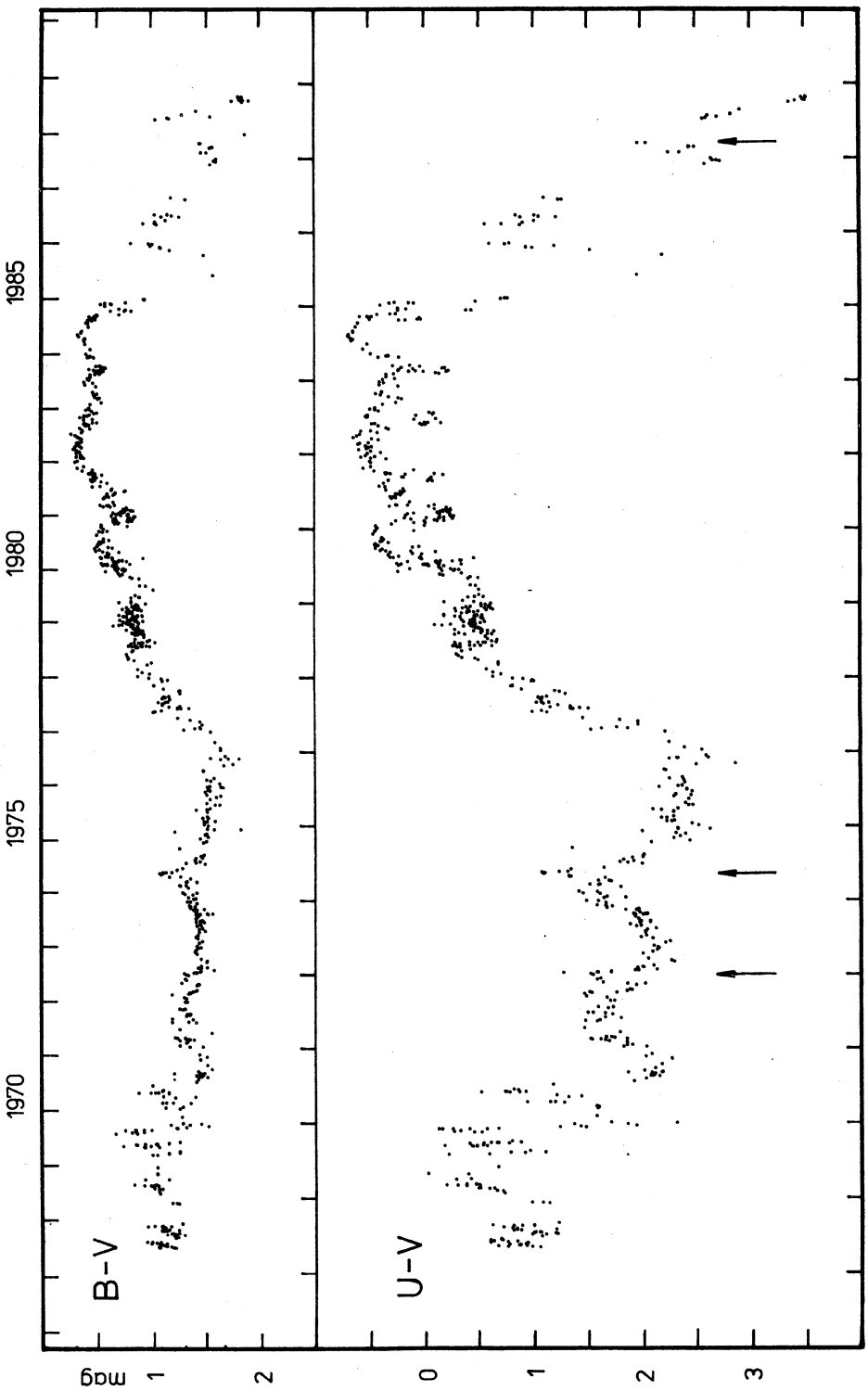

Fig. 2. U-V and B-V colours of CH Cyg. References are the same as at the figure 1.

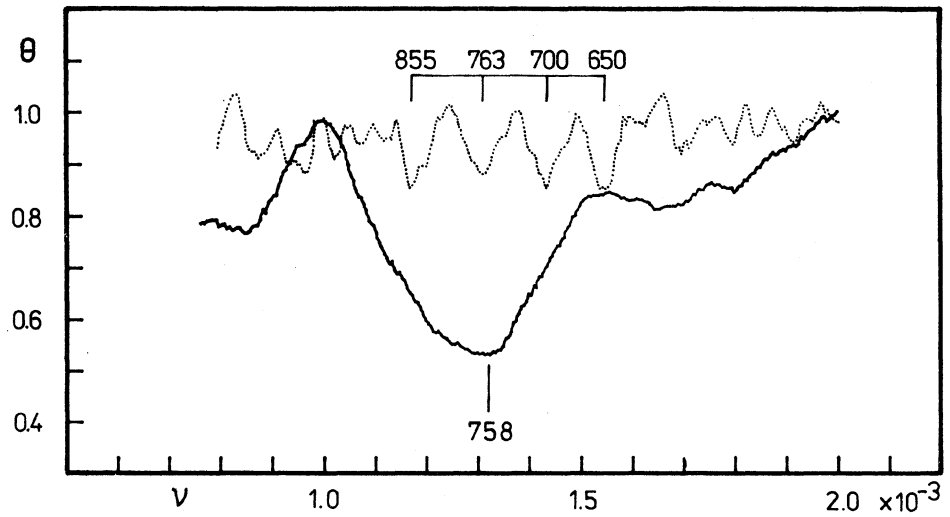

Fig. 3. Periodogram of the V-magnitude observed in the interval 1967 - 1977 (full line) and of the radial velocities of the cool component (dotted line).

pulsations of the star and finally lead to irregular oscillations in mass transfer to the compact component of the binary system. The rapid fluctuations of the radial velocity of the absorption components of singly ionized metals in the maximum of the activity phase (Chochol et al., 1986; Skopal et al., 1987) are clearly the direct observational consequence of this mechanism. This would represent a kind of analogy with the concept demonstrated and for cataclysmic variables considered by Bath (1984). This concept would allow the short outbursts ($\Delta U \sim 1$ to 1.5 mag., lasting roughly a month) also observed during the quiescent phase of CH Cyg, to be related with this activity of the red giant.

3.2. End of the Activity Phase of CH Cyg

The most recent activity phase assigned the symbiotic star CH Cyg to the most interesting astrophysical objects of the recent 10 years. Its outbursts occurred in May 1977 (Fehrenbach, 1977). This corresponded to an increase of brightness by about 2.5 - 3.5 mag. in the U-filter (Fig. 1) which continued into the summer of 1981. From 1981 to July 1984, a strong blue continuum affected the radiation of CH Cyg in the whole optical region of the spectrum, $\lambda < 550$ nm (Ipatov et al., 1984). Between July 25 and August 15, 1984, a sudden decrease in the star's brightness was observed, amounting to 1 - 1.5 mag. (Panov et al., 1985b; Luud et al., 1986). Since April 1984, a radio outbursts and bipolarly expanding jets were observed (Taylor et al., 1985) and, in May 1985, a soft X-emission was detected (Leahy and Taylor, 1986). Mikolajewski et al., (1987) found two minima on the U light curve, observed in 1969 and 1985, which they interpreted as the eclipse of the hot active component by the cool giant.

The period following the eclipse was characterized by a gradual decrease of the star's brightness in the U-filter down to values of about 10.5 - 11 mag.,

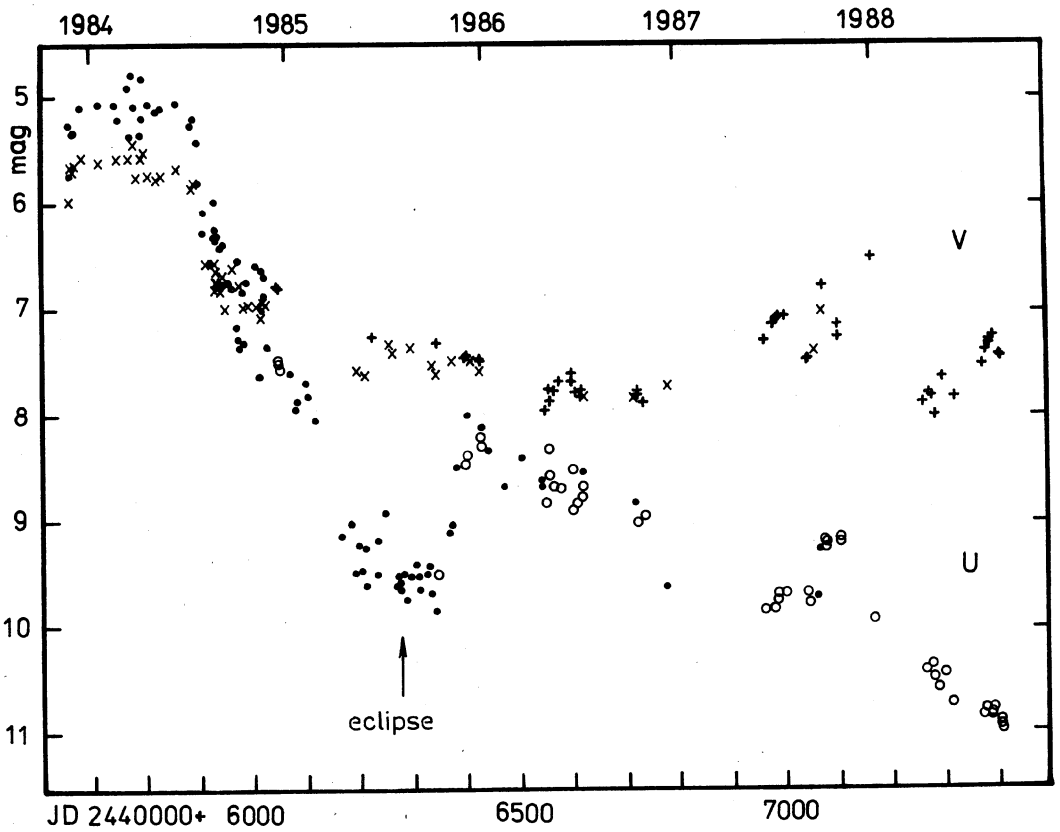

Fig. 4. The U and V light curve of CH Cyg in November 1983 to September 1988. •-U, ×-V light curve according to data published by Vennik et al. (1987), Mikolajewski et al. (1987), Milone et al. (1986), Mikolajewski and Mikolajewska (1985), Mikolajewski and Wikierski (1986), Panov et al. (1985a,b), Taranova and Yudin (1988). o, +- Observations carried out at the Skalnaté Pleso Observatory: Skopal (1987) and from JD 2 446 700 this paper.

which were even lower than the values observed during the quiescent phase of CH Cyg in 1976 (Fig. 1) and which are about 1 mag. higher than the values observed during the period of total eclipse in 1985. These facts indicate a weakening of the source of the blue continuum, which was still contributing in the U-region of the spectrum even in the period of the total eclipse (Figs 1 and 4). The brightness of the star in the V-filter varied roughly between 6.7 and 7.9 mag. between the end of 1984 and the last observations in 1988. Its value was close to that derived from measuring the visual magnitude until 1960 (Gusev, 1976) and of the V-magnitude during the quiescent phase of CH Cyg in the years 1970 - 1977 (Luud et al., 1982). The difference between the values of the U- and V-magnitudes was observed until the beginning of the eclipse in May 1985. In the years 1987 - 1988 this difference amounted to 2.5 mag. The weakening of the blue continuum thus enabled better observation of the beha-

viour of the cool component and the hot source separately also in the optical part of the spectrum.

The amplitudes of the rapid variations of the U, B, V photometry decreased during the whole period after the eclipse. In 1987 - 1988 the brightness of CH Cyg in these filters were practically constant during the night ($\Delta m < 0.1$ mag.), although the difference between their amplitudes in the U- and V-filters could be observed ($\Delta U > \Delta V$). In the spring of 1986 $\Delta U \sim 0.3$ mag., but $\Delta V \sim 0.1$ mag. (Skopal, 1987: Fig. 6), as opposed to the activity maximum in which $\Delta U \sim \Delta V$ (e.g., Reshetnikov and Khudyakova, 1984). This behaviour of the rapid fluctuations of the blue continuum can be explained naturally by its overall decrease. The degree to which the particular spectral region UV is affected by the radiation of the hot component is given by the ratio of its intensity and the intensity of the radiation of the red giant on a particular wavelength. From the point of view of the distribution of the energy of the cool red giant (e.g. Ipatov et al., 1984), this means that the overall weakening of the UV radiation flux will lead to the gradual vanishing of its rapid fluctuations as one proceeds from the V into U spectral region.

If the source of the rapid variations in the brightness of the star and blue continuum is the accretion material around the hot component of CH Cyg, the photometric observations made in the years 1985 - 1988 have proved that the size of the accretion complex has decreased appreciably and that the activity phase of CH Cyg has come to an end.

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