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Outburst parameters and the long-term activity of the dwarf nova CH Ursae Majoris*

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Abstract. An analysis of the historical light curve of the dwarf nova CH UMa, spanning 25 years, is presented. The statistical distribution of the maximum brightness is bimodal and the outbursts can be divided into two classes: "bright" and "faint", the division magnitude being 12 $\mathrm{mag_{vis}}$ and separation almost 2 $\mathrm{mag_{vis}}$. The maximum brightness of the bright outbursts tends to decrease in the course of the covered interval. The bright outbursts fall into two subtypes according to their decay branches (fast and slow). The typical recurrence time of the outbursts 300–370 days is one of the longest among CVs above the period gap. Variations of the cycle-length of the bright outbursts are very prominent and display a strong secular trend of the period decrease. The long-term activity and the outburst parameters, discussed in the framework of the thermal instability, put constraints on the model.

Key words: stars: activity – stars: binaries: close – stars: binaries: general – stars: circumstellar matter – stars: novae, cataclysmic variables – stars: individual: CH UMa

1. Introduction

CH UMa was listed as a U Gem type variable star in the second supplement to the *Third Edition of GCVS* (Kukarkin et al. 1974). The object was reported to vary within 10.7–15.9 mag in a cycle of about 400 days. Green et al. (1982) listed it as an emission line object and cataclysmic variable (CV) candidate PG1003+678 in the Palomar Green survey.

CH UMa was identified with an *Einstein* X-ray source 1E1003+67 by Becker et al. (1981, 1982). It was also detected in the *ROSAT PSPC* All Sky Survey (Verbunt et al. 1997). Becker et al. (1982) have shown that in quiescence, CH UMa is characterized by a hard X-ray spectrum (most photons at energies above 0.5 keV) and low X-ray to the optical flux ratio about 0.04. Several brightenings, found on the Harvard plates, confirmed that CH UMa varies by 4 magnitudes. The quiescent optical spectrum consists of strong emission lines, strong red continuum and a variable blue component (Becker et al. 1982).

* This research has made use of the AFOEV database, operated at CDS, France.

CH UMa appears to exhibit several types of outbursts. Szkody & Mattei (1984) included it in a list of the secondary candidates for the SU UMa subgroup of CVs. However, Thorstensen (1986) determined the spectroscopic orbital period $P_{\rm orb} = 8.28$ hours, later refined to 8.23 ± 0.04 hours by Friend et al. (1990). This is one of the longest orbital periods among CVs and clearly rules out the membership in the SU UMa subtype. The contradiction between the outburst properties and the orbital period thus makes CH UMa an interesting object for a study of its activity.

The spectroscopic study by Friend et al. (1990) suggests that CH UMa is seen rather pole-on, the inclination angle lies within $17^{\rm o}$–$25^{\rm o}$. The secondary is both undermassive and too cool for its $P_{\rm orb}$; the spectrum suggests that it is by 1200 K cooler than expected. The apparent orbital eccentricity of the secondary 0.10 ± 0.03, found by Friend et al. (1990), was modeled by an asymmetric heating of its hemisphere, facing the white dwarf, and tentatively interpreted as an asymmetry of the convective flow (Davey & Smith 1992).

Howell & Szkody (1990) included CH UMa to a list of CVs which may be members of the Galactic halo or intrinsically very faint systems. If the former is true then it has by far the longest $P_{\rm orb}$ among the halo CVs. Later, Sproats et al. (1996) argued that most of these systems are rather nearby faint CVs.

2. The sources of the data

From the observational point of view, the character of the long-term brightness variations of the dwarf novae, especially those of the U Gem subtype, represents a big problem for professional observers. These systems spend most time (sometimes even hundreds of days) in the quiescent level while the outbursts are completed within just a few days. Monitoring of the dwarf novae is therefore almost entirely the domain of the associations of amateur observers. These observations are mostly visual but since they are very numerous (often several thousands for a given object) and come from a large number of observers, the objectivity of the features of the light curve can be assessed. Visual data, if treated carefully, can therefore be very useful for analysis of the long-term activity. Accuracy even better than 0.1 mag can be achieved by averaging the data and is quite sufficient for analyses of these large-amplitude variable stars.

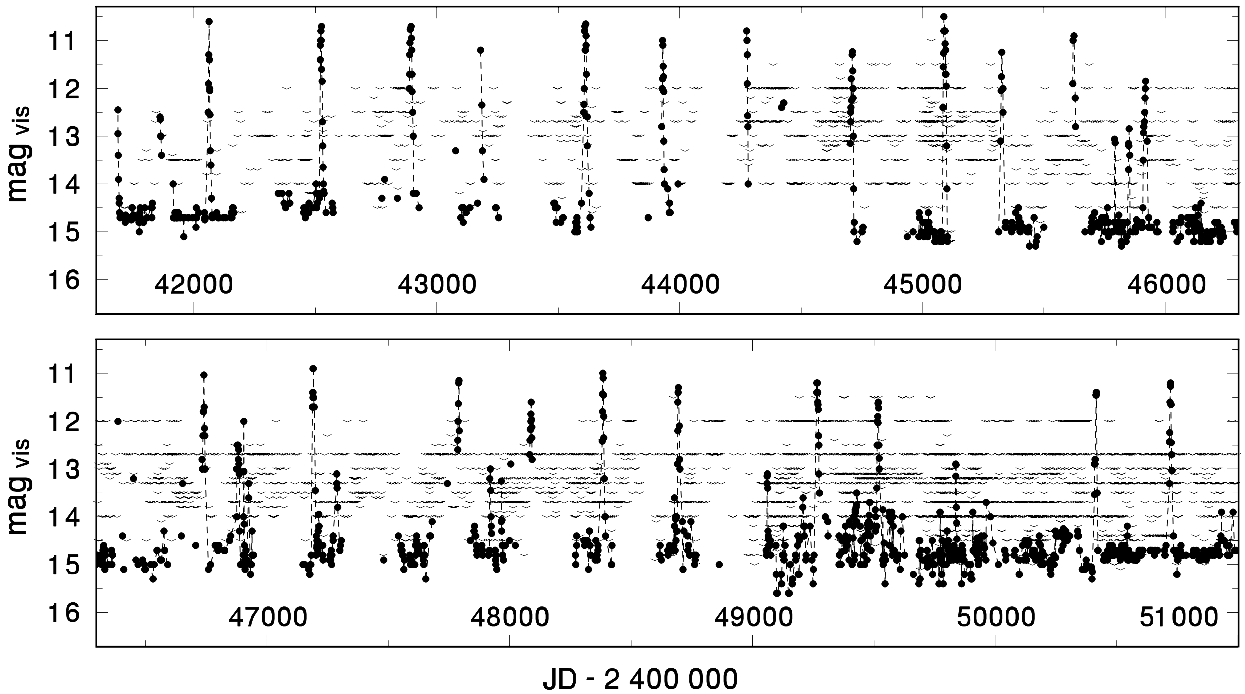

Fig. 1. The outburst history of CH UMa over the years 1973–1998. The points denote the positive observations and are connected by line for the densely covered intervals. The v symbols mark the upper limits of brightness and can be used to constrain the possibly missed outbursts. See Sect. 3.1 for details.

The bulk of the data used in this analysis of CH UMa was obtained from the database of Association Francaise des Observateurs d'Etoiles Variables (AFOEV), operated at CDS, Strasbourgh, France. The original file contained 6144 measurements, covering the years 1973–1998. The light curve was plotted and submitted to a visual inspection. The observations already marked as unreliable in the original file were rejected in most cases. Further, several observations, largely deviating from the neighbouring points on the light curve, were rejected. In order to smooth the light curve, the positive observations (1756) were then binned into one-day means (1366). The negative observations (4302) were used to constrain the number of possible missing outbursts and duration of some not fully covered events. Only the outbursts defined by multiple observations from several nights were considered for further analysis.

The bandpass of the eye sensitivity is similar to the Johnson V-filter but not quite identical. We will therefore abbreviate the brightness determined from the visual data as $\mathrm{mag_{vis}}$.

3. Analysis of the data

3.1. General description

Fig. 1 shows the outburst history of CH UMa over the years 1973 – 1998. It can clearly be seen that about 21 outbursts reached up to 11.5–10.5 $\mathrm{mag_{vis}}$ from the quiescent level (≈ 15 $\mathrm{mag_{vis}}$). Several fainter outbursts are apparent, too. The examples can be seen in Figs. 3 and 2 and will be analyzed in turn.

In order to assess the total coverage and to constrain the possibly missed outbursts, we also display the upper limits of brightness in Fig. 1. It can be seen that although the coverage of the quiescent level displays large seasonal gaps prior to JD = 2 449 000, the coverage by the upper limits is much denser and almost continuous for magnitudes brighter than about 12.6 $\mathrm{mag_{vis}}$ after JD = 2 444 300. This non-uniform coverage of various brightness levels can be ascribed to the variable height of the star above the horizon through the year and the ability to reach a particular magnitude near the horizon. We therefore believe that most of the outbursts brighter than 12 $\mathrm{mag_{vis}}$ were covered by the observations. The situation may be less favourable in the case of the fainter outbursts.

The overall appearance of the light curve is typical for the U Gem subtype – the system spends much more time in a well defined quiescent level than in outburst. The typical recurrence time of the brighter outbursts in CH UMa is 300–370 days. A thorough analysis of the cycle-length T_{C} is given in Sect. 3.4.

The moment of the maximum light and the level of the peak brightness were determined by fitting a polynomial (the 2^{nd} – 5^{th} degree) to the upper part of the outburst light curve. The typical error of the determination of the moment of the maximum light is 1 – 2 days. Even in the case of incompletely covered outbursts the negative observations allow us to constrain this time to within 8 – 12 days. This error is much smaller than the cycle-length and is reflected in the weights, listed in Table 1.

The respective well-covered outbursts were also plotted on the separate graphs. This allowed us to examine them in detail, classify their types and search for the common features.

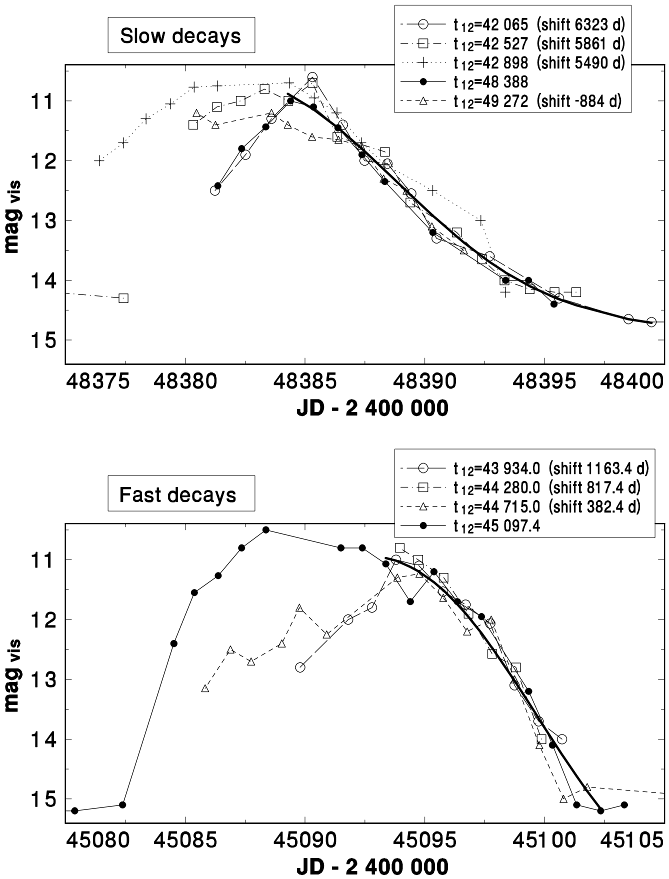

Fig. 2. Types of the decay branches of the bright outbursts. The respective outbursts of each group were shifted along the time axis to match the decay branch of the template – the shifts are listed in the figure. The thick lines represent the smoothed decay curves. The range of the axes is identical for both groups and enables a direct comparison of the course of the decay. See Sect. 3.3 for details.

Table 1. Parameters of the outbursts in CH UMa. T_{max} refers to the maximum brightness in JD–2 400 000. Epoch and $O-C$ (days) are calculated according to Eq. (1). Weight refers to the accuracy of determination of $T_{\max}$. Maximum brightness of outburst is abbreviated as mag(max). Type of outburst (b...bright, f...faint) and meaning of the relative energy (RE) are explained in Sect. 3.2.

$T_{\max}$JD	Epoch	$O-C$	Weight	mag(max)	Type	RE
41686	−16	−593	0		b?	
41859	−16	−420	0		f?	
42063	−15	−523	1	11.0	b	140
42522	−14	−371	1	10.9	b	212
42893	−13	−307	1	10.6	b	297
43180	−12	−327	1/3	11.2	b	
43612	−11	−202	1	10.8	b	300
43931	−10	−190	1	11.1	b	111
44276	−9	−152	1/3	10.8	b	
44711	−8	−24	1	11.5	b	127
45090	−7	48	1	10.5	b	314
45328	−6	−21	1	11.4	b	128
45624	−5	−32	1	10.8	b	223
45792	−5	136	1/3	13.1	f	13
45851	−4	−112	1	12.9	f	16
45920	−4	−43	1	12.0	b	106
46740	−1	−144	1	11.4	b	118
46881	−1	−3	1	12.5	f	41
46905	−1	21	1	12.0	f	13
47191	0	0	1	11.2	b	167
47288	0	97	1/3	13.1	f	
47791	2	−14	1	11.1	b	88
47919	2	114	1	12.9	f	12
48089	3	−23	1	11.8	b	81
48385	4	−34	1	11.1	b	117
48695	5	−31	1	11.2	b	112
49062	6	29	1	13.0	f	8
49266	7	−74	2/3	11.2	b	131
49517	8	−130	1	11.6	b	84
49838	9	−116	1	12.9	f	12
50415	11	−153	2/3	11.4	b	94
50722	12	−153	1	11.2	b	110

3.2. Types of outbursts according to their brightness and energy

The statistical distribution of the maximum brightness is bimodal (Fig. 4), having the peaks at ≈ 11.1 mag$_{\rm vis}$ and $\approx$ 13 mag$_{\rm vis}$. In the following text we will use this for division of the outbursts into two classes: "bright" and "faint", the division magnitude being 12 mag$_{\rm vis}$. Parameters of all measured outbursts are listed in Table 1.

The examples of the *bright* outbursts are displayed in Fig. 2. They are aligned according to their decay branches for the purposes discussed in Sect. 3.3. This figure, however, enables us to assess their more general characteristics, too. The peak brightness of the bright outbursts is not variable by more than ≈ 0.8 mag$_{\rm vis}$ but the position of the peak with respect to the center of the outburst varies appreciably. Also the outburst width is largely variable. The time that the system spends at the maximum brightness largely varies for the respective events. Notice that there are outbursts with a very sharp top and, on the other hand, outbursts whose upper part is markedly flat or rounded (e.g. compare the events labeled by JD = 2 442 065 and 2 442 898 in Fig. 2). Although the rising branches of the bright outbursts are covered just in a few cases, the outbursts usually appear to be rather symmetric, in some cases the rise to maximum is very slow (e.g. the outburst labeled as JD = 2 444 715 in Fig. 2).

Both the maximum brightness and the width of the faint outbursts are considerably smaller than those of the bright ones. Three superposed examples of the faint outbursts can be seen in Fig. 3. Their maximum brightness is approximately 13 mag$_{\rm vis}$. The light curve is asymmetric, the decay being slower than the rise (the course of the rise is unresolved because of its short duration – of the order of one day).

The division into types is clear for most outbursts, only a few cases deserve a comment. Just the decay branch was covered for the outburst in JD = 2 441 686 but it had to be brighter than 12.4 mag$_{\rm vis}$. This event appears to belong to the bright outbursts,

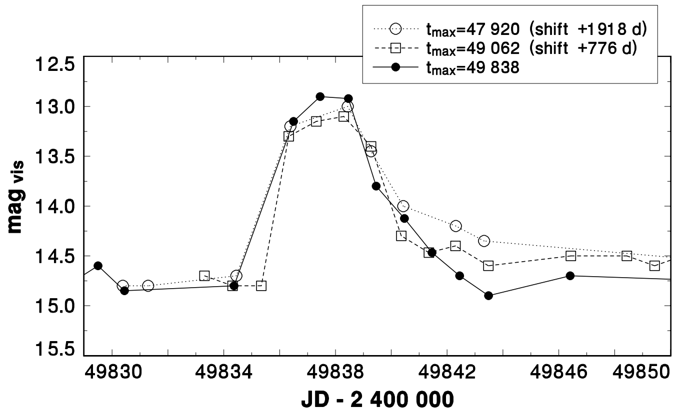

Fig. 3. Examples of three well covered faint outbursts (that is fainter than 12 mag_{vis} at maximum). See Sect. 3.2 for details.

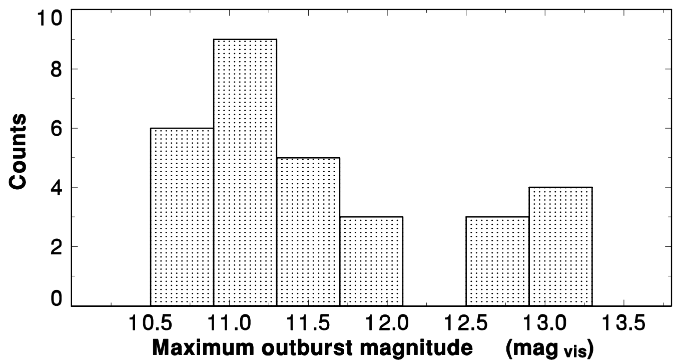

Fig. 4. Histogram of the maximum brightness of the outbursts. Notice that the distribution is bimodal, having the peaks at ≈ 11.1 mag_{vis} and ≈ 13 mag_{vis}.

also because it nicely fits their linear $O-C$ course in Fig. 9 where it attains $E=-8$, $O-C=-55$ days (see Sect. 3.4 for details). The decay branch and possibly the top at 12.6 mag_{vis} were observed for the outburst in JD = 2 441 859. It seems to be a faint outburst; its $O-C=110$ days for $E=-8$ deviates from the $O-C$ curve in Fig. 9 much more than of its precursor. The last case which needs a comment is the outburst at JD = 2 446 905 which peaks at 12.0 mag_{vis}, that is, it just attains the division magnitude. However, its small width and the very low relative energy $RE=13$, defined below, are very typical for the faint outburst.

The outburst maxima versus Julian Date are plotted in Fig. 6a. One can see that the maximum brightness tends to decrease in the course of the covered interval. Outbursts prior to JD = 2 446 000 reach up to 10.5 mag_{vis} while no maximum is brighter than 11 mag_{vis} after this date.

When comparing the energy output of the respective outbursts in a given dwarf nova, we can get a better insight if we introduce the so called relative energy (RE) of outburst. For this purpose, the whole light curve of CH UMa was transformed into intensity, normalized to unity at 14.5 mag_{vis}. This reference magnitude was slightly brighter than the quiescent level so that the outbursts were clearly resolved from the quiescent levels. At the same time, it was faint enough to contain all outbursts. The

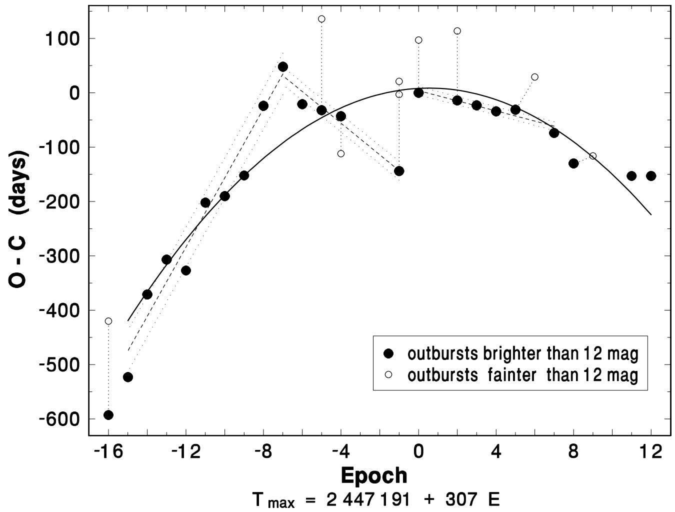

Fig. 5. The $O-C$ diagram for the outbursts in CH UMa. The $O-C$ values were calculated according to Eq. (1). The bright and faint outbursts are resolved. The $O-C$ values of the faint outbursts are negative (positive) if they occurred before (after) the following (preceding) bright outburst. The faint outbursts are connected with the bright outburst, having the same epoch number, by line for clarity. The $O-C$ curve of the bright outbursts was fitted by a parabola. The straight lines denote the segments of the curve during which the cycle-length of the bright outbursts may be regarded as constant; the standard deviation of the linear fit is marked by dotted lines. See Sect. 3.4 for details.

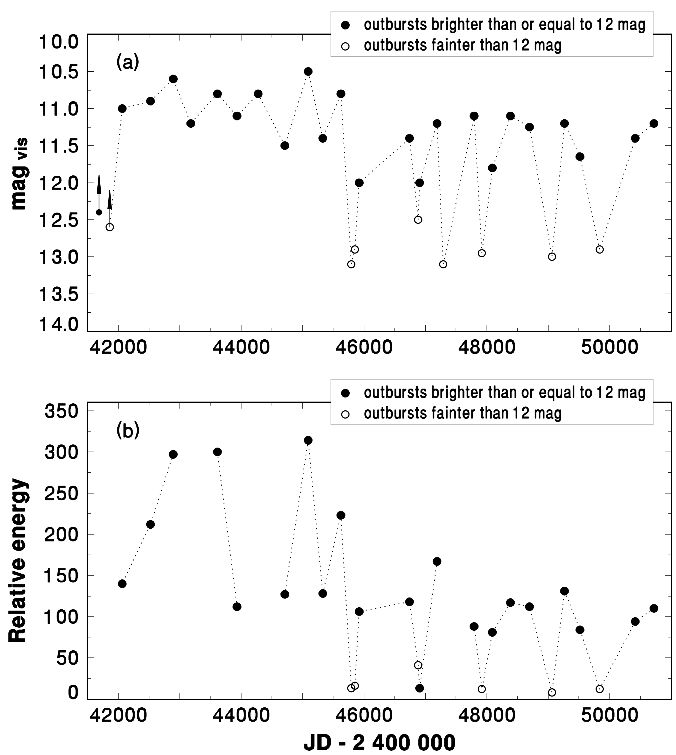

Fig. 6a and b The maximum brightness **a** and the relative energy **b** of the outbursts. Notice that the bright and faint outbursts tend to alternate. The neighbouring outbursts are connected by lines to guide the eye. See Sect. 3.2 for details.

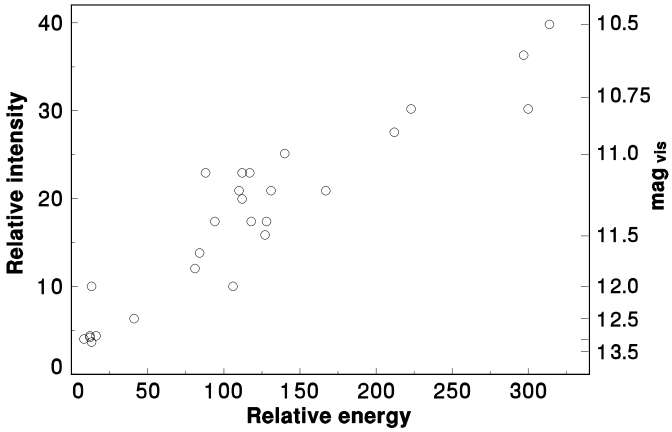

Fig. 7. The relation between the outburst energy RE and the maximum brightness of the outbursts. See Sect. 3.2 for details.

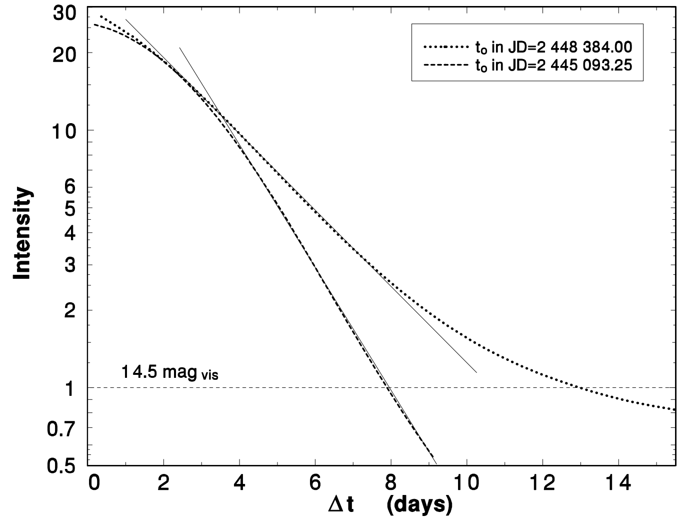

Fig. 8. The smooth decay branches of the bright outbursts for the fast type (dashed line) and the slow type (dotted line). The thin lines approximate parts of the light curves which can be regarded as exponential. The brightness is expressed in intensities, normalized to unity at 14.5 mag_{vis}. See Sect. 3.3 for details.

relative energy of each outburst was then calculated by integration of the light curve – i.e. it represents the area outlined by the outburst light curve having intensity greater than unity. Since we are only interested in comparing the relative outputs of outbursts in a given binary, RE may be expressed in dimensionless units. This method is similar to that used by Cannizzo & Mattei (1992). In a few cases RE is a lower limit because the bottom part of the rise (and sometimes also of the decay) is not covered in CH UMa. However, the uncertainty is relatively small since most energy is radiated within 1 mag below the maximum light. The mean relative energy of all measured bright and faint outbursts is $RE = 146 \pm 77$ and 17 ± 11, respectively.

It can be seen in Fig. 6b that especially prior to JD = 2 446 000 several extra energetic outbursts occurred, having $RE > 200$ in five cases, even reaching $RE \approx 300$ in three cases. Fig. 6ab shows that the bright and faint outbursts tend to alternate – usually one or two faint outbursts are inserted between two bright ones. Most faint outbursts were observed after JD = 2 446 000 but this fact may be at least partly ascribed to the weaker coverage of the light curve for the faint brightness levels prior to this date.

The relation between the outburst energy RE and the maximum brightness is displayed in Fig. 7. A loose correlation of RE and the maximum brightness can be resolved. The faint outbursts form a distinct group with $RE < 50$. Their RE is considerably lower than that of the bright outbursts because obviously they are both fainter and more narrow. The largest scatter is observed around $RE \approx 130$ where most bright outbursts accumulate. Since the points are dispersed in both the direction of equal brightness and equal RE, it can be inferred that variations of both the maximum brightness and the width of the individual bright outbursts must contribute to the scatter.

3.3. *Types of the decay branches*

With respect to the decay branches, the bright outbursts in CH UMa fall into two types: *fast* and *slow*. It will be shown that they differ in both the rate and the course of the decay. The well covered outbursts were plotted and superposed. One fast and one slow outburst with a well covered decay branch were chosen as the templates. The remaining outbursts were shifted along the time axis to match the decay branches of the templates. The result is shown in Fig. 2. The decay branches of the respective outbursts of a given type were then merged into a common file and smoothed by the program HEC13 (author Dr. P. Harmanec). This program is based on the method of Vondrák (1969 and 1977) and can fit a smooth curve to the data no matter what their course is. After several trials it was found that the input parameters of the fit $\epsilon = 10^{-2}$, the length of the bin $\Delta T = 0.5$ day satisfy the course of the decays in both types. *The input ϵ parameter determines how "tight" the fit will be (if just the main course or if also the high-frequency variations are to be reproduced). In our case ϵ was chosen so that the fit reproduces just the main course of the decay*. Smoothed decays are plotted as thick solid lines in Fig. 2.

No strong dependence of the decay rates on the preceeding outburst history is apparent. It can be seen in Fig. 2 that although the width and the rise rates differ for a given group of decays, the decay branches remain very similar.

The detailed comparison of the decay branches and an assessment to what extent they can be regarded as exponential can be made from Fig. 8. Both the fast and the slow smooth decay branches, transformed into intensities as before, were plotted on the logarithmic scale in Fig. 8. The respective curves were aligned along their upper parts where a plausible match can be made. It is clear that the light curves for both types agree just for the parts having intensity larger than about 13.0 but are more and more divergent as the intensity decreases. The part of the *fast* decay having intensity smaller than 9.0 down to the quiescent level is very well exponential (i.e. linear in the logarithmic scale). The *slow* decay within intensities 2.7–17.0 can be regarded as exponential, too, but its bottom part (intensity smaller than about 2.7) is slower than exponential – notice the long tail before the final quiescent level is reached.

3.4. The outburst cycle-length and its variations

There are several methods for how to search for the cycle-lengths and their changes with time. The usual one in the case of the dwarf novae is to measure the time of crossing a particular magnitude or the moment of maximum brightness and then to determine the separation of the neighbouring outbursts. This method, however, has its drawbacks. Firstly, if some outbursts were missed due to bad weather or seasonal gaps then counting the events may become uncertain. Secondly, if several types of outbursts are present in a given CV then some may recur with a better defined period than the others.

On the other hand, the method of using the $O-C$ residuals from some reference period removes the above mentioned drawbacks. This method is widely used in the study of the orbital period changes of eclipsing binaries but very rarely applied for the study of outbursts in dwarf novae. Vogt (1980) used this method for a study of the superoutbursts in the SU UMa subtype and long outbursts in two U Gem-type CVs and Warner (1988) studied U Gem. The method of the $O-C$ residuals is not sensitive to the exact length of the reference period. A slightly different reference period gives rise only to an additional linear trend of the $O-C$ values and can be corrected later. The $O-C$ diagram can be constructed even if there are gaps in the data and also allows us to examine the course of the $O-C$ values for the respective types of outbursts in a given CV.

The reference period for CH UMa was determined from the mean separation of the respective *bright* outbursts. It was found that the mean cycle-length $T_{\rm C}$ is 300–370 days. The negative observations were used to constrain the number of possible missing bright outbursts and confirmed that on average $T_{\rm C}$ cannot be shorter. A set of the $O-C$ curves for slightly different reference periods was generated. Large $O-C$ changes of the bright outbursts were found, so large that their absolute values in a part of the $O-C$ curve were always larger than the reference period. One therefore has to be cautious in constructing the course of the $O-C$ curve. The parts of the $O-C$ curve which contained the large variations therefore were examined using several reference period lengths to obtain the smallest slope of the curve in the vicinity of the change.

The length of $T_{\rm C}$ in the respective segments, discussed below, was also checked by the PDM program, based on the method of Stellingwerf (1978) and written by Horn (1992). The PDM method is suitable for nonsinusoidal time variations.

The final $O-C$ diagram for CH UMa is displayed in Fig. 5. The bright and faint outbursts are resolved. The $O-C$ values of the faint outbursts are negative (positive) if they occurred before (after) the following (preceeding) bright outburst. The reference period of 307 days (Eq. 1) was proven to show the course of the $O-C$ values of the bright outbursts with the best clarity. The respective bright outbursts keep the period from cycle to cycle much better than the faint ones. They, however, display striking variations of $T_{\rm C}$ on long timescales. The $O-C$ diagram shows a clear trend of a strong decrease of $T_{\rm C}$ which can be fitted by a parabola for the bright outbursts, at least in the first approximation. In most cases the error bars in Fig. 5 would be smaller than the symbols used.

$$T_{max} = 2\,447\,191 + 307\,E \tag{1}$$

A closer examination of the $O-C$ diagram (Fig. 5) for the bright outbursts reveals that their maxima approximately follow a linear course (that is they have a constant period) for several consecutive epochs. These segments are then interrupted by abrupt changes of $O-C$ which occurred within a single cycle and can be placed to $E=-7$, -1 to 0, 7 to 8. We only note that the outburst in JD = 2 445 090 which attains $E=-7$ in Fig. 5 and heralds the large change in the $O-C$ curve was the most energetic outburst ever observed in CH UMa ($RE=314$, see also Fig. 6b).

Let us make a comment on the outstanding position of the bright outburst which occurred in JD = 2 446 740 and attains $E=-1$, $O-C = -144$ days in Fig. 5. We argue that this epoch and reconstruction of this part of the $O-C$ curve is correct because it yields the simplest course of the $O-C$ values. The other alternative, that is $E=-2$ and $O-C = 163$ days, is less favourable because it would need a more cumbersome course of change.

In order to show that the part of the curve, which has the steepest slope in Fig. 5, is correctly reconstructed, we redisplay it with the $O-C$ values now calculated according to Eq. (2) in Fig. 9. It can be seen that the maxima of the bright outbursts follow the linear ephemeris (Eq. 2) with a standard deviation $\sigma=35$ days and confirm that this part is correctly reconstructed in Fig. 5. The PDM program detected $T_{\rm C}=218$ days instead of 371 days in this segment, probably because the latter value is too close to one year. The cycle-length as short as 218 days would demand that almost 40% bright outbursts are missed within JD = 2 441 600 – 2 445 100. The negative observations, however, show that any average $T_{\rm C}$ short like this is rather unlikely. Moreover, Fig. 9 shows that no outburst is missing in the above mentioned interval if the $O-C$ values are calculated according to Eq. (2). $T_{\rm C}=218$ days therefore appears to be an alias of the 371 day period and may also explain $T_{\rm C}=204$ days, quoted by Warner (1995).

$$T_{max} = 2\,444\,711 + 371\,E \tag{2}$$

For the sake of completeness, let us note that there are a few missing bright outbursts also in the remaining interval. Because the outbursts are very narrow in comparison with $T_{\rm C}$, it cannot be ruled out completely that a few events passed unnoticed. In any case, Fig. 5 clearly shows that the $O-C$ method allows to analyze the general course of the variations of the cycle-length even if counting some outbursts is uncertain and that it can become a powerful tool for analysis of activity in dwarf novae.

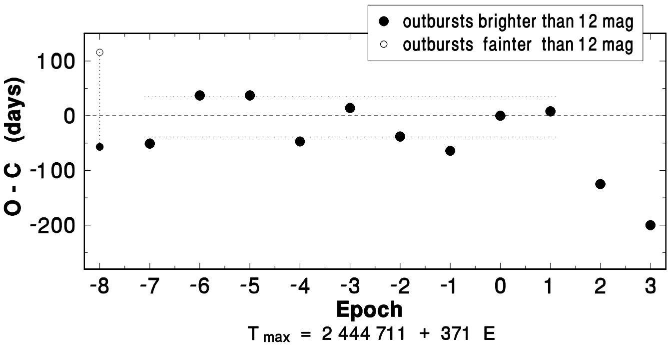

Fig. 9. The $O-C$ curve of the early outbursts which have the steepest slope in Fig. 5, now calculated according to Eq. (2). The maxima of the bright outbursts follow the linear ephemeris within $E = -8$ to $E = 1$ now and confirm that this part is correctly reconstructed in Fig. 5. The dotted lines denote the standard deviation of the $O-C$ values ($\sigma = 35$ days) with respect to Eq. (2). The maxima at $E = 2$ and 3 are displaced due to a real change of the cycle-length.

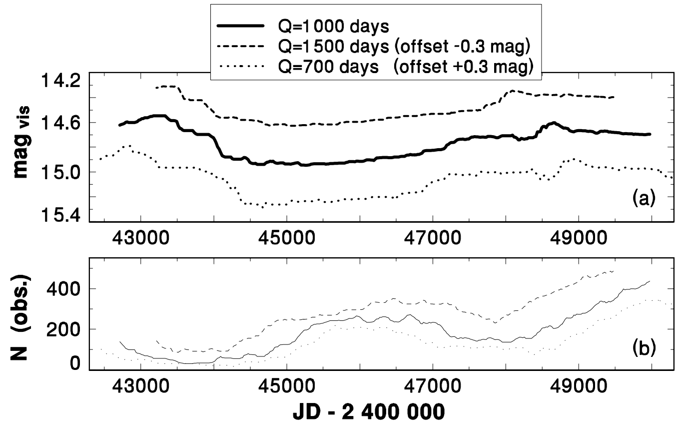

Fig. 10a and b Two-sided moving averages of the quiescent level of brightness **a** and the number of observations inherent in each mean **b**. Three curves for different Q are shown to confirm the course of the light curve. See Sect. 3.5 for details.

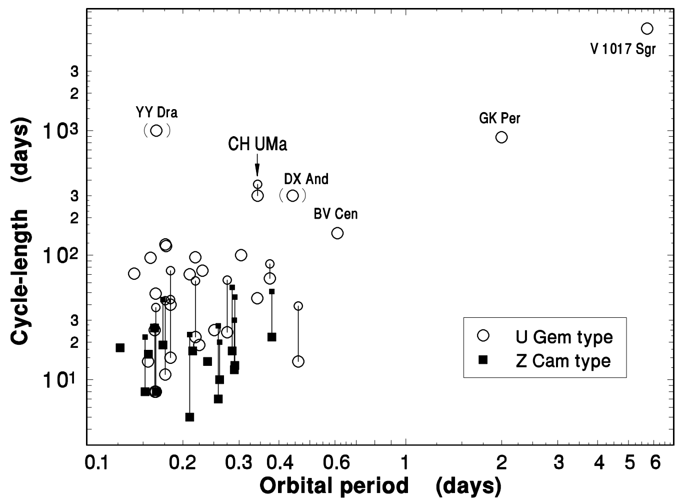

Fig. 11. Dependence of the cycle-length T_C of the outbursts on the orbital period of dwarf novae. Only systems above the period gap are displayed ($P_{orb} > 3$ hours). The U Gem (29 systems) and Z Cam (15) subtypes are resolved. If a range of T_C in a particular CV is known then both the maximum and the minimum value are plotted and connected by the vertical line. Position of CH UMa and several other systems are marked. See Sect. 4 for details.

3.5. Possible changes of the quiescent level

We searched for possible variations of the quiescent level of brightness. In general, these changes have a small amplitude, therefore only a search for the long-term trends is meaningful, having just the visual data at hand. Moving averages is one method which enables us to suppress the high frequency variations, caused by both the observational noise and the real rapid changes, and pick out the general trends in the light curve. This method allowed Cannizzo & Mattei (1992) to resolve variations of the quiescent level of SS Cyg with an amplitude of just 0.1 mag in the visual data.

In order to confirm the course of the smooth light curve, two-sided moving averages were calculated for several values of Q (Fig. 10a). Here the values of Q refer to the semi-interval of days, within which the data were averaged. $Q = 700$, 1000 and 1500 days were used.

We do not give much weight to the course of the light curve prior to JD = 2 444 500 because the number of observations is relatively small there (Fig. 10b). However, the averages after this date reveal a gradual brightening of the quiescent level, apparent for all Q values. This change amounts approximately to 0.3 mag_{vis}.

4. CH UMa and the outburst activity above the period gap

In order to put the activity of CH UMa into a broader context of dwarf novae, we examined the dependence of T_C on the orbital period in systems above the period gap ($P_{orb} > 3$ hours) (Fig. 11). This diagram, updated from Cannizzo et al. (1988), makes use of the latest parameters of 44 systems (Ritter & Kolb 1998); their cycle-lengths were compiled from Ritter & Kolb (1998), Cannizzo et al. (1988) and Warner (1995). The positions of CH UMa and several other systems are marked.

CH UMa has the second longest T_C among the systems with $P_{orb} < 3$ hr< 1 day. The longest value of $T_C = 1000$ days in this range of P_{orb}, YY Dra, is quoted as uncertain by Warner (1995). Moreover, YY Dra contains a magnetized white dwarf (Patterson et al. 1992) which may influence its outburst characteristics. Only T_C for the bright outbursts in CH UMa are assumed. We can easily clarify why we do not take the faint outbursts in CH UMa into account here. Firstly, one can hardly speak about any cycle-length of the faint outbursts (Figs. 1 and 5) because they are rather randomly distributed among the bright ones and sometimes they even occur in clusters. Secondly, the difference of the maximum brightness between the bright and faint outbursts is large (about 2 mag_{vis}). Some authors tend to regard such small events as fluctuations of the quiescent level rather than outbursts, which may introduce a bias towards longer T_C in some systems in Fig. 11.

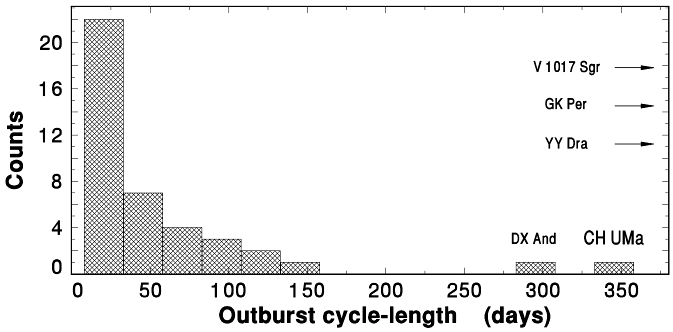

Fig. 12. Statistical distribution of $T_{\rm C}$ of the outbursts in dwarf novae above the period gap. Width of the bin is 25 days. No resolution of the U Gem and Z Cam subtypes is applied. If a range of $T_{\rm C}$ in a particular CV is known then the mean value is plotted. Position of CH UMa and several other systems are marked. See Sect. 4 for details.

The statistical distribution of $T_{\rm C}$ of the outbursts in dwarf novae above the period gap is displayed in Fig. 12. In order to keep a reasonable number of values in a single bin, no resolution of the U Gem and Z Cam subtypes was applied. If a range of $T_{\rm C}$ in a particular CV is known then the mean value is plotted. The distribution of $T_{\rm C}$ is highly asymmetric with a sharp cut off and a prominent tail towards long cycle-lengths, but not exceeding $T_{\rm C} \approx 170$ days. CH UMa along with YY Dra, DX And, GK Per and V 1017 Sgr are clear outliers.

5. Discussion

We have presented an analysis of the long-term activity of the dwarf nova CH UMa. $T_{\rm C}$ of the bright outbursts is about 300 days or longer, that is why only about 30 outbursts of several kinds have been observed. We revealed that the system exhibits two largely divergent types of outburst, in regard to their maximum brightness and relative energy. They may be analogous to the outbursts observed for example in SS Cyg ("long" and "short"–e.g. Cannizzo & Mattei 1992). However, in the case of CH UMa all faint outbursts are not only more narrow than the bright ones but the difference in their maximum brightness is very large, approximately 2 $\rm mag_{vis}$, and the ratio of their relative energies is almost 9:1. Fig. 6ab shows that the bright and faint outbursts tend to alternate, again in a way similar to SS Cyg.

The course of the light curve can help to resolve the type of outburst (A versus B). These types were defined by the models of Smak (1984). The onset of the thermal instability, giving rise to the outburst, occurs in the outer parts of the disk in type A (outside-in outburst). The light curve of the A type outburst is characterized by a large asymmetry (rapid rise and slow decay). On the contrary, the instability of the B type outburst, starting in the inner parts of the disk and propagating outwards (inside-out outburst), produces a rather symmetric light curve with a slow rise. The B type is typical for systems with a relatively low mass transfer rate $\dot{m}$ (Smak 1984). The outburst rising branch in CH UMa is covered only in a few cases but several outbursts with a slow rise can definitely be resolved. Some others are rather symmetric with a sharp top – they bear a close resemblance to the type B. This classification is also supported by the occurrence of the alternating bright and faint outbursts, predicted for the B type by Smak (1984).

The properties of the decay from the outburst in the framework of the thermal instability model are determined by velocity of the cooling front as it moves inwards and samples the respective radii of the disk. The computations by Cannizzo (1994) can serve as a guide line here. They make use of the viscosity parameter α as a function of the disk radius in the form $\alpha = \alpha_0 (r/r_{\rm outer})^{\epsilon}$. *The parameter ϵ gives the degree of dependence of α on the disk radius (α independent of r for $\epsilon = 0$). Cannizzo's models were computed for ϵ between -0.3 and 0.6.* The exponential parts of both types of decay in CH UMa which differ just in the decay rate can be interpreted in terms of different values of α for each type (the lower α, the slower decay). The upper part of the fast decay which is curved downwards may be accounted for by the radial dependence of α, having $\epsilon < 0$, in the outer part of the disk where the cooling front starts.

The slow decay type which displays a departure from the exponential decay (the tail) in the bottom part of the light curve bears some analogy to the glitch in the slow decays in SS Cyg (Cannizzo & Mattei 1998). However, in CH UMa the original slope is not resumed after the glitch, instead, the decay rate slows down until the quiescent level is achieved. This similarity, if really of a common physical origin, would imply that because the slow bottom part of the decay or the glitch occurs only for the decays which are slow throughout, it is also related to low α in the outer and middle parts of the disk.

The typical time-scale on which the outbursts in CH UMa recur is 300–370 days. It is clear from Fig. 11 that this is the longest, or the second longest $T_{\rm C}$ among the systems with 3 hr$<$ $P_{\rm orb} < 1$ day, that is among CVs whose secondaries do not differ very much from the main-sequence stars (Beuermann et al. 1998). The two CVs (GK Per; $P_{\rm orb} = 2$ days and V 1017 Sgr; $P_{\rm orb} = 5.7$ days) for which much longer $T_{\rm C}$ is confirmed (Warner 1995) have significantly evolved secondaries. Two of the systems with the longest $T_{\rm C}$ contain magnetized white dwarf (YY Dra – Patterson et al. 1992; GK Per – Watson et al. 1985) which may play a role in their outburst characteristics. The long $T_{\rm C}$ in CH UMa implies a very low mass transfer rate $\dot{m}$ and/or α (Ichikawa & Osaki 1994, see below). The normalized $\dot{m}$ versus $T_{\rm C}$ (Fig. 3.33 in Warner 1995) even predicts that CH UMa falls beyond the allowed cycle-lengths unless its α is very low. The inferred type B of the outbursts is in accordance with the low $\dot{m}$.

Changes of $T_{\rm C}$ in CH UMa are very prominent, but not quite chaotic. The $O-C$ curve is plausibly defined only for the bright outbursts; it implies that the "clock" holds only for outbursts in which the entire disk is brought into the hot state. The $O-C$ changes of the bright outbursts can be described by a strong secular parabolic trend with a superposed "fine" structure or, alternatively, as a result of several jumps in $T_{\rm C}$. The general trend of the $O-C$ changes suggests a secular decrease of $T_{\rm C}$. The fine structure of the $O-C$ diagram often consists of segments within which the bright outbursts follow a linear course (that is they have a constant period) for several epochs.

These segments are separated by episodes of abrupt changes. This phenomenon is also seen in SS Cyg and U Gem, again only for the long outbursts (Vogt 1980). It is rather surprising that no attention seems to have been paid to this behaviour since Vogt's (1980) paper.

The course of the $O - C$ curve in Figs. 5 and 9 definitely requires a mechanism for occasional rapid changes of $T_{\rm C}$. However, variations of $T_{\rm C}$ are far from being well understood in the framework of the current models of the thermal instability. Changes of the parameters like $\dot{m}$, α or the rate of removing the angular momentum J from the disk are promising. The models by Ichikawa & Osaki (1994), assuming $\dot{m}$ stable at some level, show that $T_{\rm C}$ is inversely proportional to $\dot{m}$, but only if $\dot{m}$ is sufficiently high so that the mass accumulation time is shorter than the viscous diffusion time. The latest model with variable outer disk boundary $r_{\rm outer}$ (Hameury et al. 1998) confirms this conclusion and shows that increasing $\dot{m}$ leads to both the more frequent and wider outbursts while the previous parametric study by Cannizzo (1993), using fixed $r_{\rm outer}$, led only to increasing outburst width at constant $T_{\rm C}$. Considering the rapid changes of $T_{\rm C}$, the situation is more complicated. Model with the fixed $r_{\rm outer}$ by King & Cannizzo (1998) implies that an abrupt decrease of $\dot{m}$ leads to decrease of the peak brightness and width of the outbursts, but not to a rapid change of $T_{\rm C}$ – the outbursts keep their original period even for more than 20 following epochs after the change of $\dot{m}$ because mass of the disk has to decrease to a new equilibrium value. It remains unclear whether the variable $r_{\rm outer}$ alters this result. The reverse case, that is relation of $T_{\rm C}$ to an abrupt increase of $\dot{m}$, remains to be modeled. Both the outburst relative energy and brightness of maxima in CH UMa (Fig. 6b) tend to decrease over the covered interval, while the secular term in the $O-C$ curve suggests prevailing shortening of $T_{\rm C}$ – this anticorrelation contradicts the variations of $\dot{m}$.

Another mechanism for rapid variation of $T_{\rm C}$ is a variable removal of the angular momentum J from the matter in the torus, for example if the magnetic field from the star spots on the secondary reaches over to the disk (e.g. Meyer-Hofmeister et al. 1996). The observable outburst parameters in CH UMa – general decrease of their relative energy and maximum brightness (Fig. 6b) with the decrease of $T_{\rm C}$ through the covered interval – are in accordance with this model. However, the abrupt changes are inconsistent with cycles of magnetic activity of the secondary. Such solar-type cycles are sometimes searched for in the activity of CVs (e.g. Warner 1988, Bianchini 1990). In contrast, for CH UMa we need J to change rapidly and persist on a given level for several following outbursts. A more plausible interpretation is that the rate at which J is removed is tightly related to existence of individual spot(s) and can change with appearance and vanishing of a spot. In this context, it may be worthy of further analysis if densely spotted regions would be able to cause the underluminosity of the secondary, found by Friend et al. (1990).

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