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On the character of the orbital period changes in the interacting binary RW Tauri

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Abstract. An analysis of the minima timings covering more than a century showed that two seasons of activity can be established (JD = 2 410 000 – 2 423 000 and JD = 2 435 000 – 2 450 000), separated by an interval about 12 000 days (33 years) long in which the period was almost invariable. Most period variations in each season have character of episodes of abrupt changes of both signs and are separated by intervals of almost constant period. The length of interval separating the episodes is more than a thousand days. The net result of the respective episodes was shortening of the orbital period. The episodes of the period decrease in 1982 and 1987 coincide with the minimum brightness of the loser (photometry of Olson and Etzel 1993). It is concluded that variations of the orbital period in RW Tau are not evolutionary and probably are not directly related to the mass transfer events. Instead, an alternative interpretation incorporating changes of the internal structure of the convective loser is offered.

Key words: stars: activity – binaries: close – binaries: eclipsing – circumstellar matter – stars: interiors – stars: individual: RW Tau

1. Introduction

RW Tau is an Algol-type binary with deep total eclipses (8.0 – 11.5 mag(V)) and orbital period P = 2.77 days. The spectral types of the primary and secondary component are B8V and K0III-IV, respectively (Grant 1959, Plavec and Dobias 1983). The cold secondary fills in its Roche lobe.

RW Tau is one of the first binaries where the circumstellar matter (CM) was detected spectroscopically (Wyse 1934, Joy 1942). Analysis of the full orbit emission Hα profiles by Vesper and Honeycutt (1993, hereafter VH93) showed two seats of emission from CM: the region of impact of the mass stream on to the gainer and a possible transient disk. The UV observations by *IUE* carried out by Plavec and Dobias (1983) revealed high-excitation lines visible during the primary eclipse which were attributed to an extended envelope typical for the W Serpentis stars (Plavec 1980).

The intrinsic photometric activity of RW Tau was interpreted in terms of two mechanisms: the transient disk with an almost photospheric density was used for the explanation of the distorsions of the shoulders of the eclipse light curve (Olson 1982) while the variations of the level of the totality in RW Tau (and several other Algols) were interpreted in terms of temperature variations of the cold loser by Olson (1981) and Olson and Etzel (1993).

The orbital period of RW Tau is highly variable. Plavec (1960) brought arguments against the apsidal motion and the light-time effect as the causes of these variations. Frieboes-Conde and Herczeg (1973) concluded that the light-time effect is improbable and that the $O - C$ variations may be better described as the episodes of abrupt changes.

The preliminary version of this analysis was presented by Šimon (1996).

2. Collection of the data

The very deep eclipses (ΔV = 3.5 mag(V)) of RW Tau have been attracting many observers for almost a century. The timings up to 1960 were compiled by Plavec (1960) while the newer ones come from Frieboes-Conde and Herczeg (1973), Vesper and Honeycutt (1993), Hanžl (1990) and Baldwin and Samolyk (1993). Many other timings (mostly visual) were also published in Contrib. Obs. Plan. Brno, BBSAG Bull. and BAV Mitt. (see the references). The minima published by Plavec (1960) were used for the interval of 1890–1960. The plots of the newer timings were visually inspected and several largely deviating minima were rejected from the set. The photoelectric timings were given weight w = 10, the other ones (mostly visual) usually received weight w = 1. Although a large part of the following analysis deals with the individual timings the one-year means were calculated, too, and are given in Table 1 along with their standard deviations.

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Table 1. The one-year means of the minima timings since the year 1960. $Min.$ (HJD) gives the Julian Date of the mean. The corresponding epoch E and $O-C$ values calculated according to equation 5 are listed, too. The last column gives the standard deviation of the $O-C$.

$Min.(HJD)$	E	$O-C)$	σ
36569.1945	-3957	-0.1464	0.0020
36851.6140	-3855	-0.1436	0.0020
37560.4302	-3599	-0.1380	0.0036
38399.3932	-3296	-0.1188	0.0018
38759.3413	-3166	-0.1136	0.0008
39033.4600	-3067	-0.1053	0.0020
39473.7048	-2908	-0.0983	0.0016
40160.3762	-2660	-0.0872	0.0019
40531.4016	-2526	-0.0798	0.0017
40938.4254	-2379	-0.0684	0.0028
41334.3768	-2236	-0.0542	0.0022
41622.3330	-2132	-0.0523	0.0010
42815.6992	-1701	-0.0352	0.0010
43128.5771	-1588	-0.0307	0.0018
43820.7827	-1338	-0.0230	0.0018
44180.7318	-1208	-0.0168	0.0011
44612.6683	-1052	-0.0117	0.0012
44928.3186	-938	-0.0036	0.0030
45357.4850	-783	0.0001	0.0018
45753.4247	-640	0.0026	0.0021
46005.3852	-549	0.0031	0.0020
46401.3235	-406	0.0042	0.0029
46819.4126	-255	0.0058	0.0007
47140.5927	-139	0.0061	0.0025
47525.4492	0	0.0006	0.0020
47907.5386	138	-0.0032	0.0040
48292.3965	277	-0.0073	0.0020
48652.3363	407	-0.0104	0.0023
48920.9045	504	-0.0150	0.0011
49693.3899	783	-0.0224	0.0032

The whole $O-C$ curve calculated according to Eq. 1 and representing about a century of continuous observing can be seen in Fig. 1. This ephemeris keeps a low slope of a large part of the $O-C$ curve and the changes are therefore easily discernible. Moreover, two possible maxima of the $O-C$ curve around JD = 22 500 and 44 000 have equal height. In the following text we will use the Julian Date with subtracted 2 400 000.

$$T(min.I) = 47\,525.4486 + 2.768827318\ E \qquad (1)$$

The full range of the orbital period changes is more than 0.2 days (about five hours) and it can be readily seen that the overall shape of the $O-C$ curve in Fig. 1 is far from being strictly periodic.

3. Influence of the eclipse light curve changes

Variations of the light curve of the primary eclipse of RW Tau were analysed by Olson (1982) and as can be seen from his graphs especially the descending branch is often affected. If the distorsions in Fig. 3 in Olson (1982) are taken as the representative ones then the shift of a minimum timing due to them shouldn't exceed 4–5 min if the whole eclipse light curve is assumed and 10 min if only the bottom part is taken. We can therefore conclude that although the distorsions of the light curve may increase the noise of the $O-C$ values they can hardly contribute significantly to the overall course of the $O-C$ changes analysed here.

4. Analysis of the data

There were developed several methods for the analysis of irregular period changes. It is possible to inspect visually the data, divide the $O-C$ curve into segments of apparently constant period and determine the period length valid for each part. This procedure is suitable for abrupt changes but was also used for an analysis of the possibly smooth variations of SW Cyg (Berrington and Hall 1994).

Another method described by Kalimeris et al. (1994) is based on the fit of the $O-C$ curve by a high-order polynomial. Its derivative then gives an information about the period changes. This method can give very good results for smooth continuous variations but may fail when it is applied to a data set which contains abrupt changes or intervals of constant period.

Usually we have to make some assumptions about the character of the $O-C$ variations first and it may influence the choice of the method. It may be therefore convenient to try more methods and compare their results. Also the period length used for the calculation of the $O-C$ values plays an important role in the searching for the $O-C$ changes since the increasing slope of the curve significantly suppresses the visibility of the period variations.

The analysis of the data of RW Tau was divided into several steps. In the first step the $O-C$ values were calculated using various period lengths and the plots were visually inspected. Particular attention was paid to the seasons where the period was most variable. The analysis led to conclusion that two epochs of activity can be established: Season I (JD = 10 000 – 23 000) and Season II (JD = 35 000 – 50 000). These two epochs are separated by an interval about 12 000 days (33 years) long in which the period can be considered almost constant. Detailed inspection of the timings with the weights given by Plavec (1960) revealed that although some changes (noted already by Plavec) may be present their course is in most cases formed by the timings with the lowest weight. It should be noted that there are not any photoelectric timings before 1948. In any case, no $O-C$ changes with amplitude larger than 0.01 days occured within JD = 23 000 – 35 000.

Since also the photoelectric data are available for the Season II and as the experiments showed the period changes are better defined there it was decided to perform the analysis of Season II first and then to return to Season I.

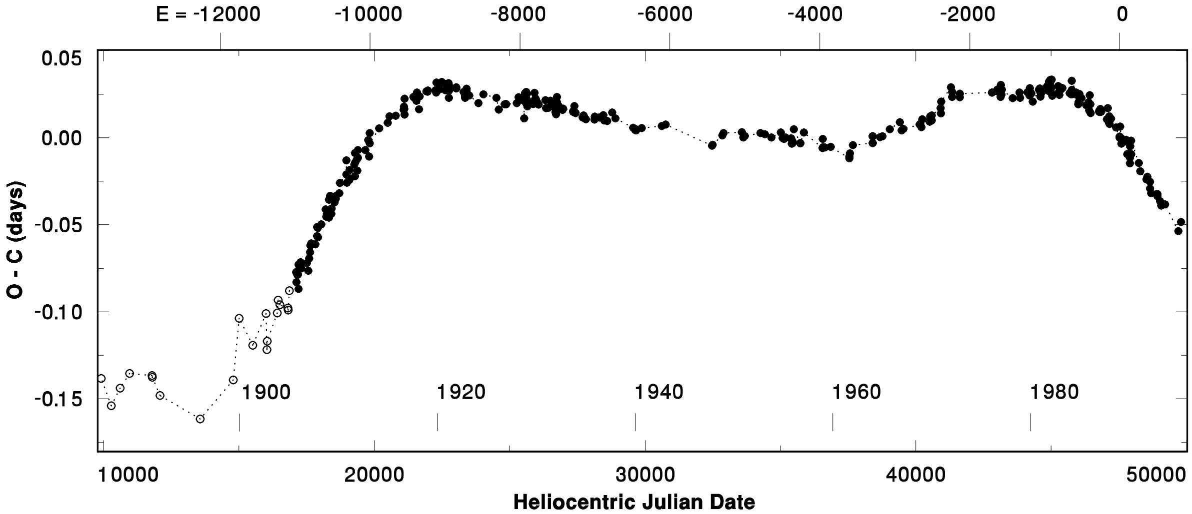

Fig. 1. The whole set of the minimum timings of RW Tau. The ephemeris given in Eq. 1 was used for calculation of the $O-C$ values. The data before JD = 17 000 coming from the Harvard archival plates are marked by empty circles.

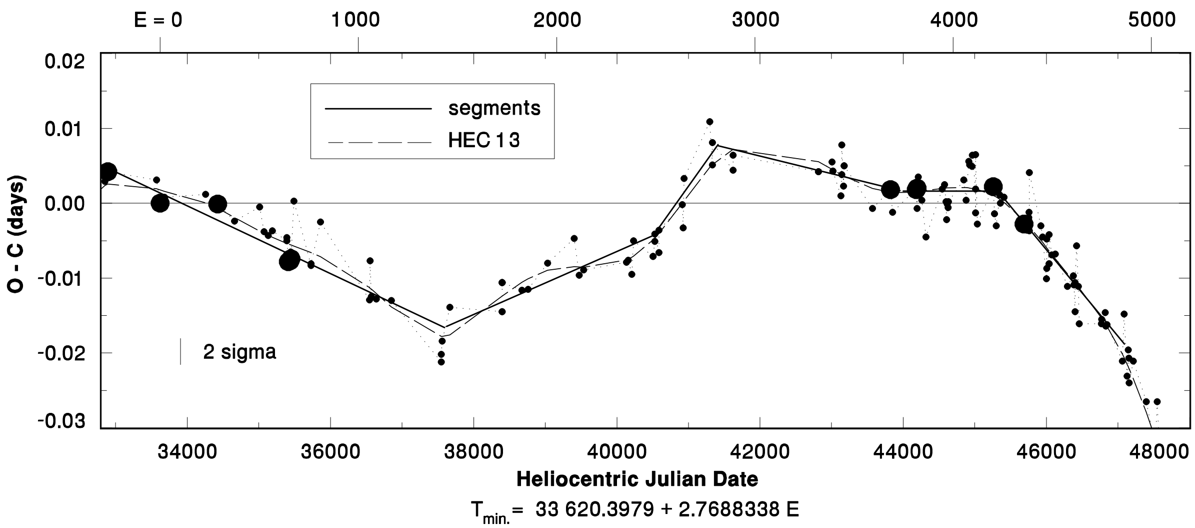

Fig. 2. A part of the $O-C$ curve in years 1950–1987 when a series of period changes occured. The fits by two different methods are shown. Notice the very good agreement of the photoelectric and visual timings. See the text for details.

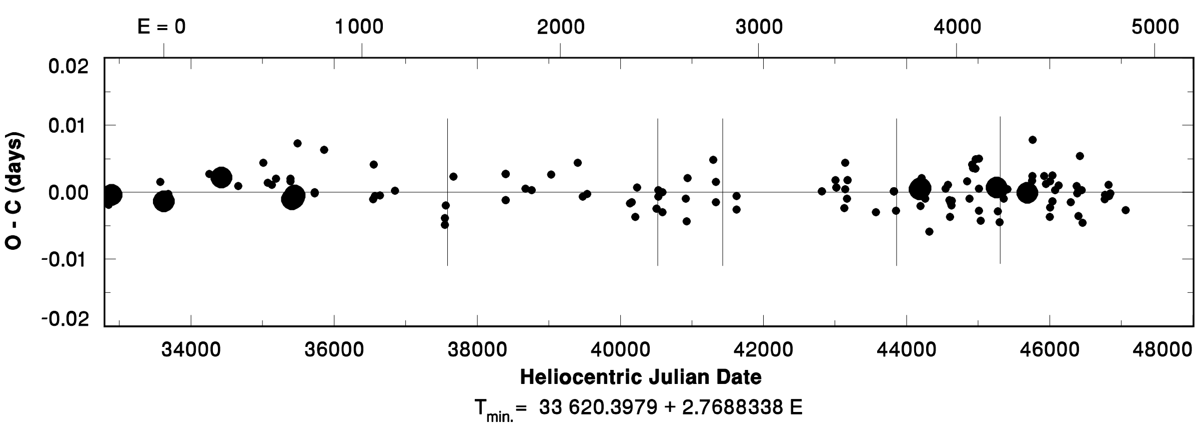

Fig. 3. The residuals of fit of the $O-C$ values after correction for the abrupt changes using the method of segments. The vertical lines mark the positions of the changes.

4.1. Analysis of Season II

The individual data for Season II, computed using Eq. 2, are displayed in Fig. 2. Since the course of the $O-C$ changes is complicated two independent approaches were applied to resolve character of these variations. In the "classic" method the plots of the data were visually inspected and divided into segments of apparently constant period. The period for each segment was then determined by the linear fit using the method of the least squares. The moment of each episode of the period change was derived from the intersection of the fits in the neighbouring segments. These linear fits are displayed as the solid lines in Fig. 2 and the respective period lengths along with the standard deviations of the fits are given in Table 2. The residuals can be seen in Fig. 3.

$$T(min.I) = 33\,620.3979 + 2.7688338\ E \quad (2)$$

An independent test was carried out using the program HEC 13 written by Dr. Harmanec at the Ondřejov Observatory. This program is based on the method of Vondrák (1969 and 1977) and can fit a smooth curve to the data no matter what is their course. The output file from HEC 13 contains the coordinates of each original data point along with the corresponding ones of the point of the smooth curve. This fit is represented by a dashed line in Fig. 2 and one can see that both methods agree within the observational errors. The input parameters characterizing the smooth curve were adjusted interactively to yield curve which plausibly fits the long-term changes but is free of false features arising from scatter of the data and/or seasonal gaps. This impersonal fit by HEC 13 again led to the evidence that most period variations in RW Tau do have a character of abrupt changes and that the representation by the segments is justified. The program HEC 13 identified one more possible episode around JD = 39 000. Nevertheless, the fits by both methods are within the 1σ error there and available data (only visual in this segment) don't allow to decide whether this change is real. Fig. 4 brings the comparison of the statistical distributions of the residuals obtained by both methods. The residuals don't differ significantly and both distributions are approximately Gaussian.

Although the period changes of both signs were detected the net result of these episodes is shortening of the orbital period. Moreover, notice that apart from one episode, in all cases the magnitudes of the respective changes have ratio less than one to two.

For the future observations of RW Tau the following ephemeris determined from the last segment can be recommended:

$$T(min.I) = 47\,907.5386 + 2.76876044\ E \quad (3)$$

4.2. Analysis of Season I

A too high slope of a part of the $O-C$ curve in 1900–1922 in Fig. 1 makes the variations less discernible in Season I. The ephemeris in Eq. 4 was therefore determined from the linear fit to the data in Season I and used for the analysis of this part of the data.

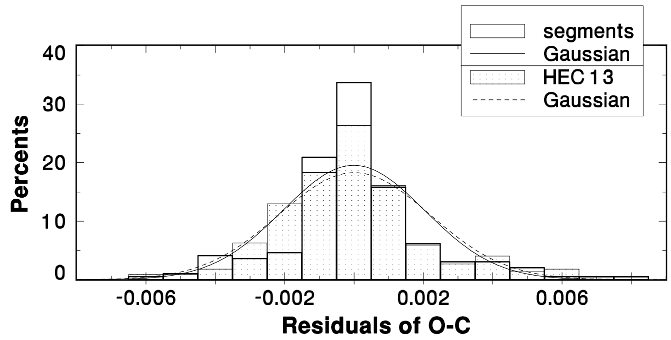

Fig. 4. Comparison of the statistical distributions of the residuals of the fit to the $O-C$ values obtained by the method of segments and by the program HEC 13 (as can be seen in Figs.2 and 3). The distributions are approximately Gaussian and are almost identical for both methods.

$$T(min.I) = 47\,525.4486 + 2.7688643\ E \quad (4)$$

Since the data before JD = 17 000 come from the Harvard archival plates and their scatter is very high one can only state that at least one episode of period increase took place in this interval (probably near JD = 16 000). It was therefore decided to analyse only the timings within JD = 17 000 – 25 000 in more detail. The data in this interval were fitted by the program HEC 13 again.

The statistical distribution of the residuals of this fit is well represented by a Gaussian, nevertheless, the Gaussian curve of the data from Season I is considerably broader than that for Season II (Fig. 4) what can be plausibly explained by a lower accuracy of the old data. This fact may be the reason why the character of the period changes in Season I cannot be unambiguously recognized. Although the impersonal fit by HEC 13 revealed some pattern in the changes the data don't allow for a conclusive interpretation.

The best defined episode of period change in Season I took place around JD = 22 500. The magnitude of the change of period was $\Delta P/P = -1.24 \times 10^{-5}$ and this value was determined from the linear fits to the segments in the intervals of JD = 20 670 – 22 330 and 22 600 – 27 180, respectively.

4.3. Comparison with U Cep

Comparison of a part of the $O-C$ diagram for RW Tau (Fig. 2) with that for a similar active system U Cep (Fig. 5) reveals some common features in the $O-C$ changes (the data for U Cep taken from Olson et al. 1981). The intervals of epochs of both graphs are almost equal and since the periods of these two systems differ only by about 10% also the intervals of JD are not very different. Changes of both signs can be seen in both systems and even their time scales are comparable (see also below).

Table 2. Abrupt changes of the orbital period in RW Tau. $JD(change)$ represents the Julian Date of the episode. Δt (days) gives the time interval separating two consecutive episodes while P (days) is the period length in each interval. ΔP and $\Delta P/P$ refer to the change of the period in a particular episode.

$JD(change)$	Δt (days)	P (days)	ΔP (days)	$\Delta P/P$
		2.76882134		
37 580			2.38×10^{-5}	0.86×10^{-5}
	2 940	2.76884515		
40 520			2.67×10^{-5}	0.96×10^{-5}
	910	2.76887181		
41 430			-4.47×10^{-5}	-1.61×10^{-5}
	2 430	2.76882715		
43 860			0.69×10^{-5}	0.25×10^{-5}
	1 440	2.76883403		
45 300			-3.17×10^{-5}	-1.14×10^{-5}
	1 800	2.76880232		
47 000			-4.19×10^{-5}	-1.51×10^{-5}
	$> 2\,700$	2.76876044		

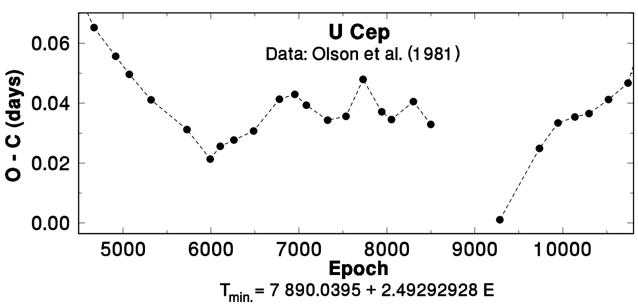

Fig. 5. A detailed view of a part of the period changes in U Cep. These averaged data were taken from Olson et al. (1981). Notice that the short-term changes of both signs are apparent. See the text for details.

4.4. Relation of the $O - C$ and brightness changes

In addition to the $O - C$ data also the Stromgren photometry of changes of the level of the center of the total primary eclipse (published by Olson and Etzel 1993) in JD = 43 800 – 49 100 is available therefore this epoch deserves a special attention. The $O-C$ changes in this interval, calculated using the ephemeris in Eq. 5, are plotted in Fig. 6b while the photometry of the center of the total primary eclipse in the b-band can be seen in Fig. 6a. The same time scale was used for both figures. The period length used in Eq. 5 was determined to give the zero slope of the linear fit in this interval and shows the period changes with the best clarity.

$$T(min.I) = 47\,525.4486 + 2.76879143\ E \qquad (5)$$

The orbital period is far from being constant in this interval. Two abrupt changes around JD = 45 100 and 47 000 can be recognized and the fit by three straight lines satisfactorily represents the $O - C$ values within the given error bars.

Although the coverage of the light curve in Fig. 6a is not quite complete two minima of brightness are apparent. Comparison of both figures reveals some coincidence of the abrupt changes of the orbital period with the minima of brightness.

The individual timings in this interval, plotted on the expanded time scale, can be seen in Fig. 7. The photoelectric timings were given weight 10, the visual ones with more than twenty points on the light curve received weight 2 and the rest visual observations were evaluated by weight 1. The correspondence of the photoelectric and visual timings is excellent and the $O-C$ curve is well defined in the vicinity of both episodes. Also the fit by the program HEC 13 (solid line) again confirmed two large changes.

4.5. Relation of the $O-C$ changes and the mass transfer events

The comparison of the period changes with the observations of mass transfer events (MTE) is difficult since the latter data are scarce. Distorsion of the RV curve due to the gas stream, observed in years 1939–1947 and as strong as in U Cep, was reported by Plavec (1962). The orbital period was almost constant in this interval (see Fig. 1).

Other spectroscopic evidences for circumstellar matter in RW Tau were brought by Wyse (1934), Joy (1942 and 1947), Baldwin (1976), Plavec and Dobias (1983) and VH93 (see also sect.1).

Photometric observations of mass transfer come from Olson (1980, 1981 and 1982). Olson (1981) discussed observations of RW Tau and U Cep and suggested that brightening of the loser in both systems often accompanies episodes of MTE.

The diagram in Fig. 8, constructed from the measurements published by VH93, shows variations of the equivalent width (EW) of the Hα emission in the course of the years 1988–1992. The component B, attributed to the transient disk by Vesper and Honeycutt, was used here. Usually, some emission is present and its intensity was often increased after JD = 48 200. The respective runs are marked by vertical lines in Fig. 6b and this figure reveals that the orbital period can be considered constant

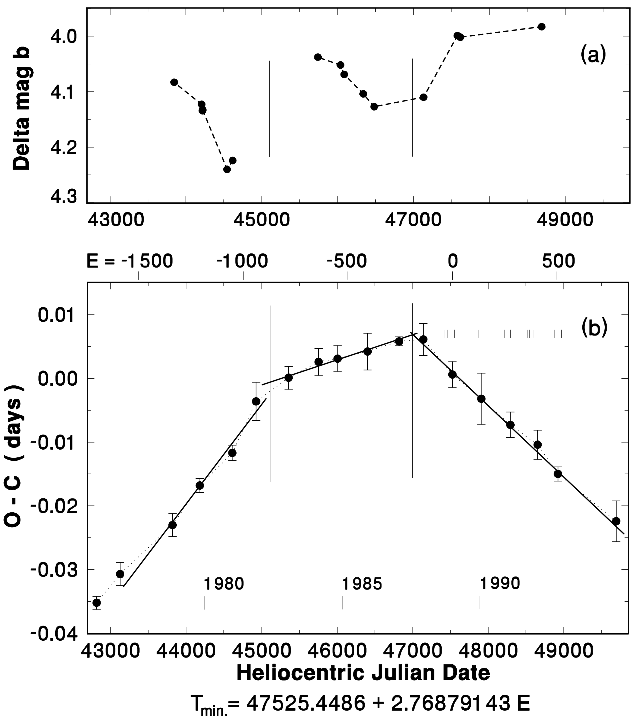

Fig. 6a and b. Comparison of the $O - C$ changes (**b**) with the Stromgren photometry of variations of the level of the center of the total primary eclipse (**a**) in RW Tau. The one-year means were used for the $O - C$ values here and are plotted together with their standard deviations. The photometry was published by Olson and Etzel (1993). Two abrupt changes of the period around JD = 45 100 and 47 000 can be recognized. The same time scale was used for both figures and it can be seen that two minima of brightness occured in the vicinity of the discontinuities of the period as is marked by the long vertical lines. The series of short lines in **b** marks the runs of observations by VH93.

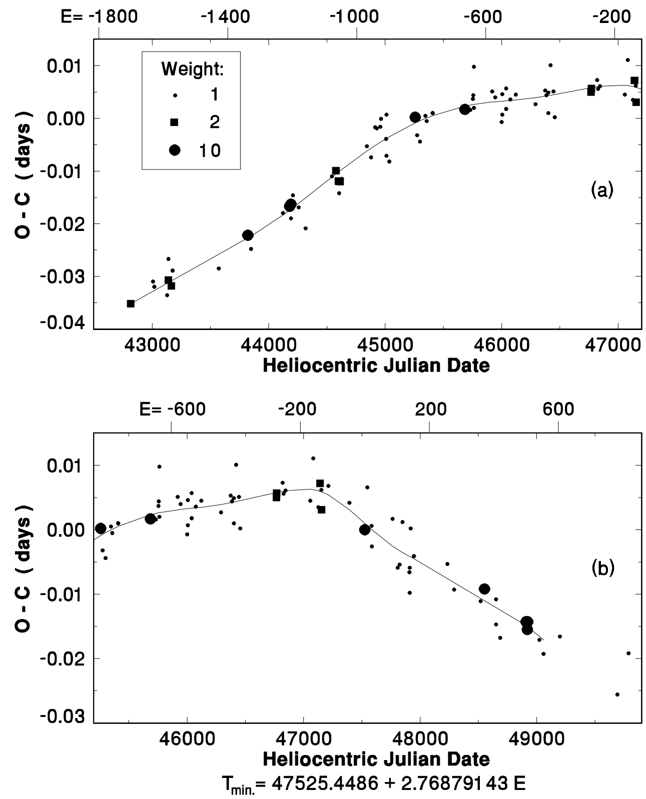

Fig. 7a and b. The individual timings of the same part of the $O - C$ curve as in Fig. 6. The fit by the program HEC 13 (solid line) again revealed two large changes in this interval.

in 1988–1992 and even the event of enhanced emission strength wasn't accompanied by any detectable period change. The mass transfer rate $\dot{m}$ of the order of $10^{-9} M_{\odot} yr^{-1}$ was estimated by VH93 from the Hα emission strength.

In summary, we can say that whenever the search for activity connected with mass transfer in RW Tau was undertaken manifestations of interaction in the system were detected in most cases.

5. Discussion

The overall course of the $O-C$ changes displayed in Fig. 1 is far from being strictly periodic. The data spanning an interval more than a century long ruled out the presence of the third body with the orbital period of 88 years which was offered by Frieboes-Conde and Herczeg (1973) as an alternative explanation for the period changes.

Instead, the detailed analysis led to the evidence that most period variations in RW Tau have character of abrupt changes and confirmed the earlier proposal of Schneller (1962). Very dense coverage of the $O - C$ curve is necessary to determine the time scale of these abrupt changes but now we can already state that at least the duration of the last observed and well covered episode wasn't longer than one or two years.

A "typical time scale" longer than a thousand days is present in the occurrence of most episodes of the orbital period changes in RW Tau. The period in the segments separating the episodes is often almost constant. A characteristic value of $\Delta P/P$ is of the order of 1×10^{-5} and a change of any sign is possible. There doesn't appear to be any rule in the distribution of the signs of $\Delta P/P$. It is even possible that each episode produces a decrease or increase of the period length at random. The observed pattern in Fig. 1 is then a sum of the particular episodes and the net result is shortening of the orbital period.

It is difficult to interpret these changes of the orbital period in RW Tau in terms of traditional scheme of the mass transfer (e.g. Huang 1963). The conservative case can lead only to increase of the period in RW Tau. Only non-conservative transfer (intermediate mode in Huang 1963) where part of matter forming a ring around the binary removes angular momentum would be able to give an explanation but a complicated scheme with many free parameters is needed. As was pointed out above manifestations of the mass transfer were detected in many occasions, even in epoch of the constant period, but any corresponding period change wasn't detected during MTE in 1991. To explain the episodes of period changes in Season II (Table 2) in terms

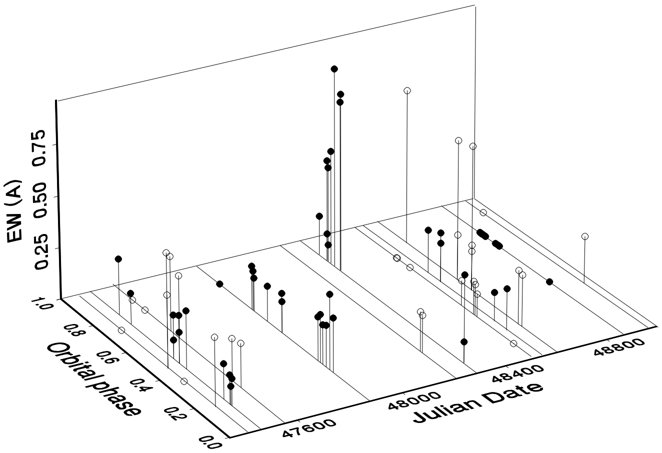

Fig. 8. Equivalent widths of the Hα emission in RW Tau. The diagram is constructed from the measurements published by Vesper and Honeycutt (1993) and shows variations of the strength of the emission (component B) in the course of the years 1988–1992. The episode of enhanced emission after JD=48 200 wasn't accompanied by any period change (see Fig. 6b).

of intermediate mode, one would have to postulate additional very large unnoticed mass transfer bursts. Moreover, the values of $\Delta P/P$ in the respective episodes don't differ by more than one to two therefore also the parameters of the particular events (e.g. radius of the circumbinary ring and amount of matter in it) would have to be quite similar to each other. It is therefore quite probable that the period changes and MTEs are not directly connected. It is interesting to note that the analysis of U Cep by Olson et al. (1981) revealed similar behaviour: the period changes of both signs were completed in several tens of days and were separated by epochs of constant period. These episodes weren't usually accompanied by MTE (with one exception of a period increase in 1974).

It is worth noting that character of the period variations seen in RW Tau can also be found in other Algol-type binaries and even the value $\Delta P/P \approx 1 \times 10^{-5}$ is typical (e.g. XZ Aql, RR Dra, CT Her (Pokorný and Zlatuška 1976), BG Peg (Wagner and Šilhán 1988), U Cep (Olson et al. 1981, see below)). However, the series of data for XZ Aql, RR Dra and BG Peg show that the intervals separating the episodes are significantly longer than in RW Tau. On the other hand, the intervals between the respective episodes in RW Tau have about the same length as those in U Cep, as can be seen from comparison of Figs. 2 and 5.

The possible connection of the decrease of brightness of the totality with the episodes of period changes in RW Tau, visible in Figs. 6a and b, can help to trace the source of the period changes. An objection can be made that the brightness variations are smooth while the orbital period displays abrupt discontinuities. Nevertheless, slight curvature may be present in the vicinity of most abrupt changes and a single episode may last up to two years, with maximum period change coinciding with the extreme of brightness. Olson (1981) and Olson and Etzel (1993) successfully modelled these brightness changes in the *u,v,b,y,* I(Kron) bands by the temperature variations of the cold component (loser). If this correlation is real it allows us to identify the secondary component with the source of changes of the orbital period in RW Tau. Certainly, one can ask whether the course of the brightness variations displayed in Fig. 6a isn't a pure consequence of a small number of the data. Nevertheless, the plots of variations in six systems analysed by Olson and Etzel (1993) (their Fig. 5) support rather smooth course of the brightness changes.

Applegate (1992) presented a theory which explains the cyclic orbital period variations by changes of the internal structure caused by the sub-surface magnetic field in the convective envelope of the component of the binary (the active star). According to this theory the period changes through the cycle should be accompanied by corresponding changes of the brightness of the active star. In case of RW Tau, however, although one may see some periodicity in the light curve displayed in Fig. 6a the comparison with Fig. 6b reveals that both minima of brightness were accompanied by shortening of the orbital period. We can therefore conclude that this mechanism in the form proposed by Applegate (1992) isn't responsible for the period changes in 1982 and 1987.

Instead, we offer an alternative interpretation, though in the present state only qualitative. According to Olson (1981) the brightness variations of the loser could be explained by the recombination radiation originating in the matter moving upwards in the outer layer of the star. As the recent calculations presented by Petrova (1995) showed (although carried out only for single stars) for evolved cold stars with convective envelope the constant of the apsidal motion k_2 is significantly influenced by the outer layers of the star (even those lying close to the photosphere). k_2 is therefore very sensitive to any change of the density profile in the outer layer of the convective secondary (and these layers are subject to the mass loss).

As was shown by Matese and Whitmire (1983) the observed period changes of the order of $\Delta P/P = 10^{-5}$ can be invoked by quite small variation of k_2. If we consider the two last observed changes in RW Tau both these events led to shortening of the period. In the framework depicted above, this shortening requires increase of k_2 which can be achieved by increase of density in the outer layer of the secondary even without any change of the stellar radius.

The calculations by Petrova (1995) also revealed that for evolved stars with convective envelopes k_2 steeply grows with decreasing effective temperature T_{eff} with only very small dependence on the stellar mass (e.g. k_2=0.0036 for T_{eff} = 5 620 K but grows to 0.030 at T_{eff} = 5 150 K for a 1.58 $M_\odot$ star). Indeed, the increase of k_2 necessary for shortening of the period of RW Tau is in accordance with the temporary decrease of T_{eff} of the loser.

In summary, the above hypothesis interprets the period changes in terms of response of the outer layers of the convective loser to the mass loss. For the sake of completeness, we should add that the early-type primary with its radiative outer layer is considerably more centrally condensed and is therefore less likely to produce the observed period changes in RW Tau.

We can also offer an idea that while the strong mass transfer rate $\dot{m}\approx 10^{-6}M_{\odot}yr^{-1}$ in U Cep can give rise to the parabolic term superposed on the short-term variations, significantly lower $\dot{m}\approx 10^{-9}M_{\odot}yr^{-1}$ in case of RW Tau (estimated by VH93 from the Hα emission strength) makes the evolutionary changes completely masked by the variations on the short time scales.

More future timings with simultaneous multi-band photometric and spectroscopic observations are needed to resolve to what extent these changes of the secondary can influence the mass transfer rate.

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References

Applegate, J.H., 1992, ApJ, 385, 621
Baldwin, B.W., 1976, IAU Symposium No.73, *Structure and Evolution of Close Binary Systems*, eds. P. Eggleton, S. Mitton, J. Whelan, 311
Baldwin, M.E., Samolyk, G., 1993, Observed minima timings of eclipsing binaries, No.1, American Association of Variable Star Observers, Cambridge, MA (USA)
BAV Mitt., No.36
BBSAG Bull., No.: 41, 45, 46, 47, 51, 52, 56, 58, 59, 63, 64, 65, 70, 71, 73, 74, 75, 76, 78, 79, 82, 83, 85, 86, 89, 90, 91, 92, 93, 94, 97, 99, 100, 101, 103, 104
Berrington, R.C., Hall, D.S., 1994, AJ, 107, 1868
Contrib. Obs. Plan. Brno, No.: 17, 26, 30
Frieboes-Conde, H., Herczeg, T.J., 1973, A&A Suppl., 12, 1
Grant, G., 1959, ApJ, 129, 62
Hanžl, D., 1990, IBVS, No.3423
Huang, Su-Shu, 1963, ApJ, 138, 471
Joy, A.H., 1942, PASP, 54, 35
Joy, A.H., 1947, PASP, 59, 171
Kalimeris, A., Rovithis-Livaniou, H., Rovithis, P., 1994, A&A, 282, 775
Matese, J.J., Whitmire, D.P., 1983, A&A, 117, L7
Olson, E.C., 1980, IBVS, No.1839
Olson, E.C., 1981, ApJ, 250, 704
Olson, E.C., Crawford, R.C., Hall, D.S., Louth, H., Markworth, N.L., Piirola, V., 1981, PASP, 93, 464
Olson, E.C., 1982, ApJ, 259, 702
Olson, E.C., Etzel, P.B., 1993, AJ, Vol.106, No.1, 342
Petrova, A.V., 1995, AZh, Vol.72, No.6, 924
Plavec, M.J., 1960, Pub. Astr. Inst. Czechoslovak Acad. Sci. Prague, No.46
Plavec, M., 1962, Bull. Astron. Inss. Czechosl., Vol.13, 224
Plavec, M.J. in Plavec, M.J., Popper, D.M., Ulrich, R.K., 1980, *Close Binary Stars: Observations and Interpretation*, 251, Dordrecht, Holland
Plavec, M.J., Dobias, J.J., 1983, ApJ, 272, 206
Pokorný, Z., Zlatuška, J., 1976, Bull. Astron. Inss. Czechosl., Vol.27, 341
Schneller, H., 1962, Mitt. Sternw. Ungar. Akad. Wiss., No.53
Šimon, V., 1996, The Proceedings of the 27th Conference on Variable Star Research, Brno, Czech Republic
Vesper, D.N., Honeycutt, R.K., (VH93), 1993, PASP, 105, 731
Vondrák, J., 1969, Bull. Astron. Inst. Czechosl., 20, 349
Vondrák, J., 1977, Bull. Astron. Inst. Czechosl., 28, 84
Wagner, V., Šilhán, J., 1988, Contrib. Obs. Plan. Brno, No.28, p.42
Wyse, A.H., 1934, Lick Obs. Bull., No.464

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