RESEARCH INTO THE CLOSE BINARY QQ CASSIOPEAE WITH THE PRIMARY COMPONENT OF THE EARLY SPECTRAL TYPE

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ABSTRACT. Photoelectric observations of QQ Cassiopeae, a close binary with the primary component of the early spectral type, were made. The observations were made at the Skalnaté Pleso Observatory in the blue and yellow part of the spectrum on five nights in 1986 and 1987. The published minimum epochs, derived from our observations, were used to study the changes of the orbital period. The light elements were calculated and a secular increase of the orbital period has been proved. The hypothesis of explaining the changes observed are discussed: a gradual or sudden change in the orbital period as a result of mass transfer between the binary components and the light-time effect.

ИССЛЕДОВАНИЕ ТЕСНОЙ ДВОЙНОЙ СИСТЕМЫ QQ КАССИОПЕИ С ПЕРВИЧНЫМ КОМПОНЕНТОМ РАННЕГО СПЕКТРАЛЬНОГО КЛАССА. Были получены фотоэлектрические наблюдения QQ Кассиопеи, тесной двойной системы с первичным компонентом раннего спектрального класса. Наблюдения были получены в обсерватории Скалнате Плесо в 1986 - 1987 гг. в синей области спектра, за исключением одной серии наблюдений, которая была получена в жёлтой области спектра. Опубликованные эпохи минимумов и новые эпохи были использованы для исследования изменений орбитального периода. Были вычислены элементы и было найдено вековое нарастание орбитального периода. Предлагаются гипотезы для объяснения найденных изменений: непрерывное или внезапное изменение орбитального периода как результат переноса материи или наличие третьего тела в системе.

VÝSKUM TESNEJ DVOJHVIEZDY QQ CASSIOPEAE S PRIMÁRNOU ZLOŽKOU RANÉHO SPEKTRÁLNEHO TYPU. Získali sa fotoelektrické pozorovania QQ Cassiopeae, tesnej dvojhviezdy s primárnou zložkou raného spektrálneho typu. Pozorovania sa získali v piatich nociach v období 1986 - 1987. Publikované epochy minima a nové epochy minima odvodené z nami získaných pozorovaní sa použili na štúdium zmien orbitálnej periódy. Diskutujú sa hypotézy vysvetlenia pozorovaných zmien: plynulá alebo náhla zmena orbitálnej periódy ako dôsledok prenosu hmoty medzi zložkami dvojhviezdy a light-time efekt.

1. INTRODUCTION

The star QQ Cas ($\alpha_{1950.0} = 23^h43^m11^s$, $\delta_{1950.0} = +59°37'.7$), tentative designation BV 73=BD +59°2765, was discovered by Kippenhahn (Geyer et al., 1955) who classified it as an eclipsing binary. He found that the amplitude of the light variations was 0.9 mag and determined the orbital period to be less than one day. Erleksova (1957) claims that the orbital period is much longer : 28.97 days. Later observations did not lend support to either of these values. Kukarkin (1957, 1959) was the first to publish its mean light curve, he classified it as a Beta Lyr type and derived its elements. He found the period of the light variations to be $P = 2^d.14030$, which is close to the orbital period derived from a long series of observations. Zonn and Semeniuk (1959) published the light curve and supported Kukarkin's conclusions. A comparison of the light curves from the end of the 1950's and 1975 indicated that the light curve was stable and that the observed differences were due to inaccuracies in observations.

QQ Cas was then frequently observed photographically, however, in view of the shape of the light curve and the length of the orbital period; the minimum epochs were derived with but small accuracy. The tables of the minimum epochs were published by, among others, Strohmeier and Bauernfeind (1968), Busch (1975), Braune and Lichtenknecker (1986). The accuracy of the orbital period derived by Kukarkin (1957) was gradually improved, and it was still assumed that the elements were linear. In analysing the observations made earlier by others, we found that the photographic minimum epoch, published by Hübscher and Mundry (1984), first and the photoelectric minimum ever, published by Hübscher et al. (1985), do not satisfy linear elements.

The spectral type of the primary component is B2, and that of the secondary component is not known. Since the star was observed only sporadically in the recent decades and only one photoelectric minimum epoch was obtained, and this did not satisfy the linear elements, we included the star in the observation program of the Astronomical Institute at Skalnaté Pleso. The preliminary results of our research were presented at the symposium "Variable phenomena in close binary stars", March 7 - 10, 1988, held in Budapest (Kreiner and Tremko, 1988, in press).

2. OBSERVATIONAL MATERIAL

This material was obtained with the 0.6/7.5 m mirror telescope of the Astronomical Observatory at Skalnaté Pleso in the years 1986 and 1987. The photoelectric photometer is mounted in the Cassegrain focus and operates in the principles of the method of pulse counts. It is equipped with an EMI 6295B electron multiplier with three sets of filters. One set of filters is designet for standard UBV photometry, another set of three filters for medium-band photometry and three filters for narrow-band photometry. Horak et al. (1976) have published a detailed description of the mechanical and optical parts of the photometer, as well as its photometric properties. The electronic part of the photoelectric photometer and its operation in connection with an EMG 666 desk calculator are described in (Klocok et al., 1986). The operation of the photometer was briefly described in our previous paper (Kreiner and Tremko, 1987).

The variable star was observed with the standard B filter with the exception of the night of Nov. 8-9, 1986 when a standard V filter was used. The interval over which the pulse count was taken was 10 seconds. The brightness of the sky was measured befor every observations of the variable, comparison and check star.The comparison star was measured twice before measuring the variable and twice after each series of measurements of the eclipsing variable. One series of measurements of the variable consisted of five individual measurements. The check star was measured only sporadically. The series of five measurements was made within 50 seconds.Since intrinsic variations of the variable's brightness on a time scale shorter than one minute were not expected, we reduced the measurements by creating a single observation from the series of measurements,which resulted in cutting down the size of the observations table by a factor of five without loss of information content.

Star BD $+58^{\circ}2638$ served as the comparison star and star BD $+59^{\circ}2777$ = HD 22386 as the check star.

Since the angular distance between the stars is not large, no correction was made for differential atmospheric extinction. The declination of stars is close to 60° and their mutual distance few angular minutes only. As the star was observed not far from the meridian the correction for the differential extinction is below 0.001 mag. Nearly 100 observations were made during 5 nights and these were grouped as described at the beginning of this section, see Tab. 1. Table 1 is self-explanatory.The observations from 1987 were made under very good observational conditions, whereas the 1986 observations have a lower accuracy.

T a b l e 1

J.D. hel	ΔB	J.D. hel	ΔB	J.D. hel	ΔV	J.D. hel	ΔB
2446685.+		.4710	1.471	.3122	1.341	2446756.+	
.3501	1.176	.4747	1.491	.3141	1.320	.2488	1.677
.3523	1.188	.4788	1.495	.3162	1.333	.2511	1.671
.3547	1.183	.4821	1.486	.3187	1.344	.2531	1.659
.3570	1.177	.4863	1.520	.3212	1.356	.2553	1.662
.3602	1.187	.4925	1.520	.3234	1.358	.2575	1.676
.3630	1.186	.4960	1.530	.3254	1.384	.2598	1.671
.3654	1.189	.4991	1.544	.3723	1.549	.2619	1.668
.3683	1.199	.5023	1.548	.3766	1.555	.2639	1.670
.3711	1.205	.5064	1.555	.3791	1.556	.2662	1.672
.3735	1.202	.5098	1.584	.3817	1.547	.2686	1.675
.3774	1.206	.5124	1.598	.3843	1.542	.3398	1.447
.3797	1.202	.5153	1.598	.3873	1.568	.3419	1.431
.3860	1.228	.5188	1.604	.3915	1.554	.3451	1.412
.3891	1.234	.5220	1.620	.3947	1.557	.3502	1.405
.3918	1.241	.5245	1.638	.3972	1.576	.3527	1.389
.3947	1.242	.5270	1.644	.4045	1.565	.3555	1.380
.3975	1.256	.5302	1.654	.4074	1.573	.3897	1.295
.4009	1.264	.5336	1.666	.4109	1.574	.3933	1.292
.4035	1.271			.4132	1.565	.3959	1.288
.4059	1.280	2446743.+	ΔV	.4159	1.572	.3984	1.291
.4091	1.300	.2519	1.177	.4187	1.585	.4010	1.270
.4120	1.301	.2562	1.180	.4447	1.490	.4038	1.272
.4149	1.302	.2592	1.199	.4469	1.476	.4130	1.241
.4179	1.291	.2619	1.206	.4523	1.460	.4158	1.227
.4209	1.293	.2644	1.222	.4571	1.442	.4184	1.245
.4252	1.304	.2669	1.222	.4592	1.431	.4208	1.228
.4276	1.319	.2697	1.223	.4621	1.414	.4239	1.227
.4299	1.336	.2725	1.195	.4645	1.403		
.4326	1.348	.2554	1.230	.4668	1.399	2447060.+	
.4356	1.336	.2780	1.214	.4690	1.385	.3557	1.513
.4387	1.335	.2810	1.236	.4712	1.381	.3592	1.516
.4419	1.362	.2832	1.241	.4753	1.372	.3664	1.556
.4454	1.356	.2949	1.260	.4791	1.356	.3695	1.545
.4479	1.387	.2975	1.285	.4817	1.326	.3725	1.552
.4504	1.368	.3001	1.291	.4843	1.320	.3764	1.595
.4532	1.389	.3024	1.301	.4898	1.294	.3797	1.580
.4560	1.398	.3045	1.308	.4924	1.277	.3825	1.595
.4586	1.420	.3064	1.296	.4989	1.282	.3855	1.619
.4614	1.408	.3083	1.320	.5011	1.261	.4058	1.664
.4671	1.461	.3101	1.312			.4163	1.705

Table 1 - continued

J.D. hel	Δ B	J.D. hel	Δ B	J.D. hel	Δ B	J.D. hel	Δ B
.4206	1.688	.5382	1.375	.4600	1.507	.5151	1.562
.4247	1.697	.5414	1.352	.4631	1.513	.5180	1.562
.4287	1.707			.4663	1.519	.5209	1.563
.4623	1.649	2447061.+		.4690	1.520	.5300	1.531
.4747	1.605	.4096	1.353	.4720	1.540	.5334	1.538
.4778	1.601	.4124	1.368	.4761	1.548	.5395	1.523
.4890	1.566	.4154	1.372	.4793	1.557	.5473	1.516
.4935	1.551	.4184	1.374	.4823	1.553	.5505	1.481
.4970	1.521	.4217	1.390	.4906	1.584	.5537	1.477
.5009	1.503	.4248	1.400	.4937	1.575	.5570	1.483
.5043	1.501	.4279	1.413	.4969	1.566	.5601	1.461
.5075	1.498	.4309	1.418	.4998	1.584	.5709	1.448
.5107	1.468	.4341	1.424	.5028	1.569	.5740	1.432
.5140	1.451	.4372	1.438	.5058	1.574	.5775	1.434
.5169	1.462	.4402	1.451	.5088	1.585	.5805	1.394
.5319	1.397	.4571	1.498	.5122	1.587	.5840	1.393
.5352	1.351						

3. RESULTS AND DISCUSSION

We derived three epochs of the primary and one epoch of the secondary minimum from the observations made at Skalnaté Pleso. These minimum epochs, together with their standard errors in determining the epochs, are given in Tab.2 under ordinal numbers 24 through 27. The scatter of the individual minimum epochs in the O-C diagram, published by Busch (1975), is very large. Many of the published minimum epochs are only in fact epochs when the star was fainter. Consequently, we decided to divide the whole period of observation into 18 observational intervals. The beginnings and ends of the intervals, as a rule, coincide with a period in which no observations were made. Since no mutual shift of primary and secondary minima was observed, both types of minima were interpreted together. The number of minima in every interval varied from 8 to 23. In this way we obtained 18 minimum epochs. The visual minimum epoch from the table of Braune and Lichtenknecker (1986) was omitted from the interpretation because of its large deviation. Two minimum epochs obtained by Zonn and Semeniuk (1959) and mentioned in Busch's paper (1975) were not used to derive the new epochs but they were used directly to calculate the elements.

The recent calculation of the elements, published by Braune and Lichtenknecker (1986), indicated that the orbital period was longer if only the observations of recent years were taken into account in the calculations.

At the beginning of our research, we derived the initial mean linear elements (1). The deviations of the minimum epochs can be found in Tab. 2, in the column marked $O-C_1$.

$$\text{(1)} \qquad \text{Min I} = \text{J.D. } 2434330.169 + 2.1420416 \text{ E}$$

The diagram of $O-C_1$ deviations indicated that the approximation of the light variations by linear elements over the whole observational interval was inacceptable.For this reason we calculated the elements with a quadratic term,(2):

$$(2) \quad \text{Min I} = \text{J.D. } 2434330.1918 + 2.14204474 \text{ E} + 1.71 \times 10^{-9} \text{E}^2$$
$$\pm 38 \qquad \pm 43 \qquad \pm 11$$

The deviations of the minimum epochs from these elements are given in Tab. 2, column $O-C_2$.

The standard error of determining the secular term is relatively small and, therefore, the increase in the orbital period is a real effect. The approximation of the light variations with a parabola is much better than the approximation with linear elements and constant orbital period over the whole observational period. The variation of the orbital period can be approximated by two linear elements if we assume that an erratic cjange in orbital period occured around J.D. 2435000. This epoch of erratic change was identified after analysing the deviations from linear elements. Therefore, the linear elements were calculated separately for the two observational intervals, i. e. prior to and after J.D. 2435000. The linear elements which refer to the observational interval before J.D. 2435000 read

$$(3) \quad \text{Min I} = \text{J.D. } 2434330.1749 + 2.14203027 \text{ E}$$
$$\pm 47 \qquad \pm 96$$

The linear elements for the observational interval after J.D. 2435000 are

$$(4) \quad \text{Min I} = \text{J.D. } 2434330.1726 + 2.1420579 \text{ E}$$
$$\pm 68 \qquad \pm 14$$

The corresponding deviations from elements (3) and (4) are given in Tab. 2, in the columns marked $O-C_3$ and $O-C_4$, respectively.

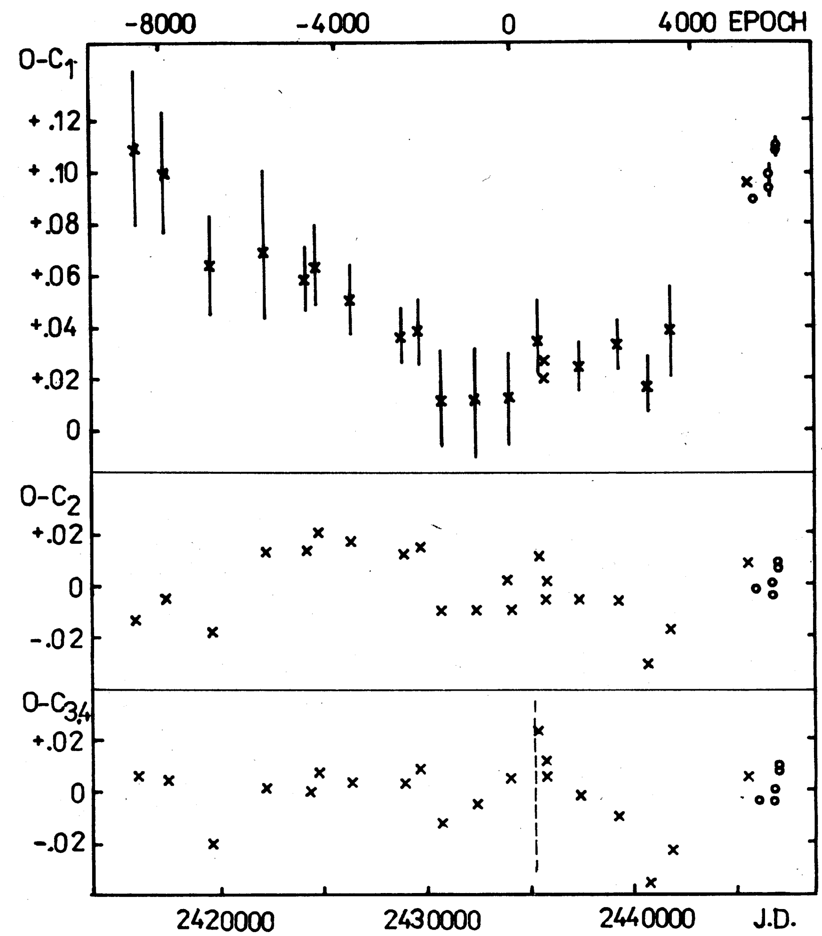
The sum $(O-C)^2$ of the values for the quadratic and linear elements with two different orbital periods for the intervals before and after J.D. 2435000 is very close each other, but 3.5% smaller for the linear elements.

The secular increase in the orbital period could be explained by the theory of mass transfer between the binary components.According to Brancewicz and Dworak (1980), the secondary component fills the Roche lobe to 84%. One could assume mass transfer by stellar wind. A definite conclusion cannot be drawn, because the physical parameters of the secondary component, with which one has to assume a mass smaller than that of the primary component, are not known. Moreover, one can assume that the mass transfer may have occurred quite suddenly within a shorter time interval around 2435000. If we accept the reasonable value of q = 0.77 for the ratio of the components' masses and use the value of the secular term from elements (3), we arrive at the formal value $\Delta m = 1.6 \times 10^{-7}\ M_\odot/yr$ for the mass transfer. Nor can one exclude another cause of the apparent change in period. If the QQ Cas system is triple, this change could be explained by the light-time effect. At this stage of the research no decision can be taken as to the cause of the observed variation in the orbital period.

Table 2

MINIMA OF QQ CAS

No	J.D.		n	σ	w	E	$O-C_1$	$O-C_2$	$O-C_3$	$O-C_4$	References
1	2415949.419	p	8	±.030	1	-8581	+.109	-.013	+.006		Busch (1975)
2	7397.430	p	16	±.024	1	-7905	+.100	-.005	+.004		-"-
3	9665.816	p	16	±.019	1	-6846	+.064	-.018	-.020		-"-
4	2422630.407	p	11	±.026	1	-5462	+.069	+.013	+.001		-"-
5	4239.070	p	15	±.013	1	-4711	+.059	+.013	.000		-"-
6	4738.170	p	16	±.014	1	-4478	+.063	+.020	+.007		-"-
7	6458.217	p	18	±.014	1	-3675	+.051	+.016	+.003		-"-
8	7053.743	p	10	±.020	0	-3397					-"-
9	8949.398	p	18	±.011	1	-2512	+.037	+.012	+.003		-"-
10	9756.948	p	16	±.013	1	-2135	+.038	+.014	+.008		-"-
11	2430712.273	p	13	±.018	1	-1689	+.012	-.010	-.013		-"-
12	2466.604	p	13	±.022	1	- 870	+.011	-.010	-.005		-"-
13	4120.261	p	15	±.018	1	- 98	+.012	-.010	+.005		-"-
14	5426.929	p	23	±.013	1	+ 512	+.035	+.010		+.023	-"-
15	5838.186	p			1	+ 704	+.020	-.006		+.005	Zonn, Semeniuk (1959)
16	5839.264 s	p			1	+ 704.5	+.027	+.001		+.011	-"-
17	7466.143	p	23	±.009	1	+1464	+.025	-.006		-.002	Busch (1975)
18	9327.584	p	16	±.009	1	+2333	+.032	-.007		-.010	-"-
19	2440818.430	p	13	±.011	1	+3029	+.017	-.031		-.036	-"-
20	1848.773	p	9	±.018	1	+3510	+.038	-.017		-.023	-"-
21	5614.539	p			1	+5268	+.095	+.008		+.005	Hübscher, Mundry (1984)
22	5989.3902	e			3	+5443	+.0888	-.0018		-.0040	Hübscher et al. (1985)
23	5990.410:s	v			0	+5443.5					-"-
24	6743.3985:	e		±.0025	2	+5795	+.0984	.0000		-.0002	this paper
25	6756.2465	e		±.0025	2	+5801	+.0942	-.0044		-.0045	-"-
26	7060.4305	e		±.0015	3	+5943	+.1083	+.0064		+.0073	-"-
27	7061.5030 s	e		±.0010	3	+5943.5	+.1098	+.0079		+.0087	-"-



Fig

Fig. 1. The (O-C) diagram for QQ Cas. The data are taken from Table 2. The symbols: crosses - Photographic observations, circles - photoelectric observations. The errors are given by vertical bars.

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REFERENCES

Brancewicz, H., Dworak, T.Z.: 1980, Acta Astron. 30, 501.

Braune, W., Lichtenknecker D.: 1986, B.A.V. Rundbrief 35, 1.

Busch, H.: 1975, Mitt. Bruno-Bürgel Sternw. Hartha 8, 15.

Erleksova, G.E.: 1957, Astron. Circ. USSR 178, 24.

Geyer, E., Kippenhahn, R., Strohmeier, W.: 1955, Kl. Veröff. Bamberg 9, 4.

Horák, J., Mayer, P., Tremko, J., Weidlich, M.: 1976, Contr. Astron. Obs. Skalnaté Pleso 7, 39.

Hübscher, J., Lichtenknecker, D., Mundry, E.: 1985, B.A.V. Mitt. 39.

Hübscher, J., Mundry, E.: 1984, B.A.V. Mitt. 38.

Klocok, Ľ., Zverko, J., Žižňovský, J.: 1986, Contr. Astron. Obs. Skalnaté Pleso 14, 97.

Kreiner, J.M., Tremko, J.: 1987, Contr. Astron. Obs. Skalnaté Pleso 16, 191.

Kreiner, J.M., Tremko, J.: 1988, Mitt. der Sternw. der Ung. Acad. Wissen., in press.

Kukarkin, B.V.; 1957, Astron. Circ. USSR 181, 22.

Kukarkin, B.V.: 1959, Per. Zvezdy 12, 78.

Strohmeier, W., Bauernfeind, H.: 1968, Veröff. Bamberg 7, 72.

Zonn, W., Semeniuk, I.: 1959, Acta Astron. 9, 141.