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The Light Curve of RU Cam from 1969.8 to 1970.6 and the Variation of its Period

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Two colour photoelectric light curves of RU Cam for the interval October 1969—August 1970 are presented. The period has decreased relative to the value of the previous year and was still changing when the present measurements were made. The residuals of the epochs of maximum and minimum of the years 1962—70 change abruptly from a linear to an oscillatory trend at the end of 1965, about a year after the quasi cancellation of the light pulsation. The oscillation of the *O—C* is almost sinusoidal, but with a non constant period.

An analysis of the light curves confirms that an erratic component is superimposed on the periodic one. The substantially constant mean luminosity and colour of the variable support the hypothesis of Wallerstein on why the light pulsation ceased.

Key words: variable stars — evolution of a pulsating star — population II cepheids

I. Introduction

The peculiar behaviour of the variable RU Cam, whose light variation abruptly stopped and then resumed on a much smaller scale, whilst the period, although varying, kept on average its old value, offers a unique opportunity for studying the mechanism of stellar pulsation. RU Cam is situated about 1200 pc above the Galactic plane according to the absolute magnitude derived by Faraggiana and Hack (1967) and by Wallerstein (1968), so it belongs to the spherical component of the Galaxy. However, these Authors conclude from their spectral analysis that RU Cam has a metal abundance different from that of the W Vir variables and it differs also from the long period variable carbon stars and from the non variable carbon stars. The question of whether the cessation of the pulsation is produced by an interference between different modes of pulsation and is a transitory stage in the evolution of the star or whether it is a lasting consequence of its evolution is not settled. There is, therefore, a real need for continued observations.

This note gives the results of photometric observations of RU Cam made from October 1969 to August 1970. These measurements follow the series completed in Merate during the periods December 1966 — July 1967 (Broglia, 1969) and November 1967 — August 1968 (Broglia and Guerrero, 1969). The observations were made with the Zeiss 40″ reflector and the same equipment described in the previous papers.

Each night, RU Cam was compared with the star a_2 = BD + 70°448; a_1 = BD + 70°447 and a_3 = BD + 70°450 were used as reference stars.

Table 1. *Test for the constancy of the comparison stars. In parentheses is given the standard deviation of a single Δm*

Observing season	ΔB			ΔV		
	a_2-a_1	a_2-a_3	a_1-a_3	a_2-a_1	a_2-a_3	a_1-a_3
1966.9—67.5	$+0^m_.802$ ($0^m_.020$)	$+1^m_.001$ ($0^m_.016$)	$+0^m_.199$ ($0^m_.021$)	$+0^m_.057$ ($0^m_.013$)	$+0^m_.348$ ($0^m_.013$)	$+0^m_.291$ ($0^m_.018$)
	± 2 e.m.	3	4	± 1 e.m.	2	3
1967.8—68.7	0.776 (0.026)	0.998 (0.024)	0.222 (0.017)	0.045 (0.016)	0.337 (0.017)	0.292 (0.016)
	2	3	2	2	3	2
1969.8—70.6	0.838 (0.019)	1.048 (0.016)	0.210 (0.015)	0.069 (0.011)	0.359 (0.013)	0.290 (0.017)
	2	2	2	1	2	2

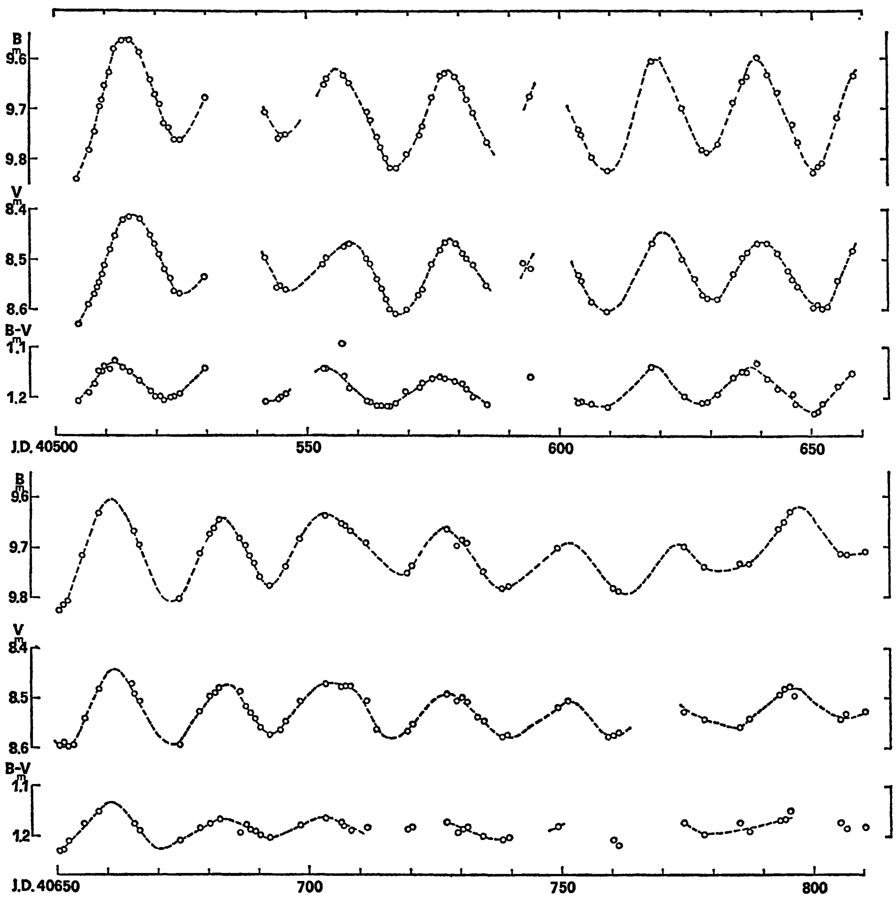

Fig. 1. Light and colour curves of RU Cam from 1969 October to 1970 August

All the measures were corrected for differential extinction using mean extinction coefficients. In Table 1 we give the average values of Δm for the comparison stars, as obtained during the three observing seasons, with the corresponding mean errors and the standard deviations of a single Δm. We note that, whilst the brightness difference $a_1 - a_3$ is constant in the visual and nearly constant in the blue, ΔB and ΔV between a_2 and a_1 and between a_2 and a_3 show differences of several hundreths of a magnitude. We note also that such apparent variations grow with the colour differences: for $a_1 - a_3$, $\Delta(B-V) = 0\overset{m}{.}08$; for $a_2 - a_1$, $\Delta(B-V) = 0\overset{m}{.}75$; and for $a_2 - a_3$, $\Delta(B-V) = 0\overset{m}{.}66$. If we bear in mind that the standard deviations of one measure are nearly the same for the two colours, we can conclude that the main comparison was constant during each observing season. The above differences can be due either to a shift of the instrumental response or more probably to an incomplete correction of the colour differential extinction. Because the difference of colour between RU Cam and a_2 is small, on the average $0\overset{m}{.}1$, we are confident that such effects do not influence appreciably the magnitudes deduced for RU Cam and that, in the analysis, it is possible to combine the light curves of the three series of measurements.

The B and V magnitudes of the variable-altogether 3050 were obtained during 120 nights-have been assembled in the normal points listed in the Tables 2 and 3 with the corresponding mean errors and the number of the individual observations concurring to each normal. As in the previous papers for the comparison star a_2 we have assumed the values:

$$V = 9\overset{m}{.}09,\ B-V = +1\overset{m}{.}10 .$$

The light and the colour curves are shown in Fig. 1.

Table 2. *Normal* B *points*

N°	J. D. 2440 000.+	B	e.m.	*n*
1	504.443	9.840	±0.004	12
2	506.632	.783	3	14
3	507.607	.746	2	8
4	508.634	.696	2	10
5	509.283	.681	4	17
6	509.647	.653	3	9
7	510.656	.626	3	17
8	511.673	.580	3	10
9	513.438	.562	4	22
10	514.660	.562	3	9
11	516.642	.587	3	12
12	518.658	.642	1	10
13	519.653	.671	2	12
14	520.564	.691	4	19
15	521.539	.730	2	11
16	522.545	.738	2	12
17	523.531	.761	4	13
18	524.666	.761	5	17
19	529.611	.678	3	18
20	541.666	.707	3	13
21	544.253	.760	5	25
22	544.629	.753	1	14
23	545.662	.753	1	12
24	553.240	.652	2	14
25	553.663	.640	1	10
26	557.376	.633	2	15
27	558.388	.648	4	10
28	561.664	.707	2	14
29	562.455	.722	2	8
30	563.666	.756	1	14
31	564.682	.777	2	12
32	565.562	.799	1	14
33	566.431	.817	3	10
34	567.498	.818	1	12
35	569.652	.790	2	12
36	572.244	.752	1	10
37	572.704	.735	3	10
38	574.715	.676	4	18
39	576.288	.635	3	18
40	577.435	.627	3	19
41	579.429	.635	2	8
42	580.597	.659	1	10
43	581.495	.683	2	8
44	582.720	.707	5	13
45	585.494	.765	4	6
46	594.275	.675	3	15
47	603.700	.740	5	28
48	604.364	.751	2	11
49	606.286	.798	2	13
50	609.521	.822	2	12
51	618.289	.604	5	24
52	624.355	.697	4	14
53	628.389	.780	2	13
54	629.281	.785	1	9
55	631.285	.770	2	11

Table 2 (continued)

N°	J. D. 2440 000.+	B	e.m.	*n*
56	634.477	9.686	±0.003	10
57	636.311	.645	2	12
58	637.277	.635	2	12
59	639.330	.598	4	14
60	641.303	.630	4	17
61	643.356	.667	2	10
62	646.347	.730	2	15
63	647.489	.765	2	20
64	650.501	.826	7	8
65	651.302	.814	4	21
66	652.298	.808	3	10
67	655.321	.716	2	11
68	658.376	.631	4	20
69	665.307	.667	3	10
70	666.297	.696	2	12
71	674.316	.802	3	14
72	678.379	.711	2	15
73	680.446	.673	2	11
74	681.335	.660	2	8
75	682.360	.646	2	14
76	686.397	.680	3	11
77	687.493	.695	1	8
78	688.396	.716	2	12
79	689.330	.731	1	9
80	690.394	.758	5	12
81	692.386	.778	2	12
82	695.335	.738	3	15
83	698.336	.684	1	12
84	703.345	.636	1	10
85	706.457	.651	3	14
86	707.348	.656	1	12
87	708.347	.666	2	11
88	711.389	.690	1	13
89	719.505	.750	3	25
90	720.405	.737	1	14
91	727.358	.663	5	16
92	729.390	.696	9	15
93	730.401	.685	3	10
94	731.408	.692	9	14
95	734.467	.747	3	11
96	738.381	.784	3	12
97	739.457	.778	4	14
98	749.430	.700	10	8
99	760.392	.782	5	14
100	761.397	.786	6	16
101	774.389	.698	5	10
102	778.392	.737	1	9
103	785.384	.731	4	14
104	787.398	.731	4	16
105	793.368	.662	3	12
106	794.375	.649	3	10
107	795.462	.628	5	14
108	805.499	.712	3	8
109	806.555	.714	1	10
110	810.365	.707	4	15

Table 3. *Normal* V *points*

N°	J.D. 2440 000.+	V	e.m.	*n*
1	504.444	8.631	±0.003	12
2	506.632	.593	2	14
3	507.607	.573	1	8
4	508.300	.557	6	11
5	508.634	.548	2	10
6	509.281	.532	5	16
7	509.648	.514	2	9
8	510.673	.483	1	14
9	511.672	.454	2	15
10	513.415	.422	3	20
11	514.661	.415	2	9
12	516.656	.421	2	14
13	518.657	.453	1	12
14	519.639	.472	3	12
15	520.535	.492	4	23
16	521.551	.524	1	10
17	522.561	.538	5	11
18	523.548	.563	4	13
19	524.656	.569	3	14
20	529.589	.535	2	19
21	541.665	.497	4	13
22	544.228	.556	3	18
23	544.629	.554	1	14
24	545.662	.560	1	12
25	553.235	.510	3	18
26	553.651	.497	1	12
27	557.366	.475	2	15
28	558.370	.468	3	8
29	561.650	.501	2	14
30	562.456	.512	2	8
31	563.652	.539	1	12
32	564.669	.561	1	13
33	565.547	.582	1	14
34	566.431	.600	3	10
35	567.486	.607	1	13
36	569.643	.601	1	12
37	572.234	.572	1	9
38	572.719	.562	3	7
39	574.697	.513	3	15
40	576.268	.476	2	16
41	577.415	.465	2	12
42	579.416	.467	1	8
43	580.585	.487	1	10
44	581.486	.499	2	11
45	582.702	.511	3	19
46	585.478	.554	2	18
47	592.700	.507	8	11
48	594.287	.518	2	10
49	603.671	.530	4	23
50	604.362	.543	1	11
51	606.273	.585	2	12
52	609.511	.604	1	10
53	618.257	.467	5	20
54	624.343	.501	2	13
55	626.706	.537	3	14

Table 3 (continued)

N°	J.D. 2440 000.+	V	e.m.	*n*
56	628.344	8.570	±0.002	19
57	629.269	.577	1	12
58	631.274	.578	2	10
59	634.467	.528	2	10
60	636.297	.496	2	12
61	637.264	.485	2	17
62	639.291	.467	7	16
63	641.287	.467	2	14
64	643.346	.486	6	10
65	645.463	.521	5	21
66	646.334	.539	2	12
67	647.363	.552	2	19
68	650.469	.595	2	26
69	651.283	.587	3	16
70	652.290	.598	1	9
71	653.298	.593	11	8
72	655.310	.540	1	12
73	658.351	.481	4	23
74	664.687	.472	6	8
75	665.297	.492	3	12
76	666.287	.507	2	12
77	674.302	.594	3	15
78	678.356	.528	3	20
79	680.447	.498	2	10
80	681.327	.490	1	8
81	682.344	.480	3	16
82	686.368	.488	3	18
83	687.482	.518	2	8
84	688.381	.530	2	16
85	689.320	.541	1	12
86	690.381	.559	2	14
87	692.370	.574	2	13
88	694.372	.564	5	6
89	695.321	.548	3	14
90	698.314	.506	3	19
91	703.334	.472	1	10
92	706.442	.477	5	16
93	707.337	.476	2	12
94	708.337	.478	3	10
95	711.375	.506	2	14
96	713.434	.564	6	4
97	719.481	.565	2	13
98	720.399	.554	3	20
99	727.340	.492	4	19
100	729.376	.505	3	11
101	730.391	.500	5	14
102	731.380	.508	6	21
103	733.381	.538	13	8
104	734.454	.547	3	12
105	738.366	.578	2	13
106	739.446	.575	3	14
107	749.419	.519	8	10
108	751.375	.505	7	12
109	759.376	.576	8	12
110	760.379	.575	3	14

Table 3 (continued)

N°	J.D. 2440 000.+	V	e.m.	n
111	761.383	8.568	±0.005	14
112	774.368	.526	4	10
113	778.371	.541	3	12
114	785.370	.557	4	12
115	787.384	.541	3	14
116	793.355	.493	2	16
117	794.363	.481	3	10
118	795.445	.479	3	18
119	796.367	.495	13	10
120	805.487	.541	3	15
121	806.544	.530	2	9
122	810.352	.526	2	10

II. The Oscillation of the Period

According to Vasiljanovskaja and Erleksova (1970), who have investigated the periods of 34 cepheids belonging to the spherical component of the Galaxy, all the cepheids of Population II with $P > 2^{\mathrm{d}}4$ show a variation of the period. From this point of view, RU Cam behaved normally before the cessation of the pulsation in the summer of 1964 as during seventy years its period fluctuated, according to Huth (1967), between $22^{\mathrm{d}}183$ and $22^{\mathrm{d}}073$. In the years 1966—67 the light amplitude grew progressively and afterwards a slow decrease occurred. Simultaneously, the period showed a remarkable decrease to $P = 21^{\mathrm{d}}6$, and afterwards, during the season 1967—68, a very rapid rise to the value $P = 23^{\mathrm{d}}2$ (Broglia and Guerrero, 1969). In other words, the period (the most significant quantity characterizing the pulsation of a variable star) also responded to the peculiar stage in the evolution of RU Cam. It is, therefore, useful to check further its behaviour. From the actual measurements, we have derived eighteen epochs of minimum or maximum light by bisection of the ascending and descending branches of the light curves (represented by least squares fits). The average deviation of a value, computed from the B and V instants, is $0^{\mathrm{d}}4$. On the average, the V epochs are $0^{\mathrm{d}}7$ later than the B ones.

A linear ephemerides does not represent satisfactorily these epochs since it gives residuals three times greater than the average deviation $0^{\mathrm{d}}4$. On the contrary we obtain the $(O-C)$ of this order representing separately the first fourteen instants ($P=20^{\mathrm{d}}94 \pm 0^{\mathrm{d}}52$) and the last four ($P=22^{\mathrm{d}}60 \pm 0^{\mathrm{d}}24$). This behaviour indicates that the period is still changing quickly.

We then searched to see if its variation is erratic or if it has a systematic trend. Unfortunately, the observations are not distributed uniformly and, in particular, we have a rather broad gap between the intervals 1967.8—68.7 and 1969.8—70.6. Bearing in mind the strong variation of the period, it is difficult to estimate the number of cycles in between. Therefore, we have searched in the literature for further epochs given directly or derived by us from these measurements, and, in addition, simply by a direct inspection of all our light curves, we have evaluated seven additional instants for which a computation by least squares was impossible on account of the unfavourable location of the normals. We have then computed by least squares the linear ephemerides:

$$\text{Min J.D.} = 2439535.16 + 22.354\, n$$
$$\pm 74 \qquad \pm 22 \text{ e.m.} \qquad (1)$$

The residuals $(O-C)$ are given in Table 4 with the corresponding epochs, 58 altogether, the number n of cycles and the square-root $\sqrt{w}$ of the estimated weight. Figure 2 displays the trend of the $(O-C)$ as a function of n including some epochs prior to those of Table 4 (Huth, 1967; Vasiljanovskaja and Erleksova, 1970). We note:

a) the strong and abrupt change of the residuals from a linear trend to an oscillatory one;

b) bearing in mind the mean photographic seasonal light curves given by Huth (1967), one for each three months from the beginning of 1962 to the end of 1966, we see that the decrease of the amplitude and its quasi complete cancellation in the second half of 1964 occurred whilst the period was constant and that only one year later the period also changed abruptly;

c) the oscillation of the $(O-C)$ is almost sinusoidal as if a beat phenomenon was appearing. However, the period of this transient situation is not constant. We have determined the best sinusoidal fit by the method of least squares: for the interval $-17.5 < n < +22$ we obtained: $P_b = 850^{\mathrm{d}}$, an amplitude $A = 5^{\mathrm{d}}4$ and we obtained for an $(O-C)$ a standard deviation $\sigma = 0^{\mathrm{d}}8$. For the interval $13 < n < 56.5$, $P_b = 1200^{\mathrm{d}}$, $A = 9^{\mathrm{d}}7$, $\sigma = 1^{\mathrm{d}}2$. During the interval of constant period, we obtained $\sigma = 1^{\mathrm{d}}0$. The fact that the values of σ are comparable gives weight to the assumption that the sinusoidal trend is real. Of course, the changing value of P_b implies that RU Cam is in a variable state so this apparent

Table 4. *Observed epochs of minimum or maximum light*

n	J.D.⊙ 24.	$\sqrt{w}$	$O-C$	Ref.	n	J.D.⊙ 24.	$\sqrt{w}$	$O-C$	Ref.
−22.5	39025.5	2	−6.7	[1]	+19.5	39974.6	2	+3.5	[6]
21.5	39048.5	2	−6.0	[2]	20.0	39984.5	2	+2.3	[6]
21.0	39058.0	1	−7.7	[1]	22.0	40031.0	2	+4.1	[6]
17.5	39149.5	1	+5.5	[2]	40.5	40449.0	1	+8.5	[7]
7.0	39386.0	1	+7.3	[3]	42.5	40494.0	1	+8.8	[7]
1.5	39503.5	1	+1.9	[4]	43.5	40514.2	2	+6.7	[7]
− 0.5	39530.0	1	+6.0	[4]	43.5	40514.6	4	+7.1	[8]
0.0	39538.6	4	+3.4	[4]	44.0	40524.0	1	+5.8	[7]
+ 1.0	39560.5	2	+3.0	[4]	44.0	40525.3	2	+6.6	[8]
1.5	39571.0	4	+2.3	[4]	44.5	40536.0	3	+6.1	[7]
2.0	39579.8	1	−0.1	[4]	45.0	40546.0	1	+4.9	[8]
2.5	39591.0	4	0.0	[4]	45.5	40556.8	3	+4.6	[8]
3.0	39601.5	4	−0.7	[4]	46.0	40568.0	4	+4.6	[8]
3.5	39612.0	3	−1.4	[4]	46.5	40577.9	4	+3.3	[8]
4.5	39635.1	3	−0.7	[4]	48.0	40609.5	1	+1.4	[8]
5.0	39646.5	1	−0.4	[4]	48.5	40619.5	1	+0.2	[8]
5.5	39657.0	1	−1.1	[4]	49.0	40629.9	4	−0.6	[8]
6.0	39667.9	4	−1.4	[4]	49.5	40639.7	4	−2.0	[8]
6.5	39678.3	4	−2.2	[4]	50.0	40651.4	4	−1.4	[8]
7.5	39701.5	1	−1.3	[5]	50.5	40661.4	3	−2.6	[8]
9.0	39735.5	1	− .8	[5]	51.0	40672.2	1	−3.0	[8]
13.0	39823.3	3	−2.5	[6]	51.5	40683.3	4	−3.1	[8]
13.5	39834.5	4	−2.4	[6]	52.0	40692.4	4	−5.1	[8]
13.5	39834.0	2	−2.9	[5]	52.5	40703.8	3	−4.9	[8]
14.0	39844.8	1	−3.3	[6]	53.0	40716.7	2	−3.2	[8]
14.5	39857.5	3	−1.8	[6]	53.5	40727.0	2	−4.1	[8]
15.0	39867.9	4	−2.6	[6]	54.0	40739.5	2	−2.8	[8]
15.5	39880.4	4	−1.2	[6]	56.5	40795.5	2	−2.6	[8]
17.5	39924.5	4	−1.8	[6]					
18.0	39938.3	4	+0.8	[6]					

Ref.: 1. Wamsteker (1966). 2. Demers, Fernie (1966). 3. Wamsteker (1968). 4. Broglia (1969). 5. Zaitzeva (1968). 6. Broglia, Guerrero (1969). 7. Zaitzeva, Ljutiy (1969). 8. present note.

beat phenomenon may also quickly decay in the near future.

III. The Light Curves

From an inspection of the light curves, we see that we can assume that the observed magnitudes of RU Cam can be represented in the form:

$$m\,(t) = m_1(P) + m_2(t)$$

Here the first term, a function periodic in P, describes the cyclic variation. According to the results of the preceding analysis, P is subject to a modulation. The second term represents the irregular component. Figure 1 indicates that, during the season 1969–70, the amplitude of the light oscillation was slowly decreasing. This trend is opposite to that of 1966–67, whereas we see from the Fig. 2 that during both these periods the $(O-C)$ have a similar trend. Moreover the component $m_1(P)$ seems to dominate whilst, in the middle of 1968, with an opposite trend of the $(O-C)$, the term $m_2(t)$ was dominant.

We then analysed the light curves using an IBM 360/40 in order to see the relative weight of the two components $m_1(P)$ and $m_2(t)$. A Fourier representation of the normals of the Tables 1 and 2 (a separate representation for each of the two groups mentioned in the paragraph 2) by means of the corresponding periods, shows that terms higher than $\sin 2\pi t/P$ and $\cos 2\pi t/P$ are negligible. This confirms that the component $m_1(P)$ behaves like a sinusoid although, as in past seasons, each cycle has its own peculiarities.

However, the r.m.s. deviations of a normal from the computed sinusoids are, for the B measures, $0^m.023$, and, for the V, $0^m.016$. Considering that the

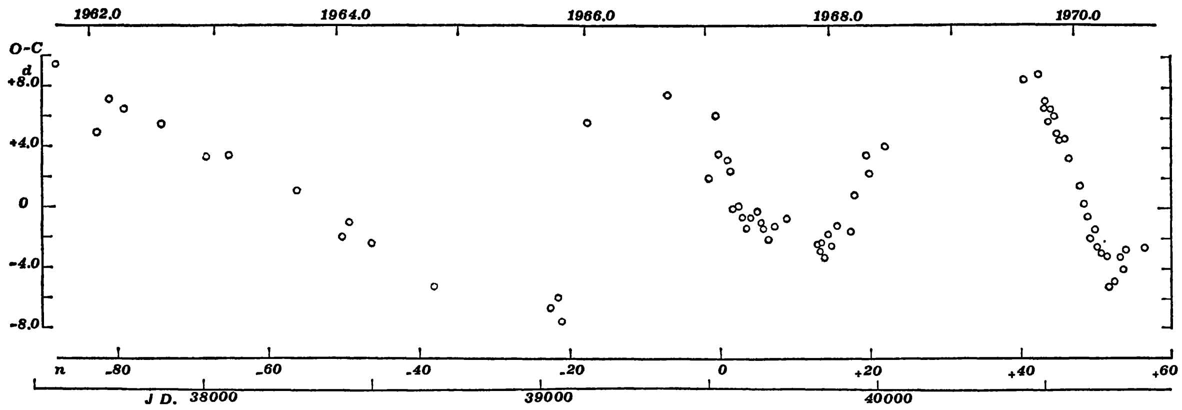

Fig. 2. Trend of the residuals of the epochs of minimum and maximum light with respect to the linear ephemeris (1)

standard deviation of one normal has a mean value of $0^m.003$ in both colours and that the r.m.s. of the B and V normals from their means are respectively $0^m.063$ and $0^m.044$, we conclude that even when the component $m_1(P)$ prevails the erratic component is still important.

As the amplitude of the light curves seems to be subject to a modulation, in order to demonstrate a possible beat phenomenon we have tried a representation which includes a secondary period P_1 in addition to the primary P. For a range of values of P_1 we have computed the amplitudes of the two interfering sinusoids to minimize σ. The plot of σ as a function of the beat period P_b does not show a sharp minimum but only a maximum reduction of 16% relative to the σ obtained with only one sinusoid.

Subsequently we have tried to analyse all our V measures subsequent to 1966 by changing P_b step by step between 10 P and 100 P and assuming for P the value (1). We obtained no substantial reduction for σ. This result confirms the remarkable weight of the erratic component $m_2(t)$ in the light curves after the cessation of the pulsation.

Looking at the intervals when the component $m_1(P)$ is dominant, it appears from Fig. 1 that the maxima of the colour index ($B-V$ more negative) preced the maxima of the light curves, as happens normally in all pulsating stars.

Finally, we have obtained, assuming the average of the magnitudes observed during successive seasons, the following mean luminosities:

	1966.9 – 67.5	67.8 – 68.7	69.8 – 70.6
B	9.73 ± 0.01	9.72 ± 0.01	9.71 ± 0.01
V	8.55 ± 0.01	8.53 ± 0.01	8.53 ± 0.01

These values confirm indirectly the constancy of the comparison star a_2.

IV. Concluding Remarks

According to the observations of Huth (1967), the mean luminosity of RU Cam did not change when the pulsations ceased nor during the fifteen years before this phenomenon occurred. The mean m_{ph} was between $9^m.54$ and $9^m.85$. This is true also during the last few years as may be seen from the above values, although, during the interval 1967.8–1968.7, there occurred a slow decrease in the brightness of about $0^m.05$ (Broglia and Guerrero, 1969).

This fact indicates that RU Cam is undergoing a change only in the superficial layers and that the flux arriving from the core of the star remains constant.

Considering also the fact that the mean ($B-V$) index, and, therefore, the temperature do not changed after the stopping of the pulsation, we support the hypothesis of Wallerstein (1968) that RU Cam is probably in a transitory stage for which the pulsations have stopped because of strong modifications occuring in the outer layers of the star. These modifications, according to Wallerstein, are associated with the processes of mass loss and mixing.

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