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THE PHOTOMETRIC BEHAVIOUR OF RU CAM FROM 1966 TO 1977

P. BROGLIA, P. CONCONI and G. GUERRERO
Milano-Merate Astronomical Observatory, Merate, Italy

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Two-colour photoelectric light curves of RU Cam, obtained from 1973.0 to 1977.6, are presented. The variable appears to maintain the same photometric behaviour as during the years after 1964, when the pulsations died down. The period, which up to 1965 was relatively constant, excluding the secular and continuous lengthening, during the following years shows a strong instability without any systematic behaviour in the fluctuations. An analysis of the light curves confirms that a random component is superimposed on a sinusoid.

Considering all the observations obtained at Merate after 1966 we conclude that: 1) RU Cam after 1964 has maintained substantially the same brightness; 2) a correlation seems to exist between the best fitting period for single cycles and the amplitudes of oscillations. The hypothesis that RU Cam underwent strong modifications in the outer layers is confirmed.

Key words: pulsating stars – population II cepheids

1. INTRODUCTION

The W Vir type variable RU Cam has already been observed photometrically at the Merate Observatory from December 1966 to 1972 with the aim of monitoring the variable light curves and the period, after the well known strong amplitude reduction in the summer of 1964. The study of these measurements gave evidence of the following facts (Broglia and Guerrero 1972, 1973):

a) the light curves have roughly a sinusoidal shape, whereas before 1964, when the amplitude was large, the minimum was much sharper than the maximum. The total amplitude moreover, never in excess of a few tenths of magnitude, varies remarkably during a few cycles and can reduce nearly to zero;
b) a search to detect a possible modulation effect over the light curves gave no conclusive findings. At times a random component seems to prevail, followed then by a recovering of a regular light oscillation;
c) the period changed slightly around the value 22 days, in particular during the well-observed fifteen year interval before 1964. Afterwards the period instability strengthened together with the occurring peculiar photometric behaviour, but with a delay of about one year. The residual $O-C$ of the epochs of maximum or minimum light moreover, calculated with a linear ephemeris, have an irregular course and bear out the uncertainty of the search for a beat phenomenon;
d) no correlation appears between the variation of the period and the changes of the light curve amplitude;
e) after 1966 RU Cam did not alter its mean luminosity, within the observational uncertainty;
f) the epochs of maximum or minimum light in V colour are on the average $0^{d}.7$ later than the B ones.

The exceptional behaviour of this pulsating star, which has several characteristics of the W Vir stars, but shows also some peculiarities like the colour, the spectral type cooler and some spectral features at the minimum, did not give rise to specific theoretical studies or detailed calculations. To the best of our knowledge, only qualitative explanations have been put forward till now (Wallerstein 1968; Zaitseva *et al.* 1973b). As the observational facts mentioned above did not indicate a certain persistence of small oscillations or a possible growing to the larger ones and since this alternative can involve significant modifications for the model of the variable, we thought it useful to continue the photometric monitoring. In this note new observations are reported, spanned over a five year interval from 1973 through July 1977 and a new analysis is made based on all the photometric material gathered after 1966.

2. LIGHT CURVES AND PERIOD VARIATIONS

The B and V measurements of RU Cam, altogether 2051 for B and 2624 for V colour, were made differentially with respect to $a_2 = BD+70°448$ as comparison star ($V=9^{m}.09$, $B-V=+1^{m}.10$) and $a_1 = BD+70°477$

and $a_3 = BD + 70°450$ as check stars, during 222 nights spread over the intervals: 1973.0–1973.5, 1975.1–1975.4, 1975.8–1976.3, 1976.8–1977.6. The equipment and observing technique were those used by the authors in the previous photometric studies of RU Cam. The measurements have been corrected for the differential extinction using mean extinction coefficients. The normal points are listed in tables 2 and 3 with the corresponding mean errors and the number n of observations concurring to the normals. In table 1 the Δm's between a_2 and the check stars are given. We notice a small difference between the ΔB's obtained in the interval 1973.0–1973.5 and those of subsequent seasons, but it is not clear which star varied. Part of the disagreement can be accounted for as mean colour extinction coefficients were used. Moreover this possible effect should have a minor influence on the magnitude of RU Cam since the variable has a small colour difference in comparison with the star a_2.

The light and the colour curves are plotted in figures 1a, b, c, d. RU Cam appears to maintain the same photometric behaviour as during the years after 1964: the variability remains around some tenths of magnitude at the most, but after some cycles the oscillations grow less and disappear; afterwards a new group of oscillations rises. The light variation can be thought of as the sum of a sinusoid and of a random component since the amplitude and the shape are slightly irregular from cycle to cycle.

To know more about the mechanism of pulsation at work after 1964 some epochs of maximum and minimum light have been derived by least squares fitting. In table 4 these values, mean of the B and V determinations, are listed. It appeared that the epochs in the two colours are not in phase, but the V minima and maxima occur on the average $0^{d}.7$ later than the B ones, as happened also during the past observing seasons.

During the last few years two notes have appeared reporting on new observations of RU Cam obtained during the intervals 1971.0–1972.5 and 1973.5–1974.5 (Zaitseva *et al.* 1973a; Kovalenko 1974), which are in part complementary to the intervals of our observations. Unfortunately the measurements are not listed in these reports, but the light curves only are represented. It has been possible however to estimate some epochs of minimum and maximum light so that an almost complete coverage of the variation of the period over the recent years was obtained. As has already been noted by the observers of RU Cam and in particular by Zaitseva *et al.* (1973b), intervals when the brightness fluctuations of the variable are near regular alternate with periods when the amplitude nearly cancels out. Since during the last few years the pulsations suffered a phase drift even of half a period between two consecutive groups of oscillations, it is not possible to link all the epochs with an ephemeris because an uncertainty of one cycle in the counting of cycles can occur. On the contrary a period can be derived separately for each group of oscillations and the variation of the period can be monitored. In figure 2 the results of this analysis are represented. Disregarding the slow and continuous lengthening of the period in the course of the last half century, it appears clearly that whilst just before 1965 the period was relatively constant, soon after a strong instability arose and that no systematic behaviour can be assumed in the period fluctuations.

3. DISCUSSION

A qualitative indication of the characteristics of the pulsation now at work in RU Cam can be sought by trying to correlate between the parameters that define a single oscillation: amplitude, period, mean magnitude and by looking for their possible dependence in time. To this end all the observations obtained at Merate Observatory after 1966 have been examined. As already has been seen (Broglia and Guerrero 1972) no substantial gain in accuracy can be obtained by representing the light curves by means of Fourier terms superior to the first. Therefore, since the sine-component in the light variation is sometimes seriously disturbed by an irregular component, a sine-fitting by least squares to the measurements included in single cycles has been performed. The period of the sinusoid was changed step by step till the best representation was obtained. The fitting generally was only approximate because of the effect of the irregular component or because the observations in some cycles are few or unfavourably distributed. In very few cycles indeed the sine-fitting error was reduced to the level set by observational uncertainty.

In figure 3 the mean magnitudes $\overline{B}$ and $\overline{V}$ are represented versus J.D. The variable after 1964 has maintained substantially the same brightness; the random character of the small fluctuations for $\overline{B}$ and $\overline{V}$ is prevalent even if a cyclic variation at times seems to be rising.

No correlation exist between $\overline{B}$ and $\overline{V}$ and the best fitting period P_f.

On the contrary a correlation seems to exist between the sinusoidal amplitudes A_B and A_V and P_f (figure 4). When a pulsation aims to take place in the variable the period of the light variation tends to adjust to values near the period before 1964, but when conditions in the star hamper the normal pulsation and give rise to oscillations with period longer or shorter than this value, the amplitude decreases to zero. The remarkable dispersion of the amplitudes corresponding to a given period is only in part due to the uncertainties in the fitting, but chiefly reflects the presence of a random component in the physical process now at work in the variable.

Taking all the photometry of RU Cam into consideration it appears that some results found in the preceding notes and summarized in the introduction have been confirmed. In particular the mean colour, practically the same before and after 1964, and the mean brightness, constant within two tenths of magnitude during the same interval, prove that the flux emerging from the core kept substantially constant. The phenomenon is probably due to a mass loss or to a mixing (Wallerstein 1968), so the conditions for the dissipation of energy coming from the core are now unstable.

Some few measurements of linear polarisation in V light have been performed during cycles when the pulsation had a 0.2 mag. total amplitude, to look for time-dependent changes due to a non-uniformity of temperature on the surface of the star associated with mass loss or with mixing processes. No dependence of polarisation on the phase was detected at the level of the internal consistancy of the measurements, of the same order of the precision of a normal point.

The attempts made to recognize some regularities in the light variations post the 1964 event, like the appearance of a beat phenomenon or a cyclic variation of amplitude, or a progression in the number of pulsations belonging to a group or in the length of quiescent phases, were disproved gradually as more observations were obtained. So an irregular activity seems at times to prevail over the 22-days reduced pulsation mechanism.

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P. Broglia
P. Conconi
G. Guerrero

Osservatorio Astronomico
I–22055 Merate (Como), Italy

Table 1 Δm between comparison and check stars

Observing season	Δ_B			Δ_V		
	a_2-a_1	a_2-a_3	a_1-a_3	a_2-a_1	a_2-a_3	a_1-a_3
1973.0-1973.5	+0.817±.003	+1.035±.003	+0.218	+0.063±.002	+0.370±.002	+0.307
1975.1-1975.4	.839 .004	1.045 .005	.206	.072 .002	.369 .003	.297
1975.8-1776.3	.841 .003	1.049 .002	.208	.075 .002	.371 .002	.296
1976.9-1977.6	.836 .003	1.042 .003	.206	.073 .002	.367 .002	.294

Table 4 Observed epochs of minimum or maximum light

n	J.D.24..	n	J.D.24..	n	J.D.24..
-0.5	41717.9	0	42465.8	-1.5	43131.5
0	729.0	+2.5	519.2	0	164.3
+0.5	739.2	11.5	714.8	+2	208.9
1	750.8	12.5	739.7	2.5	217.9
1.5	762.3	14	774.4	4	250.6
6	41860.5	14.5	786.1	8.5	43344.9
		15	797.4		
		17	837.5		
		18.5	42867.7		

Table 2 Normal *V* points

Hel. J.D. 24..	V	n	σ	Hel. J.D. 24..	V	n	σ	Hel. J.D. 24..	V	n	σ	Hel. J.D. 24..	V	n	σ	Hel. J.D. 24..	V	n	σ
41692.450	8.510	14	±.001	41788.326	8.482	15	±.002	42568.379	8.620	17	±.006	42817.341	8.564	12	±.002	43204.473	8.493	9	±.002
694.464	8.477	16	.002	802.339	8.513	15	.001	689.655	8.469	11	.002	829.437	8.465	12	.002	207.277	8.565	18	.006
708.445	8.654	14	.001	812.396	8.555	10	.002	692.638	8.403	12	.002	830.333	8.473	7	.001	208.325	8.589	14	.003
709.504	8.636	14	.003	816.355	8.668	17	.002	700.576	8.587	8	.006	831.403	8.482	8	.001	212.316	8.527	17	.004
711.299	8.588	10	.002	826.370	8.420	14	.002	709.548	8.617	11	.002	832.484	8.492	9	.002	215.451	8.433	17	.003
712.435	8.539	14	.001	830.381	8.414	21	.018	710.582	8.581	12	.002	833.307	8.500	4	.006	216.281	8.424	10	.002
713.440	8.486	8	.005	833.387	8.491	26	.005	711.593	8.556	14	.003	834.363	8.518	15	.003	217.346	8.418	10	.002
717.423	8.411	10	.001	834.403	8.528	17	.005	712.578	8.532	10	.002	835.301	8.520	10	.001	218.276	8.415	8	.001
718.393	8.408	11	.002	843.367	8.573	11	.002	713.532	8.510	12	.005	836.314	8.536	8	.001	219.329	8.418	9	.005
719.456	8.412	16	.002	844.389	8.546	10	.002	714.577	8.495	12	.002	837.314	8.543	7	.001	220.330	8.422	7	.001
721.432	8.451	20	.003	845.381	8.513	16	.004	715.595	8.500	7	.003	838.295	8.545	17	.004	227.425	8.561	13	.002
725.379	8.573	8	.002	853.382	8.499	21	.004	716.356	8.510	11	.005	840.348	8.531	20	.005	228.345	8.571	10	.002
729.378	8.648	17	.002	858.389	8.670	25	.003	721.335	8.570	10	.003	849.300	8.439	9	.001	246.310	8.485	6	.001
732.347	8.592	19	.002	859.379	8.689	19	.002	727.548	8.743	10	.001	855.293	8.509	11	.001	247.308	8.508	12	.002
733.336	8.560	13	.002	862.383	8.673	20	.005	737.506	8.466	10	.002	862.306	8.503	11	.002	248.301	8.534	14	.004
734.395	8.530	15	.004	863.367	8.656	11	.007	738.514	8.455	10	.001	863.346	8.499	10	.001	249.309	8.563	8	.005
735.365	8.494	8	.007	864.379	8.611	27	.003	739.478	8.449	12	.003	864.349	8.484	10	.003	250.302	8.564	8	.001
736.339	8.468	13	.002	865.377	8.577	25	.007	740.502	8.443	10	.001	865.348	8.470	14	.006	252.333	8.547	12	.004
738.312	8.440	12	.001	42461.392	8.590	9	.001	741.571	8.452	6	.001	866.311	8.467	12	.003	255.351	8.481	12	.002
739.350	8.436	11	.001	462.409	8.629	10	.002	746.238	8.557	11	.002	867.355	8.470	9	.002	257.323	8.450	15	.005
740.414	8.435	19	.003	463.348	8.661	6	.002	751.249	8.661	13	.003	868.356	8.470	11	.005	258.362	8.439	8	.003
741.268	8.443	10	.001	466.310	8.686	11	.001	752.317	8.657	8	.001	869.447	8.459	10	.003	259.352	8.426	8	.001
742.288	8.461	15	.002	467.276	8.674	8	.001	756.299	8.570	10	.006	870.359	8.469	14	.003	269.351	8.535	3	.008
743.272	8.484	16	.002	468.308	8.660	8	.001	758.252	8.501	7	.001	872.310	8.491	8	.002	273.397	8.556	11	.001
744.482	8.504	19	.002	469.273	8.656	10	.007	759.445	8.470	12	.003	874.349	8.526	8	.001	274.353	8.545	8	.001
745.317	8.526	18	.001	470.281	8.632	12	.001	767.474	8.507	9	.002	43124.491	8.592	8	.001	275.365	8.530	16	.004
746.352	8.549	15	.002	471.281	8.588	10	.002	768.456	8.533	7	.001	125.488	8.558	8	.001	277.385	8.510	8	.008
747.367	8.574	11	.003	478.387	8.433	14	.002	769.394	8.552	22	.003	126.468	8.523	8	.001	292.360	8.598	8	.003
750.282	8.641	19	.003	492.376	8.526	7	.001	770.365	8.570	10	.001	134.446	8.448	13	.004	293.376	8.625	14	.004
751.420	8.634	16	.002	493.295	8.488	10	.001	776.428	8.641	10	.001	136.494	8.506	9	.001	307.366	8.501	8	.003
753.285	8.618	14	.002	496.502	8.409	7	.001	777.464	8.625	15	.003	152.302	8.422	8	.001	311.390	8.630	8	.002
759.280	8.468	21	.001	497.310	8.402	8	.001	781.281	8.488	16	.003	157.341	8.474	8	.001	312.377	8.624	10	.005
760.293	8.435	22	.002	514.328	8.523	8	.001	782.277	8.446	8	.003	159.350	8.530	10	.001	314.422	8.636	10	.002
761.297	8.421	14	.001	515.342	8.497	8	.001	783.440	8.424	10	.002	161.480	8.593	7	.002	322.389	8.468	10	.001
762.297	8.414	14	.001	519.407	8.438	8	.003	784.384	8.401	12	.003	162.381	8.601	7	.001	326.377	8.472	8	.003
763.373	8.420	14	.002	520.383	8.429	9	.001	785.441	8.403	15	.003	168.348	8.579	10	.002	327.399	8.474	14	.002
764.293	8.427	17	.002	521.448	8.445	10	.003	787.365	8.405	12	.003	173.494	8.409	5	.001	335.401	8.676	11	.006
765.292	8.451	11	.004	522.352	8.450	12	.003	793.414	8.554	11	.004	174.242	8.388	8	.001	336.396	8.670	13	.003
766.313	8.467	31	.004	529.336	8.609	15	.002	798.381	8.605	11	.002	177.252	8.361	5	.003	340.375	8.525	10	.003
770.330	8.605	13	.002	547.343	8.547	8	.002	801.678	8.586	8	.002	189.510	8.598	12	.002	344.377	8.481	10	.003
776.385	8.624	10	.002	549.346	8.591	8	.002	803.321	8.493	9	.002	190.447	8.589	4	.011	348.362	8.510	9	.003
777.336	8.598	17	.002	551.333	8.599	8	.002	804.676	8.472	8	.003	199.336	8.407	10	.002	349.364	8.517	14	.002
779.426	8.536	22	.004	563.459	8.508	20	.002	805.374	8.458	10	.002	200.290	8.419	11	.003				
786.300	8.440	13	.002	566.387	8.535	18	.005	806.336	8.441	13	.003	202.366	8.446	9	.002				
787.310	8.458	8	.001	567.417	8.558	17	.005	816.352	8.548	8	.002	203.276	8.457	9	.003				

Table 3 Normal *B* points

Hel. J.D. 24..	B	n	σ	Hel. J.D. 24..	B	n	σ	Hel. J.D. 24..	B	n	σ	Hel. J.D. 24..	B	n	σ	Hel. J.D. 24..	B	n	σ
41692.436	9.657	14	±.001	41802.355	9.665	15	±.002	42715.587	9.648	8	±.007	42831.422	9.652	20	±.002	43204.456	9.697	16	±.005
694.451	9.609	16	.002	812.384	9.765	8	.001	716.369	9.671	8	.012	832.475	9.680	12	.002	208.348	9.783	18	.004
708.432	9.881	16	.001	816.369	9.895	16	.004	721.345	9.767	8	.004	834.380	9.717	11	.002	215.452	9.567	8	.002
709.492	9.846	12	.002	827.385	9.546	15	.002	727.538	10.006	9	.002	835.291	9.738	10	.001	216.289	9.554	10	.002
711.299	9.779	12	.003	843.385	9.750	14	.003	737.494	9.597	11	.002	836.323	9.751	8	.003	217.357	9.552	11	.003
712.420	9.708	9	.001	844.401	9.710	14	.004	738.503	9.584	10	.002	837.325	9.749	10	.002	218.288	9.556	8	.001
717.438	9.533	12	.001	42461.403	9.837	10	.002	739.465	9.587	13	.006	838.316	9.739	17	.004	220.338	9.592	10	.004
718.406	9.537	9	.002	462.400	9.880	7	.001	740.491	9.585	8	.002	840.369	9.702	8	.004	227.438	9.770	8	.003
719.433	9.542	16	.003	466.295	9.922	10	.001	741.564	9.610	8	.001	855.308	9.710	11	.002	228.352	9.790	8	.003
721.450	9.615	18	.004	467.289	9.896	10	.004	746.251	9.761	10	.003	862.292	9.661	10	.003	246.318	9.662	10	.006
725.391	9.799	10	.002	468.296	9.872	10	.004	751.268	9.897	12	.002	864.340	9.636	10	.004	247.319	9.712	10	.001
729.398	9.875	22	.004	469.263	9.815	8	.002	752.329	9.883	7	.002	866.320	9.613	10	.002	248.359	9.763	7	.002
733.352	9.736	13	.001	470.308	9.797	14	.002	758.263	9.641	7	.003	867.364	9.611	11	.002	249.318	9.779	7	.001
734.410	9.685	15	.001	471.294	9.743	10	.002	759.476	9.617	12	.004	868.371	9.613	10	.005	250.313	9.778	8	.001
736.362	9.600	25	.003	478.400	9.599	16	.002	767.489	9.688	8	.002	869.457	9.609	7	.002	252.346	9.725	10	.002
738.325	9.566	12	.003	492.384	9.675	10	.001	768.467	9.719	10	.002	870.384	9.611	15	.002	255.366	9.633	13	.002
739.364	9.571	12	.002	493.281	9.621	9	.002	769.407	9.757	11	.002	872.318	9.667	7	.002	258.370	9.567	10	.004
740.399	9.584	15	.003	496.516	9.542	9	.002	770.380	9.756	8	.002	874.371	9.722	13	.006	259.358	9.562	8	.002
741.278	9.597	11	.002	497.320	9.541	7	.001	776.447	9.851	13	.002	43124.501	9.778	7	.002	273.410	9.743	12	.004
742.273	9.628	23	.002	514.339	9.676	8	.001	777.447	9.810	17	.002	125.498	9.741	8	.001	274.369	9.724	9	.002
743.285	9.674	12	.002	515.549	9.648	10	.002	781.298	9.628	14	.002	126.478	9.689	8	.002	275.382	9.687	8	.004
744.505	9.714	20	.002	519.425	9.581	6	.002	782.293	9.591	12	.003	134.461	9.643	9	.001	277.385	9.638	8	.006
746.368	9.771	19	.002	520.376	9.597	8	.001	783.450	9.561	10	.003	136.503	9.716	8	.001	292.371	9.842	12	.004
750.316	9.876	21	.003	521.462	9.633	10	.003	784.434	9.524	9	.001	152.311	9.583	6	.003	293.390	9.838	6	.003
751.436	9.872	16	.002	529.320	9.833	16	.002	785.457	9.533	13	.003	157.350	9.668	8	.001	307.376	9.687	10	.003
753.298	9.818	12	.003	547.349	9.787	8	.003	787.373	9.575	9	.001	159.359	9.743	6	.001	311.401	9.864	10	.003
760.310	9.577	20	.002	549.356	9.847	12	.003	793.400	9.771	7	.003	161.481	9.808	9	.004	312.390	9.883	9	.002
761.283	9.561	16	.002	551.349	9.830	8	.001	798.392	9.805	10	.002	162.380	9.838	8	.003	314.433	9.866	12	.004
762.312	9.561	14	.001	689.646	9.621	12	.002	801.670	9.752	8	.003	168.360	9.754	8	.002	322.405	9.599	16	.011
763.340	9.568	13	.003	692.627	9.531	11	.003	803.336	9.645	12	.002	173.482	9.544	8	.002	326.386	9.608	8	.002
764.310	9.593	16	.002	700.557	9.818	16	.004	804.684	9.619	8	.004	174.243	9.520	8	.002	327.416	9.668	14	.006
770.316	9.841	17	.001	709.541	9.821	10	.002	805.386	9.602	11	.002	189.529	9.770	13	.002	336.414	9.893	11	.004
776.397	9.829	12	.002	710.570	9.777	9	.001	806.351	9.578	13	.005	192.455	9.641	5	.012	340.390	9.706	8	.002
777.321	9.787	14	.001	711.580	9.719	7	.008	816.365	9.756	8	.001	199.335	9.569	13	.004	344.394	9.617	10	.005
786.314	9.603	9	.002	712.570	9.687	11	.003	817.357	9.756	13	.006	200.290	9.594	11	.006	348.376	9.677	12	.004
787.322	9.640	9	.002	713.519	9.659	9	.001	829.451	9.619	13	.002	202.355	9.649	9	.001	349.381	9.711	13	.006
788.346	9.675	16	.002	714.565	9.639	11	.004	830.344	9.645	9	.003	203.267	9.658	12	.002				

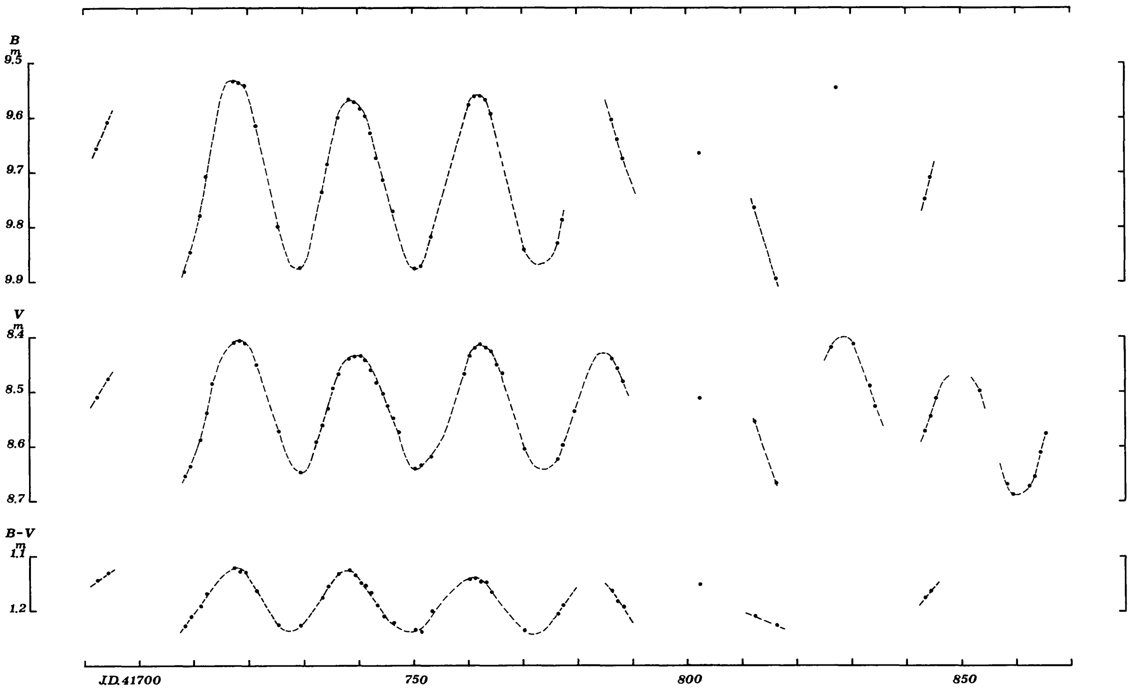

Figure 1 a Light and colour curves of RU Cam from 1973.0 to 1973.5.

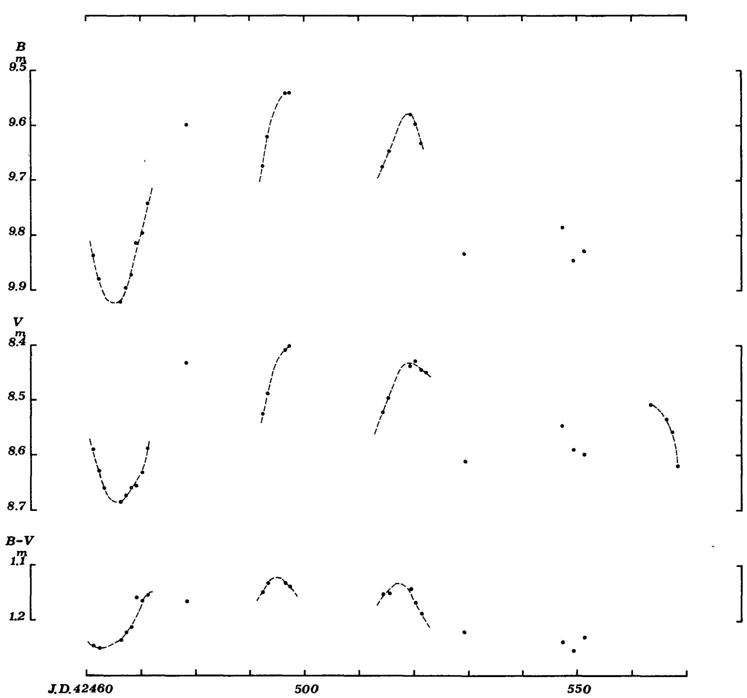

Figure 1 b Light and colour curves of RU Cam from 1975.1 to 1975.4.

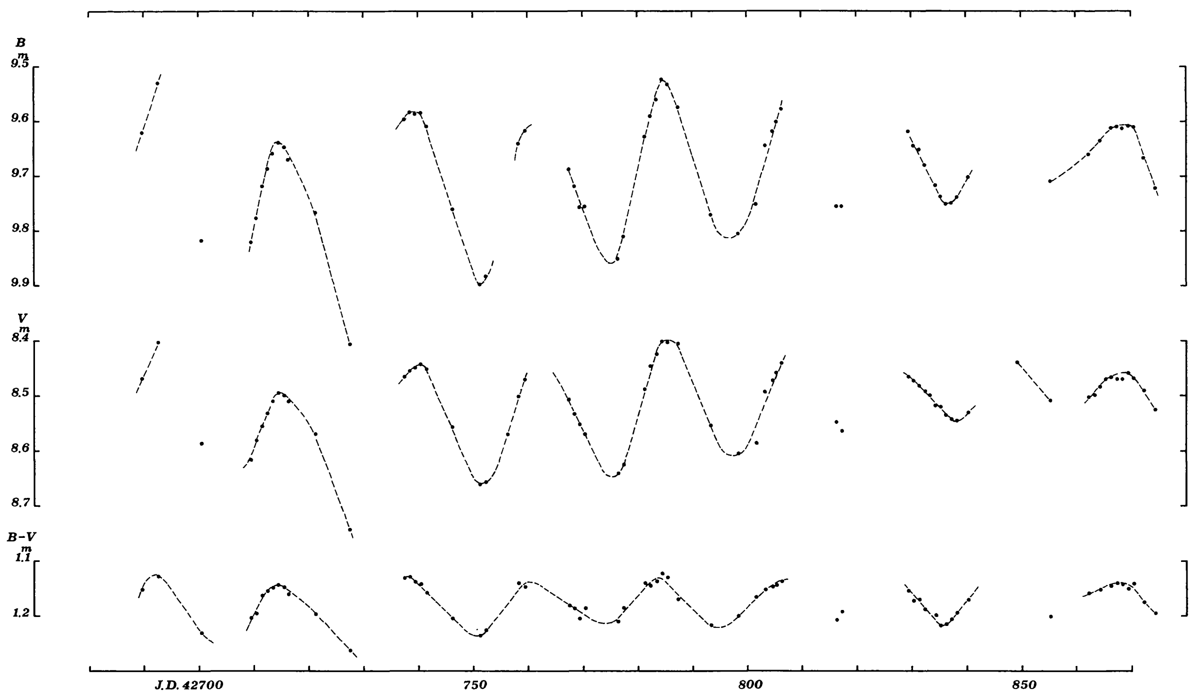

Figure 1 c Light and colour curves of RU Cam from 1975.8 to 1976.3.

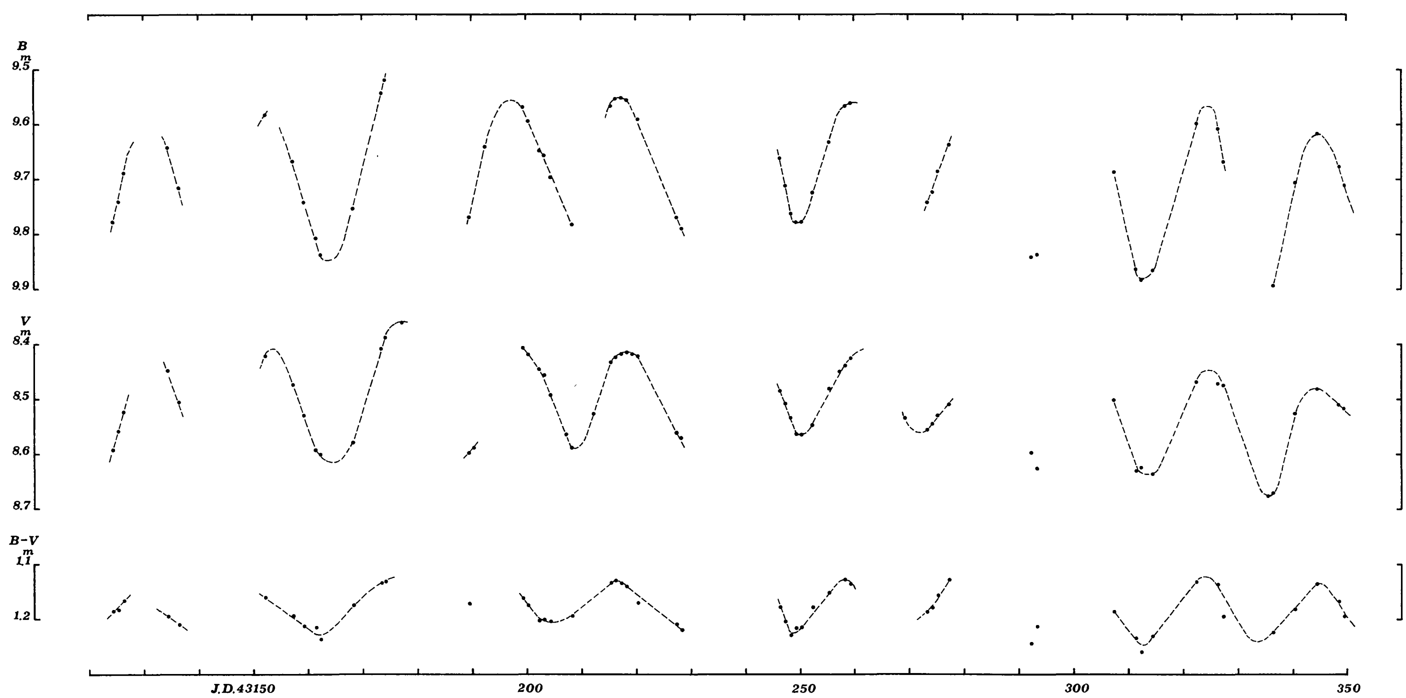

Figure 1 d Light and colour curves of RU Cam from 1976.8 to 1977.6.

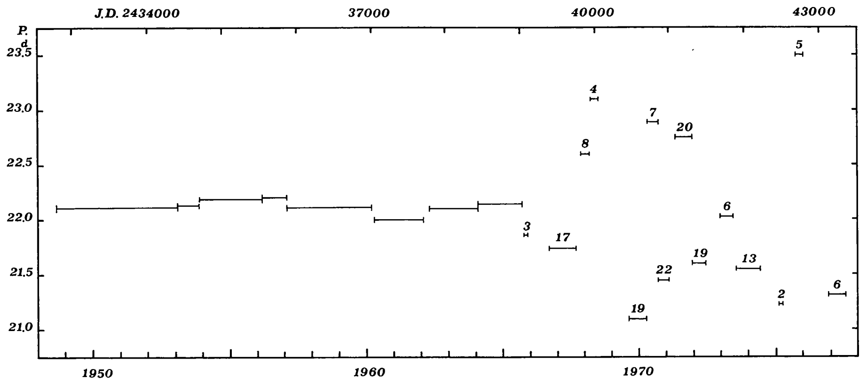

Figure 2 The trend of the period of RU Cam during the last thirty years. The figures indicate the number of epochs by which the period has been derived.

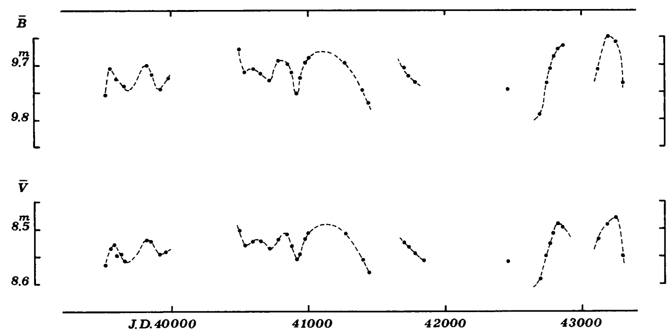

Figure 3 Small irregular fluctuations in the mean brightness of RU Cam, calculated by means of sinusoid fitting to single cycles.

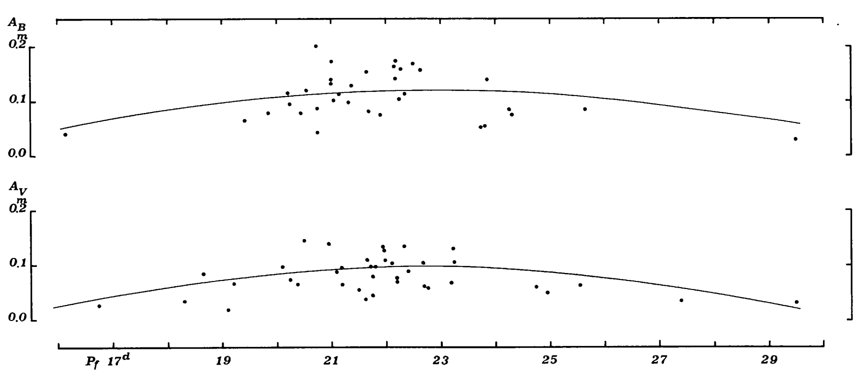

Figure 4 The amplitudes of pulsation of RU Cam after 1964 rise when the period approaches the value before 1964 and fall to zero as the period deviates from this value.