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STUDY OF THE VARIABILITY OF THE DELTA SCUTI STARS
I. PHOTOMETRIC OBSERVATIONS OF THE STAR 38 CANCRI*

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Photoelectric observations of the variable bright star 38 Cancri, obtained in 1975 (four nights) and in 1976 (twelve nights), are presented. The spectral analysis of the data denotes a fair stability in the pulsational characteristics during the period of observation, and gives evidence of the existence of the three frequencies: $f_1 = 7.14417 c/d$, $f_2 = 7.17378 c/d$ and $f_3 = 9.77704 c/d$ that are able to represent the light curves satisfactorily. The mode of pulsation corresponding to f_3 records greater excitation than f_1 and f_2.

Comparison of the ratios of the periods and of the Q's observed with those envisaged by the theory leads us to regard 38 Cancri as a possible non-radial pulsator.

Key words: Delta Scuti Stars – photometry – multiple periodicity

1. INTRODUCTION

One of the problems that is still open concerning the variability of the Delta Scuti stars is the interpretation of the observations of these stars, both spectroscopic and photometric. In fact the relative curves of variation usually present a very complex trend in which it is often difficult to identify stable characteristics.

During the last few years sophisticated mathematical methods for the spectral analysis of observational time-series have been applied to some Delta Scuti. The findings of these analyses may be summarized in the following two alternative hypotheses: 1) the variation observed may be entirely explained in terms of superposition of modes of radial or non-radial pulsations, that is to say, the curves are stable (repetitive) albeit complex in form (Fitch 1975); 2) these variations have intrinsic irregularities: that is to say, other complex effects may play an important role as regards this type of variables (Le Contel *et al.* 1974).

To throw any light on this problem it is clearly necessary to have available long series of observed data: however to date the number of variables studied in depth is not great, because until a few years ago the general tendency was to do research on Delta Scuti stars in order to provide preliminary data for statistical purposes.

Bearing all this in mind, we decided to start at the Merate Astronomical Observatory making prolonged photometric observations of some Delta Scuti stars, with a view to assembling sufficient data to make a precise analysis of the pulsation modalities present.

In this first article we give our results for the star 38 Cancri.

2. THE OBSERVATIONS

The variability of 38 Cnc (HD 73575, spectral type FO III), one of the evolved Delta Scuti stars, was discovered by Breger (1970) by observing photoelectrically all the stars of the Praesepe cluster which are in or near the strip of instability. Later Gupta (1974) measured the star for only one night, determining the period $P = 0^{\mathrm{d}}.108$ and the amplitude $\Delta m = 0^{\mathrm{m}}.07$.

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38 Cnc was observed by us for four nights at the beginning of 1975 and for twelve nights at the beginning of 1976, using an ice refrigerated Lallemand photomultiplier (19 stages) with S4 response and standard *UBV* filters, applied to the 40″ reflector. Use was also made of a Weitbrect-Gardiner amplifier with the integrating time set at 15 secs.

The comparison and check stars were HD 73711 (spectral type FO) and HD 73210 (spectral type A5) respectively. As a rule, six observations were performed of the variable in alternation with the comparison star: these Δm magnitudes ($m_c - m_v$) have been averaged to give normal points. Each measurement was adjusted to take into consideration the differential extinction using the coefficients determined, whenever possible, during the course of the same night or by means of averages values. Tables 1, 2 and 3 show the *UBV* values of the normal points with observational times and standard errors σ. Figures 1a, b, c, d show the normal points for the three colours.

3. SPECTRAL ANALYSIS OF THE OBSERVATIONS

The observations were analyzed according to the method first used by Vanîcek (1971) which is a generalization of the traditional LS spectrum (see, for example Lomb 1976). The 1976 measurement were divided into three groups of near nights, and specifically: group I: J.D. 42783–784–785–787; group II: J.D. 42793–798–800–803–804–806; group III: J.D. 42815–818. Table 4 gives the results of the spectral analysis for the three groups indicated above and for the three colours *UBV*: here f_i are the frequencies found expressed in cycles to day and A_i the relative amplitudes; the initial residuals represent the averages of the deviations from the mean value, and the final residuals the averages of the deviations between the observed and calculated curves.

From a study of table 4 it seems evident that the frequencies $f_2 = 7.2 c/d$ and $f_3 = 9.8 c/d$ are fairly stable throughout the whole period of observation, whereas the third frequency found f_1 presents greater fluctuations and must be considered with some circumspection also because of the small corresponding amplitudes.

Because only a few observations were made in 1975, it is not possible to determine the frequencies present with a precision comparable to that of 1976. Nonetheless it may be stated that these results are not such as to conflict with the values found for 1976 and indicated in table 4.

In the interests of making a unified representation of the variability of 38 Cnc during the two years when it was observed, we applied the method of spectral analysis indicated above using all the data of 1975 and 1976. This representation is expressed in the following equation:

$$\Delta m(t_i) = \Delta m_0 + \sum_{j=1}^{3} \left[c_j \cos 2\pi f_j (t_i - t_0) + s_j \sin 2\pi f_j (t_i - t_0) \right] \qquad (1)$$

$$i = 1, N \text{ with } N = \text{number of observations}$$

whose values for f_j, c_j, s_j, Δm_0 and t_0 are listed in table 5 for the three colours *UBV*. The light curves calculated by (1) are represented by means of a continuous line in figures 1a, b, c, d. The mean residues between the observed and calculated curves, for the three colours *UBV* respectively, are as follows: $0\overset{m}{.}005$, $0^{m}005$ and $0\overset{m}{.}006$. The differences between table 4 and 5, in particular the identification of a third real frequency in table 5, may be explained by the fact that the overall analysis of all the data makes for a more satisfactory resolution than the analysis of the individual groups separated timewise.

4. CONCLUSIONS

1. It is a known fact that the possibility of comparing the ratios of the periods drawn from the analysis of the observed light curves and the relative values of the pulsation constant Q with those deduced from the theory of pulsations, constitutes one of the few resources at our disposal for identifying the variability mechanism of Delta Scuti stars.

The following ratios may be immediately deduced from table 5: $P_2/P_1=0.996$, $P_3/P_1=0.731$ and $P_3/P_2=0.734$. The notable difference between these values and those envisaged by the theory of radial pulsations (see, for example, Petersen and Jorgensen 1972) obliges us to rule out the presence of this type of oscillations. On the other hand, we can determine the observational values of the pulsation constants by introducing into equation (5) quoted in Petersen and Jorgensen (1972), the periods found and the values: $\log g=3.51$, $M_{\rm bol}=0^{\rm m}.24$ and $\log Te=3.885$ relating to 38 Cnc (Crawford and Barnes 1969). The Q's thus obtained, namely: $Q_1=0^{\rm d}.023$, $Q_2=0^{\rm d}.023$, $Q_3=0^{\rm d}.017$ are also in contrast with those envisaged by the theory of radial pulsations for the fundamental mode and the first overtones, also taking into account the error made in determining them, corresponding to a factor equal to 1.2–1.4 (Petersen 1975).

Let us now consider the possibility that non-radial pulsations are involved. In this case it is a known fact that the values of Q depend critically upon the evolutionary status of the star. Taking as comparison the evolved model worked out in detail by Dziembowski (1975) for non-radial pulsations, we reach the following conclusions: a) the ratios of the observed periods agree with those determined theoretically in a more satisfactory way than occurs for radial pulsations; b) the observed values of Q, taking into account the errors indicated above, are sufficiently near to the theoretical values.

Taking into account the fact that the physical parameters of Dziembowski's model do not agree completely with those relating to 38 Cnc and that hence this difference could be the cause of the absence of complete agreement, summing up we would suggest that the star may in effect be a non-radial pulsator.

2. The coefficients c_j and s_j of table 5 indicate that the greater pulsation amplitude corresponds to the frequency of the highest order f_3: this fact may be observed in other Delta Scuti stars (for example HR 1170, see Gupta 1977).

3. From a comparison of the observed value $P_3=0^{\rm d}.102$, corresponding to the mode of pulsation of greater amplitude, with that deduced from the relation P–L–C (eq. (6) in Breger and Bregman 1975), equal to about $0^{\rm d}.2$, we may state that the difference is a significant one, even taking into account the error in the determination of $M_{\rm bol}$ and $\log Te$. Since the relation P–L–C has been deduced working on the assumption of radial pulsations, this fact could be a further indication of the presence of non-radial pulsations.

4. Danziger and Faber (1972) have advanced the hypothesis that, for the brighter Delta Scuti stars, "slow rotation seems to be a necessary condition for pulsational instability": 38 Cnc presents both a high rotational velocity (about 160 km/sec) and stable oscillations, and hence represents an example that conflicts with the above hypothesis.

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Table 1

Hel.J.D. 2442...	ΔU	ε	Hel.J.D. 2442...	ΔU	ε	Hel.J.D. 2442...	ΔU	ε	Hel.J.D. 2442...	ΔU	ε	Hel.J.D. 2442...	ΔU	ε	Hel.J.D. 2442...	ΔU	ε
497.380	.086	.002	497.484	.092	.002	787.478	.136	.004	793.586	.097	.003	800.616	.079	.003	804.567	.150	.010
.385	.086	.001	.491	.096	.007	.500	.127	.003	.607	.117	.004	.633	.083	.005	.589	.126	.009
.391	.095	.002	.496	.110	.004	.521	.097	.002	.626	.140	.006	.660	.123	.008	.613	.087	.003
.396	.107	.002	.521	.117	.004	.540	.083	.002	.644	.117	.004	803.426	.130	.008	.652	.083	.005
.401	.113	.002	783.488	.117	.001	.560	.110	.003	.662	.101	.003	.445	.143	.004	.663	.116	.003
.406	.116	.002	.512	.125	.001	.578	.140	.001	.680	.088	.004	.473	.112	.002	806.417	.148	.004
.412	.123	.002	784.470	.077	.002	.596	.135	.004	798.463	.097	.005	.495	.091	.003	.443	.102	.011
.417	.124	.001	.491	.102	.005	.614	.108	.002	.508	.116	.004	.514	.093	.003	.462	.077	.001
.422	.123	.001	.512	.130	.002	.633	.088	.003	.529	.131	.003	.533	.117	.002	.487	.102	.002
.427	.128	.001	.535	.132	.004	.656	.093	.004	.550	.120	.004	.553	.135	.005	.504	.137	.001
.432	.123	.001	.559	.108	.003	.673	.118	.004	800.451	.088	.006	.573	.117	.005	.522	.134	.001
.436	.120	.002	.580	.098	.004	.690	.132	.004	.471	.123	.004	.598	.085	.003	.542	.106	.002
.441	.112	.004	.606	.117	.002	793.452	.103	.003	.491	.131	.003	.620	.090	.003	.559	.084	.001
.446	.109	.002	.628	.133	.003	.471	.091	.004	.510	.116	.003	804.436	.108	.004	.576	.083	.003
.454	.095	.004	.648	.116	.004	.490	.088	.003	.530	.098	.004	.459	.138	.004	.596	.111	.003
.460	.092	.004	.670	.089	.007	.524	.128	.010	.534	.097	.002	.482	.120	.004	.614	.125	.005
.467	.084	.001	785.494	.086	.003	.532	.135	.005	.565	.127	.002	.503	.098	.005	.633	.122	.003
.474	.083	.003	787.438	.089	.003	.550	.111	.003	.582	.121	.002	.524	.087	.004	.650	.102	.004
.479	.086	.003	.459	.115	.003	.568	.088	.003	.598	.108	.003	.545	.123	.004	815.418	.122	.005

Table 2

Hel.J.D. 2442...	ΔB	ε	Hel.J.D. 2442...	ΔB	ε	Hel.J.D. 2442...	ΔB	ε	Hel.J.D. 2442...	ΔB	ε	Hel.J.D. 2442...	ΔB	ε	Hel.J.D. 2442...	ΔB	ε
468.474	.150	.002	784.528	.155	.003	787.667	.128	.002	800.517	.123	.002	804.489	.133	.002	806.655	.117	.002
.489	.154	.002	.552	.131	.003	.684	.151	.002	.543	.119	.002	.511	.100	.002	815.425	.135	.004
.503	.141	.002	.573	.114	.003	793.446	.136	.002	.547	.126	.003	.532	.113	.002	.438	.124	.005
.518	.110	.002	.598	.116	.005	.464	.111	.002	.571	.139	.002	.553	.153	.004	.452	.116	.002
.533	.097	.002	.621	.139	.002	.482	.108	.001	.588	.130	.001	.575	.169	.004	.466	.116	.004
.549	.111	.003	.641	.133	.003	.503	.130	.002	.605	.112	.001	.597	.133	.002	.480	.129	.003
.566	.139	.001	.663	.125	.004	.544	.144	.004	.622	.109	.002	.627	.097	.002	.492	.150	.002
.580	.151	.003	785.475	.103	.003	.562	.120	.001	.638	.115	.004	.655	.109	.003	.505	.159	.002
.591	.143	.004	.501	.103	.003	.580	.111	.002	803.410	.109	.003	.666	.143	.004	.517	.150	.002
469.381	.125	.001	787.431	.108	.001	.601	.129	.002	.433	.151	.003	806.424	.150	.004	818.363	.140	.002
.395	.136	.002	.451	.116	.002	.619	.148	.004	.451	.161	.002	.450	.093	.003	.388	.141	.002
.409	.132	.004	.465	.136	.003	.637	.147	.003	.465	.143	.002	.470	.091	.003	.408	.122	.002
.421	.119	.003	.493	.154	.003	.656	.120	.005	.486	.114	.002	.494	.134	.002	.430	.107	.002
.436	.114	.002	.513	.126	.002	.674	.111	.003	.507	.107	.002	.510	.157	.002	.449	.103	.002
.451	.117	.002	.533	.101	.002	798.457	.119	.003	.526	.127	.002	.530	.144	.002	.468	.127	.001
783.482	.128	.002	.553	.118	.002	.514	.135	.004	.546	.147	.003	.548	.113	.001	.488	.136	.002
.505	.139	.002	.572	.149	.001	.535	.148	.001	.566	.141	.002	.565	.102	.002	.507	.122	.003
.519	.137	.003	.589	.154	.002	.556	.117	.004	.587	.117	.004	.582	.105	.003	.528	.115	.001
784.462	.101	.004	.607	.137	.002	800.458	.124	.003	.615	.110	.003	.602	.134	.004	.549	.123	.003
.484	.094	.001	.626	.107	.002	.478	.139	.001	804.442	.134	.002	.621	.145	.002	.568	.135	.001
.505	.133	.002	.646	.096	.002	.498	.141	.003	.467	.151	.002	.639	.122	.003	.587	.132	.001

Table 3

Hel.J.D. 2442...	ΔV	ε	Hel.J.D. 2442...	ΔV	ε	Hel.J.D. 2442...	ΔV	ε	Hel.J.D. 2442...	ΔV	ε	Hel.J.D. 2442...	ΔV	ε	Hel.J.D. 2442...	ΔV	ε
471.396	.094	.002	784.499	.100	.002	787.639	.086	.001	800.483	.124	.003	804.496	.100	.004	806.661	.102	.002
.411	.103	.002	.520	.130	.002	.661	.102	.002	.504	.118	.002	.518	.085	.002	815.431	.112	.004
.422	.117	.001	.544	.118	.003	.678	.126	.002	.523	.100	.002	.538	.106	.003	.445	.103	.002
.432	.123	.001	.566	.106	.002	793.439	.123	.005	.557	.116	.002	.560	.140	.003	.459	.092	.003
.443	.122	.001	.590	.101	.002	.458	.105	.003	.577	.117	.002	.582	.131	.003	.473	.102	.003
.453	.112	.003	.614	.118	.002	.476	.095	.005	.593	.109	.002	.604	.099	.002	.486	.116	.002
.465	.104	.001	.635	.115	.002	.497	.107	.003	.610	.097	.002	.640	.080	.004	.499	.126	.002
.475	.088	.002	.655	.108	.004	.538	.130	.003	.627	.090	.002	.659	.102	.003	.512	.132	.004
.487	.084	.001	785.475	.094	.002	.556	.112	.002	.652	.112	.005	.669	.128	.002	818.372	.119	.002
.497	.082	.001	.495	.092	.001	.574	.102	.003	803.416	.110	.003	806.433	.116	.006	.394	.119	.002
.508	.089	.003	787.424	.105	.002	.592	.102	.003	.439	.135	.002	.457	.080	.002	.415	.097	.001
.518	.099	.001	.445	.096	.001	.613	.123	.004	.458	.134	.001	.481	.094	.002	.436	.095	.002
.529	.117	.002	.472	.128	.002	.631	.134	.004	.480	.102	.002	.499	.125	.002	.455	.102	.002
.541	.127	.003	.486	.130	.001	.650	.115	.004	.501	.090	.002	.516	.134	.001	.475	.115	.001
.553	.126	.001	.507	.118	.003	.668	.097	.002	.520	.104	.003	.536	.116	.002	.494	.111	.001
.562	.120	.001	.527	.104	.003	798.435	.117	.003	.539	.121	.002	.554	.096	.002	.513	.105	.003
.567	.112	.001	.546	.098	.002	.450	.115	.005	.560	.124	.002	.570	.089	.003	.535	.100	.001
783.474	.109	.003	.566	.119	.002	.521	.127	.003	.579	.107	.002	.588	.101	.001	.556	.110	.002
.496	.124	.003	.584	.133	.002	.543	.124	.002	.609	.094	.003	.608	.116	.003	.574	.118	.001
784.454	.091	.002	.602	.125	.001	.563	.108	.005	804.451	.127	.003	.627	.117	.005			
.477	.081	.004	.620	.101	.003	800.464	.109	.001	.476	.128	.002	.644	.109	.003			

Table 4

	GROUP I	GROUP II	GROUP III
V Colour			
Initial residual	$0^m.012$	$0^m.012$	$0^m.009$
Final residual	$0^m.003$	$0^m.005$	$0^m.002$
f_1	7.01 c/d	7.16 c/d	-
f_2	7.23 c/d	-	-
f_2	9.78 c/d	9.77 c/d	9.76 c/d
A_1	$0^m.006$	$0^m.007$	-
A_2	$0^m.006$	-	-
A_3	$0^m.019$	$0^m.017$	$0^m.013$
B Colour			
Initial residual	$0^m.016$	$0^m.016$	$0^m.012$
Final residual	$0^m.003$	$0^m.004$	$0^m.006$
f_1	7.06 c/d	8.86 c/d	-
f_2	7.27 c/d	7.16 c/d	-
f_3	9.80 c/d	9.77 c/d	9.75 c/d
A_1	$0^m.005$	$0^m.005$	-
A_2	$0^m.008$	$0^m.009$	-
A_3	$0^m.023$	$0^m.022$	$0^m.017$
U Colour			
Initial residual	$0^m.016$	$0^m.016$	-
Final residual	$0^m.003$	$0^m.006$	-
f_1	7.04 c/d	7.16 c/d	-
f_2	7.22 c/d	-	-
f_3	9.79 c/d	9.77 c/d	-
A_1	$0^m.004$	$0^m.004$	-
A_2	$0^m.005$	-	-
A_3	$0^m.024$	$0^m.025$	-

Table 5

	U		B		V	
f_j	c_j	s_j	c_j	s_j	c_j	s_j
f_1 = 7.14417 c/d ± 0.00004	$0^m.0023$ ±.0010	$-0^m.0035$ ±.0010	$0^m.0004$ ±.0009	$0^m.0061$ ±.0009	$0^m.0013$ ±.0010	$-0^m.0044$ ±.0010
f_2 = 7.17378 c/d ± 0.00026	$0^m.0047$ ±.0010	$-0^m.0010$ ±.0010	$-0^m.0036$ ±.0009	$-0^m.0050$ ±.0009	$-0^m.0017$ ±.0010	$0^m.0029$ ±.0010
f_3 = 9.77704 c/d ± 0.00002	$0^m.0209$ ±.0010	$-0^m.0122$ ±.0010	$-0^m.0119$ ±.0009	$0^m.0188$ ±.0009	$0^m.0025$ ±.0010	$0^m.0155$ ±.0010
m_0	$0^m.1091$		$0^m.1266$		$0^m.1041$	
t_0	736.5615		760.8606		755.0428	

Figure 1a, b, c, d. *UBV* light curves of the Delta Scuti star 38 Cancri.

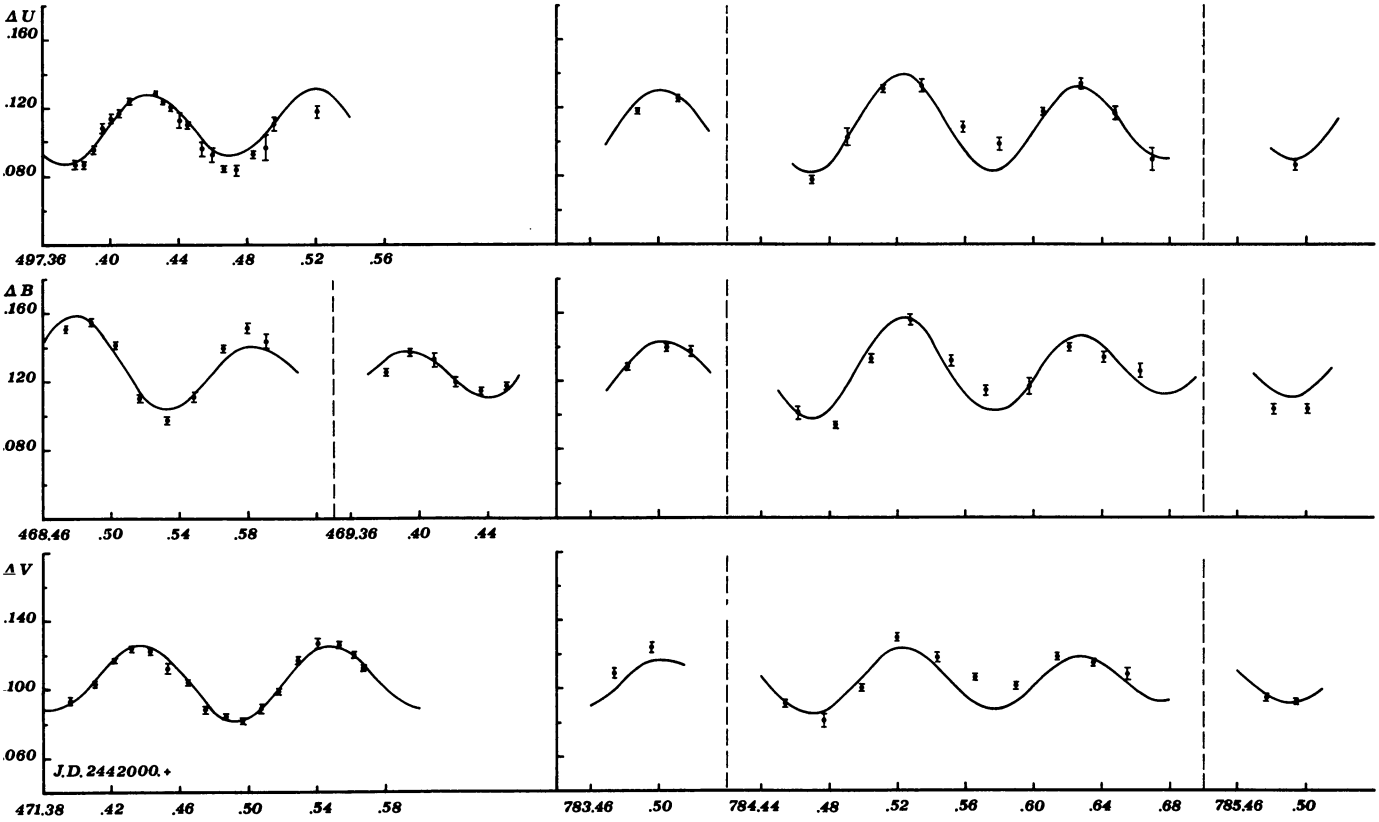

Figure 1a

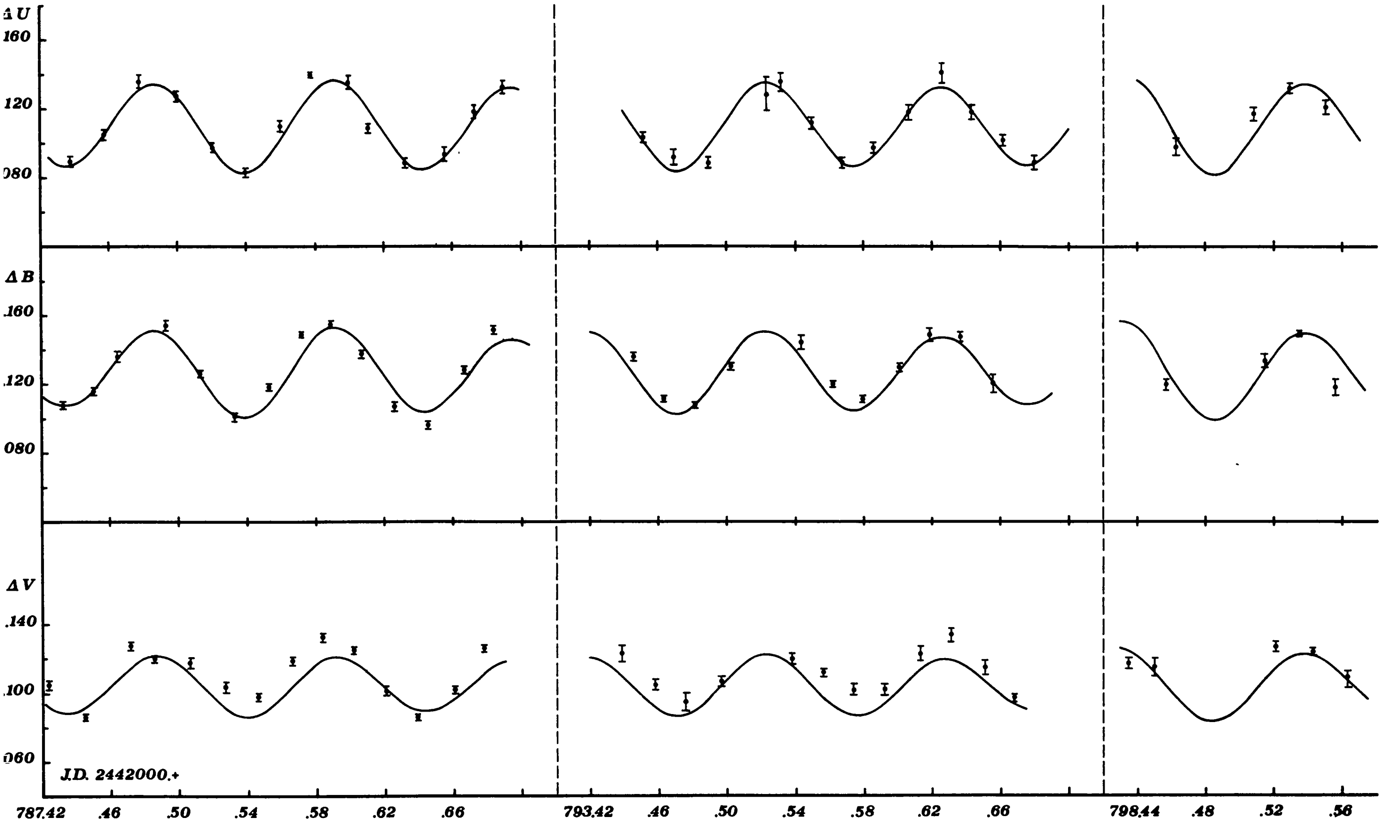

Figure 1b

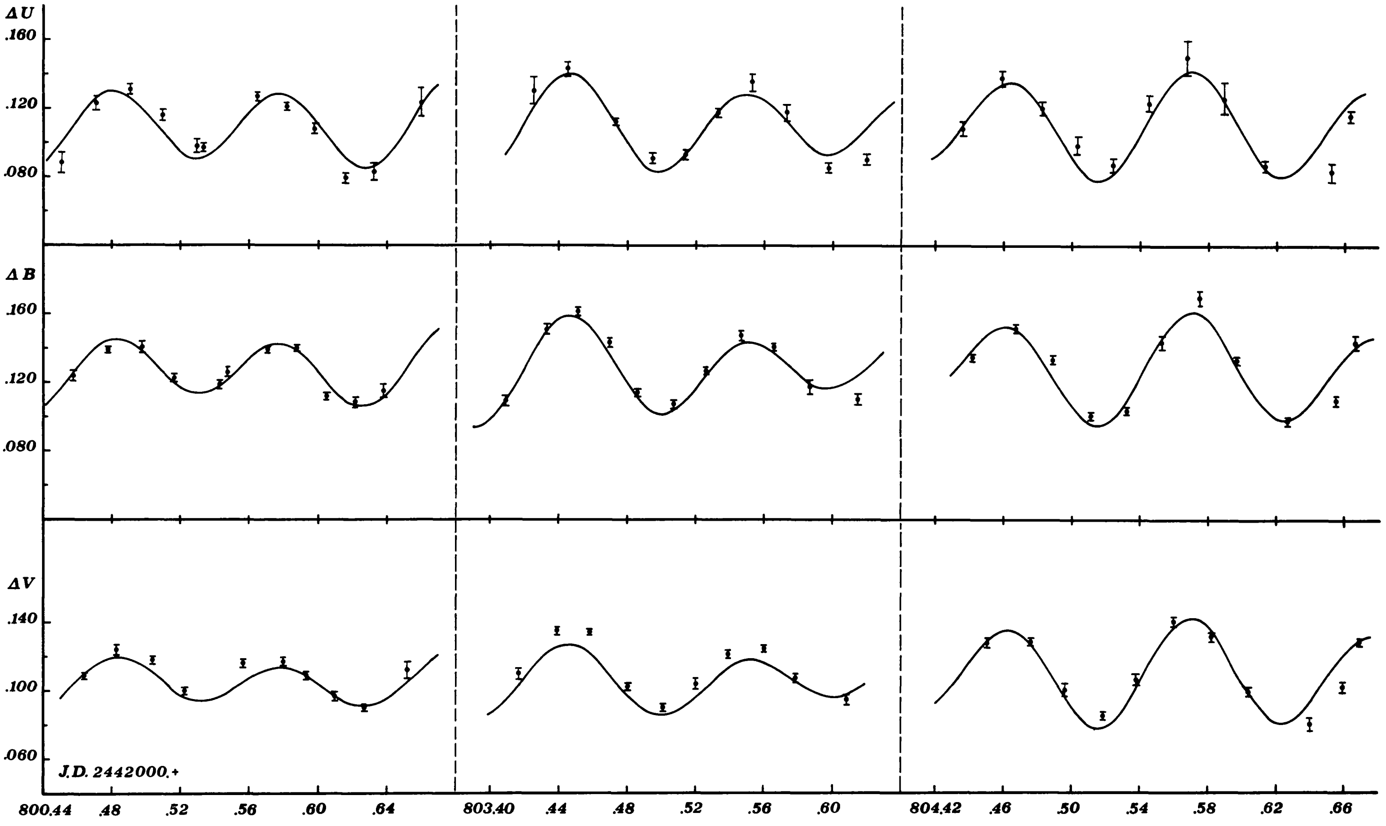

Figure 1c

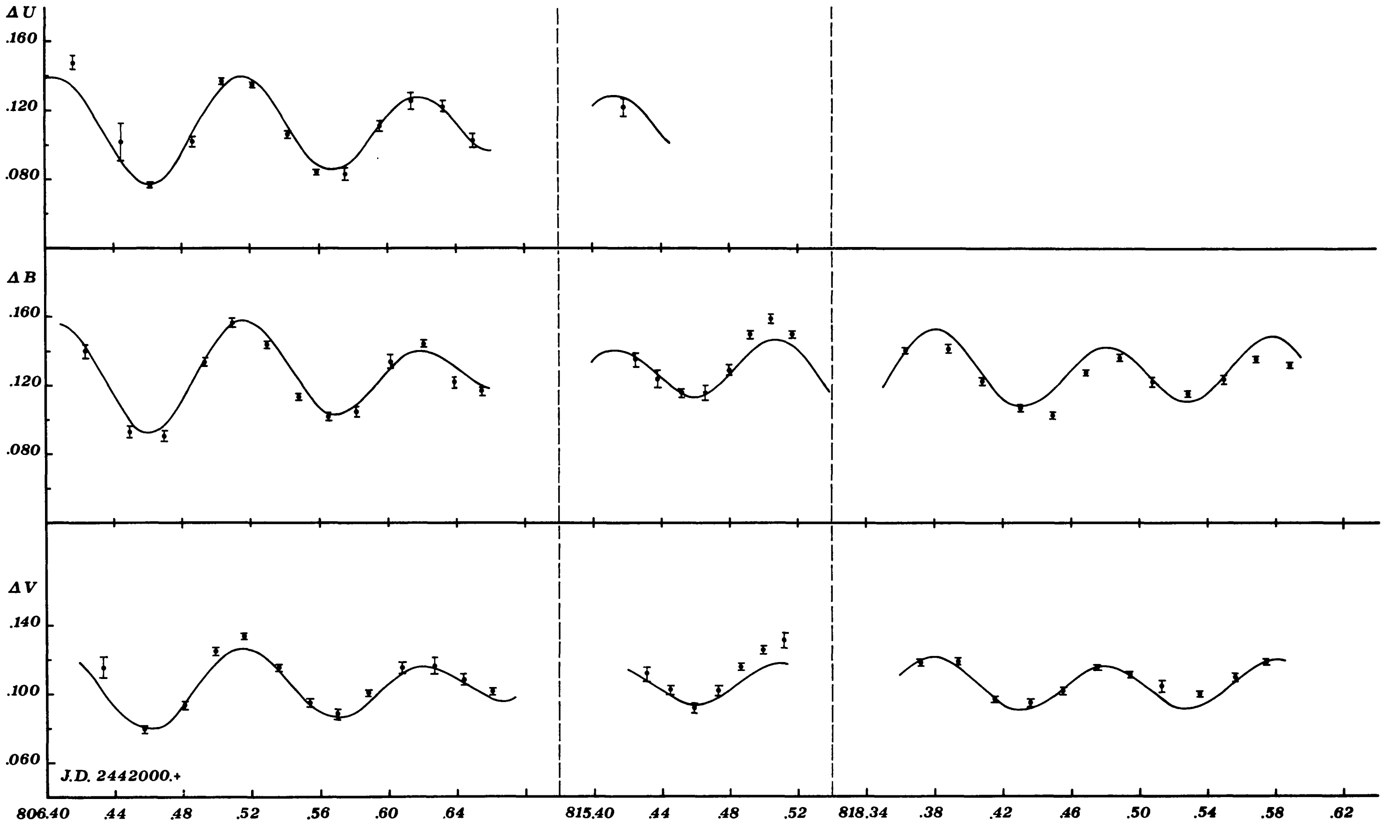

Figure 1d