

The Light Variation and Orbital Elements of W Ursae Majoris

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Photoelectric observations are presented of 551 yellow and 540 blue magnitudes of W Ursae Majoris obtained on 5 nights during 1965. New orbital elements have been determined based on primary minimum being caused by a total eclipse.

1. INTRODUCTION

THE variability of W Ursae Majoris was discovered in 1903 by Müller and Kempf (1903). Numerous times of minimum light are available for this system. Photographic light curves have been published by Schilt (1925), Walter (1928, 1930), Plaut (1936), and Woodward (1942). The latter author also compiled the earlier literature. Photoelectric light curves have been published by Huffer (1934), Kwee (1956), Schmidt and Schrick (1956), and Hinderer (1960). These observations show that the period is variable and that the light curve changes its shape. Radial velocity curves have been given by Adams and Joy (1919), Popper (1950), and Struve and Horak (1950).

2. OBSERVATIONS

The variable was observed photoelectrically in two wavelength regions with the 28-inch reflecting telescope of the Flower and Cook Observatory. The yellow and blue filters used are the same as those in the *U*, *B*, *V* system. The output of a 1P21 multiplier photocell was fed into a direct current amplifier and the amplified current was registered by a Brown recorder. The duration of each deflection was one minute.

TABLE I. Variable and comparison stars.

Star	BD No.	R.A. (1900)	Dec. (1900)	Sp.
W Ursae Majoris	+56°1400	9 ^h 36 ^m 44 ^s	+56°24'.5	F8p
comparison	+56 1399	9 35 40	+56 6.8	...
check star	+56 1398	9 35 26	+56 37.8	...

Table I lists the BD numbers, the positions of the stars, and the spectral type of the variable according to Struve and Horak. A total of 551 observations in yellow light and 540 observations in blue light were obtained on 5 nights during 1965. The observing interval during the first two nights was longer than the period so that an overlap occurred without any systematic differences. The eclipsing system is the brighter component of the visual binary ADS 7494. The fainter component which is at a distance of 7'' and which differs by 4^m.8 from the variable at maximum light was included in the measurements. It was unnecessary to apply corrections for differential extinction.

3. EPOCHS OF MINIMUM LIGHT

Table II lists normal points of the epochs of minimum light determined from the visual and photographic observations but the epochs determined from photoelectric observations are listed individually. Nine epochs of minimum light were determined from the present observations by using the method of Hertzprung (1928). Five unpublished times of minimum light by Bertiau, one by Kwee, and two by Kuhl were kindly placed at our disposal. The material of Hinderer, and of Schmidt and Schrick, was used by the author to compute the times of minimum light that are shown. The *O-C*'s were computed from Huffer's ephemeris,

$$\text{JD Hel. Min. I} = 2421856.9401 + 0.333637665E.$$

In Fig. 1 the normal points covering the entire observing interval of 60 years have been plotted on a small scale. In Fig. 2 the times of minimum light determined from only the photoelectric observations obtained during the last 17 years have been plotted on a larger scale. The points refer to primary minima; the crosses represent secondary minima. In the latter case the computed values correspond to phase 0.5000. There seems to be a systematic difference during the last ten years in the sense that secondary minimum arrives about two minutes later than expected. However, for W UMA systems this does not necessarily mean an eccentric orbit but may be correlated with a difference in the heights of the maxima. The arrow indicates the epoch

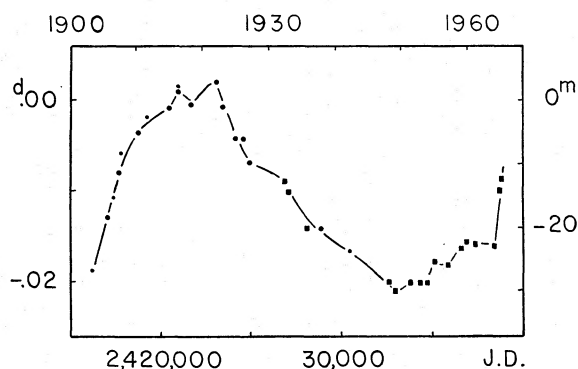


FIG. 1. Period variation of W Ursae Majoris. Small dots represent mean values of visual observations, large dots denote mean values of photographic data, squares refer to mean values of photoelectric data.

TABLE II. Times of minimum of W Ursae Majoris.

JD Hel.	Min.	$O-C$	n	Meth.	Obs. ^a	Ref.
2416229.452	I	-0.019	4	v	M, K	1, 2
7159.803	II	-0.013	2	pg	P, J	3
7337.471	I	-0.011	2	v	Mu	4
7668.445	I	-0.008	1	pg	Ti	13
7916.342	I	-0.006	2	v	Ba	5
8748.4343	I	-0.0037	1	pg	He	6
9232.377	II	-0.002	1	v	La	7
2420526.726	I	-0.0005	2	pg	J	8
0980.809	I	+0.001	1	pg	Sh	8
1001.494	I	+0.0012	7	v	Bt	8
1670.4358	I	-0.0006	2	pg	He	6
3164.4679	I	+0.0018	1	pg	Sc	9
3367.3136	I	-0.0011	2	pg	Au	11
4225.4269	I	-0.0045	2	pg	Sc	10
4527.7048	I	-0.0045	4	pg	Ge	12
4852.3322	I	-0.0070	3	pg	Wa	13
6811.7844	I	-0.0087	1	pe	Hu	14
7103.7157	I	-0.0103	1	pe	Hu	14
8164.8455	II	-0.0151	1	pe	Ca	15
8165.8465	II	-0.0140	1	pe	Ca	15
8994.711	I	-0.0145	4	pg	Wo	16
2430455.4332	I	-0.0168	1	v	Ka	17
2599.3856	I	-0.0200	1	pe	Be	...
2599.5526	II	-0.0199	1	pe	Be	...
2622.5732	II	-0.0203	1	pe	Be	...
2945.5336	II	-0.0211	1	pe	Be	...
3779.4620	I	-0.0201	1	pe	Sn	21
3943.61155	I	-0.02024	1	pe	Kw	18
3944.61230	I	-0.02040	1	pe	Kw	18
3994.65800	I	-0.02035	1	pe	Kw	18
4455.746	I	-0.020	1	pe	Fi	19
4489.44288	I	-0.02013	1	pe	Kw	18
4759.68933	I	-0.02019	1	pe	Kw	18
4766.36224	I	-0.02003	1	pe	Kw	18
4766.53051	II	-0.01858	1	pe	Kw	...
4809.4017	I	-0.0198	1	pe	Hi	20
4809.5684	II	-0.0199	1	pe	Hi	20
5217.4427	I	-0.0177	1	pe	S, S	21
5222.4471	I	-0.0179	1	pe	S, S	21
5461.5005	II	-0.0159	1	pe	S, S	21
5508.3745	I	-0.0179	1	pe	S, S	21
5918.41483	I	-0.01830	1	pe	Kw	18
5918.58213	II	-0.01782	1	pe	Kw	18
6611.7163	I	-0.0159	1	pe	C	22
6634.7367	I	-0.0165	1	pe	Bo	23
6635.7377	I	-0.0164	1	pe	Bo	23
6968.7090	I	-0.0155	1	pe	Bo	23
7369.7408	I	-0.0162	1	pe	B, C	24
7367.5805	II	-0.0160	1	pe	B, C	24
7376.7475	I	-0.0159	1	pe	B, C	24
7379.5833	II	-0.0160	1	pe	B, C	24
7379.7500	I	-0.0161	1	pe	B, C	24
7384.5892	II	-0.0146	1	pe	B, C	24
7398.4340	I	-0.0158	1	pe	Be	...
8446.7233	I	-0.0160	1	pe	Ku	...
8449.7258	I	-0.0163	1	pe	Ku	...
8792.7120	I	-0.0096	1	pe	Bi	...
8794.5493	II	-0.0073	1	pe	Bi	...
8794.7136	I	-0.0098	1	pe	Bi	...
8794.8823	II	-0.0080	1	pe	Bi	...
8820.7378	I	-0.0095	1	pe	Bi	...
8833.5852	II	-0.0071	1	pe	Bi	...
8833.7508	I	-0.0083	1	pe	Bi	...
8850.6012	II	-0.0065	1	pe	Bi	...
8850.7665	I	-0.0081	1	pe	Bi	...

^a M, K=Müller and Kempf 1 (1903), 2 (1905); P, J=Parkhurst and Jordan 3 (1906); Mu=Münch 4 (1909); Ti=Tikhoff, see 13; Ba=Baldwin 5 (1908); He=Hertzprung, see Plaut 6 (1936); La=Lazzarino 7 (1912); J=Jordan, see 8; Sh=Shapley 8 (1917); Bt=van der Bilt, see 8; Sc=Schildt 9 (1923); 10 (1925); Au=Aurino 11 (1929); Ge=van Gent 12 (1929); Wa=Walter 13 (1928); Hu=Huffer 14 (1934); Ca=Calder 15 (1936); Wo=Woodward 16 (1942); Ka=Kapko 17 (1949); Be=Bertiau; Sn=Schneller, see 21; Kw=Kwee 18 (1956); Fi=Fitch 19 (1964); Hi=Hinderer 20 (1960); S, S=Schmidt and Schrick 21 (1956); C=Chou 22 (1959); Bo=Bookmyer 23 (1961); B, C=Blitzstein and Chou 24 (1964); Ku=Kuhi; Bi=Binnendijk.

at which Kuhi (1965) observed a flare in the system in the ultraviolet wavelength region. This flare was observed with a reflecting telescope and the electrical equipment was checked immediately. This observation seems to be well established.

The observation times were corrected for light time variation by reducing them to the sun. The formula used was

$$\Delta t = +0^d00265X - 0^d00391Y,$$

where X and Y represent the rectangular coordinates of the sun as given in the American Ephemeris for the time of each observation. The following light elements were used to reduce the present observations:

$$t_{\min} = \text{JD Hel. Min. I} = 2438792.7120 + 0.33364667E.$$

The phases were computed from the formula phase = $(t - t_{\min})/P$. Tables IIIa and IIIb tabulate the heliocentric Julian Date, the phase counted from primary minimum, and the magnitude difference, variable minus comparison star. Observations covering the lower regions of the eclipse curves seem to reveal an interval of constant light. This can also be noticed in the eclipse curves defined by the observations made by Kwee (1956), Hinderer (1960), and Bookmyer (1961). Consequently, complete eclipses have been assumed.

There is a good agreement among the author's five nightly runs except near the bottom part of primary minimum in the phase interval 0^m97 and 0^m03 . During two nights (JD 2438794 and 2438820) the depth is 0^m04 less than during the other three nights. A similar occurrence can be noticed in the blue observations made by Schmidt and Schrick (1956) by comparing the nightly runs of 4 February and 8 March 1956 in Fig. 1 of their publication.

Table IVa and IVb list the normal points which are shown plotted in Fig. 3. The asterisks in the table and the crosses in the figure refer to the fainter primary minimum. Zero-point corrections of $+1^m160$ and $+1^m360$ were applied to the observations in yellow light and in blue light, respectively, in order to make the magnitude difference equal to zero at maximum light. The probable error of a single observation is $\pm 0^m008$ for yellow and $\pm 0^m009$ for blue light. The probable error of a normal point consisting of about ten observations is $\pm 0^m0026$.

4. ORBITAL ELEMENTS

The magnitudes and phases of the normal points were converted into intensities and phase angles. Least-squares solutions were made for the light in the maxima according to the formula

$$I = A_0 + A_1 \cos\theta + A_2 \cos 2\theta + B_1 \sin\theta + B_2 \sin 2\theta.$$

The values of the constants and the probable errors are given in Table V. The coefficient of $\cos\theta$ has the

TABLE IIIa. Yellow observations of W Ursae Majoris.

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
8792.5229	0.4333	-0.854	8792.7266	0.0438	-0.605	8794.5639	0.5505	-0.705	8794.7736	0.1790	-1.092
.5247	0.4385	0.847	.7280	0.0480	0.644	.5710	0.5716	0.816	.7751	0.1835	1.090
.5260	0.4427	0.816	.7376	0.0768	0.819	.5726	0.5765	0.830	.7806	0.1999	1.117
.5376	0.4774	0.603	.7389	0.0806	0.831	.5743	0.5817	0.880	.7819	0.2040	1.112
.5391	0.4819	0.587	.7403	0.0848	0.855	.5757	0.5859	0.897	.7835	0.2085	1.121
.5405	0.4861	0.585	.7417	0.0889	0.887	.5773	0.5907	0.910	.7847	0.2124	1.131
.5419	0.4902	0.579	.7431	0.0931	0.902	.5788	0.5952	0.919	.7903	0.2290	1.153
.5472	0.5062	0.554	.7444	0.0973	0.918	.5801	0.5990	0.935	.7917	0.2332	1.143
.5487	0.5107	0.564	.7501	0.1143	0.981	.5998	0.6580	1.041	.7931	0.2373	1.136
.5500	0.5145	0.577	.7514	0.1181	0.997	.6012	0.6622	1.056	.7961	0.2463	1.161
.5514	0.5187	0.577	.7528	0.1222	1.001	.6026	0.6664	1.069	.8028	0.2665	1.168
.5573	0.5363	0.621	.7542	0.1264	1.025	.6039	0.6705	1.078	.8042	0.2706	1.160
.5586	0.5402	0.654	.7640	0.1559	1.073	.6098	0.6882	1.105	.8056	0.2748	1.164
.5600	0.5443	0.675	.7807	0.2058	1.120	.6112	0.6924	1.109	.8071	0.2793	1.165
.5613	0.5485	0.693	.7821	0.2100	1.130	.6125	0.6962	1.113	.8134	0.2983	1.147
.5627	0.5527	0.715	.7835	0.2142	1.131	.6139	0.7004	1.109	.8148	0.3025	1.149
.5681	0.5686	0.789	.7972	0.2554	1.165	.6201	0.7191	1.140	.8165	0.3077	1.155
.5694	0.5728	0.808	.7987	0.2600	1.167	.6215	0.7232	1.145	.8236	0.3289	1.102
.5708	0.5769	0.830	.8050	0.2787	1.161	.6229	0.7274	1.156	.8250	0.3331	1.111
.5722	0.5811	0.856	.8063	0.2825	1.169	.6244	0.7319	1.162	.8264	0.3372	1.104
.5779	0.5981	0.921	.8085	0.2891	1.159	.6321	0.7548	1.128	.8328	0.3563	1.089
.5792	0.6019	0.958	.8097	0.2929	1.161	.6333	0.7586	1.130	.8340	0.3601	1.081
.5891	0.6317	1.022	.8159	0.3113	1.127	.6348	0.7631	1.127	.8355	0.3646	1.076
.5905	0.6359	1.038	.8174	0.3158	1.134	.6361	0.7669	1.127	.8370	0.3692	1.073
.5924	0.6415	1.040	.8189	0.3203	1.146	.6433	0.7885	1.110	.8385	0.3737	1.057
.5938	0.6456	1.043	.8201	0.3241	1.131	.6447	0.7926	1.120	.8470	0.3990	0.989
.5993	0.6623	1.052	.8215	0.3283	1.128	.6461	0.7968	1.115	.8484	0.4032	0.983
.6007	0.6664	1.072	.8272	0.3453	1.116	.6475	0.8009	1.110	.8499	0.4076	0.961
.6021	0.6706	1.089	.8286	0.3495	1.116	.6537	0.8197	1.082	.8560	0.4260	0.886
.6035	0.6748	1.105	.8300	0.3536	1.108	.6551	0.8238	1.078	.8574	0.4302	0.874
.6141	0.7067	1.140	.8313	0.3574	1.106	.6573	0.8304	1.083	.8587	0.4340	0.849
.6154	0.7105	1.150	.8425	0.3911	1.022	.6642	0.8513	1.047	.8674	0.4600	0.708
.6236	0.7351	1.143	.8439	0.3952	1.008	.6655	0.8551	1.046	.8688	0.4642	0.682
.6250	0.7393	1.140	.8453	0.3994	1.004	.6673	0.8603	1.038	.8704	0.4691	0.658
.6264	0.7435	1.149	.8466	0.4036	0.994	.6686	0.8644	1.034	.8718	0.4732	0.620
.6279	0.7479	1.159	.8536	0.4244	0.898	.6841	0.9109	0.882	.8764	0.4871	0.569
.6292	0.7518	1.158	.8549	0.4282	0.894	.6854	0.9147	0.874	.8778	0.4912	0.567
.6350	0.7691	1.141	.8564	0.4327	0.877	.6868	0.9189	0.866	.8792	0.4954	0.567
.6363	0.7733	1.139	.8576	0.4365	0.855	.6924	0.9355	0.739	.8806	0.4996	0.560
.6377	0.7774	1.143	.8675	0.4660	0.673	.6939	0.9400	0.713	.8819	0.5037	0.554
.6391	0.7816	1.142	.8688	0.4698	0.637	.6951	0.9439	0.689	.8835	0.5083	0.560
.6451	0.7996	1.131	.8701	0.4740	0.622	.6965	0.9480	0.675	.8847	0.5121	0.560
.6466	0.8041	1.121	.8715	0.4782	0.613	.7021	0.9647	0.554	.8861	0.5162	0.570
.6479	0.8080	1.120	.8771	0.4948	0.543	.7035	0.9688	0.532	.8875	0.5204	0.575
.6493	0.8121	1.115	.8785	0.4990	0.548	.7049	0.9730	0.512	.8890	0.5249	0.571
.6556	0.8308	1.078	.8799	0.5031	0.549	.7088	0.9848	0.478	.8904	0.5291	0.603
.6570	0.8350	1.081	.8813	0.5073	0.554	.7102	0.9890	0.492	.8918	0.5332	0.612
.6583	0.8392	1.079	.8869	0.5243	0.565	.7116	0.9931	0.498	.8965	0.5475	0.702
.6597	0.8433	1.074	.8883	0.5285	0.582	.7130	0.9973	0.506	.8979	0.5516	0.731
.6653	0.8600	1.042	.8896	0.5323	0.593	.7144	0.0015	0.496	.8993	0.5558	0.750
.6667	0.8642	1.052	.8910	0.5364	0.624	.7158	0.0056	0.488	.9056	0.5745	0.833
.6682	0.8687	1.032	8794.5112	0.3927	1.018	.7170	0.0094	0.486	.9080	0.5818	0.868
.6694	0.8725	1.039	.5132	0.3986	1.004	.7189	0.0150	0.486	.9095	0.5863	0.893
.6750	0.8891	0.988	.5146	0.4027	1.004	.7204	0.0195	0.486	.9109	0.5905	0.907
.6764	0.8933	0.971	.5161	0.4072	0.996	.7218	0.0236	0.498	.9122	0.5943	0.912
.6778	0.8974	0.954	.5230	0.4280	0.901	.7232	0.0278	0.530	8820.6718	0.8007	1.124
.6868	0.9245	0.812	.5245	0.4326	0.888	.7243	0.0313	0.545	.6736	0.8059	1.123
.6882	0.9287	0.797	.5259	0.4367	0.861	.7286	0.0441	0.604	.6748	0.8097	1.136
.6896	0.9328	0.770	.5273	0.4408	0.839	.7299	0.0479	0.634	.6762	0.8139	1.129
.6910	0.9370	0.744	.5328	0.4572	0.737	.7313	0.0521	0.650	.6878	0.8486	1.055
.6993	0.9620	0.584	.5340	0.4610	0.720	.7326	0.0563	0.694	.6892	0.8527	1.046
.7007	0.9661	0.559	.5355	0.4655	0.690	.7384	0.0736	0.846	.6907	0.8572	1.046
.7021	0.9703	0.539	.5368	0.4693	0.661	.7397	0.0774	0.857	.6920	0.8611	1.040
.7035	0.9745	0.508	.5431	0.4881	0.556	.7412	0.0819	0.852	.6976	0.8781	0.994
.7049	0.9786	0.481	.5444	0.4922	0.547	.7426	0.0861	0.892	.6989	0.8819	0.986
.7104	0.9953	0.451	.5458	0.4964	0.552	.7440	0.0902	0.893	.7004	0.8864	0.978
.7118	0.9994	0.456	.5472	0.5005	0.547	.7454	0.0944	0.887	.7017	0.8902	0.968
.7132	0.0036	0.463	.5486	0.5047	0.543	.7612	0.1419	1.047	.7076	0.9079	0.883
.7146	0.0078	0.459	.5500	0.5089	0.542	.7625	0.1457	1.062	.7089	0.9117	0.873
.7160	0.0119	0.461	.5514	0.5130	0.539	.7639	0.1499	1.064	.7102	0.9158	0.864
.7225	0.0314	0.541	.5597	0.5380	0.620	.7653	0.1540	1.072	.7116	0.9200	0.859
.7238	0.0355	0.564	.5611	0.5422	0.645	.7710	0.1711	1.075	.7170	0.9360	0.738
.7252	0.0397	0.594	.5625	0.5463	0.675	.7723	0.1752	1.090	.7183	0.9402	0.738

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TABLE IIIa (continued)

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
8820.7197	0.9443	-0.709	8833.5887	0.5150	-0.542	8833.7612	0.0318	-0.544	8850.6684	0.7060	-1.104
.7211	0.9485	0.684	.5901	0.5191	0.554	.7625	0.0360	0.566	.6699	0.7105	1.090
.7267	0.9651	0.557	.5916	0.5236	0.582	.7686	0.0540	0.680	.6713	0.7147	1.095
.7281	0.9693	0.544	.5928	0.5271	0.590	.7700	0.0582	0.715	.6823	0.7476	1.135
.7294	0.9734	0.512	.5985	0.5445	0.673	.7718	0.0638	0.755	.6853	0.7566	1.126
.7308	0.9776	0.492	.5998	0.5483	0.694	.7732	0.0679	0.783	.6867	0.7608	1.137
.7364	0.9943	0.482	.6014	0.5531	0.729	.7783	0.0832	0.874	.6920	0.7767	1.131
.7378	0.9984	0.497	.6027	0.5569	0.735	.7797	0.0873	0.894	.6934	0.7809	1.124
.7392	0.0026	0.501	.6085	0.5743	0.814	.7813	0.0922	0.906	.6950	0.7858	1.100
.7408	0.0074	0.480	.6099	0.5785	0.845	.7825	0.0957	0.941	.6962	0.7892	1.097
.7422	0.0116	0.486	.6114	0.5830	0.877	.7880	0.1123	0.999	.7019	0.8062	1.099
.7437	0.0161	0.506	.6173	0.6007	0.934	.7894	0.1165	0.998	.7031	0.8101	1.099
.7448	0.0196	0.513	.6186	0.6045	0.944	.7910	0.1213	1.000	.7048	0.8149	1.067
.7468	0.0255	0.527	.6201	0.6090	0.953	.7924	0.1255	1.032	.7063	0.8194	1.070
.7482	0.0296	0.561	.6213	0.6128	0.964	.7977	0.1414	1.051	.7115	0.8350	1.077
.7539	0.0466	0.669	.6300	0.6388	1.016	.7998	0.1477	1.055	.7130	0.8395	1.064
.7551	0.0504	0.698	.6314	0.6430	1.025	.8012	0.1519	1.066	.7143	0.8434	1.069
.7565	0.0546	0.717	.6331	0.6482	1.029	.8026	0.1560	1.082	.7158	0.8479	1.064
.7579	0.0588	0.729	.6345	0.6523	1.038	.8081	0.1727	1.089	.7170	0.8517	1.062
.7635	0.0754	0.837	.6408	0.6711	1.081	.8095	0.1768	1.108	.7227	0.8687	1.034
.7649	0.0796	0.853	.6422	0.6752	1.079	.8110	0.1814	1.109	.7240	0.8725	1.026
.7663	0.0837	0.898	.6437	0.6797	1.083	.8123	0.1852	1.123	.7257	0.8777	0.984
.7676	0.0879	0.921	.6450	0.6836	1.093	8850.5644	0.3941	0.987	.7275	0.8829	0.964
.7733	0.1049	0.978	.6505	0.7002	1.116	.5656	0.3980	0.975	.7288	0.8871	0.960
.7746	0.1087	0.994	.6519	0.7044	1.114	.5670	0.4021	0.972	.7344	0.9037	0.901
.7761	0.1132	1.021	.6534	0.7089	1.114	.5684	0.4063	0.953	.7358	0.9079	0.890
.7774	0.1170	1.030	.6547	0.7127	1.117	.5740	0.4229	0.909	.7373	0.9124	0.864
.7830	0.1341	1.046	.6658	0.7460	1.131	.5754	0.4271	0.895	.7386	0.9162	0.863
.7843	0.1379	1.065	.6672	0.7502	1.129	.5769	0.4316	0.854	.7441	0.9329	0.761
.7857	0.1420	1.071	.6688	0.7550	1.124	.5781	0.4354	0.844	.7455	0.9370	0.753
.7871	0.1462	1.063	.6700	0.7585	1.121	.5837	0.4521	0.728	.7471	0.9419	0.726
.7930	0.1639	1.089	.6755	0.7751	1.134	.5851	0.4562	0.710	.7484	0.9457	0.695
.7945	0.1684	1.101	.6769	0.7793	1.135	.5866	0.4607	0.679	.7538	0.9620	0.576
.7959	0.1725	1.109	.6786	0.7845	1.135	.5879	0.4646	0.679	.7553	0.9665	0.546
.8017	0.1899	1.122	.6797	0.7876	1.128	.5934	0.4812	0.565	.7567	0.9707	0.520
.8031	0.1941	1.129	.6852	0.8043	1.130	.5948	0.4854	0.574	.7580	0.9745	0.510
.8049	0.1996	1.137	.6866	0.8084	1.120	.5963	0.4899	0.565	.7636	0.9911	0.445
.8061	0.2031	1.147	.6922	0.8251	1.101	.5976	0.4937	0.549	.7650	0.9953	0.443
.8116	0.2197	1.157	.6936	0.8293	1.094	.6034	0.5110	0.547	.7666	0.0001	0.453
.8130	0.2239	1.160	.6961	0.8369	1.082	.6046	0.5149	0.561	.7678	0.0040	0.447
.8144	0.2280	1.158	.6977	0.8417	1.059	.6062	0.5194	0.577	.7693	0.0085	0.446
.8158	0.2322	1.160	.7034	0.8588	1.040	.6075	0.5235	0.595	.7707	0.0126	0.453
8833.5235	0.3197	1.147	.7047	0.8626	1.038	.6129	0.5395	0.647	.7721	0.0168	0.445
.5248	0.3235	1.148	.7069	0.8692	1.040	.6143	0.5436	0.693	.7739	0.0220	0.486
.5263	0.3280	1.122	.7081	0.8730	1.032	.6158	0.5482	0.725	.7754	0.0265	0.497
.5276	0.3318	1.130	.7141	0.8907	0.980	.6170	0.5520	0.743	.7809	0.0432	0.600
.5291	0.3363	1.144	.7154	0.8948	0.963	.6226	0.5686	0.776	.7823	0.0473	0.642
.5360	0.3571	1.087	.7172	0.9000	0.944	.6240	0.5728	0.813	.7838	0.0519	0.667
.5373	0.3610	1.088	.7186	0.9042	0.923	.6254	0.5770	0.841	.7851	0.0556	0.689
.5388	0.3655	1.080	.7241	0.9208	0.859	.6270	0.5818	0.871	.7909	0.0730	0.809
.5401	0.3693	1.080	.7255	0.9250	0.834	.6330	0.5999	0.935	.7923	0.0771	0.848
.5451	0.3842	1.029	.7272	0.9302	0.804	.6344	0.6040	0.935	.7938	0.0817	0.858
.5470	0.3901	1.022	.7290	0.9354	0.785	.6359	0.6085	0.946	.7950	0.0855	0.868
.5485	0.3946	1.006	.7348	0.9527	0.617	.6374	0.6130	0.974	.8006	0.1021	0.934
.5498	0.3984	0.999	.7366	0.9583	0.601	.6389	0.6175	0.978	.8020	0.1063	0.950
.5557	0.4161	0.925	.7396	0.9673	0.536	.6402	0.6213	0.992	.8035	0.1108	0.972
.5568	0.4192	0.912	.7410	0.9715	0.526	.6462	0.6394	1.020	.8048	0.1146	0.985
.5585	0.4244	0.885	.7456	0.9854	0.458	.6478	0.6442	1.037	.8101	0.1306	1.046
.5597	0.4279	0.875	.7470	0.9895	0.465	.6497	0.6498	1.040	.8115	0.1348	1.043
.5658	0.4463	0.761	.7485	0.9940	0.467	.6511	0.6540	1.045	.8134	0.1406	1.046
.5672	0.4504	0.733	.7498	0.9979	0.469	.6566	0.6706	1.069	.8149	0.1452	1.046
.5790	0.4858	0.538	.7513	0.0023	0.477	.6580	0.6748	1.095	.8224	0.1674	1.081
.5804	0.4900	0.554	.7526	0.0062	0.468	.6596	0.6796	1.072	.8240	0.1722	1.122
.5819	0.4945	0.555	.7584	0.0235	0.493	.6608	0.6831	1.090	.8254	0.1764	1.129
.5831	0.4983	0.548	.7595	0.0270	0.511	.6670	0.7019	1.088			

TABLE IIIb. Blue observations of W Ursae Majoris.

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
8792.5236	0.4354	-1.035	8792.5384	0.4798	-0.745	8792.5426	0.4923	-0.708	8792.5507	0.5166	-0.709
.5254	0.4406	1.005	.5398	0.4840	0.736	.5480	0.5086	0.704	.5521	0.5207	0.711
.5267	0.4448	0.976	.5412	0.4881	0.724	.5494	0.5128	0.711	.5579	0.5381	0.805

TABLE IIIb (continued)

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
8792.5593	0.5423	-0.819	8792.7828	0.2121	-1.334	8794.6132	0.6983	-1.305	8794.8271	0.3393	-1.281
.5607	0.5464	0.844	.7840	0.2159	1.331	.6146	0.7024	1.297	.8333	0.3580	1.281
.5621	0.5506	0.854	.7980	0.2579	1.366	.6208	0.7212	1.333	.8347	0.3622	1.277
.5634	0.5547	0.876	.7995	0.2624	1.368	.6222	0.7253	1.335	.8363	0.3671	1.275
.5690	0.5714	0.969	.8056	0.2804	1.355	.6236	0.7295	1.327	.8378	0.3716	1.255
.5701	0.5749	0.998	.8070	0.2846	1.372	.6251	0.7340	1.327	.8391	0.3754	1.236
.5715	0.5790	1.018	.8090	0.2908	1.360	.6326	0.7565	1.312	.8463	0.3969	1.185
.5729	0.5832	1.039	.8104	0.2950	1.359	.6340	0.7607	1.303	.8477	0.4011	1.180
.5785	0.5998	1.107	.8166	0.3134	1.328	.6354	0.7649	1.312	.8491	0.4052	1.164
.5799	0.6040	1.128	.8181	0.3178	1.331	.6369	0.7693	1.314	.8507	0.4101	1.135
.5898	0.6338	1.204	.8194	0.3220	1.328	.6440	0.7905	1.321	.8567	0.4281	1.055
.5914	0.6387	1.204	.8208	0.3262	1.314	.6454	0.7947	1.307	.8580	0.4319	1.036
.5931	0.6435	1.210	.8221	0.3300	1.299	.6468	0.7989	1.315	.8593	0.4358	1.023
.5944	0.6477	1.209	.8278	0.3470	1.293	.6483	0.8034	1.297	.8681	0.4621	0.874
.6000	0.6644	1.243	.8293	0.3515	1.283	.6544	0.8218	1.274	.8694	0.4663	0.844
.6014	0.6685	1.254	.8307	0.3557	1.273	.6561	0.8270	1.272	.8711	0.4711	0.811
.6028	0.6727	1.266	.8320	0.3595	1.263	.6582	0.8332	1.268	.8723	0.4749	0.785
.6042	0.6769	1.275	.8432	0.3932	1.196	.6649	0.8533	1.231	.8771	0.4892	0.728
.6132	0.7039	1.310	.8446	0.3973	1.181	.6663	0.8575	1.203	.8785	0.4933	0.724
.6148	0.7087	1.305	.8460	0.4015	1.172	.6678	0.8620	1.199	.8799	0.4975	0.718
.6243	0.7372	1.323	.8472	0.4053	1.158	.6694	0.8668	1.197	.8812	0.5016	0.719
.6258	0.7417	1.330	.8542	0.4261	1.055	.6847	0.9126	1.060	.8841	0.5100	0.718
.6271	0.7455	1.330	.8556	0.4303	1.048	.6861	0.9168	1.037	.8854	0.5142	0.728
.6285	0.7497	1.331	.8569	0.4344	1.029	.6875	0.9210	1.032	.8868	0.5183	0.738
.6299	0.7539	1.316	.8585	0.4390	1.011	.6931	0.9376	0.878	.8883	0.5228	0.741
.6356	0.7712	1.318	.8682	0.4681	0.828	.6946	0.9421	0.850	.8910	0.5308	0.773
.6370	0.7754	1.317	.8694	0.4719	0.807	.6958	0.9459	0.824	.8972	0.5495	0.899
.6384	0.7795	1.322	.8708	0.4761	0.792	.6972	0.9501	0.818	.8986	0.5537	0.916
.6398	0.7837	1.309	.8722	0.4802	0.768	.7028	0.9668	0.686	.9063	0.5766	1.017
.6458	0.8017	1.321	.8778	0.4969	0.716	.7042	0.9709	0.668	.9088	0.5842	1.053
.6472	0.8059	1.315	.8792	0.5010	0.718	.7056	0.9751	0.658	.9102	0.5884	1.078
.6486	0.8100	1.300	.8807	0.5056	0.713	.7109	0.9910	0.642	.9115	0.5922	1.094
.6500	0.8142	1.285	.8819	0.5094	0.710	.7123	0.9952	0.652	.9129	0.5964	1.099
.6563	0.8329	1.265	.8875	0.5260	0.735	.7137	0.9994	0.654	8820.6724	0.8024	1.307
.6576	0.8371	1.269	.8889	0.5302	0.748	.7151	0.0035	0.645	.6742	0.8080	1.315
.6590	0.8412	1.256	.8903	0.5343	0.786	.7164	0.0077	0.640	.6755	0.8118	1.306
.6604	0.8454	1.256	.8917	0.5385	0.806	.7197	0.0174	0.640	.6769	0.8160	1.283
.6660	0.8621	1.221	8794.5126	0.3968	1.161	.7211	0.0215	0.649	.6885	0.8507	1.237
.6674	0.8662	1.218	.5139	0.4006	1.166	.7225	0.0257	0.671	.6899	0.8548	1.222
.6688	0.8704	1.207	.5153	0.4048	1.163	.7237	0.0295	0.697	.6913	0.8590	1.224
.6701	0.8746	1.189	.5169	0.4096	1.148	.7250	0.0333	0.714	.6926	0.8631	1.200
.6757	0.8912	1.154	.5237	0.4301	1.054	.7292	0.0459	0.791	.6982	0.8798	1.176
.6771	0.8954	1.133	.5252	0.4346	1.033	.7306	0.0500	0.812	.6996	0.8840	1.168
.6785	0.8995	1.117	.5266	0.4388	1.015	.7319	0.0542	0.837	.7011	0.8884	1.157
.6875	0.9266	0.962	.5280	0.4430	0.976	.7333	0.0583	0.841	.7024	0.8923	1.142
.6889	0.9308	0.943	.5335	0.4592	0.876	.7404	0.0795	1.046	.7082	0.9096	1.053
.6903	0.9349	0.920	.5347	0.4631	0.866	.7419	0.0840	1.075	.7095	0.9138	1.036
.7000	0.9641	0.726	.5361	0.4672	0.831	.7433	0.0882	1.081	.7109	0.9179	1.023
.7014	0.9682	0.705	.5375	0.4714	0.806	.7447	0.0923	1.090	.7123	0.9221	1.003
.7028	0.9724	0.673	.5438	0.4901	0.704	.7618	0.1436	1.254	.7176	0.9380	0.909
.7042	0.9765	0.645	.5451	0.4943	0.703	.7632	0.1478	1.269	.7190	0.9422	0.885
.7056	0.9807	0.621	.5465	0.4985	0.700	.7645	0.1516	1.270	.7204	0.9464	0.854
.7111	0.9974	0.626	.5479	0.5026	0.703	.7660	0.1562	1.271	.7218	0.9505	0.840
.7125	0.0015	0.626	.5493	0.5068	0.698	.7716	0.1731	1.283	.7274	0.9672	0.730
.7139	0.0057	0.618	.5507	0.5109	0.698	.7729	0.1770	1.298	.7288	0.9714	0.693
.7153	0.0099	0.618	.5521	0.5151	0.696	.7743	0.1811	1.283	.7301	0.9755	0.671
.7218	0.0293	0.690	.5535	0.5193	0.697	.7758	0.1856	1.274	.7371	0.9964	0.654
.7232	0.0334	0.710	.5604	0.5401	0.800	.7813	0.2020	1.307	.7385	0.0005	0.654
.7247	0.0379	0.737	.5618	0.5442	0.828	.7826	0.2061	1.295	.7399	0.0046	0.654
.7259	0.0418	0.762	.5632	0.5484	0.853	.7840	0.2103	1.323	.7415	0.0095	0.649
.7273	0.0459	0.789	.5646	0.5526	0.881	.7854	0.2144	1.336	.7429	0.0137	0.655
.7383	0.0789	1.011	.5716	0.5737	0.991	.7910	0.2311	1.368	.7443	0.0178	0.664
.7396	0.0827	1.026	.5735	0.5793	1.032	.7924	0.2352	1.354	.7457	0.0220	0.672
.7410	0.0868	1.050	.5750	0.5838	1.059	.8035	0.2685	1.351	.7475	0.0275	0.691
.7424	0.0910	1.074	.5764	0.5880	1.070	.8049	0.2727	1.363	.7489	0.0317	0.738
.7438	0.0952	1.094	.5780	0.5928	1.085	.8062	0.2768	1.347	.7545	0.0484	0.857
.7451	0.0994	1.110	.5794	0.5969	1.105	.8076	0.2810	1.345	.7558	0.0525	0.870
.7507	0.1160	1.175	.5807	0.6008	1.118	.8141	0.3004	1.349	.7572	0.0567	0.890
.7521	0.1202	1.185	.6005	0.6601	1.232	.8156	0.3050	1.350	.7586	0.0608	0.913
.7535	0.1243	1.200	.6020	0.6646	1.240	.8171	0.3095	1.345	.7642	0.0775	1.014
.7549	0.1285	1.217	.6032	0.6684	1.261	.8229	0.3268	1.310	.7656	0.0817	1.044
.7646	0.1576	1.273	.6046	0.6726	1.259	.8243	0.3310	1.294	.7670	0.0858	1.064
.7813	0.2076	1.331	.6119	0.6944	1.295	.8257	0.3351	1.282	.7683	0.0900	1.081

TABLE IIIb (continued)

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
8820.7739	0.1066	-1.152	8833.6338	0.6503	-1.220	8833.7917	0.1234	-1.201	8850.6874	0.7629	-1.310
.7753	0.1108	1.171	.6352	0.6544	1.228	.7931	0.1276	1.232	.6927	0.7788	1.312
.7767	0.1150	1.180	.6416	0.6735	1.262	.7991	0.1456	1.227	.6941	0.7830	1.311
.7781	0.1191	1.191	.6429	0.6773	1.262	.8005	0.1498	1.243	.6956	0.7875	1.310
.7836	0.1358	1.219	.6443	0.6815	1.265	.8019	0.1539	1.257	.6969	0.7913	1.304
.7850	0.1399	1.231	.6456	0.6856	1.267	.8033	0.1581	1.257	.7024	0.8080	1.306
.7864	0.1441	1.242	.6512	0.7023	1.295	.8088	0.1748	1.282	.7038	0.8121	1.289
.7878	0.1483	1.244	.6526	0.7065	1.297	.8102	0.1789	1.305	.7056	0.8174	1.272
.7938	0.1663	1.278	.6540	0.7106	1.295	.8117	0.1834	1.304	.7068	0.8212	1.272
.7952	0.1705	1.290	.6554	0.7148	1.303	.8130	0.1872	1.321	.7137	0.8416	1.241
.7968	0.1753	1.304	.6665	0.7481	1.314	8850.5650	0.3959	1.164	.7150	0.8454	1.234
.8024	0.1920	1.329	.6679	0.7523	1.307	.5663	0.4000	1.150	.7163	0.8496	1.231
.8043	0.1979	1.323	.6693	0.7564	1.312	.5677	0.4042	1.143	.7177	0.8538	1.233
.8055	0.2014	1.327	.6706	0.7606	1.306	.5691	0.4084	1.132	.7233	0.8704	1.205
.8067	0.2048	1.334	.6762	0.7772	1.334	.5747	0.4250	1.083	.7247	0.8746	1.179
.8123	0.2218	1.347	.6776	0.7814	1.329	.5761	0.4292	1.062	.7268	0.8808	1.169
.8137	0.2260	1.355	.6792	0.7862	1.320	.5775	0.4334	1.039	.7281	0.8850	1.159
.8151	0.2301	1.361	.6804	0.7897	1.333	.5788	0.4375	1.016	.7295	0.8891	1.143
.8165	0.2343	1.365	.6859	0.8064	1.325	.5844	0.4542	0.886	.7351	0.9058	1.077
8833.5241	0.3214	1.341	.6873	0.8105	1.287	.5858	0.4583	0.863	.7365	0.9100	1.069
.5256	0.3259	1.336	.6929	0.8272	1.284	.5872	0.4625	0.840	.7379	0.9141	1.047
.5270	0.3301	1.321	.6943	0.8313	1.276	.5886	0.4666	0.823	.7393	0.9183	1.020
.5284	0.3342	1.321	.6969	0.8393	1.268	.5941	0.4833	0.722	.7448	0.9349	0.915
.5298	0.3384	1.333	.6984	0.8438	1.249	.5955	0.4875	0.717	.7462	0.9391	0.900
.5366	0.3589	1.277	.7040	0.8605	1.242	.5969	0.4916	0.714	.7478	0.9440	0.861
.5380	0.3630	1.267	.7054	0.8647	1.240	.5983	0.4958	0.704	.7490	0.9474	0.833
.5394	0.3652	1.260	.7075	0.8709	1.231	.6040	0.5128	0.709	.7545	0.9641	0.686
.5408	0.3714	1.253	.7088	0.8751	1.228	.6053	0.5169	0.721	.7559	0.9682	0.658
.5463	0.3880	1.209	.7147	0.8927	1.159	.6068	0.5214	0.738	.7573	0.9724	0.648
.5477	0.3922	1.200	.7163	0.8973	1.121	.6082	0.5256	0.760	.7587	0.9766	0.626
.5491	0.3963	1.184	.7179	0.9021	1.119	.6136	0.5416	0.846	.7643	0.9932	0.595
.5505	0.4005	1.171	.7193	0.9063	1.082	.6150	0.5457	0.863	.7656	0.9974	0.595
.5562	0.4175	1.102	.7248	0.9229	0.986	.6163	0.5499	0.885	.7673	0.0022	0.607
.5575	0.4213	1.092	.7262	0.9271	0.970	.6177	0.5540	0.893	.7684	0.0057	0.607
.5591	0.4262	1.066	.7282	0.9330	0.960	.6233	0.5707	0.966	.7700	0.0106	0.600
.5605	0.4303	1.045	.7297	0.9375	0.931	.6247	0.5749	0.992	.7714	0.0147	0.603
.5665	0.4484	0.920	.7373	0.9604	0.713	.6262	0.5794	1.020	.7728	0.0189	0.599
.5679	0.4525	0.886	.7403	0.9694	0.688	.6277	0.5839	1.038	.7747	0.0244	0.625
.5797	0.4879	0.720	.7415	0.9729	0.674	.6337	0.6019	1.096	.7761	0.0286	0.648
.5811	0.4921	0.728	.7463	0.9875	0.610	.6351	0.6061	1.108	.7816	0.0453	0.773
.5825	0.4962	0.725	.7477	0.9916	0.605	.6366	0.6106	1.117	.7830	0.0494	0.807
.5838	0.5004	0.725	.7491	0.9958	0.607	.6380	0.6147	1.137	.7844	0.0536	0.841
.5894	0.5170	0.725	.7505	0.9999	0.610	.6395	0.6193	1.147	.7858	0.0577	0.876
.5908	0.5212	0.731	.7520	0.0044	0.623	.6409	0.6234	1.167	.7916	0.0751	1.003
.5922	0.5254	0.744	.7532	0.0079	0.615	.6469	0.6415	1.195	.7930	0.0792	1.017
.5934	0.5292	0.763	.7590	0.0253	0.652	.6483	0.6456	1.209	.7943	0.0834	1.049
.5991	0.5462	0.850	.7602	0.0291	0.666	.6504	0.6519	1.206	.7957	0.0876	1.051
.6006	0.5507	0.874	.7619	0.0339	0.704	.6517	0.6560	1.223	.8013	0.1042	1.110
.6019	0.5545	0.884	.7631	0.0377	0.725	.6572	0.6723	1.266	.8027	0.1084	1.125
.6034	0.5590	0.903	.7693	0.0561	0.871	.6587	0.6768	1.272	.8041	0.1125	1.148
.6092	0.5764	1.006	.7706	0.0603	0.912	.6602	0.6813	1.284	.8055	0.1167	1.152
.6106	0.5805	1.027	.7724	0.0655	0.951	.6615	0.6852	1.295	.8108	0.1327	1.201
.6120	0.5847	1.049	.7738	0.0696	0.973	.6677	0.7039	1.299	.8122	0.1368	1.219
.6179	0.6024	1.104	.7790	0.0853	1.052	.6691	0.7081	1.301	.8142	0.1431	1.213
.6193	0.6065	1.113	.7804	0.0894	1.071	.6706	0.7126	1.294	.8158	0.1476	1.211
.6206	0.6107	1.120	.7818	0.0936	1.095	.6720	0.7167	1.307	.8217	0.1653	1.262
.6220	0.6149	1.142	.7831	0.0977	1.121	.6830	0.7497	1.305	.8230	0.1694	1.267
.6307	0.6409	1.203	.7887	0.1144	1.178	.6844	0.7538	1.312	.8247	0.1743	1.294
.6321	0.6451	1.223	.7901	0.1186	1.180	.6860	0.7587	1.305	.8261	0.1785	1.298

sign expected from theory. The absolute values of B_1 and B_2 are quite large.

The observed intensities were first freed from the extra light of the companion star by subtracting 0.0120. Then the intensities were rectified for the $\sin\theta$ and $\sin 2\theta$ terms by subtraction. These corrected intensities are denoted by I' . The constant term in the reflection effect and the term in $\cos 2\theta$ or $\cos^2\theta$ were obtained from the formula (111) of the monograph by Russell and Merrill (1952). This gave the same result as that obtained by

substituting the provisional orbital elements into formula (108) from the same monograph. The rectified intensities, I_r , are

$$I_r(Y) = \frac{I' + 0.0240 + 0.0102 \cos\theta + 0.0233 \cos^2\theta}{1.0031 - 0.1919 \cos^2\theta},$$

$$I_r(B) = \frac{I' + 0.0240 + 0.0085 \cos\theta + 0.0233 \cos^2\theta}{0.9960 - 0.2145 \cos^2\theta}.$$

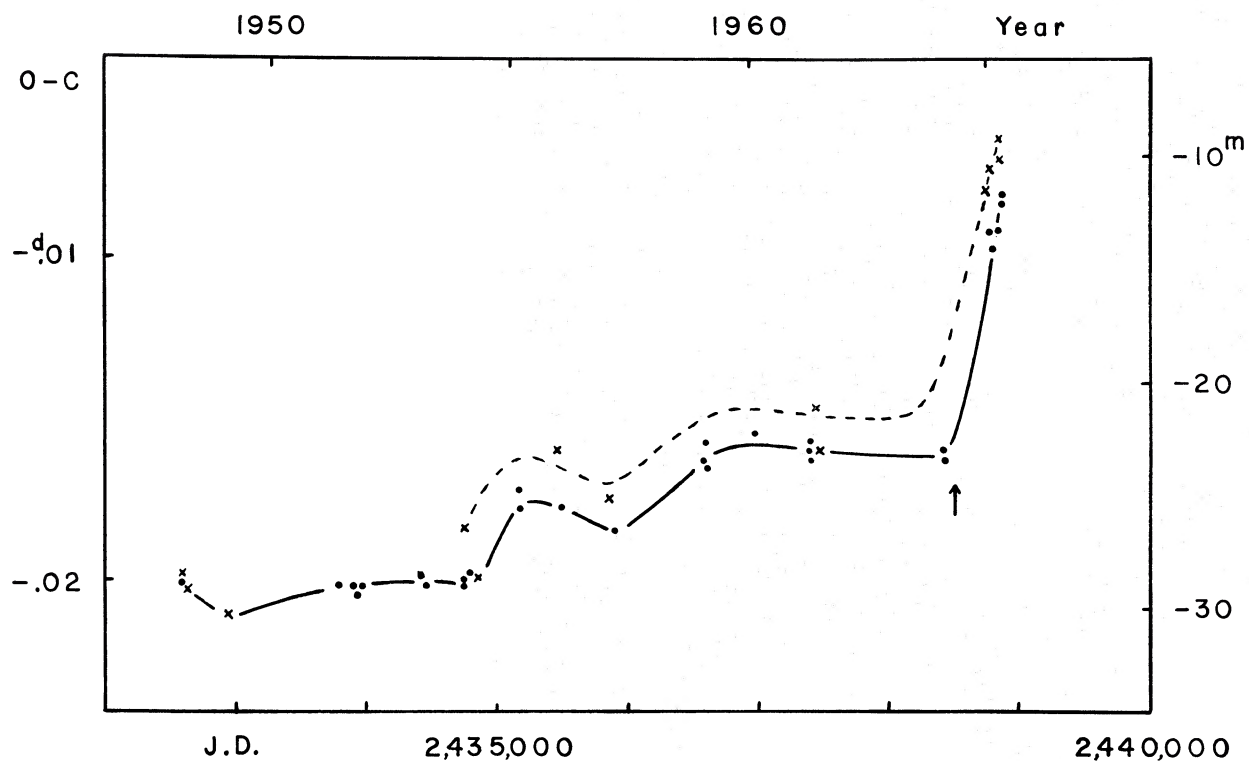


FIG. 2. Photoelectrically determined times of minimum light during the last 17 years. Dots refer to primary minimum, crosses to secondary minimum. The arrow denotes the epoch of a flare observed by Kuhi.

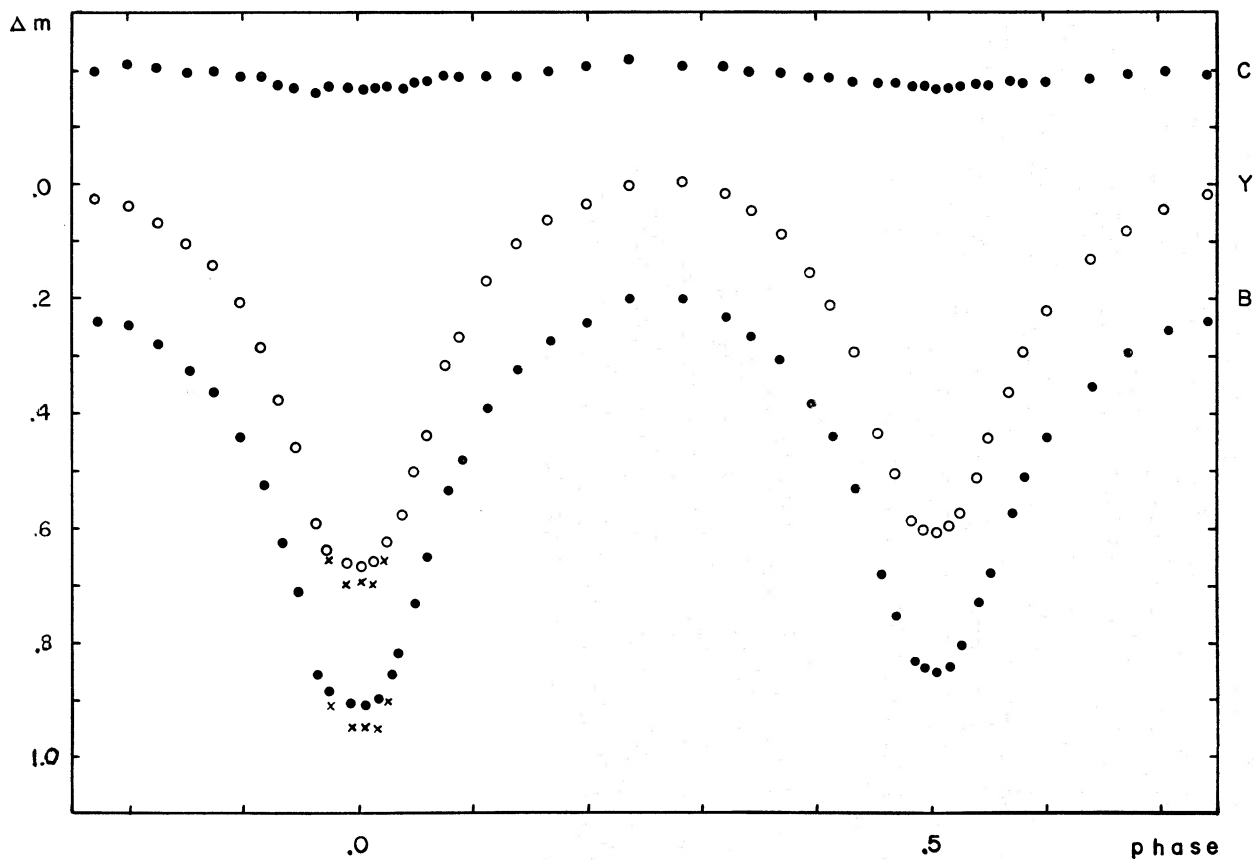


FIG. 3. The light curves and color curve of W Ursae Majoris. The observations are B=blue, Y=yellow, C=color.

TABLE IVa. Normal points of yellow observations.

Phase	Obs. Δm	n	$O-C$	Rect. Δm
*0.0032	0.698	5	...	+0.381
0.0053	0.670	5	+0.001	+0.355
*0.0115	0.707	5	...	+0.390
0.0164	0.665	5	+0.005	+0.354
*0.0261	0.655	5	...	+0.356
0.0276	0.628	5	-0.003	+0.324
0.0383	0.581	6	+0.006	+0.287
0.0485	0.509	8	-0.002	+0.230
0.0586	0.440	8	-0.004	+0.177
0.0767	0.322	8	-0.006	+0.090
0.0878	0.271	15	-0.003	+0.059
0.1120	0.176	15	-0.004	+0.008
0.1393	0.109	15	-0.009	-0.009
0.1668	0.068	14	-0.004	-0.004
0.1980	0.039	15	+0.009	+0.009
0.2365	0.004	10	+0.005	+0.005
0.2835	0.000	10	+0.002	+0.002
0.3199	0.022	9	-0.003	-0.003
0.3429	0.049	10	-0.004	-0.004
0.3695	0.091	10	-0.001	-0.001
0.3957	0.159	9	+0.005	+0.023
0.4128	0.215	15	+0.003	+0.051
0.4339	0.298	15	-0.013	+0.099
0.4555	0.438	8	+0.005	+0.207
0.4693	0.507	10	-0.003	+0.259
0.4854	0.589	10	+0.009	+0.324
0.4946	0.605	10	+0.006	+0.334
0.5053	0.607	10	+0.001	+0.331
0.5150	0.601	9	0.000	+0.324
0.5253	0.577	10	+0.001	+0.302
0.5398	0.514	10	+0.008	+0.247
0.5499	0.449	10	-0.003	+0.192
0.5692	0.364	10	+0.011	+0.129
0.5814	0.294	10	+0.002	+0.076
0.6015	0.224	15	+0.010	+0.036
0.6414	0.133	15	+0.007	+0.007
0.6727	0.081	15	0.000	0.000
0.7049	0.046	15	-0.001	-0.001
0.7436	0.019	14	-0.007	-0.007
0.7728	0.029	15	0.000	0.000
0.8002	0.041	15	-0.004	-0.003
0.8250	0.072	15	+0.002	+0.002
0.8515	0.107	15	+0.001	+0.001
0.8740	0.147	15	+0.003	+0.005
0.8971	0.213	10	+0.003	+0.032
0.9151	0.291	10	-0.004	+0.078
0.9318	0.381	10	-0.005	+0.139
0.9442	0.461	10	-0.011	+0.199
0.9640	0.596	8	+0.003	+0.304
0.9724	0.642	5	+0.008	+0.340
*0.9733	0.646	6	...	+0.343
0.9928	0.668	6	+0.001	+0.354
*0.9935	0.703	8	...	+0.386

TABLE IVb. Normal points of blue observations.

Phase	Obs. Δm	n	$O-C$	Rect. Δm
*0.0052	0.746	5	...	+0.388
0.0063	0.713	4	+0.001	+0.357
*0.0135	0.755	4	...	+0.397
0.0185	0.704	5	+0.001	+0.351
*0.0273	0.704	5	...	+0.357
0.0295	0.658	5	-0.009	+0.316
0.0350	0.625	6	+0.007	+0.290
0.0500	0.535	8	-0.004	+0.222
0.0606	0.457	8	-0.004	+0.163
0.0792	0.337	7	-0.004	+0.078
0.0893	0.285	14	-0.003	+0.047
0.1140	0.196	15	0.000	+0.009
0.1415	0.127	15	-0.004	-0.004
0.1686	0.079	15	-0.002	-0.002
0.2001	0.043	15	+0.008	+0.008
0.2374	0.000	8	-0.003	-0.002
0.2855	0.005	10	+0.002	+0.004
0.3223	0.035	10	-0.001	-0.001
0.3449	0.068	10	+0.001	+0.001
0.3715	0.110	10	-0.003	-0.003
0.3979	0.186	10	+0.006	+0.023
0.4148	0.245	15	+0.003	+0.050
0.4360	0.337	15	-0.010	+0.102
0.4575	0.484	8	+0.008	+0.213
0.4713	0.553	10	-0.003	+0.262
0.4874	0.634	10	+0.006	+0.323
0.4966	0.646	10	+0.003	+0.329
0.5076	0.652	9	+0.003	+0.330
0.5172	0.644	10	+0.003	+0.320
0.5273	0.606	9	-0.001	+0.286
0.5426	0.531	9	-0.005	+0.221
0.5519	0.478	10	-0.003	+0.178
0.5730	0.374	9	+0.004	+0.103
0.5835	0.315	10	-0.006	+0.061
0.6034	0.248	15	+0.006	+0.028
0.6435	0.155	15	+0.006	+0.006
0.6748	0.095	15	-0.004	-0.004
0.7075	0.057	14	-0.003	-0.003
0.7462	0.041	15	+0.002	+0.002
0.7748	0.045	15	+0.003	+0.003
0.8022	0.049	15	-0.010	-0.010
0.8266	0.086	14	-0.001	0.000
0.8535	0.132	15	+0.005	+0.005
0.8761	0.169	15	-0.001	+0.002
0.8992	0.244	10	+0.001	+0.032
0.9170	0.329	10	+0.004	+0.082
0.9340	0.431	10	-0.003	+0.152
0.9461	0.514	8	-0.007	+0.213
0.9660	0.661	8	+0.013	+0.327
0.9732	0.688	4	+0.009	+0.346
*0.9752	0.714	6	...	+0.369
0.9965	0.709	5	-0.001	+0.356
*0.9955	0.751	8	...	+0.393

Finally the phase angles were rectified with the ellipticity coefficients $z(Y)=0.1921$ and $z(B)=0.2118$.

A consistent solution, shown below, was obtained by using the brighter of the primary eclipse curves, as defined by the observations of JD 2438794 and 2438820 (dots and open circles in Fig. 3).

$$\begin{aligned}
 x &= 0.6 & k &= 0.57 \\
 \alpha_0^{oc} &= 1.00 & \alpha_0^{tr} &= 1.02 \\
 a_g &= 0.481 & a_s &= 0.274 \\
 b_g &= 0.428 & b_s &= 0.244 \\
 \epsilon &= 0.11 & i &= 80^\circ 3
 \end{aligned}$$

$$\begin{aligned}
 & \text{yellow} & & \text{blue} \\
 L_g &= 0.722 & L_g &= 0.720 \\
 L_s &= 0.278 & L_s &= 0.280 \\
 I_g &= 0.844 I_s & I_g &= 0.836 I_s
 \end{aligned}$$

In this list the symbols have the usual meanings. The oblateness is defined as $\epsilon = (a-b)/a$, the inclination i is corrected for polar flattening, and the I refers to the mean surface brightness of the component. The observed normal points were compared with the theoretical ones computed from these elements. Tables IVa and IVb list the $O-C$'s and the normal points which define the rectified light curve. The probable error of

TABLE V. Coefficients of the light in the maxima.

λ	A_0	A_1	A_2	B_1	B_2
Y	+0.8835 ± 17	-0.0102 ± 18	-0.1076 ± 25	+0.0143 ± 9	-0.0103 ± 11
B	+0.8651 ± 15	-0.0085 ± 16	-0.1189 ± 23	+0.0178 ± 8	-0.0123 ± 10

one observed normal point as compared with the theoretical light curve is $\pm 0^m0035$.

By combining the spectroscopic elements of Struve and Horak (1950) and the photometric elements shown above, the following absolute elements were obtained:

$$\begin{aligned}
 a_1 &= 581000 \text{ km} & a_2 &= 1164000 \text{ km} \\
 a_g &= 1.20 \odot & a_s &= 0.69 \odot \\
 b_g &= 1.07 \odot & b_s &= 0.61 \odot \\
 \mathcal{M}_g &= 1.27 \odot & \mathcal{M}_s &= 0.61 \odot \\
 \rho_g &= 0.92 \odot & \rho_s &= 2.45 \odot \\
 P\sqrt{\rho_g} &= 0.32 & P\sqrt{\rho_s} &= 0.52
 \end{aligned}$$

5. DISCUSSION

It seems to be well established from the appearance of the more accurate light curves that the eclipses of W Ursae Majoris are complete and that primary minimum is caused by the total eclipse. In Table VI the principal orbital elements determined by the author are compared with those published by other authors who also give solutions based on complete eclipses. The variation among the results is at once apparent. Plaut (1950) derived orbital elements from the material of Huffer (1934) by using complete but grazing eclipses. Our orbital elements agree closely with his solution.

TABLE VI. Comparison of orbital elements.

Element	Binnendijk	Plaut	Kwee	Kitamura
k	0.57	0.57	0.74	0.73
a_g	0.481	0.448	0.424	0.439
a_s	0.274	0.256	0.314	0.322
i	80.3	79.3	90.0	89.2
x	0.6	1.0	0.8	0.65
L_g	0.722	0.718	0.432	0.614
L_s	0.278	0.282	0.311	0.386
L_3	0.257	...

Kwee (1956) derived orbital elements from one night's observations. A systematic difference of 0^m014 was found in the overlapping portions of the curve. His observations agree satisfactorily with those obtained by the author in blue light if the comparison is made with the fainter of the primary eclipse curves. Kwee's rectification coefficients are rather small because the angle of external tangency $\theta_e = 28^\circ$ was used in the formula rather than the second approximation $\theta_e = 43^\circ.5$. If the latter value is used, there is improved agreement

between the rectified light curves. However, no consistent solution could be derived from these eclipse curves which is in accordance with Kwee's findings. He was forced to assume 26% extra light in the system in order to make the solution consistent. Freeing the observations from this extra light would give a depth of 1^m2 to primary minimum and 1^m1 to secondary minimum which is deeper than is observed in any other W UMa-type system.

Kitamura (1965) used Kwee's observations and computed the coefficients, up to the argument 4θ , of the Fourier series used to represent the light in the maxima. In the rectification the constant term and the $\cos 2\theta$ term in the reflection effect were not considered. No extra light was necessary in this solution. The geometrical elements obtained by Kwee and Kitamura are in good agreement.

The tables published by Plavec and Kratochvil (1964) were entered with the mass ratio 0.50 found by Struve and Horak in order to determine the sizes of the Roche limiting surfaces. The semimajor axes of the nonfacing hemispheres are found to be 0.47 and 0.34, respectively. In both Plaut's and the present solution the greater star fills up this lobe but the smaller star does not. In Kwee's and Kitamura's solutions both stars are smaller than their respective limiting surfaces. The observed changes in the period and in the shape of the light curve suggest that the dimensions of at least one of the components should equal its limiting surface.

From the photometric intensities the magnitude difference between the components can be determined. The results are $\Delta m = 0.36$ from Kwee's elements, 0.50 from Kitamura's, and 1.03 from Plaut's and the author's results. All values exceed the result $\Delta m = 0.23 \pm 0.05$ published by Petrie (1950) and found from measurements of the equivalent widths of the absorption lines.

The variance among the results can be attributed partly to the different rectification procedures used by the authors and partly to the observed differences in the depth of primary minimum. Additional accurate light curves are necessary to resolve this discrepancy, and a better understanding of the changes in the shape of the light curve is needed before one can state the preferred solution.

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REFERENCES

- Adams, W. S., and Joy A. H. 1919, *Astrophys. J.* **49**, 186.
 Aurino, S. 1929, *Capodimonte Contrib.* **2**, 12.
 Baldwin, J. M. 1908, *Monthly Notices Roy. Astron. Soc.* **69**, 78.
 Blitzstein, W., and Chou, K. C. 1964, *Astron. J.* **69**, 365.
 Bookmyer, B. B. 1961, *ibid.* **66**, 24.
 Calder, W. A. 1936, *Harvard Bull.* No. 903, 15.
 Chou, K. C. 1959, *Astron. J.* **64**, 468.
 Fitch, W. S. 1964, *ibid.* **69**, 316.
 Gent, H. van 1929, *Bull. Astron. Inst. Neth.* **5**, 99.

- Hertzsprung, E. 1928, *ibid.* 4, 179.
 Hinderer, F. 1960, *J. Observateurs* 43, 161.
 Huffer, C. M. 1934, *Astrophys. J.* 79, 369.
 Kapko, J. T. 1949, *Astron. Circ. USSR* 88, 7.
 Kitamura, M. 1965, *Adv. Astr. Astrophys.* 3, 80.
 Kuhi, L. V. 1965, *Publ. Astron. Soc. Pacific* 76, 430.
 Kwee, K. K. 1956, *Bull. Astron. Inst. Neth.* 12, 330.
 Lazzarino, O. 1912, *Mem. Soc. Spetr. Italiana* 1, 41.
 Müller, G., and Kempf, P. 1903, *Astrophys. J.* 17, 201.
 ——. 1905, *Astron. Nachr.* 167, 347.
 Münch, W. 1909, *ibid.* 183, 78.
 Parkhurst, J. A., and Jordan F. C. 1906, *Astrophys. J.* 23, 82.
 Petrie, R. M. 1950, *Publ. Dom. Astrophys. Obs.* 8, 319.
 Plaut, L. 1936, *Bull. Astron. Inst. Neth.* 8, 51.
 ——. 1950, *Publ. Kapteyn Astron. Laboratory, Groningen* No. 54.
 Plavec, M., and Kratochvil, P. 1964, *Bull. Astron. Inst. Czechoslovakia* 15, 165.
 Popper, D. M. 1950, *Publ. Astron. Soc. Pacific* 62, 115.
 Russell, H. N., and Merrill J. E. 1952, *Contrib. Princeton Obs.* No. 26.
 Schilt, J. 1923, *Bull. Astron. Inst. Neth.* 2, 1.
 ——. 1925, *ibid.* 3, 20.
 Schmidt, H., and Schrick, K. W. 1956, *Z. Astrophys.* 41, 1.
 Shapley, H., and van der Bilt, J. 1917, *Astrophys. J.* 46, 281.
 Struve, O., and Horak, H. G. 1950, *ibid.* 112, 178.
 Walter, K. 1928, *Königsberg Beob.* 45, 1.
 ——. 1930, *Astr. Nachr.* 239, 1.
 Woodward, E. J. 1942, *Harvard Circ.* No. 446.