TWO NEW VARIABLE STARS OF THE TYPE OF W URSAE MAJORIS[1]

By J. SCHILT

ABSTRACT

Two new variables like W Ursae Majoris.—The variability of 44*i* Boötis (fainter component) = Boss 3846 = Σ 1909 (ft.), and of B.D. +75°752 = Cin. 4000, have been investigated on account of *peculiarities in their spectra*. The variability of both stars is demonstrated. The periods of revolution (i.e., the double light-period) are of the order of 0^d3, and the light-curves very much resemble that of W Ursae Majoris. The range of magnitude is about 0.7 for 44*i* Boötis and 0.35 for B.D. +75°752. 44*i* Boötis is of special interest because it is a *component* of a *visual binary* of well-marked orbital motion and of large parallax. Both stars have large proper motions.

44*i* BOÖTIS (FAINTER COMPONENT)

$15^h\ 0^m\ 29^s, +48°\ 2'\ 34''$ (1900), Harvard Visual Magnitude 6.1

This star is the fainter component of the well-known binary Σ 1909. The two components show a well-marked binary motion. The companion reached apastron about 1870 at a distance of 5″ from the brighter star. Since then the distance has decreased with an accelerating rate and amounts at present to about 3″, so that it is still just possible to get separate images with a long-focus instrument for the purpose of photographic photometry. Measurements by Hertzsprung[2] of four plates taken in the years 1915–1916 show differences which at the time were not regarded as real. The present observations were suggested by the resemblance of the spectrum to that of W Ursae Majoris.[3] The 60-inch telescope has been used with the Cassegrain (80 ft.) focus, for which the distance between the components on the plates is 0.36 mm. The plates used were Eastman 33.

About one hundred exposures of 5 and 10 seconds, alternately, were usually made on each plate. The total number of plates is thirty. The images have been measured with a thermopile photome-

[1] *Contributions from the Mount Wilson Observatory*, No. 316.

[2] *Publikationen des Astrophysikalischen Observatoriums zu Potsdam*, **24**, Stück 2, 32, 1920.

[3] Adams, Joy, Strömberg, and Burwell, *Mt. Wilson Contr.*, No. 199; *Astrophysical Journal*, **53**, 94, 1921. Estimated spectrum G2p; measured, G4. Lines described as very poor, resembling those of W Ursae Majoris.

TABLE I

OBSERVATIONS OF 44*i* BOÖTIS

Plate No.	Astronomical Date	No. Images Measured	J.D. Hel. G.M.T.	Epoch and Phase*	Δ*m*	Quality†
	1926		2424000+			
SS 161......	April 18	23	642.7996	0.013	0.61	p
SS 162......	April 18	16	.8948	.369	1.03	f
		23	.8981	.381	1.00	
SS 163......	April 18	14	.9310	.437	0.80	f
		13	.9152	.445	.75	
		22	.9179	.455	.76	
SS 164......	April 18	21	.9410	.541	.55	p
		33	.9452	.557	.60	
SS 168......	April 19	22	625.7158	3.435	.95	p
		13	.7190	.447	.87	
SS 169......	April 19	20	.8916	4.091	.80	p
		21	.8946	.102	.80	
		21	.8977	.114	.75	
		18	.9009	.126	.70	
SS 192......	May 7	25	643.7495	70.784	.95	f
		22	.7532	.798	0.99	
		24	.7572	.812	1.04	
		22	.7608	.826	1.15	
SS 193......	May 10	24	646.6754	81.711	0.85	f
		14	.6796	.726	.84	
		20	.6827	.738	0.97	
SS 194......	May 10	24	.6988	.798	1.18	f
		26	.7034	.815	1.28	
		28	.7075	.831	1.38	
		18	.7113	.845	1.15	
		25	.7141	.855	1.15	
SS 195......	May 10	22	.7258	.899	1.07	f
		30	.7293	.912	0.98	
		25	.7376	.943	.87	
		24	.7411	.956	.86	
SS 196......	May 10	27	.7584	82.021	.75	f
		34	.7625	.036	.73	
		29	.7674	.054	.72	
		26	.7736	.078	.71	
SS 197......	May 10	27	.7930	.150	.85	p–f
		30	.8006	.178	.90	
		32	.8068	.202	.96	
		28	.8131	.225	0.98	
SS 198......	May 10	30	.8311	.292	1.19	g
		26	.8608	.403	0.98	
		27	.8663	.424	.82	
		27	.8705	.439	.88	
SS 199......	May 10	25	.8864	.499	.78	g
		27	.8906	.514	.72	
		23	.8955	.533	.69	
SS 200.......	May 10	28	.9101	.587	.75	f
		30	.9156	.608	.75	
		24	.9239	.639	.86	
		24	.9288	.657	0.80	

* Phase is expressed as a fraction of the period.

† p = poor; f = fair; g = good.

TABLE I—*Continued*

Plate No.	Astronomical Date	No. Images Measured	J.D. Hel. G.M.T.	Epoch and Phase*	Δm	Quality†
	1926		2424000+			
SS 201......	May 10	32	646.9455	82.720	1.00	f
		27	.9517	.743	0.99	
		29	.9579	.766	1.07	
		31	.9627	.784	1.34	
SS 202......	May 10	26	.9800	.848	1.19	p
		21	.9869	.874	1.06	
		26	.9911	.890	1.04	
		22	.9952	.905	0.96	
SS 240......	June 11	28	678.6665	201.185	.80	f
		26	.6702	.199	.81	
		25	.6737	.212	.87	
SS 241......	June 11	24	.7662	.558	.77	f
		20	.7709	.575	.71	
		18	.7756	.593	.82	
		27	.7795	.607	.75	
SS 242......	June 11	25	.7954	.667	.75	f
		29	.8032	.696	.87	
		30	.8078	.713	.87	
		26	.8120	.729	0.87	
SS 243......	June 11	30	.8271	.785	1.10	f–p
		24	.8334	.809	1.19	
		24	.8376	.824	1.25	
		24	.8411	.837	1.37	
SS 244......	June 11	21	.8684	.939	0.84	f–p
		28	.8752	.965	.89	
		24	.8829	.994	.85	
		26	.8862	202.006	.83	
SS 245......	June 11	25	.8993	.055	.80	f
		25	.9055	.078	.80	
		25	.9103	.096	.77	
		22	.9136	.108	.76	
SS 246......	June 11	29	.9279	.162	.78	p–f
		24	.9318	.176	.80	
		25	.9374	.197	.84	
		23	.9428	.217	.87	
SS 247......	June 11	23	.9555	.265	0.98	p–f
		24	.9590	.278	1.02	
		21	.9621	.289	1.10	
		10	.9642	.297	1.09	
SS 293......	July 9	23	706.6682	305.761	1.05	f–p
		25	.6725	.777	1.04	
		20	.6756	.788	1.19	
		23	.6786	.800	1.17	
SS 294......	July 9	15	.6843	.821	1.40	f
		21	.6868	.830	1.25	
		15	.6892	.839	1.35	
SS 295......	July 9	21	.7799	306.178	0.75	g
		26	.7836	.192	.80	
		24	.7884	.210	.85	
		24	.7932	.228	0.85	

* Phase is expressed as a fraction of the period.
† p=poor; f=fair; g=good.

TABLE I—*Continued*

Plate No.	Astronomical Date	No. Images Measured	J.D. Hel. G.M.T.	Epoch and Phase*	Δm	Quality†
	1926		2424000+			
SS 296......	July 9	26	706.8121	306.298	1.08	f
		22	.8160	.313	1.07	
		24	.8203	.329	1.17	
		23	.8237	.342	1.14	
SS 297......	July 9	24	.8321	.373	1.18	g
		29	.8380	.395	1.13	
		25	.8426	.412	1.10	
		24	.8467	.428	1.05	
SS 298......	July 9	18	.8547	.457	0.92	g
		18	.8575	.468	.94	
		22	.8605	.479	.92	
		23	.8640	.492	0.87	

* Phase is expressed as a fraction of the period.
† p = poor; f = fair; g = good.

ter, an occasional image being rejected because of poor quality. The readings for successive exposures of the same duration were combined into means of from two to five groups for each plate. The difference in brightness of the two components of the binary was then computed for each group from

$$\Delta m = \frac{(f_{10}+f_5)-(b_{10}+b_5)}{(f_{10}-f_5)+(b_{10}-b_5)} \times 0.75 \ ,$$

where b_5, b_{10}, f_5, and f_{10} are the mean readings for the 5- and 10-second exposures on the bright and faint images, respectively, and where it is assumed that the difference between the images of a 5- and 10-second exposure is equivalent to 0.75 mag. The results are given in Table I. The corresponding epochs of observation are in J.D. Heliocentric G.M.T., and refer to the mean of the beginning of the first and the end of the last exposure of each group.

The period of revolution, derived by least squares, is 0.267765 ± 0.000012 day. The corresponding epoch numbers and phases given in Table I have been counted from an arbitrary zero. The phases are expressed in fractions of the period. The individual observations are plotted in Figure 1. Combining them into groups of five in order of phase, we obtain the normal points given in Table II. These are indicated by the crosses in Figure 1 which are connected by the broken line.

The figure shows a number of discordant observations. An attempt has been made to connect these with the quality of the plates, but with only partial success. It is to be expected that the measured difference Δm between the rather close components will depend on the seeing. The seeing was often rather bad and, in consequence, the images are frequently large and even tend to overlap. In these cases the measured Δm is probably too small, since a setting on the larger star does not include the whole image, while one on the smaller

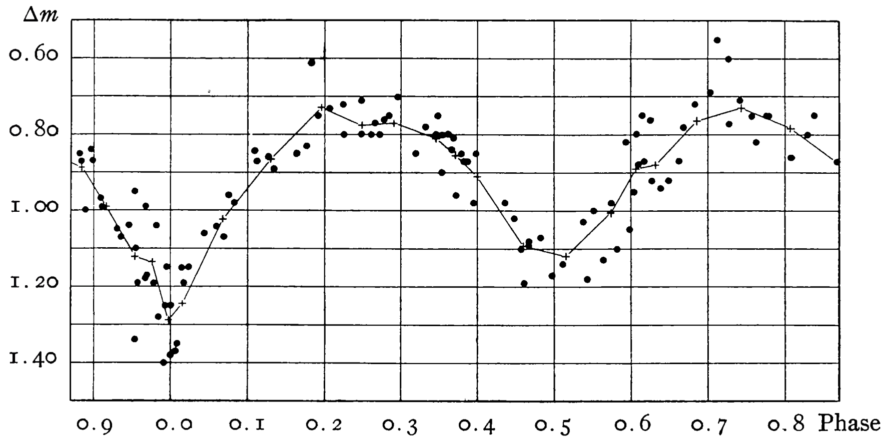

FIG. 1.—44*i* Boötis

star may include a portion of the image of the larger star; further, the Eberhard effect may also enter as a possible source of disturbance. In fact, the three measures giving Δm less than 0.68 are all from poor plates.

Considering the difficulty of the object and the poor conditions under which part of the plates have been taken, the light-curve is satisfactory, and reveals at once a variation of the type of W Ursae Majoris. Without laying too much stress on the observed inequality in the depth of the minima, the one to the left in the figure may be considered as the primary. The primary minimum has been determined to be at phase 0.832P, the secondary at 0.332P. The resulting elements are

$$\text{Min. Hel. J.D. G.M.T.} = 2424646.976 + 0.267765\,E.$$
$$\pm 0.002 \pm 0.000012 \text{ (m.e.)}$$

Δm at maximum is 0.76; at primary minimum, 1.29; at secondary minimum, 1.12.

Remarks.—1. A spectrogram obtained on May 28, 1926, with the 18-inch camera at the 60-inch telescope during predicted time of maximum light gives good indication of double lines, which, however, are wide and diffuse. The separation corresponds to about 350 km/sec. Spectrograms taken during minimum on July 17 and 18 by Mr. Joy with the 10-inch camera at the 100-inch reflector, and by the writer with the 7-inch camera at the 60-inch, show the lines to be distinctly narrower at the time of eclipse. Mr. Joy states: "The lines are quite measurable during minimum. They diminish in width during the half-hour preceding minimum."

TABLE II

NORMAL POINTS FOR 44*i* BOÖTIS

Phase	Δm	Phase	Δm	Phase	Δm
0.015	1.24	0.399	0.91	0.806	0.78
.066	1.02	.461	1.10	.883	0.89
.129	0.86	.515	1.12	.917	0.99
.196	0.73	.573	1.01	.954	1.12
.248	0.78	.607	0.89	.976	1.14
.290	0.77	.631	0.88	0.996	1.29
.346	0.81	.686	0.76		
0.370	0.85	0.744	0.73		

2. The proper motion for the center of gravity of the visual pair, assuming equal masses, is 0″.407. The trigonometric parallax is 0″.076, the mean of the Allegheny and Yerkes determinations. The star is evidently a dwarf; the spectroscopic absolute magnitude is +5.2;[1] and its apparent magnitude, 6.1, is the brightest known for this class of variation.

3. As a consequence of the motion in the visual orbit, the apparent period of the variable in all probability cannot be constant. The projected distance between the visual components at present is about 40 astronomical units, and a rough calculation shows that the change in period should be perceptible as soon as uniform observations cover a period of about ten years.

4. The observed amplitude corresponds to a range of 0.1 mag. in the total light of the visual pair, which is perfectly within the reach of the photo-electric cell. This perhaps affords the only meth-

[1] *Mt. Wilson Contr.*, No. 199, p. 57; *Astrophysical Journal*, **53**, 69, 1921.

od by which the variation can be followed when the distance between the components becomes very small.

5. From the range in radial velocity, provisionally adopted as 350 km/sec., the distance of the components is 1.33 million km; and the masses, assumed equal, are $m_1 = m_2 = 0.64\odot$. A rough calculation gives for the average radius of the ellipsoidal bodies 0.43 million km, and a density 2.2 times that of the sun. Since the absolute magnitude for each component is 6.25, the surface brightness is +0.38 mag. ($\odot = 0$). The value given by Seares for dwarfs of estimated spectrum G2 is +0.10 mag.[1] The effective temperature T

TABLE III

Comparison Stars for B.D.+75°752

Star	B.D. No.	*Draper Catalogue*		Adopted Pg. Mag.
		Pg.	Spectrum	
a	+75°765	7.93	K2	8.00
b	74 890	7.47	A3	7.36
c	74 889	8.7	G5	8.52
d	76 809	7.41	F2	7.48
e	+74 877	8.6	A2	8.83

by Hertzsprung's[2] formula is 5500°. The star falls almost exactly on Eddington's curve, giving the relation between mass and absolute magnitude. The ratio of the distance between the eclipsing components to the projected distance on the sphere between the visual components is 1:4500.

B.D.+75°752 = CIN. 4000

$20^h\ 38^m\ 42^s$, +75° 13′ 51″ (1900) Harvard Visual Magnitude 8.4, Sp. G5

The spectrum of this star has also been classified as resembling that of W Ursae Majoris by Mr. Adams, who kindly drew my attention to it.

One hundred and six plates have been obtained with the 10-inch Cooke refractor of 45-inch focal length. With the exception of the first two, which were test plates, they were all secured

[1] *Mt. Wilson Contr.*, No. 226, p. 34; *Astrophysical Journal*, **55**, 198, 1922.

[2] *Zeitschrift für Wissenschaftliche Photographie*, **4**, 43, 1906.

TABLE IV

OBSERVATIONS OF B.D.+75°752

Plate No.	Astron. Date	J.D. G.M.T	Pg. Mag.	Plate No.	Astron. Date	J.D. G.M.T.	Pg. Mag.
	1926	2424000+			1926	2424000+	
116	May 8	644.9448	8.51	177	May 12	.9394	8.25
117		.9635	8.37	178		.9429	8.22
120	May 9	645.7590	8.08	179		.9463	8.14
121		.7631	8.15	180		.9498	8.17
122		.7666	8.09	181		.9533	8.20
123		.7700	8.13	182		.9567	8.26
124		.7735	8.18	183		.9602	8.21
125		.7770	8.11	184		.9637	8.15
126		.7805	8.08	185		.9672	8.26
127		.7839	8.20	186		.9706	8.22
128		.7874	8.23	187		.9741	8.26
129		.7909	8.16	188		.9776	8.32
130		.7943	8.34	189		.9811	8.20
131		.7878	8.39	190		.9845	8.36
132		.8013	8.36	191		.9880	8.34
133		.8048	8.34	192		.9915	8.22
134		.8082	8.45	193		....	Rejected
135		.8117	8.38	203	June 13	680.6958	8.27
136		.8152	8.37	204		.7132	8.32
137		.8187	8.39	205		.7166	8.35
138		.8221	8.43	206		.7201	8.37
139		.8256	8.35	207		.7236	8.33
140		.8659	8.14	208		.7270	8.43
141		.8693	8.13	209		.7305	8.45
142		.8728	8.08	210		.7340	8.47
143		.8763	8.11	211		.7375	8.52
144		.8798	8.23	212		.7409	8.48
145		.8832	8.13	213		.7444	8.56
146		.8867	8.11	214		.7479	8.55
147		.8902	8.13	215		.7514	8.53
148		.8937	8.19	216		.7548	8.53
149		.8971	8.10	217		.7583	8.48
150		.9006	8.14	218		.7618	8.43
151		.9041	8.25	219		.7652	8.40
152		.9075	8.21	220		.7687	8.36
153		.9110	8.26	221		.7722	8.37
154		.9145	8.24	222		.7757	8.33
155		.9180	8.26	223		.7791	8.29
162	May 12	648.8873	8.44	224		.7826	8.27
163		.8908	8.44	225		.7861	8.25
164		.8942	8.33	226		.7896	8.13
165		.8977	8.33	227		.7930	8.24
166		.9012	8.41	228		.7965	8.05
167		.9047	8.32	229		.8000	8.12
168		.9081	8.24	230		.8034	8.25
169		.9116	8.36	231		.8069	8.12
170		.9151	8.26	232		.8104	8.27
171		.9185	8.22	233		.8139	8.15
172		.9220	8.22	234		.8173	8.13
173		.9255	8.20	235		.8208	8.13
174		.9290	8.13	236		.8243	8.25
175		.9324	8.15	237		.8277	8.12
176		.9359	8.22	238		.8313	8.17

during three runs. Each plate has one exposure of 3 minutes,[1] and, as a rule, the beginning of successive exposures is every fifth minute. The plates used were Eastman 40 for the May runs and Eastman 33 for the series of June 13. The use of a separate plate for each exposure has the advantage that no systematic plate errors occur. The variable and five comparison stars have been measured with the thermopile photometer. One plate was rejected. Separate reduction

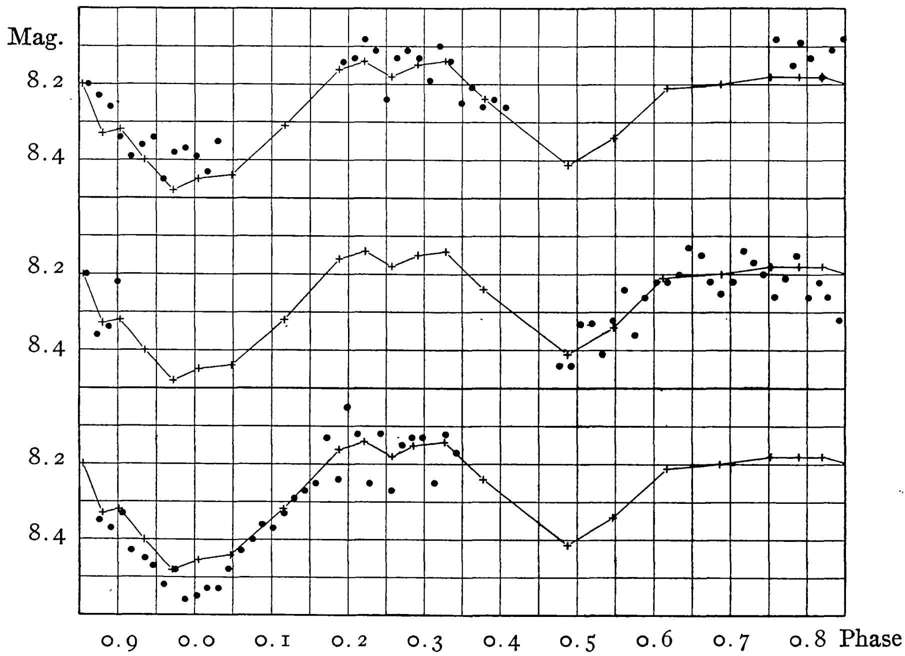

FIG 2.—B. D.+75° 752

curves have been drawn for all the plates. The comparison stars are given in Table III. The adopted magnitudes are smoothed values derived from measures on the plates.

The results of the measurements are given in Table IV. The times of mid-exposure are given in J.D. G.M.T. not reduced to the sun. The three main runs of observations are represented graphically in Figure 2, which shows that the variable is of the type of W Ursae Majoris.

The provisional interval of 0.123 day from minimum to minimum gives a revolution time of only 5^h54^m, which is three-fourths of the

[1] Plates 116 and 117 had an exposure time of 5^m.

period of W Ursae Majoris. The maximum brightness is 8.13, and the depth of the minimum 0.35 mag. There is some uncertainty in the number of epochs[1] between the two minima of May 9 and June 13, and, on this account, the phases are not printed in Table IV. The number adopted is 284 (number of half-periods), which fits all of the

TABLE V

NORMAL POINTS FOR B.D.+75°752

Phase	Pg. Mag.	Phase	Pg. Mag.	Phase	Pg. Mag.
0.005	8.45	0.328	8.14	0.790	8.18
.048	8.44	.378	8.24	.820	8.18
.116	8.32	.488	8.41	.854	8.20
.188	8.16	.548	8.34	.880	8.33
.222	8.14	.617	8.21	.903	8.32
.257	8.18	.688	8.20	.935	8.40
0.292	8.15	0.753	8.18	0.972	8.48

observations. The revolution period thus derived is 0.2460±0.0002 day, the reciprocal of which has been used for the computation of the normal points. These are given in Table V, and are shown graphically in Figure 2 by the broken lines. The minima occur at phases 0.99P and 0.49P, whence the elements are:

$$\text{Min. J.D. G.M.T. } 2424680.744 + 0.2460\,E. \quad \pm 0.0003 \pm 0.0002 \text{ (m.e.)} .$$

Attention may be called to the large proper motion, viz., $+0^{s}.0895$ and $+0''.531$. The trigonometric parallax, the mean of the determinations at Greenwich and Yale, is $0''.044$.

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[1] The uncertainty as to the period has been much decreased by a minimum observed by Mr. van Gent at Leiden, which Professor Hertzsprung kindly communicated. This minimum, June 28, 1926, G.M.T. $11^{h}49^{m}7$, occurs at phase 0.945P.