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THE LIGHT CURVES OF FOUR VARIABLE STARS IN THE HERCULES CLUSTER MESSIER 13

by

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by HELEN B. SAWYER

THE globular cluster Messier 13 (NGC 6205) in Hercules is one of the best known objects in the sky, and is frequently shown in telescopes, both big and little, and frequently photographed. But for all our familiarity with this rich cluster as a beautiful object, our knowledge of the variable stars in it has been amazingly scanty.

Bailey[1] in 1902 published the discovery of two bright variables. Barnard[2] in 1900, hearing of Bailey's discovery before publication, independently found Variable No. 2, and made a series of 36 visual observations of this star, from which he determined that the period was 5.1 days. In 1909[3] he commented that he had determined a period of 6.0 days for Bailey's Variable No. 1, and had also found a third variable. In 1915, Shapley[4] announced the discovery of four additional variables, and gave the magnitudes[5] of all seven variables as measured on seven plates. For twenty-five years the sum total of all our knowledge of the variables in the Hercules cluster was that there were seven; of these, one had a period of 5.1 days as deduced from the series of published observations, and one a period of 6.0 days, but with no published observations.

A recent paper[6] from this observatory increased the number of known variables to 11, and a preliminary report[7] on the periods was presented to the American Astronomical Society in 1940.

Eleven years ago at the Dominion Astrophysical Observatory the writer began accumulating large scale plates on this cluster. Although the variables are quite bright—all of them as bright as 15.0 at minimum, a large telescope is necessary for the investigation because of the crowding in the cluster. The program has been continued at the David Dunlap Observatory, and a total of 150 plates is now available. For assistance in taking the plates I am indebted to Dr. F. S. Hogg, Mr. T. T. Hutchison, Mr. Gerald Longworth, and others.

Of the eleven variables, light curves are given in this paper for four. Of these four periods now determined, three are long period Cepheids, and one is a cluster type variable. Series of plates from several seasons showed at once that Barnard's period of 5.1 days for No. 2 is correct. The period derived by the writer is 5.11003 days. But the present series of observations showed also that Barnard's period of 6.0 days for No. 1 is quite erroneous. Figure 1 shows Barnard's observations as computed from his period for No. 2; and shows for No. 1 several years of the writer's observations with phases computed from Barnard's period of 6.0 days.

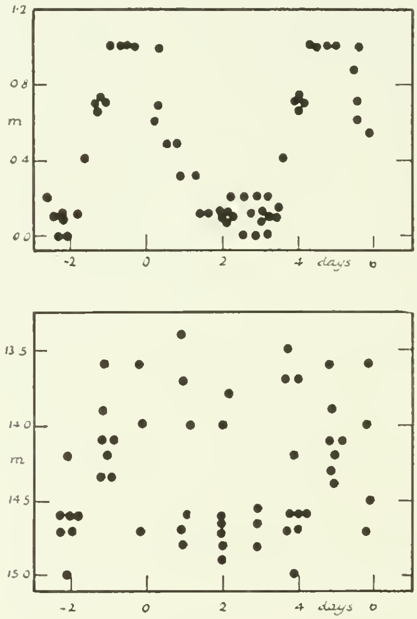

FIGURE 1

Upper: Barnard's visual observations of Variable No. 2 with phases computed from his period of 5.1 days.

Lower: Recent series of observations of Variable No. 1 with phases computed from Barnard's period of 6.0 days.

Obviously this period is quite untenable, and all attempts to correct it by a small refinement failed. When sufficient observations had accumulated in series over large hour angles, the true period for No. 1 was determined to be almost exactly one quarter of that given by Barnard, namely 1.45899 days.

A third long period Cepheid is now added to the other two as Variable No. 6 has a period of 2.11283 days. Variable No. 8, found by the writer, is a cluster type variable with good range and period of three quarters of a day.

Considerable work has been done to determine the periods of the other variables. For Variable No. 7 a period of 0.428024 day or 0.299724 day fits practically all the measures, and it appears impossible on the basis of existing data to decide which is the true and which is the fictitious period. Since the effective range is only about 0.3 magnitude, the star is a difficult one for period determination. Variables 3 and 4 are faint stars with small ranges, and rather near the limiting magnitude of many of the plates. Variables 5 and 9 are the components of a close double which is resolved only under very good seeing conditions. Both of these are probably cluster type variables. Variables 10 and 11 are bright stars with small ranges. It is possible that they belong to the bright irregular class. It is planned to keep the cluster on the observing list until more of the cluster type periods have been determined.

The sequence used was that given in a previous paper, with the magnitudes determined earlier by Shapley.[5] This sequence has now been checked by two sequence plates of 2 and 6 minutes' exposure time on Selected Area 61. The values of the comparison stars as estimated on these plates corroborate Shapley's values.

Table I gives the elements of the variables, with maximum,

TABLE I

Elements of Four Variable Stars in Messier 13

Var.	Max.	Min.	Med.	Epoch	Period
				2,400,000+	
1	13.2	15.0	14.1	27685.763	1ᵈ.45899
2	12.6	14.1	13.3	27308.868	5.11003
6	13.5	14.8	14.1	27274.867	2.11283
8	14.2	15.6	14.9	28038.654	0.750306

minimum, and median magnitudes. Table II gives the observations of the variables with phases computed on the basis of the elements derived. The plates through Julian Day 2427728 were taken at the Dominion Astrophysical Observatory; although there are 51 plates, only 27 observations are published. On dates on

TABLE II

OBSERVATIONS OF VARIABLE STARS IN MESSIER 13

Plate	Julian Day	Var. No. 1		Var. No. 2		Var. No. 6		Var. No. 8	
		Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase
20573	6923.83	13.9	1.12	13.6	3.33	14.4	1.80	14.6	.13
20599	25.84	14.1	0.22	12.6	0.23	14.4	1.70	14.5	.64
20612	30.745	14.7	0.74	12.8	0.02	13.6	0.26	14.9	.243
20648	44.81	14.0	0.21	13.2	3.86	14.4	1.65	14.5	.10
20678	46.79	14.8	0.74	12.9	0.74	14.7	1.52	15.2	.58
21388	7273.83	14.3	0.96	12.9	0.74	14.1	1.08	15.1	.49
21403	74.87	14.5	0.54	13.0	1.77	13.6	0.00	14.3	.02
21418	75.89	13.6	0.11	13.6	2.80	14.3	1.03	14.9	.30
21516	306.80	14.3	0.37	14.0	3.04	13.8	0.24	15.0	.44
21530	07.71	13.5	1.28	13.3	3.95	14.4	1.15	15.1	.60
21559	08.86	14.2	0.98	12.6	5.11	13.6	0.19	14.7	.26
21575	09.858	14.5	0.51	12.8	0.99	14.2	1.19	15.1	.502
23075	597.924	14.0	1.16	13.6	2.89	14.4	1.91	15.1	.450
23173	638.917	13.4	1.30	13.8	3.01	13.6	0.64	14.8	.176
23179	39.805	14.6	0.73	13.2	3.90	15.0	1.53	15.0	.314
23221	52.861	14.6	0.65	12.9	1.32	14.2	1.91	15.0	.615
23222	.867	14.7	0.66	12.9	1.63	14.4	1.92	15.0	.621
23243	58.867	14.6	0.82	13.5	2.52	14.8	1.58	15.0	.618
23257	59.853	14.3	0.35	13.8	3.50	13.7	0.45	14.6	.104
23311	64.853	14.4	0.97	13.7	2.39	14.4	1.23	15.2	.602
23401	85.763	13.1	0.00	13.5	3.86	14.4	1.01	15.0	.503
23402	.772	13.2	0.01	13.3	3.87	14.0	1.02	....	.512
23403	.780	13.2	0.02	13.2	3.88	....	1.04	....	.520
23524	713.692	14.0	0.21	12.9	1.13	14.5	1.47	14.5	.671
23527	14.619	13.9	1.14	13.7	2.06	13.7	0.28	14.7	.097
23536	15.628	14.7	0.69	13.7	3.07	14.8	1.30	15.0	.356
23598	28.603	14.6	0.53	12.9	0.71	14.8	1.59	15.1	.576
190	8038.654	13.7	1.27	13.0	4.16	14.1	1.06	14.1	.000
193	.719	13.2	1.34	12.8	4.23	14.4	1.12	14.6	.065
222	43.656	14.6	0.44	13.6	4.05	14.2	1.83	14.9	.500
225	44.699	13.6	0.02	12.7	5.10	14.1	0.76	14.5	.043
826	309.603	14.9	0.85	13.0	4.28	14.8	1.56	14.6	.089
832	.705	14.7	0.95	13.0	4.38	14.4	1.66	14.9	.191
1116	65.781	14.0	0.13	13.1	4.25	14.1	0.69	14.3	.744
1129	66.781	14.0	1.13	12.7	0.14	14.3	1.69	14.9	.243
1231	91.715	13.7	1.26	12.7	4.63	14.5	1.27	15.0	.417
1246	92.735	15.0	0.82	12.6	0.54	13.8	0.18	14.6	.687
1270	98.632	14.5	0.88	13.0	1.33	14.2	1.85	15.1	.581
1277	.794	14.0	1.04	13.0	1.49	14.0	2.01	14.3	.743
1289	99.669	14.6	0.46	13.3	2.36	14.2	0.78	14.6	.118
1975	688.615	14.7	0.53	12.8	0.04	13.6	0.26	14.8	.196
1979	.683	14.5	0.59	12.7	0.11	13.5	0.33	14.9	.264

TABLE II—*Continued*

Observations of Variable Stars in Messier 13

Plate	Julian Day	Var. No. 1 Mag.	Var. No. 1 Phase	Var. No. 2 Mag.	Var. No. 2 Phase	Var. No. 6 Mag.	Var. No. 6 Phase	Var. No. 8 Mag.	Var. No. 8 Phase
1987	8688.856	14.7	0.77	12.9	0.28	13.6	0.51	....	.437
1988	89.612	13.8	0.06	13.0	1.04	14.7	1.26	15.5	.443
1992	.676	14.0	0.13	12.9	1.10	14.7	1.33	15.3	.507
2004	92.612	14.1	0.15	13.9	4.04	13.8	0.04	15.4	.441
2008	.664	14.0	0.20	13.2	4.09	13.8	0.09	15.5	.493
2017	93.836	13.4	1.37	12.6	0.15	14.6	1.26	14.7	.165
2027	96.605	13.9	1.22	14.1	2.92	14.6	1.92	14.6	.683
2030	.636	13.7	1.25	14.0	2.95	14.2	1.95	14.2	.714
2042	.849	13.6	0.00	14.1	3.16	13.6	0.05	14.7	.177
2107	715.626	13.6	1.28	13.1	1.50	14.4	1.92	14.9	.196
2118	.819	13.1	0.02	13.0	1.69	13.6	0.00	14.9	.389
3245	9071.614	13.8	1.27	12.7	4.90	14.2	0.84	15.1	.539
3255	.841	14.0	0.04	12.8	0.11	14.2	1.07	14.3	.016
3267	72.847	14.4	1.04	13.2	1.02	14.4	2.07	14.9	.271
3268	73.594	14.4	0.33	13.2	1.77	14.2	0.71	14.8	.268
3272	.628	14.5	0.37	13.3	1.80	14.0	0.74	14.8	.302
3282	.847	14.6	0.58	13.6	2.02	....	0.96	14.9	.521
3283	76.593	14.6	0.41	12.9	4.76	....	1.59	14.7	.266
3286	.622	14.6	0.44	12.9	4.79	14.5	1.62	14.9	.295
3295	.845	14.9	0.66	13.0	5.02	14.1	1.85	15.3	.518
3297	77.601	13.6	1.42	12.9	0.66	14.0	0.49	15.6	.523
3299	.633	13.5	1.45	12.9	0.69	13.6	0.52	15.2	.555
3308	.837	14.3	0.20	12.9	0.90	14.0	0.73	14.5	.009
3311	78.603	15.0	0.96	13.3	1.66	14.4	1.49	14.4	.025
3313	.633	14.6	0.99	13.1	1.69	14.3	1.52	14.6	.055
3323	.822	13.8	1.18	13.1	1.88	14.5	1.71	15.0	.244
3326	79.611	15.0	0.51	13.9	2.67	14.0	0.39	15.2	.283
3329	81.830	13.9	1.27	12.7	4.89	13.8	0.49	14.9	.251
4576	429.607	14.2	0.35	12.8	0.08	14.5	1.77	14.7	.636
4579	30.603	13.6	1.35	13.1	1.07	14.0	0.65	14.6	.131
4691	63.606	14.7	0.79	14.0	3.42	14.2	1.96	14.6	.121
4701	64.599	14.6	0.43	13.0	4.41	14.2	0.84	15.2	.364
4799	87.746	14.0	0.13	13.6	2.01	14.4	0.75	14.7	.251
4803	89.569	14.7	0.49	14.0	3.83	14.0	0.46	15.4	.574
4804	.583	15.0	0.51	14.5	3.84	13.9	0.47	15.6	.588
4809	.735	14.6	0.66	13.6	3.99	14.2	0.62	14.3	.740
4816	90.583	13.9	0.05	12.9	4.84	14.7	1.47	14.3	.087
4817	.597	14.1	0.06	13.0	4.86	14.7	1.48	14.6	1.01
4826	91.569	14.7	1.04	13.0	0.72	13.9	0.34	15.0	.323
4969	518.572	14.6	0.32	13.3	2.17	14.3	1.99	14.9	.315
4976	19.599	13.5	1.34	14.0	3.20	14.0	0.91	15.3	.591
4981	20.685	14.3	0.97	13.0	4.28	14.2	1.99	14.6	.177

TABLE II—*Continued*

OBSERVATIONS OF VARIABLE STARS IN MESSIER 13

Plate	Julian Day	Var. No. 1 Mag.	Phase	Var. No. 2 Mag.	Phase	Var. No. 6 Mag.	Phase	Var. No. 8 Mag.	Phase
5698	9785.692	14.5	0.44	14.1	3.57	14.1	0.78	15.3	.326
5708	86.637	13.7	1.39	13.1	4.51	14.4	1.73	14.9	.520
5719	.846	14.0	0.14	13.0	4.72	14.0	1.94	14.1	.729
5722	87.635	14.8	0.93	12.9	0.40	13.9	0.61	14.5	.018
5723	.642	14.8	0.93	12.9	0.41	13.9	0.62	14.3	.025
5724	.689	14.7	0.98	12.9	0.46	13.9	0.67	14.5	.072
5805	813.615	14.6	0.64	12.9	0.83	14.3	1.24	15.1	.487
5807	.647	14.7	0.68	12.9	0.86	14.3	1.27	15.1	.519
5813	.801	14.6	0.83	12.8	1.02	14.4	1.43	14.6	.673
5816	14.600	14.2	0.17	13.1	1.82	13.8	0.17	14.4	.722
5819	.644	14.2	0.21	13.1	1.86	13.5	0.16	14.2	.016
5828	.824	14.2	0.39	13.1	2.04	14.0	0.34	14.7	.196
5831	15.600	14.0	1.17	13.8	2.82	14.4	1.11	14.7	.221
5834	.642	13.6	1.21	13.6	2.86	14.5	1.15	14.8	.263
5838	16.598	14.7	0.71	13.8	3.82	13.9	2.11	15.1	.469
5841	.645	14.7	0.76	13.8	3.86	13.8	0.04	15.1	.516
5851	.826	14.6	0.94	13.2	4.04	13.9	0.22	14.5	.697
5938	40.586	13.2	1.35	13.3	2.25	14.2	0.74	15.0	.447
5942	41.593	14.6	0.90	13.4	3.26	14.4	1.75	14.5	.704
5953	.810	13.8	1.12	13.8	3.48	14.2	1.97	14.6	.171
5957	42.581	14.8	0.43	13.5	4.25	14.1	0.63	14.6	.191
5965	.722	14.6	0.57	13.4	4.39	14.3	0.77	14.9	.332
5972	43.579	13.7	1.43	13.0	0.14	14.4	1.62	15.0	.439
5981	.747	13.7	0.14	12.7	0.30	14.2	1.79	15.1	.607
6832	0169.603	14.7	0.64	13.6	4.23	13.5	0.16	14.4	.080
6835	.665	14.6	0.70	13.3	4.29	13.5	0.22	14.5	.142
6841	.825	14.6	0.86	13.2	4.45	13.9	0.38	14.8	.302
6843	70.610	14.1	0.19	12.8	0.13	14.2	1.17	15.2	.337
6846	.673	14.0	0.25	12.7	0.19	14.4	1.23	14.8	.400
6852	.818	14.4	0.39	12.8	0.33	14.6	1.37	15.0	.545
6854	71.606	14.0	1.18	13.0	1.12	13.8	0.05	15.0	.582
6857	.643	13.6	1.22	12.9	1.16	13.8	0.09	15.1	.619
6858	.661	13.7	1.24	12.9	1.18	13.7	0.10	14.9	.637
6867	72.603	14.8	0.72	13.2	2.12	14.4	1.05	14.5	.079
6871	.653	14.6	0.77	13.2	2.17	14.3	1.10	14.5	.129
6879	.838	14.8	0.96	13.5	2.35	14.6	1.28	14.9	.314
6924	97.588	14.6	0.90	13.1	1.55	14.3	0.68	15.0	.304
6932	.764	14.1	1.08	13.0	1.73	14.3	0.85	15.0	.480
6934	99.597	13.4	1.45	13.7	3.56	14.2	0.57	14.3	.062
6941	.806	14.2	0.20	14.0	3.77	14.2	0.78	14.7	.271
6945	200.590	14.6	0.99	12.9	4.56	14.6	1.57	14.9	.304
6955	.786	13.8	1.18	12.8	4.75	14.4	1.76	....	.500

which the Julian Day is given only to the second decimal a mean of several plates taken in quick succession is given. The 99 plates later than J.D. 2427728 were taken at this observatory.

Figure 2 shows the light curves of the four variables. For

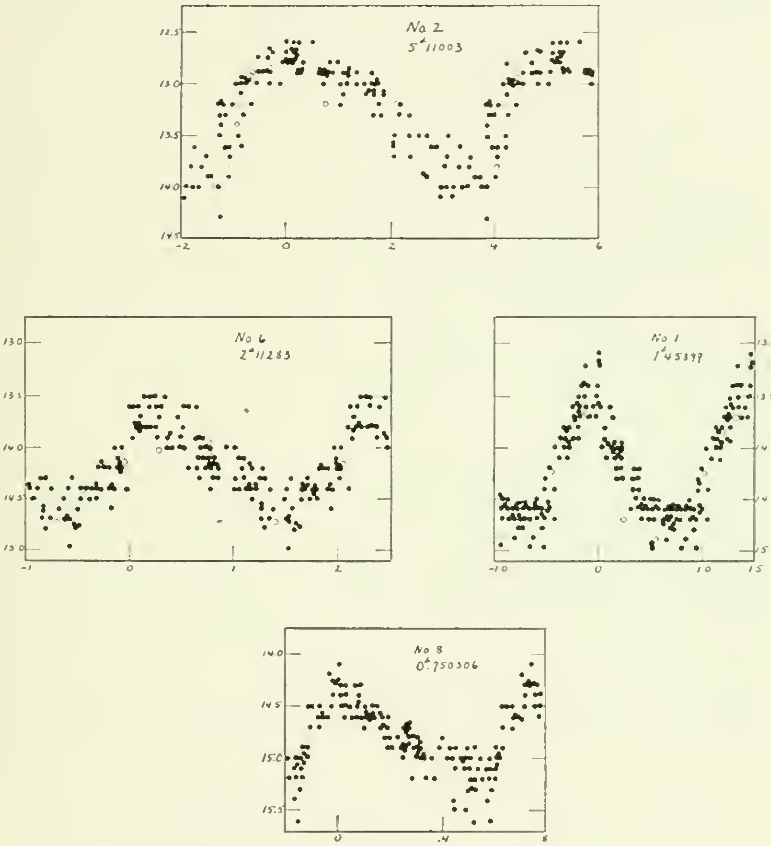

FIGURE 2

The light curves of four variable stars in Messier 13; three are long period Cepheids, and one a cluster type variable. Early observations by Shapley are indicated by open circles.

Variables 1, 2 and 6, Shapley's observations are indicated by open circles. The scatter of the points for No. 6 is probably increased by the presence of a moderately bright star close to the variable.

The four periods so far determined outline a good period-luminosity relation in this cluster, as shown in Figure 3. The correct determination of the period of No. 1 removes a discrepancy which existed in the period-luminosity relation when, according to Barnard's work, a Cepheid with period of 6 days had a brightness fainter by one magnitude than a Cepheid of 5 day period.

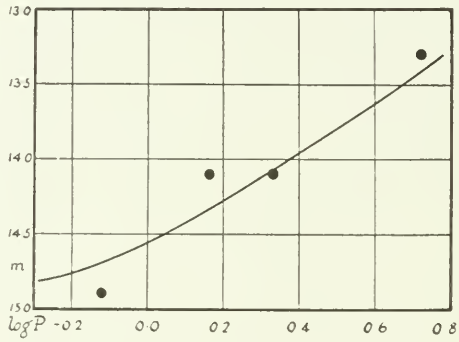

FIGURE 3

The period-luminosity relation in Messier 13.

Messier 13 is now the seventh globular cluster in which both long period and cluster type Cepheids are found, and in which a good period-luminosity relation is defined. Table III summarizes these clusters. It is important to note that no cluster so far investigated has afforded evidence against the validity of the period-

TABLE III

CLUSTERS IN WHICH A PERIOD LUMINOSITY RELATION IS ESTABLISHED

Name	NGC	No. Long Period Cepheids
Omega Centauri..	5139	6
Messier 3........	5272	1
Messier 5........	5904	2
Messier 13.......	6205	3
Messier 14.......	6402	3
Messier 15.......	7078	1
Messier 2........	7089	4

The references can be found in Pub. D.D.O. Vol. I, no. 4, 1939.

luminosity relation. In the one case, NGC 362, in which long period Cepheids were found by the writer[8] to be of the same brightness as cluster type variables, the evidence indicates that the long period Cepheids are actually members of the Small Magellanic Cloud, rather than of the cluster. Most of the clusters listed are very rich in cluster type Cepheids; Messier 13 is the only one in which there are so few.

Although in no cluster does the period-luminosity relation rest on an abundance of evidence, the corroboration from globular clusters, one by one, may be considered important because two effects which increase the scatter of the relation in the Magellanic Clouds and in extragalactic nebulae are reduced to a minimum in globular clusters; namely, a great depth of the system itself, and large amounts of obscuring nebulosity in the system.

The distance of the Hercules cluster as determined from this study of the variables is somewhat smaller than that determined earlier.[9] A mean modulus of the cluster from these four variables is 14.8, corresponding to 9.2 kiloparsecs, to be compared with the previous modulus of 15.07 or 10.3 kiloparsecs (both uncorrected for absorption, which is probably small at galactic latitude +40°). To include the other variables which are almost certainly cluster type, but whose periods are not yet definitive would not change the modulus appreciably. At this distance the cluster has an absolute photographic magnitude of −8.0 independent of absorption, as computed from Christie's schraffierkassette magnitude[10] of 6.78. This is bright for a globular cluster, but not in a class with 47 Tucanae, determined recently by Shapley[11] to be of absolute magnitude −10.2.

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Richmond Hill, Ontario.
March 31, 1942.