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TWELVE NEW VARIABLE STARS IN THE GLOBULAR CLUSTERS NGC 6205, NGC 6366, AND NGC 6779

BY

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TWELVE NEW VARIABLE STARS IN THE GLOBULAR CLUSTERS NGC 6205, NGC 6366, AND NGC 6779

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(with Plates XXV and XXVI)

An intensive search of three globular clusters on plates taken with the large reflectors at both the Dominion Astrophysical and the David Dunlap Observatories has resulted in the discovery of a few new variable stars. Material is being accumulated which will enable a determination of the periods in all three clusters. Although each of these clusters is rather poor in variables, at least two of them contain long period Cepheids. The study of even a few variables should yield interesting results.

1. NGC 6205 = MESSIER 13 HERCULIS

Although the great star cluster in Hercules, situated in R.A. $16^h\ 39^m.9$, Dec. $+36°33'$ (1950), is one of the best known objects in the sky, the variable stars in this cluster have received very little attention. It is frequently cited as an example of a globular cluster in which variable stars are practically absent, but the writer's study of this cluster brings the total of known variables to eleven, which are certainly sufficient to make an interesting study. However, in comparison with the clusters Messier 3, Omega Centauri, and Messier 5, the Hercules cluster is poor in variables.

Two variable stars, both of them relatively bright with large ranges, were discovered many years ago in this cluster. Bailey[1] found them in 1898 but did not publish their positions until 1902. Barnard,[2] hearing of Bailey's discovery, independently found Variable No. 2. In 1914 Barnard[3] also announced the discovery of a third variable. Shortly afterward, in his comprehensive study of the Hercules cluster, Shapley[4] announced the discovery of additional variables, refinding those previously announced, so that the total stood at seven. The ranges for several of these were small and no further work has been done in confirming them in the intervening years.

The writer has intensively compared, by the method of positive and negative, about fifty plates of the Hercules cluster, and has found four additional variable stars, besides rediscovering most of those previously announced. About ten other stars were suspected

of variability by the writer, and measured on a hundred plates, but finally rejected. The variation was no larger than might be expected from stars in rather crowded regions under different conditions of seeing. One suspected variable is the star Ludendorff 928 which though usually of magnitude 14.8 was found to be definitely fainter on one plate only with a magnitude of 15.2.

Table I lists the variables in the cluster and Plate XXV gives the identification. For variables 3 and 4, found by Shapley, the ranges are small, and the variables near the limiting magnitude of many of the plates. But the writer's plates give no evidence for rejecting them as variables. The other variables on the list have ranges sufficiently large to establish their variability.

The magnitudes of the comparison stars were taken from Shapley's catalogue[5] of the Hercules cluster; the positions are computed from Ludendorff's catalogue.[6] A correction should here be noted to the positions of the first seven variables as catalogued by the writer[7] in 1939. The co-ordinates referred to there as x'' are really $\Delta\alpha''$, and should therefore be multiplied by a factor of .8023 to transform them to x''. Bailey's sequence was used to start the investigation (except for his stars *a* and *b* which are too distant from the centre) but as this was not sufficient to cover the large area of the cluster, supplementary sequence stars were selected close to the variables. This was not so satisfactory a procedure as hoped, since Shapley did not publish magnitudes within 2′ of the centre of the cluster. When accurate magnitudes are determined closer to the centre of the cluster the magnitudes of the variables can then be reduced to them.

When the writer came to measure Shapley's variable Ludendorff 806β on her plates, after much struggling with the measures of this close double star, she became convinced that both its components vary. Shapley's variable is the northern component; accordingly the preceding and southern component of this double is called α. There is a range of a full magnitude in each component, even on plates taken under good seeing conditions.

The eleven variables have been measured on over one hundred plates and a number of the periods determined. The writer expects to publish periods and light curves for these very soon.

In 1900 Barnard[2] published a series of 36 visual observations of Variable No. 2, made mostly during the summer of 1900, and announced a period of 5.10 days. The writer's observations con-

TABLE I

VARIABLE STARS IN NGC 6205 = MESSIER 13 HERCULIS

No.	Lud.	x''	y''	Magnitudes Max.	Min.	Mean	Discoverer
1	816	+73.06	−24.86	13.1	15.2	14.2	Bailey
2	306	−54.10	− 3.04	12.6	14.0	13.3	Bailey, Barnard
3	135	−127.70	+16.52	15.4	15.8	15.6	Shapley
4	322	−47.34	+58.18	14.9	15.6	15 2	Shapley
5	806β	+71.62	−14.06	14.0	15.1	14.6	Shapley
6	872	+92.68	+76.60	13.5	14.8	14.2	Shapley
7	344	−39.78	−82.72	14.5	15.5	15.0	Barnard, Shapley
8	206	−93.02	+11.29	14.2	15.5	14.8	Sawyer
9	806α	+71.62	−14.06	14.0	15.1	14.6	Sawyer
10	487	− 5.40	−70.73	13.1	14.0	13.6	Sawyer
11	324	−45.78	−75.88	12.9	13.8	13.4	Sawyer

COMPARISON STARS

Bailey	Lud.	x''	y''	Shapley Mag.
	222	− 82.01	−103.40	12.54
	835	+ 79.03	−115.34	13.23
c	954	+117.50	−217.87	13.45
d	1073	+244.16	−209.44	13.75
e	919	+105.24	−185.88	13.88
f	948	+114.83	−162.85	13.94
g	921	+106.34	−146.85	14.16
h	833	+ 78.40	−234.26	14.52
k	946	+113.83	−139.06	14.71
l	943	+113.11	−150.46	14.80
m	1011	+155.44	−196.23	15.23
n	1035	+177.21	−205.27	15.85
	123	−139.39	− 14.35	15.54
	170	−113.33	− 4.92	14.98
	194	−100.47	+ 38.95	13 58
	195	− 99.55	+ 32.91	15.90
	313	− 51.66	+ 95 81	15.42
	953	+116 93	+ 65.45	15.20
	985	+136.60	− 20 92	14.74
	1001	+145.42	+ 45.61	14 65

firm this period. In a later paper on the Hercules cluster in 1909,[8] he commented that he had determined a period of 6.0 days for Variable No. 1. The writer's observations show that this is an erroneous period.

2. NGC 6366

This little known cluster lies in the constellation of Ophiuchus, at R.A. $17^h\ 25^m.1$, Dec. $-05°02'$ (1950). It is an outstanding example of the type of globular cluster which is exceedingly faint, but possesses a large angular diameter, like the cluster NGC 5053 investigated by Baade.[9] The modulus adopted in 1929[10] from integrated apparent magnitude and diameter alone, uncorrected for absorption, was 17.34.

A search for variables on 30 existing plates, mostly taken at the David Dunlap Observatory with half-hour exposures has resulted in the discovery of two variable stars. These are fairly conspicuous because of their large ranges and brightness compared with other cluster stars. Variable No. 1 is one of the brightest stars in the cluster. Variable No. 2 is equally bright but is situated at a considerable distance from the centre of the cluster. The other four variables mentioned in D.D.O. Pub. 1, no. 4, could not be confirmed. The observational material is as yet insufficient to determine whether the periods of these variables are greater than one day.

Table II gives the positions of the variables and comparison stars, and the maximum and minimum magnitudes of the variables. The magnitudes are considered as preliminary as they are based on only one sequence plate, exposed for twenty minutes on the cluster and for twenty minutes on Selected Area 109.* The positions were measured by means of a reseau which was oriented by a trail

TABLE II

Variable Stars in NGC 6366

No.	x''	y''	Magnitudes Max.	Min.	Mean
1	− 26	− 42	15.5	17.0	16.2
2	+305	−390	15.7	16.8	16.2
		Comparison Stars			
a	+ 69	−104	14.2		
b	−206	+106	15.1		
c	− 12	− 35	15.5		
d	− 47	− 48	16.0		
e	− 48	− 67	16.7		
f	− 75	− 6	17.1		

*Note added to proof. Two additional sequence plates taken in July, 1940, confirm that these magnitudes are of the right order.

in right ascension. An arbitrary origin was selected as being near the centre of the cluster. This origin is indicated on the print by a cross. Plate XXV shows the cluster with the variables and comparison stars indicated.

Baade[9] and Hubble pointed out in 1927 the similarity between the clusters NGC 5053, 6366 and 6539. As more data are now available on NGC 6366, it is interesting to make a table of comparison of these first two clusters. The writer has estimated the magnitudes of the brightest stars on the one available sequence plate and determined a preliminary modulus from these by the usual method. Unless otherwise noted, the data in Table III are taken from Baade's paper for NGC 5053 or determined by the writer for NGC 6366.

TABLE III

	NGC 5053	NGC 6366
Concentration class[11]	XI	XI
Integrated apparent magnitude[12] (on int. photographic scale[13])	10.9	12.1
Angular diameter (large scale plates)	13′.4	12′
Number of variables	9	2
Median magnitude of variables	16.19	16.2
Magnitude 25 brightest stars	15.65:	15.78
Magnitude 6th brightest star	15.1	14.2
Magnitude 30th brightest star	16.0	16.5
Colour excess[14]	0.0*	.55
Modulus uncorrected for absorption	16.20	16.2
Modulus corrected for absorption (if pg. abs. = 9 times colour excess[15])	16.2	11.2
Distances allowing for absorption	17,400 parsecs	1,740 parsecs
Galactic longitude	309°	346°
Galactic latitude	+78°	+15°

*Assumed

The extreme faintness of these clusters combined with their large angular diameters has made it difficult to obtain measures of integrated brightness or diameter from small scale plates. Shapley and Sayer[16] did not measure the angular diameter of either. The diameter of NGC 6366 was determined as 4′: by Shapley and Sawyer,[17] while Baade has estimated that a diameter of 6′.25 contains 90% of the stars in NGC 5053.

A comparison of the absolute magnitudes of these two clusters should be of great interest. Christie[13] has not yet determined the integrated magnitude of either with the schraffierkassette, and the

magnitudes in NGC 6366 must be regarded as preliminary. But if we use the data available at present, and Christie's formula, we derive a value of −5.3 for NGC 5053 and −4.0 for NGC 6366. These clusters are at the lower end of the luminosity scale for globular clusters.

But although these clusters are very similar in appearance they differ radically in their position in the sky. NGC 5053 is near the north galactic pole, whereas NGC 6366 is toward the general direction of the galactic centre. Stebbins and Whitford gave a colour excess of 0.55 magnitudes for NGC 6366. They were unable to determine that for NGC 5053, stating it "too faint and diffuse for measurement of color," but they determined the colour excess of NGC 5024, only a degree away, as 0.0 magnitudes. If the ratio of total photographic absorption to colour excess is large, as much as 9, the latest value given by Stebbins, Huffer and Whitford, then, corrected for absorption, the brightest stars in NGC 6366 are of the eleventh magnitude. Since there is no absorption correction to be applied to NGC 5053 the bright stars remain in the fifteenth magnitude. Therefore the similarity in appearance of magnitude in these clusters is caused by the absorbing cloud. NGC 6366 may be one of the nearest globular clusters.

3. NGC 6779 = Messier 56.

This cluster is one of the most northern of the globular clusters, situated at R.A. $19^h\ 14^m.6$, Dec. +30°05′ (1950). It is in a rich region of the sky, at galactic latitude +8°, and has the appearance of a knot of stars in a rich star field, though it is, of course, definitely a globular cluster. The cluster is classed as X on the basis of its central concentration[11]; the angular diameter as determined by Shapley and Sayer[16] is 7′.2, but the writer's plates indicate at least 10′. This diameter is similar to that of NGC 6366 but the appearance of the cluster is vastly different. The magnitude of the 25 brightest stars is 15.31.[10]

Several investigators have previously worked on this cluster. Miss Helen Davis[18] first published the discovery of a variable star in this object, commenting that the variable was one of the brightest stars in the cluster at maximum. Later, Shapley[19] published the discovery of one variable, one suspected variable, and Miss Davis' star. At about the same time Küstner[20] published an extensive catalogue of the positions and magnitudes of 532 stars

in this cluster but did not work especially with the variables. Since 1920 the cluster has been apparently untouched.

The writer has examined carefully about 35 David Dunlap Observatory photographs and has found six new variable stars. The two variables found by Miss Davis and by Shapley are very definitely confirmed, but the one suspected by Shapley is neither confirmed nor rejected. The star which the writer identified as Shapley's suspected variable has only a small variation, if any, on these plates. One of the new variables found by the writer is quite definitely the brightest star in the cluster at maximum. It is estimated that about 500 stars were searched for variability, of which, however, probably only half are actually members of this cluster.

Table IV gives the positions and magnitudes of the variables and comparison stars. The sequence was established by means of

TABLE IV

VARIABLE STARS IN NGC 6779

No.	Küstner No.	x''	y''	Magnitudes Max.	Min.
1	363	+ 44.69	+ 74.10	15.0	16.2
2	326	+ 18.16	+ 33.09	15.1	15.6
3	337	+ 25.10	+ 91.69	14.2	15.1
4	141	−112.13	−159.46	15.9	16.4
5	305	+ 6.79	−134.78	14.5	15 0
6	284	− 2.02	+ 37.05	12.9	14.8
7	504	+293.48	−213.24	15.5	16 2
8	150	− 97.63	−335.90	15.9	16.6
9	...	+177	+525	15.5	16.1

Variable No. 6 has a close companion, Küstner No. 285

COMPARISON STARS

				Magnitudes Küstner	Sawyer
a	412	+ 87.34	+159.20	12.10	11.5
b	195	− 62.15	+115.95	13.46	13 0
c	161	− 88.77	+108.70	13.82	13.5
d	117	−144.19	−105.88	14.43	14.8
e	85	−205 82	− 22 66	15 22	15.2
f	125	−133 19	− 81 48	15.33	15.8
g	118	−141.12	− 82.35	16.01	16.3
h	...	−168	− 82	.....	16.7
k	...	−176	− 76	.....	17.0

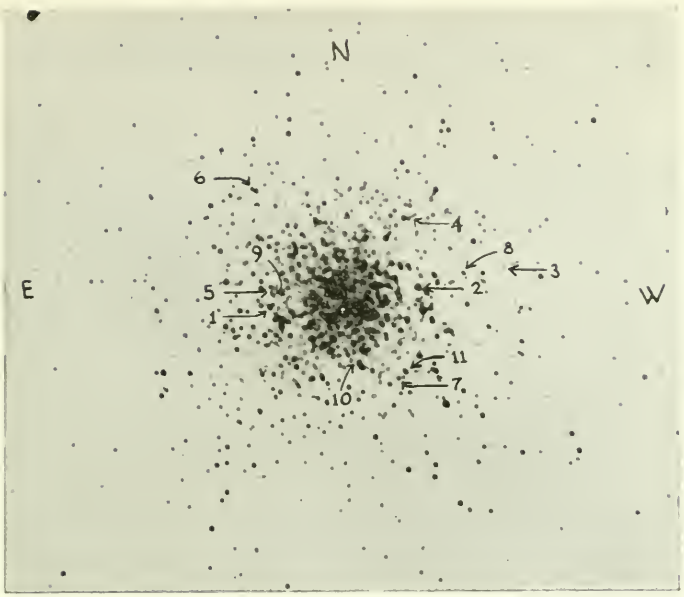
two plates with exposures on Kapteyn Area 64 of 15 and 20 minutes' duration. The magnitude of the sequence stars as determined by the writer agrees with Küstner's magnitude at 15.2, but diverges at the ends, particularly for the brighter stars. The positions of the variables are taken from Küstner's Catalogue except for Variable No. 9, which is outside the limits of this catalogue and was measured on a D.D.O. plate with a reseau. The positions of the comparison stars also are taken from Küstner except for stars *h* and *k* which were too faint to be included in his catalogue and were measured on plates here and reduced to Küstner's origin. The variables and comparison stars are marked on Plate XXVI.

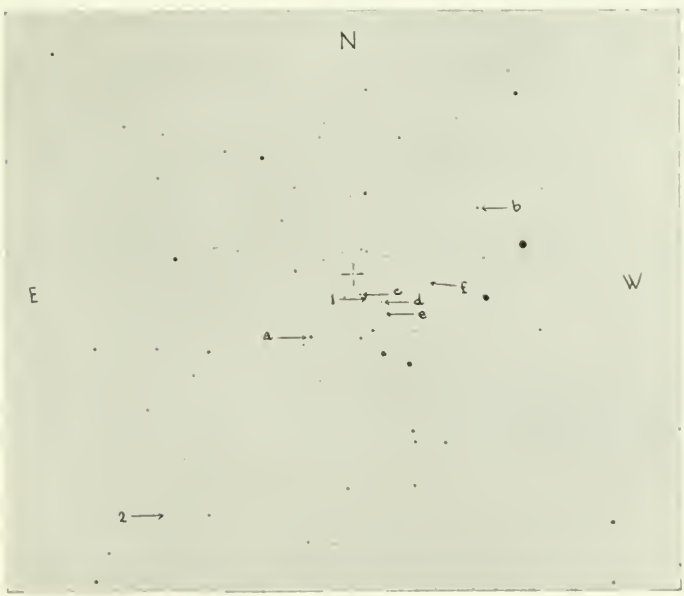
From an inspection of the measures on the existing plates it would appear that several of these variables probably have periods greater than one day. The fainter variables are probably cluster type Cepheids. At present 56 plates are available for this cluster. It is hoped that at the end of another season the plates will be sufficiently numerous for a determination of the periods in this cluster. It should prove an exceedingly interesting one.

References

[1]Bailey, *H.A.*, v. 38, 1902.
[2]Barnard, *Ap.J.*, v. 12, p. 183, 1900.
[3]Barnard, *Ap.J.*, v. 40, p. 179, 1914.
[4]Shapley, *P.A.S.P.*, v. 27, p. 134, p. 238, 1915.
[5]Shapley, *Mt. W. Cont.*, no. 116, 1915.
[6]Ludendorff, *Potsdam Pub.*, no. 50, 1905.
[7]Sawyer, *D.D.O. Pub.*, v. 4, p. 161, 1939.
[8]Barnard, *Ap.J.*, v. 29, p. 75, 1909.
[9]Baade, *Ham. Mitt.*, no. 29, 1927.
[10]Shapley and Sawyer, *H.B.*, no. 869, 1929.
[11]Shapley and Sawyer, *H.B.*, no. 849, 1927.
[12]Sawyer and Shapley, *H.B.*, no. 848, 1927.
[13]Christie, *Mt. W. Cont.*, no. 620, 1940.
[14]Stebbins and Whitford, *Mt. W. Cont.*, no. 547, 1936.
[15]Stebbins, Huffer and Whitford, *Ap.J.*, v. 90, p. 209, 1939.
[16]Shapley and Sayer, *P.N.A.S.*, v. 21, pp. 593-597, 1935.
[17]Shapley and Sawyer, *H.B.*, no. 852, 1927.
[18]Davis, *P.A.S.P.*, v. 29, p. 210, 1917.
[19]Shapley, *Mt. W. Cont.*, no. 190, 1920.
[20]Küstner, *Bonn Veröff.*, no. 14, 1920.

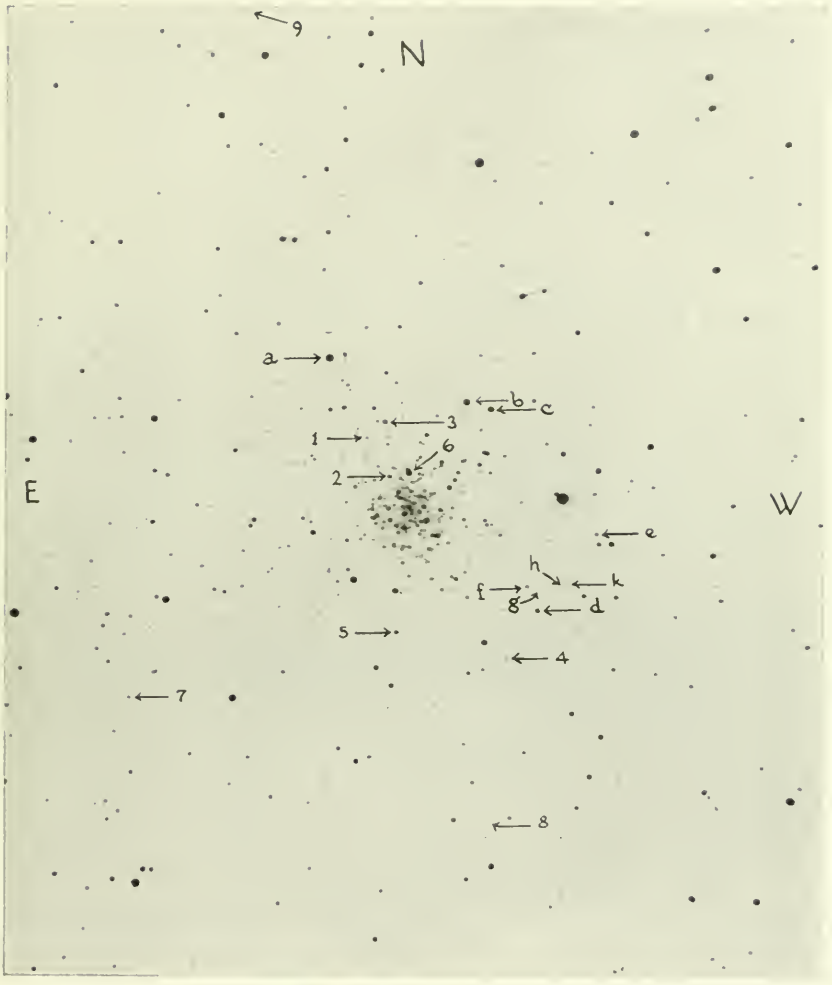
Richmond Hill, Ontario,
July 2, 1940





Upper. The globular cluster NGC 6205 = Messier 13 Herculis, with the eleven variables indicated. Comparison stars have been omitted to avoid congestion.
Scale, 1mm = 6″.4. Enlarged from D.D.O. plate 4816, 1939 Aug. 14.

Lower. The globular cluster NGC 6366, a heavily obscured object, showing two variables and comparison stars.
Scale, 1mm = 12″.2. Enlarged from D.D.O. plate 1996, 1937 June 5.



The globular cluster NGC 6799 = Messier 56, showing nine variables and comparison stars.
Scale, 1 mm = 8″.2. Enlarged from D.D.O. plate 4967, 1939 Sept. 11.