HARLOW SHAPLEY AND GLOBULAR CLUSTERS*

HELEN SAWYER HOGG

David Dunlap Observatory, University of Toronto

Beginning in 1914 the name of Harlow Shapley was signed to a series of papers on globular clusters, so important and so lengthy, that its mark on this field is ineradicable. It was my privilege in 1926 to become a graduate student working under Dr. Shapley at the Harvard College Observatory in this field of globular clusters. His exuberant personality, his flair for ideas and his equally great flair for words, his phenomenal memory, his enormous interest in his students and associates as individuals, his amazing capacity for work made a profound impression on all of us. These, combined with the glorious lure of globular clusters, provided an inspiration so forceful that it locked me into the same field for my astronomical working life. The long hours of work which Dr. Shapley maintained made us worry that he would not last out the decade of the twenties. It is therefore particularly gratifying to take part in a series honoring his eightieth birthday!

Shapley's first work on globular clusters was with the 60-inch telescope of the Mount Wilson Observatory, at that time the largest telescope in the world. His research pattern involved the two lines of intensive and extensive treatment. For some clusters he worked star by star, constructing catalogs of both photographic and photovisual magnitudes. For most of the clusters recognized as globular at that time, however, knowledge could not be so detailed, and he looked for characteristics common to the majority of clusters, from which the over-all pattern of their significance could be derived. During the Mount Wilson years, from 1914 to 1921, Shapley kept two different series of papers flowing steadily from his telescope and his pen. One set, "Studies Based on the Colors and Magnitudes in Stellar Clusters," appeared in the *Mount Wilson Contributions,* and most

* This is the second in a group of five articles honoring Harlow Shapley on the occasion of his eightieth birthday on November 2, 1965.

of them also in the *Astrophysical Journal.* The first paper of this series was "The General Problem of Clusters"[1] and the final paper, XIX, joint with M. L. Richmond was "A Photometric Survey of the Pleiades."[2] The second series appeared as *Proceedings of the National Academy of Sciences* and as *Mount Wilson Communications* entitled "Studies of Magnitudes in Star Clusters." Its first paper was "On the Absorption of Light in Space,"[3] and the concluding, XIII, joint with B. W. Mayberry, "Variable Stars in N.G.C. 7006."[4] These two series do not represent all the papers pouring out during those years over the Shapley by-line. Before he left Mount Wilson he had published, some with collaborators, more than eighty papers on star clusters and related topics, of which over half concerned globular clusters. Some of his collaborators were junior assistants, while others were astronomers of distinction like F. G. Pease.

Apparently variable stars first lured Shapley into star clusters. His first paper from Mount Wilson in 1914[5] announced the discovery of new variables in Messier 3, an extension of Prof. Bailey's work on this cluster, the richest of all in variables. The 60-inch reflector permitted further resolution in the center, and Shapley found 23 new variables and 7 others suspected of variation. A more comprehensive paper on variables quickly followed: "On the Nature and Cause of Cepheid Variation"[6] in which Shapley rejected the binary-star interpretation of cepheids, and concluded that the "simplest solution of most, if not all cepheid phenomena is founded on the rather vague conception of periodic pulsations in the masses of isolated stars" noting that "a change in the spectrum of a given radiating surface from one type to the next will change the visual brightness of that surface by approximately one stellar magnitude." In the following year, he published several miscellaneous papers on variable stars, on one of which, for the first time, appeared the name of Martha Betz Shapley[7] as collaborator in papers she has shared with her husband Harlow from time to time over several decades.

In 1915 came the first of the massive series of papers that in a few short years was to make Shapley an astronomer of great international renown. In this first paper[1] of his major series he summarized all aspects of the cluster problem. His early work appeared simultaneously with some of that by S. I. Bailey[8] along similar lines, with a catalog of globular clusters. Shapley's second paper[9] "Thirteen Hundred Stars in the Hercules Cluster (Messier 13)" was an intensive 92-page treatment of that cluster. In this paper on Messier 13 he made several notable contributions. He determined that Messier 13 and similar globular clusters are very distant systems. (At that time he regarded them as distinct from our galaxy and even comparable to it.) He specially noted the curious color-magnitude diagram of the cluster, in which the average color index decreased with decreasing brightness. This paper was his first use of the derivation of the parallax from variable stars, now known as the period-luminosity relation. It would be glossing over reality to suggest that all of Shapley's early work and conclusions with regard to clusters were correct. Many revisions, both by him and others have been necessary as further observational facts and knowledge were added by the study of these objects. In the Hercules paper, for example, Shapley rejects K. Bohlin's earlier hypothesis[10] that the asymmetric arrangement of globular clusters indicates that they form a system at the center of the galactic system and that the sun is eccentrically situated. However, Shapley promoted this hypothesis in 1918 when the distances and space distributions of 69 globular clusters were determined.

The concept of the period-luminosity relation gradually evolved in the following way. In her original paper "1777 Variables in the Magellanic Clouds"[11] Henrietta S. Leavitt used neither the word "cepheid" nor the expression "period-luminosity relation." She stated, "It is worthy of notice that in Table VI the brighter variables have the longer periods." Later Edward C. Pickering emphasized these variables,[12] but again without using the word "cepheid." "They resemble the variables found in globular clusters, diminishing slowly in brightness, remaining near minimum for the greater part of the time, and increasing very rapidly to a brief maximum. A remarkable relation between the brightness of these variables and the length of their periods will be noticed. . . . The relation is shown graphically in Figure 1, in which the abscissas are equal to the periods, expressed in days, and the ordinates are equal to the corresponding magnitudes at maxima and at minima."

In the following year Ejnar Hertzsprung[13] used Miss Leavitt's results, called these the Delta Cephei stars, and derived a parallax of the Small Magellanic Cloud from them. Shapley then used Hertzsprung's method in his paper on Messier 13. Meanwhile H. N. Russell was calling attention to the extraordinary brightness of the cepheids.[14] It was Shapley who named the curve "Luminosity-period curve of Cepheid variation" in his paper "On the Determination of the Distances of Globular Clusters"[15] (See Fig. 1) and applied it on a large scale. In this paper he concentrated on cepheid variables and managed from parallactic motions to derive the mean absolute magnitude of eleven isolated cepheids, concluding that "the luminosities of

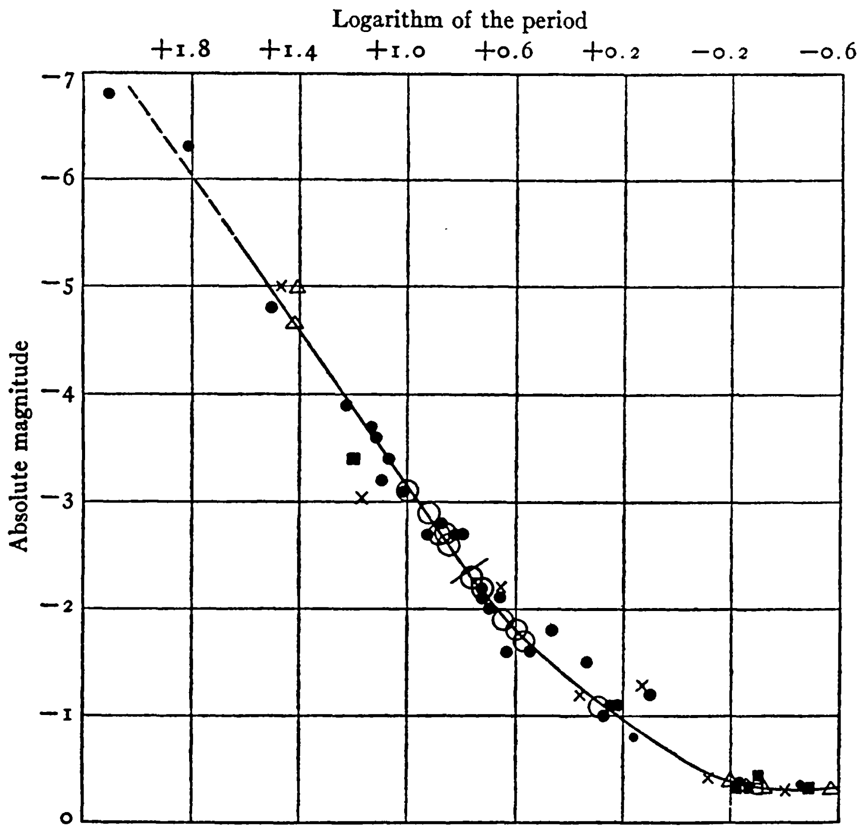

FIG. 1.—Luminosity-period curve of Cepheid variation. The various symbols designate variables from seven different systems. The short bisecting line at absolute magnitude −2.35, log period 0.775, indicates the mean values for Cepheids of known proper motion. Most of the symbols for periods less than a day represent averages of about ten variables. Of the six largest deviations, four refer to values of particularly low weight.

the individual stars are shown to be uniquely defined by their periods."

The period-luminosity relation burst into full flower with his summarizing paragraph: "An extension of these results gives a relation connecting the periods of both the ordinary Cepheids and the cluster-type variables with their absolute magnitudes, which permits the derivation of the distances of all such variable stars as soon as their periods and apparent magnitudes are measured; and when we adopt the plausible hypothesis that Cepheids of a given period are comparable wherever found, the relation also yields the parallax of any cluster containing Cepheid variables. Data for more than 200 individual variables from seven different stellar systems contribute to the determination of the luminosity-period relation. Fainter than a definitely fixed luminosity Cepheid variation probably never occurs." This "plausible hypothesis" had to be revised years later after the population difference between type I and type II cepheids became apparent, but nevertheless it was one of the most important hypotheses ever produced for the determination of the distances of stellar systems.

In the paper on M 13,[9] one observational fact determined by Shapley proved to be a "sleeper," that is, it lay relatively dormant for over three decades before Walter Baade made a population explosion out of it, classifying it type I and type II populations. For in 1915 Shapley drew attention to the difference in the color-magnitude diagram in various types of clusters and in the solar neighborhood. In that paper he published color-class and photovisual magnitudes for various regions in M 13 and commented (p. 61): "Hardly less striking than the apparent absence of light-scattering in space is the unexpected relation brought to light by plotting magnitude against color for any or all of the regions in the cluster. . . . The successive lines of Table XVII show that for every region the average magnitude is brighter for the redder color-classes than for the blue. . . . For open clusters such as Messier 67 and the Pleiades, and for stars in the sky at large, the relation between apparent or absolute magnitude and color has been found always in the sense of increasing redness with decreasing brightness. . . . Verification for other clusters is an obvious desideratum, but preliminary work on other globular systems has already verified the result provisionally. . . . The present result suggests that in this globular cluster, at least, the giants are brightest when reddest. The relation between absolute brightness and color is therefore the inverse of that for dwarfs, where, without much doubt, the cooling stars are growing redder and smaller with age."

Later he reaffirmed his conclusion[16] when colors from Messier 3, 5, and 15 had been added to the table. ". . . in these four clusters the average color index is decidedly larger for the brighter stars." A decade or so later P. ten Bruggencate[17] and R. J. Trumpler[18] also discussed the difference in the color-magnitude diagrams of the globular and galactic clusters. The resolution of the Andromeda nucleus and elliptical galaxies by Baade[19] proved the final key to the puzzle.

It was in the next paper,[20] "The Distances, Distribution in Space, and Dimensions of 69 Globular Clusters," and two succeeding ones, "A Comparison of the Distances of Various Celestial Objects"[21] and "Remarks on the Arrangement of the Sidereal Universe"[22] that Shapley wove together his observations and theories, tidying and revising some of the earlier conclusions, to give us the picture that still prevails, of our galaxy, surrounded by the system of distant, but not independent globular clusters, with the sun thousands of parsecs off center as described by P. van de Kamp in the first article of this series. Shapley[15] outlined the methods used to determine the distances of the clusters: He used cepheids for those clusters possessing them. Then he used the apparent magnitudes of the brightest stars stating that stars brighter than photographic absolute magnitude —2 are exceedingly rare in globular clusters. Angular diameters from the Franklin-Adams charts were next employed in extending the work to as many clusters as possible in both hemispheres. In order to appraise the position of globular clusters in the universe he made some working assumptions: that the linear diameter and mean absolute magnitude of the brightest stars were the same for each cluster, and that there was no absorption of light in space. Now we know that each of these is erroneous. Nevertheless the errors of the assumptions did not mask the spread in the distance of globular clusters or the extent of the Galaxy. The beautiful simplicity of these assumptions, however, was so potent that it prevailed for decades, but in recent years the individuality of globular clusters has come to be stressed, as in the A.A.S. symposium in Toronto in 1959, "The Differences Among Globular Clusters."[23]

In a footnote to Reference 20 some now well-known clusters entered the globular list for the first time. Among these was NGC 7006 which jumped into the forefront as the most remote of all the globular clusters, at a distance of 67 kpc. Its currently accepted distance of 40 kpc still leaves it as one of the more distant. This was the cluster that really tricked Shapley into concluding that there is no absorption of light in space. For several years he had been looking for evidence of such absorption. When he measured the magnitudes and color indices of 38 of the brightest stars in the most distant globular cluster and found that they showed no abnormal redness or peculiarity in color when compared with the bright stars in Messier 13 and Messier 3, though its distance was about five times greater, he concluded that the reddening could not exceed a tenth of a magnitude. Indeed with a galactic latitude of $-19°$, the absorption is very small for NGC 7006; its color excess $E_{(P-V)}$ as measured by G. E. Kron and N. U. Mayall is only 0.14 mag.[24] It remained then for Trumpler,[25] working amongst several hundred galactic clusters in the low latitudes of the Milky Way, to realize that his observations showed the effect of absorption strongly concentrated to the galactic plane.

NGC 7006 was one of many clusters in which Shapley studied the variables. In his paper with Mayberry[4] he notes that the variables in NGC 7006 are the faintest and most distant on record. This was before an accurate distance to the Magellanic Clouds was established, and before Hubble's pioneer work on M 33 and M 31. They still remain among the most distant variables in our galaxy, however, their distances are exceeded by those in NGC 2419 and in some of the new clusters from the National Geographic-Palomar Sky Survey.

After his appointment as director of the Harvard College Observatory in 1921 Shapley's interest in globular clusters continued unabated. He now had at his disposal thousands of small-scale plates, and Southern Hemisphere plates which he had previously lacked, as well as a constant stream of graduate students as assistants in his program. However, the administrative load of that great observatory, plus the enormous attraction of the magnificent collection of Southern Hemisphere plates on the Magellanic Clouds and the Bruce plates on external galaxies, made him curtail his hours of globular cluster research.

Many additional papers appeared however on clusters and variable stars. One of his assistants then was Henrietta Swope, whose enthusiasm, thus sparked, for the study of variables has continued unabated through her recent superb papers on the Andromeda galaxy.[26] In collaboration with the writer of this article, a series of globular cluster papers appeared with new measures of integrated magnitudes and diameters from small-scale plates, which led to the classification of globular clusters on the basis of concentration class, I to XII, and revised distances of 93 globular clusters.[27] Later a major contribution to our understanding of clusters came from a post-doctoral fellow at Harvard, Martin Schwarzschild, who first noted the cluster-variable gap in the color-magnitude diagram of a cluster, in Messier 3.[28]

In 1930 Shapley tidied up the existing information by publishing in the Harvard Monograph Series, the most comprehensive volume ever written on star clusters.[29] The excellence of this book is shown by the fact that even now, 35 years later, students and staff alike still reach for it as a handy reference. He also summarized star clusters in the *Handbuch der Astrophysik*.[30] In later years he cast a backward glance over clusters in his article "A Half Century of Globular Clusters" which appeared in *Popular Astronomy*[31] during one of the last years of publication of that admirable periodical.

It is small wonder, then, that the term "globular cluster" and the name of Harlow Shapley seem inextricably woven together, for my brief article has mentioned only a few of the areas in which Shapley contributed to our understanding of globular clusters. An added feature of Shapley's research is his ability to express his results in terms that could be easily followed. This has enabled the knowledge of his work to be more widespread than if he were a taciturn technical expert. An example of this is the way he summed up some of his ideas in a paper to the American Philosophical Society in 1919: "Social relationships among stars are nearly as common as among men and the lower animals. Sidereal bodies completely independent of all star societies are difficult of conception."[32]

Since those two golden decades when Shapley produced most of his globular cluster papers, a vast amount of new observational material has been acquired, and the size of telescope available for such work has increased to 200 inches. The number of globular clusters cataloged in our galaxy has increased rather slowly and now reaches 120 — not yet twice as many as Shapley first worked with, a situation in marked contrast to the galactic clusters. The distance to the center of our galaxy has been determined by more methods, but is still not settled unequivocally. The work of Allan Sandage[33] on highly precise determinations of color-magnitude diagrams to absolute magnitude $+5$ and his interpretations of them have brought understanding of the evolutionary pattern of stars—a pattern which, over and over Shapley emphasized, would be understood when more knowledge could be obtained. From these patterns have resulted startling estimates of the ages of globular clusters, in the range 10 to 20×10^9 years, causing a revision in the estimated age of the universe.

The variables known in clusters have increased markedly. In 1930 fewer than 800 had been found in a search of 45 clusters, and periods were known in only 9 clusters. Now the number has swelled to more than 1600 in nearly twice as many clusters, and periods are known in 49.[34] In general the conclusions Shapley derived from the scantier material are still valid, except for the split in the period-luminosity relation into two types.

The integrated spectra of globular clusters, which Miss Cannon painstakingly classified at Shapley's urging, have now been looked at more closely and, as shown by W. W. Morgan,[35] indicate significant differences in metal abundance. The cause of the differences remains to be adequately explained. Tedious determinations of the radial velocities of most of the globular clusters by Mayall[36] and T. D. Kinman[37] give a picture of the orbits of globular clusters around the galactic center. Though the rotational motion of a globular cluster around its center has been assumed for decades, the observational proof was first obtained last year for the cluster ω Centauri by Sir Richard Woolley and his collaborators at Greenwich.[38]

The long-standing controversy on the apparent wisps of obscuring nebulosity in globular clusters seems now to be settled. That this nebulosity exists in certain clusters has been shown by M. S. Roberts[39] and G. M. Idlis,[40] though the source of the nebulosity is still not clear.

Many questions still remain unanswered, and many observations still to be achieved. Although radio telescopes have been turned at globular clusters, they have not yet made a major contribution to our understanding of them. We do not yet know how many globular clusters are actually associated with our galaxy. In no globular cluster has the faintest star yet been photographed. Can this ever be done from the surface of the earth, or must this be carried out in space? What is the factor that makes some masses evolve as galactic clusters, and some as globular, and what is the demarcation line between the borderline clusters? Why do objects of such great age show such a range in metal abundance?

An intriguing exercise is to try to visualize the appearance of the sky from inside a globular cluster. Unfortunately no globular cluster is sufficiently close that we can imagine travelling to it in a man-made space ship. An optimistic lover of globular clusters, however, can hope that our human race will last long enough so that eventually our space ship earth will come a little closer to one of these dazzling objects and earth-people can bask in the radiance.

---

1 H. Shapley, *Mt. Wilson Cont.* No. 115, 1915.
2 H. Shapley and M. L. Richmond, *Mt. Wilson Cont.* No. 218, 1921.
3 H. Shapley, *Mt. Wilson Comm.* No. 18, 1916.
4 H. Shapley and B. W. Mayberry, *Mt. Wilson Comm.* No. 74, 1921.
5 H. Shapley, *Mt. Wilson Cont.* No. 91, 1914.
6 H. Shapley, *Mt. Wilson Cont.* No. 92, 1914.
7 H. Shapley and M. B. Shapley, *Mt. Wilson Cont.* No. 104, 1915.
8 S. I. Bailey, *Harvard Obs. Ann.,* **76**, No. 4, 1915.

[9] H. Shapley, *Mt. Wilson Cont.* No. 116, 1915.
[10] K. Bohlin, *Küngl. Svenska Vetens. Hand.,* **43,** No. 10, 1909.
[11] H. S. Leavitt, *Harvard Obs. Ann.,* **60,** No. 4, 1908.
[12] E. C. Pickering, *Harvard Obs. Circ.* No. 173, 1912.
[13] E. Hertzsprung, *A. N.,* **196,** 201, 1913.
[14] H. N. Russell, *Science NS,* **37,** 651, 1913.
[15] H. Shapley, *Mt. Wilson Cont.* No. 151, 1918.
[16] H. Shapley, *Mt. Wilson Comm.* No. 34, 1916.
[17] P. ten Bruggencate, "Sternhaufen," Berlin, 1927.
[18] R. J. Trumpler, *Pub. A.S.P.,* **37,** 307, 1925.
[19] W. Baade, *Mt. Wilson Cont.* No. 696, 1944.
[20] H. Shapley, *Mt. Wilson Cont.* No. 152, 1918.
[21] H. Shapley, *Mt. Wilson Cont.* No. 156, 1918.
[22] H. Shapley, *Mt. Wilson Cont.* No. 157, 1918.
[23] A. Sandage, ed., *A. J.,* **64,** 425, 1959.
[24] G. E. Kron and N. U. Mayall, *A. J.,* **65,** 581, 1960.
[25] R. J. Trumpler, *Lick Obs. Bull.,* **14,** 154, 1930.
[26] W. Baade and H. H. Swope, *A. J.,* **68,** 435, 1963; **70,** 212, 1965.
[27] H. Shapley and H. B. Sawyer, *Harvard Obs. Bull.* Nos. 848, 849, 852, 1927; 869, 1929.
[28] M. Schwarzschild, *Harvard Obs. Circ.* No. 437, 1940.
[29] H. Shapley, "Star Clusters," *Harvard Obs. Monograph* No. 2, 1930.
[30] H. Shapley, in *Handbuch der Astrophysik,* Vol. 5, pt. 2 (Berlin: Springer, 1933), p. 698.
[31] H. Shapley, *Pop. Astr.,* **57,** 203, 1949.
[32] H. Shapley, *Proc. Am. Phil. Soc.,* **58,** 337, 1919.
[33] A. R. Sandage, *A. J.,* **58,** 61, 1953 and subsequent papers in *A. J.* and *Ap. J.*
[34] H. Sawyer Hogg, *Kl. Veröff. Remeis Sternw. Bamberg,* No. 34, 1962.
[35] W. W. Morgan, *Pub. A.S.P.,* **68,** 509, 1956.
[36] N. U. Mayall, *Ap. J.,* **104,** 290, 1946.
[37] T. D. Kinman, *M.N.R.A.S.,* **119,** 157, 559, 1959.
[38] R.v.d.R. Woolley, *Nature,* **203,** 961, 1964.
[39] M. S. Roberts, *A. J.,* **65,** 457, 1960.
[40] G. M. Idlis, *Soviet Ast. AJ,* **5,** 135, 1961.