SOLON BAILEY AND THE PERIOD-LUMINOSITY RELATION

Horace A. Smith
Dept. of Physics and Astronomy
Michigan State University
East Lansing, MI 48824

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Abstract

Data in Solon Bailey's 1902 paper on variable stars in the globular cluster Omega Centauri showed, in crude form, the existence of a Cepheid period-luminosity relation several years before Henrietta Leavitt's discovery of a period-luminosity relation among the Cepheids of the Small Magellanic Cloud. Bailey's pioneering observations remain useful in studies of changes in the pulsation periods of variable stars within globular clusters. The study of period changes among globular cluster variable stars is a field in which amateur astronomers may be able to make a significant contribution.

1. Bailey, Leavitt, Shapley, and the period-luminosity relation

Solon I. Bailey (1854–1931) was dispatched by Director Edward C. Pickering in 1893 to assume control of the Harvard Observatory station in Arequipa, Peru. Within a few years he had secured hundreds of photographs of globular clusters, mainly with the Arequipa station's 13-inch Boyden refractor. Between 1895 and 1898, Bailey identified more than 500 variable stars in globular clusters, including the vast majority of globular cluster variables then known to exist (Pickering 1898; Jones and Boyd 1971; Bailey 1902).

Bailey's findings began to be reported in short publications beginning in the 1890's. However, his most important papers are extensive discussions of the variable stars within the globular clusters Omega Centauri, M3, M5, and M15. His studies of these clusters were published between 1902 and 1919 in a series of papers in the *Annals of Harvard College Observatory*. The first of these dealt with the southern globular cluster Omega Centauri (Bailey 1902).

The main initial result of Bailey's studies was the realization that some globular clusters were very rich in variable stars, and that the large majority of the variable stars in globular clusters were of a particular type, hitherto unknown. These variables were at first known as "cluster variables," but later were called RR Lyrae stars. The RR Lyrae variables have periods of less than a day and are now known to be pulsating giant stars of spectral type A-F. However, a small proportion of the globular cluster variables had longer periods. These longer-period variables include a different group of pulsating stars, which we now recognize to be Population II Cepheids.

A few years after the publication of Bailey's study of the Omega Centauri variables, Harvard astronomer Henrietta Leavitt (1868–1921), also using plate material from Arequipa, pointed out that Cepheid variable stars in the Small Magellanic Cloud (SMC) obey a period-luminosity relation (Leavitt 1908; Pickering 1912): the longer the period of a Cepheid, the brighter its apparent magnitude. That all Cepheids in the SMC could be regarded as being about equally distant implied that there existed a one-to-one relationship between the period of a Cepheid and its absolute magnitude. In 1912, no one knew the distance to the SMC, and therefore Leavitt was unable to calibrate the period-luminosity relation in terms of absolute magnitude. When calibrated, the Cepheid period-luminosity relation would be the key to determining the distances to systems containing Cepheids. Edwin Hubble would use the Cepheid period-luminosity relation in his determination of the distance to the Andromeda nebula, demonstrating that it was in fact a galaxy external to the Milky Way (Hubble 1925).

Hubble's exploitation of the period-luminosity relation was preceded by Harlow Shapley's (1885–1972) use of the relation in his demonstration that the Milky Way Galaxy was larger than generally believed, and that the Sun was not at its center. Shapley (1918) used his calibration of Leavitt's period-luminosity relation to determine the distances to globular clusters containing Cepheid variables. We now know that this was not quite right, since the Cepheids in globular clusters are of Population II, whereas the Cepheids observed by Leavitt and those used by Shapley in calibrating the period-luminosity relation are of Population I. Population I and II Cepheids obey different period-luminosity laws, but Baade's (1944) paper defining these two population types lay more than two decades in the future, and Shapley's error was understandable.

In his epochal work Shapley made extensive use of Bailey's observations of globular cluster variables. Since Shapley used Bailey's observations to demonstrate that Cepheids within globular clusters did obey a period-luminosity relation similar to that found by Leavitt, it is of interest to inquire whether Bailey could have anticipated Leavitt's discovery. The answer would seem to be yes, but that Bailey would have been able to make only a weak case.

2. The Cepheids in Omega Centauri

Of Bailey's *Harvard Annals* papers, only the first, the 1902 paper on the Omega Centauri variables, was published before Leavitt's 1908 paper reporting the existence of a period-luminosity relation. In his paper, Bailey reported the discovery of 128 variable stars in Omega Centauri. He was able to determine periods for 95 variables, and possible periods for another 20. Of these, the great majority were of the RR Lyrae type, but five were longer-period Population II Cepheids.

The relationship between average photographic magnitude (defined here as the magnitude at maximum plus the magnitude at minimum divided by two) and the logarithm of the period is shown in Figure 1 for the five Cepheids in Omega Centauri. A correlation between period and brightness is evident. However, the number of Cepheids is small, and for two of these variables (plotted as open circles), Bailey regarded either the periods or the magnitudes as being uncertain. The period-luminosity relation for the same variables as given in Dickens and Carey (1967) is shown in Figure 2. Although in Figure 2 the magnitude scale has been adjusted to the B system, the periods have been refined but not greatly changed. The brightest Cepheid, V1 in Bailey's tabulation, is noted by Sawyer Hogg (1973) to straddle the dividing line between the W Virginis and RV Tauri variables. If included in the latter category, its period would be twice as long as the plotted value. Leavitt (Pickering 1912) remarked that for each increase of one magnitude in apparent brightness, the logarithm of the period of a Cepheid in the SMC decreased by 0.48. The corresponding, rather uncertain, number based upon Bailey's observations of Cepheids in Omega Centauri is 0.6.

In his 1902 paper, Bailey did not note the correlation between the brightness and the period of the Omega Centauri Cepheids. His attention was clearly focused on the far more numerous RR Lyrae variables, which do not lie upon a linear extension of the Cepheid period-luminosity relation. In fact, Bailey's 1902 paper presented the first detailed study of a significant sample of RR Lyrae stars and introduced the Bailey types by which varieties of RR Lyrae stars are still known. Given the weakness of the

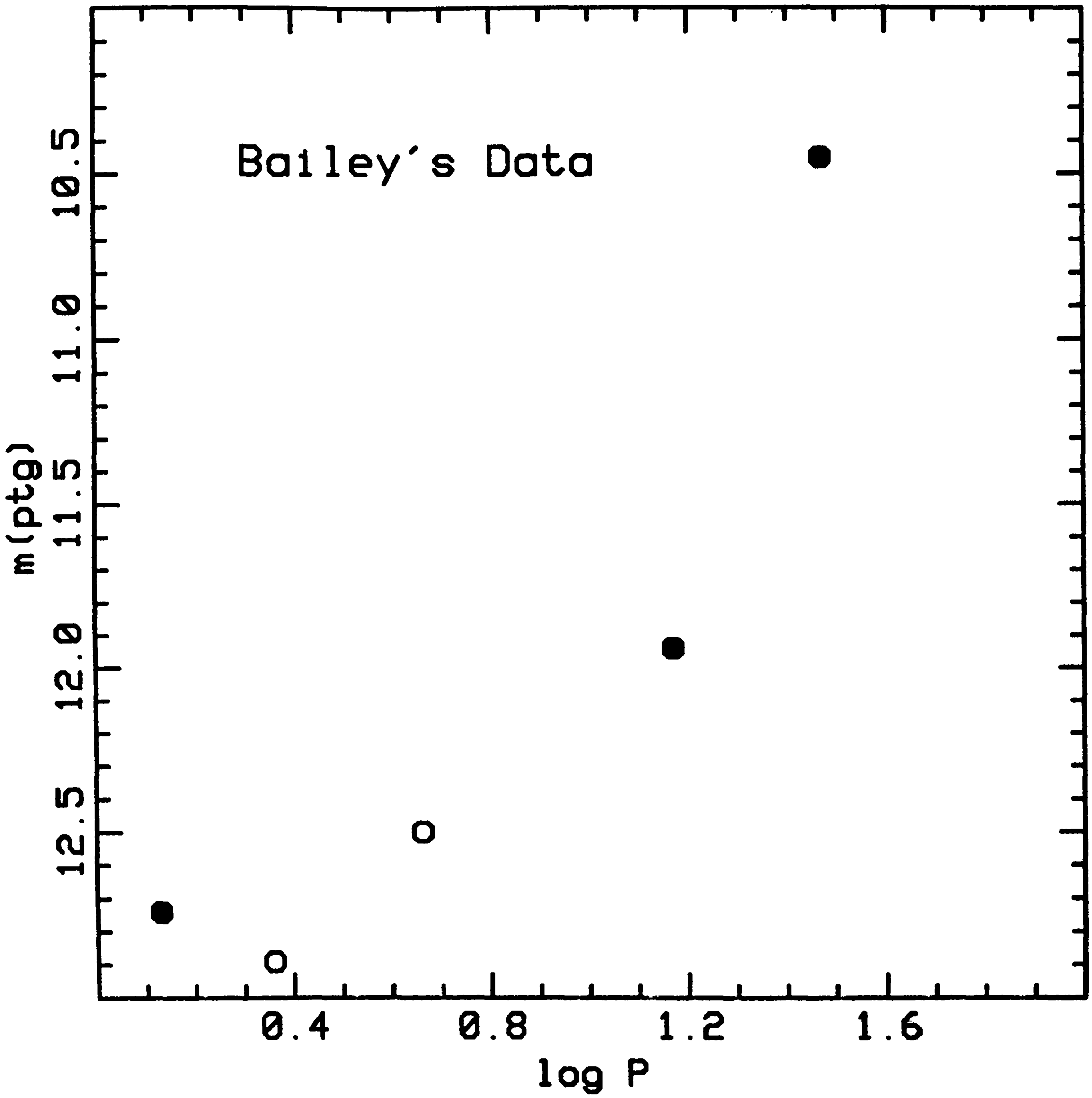

Figure 1. Period-luminosity relation for the Cepheids V1, V29, V48, V60, and V61 in Omega Centauri, based upon data in Bailey (1902). Open circles indicate stars which Bailey regarded as having uncertain periods or magnitudes.

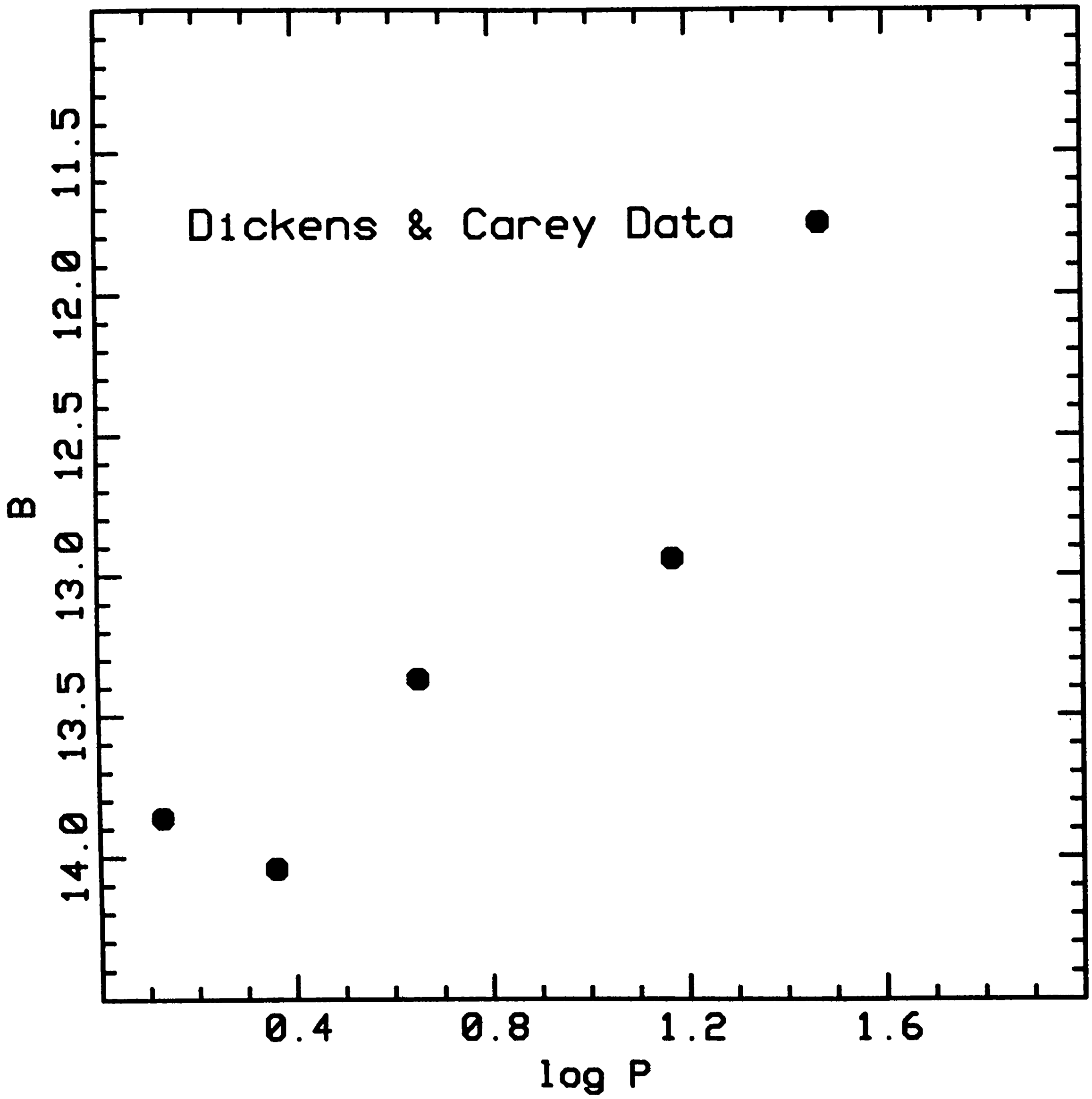

Figure 2. Period-luminosity relation for the same five Cepheids from Figure 1, from data in Dickens and Carey (1967).

evidence for a period-luminosity relation in the Omega Centauri data, and the importance of categorizing the properties of the newly-discovered RR Lyrae variables, it is difficult to fault Bailey's 1902 study. It is noteworthy, however, that when the period-luminosity relation was at last applied to globular cluster variables, Bailey would not be in the forefront. Only in his study of the variables in the globular cluster M15 (Bailey 1919), published after Shapley had begun his investigations, did Bailey consider whether globular cluster Cepheids might obey Leavitt's period-luminosity relation, and even then his approach was cautious and skeptical.

3. The importance of Bailey's observations today

The importance of Bailey's early studies of globular cluster variable stars is not merely historical. Tiny changes in the structure of a pulsating variable star are revealed by small changes in the period of the star long before they can be discerned by any other means (e.g., Eddington 1918). In this connection, particular interest has centered upon the RR Lyrae variable stars in globular clusters. Observations of these stars, if carried out over a long enough interval of time, may show the speed and direction of their evolution through the Hertzsprung-Russell diagram. This would provide a valuable test of stellar evolution theory. Bailey's pioneering observations are of great importance in providing long-time baselines for period change studies which, in the case of some globular clusters, extend for a century (Smith 1995).

4. The task for amateurs

The AAVSO RR Lyrae Committee, and other mainly visual observers, have done excellent work in monitoring the period changes of many RR Lyrae variables outside of globular clusters. On the other hand, the study of period changes among the variable stars within globular clusters has rested entirely upon observations obtained by professional astronomers. This has occasionally proven unfortunate, in that important globular clusters have not always been observed as frequently as is desirable for period change studies.

The amateur may now be in a position to insure that the cluster variables are kept under frequent surveillance. The proliferation of CCD detectors among amateur observers has improved the ability of amateurs with moderate-sized telescopes both to record images of globular clusters and to measure the brightnesses of the variable stars they contain. The work is, however, challenging. To observe variable stars within a globular cluster efficiently, the CCD field of view must be large enough to include a significant fraction of the cluster's stars. To obtain data on the RR Lyrae variables in many globular clusters, stars as faint as 15th and 16th magnitude (in B or V) must be recorded with good signal-to-noise. Measuring magnitudes for variable stars within a globular cluster is made more difficult by crowding and blending of images than is the case for observations of isolated field variables. These are, however, difficulties which can be overcome. The author would like to hear from amateur observers interested in experimenting along these lines.

References

Baade, W. 1944, *Astrophys. J.*, **100**, 137.
Bailey, S. I. 1902, *Ann. Harvard Coll. Obs.*, **38**, 1.
Bailey, S. I. 1919, *Ann. Harvard Coll. Obs.*, **78**, 199.
Dickens, R. J., and Carey, J. V. 1967, *Roy. Obs. Bull.*, No. 129, 1.
Eddington, A. S. 1918, *Month. Not. Roy. Astron. Soc.*, **79**, 2.
Hubble, E. 1925, *Pub. Amer. Astron. Soc.,* **5**, 261.
Jones, B. Z., and Boyd, L. G. 1971, *The Harvard College Observatory*, Belknap Publ. (of Harvard Univ. Press), Cambridge, MA.
Leavitt, H. 1908, *Ann. Harvard Coll. Obs.*, **60**, 87.
Pickering, E. C. 1898, *Circ. Harvard Coll. Obs.*, No. 33, 1.
Pickering, E. C. 1912, *Circ. Harvard Coll. Obs.*, No. 173, 1.
Sawyer Hogg, H. 1973, *Pub. David Dunlap Obs.*, **3**, No. 6, 1.
Shapley, H. 1918, *Astrophys. J.*, **48**, 81.
Smith, H. A. 1995, *The RR Lyrae Stars*, Cambridge Univ. Press, Cambridge.