RR LYRAE STARS

MARTHA L. HAZEN
Harvard-Smithsonian Center for Astrophysics
Cambridge, MA 02138

I. Introduction

As some of the very oldest stars in our galaxy, the RR Lyrae variables are of interest to astronomers concerned with the evolution of stars, to those studying the early history of the Milky Way Galaxy, and to those working on stellar pulsation. These variables are also valuable as distance indicators for the systems in which they occur, although, as can be seen below, their exact intrinsic brightness is a subject of considerable discussion at the present time.

In the following discussion, I will first describe some characteristics of the RR Lyrae stars, and then focus on the history of their discovery. Since RR Lyrae variables are often abundant in globular clusters, I will describe some of the work being done in this area. Finally, I will outline a few of the outstanding problems in RR Lyrae research that are being investigated today.

II. Characteristics of RR Lyrae Stars

Found among the old population (II) in our galaxy, the RR Lyrae stars are pulsating variables with periods generally between 0.2 and 1.0 days. The RR's are common in globular clusters, in the bulge at the center of the Milky Way Galaxy, and in the spherical halo surrounding the Galaxy. There are other short period pulsating variables that lurk in these places as well: the W Virginis stars, brighter than the RR's and with periods generally of 1 day or more; and the Delta Scuti, or dwarf Cepheid stars, fainter than the RR's and with periods of 0.1 or 0.2 days. But the RR Lyrae stars far outnumber either of the above classes, and it is with the RR's that we will be concerned here.

The RR Lyrae stars seem to divide themselves naturally into two groups by period, with the dividing line coming at about 0.45 days. The first group, the longer-period type RR_{ab}, contains stars pulsating in their fundamental modes with amplitudes of from 0.4 to more than 2 mag. The light curves of these variables are often very asymmetric, especially among the shorter periods, with rise from minimum to maximum light taking only one-tenth of the total period or less. With somewhat lower amplitudes and more symmetrical light curves, the second group, the shorter-period type, RR_c, are pulsating in a first harmonic mode.

In the color-magnitude diagram for globular clusters (or for any population II system), the RR Lyrae stars are positioned in the "horizontal branch", the sequence of stars running horizontally across the diagram at a visual absolute magnitude of about +0.6. Across a color range of (B-V) = 0.2-0.5 mag, the stars are unstable and rhythmic pulsations will occur.

III. The Discovery and Nature of RR Lyrae Stars

The first two variable stars to be discovered with period substantially shorter than that of the several known long period variables were Delta Cephei and Eta Aquilae, whose variations were detected in 1784 by Goodricke and Pigott respectively. The name Cepheid, after Goodricke's discovery, was thus attached to all variable stars with periods of a few days to a few weeks.

In 1895 S. I. Bailey discovered that "Cepheids" occurred in large numbers in several globular star clusters (Bailey 1895, 1899, 1902). He noted that these cluster variables, as he called them, had periods of only a few hours rather than days and that the rise from minimum to maximum light was often very rapid. Bailey proposed three categories of these new types of stars: a, b and c. Today we find that types a and b are virtually indistinguishable and we lump them together.

It was not until 1901 that the first cluster variable outside a globular cluster was discovered. W. P. Fleming (1901) found a short-period variable in Lyra that seem identical to the variables Bailey had found in the globular clusters. Since the term cluster variables no longer seemed appropriate, Fleming's star, RR Lyrae, gave its name to the group. By 1976 the number of known RR Lyrae stars in the field of the Milky Way Galaxy (as opposed to those in globular clusters) far outnumbered the known Cepheids, by 5817 to only 773 (Hoffmeister et. al. 1985).

Although the existence of RR Lyrae stars was known by the turn of the century, the mechanism that produced the light variation in them and in the Cepheids was the subject of understandable confusion. Belopolsky, in 1894, observed that Delta Cephei has a regular radial velocity variation with the same period as the light variation. By this time it was known that close binary stars showed a regular variation of radial velocity, and the obvious conclusion therefore was that the Cepheids (and subsequently the RR Lyrae stars) were binaries. It is interesting to note that as early as 1879, Ritter suggested that radial pulsation accompanied by a change in surface temperature could produce periodic variation in brightness of a star. Also, in 1900, K. Schwarzschild observed that the light variations of Cepheids were accompanied by a change in spectral type, unlikely if binarism were the cause of the radial velocity variation.

It was Shapley (1914) who finally pointed out that there were simply too many difficulties with the binary hypothesis, the most obvious being that to produce the observed velocity curves the two stars would have to be inside each other. Shapley therefore strongly recommended a thorough investigation of the possibility of stellar pulsation as the mechanism for producing variations of light and radial velocity. In time, of course, pulsation proved to be the correct solution to the problem.

IV. RR Lyrae Stars in Globular Clusters

For the rest of this paper, I propose to concentrate on what is known and not known about RR Lyrae stars in globular clusters. The reasons for this narrower view are twofold: first, many current studies of these variables concentrate in the globular clusters; and second, I am permitting myself to be rather chauvenistic (the title of this section is equally applicable to my own research).

More than ten years ago, Helen Sawyer Hogg (1973) published her monumental work "A Third Catalog of Variable Stars in Globular Clusters" listing 2119 variables in 108 globular clusters. Of these variables, approximately 90 per cent are of the RR Lyrae type. Some clusters were known to contain several hundred variables, and 13 clusters had no known variables.

In 1973 globular cluster research was somewhat "out of fashion", but today these clusters are among the hottest topics in astronomy. The change has come because of the discovery in the late 1970's of sources of x-radiation in globular clusters, and because of renewed interest in the early history of the Milky Way Galaxy, the period in which the globular clusters were formed.

The beginning of my own love affair with globular clusters and their variables coincided with the appearance of Helen Hogg's catalog. In the introduction to that volume, Dr. Hogg says "...the most frequent number [of variables found in a single globular cluster] is zero." Such a statement seems to challenge the reader. Over several years I evolved the program of searching all the clusters that had not been "adequately" studied for variables and that could be reached photographically with the 1-m Yale telescope at the Cerro Tololo Inter-American Observatory in Chile. To date (with collaborators in many cases) work has been published on 18 clusters; I have plates for 15 more. In many, but not all, of these clusters, a few to several dozen RR Lyrae stars are present.

Why are we interested in the RR Lyrae stars in globular clusters? The first reason is that these variables provide, within limits discussed in the next section, one of the best ways to determine distances to globular clusters. The mean absolute visual magnitude of RR Lyrae stars is currently believed to be at 0.9 ± 0.3 mag. If we can measure accurately the mean apparent visual magnitudes, we can then directly get distances (assuming that somehow a value can be put on any interstellar absorption).

The second topic on which RR Lyrae stars can shed light is studies of the late stages of stellar evolution and theory of stellar pulsation. The RR's are low-mass (~0.6 solar masses) stars that have long since used up in nuclear reactions the hydrogen in their cores and thus are no longer on the main sequence in the color-magnitude diagrams. They have evolved through the red-giant phase where energy is generated through nuclear burning of hydrogen in a shell around the inert helium core that remains from earlier reactions. In the RR's and other horizontal branch stars, the helium core has become dense enough and hot enough to permit energy generation by conversion of helium into carbon and oxygen. The stars will stay near the horizontal branch until this newest energy source is used up, when they will once again become yellow or red giant stars. The general outline of the horizontal-branch helium-burning stages is known; the details of the theory are still being worked out. Observational data needed to test the theory include periods, amplitudes, colors (position in the horizontal branch), period changes, and even absolute magnitudes, if they can somehow be independently determined.

V. Current Problems in RR Lyrae Research

There are a couple of areas in RR Lyrae research where there is considerable activity and discussion today. The first concerns how the characteristics of the variables differ among the globular clusters and the second deals with variations in light curve shape that occur in a single variable.

A. The Oosterhoff Effect

Many years ago, Oosterhoff (1939) noted that globular clusters seemed to be divided into two distinct groups according to characteristics of their variable stars. The first group of clusters called Oo (Oosterhoff) I contains RR Lyrae stars that are mostly type RR_{ab}; very few RR_c pulsators are found in these clusters. The average period of the RR_{ab} stars in OoI clusters is 0.55 days and the few RR_c stars have an average of 0.32 days. The OoII clusters, in contrast, have about as many RR_c stars as RR_{ab} stars, and the average periods are somewhat longer - 0.65 days for RR_{ab} and 0.37 days for RR_c. The other difference between the two types of clusters is one of relative heavy element abundances: The OoI clusters have moderate values (~1/20 that of the sun) and the OoII clusters very low abundances (~1/100 of solar value).

To discuss what the Oosterhoff Effect is trying to tell us, we must look in detail at the small area of the horizontal branch on a color-magnitude diagram where the RR Lyrae variables lie. Pulsation theory tells us, for each combination of color and magnitude, what period a variable will have. The RR_c variables lie to the bluer end (smaller B-V) of the instability region, and the RR_{ab} to the redder side. As one goes from bluer to redder across the instability region, periods become longer for both RR_c and RR_{ab}. So, one way theoretically to increase the average period of variables in a cluster is to change the location of the dividing line in color between the area of the RR_c pulsators and that of the RR_{ab} variables. However, observational evidence seems to indicate that such a change in the dividing line does not occur between the two Oosterhoff types of clusters.

Recently in a series of papers, Sandage, Katem and Sandage (1981), and Sandage (1981; 1982a, b) have proposed another explanation of the Oosterhoff Effect. Theory also tells us that if you make a variable fainter in the instability strip (ie., move it downward in the color magnitude diagram), you will decrease its period. Thus the Oosterhoff Effect could be produced by allowing the OoI clusters with their higher heavy element abundances to have fainter horizontal branches than the OoII clusters. Sandage and his co-authors argue very effectively that this is, indeed, what happens; and further, they claim that the effect is continuous - that is there is no real dividing line between OoI and OoII clusters. This continuous Oosterhoff Effect is often referred to today as the Sandage Effect.

If the Sandage Effect is indeed the explanation for variation of mean periods among clusters, then we can no longer assume that all RR Lyrae stars have the same absolute magnitude everywhere. The heavy element abundance of an RR Lyrae star must now also be considered, in the sense that a higher abundance means a fainter absolute magnitude. The absolute visual magnitudes that Sandage derives for the RR Lyrae stars run from +0.6 for the most heavy-element-poor to +1.2 for the heavy-element-rich RR's. If we use absolute magnitudes to derive distances, a difference of 0.6 mag translates to a change of 30% in the distance.

Clearly, it is important to ascertain whether Sandage's results are indeed correct. There are many research projects underway today to determine observationally if the characteristics of the RR Lyrae variables do vary with heavy element abundances. It is quite possible that we will have definite confirmation (or negation) of Sandage's results within a few years.

B. Variability of Light Curves

Almost from the beginning of studies of RR Lyrae variables it was realized that individual stars have changes with time in their light curves. Such variations can show up as differences in light curve shape, amplitude, and/or period. There are three areas concerning variability of light curves that are subjects for intensive research today.

1. The Blazhko Effect

Early in this century, Blazhko noted periodic variations in the light curve shape of some RR Lyrae stars. These variations may appear as changes in the slope of rise to maximum, changes in the height of maximum, or other changes of the shape of the light curve. Such changes seem to be periodic, with a cycle of variations of many tens of days. RR Lyrae itself shows the Blazhko Effect, with cycle periods of 41 and 62 days.

There is still no accepted theoretical explanation of the Blazhko Effect. Mechanisms that have been proposed to produce it include effects of magnetic fields, stellar rotation, or a combination of the two.

2. Period Changes

Because the theories of evolution of RR Lyrae stars tell us that these stars are slowly moving in the color-magnitude diagram, we expect to find a corresponding slow change in periods for these stars. By now the time intervals over which RR Lyrae Stars have been observed are long enough that such effects may be showing up observationally. Many studies have been completed or are now underway to determine the magnitude and characteristics of period changes of RR Lyrae stars in globular clusters and in the field.

The results to date are inconclusive. Some workers feel that the period changes are sudden and random, while others find evidence for smoother variation with time. There seems to be no correlation of type or direction of period change with position in the instability strip on the color-magnitude diagram. And period changes found to date appear to occur much faster than is predicted by current theories of stellar evolution.

Studies of period changes clearly need more observations, but they also need passage of time. Although much work is being done in this area today, it seems unlikely that general, definitive results will be produced in the very near future.

3. Double Mode Variation

In the last decade or so, observers have become aware of the occurrence of both RR_{ab} and RR_c variation in a single star. The double mode stars, or RR_d, seem to be in a transition mode between the two conventional Bailey types. Such variables are recognized by a large amount of scatter occurring in a supposed R_c light curve. RR_d variables seem to be present in several globular clusters and dwarf spheroidal galaxies (see Clement et al., 1986 for references), and there is at least one field variable that can be classed as RR_d - AQ Leonis.

The exciting thing about the RR_d variables is that they seem to provide a way to get masses for the stars. And since RR Lyrae variables are in the late stages of stellar evolution, the theory thus tells us their ages, if there has not been significant mass loss (and this last point may indeed pose a rather thorny problem). Cox et al. (1983) provide a diagram for double mode pulsations in which the ratio of first harmonic (RR_c) period to the fundamental (RR_{ab}) period is plotted against the fundamental period. The diagram shows lines of constant mass, so that where the RR_d variables are plotted on this diagram a mass can be immediately read off, and thus an age inferred.

Searches for double-mode RR Lyrae stars are being carried out actively today, mostly in globular clusters and related systems. However, there seem to be good candidates for RR_d behavior among field variables. For example Tsesevich (1969) lists as "strange" RR Lyrae stars BV and BT Aqr, AH Cam and AS Vir. These four stars, and surely others, may very well be double mode pulsators.

In closing, in the 90 or so years since the discovery of the first RR Lyrae stars in globular clusters, we have learned much about their characteristics and their nature. But there remains much to be learned from these stars both observationally and theoretically. And it is with the observational side that the AAVSO can help - describing for the nature of period changes and light curve variation, and exploring for possible examples of double-mode behavior.

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