Things We Don't Understand About RR Lyrae Stars

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Abstract RR Lyrae stars have been identified as a distinct class of variable star for slightly longer than the century the AAVSO has existed as an organization. Although considerable progress has been made in understanding RR Lyrae variables over the past century, several aspects of their pulsation remain puzzling. This paper reviews some of the more poorly understood properties of these pulsating variable stars, with emphasis on the contributions that might be made by observers associated with the AAVSO and similar organizations.

1. RR Lyrae stars

Although RR Lyrae itself, the brightest known member of its namesake type of variable star, was discovered by Williamina Fleming at the end of the 19th century (Pickering 1901), it was through observations of globular clusters that the properties of these short period variables were first defined. Solon Bailey and his associates identified numerous variable stars in their photographic studies of globular clusters during the 1890s and early 1900s. Most of these variables had short periods, between 0.2 and 0.9 day, and are what we should today call RR Lyrae stars. However, so closely were these short period variables associated with globular clusters that they were often called "cluster variables" until the 1950s (Smith 1995). Bailey (1902) divided RR Lyrae stars into subclasses based upon the periods and light curve shapes of variables in the globular cluster ω Centauri. Originally three in number, types a, b, and c, these Bailey types are now usually condensed to two varieties, type ab and type c. RRc variables have shorter periods than RRab stars, and usually have smaller amplitudes as well. Because of the smaller amplitudes, RRc stars are often more incompletely discovered than RRab stars in variable star surveys. It was later realized that RR Lyrae of type ab are pulsating in the fundamental radial mode, whereas those of type c are pulsating in the first overtone radial mode. Because of this, RRab stars are sometimes called RR0 stars, while RRc variables are RR1 stars. Double mode RR Lyrae stars (RRd or RR01 stars) have also been discovered, which pulsate simultaneously in the fundamental and first overtone modes. The existence of RR Lyrae variables pulsating in the second overtone mode, RRe stars, remains more controversial (Kovacs 1998).

Shapley (1918) realized that RR Lyrae stars were important standard candles for measuring the distances to globular clusters, and they remain among the main objects for determining the distances to very old stellar populations. RR Lyrae stars are relatively low mass ($\approx 0.6–0.8\mathrm{M}_\odot$) stars that are undergoing core helium burning on the horizontal branch in the HR diagram. The very existence of RR Lyrae variables in a stellar system is indicative of a stellar population older than about 10 Gyr (Smith 1995; Percy 2007).

Despite the progress that has been made in understanding RR Lyrae stars, there are important questions that remain unanswered. The solutions to some of these questions probably will fall to professional astronomers. For example, accurate parallaxes for RR Lyrae stars are needed to calibrate their absolute magnitudes (Benedict *et al.* 2011), and space-based efforts such as the GAIA mission (de Bruijne 2012) may be needed fully to resolve that issue.

However, other open questions are more amenable to being tackled by amateur observers, or by amateurs and professionals working in tandem. These areas where ignorance continues are the focus of the remainder of this paper.

2. Long term period changes

Eddington (1918) posed an important observational question regarding the period changes of Cepheid variable stars that applies equally to RR Lyrae variables: “It would be of great interest to determine the change in period (if any) of these stars, some of which have been under observation for many years; because this would give a means of measuring a very slight change of density, and so determine the rate of stellar evolution and the length of life of a star.” The connection of period changes to density changes comes via the basic pulsation equation: $P\sqrt{\rho} = Q$, where P is the pulsation period, ρ is the mean density of the star, and Q is the so-called pulsation constant.

Stellar evolution theory predicts that there ought to occur slow changes in the period of an RR Lyrae star as it gradually fuses its central helium into carbon and oxygen. These changes are predicted to occur at a small and nearly constant rate during the span of a century or two (Koopmann *et al.* 1994), though the rates of period change can become larger as the RR Lyrae star begins to exhaust its core helium. To test these predictions, photometry of RR Lyrae stars is needed extending over as long a time interval as possible. For some RR Lyrae variables, the observational record already spans more than a century.

While there are indeed some RR Lyrae variables for which the observed rates of period change are small and nearly constant, consistent with the predictions of stellar evolution theory, others present challenges to the theoretical framework. More RR Lyrae stars show large period changes than would be expected from their theoretical rates of period change. Moreover, some RR Lyrae stars have been observed to swing between period increases and period decreases on a timescale of a few years, something not predicted by stellar evolution theory. XZ Cygni, one example of such a misbehaving variable, is an RR Lyrae star to which AAVSO observers have devoted particular attention. Discovered in 1905, XZ Cyg showed only a modest decrease in period during the first half century that it was observed (Klepikova 1958). However, beginning in 1965, the period of XZ Cyg declined steeply in several steps before sharply increasing again in 1979 (Baldwin and Samolyk 2003).

Thus, RR Lyrae stars appear to show some sort of period noise on top of any long term evolutionary period changes. Some have hypothesized the existence of short term instabilities that produce this period change noise but which, when observed long enough, would average out to the period change rate expected from stellar evolution theory (Sweigart and Renzini 1979).

Continued monitoring of the long term period behavior of field RR Lyrae stars is thus necessary to resolve several outstanding problems relating to period changes. Over the long term, will the period changes of all RR Lyrae stars fall into line with the predictions of stellar evolution theory? If so, how long do we have to watch an RR Lyrae star before the noisy observed period changes average out to the evolutionary rate? How often do episodes of large period change occur in a star like XZ Cygni?

In the 1960s Marvin Baldwin pioneered long term monitoring of the period changes of RR Lyrae stars by the AAVSO. Targeted RR Lyrae stars were at first observed visually but more recently almost entirely with CCD cameras (Baldwin 2011). The determination of the period changes of RR Lyrae variables has also been a major focus of the GEOS RR Lyrae survey (Le Borgne *et al.* 2011). All-sky surveys, such as ASAS (Pojmański 1998), are also useful for monitoring RR Lyrae period changes. It is important that these efforts continue long into the future if the questions associated with period changes are to find answers.

3. The Blazhko effect

Some RR Lyrae stars have light curves that repeat very precisely from one cycle to the next. That is not true of all RR Lyrae stars. Some exhibit periodic changes in light curve shape on a time scale typically of tens of days to hundreds of days—the Blazhko effect (Percy 2007; Smith 1995). Although the Blazhko effect was discovered a century ago, our understanding of what causes the phenomenon remains incomplete.

There has, nonetheless, been recent progress in several aspects of our understanding of the Blazhko effect. Smith (1995) stated that almost all of the Blazhko effect stars known at that time were RRab stars, and that perhaps 15–20% of all RRab variables showed the Blazhko effect. More recent researchers have upped that percentage nearer to 50% for RRab stars while more RRc variables have also been found to exhibit the Blazhko effect. This increase is attributable to high precision CCD photometry of RR Lyrae stars obtained from the ground (Jurcsik *et al.* 2009), and also to the monitoring of RR Lyrae variables from space by the Kepler mission (Benkő *et al.* 2010). The Blazhko effect is thus something that occurs in many RR Lyrae variables, if they are watched carefully enough to detect it (Figure 1).

Recent observations with the Kepler mission (Szabó *et al.* 2010; Kolenberg *et al.* 2011) have shown that alternate peaks in the primary light cycle of at least some Blazhko effect stars can differ in brightness (Figure 2). The size of the difference is not the same for all Blazhko stars, and even changes over time for a single star. In studying this so-called period doubling, the Kepler mission has the advantage of being able to continuously observe its targets, without a dirunal gap in the observations. Successive peaks of a half-day period variable star are difficult to observe from a single ground-based location because of the interference of daylight unless the observer is so fortunate (if that is the right word) as to be observing during winter in the arctic or antarctic.

Although the primary light cycle of an RR Lyrae star may be only half a day, the Blazhko periods are many times longer. Determining the period of the Blazhko effect in RR Lyrae stars requires many observations over a time span considerably longer than the Blazhko period itself. Accomplishing that is not a project for one night or even a few nights of observing. Thus, there are RR Lyrae stars for which the primary pulsation period is known, and for which it is suspected that the Blazhko effect exists, but which do not have well determined Blazhko periods. Intensive CCD observations of such stars are needed to establish definitively whether or not the Blazhko effect exists and, if so, to determine the Blazhko period and the manner in which the primary light curve changes over the longer Blazhko cycle. This can be done by observers at a single longitude, but, as Doug Welch has noted (http://www.aavso.org/now-less-mysterious-blazhko-effect-rr-lyrae-variables), observers spread around the world at different longitudes potentially have the ability to detect the recently discovered differences in alternate maxima. The study of CX Lyr by de Ponthiere *et al.* (2009) illustrates the type of study that can be carried out to determine the Blazhko period of an RR Lyrae star, and also some of the complications that can make fixing that period difficult.

Much is unknown about the long term stability of the Blazhko effect and its relationship to changes in the primary pulsation period. Some well-known Blazhko variables, such as RR Lyrae itself, have been studied for several decades. The type of light curve changes that occur during the Blazhko cycle sometimes have been observed to themselves vary on a timescale of years, perhaps in some cases indicating a cycle even longer than that of the Blazhko effect itself (Szeidl and Kolláth 2000). Monitoring of Blazhko effect stars over a span not just of years but of decades is needed to keep track of these very poorly understood long term changes. XZ Cyg again affords an example of a study of this type (LaCluyzé *et al.* 2004). Not only have the amplitude and period of the Blazhko effect changed over time for this star, but at least some of the changes appear to be coincident with changes in the primary pulsation period.

4. Double-mode RR Lyrae stars

Double-mode RR Lyrae stars are rarer than those for which a single pulsation mode is dominant. Are these double-mode stars in the process of switching from one main pulsation mode to another, and, if so, on what timescale does the shift occur? By obtaining photometry of these stars over a timescale of years, one can determine whether the relative amplitudes of the fundamental mode and first overtone mode pulsations are changing. If they are observed to change, are the changes all in one direction (i.e. does the fundamental mode amplitude increase while the first overtone mode decreases, or vice versa) or does the direction of change itself switch over time? It is also perhaps noteworthy that, so far as I am aware, no one has yet detected the Blazhko effect in a double-mode RR Lyrae star. A good example of the type of work that can be done along these lines is the study of the double-mode RR Lyrae star NSVS 5222076 by Hurdis and Krajci (2010, 2011).

5. RR Lyrae stars in globular clusters

The AAVSO RR Lyrae program and the GEOS project have focused upon RR Lyrae stars in the field of the Galaxy, rather than those that are members of globular clusters. This is understandable. Many field RR Lyrae stars are brighter than their cluster counterparts. Moreover, magnitudes of field RR Lyrae stars can usually be obtained from CCD observations with aperture photometry, whereas observations of globular cluster RR Lyrae stars often require the more complicated methods of profile fitting photometry (Stetson 1987) or image differencing (Alard 2000). Nonetheless, RR Lyrae stars in a number of globular clusters are within the reach of modest telescopes equipped with CCD cameras, and observing clusters does have the advantage that many RR Lyrae stars can be recorded on a single image. The unknowns relating to RR Lyrae stars mentioned above apply to cluster as well as field stars (Jurcsik *et al.* 2012) and, in the future, more amateurs may decide to attempt observations of cluster variables.

6. The long haul

A theme that recurs in the discussions above is the need for observations of RR Lyrae stars that span years and decades. I don’t know how much time will pass before all of these things we don’t understand about RR Lyrae stars become things we do understand. I suspect that decades will go by before the answers to some of the questions posed are fully known. Who is going to provide those observations over such a timescale? An individual observer might be active for only a few years, or perhaps a few decades. However, the AAVSO is now into its second century, and it, and organizations like it, can be key to organizing and encouraging observational programs that continue beyond the lifetimes of any individual observer.

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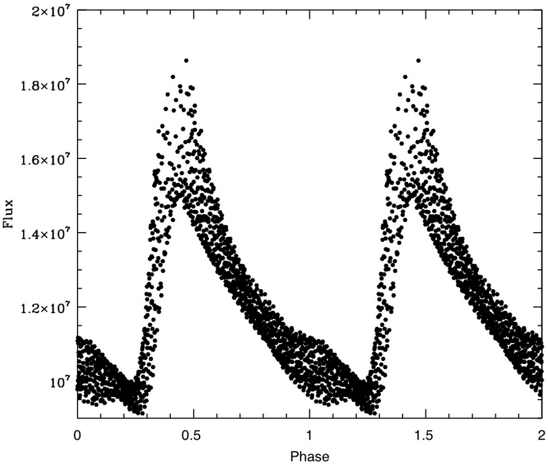

Figure 1. The Blazhko effect is shown in this light curve of RR Lyrae itself, based upon Kepler mission long cadence data. The data are folded with a primary period of 0.566868 day.

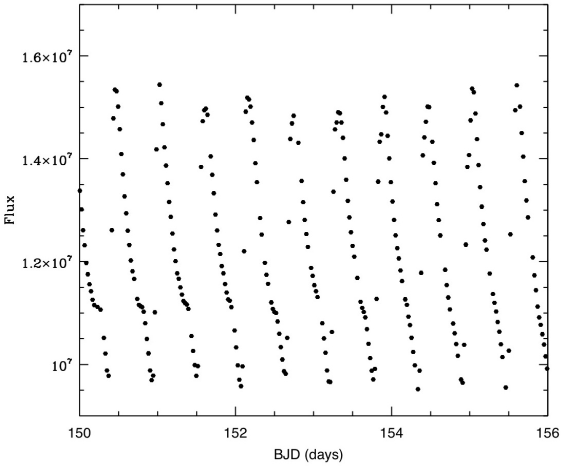

Figure 2. A portion of the Kepler data used to construct the light curve in Figure 1 is plotted against baryocentric Julian date.