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Blazhko effect and double-mode RR Lyrae stars

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Abstract. There are two kinds of multi-periodic RR Lyrae stars. The Blazhko effect is a modulation of the primary light cycle that takes place on a typical timescale of tens of days. Double-mode RR Lyrae stars pulsate simultaneously in the fundamental and first overtone radial modes. The state of our knowledge of these multi-periodic variables is reviewed.

Key words. Stars: Population II – Stars:variables: RR Lyrae

1. Introduction

To within the accuracy of the observations, many RR Lyrae stars are singly periodic, and appear to pulsate in only one mode. Singly periodic RRab (or RR0) stars pulsate in the fundamental radial mode, whereas singly periodic RRc (RR1) stars pulsate in the first overtone radial mode. A few RR Lyrae stars may pulsate in the second overtone radial mode, but the existence of second overtone pulsators remains controversial. However, two types of RR Lyrae stars are not singly periodic, but show multi-periodic behavior: Blazhko effect stars and double-mode stars. RR Lyrae stars that show the Blazhko effect exhibit a periodic modulation of the primary light curve on a timescale typically tens of days long. Double-mode RR Lyrae stars (also known as RRd or RR01 stars) pulsate simultaneously in the fundamental and first overtone radial modes. The existence of the Blazhko effect has now been known for almost a century. The first double-mode RR Lyrae was identified almost three decades ago. Nonetheless, outstanding observational and theoretical questions remain open regarding the nature of both of these types of multi-periodic star.

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2. The Blazhko effect

Recent summaries of the Blazhko effect have been given by Szeidl (1988), Smith (1995), Szeidl & Kolláth (2000), and Kolenberg et al. (this proceedings). Blazhko (1907) discovered that the RR Lyrae star RW Dra exhibited a cyclical 41.6 day variation in the phase of maximum light. It was almost a decade later that Shapley (1916) found that the amplitude and light curve shape of RR Lyrae itself, which has a primary period of 0.567 day, changed with a 41 day secondary period. It is now known that this phenomenon, the Blazhko effect, is relatively common among RRab stars and that it is rarer, but can sometimes occur, in RRc type stars. Figure 1, after LaCluyzé et al. (2004), shows how the Blazhko effect modifies the primary light curve of the RRab star XZ Cyg. Because the Blazhko period is much longer than the primary period, the Blazhko effect is unlikely to be caused by interference between

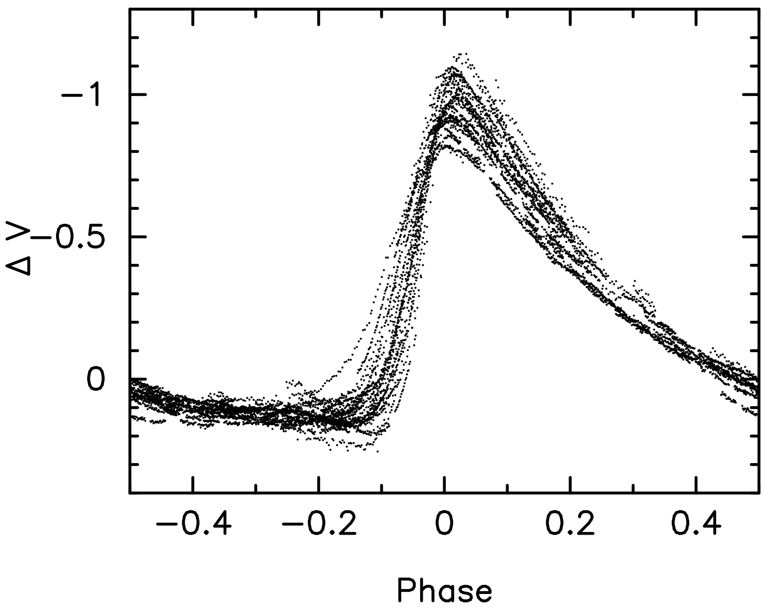

Fig. 1. V-band observations of XZ Cyg obtained between 1999 and 2002 have been folded with a primary period of 0.4666 d. The scatter in the primary light curve is caused by the Blazhko effect.

the primary mode and another radial pulsation mode.

Fourier analysis of RR Lyrae light curve data has become a fundamental tool for identifying RR Lyrae stars that show the Blazhko effect. Frequency spectra of the light curves of Blazhko stars can exhibit either a doublet or a triplet structure. The properties of the frequency structure of Blazhko effect stars are discussed further in the paper by Kolenberg et al. in these proceedings, and the reader is directed there for more on that important subject. The period of the Blazhko modulation can be as short as about 7 days or as long as a few hundred days, but is typically several tens of days. Moskalik et al. (2004) have reported amplitude and phase modulations in Cepheids that may be related to the Blazhko effect observed among RR Lyrae stars.

Because the investigation of the Blazhko effect requires a relatively large number of photometric observations, until recently comparatively few RR Lyrae stars had well established Blazhko periods. That changed when large photometric surveys such as MACHO and OGLE began to produce well-sampled light curves for many RR Lyrae stars in the Galactic bulge and in the Magellanic Clouds. It was through observations of RR Lyrae stars in these surveys that it was finally established that the Blazhko effect occurs among RRc variables as well as RRab stars. Table 1 summarizes recent results on the frequency of occurrence of the Blazhko effect in different systems, based upon a number of recent surveys. This table lists the percentage of RRab and/or RRc variables that show the Blazhko effect in the solar neighborhood, the Galactic bulge, and the Large Magellanic Cloud (LMC). Cacciari et al. (2005) have also recently reported that 32% of the RR Lyrae stars in the globular cluster M3 show the Blazhko effect. These statistics confirm that the Blazhko effect is not a rare phenomenon, but that its frequency of occurrence may differ in different systems. Smolec (2005) concluded that the higher frequency of occurrence of the Blazhko effect in the Galactic bulge than in the LMC could not be attributed to differences in metallicity. Jurcsik et al. (2005) found that RR Gem exhibits a Blazhko effect with a very short period (7.2 d) and a very small amplitude (the amplitude is modulated by less than 0.1 mag in *V*). It is thus possible that some low amplitude Blazhko variables exist that may have been missed in recent surveys, and that the percentages listed in Table 1 may in some instances be lower limits.

There is still no consensus as to the reason why the Blazhko effect occurs. Explanations for the Blazhko effect generally fall into one of two categories. In resonance models a nonradial mode is excited in addition to the radial pulsation mode. In magnetic models, the radial pulsation is modified by the existence of a magnetic field. These models, and possible ways of testing them, are discussed further in Kolenberg et al. (these proceedings). It is noteworthy in this connection that the recent study by Chadid et al. (2004) did not detect a magnetic field in the Blazhko variable RR Lyrae, contradicting some earlier studies of that star.

It has been proposed that the Blazhko period of an RR Lyrae star is equal to its surface rotation period (see, for example, Jurcsik et al. (2005b)). However, the fact that the Blazhko period has been observed to change in a few Blazhko variables (LaCluyzé et al. 2004; Jurcsik et al. 2002) suggests that the Blazhko period and the rotation period may not always be equal.

XZ Cyg, one of the RRab stars with a changing Blazhko period, is also one of the few Blazhko variables reported to exhibit more than one secondary period (LaCluyzé et al. 2004). How long an RR Lyrae star that shows the Blazhko effect continues to show the Blazhko effect remains to be established observationally. XZ Cyg, RR Lyr, and a number of other well-known RR Lyrae stars have now been observed to show the Blazhko effect for several decades, but the amplitude of the Blazhko effect can change during that span (Szeidl 1988; LaCluyzé et al. 2004).

3. Double-mode RR Lyrae Stars

Jerzykiewicz & Wenzel (1977) identified the field star AQ Leo as the first known double-mode RR Lyrae star. Since then double-mode RR Lyrae have been identified in globular clusters, in dwarf spheroidal galaxies, in the Magellanic Clouds, and in the galactic field. At least one double-mode RR Lyrae has been identified in the field of the Andromeda galaxy (Brown et al. 2004). Though it was quickly realized that these double-mode variables pulsate simultaneously in the fundamental and first overtone radial modes, a full understanding of why the stars pulsate as they do, and why some stellar systems are rich in double-mode RR Lyrae stars whereas others contain no such stars, has proven much harder to achieve.

In most double-mode RR Lyrae stars, the amplitude of the first overtone mode is stronger than that of the fundamental mode. This is not, however, true of all double-mode RR Lyrae. Figure 2 shows the deconvolved first overtone and fundamental mode light curves of NSVS 5222076, a newly discovered double-mode RR Lyrae in the galactic field (Oaster et al. 2005). This particular double-mode RR Lyrae has a fundamental mode amplitude twice as large as its first overtone mode amplitude.

The Petersen diagram (Petersen 1973), which plots the ratio of first overtone to fundamental mode period against the fundamental mode period, has become an important tool for studying the properties of double-mode RR Lyrae stars. Figure 3 shows the Petersen diagram for a sample of double-mode RR Lyrae stars in several globular clusters, the LMC, and several dwarf spheroidal galaxies, using data taken from the literature (see Clementini et al. (2004) and references therein). The squares indicate the locations of two double-mode RR Lyrae stars in the globular cluster M3 recently reported to have atypical period ratios (Clementini et al. 2004). The X marks the location of NSVS 5222076. In this figure the upper panel shows stars for which the fundamental mode amplitude (A0) is as strong or stronger than that of the first overtone mode amplitude (A1). Note that the stars with strong fundamental mode pulsation tend to have shorter periods, but that not all stars with short fundamental mode periods have a dominant fundamental mode.

Attempts to theoretically define the location of double-mode RR Lyrae stars in the Petersen diagram, and to use the diagram to derive physical properties of RR Lyrae stars

Table 1. Percentages of Blazhko effect Stars

System	RRab	RRc	Reference
Solar Neighborhood	>18	...	Oaster (2005)
Galactic Bulge	23	5	Moskalik & Poretti (2003)
Galactic Bulge	23	10	Mizerski (2003)
LMC	13	4	Alcock et al. (2003)
LMC	15	6	Soszynski et al. (2003)

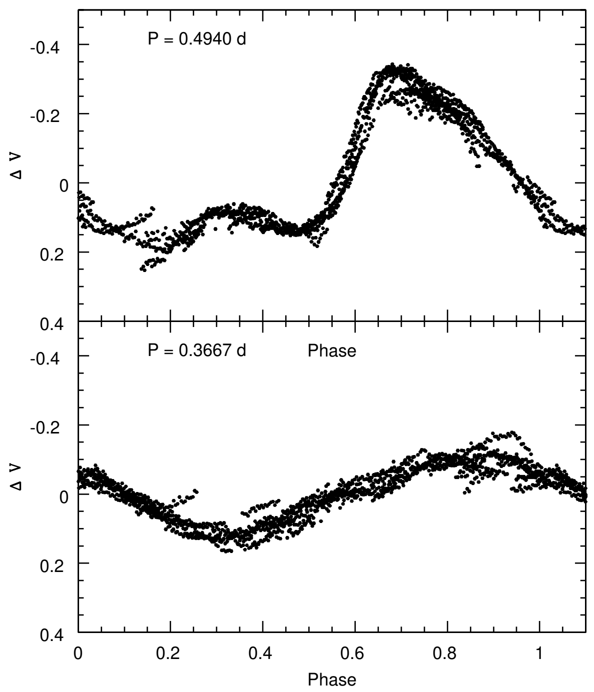

Fig. 2. Fundamental mode and first overtone mode light curves are shown for the double-mode RR Lyrae NSVS 5222076. This star is unusual in having an extraordinarily strong fundamental mode amplitude compared to its first overtone mode amplitude.

have a long history (Cox et al. 1983; Bono et al. 1996; Popielski et al. 2000; Kovács 2001). Most recently, Szabó et al. (2004) have combined stellar pulsation and stellar evolution models to constrain the region of the Petersen diagram that can be actually occupied by double-mode RR Lyrae stars.

One ordinarily expects RR Lyrae stars to obey the basic pulsation equation, $P(\sqrt{\rho}) = Q$, where P is the period, ρ is the mean stellar density, and Q is the pulsation constant. One might therefore expect that if the period of the fundamental mode in a double-mode star increased, then the period of the first overtone

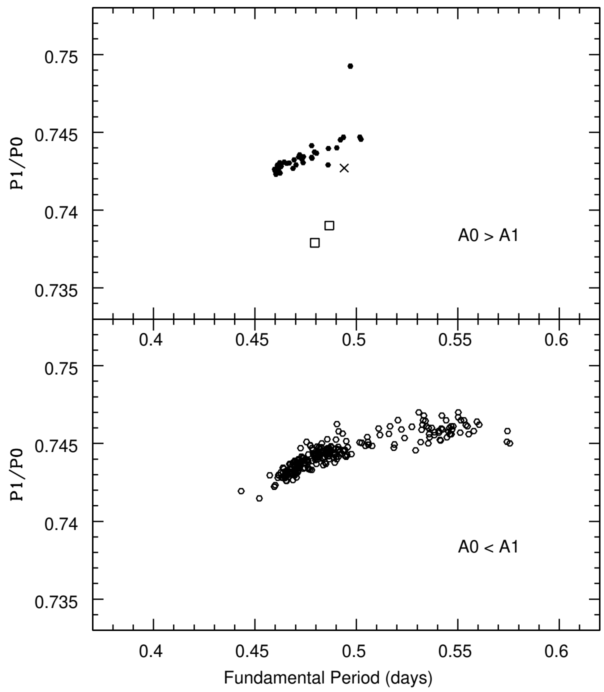

Fig. 3. Petersen diagram for double-mode RR Lyrae stars. Stars with fundamental mode amplitudes larger than those of the first overtone mode are shown in the upper panel. Stars with first overtone mode amplitudes larger than those of the fundamental mode are shown in the lower panel. Squares are two RR Lyrae in M3. The X indicates NSVS 5222076.

mode would also increase, reflecting a change in the mean stellar density. Paparó et al. (1998) have shown that the actuality is more complicated. They found that, among some of the double-mode RR Lyrae in the globular cluster M15, the fundamental mode and first overtone mode periods were changing in different directions. Cox (1998) proposed a possible theoretical explanation for some such stars, but one that requires rather special conditions.

There are observations that indicate that not all double-mode RR Lyrae stars pulsate in a stable mix of fundamental and first overtone modes. Clement & Goranskij (1999) found that the variable v79 in the globular cluster M3 switched from being a fundamental mode pulsator to being a double-mode RR Lyrae. There have also been reports of changes in the relative amplitudes of the modes in double-mode RR Lyrae (Clementini et al. 2004, and references therein). However, Benko et al. (this proceedings) have cautioned that, if the number of photometric observations and their phase coverage are insufficient, then spurious amplitude changes can be produced. The long term stability of double-mode behavior in RR Lyrae stars remains an unsettled issue. Nor is it yet known whether changes in mode amplitude are caused by switching of the dominant mode as the RR Lyrae star evolves through the instability strip, or whether they reflect short-term, temporary changes in the relative amplitudes of the different modes. Continued monitoring of selected double-mode RR Lyrae stars is needed to resolve the question.

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