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The Pulsation Mode Changes of the RR Lyrae Type Variable Star V79 in the Globular Cluster M3

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Abstract. We report the results of our analysis of period variations and mode changing of the RR Lyrae variable, V79 in M3, based on 1810 photographic and 7530 CCD observations obtained over the interval 1895 to 2009. Our analysis suggests that mixed mode pulsations and the Blazhko effect are both the result of resonances between different radial modes.

1. Introduction

From the time of its discovery in the 1890s, V79 in M3 has displayed strong period changes accompanied by amplitude variations (Goranskij 1980). From 1895 to 1988, the star was a fundamental (F) mode pulsator with an irregular light curve, and its period varied between $0\overset{d}{.}48285$ and $0\overset{d}{.}48334$. In April 1989, the pulsations stopped for two weeks, and later reappeared with a much shorter period, $0\overset{d}{.}4797$. Three years later, sometime between April 1 and May 12, 1992, the star suddenly switched modes. It became a mixed mode pulsator with the first overtone (1H) dominating (Corwin et al. 1999; Kaluzny et al. 1998; Clement & Goranskij 1999). Later investigations by Clement & Thompson (2007) and Goranskij & Barsukova (2007) showed that in 2006, the F mode pulsations were gaining strength. By 2007, the star had returned to the F mode. In this paper, we perform a detailed examination of the star's behaviour since 1998.

2. Data and analysis

Our study is based on all the available photographic and CCD observations of V79. The 7530 CCD observations include data obtained by V. G. at the Sternberg Astronomical Institute, Moscow University and at the Special Astrophysical Observatory, Russian Academy of Sciences in 1998–2007, and by M. T. with his 14 inch telescope in 2006–2009, in addition to the data cited above. The photographic data, a total of 1810 plates obtained between 1895 and 1992 were discussed by Clement & Goranskij (1999) and Nemec & Clement (1989). For the period searches, we used the Deeming (1975) and Lafler & Kinman (1965) methods. The amplitude modulation was studied with the search method described by Goranskij (1976).

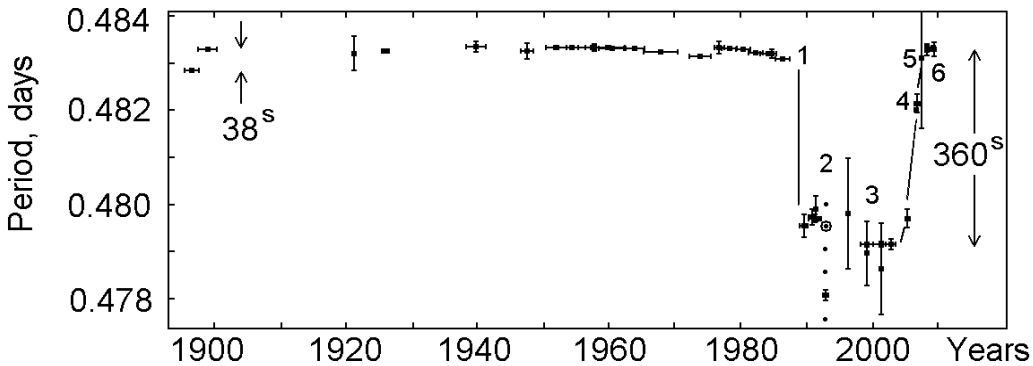

Figure 1. The fundamental mode period vs. time relation for V79. The events described in the text are indicated by digits 1 to 6. The vertical points below "2" are alias periods determined from the 1992 observations of Corwin et al. (1999).

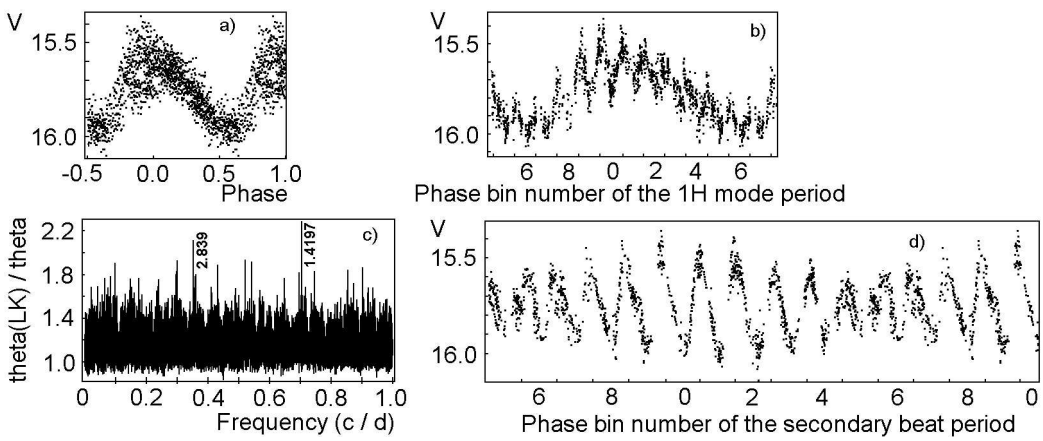

Figure 2. The light curve of the 1st overtone in 1998–2002, event 3 (a). The light contribution of the F mode wave in different phases of the 1H mode period (b). The 'modulation' periodogram reveals a period of $1\overset{d}{.}4197$ (c). A plot of the 1H mode light curve modulated with this period (d). Observations by V. Goranskij.

3. Results

The history of the F mode period variations of V79 is shown in Fig. 1. The diagram is dominated by a strong feature that includes a sudden period decrease of 300 s ($0\overset{d}{.}0035$) in April 1989, after a two week cessation of pulsations (event 1). Sixteen years later, a reverse period change occurred. It continued for two years, finishing in 2007 (events 4 and 5). These are the largest period changes ever observed in an RR Lyrae variable. The sudden mode switch from the F mode to mixed mode pulsations with the 1H mode dominating (event 2) occurred in 1992.

In the mixed mode stage (event 3, 1998–2002), the two waves have constant periods: $0\overset{d}{.}35823865$ (1H), and $0\overset{d}{.}47914585$ (F) with the 1H mode dominant (Fig. 2a). The contribution of the F mode wave is variable: it is largest

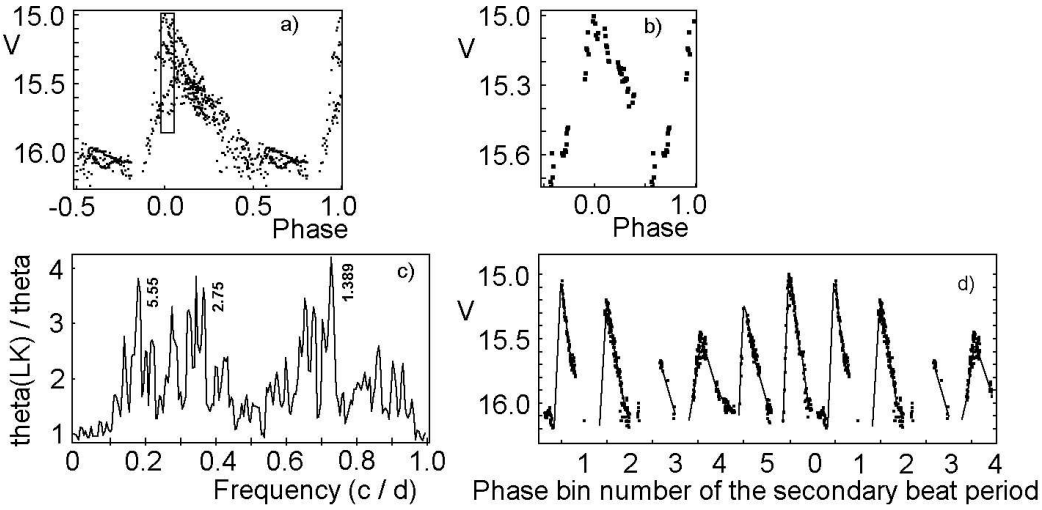

Figure 3. The light curve of the F mode in 2007, event 5, plotted with $P = 0\overset{d}{.}48311$ (a). The observations near F mode maximum plotted with a period of $0\overset{d}{.}35788$, the 1H mode (b). The 'modulation' periodogram reveals a period of $1\overset{d}{.}389$ (c). The F mode light curve modulated with $P = 1\overset{d}{.}389$ resembles the classical Blazhko effect (d). Observations by Goranskij & Barsukova (2007).

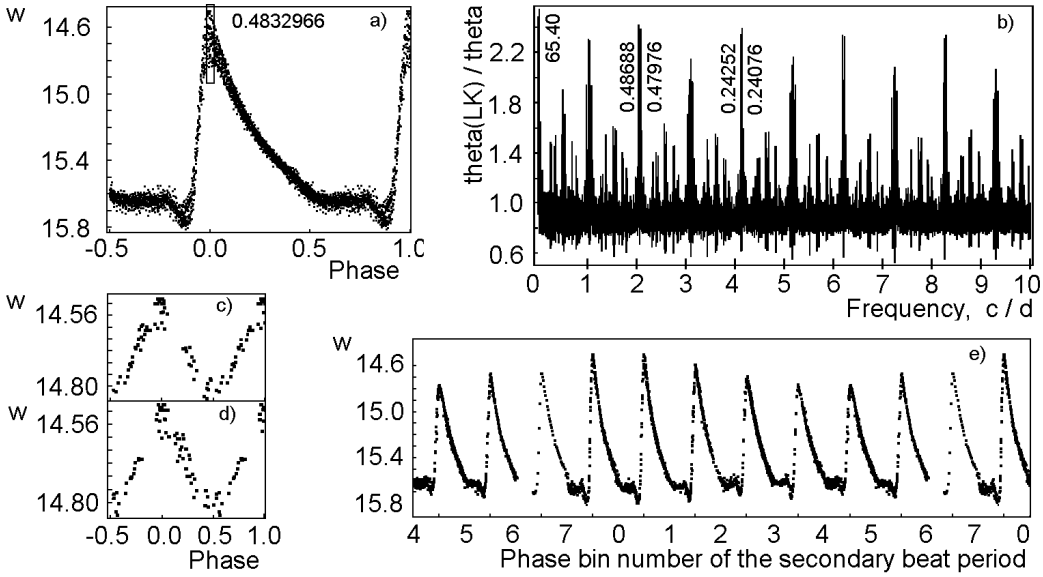

Figure 4. The light curve of the F mode in 2008–2009, event 6 (a). The 'modulation' periodogram reveals a 65 day beat period and a number of aliases at higher frequencies. (b). The observations near F mode maximum fit two periods, $0\overset{d}{.}24252$ (c), and $0\overset{d}{.}24076$ (d), both candidates for the 3rd overtone (3H) mode. The modulation of the F mode wave with the 65.4 day period (e). Observations by M. Thompson in white light.

when the two wave maxima coincide and smallest when they are in antiphase (Fig. 2b). This phenomenon resembles the Blazhko effect, and suggests that the Blazhko effect is actually caused by the mixing of pulsation modes (Clement et

al. 1997). Goranskij's method reveals a short-periodic amplitude modulation, with $P = 1\overset{d}{.}4197$ (Fig. 2c,d). Such a resonant wave interaction is typical of Blazhko variables, so we call this the "Blazhko effect of the 1st overtone".

In the summer of 2007, we caught the star as a double mode (F+1H) pulsator with the F mode wave dominating ($P = 0\overset{d}{.}48311$, event 5, Fig. 3a). The influence of the 1H mode, particularly near maximum light, is readily observed (Fig. 3a,b). A pronounced amplitude modulation of the F mode wave with $P = 1\overset{d}{.}389$ is revealed with Goranskij's method (Fig. 3c,d). Thus we conclude that this kind of Blazhko effect is a resonance between the F mode and the 1H mode.

Since March 2008, we have observed full-amplitude F mode pulsations with $P = 0\overset{d}{.}48330$, and a classical Blazhko effect (event 6, Fig. 4a). The 'modulation' periodogram (Fig. 4b) reveals a typical Blazhko period of $65\overset{d}{.}4$. Along with the 65 day peak in the periodogram, there are pairs of peaks located symmetrically relative to the F mode frequency and its harmonics. These peaks correspond to the aliases of a secondary wave that can be seen in a narrow phase range near maximum of the F mode light curve (Fig. 4a,c,d). We treat the long-periodic Blazhko effect in V79 (Fig. 4e) as a 2:1 resonance between the F mode and a higher overtone, probably the 3H mode. This treatment is similar to that of Borkowski (1980) in his investigation of the Blazhko variable AR Her. On the basis of Borkowski's formula, we conclude that a 3H mode wave with $P = 0\overset{d}{.}24076$ interacts with the primary F mode wave in V79 to produce a Blazhko period of $65\overset{d}{.}4$.

4. Conclusion

V79 has one of the shortest RRab periods in M3 and is evidently located near the boundary between RRab and RRc pulsators in the CM diagram. It seems that V79 has experienced a change of internal structure, accompanied by a decrease of radius so large, that the star shifted to the region of RRc pulsators for many years. Our observations suggest that both the Blazhko effect and mixed mode pulsations are associated with resonances between different radial modes of the star.

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