On the Mode Switching of RRd Stars in the Globular Cluster M3

József M. Benkő

Konkoly Observatory

P.O. Box 67. H-1525 Budapest, Hungary

benko@konkoly.hu

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Abstract

M3 is so far the only cluster in which RRd variable stars have been reported to switch from one dominant mode to another while remaining RRd variables. Investigating synthetic double mode light curves sampled according to the published photometric data sets has been concluded that the observational material is not sufficient to decide whether any mode switchings were happend or not. As it is demonstrated the previously published mode switchings were – most likely – artifacts of the bad sampling.

Introduction

Variations in the double-mode behaviour have been observed in a number of RRd variable stars (Jerzykiewicz et al. 1982, Jurcsik & Barlai 1990, Clement et al. 1993, 1997, Pardue et al, 1995). These variations concern initiation or cessation of the double-mode behaviour and changes in the lenght and amplitude ratios of the two periodicities. However, none of these studies reports a switch between dominant modes to have actually occured in these stars.

In the case of M3 almost all double-mode RR Lyrae stars have been reported such a possible mode switch.

- For V68 and V166 by Corwin et al. (1999),
- for V99 by Benkő & Jurcsik (2000),
- for V200 and V251 by Clementini et al. (2004).

To investigate the mode switching phenomenon all published photometry (both photographic and CCD) was collected. Six RRd stars (V13, V68, V79, V87, V99 and V166) have sufficient amount of historical data to study the possible long term changes of modal content. In the case of V13 and V79 no alternate periods have been found from any parts of historical data while V251 and V252 have not any old observations because of their central position in the cluster. For a practical review of data distributions see the lower panels of Fig. 2. where all different data sets are plotted with different symbols.

Amplitude ratios

Due to the period changes of modes the data were divided into groups containing as many measurements as possible in a moderate lengths of time interval. When different photometric observations belonged to the same group, zero point corrections were applied to match the photometries. Each data group were analyzed applying Fourier techniques by using the program package MUFRAN (Kolláth 1990). First the period of the dominant mode had been determined, then, after prewhitening the data with this frequency and its low order harmonics (2-3 and 5-7 in the case of photographic and CCD data, respectively) the frequency of the other mode was searched. If both the fundamental and the first overtone modes were nearly equally dominant, the process was applied using each mode first, and consistent solution was accepted.

Using the actual frequencies of the fundamental and first overtone modes in each data set, least square fit solutions were calculated in order to determine the amplitudes. The fitting formula is

$$m(t) = a_{00} + \sum_{i,j} a_{ij} \sin[2\pi\nu_{ij}(t - t_0) + \varphi_{ij}],$$

where the designations are the usual: the Fourier amplitudes a_{ij}, phases φ_{ij}, the epocha t_0, the frequencies $\nu_{ij} = if_0 + jf_1$, i and j integers.

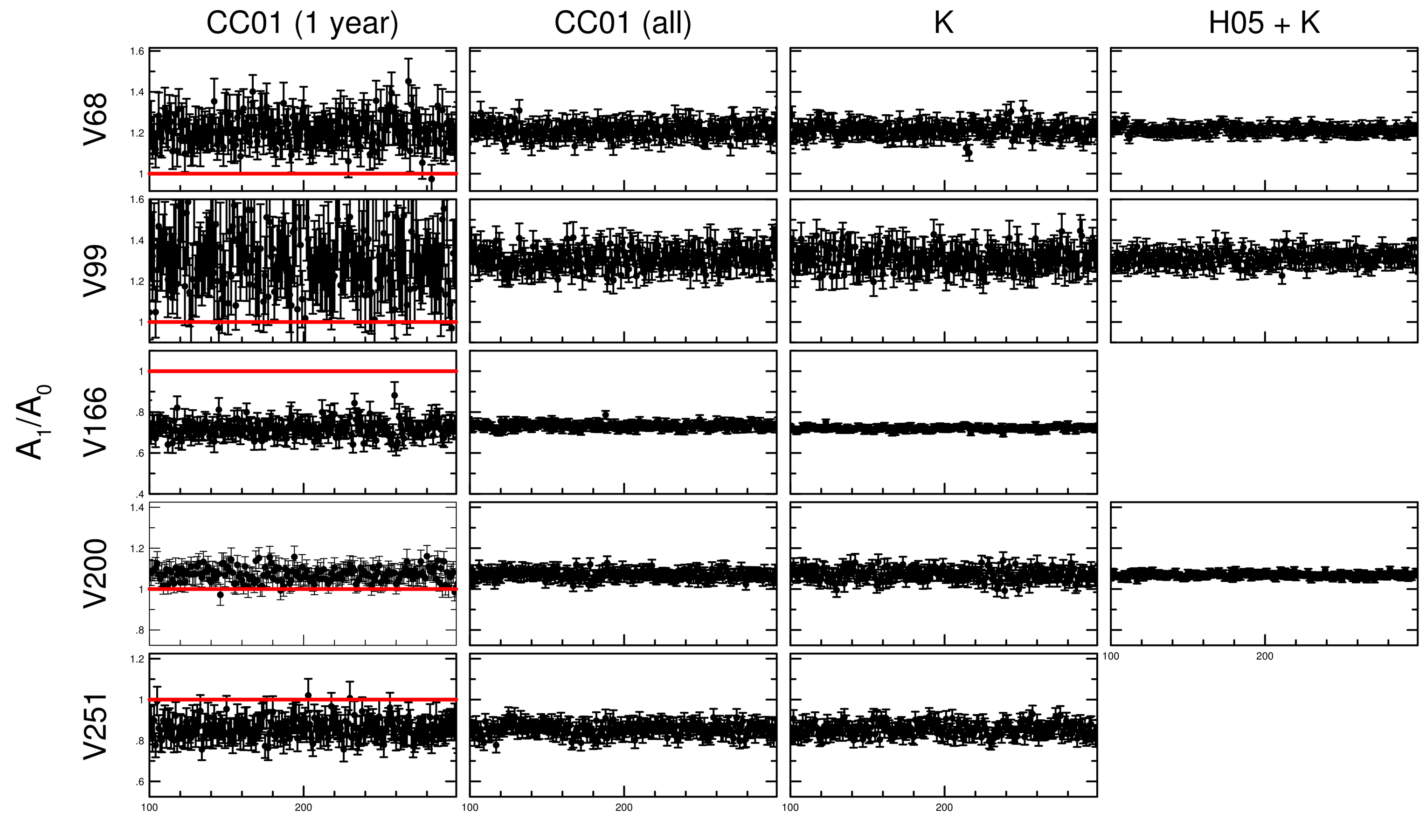

Figure 1. *Calculated amplitude ratios of sythetic light curves determined from CCD observations versus iteration number n, where n are defined by $T_0 = t_0 + n * 0.01$ days. Here t_0 and T_0 are the epoch of the beginning of the sythetic light curves and a given sampled ones, respectively. The rms error of the fit is also marked for each point. CC01 = Corwin & Carney (2001), H05 = Hartmann et al. (2005), K = CCD obs. at Konkoly in 1998-1999*

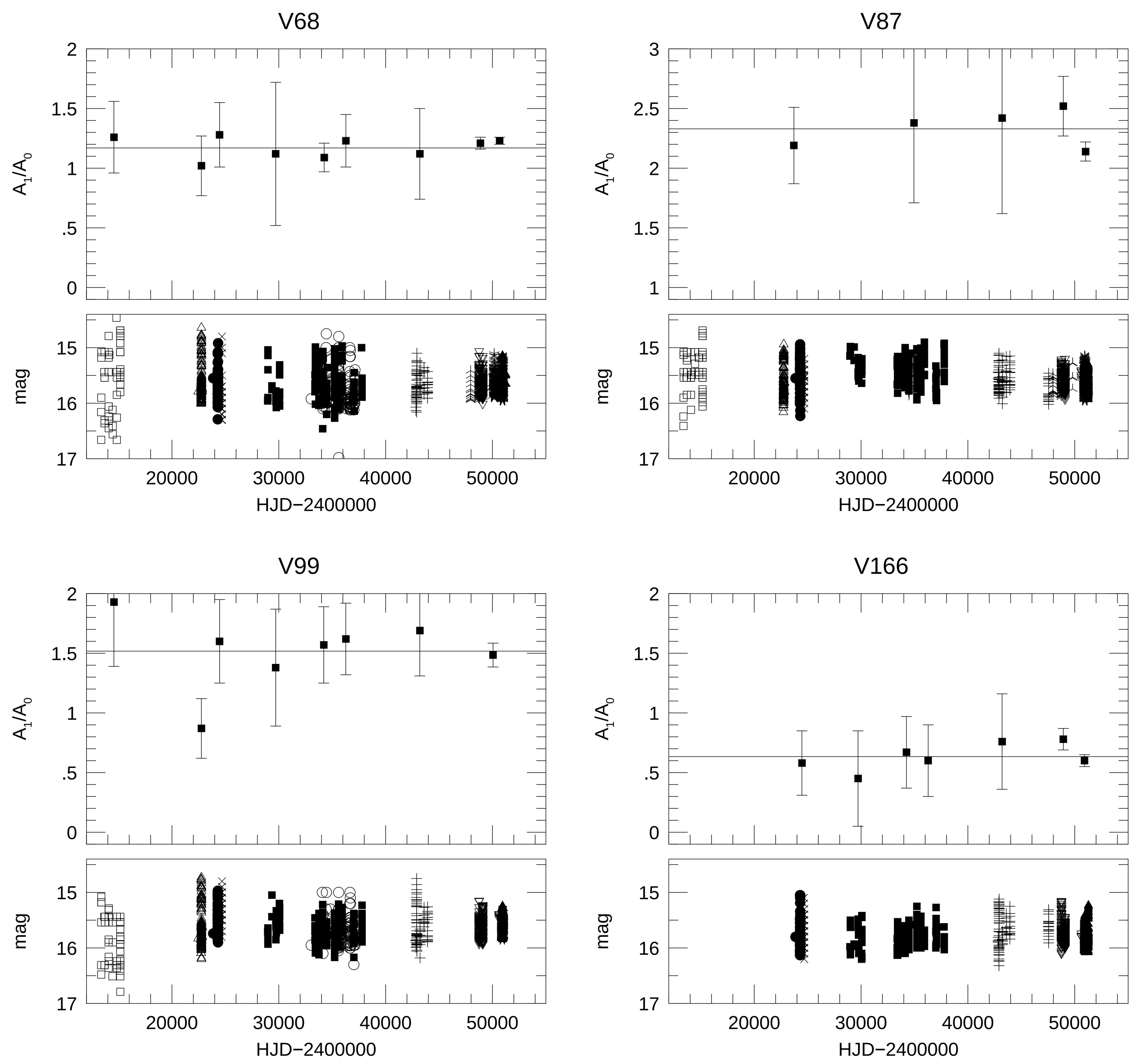

Figure 2. *Upper panels: amplitude ratios of the RRd variables in M3 determined for the different group of the data. Lower panels: the time distributions of the photometric observations of each variables. Symbols: open squares: Bailey (1913), open triangles: Larink (1922), dots: Müller (1933), crosses: Greenstein (1935), filled squares: Szeidl (1965), open circles: Kukarkin & Kukarkina (1970), letters Y: Roberts & Sandage (1955), pluses: photographic obs. at Konkoly (unpublished), trident stars: Carretta et al. (1998), pentagrams: Kaluzny et al. (1998), open triangles in upside down: Corwin & Carney (2001), stars: Hartman et al. (2005), filled triangles: CCD observations at Konkoly in 1998-1999.*

As the parameters of the fits proved to be very sensitive to the number of harmonics and linear combinations concerned, we used only those components which actually appeared in the Fourier spectrum. Because of the inhomogeneity of the used photometry amplitude ratios were determined, which are more independent of photometric systems than the amplitudes themselves (See Tab. 1. for a demonstration of colour independency). The Fourier amplitude of the fundamental mode and the first overtone are denoted as $A_0(= a_{01})$ and $A_1(= a_{11})$, respectively, and the modal content of the pulsation is quantified by A_1/A_0 ratio. It has to be call the attention that the amplitude ratio defined here may differ significantly from the ratio of total amplitudes which is generally used in the literature (e.g. Nemec & Clement 1989, Corwin et al. 1999).

Error analyzis

The estimation of errors plays an important role in justifying amplitude ratio changes. The errors of the amplitude ratios were calculated by a simulation: synthetic time series were generated using the actual frequencies, amplitudes, phases and observational times of each data set. The initial epoch of simulated light curves were shifted at every iteration steps with 0.01 days and white noise with variance corresponding to the original data was also added. Fourier amplitudes of the modes were determined in the same way as for the original data in 1000 simulations/each data set/each star.

Table 1. *The colour dependence of the amplitude ratios of multicolour CCD observations. $(A_1/A_0)_B$, $(A_1/A_0)_V$, $(A_1/A_0)_I$ denote the measured amplitude ratios in Johnson–Cousins BVI colours. Column Ref. show the sources of used data.*

Star	$(A_1/A_0)_B$	$(A_1/A_0)_V$	$(A_1/A_0)_I$	Ref.
V68	1.21 ± 0.06	1.21 ± 0.05	1.16 ± 0.23	1,3
V68	1.25 ± 0.06	1.23 ± 0.03	1.14 ± 0.05	2,4,5
V79	1.36 ± 0.12	1.37 ± 0.12		3
V79	1.72 ± 0.06	1.87 ± 0.05	1.80 ± 0.05	2,4,5
V87	2.45 ± 0.18	2.52 ± 0.25		1,3
V87	2.62 ± 0.15	2.28 ± 0.05	2.25 ± 0.08	4,5
V99	1.88 ± 0.07	1.48 ± 0.02		3,4,5
V166	0.72 ± 0.18	0.78 ± 0.09	0.59 ± 0.25	3
V166	0.65 ± 0.15	0.60 ± 0.05	0.62 ± 0.05	5
V200	1.11 ± 0.08	1.01 ± 0.07	1.13 ± 0.12	5
V251	0.49 ± 0.15	0.81 ± 0.10		5
V252	1.14 ± 0.05	1.10 ± 0.03		4,5

Ref.: 1. Carretta et al. (1998), 2. Kaluzny et al. (1998), 3. Corwin & Carney (2001), 4. Hartman et al. (2005), 5. CCD observations at Konkoly in 1998-1999

The errors in Tab. 1. and errorbars in Fig. 2. show the standard deviation of the amplitude ratios obtained from these simulations.

Conclusions

- The real errors of the amplitude ratios are higher of an order of magnitude than their fitting errors.
- The same sampling rate serves strongly different accuracy of amplitude ratio from star by star, that is for different periods.
- Improving of time coverage of data is reduced this systematic error, but it is hard to find a sampling good for all period combinations.
- The amplitude ratios were severely affected by the value of the initial phase in those cases when only few nights of observations were involved even in high precision CCD observations (see Fig. 1.)!
- All studied RRd star has a well defined amplitude ratio within the calculated error. (Top panels in Fig. 2.)

Nor mode switch nor slight amplitude ratio modification were found (except the case of V79). This negative result are also supported by the theoretical calculations of Buchler & Kolláth (2002) who showed that the mode-switching time scale is about hundred years in the most dramatic case.

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