COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 5666

Konkoly Observatory
Budapest
16 December 2005

HU ISSN 0374 – 0676

ON THE DISTRIBUTION OF THE MODULATION AMPLITUDES OF BLAZHKO TYPE RRab STARS

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The fact that the light curves of some RR Lyrae stars show variation in phase and/or in amplitude (the so called Blazhko effect) has been known since more than a century, but the adequate explanation of the phenomenon is still missing.

For long, no connection between any of the properties of the modulation and that of the pulsation (which might have served as guidance how to explain the modulation) was found. Quite recently, it has been shown (Jurcsik et al., 2005b) that the possible range of the modulation frequency depends on the pulsation frequency. Short period modulations occur only in the case of variables with short pulsation period. This result was interpreted as the first direct evidence for the identification of the modulation period with the rotation period of the stars.

In this note we examine the distribution of the modulation amplitudes of RRab stars using all available data. It is, however, not at all straightforward how to define the amplitude of the modulation. For example, when the modulation is not pure amplitude modulation, than the amplitude of the variation in the height of maxima may significantly underestimate the real 'power' of the modulation. A further problem is that different types of information are available in different sets of data, e.g., different wavelength bands are used, Fourier parameters or time-series data are given, etc. The bulk of the modulation amplitude data comes from the results of the LMC Blazhko stars (Alcock et al., 2003) where Fourier V amplitudes of six pulsation ($A_{\mathrm{f}}, \dots A_{6\mathrm{f}}$), and four modulation frequency components ($f \pm f_{\mathrm{mod}}, 2f \pm f_{\mathrm{mod}}$) are given for 731 RRab stars. Therefore, we decided to measure the modulation amplitude as the sum of the Fourier amplitudes of the first four modulation components. In order to get the possible most homogeneous information about the amplitude of the modulation only those data are used when this sum of the Fourier amplitudes can be reliably determined.

We used all the MACHO data with the exception of MACHO 6.6212.112 (for explanation see Jurcsik et al., 2005b) in our analysis. Fourier amplitudes of the modulation components are available for the Galactic Bulge variables (OGLE, Moskalik & Poretti, 2003), Wils & Sódor (2005) list Fourier parameters of 43 field Blazhko variables utilizing the ASAS data (ASAS3; Pojmanski, 2002 and 2003 and Pojmanski and Maciejewski, 2004 and 2005). The literature has been searched for additional field stars with photometric data suitable to derive Fourier amplitudes of the modulation components. These data are listed in Table 1.

Table 1:

f_{puls} [c/d]	A_{puls} [mag]	A_{mod} [mag]	star	note	reference
2.7223	1.20	0.03	SS Cnc	2	
2.7127	0.76	0.32	AH Cam	3	Smith et al. (1994)
2.6501	0.84	0.17	RS Boo	4	Oosterhoff (1946)
2.5171	1.18	0.03	RR Gem	5	Jurcsik et al. (2005a)
2.3136	0.97	0.12	CZ Lac	2	
2.2577	1.24	0.43	RW Dra	6	Szeidl et al. (2001b)
2.2334	0.76	0.24	RV Cap	1	
2.2066	1.02	0.11	BI Cen	1	
2.1432	1.05	0.09	XZ Cyg	7	LaCluyzé et al. (2004)
2.1365	1.04	0.19	RV UMa	8	
2.1278	1.00	0.34	AR Her	9	Smith et al. (1999)
2.0986	0.65	0.21	XZ Dra	10	Szeidl et al. (2001a)
1.7641	0.56	0.23	RR Lyr	11	Onderlička & Vetešník (1968), Szeidl et al. (1999)
1.7641	0.63	0.08	RR Lyr	12	Smith et al. (2003)
1.7379	0.50	0.15	AR Ser	1	

Notes: (1) ASAS V data. (2) Konkoly Observatory unpublished data, CCD, V band. (3) Combined data from 1989-1992 are used, CCD, V band. (4) Photographic, B band. (5) CCD, V band. (6) Photoelectric, V band. (7) CCD, V band. (8) Photoelectric, V band, Fourier solution is taken from Kovács (1995). (9) CCD, V band. (10) Data between JD 2440494 and JD 2441133 are used, photoelectric, V band. (11) High modulation amplitude between JD 2437477 and JD 2438002, photoelectric, B band. (12) Low modulation amplitude state, CCD, V band.

The OGLE data correspond to I_c band measurements. For RS Boo, and for RR Lyr at the large modulation amplitude phase, photographic and photoelectric B observations are utilized, respectively. To make these data comparable with the V band MACHO results, it has to be defined, how the modulation amplitudes in the different wavelength bands relate. The following data sets were used to define the average wavelength dependence of the amplitude of the modulation: RR Gem (Jurcsik et al., 2005a), SS Cnc (Jurcsik et al., in prep.), RR Lyrae (Smith, 2003), CZ Lac (Jurcsik et al., in prep.), V2 and V25 in M 68 (Walker, 1994). The ratios of the sum of the Fourier amplitudes of the modulation frequency components and the ratios of the amplitudes of the heights of the maximum variations in the different bands were determined from these multicolour observations. We have found that both methods give $A_{\rm mod}(B)/A_{\rm mod}(V)$ and $A_{\rm mod}(V)/A_{\rm mod}(I_c)$ within the ranges of $1.23-1.39$ and $1.50-1.66$ with mean values of 1.30 and 1.58, respectively. The I_c and B band results were transformed to V amplitudes according to these mean amplitude ratio values.

In Fig. 1 the sum of the Fourier amplitudes of the first four modulation frequency components is plotted against the frequency of the pulsation for all the Blazhko stars where this value could be reliably determined. For comparison, a similar plot for the pulsation amplitude quantified as the sum of the amplitudes of the first six harmonic components of the pulsation ($\sum_{i=1}^{6} A_{if}$) is also shown.

Fig. 1 shows that the possible largest value of the modulation amplitudes increases towards longer pulsation frequencies. At pulsation frequencies about 1.5 c/d ($P = 0.67$ d) the largest modulation amplitudes are $0.1-0.2$ mag, while at $2.0-2.2$ c/d pulsation frequencies ($P = 0.5-0.45$ d) the amplitude of the modulation can be as large as $0.3-0.4$ mag. The increase of the pulsation amplitude towards shorter periods (right panel in Fig. 1) has been already known from both observational and theoretical investigations (e.g., Dorfi & Feuchtinger, 1999; Marconi et al., 2002).

The similar behaviour of the modulation and pulsation amplitudes (i.e., their dependence on the pulsation period) might be considered as an indication that the triggering mechanisms of the two phenomena are somehow connected.

However, we have to be cautious with this interpretation, as we do not indeed know, how to measure correctly the amplitude of the modulation, and what the used Fourier amplitude sum indeed means. Just to illustrate the problem, Table 2 lists different measures of the modulation amplitudes of some Blazhko type variables using data listed in Table 1.

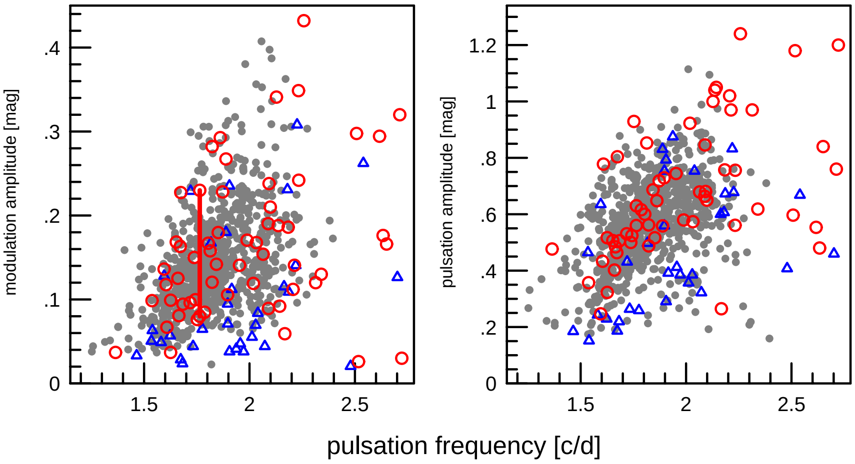

Figure 1. Left panel shows the modulation amplitude (the sum of the Fourier amplitudes of the first four modulation frequency components) versus the pulsation frequency for different samples of Blazhko RRab stars. Dots are for MACHO LMC data, triangles for galactic bulge OGLE data, and circles for galactic field stars. Vertical line connects the two points corresponding to RR Lyrae in its small and large amplitude phase of the modulation. In the right panel the pulsation amplitude (the sum of the Fourier amplitudes of 6 pulsation frequency components) versus the pulsation frequency of the same stars are plotted. The anomalously low pulsation amplitude of the field star at 2.17 c/d is due to the contamination of a close companion. Both plots indicate an amplitude increase towards shorter pulsation periods.

From Table 2 it is evident that the Fourier amplitude sum of the first four modulation components is significantly smaller than both the sum of the amplitudes of all the detectable modulation components, and the amplitude of the maximum brightness variation. Furthermore, only slight connection between these three different measures of the modulation amplitude is evident. Therefore, the possibility cannot be ruled out that the detected increase of the modulation amplitudes is just an artifact of cutting off the modulation components at four terms. If this would be the case then, in order to keep the distribution of the modulation amplitude uniform, the amplitude contribution of the higher order modulation components must be larger for the longer period variables than for the shorter period ones. Unfortunately, there are not enough data to check the validity of this possibility, therefore, as a conclusion we can only say that the correlation shown in Fig. 1 has to be further investigated both from observational and theoretical aspects.

Table 2: Modulation amplitudes*

star	filter	period [d]	$A1$	$A2$ [mag]	$A3$
SS Cnc	B	0.3673	0.11	0.14	0.04
RS Boo	B	0.3773	0.30	0.40	0.18
RR Gem	B	0.3973	0.14	0.13	0.04
CZ Lac	B	0.4322	0.60	0.62	0.15
XZ Cyg	V	0.4666	0.35	0.44	0.09
RV UMa	B	0.4681	0.80	0.47	0.23
AR Her	V	0.4700	0.50	0.50	0.34
RR Lyr	B	0.5668	0.24	0.22	0.08

*Notes:
$A1$ is the amplitude of the maximum brightness variation,
$A2$ is $\sum f_{mod}$ for all the detectable modulation components,
$A3$ is $\sum f_{mod}$ for the first four modulation components.

Acknowledgements:
The authors would like to thank Béla Szeidl for fruitful discussions, and for valuable comments. This research has made use of the SIMBAD database, operated at CDS Strasbourg, France. The financial support of OTKA grants T-043504 and T-048961 is acknowledged.

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[*] This version of the paper contains corrections, and differs from the one appeared on-line originally. Date of last modification: Tue Mar 8 13:25:54 CET 2011