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Amplitude variability of the cepheid V473 Lyr

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Abstract

The star V473 Lyr is a short-period cepheid (P = 1.49d) with a very strong modulation of the amplitude on a time scale near 1200d. Previously unpublished photometry is presented. This includes good coverage near the maximum amplitude. The available photometry and radial-velocity measurements going back to 1966 are analyzed with PERIOD04 to examine whether the amplitude variability is caused by beating between close frequencies. In particular, we have looked for the existence of a close frequency triplet with equidistant frequency spacing. This is required by the Combination Mode Hypothesis, which explains equidistant frequency triplets by a combination of two frequencies. The frequency triplet determined by us for V473 Lyr misses equidistancy by 0.00005 $\pm$ 0.00001 cd^{-1}.

Introduction

V473 Lyr (HR 7308) is probably the best-studied cepheid with a strong Blazhko Effect. This 1.49d cepheid has a modulation period near 1200d. Breger (1981) as well as Burki, Mayor & Benz (1982) have shown that a simple model based on beating between two closely spaced frequencies cannot explain the observed phase and amplitude variability. Furthermore, the long modulation period rules out rotational splitting of nonradial modes as well.

The purpose of this paper is to examine the amplitude and phase variability of this cepheid. In particular, we are interested in testing the Combination Mode Hypothesis, which could explain equidistant frequency triplets seen in different types of pulsating stars (Breger & Kolenberg 2006). Here, the third frequency, f_3 would be related to the combination of the other two modes of higher amplitude by $f_3 = 2f_1$-f_2. A necessary condition is that the three modes are equidistant (or nearly so, if another mode is excited by resonance).

An equidistant or near-equidistant frequency triplet has been reported for V473 Lyr: Koen (2001) analyzed the available Hipparcos photometry and proposed that the amplitude variations of V473 Lyr could be described by symmetrical frequency triplets separated by 0.0011 c/d. His analysis of the Burki, Mayor & Benz (1982) radial-velocity data showed a small departure from equidistancy: 0.0008 vs 0.0009 c/d.The star, therefore, is an interesting candidate for further investigation.

Previously unpublished photometric data

During 1980 and 1981, photometry of V473 Lyr was obtained with the 0.9-m telescope at McDonald Observatory. The measurements used the V filter and the observers were led by the present author. The measurements relative to the comparison star, HR 7280, are listed in Table 1.

One of the aims of these observations was to measure the night-to-night variations of the cepheid light curves near the Blazhko phase of maximum amplitude. A few closely spaced nights are shown in Fig. 1, which confirm the rapid change from night to night of the light curve near maximum. Note that the 1.49d period allows a comparison every three nights.

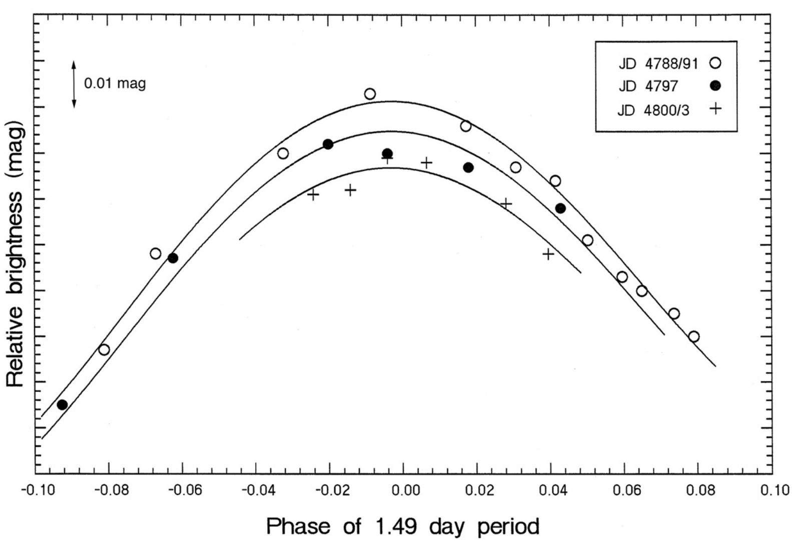

Figure 1: Rapid amplitude variations near maximum light. The times are listed relative to HJD 244 0000.

Table 1: Photometric measurements of V473 Lyr (V filter)

HJD 2440000+	δV mag	HJD 2440000+	δV mag	HJD 2440000+	δV mag	HJD 2440000+	δV mag
4416.7562	-0.133	4788.8760	-0.368	4798.6450	-0.006	4800.8910	-0.340
4416.7686	-0.129	4791.8120	-0.361	4798.6580	-0.007	4800.9050	-0.328
4439.6596	-0.162	4791.8200	-0.363	4798.6730	-0.009	4803.6550	-0.327
4439.7259	-0.188	4791.8270	-0.362	4798.6830	-0.004	4803.6680	-0.337
4439.7931	-0.211	4791.8350	-0.373	4798.7310	0.005	4803.6760	-0.348
4440.6466	-0.124	4791.8420	-0.369	4798.7420	-0.006	4803.7200	-0.368
4440.7220	-0.115	4791.8490	-0.367	4798.7560	-0.008	4803.7280	-0.370
4440.7972	-0.109	4791.8600	-0.370	4798.7760	-0.006	4803.7550	-0.379
4440.8670	-0.108	4791.8900	-0.359	4798.7900	-0.002	4803.7630	-0.383
4440.8939	-0.110	4791.9000	-0.355	4798.8000	-0.002	4803.7820	-0.380
4441.6518	-0.238	4791.9070	-0.348	4798.8080	-0.005	4803.8380	-0.364
4441.6961	-0.233	4791.9220	-0.342	4798.8180	-0.007	4803.8510	-0.351
4441.7393	-0.222	4796.6810	-0.188	4798.8270	-0.016	4803.8700	-0.342
4441.7785	-0.215	4796.7140	-0.176	4798.8470	-0.007	4803.8780	-0.333
4441.8059	-0.206	4796.7230	-0.176	4798.8610	-0.017	4803.8860	-0.335
4441.8362	-0.196	4796.7330	-0.164	4798.8750	-0.032	4803.8940	-0.330
4441.8691	-0.190	4796.7430	-0.156	4798.8850	-0.032	4803.9170	-0.314
4445.6707	-0.181	4796.7550	-0.141	4798.9010	-0.028	4805.6470	-0.180
4445.7266	-0.199	4796.7690	-0.141	4798.9100	-0.035	4805.7230	-0.139
4445.7469	-0.209	4797.6280	-0.262	4799.6690	-0.182	4805.7350	-0.132
4445.7738	-0.219	4797.6420	-0.287	4799.6820	-0.173	4805.7480	-0.126
4445.7995	-0.225	4797.6560	-0.295	4799.7190	-0.155	4805.7560	-0.117
4445.8228	-0.231	4797.6740	-0.315	4799.7290	-0.147	4805.7710	-0.118
4445.8660	-0.240	4797.6870	-0.317	4799.7370	-0.146	4805.7820	-0.114
4786.8250	-0.010	4797.7190	-0.347	4799.7460	-0.146	4805.7900	-0.110
4786.9010	-0.013	4797.7370	-0.350	4799.7590	-0.145	4805.8030	-0.106
4786.9080	-0.020	4797.7680	-0.358	4799.7950	-0.123	4805.8150	-0.092
4786.9170	-0.013	4797.7820	-0.372	4799.8160	-0.122	4805.8310	-0.089
4787.7690	-0.171	4797.7920	-0.375	4800.8200	-0.376	4805.8400	-0.081
4787.7830	-0.158	4797.8060	-0.370	4800.8270	-0.373	4805.8480	-0.079
4787.8040	-0.150	4797.8240	-0.371	4800.8400	-0.367	4805.8570	-0.073
4787.8170	-0.144	4797.8390	-0.367	4800.8480	-0.363	4805.8790	-0.069
4787.8230	-0.146	4797.8580	-0.367	4800.8620	-0.355	4805.8910	-0.066
4787.8320	-0.143	4797.8760	-0.358	4800.8750	-0.347	4805.9090	-0.058
4787.9340	-0.084	4797.8870	-0.355	4800.8830	-0.343	4805.9170	-0.051

Multifrequency analysis

We have collected the available photometric data from 1966 to 1983 (Percy & Evans 1980, Breger 1981, Henrikssen 1983, Burki et al. 1986) as well as photometry in Table 1. The periodicities in the data were analyzed with the PERIOD04 statistical package (Lenz & Breger 2005). We ignore complications such as the increase in asymmetry of the light curve shape with increasing amplitude. Not surprisingly, the previously known main frequency of 0.67075 cd^{-1} is correctly determined. However, in the Fourier spectrum many additional peaks in the vicinity of the main peak are present (before and after prewhitening the main frequency) and no unique multifrequency solution can be obtained. This failure is caused in part by the long modulation period of ~ 3 years together with a spotty coverage (e.g., annual aliasing).

Next, we added the excellent radial-velocity data by Burki, Mayor & Benz (1982). Since the radial-velocity variations resemble inverted light curves, we have converted the radial-velocity variations to light variations, using the phase differences and amplitude ratios determined for this star by Burki et al. (1986) in their Table 4. The results are now improved: the larger data set revealed three close main frequencies with their harmonics and a combination. This is shown in Table 2.

The multifrequency analysis confirmed the existence of the frequency triplet (f_1 to f_3 in Table 2). The frequency triplet determined by us misses equidistancy by 0.00005 ± 0.00001 cd^{-1}. Because of the small formal error the result appears to be statistically significant. However, the solution may be less certain for the following reasons:

(i) Examination of the observed and fitted light curves reveals that the fits are not good: the standard deviation is 0.023 mag per single measurement.

(ii) Even after the inclusion of the radial-velocity data, the spectral window indicates that the frequencies and their harmonics are not statistically independent of each other. Note here the unfavorable main pulsation period of 1.49 d. This represents a severe problem.

(iii) Furthermore, analysis of the residuals shows additional periodicities near the main frequencies.

We conclude that the data for the best-studied Blazhko cepheid are insufficient to test the Combination Mode Hypothesis.

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Table 2: Multiple frequencies of V473 Lyr

	Frequency cd^{-1}	Amplitude in V mag
f_1	0.67075	0.0764
f_2	0.67157	0.0354
f_3	0.66988	0.0292
$2f_1$	1.34150	0.0132
$2f_2$	1.34313	0.0061
$2f_3$	1.33977	0.0081
$3f_1$	2.01226	0.0023
$3f_2$	2.01470	0.0025
$3f_3$	2.00965	0.0004
f_1+f_2	1.34232	0.0110

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