

FREQUENCY ANALYSIS OF PHOTOGRAPHIC OBSERVATIONS OF PULSATING STARS

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ABSTRACT. The Fourier analysis are performed for photoelectric and photographic B-observations (Goranskij and Shugarov, 1979) of RR Lyrae star RW Ari. Besides the main frequency f_0 and four its first harmonics two more frequencies are found: $f_1=f_0/3$ and $f_2=0.711f_0$ c/d. It permits to identify frequencies: f_0 as f_s , introduced by us earlier (Bezdenzhnyi, 1997b) for RR Lyrae star T Sex, and f_2 - as f_{1H} .

Such analysis of photographic author's observations of RR Lyrae star BK Dra is performed too. It is shown that BK Dra is a multiperiodic variable star. Its frequencies identifications are carried out and given.

Three data sets of Cepheid V477 Oph: visual author's (Bezdenzhnyi and Mandel, 1977), photographic Mandel's (1970) observations and (O-C) - residuals (Hacke, 1988) show that V477 Oph apparently can be referred to bimodal Cepheids.

Key words: Stars: RR Lyrae, individual: RW Ari, BK Dra; Cepheids, individual: V477 Oph; Fourier analysis, mode identifications

1. Introduction

By using Breger's (1991) program PERIOD the Fourier analysis for photographic (and some photoelectric and visual) observations of two RR Lyrae stars RW Ari and BK Dra, and Cepheid V477 Oph has been carried out. Identifications for all frequencies have been performed. There are some overtones and their harmonics. These are related with multiplicity ratios.

2. Multiperiodicity of RR Lyrae star RW Ari

The Fourier analysis of photoelectric B-observations (n=132) from Goranskij and Shugarov's work (1979) are performed. The observations have been obtained on 60-cm telescope of Astronomical Institute of Uzbekistan Academy of Sciences (at the Maidanak mountain) and at Crimean Station of Sternberg Astronomical Institute. The main frequency $f_0=2.8222241$ c/d with B-amplitude $A=0.267$ mag has been obtained as well as its first four harmonics: $2f_0=5.6467821$ c/d ($A=0.028$ mag), $3f_0=8.4758498$ c/d ($A=0.021$ mag), $4f_0=11.2864165$ c/d ($A=0.015$ mag) and $5f_0=14.1199694$ c/d ($A=0.016$ mag).

Photographic B-observations (n=122) of the same authors obtained from the plates collection of Sternberg Astronomical Institute also show frequency $f_0=2.8222747$ c/d ($A=0.257$ mag) and the secondary frequency $f_1=0.93564$ c/d ($A=0.039$ mag at amplitude of 0.01 level false alarm probability $a=0.022$ mag). The frequency ratio $f_1/f_0=0.332$ enables to assume that the frequencies be related with the multiplicity ratio $f_0=3f_1$. This value of frequency f_1 is close to that of a triple frequency of the orbital period given by Wisniewski (1971): $3f_{orb} = 0.9448$ c/d. It is because of the multiplicity of these frequencies that the question may have arisen on a possible star binarity.

Photoelectric observations show one more frequency $f_2=2.01018$ c/d ($A=0.029$ mag at amplitude of 0.01 level false alarm probability $a=0.012$ mag) which has not been found when analyzing photographic observations. If it is a real one, then from the ratio $f_2/f_0=0.712$, which is close to the theoretical ratio of a frequency of the first overtone to frequency f_s introduced by us (Bezdenzhnyi, 1997b) for RR Lyrae star T Sex and also observed in other RR Lyrae stars (see for BK Dra in this paper) and in bimodal Cepheids (Bezdenzhnyi, 1997a), we can identify frequencies of RW Ari. Thus, $f_0=f_s$, $f_1=f_s/3$ and $f_2=f_{1H}$. Then rather numerous Penston's (1972) B-observations (n=29) have been added to above set and the Fourier analysis for general photoelectric set (n=161) was performed. The meaning of the frequency $f_2=3.0133114$ c/d ($A=0.029$ mag at $a=0.012$ mag) was revealed.

We can conclude that RW Ari is rather a multimodal of RR Lyrae star than a binary variable. Further analysis of photoelectric Wisniewski's (for 19 nights) and photographic Detre's (1937) observations (n=293) would be needed in order to confirm these results.

3. Multiperiodicity of RR Lyrae star BK Dra

The analysis has been performed of the light variation of BK Dra based on 165 light determination from the Dushanbe plate collection in the interval of 28 years (J.D. 2430166 - 2440448). Range of the brightness variations is 10.59-11.87 mag (pv), the meaning of one degree is 0.05 mag. The observations fit well the lin-

ear elements of General Catalogue of Variable Stars (Kholopov et al., hereafter GCVS, 1985):

$$Max_{hel} = J.D.2425523.305 + 0.5920815 E, \quad (1)$$

acting from 1905 (J.D.2416940). However, before an interval of time J.D. (2414900 - 2416150) another elements were true (GCVS, 1985):

$$Max_{hel} = J.D.2415150.817 + 0.592019 E. \quad (2)$$

For all the observational seasons mean light variation curves have been plotted. There is not any progressive deviation of the maximum light phase from zero but slight variations ranging from 0.99 - 0.02 are possible. The stellar light at minimum is constant, and that at maximum varies and the amplitude does respectively.

The frequency analysis of observations has shown that BK Dra is a multiperiodic star. Besides the main frequency $f_0=1.68896$ c/d ($P_0=0.5920803$ days fits well the linear elements (1)) and its first three harmonics three more frequencies are found. It permitted to identify the main frequency as the one f_s introduced by the author (Bezdenzhnyi, 1997b) for RR Lyrae star T Sex observed in bimodal Cepheids (Bezdenzhnyi, 1997a) too. The main frequency amplitude $A_0=0.36$ mag, its first harmonic $2f_s=3.37793$ c/d ($A=0.17$ mag), the second harmonic $3f_s=5.06687$ c/d ($A=0.10$ mag) and the third one $4f_s=6.75582$ c/d ($A=0.08$ mag).

Three additional frequencies are identified as double frequencies of known ones f_{1H} , f_{2H} and frequency f_e introduced by us earlier (Bezdenzhnyi, 1994) for RR Lyrae star AE Boo. So, these frequencies are: $f_1=2f_{1H}=2.38671$ c/d ($A=0.08$ mag at amplitude of 0.01 level false alarm probability $a=0.04$ mag), $f_2=2f_{2H}=3.00325$ c/d ($A=0.07$ mag) and $f_3=2f_e=4.50194$ c/d ($A=0.08$ mag).

Thus, BK Dra seems to be a multiperiodic RR Lyrae star as AE Boo and T Sex studied by us (Bezdenzhnyi, 1994, 1997b) earlier. But more precise photoelectric observations of this star are needed to confirm these results.

4. The multimodality of Cepheid V477 Oph

In our work (Bezdenzhnyi and Mandel, 1977) from Simeiz photographic observations period of 2.01566917 days was found, the star was classified as Cepheid similar to VZ Aql and V439 Oph. The period found has shown a good agreement for over 17000 days.

Unfortunately, Simeiz observatins are not numerous therefore we added to them photographic Mandel's (1970) observatins obtained from Odessa plates collection. The Fourier analysis of the data ($n=46$) was performed. It gave frequencies: the main one $f_0=0.4961166$ c/d (with amplitude $A=6.9$ degrees at amplitude of 0.01 level false alarm probability $a=0.6$ deg) and two its harmonics $2f_0=0.9921909$ c/d ($A=1.9$ deg), $3f_0=1.4882756$ c/d ($A=1.5$ deg). Two more frequencies were found: $f_1=0.464799$ c/d ($A=1.9$ deg)

and $f_2=1.097299$ c/d ($A=1.1$ deg). The frequency ratio $f_1/f_0=0.737$ is close to the theoretical ratio (0.738) of a frequency f_e to frequency of the first overtone f_{1H} . And the frequency ratio $f_2/f_0=2.212$ approaches the theoretical one (2.25) for double frequency f_g introduced by us (Bezdenzhnyi, 1994). Due to this it is possible to identify these frequencies as $f_0=f_{1H}$, $f_1=f_e$ and $f_2=2f_g$.

The Fourier analysis was done for 98 visual author's observatins (Bezdenzhnyi and Mandel, 1977) covering 17 nights within 363 days. The same frequencies as before has been obtained: the main one $f_{1H}=0.4962053$ c/d ($A=4.4$ deg at $a=0.4$ deg), the first harmonic of this frequency $2f_{1H}=0.9920007$ c/d ($A=3.5$ deg), $3f_{1H}=1.489035$ c/d ($A=2.1$ deg), $f_e=0.4635215$ c/d ($A=3.1$ deg) and $2f_g=1.0980822$ c/d ($A=1.5$ deg).

Then Fourier analysis of 135 (O-C)-residuals within 20439 days (Hacke, 1988) was performed. (O-C)-residuals were given with period $P_0=2.015669$ days ($f_0=0.496113$ c/d) from our work (Bezdenzhnyi and Mandel, 1977). Fourier analysis showed: peak at frequency $2f_0=0.992225$ (that is equal sharp to above our double one) had the biggest amplitude. Two higher harmonics $3f_0$ and $5f_0$ are present too. We have done a fitting with these three frequencies: $2f_0=0.9922261$ c/d ($A=0.403$ days), $3f_0=1.4883391$ c/d ($A=0.192$ days) and $5f_0=2.4805642$ c/d ($A=0.020$ days). After subtraction of this fitting the frequencies $7f_0=3.4728$ c/d ($A=0.006$ days at $a=0.002$ days) and $f_e=0.4673$ ($A=0.004$ days) were found.

Thus, V477 Oph apparently can be referred to bimodal (or even multimodal) Cepheids. To confirm these results the analysis of more precise photoelectric observations of V477 Oph are needed.

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