FREQUENCY ANALYSIS OF BIMODAL CEPHEIDS

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ABSTRACT. The Fourier analyses of photoelectric Berdnikov's (1992) V-observations some of bimodal Cepheids (AS Cas, EW Sct, V 367 Sct, TU Cas and CO Aur) are performed. For stars with two known periods new identifications are carried out. EV Aql and S Sge are attributed to bimodal Cepheids and added to them. More detailed subdivision of bimodal Cepheids is suggested on the ground of their mode classification.

Key words: Stars: δ Sct, Cepheids, RR Lyrae, mode identifications

Frequency analyses of photoelectric Berdnikov's (1992a, 1992b, 1992c, 1992d, 1992e, 1992f) V-observations, received at the Mt. Maidanak Observatory, some of bimodal Cepheids (AS Cas, EW Sct, V 367 Sct, TU Cas and CO Aur) were performed. EV Aql and S Sge were attributed to bimodal Cepheids and added to them. The following results are obtained.

AS Cas: This star is known as bimodal Cepheid with the ratio of the secondary period to the main one P_1/P_0=0.7127 (Berdnikov, 1992g). P_0=3.02467 (f_0=0.3306145) and P_1 = 2.15555 (f_1=0.4639187). In the fourth edition of the General Catalogue of Variable Stars (Kholopov et al., hereafter GCVS, 1985a) close value of the main period P_0=3.02125 (f_0=0.330989) is given. Our analysis of 1988-1991 season's observations gives bigger (by 0.0027) values of these frequencies: f_0=0.3333485 and f_1=0.4666516, and their ratio of 0.7143. The respective amplitudes are equal to: A_0=0.253 and A_1=0.133 mag. Besides, two more frequencies with smaller amplitudes are found: f_2=0.797269 (A_2=0.073) and f_3=1.1333678 (A_3=0.056). The ratio of the secondary period to the main one is close to theoretical value 0.711, if the main period is taken as P_{1H}, and the secondary - as P_s, instead of the main tone and the first overtone. This identification holds true also for 12 bimodal Cepheids from the above Berdnikov's work, except CO Aur, at which this ratio P_1/P_0=0.8008, that confirms a conclusion (Mantegazza, 1983) about its pulsations in the first and second overtones. The frequencies f_2 and f_3 are linear combinations of two main frequencies f_0 and f_1: $f_2 = f_1 + f_0$ and $f_3 = 2f_0 + f_1$.

S Sge: According to GCVS (1987) the star is a spectral binary system (SB1) with an orbital period of 675 days. A main component is a Cepheid with a period of 8.382086 days (f=0.119302). Up to JD=2418000 the period was a little smaller: 8.381968 days (f=0.119304). From 146 observations we find the main frequency f=0.119293 (A=0.323) and three its harmonics 2f=0.238588 (A=0.070), 3f=0.357907 (A=0.050), 4f=0.477182 (A=0.035). Besides, the frequency 1.006338 (A=0.020) is found. From multiple ratio we have identified it as $6f_s$ and the main frequency - as f_{1H}. It permits to attribute S Sge to the group of bimodal Cepheids similar to AS Cas.

EW Sct: The star is known as a bimodal Cepheid (Cuypers, 1985) with the main period P_0=5.8195 (f_0=0.171836), the secondary period P_1=4.0646 (f_1=0.2460266) and their ratio P_1/P_0=0.6984. Our analysis has confirmed these results with a little smaller values of frequencies f_0=0.1717212 (A=0.176) and f_1=0.2458112 (A=0.120). Their ratio coincides with the above f_0/f_1=0.6986. A fact of interest is a detection at this star another three frequencies - the first harmonic of the main frequency $2f_0$=0.3434215 (=0.024) and linear combinations of two frequencies f_1

and f_0: $f_1 + f_0$=0.4175041 (A=0.033) and $f_1 - f_0$=0.0741082 (A=0.024). Thus, this star as well as AS Cas is multimodal Cepheid similar to RR Lyr or delta Sct stars.

V367 Sct: According to GCVS (1987) this star is known as a bimodal Cepheid with the main period P_0=6.29307 (f_0=0.1589049), the period of the first overtone P_1=4.38466 (f_1=0.2280678) and their ratio P_1/P_0=0.696744. The star is a member of the open cluster NGC 6649. Our analysis has given close values of the frequencies and their ratio: f_0=0.1589009 (A=0.174) and f_1=0.2280611 (A=0.119), f_0/f_1=0.696747. Besides, similarly to the case of EW Sct, the first harmonics of these frequencies $2f_0$=0.3177947 (A=0.028) and $2f_1$=0.4536010 (A=0.014), as well as their linear combinations $f_1 + f_0$=0.3869774 (A=0.018) and $f_1 - f_0$=0.0691491 (A=0.017), are found.

TU Cas: It is known as a bimodal Cepheid. Hodson et al. (1979) give the following value for the ratio of the secondary period to the main one: P_1/P_0=0.7097, where P_0=2.139298 (f_0=0.467443) and P_1=1.51830 (f_1=0.6586313). It is noted, that the amplitude A_1 for 67 years has decreased from 0.4 V to 0.25 V. Asymmetry of the light curve M-m changes within the limits of 0.17-0.35 of the period value.

The frequency analysis has confirmed these results: f_0=0.4674420 (A_0=0.289), f_1=0.6586474 (A_1=0.109) and f_0/f_1=0.7097. Besides, we have also found other five frequencies: two harmonics of the main frequency $2f_0$=0.9348839 (A=0.099) and $3f_0$=1.3996948 (A=0.036), as well as three linear combinations of two main frequencies f_0 and f_1: $f_1 + f_0$=1.1260941 (A=0.072), $f_1 - f_0$=0.1912007 (A=0.038) and $2f_0 + f_1$=1.5909257 (A=0.047).

CO Aur: This star is unique of all known bimodal Cepheids, which pulsate in the first and second overtones (Mantegazza, 1983): P_{1H}=1.7841 (f_{1H}= 0.5605066), P_{2H}=1.4255 (f_{2H}=0.7015082) and P_{2H}/P_{1H}=0.799, wich is close to the theoretical value of 0.8. Our analysis has also picked out these main frequencies: f_{1H}=0.5608409 (A=0.175) and f_{2H}=0.7025039 (A=0.040); their ratio f_{1H}/f_{2H}=0.798. Frequencies $2f_{1H}$=1.1138610 (A=0.036), $2f_e$=1.0540236 (A=0.012), $2f_g$=1.2644378 (A=0.011) and f_{3H}=0.8450646 (A=0.010) are found too. Thus, it is possible to name this Cepheid as a multimodal one.

EV Aql: In GCVS (1985a) it is noted, that its period is variable, and are resulted its values up to JD2423900 P=38.67 days (f=0.02586) and after the date P=38.767 days (f=0.02580). Our determinations have confirmed this frequency: f_0=0.0258636 (A=0.324). Three its harmonics are found too: $2f_0$=0.0517686 (A=0.112), $3f_0$=0.0775896 (A=0.041) and $4f_0$=0.1034960 (A=0.022). However, the third (from amplitude) in a power spectrum is the frequency f_1=0.0227485 (A=0.047), the ratio of which to the main frequency f_1/f_0=0.880. It is close to the theoretical value of the ratio - the frequency of the second overtone to the frequency f_s: f_{2H}/f_s=0.889.

It can be summarized, that the most characteristic frequencies of bimodal Cepheids are f_{1H} and f_s, one of which (more frequently f_{1H}) acts the part of the main frequency.

At CO Aur in a role of the main frequency is f_{1H}, the secondary one is the frequency f_{2H}, and f_s is absent. There are first harmonics of the frequencies f_e and f_g introduced by the author earlier (Bezdenezhnyi, 1994a, 1994b) for RR Lyr and δ Sct stars. CO Aur is the most interesting case among multimodal Cepheids.

However, at EV Aql the main frequency is f_s (f_{1H} is away), and the secondary one is f_{2H}. Probably, at EW Sct and V367 Sct the main frequency is f_s, instead of f_{1H}. Then, the second frequency will be the harmonic of f_{1H}: f_1=$2f_{1H}$, and the ratio of frequencies f_0/f_1 of these stars equal respectively to 0.699 and 0.697 will be closer to the theoretical value $f_s/2f_1H$=0.703.

This more detailed subdivision of bimodal Cepheids, pulsating in the frequencies f_{1H} and f_s, into two subgroups follows from Berdnikov's data (1992g) for 13 bimodal Cepheids too. The average ratios of periods P_1/P_0 for two samples are equal to 0.703 and 0.711.

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