PULSATIONAL AND ORBITAL PERIODS OF SMALL-AMPLITUDE CEPHEID SU CAS

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ABSTRACT. New seven high-resolutional spectra of small-amplitude Cepheid SU Cas have been obtained to determine its atmosphere parameters (T_{eff}=6384 K; $\log g$=2.4; V_t=3.3 km s^{-1}) and to measure its radial velocities. The last ones were added to the total list (360 values) and using the frequency analysis we can specify the pulsational and orbital periods of this Cepheid. With the well-known main pulsational period of 1.949329 days, classified as fundamental tone, we can detect the presence of two equidistant periods at a distance of ±0.003 c/d from it, and the secondary (possible first overtone) one of 2.040461 day. Their ratio $P_1/P_0 = 0.96$ supposed about an an existence of non-radial pulsations in the Cepheid's atmosphere. Changes of the mean colour-index, effective temperature and γ-velocity confirmed the presence of one or more companions with possible periods of 463.7 – 483.8, 1738.8 and 7490.3 days.

Key words: Stars: Pulsational periods – Stars: Orbital periods - Stars: Cepheids – Stars: individual – SU Cas

1. Introduction

S-Cepheid (DCEPS) SU Cas is an interest object for astrophysical research due to the following aspects:

1. It is one of the nearest (d = 258 pc (Turner & Evans 1984) Cepheid in the Galaxy.
2. SU Cas is a member of Cas OB2 association (Racine 1968).
3. CNO-abundances analysis data for Cepheid agree well with theoretically predicted ones for 3rd crossing of the Cepheids instability strip in case if it mass is close to 3.7 $M_\odot$ (Usenko et al. 2001).
4. SU Cas has a close companion $B9.5 - -A5V$ (Turner & Evans 1984, Usenko 1990, Evans 1991) with possible orbital periods of 462.5, 928, 1375 and 1682 days, respectively (Szabados 1991).

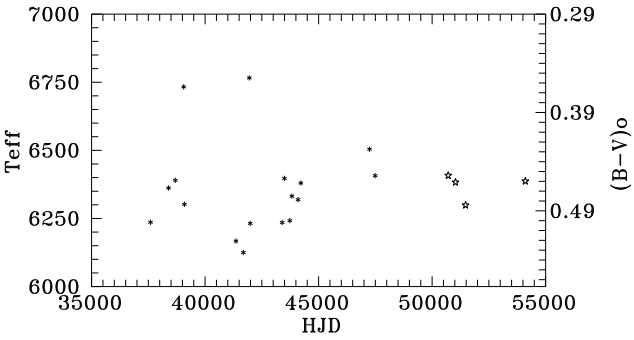

Figure 1: Variations of the mean effective temperature and colour-index during the last fourty years. Six-point stars, – the photometrical data from Mitchell et al. (1964), Wisniewski & Johnson (1968), Milone (1970), Sudzius (1969), Feltz & McNamara (1980), Szabados (1977), Niva & Schmidt (1979), Moffett & Barnes (1984); five-point stars, – the data obtained from spectroscopy (Usenko et al. 2001, Luck 2001, and this work).

Nevertheless there are some problems connected with unusual character of this Cepheid, namely:

1. Identification of its pulsational mode:
   a) Fundamental mode: R = 18.2 $R_\odot$; T_{eff} = 6328 K; d = 258 pc (Turner & Evans 1984); $\log g$ = 2.35 (Usenko et al. 2001);
   b) First overtone: R = 29 $R_\odot$; T_{eff} = 6600 K; d = 407 pc; M_{ev} = 4.3 $M_\odot$ (Gieren 1976);
   c) Second overtone: R = 33.8 $R_\odot$; T_{eff} = 6300 K; d = 433 pc; (ESA 1997; Evans 1991).
2. Noticeable variations of the mean $(B-V)_0$ duling last decades (see Figure 1).
3. Relatively small number of radial velocity measurements (353 estimates from 1918 to 1999 in 20 observational sets).

Thus, the main task consist in:

Table 1: Observations and radial velocities of SU Cas

Spectrum	HJD 2400000+	RV ($\mathrm{km\,s^{-1}}$)	σ ($\mathrm{km\,s^{-1}}$)	NL
s482013	54074.392	1.52	1.3	512
s484026	54076.583	-7.41	1.3	463
s485017	54077.315	-8.72	1.2	559
s490017	54137.430	-13.79	1.4	599
s492002	54139.142	-14.76	1.6	471
s493012	54139.595	-15.91	1.2	472
s494020	54169.542	0.43	1.3	594

Table 2: Atmosphere parameters of SU Cas

Spectrum	T_{eff} (K)	$\log g$	V_t ($\mathrm{km\,s^{-1}}$)
s482013	6298±11	2.30	3.00
s484026	6485±65	2.50	3.30
s485017	6256±38	2.25	2.70
s490017	6514±13	2.40	3.15
s492002	6548±38	2.55	4.30
s493012	6427±62	2.55	4.00
s494020	6162±17	2.30	2.85
Mean	6384±35	2.40	3.30

1. To obtain the high-resolutioned spectra set of SU Cas ($F6IIb - -F8IIb$), to determine its atmospheric parameters and to compare its with the same from other authors.

2. To measure the radial velocities of SU Cas from this set.

3. To add these radial velocity's data to the tolal list, obtained during the lond observational period (1918-2007).

4. To make more exact of SU Cas pulsational and possible orbital periods using Fourier analysis.

2. Observations

Observations of these objects have been realized using 6m telescope BTA - SAO RAS(Russia) equiped by LYNX(Panchuk et al. 1999), PFES(Panchuk et al. 1998), NES(Panchuk et al. 2002) spectrometers ($\lambda\lambda$ 4800 – 6600 Å.)

The reduction was made using IRAF software, the MIDAS context ECHELLE modified for extraction of echelle spectra obtained with an image slicer (Yushkin & Klochkova 2005) , DECH20 software (Galazutdinov, 1992). The observational log is given in Table 1.

3. Atmosphere parameters and chemical composition

Atmosphere parametrs were determined:

1) T_{eff} : line deph ratio (Kovtyukh & Gorlova, 2000).

2) $\log g$: by adopting the same iron abundance for Fe I and Fe II lines. (accuracy: 0.15 dex)

3) V_t – by assuming abundances of the Fe II lines independent of the W_λ for Polaris (accuracy: 0.25 km/s).

The mean atmosphere parametrs are given in Table 2.

4. Frequency analysis

Frequency analysis have been completed for SU Cas radial velocity data using **PERIOD 98** software (Sperl 1998). **PERIOD 98** allows to search for and to fit sinusoidal patterns within the time series of data containing huge gaps. It used techniques of Fourier and Fast Fourier analysis with residuals minimization of sinusoidal fits to the data.

For calculations we have 360 radial velocities totally, obtained during the period of 1918-2007 (357 values from other authors and 7 our ones). The Fourier amplitude spectra were obtained over the frequency range 0 – 1 c/d at a resolution of 0.00002 c/d. These calculations were based on the original data (pulsational periods search), and the residuals at original (orbital periods search).

4.1. Pulsational periods

As seen from Figure 2, we can observe the main pulsational period of 1.949329 days with two equidistant ones ±0.003 c/d (1.939059 days and 1.959787 days, respectively). And, the presence of secondary pulsational period is visible well too, – 2.040461 days. Their ratio consists 0.96 what is typical for non-radial pulsations. It is interesting that Stobie's model 9e for 5 $M_\odot$ star gives the period of 2.07 days in case of *first* harmonic (Stobie 1969).

4.2. Orbital periods

An existence of SU Cas hot companion is a notorious fact. Turner & Evans (1984), Usenko (1990) and Evans (1991) have predicted its spectral type within the limits of *B9.5 – A5 V*. Szabados (1991) has estimated its orbital period of 462.5, 928, 1375 and 1682 days, at that he has gave preference to the first value. In Table 3 we represented the γ - velocities, estimated for different observational sets. As seen from Figure 3, these changes show an evidence of SU Cas system

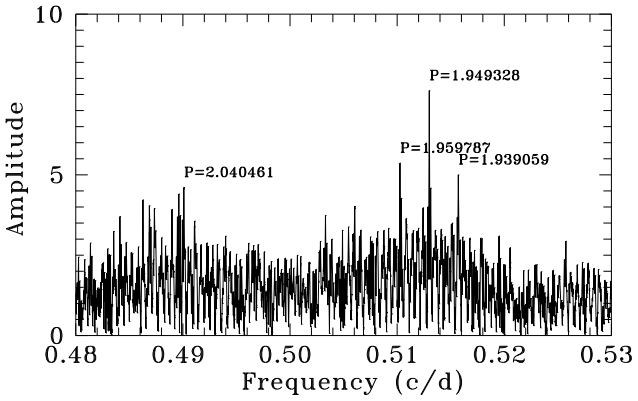

Figure 2: Fragment of Fourier amplitude spectrum of SU Cas over a narrow frequency range corresponding to pulsational periods with calculations based on the original data.

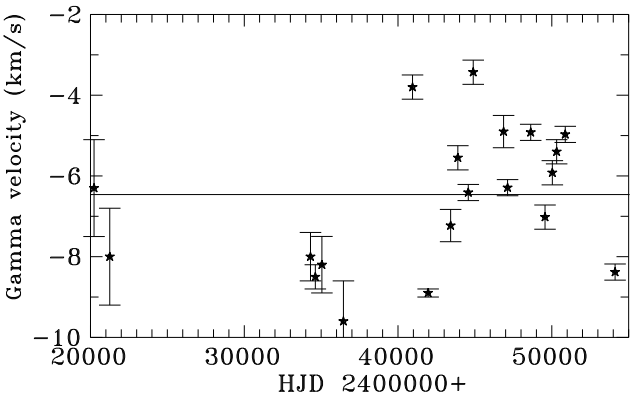

Figure 3: γ – velocity values of SU Cas during 1918 - 2007.

Table 3: γ-velocities of SU Cas

HJD 2400000+	γ (km s^{-1})	σ (km s^{-1})	N	Reference
20229	-6.3	1.2	4	Adams & Shapley (1918)
21252	-8.0	1.2	4	Adams & Shapley (1918)
34307	-8.0	0.6	4	Abt (1959)
34621	-8.5	0.3	14	Abt (1959)
35051	-8.2	0.7	3	Abt (1959)
36451	-9.6	1.0	1	Abt (1959)
40943	-3.8	0.3	7	Niva & Schmidt (1979)
41962	-8.9	0.1	63	Gieren (1976)
43421	-7.2	0.4	39	Niva & Schmidt (1979)+ +Wilson et al. (1989)
43889	-5.6	0.3	72	Beawers & Eitter (1986)+ +Barnes et al. (1987)
44570	-6.4	0.2	15	Häupl (1988)+ +Barnes et al. (1987)
44895	-3.4	0.3	12	Häupl (1988)+ +Barnes et al. (1987)
46866	-4.9	0.4	2	Gorynya et al. (1992)
47126	-6.3	0.2	19	Bersier et al. (1994)
48630	-4.9	0.2	18	Gorynya et al. (1992, 1996)
49563	-7.0	0.3	14	Gorynya et al. (1996)
50035	-5.9	0.2	16	Sachkov et al. (1998)
50318	-5.4	0.3	9	Sachkov et al. (1998)
50741	-5.0	0.3	27	Sachkov et al. (1998) + Luck (2001)+SAO (2001)
54116	-8.4	0.3	7	This work

Reference: SAO (2001) – two spectra from Usenko et al. (2001) with radial velocities, measured by author.

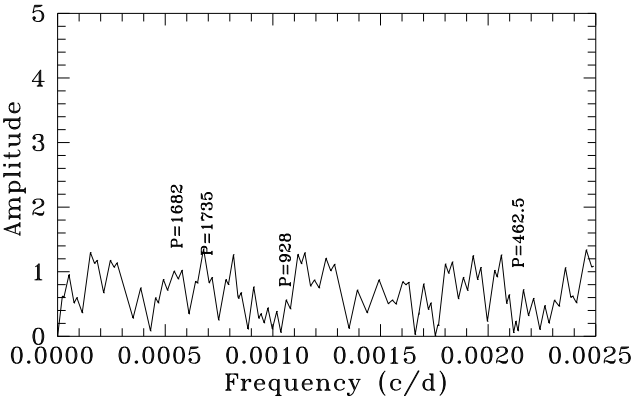

Figure 4: Fragment of Fourier amplitude spectrum of SU Cas over a narrow frequency range corresponding to orbital periods with calculations based on the original data. Periods values from Szabados (1991)

orbital motion, at that the mean γ velocity is equal to -6.46 km s^{-1}.

To confirm Szabados' conclusions, we have began a search of peaks on the Fourier amplitude spectrum, which could be correspond to his orbital periods, mentioned above (see Figure 4). Evidently, these peaks are very slight and insignificant in case of calculations based on the original data. To improve this situation we calculated the Fourier amplitude spectrum based on the residuals at original ones (see Figure 5). As seen from this figure, the highest amplitude corresponds to 7490.3, 1738.8, 483.8 and 463.7 days, at that last two values are very close to Szabados' (1991) data.

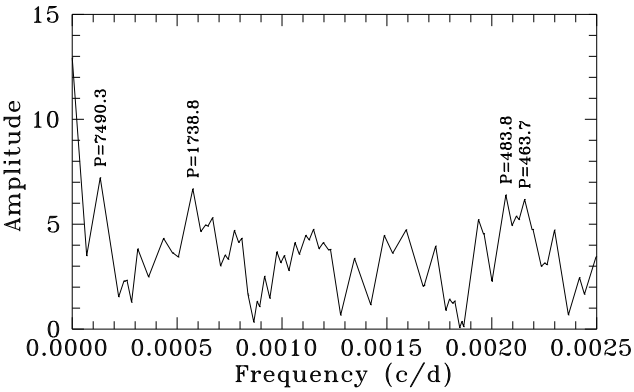

Figure 5: Fragment of Fourier amplitude spectrum of SU Cas over a narrow frequency range corresponding to orbital periods with calculations based on the residuals at original data.

5. Conclusions

1. According to our determination of T_{eff} and $(B-V)_0$ data, SU Cas demonstrates their sporadic changes with unestablished period.

2. In case of mean gravity value 2.35 – 2.40 we can consider SU Cas as *fundamental mode* pulsator with period of 1.949329 days.

3. The presence of two equidistant periods at a distance of ± 0.003 c/d from the main pulsational period and possible *first overtone* period of 2.040461 days, and $P_1/P_0 = 0.96$ suggest an idea to an existence of non-radial pulsations in the Cepheid's atmosphere.

4. Szabados'(1991) 462.5 days orbital period need to be improved. Its value could be consist with in the limits of 463.7 – 483.8 days. We need as much as possible new radial velocity data to make it.

5. It is possible that SU Cas has one more companion(s) with long orbital periods near 7490.3 and 1738.8 days.

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