NEW ASPECT
OF SMALL-AMPLITUDE CEPHEID SU CAS

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ABSTRACT. New 17 high-resolutional spectra of small-amplitude Cepheid SU Cas have been obtained to determine its atmosphere parameters (T_{eff}=6353 K; $\log g$=2.38; V_t=3.25 km s^{-1}) and to measure its radial velocities. The last ones were added to the total RV list (378 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 1.9493 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 2.0405 day. Their ratio $P_1/P_0 = 0.96$ supposed about 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).
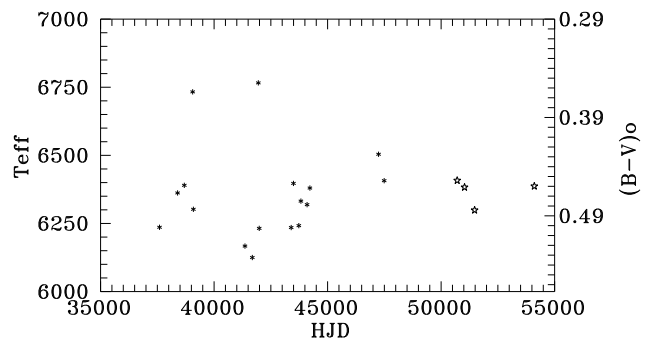

Figure 1: Variations of the mean effective temperature and colour-index during the last fourty years. Six-point stars, – the photometrical data from Mitchell et al. (1964), Wisniewski & Johnson (1968), Milone (1970), Sudzius (1969), Feltz & McNamara (1980), Szabados (1977), Niva & Schmidt (1979), Moffett & 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 $(B-V)_0$ during last decades (see Figure 1).

3. Relatively small number of radial velocity measurements (349 estimates from 1918 to 1999 in 20 observational sets).

Table 1: Observations and radial velocities of SU Cas

Spectrum	HJD 2400000+	RV (km s^{-1})	σ (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
s495015	54170.449	-16.43	1.3	492
s497015	54225.247	-13.14	1.3	535
s498013	54226.241	2.53	1.3	518
s500036	54305.546	-5.89	1.3	571
s514035	54481.655	-10.32	1.4	538
s515022	54483.148	-2.15	1.1	599
s516012	54518.359	-0.38	1.2	580

Table 2: Atmosphere parameters of SU Cas

Spectrum	T_{eff} (K)	$\log g$	V_t (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
s495015	6502±85	2.50	4.20
s497015	6502±9	2.40	3.00
s498013	6207±10	2.30	3.00
s500036	6250±11	2.30	2.80
s514035	6388±9	2.40	2.90
s515022	6272±15	2.40	3.20
s516012	6127±8	2.20	3.10
Mean	6353±28	2.38	3.25

Thus, the main task consist in:

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 velocities to the tolal list, obtained during the long observational period (1918–2008).

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 ÅÅ.)

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) Effective temperature T_{eff}: by the line deph ratio (Kovtyukh & Gorlova, 2000).

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

3) Microturbulent velocity V_t: by assuming abundances of the Fe II lines independent of the W_λ for Polaris (accuracy: 0.25 km s^{-1}).

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 378 radial velocities totally, obtained during the period of 1918-2008 (364 values from other authors and 14 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).

4a. 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
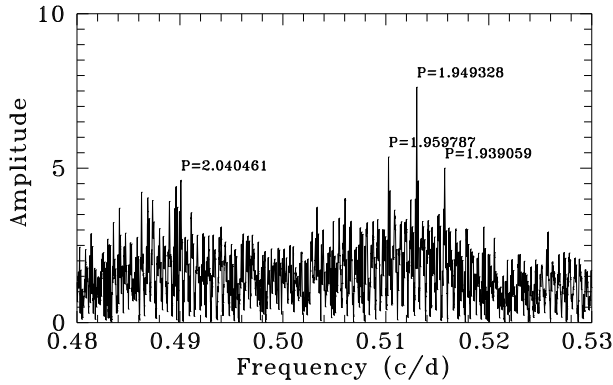
Figure 2: Fragment of Fourier amplitude spectrum of SU Cas over a narrow frequency range corresponding to pulsational periods with calculations based on the original data.

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).

4b. 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 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.

5. Conclusions

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

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)
54296	-6.5	0.3	14	This work

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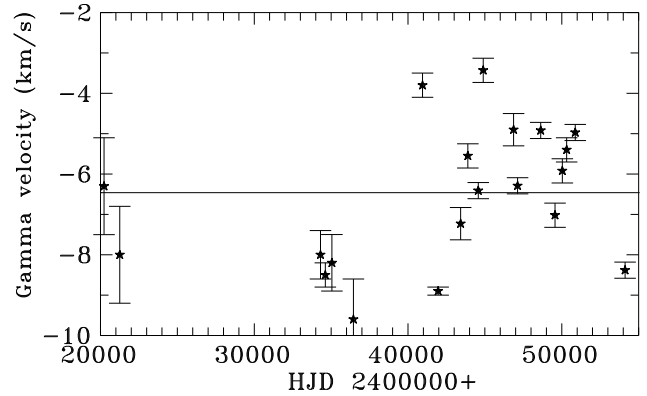

Figure 3: γ – velocity values of SU Cas during 1918 – 2008.
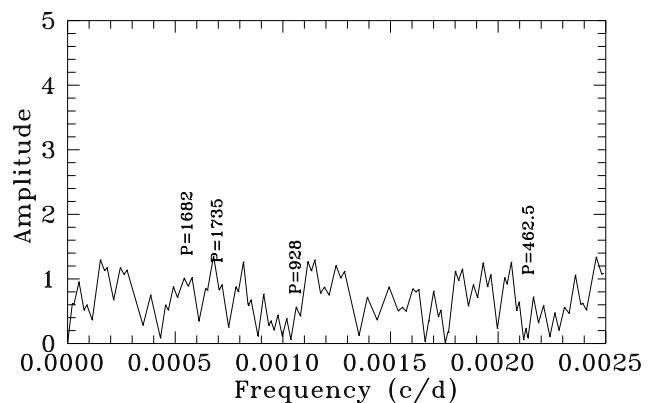

Figure 4: Fragment of Fourier amplitude spectrum of SU Cas over a narrow frequency range corresponding to orbital periods with calculations based on the original data. Periods values from Szabados (1991)
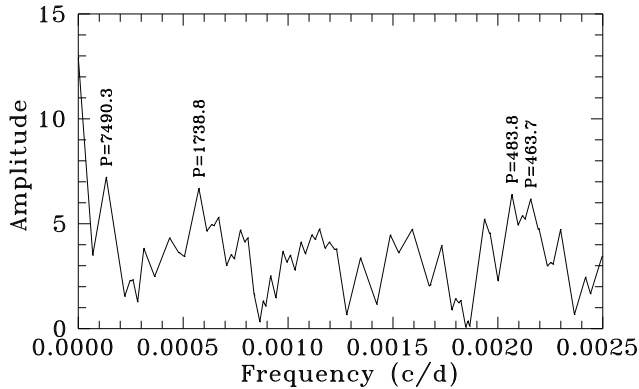
Figure 5: Fragment of Fourier amplitude spectrum of SU Cas over a narrow frequency range corresponding to orbital periods with calculations based on the residuals at original data.

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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