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Spectroscopic investigations of classical Cepheids and main-sequence stars in galactic open clusters and associations

I. Association Cas OB2 and the small-amplitude Cepheid SU Cassiopeae

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Abstract. The small-amplitude Cepheid SU Cas and four members of the association Cas OB2 (HD 16893, HD 17327a and b, HD 17443) were investigated, using high-resolution CCD spectra. The following results were obtained: 1) All these objects have the same metallicity values, close to that of the Sun; 2) Elemental abundance indicates that SU Cas is a post first dredge-up star with an age from 1 10^8 to 1.45 10^8 yr, and it is not crossing the Cepheid instability strip for the first time. The mean value of $\log g = 2.35$ corresponds to pulsations in the fundamental tone, although errors in gravity estimations provide overtone pulsations. The questions about its pulsational mode and membership in Cas OB2 remained open; 3) HD 17327a is a slowly rotating HgMn–star with the highest helium content among such objects, while HD 16893 also has a manganese overabundance and might be classified as an Am–star; 4) HD 17327b and HD 17443 are rapidly rotating main-sequence stars, while HD 17443 has a helium content comparable with that of the Sun.

Key words. associations – stars: abundances – stars: Cepheids – stars: main-sequence

1. Introduction

The method of distance determination inside and outside our Galaxy by means of the period–luminosity–colour (P–L–C) relation for Cepheids, is currently the most accurate one. Using the surface brightness method (Barnes et al. 1977), one can obtain Cepheid luminosities and distances through changes in their radii and colour–indices (which measure $T_{\rm eff}$) during the pulsational periods. However, this process requires numerous, long–term spectroscopic observations. Moreover, additional difficulties arise from the brightness limit for spectroscopy: Cepheids with various values of pulsational period need to be studied, but the majority of them are comparatively faint objects.

A better method is to use Cepheids which belong to open clusters and associations. Although the majority of these are fainter than $8^{\rm m}$ (see Table 1), one can derive their luminosities through distances to these stellar groups.

This method is based on matching the composite zero–age main sequence (ZAMS) and the colour–absolute magnitude diagram. The composite ZAMS is determined by the Hyades (or Pleiades) group parallax with addition of non–evolved main sequence (MS) stars from other, younger clusters, to their diagrams. Therefore, having multicolour (broad- or, better, narrow-band) photometric data for MS stars in an open cluster and using corresponding calibrations, one can derive distances and colour-excesses for these stars and use them to determine colour-indices and luminosity of Cepheids from the same cluster.

At first, this is a very good, simple method. In reality, the discrepancy in determination of the distance modules for open clusters are, on average, $\pm 0\overset{\rm m}{.}1$–$0\overset{\rm m}{.}2$. This leads to a corresponding discrepancy in Cepheids luminosities of about $0\overset{\rm m}{.}3$–$0\overset{\rm m}{.}5$. It is obvious that all these P–L–C relations have some important shortcomings, based on the following:

1) Inaccurate determination of colour-excesses, especially for Cepheids situated far from the open cluster field.

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2) The relationship of the distance calibration based on open clusters to the composite ZAMS. Such a ZAMS contains stars with a different degree of heavy element abundance, which has a very significant influence on the open cluster stars colour-indices and absolute magnitudes and on the ZAMS position in the diagram. For example, Hyades has a more metal rich content (1.5–2 times higher) than an average open cluster in the solar neighbourhood. The same can be said for the helium abundance.

3) The errors due to metallicity index determination from the multicolour (mainly broad-band) photometrical data. This problem is not limited only to Cepheids (the authors have often run across such cases, when [Fe/H] values, determined by the model atmospheres method, have differed from the those determined using broad-band photometry, by 0.5–0.7 dex), – a similar situation also exists for the MS stars in open clusters.

4) The presence of a hot companion near a Cepheid. Such a presence might affect the Cepheid colour-index (especially $(B-V)$). According to Evans (1995) and Szabados (1992), the percentage of binary systems among classical Cepheids is from 21% to 50%.

5) The Cepheid position on the Cepheid instability strip and the number of its crossings (Stift 1982).

In spite of these obstacles, open clusters and associations containing the Cepheids became a paradigm to investigations of the evolution of yellow supergiants, for comparisons of the observational data with theory predictions, and, moreover, for more precise definition of the P–L–C relation calibration.

All the usefulness of the spectroscopic investigations of Cepheids and MS stars in open clusters lies in the fact that the MS B–stars are the Cepheids progenitors. Therefore, it would be possible to determine the helium abundance in open clusters and associations through its abundance in the atmospheres of MS B–stars and the lower level of the helium content in the atmospheres of Cepheids, which belong to these clusters and associations also the CNO–element abundances (as the key elements in the yellow supergiant evolution) in the Cepheids and MS stars atmospheres can be determined, and we can then perform their comparative analysis; the odd-elements (Na and Al) abundances can be verified, and as well as their connection to the luminosities of the Cepheids. The same can be performed for heavy α-elements, iron group and s–process elements, and average metallicities for open clusters and associations can be obtained; $T_{\rm eff}$ and $\log g$ values with a high precision are available and then the intrinsic colours and colour-excesses for Cepheids, and their masses can be specified. We can also check the influence of the different values of helium content and metallicity in calibrating Cepheids for P–L–C relation.

Until recent time, such an investigation was not feasible. The main reason for that is the availability of only a small number of open clusters and associations that contain comparatively bright Cepheids and MS stars. This situation has since changed radically. Availability of large telescopes, equipped with echelle–spectrographs and CCD detectors allow one to obtain high-resolution spectra with a high S/N ratio for objects as faint as $14^{\rm m}$. Since these developments, the tasks mentioned above have become more feasible.

With this paper, we start a series of publications devoted to investigations of Cepheids and MS stars in selected Galactic open clusters.

Table 1. Galactic Cepheids in open clusters

Cepheid	P (days)	$V_{\rm mean}$ (mag)	Cluster or Association	Comments
SU Cas	1.95	5.970	Cas OB2	DCEPS
IR Cep	2.11	7.784	Per OB1	DCEPS,(?)
EV Sct	3.09	10.137	NGC 6664	DCEPS
SZ Tau	3.15	6.531	NGC 1647	DCEPS,CM,NM
BY Cas	3.22	10.366	NGC 663	DCEPS,(?)
GU Nor	3.45	10.411	NGC 6067	DCEPS,CM,SC,(?)
QZ Nor	3.79	8.866	NGC 6067	DCEPS,CN,SC
AH Vel	4.22	5.695	Cr 173	CM,(?)
V1726 Cyg	4.24	9.009	Platais 1	DCEPS
CG Cas	4.37	11.335	NGC 7790	CM,SC,(?)
CE Cas b	4.48	11.062	NGC 7790	
CF Cas	4.88	11.136	NGC 7790	
CE Cas a	5.14	10.922	NGC 7790	
CV Mon	5.38	10.299	Anonym	
V Cen	5.49	6.836	NGC 5662	CM
UY Per	5.37	11.344	King 4	CM,SC
VY Per	5.53	11.257	h,χ Per	SC
CS Vel	5.90	11.687	Rup 79	
V367 Sct	6.29	11.596	NGC 6449	DMC,FP
BB Sgr	6.64	6.947	Coll 394	CM
U Sgr	6.75	6.745	M 25	
V440 Per	7.57	6.282	h,χ Per	CM,(?)
DL Cas	8.00	8.969	NGC 129	
AC Mon	8.01	10.067	NGC 2323	(?)
S Nor	9.75	6.394	NGC 6087	
AQ Car	9.77	9.769	Pup OB2	SC,(?)
TW Nor	10.79	11.704	Lynga 6	
VX Per	10.89	9.312	h,χ Per	SC
V340 Nor	11.29	8.375	NGC 6067	
SZ Cas	13.63	9.853	h,χ Per	DCEPS,SC
VY Car	18.99	7.443	Car OB2	SC
RU Sct	19.70	9.466	Trump 35	CM,SC
RZ Vel	20.40	7.079	Vel OB1	SC
WZ Sgr	21.85	8.030	C1814-191	SC
SW Vel	23.44	8.120	Vel OB5	SC
T Mon	27.02	6.124	Mon OB2	SC,NM
KQ Sco	28.69	9.807	Sco OBa	SC
U Car	38.77	6.288	Car OB2	SC,NM
RS Pup	41.39	6.947	Pup OB3	SC,(?)
SV Vul	44.99	7.220	Vul OB1	SC,NM
GY Sge	51.06	10.151	OBanon	SC
S Vul	68.46	8.962	Vul OB2	SC

DCEPS – s-Cepheid.
CM – coronae member.
SC – stellar complex.
FP – fundamental period.
NM – non-member according to Gieren, Fouque & Gomez (1997).
(?) – membership in cluster (association) needs confirmation.

2. Association Cas OB2

The association Cas OB2, in spite of its small population, is significant, because it contains the $1\overset{\rm d}{.}95$ bright small-amplitude Cepheid (DCEPS) SU Cas, which is a calibrating object for the P–L–C - relation with the lowest value of the pulsational period.

The investigation of this association has a comparatively short history. First, Racine (1968), who suggested the existence of an OB–association on the basis of the association of some B–stars (HD 17327, HD 17443, HD 17706) with the dust complex, noted that SU Cas is not a member of the association, though it does illuminate a reflection nebulosity (a segment of a dusty path along Orion's arm) in this complex.

The real discussion about the luminosity and corresponding distance value for SU Cas has arisen due to the differences in its mean radius, determined by various methods and authors. The use of the traditional Baade–Wesselink (BW) method produced values near 19.1–21.8 $R_\odot$, whereas the maximum likelihood (ML) method and pulsational analysis (PA) resulted in values from 29 $R_\odot$ to 40.3 $R_\odot$. The minimum radius of 18.6 $R_\odot$ was determined by means of the surface brightness (SB) method by Niva & Schmidt (1979) (see Table 1 from Gieren 1982). It is clear that such a disagreement in the radius might be interpreted as pulsational in *fundamental* tone or even in *first* and *second* overtone.

The problems mentioned above were resolved by Turner & Evans (1984). They investigated in detail all stars below $14^{\rm m}$ in the vicinity of SU Cas with membership in the Cas OB2 association. They found five stars to be association members: HD 16893, HD 17327a, HD 17327b, HD 17443 and HD 23475. A distance of 258±3 pc found for SU Cas with the colour-excess $E_{B-V} = 0.27$ and $T_{\rm eff} = 6383$ K gave an absolute magnitude of about $-1\overset{\rm m}{.}94$. This value is in good agreement with the P–L relation for galactic Cepheids pulsating in the *fundamental* tone. The mean radius of SU Cas derived from these data is 18.2 ± 0.9 $R_\odot$ (with an account of a close companion A0–A5 V presence based on *IUE* observations).

As is seen, such a radius value, derived by Turner & Evans (1984), is in good agreement with that determined by the SB method (Niva & Schmidt 1979) and is close to the BW radius values. It also is significantly difference to the ML and PA data. This might be explained partly by the presence of a hot companion, mentioned above. Such a companion (A0–A5 V, Turner & Evans 1984; A0 V, Usenko 1990; B9.5 V, Evans 1991), with an orbital period of about $462\overset{\rm d}{.}5$ (Szabados 1991) and brightness differences $\Delta V = 0\overset{\rm m}{.}109$ and $\Delta(B-V) = 0\overset{\rm m}{.}072$ (Gorynya et al. 1996), affects the colour-indices of SU Cas, especially $(B-V)_0$, and the radial velocity curve during orbital motion. Since the SB method used $(V-R)_0$ colour-indices, for which influence of the hot companion is insignificant, the Niva & Schmidt (1979) radius value is the closest to that of Turner & Evans (1984).

Nevertheless, Evans (1991), using the *IUE* spectra of the SU Cas blue companion (B9.5 V) arrived at an unexpected value of the Cepheid's absolute magnitude, $-3\overset{\rm m}{.}14$. This result was confirmed by recent measurements of the SU Cas trigonometric parallax (2.31±0.54 milliarcsec) using the *HIPPARCOS* satellite data. It gives a distance of 433^{+132}_{-82} pc (Szabados 1997) and $M_V = -3\overset{\rm m}{.}25 \pm 0\overset{\rm m}{.}98$ for $E_{B-V} = 0\overset{\rm m}{.}287$ (Fernie et al. 1995). Therefore, SU Cas is placed by a factor of 1.7 farther than the association stars and is not a member of Cas OB2.

Using the mean value of $T_{\rm eff} = 6300$ K, taken from Luck & Lambert (1981) and Andrievsky et al. (1996) (determined from spectroscopic analysis using the model atmospheres method), we can obtain a radius value equal to 33.8 $R_\odot$. This value corresponds to pulsation in the *second* overtone (Gieren 1982). Thus, the same problem calls for a new solution.

Nevertheless, the *HIPPARCOS* distance for SU Cas is close to that the nearby the same for background association with HD 17706 (401 ± 38 pc from Turner & Evans 1984), which is not a member of Cas OB2. Besides, using polarimetric observations, Pavlova & Rspaev (1986) have detected unusual changes in the polarization degree with wavelength for HD 17443 and SU Cas. They explained this effect by the presence of S-shaped fibres in the nebulosity structure which have the same orientation as the polarization vector. The polarization positional angles for SU Cas and HD 17443 are close to each other. The polarization degree for SU Cas in the V–band is somewhat larger than for other stars, probably due to mass loss through the stellar wind (Welch & Duric 1988). All field stars in this region show polarization vectors almost parallel to the galactic plane.

3. Selection of the stars and observational material

In our observational program we have included SU Cas (F6 IIb–F8 IIb) itself and four stars, members of Cas OB2 from the Turner & Evans (1984) list: HD 16893 (A3 Vp), HD 17327a and b (B8 III and A2 Vn) and HD 17443 (B9 V). Except for SU Cas, each star from this list is interesting itself: HD 16893, according to Turner & Evans (1984), is a spectroscopic binary; HD 17327a and b are components of a visual binary ADS 2142, in which HD 17327a is located near the turn-off point of Cas OB2 (see Fig. 5 in Turner & Evans 1984); HD 17443 is clearly embedded in the same dust cloud as SU Cas.

The high–resolution spectra of these stars were obtained with the echelle–spectrometers PFES (Panchuk et al. 1998) and LYNX (Panchuk et al. 1999) at the 6-m telescope of the Special Astrophysical Observatory, Russian Academy of Sciences (Russia, Northern Caucasus). The resolving power was 14 000 and 25 000, respectively, $S/N \approx 70$–100. The information concerning the program stars and their CCD spectra is given in Table 2.

Using the MIDAS software, we extracted spectra from CCD frames, made dark and cosmic ray hit subtraction, and wavelength calibration. The line equivalent widths (W_λ) were determined using the DECH20 code (Galazutdinov 1992). In our analysis we did not use lines with $W_\lambda \gtrsim 150$ mÅ. The accuracy of the equivalent widths is of the order of 5–10%. This estimate is based on the comparison of the values derived from lines present in the overlapping spectral orders.

Before the atmospheric parameter determination and abundance calculations we made visual inspections of the program stars spectra (excluding SU Cas), because some of them have high projected rotational velocities. As an example we demonstrate in Fig. 1 two fragments of the

Table 2. Program stars and their CCD spectra

Star	Spectrum No.	HJD 2450000+	V (mag)	Region (Å)	Exposure (min)
SU Cas(1)	s20716	1003.5000	5.70-	4682 – 8596	10
SU Cas(2)	s21012	1006.4960	−6.18	4420 – 7764	10
HD 16893	s21011	1006.5280	8.53	4682 – 8596	20
HD 17327a	s20715	1003.5270	7.53	4420 – 7767	20
	s23204	1246.1720		4383 – 7960	13
	s23205	1246.1790		4383 – 7960	17
HD 17327b	s23206	1246.2020	10.33	4383 – 7960	30
HD 17443	s20714	1003.4800	8.74	4420 – 7767	30

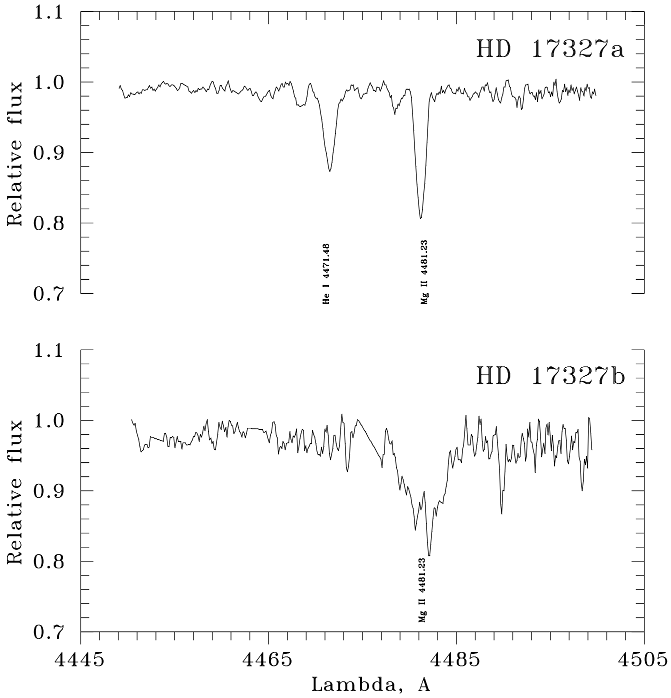

Fig. 1. Fragments of spectra for HD 17327a and b in the vicinity of the He I 4471 Å and Mg II 4481 Å lines

Table 3. Projected rotational velocities for program stars

Star	$v \sin i$ (km s^{-1})	Remarks
SU Cas	10	
HD16893	25	Spectroscopic binary
HD 17327a	40	Primary component of ADS2142
HD 17327b	200	Secondary component of ADS 2142
HD 17443	180	in the same dust cloud as SU Cas

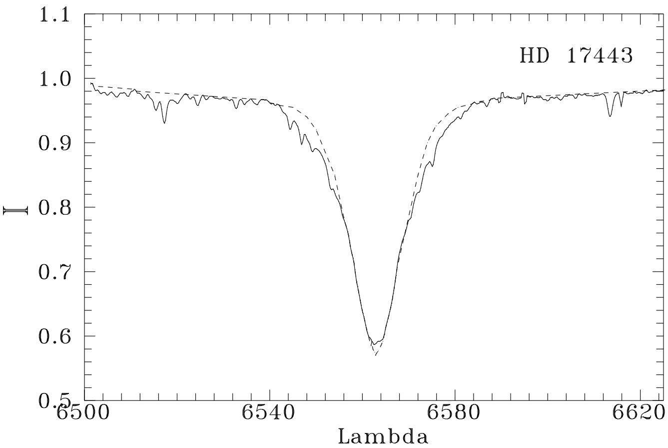

Fig. 2. The synthetic and observed profiles of H_α in the spectrum of HD 17443

same spectral region (He I 4471 Å and Mg II 4481 Å lines) for two components of the visual binary ADS 2142, HD 17327a and b.

To evaluate line blends for objects with high projected rotational velocities, the spectral synthesis technique was applied. This was performed with the help of the SYNSPEC code (Hubeny et al. 1994). For SU Cas we used $v \sin i$ from Takeda et al. (1997). Projected rotational velocities for program stars were estimated by fitting the synthetic spectrum to the observed one. The results are given in Table 3.

Figure 2 shows the observed and synthetic spectra for the Hα region of HD 17443. As is seen, HD 17443 is an ordinary main-sequence B-star.

4. Atmospheric parameters and chemical composition

4.1. Atmospheric parameters

Determination of the atmospheric parameters of the Cas OB2 objects was performed by different methods. For SU Cas, as a variable yellow supergiant, we obtained values of $T_{\rm eff}$ based on the ratio of the spectral line depths (Kovtyukh et al. 1998). This method, based on spectroscopic criteria only, allows us to estimate these values with an accuracy of 50–80 K.

For other program stars we used:

1) $(U-B)$, $(B-V)$ – ($T_{\rm eff}$, $\log g$) calibrations (Castelli 1991);
2) $(b-y)$, $m1$, $c1$, β – ($T_{\rm eff}$, $\log g$) calibrations (Moon & Dworetsky 1985; Napivotzki et al. 1993);
3) $(b-y)$ – ($T_{\rm eff}$, $\log g$) calibrations (Castelli 1991);

Table 4. $T_{\rm eff}$ and $\log g$ determination

Star	Phase	$T_{\rm eff}$ (ratio)	$T_{\rm eff}$ $(B-V)_0$	$T_{\rm eff}$ $(U-B)_0$	$T_{\rm eff}$ $(ubvy\beta)$	$T_{\rm eff}$ (H_α)	$T_{\rm eff}$ (H_β)	$\log g$ $(ubvy\beta)$	$\log g$ (H_α)	$\log g$ (H_β)	$\log g$ (Fe)
SU Cas (1)	0.498	6200	-	-	-	-	-	-	-	-	2.30
SU Cas (2)	0.965	6450	-	-	-	-	-	-	-	-	2.40
HD 16893	-	-	8500	-	-	-	-	-	-	-	4.00
HD 17327a	-	-	12 400	12 500	12 450	12 000	12 000	3.40	3.20	3.20	-
HD 17327b	-	-	7800	7800	-	10 000	10 000	-	4.00	4.00	-
HD 17443	-	-	11 000	11 000	10 800	10 900	10 900	4.05	4.05	4.05	-

Phases were calculated according to Berdnikov & Pastukhova (1994).

Table 5. Adopted atmospheric parameters

Star	Phase	$T_{\rm eff}$	$\log g$	V_t
SU Cas (1)	0.498	6200	2.30	3.3
SU Cas (2)	0.965	6450	2.40	3.3
HD 16893	-	8500	4.00	3.0
HD 17327a	-	11 700	3.20	1.0
HD 17327b	-	10 000	4.00	3.0
HD 17443	-	10 900	4.05	3.0

4) Comparisons of the observed H_α and H_β line profiles with the synthetic spectra.

The $(B-V)$ and E_{B-V} data were taken from Turner & Evans (1984), the $(b-y)$ and E_{b-y} data from Schmidt (1978). All the preliminary $T_{\rm eff}$ determinations (with a mean uncertainty of 100 K) are given in Table 4.

For cooler stars, SU Cas and HD 16893, the surface gravities were determined assuming equal abundances of Fe I and Fe II. The preliminary $\log g$ determinations (with mean uncertainties of ± 0.15 and ± 0.2 dex, respectively) are given in Table 4.

The microturbulent velocities ($V_{\rm t}$) for SU Cas, HD 16893 and HD 17327a were obtained assuming the abundances from Fe II lines to be independent of the equivalent line widths with a mean uncertainty of 0.25 $\rm km\,s^{-1}$. For HD 17443 the corresponding value of $V_{\rm t} = 3\ \rm km\,s^{-1}$ was adopted as a more appropriate one for late B stars. Finally, adopted atmospheric parameters are listed in Table 5.

4.2. Analysis technique

The analysis was carried out using our implementation of Kurucz's WIDTH9 code. Atmosphere models were interpolated from the Kurucz (1992) grid. All the oscillator strengths were taken from various sources. For SU Cas we used so-called "solar" $\log gf$ values (Kovtyukh & Andrievsky 1999). They were derived by us using unblended solar lines (solar spectrum by Kurucz et al. 1984).

For B– and A–type stars we used oscillator strengths from the Kurucz (1995) database (CD-ROM 15, 18). For HD 16893 we also used additional data from Adelman et al. (1996)

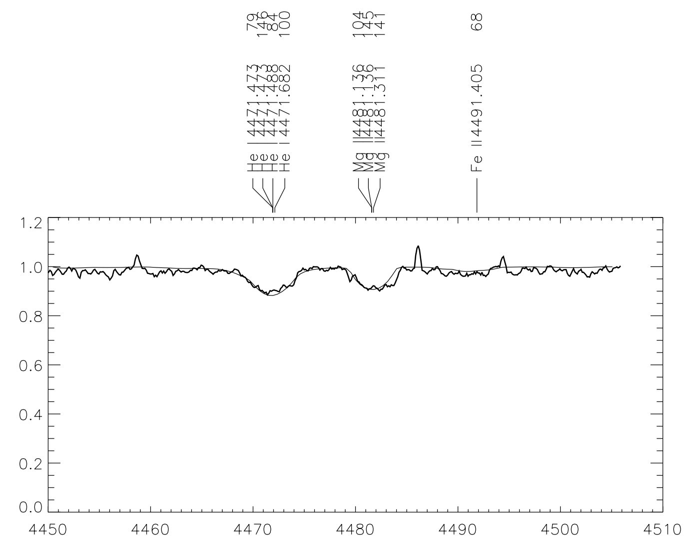

Fig. 3. The observed and synthetic spectra for the HD 17443 region near the He I 4471 Å and Mg II 4481 Å lines

4.3. Abundances for the Cas OB2 members

In Tables 6, 7 and 8 we give the calculated abundances for SU Cas, HD 17327a and HD 16893, respectively. It should be noted that for the rapidly rotating B-star HD 17443 we estimated only helium and magnesium abundance from two strong lines He I 4471 Å and Mg II 4481 Å. This was performed using spectral synthesis (see Fig. 3). In this case, helium and magnesium abundances are solar.

From the data shown in Table 6 one can conclude that SU Cas has a carbon deficit, a nitrogen overabundance, and a solar-like oxygen content. Sodium and aluminium are in a slight overabundance, while the α- and Fe-group elements content is close to solar. Some heavy s-process elements demonstrate a small overabundance (see Fig. 4). All these data are in good agreement with those of Andrievsky et al. (1996). Therefore, SU Cas is not crossing the Cepheids instability strip for the first time.

According to Tables 5 and 7, one can notice that HD 17327a has the atmospheric parameters and chemical composition typical of $mercury-manganese$ stars: some overabundance of carbon, solar-like or deficient nitrogen and oxygen content, a very noticeable deficit of Mg and Si, and an overabundance of P, S, Mn, Y, Zr, and Hg (see Fig. 5). The overwhelming majority of these chemically

Table 6. Abundances for SU Cas

Element	Average			Paper II
	[El/H]	σ	NL	(Average)
CI	−0.27	0.17	8 − 11	−
N I	+ 0.53	0.09	3 − 3	−
O I	−0.01	0.04	0 − 2	−
Na I	+0.25	0.07	2 − 4	+0.50
Mg I	−0.18	0.22	1 − 4	−0.05
Al I	+0.20	0.08	3 − 3	−
Si I	+0.09	0.11	16 − 31	−
Si II	−0.01	−	1 − 1	−
S I	+0.19	0.16	4 − 5	−0.30
Ca I	−0.02	0.19	9 − 10	+0.04
Sc II	+0.05	0.17	6 − 9	−0.05
Ti I	+0.11	0.22	12 − 20	+0.11
Ti II	−0.00	0.15	2 − 8	−0.01
V I	+0.10	0.09	3 − 4	+0.10
V II	−0.04	0.08	2 − 5	−0.05
Cr I	−0.05	0.23	4 − 17	−0.05
Cr II	−0.04	0.14	8 − 12	−0.03
Mn I	−0.34	0.19	7 − 8	−0.17
FeI	−0.03	0.13	152 − 182	−0.10
Fe II	−0.03	0.10	18 − 28	−0.10
Co I	−0.03	0.20	4 − 6	+0.10
Ni I	−0.06	0.21	33 − 63	−0.10
Cu I	−0.26	0.47	1 − 3	−
Zn I	−0.23	0.30	1 − 2	−0.09
Y II	+0.01	0.17	6 − 7	−
Zr II	+0.06	0.21	2 − 5	+0.35
Ba II	+0.17	−	0 − 1	−
La II	+0.30	0.08	1 − 2	+0.08
Ce II	−0.04	−	3 − 6	+0.32
PrII	−0.66	0.09	1 − 2	+0.01
Nd II	+0.06	0.21	3 − 8	+0.22
Eu II	+0.24	0.05	1 − 2	−
Gd II	+0.28	−	0 − 1	+0.26

Paper II – data from Andrievsky et al. (1996).
NL – minimal and maximal number of lines.

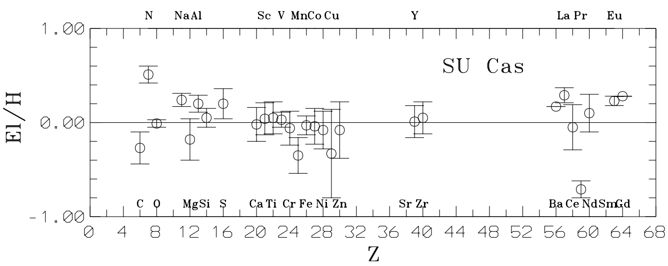

Fig. 4. Elemental abundance for SU Cas

peculiar stars belong to binary systems. In 39 such systems they are primary components (Batten et al. 1989; Lebedev 1987).

As is known, single HgMn–stars or primary components of SB1 binaries belong to the classical group (log (Mn/Fe) ≈ 0 dex), while SB2 ones belong to the Searl–Sargent group (log (Mn/Fe) ≈ −1.0 dex) (Searle & Sargent 1967; Ryabchikova et al. 1996). In Fig. 6 we show the positions of HD 17327a on the log (Mn/H) – $T_{\rm eff}$

Table 7. Average abundance for HD 17327a

Element	[El/H]	σ	NL
He I	+ 0.24	−	1− 2
C I	+ 0.56	0.31	1− 3
N I	+ 0.31	−	0− 1
O I	−0.12	0.35	2− 5
Mg I	−0.51	−	1− 1
Mg II	−0.21	0.44	1− 3
Al II	−0.36	−	0− 1
Si II	−0.60	0.26	6− 6
P II	+ 1.02	−	1− 1
S II	+ 0.34	0.18	1− 3
Sc II	+ 1.30	−	1− 1
Ti II	+ 0.58	0.36	4− 9
Cr II	+ 0.46	0.31	9− 15
Mn II	+ 1.89	0.23	11− 18
Fe II	−0.10	0.24	26− 66
Y II	+ 1.87	−	1− 2
Hg I	+ 4.39	−	1− 1

NL – minimal and maximal number of lines.

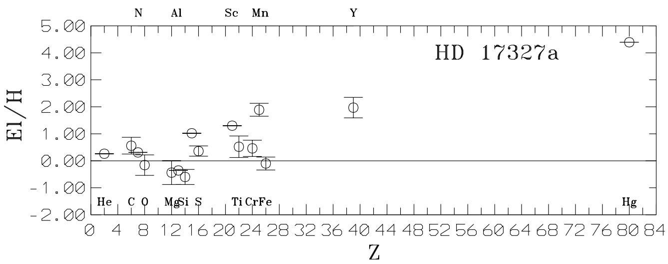

Fig. 5. Elemental abundance for HD 17327a

relation (Ryabchikova 1997). A good agreement with this relation is noticeable.

In Fig. 7 the position of HD 17327a on the graph is located within the classical HgMn–star group.

The most interesting feature of this star is the helium overabundance, while the main-sequence B star HD 17443 has a solar content. This fact can be due to the position of HD 17327a near the turn–off point for Cas OB2. Helium overabundance for this star is not a result of atmosphere enrichment by the products of the CNO-cycle (in this case the N/C ratio would reach 1.0 dex and more, while for HD 17327a this ratio is ≈0.7 dex), but it is more likely as a result of the so-called light-induced drift (LID) mechanism (Atutov & Shalagin 1988).

On the other hand, the results for HD 16893 are very interesting, too (Table 8). We can say that carbon has a noticeable deficit, while nitrogen and oxygen have a solar-like content. This is very unusual. It is seen that the abundances of Al, Mg and Si in HD 16893 are opposite to those of HD 17327a. The overabundance of Mn is of a factor of 3 less and the iron abundance is the same as that for HD 17327a. But content of the *s*-process elements is rather high (see Fig. 8). Moreover, log (Mn/H) and log (Mn/Fe) are comparable to those of SB2 stars (see Fig. 6

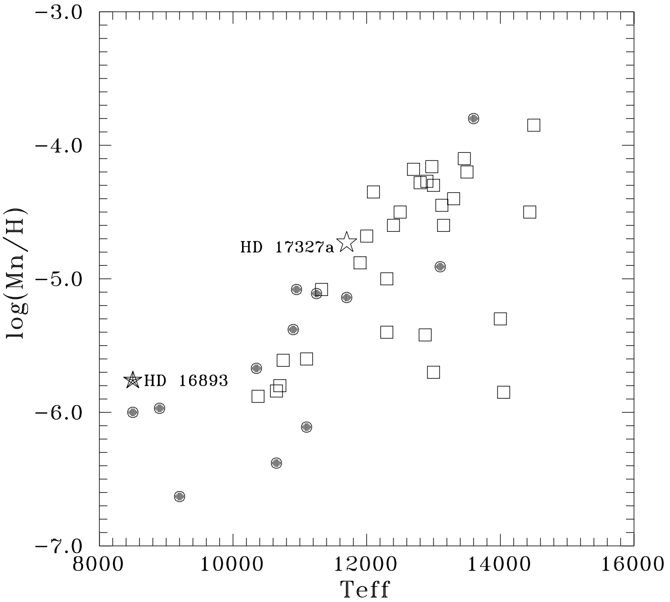

Fig. 6. The manganese abundance relation from $T_{\rm eff}$ in atmospheres of HgMn stars. Open squares represent classical and SB1 HgMn stars, filled circles – Searle-Sargent (SB2) group HgMn stars, the open star indicate HD 17327a, while the filled star, – HD 16893

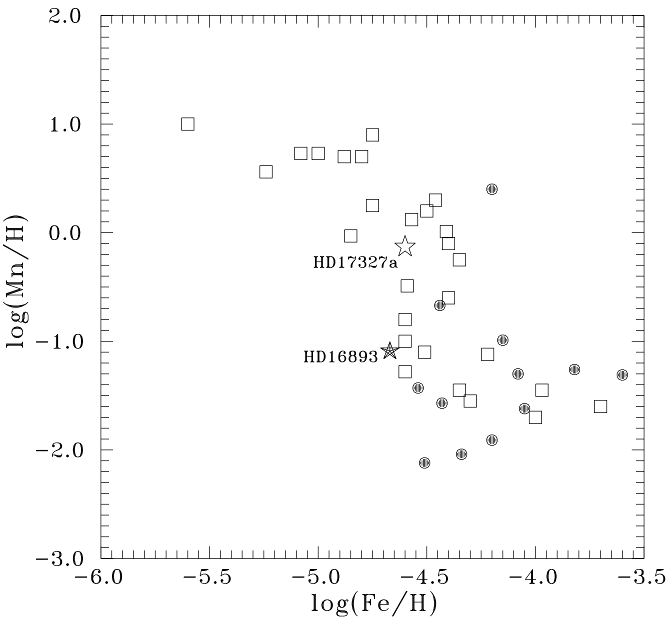

Fig. 7. The $\log g$(Mn/Fe) vs. log (Fe/H) abundances relation. All symbols are the same as in Fig. 6

and Fig. 7). It would be reasonable to check this object for a presence of a strong magnetic field.

5. Luminosities, radii and masses

To estimate the luminosities and radii of the Cas OB2 objects we can use $T_{\rm eff}$ determined spectroscopically and M_V taken from Turner & Evans (1984). Since we have obtained two spectrograms for SU Cas near the brightness minimum and maximum, the mean $T_{\rm eff}$ = 6325 K was used.

Table 8. Abundances for HD 16893

Element	log gf (Kurucz)			log gf (Adelman et al.)		
	[El/H]	σ	NL	[El/H]	σ	NL
C I	−0.45	0.17	7	−0.50	0.18	5
N I	+ 0.09	0.03	2	−0.20	0.51	5
O I	−0.12	–	1	−0.07	0.18	4
Na I	+ 0.29	–	1	–	–	–
Mg I	−0.98	0.22	2	−0.58	–	1
Mg II	–	–	-	+ 0.54	–	1
Al I	+ 0.92	0.08	2	+ 0.92	0.08	2
Si II	−0.45	–	1	−0.14	0.38	3
S I	+ 0.20	0.20	3	+ 0.20	0.20	3
Ca I	−0.02	0.23	15	–	–	–
Sc II	+ 0.04	0.38	6	−0.12	0.12	2
Ti I	–	–	-	+ 0.37	0.26	2
Ti II	−0.20	0.15	13	−0.05	0.28	13
V II	+ 0.78	–	1	+ 0.78	–	1
Cr II	−0.09	0.15	10	−0.03	0.24	10
Mn I	+ 0.65	0.24	4	–	–	–
Mn II	–	–	-	+ 1.05	0.02	2
Fe I	−0.21	0.17	18	−0.68	–	1
Fe II	−0.17	0.09	10	−0.14	0.42	13
Co I	+ 1.10	0.18	5	+ 1.19	0.26	6
Ni I	+ 0.06	0.20	8	–	–	–
Cu I	+ 0.22	–	1	+ 0.22	–	1
Zn I	−0.01	0.27	2	–	–	–
Sr I	+ 1.43	–	1	–	–	–
Y I	+ 2.56	–	1	–	–	–
Y II	+ 0.58	0.49	5	+ 0.41	0.34	3
Zr II	+ 0.63	0.28	3	+ 0.63	0.28	3
Ba II	+ 0.23	0.42	4	+ 0.35	–	1
La II	+ 1.14	0.01	2	+ 1.14	0.01	2
Ce II	+ 1.21	0.43	3	+ 1.43	0.56	4
Pr II	–	–	-	+ 1.72	–	1
Nd II	+ 1.85	–	1	+ 1.85	–	1
Sm II	+ 1.90	–	1	–	–	–

NL – number of lines.

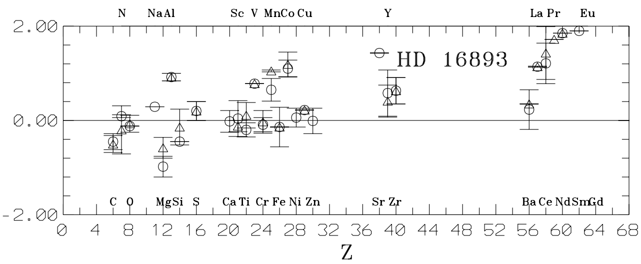

Fig. 8. Elemental abundance for HD 16893. Circles, – data, obtained using Kurucz (1995) log gf values, triangles, – using Adelman et al. (1996) ones

We have also used bolometric corrections from Strajzys (1982) for all the stars, excluding SU Cas. Moreover, in case of SU Cas we have also used its absolute magnitude from Szabados (1997).

Evolutionary masses for Cas OB2 members were determined by various methods. According to the CNO-abundance data, SU Cas is an object in the post red

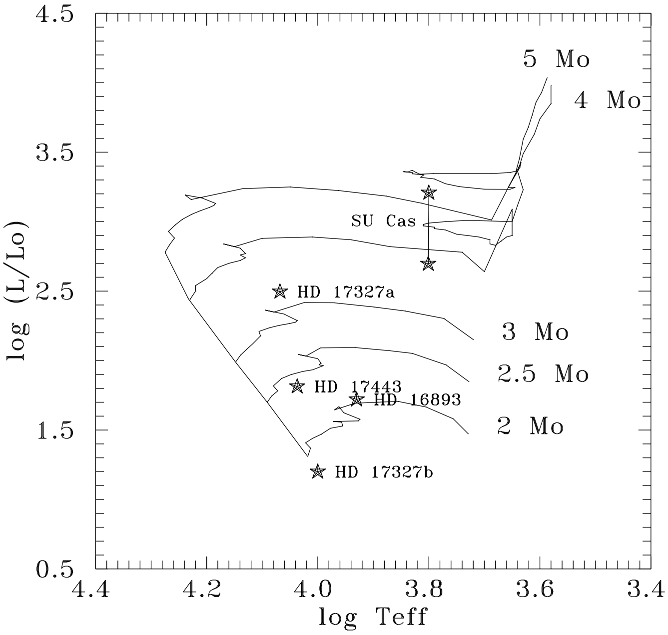

Fig. 9. HR diagram for Cas OB2 members. Evolutionary tracks from Schaller et al. (1992) recalculated for $Z = 0.02$

Table 9. Luminosities, radii and masses for the Cas OB2 members

Star	$M_{\rm bol}$	log $(L/L_\odot)$	$R/R_\odot$	$M_{\rm ev}$	$M_{\rm in}$
SU Cas (1)	−1.94	2.696	18.6	3.7	–
SU Cas (2)	−3.25	3.208	34.5	5.2	–
HD 16893	+ 0.44	1.720	3.4	2.1	–
HD 17327a	−1.50	2.496	4.3	3.3	–
HD 17327b	+ 1.74	1.200	1.3	–	2.0
HD 17443	+ 0.21	1.814	2.3	–	2.8

(1) – M_V from Turner & Evans (1984).
(2) – from Szabados (1997).

supergiant evolutionary phase, and we can use the equation from Chiosi et al. (1992) for a case of mild overshooting:

$$\log{(L/L_\odot)} = 3.52 \log{(M/M_\odot)} + 0.7. \quad (1)$$

For other objects the evolutionary and initial mass estimations were obtained from their positions in the HR diagram with the evolutionary tracks from Schaller et al. (1992) (recalculated using an interpolation for the metallicity value $Z = 0.02$) for stars with 2 $M_\odot$, 2.5 $M_\odot$, 3 $M_\odot$, 4 $M_\odot$, and 5 $M_\odot$, respectively. All these evolutionary tracks in the HR diagram and the positions of the Cas OB2 members are given in Fig. 9. Their bolometric magnitudes $M_{\rm bol}$, luminosities L, radii R and evolutionary $M_{\rm ev}$ and initial $M_{\rm in}$ masses are given in Table 9. For the two MS–stars we can apply the following relation:

$$\log{(L/L_\odot)} \approx 4 \log{(M/M_\odot)}. \quad (2)$$

6. Identification of the pulsation mode for SU Cas and its membership in the association Cas OB2

According to the conclusions derived in 2, the main question arising is whether SU Cas is a member of Cas OB2 with a pulsation in the fundamental tone (Turner & Evans 1984), or it is a Cepheid pulsating in an overtone (Evans 1991; Szabados 1997)? The first conclusion was based on photometric and radial velocity data, while the second one on the distance value determined from the hot companion parameters and on the *HIPPARCOS* parallax. It should be noted that Evans obtained $M_V \sim -3\overset{\rm m}{.}14$ from the Kurucz (1979) model atmospheres using the *IUE* spectra with the obviously underestimated $\log g = 1.5$.

We can check these positions on the HR diagram, using the gravity values determined from our spectroscopic observations. The mean value is $\log g = 2.35$, and it is very close to $\log g_{\rm puls}$ for pulsation in the fundamental tone for a Cepheid with a pulsational mass of 2 $M_\odot$ and a pulsational period of $1\overset{\rm d}{.}95$, according to Wood et al. (1997). In case of the second overtone, the theoretical values are $\log g_{\rm puls} = 2.2$, $M_{\rm puls} = 3.0\ M_\odot$ and $M_{\rm evol} = 4.6\ M_\odot$. Using the *HIPPARCOS* distance $d = 433$ pc and the absolute magnitude $M_V = -3\overset{\rm m}{.}25$ we can obtain the $M_{\rm evol} = 5.2\ M_\odot$ and $M_{\rm puls} = 3.7\ M_\odot$.

Nevertheless, the uncertainty in $\log g = 0.15$ dex would be a reason for some uncertainty in the pulsational mode identification. Furthermore, judging from Fig. 9, it is difficult to make a definite conclusion about it. The Cepheid's positions for the two values of luminosity in the HR diagram near the evolutionary tracks for 4 $M_\odot$ and 5 $M_\odot$ seems to be very uncertain. In short, the question about the pulsational mode of SU Cas remains open.

7. Conclusions

Based on the results of our detailed high-resolution spectroscopic investigation we can draw the following conclusions:

1) All studied Cas OB2 objects have metallicity values close to those of the Sun.

2) The mean $T_{\rm eff}$ for SU Cas (6325 K) is the same as that (6328 K) determined by Turner & Evans (1984) from $UBV-$ photometry and improved by accounting for the presence of a hot companion. The mean value of $\log g = 2.35$ corresponds to pulsation in the fundamental tone, but the uncertainty in $\log g$ might suggest pulsation in an overtone. Nevertheless, the chemical abundance data for SU Cas show that the Cepheid is a post first dredge-up star. Hence, SU Cas is not crossing the instability strip for the first time. On the basis of these results and the positions of this Cepheid in the HR diagram for the two luminosity estimates, it is difficult to draw a conclusion regarding its evolutionary state and membership in the Cas OB2 association. Since overtone pulsations might suggest the first crossing of the Cepheid instability strip, the question about identification of the pulsational mode for SU Cas remains open.

It would be interesting to estimate the age of SU Cas. From the Schaller et al. (1992) grids of models we can obtain the age values from 1 10^8 (5 $M_\odot$) to 1.45 10^8 (4 $M_\odot$) years. These values are close to those found by Turner & Evans (1984), 1.2 10^8 yr.

3) Two stars of Cas OB2, HD 17327a and HD 16893, have approximately the same positions on the corresponding evolutionary tracks (see Fig. 9) and similar low rotational velocities. HD 17327a was discovered by us to be a HgMn–star, which lies near the turn–off point of the association with the highest helium content among HgMn–stars and typical overabundance of Mn, Hg, Sc, Ti, Cr, and Y and a deficit of Al, Mg and Si. This star is a primary component of a binary system with an uncertain orbital period. On the one hand, it is similar to the objects of the Searle–Sergeant group, while on the other hand, it is very similar to classical HgMn–stars. The overabundance of helium and other elements can be well explained by the LID mechanism in the stellar atmosphere. HD 16893 has an overabundance of Mn, too, but it has a deficit of C, Mg and Si with an overabundance of Al and *s*-process elements. Suggested as an Ap-type star (Turner & Evans 1984), this object can be classified as an Am-star due to its manganese content. Additionally, it might have a strong magnetic field.

4) HD 17327b and HD 17443 are typical MS stars with high rotational velocities. Although HD 17443 is a more massive and more evolved object, it has a smaller $v \sin i$ value. It is remarkable that HD 17443 has a helium content, similar to that of the Sun.

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References

Adelman, S. J., Philip, A. G. D., & Adelman, C. J. 1996, MNRAS, 282, 953
Andrievsky, S. M., Kovtyukh, V. V., Usenko, I. A., Klochkova, V. G., & Galazutdinov, G. A. 1996, A&A, 305, 551
Atutov, S. N., & Shalagin, A. M. 1988, SvA Lett., 14, 664
Barnes, T. G, Dominy, J. F., Evans, D. S., et al. 1977, MNRAS, 178, 661
Batten, A. H., Fletcher, J. M., & McCarthy, D. G. 1989, Publ. Dominion Astroph. Obs., 17, 1
Berdnikov, L. N., & Pastukhova, E. N. 1994, SvA Lett., 20, 567
Castelli, F. 1991, A&A, 251, 106
Chiosi, C., Wood, P. R., Bertelli, G., Bressan, A., & Mateo, M. 1992, ApJ, 385, 205
Evans, N. R. 1991, ApJ, 372, 597
Evans, N. R. 1995, in Astrophysical Applications of Stellar Pulsations, ed. R. S. Stobie & P. A. Whitelock, ASP Conf. Ser., 89, 252
Fernie, J. D., Beattie, B., Evans, N. R., & Seager, S. 1993, IBVS, No. 4148
Galazutdinov, G. A. 1992, Preprint SAO RAS, No. 92
Gieren, W. P. 1982, PASP, 94, 960
Gieren, W. P., Fouque, P., & Gomez, M. 1997, ApJ, 488, 74
Gorynya, N. A., Rastorguev, A. S., & Samus, N. N. 1996, SvA Lett., 22, 38
Hubeny, I., Lanz, T., & Jeffrey, C. S. 1994, Newsletter Analys. Astron. Spec., No. 20, 30
Kovtyukh, V. V., & Andrievsky, S. M. 1999, A&A, 351, 597
Kovtyukh, V. V., Gorlova, N. I., & Klochkova, V. G. 1998, SvA Lett., 24, 372
Kurucz, R. L. 1979, ApJS, 40, 1
Kurucz, R. L., Furenlid, I., Brault, J., & Testerman, L. 1984, The solar flux atlas from 299 nm to 1300 nm, Nat. Sol. Obs., USA
Kurucz, R. L. 1992, The Stellar Populations of Galaxies, ed. B. Barbuy, A. Renzini, IAU Symp., 149, 225
Kurucz, R. L. 1995, Laboratory and Astronomical High Resolution Spectra, ed. A. J. Sauval, R. Blomme, & N. Grevesse, ASP Conf. Ser., 81, 595
Lebedev, V. S. 1987, Astroph. Issled. Izv. SAO, 25, 41, in Russian
Luck, R. E., & Lambert, D. L. 1981, ApJ, 245, 1018
Moon, T. T., & Dworetsky, M. M. 1985, MNRAS, 217, 305
Napiwotzki, R., Schönberner, D., & Wenske, V. 1993, A&A, 268, 653
Niva, G. D., & Schmidt, E. G. 1979, ApJ, 234, 245
Panchuk, V. E., Najdenov, I. D., Klochkova, V. G., et al. 1998, Bull. SAO RAS, 44, 127
Panchuk, V. E., Klochkova, V. G., Najdenov, I. D., et al. 1999, Preprint SAO RAS, No. 139
Pavlova, L. A., & Rspaev, F. K. 1986, Astrofizika, 25, 461
Racine, R. 1968, AJ, 73, 588
Ryabchikova, T. A. 1997, The Chemical Composition of Binary Stars with Mercury-Manganise Primary Components., in Binary Stars, ed. INASAN, Moscow, 105, in Russian
Ryabchikova, T. A., Zakharova, L. A., & Adelman, S. J. 1996, MNRAS, 283, 1115
Schmidt, E. G. 1978, AJ, 83, 960
Searle, L., & Sargent, W. L. W. 1967, The Magnetic and Related Stars (Baltimore: Mono Book Corp), 219
Schaller, G., Schaere, D., Meynet, G., & Maeder, A. 1992, A&AS, 96, 269
Stift, M. I. 1982, A&A, 112, 149
Strajzys, V. 1982, in Metal-Deficient Stars, ed. Mokslas, Vilnius, 298
Szabados, L. 1991, Bud. Mitt. 11, No. 96, 125
Szabados, L. 1992, in Complementary Approaches to Double and Multiple Star Research, Proc. IAU Coll. 135, ed. H. A. McAlister, & W. I. Hartkopf, ASP Conf. Ser. 32, 358
Szabados, L. 1997, in Proceed. of the ESA Symp. HIPPARCOS – Venice"97", 13–16 May, Venice, Italy, ESA SP-402, 657
Takeda, Y., Kawanomoto, S., & Ando, H. 1997, PASJ, 49, 493
Turner, D. G., & Evans, N. R. 1984, ApJ, 283, 254
Usenko, I. A. 1990, Kinemat. i Fizika Nebesn. Tel. 6, No. 3, 91
Welch, D. L., & Duric, N. 1988, AJ, 95, 1794
Wood, P., Capitanio, N., & Chiosi, C. 1997, ApJS, 86, 541