MULTIPHASE SPECTROSCOPIC OBSERVATIONS OF THE LONG-PERIOD CEPHEIDS l CARINAE

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ABSTRACT. Thirty three spectra (one spectrum for the each of 33 observational nights) have been performed to cover all pulsational period of the 35.5-days Cepheid l Car. Due to these data we have obtained for the first time the detailed curves of effective temperature, gravity and turbulent velocity. Curves of gravity and turbulent velocity show complicated changes, connceted probably with dynamics of extensive Cepheid's atmosphere. The mean atmosphere parameters of l Car are: T_{eff} = 4984±15 K; $\log g$ = 1.13; V_t = 6.67 km s^{-1}. Having a solar metallicity [Fe/H] = +0.02 dex, this Cepheid demonstrate sudden results for the "key" elements abundances of yellow supergiants evolution, – all they are close to the solar ones. In this case l Car resembles to SV Vul, – Cepheid with 45-days pulsational period and nearly like spectral type. It is possible that l Car is an object crossing the Cepheids instability strip for the first time. The content of other elements is close to solar one too.

Key words: Stars: Cepheids; stars: individual: l Car.

1. Introduction

l Car is the famous Cepheid due to the some aspects. It is one of the brightest Cepheids (<V> = $3.^m724$) having the long period (P = $35.^d5$), and been as a calibration object for the "period-luminosity" relation. Having a *G3Ib* spectral type it has attracted attention of observers by the presence of extensive hydrogen envelope around the star (Kervella et al. 2006). At the same time, the results of mean atmosphere parameters and chemical composition were rather discrepant. Therefore we have set a problem to obtain as soon as possible spectra of this Cepheid during its pulsational period and to obtain its atmosphere parameters and chemical composition.

2. Observations

Observations of these objects have been realized using 0.8 m telescope of Joint Observatory of Northern Catholic University (Antofagasta, Chile) and Ruhr University (Bohum, Germany), equipped by echelle spectrograph IRIS: $\lambda\lambda$ 4300–8300 Å in 45 orders, and resolving power R=50 000, and S/N ratio =100. The exposition time consists 1800 s for the each spectrum. Observational set have been carried out from 21 April to 11 June 2012. As a result we have obtained 33 spectra one at a time for one night, – see Table 1. The phases have been calculated according to Berdnikov (2013)

$$HJD_{max} = 2455134.5312 + 35.544719E \qquad (1)$$

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).

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 (accuracy: 0.25 km/s).

The atmosphere parametrs for each spectrum are given in Table 1.

Table 1: Observations and atmosphere parameters

HJD 2450000+	Phase	T_{eff} (K)	$\log g$	V_t (km s^{-1})
6039.0455	0.477	4732±15	0.95	6.00
6048.4517	0.712	4793±20	1.05	6.80
6049.4611	0.740	4741±18	1.05	7.00
6051.4761	0.797	4896±22	1.10	7.40
6052.4825	0.825	4989±16	1.10	7.40
6054.4507	0.881	5273±14	1.20	7.00
6055.4679	0.909	5413±12	1.45	7.40
6056.4524	0.937	5516±12	1.50	6.60
6057.4634	0.965	5550±17	1.50	6.60
6058.4599	0.993	5530±13	1.40	6.30
6059.4528	0.021	5460±12	1.40	6.50
6062.0745	0.095	5296±13	1.35	6.30
6062.4561	0.106	5237±12	1.10	5.30
6063.4754	0.135	5159±12	1.10	5.40
6064.4595	0.162	5110±10	1.10	5.20
6065.4599	0.190	5027±11	1.10	5.10
6066.4611	0.219	4997±11	1.05	5.20
6067.4473	0.246	4982±12	1.00	5.40
6068.4492	0.275	4945±12	1.00	5.70
6069.4540	0.303	4884±13	1.00	5.90
6071.0368	0.347	4861±12	0.95	5.00
6073.4499	0.415	4779±13	0.90	5.00
6074.4660	0.444	4757±13	1.05	7.90
6075.4424	0.471	4720±11	1.05	7.90
6078.0265	0.544	4673±15	1.00	8.00
6079.0058	0.572	4624±13	1.10	8.80
6082.4535	0.668	4677±22	1.10	8.50
6083.4653	0.697	4727±23	1.05	7.00
6085.0270	0.741	4765±21	1.05	7.20
6085.4566	0.753	4803±23	1.15	7.70
6087.4568	0.809	4891±20	1.15	7.90
6088.4488	0.837	4994±22	1.20	7.50
6089.4536	0.865	5132±17	1.15	7.00

The effective temperature, gravity and turbulent velocity curves are given in Figure 1.

The mean effective temperature obtained by the integration of effecive temperature curve area and its di-

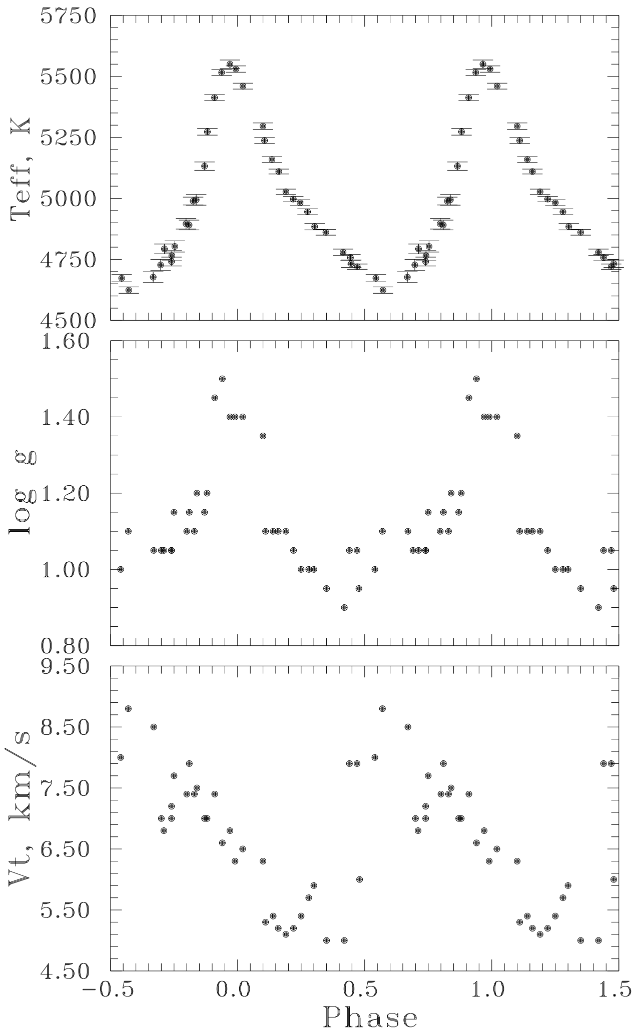

Figure 1: Effective temperature, gravity and turbulent velocity curves for l Car.

Table 2: Elemental abundance for l Car

Element	[El/H]	σ	NL	Element	[El/H]	σ	NL	Element	[El/H]	σ	NL
C I	–0.01	0.23	564	Ti I	–0.09	0.17	1613	Sr I	+0.07	0.37	53
N I	–0.00	0.22	67	Ti II	–0.10	0.16	98	Y I	–0.09	0.40	44
O I	+0.11	0.18	175	V I	–0.14	0.15	588	Y II	+0.06	0.17	144
Na I	–0.01	0.16	128	V II	–0.15	0.05	120	Zr II	+0.01	0.15	119
Mg I	+0.05	0.17	215	Cr I	–0.08	0.19	1239	Ru I	–0.01	0.33	128
Al I	+0.15	0.17	225	Cr II	–0.15	0.17	204	La II	+0.04	0.21	97
Si I	–0.04	0.13	1371	Mn I	–0.27	0.20	324	Ce II	–0.06	0.18	43
Si II	+0.26	0.27	45	Fe I	+0.02	0.14	7105	Pr II	–0.12	0.26	103
S I	+0.11	0.23	218	Fe II	+0.02	0.12	1046	Nd II	–0.07	0.14	336
K I	+0.28	0.21	31	Co I	–0.12	0.16	962	Sm II	–0.08	0.21	107
Ca I	–0.02	0.25	232	Ni I	–0.12	0.17	2445	Eu II	+0.02	0.16	98
Sc I	–0.19	0.22	159	Cu I	–0.25	0.21	67	Gd II	+0.09	0.14	28
Sc II	–0.12	0.11	130	Zn I	+0.15	0.41	39				

NL - number of lines

Table 3: Abundances of the "key" elements for l Car and Cepheids with closed pulsational periods

Object	Period (days)	Sp. type	C sci	N I	O I	Na I	Mg I	Al I	Authors
l Car	35.545	*G3Ib*	–0.01	–0.00	+0.11	–0.01	+0.05	+0.15	1
U Car	38.768	*G0Ib*	–0.38	–	–0.01	+0.30	–0.13	–0.03	2
RS Pup	41.390	*F8Iab*	+0.03	+0.73	+0.10	+0.42	–	+0.17	3
SV Vul	44.995	*G2.5Iab*	–0.02	+0.17	–0.01	+0.05	–0.17	+0.12	4

1 – This paper 2 – Usenko et al. (2011) 3 – Luck et al. (2003) 4 – Luck et al. (2001)

vision for equal parts. The mean atmosphere parameters are such:

$T_{eff} = 4984\pm15$ K; $\log g = 1.13$; $V_t = 6.67$ km s^{-1}.

As seen from Figure 1, the minimum of gravity curve mismatched with the one in effective temperature curve and has a left shift by 0.2 phase. But the minimum of effective temperature curve agrees with the small crest on the ascending branch of gravity curve. Turbulent velocity data formed two curves with different amplitudes and shift by 0.2 phase too.

4. Chemical composition

All the atmosphere models and chemical composition for each spectrum were calculated using our version of the WIDTH9 code on the basis of the Kurucz (1992) grid with the "solar" log gf values, adopted from Kovtyukh & Andrievsky (1999). All the data about the element abuundances for this Cepheid are given in Table 2.

As seen from Table 2, l Car has not only solar metallicity but also "key" elements of yellow supergiants evolution (CNO, Na, Mg, Al) show its content, close to the solar one. Abundances of $\alpha-$, Fe-group, "light" and "heavy" – s-process and r-process elements close to the solar ones. It is interesting that among the Cepheids with closed pulsational periods the most similar content of these elements exists for SV Vul (Luck et al. 2001). These authors provided this object as a crossing the Cepheids instability strip for the *first time*.

5. Conclusions

1. Firstly we obtained the very careful effective temperature curve for l Car, and these data allows us to estimate the precise mean T_{eff} value near 4984±15 K.

2. In contrast to smooth effective temperature curve the gravity and turbulent velocity ones show the presence of small crest on the ascending branch in the first case and division into two curves in the second one. The maximum of this crest agrees with the minimum of the effective temperature curve.

3. The mean atmosphere parameters, estimated by us ($T_{eff} = 4984\pm15$ K; $\log g = 1.13$; $V_t = 6.67$ km s^{-1}), are some lower, than in the models of Nardetto et al. (2006): $T_{eff} = 5091$ K; $\log g = 1.5$.

4. In comparison with the results of hydrodynamical models of Simon & Kanbur (1995) we can estimate the Cepheid mass near 9 $M_{\odot}$.

5. l Car has metallicitity, close to solar one: [Fe/H] = +0.02 dex.

6. Judging from the CNO-, odd elements, and Mg content, their abundances are close to solar one too. This fact is very unusual, because according to Berdnikov et al.(2003) l Car has a velocity of pulsational period growth in the O–C diagram dP/dt = +16.39 c yr^{-1}, and this result corresponds (according to authors) to the *third crossing* of the Cepheids instability.

7. From the our results, l Car did not still passed through the stage after the first dredge-up and probably, crossing it for the *first time*.

8. α-elements abundances for l Car are close to solar ones, just as we can say about the content of Fe-group, "light" and "heavy" – s- process and r-process elements.

9. "Key" elements abundances for l Car are very close with SV Vul ones.

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