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INVESTIGATION O φCas(F0I*a*) SUPERGIANT ATMOSPHERE

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The atmosphere of supergiant φCas(F0Ia) is investigated by the method of atmospheric model. Effective temperature and surface of gravity are determined by comparing the observed and theoretical values of photometrical indices [c_1], Q, and equivalent widths of Balmer lines: T_{eff}= 7350±200 K, logg=0,4±0.2.

The microturbulence parameter is evaluated as $_t=7.5km/s$ on the basis of studies of FeII lines. The chemical composition of the star is determined. In the atmosphere of φCas the C turned out to be a deficit, N, and Na in excess, other investigated elements practically display solar content.

Key words: *φCas(F0Ia); fundamental parameters of a star, chemical composition of a star.*

1. INTRODUCTION

The chemical content of A, F, and G class giants has attracted particular attention during the last decades. According to the theory of chemical evolution in the stage A, F, G class giants occur deep mixing which leads to the variation of the content of the CNO cycle (He, C, N, O) in the atmospheres of giants.

In particular, a deficit of carbon (C) and abundance of nitrogen (N) should be observed in atmospheres of supergiants of spectral classes A, F, and G.

Therefore a study of the chemical composition of A, F, and G supergiants and comparison of the obtained datum with the predictions of chemical evolution theory remains a topical issue in astrophysics.

Boyarchuk and Lyubimkov [1] have paid attention to the fact that in addition to the deviations in the content of C, N, and O in the atmosphere of A, F, and G class supergiants, apparently, an abundance of Na is observed.

It was hypothesized that an excess content of Na can be explained by the conversion of some amount of neon into sodium in the cyclic Ne-Na reactions. This Na excess must be released into the atmosphere as a result of deep mixing.

In the present work, we determine the chemical composition of supergiant F from the φCas (HR382, HD7927) class. The star *φCas* one is of the brightest stars in our Galaxy:
M_v= -9^m.16 [2].

This star due to its high luminosity is possibly approaching hypergiants (this is a very rare type of star, only a few hypergiants were found in our Galaxy). An object is very interesting.

2. **OBSERVATIONAL MATERIAL**

Spectra of stars were obtained on the 2-m telescope of Shamakhy Observatory of ANAS by using the spectrograph with CCD - matrix (R=56000, S/N=150-400). Spectra were processed with program DECH. The equivalent width of spectral lines was measured. The equivalent width of the used spectral lines is shown in Table 1,2.

3. PARAMETERS OF ATMOSPHERE: EFFECTIVE TEMPERATURE AND SURFACE GRAVITY

Effective temperature T_{eff} of star and surface gravity on its surface was measured by the method of an atmospheric model, described in [3]. Where in the following criteria are considered:

1. Comparison of observed and theoretically calculated values for equivalent widths of Balmer lines.
2. Comparison of observed and theoretically calculated values for index [c_1].
3. Comparison of observed and theoretically calculated values for index Q.

In narrowband four colors photometrical system uvby and photometrical system UBV indices [c_1] and Q are given by the formulas [c_1]=c_1-0.2(b-y) and Q=(U-B)-0.72(B-V) respectively.

Comparing experimental values of the above-mentioned indices with their theoretical values the log*g* and T_{eff} are determined. The observed values of [c_1] and Q are found by means of catalog [4]. Calculations of color indices in the systems of UBV and uvby being important for calculations Q and [c_1] were carried out by Kastelli and et. [5]. Calculations of equivalent widths of Balmer lines are presented by Kurucza [6].

Diagram for determination T_{eff} T_{eff} and logg is depicted in Fig.1

On the basis of Fig.1 for parameters of the atmosphere of *φCas* star following values are taken: T_{eff} =7350±200K, logg=0.4±0.2.

Fundamental parameters of *φCas* have been determined by several authors. Rosensweig et. all [7] plotted a non-LTE model of the atmosphere and determined T_{eff} =7200±100K, logg=0.4±0.1 from the comparison of theoretical and observed distributions of energy in the UV and visible region of the spectrum as well as comparison of theoretical and observed profiles of H_{δ}, CaII(H and K) and MgII lines.

The effective temperature was determined T_{eff} =7300K from UBVRI and uvby photometry in [8]. Accepting M_V= -8^m,4 and T_{eff} =7300K authors calculated the radius of star R=245R⊙, according to evolutionary tracks, as well as the mass of the star as M=17M⊙ and logg=0.9 [9]. In [2] and [10] effective temperature was determined knowing the ratio of the central intensities of the pair of lines as T_{eff}=7340K and T_{eff}=7160K respectively. Also values logg=1.0 and logg=2.0 were determined according to ionization equilibria in [2] and [10] respectively.

It can be seen that the T_{eff} values in published works are in good agreement with each other and with our results.

There is a significant discrepancy in the values of logg. Note that logg=2.0 is too high a value for the Ia luminosity class.

When determining logg the ionization equilibrium over FeI-FeII is used and calculations were performed in the LTE approximation [2,10].

This led to an overestimation of log*g* since deviations LTE had to be taken into account in the calculations of lines FeI. In [8] calculation of logg is related to parameters M_V, R, and M. The accuracy of the determination of these parameters is not high. In [7] log*g* was determined by comparison of observed and theoretically calculated values of some spectral and photometrical quantities. Theoretical values are calculated from the non-LTE atmospheric model. Therefore the value of log*g* determined in [7] is more accurate which completely coincides with our results. And so we believe that the results we got are preferable. The method we apply is widely described in [3] accuracy of this method is substantiated.

4. MICROTURBULENT VELOCITY

In some studies (for example [11]) the nature of micro-and macroturbulence is clarified.In [11] it was found that in the 3D model analysis of the solar photosphere the calculated and observed spectral line profiles completely coincide and there is no need to introduce the concepts of micro-and macroturbulence. The classical concepts of micro-and macroturbulence are fully explained by convective-granulation fields of velocities, vibrational motions of the photosphere, and nonuniformity of temperature.

To determine microturbulence velocity ξ_t it is necessary to have a list of lines of any atom or ion in a wide range of equivalent widths W_λ and microturbulence velocity is chosen so that the determined abundances of the element do not show enhancement with the increase in W_λ. $W\lambda$

The most numerous lines in the spectra of studied stars were the lines of neutral iron FeI, followed by the lines of ionized iron FeII. However, the lines of neutral iron can be subjected to significant deviations of LTE.

If deviations from LTE are not taken into account this will lead to underestimation of determined iron content logε(Fe).

This first was shown by Boyarchuk et all for the F-supergiants [12], later confirmed by other authors for F- and G- stars (for example [13]). Interestingly, in contrast to the lines, the FeII lines turned out to be insensitive to LTE effects.

Therefore when determining microturbulent velocity in the stellar atmosphere we used FeII lines. When determining ξ_t we use only FeII lines with equivalent width $W<250$m $A^{[?][?]}$. These lines are formed in deep layers which can be considered plane-parallel layers in the LTE state.

Based on the found parameters T_{eff} and logg we calculated the corresponding model of the atmosphere; for this Kurucz's ATLAS 9 program was used [6]. Using the model obtained by us we calculated the iron content logε(FeII) for several values of ξ_t (the content of iron on the basis of considered spectral lines FeII at ξ_t =7.5 km/s is shown in Table 1).

Table 1. List of the used FeII lines

Line (λ, Å)	E_{excit} (eV)	log gf	W, m Å	logε(Fe)	Line (λ, Å)	$E_{excit.}$ (eV)	log gf	W, m Å	logε(Fe)
4031.46 4413.60 4635.32 4993.36 5100.66 5136.785256.895414.075425.2759 91.376084.106113.32	4.71 2.66 5.93 2.79 2.79 2.83 2.88 3.21 3.19 3.14 3.19 3.21	-3.20 -4.01 -1.48 -3.58 -4.22 -4.38 -4.33 -3.85 -3.35 -3.63 -3.85 -4.20	79 169 168 258 189 122 140 18022318 914398	7.61 7.35 7.31 7.41 7.70 7.58 7.66 7.59 7.31 7.39 7.42 7.55	6147.73 6149.24 6238.38 6239.95 6369.46 6416.92 6432.65 6446.43 7449.34 7515.88 7711.71	3.87 3.87 3.87 3.87 2.88 3.87 2.88 6.20 3.87 3.89 3.89	-2.73 -2.73 -2.64 -3.44 -4.29 -2.75 -3.75 -2.02 -3.30 -3.42 -2.54	2812792671381272462295113878269	7.63 7.62 7.38 7.52 7.53 7.38 7.48 7.35 7.41 7.27 7.32
									logε(Fe) =7.47±0.13

The iron content was determined by comparing the calculated and observed equivalent width of the FeII spectral lines.

Calculations of the equivalent width of spectral lines have been carried out using the program DASA developed by Kr. AO RAS (one of the most widely used programs is the WIDTH program created by Kurucz. The program DASA is its analog in Crimean Astrophysical observatory). We used atomic data for the spectral lines from the WALD-3 database (http://vald.astro.uu.se). The determination the of ξ_t parameter for the star *φCas* is shown in Fig.2 . Fig.2 shows the definition of the parameter ξ_t for the star *φ*Cas. As can be seen from Fig.2 there is no correlation between logε and W_λ at ξ_t =7.5 km/s

5. ABUNDANCE OF THE ELEMENTS

When analyzing ξ_t the iron content is simultaneously found from the FeII lines**:** logε(Fe)=7.47. Note that the abundances of elements are given on a logarithmic scale.

$$lg[?T?](el) = lg\frac{N(el)}{N(H)} + 12$$

For hydrogen, it is assumed that logε(H)=12. Applying our model (basic parameters: T_{eff}=7350K, logg=0.4) we calculated the abundance of the elements at ξ_t =7.5km/s. We present the results in Tables 1 and 2. The difference in the abundances of elements [illegible] in a star and Sun is presented in Tab.3 and Fig.3. Solar content $\log\varepsilon_{\odot}$(el) is taken from [14,15].

Open circles show elements (C, N, O, Na) whose abundances according to literature data require non-LTE corrections.

The arrows indicate that the effect of these corrections is in the direction of decreasing. According to [16,17,18] the NI and CI lines are subject to non-LTE effects. It is necessary to insert corrections – (0.3-0.4)dex ., into the value of logε(N), – (0.2-0.3)dex into the value of logε(C).

Table 2. List of used lines

Line (λ, Å)	E_{excit} (eV)	Loggf	W, mÅ	logε	Line (λ, Å)	E_{excit} (eV)	loggf	W, mÅ	Logε
C I 4770.03 4932.65 5052.17 6014.84 6587.61 7087.83 7108.93 7111.47 7113.18 7115.17 7116.99 7476.18 7483.45	 7.45 7.65 7.68 8.64 8.50 8.64 8.64 8.64 8.65 8.64 8.65 8.77 8.77	 -2.44 -1.66 -1.30 -1.58 -1.00 -1.44 -1.59 -1.08 -0.77 -0.93 -0.91 -1.57 -1.37	 21 58 122 13 51 14 21 55 90 78 53 16 23	 8.46 8.30 8.37 8.24 8.20 8.13 8.48 8.43 8.41 8.48 8.25 8.45 8.43	**OI** 6300.30	 0.0	 -9.72	 18	 8.96
									logε(O) =8.96
					NaI 4668.56 5682.63 5688.21 6160.75	 2.10 2.09 2.10 2.10	 -1.31 -0.71 -0.45 -1.26	 13 35 84 18	 6.67 6.50 6.87 6.74
									logε(Na) = 6.70±0.15
					MgI 4057.51 4702.99 5528.41 5711.09	 4.33 4.33 4.33 4.33	 -1.20 -0.67 -0.62 -1.83	 97 143 172 22	 7.63 7.45 7.42 7.49
				logε(C) = 8.36±0.12					
N I 7423.64 7442.30 7468.31	 10.33 10.33 10.33	 -0.71 -0.38 -0.19	 122 189 159	 8.74 8.82 8.54					
									logε(Mg) = 7.50±0,09
				logε(N) = 8.70±0.2					

Line (λ, Å)	E_{excit} (eV)	loggf		W, mÅ	Logε	Line (λ, Å)	E_{excit} (eV)	loggf	W, mÅ	Logε
SiI						**V II**				
5690.43	4.91	-1.77		15	7.53	5303.25	2.27	-2.05	20	3.91
7165.55	5.85	-0.59		31	7.60					
7409.08	5.59	-0.62		21	7.41					
7918.38	5.93	-0.66		19	7.62					
										logε(V)= 3.90±0.13
					logε(Si) = 7.54±0.09	**Cr II**				
						4145.78	5.30	-1.20	140	5.72
						4252.63	3.84	-2.05	194	5.33
						4812.35	3.85	-2.03	183	5.61
						4836.23	3.84	-1.96	210	5.69
						4884.60	3.85	-2.16	178	5.71
						5279.88	4.06	-1.93	231	5.79
						5305.86	3.81	-2.30	184	5.73
						5313.58	4.06	-1.50	220	5.40
						5334.87	4.05	-1.59	230	5.53
						5478.37	4.16	-1.90	166	5.62
						5502.08	4.15	-2.04	133	5.58
						5503.22	4.13	-2.29	104	5.68
						6053.47	4.72	-2.20	33	5.56
CaI										
4425.44	1.87	-0.45		41	6.08					
4434.96	1.88	-0.10		104	6.25					
4435.68	1.88	-0.57		37	6.16					
4454.78	1.89	0.17		173	6.35					
5512.99	2.92	-0.26		20	6.31					
5594.46	2.51	0.09		65	6.20					
5857.45	2.92	0.33		40	6.10					
6122.22	1.88	-0.26		83	6.17					
6162.17	1.89	-0.04		120	6.19					
6169.04	2.51	-0.80		14	6.37					
6169.57	2.51	-0.53		15	6.15					
6439.08	2.51	0.44		92	6.13					
										logε(Cr)= 5.61±0.13
					logε(Ca)= 6.21±0.09	**Y II**				
						4398.01	0.13	-0.90	240	2.31
						4900.12	1.03	0.10	286	2.20
						5205.72	1.03	-0.19	274	2.39
						5402.78	1.83	-0.36	70	2.18
						5544.61	1.73	-0.83	43	2.30
Sc II										
4354.60	0.60	-1.55		146	2.93					
5239.82	1.45	-0.74		202	2.98					
5318.35	1.35	-1.87		57	3.23					
5641.00	1.49	-0.99		168	3.08					
5667.15	1.49	-1.18		123	3.06					
5669.03	1.49	-1.07		147	3.06					
6245.62	1.50	-1.02		134	2.95					
6320.85	1.49	-1.82		45	3.14					

										logε(Y)= 2.28±0.09
						ZrII				
						4077.04	0.96	-1.69	14	2.56
						4149.20	0.80	-0.04	278	2.61
						4211.88	0.52	-1.04	132	2.62
						4359.72	1.23	-0.51	131	2.64
						4496.96	0.71	-0.89	160	2.72
					logε(Sc)= 3.05±010					
Ti II										
4184.31	1.08	-2.50		237	5.09					
4316.79	2.04	-1.61		276	5.17					
4411.06	3.08	-0.57		280	4.98					
4421.94	2.05	-1.38		240	4.73					
4544.02	1.24	-2.49		159	4.77					
4545.14	1.13	-2.80		176	5.06					
4708.66	1.23	-2.40		234	5.02					
4798.53	1.08	-2.68		175	4.88					
5010.21	3.08	-1.33		127	4.88					
5013.69	1.57	-2.01		243	4.90					
5069.09	3.11	-1.41		128	5.00					
5381.02	1.56	-1.96		242	4.81					
										logε(Zr)= 2.63±0.06
						BaII				
						5853.68	0.60	-1.00	93	2.26
						6141.71	0.70	-0.08	287	2.32
						6496.90	0.60	-0.38	258	2.38
										logε(Ba)= 2.32±0.06
						LaII				
						4086.71	0.00	-0.15	54	1.07
						4429.72	0.23	-0.49	26	1.18
						4748.73	0.92	-0.54	10	1.03
					logε(Ti) = 4.94±0.14					**logε(La)= 1.09±0.08**
V II						**CeII**				
4035.63	1.79	-0.68	266		3.96	4042.58	0.49	0.18	30	1.57
4036.76	1.97	-1.67	93		4.01	4222.59	0.12	-0.30	20	1.53
4039.57	1.81	-1.73	31		3.72	4364.65	0.49	-0.23	10	1.42

Line (λ, Å)	E_{excit} (eV)	loggf	W, mÅ	Logε	Line (λ, Å)	E_{excit} (eV)	loggf	W, mÅ	Logε
CeII					**GdII**				
4449.33	0.61	0.04	20	1.56	4251.74	0.38	-0.37	15	1.09
4486.91	0.29	-0.47	13	1.61	4280.53	0.35	-0.67	8	1.07
5393.39	0.62	-0.06	13	1.40					
				logε(Ce)= 1.52±0.09					**logε(Gd)= 1.08±0.01**

NdII 4069.27 4156.08 4358.17 5092.79	 0.06 0.18 0.32 0.38	 -0.57 0.20 -0.28 -0.70	 13 72 11 6	 1.43 1.58 1.22 1.35					
				logε(Nd)= 1.40±0.15					

Table 3 The difference in the abundance of elements between φCas and the Sun

Element	logε	$\log\varepsilon_{\odot}$	Δlogε= $\log\varepsilon-\log\varepsilon_{\odot}$	Element	logε	$\log\varepsilon_{\odot}$	Δlogε= $\log\varepsilon-\log\varepsilon_{\odot}$
C	8.36	8.43	-0.07	Cr	5.61	5.62	-0.01
N	8.70	7.83	0.87	Fe	7.47	7.47	0.00
0	8.96	8.69	0.27	Y	2.28	2.21	0.07
Na	6.70	6.21	0.49	Zr	2.63	2.59	0.04
Mg	7.50	7.59	-0.09	Ba	2.32	2.25	0.07
Si	7.54	7.51	0.03	La	1.09	1.11	-0.02
Ca	6.21	6.32	-0.11	Ce	1.52	1.58	-0.06
Sc	3.05	3.16	-0.11	Nd	1.40	1.42	-0.02
Ti	4.94	4.93	0.01	Gd	1.08	1.08	0.00
V	3.90	3.89	0.01				

In the spectrum of φCas star, both neutral and ionized lines of iron-group elements were observed. The contents of iron group elements were found from ion lines, the effect of non-LTE on these lines is insignificant.

As can be seen from Fig.3. in the atmosphere of φCas the C turned out to be a deficit, N, and Na in excess, other investigated elements practically display solar content.

This means that a star φCas was formed from matter with the same chemical composition as the Sun. The oxygen content and metallicity have retained their original content, but evolutionary changes were observed in the composition of C, N, and Na elements. This conclusion is interesting from the point of view of models of galactic chemical evolution. Contents of elements in the atmospheres of giants and supergiants have been determined by numerous authors (for example, [3,16,17,18,20,21]) and it has been shown that the oxygen content and metallicity of these stars are close to those of the Sun, carbon is in deficit, nitrogen, and sodium are in excess.

4. CONCLUSION

Let us list the chief results obtained in this study.

1. The effective temperature and surface of gravity of φCas (HR382, HD7927) star are determined by the method of atmospheric model. The following values of effective temperature and surface of gravity were found: T_{eff}=7350±200 K, logg=0.4±0.1.

2. The microturbulence parameter was found as $_{t}=7.5 km/s$ on the basis of studies of FeII lines.

3. The content of elements in the atmosphere of φCas star was determined and compared with their abundances on the Sun. Deficiency of C and excess of N and Na were found. The content of other studied elements is close to solar. This means that a star φCas was formed from matter with the same chemical composition as the Sun. The oxygen content and metallicity have retained their original content, but evolutionary changes were observed in the composition of C, N, and Na elements. Thus the predictions of the theory of evolution are confirmed by observations.

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FIGURE CAPTURE

Fig.1. The diagram for determination of parameters T_{eff} and logg.

Fig.2. Determination microturbulence parameter ξ_t.

Fig.3. Chemical composition of supergiant φCas in comparison with that of the Sun.

Fig.1. The diagram for determination of parameters T_{eff} and log*g*.

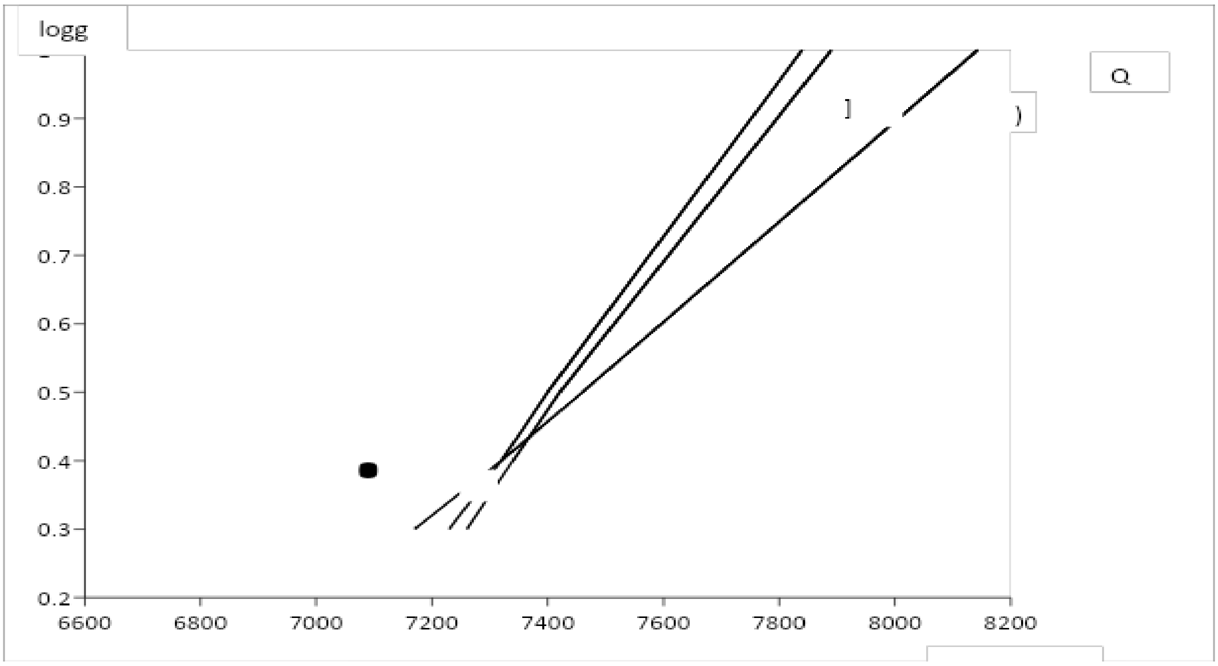


Fig.2. Determination microturbulence parameter ξ_t.

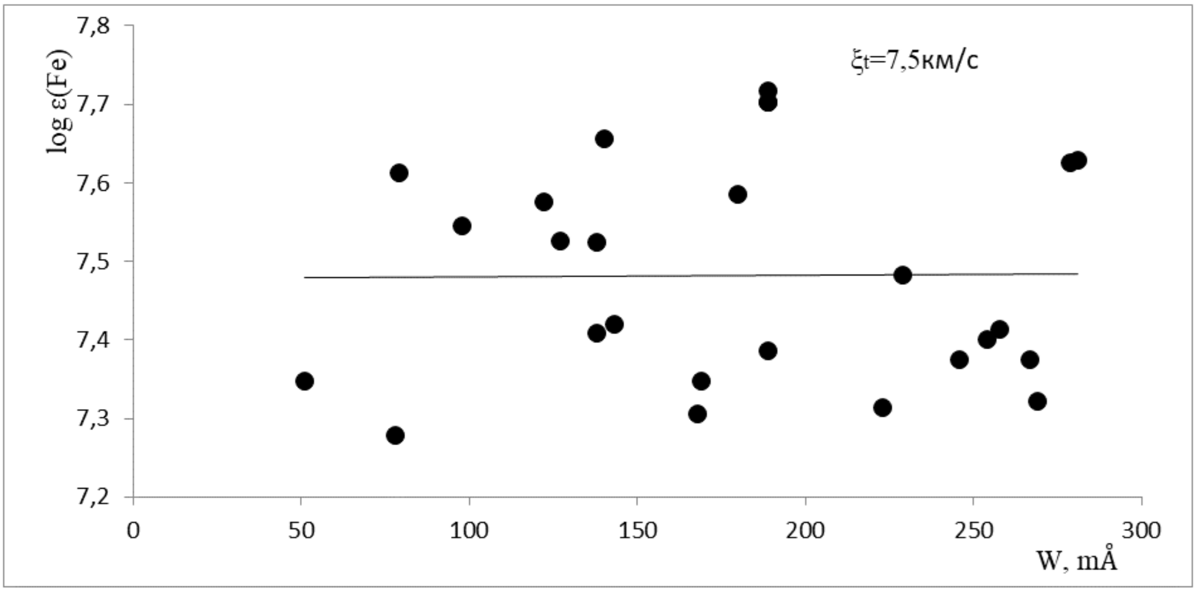
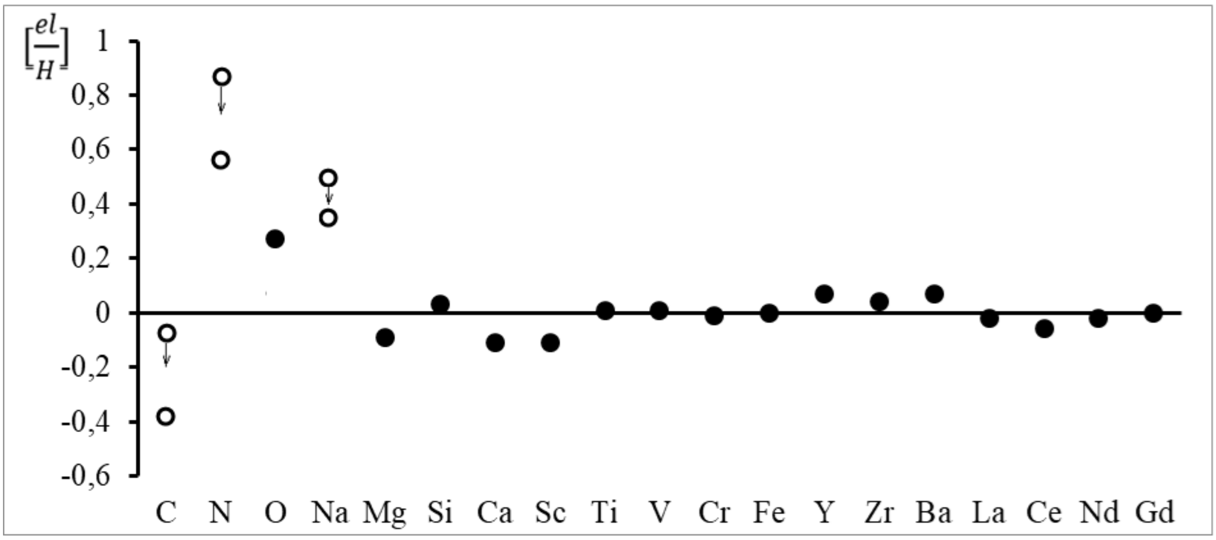


Fig.3. Chemical composition of supergiant φCas in comparison with that of the Sun.



[el/H]
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
C N O Na Mg Si Ca Sc Ti V Cr Fe Y Zr Ba La Ce Nd Gd