DETAILED CHEMICAL ABUNDANCES OF SEVERAL CP-STARS OF THE UPPER MAIN SEQUENCE

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We present a study of the chemical composition of atmospheres of five stars of the upper main sequence. Investigations of the SB2 system 66 Eri permit to find the gallium spots in atmospheres of the components, the secondary component of the system is a HgMn star, the primary can also be a HgMn star with less pronounced anomalies. The components of the double system HD 153720 appear to be metallic-lined stars. A review of studies of the abundance of SB2 systems with A4–F1 components shows that the usually accepted fraction of stars with the solar chemical composition in this region of the HR diagram can be decreased. The abundance patterns of Sirius (>50 elements) in the region of heavy elements give us additional arguments for the hypothesis that not only a diffusion is responsible for the overabundances of these elements in Sirius. The abundance pattern of δ Sct (49 elements) appears to be similar to δ Del type stars, maybe, a subtype of the prototype of one of the largest class of pulsating variables should be changed. The abundance pattern of the Przybylski's star is the best stellar abundance pattern (after that of the Sun). The possible identification of radioactive elements ($84 \leq Z \leq 99$) in the atmosphere of the Przybylski's star needs abundance determinations and can be the clue to the understanding of the nature of all CP stars.

INTRODUCTION

Preston was the first who named an inhomogeneous group of stars of the upper main sequence "chemically peculiar star" – CP stars [12]. The significant part of stars in this region of the HR diagram is CP stars. We investigated in details the following stars of the main classes of chemically peculiar stars: 66 Eri (the secondary component of this SB2 system is mercury-manganese star, the primary one can also be a HgMn star), the metallic-lined (Am) stars – Sirius, δ Sct (the prototype of the class of pulsating variables), the SB2 system HD 153720, and the roAp star HD 101065 (Przybylski's star). In the subsequent sections of the paper, we will try to give a short description of each star, to outline our recent studies as well as new data, and to discuss the main results, obtained from the abundance patterns.

A detailed discussion of methodics can be found in [7, 26, 27]. The main feature of those methodics is the use of synthetic spectra at all stages of spectra processing – from the continuum placement and lines identification to the abundance determinations. We show that it permits to make a qualitative step in stellar abundance determinations – the abundance patterns of 50–70 chemical elements for sharp-lined stars. The solar abundance pattern is the most complete one, but it is possible that, in the nearest future, the best stellar patterns will reach the solar level.

66 ERIDANI – A SYSTEM OF HgMn STARS?

HgMn stars cover the temperature range near 11 000–16 000 K. All stars with this peculiarity are slow rotators ($v \sin i < 100$ km s^{-1}). The majority of HgMn stars (the CP3 group in the Preston classification) has rotational velocities $30 < v \sin i < 70$ km s^{-1} and contains all the stars for which Hg II 3984 Å and/or the strong lines of Mn I are the most remarkable features in the spectrum [12]. No magnetic field are detected in HgMn stars: Am and HgMn stars are much more common than the magnetic Ap-stars. The coolest HgMn stars and the hottest Am stars have the same evolutionary tracks [1].

66 Eri is one of the targets of a program for investigations of chemical abundances of SB2 systems with non-evolved main sequence components of equal masses. The mass ratio of the components of 66 Eri (HD 32964) $M_A/M_B = 0.98$ is most close to the unity among stars, which were investigated in this program: AR Aur [10] and 46 Dra [21]. The last spectroscopic orbit solution was given by Yushchenko *et al.* [24]. The detailed study of the chemical abundance of the components was made by Yushchenko *et al.* [23]. The remarkable aspect of 66 Eri is the fact that the two components are nearly identical by all the physical characteristics except the chemical composition.

We obtained the abundances of chemical elements in the atmospheres of the A and B components of the system from high resolution CCD echelle spectra with S/N >100 in the wavelength region 4385–6695 Å taken with the 1-m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences at Zelenchuck [23]. The values of atmospheric parameters of the components were found as follows: $T_{\rm eff}(\rm A) = 11\,100$ K, $T_{\rm eff}(\rm B) = 10\,900$ K, $\log g(\rm A) = 4.25$, $\log g(\rm B) = 4.25$, the microturbulent velocities $v_{\rm micro}(\rm A) = 0.9$ km s^{-1}, $v_{\rm micro}(\rm B) = 0.7$ km s^{-1}, the rotational velocities $v \sin i\,(\rm A, B) = 17$ km s^{-1}. The value of the projected rotation velocity of the components, HIPPARCOS parallax, and photometry allow us to conclude that the rotation of the components is synchronized with their orbital motion. The abundances of 15 elements were determined in the atmosphere of the component A and 26 elements – in the atmosphere of the component B. These data can be found in Table 1, where the mean abundances of chemical elements in the atmospheres of several stars, discussed in this paper, are listed with respect to the abundance of these elements in the Solar System.

The chemical compositions of A and B components are found to be different: the component B, previously classified as a HgMn star, does not show the typical for this group anomalies such as the deficit of He and Al and excess of P and Ga, but it shows the strong heavy elements overabundances up to 4–5 dex. The component A also reveals a moderate Mn and Ba excess, but the lines of other heavy elements are not found. Evaluations of the upper limits of their abundances do not permit to exclude completely a presence of anomalies of heavy elements for the A component.

Additionally, for 66 Eri, the more complete line identification was carried out using five spectra obtained at the McDonald Observatory 2.7-m telescope. We do not find any significant differences between the previous and new abundances, any differences were also found between five spectra. An exception was only the gallium lines. Our previous results did not supported the so-called secondary characteristics of the HgMn group – the excess of gallium and phosphorus in B component. The main characteristics are confirmed well, there are the excess of Hg (about 6 dex) and Mn (about 1 dex). As for gallium, its behaviour is very strange: the gallium lines are well identified in some spectra at the definite phases, at other phases, these lines are absent. The equivalent widths of the line λ 6396.577 Å for both components are 4 and 5 mÅ (for A and B, respectively) in the first two spectra, 5 and 2 mÅ for the fifth spectrum, the lines are absent in the fourth spectrum. The third spectrum has a defect at this wavelength. No lines of phosphorus are seen in our spectra – they are located between the observed spectral orders. The spectra were obtained during four days – slightly less than one orbital period of the system [24].

The variability of the line λ 6396.577 Å is confirmed by other gallium lines, but these lines are not clean. This result permits us to suggest that the gallium distribution in the atmospheres of the 66 Eri components are not uniform. Maybe, the described observations can be explained by the existence of gallium spots on the surfaces of the components. It should be noted that the gallium spots were not found in HgMn stars previously.

The component A can also be a HgMn star. This component also reveals a moderate Mn and Ba excess, but the lines of other heavy elements are not found. Estimates of upper limits of their abundances do not permit to exclude completely a presence of anomalies of heavy elements for A component. If these anomalies are on the order of 2–3 dex, it is impossible to detect it. The secondary characteristics of HgMn stars in the spectrum of the component A are less pronounced than in that of the component B. That is why we can expect that the Hg abundance will be high but undetectable. As it was mentioned before, the coolest HgMn stars and the hottest Am stars have some similarities. The overabundances of heavy elements in the hot Am stars are not so big as in HgMn stars but, due to a lower temperature, these smaller peculiarities are detectable in Am stars. For example, the abundance pattern of the primary component of 66 Eri is very close to that of one of the hottest Am stars, Sirius.

SIRIUS – DIFFUSION OR ACCRETION?

The Am stars were first recognized as a group by Titus & Morgan in 1940 [19]. They found that the Ca K lines did not lead to the same classification as the hydrogen lines for some of the Hyades A stars. Since then, it has been noticed that most if not all slowly rotating A and F stars exhibit abundance anomalies. The abundances of CNO are generally below solar, while those of iron peak elements are generally above solar. The classical Am stars are characterized by a general enhancement of the metallic lines but a marked weakness of the Ca and Sc lines when compared to normal A stars at the resolution of the classification spectra. Heavy elements abundances are enhanced for most stars. The best investigated Am star is Sirius (HD 48915). This star has an effective temperature near 10 000 K, it is one of the hottest Am stars. Sirius is often used as reference star in analysis of A-type stars. We redetermined the abundance of elements with atomic numbers $Z > 29$ in the atmosphere of Sirius A (Sirius B is a white dwarf).

By comparing the ultraviolet (λ = 1649–3170 Å) atlas of the Sirius A spectrum [14] with a synthetic spectrum, we have identified the absorption lines of copper, zinc, gallium, yttrium, zirconium, molybdenum, cadmium, tullium, hafnium, tantalum, tungsten, rhenium, osmium, iridium, mercury, lead, thorium, and uranium. The synthetic spectrum technique is used to determine the abundance of these elements in the Sirius atmosphere. The parameters of the atmosphere were $T_{\rm eff} = 10\,000$ K, log $g = 4.3$, $v_{\rm micro} = 2$ km s^{-1}. A summary of the abundance of 29 heavy elements is given in Table 1. The abundance of these elements are non-solar in Sirius. The detected overabundances of heavy elements lie in the range of 0.4–3.2 dex. Table 1 contains only our determinations, a whole abundance pattern of Sirius consists of more than 50 chemical elements.

A comparison of the abundance pattern of Sirius A with that of a typical barium star, for example, with HD 202109 [26], shows that the mass transfer from Sirius B could play a significant role in the formation of overabundances of heavy elements in the atmosphere of Sirius A. Diffusion is also important, but may be not sufficient to explain the abundance anomalies in this star.

δ SCUTI – HOW TO CLASSIFY THIS STAR?

δ Sct is a prototype of one of the classes of pulsating variables. δ Sct type stars have the peculiar abundances. Abundances in atmospheres of several δ Sct type stars were investigated in [6, 9, 13]. Rachkovskaya ([13] and references therein) pointed that all the studied objects had more or less anomalous abundances compared with the Sun and proposed to divide the δ Sct type stars into two groups in accordance with their abundances. The first group includes the stars with overabundances of some or all elements. The group includes, for example, 14 Aur, 20 CVn, 28 And. Especially, it is to note the case of 20 CVn. This star displayed 0.5–1.5 dex excesses (relative to the solar values) for all observed elements from Na to Gd. The second group unites the stars whose abundances depend on atomic number in the same way as the classical Am stars. The typical members of this group are δ Del, 44 Tau, V644 Her, HD 127986.

We derived the chemical abundances in the photosphere of δ Sct from the analysis of a spectrum obtained at the 2-m telescope of the Terskol Observatory. The spectral resolution was $R = 52\,000$, a signal to noise ratio was more than 250 in the red spectral region. We also used the IUE spectra of δ Sct. The atmosphere parameters were accepted as follows: $T_{\rm eff} = 7000$ K, $\log g = 3.5$, $v_{\rm micro} = 3.8$ km s^{-1}. We derived the abundances of 48 chemical elements (see Table 1). The lithium abundance was found by Russel [15].

So, the abundance pattern of δ Sct consists of 49 chemical elements. Be, P, Ge, Nb, Mo, Ru, Er, Tb, Dy, Tm, Yb, Lu, Hf, Ta, Os, Pt, Th were not investigated previously. The lines of the third spectra of Pr and Nd are also found for the first time. The values of abundances of these elements obtained from the lines of the second and third spectra are equal. The abundances of heavy elements show the overabundances up to 1 dex with respect to the Sun. The abundance pattern of δ Sct is similar to the abundance patterns of AmFm stars. The splitting of the cores of all the not blended spectral lines was found in the spectrum of δ Sct. It can be the sign of non-radial pulsations of high orders in the atmosphere of this star. The splitting was observed at the ascending branch of the light curve of the main pulsational period of δ Sct.

The result of our investigation of δ Sct is as follows: the abundance pattern of δ Sct is similar to the abundance patterns of the δ Del type stars. What is the difference between these two types? It will be a subject of the next paper.

HD 153720 AND OTHER "NORMAL" BINARIES

Yushchenko *et al.* [27] have published the chemical composition of the components of the spectral binary HD 153720. The star was selected for observation as a comparison star and we expected the normalcy of the chemical composition. But it appears that the components are metallic-lined stars. In Table 1 we show the abundances of both components of the binary. The 2.7-m telescope of the McDonald Observatory was used for observations, the spectral resolution was 60 000. The atmospheric parameters of the components derived are: $T_{\rm eff}({\rm A}) = 7425$ K, $T_{\rm eff}({\rm B}) = 7125$ K, $\log g\,({\rm A}) = 4.0$, $\log g\,({\rm B}) = 3.9$, the microturbulent velocities $v_{\rm micro} = 2.7$ km s^{-1}, the rotational velocities $v \sin i = 15$ km s^{-1} for both components. Other details can be found in [27]. The result shows that the photometrical classification and even low- and middle-resolution spectroscopy can not be sufficient to classify the stars in this part of the HR diagram.

Table 1. Abundances in the investigated stars

N	Z	Element	66 Eri A	66 Eri B	Sirius	δ Sct	HD 153720 A	HD 153720 B	Przybylski's star
1	2	He I	−0.01	−0.1					
2	3	Li I							3.1
3	4	Be I				−0.29			
4	6	C I	−0.16	−0.19		0.00	−0.37	−0.40	
5	7	N I				0.15	−0.31	−0.52	
6	8	O I	−0.14	−0.25		0.21	−0.19	−0.48	−0.53
7	10	Ne I	0.06						
8	11	Na I				0.01	−0.16	0.16	−0.14
9	12	Mg I	−0.09	−0.43		−0.07	−0.16	−0.37	
		Mg II	−0.09	−0.30		0.02		−0.21	
10	13	Al II	0.17	−0.15		0.04	−0.09	−0.09	
11	14	Si I					−0.11	−0.14	
		Si II	−0.58	−0.68		−0.08	−0.09	−0.14	
12	15	S I				0.02	0.23	0.15	
		S II	0.13	0.05					
13	19	K I					0.09	0.17	
14	20	Ca I				−0.09	−0.17	−0.49	−0.68
		Ca II	0.26			0.03	−0.19	−0.47	
15	21	Sc II	0.25	0.04		−0.03	−0.03	−0.47	
16	22	Ti I					0.18	−0.23	
		Ti II	0.25	0.91		−0.03	−0.14	−0.37	
17	23	V I				0.06			
		V II				0.21			
18	24	Cr I	0.41			−0.02	−0.08	−0.01	
		Cr II	0.25	0.75		0.02	−0.21	−0.07	
19	25	Mn II	0.61	1.01		−0.04	0.00	0.03	
20	26	Fe I	0.24	0.07		0.02	−0.03	0.02	−0.96
		Fe II	0.08	0.02		−0.01	0.04	0.14	−0.58
21	27	Co I				0.14			
		Co II				0.25			
22	28	Ni I		0.37		0.18	−0.07	0.01	
23	29	Cu I			1.06	0.25		0.05	
24	30	Zn I		1.29	1.17	0.22	0.11	0.22	
25	31	Ga I	spot	spot	1.11				
26	32	Ge I				0.49			
27	34	Se I			1.40	0.23			
28	38	Sr II				0.38			
	39	Y II		2.97	1.18	0.58	0.36	0.53	
29	40	Zr II		1.59	1.18	0.36	0.21	0.23	
		Zr III			1.16				
30	41	Nb II			1.77	0.47			
		Mo II			1.18	0.72			
31	43	Tc I							3.5:
32	44	Ru II			1.61	0.53			
33	48	Cd II			1.77				
34	50	Sn II			1.79				
35	56	Ba II	1.28	1.69		0.56	0.23	0.37	
36	57	La II		2.83		0.61			2.52
37	58	Ce II		2.40	2.29	0.49	0.19		2.83
38	59	Pr II				0.52			1.79
		Pr III				0.50			2.16
39	60	Nd II				0.51			2.93
		Nd III				0.49			3.66
40	61	Pm I							exist
41	62	Sm II				0.51			3.41
42	63	Eu II				0.76			2.34
43	64	Gd II			2.16	0.97			3.34
44	65	Tb II				0.89			2.85
45	66	Dy II				0.78			3.19
46	68	Er II			1.61	0.84			2.90
47	69	Tm II			2.28	0.79			
48	70	Yb II		3.24	2.59	0.97			
49	71	Lu II		3.24		0.99			3.11
50	72	Hf II		3.49	2.40	0.76			

Table 1. <continuation>

N	Z	Element	66 Eri		Sirius	δ Sct	HD 153720		Przybylski's
			A	B			A	B	star
51	73	Ta II			2.99	1.18			
52	74	W II			2.91				
53	75	Re II			2.04				3.32
54	76	Os I							3.76
		Os II			1.79	0.92			
55	77	Ir I							3.60
		Ir II			1.80				
56	78	Pt I		4.95		0.83			
		Pt II			2.24				
57	79	Au I		5.65					
58	80	Hg I		4.79					
		Hg II		5.31	1.58				
59	82	Pb II			3.03				< 2.8
60	83	Bi II			3.29				< 1.4
61	84	Po I							exist
62	86	Rn I							exist
63	88	Ra I							< -1
64	89	Ac I							exist
		Ac II							exist
65	90	Th II			3.29	1.02			
66	91	Pa I							exist
		Pa II							exist
67	92	U II			3.04				
68	93	Np I							exist
69	94	Pu I							exist
		Pu II							exist
70	95	Am I							exist
		Am II							exist
71	96	Cm I							exist
		Cm II							exist
72	97	Bk I							exist
		Bk II							exist
73	98	Cf I							exist
		Cf II							exist
74	99	Es							exist

It is interesting to ask, why a "normal" binary appears to be a AmFm system? It should be noted that the fraction of Am and other chemically peculiar stars in this region of the HR diagram is significantly larger than the fraction of normal stars. Budaj [2] published a list of 61 standard non-chemically peculiar binaries with spectral classes from A4 to F1. Since 1996, high resolution spectroscopic observations were made for eight stars from this list. These include HD 153720, the subject of this paper, and HD 28052, HD 28910, HD 35557, HD 83808, HD 178449, HD 205767, HD 217796. Let us discuss the results of these observations.

HD 28052 (71 Tau) was investigated by Simon & Ayres [16]. HST observations showed a close companion with the separation near $0.1''$. This companion may be an active close binary of dG/dK stars. The primary may be a system of two identical early F stars with orbital period on the order of one year. Additional observations are necessary to study the nature of this star.

HD 28910 (86 Tau). Varenne & Monier [22] and Takeda & Sadakane [18] investigated the abundances of C, N, O, Na, Mg, Si, Ca, Sc, Fe, Ni, and Ba. The largest anomalies was found for sodium and barium – 0.54 and 0.7 dex overabundances, respectively.

HD 35557 (9 Aur). Hui-Bon-Hoa [9] determined the abundances of Mg, Ca, Sc, Cr, Fe, and Ni. The largest deviation from the solar abundance is the underabundance of Ni by -0.35 dex. The star was classified as normal.

HD 83808 (o Leo) was investigated by Griffin [8]. She found that both components of this binary have the Am characteristics. The abundance analysis showed that Fe, V, Cr, and Ti have solar abundances, Ca is underabundant by 0.45 dex, Y, Zr, Ba, La, Ce, Nd, and Sm are overabundant by an average of 0.67 dex, Eu is more abundant. The primary has the spectral type F9 III, the secondary – A7m. The primary giant star of a roughly solar temperature with the Am spectral characteristics is a challenge to the diffusion theory. While this exceptional system needs further investigation, it is clear that neither star is a standard.

HD 178449. The abundances of Li, S, Fe, and Ba in this star were found by Budaj & Iliev [3]. The underabundance of iron (−0.40 dex) and overabundance of Ba (+0.19 dex) and Li (+2.08 dex) show that the star can not be described as normal.

HD 205767 and H D217796 were in the list of stars given by Erspamer & North [6]. Abundances of 23 and 25 elements, respectively, were found for these stars. There are overabundances of Na (0.63 dex), Co (0.80 dex), Nd (0.89 dex), and Eu (0.57 dex) in the atmosphere of HD 205767. So, this star can not be used as a standard star. HD 217796 shows the underabundance of most of the elements. The iron and manganese deficiencies are 0.28 dex and 0.43 dex, respectively.

In summary, since 1996, eight stars (the above seven and HD 153720) from Budaj's list were investigated spectroscopically with a high resolution. Only one star (HD 35557) was classified as normal. But it should be noted that the abundances of only six chemical elements were found in this star and the heaviest investigated element was Ni. If the abundances of heavier elements were measured, it is possible that the classification of the star may be changed. The other seven stars show abundance peculiarities and illustrate the contention that it is quite difficult to find a normal star in this region of the HR diagram.

Before 1996, the chemical composition of the binary stars from Budaj's list [2] was investigated with a high resolution only for HD 57167 (R CMa). Tomkin & Lambert [20] found the abundances of C, N, O, S, and Fe in the atmosphere of the primary. The abundances were quite close to the solar values, but there are only five chemical elements. What are the abundances of other elements?

A detailed investigation of abundances using high-resolution spectroscopy permits one to find the peculiarities in stars which were known as normal. We are planning the observations of a set of binaries in this region of HR diagram, a big fraction of the set will be normal systems. Small deviations from the normalcy can be more useful for the understanding of the nature of peculiarities of CP stars. When different peculiarities in a star are well defined it is hard to explain the nature of this phenomena. A good illustration for this statement is the next section of the paper.

roAp STAR HD 101065 (PRZYBYLSKI'S STAR) – SHORT-LIVED RADIOACTIVE ELEMENTS?

The most peculiar main-sequence star HD 1010165 (Przybylski's star) was discovered more than 40 years ago. A review of investigations of the star can be found in [5]. The spectrum is crowded by a numerous lines of lanthanides. The existence of iron lines, which are common in all other stars, was a subject of several papers. The big part of the lines can not be identified as the lines of any stable chemical element or molecule. All these peculiarities have no exhaustive explanation up to now.

The star has been analyzed with the aim to identify the lines of some radioactive elements in its spectrum. Using the high-resolution VLT-spectra ($R = 80\,000$), we have identified the lines of the following elements: polonium ($Z = 84$), radon ($Z = 86$), radium ($Z = 88$), actinium ($Z = 89$), protactinium ($Z = 91$), neptunium ($Z = 93$), plutonium ($Z = 94$), americium ($Z = 95$), curium ($Z = 96$), berkelium ($Z = 96$), californium ($Z = 97$), and einsteinium ($Z = 99$). We proposed that the existence of short-lived isotopes of the above mentioned elements can be explained as a result of the radioactive decay of thorium and uranium whose presence in the Przybylski's star atmosphere was detected earlier. At the same time, the creation of the transuranium elements can be explained as a result of the neutron capture by some isotopes of thorium and uranium in the layers of their increased concentration as suggested by the diffusion theory.

It should be mentioned that the observed overabundances of thorium and uranium in this star is by three orders higher [4] than the solar system abundances. This result was obtained without taking into account the stratification of chemical elements in the atmosphere of the Przybylski's star. The real overabundances of thorium and uranium in certain levels of the atmosphere can be much higher. So, the natural nuclear reactor can work on these layers.

Also, the indications on surface spallation reactions in connection with a high ^{6}Li/^{7}Li ratio [17] and p-process reactions, related to promethium [5], were reported. It seem's reasonable that not only diffusion process is responsible for abundance anomalies in this star, but radioactive decay of uranium, thorium, and other radioactive elements. Several types of accretion processes can be important as well.

The abundances of 54 chemical elements in this star were investigated by Cowley *et al.* [4], the lithium abundance was found by Shavrina *et al.* [17], the identification of the lines of radioactive elements Tc and Pm were made by Cowley *et al.* [5]. We show our measurements of the abundances of chemical elements in the atmosphere of the Przybylski's star in Table 1. The abundances of technetium, lead, bismuth, and radium and identifications of the lines of radioactive elements heavier than bismuth, excluding thorium and uranium, are made for the first time. The atmosphere parameters were taken from [17]. A whole abundance pattern of Przybylski's star consists of 59 elements. This is the second stellar abundance pattern, after the Sun. In the case of evidence for the existence of 12 radioactive elements, the abundance pattern will be 71 elements. The star presents an unique astrophysical laboratory for testing of theories of stellar evolution.

CONCLUSION

The spectra of some stars, which belong to Hg–Mn, Am, roAp groups, were analyzed in detail. This analysis helps us to understand the nature of phenomena of stars at a particular stage of their evolution.

1. The more hot star of the double system 66 Eri has probably gallium spots on their surface. From five available spectra of the star, the gallium lines are found only in three spectra (probably for certain rotational phases).
2. The analysis of the spectrum of the hot Am-star Sirius shows the excess for thorium and uranium up to 3 dex. The star HD 153720 has the weakly expressed properties of Am stars. The pulsating star δ Sct has the usual characteristics of a Am-star. Therefore, there is no reason to mark out an subclass of δ Sct from δ Sct stars (as an Am-star).
3. The most surprising ro-Ap star, Przybylski's star, shows the lines of short-lived radioelements. It is a new result. We explain their presence by the natural decay of long-lived isotopes of thorium and uranium. The formation of elements, heavier than uranium and thorium, can be explained by an analogy with similar processes in uranium autunites on the Earth. The rather high lithium abundance may be product of spallation reactions and the preservation by a strong magnetic field.
4. The analysis of the chemical composition of atmospheres of peculiar stars of the main sequence has shown that we can investigate more chemical elements in atmospheres of these stars, in comparison with the Sun. Also, this quantity of elements transforms in a new quality, allowing us the further development of the theory of stellar evolution as well as theory of chemical evolution of the Universe.

Yushchenko *et al.* [25] described the main problems in the investigations of sharp-lined stars. To increase the quantity of the elements in the stellar abundance patterns it is necessary to use:

1. high signal/noise ratio and spectral resolution in stellar spectroscopy and in the spectra;
2. spectra in the blue and ultraviolet wavelength regions;
3. new atomic and molecular data;
4. the spectrum synthesis method by taking into account – for the majority of lines in the spectrum – hyperfine and isotopic splitting, magnetic fields, spots, detailed analysis of spectral binaries, individual atmosphere models, *etc.*

Yushchenko *et al.* [26] listed seven best stellar abundance patterns with amount of the elements more than 50. There are the Sun (73 elements), the halo stars GS 22892–05 and GS 31082–001, Procyon, Przybylski's star, the HgMn star χ Lup, and the barium star ζ Cyg.

The abundance pattern of Przybylski's star should be increased by five, maybe, by seventeen elements. The abundance pattern of Sirius also has more than 50 elements. We hope in the nearest future to add several elements to the abundance pattern of δ Sct. The curves of chemical abundances of this level of completeness permit one to get new astrophysical results.

It should be noted that two of nine above listed stars with the best abundance patterns were investigated using the spectra obtained at the 2-m telescope of the Terskol Observatory. The excellent quality of the MAESTRO spectrograph [11] makes these results available.

The list of chemical elements in Table 1 consists of 74 items. It includes abundance patterns of seven stars, five of them are the members of binary systems. The possible difference between the solar abundance pattern and the best of these seven patterns is only two elements. It means that stellar atmospheres become a powerful source of information on the chemical composition of the Universe.

Maybe, one of the main results of this short review is the possibility that the diffusion theory can be not the unique reason of abundance anomalies in Sirius and in Przybylski's star. Accretion, radioactive decays and spallation reaction, and, maybe, other unknown effects can be the additional mechanisms.

We listed a set of papers (for example [8]) where the validity of the diffusion theory is discussed. We hope that, as usually, a new level of the observational data analysis will lead us to a new understanding of the physical phenomena. It seems reasonable that accretion processes, spallation reactions, radioactive decays and other nuclear reactions, and, maybe, some additional phenomena need a careful investigation to show their role in stellar evolution.

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[1] *Adelman S. J., Adelman A. S., Pintado O. I.* On the relationship between the mercury-manganese stars and the metallic-lined stars // Astron. and Astrophys.–2003.–**397**, N 1.–P. 267–273.

[2] *Budaj J.* On the nature of the AM phenomenon or on a stabilization and the tidal mixing in binaries. I. Orbital periods and rotation // Astron. and Astrophys.–1996.–**313**, N 2.–P. 523–531.

[3] *Budaj J., Iliev I. K.* Abundance analysis of Am binaries and search for tidally driven abundance anomalies. I. HD 33254, HD 178449 and HD 198391 // Mon. Notic. Roy. Astron. Soc.–2003.–**346**, N 1.–P. 27–36.

[4] *Cowley C. R., Ryabchikova T., Kupka F., et al.* Abundances in Przybylski's star // Mon. Notic. Roy. Astron. Soc.–2000.–**317**, N 2.–P. 299–309.

[5] *Cowley C. R., Bidelman W. P., Hubrig S., et al.* On the possible presence of promethium in the spectra of HD 101065 (Przybylski's star) and HD 965 // Astron. and Astrophys.–2004.–**419**, N 2.–P. 1087–1093.

[6] *Erspamer D., North P.* Automated spectroscopic abundances of A and F-type stars using echelle spectrographs. II. Abundances of 140 A–F stars from ELODIE // Astron. and Astrophys.–2003.–**398**, N 3.–P. 1121–1135.

[7] *Gopka V. F., Yushchenko A. V., Mishenina T. V., et al.* Atmospheric Chemical Composition of the Halo Star HD 221170 from a Synthetic-Spectrum Analysis // Astron. Rep.–2004.–**48**, N 7.–P. 577–587.

[8] *Griffin R. E.* Composite Spectra. XII. Omicron Leonis: An Evolving Am Binary // Astron. J.–2002.–**123**, N 2.–P. 988–1001.

[9] *Hui-Bon-Hoa A.* Metal abundances of field A and Am stars // Astron. and Astrophys. Suppl. Ser.–2000.–**144**, N 1.–P. 203–209.

[10] *Khokhlova V. L., Zverko Yu., Zhizhnovskii J., et al.* Chemical composition of components A and B of the HgMn chemically-peculiar eclipsing SB2 star AR Aur // Astron. Lett.–1995.–**21**, N 6.–P. 818–834.

[11] *Mysaev F., Galazutdinov G., Sergeev A., et al.* The new coude-echelle spectrograph for 2-m telescope IC AMER (Northern Caucasus) // Kinematics and Physics of Celestial Bodies.–1999.–**15**, N 3.–P. 282–285.

[12] *Preston G. W.* The chemically peculiar stars of the upper main sequence // Annu. Rev. Astron. and Astrophys.–1974.–**12**.–P. 257–277.

[13] *Rachkovskaya T. M.* Abundances of C, N, O, and other Elements in the Atmospheres of the delta Scuti Variables 14 Aur, delta Sct, and HD 127986 // Astron. Rep.–2000.–**44**, N 4.–P. 227–234.

[14] *Rogerson J. B.* The Copernicus ultraviolet spectral atlas of Sirius // Astrophys. J. Suppl. Ser.–1987.–**36**, N 2.–P. 369–486.

[15] *Russell S. C.* Lithium Abundances in delta Scuti Stars and Their Relationship with the Lithium Dip // Astrophys. J.–1995.–**451**, N 2.–P. 747–757.

[16] *Simon T., Ayres T. R.* 71 Tauri: Hyades Enigma Resolved? // Astrophys. J.–2000.–**539**, N 1.–P. 325–330.

[17] *Shavrina A. V., Polosukhina N. S., Pavlenko Ya. V., et al.* The spectrum of the roAp star HD 101065 (Przybylski's star) in the Li I 670.8 nm spectral region // Astron. and Astrophys.–2003.–**409**, N 2.–P. 707–717.

[18] *Takeda Y., Sadakane K.* Oxygen lambda 7771–7775 Triplet in Hyades A-Type Stars: A Quest for the Key to the AM Phenomenon // Publs Astron. Soc. Jap.–1997.–**49**, N 3.–P. 367–382.

[19] *Titus J., Morgan W. W.* On the Classification of the a Stars. I. The Spectral Types of the Brighter Members of the Hyades Cluster // Astrophys. J.–1940.–**1**.–P. 256–261.

[20] *Tomkin J., Lambert D. L.* The chemical composition of algol systems. IV. The primary of R CMa // Mon. Notic. Roy. Astron. Soc.–1989.–**241**, N 4.–P. 777–785.

[21] *Tsymbal V. V., Kotchukhov O. P., Khokhlova V. L., et al.* Chemical composition of the CP Hg–Mn components of approximately equal mass in the SB2 system 46 Draconis // Astron. Lett.–1998.–**24**, N 1.–P. 90–105.

[22] *Varenne O., Monier R.* Chemical abundances of A and F-type stars: the Hyades open cluster // Astron. and Astrophys.–1999.–**351**, N 1.–P. 247–266.

[23] *Yushchenko A. V., Gopka V. F., Khokhlova V. L., et al.* Atmospheric chemical composition of the "twin" components of equal mass in the CP SB2 system 66 Eri // Astron. Lett.–1999.–**25**, N 7.–P. 453–466.

[24] *Yushchenko A. V., Gopka V. F., Khokhlova V. L., et al.* Orbital Elements of SB2 System 66 Eri // Information Bulletin on Variable Stars.–2001.–**5213**.–P. 1–4.

[25] *Yushchenko A. V., Gopka V. F., Kim C., et al.* Chemical Abundance Patterns for Sharp-Lined Stars // J. Korean Astron. Soc.–2002.–**35**, N 4.–P. 209–220.

[26] *Yushchenko A. V., Gopka V. F., Kim C.* The chemical composition of the mild barium star HD 202109 // Astron. and Astrophys.–2004.–**413**, N 3.–P. 1105–1114.

[27] *Yushchenko A. V., Gopka V. F., Khokhlova V. L., et al.* HD 153720 – A SB2 system with twin metallic-line components // Astron. and Astrophys.–2004.–**425**, N 1.–P. 171–177.