THE PLANETARY HOST RED GIANT HD47536 – CHEMICAL COMPOSITION AND SIGNS OF ACCRETION

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ABSTRACT. The spectra of HD47536 with resolving power R=30,000 and signal to noise ratio near 100 was obtained at 1.5 meter SMART telescope of CTIO, Chile. The analysis of chemical composition allowed to find the abundances of 33 chemical elements including thorium. The star belongs to halo or intermediate population, it's metallicity is [Fe/H]=-0.58±0.11, the *r*- and *s*-processes elements are overabundant with respect to iron. The overabundance of thorium with respect to iron is +0.72 dex. The abundance pattern exhibits the clear signs of accretion. The star is a host of two planets, that is why it can be the result of the accretion in planetary system or the accretion of interstellar gas. The signs of accretion are clearly detected and prevent the determination of stellar age.

Key words: stars: late-type - stars: individual: HD 47536 – stars: abundances – stars: planetary systems

1. Introduction

HD47536 is a bright (V=5.25) halo or intermediate population K-type giant. The metallicity of HD47536 was found by different investigators in the range from [Fe/H]=-0.54±0.10 (Sadakane et al. 2005) to [Fe/H]=-0.68 (da Silva et al. 2006). It hosts two planets, the first of them was discovered by Setiawan et al. (2003). The mass of this planet exceeds 5 mass of Jupiter, the semimajor axis of orbit can be more than 1.6 astronomical units, the excentricity of orbit is 0.2. Note that the radius of the star is 21.36±1.47 $R_\odot$ (van Belle & von Braun, 2009). It means that the closest distance between the planet and the host star can be as small as only 1.3 astronomical units or 13 radiuses of the host star.

The chemical composition of HD47536 was analysed earlier, the metallicity (Sadakane et al., 2005) and the abundances of few chemical elements were found, namely the upper limits of lithium and beryllium by Galvez-Ortiz et al. (2011), the abundances of oxygen by Ecuvillon et al. (2006), of sodium, magnesium, and aluminium by Beirao et al. (2005), of sulphur by Caffau et al. (2005), and of Si, Ca, Sc, Ti, V, Cr, Mn, Co, and Ni by Gilli et al. (2006).

That is why HD47536 was included in our program of investigating the chemical composition of stars with planets. The abundances of planetary hosts were compared with the abundances of stars without planets in numerous researches.

As an example it is possible to notice that the survey of 1111 FGK stars (Adibekyan et al., 2012) shows for the stars with giant planets up to 0.5 dex higher abundances of N, Mg, Al, Si, Ca and iron group elements than for the stars without planets or with Neptunian and super-Earth planets. In accordance with this investigation the stars without planets and stars with non-giant planets have similar abundances of above pointed chemical elements.

Is it possible to predict the existence of planets having the information about the abundance pattern only? Is it possible to distinguish the stars with non-giant planets and the stars without planets? To answer these questions it is necessary to find the reliable abundance patterns of different stars and to analyze the derived abundances.

In the next sections of this paper we will show the abundances of 33 chemical elements in the atmosphere of HD47536 derived by model atmospheres method and discuss the features of this abundance pattern possibly derived by the accretion from planetary system.

2. Observations

Four spectra of HD47536 were observed with Chiron spectrograph installed at 1.5 meter SMART telescope of CTIO, Chile in 2012. The spectral resolving power was R=30,000, the wavelength range – 4105-8170 Å, the signal to noise ratio exceeds S/N=100 at the centers of echelle orders.

The initial reduction of spectra was made using standard IRAF package, the final spectra process-

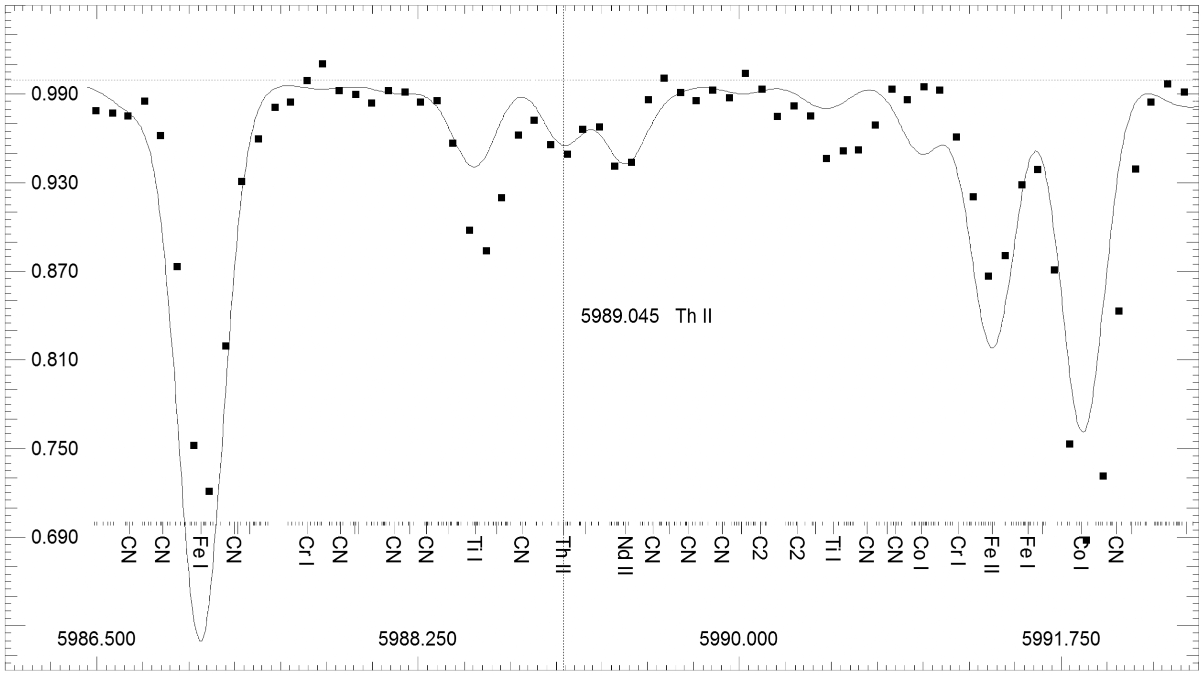

Figure 1: The spectrum of HD47536 in the vicinity of thorium line λ 5989.045 Å. The axes are the wavelength in angstroms and the relative intensities. One of the observed spectra is shown by filled squares. The solid line indicates the synthetic spectrum. The abundances of chemical elements with Z<38 are accepted to be deficient by -0.5 dex with respect to the Sun. The solar abundances of heavier elements were selected for this calculation. The wavelengths of used atomic and molecular lines are indicated in the bottom part of the plot. The identifications of strongest lines are shown.

ing, including continuum placement, coadding of the spectra, identification of spectral lines, and equivalent widths measurements was made using URAN program (Yushchenko, 1998).

The example of spectrum in the vicinity of thorium line 5989.045 Å is shown in Fig. 1. Note that the synthetic spectrum of HD47536 was calculated for the whole observed wavelength region. It was taken into account in continuum placement and identification of spectral lines.

3. Atmospheric parameters

To find the values of effective temperature, surface gravity, microturbulence and metallicity of the host star we calculated the iron abundances for a grid of atmosphere models taken from Castelli & Kurucz (2003). The grid was interpolated in the ranges of 4000 K$\leq T_{\rm eff} \leq$4000 K, 1.0$\leq \log g \leq$3.0 by steps 50 K in $T_{\rm eff}$ and 0.05 in $\log g$ respectively.

The equivalent widths of 90 and 18 clean lines of neutral and singly ionized iron respectively were measured in the observed spectrum of HD47536. Using these lines the iron abundances were calculated for grids of models described here before with nine values of microturbulent velocity distributed in the range from 0.1 to 6 km s^{-1}.

The obtained abundances were analyzed to find the values of atmosphere parameters which satisfy several conditions, namely the zero correlations of abundances with equivalent width, energies of low levels, and wavelengths of used lines, as well as the equality of mean iron abundances calculated for neutral and ionized species.

After several iterations the values of 4400 K, 1.80, 1.5 km s^{-1}, and -0.58 were found for effective temperature, surface gravity, microturbulent velocity and metallicity respectively. More detailed description of used method can be found in resent papers by Kang et al. (2012, 2013) and our earlier publications.

The obtained results coincide with previous determinations of these parameters. For example Chezzi et al. (2010) found for the above listed parameters the values of 4588 K, 2.17, 2.03, and -0.61 respectively. The values of effective temperature of HD47536 published by different researches ranged from 4352±70 K (da Silva et al. 2006) to 4853±130 K (van Belle & von Braun 2009).

4. Chemical composition

The identification of spectral lines in observed spec-

Table 1: Chemical composition of HD47536

Z	Ion	ΔlogN	σ	n
6	C I	-0.32		1
11	Na I	-0.14	0.34	8
12	Mg I	-0.34	0.18	8
13	Al I	-0.41	0.31	8
14	Si I	-0.32	0.19	11
16	S I	-0.19		1
19	K I	-0.06		1
20	Ca I	-0.32	0.20	11
21	Sc I	-0.56	0.07	4
	Sc II	-0.29	0.27	8
22	Ti I	-0.31	0.29	18
	Ti II	-0.76	0.24	2
23	V I	-0.15	0.26	17
24	Cr I	-0.40	0.29	15
	Cr II	-0.49		1
25	Mn I	-0.31	0.34	10
26	Fe I	-0.58	0.11	90
	Fe II	-0.59	0.14	18
27	Co I	-0.21	0.36	18
28	Ni I	-0.42	0.24	25
30	Zn I	-0.17	0.22	3
37	Rb I	0.07	0.10	2
38	Sr I	-0.16	0.25	2
39	Y I	-0.55		1
	Y II	-0.46	0.22	10
40	Zr I	-0.30	0.30	10
	Zr II	0.00	0.06	2
41	Nb I	-0.19		1
42	Mo I	-0.08	0.26	4
44	Ru I	-0.17	0.11	3
57	La II	-0.19	0.21	14
58	Ce II	-0.48	0.16	6
59	Pr II	-0.21	0.27	4
60	Nd II	-0.04	0.38	12
62	Sm II	0.11	0.23	9
64	Gd II	0.34	0.20	4
68	Er II	-0.07		1
74	W I	-0.32	0.12	2
90	Th II	0.14		1

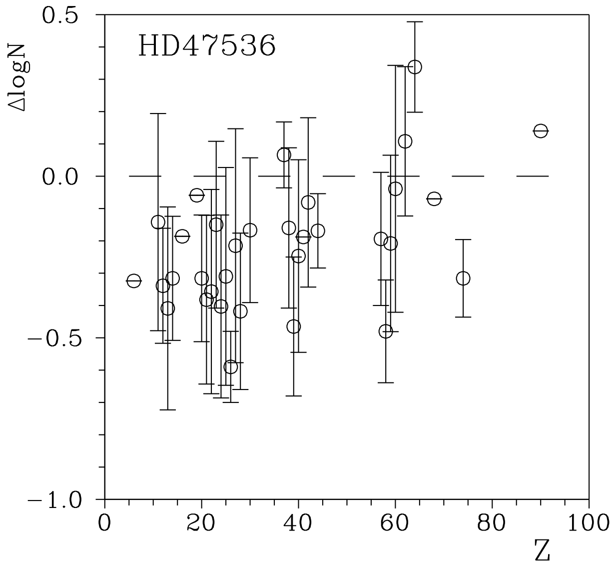

Figure 2: The abundances of chemical elements in the atmosphere of HD47536 with respect to the solar abundances (horizontal dashed line). The axes are the atomic numbers and the relative abundances.

trum of HD47536 was based on the comparison with synthetic spectrum calculated for the whole wavelength region of observed spectra. After several iterations we selected the atmosphere model (parameters were pointed in previous section) with the enhanced abundances of heavy neutron captured elements, namely the abundances of elements with atomic numbers Z≥38 were accepted to be solar, while all lighter elements were underabundant by 0.5 dex with respect to the solar values. It allowed to reach the better fit of observed spectrum by calculated one.

To find more precise result the equivalent widths of identified lines were measured and the abundances for individual lines were calculated using Kurucz's program WIDTH9. Table 1 contains the mean values of abundances of 33 chemical elements with respect to the solar or solar system values (Grevesse et al. 2010), the errors, and the number of used lines.

Fig. 2 shows the abundance pattern of HD47536. The r- and s-processes elements are slightly overabundant with respect to iron. It resembles the usual case of halo star with enhanced abundances of heavy elements.

Note that the overabundance of thorium is found using the line λ 5989.045 Å. This line was identified for the first time in stellar spectra by Yushchenko et al. (2005).

5. Discussion

Usually the low abundances of chemical elements in metal-poor stars were explained by formation of these stars at the early evolutionary stages of the Universe, when the synthesis of elements heavier than helium in stellar interiors took place and the abundances of these elements were lower than those at present time.

If the mass of star is low enough to exist up to the present time the abundance pattern of such star can reflect the chemical composition of the Galaxy at the birth time of the star. That is why one can try to estimate the stellar age using the abundance ratio of radioactive and stable or of two radioactive elements. Usually the ratio of Th and Eu abundances is used.

To calculate the age one should know the initial abundance ratio and to find the present value of this ratio from observations. The application of this method allowed to find the ages of metal-poor stars with enhanced abundances of heavy elements.

The necessary conditions to determine the reliable age are:

1) the information about the initial abundance ratio, usually it is taken from the standard cosmology; that is why it is necessary to believe the validity of this theory;

2) the universality of r-process, more exactly it is the hypothesis that the abundance ratios in the products of different supernova explosions are equal;

3) the changes of abundance ratios mainly due to natural radioactive decay; the influence of other factors should be neglected of estimated.

To make the result independent on the validity of any theory it was proposed to find not the age but the age difference between different halo type stars, in this case the knowledge of initial abundance ratio is not necessary. Yushchenko et al. (2005) showed that the age difference between HD115444 and GS31082-001 can be as high as 48±14 billions years. To explain this result in the frames of standard cosmology it is necessary to reject the universality of r-process or to suppose the changes of abundance ratios not only due to natural radioactive decay.

The latest provement of nonuniversality of r-process was made by Ren et al. (2012), but the validity of the third condition (the changes of abundance ratios mainly due to natural radioactive decay) seems to be not doubted before. The abundance pattern of HD47536 allow us to discuss this item.

Fig. 3 shows the abundances of heavy elements in the atmosphere of HD47536 in comparison with solar system r-process abundances. The coincidence of abundances in the top panel seems to be satisfactory, but the bottom panel indicates that the deviations are as high as 0.3-0.5 dex.

Note that the metallicity of the star is only -0.58 dex and the heavy elements (except Rb, Sm, Gd, and Th) are overabundant with respect to iron by less than this

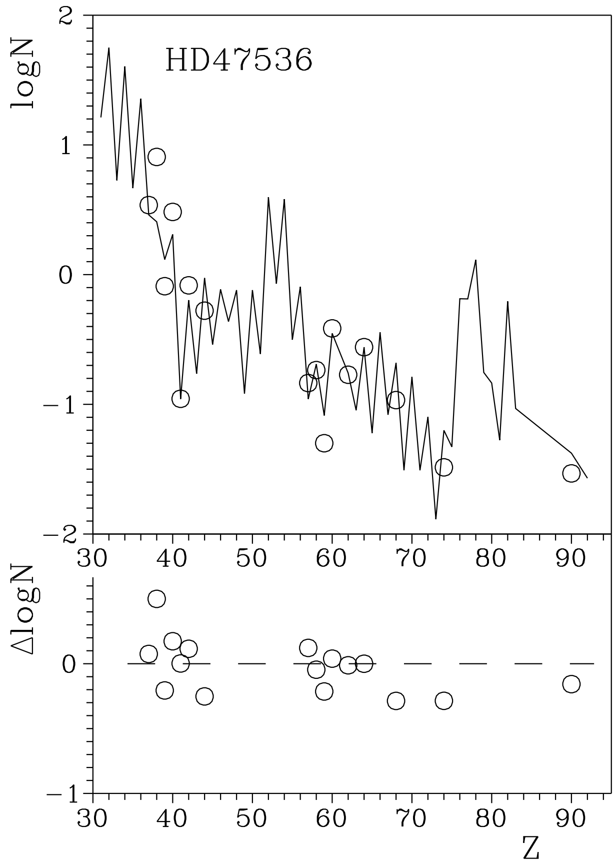

Figure 3: The top panel: the comparison of surface abundances in HD47536 (circles) with solar system $r-$process abundance distribution (line) taken from Simmerer et al. (2004). and scaled to the observed abundance of gadolinium. The bottom panel: the deviations of observed abundances in HD47536 from scaled solar system $r-$process abundance distribution.

value. That is why it seems desirable to find additional scenario which can influence the surface abundances in HD47536. Maybe the interaction of several physical phenomenons produce the observed abundance pattern.

Fig. 4 plots the relative abundance of chemical elements in the atmosphere of HD47536 against the condensation temperatures of these elements. The elements with condensation temperatures above 500 K exhibit the negative correlation of relative abundance and condensation temperatures. Similar correlations are observed also in λ Boo type stars, as it was discussed, for example, by Venn & Lambert (1990, 2008). It was explained by dust-gas separation mechanism in circumstellar envelopes.

HD47536 has a planetary system, that is why it is natural to expect the existence of circumstellar envelope. It is worth to note that the star shows the detectable IRAS fluxes. The observed values are higher than it can be predicted using the visual magnitude

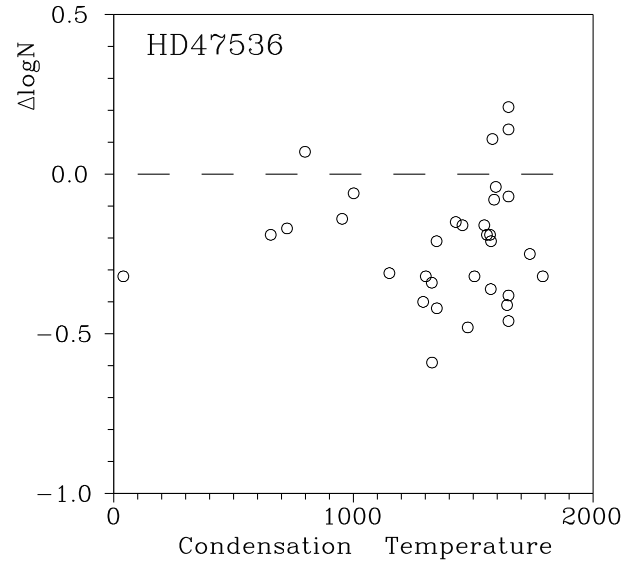

Figure 4: The plot of relative surface abundances of chemical elements in HD47536 as a function of the condensation temperature of these elements. The values of condensation temperatures for a solar-photosphere composition gas are taken from Lodders (2003).

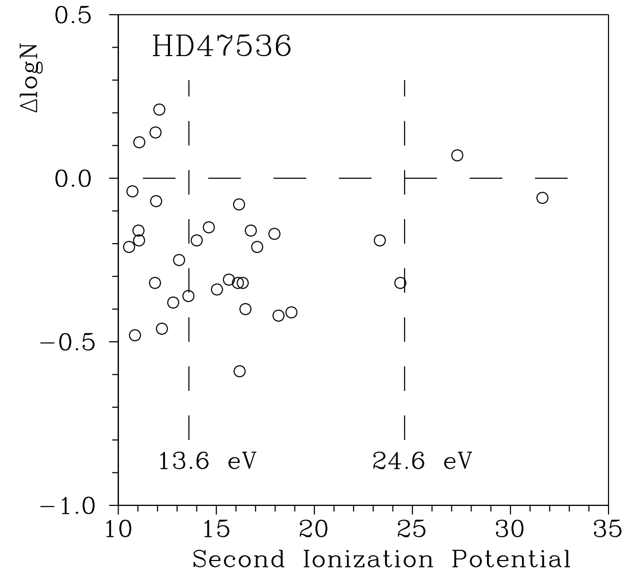

Figure 5: The plot of relative surface abundances of chemical elements in HD47536 as a function of second ionization potentials of these elements. The positions of the ionizations energies of hydrogen (13.6 eV) and helium (24.6 eV) atoms are marked by vertical dotted lines.

and effective temperature, that is why it is possible to claim the existence of infrared excess, which is usually explained by dust envelope.

Note that the star hosts two planets, one of them has the mass not less than 5 masses of Jupiter. Taking into account the parameters of orbital motion published by Setiawan et al. (2003) it is easy to estimate that the closest distance between the host star and the planet is only 13 radiuses of the host star. The discovery of two planets allow to suppose the existence of smaller planets at closer orbits. The accretion of matter from the planetary system can explain the λ Boo type features in the abundance pattern of HD47536.

We also tried to find the possible dependence between the relative abundances of chemical elements and the second ionization potentials of these elements (Fig. 5). It was first noticed by Greenstein (1949), one of the latest investigations of this effect was published by Böhm-Vitense (2006). Greenstein (1949) investigated Am stars and found that the relative abundances of elements with second ionization potentials close to the ionization potential of hydrogen are lower than relative abundances of other elements.

It was explained by the accretion of interstellar gas and the charge-exchange reactions between the atoms of interstellar gas (mainly hydrogen) and the target atoms in radiative stellar atmosphere. Kang et al. (2012, 2013) showed that in the case of strong accretion this effect can be detected in the atmospheres of cooler stars with convective atmospheres.

Fig. 5 allows to point the deficiency of elements with ionization potentials close to 13.6 eV (the ionization potential of hydrogen) and also the positive correlation of relative abundance and ionization potentials for chemical elements with second ionization potentials higher than 13.6 eV. Similar correlations was found by Kang et al. (2013) for both components of RS CVn type eclipsing binary LX Per.

Unfortunately the theory of charge-exchange reactions in stellar atmospheres was not developed in details. Recent observations shows that the results of this reactions can be detected not only is stars with radiative atmospheres but also in stars with effective temperatures as low as 5000 K (Kang et al. 2013). HD47536 has even lower effective temperature.

Figures 4 and 5 prove that the atmosphere of HD47536 is influenced by accretion from the outer space, and the relative abundances of chemical elements are changed due to accretion.

We found the abundance of thorium and it seems possible to determine the age of the star. But the clear signs of accretion prevent it. It is impossible to accept that the abundance ratios in the atmosphere of HD47536 were changed only due to natural radioactive decay.

It is hard to expect that the atmospheres of all metal-poor stars are influenced by the accretion of dust or gas. For example Kim et al. (2012) found no signs of dust accretion in the abundance pattern of BE Lyn. This halo star can be SX Phe type pulsating variable. But the accretion of interstellar gas should influence all galactic stars as any object should cross the plane of the Galaxy where the density of interstellar gas is enhanced. Even if the signs of this type accretion will be destroyed by convection or other effects it is not possible to neglect the importance of charge-exchange reactions on stellar and Galactic evolution.

As an example it is necessary to note that Havnes (1971) discussed the charge-exchange reactions as the effective mechanism of braking the rotation of magnetic stars and generating the cosmic rays.

6. Conclusion

The high resolution spectra of bright (V=5.25) planetary host star HD47536 was used to find the abundances of 33 chemical elements including thorium. HD47536 is a halo or intermediate population star. The heavy elements are enhanced with respect to iron. The relative oveabundance of thorium with respect to iron is +0.72 dex. The signs of accretion are clearly detected in the atmosphere of this object. The IRAS fluxes of HD47536 allow to point the existence of infrared excess.

It is impossible to accept that the abundance ratios of thorium and stable chemical elements in the atmosphere of HD47536 were changed mainly due to natural radioactive decay. It makes impossible the calculation of stellar age.

The results of this investigation will be used as the first iteration to determine the more accurate abundance pattern of this star by spectrum synthesis method.

Acknowledgements. This work was supported in part by Mid-career and General Researcher Programs, and Science and Technology grants 2011-0028001 and 2011-0010696 respectively, through the National Research Foundation (NRF) funded by the Ministry of Education of Korea. One of the authors was granted by the Swiss National Science Foundation (SCOPES project No. IZ73Z0 -128180/1).

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