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About the possiblility of explanation of the spectrum of Przybylski's star by the lines of radioactive elements.

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We made a short review of previous investigations of lines of short-lived radioactive elements in the spectrum of Przybylski's star (HD101065) and show that the best atmosphere model available today should be significantly improved. The synthetic spectra in the vicinities of lines of neutral and ionized technetium are calculated. Comparison of these spectra with high resolution VLT and IUE spectra permits to discuss the possibility of existence of technetium in the atmosphere of Przybylski's star.

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1. Introduction

The first detection of short-lived radioactive elements in stellar atmospheres was made by Merrill in 1952 [14]. This discovery help Burbidge et al. [7] to construct the theory of synthesis of chemical elements in stars. Przybylski's star was discovered in 1961 [16]. Many attempts were made to explain it's nature. There are a lot of unidentified lines in the spectrum. In many cases the number of unidentified lines is at least few lines per angstrom. The most numerous group of identified lines is lanthanides lines. In 60s and 70s of the last century radioactive elements were discussed as a possible source of absorption lines in the spectrum of Przybylski's star and other Ap stars (see [12] as an example). Later diffusion theory was proposed by Michaud (see [13] for latest review). The biggest problems is the different abundances for stars with very similar temperatures and gravities. Maybe additional phenomena can influence the chemical composition. One of these phenomena can be accretion. It was discussed in many papers from [17] to [6]. The numerical model of accretion in this type stars is not constructed yet.

Recently Cowley et al. [9] identified lines of Tc and Pm in the spectrum of Przybylski's star and made a review of previous investigations of this object. Later Gopka et al. [10] and Bidelman [4] identified the lines of short lived actinides and elements with $83 < Z < 89$ in the spectrum of Przybylski's star. In both papers NIST [18] line lists were used. [10], [11], and [21] discussed three possible phenomena, which can produce the short lived radioactive elements in the atmosphere of Przybylski's star and related stars. These are: natural radioactive decays of U and Th and other reactions in the layers of atmosphere with overabundances of Th and U; contamination of the atmosphere by close Supernova event near one million years ago; spallation reactions at the stellar surface.

Yushchenko et al. [21] used new actinides line data [5] and found new identifications of short-lived actinides in the spectra of Przybylski's star. It can be the confirmation of the hypothesis that these elements really exist in the stellar atmosphere. [21] also investigated the stratification of Fe, Ba, Th and U in the atmosphere of Przybylski's star, estimated the low limit of abundances of actinides, and showed that the contamination of atmosphere by SN or spallation reactions can explain the observed abundances.

It should be noted that information about atomic parameters of lines of short-lived radioactive elements is very limited. For lines of several elements even the ionization stage is not known. The existence of these elements in the stellar atmospheres is still in question. It should be noted that the majority of papers about the short-lived radioactive elements in the atmospheres of Ap and roAp stars (Przybylski's star is a prototype of roAp stars) usually discuss only line identifications. To prove the existence of these elements it is necessary to make more detailed investigation.

In this paper we tried to make the classical abundance analysis of radioactive elements in the atmosphere of Przybylski's star. Unfortunately oscillator strengths and other atomic parameters are available only for technetium. That is why we restricted this paper by Tc abundance only. In the next sections we will discuss the selection of atmosphere model and the abundance of Tc in Przybylski's star.

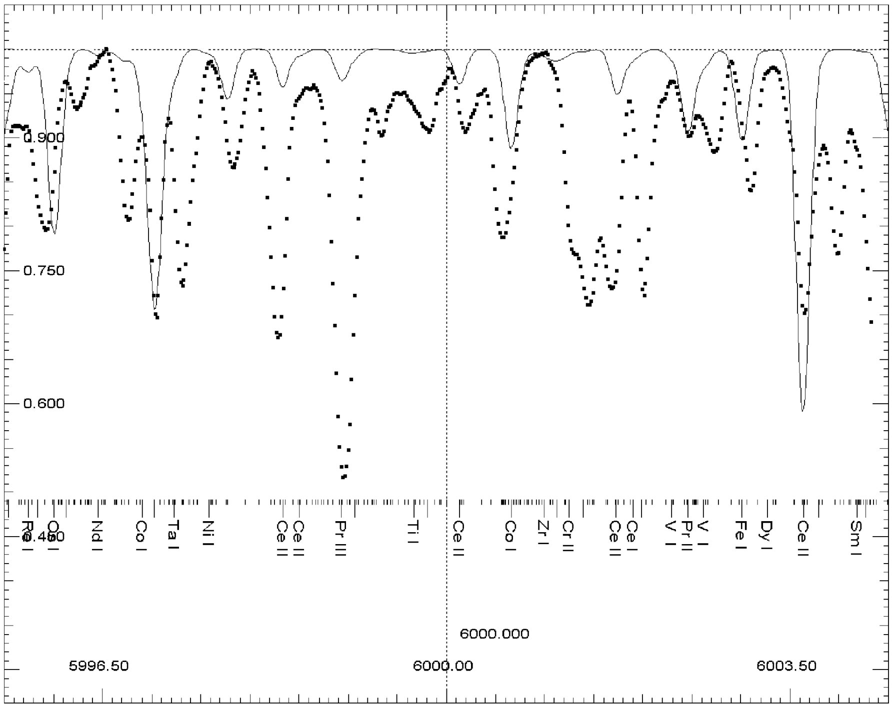

Figure 1: Spectrum of Przybylski's star at 6000 Å. Axes are wavelength in angstroms and relative fluxes. Points is VLT spectrum. Line – synthetic spectrum without stratification. Part of the strongest lines are marked in the bottom part of the figure..

2. Atmosphere model and observations

The most detailed chemical composition of Przybylski's star was made by Cowley et al. [8]. Abundances of 54 chemical elements was found in the atmosphere of the star. Later Shavrina et al. [19] found Li abundance. Upper limits of Pb and Bi abundances was found by [10]. As it was mentioned in previous section, identification of Tc and Pm was made by [9]. [20] pointed that the abundance pattern of Przybylski's star is second after the solar one. That is why it is naturally to expect that the atmosphere model of Przybylski's star is well defined and the approximation of observed spectrum by calculated one is at least satisfactory. Is it true ?

Maybe the best model of Przybylski's star was found by [8]. All investigations of Przybylski's star during the next six years used the parameters of this model. Cowley et al. [8] found $T_{\rm eff}$=6600 K, log g=4.2, $v_{\rm micro}$=2 km s^{-1} using the spectra in the wavelength range from 3959 to 6652 Å.

We used the spectrum of Przybylski's star observed at VLT [2] in the wavelength range from 3040 to 10400 Å, with signal to noise ration near 300 in red part of the spectrum. Resolving power was pointed by [2] to be equal R=80,000. IUE exposure LWR06999HL was also used. It's quality can not be compared with VLT, that is why IUE spectrum was used for identifications only.

[19] calculated new model with these parameters and Cowley et al. [8] abundances. We calculated synthetic spectrum and colors using this model and found that the fitting of observed spectrum and colors of Przybylski's star in red spectral region is satisfactory.

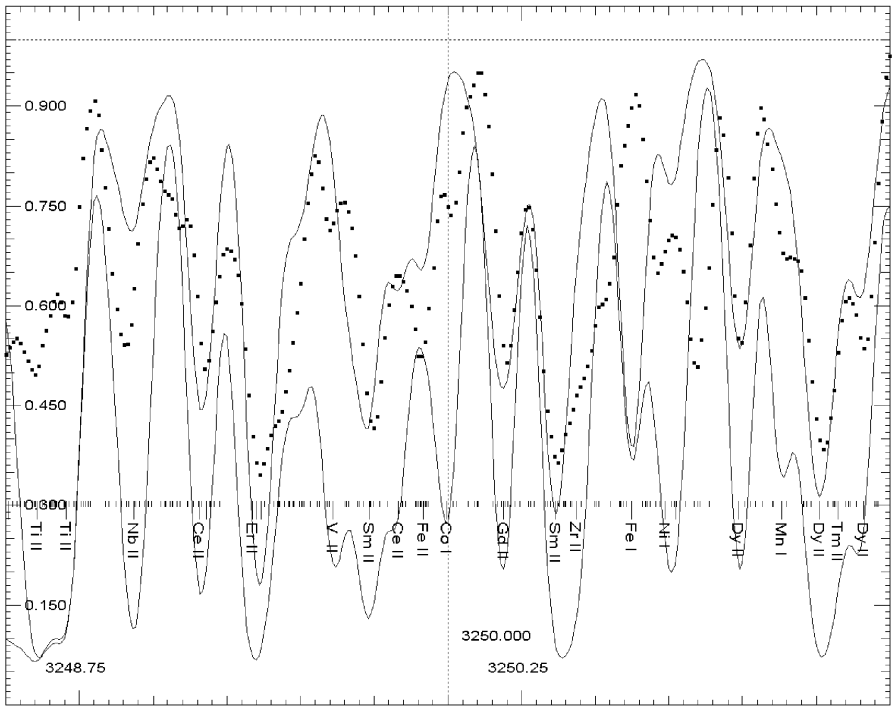

Figure 2: The same as Fig. 1 at 3250 Å. Lines – synthetic spectrum without stratification (low curve) and with stratification (upper curve).

Unfortunately blue colors and fitting of the spectrum shortward of 4000 Å seems unreliable. It should be noted that bad coincidence of observed and calculated U-B colors was pointed by [8]. Fig. 1-2 show the typical examples of the spectrum in red and near ultraviolet regions. The synthetic spectrum, calculated without the stratification, in ultraviolet is deeper than the observed one. We tried to find the reason of this discrepancy. It is well known that Ap and roAp stars shows the stratification of chemical elements in their atmospheres. [21] found the stratification of Fe, Ba, Th, U in the atmosphere of Przybylski's star, and constructed preliminary model of stratification for all elements. Fig. 2 shows two synthetic spectra, calculated with stratified and not stratified abundances. It is clear that stratification strongly influence on synthetic spectrum, and new stratified model can change the abundances of all elements significantly.

Diffusion of chemical elements can be the reason of stratification. It seems that another phenomena, namely accretion, can be more important for Przybylski's star. As it was mentioned here before, accretion has been discussed in many papers as the reason of abundance anomalies in Ap stars. We tried to construct 3D and 2D numerical models of accretion for Przybylski's star. The first results show that the stratification can be produced by accretion and it is possible to select the accretion model to fit the observed stratification of chemical elements.

In spite of unsatisfactory fit in ultraviolet spectral region, Cowley et al. [8] temperature, surface gravity, and abundances in combination with atmosphere model, calculated by [19] with these parameters is the best approximation for Przybylski's star today. That is why we used these parameters to estimate the abundance of technetium in the atmosphere of Przybylski's star. Stratification was not taken into account. Influence of stratification can change the exact value of abundance of certain element in the atmosphere, but the main aim of this paper is to show, is Tc exists in Przybylski's star ?

3. Technetium lines

We used the list of oscillator strengths of lines of the first and second spectra of Tc published in [3, 1, 15] and other papers. Kurucz partition functions and ionization potentials were used. Four synthetic spectra with different Tc abundance were calculated in the vicinities of all Tc lines. The used Tc abundances were logN(Tc)=3.9, 3.4, 2.9 in the scale logN(H)=12. The last spectrum was calculated without Tc lines. The detailed description of used line lists, programs, and atmosphere model can be found in [20, 19].

Figures 3–4 shows the examples of Tc lines. Observed spectrum is shown by filled squares. For wavelength longer than 3040 Å VLT spectrum is used, for shorter wavelength - IUE spectrum. synthetic spectra with different Tc abundances are shown by lines. Inspection of these and other strongest Tc lines permits to claim that the abundance of Tc in Przybylski's star can be of the order of logN(Tc)=3-4. It is quit close to the abundances of other chemical elements with Z=40-50. In some cases the approximation of observed spectrum is not satisfactory. Maybe better atmosphere model with stratified abundances, magnetic field, better oscillator strengths, other improvements will permit to reach closer agreement with observation.

4. Conclusion

In the conclusion of Cowley et al. [9] it was pointed out that the spectroscopic evidence presented in [9] paper is more than adequate to justify asserting the presence of one of the stable elements in the atmosphere of Przybylski's star. But Tc is not stable element. That is why the final conclusion on the existence of this element in Przybylski's star should be done later, when the better atmosphere model will be constructed. It seems to us, that new model will change the abundances, of course, but it will not influence on the main result of this and Cowley et al. [9] papers. Technetium lines can be present in the spectrum of Przybylski's star. It is necessary to built very complicated physical model to explain Tc lines by lines of other elements. [10, 11, 21] proposed three different scenarios to explain the existence of short-lived radioactive elements in stellar atmospheres.

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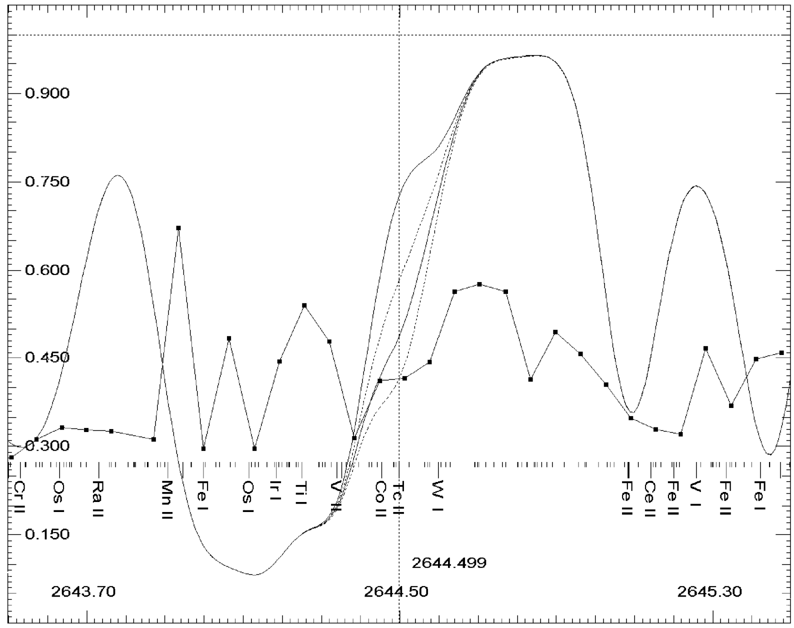

Figure 3: Spectrum of Przybylski's star in the vicinity of Tc II line 2644.499 Å. Axes are wavelength in angstroms and relative fluxes. Points and line is IUE spectrum. Dotted and solid lines – synthetic spectra with different Tc abundances, namely no Tc, logN(Tc)=2.9, 3.4, and 3.9 in the scale logN(H)=12.

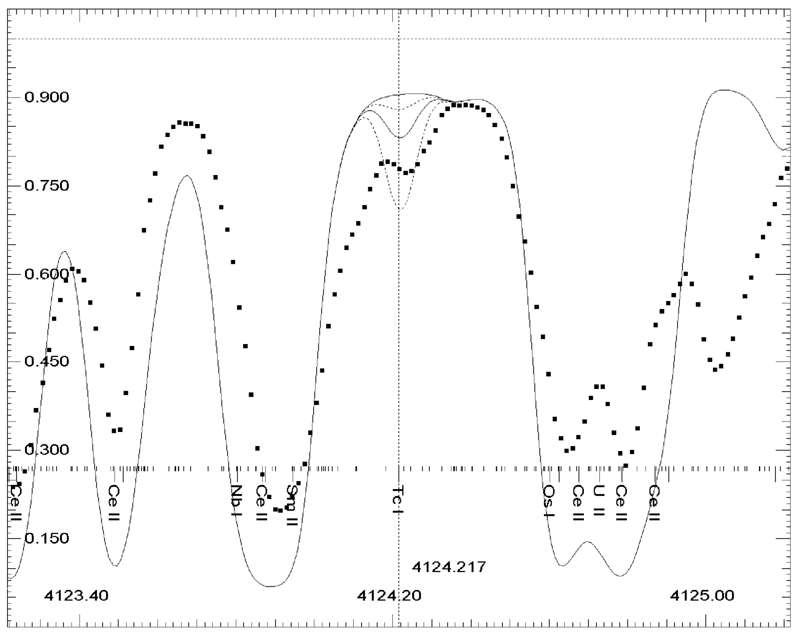

Figure 4: The same as Fig. 3 in the vicinity of Tc I line 4124.217 Å.. Axes are wavelength in angstroms and relative fluxes. Points is VLT spectrum.