On the evolutionary status of high-latitude variable V534 Lyr

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Abstract Based on the high resolution spectral monitoring conducted at the 6-m BTA telescope, we study the optical spectrum of the high-latitude variable V534 Lyr. Heliocentric radial velocities $V_r$ corresponding to the positions of all metal absorption components, as well as the Na I D and Hα lines were measured during all the observational dates. The analysis of the velocity field examining the lines of various nature revealed a low-amplitude variability of $V_r$ based on the lines with a high excitation potential, which are formed in deep layers of the stellar atmosphere, and allowed to estimate the systemic velocity of $V_{sys} \approx -125 \text{ km s}^{-1}$ ($V_{lsr} \approx -105 \text{ km s}^{-1}$). The distance estimate of $d \approx 6 \text{ kpc}$ for the star leads us to its absolute magnitude of $M_V \approx -5.3$, what corresponds to the MK spectral classification. The previously undetected for this star spectral phenomenon was revealed: at certain times a splitting of the profiles of low-excited absorptions is observed, reaching $\Delta V_r = 20-50 \text{ km s}^{-1}$. A combination of the parameters: reduced metallicity $[\text{Met}/H]_\odot = -0.28$, increased nitrogen abundance $[\text{N}/\text{Fe}] = +1.10$, large spatial velocity, high luminosity, a strong variability of the emission-absorption profiles of H1 lines, splitting of metal absorptions at different times of observations and the variability of the velocity field in the atmosphere allow us to classify V534 Lyr as a pulsating star near the HB and belonging to the thick disk of our Galaxy.

Keywords: stars, evolution, post-AGB stars, pulsating stars, optical spectroscopy.

1. Introduction

During the past two decades, the 6-meter telescope BTA hosts an investigation of the spectra of numerous supergiants with a large excess of IR-radiation, presumably belonging to the stage of the asymptotic giant branch (AGB) and post-AGB. The program also includes a study of some related stars with an unclear evolutionary status. At the post-AGB stage, far evolved intermediate-mass stars are observed, with initial masses at the main sequence $2 \div 9 \text{M}_\odot$. Before the AGB stage, these stars are cool (with effective temperature of $T_{eff} \approx 3000-5000 \text{ K}$) red supergiants. After they have exhausted helium, a degenerate carbon-oxygen core is formed in the core of AGB stars with an initial mass between $2-4 \text{M}_\odot$. This core is surrounded by alternately energetically active layers of He and H combustion. Most of the time, the hydrogen layer provides the energy release, but as the products of hydrogen burning join the helium
layer, a brief ignition of helium occurs in the latter. This configuration of the internal structure of the star is unstable, the theory predicts a fairly effective mixing and dredge-up (due to the penetrating convection) of heavy metals synthesized in nuclear reactions, accompanying these processes of energy release into the atmosphere of the star (see the survey \cite{1} and references therein).

Our initial goal was to determine the fundamental parameters of investigated stars and to search for the chemical composition anomalies in their atmospheres, related with the synthesis of chemical elements during the previous evolutionary stages. As the program runs, additional research became crucial, aimed to search for the time variability of spectral features and the velocity fields in the atmospheres and envelopes of studied stars. This expansion of the task required conducting for each program object of multiple observations with high spectral resolution in a broad wavelength range. The main results we have obtained from the spectroscopic data at the 6-m telescope are summarized in a number of recent publications \cite{2, 3, 4}. Let us briefly note the most important of them. Firstly, the parameters and chemical composition of the atmospheres for several tens of stars with an excess in infrared flux were determined. Secondly, evolutionary variations in chemical composition (a large excess of the s-process or hot-bottom-process elements) were found for seven stars \cite{5, 6, 7, 8, 9}. Based on the representative sample of stars, studied by us and the authors of \cite{10}, we formed a subsample of post-AGB stars with the atmospheres rich in the s-process carbon and heavy metals, and with the carbon-rich circumstellar envelopes. The analysis of properties of this subsample led us to the conclusion on the interrelation of the peculiarity of line profiles, manifested in the presence of the emission component of the NaI doublet D lines, in the character of molecular features, asymmetry, permitted or forbidden metal emissions, formed in the envelopes, and in the splitting of strong absorption profiles with a low lower-level excitation potential, with kinematic and chemical properties of the circumstellar envelope and with the type of its morphology \cite{2}.

The presence of the above-mentioned features is the main difference of the spectra of post-AGB stars from the spectra of massive supergiants. The splitting into the components of the profiles of strongest heavy-metal absorptions in the spectra of selected post-AGB supergiants we have detected allowed us to conclude that the process of formation of a structured circumstellar envelope is accompanied with an enrichment by the products of stellar nucleosynthesis \cite{3}. Variability of the observed profiles of the absorption-emission Hα line and metal lines, as well as the type change (absorption/emission) of the C2 molecule Swan bands registered in several objects are caused by the variations of the parameters or the structure of the circumstellar envelope. The Hα profile type (pure absorption, pure emission, P Cyg or inverse P Cyg-type, with two emission components in the wings) is not related to the chemical composition of the atmosphere of the central star. The main factors influencing the Hα profile type and its variability are the mass loss rate, the velocity of stellar wind, kinematics and optical thickness of the envelope.

We have discovered the peculiarities, previously unknown in the optical spectra of the AGB-candidate stars. In particular, based on the observations, also performed with the NES echelle spectrograph of the 6-m telescope, the spectral features and the velocity fields in the atmosphere and the envelope of the cool AGB-supergiant V1027 Cyg \cite{11}, the optical component of the IR source IRAS 20004+2955 were studied. For the first time, the spectrum of this star revealed the splitting of the cores of strong metal absorptions and their ions (Si II, Ni I, Ti I, Ti II, Sc II, Cr I, Fe I, Fe II, Ba II). The broad profile of these lines contains a stably located weak emission
in the core, the position of which can be considered as the velocity of the center of mass of the system (for brevity, we shall further refer to it as the systemic velocity) \( V_{\text{sys}} = 5.5 \text{ km s}^{-1} \). From the symmetric small and moderate-intensity absorptions, weak radial velocity variations were revealed with an amplitude of 5–6 km s\(^{-1}\), caused by pulsations. A red-wave H\(\alpha\) profile shift was observed, caused by the distortion of the line core. In the red spectral region, numerous weak lines of the CN molecule and the K\(17696\) Å line, which has a P Cyg-type profile are identified. An agreement of radial velocity, measured from the symmetric absorptions of metals and the CN lines indicates formation of a CN spectrum in the atmosphere of the star. Numerous interstellar bands, DIBs, were identified, the position of which in the spectrum, \( V_r(\text{DIBs}) = -12.0 \text{ km s}^{-1} \), corresponds to the velocity of the interstellar medium in the Local Arm of the Galaxy.

Absolutely new results were obtained for a nameless faint star [12], associated with a powerful source of IR radiation RAFGL 5081. Its optical spectrum has been studied for the first time based on the long-term spectral monitoring with high spectral resolution. The estimates of the spectral class of the star \( \text{Sp} \approx G5–8\) II and its effective temperature \( T_{\text{eff}} \approx 5400 \text{ K} \) were made. We detected a hard-to-explain spectral phenomenon: a splitting of the medium and low-intensity profiles of stationary absorptions. Stationarity of absorptions eliminates the possibility of explaining the double peaks owing to the spectral binarity of the star. Radial velocities for the wind components of the NaI D lines and H\(\alpha\) line profiles reach \(-250 \text{ km s}^{-1}\) and \(-600 \text{ km s}^{-1}\) respectively. These profiles contain narrow components, the number, the depths and positions of which vary with time. The time-variable multicomponent structure of the NaI D lines and H\(\alpha\) line profiles indicates the heterogeneity and instability of the circumstellar envelope of RAFGL 5081. According to the presence in the NaI (1) line profiles of the components with the velocity of \( V_r(\text{IS}) = -65 \text{ km s}^{-1} \), it is concluded that RAFGL 5081 is located behind the Perseus Arm, i.e. not closer than 2 kpc. Note that this object is associated with a reflective nebula GN 02.44.7. The problem of photometric monitoring for determining the variability parameters of the central star RAFGL 5081 is set.

In the study of sources with a large IR flux excess, we identified the stars outside the expected AGB and post-AGB stages. It turned out that among such objects, in addition to AGB- and post-AGB stars, there exist massive stars of extremely high luminosity with extended and structured circumstellar envelopes. The most famous object that has for many years been preferably considered as a star in the post-AGB stage is V1302 Aql, which has numerous peculiarities in the spectrum. For a long time, the evolutionary status of this supergiant, associated with a powerful IR source IRC+10420, was unclear. The set of observed properties of V1302 Aql allowed to consider it as a star at the post-AGB stage or as a very massive star, past the red supergiant stage. It is obvious that depending on the accepted status, and hence on the luminosity of the object too, the estimate of its distance from the observer may differ several times. One of the decisive arguments, confirming the status of a massive evolved star for V1302 Aql was obtained by us in the analysis of spectral data at the 6-m telescope when the chemical composition of its atmosphere was first determined and a significant excess of nitrogen was found [13]. Detection of a rapid growth of the effective temperature [13, 14] allowed to assume that the star quickly evolves with the \( T_{\text{eff}} \) increase rate of about 120 K a year. The phenomenon was for us an incentive to continue the spectral monitoring of this mysterious object. In the study of the V1302 Aql spectra over the period of observations of 1992–2014 the conclusion was drawn that the yellow hypergiant entered the phase of deceleration (or the suspension) of growth of the effective temperature and approached at the H–R diagram the high-temperature boundary.
of the Yellow Void [15]. It is appropriate to mention here the star HD 179821, which has for several decades appeared in the papers as a post-AGB candidate, and only a detailed analysis of the high-quality data of a long-term spectral monitoring with the echelle spectrographs of the SAO RAS 6-m BTA telescope and the McDonald observatory 2.7-m telescope (USA) led to the conclusion that it belonged to a family of massive evolved stars [16].

The experience obtained in the analysis of the spectra of stars of different luminosity and mass allows us to hope for a success in the study of stars with an obscure evolutionary status. The object of the present study is the star V534 Lyr (HD 172324, HIP 91359), located at the galactic latitude $b = 18^\circ 58$. Our interest to this relatively bright ($V = 8.16$) star is due to the fact that Trams et al. [17] included V534 Lyr in the list of high-luminosity stars at high Galactic latitudes (HGL). These authors attributed the major part of investigated objects to the post-AGB candidates. However, due to the lack of data on the IR flux, they classified V534 Lyr only as an alleged candidate in post-AGB. An additional stimulus to the study of V534 Lyr for us is the emission in the H I lines, found in the early paper by Bonsack and Greenstein [18] and confirmed later [19]. This star was repeatedly studied using various photometric systems [20, 21, 22] and spectral methods, but up to now, none of the available publications has a definite conclusion on its evolutionary status (see Table 1, in which the basic papers examining V534 Lyr are listed [23, 19, 24]).

### Table 1. Some previously published V534 Lyr research results

| Methodology                       | Results                  | Status                        | Reference |
|-----------------------------------|--------------------------|-------------------------------|-----------|
| IR Photometry                     | Lack of IR excess        | Post-AGB star?                | [23]      |
| Optical spectroscopy, method of model atmospheres | $M_V$, $V_r$, chemical composition | Post-AGB star? | [19]      |
| Optical Spectroscopy, method of model atmospheres | $V_r$ Variability and HI profiles, chemical composition | High Speed | HGL star? | [24] |

The purpose of this paper is to determine the main parameters of V534 Lyr using the high-quality optical spectral data, to search for the possible variability in time of the spectrum and the pattern of radial velocities in the atmosphere of the star, and to refine its evolutionary status. Section 2 briefly describes the used observational data and details of its processing. The data on the spectral features obtained from the high-resolution spectra and the detected profile features are given in Section 3. We make an attempt here to apply our data for the determination of luminosity, remoteness and evolutionary status of the star, as well as present a method for determining the parameters of the stellar atmosphere and calculating the abundances of chemical elements. Section 4 discusses the results of our study. The main conclusions are summarized in the final Section 5.

### 2. Observations and processing of spectra

In this study we used seven high-resolution spectra of V534 Lyr ($R = 60000$), obtained with the NES echelle spectrograph [25] of the 6-m BTA telescope on arbitrary dates in 2010 and 2017, as well as the earliest of our spectra, which was obtained on July 8, 2000 with the PFES echelle spectrograph installed in the primary focus of the 6-m telescope with a lower resolution of $R = 15000$ [26, 27], which imposed some restrictions on its use. Extraction of one-dimensional
spectra from two-dimensional echelle frames was executed using a modified version [28] of the ECHELLE context from the MIDAS software suite. The removal of traces of cosmic particles was done by the median averaging of two spectra obtained successively one after another. The wavelength calibration was carried out using the spectra of the hollow-cathode Th-Ar lamp. For the subsequent spectrophotometric and positional reduction of one-dimensional spectra we used a modified version of the DECH20t code [29]. The control of instrumental matching of the spectra of the star and the hollow-cathode lamp is made from the telluric lines [O I], O₂ and H₂O.

In more detail, the procedure for measuring the radial velocity \( V_r \) based on the spectra obtained with the NES spectrograph, and sources of error are described in [30]. The mean square \( V_r \) measurement error for stars with narrow absorptions in the spectrum does not exceed 1.0 km s\(^{-1}\) (one-line accuracy [30]). The initial data concerning the obtained spectra are presented in the first three columns of Table 2.

### 3. Main results

#### 3.1. Peculiarities of the V534 Lyr spectrum

A peculiar feature of the optical spectrum of V534 Lyr is a powerful emission of the H\( \alpha \) profile, which was noted in all the papers dealing with the spectroscopy of this star (see, for example, [19, 24] and references therein). The H\( \alpha \) line, which is present in seven of eight our spectra, is the most intense. The variations of its profile with a two-peak emission are significant. In the earliest
spectrum (July 8, 2000) the entire emission profile is located above the continuum. However, in the subsequent spectra the core of the absorption component which is formed in the surface layers of the atmosphere falls below the level of the continuum. The position of the absorption component, as well as the intensities and positions of the emission components vary, but the intensity of the long-wave peak is always higher than that of the short-wave peak (Fig. 1). The shift of the blue border of the absorption component relative to the vertical dashed line, corresponding to \( V_{\text{sys}} \) increases in the spectrum of September 24, 2010: \( V_r - V_{\text{sys}} \approx -50 \text{ km s}^{-1} \).

A drastic profile variation is observed in the 2017 spectrum. Instead of the two-peak profile we observe a P Cyg-type profile, the absorption component of which is shifted by \( V_r - V_{\text{sys}} \approx -70 \text{ km s}^{-1} \). The H\( \beta \) profile is registered in a smaller number of dates, but this is enough to notice how the stronger of the emission components passes from the red wing to the blue wing (Fig. 2). Similar variations of H\( \alpha \) and H\( \beta \) profiles in the spectrum of V534 Lyr were found in the paper [24]. As it can be seen in Fig. 2 in the spectrum obtained on June 8, 2017, there was

![Figure 1. H\( \alpha \) line profiles at different observation times. The dashed vertical line is the adopted systemic velocity \( V_{\text{sys}} \approx -125 \text{ km s}^{-1} \).](image_url)

Note that the V534 Lyr spectrum is characterized by a strengthening of neutral helium He I lines, with an appreciable weakening of metal lines. This is well illustrated in the upper panel of Fig. 3 where a fragment of the spectrum of this star with the He I 4026 Å line is compared with
an analogous spectral region of a massive supergiant α Cyg. The MK-spectral class of α Cyg, namely A2 Ia, is close to V534 Lyr, but the intensities of the HeI 4026 Å line are markedly different.

### 3.2. Radial velocity pattern

Generalized results of radial velocity measurements for each time of observations are presented in Table 2. Columns (5)–(8) contain the values obtained by averaging the velocities for: the FeII 6318, 6384 and 6385 Å emission, in the 2017 spectra the FeII 6493, 7496, 7513 Å, emissions, the HeI, SII absorption cores, and the doublet SiII (2) absorption core, the cores of the components of FeII absorptions, respectively. The last column lists velocity from the FeII lines with a lower lower-level excitation potential. In the spectra for four dates, these lines are split into two components, hence two mean velocity values are given: based on the long-wave components, and below these values the mean velocity for the short-wave components is indicated. Let us stress that for all the times when it is present in the spectrum the splitting reaches large values: \( \Delta V_r = 20–50 \text{ km s}^{-1} \). In the 2000 spectrum, due to its reduced spectral resolution the absorption component measurements are unreliable. For this reason, the data for this spectrum are not given in Fig.4 which presents the dependences of radial velocity from the central residual intensity of the corresponding line, \( V_r(r) \). One or two signs (in cases of the split absorptions)
Figure 3. A comparison of fragments of the spectrum of V534 Lyr with similar fragments of the spectrum of the massive supergiant α Cyg. The main absorptions of the fragment are identified. The circles mark the high-excitation Fe II absorptions, the squares – the low-excitation Fe II absorptions, the rings – He I, S II, the horizontal lines – mainly the Fe II 6318, 6384, 6385 Å emissions, and in the spectra of 2017 – the Fe II 6493, 7496, 7513 Å emissions as well. These Fe II emissions are formed in extended envelopes and, being stationary for some super- and hypergigants, are used to estimate their systemic velocities $V_{\text{sys}}$. According to our data, in the investigated star V534 Lyr the velocities determined based on the emissions at different dates of 2010 differ by approximately 5 km s$^{-1}$, and different lines are shifted by various values, though all in one direction. In the 2013 spectrum, the position of these emissions is significantly different from the previous ones. At the same time, in each of the dates, the position of the emissions is close to those for the unsplit absorptions, and hence the velocities in column (5) are close to the velocities in column (6), measured from the upper parts of absorptions.
Figure 4. The \( V_r (r) \) dependences, determined from all the obtained spectra. Filled circles – high-excitation Fe II absorptions, squares – low-excitation Fe II absorptions, rings – He I, S II, horizontal lines – Fe II 6318, 6384, 6385 Å emissions.

The half-width of the Mg II 4481 Å line in the V534 Lyr spectrum is \( \delta \lambda = 0.5 \) Å. Using the dependences of the half-widths of this line on the rotation velocity of the star from [32], we get a low rotation velocity \( v \sin i = 5–6 \) km s\(^{-1}\).

Table 2 and Fig. 4 show temporal variations of the positions of all lines and profile shapes of some of them. The latter phenomenon is mainly associated with the upper layers of the atmosphere. This can be seen, for example, from the fact that the low-excitation Fe II absorptions in the spectra obtained on 6 April, 2010, June 1, 2010 and October 12, 2013 are split, and the high-excitation absorptions formed deeper remain single in these dates. Figure 5 demonstrates this for the Fe II 5363 and 5506 Å lines (the low-level excitation potentials 3.2 eV and 10.2 eV respectively), while Fig. 6 – for the Fe II 5169 Å line, the strongest of the of the low-excitation absorptions in the visible part of the spectrum (its low-level excitation potential is 2.9 eV), and Si II 6371 Å (the lower-level potential is 8.1 eV). In the bottom plot of Fig. 5 (July 30, 2010 and September 24, 2010) the profile of Fe II 5363 Å is only slightly asymmetric, and in the top plot (April 6, 2010) it is split into two components, close in depth and spaced from each other by 48 km s\(^{-1}\). The profile of Fe II 5169 Å (Fig. 6) from April 6, 2010 also consists of two components, though possessing different depths, separated by 56 km s\(^{-1}\). Figure 6 shows an intermediate case of profile transformation. The absorption of Si II 6371 Å (the lower-level excitation potential of 8.1 eV) in the results of April 6, 2010 observations is clearly not split, but it is noticeably broadened as compared with the data obtained on September 24, 2010 (in the spectrum of July 30, 2010 it is absent).

Table 3 contains the parameters of the line profiles, presented in Figs. 5 and 6, their depths \( R \), widths in the wings (at \( r = 0.99 \)) \( \delta V_r \), and equivalent widths \( W_\lambda \). In the spectrum of April 6, 2010 the absorptions are shallower and wider in the wings than in the data from July 30, 2010 and September 24, 2010, while these differences are relatively small in the high-excitation Fe II lines, as well as in the He I and S II lines, and are noticeably larger in the low-excitation Fe II lines. The depths of Fe II 5506 Å, determined from the spectra on the dates indicated are practically identical, while for Fe II 5363 Å and Fe II 5169 Å they differ by 2.5 and 2.6 times, respectively. The absorption growth of the Fe II 5363 Å line in the observations of April 6, 2010 was by September 24, 2010 compensated by the narrowing the way that its equivalent width has returned to the previous value. We believe that the broadening and splitting of the low-excitation Fe II lines are related to the features of the velocity field in the upper layers of
Table 3. The parameters of some absorptions in the V534 Lyr spectrum: depths $R$, widths $\delta V_r$, km s$^{-1}$, and equivalent widths $W_{\lambda}$, Å

| Parameter | Date      | Fe II 5506 | Fe II 5363 | Fe II 5169 | Si II 6371 |
|-----------|-----------|------------|------------|------------|------------|
|           |           | 6.04.2010  | 30.07.2010 | 24.09.2010 |            |
| $R$       | 0.037     | 0.039      | 0.036      |            |            |
| $\delta V_r$ | 66        | 52         | 45         |            |            |
| $W_{\lambda}$ | 0.030     | 0.026      | 0.022      |            |            |

The difference in velocities is small: the $V_r$ variations from date to date are from 11 km s$^{-1}$ for He I and S II to 24 km s$^{-1}$ for the high-excitation Fe II absorptions. From the data given in the tables and figures with line profiles, it can be concluded that the radial velocity gradient in the atmosphere of V534 Lyr was minimal, and it was the most stable on July 30, 2010, September 24, 2010 and on June 8, 2017: the differential shifts of lines on these dates are close to the measurement errors, the widths and anomalies of their profile shapes are minimal. Assuming that the average radial velocity on these dates were close to the velocity of the center of mass of the star, we accept $V_{\text{sys}} \approx -125$ km s$^{-1}$ ($V_{\text{lsr}} \approx -105$ km s$^{-1}$) as the first approximation. This estimate is also close to the average velocity values in columns (5)–(7) of Table 2. Close values of the means and amplitudes are given in [18] and [24], but one must bear in mind that in these papers the velocities were obtained by averaging over all the measured lines, not analyzing their features.

### 3.3. Luminosity and distance of the star

The first estimate of the two-dimensional spectral class of V534 Lyr was made by V. Morgan: B9 Ib [33]. Bonsack and Greenstein [18] changed its spectral class to A0 Iabe, based on the
Figure 5. The Fe II 5363 Å (3 eV, dashed) and Fe II 5506 Å (10 eV, solid) line profiles. The vertical dotted line is the same as in Fig. 1.

The fact that the Balmer series in the spectrum extends to H₂₄, and the Hβ and Hγ lines have the emission components, while the amplitude of radial velocity variation is higher than the typical for the Ib supergiants. The latter argument reinforces the significant and variable differential shifts of the lines, in particular, the Balmer progress observed on October 12, 2013 (the growth of $V_r$ from Hα to Hδ from $-157$ km s⁻¹ to $-133$ km s⁻¹), and noted by the authors of [24, 18] and observed by us variability of intensities and positions of the emission features of the HI line profiles. As can be seen in Fig. 1 in the 2000 and 2010 spectra the Hα emission is two-peak, and the intensity of the red peak is always above the blue one. However, in June 2017, Hα has a P Cyg-type profile, which in a couple of months acquires the character of a two-peak emission. The variability of the Hβ profile is similar: as illustrated in Fig. 2 its emission component passes from the red wing to the blue one. According to the results of observations from June 8, 2017, the Hβ profile is of a P Cyg-type with a powerful and shifted into the short-wave region absorption, which gets split in the spectrum obtained a few days later, on June 13, 2017.
Figure 6. The Fe II 5169 and Si II 6371 Å line profiles for two observations: April 6, 2010 (dashed), October 12, 2013 (solid). The vertical dotted line is the same as in Fig. 3.

The spectral class A0 Iab corresponds to the distance to V534 Lyr of $d = 5.7$ kpc [18]. The interstellar Na I (1) and Ca II (1) line profiles in the stellar spectrum also imply its great remoteness. The presence in them of the components with $V_r = -46$ km s$^{-1}$ (Fig. 7), taking into account the data of Brand and Blitz [34] points to $d > 7$ kpc. A great remoteness of the star could be confirmed by its parallax $\pi = 0.379$ mas, measured by the GAIA, however, in the DR1 catalog it is burdened with a large error of ±0.378 mas. A noticeable own motion $3'6 \pm 0'8$ in the 35 catalog at $d \approx 6$ kpc corresponds to the velocity 103 km s$^{-1}$, directed to the plane of the Galaxy. In combination with $V_{\text{lsr}} \approx -105$ km s$^{-1}$ this yields the spatial velocity of about 140 km s$^{-1}$.

The presence of interstellar components in the Na I (1) and Ca II (1) lines forced us to undertake a search for possible DIBs. Luna et al. [36] in their study of interstellar and circumstellar absorption for the sample of post-AGB stars, found two such features (5780 and 5797 Å) in the spectrum of V534 Lyr. However, their measurements of the DIB positions are widely scattered. In our spectra, there are no features that could be reliably identified with the known DIBs.
The only feature that can be identified with the strongest of the known bands, 5780 Å is very weak in the spectrum of V534 Lyr – its depth is only around 0.015.

The obtained distance estimate of $d \approx 6$ kpc for the high-latitude star with the apparent stellar magnitude of $V = 8^m58^{[21]}$ leads us to the value of its absolute magnitude: $M_V \approx -5^m3$, which, according to $^{[37]}$, corresponds to the spectral class of V534 Lyr. Vickers et al. $^{[38]}$, modeling the energy distribution in the spectrum stars, obtained the distance of $d \approx 3.19 \pm 0.43$ kpc. This reduced distance estimate leads to a decrease in the absolute magnitude, $M_V \approx -3^m94$, and worsens the agreement of spectral class and luminosity.

The luminosity of the star can be determined from the equivalent width of the oxygen IR triplet O I 7773 Å in the spectrum of V534 Lyr: $W_\lambda = 1.99$ Å. Using the calibration from $^{[39, 40]}$, we get a very high luminosity, $M_V \approx -8^m0$. However, this estimate is burdened by considerable errors, since both calibrations were obtained by the authors of $^{[39, 40]}$ for the population I supergiants. The star we are investigating, V534 Lyr, obviously does not refer to massive supergiants. In addition, its luminosity estimate is also distorted by the specific chemical composition of the atmosphere, primarily, by an anomalous oxygen abundance.
To determine the main parameters of the model: effective temperature $T_{\text{eff}}$ and surface gravity $\log g$, we used our standard method \[41\], which was successfully used in the studies of spectra of various types of stars. The parameters $T_{\text{eff}}$ and $\log g$ were determined based on the requirement of the ionization balance, i.e. the equality of iron abundance, calculated from the FeI and FeII lines. Microturbulent velocity $\xi_t$ was also found using the standard method from the condition of absence of the dependence of iron abundances $\log \epsilon$ (FeI, FeII), determined from a set of lines, on their equivalent widths $W_{\lambda}$. To account for possible variations, the parameters $T_{\text{eff}}$ and $\log g$ were found for each available time of observations. The obtained individual temperatures $T_{\text{eff}}$, given in column (4) of the Table2, differ from each other only slightly. Their differences are within the error limits of determining this parameter; therefore, to calculate the abundances of chemical elements, we used the mean value of $T_{\text{eff}} = 10000$ K. This estimate agrees with the previous $T_{\text{eff}}$ estimate from \[24\] perfectly well, which is an additional indication of the constancy of stellar temperature. Note that earlier in the paper by Arellano Ferro et al. \[19\] the condition of solar helium abundance in the atmosphere was accepted for determining the temperature of V534 Lyr which led to a higher value $T_{\text{eff}} = 11500$K.

We controlled the identification of features in the spectrum of V1534 Lyr involving the atlas \[42\] with high-resolution spectra of A-supergiants. The content of chemical elements in the atmosphere of the studied star is calculated from the equivalent line widths in the LTE approximation. The calculation of the model atmosphere, the abundance of chemical elements and the calculation of synthetic spectra are performed using the WIDTH9 code based on the Kurucz model grid \[43\], adapted for the OS Linux environment \[44\]. The excitation potentials and oscillator strengths for all the lines, as well as the broadening constants are taken from the Vienna Atomic Line Database (VALD) \[45\].

Taking into account the above-described peculiarities of the V534 Lyr spectrum, we calculated its chemical composition from the equivalent widths of the absorptions measured in the spectrum of June 8, 2017. In the choice of observational material, we were guided by the registered wavelength range and the absence of absorption splitting in the spectrum (Fig.3 and Table2). To increase the number of lines we partially involved the data on the equivalent widths of unsplit lines from the 2013 spectrum. The results of the calculation performed with the parameters $T_{\text{eff}} = 10000$ K, $\log g = 2.5$, $\xi_t = 4.0$ are presented in Table4, where the number of lines used and the root-mean-square error of determining the element abundances are indicated. In the last column of the table the relative values of $[X/Fe]_{\odot}$ are given, for the calculations of which we used the information about the element abundances in the photosphere of the Sun according to Asplund et al. \[46\].

### 4. Discussion

The presence of an emission-absorption profile of the H$\alpha$ line, in which the position of the emission components and their intensity ratio vary with time is a sign of passage of a shock wave in the stellar atmosphere. In addition, we see a low-amplitude variability of radial velocity from the lines with a high excitation potential, which are formed in deep layers of the stellar atmosphere. Therefore, we have registered the signs of pulsational instability of the star. In the spectra of V534 Lyr we found a previously unknown feature: splitting of profiles of selected metal absorptions at separate times of observations. This kind of metal line splitting indicates
Table 4. The abundances of chemical elements $\log \epsilon$, calculated with the model parameters $T_{\text{eff}} = 10\,000\,\text{K}$, $\log g = 2.5$, $\xi_t = 4.0$. The error of the mean $\sigma$, the number of lines $n$ and the relative element abundances $[X/\text{Fe}]_\odot$ are indicated. The second column lists the element abundances in the solar photosphere [46].

| Element, ion | $\log \epsilon_\odot$ | $\log \epsilon \pm \sigma$ | $n$ | $[X/\text{Fe}]_\odot$ |
|-------------|----------------------|-----------------------------|-----|------------------|
| He I        | 10.32                | 11.31 ± 0.17               | 10  | +1.27            |
| C II        | 8.70                 | 8.70 ± 0.06                | 3   | +0.28            |
| N I         | 7.83                 | 8.65 ± 0.21                | 2   | +1.10            |
| N II        | 8.53 ± 0.10          |                             | 3   | +0.98            |
| O I         | 8.69                 | 8.94 ± 0.04                | 18  | +0.53            |
| Ne I        | 7.93                 | 8.37 ± 0.08                | 6   | +0.72            |
| Mg I        | 7.60                 | 7.43 ± 0.08                | 5   | +0.11            |
| Mg II       | 7.13 ± 0.09          |                             | 7   | −0.19            |
| Al II       | 6.45                 | 6.79 ± 0.08                | 2   | +0.52            |
| Si II       | 7.51                 | 7.53 ± 0.16                | 6   | +0.30            |
| P II        | 5.41                 | 6.13 ± 0.03                | 4   | +0.90            |
| S II        | 7.12                 | 7.72 ± 0.08                | 9   | +0.88            |
| Sc II       | 3.15                 | 3.14 ± 0.18                | 2   | +0.27            |
| Ti II       | 4.95                 | 4.61 ± 0.05                | 20  | −0.06            |
| V II        | 3.93                 | 3.66 ± 0.06                | 2   | +0.01            |
| Cr II       | 5.64                 | 5.14 ± 0.05                | 20  | −0.28            |
| Mn II       | 5.43                 | 5.69 ± 0.10                | 4   | +0.44            |
| Fe I        | 7.50                 | 7.23 ± 0.05                | 5   | +0.01            |
| Fe II       | 7.20 ± 0.04          |                             | 66  | −0.02            |
| Ni II       | 6.22                 | 6.02 ± 0.15                | 5   | +0.08            |
| Sr II       | 2.87                 | 2.50 ± 0.01                | 2   | −0.09            |

The pulsations of W Vir-type stars. A good example is the velocity field in the atmosphere of W Vir itself [47]. An additional argument confirming the presence of pulsations is given to us by the analysis of individual velocities based on the split lines in the spectrum of June 13, 2017, where the degree of splitting of the low-excitation absorptions varies depending on the depth of absorptions. This difference is illustrated by the data in the last line of Table 2 and the panel of $V_r(r)$ dependences in Fig. 4, obtained on June 13, 2017.

The parameters of the model atmosphere and the chemical element abundances in the atmosphere of V534 Lyr we have determined differ little from the previously published [24]. Here we will consider the features of the chemical composition only briefly. A detailed analysis of the chemical composition of this star is difficult for a number of reasons: a very limited set of obtained abundances of chemical elements; application of the standard model atmosphere in the case of a star whose atmosphere is unstable and probably subject to the influence of shock waves. A contribution of error due to the neglect of the effect of deviation from the local thermodynamic equilibrium is also possible. However, their impact on the metallicity estimate for a hot star is small [48].

The main groups of elements whose relative abundances allow us to judge on the stage of evolution of the star and its belonging to this or that population of the Galaxy are as follows:
the CNO-triad, the iron group (Cr, V, Fe, Ni), the α-process light metals (Mg, Al, Si, P, S) and the s-process heavy metals. The abundance of iron in the atmosphere of V534 Lyr is slightly lowered: $[\text{Fe}/\text{H}]_\odot = -0.28$, which, in combination with a high radial velocity $V_r \approx -125 \text{ km s}^{-1}$ points to the fact that the star belongs to the thick disk of the Galaxy. The abundance of metals of the iron group (Cr, V, Mn, Ni) is slightly different of the iron abundance: $[\text{Met}/\text{Fe}]_\odot = +0.06$.

To determine the status of a far-evolved star, the principal in the element prevalence is the abundance of elements of the CNO group. We have reliably determined a high nitrogen abundance $[\text{N}/\text{Fe}]_\odot = +1.10$ from two N I lines of low intensity. The nitrogen excess in the atmosphere of the supergiant can be the result of the first mixing, at which the removal of products of the CN-cycle during the burning of hydrogen in the core is in force. A large helium excess, $[\text{He}/\text{Fe}]_\odot = +1.27$ is a result of a sequence of nuclear reactions in the stellar core and their subsequent mixing. The excess of oxygen in V534 Lyr is illustrated in the bottom panel of Fig.3 where the fragments of the spectra of V534 Lyr and α Cyg containing the O I 6155–6157 Å oxygen lines are mapped. We can also clearly see here a weakening of the Fe II ion lines in the spectrum of V534 Lyr in comparison with the spectrum of α Cyg. The abundances of light metals (Mg, Al, Si, P, S), synthesized owing to the α-process are strengthened in the atmosphere of V534 Lyr on the average by $[\alpha/\text{Fe}]_\odot = +0.4$. The strengthening of light metals is consistent with the fact that the star pertains to the thick disk of the Galaxy, as evidenced by the results of the extensive sample of thick-disk stars with a close metallicity [49].

With respect to the observed set of properties, a hot star HD 105262, which is located in the Galaxy at a high latitude of $b = 72.47^\circ$ and has the B9–A0 spectral class can be regarded as an analog of V534 Lyr. In the SIMBAD database this star is cataloged as a post-AGB supergiant. Earlier this star, having no IR excess, was considered as a representative of an earlier stage of evolution, namely, of the horizontal branch (hereafter – HB). Klochkova and Panchuk [50], using the photographic spectra determined the parameters of $T_{\text{eff}} = 8500$ K, the surface gravity log $g = 1.5$, reduced metallicity $[\text{Fe}/\text{H}]_\odot = -1.2$ and a detailed chemical composition of the atmosphere. In their recent work, Giridhar et al. [51] obtained the same parameters of the model, though the metallicity is much lower: $[\text{Fe}/\text{H}]_\odot \approx -1.9$. This difference can be explained by a higher spectral resolution of the spectra in [51]. For the comparison we make between V534 Lyr and HD 105262, a large excess of nitrogen, found in the atmosphere of HD 105262 [51] is important. Both stars have a low rotation velocity, $v \sin i = 6 \text{ km s}^{-1}$. For HD 105262, rotation velocity is measured from the high-resolution spectra in [52]. Belonging to the HB stage can explain the absence in V534 Lyr and HD 105262 of the circumstellar dust and infrared excess caused by it.

The spectral features, similar to the peculiarities of the spectrum V534 Lyr are observed in the A-supergiant BD+48°1220. The optical high-resolution spectra based on which a significant variability of the HI and metal line profiles were obtained over several observational seasons at the 6-m BTA telescope combined with an echelle spectrograph [53]. The analysis of this spectral material by the atmospheric model method with the parameters $T_{\text{eff}} = 7900$ K, log $g = 0.0$, $\xi_t = 6.0$ has shown that the metallicity BD+48°1220 is close to solar: $[\text{Fe}/\text{H}]_\odot = -0.10$ [54], and the chemical composition of its atmosphere differs little from that of V534 Lyr. As in the case of V534 Lyr, a large helium excess was detected, $[\text{He}/\text{H}]_\odot = +1.04$ and an equally significant excess of oxygen $[\text{O}/\text{Fe}]_\odot = +0.72$ dex. At that, the carbon excess is small, $[\text{C}/\text{Fe}]_\odot = +0.09$, and the ratio $[\text{C}/\text{O}] < 1$. The abundances of light metals are changed: $[\text{Na}/\text{Fe}]_\odot = +0.87$ at $[\text{Mg}/\text{Fe}]_\odot = -0.31$. But the most
important – in the atmosphere of BD+48°1220 a large excess of lithium is detected \([\text{Li}/\text{Fe}]_\odot = +0.62\), what indicates the transfer of this element, synthesized at the AGB stage, into the atmosphere. In addition, it was concluded on the probable efficiency of the mechanism of selective separation of chemical elements onto the dust particles of the envelope. A full set of the available data (luminosity \(M_v \approx -5\)m, velocity \(V_{\text{lsr}} \approx -20 \text{ km s}^{-1}\), reduced metallicity and the features of the optical spectrum and chemical composition) confirms the status of the O-rich post-AGB star with the initial mass of \(4 \div 9 M_\odot\). Thus, the star BD+48°1220, having a number of properties close to V534 Lyr is a supergiant at a more advanced stage, after AGB.

We therefore see that the observed properties of V534 Lyr, with the exception of its high luminosity and location outside the plane of the Galaxy do not give any grounds for classifying it as a post-AGB star. The main fact is that V534 Lyr does not have an IR excess or chemical composition anomalies expected for the post-AGB supergiant. Let us consider other possible variants of its status. The lack of a dust envelope at a sufficiently high luminosity allows to consider it as an object at the stage after the red giant branch, located at an evolutionary stage above the HB. The source of energy release in the stars at this stage, past the helium flash in the core is the burning of helium in the core and hydrogen in the layer. A large mass loss is not expected in these supergiants. To confirm this status of the star one can rely on a convenient diagram \(\log g - T_{\text{eff}}\) (Fig. 1 in [52]). The set of fundamental parameters of V534 Lyr corresponds to the HB stars in the diagram. A low rotation velocity \(v\sin i = 5\div 6 \text{ km s}^{-1}\) is also consistent with the supposed status near the BHB: it is known that HB stars rotate slowly [55, 48]. The results we obtained here for V534 Lyr make up another confirmation of the conclusion [2, 56] on the heterogeneity of the sample of PPN candidates.

A combination of the observed features of V534 Lyr: the presence of pulsations in deep layers of the atmosphere, reduced metallicity, the type and variability of the emission-absorption Hα profile allows us to assume that the star belongs to pulsating population II stars that are located in the instability band above the HB and evolve to the AGB. Depending on the mass and hence on the period of pulsations, it can be a BL Her or W Vir-type star. A direct indication of the status of the pulsating star is provided by the optical spectrum features: two-peak emissions and time-variable Hα and Hβ line profiles (Figs. 1 and 2), the presence at some times of observations of the absorption splitting (Fig. 5) and the presence of a velocity gradient in the atmosphere, registered on June 13, 2017, which is clearly visible in Fig. 4.

It is useful to pay attention here to the study of the chemical composition of a sample of 19 variable population II stars [57], based on the high-resolution spectroscopy. To calculate the abundances of chemical elements, the authors used only the spectra in which there were no signs of splitting (or asymmetry) of absorptions or emissions in the Balmer line series. Maas et al. [57] made a conclusion about the fundamental difference of the chemical composition in BL Her or W Vir-type stars: in the atmospheres of the BL Her-type stars, the Na abundance is higher than that in the W Vir-type stars. This conclusion gives us grounds to more likely classify the investigated star V534 Lyr to the Virginidis: we failed to find any of the Na I lines in the spectra of V534 Lyr, expected in the case of an excess of this element in the atmosphere.

Typical representatives of the W Vir-type stars are the globular cluster members. An example is the Virginid V1 (K307), a member of the globular cluster M12. The authors of [58] determined its main parameters \((T_{\text{eff}} = 5600 \text{ K}, \log g = 1.3)\) and metallicity \([\text{Fe/H}] = -1.27\), which agrees with the metallicity of other members of M12. The atmosphere of this Virginid revealed altered abundances of CNO-elements, while nitrogen is in excess: \([\text{N}/\text{Fe}] = +1.15 \text{dex}\). Relative
abundances of Na and the α-process elements: Mg, Al, Si, Ca, and Ti are also strengthened in a various degree. The main feature of the spectrum of K 307 is the presence of complex absorption-emission profiles of the Hβ and Hα lines (see Fig. 2 in [58]), similar to the profiles in the spectrum of V534 Lyr.

The basic kinematic and chemical parameters for an extensive sample of HB stars in the thick disk are considered by Kinman et al. [59]. Our assumption that V534 Lyr can be a thick disk star in the stage above HB (post-HB) is confirmed by a large spatial velocity of the studied star, the absence of a dusty circumstellar envelope, and a specific chemical composition of the atmosphere. A factor complicating the fixation of the stellar status is that stars of several evolutionary stages can be located above the HB: it can be young enough stars, evolving to RGB, as well as the stars more advanced in the stellar evolution after or yet before the AGB.

The answer to the question critical for more specific conclusions is on the possible binarity of V534 Lyr. The $V_r$ variations with time are probably caused by pulsations, however, a spectral SB 1-type binarity is not yet excluded. The found velocity variability based on the Fe II emission (2) can be considered an indication on the possible binarity of the star. Note here the results of Şahin and Jeffery [60], who, having analyzed the variability of photometric data for V534 Lyr did not find an explicit period and assumed that the variations can be short-period. There are currently no reliable photometric and spectral data required for the study and determination of the variability parameters of brightness and spectrum. Therefore, it is extremely necessary to conduct a long-term and detailed monitoring of V534 Lyr for the final conclusions about the nature of its variability.

5. Conclusions

Based on the observations at the 6-m telescope with the NES echelle spectrograph ($R = 60,000$) we investigated the features of the optical spectrum of V534 Lyr, a high-latitude star with an uncertain status. For all the observation dates, heliocentric radial velocities $V_r$ correspond to the positions of all the components of metal absorption, as well as the Na I D and Hα lines were measured. The analysis of the velocity field from the lines of different nature revealed a small-amplitude $V_r$ variability from the lines with a high excitation potential, which are formed in deep layers of stellar atmosphere, and allowed us to estimate the systemic velocity $V_{sys} \approx -125 \text{ km s}^{-1}$ ($V_{lsr} \approx -105 \text{ km s}^{-1}$). The estimated distance $d \approx 6 \text{ kpc}$ for a high-latitude star leads to the absolute magnitude estimate of $M_V \approx -5.3^m$, which agrees with the spectral classification of V534 Lyr.

We discovered an as yet unknown for this star spectral phenomenon: splitting of profiles of the selected metal absorptions at separate times of observation. For all the moments when splitting is present in the spectrum, it reaches large values: $\Delta V_r = 20–50 \text{ km s}^{-1}$.

The spectral class of the star is close to A0 Ib, while its effective temperature is $T_{eff} \approx 10,500 \text{ K}$. Metallicity, reliably determined by metal lines of the iron group (Cr, V, Mn, Ni) slightly differs from the abundance of this element: $[\text{Met/Fe}] = +0.06$. The nitrogen and helium excess indicates an advanced evolutionary stage of the star. A low iron-group metal abundance in combination with a high radial velocity indicates that the star belongs to the thick disk of the Galaxy.

The whole of observed peculiarities of V534 Lyr: the presence of probable pulsations in deep layers of the atmosphere, splitting of metal absorption profiles with the low lower-level excitation
potential registered at separate times of observations, reduced metallicity, type and variability of the emission-absorption Hα and Hβ profile allows us to place the star amid the pulsating population II stars, which are located in the instability band near the HB. In general, we can conclude that there is a complete discrepancy between the properties of V534 Lyr we have registered and the post-AGB stage, where the star was referred to in the previously published papers.

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