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FAST AND SUPER-FAST VARIATIONS OF LINE PROFILE IN SPECTRA OF EARLY-TYPE STARS

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The results of our search for the fast line profile variations (LPVs) in spectra of selected OBA stars presented. The regular variations of the line profiles with periods ranging from several hours to days in spectra of OBA stars are well known. Our recent observations of the A0 supergiant HD 92207 using FOcal reducer low dispersion spectrographs FORS 2 in spectropolarimetric mode mounted on the 8-m telescopes of the VLT showed moderate line profile variations of various lines on a time-scale of minutes or maybe even of a fraction of a minute. This finding triggers our program of looking for the short time-scale LPVs in spectra of early-type stars. Such LPVs were detected in our spectral time series for HD 93521 (O9.5III), rho Leo (B1Iab), α^2 CVn, and other stars obtained with the multi-mode focal reducer SCORPIO at the 6-meter telescope (Northern Caucasus, Russia). Both regular LPVs with periods from 1 to 90 minutes and non-regular LPVs with amplitudes of 1-2% of the continuum level are detected. The presence of such short-term spectral variability in spectra of massive OBA stars, which are suggested to be the progenitors of Type II supernova, was not studied systematically in the past and can be critical for the current theoretical understanding of the supernova physics and for the stellar evolution modeling.

Keywords: Stars – early-type stars – variable stars – line profiles

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1. INTRODUCTION

Houtgast [7] firstly argued that line profiles in the solar spectra are variable and depend on the location on studied region of the solar disks. Later, nearly 50 years ago line profile variations (LPVs) in the stellar spectra were detected [4]. 50 years of LPV's investigations showed that the main causes of them are the rotational modulations and non-radial pulsations (NRPs). The typical time scales of LPVs in spectra of OBA stars vary from days to hours (see, for example, papers [5, 11]).

For example, for bright A0 supergiant HD 92207 Kaufer et al. [12] detected the NRPs with period of 27 days. No shorter periods were revealed. Searching fast and super-fast LPVs appeared to be far from the scientific interest. Nevertheless, recently the short time-scale line profile changes in the spectra of HD 92207 were discovered by Hubrig et al. [9].

These authors detected the clearly visible LPVs for different elements in individual subexposures up to 3% in intensities and up to 30 km/s in radial velocities. Such short-term variations were not known before for non-radially pulsating supergiants. To test whether short-periodic spectral variations are typical or not among all OBA stars, we start the investigations of the LPVs for selected OBA stars with the multi-mode focal reducer SCORPIO at the 6-meter BTA telescope and spectropolarimeter FORS 2 at the 8-meter VLT (Antu) telescope in ESO.

In the present paper we describe our program of the fast LPVs studies and review the results of our investigations of the fast LPVs in spectra of selected OBA stars at the moment. The program itself and suitable targets are presented in section 2. In section 3 it is formulated what kinds of telescopes and spectrograph can be used to reach the necessary quality of spectra. The results of our observations are given in section 4. Parameters of super-fast LPVs for observed targets are discussed in section 5. Some conclusions are given in section 6.

2. THE PROGRAM AND TARGETS

The goal of the program is to study the super-fast variations of line profiles in spectra of OBA stars at second and minute time scales and to develop the models explaining such variations. We also plan to investigate how the parameters of the super-fast LPVs depend on the spectral type, rotation velocity, chemical abundances, and other parameters of the stars.

The list of program stars includes all bright stars for which we are able to get high temporal resolution and to provide the signal to noise ratio $S/N \geq 1000$. The list of targets contains all bright OBA stars with V$\leq 4^m$. A catalog of bright stars [3] will be used as a source for selecting the targets. It means that the sample of OBA stars will be complete up to this magnitude. The list of more weak targets with V> 4^m will predominantly include the massive OB stars.

3. TELESCOPES AND INSTRUMENTS WHICH ARE NEEDED TO REVEAL THE FAST LPVS

Super-fast variability of line profiles in spectra of OBA stars on minute and second time scales can be detected for such parameters of observations only:

$$\begin{cases} \Delta T & < & 30 \text{ s}, \\ S/N & \geq & 1000. \end{cases} \tag{1}$$

Here ΔT is the time interval between successive observations. Usually ΔT is a sum of exposure and CCD matrix reading time. The selection of telescopes and spectrographs have to be made to provide such parameters of observations as those given in Eq. 1.

This means that the diameters of the telescopes used for observations must be in the any case greater than 1 meter. To provide the ratio $S/N \geq 1000$ it is necessary to use spectrographs with low resolving power $R \sim 1000/2000$. Higher spectral resolution can be only used for very large telescopes with the diameter $D > 5$ meter.

4. RESULTS OF OBSERVATIONS

4.1. List of targets

So far, we obtained spectra of 6 OBA stars with high time resolution. Next instruments were used to search the fast LPV:

1. ESO, 8-m telescope VLT with spectropolarimeter FORS 2. Standard resolving power is $R = 2000$. Typical S/N ratio is 1000-3000.
2. Special Astrophysical Observatory (SAO, Russia), 6-m telescope with spectrograph SCORPIO and resolving power $R = 2000$. Typical S/N ratio is ~ 2000.

Parameters of our observations can be found in Table 1. The object names are given in 1st column. Spectral types and visual magnitudes are presented in tables 2-3. In columns 4th and 5the we marked the total number of spectra for each star and the exposure time. Dates of observations are given in the last column. The star λ Eri from our list can be observed both in ESO and in SAO as it can be clearly seen from the finding cart in Fig. 1. We plan to organise such multisite observations in a future.

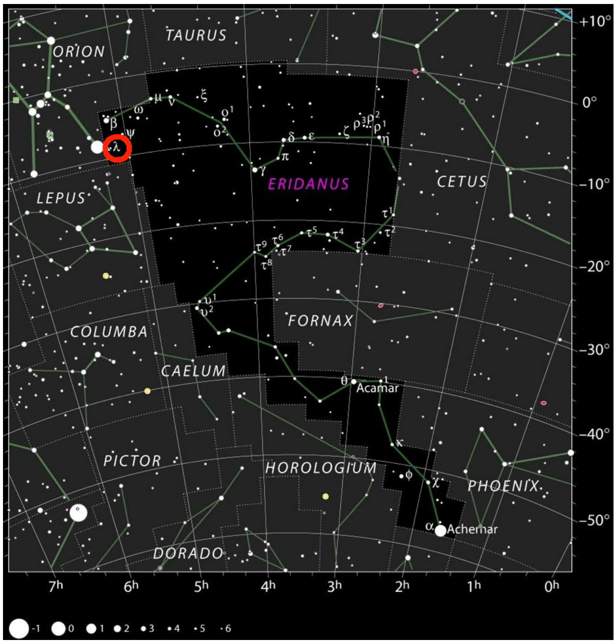

Fig. 1. Constellation Eridanus. The location of λ Eri is marked with red circle.

Table 1. Stars observed to detect the fast LPVs.

Star	Sp.Type	V	$N_{\rm sp}$	Exp (s)	Date obs.
6-m telescope, SCORPIO					
HD 93521	O9 Vp	7.06	529	3	19-20.01.2015
ρ Leo	B1 Iab	3.87	1271	1	19-21.01.2015
α^2 CVn	A0spe	2.90	387	1	21-22.01.2015
γ UMi	A2III	3.00	249	11	07.01.2017
VLT, FORS 2					
HD 92207	A0Ia	5.45	32	~ 60	2011-2012
λ Eri	B2III(e)p	4.02	155	~ 3	2006-2007, 2016

4.2. Regular LPVs

We detect the regular components of LPVs with periods from 1 to 90 minutes for all studied stars excluding HD 922207. Full time of observation for this star was too small to be sure that detected by us LPVs are periodic.

For fast rotating O9.5III star HD 93521 the regular variations of H and He line profiles with periods 4-5 and 32-36 minutes were discovered (see Figs 1-3 in paper [15]). Kholtygin et al. [15] argued that the fast LPVs in spectra of HD 93521 can be connected with the high mode of Non-Radial Pulsations (NRPs). Periods of regular line profile variations depends on the pulsation mode. It is probable that detected LPVs are connected with p modes of NRP with values of $l \sim 50 - 200$. Such high NRP modes are well known in the solar 5-minutes oscillations (see, for example, the paper [20].

Investigation of the super-fast variability of line profiles in spectra of the slowly rotating BIa supergiant ρ Leo by Kholtygin et al. [1, 16] showed the presence of the regular short-period variations of the H and He line profiles with periods ranging from 2 to 90 minutes. Using the window Fourier transform we were able to reveal the presence of short-period regular components of the LPVs with periods from 1 to 5 minutes and a slightly varying frequency, up to 20% per 2 hours. Such quasi-regular components with variable periods have not been detected previously and their nature remains unclear. The authors also revealed the irregular LPVs in spectra of ρ Leo discussed in the next subsection.

The LPVs in spectra of the magnetic standard α^2 CVn were investigated by Kholtygin et al. [17]. The regular short-time variability in spectra of this star was not studied earlier. We discovered 3 regular components in the LPVs with periods $P_1 = 50.4 \pm 3.6\,\text{min}$, $P_2 = 31.4 \pm 2.2\,\text{min}$, and $P_1 = 17.3 \pm 0.4\,\text{min}$.

Studying the LPVs in spectra of δ Sct variable γ UMi revealed the regular components with periods P from 9 to 65 minutes (see Fig. 2). The components with shorter periods can be harmonics of the main periodic component with a period $P = 64.9 \pm 6.6\,\text{min}$.

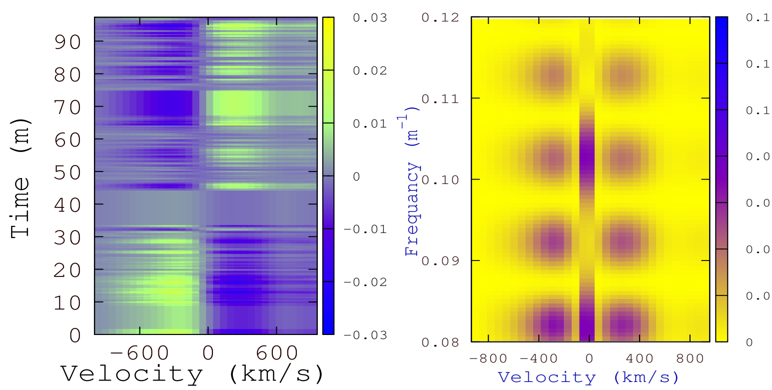

Fig. 2. Left panel: Hγ LPVs in spectra of γ UMi, **Right panel:** Fourier spectra of Hγ LPVs in spectra of this star.

Super-fast line profile variations in spectra of well-known non-radially-pulsating single bright Be star λ Eri were investigated by Hubrig et al. [10]. The LPVs with periods from 3 to 40 minutes were detected. A search for periodicity in the time series from 2006 to 2016 indicates the potential presence of a magnetic field variations with a period of $\sim 13.7\,\mathrm{min}$, which possibly indicates the presence of the small-scale local magnetic fields on the stellar surface.

4.3. Irregular LPVs

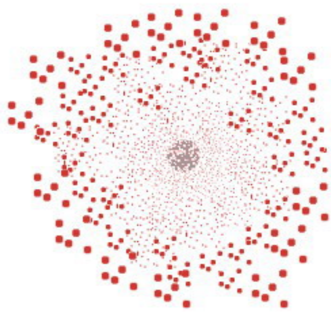

Fig. 3. Clumped wind structure.

We suppose that there can be irregular spectral variations connected with the cooling the hot plasma heated by shocks in the wind. Characteristic variability time for irregular variability can be estimated from plasma cooling time and plasma recombination time. These values for hot plasma in the clumped stellar wind (see Fig. 3) vary from $\sim 3-6$ seconds to ~ 5 minutes [13]. The typical amplitude of the variability is $\sim 10^{-2}$–10^{-3} s of the flux in the adjacent continuum.

Kholtygin et al. [16] reported that Hβ line profiles in spectra of ρ Leo obtained after 1332 and 1338 seconds from the start of observations (shown with dashed-and-dotted curves in the paper Fig. 2 in [16]) are 2-4% higher (in units of the continuum flux) than the rest of the line profiles. The same flux excess is detected for other line profiles in spectra of ρ Leo as it can be seen in Fig. 4.

5. PARAMETERS OF SUPER-FAST LPVS

We detect the LPVs in spectra of all studied stars. In Table 2 the global parameters of line profile variations in spectra of these stars are listed.

Star names are given in the 1st column of Table 2. In the 2nd column the characteristic times of fast LPV are written. In the 3rd column we put the character times of the regular LPVs. In the column 4 the *rms* magnetic fields of studied stars calculated accordingly the formula by Borra et al. [2] are given The magnetic field measurements are taken from the references given in the column 5. The connection of detected LPVs with possible magnetic field of the star is now under

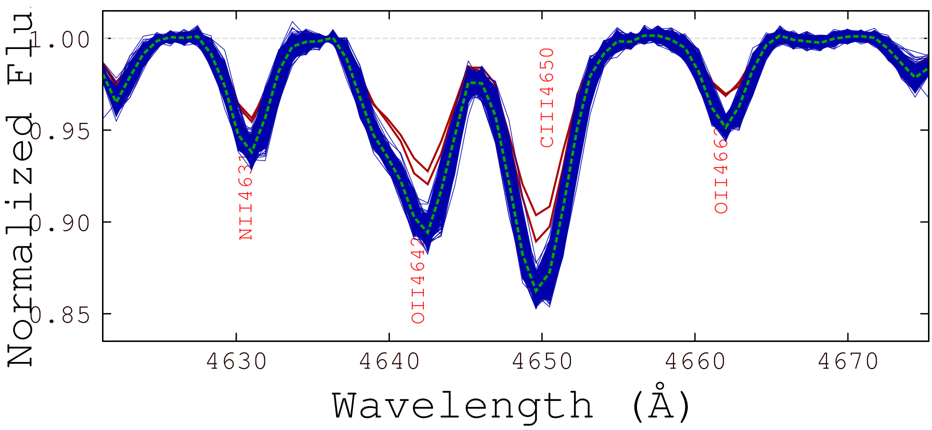

Fig. 4. Overplotted line profiles for all 1271 spectra of ρ Leo in the region $\lambda\lambda 4621 - 4675$ Å. The thick red curves show the line profiles obtained after 1332s and 1338s from the start of the observations.

Table 2. Parameters of LPVs in spectra of program stars.

Star	Char LPV time	LPV type	B, G	References
HD 93521	2-5 min	Regular	~130	[8]
ρ Leo	1-90 min	Regular+	~50	[14]
		irregular	~50	
α^2 CVn	18-135 min	Regular	~1100	[18]
γ UMi	10-65 min	Regular	non detected	[19]
HD 92207	2-3 min	probably regular	~225	[9]
λ Eri	3-40 min	Regular	~150	[10]

question. Many authors pointed out the regular variability of the line profiles can be an indicator of the stellar magnetic field. All studied by us stars excluding γ UMi appeared to be magnetic. Resuming we can preliminarily conclude that the fast line profile variability in spectra of OBA stars may be related with their magnetic fields.

6. CONCLUSIONS

Our study allowed us to make the following conclusions:

- VLT, FORS 2 and 6-m telescope BTA, SCORPIO observations show the presence of short-period LPV not known previously for OBA stars.

- Fast variations in the profiles in the spectra of HD 93521, λ Eri, ρ Leo, γ UMi, and α^2 CVn are probably associated with high modes of NRP.
- There is evidence that fast irregular LPVs can occur among OBA stars.

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