Advances in Astronomy and Space Physics, **10**, 3-6 (2020) doi: 10.17721/2227-1481.10.3-6

Short time-scale variability in the spectrum of the hot B3V star η UMa

*S. M. Pokhvala**

Main Astronomical Observatory of the NAS of Ukraine, 27 Akademika Zabolotnoho Str., 03143 Kyiv, Ukraine

We report the results of observations of short time-scale variability in the Hydrogen Balmer lines and He I lines in the hot B star η UMa. Spectral observations were carried out with the low-resolution slitless spectrograph ($R \sim 200$) installed on the 60 cm Carl Zeiss telescope in the Andrushivka Observatory, Ukraine. Spectra were obtained with a time resolution in the sub-second range. It has been found that the hot B star η UMa shows rapid variations in the Hydrogen lines Hβ, Hγ, Hδ, Hϵ and the Helium lines He I 5016 Å, He I 5047 Å as well as variations in the atmospheric oxygen lines. This can be interpreted that their variations are non-radial pulsations and strong stellar wind.

Key words: instrumentation: detectors; methods: observational; techniques: image processing, spectrometric; stars: imaging

INTRODUCTION

η UMa is a main-sequence star of the spectral class B3V, with the mass $6\,M_{\odot}$ and radius $1.8\,R_{\odot}$, the effective temperature of 22000 K. In 1951 the star was added to the Catalogue of suspected variable stars [5]. B-type stars often display a high rate of mass loss and stellar winds of speeds up to 3000 km/s. All of these factors give some ground to search for both photometric and spectral variability in the B-type stars.

Dynamic spectroscopy of η UMa with a slitless spectrograph with the spectral resolution of $R \sim 100$ showed fast variations in the Hβ, Hγ, Hδ Hydrogen lines from 0.2% to 0.5%, as well as variations in the atmospheric absorption lines [6].

In this paper we demonstrate the variability as a function of position within the line profile of η UMa and in particular the two-peaked line variations in the Hβ line profile.

In the following sections, we consider the observations, the detection of changes in the line profile, the reconstruction of the light curves of spectral lines, the results and the conclusion.

OBSERVATIONS

We present the low-dispersion ($R \sim 200$) optical (3900–8000 Å) spectra of the η UMa star obtained with the 60 cm Carl Zeiss telescope in the Andrushivka Observatory. It is equipped with the diffraction grating The Star Analyzer SA-200 for the low-dispersion spectroscopy. 200 spectra were obtained with the time resolution of 4.24 seconds and the spectral resolution 10.63 Å/pixel.

To eliminate the continuous spectrum of a star and obtain the absorption spectra we used the high-frequency filtering of spectra with the Kaiser digital filter [4, 9]. The absorption spectrum is shown in Fig. 1.

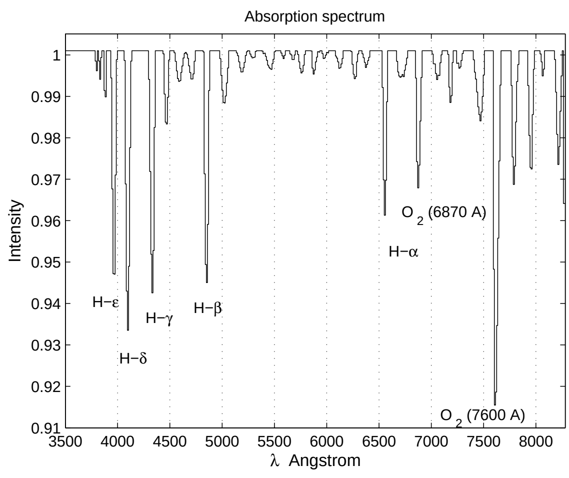

Fig. 1: The absorption spectrum of η UMa.

The following figures show the dependence of the variations of the mean intensity in the spectrum of the star. For Poisson random variables, the following

*nightspirit10@gmail.com

relation holds [7]:

$$(N-1)\,\sigma^2/mean = \chi_2^2$$

where N is the number of measurements. The formula allows setting a detection threshold by using the χ_2^2 probability distribution. For $N = 200$ the 99 % detection threshold is 1.25.

To estimate the parameters and errors of the harmonic signal, we use the data from [8]. If a series of measurements for a harmonic signal $u(t)$ is

$$u(t) = a\cos(2\pi f t + \phi) + n(t)$$

where a, f, ϕ, n are, respectively, the amplitude, frequency, phase and noise component. Next, we use the Fisher likelihood function, calculate the elements of the Fisher information matrix and find the variances D of the joint sample estimates of the amplitude, frequency and phase of the harmonic signal:

$$D[a] = \frac{\tilde{a}^2}{Q}, \quad D[f] = \frac{12}{(2\pi)^2 T^2 Q},$$
$$D[\phi] = \frac{4}{Q}, \quad Q = \frac{\tilde{a}^2}{\sigma^2}\cdot\frac{N}{2}, \qquad (1)$$

where Q is the signal-to-noise ratio (SNR) in a unit frequency band, $\tilde{a}$ is the amplitude estimate, N and T are the length and time span of a series of measurements.

The Hydrogen lines, as well as He I 4471 Å and, perhaps, 5016 Å, exhibit a bimodal structure (Figure 2, 3). Atmospheric lines of Oxygen (6870 Å and 7600 Å) and water (7180 Å) demonstrate a single peak variability structure (Fig. 3) with the periods different from those of the Hydrogen and Helium lines. This proves the reality of the bimodal structure of spectral Balmer lines. This bimodal structure in line profiles can be interpreted as the non-radial pulsations.

THE DETECTION OF LINE-PROFILE VARIATIONS

The work solved the problem of finding the intrinsic variability in lines of the spectrum of hot stars, by taking into account the difference in the intrinsic variability spectra and the noise distribution spectrum.

Phase discrimination allows to clean the spurious harmonics caused by the interference due to variations in atmospheric transparency and guiding errors from the light curve of spectral lines.

The method for constructing the map of spectra, a matrix calculated from an array of observations of spectra, the rows of which are the wavelengths and the columns are the power spectra of intensity variations, is proposed. Spectrum maps allow us to find the island of activity, which is characterised by the coordinates of the wavelength — the oscillation period. The position of an island relative to the center of a spectral line determines its offset $\Delta\lambda$. Hence, in the case of stellar wind, one can determine the wind speed and oscillation frequency at the point of their existence. The width of the island is related to the wind flow geometry. It can be judged on whether the wind is a spherically symmetric phenomenon or a directional flow.

In Figure 4 one can see the activity in the Hβ line, He I lines 5016 Å and 5048 Åand Mg b 5167 Å lines. Activity detection occurs at the SNR levels shown in the figures. These lines show several activity islands with different periods. It is important to note that not all lines are active. Figure 5 shows the activity in the Hα line and atmospheric lines. The Hα line demonstrates the double-peaked activity with long period.

Figure 6 can be used to quantify the distribution of statistically significant variability as a function of position within the line profile. In principle, the morphology of this distribution provides an insight into the nature of variability [2]. For example, radial velocity variations due to either pulsation or binarity produce the S-shape in difference spectra, which in turn produce the characteristic double-peaked structure.

Line profile variations are the very valuable diagnostic to detect both radial and non-radial oscillations (e.g. [1] and references therein, [3]) and to characterize the wave numbers (l, m) of such self-excited oscillations.

Figure 6 demonstrates the displacement of the centre of red and blue wings from the core of spectral line. To obtain the wave numbers of oscillations, the velocity spans obtained from the observations are compared with the ones calculated for the simulated line profiles [3]. For example, for η UMa amplitude of the frequency $\nu = 170$ cycles per day (2 mHz) resembles the $l = 2$, $m = 2$ mode.

RECONSTRUCTION OF THE LIGHT CURVES OF SPECTRAL LINES

In Figure 7 one can see the part of spectrum with emission in the Helium line He I 5840 Å. Figure 8 shows the Fourier reconstruction of light curves of the Hβ line and the Helium He I 5840 Å line. After cleaning the light curve of each spectral line from the spurious harmonics in the Fourier transform, harmonics with the signal-to-noise ratio exceeding the critical level are selected. Knowing the amplitudes and phases of the selected harmonics, we can reconstruct the light curve of spectral line. The frequency structure of oscillations of both lines is noticeably different, which indicates the formation of lines in different parts of the star atmosphere. Using Eq. 1 for errors, it is easy to verify that the harmonics in Fig. 8 are different.

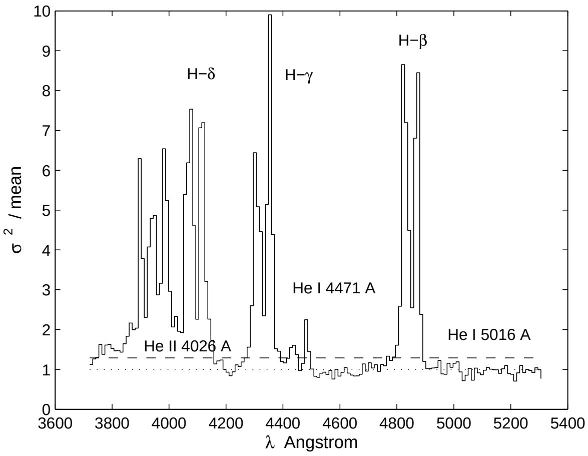

Fig. 2: Variations in the spectrum of η UMa.

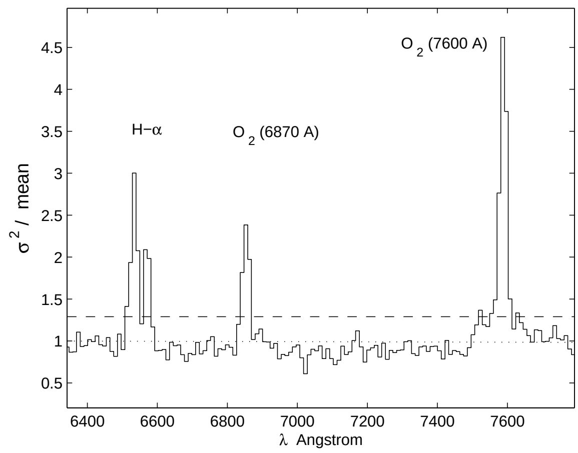

Fig. 3: Variations in the spectrum of η UMa in the long-wave region.

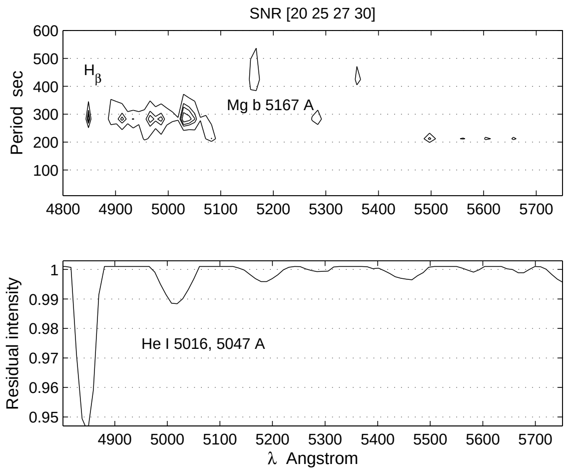

Fig. 4: The map of spectra of η UMa in the vicinity of the Hβ line.

RESULTS AND CONCLUSIONS

In present work the problem of finding the intrinsic variability in the lines of spectrum of hot stars has been solved by taking into account the difference in the spectra of intrinsic variability and the spectrum of noise distribution. Phase discrimination allows to clean the false harmonics caused by the light curve of white light from the light curve of spectral lines. To detect variability, the spectral map is constructed.

Dynamic spectroscopy of the hot star η UMa allowed us to detect rapid variations in the Hydrogen and Helium spectral lines, as well as variations in the atmospheric absorption lines. The characteristic time of observed variations ranges from minutes to hours. The atmospheric lines of Oxygen (λ 6870 Å and λ7600 Å) and water (λ7180 Å) demonstrate the single peak variability structure (Fig. 3) with the periods different from those of the Hydrogen and Helium lines.

The mechanism of variations is unknown. The Hydrogen lines, as well as the Helium lines He I 4471 Å and He I 5016 Å, exhibit the bimodal structure (Figures 2 and 3). Shifts in the spectra reach 25 Angstroms corresponding to the stellar wind speed of about 1500 km/s.

REFERENCES

[1] Aerts C., De Cat P. 2003, Space Sci. Rev., 105, 453.
[2] Fullerton A. W., Gies D. R., & Bolton C. T. 1996, ApJS, 103, 457.
[3] Hekker S., Aerts C., De Ridder J. & Carrier F. 2006, A&A, 458, 931.
[4] Kaiser J. F., Reed W. A. 1977, Rev. Sci. Instruments, 48, 1447.
[5] Kukarkin B. V., Parenago P. P., Efremov Yu. N., & Kholopov P. N. 1951, *'Catalogue of suspected variable stars'*, Acad. of Sciences USSR, Sternberg, Moscow
[6] Pokhvala S. M. 2015, Advances in Astronomy and Space Physics, 5, 21.
[7] Pollard J. H. 1979, *'A handbook of numerical and statistical techniques'*, Cambridge University Press, Cambridge.
[8] Zhilyaev B. E. 1993, Kinematics and physics of celestial bodies, 9, 89.
[9] Zhilyaev B. E., Romanyuk Ya. O., Svyatogorov O. A. et al., 2007, A&A, 465, 235.

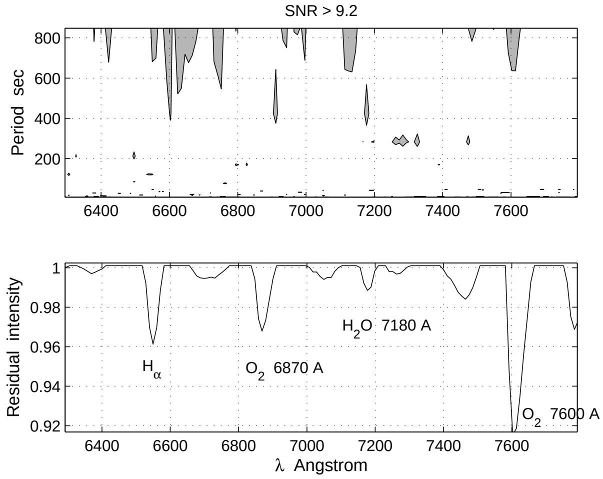

Fig. 5: Spectrum map in the long-wave region.

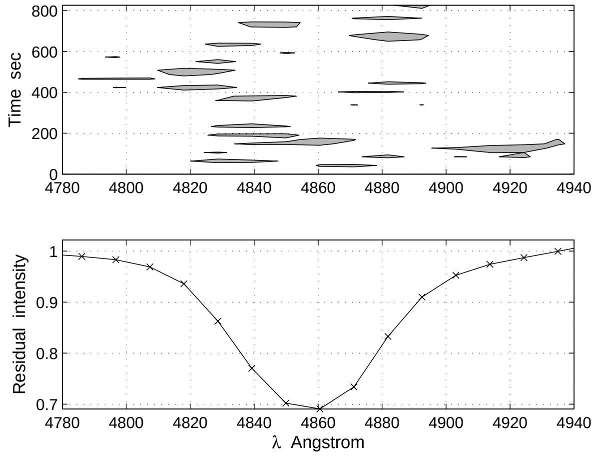

Fig. 6: The distribution of statistically significant variability as a function of position within the line profile of the Hβ line. S-shape in difference spectra produce the characteristic double-peaked structure.

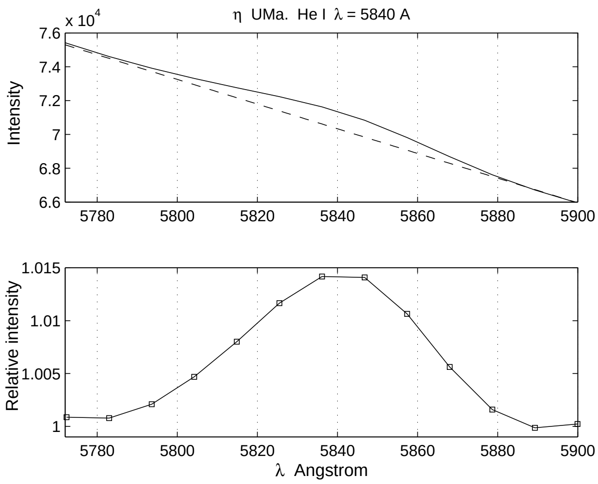

Fig. 7: The part of spectrum with emission in the Helium line He I 5840 Å.

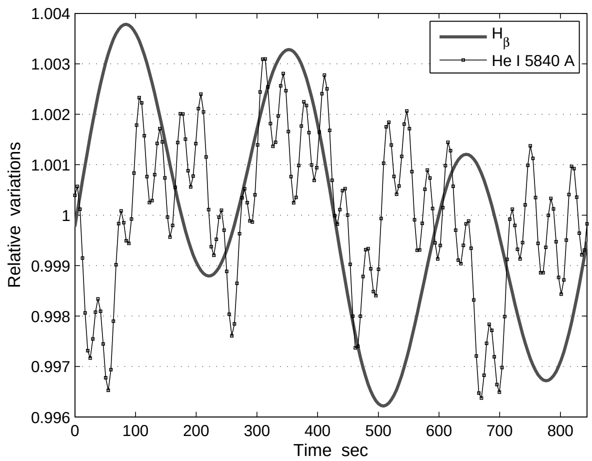

Fig. 8: Fourier reconstruction of the light curves of the the Hβ line and Helium line He I 5840 Å.