Changing Looks of the Nucleus of Seyfert Galaxy NGC 3516 during 2016–2020

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Abstract—The results of spectral observations of NGC 3516 with the 2-m telescope of the Shamakhy Astrophysical Observatory during 2016–2019 are presented. In the first half of 2016, the intensive broad component H\textbeta was found, which indicates a spectral type change compared to 2014, when the broad component was almost invisible. In the second half of 2016, the broad component H\textbeta again was weakened and was practically not observed, remaining weak until the end of 2019. At the end of 2019, the broad component H\textbeta strengthened again, and in May 2020 reached a typical level for the high state of the object. During 2016–2020 we observed several changing looks of NGC 3516.

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1. INTRODUCTION
NGC 3516 was discovered in 1785 by William Herschel and is included in the classic list of Seyfert [1]. It is the first discovered Seyfert galaxy with spectral variability (1968) and, at the same time, the first discovered active galactic nucleus (AGN), which changes its spectral type [2, 3]. However in 1968, the erroneous assumption was made that variables were forbidden lines, but the continuum and Balmer lines did not change. The discovery of the variability of the H\alpha in NGC 3516 and, at the same time, the first measurement of the time delay in this line variations relative to the continuum (for AGN as a whole) was done in 1973 [4].

AGN classification by type is based on the properties of emission lines. The first type (Sy1) includes objects which have broad lines (with half-width at half-intensity (HWHM) more than 1000 km/s) and much narrower forbidden lines with HWHM less than 1000 km/s. The second type (Sy2) includes objects in which permitted and forbidden lines have approximately the same HWHM, less than 1000 km/s (see details and links, for example, in [5]). From the point of view of the unification model (UM), these spectral differences [6] explains by the presence of a dust torus and its different orientation with respect to the observer. The existence of AGN changing their type over a relatively short time (months or less) is a serious problem for the UM. Several dozen changing their type AGNs are known by present time and they got the name Changing Look AGN (CL AGN). The nucleus of NGC 3516 has significant amplitude of variability and intensively observed during last 50 years (see the survey in [3, 7]. After a maximum in 2006, the object’s luminosity decreased, and in 2012–2015 the object was in a deep minimum. In 2014, was recorded CL event in NGC 3516, when the broad H\beta was practically invisible [3]. In the end of 2015—the first half of 2016, according to photometric observations, object had brightening [3, 7]. Unfortunately, there are no published spectra of the object in 2016. In the second half of 2016, the object was weakened and was in a low state until the end of 2018 (see, e.g., [3, 7]), and then the awakening activity of the object in 2019 and a significant outburst in the continuum (in X-rays, UV and optical range) at the beginning of 2020, accompanied by a new CL, was discovered [8]. We included nucleus of the NGC 3516 in the list of objects for our CL AGN monitoring project [9]. Our spectral observations fall on the interval in 2016–2020, when significant changes occurred in NGC 3516, and other spectral observations (according to publications) were absent or few in number. Description of these observations and results are given below in the following sections.

2. SPECTRAL OBSERVATIONS
Optical spectral observations of the galaxy NGC 3516 were carried out during 2016–2019 at 2-m telescope of Shamakhy Astrophysical Observatory within 11 nights. To obtain the spectra, three different spectrographs were used: (1) 2×2 prism spectrograph with FLI CCD cameras (4096×4096, 1 pixel = 9 μm [10]); (2) UAGS + Uranus lens (f = 250 mm, f/2.5) + FLI
CCD camera (3056×2048, 1 pixel = 9 μm); (3) UAGS + Canon EF lens (f = 200 mm, f/2) + Andor CCD camera (ikonL-936-BEX2-DD, 1 pixel = 13.5 μm). The wavelength range was from 3800 to 8000 Å, and the spectral resolution varied accordingly between 5 Å and 30 Å. Signal-to-noise ratio (S/N) in the continuum near the Hβ line was ~25–130. Spectrophotometric standard stars were observed every night. The first spectrograph was operated for a long time in the classical version with the photographical registration of spectra (see, e.g., [11]), and then was upgraded to record spectra using a CCD device [10]. This spectrograph was mainly used to obtain low-dispersion spectra of the faint non-stationary stars. The estimates made for the accuracy of equivalent widths of absorption lines (less than 10%), of course, are of little use for assessing the accuracy of broad emission lines measurement in AGN spectra, but can serve as a lower estimate of the magnitude of the errors. The investigations of AGN carried out with this spectrograph were published only in [12, 13]. Spectrographs (2) and (3) began to be used only in the last few years, and therefore there are few publications on them (see, for example, [14, 15]).

Carrying out of the spectra was realized with the help of the new version of the DECH software package. All spectra were extracted using an IRAF mask. The process included dark current subtraction, flat field corrections, cosmic ray removal, 2D linearization of wavelengths, subtraction of the sky spectrum, subtraction of the spectrum of the galaxy (stars component), etc. Table 1 provides a summary of the equipment and of observations. Spectral resolution and dispersion are indicated for the region near Hβ. We measured the intensity of the Hβ line with respect to the [OIII]λ5007 line, which was considered as a constant during our observations. Figure 1 shows examples of the calibrated nucleus spectra in relative intensities, received in 2016–2020. Figure 2 shows an example of a calibrated spectrum in absolute flux received on May 22, 2020. Figure 3 shows examples of Hβ profiles for 3 different dates. As it can be seen from Table 1, our spectral data are inhomogeneous in used equipment and quality. Data can be conventionally divided into 2 groups: data obtained in 2016–2018, where the quality was lower, and, the data obtained from December 2019 to May 2020, when data were obtained with the new spectrograph and were more homogeneous.

It is possible to judge on the accuracy of measurement of Hβ intensity (with respect to the line [OIII]λ5007) by its variations in the closest dates. The last 3 spectra were obtained within 8 days and the range of variations in the intensity of Hβ was about 10%, however these variations might be partly due to the real variability of the line. We do, however, took the conservative estimate of 10% as the mean square error of measurement lines intensities in the last four spectra.

In the first spectra obtained in 2016–2018, measurement errors are much bigger, which is associated with the features of the spectrographs, different spectral slit widths and quality of weather conditions. Influence of the width of the spectral slit for measuring the intensity of Hβ can be estimated from data received on closest dates. According to our estimates, the change in the slit width from 1″ to 2″ can give an error that does not exceed the measurement error, which according to our estimation was about 20% (for data obtained during 2016–2018). Spectra obtained in 2 neighboring nights in October 2017 were combined into one to reduce noise. Note that in the case of a weak Hβ line, when the broad component is almost invisible, errors can be much bigger. In [3] estimates of the effect of the slit width on the measured intensity Hb were investigated and the variations did not exceed 30% when the slit was changed by a factor of 2,
however the data were obtained with different telescopes. The size of the slit was chosen by us depending of the image quality, what partially reduces the role of changing conditions and the size of the slit for measuring the intensity of $H_\beta$. It should be noted that errors in the measurement of equivalent widths of lines can be significantly bigger than in measuring of the relative intensity of the lines, due to the significant correlated errors associated with the procedure of the continuum fitting. The variations of $H_\beta$ intensity during 2016–2020 are shown in the top panel of Fig. 4.

3. RESULTS

As it is clearly seen from Fig. 1, the intensity of the broad component of $H_\beta$ experienced significant changes: in the spring of 2016, this line was typical for the Sy1, then it was weakened by August 2016. In 2017–2018 the broad component of $H_\beta$ was very weak, almost invisible, which is typical for Sy1.9, and at the end of 2019 the $H_\beta$ line began to grow again and in May 2020 the spectrum became typical for Sy1. These conclusions confirm the results published earlier [7, 16]. However, in 2016 no other results of spectral observations of NGC 3516 were published. Our result on the CL event at the spring of 2016 (compared to 2014 [3]) is new. From photometry series and Swift data [7] at the end of 2015—beginning of 2016, the object had a flare and therefore, a significant enhancement of broad emission lines in spring of 2016 was connected to the increase in the flux of ionizing radiation from a central source. The weakening of emission lines in 2017–2018 and brightening from the end of 2019 to the present, when a new bright flare in the continuum was observed [16], can be explained in the same way.

Figure 2 shows one of the latest spectra obtained on May 22, 2020. It is clearly seen not only the strong Balmer lines $H_\alpha$, $H_\beta$, and $H_\gamma$ but also the $HeII \lambda 4681$ line and the $FeX \lambda 6374$ coronal line (see also [7]). Variability of $H_\beta$ profile for three dates May 10, 2016, May 16, 2018, and May 22, 2020 is shown in Fig. 3. The variability of $H_\beta$ intensity relatively to $[OIII] \lambda 5007$ is shown in Fig. 4. For comparison this figure shows previously published photometric data (see details in [7]). A bright flare in February–May 2020 was discovered in [16] and this is confirmed by our results on a significant strengthening of emission lines in May 2020. A feature of the $H_\beta$ profile in May 2020 is the appearance of a very bright peak in the blue wing, which dominates the broad line component. The red-shifted component has also been observed, but much weaker in intensity. However, the red component appears to have been present as well in 2016–2018, but the blue peak appeared and intensified only recently. Thus during 2016–2020 the object was in an unstable state and was demonstrated several CL events. High activity states and Sy1 spectrum were observed early 2016 and in May 2020.
Fig. 2. The isolated nuclear non-stellar spectrum of NGC 3516 obtained on May 22, 2020.

Fig. 3. Spectra of NGC 3516 in the Hβ region, normalized to the continuum at three dates: May 10, 2016, May 16, 2018, and May 22, 2020.
4. CONCLUSIONS

We carried out spectral observations of the nucleus of the Seyfert galaxy NGC 3516 during 2016–2020. The obtained results showed significant variability of Hβ, which can be identified as CL events in 2016 and in 2020. The interval of about 4 years between the high states of the NGC 3516 nucleus is practically coincides with the found period in the variability of the object [17]. We have compared our spectral data with published photometric data and found the agreement between the spectral variability and the changes in the continuum. Thus, CL events can be interpreted as a consequence of changes in the luminosity of the central source. There are several physical processes which could cause such dramatic changes of the luminosity: variable absorption along the line of sight, various types of instabilities in accretion disk, tidal destruction of stars by a super-massive black hole, close to black hole moving of stars with partial loss of the envelope, etc. Recurrent CL events in AGN can find a natural explanation, as in models with instability in the accretion disk as well as in the model with tidal stripping of stars which have bound elongated orbits around the central black hole. Required references and more
detailed discussion of possible physical mechanisms of CL events in AGN be found, for example, in [7, 12, 16, 18, 19].

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