ON SOME SPECTRAL FEATURES OF WW VUL IN THE EXTERME STATE OF BRIGTNESS

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By using of a homogeneous spectral material, the spectral features of the UX Ori type star WWVul in the extreme state of its brightness have been investigated. During the period of our spectral observations (2006–2010), an optical eclipse (2008–2010) of this star in the V band was occurred. A change in the character of spectral variability (along the lines: Hα, Hβ, NaI D1 and D2, HeI 5876 Å) was revealed in the spectrum of WW Vul in 2006 (before the eclipse), 2007 (beginning of the eclipses) and 2010 (after eclipse). After an optical eclipse in the spectrum of the star WW Vul in the lines Hα, Hβ, Na D1 and D2, HeI 5876 Åsynchronous variation of ejection and/or outflow directions of matter were detected. Apparently, in August 2006, rotation of the accretion disk is responsible for the spectral variability, and during 2007–2010 along with the rotation of the accretion disk, an additional mechanism appears that leads to rapid changes in the physical conditions in the region of the formation of these lines. Such a mechanism can be a magnetic field in the accretion disk and/or on the surface of a star, which determines the nature of the interaction between the star and its environment.

Keywords: Stars – UX Orionis, Eclipses – Individual, line: profiles, stellar winds

1. INTRODUCTION

One of the topical observational problems in investigating the early evolutionary phase of stars is to study the interaction between a young star and its circumstellar environment. Therefore, investigating young pre-main-sequence stars with intermediate masses (2–10 M), Herbig Ae/Be stars, is of great interest A subclass of stars with Algol like fading's, the so-called UX Ori stars (UXORs), was isolated

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by their photopolarimetric and spectroscopic properties from Herbig Ae/Be stars .Subsequently, it was ascertained that the UX Ori stars are not some special class of stars; these are mostly Herbig Ae stars among which there are also early-type T Tauri stars. These are young stars whose circumstellar disks are inclined at a small angle to the line of sight (oriented edge-on to the observer). Therefore, their radiation on the way to the observer phases through the matter of their protoplanetary disks. Their photometric variability is caused by circumstellar extinction variations on the line of sight.

The variability of emission line profiles in the spectra of UXORs may be attributable to internal factors, namely a change in the regime of accretion and/or stellar wind and their parameters or to external factors, i.e., due to the eclipse of the star or part of the circumstellar envelope by a gas–dust cloud. The Hα emission line is the best-studied one among the features in the spectra of UXORs. This is partly because the Hα emission is generally strong in the spectra for all young stars and, in particular, for UX Ori stars. These studies were also stimulated by the fact that the wavelength of this line virtually coincides with the region of the sensitivity maximum for CCD arrays used in the last decades in astronomy, which allows relatively faint young stars to be observed with medium-size telescopes. In addition to these subjective factors, the topicality of Hα emission line studies is dictated by the fact that this line probably originates in the inner parts of the accretion disks around UX Ori stars. By investigating the behavior of the Hα emission line, we obtain information about the physical conditions in the gaseous envelope, about both the structure and kinematics of the circumstellar gas in the immediate vicinity of the stellar surface WW Vul is an isolated star of the Herbig Ae type - a typical representative of UX Ori type stars not connected in a visible way with the nebula (Sp = A3e IV). Due to the special orientation of the circumstellar accretion disk, the WW Vul is the only star in UXOR, where in the Hα lines and the resonant sodium doublet, the signs of accretion and outflow can be observed simultaneously.

2. OBSERVATION.

The spectra of WW Vul in the wavelength range $\lambda\lambda$4700–6800 °A were taken at the Cassegrain focus of the 2-m Shamakhy Astrophysical Observatory telescope with an echelle spectrograph using a 580 × 530-pixel CCD camera with a dispersion of 10.5 A°/mm in Hα spectral resolution R=14 000 [1].

The mean measurement error is about ±2 km/s for the radial velocities, about 4–5% for the equivalent widths, and no more than 1% for the intensities Over the period 2006–2010, we took two spectra for the variable under study and the standard star on each night during 24 observing night.

The reduction of echelle spectra were performed with the DECH- 20 software package developed at the Special Astrophysical Observatory of the Russian Academy of Sciences [2].

3. THE PHOTOMETRIC STATE OF THE STAR WW VUL FOR THE PERIOD OF OUR SPECTRAL OBSERVATIONS - 2006-2010.

Authors of [3] by analyzing the data of photometric observations, on the time interval of about 30 years (1980 – 2010 years), revealed the eclipses in light curve of WW Vul in the V-band. During reviewing period of observations, three similar episodes of eclipses have been revealed with the duration of 2–3 years and this phenomenon repeated with a period of 13.9 years. One of these episodes of eclipses (2008–2010) coincides with the period of our spectral observations (2006–2010). Our spectral observations were carried out before (2006-2008) and after (2010) eclipses. Unfortunately, at the minimum of eclipses (2009) we made no observations. As can be seen from the light curve, the brightness of the star WW Vul [3], in the period of our spectral observations (2008 and 2010) was almost the same (in the band of V $\sim 10^m.5$).

4. Hα PROFILE VARIABILITIES.

The period of our spectroscopic observations was arbitrarily divided into four observing seasons in years (2006, 2007, 2008, and 2010). All the measured parameters (the radial velocities at half intensity and in continuum; the radial velocities of the blue and red emission peaks as well as the radial velocities of the central absorption; the equivalent widths of the red and blue components in the Hα line; the intensities of the Hα emission line components and their ratios V/R) of the Hα emission line profile in the spectrum of WW Vul in the period of our spectroscopic observations (2006–2010) show variability both during each observing season and between seasons. At the same time, the patterns of this variability differ in 2006 (especially in August 2006) and 2007–2010. In August 2006, the dominant role in the behavior of the variability probably belongs to the accretion disk rotation, as in the case of the UX Ori star RR Tau. As follows from Tambovtseva et al. (1999, 2001 [4,5]), here there is a two-component Hα profile with V/R$\sim = 1$. At the same time, the patterns of this variability differ in 2006 (especially in August 2006) and 2007–2010. In August 2006, the dominant role in the behavior of the variability probably belongs to the accretion disk rotation, as in the case of the UX Ori star RR Tau. In contrast, in the 2007-2010 observing seasons, an additional mechanism is switched on and the variability pattern becomes more complex.

The behavior of the Hα emission line in the spectrum of WW Vul qualitatively agrees with this photometric variation, because almost all of the Hα profile parameters change the direction of their variability starting from 2007–2008. Based on their long-term photometric observations of WW Vul, [6]) established a strict correlation between the brightness variations in the optical (V band) and near-infrared (JHKL bands) spectral ranges. It should be noted that this correlation is traceable from the J band, where the star itself makes a major contribution to the radiation, up to the L band, in which the circumstellar disk makes a major contribution to the radiation. This observational fact suggests that the optical photometric variability of WW Vul is related to the instability of the inner layers of gas–dust accretion disks.

The following conclusions can be drawn from a comparative analysis of the Hα emission line profiles in the spectrum of WW Vul based onour2006–2010 spectra and by invoking, published data for the period 1972–2003 [7]:

(1) According to our spectroscopic observations over the period 2006–2010, all the measured parameters of the Hα emission line profile in the spectrum of WW Vul show variability both during a single observing season and from season to season. As a result of the comparative analysis of our data with published analogous data, it can be hypothesized that the regime of nonstationary mass out flow and/or ejection in WW Vul is generally preserved for a long time (at least over the period 1972–2010) and the accretion of gas from the circumstellar disk onto the stellar surface is occasionally observed.

(2) We revealed changes in the regime of variability of the Hα emission line profile in the spectrum of WW Vul in 2006 and 2007–2010. Starting from 2007, in addition to the accretion disk rotation, an additional mechanism leading to rapid changes in physical conditions in the Hα formation region probably appears.

(3) In the period of our spectroscopic observations (2006-2010), we detected a second emission component in the blue Hα wing in four cases (for July 8, 2006, August17, 2008, June13, 2010, and August 2, 2010) emission components measured from two spectra during the night on July 8, 2006, turned out to be -280.05 and -290.24 km s-1 [8], while for the other dates there values were -256.88, -294.36, and-217.5 km s-1, respectively.

5. THE SPECTRAL VARIABILITY OF WW VUL IN LINES OF RESONANT DUBLET NAI.

The DNaI resonance line is one of the most interesting spectral features of UXOR stars. Due to the low ionization energy (5.17 eV), sodium atoms are completely ionized in the atmospheres of stars of spectral class A and in their immediate environment. At present, it can be considered generally accepted that the DNaI line observed in the spectra of UXOR stars consists of two components: narrow interstellar absorption (IS) and circumstellar (CS) component, in the form of a variable red - or blue shifted absorption component.

In some models, not only the relatively cold peripheral part of the accretion disk, but the hot and dense gas, where the H_α emission line is formed, was considered for the region of the sodium doublet formation. Such conditions are achieved in relatively small areas of the disk or wind, where the region of formation of the Hα emission line is more extended [9,10]. According to [11], the radial velocities (IS) components within a few km / s coincide with the radial velocity of the star Ae / Be Herbig. By using this method in [12] the heliocentric radial velocity of the star WW Vul was estimated as -12 km / s.

The measured parameters of the NaID line and its profiles are highly variable both during each season of observations and from season to season. The radial velocities of the interstellar component (IS) of the NaID absorption lines in the spectra of Ae /Be type stars can be taken as the heliocentric velocity of a star (for the star WW Vul: VH = -12 km / s [12]). On one profile (08/02/2010), the (IS) and (CS) components of NaID are clearly distinguished, and in general, Va show strong variability. This is apparently related to the variability of the circumstellar component (CS) of which makes up the blend with the interstellar component (IS) NaID. It is possible that this indicates the heterogeneity of the circumstellar medium at the wavelengths of this line.

It is known that the ratio of the equivalent widths [Wλ(D2/D1)] of the sodium doublet lines is a good indicator of the optical thickness of the medium at these wavelengths.

There is a change in the optical depths (CS) of the medium, however, on average, the values, [Wλ (D2/D1)$> \sim 1$], that indicates the presence of optically thick environment in the wavelengths of the resonant sodium doublet.

6. THE VARIABILITY OF WW VUL IN LINE Hβ

Few studies have been devoted to studying the behavior of the Hβ line in the spectrum of WWVul. Based on two spectra obtained on 12/12/1972 and 09/11/1974, Kolotilov was noted good agreement of the Hβ line profile of the WW Vul star with the absorption line of standard stars of the spectral class A0V - A3V. The detected emission in the red wing of the Hβ line changes synchronously with the strengthening of emission in the H_α line (09/10/1974 [13]). By using the profile of the hydrogen line Hβ, the spectral class of the star WW Vul was estimated as A2 - A3 [14].

In the period of our spectral observations (2006–2010), the Hβ line in the spectrum of the WWVul star was an absorption, in general, with a highly variable emission component on the blue or red wing of the line. The radial velocity of absorption was negative. In August 2006, when the ratios of the V / R emission components of the Hα line are close to unity, the emission in the wings of the Hβ line is practically not revealed. In 2007 and 2008 the emission is noticeable on the red wing of the Hβ line (08.08.2007, 08.20.2008). In 2010, after an optical eclipse of the star's brightness, the emission component is observed on the blue wing of the Hβ line (08/02/2010 and 08/05/2010).

7. THE VARIABILITY OF STAR WW VUL IN LINE λ5876 HEI

One of the distinctive properties of the spectra of UXOR stars is the presence of a strongly variable line of neutral helium λ5876 Å, which is absent in the spectra of normal stars of spectral class A, due to the high excitation energy (about 21 eV). According to calculations in [15], the line λ5876 HeI is formed in a hot compact region (in a narrow layer, a tenth of a star's radius) located in the region of the accretion disk adjacent to a star, at a shell temperature of at least 17,000 K. In the same region, high-speed wind components are formed [16]. Therefore, by studying these lines in the extreme states of the optical brightness of a star, it is possible to obtain important information about the physical processes occurring in the region of the accretion disk near the star's surface, where the energy of the accreting gas is released.

During our spectral observations (in 2006, 2008 and 2010), the line λ5876 HeI has an absorption profile with a complex structure and with broad emissions on the blue wing of the line and demonstrates rapid variability, both absorption and emission component.

In August 2007, the helium line λ5876 HeI is practically not visible either in emission or in absorption. This, apparently, indicates that this line is formed in a limited volume and sometimes radiation in this line is shielded by an accretion disk.

In August 2010, after the above-mentioned optical eclipse, both the absorption component and the emission component on the blue wing of the λ5876 HeI line in the spectrum of the star WWVul increased greatly.

In most spectra, the center of gravity of the absorption component of the helium line линии 5876 HeI is shifted to the shortwave region of the spectrum. The radial velocity of the emission component on the blue wing of the helium line λ5876 HeI shows strong variability and changes in the variability mode from season to season (before and after an optical eclipse) are not noticeable.

This is apparently partly due to the difficulty of determining the center of the line, due to the complexity of the emission structure. The same can be said for the measured equivalent line widths.

8. MAIN RESULTS AND CONCLUSIONS

1. By using 114 spectra (of which 24 are our spectra) obtained by different authors for the period 1972-2010 years, the statistical analysis of the behavior of the intensity ratios (V / R) of the emission components of the Hα line in the spectrum of WW Vul was performed. In many cases, the intensity of the blue emission peak is less than the intensity of the red component (V / R $<$1), in many cases V / R$\approx$1, and only in small cases V / R$>$ 1 (10 profiles out of 114). This, apparently, indicates that the outflow with variable power of the star WW Vul as a whole lasts for almost 40 years and the accretion of gas from the circumstellar disk onto the star's surface is occasionally takes place.

2. On four dates (08.07.2006, 17.08.2008, 13.06.2010, 02.08. 2010) a second emission component was detected on the blue wing of the Hα line in the spectrum of the star WW Vul. The radial velocities of these components, measured in two spectra during the night of 08.07.2006, were -280.05 km / s and -290.24 km / s, and for other dates, the values were -256.88; -294.36; -217.5 km / s, respectively

3. In 2006 - 2008 (before the eclipse) the D1, D2NaI doublet line is a blend consisting of components: interstellar absorption and strongly variable, mostly shifted to the red (some times blue) side, weak absorption components of circumstellar origin. In 2010 (after the eclipse), a narrow interstellar component is clearly revealed, and circumstellar absorption is strengthened and observed on the blue wing of the interstellar absorption.

4. Some correspondences were found between the radial velocities of the D1, D2NaI line and the central absorption of the Hα line indicating that the sodium doublet line forms in a relatively hot and dense gas, that is, in the region of the formation of the Hα line. According to the known ratio of equivalent widths [Wλ (D2 / D1)] of the sodium doublet line, a change in the optical depth of the circumstellar medium is observed. On average, it is about one, indicating optically thick media at the wavelengths of a resonant sodium doublet.

5. During our spectral observations (2006, 2008 and 2010) the helium line 5876 HeI has an absorption profile with a complex structure and with broad emissions on the blue wing of the line and revealed rapid variability, both absorption and emission components. In August 2007, the helium line 5876 HeI is practically not visible either in emission or in absorption. This, apparently, indicates that this line is formed in a limited volume and sometimes the radiation of this line is shielded accretion disk. In August 2010, after the above-mentioned eclipse, both the absorption and the emission components increased.

6. A change in the character of spectral variability (for the lines Hα, Hβ, D1, D2NaI, HeI 5876 Å) was revealed in the spectrum of WW Vul in 2006 (before the eclipse) and in 2007 (the beginning of the eclipse) and 2010 (after eclipses). On

02.08.2010, emission components were detected in one spectrum on the blue wing of the Hα line (the second) and Hβ; absorption wind components shifted to the blue side appeared in the sodium doublet lines; in the HeI 5876 Åline, both the absorption and emission components on the blue wing are noticeably strenghened.

Apparently, in August 2006, the rotation of the accretion disk is responsible for the behavior of spectral variability, and in the observation seasons of 2007–2010 years along with the rotation of the accretion disk, an additional mechanism appears that leads to rapid changes in the physical conditions in the field of the formation of these lines. Such a mechanism can be a magnetic field in the accretion disk and / or on the surface of a star, which determines the nature of the interaction between the star and its environment.

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