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Spectral line Variations of the Symbiotic Variable CH Cygni

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Abstract: A series of high resolution spectra of CH Cygni obtained at the Bohyunsan Optical Astronomy Observatory (BOAO) in April 2004 has been analyzed. The emission components of the [O I] 6300 Å lines are de-convoluted and fitted with Gaussian functions in order to investigate the characteristics and the structure of CH Cygni system along with the analysis for Hα and [O III] lines. A present geometrical structure of the components of CH Cygni system is suggested.

Keywords: high resolution spectra, symbiotic variable, CH Cygni, Gaussian functions, geometrical structure

Introduction

CH Cygni is one of the well studied symbiotic variables. Over the decades it has been in the symbiotic phenomena. During 1977-1985, 1992-1995 and 1998-2000 it was in outburst phases which strengthen the blue continuum with emission lines of [Fe II] and double-peaked Hα profiles (Yamashita and Maehara, 1979; Hack and Selvelli, 1982; Wallerstain, 1983; Yoo and Yamashita, 1991; Mikolajewski et al., 1998; Ikeda and Tamura, 2004). It also showed peculiar phenomena outside optical wavelengths in the outburst phases. In the end of 1977-1985 outburst phase a radio outburst and bi-polar flows were observed (Taylor et al., 1986). The soft X-ray emission was also detected for about a year after the observation of bi-polar jets (Solf 1987).

Yamashita and Maehara (1979) proposed a binary model and found that the orbital period of CH Cygni is 5750 days. On the other hand CH Cygni was suggested to be a triple system and the third body revolves around the outer orbit of the binary with the orbital period of 5257 days (Hinkle et al., 1993). Nevertheless CH Cygni shows more like a binary nature in recent years. The eclipsing properties in the U and B light curves were found in CH Cygni (Skopal et al., 1996). These phenomena were confirmed with the variation of the profiles of Hβ emission (Iijima, 1998). The causes of the various kinds of these observed facts may be attributed to the instabilities of an accretion disk (Sokoloski and Kenyon, 2003a, b).

In this paper a study on a high resolution optical spectra of CH Cygni in April 2004 observed at the BOAO is presented. On 2004 April 9 CH Cygni was entering a orbital phase of 0.275, according to the period and the epoch of JD2440023 (periastron) proposed by Yamashita and Maehara (1979).

In the second section, observations and data reduction are explained. Description of the Hα, [O I] and [O III] line profiles and Gaussian fitting to the [O I] line are given in the third and the fourth sections. Discussion and conclusion are given in the last section.

Observations and Data Reduction

The observations were carried out over three

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Table 1. List of observed spectra of CH Cygni

spectra file	date (UT)	JD (day)	exposure time (sec)	dispersion per pixel	wavelength range (Å)
es07892	April 9 2004	2453105.217	600	0.024~0.033	4840~6600
es07893	April 9 2004	2453105.233	900	0.024~0.033	4840~6600
es07894	April 9 2004	2453105.246	500	0.024~0.033	4840~6600
es07933	April 11 2004	2453107.261	1500	0.024~0.033	4840~6600
es07934	April 11 2004	2453107.298	1500	0.024~0.033	4840~6600

nights from April 9 2004 to April 11 2004 using high resolution echelle spectrograph BOES (BOAO Echelle Spectrograph) mounted on the 1.8 m reflector at the BOAO. A rectangle array of 2048×4096 pixels camera was used with pixel size being 15 μm. We obtained five spectra of CH Cygni over two nights during this observing period. The observed wavelength regions covered the range of 4840~6600 Å. The diameter of the used optical fiber was 200 μm, which transmits a beam of light from the focus of the telescope to the main collimator. The output dispersions range from 1.56 to 2.14 Å mm^{-1}. Details of the available files are given in Table 1.

All the spectra were reduced with IRAF practicing usual process of bias-subtracting, flat-fielding, scattered light-subtracting and spectra-extracting. We fit the relation between pixel positions and wavelengths with 4th-order polynomials. The reduced spectra around Hα region of CH Cygni are shown in Fig. 1. The spectra are given in the normalized intensity scale.

Behavior of Line Profiles

Adopting the binary model schemed by Yamashita and Maehara (1979), CH cygni consists of an M III giant ($T_{eff}=2800$ K, $R \approx 300R$. $d \approx 270$pc, Jurdana-Sepic et al., 2004; Iijima, 1998) and a normal white dwarf star. Then CH Cygni shows composite spectral behavior. It is well known that the characteristics in M type spectra almost disappeared as the blue continuum becomes stronger in eruption phase. Although we have no opportunity of observing the blue continuum since the 2000 optical flux declines, in April 2004 the variations in Balmer lines were shown quite differently compared with those in the past eruption times of CH Cygni (Hack and Selvelli, 1982; Hack et al., 1988). The spectra secured in April 2004 included only a part of present information about CH Cygni which has not a blue continuum veiled over the photographic infrared region and blue continuum lines.

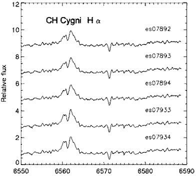

Fig. 1. High resolution Hα profiles taken on 9 and 11 April, 2004. The Hα have conspicuously changed to this period since the end of the eruption in 1998-2000.

Comparing with the spectra at quiescent phases (Kotnik-Karuza and Jurdana-Sepic 1998), the intensity of the blue component of the Hα is believed to be going to be weaker than that of red component. The double peaked emission profiles in the Hα line were, moreover, believed to have been remarkably weakened in this stage, which might have been continuously changed over last three years since it started fading out in 2000.

As seen in the spectrum in June 1986 (Bode et al., 1991) it seems that at present CH Cygni puts

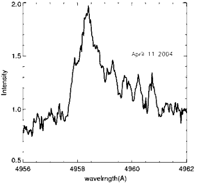

Fig. 2. The [O III] 4959 taken on 11 April, 2004.

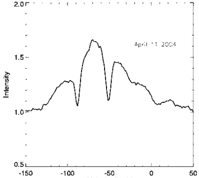

Fig. 3. The [O I] line profile taken on 11 April, 2004.

the intensity ratio of blue to red component in the Hα in reverse with respect to that in the end of eruption phase. From judging the Hα line profile after the 1998-2000 eruption stage (in the phase of around 0.881-0.042), CH Cygni seems to be currently in a beginning outburst stage. We guess that the cause of temporal variations in the Hα profiles might be due to the mass transferred into the circumference space from the system by the jets and shock waves. The H alpha line strengths have been conspicuously changed to this level compared with those in the end of the eruption in 1998-2000.

[O III] lines were appeared in the end but not in the beginning of the outburst epoch (Hack et al., 1988). In April 2004 the enhanced [O III] lines were observed and the [O III] 4959 Å is displayed in Fig. 2.

However [O I] 6300 Å line has been always detected on the spectra of CH Cygni but had two emission components in the end of the outburst epoch (Hack et al., 1988). In April 2004, the three to several emission components of [O I] 6300 Å line were also observed and given in Fig. 3. But de-convoluting the [O I] line to multi-Gaussian functions, the [O I] line has more emission components than expected.

Gaussian Fitting to the [O I] Line

Through the whole phase of CH Cygni, the temporal variations of the other lines, such as Hα, Fe II and [Fe II] lines, were remarkable. These variations might also be related to both the accretion disk and the jets which are associated with the instabilities of the accretion disk. Then to find how the [O I] line profile is affected, we try to fit the [O I] 6300 Å line to the multi-Gaussian functions. In the process of de-convolution of the [O I] line, the determination of the local continuum is very troublesome work. Throughout the tedious de-convolution procedure we separated the observed line profile of the [O I] line into several components.

It is known that the relationship between the FWHM and the standard deviation of the Gaussian function is

$$\mathrm{FWHM} = 2.355\sigma \quad (1)$$

where σ is a standard deviation of Gaussian function (Ikeda and Tamura 2004). An example of result of Gaussian de-convolution for the [O I] line is displayed in Fig. 4. The [O I] line profile has the nine emission components, indicating the interaction between outflows from the hot dwarf star and inter-

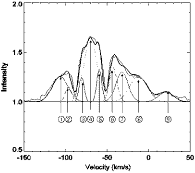

Fig. 4. An example of Gaussian de-convolution of the [O I] line. Each number represents Gaussian component.

stellar media around it, and also meaning the Kelper motion of the accretion disk. The measured FWHM values are listed in the Table 2.

Discussion and Conclusion

The differences of the observed radial velocities of emission components of the [O I] 6300 Å line from the measured ones of the Gaussian emission components for the other lines were not so remarkably detected. One possibility for the cause of the variations of the [O I] line in time would be associated with instabilities of an accretion disk around the white dwarf star as mentioned above (Yoo and Yamashita, 1991). The instabilities occurred in the inner boundary of the disk lead a high velocity stream along with magnetic fields perpendicular to the disk to move out in the circumference space faster than the matters themselves revolving around the white dwarf star (Taylor et al., 1986). The fact suggests that the jets or outflows are coming out due to matters in the inner boundary of the disk (Solf, 1987). Then the matters are no longer concentrated in the inner region of the disk and some of them are collimatedly spread around the hot star and in the case of being collimated they are moved out as the jets (Sokoloski and Kenyon, 1923a).

This jet event followed by the optical light drop seemed to be connected with the optical activity (Karovska et al., 1998; Sokoloski and Kenyon 2003a). Over the long term, the eruption phenomena seem to have an important role in the evolution of orbiting materials around the hot star. The temporal changes of line profiles happened during the eruption showed that each of ejection matter was more elongated than had been detected by Sokoloski and Kenyon (1923a). The gases which move out along a narrow band are thermal sources for the Hα line (Sokoloski and Kenyon, 2003a) and illuminating themselves, and emit the radiation which causes the Hα lines to form a complex emission profile. This is also the reason why we fit the [O I] line to Gaussian functions.

The most inner region very close to the white dwarf star causes extraordinary convection and viscosity to drive the instabilities of the system. However currently CH Cygni is not in that situation.

According to Mukkola and Tanikawa (1998), the velocity of the center of mass of CH Cygni has a value of about –60 km/sec. The [O I] 6300 Å line is always originated at a distance from the accretion disk in the process of mass flowing out the hot star. From these facts, the [O I] line profile is reflected by the orbital motions of the [O I] gases in the system.

Based on the above suggestion we propose the geometrical structure of CH Cygni in April 2004 as follows.

Table 2. FWHM (Å) of v_r (km/sec) of Gaussian fitting of [O I] 6300 Å

Component	1	2	3	4	5	6	7	8	9
FWHM (Å)	0.47	0.18	0.15	0.38	0.15	0.23	0.37	0.53	0.45
v_r (km/sec)	-106.4	-97.3	-80.6	-70.0	-59.3	-42.6	-31.9	-12.2	+21.3

The components represented by number are in the order of wavelength.

The emission components of [O I] line profile seem to be in different positions in view of the de-convoluted Gaussian components. The main emission components might result from the extended symmetric region at a distance from the accretion disk around the white dwarf and from many large patches formed by the jets and the shocks. Taking into account the central velocity of the system and the [O I] line profile, the other two emission components (1 -2, 6 -9 in the Fig. 4) of the [O I] line profile are originated by gases very slowly approaching to and receding from the main emission component. And all the emission and absorption components of the other lines for example emission peaks of the $H\alpha$ lines are also considered due to the orbital motions around the hot star.

The near future spectroscopic and radio observations are needed to better understand the characteristics and the geometry of CH Cygni even in the quiescent stage.

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