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SPECTRAL BEHAVIORS OF Hβ LINE OF CH CYGNI IN A QUIESCENT PHASE

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ABSTRACT

We analyzed the high resolution Hβ line spectra of CH Cygni obtained at the Bohyunsan Astronomical Observatory (BOAO) on April 2004. The temporal changes in the Hβ line profiles are reported. We obtained the equivalent widths of the Gaussian components. Using this we estimated the length of the gaseous nebula which emits the Hβ line and the mass loss rate from the star.

Key words: high resolution spectra, CH Cygni, present phase

1. INTRODUCTION

CH Cygni has been in similar eruption phases in irregular succession during the four epochs of 1967-1970, 1977-1986, 1992-1995 and 1998-2000 since Deutsch(1964) observed it in 1963. Eruption phase is characterized by the blue continuum veiled M type absorption spectrum, and strong Balmer lines and forbidden lines.

Many observations for CH Cygni were carried out in wavelengths from X-ray to radio.

The noticeable photometric observations were made by Mikolajewski and Mikolajewska(1988), Skopal(1987), Skopal et al.(2002), Eyres et al.(2002), and Sokoloski and Kenyon(2003a,b,c). Rapid light variations called flickering were observed, which may be used to infer the mass flow rate through the disk. When the flickering was absent, it may because the hot component was eclipsed by the M giant. Mikolajewska et al.(1990) analyzed the photometric variability and found 770 day period.

Some important spectroscopic observations were performed by Yamashita and Maehara(1979), Hack et al.(1982), Yoo and Yamashita(1991), Bode et al.(1991), and Skopal et al.(2002). From the radial velocities of emission and absorption lines in CH Cygni, Yamashita and Maehara(1979) proposed a binary model and proposed that the orbital period of CH Cygni is 5750 days. Hinkle et al.(1993) observed the infrared spectra of CH Cygni and suggested that an unseen third star has the 5257 day orb, which is so called a triple model.

Radio observations were made by Taylor et al.(1986), Solf(1987), Karovskat et al.(1998), Crocker et al.(2001) and Skopal et al.(2002). They observed that the development of the radio jet followed a decline in the blue magnitude. The cause of these observed facts is attributed to the instabilities of the inner boundary of an accretion disk(Sokoloski and Kenyon 2003a,b).

UV and X-ray observations were taken by Selvelli and Hack(1985), Leahy and Taylor(1987), Leahy and Volk(1995) and Ezuka(1995), They also attributed UV and X-ray sources to a mass accreting white dwarf.

CH Cygni now seems to be again in a quiescent phase which started in late 2000(see text in the section III).

In this paper, a study on a high resolution optical spectroscopy of CH Cygni is reported, based on the data taken in April, 2004 at the BOAO. In the second section, observation and reduction are explained. In the third section, description of Hβ line profiles and Gaussian fitting to the Hβ lines are given. Discussions are given in the last section.

2. OBSERVATIONS

The optical spectroscopic observations were carried out for three nights between April 9, 2004 and April 11, 2004 using high resolution echelle spectrograph BOES (BoaO Echelle Spectrograph) mounted on the 1.8 m reflector at the BOAO. A rectangular array of 2048 x 4096 pixels CCD detector was used with pixel sizes being $15\mu m$ x $15\mu m$ and with a readout noise of $4e^-$.

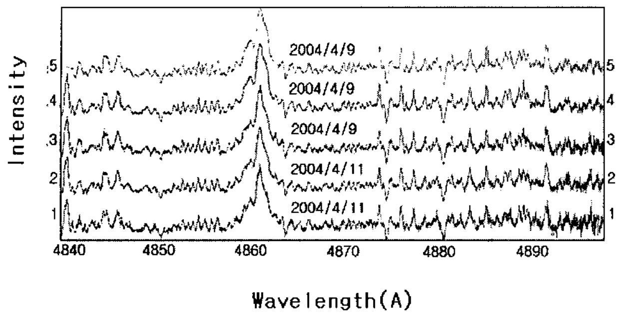

Fig. 1. High resolution Hβ profiles taken on 9 and 11 April, 2004.

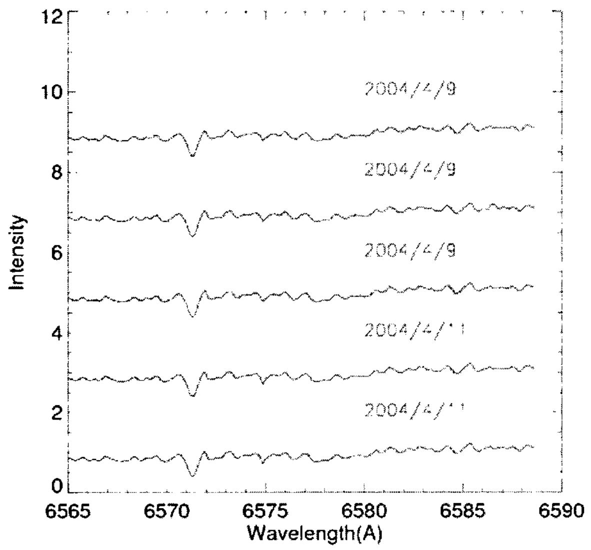

Fig. 2. High resolution spectra around 6570 Å taken on 9 and 11 April, 2004

The achieved resolving power was $\lambda/\triangle\lambda \approx 45000$. We used optical fiber of which radius was 200 μm. The observed wavelength regions covered the range of 4840 ~ 6600Å. The output dispersions range from 1.56 to 2.14 Å mm^{-1}.

All the spectra were reduced with IRAF. Usual processes were performed. The reduced spectra around Hβ and around 6570Å region of CH Cygni are shown in Figure1 and 2. The spectra are given in the normalized relative intensity scale.

3. PROFILE BEHAVIORS AND RADIAL VELOCITIES OF Hβ LINE

3.1 Profile Behaviors

During the 2000-2004 epoch, no study on the weakness in the U band flux and spectral behaviors in CH Cygni has been reported. As seen in Figure 2 on April, 2004, the CaI λ 6572 Å line is observed and known to be a photospheric line of the cool M giant. The appearance of the CaI absorption line means that its spectrum returned to that of the M giant.

Double-peaked profiles of Hβ line of having a weak absorption component cutting the broad emission profile were observed. The intensity of red component of the Hβ line is stronger than that of blue one. (The red component of the Hα line is also stronger and the ratio of peak of the both ones is about 1.7.) Within two nights a small variation in the profiles of Hβ line was observed. It might be reminiscent of a flicking phenomenon.

At present CH Cygni puts the intensity ratio of blue to red component in Hβ line in being irreversible compared with that on June.1989(Bode et al. 1991). Hence the CH Cygni might be now in the quiescent phase or the beginning of eruption phase.

We guess that the cause of variations in the Hβ line during two nights might be due to the interaction within the matter accreting to the white dwarf.

During the outburst, it was reported that double-peaked profiles of Hβ line with a sharp central absorption component were observed. Sokoloski and Kenyon(2003) suggested that disruption of the inner most disk leads to form the profile of it. Hence we suggest that on April 2004 the inner disk is being rebuilt.

Mikolajewski et al.(1990) suggested that cause of weakness of Hβ line is due to the condensation of dust in the circumference of CH Cygni. And Bodes et al.(1991) ascribed that of the Hβ line to the drop in the flux received by the matter from which the line is formed. However judging from jet configuration and the profiles of the Hβ line we insist that Hβ line is formed in the same region inside jet knots because of the synchronized variations in the above two phenomena and in the disk, and that the reason of changes in the Hβ line is the directional difference between the jet stream and the line of sight.

3.2 Gaussian Fitting of Hβ Line

The profile of Hβ line could be deconvolved with multiple Gaussian functions. We decompose the profile of Hβ line into three emission and one absorption components. The Gaussian velocity distribution of the ionized circumstellar matters which emits the Hβ line is given by

$$\phi(v) = A\exp[-\frac{1}{2}(\frac{v-v_o}{\sigma})^2] \qquad (1)$$

where σ is a standard deviation, A is the normalization factor, v_o is the velocity at the center of the Gaussian function and v is the velocity of a particle in the velocity space(Ikeda and Tamura 2004).

3.3 Radial Velocities of Emission and Absorption Components

The profile of Hβ line seems to be composed of four emission components and an absorption component. It may indicate an inhomogeneity in circumstellar gases. The widths of Gaussian emission components of Hβ line are larger than those of Hβ line except for an absorption component.

The Hβ line is reported to be originated when observed jets from CH Cygni(Skopal et al. 2002). Then through the above speculation, we deconvolve the Hβ line to multi-Gaussian components. An example of result of Gaussian de-convolution is displayed in figure 3.

This indicates that the temperature of the region emitting Balmer lines increases as a principle quantum number of HI increases. Several iterations of the de-convolution technique were applied to each of the emission and absorption components. The result of Gaussian de-convolution obtained using equation (1) is given in Table 1.

Radial velocities(v_r) were determined using emission and absorption Gaussian components fitted above of Hβ line. The Gaussian components have a well defined central core. The radial velocity is given for these peaks. All the velocities have been calibrated with respect to the Sun. These results are also given in Table 1.

In this paper, we suggested that the emission and absorption line of Gaussian components in Hβ line could be interpreted by the emission from the knots of jet and the blue continuum, that from an accretion disk.

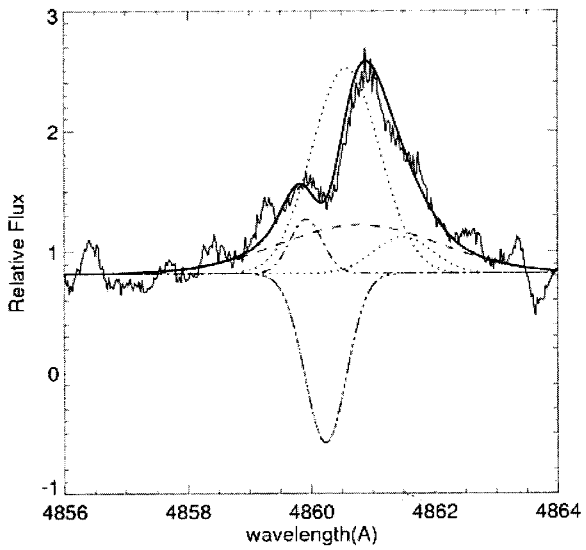

Fig. 3. An example of Gaussian de-convolution of Hβ line. The dotted lines show the Gaussian components.

4.

Table 1. FWHM(Å) of Gaussian fitting of Hβ line and radial velocities(km/sec) for Gaussian emission components

line	emission				absorption
component	comp.1	comp.2	comp.3	comp.4	comp.1
FWHM(Å)	7.0	3.0	2.6	1.4	1.8
v_r(km/sec)	−49	−70	−7	−190	−81

4. PROPERTIES OF CIRCUMSTELLAR REGION

4.1 Size of Emission Region

Hydrogen recombinations occur in the hight-density circumstellar envelope of CH Cygni and are balanced by photoionizations. If we assume that photon density N_p is nearly the same as the electron column density N_e, N_e is given by

$$N_e^2\, V \simeq 1.29\times 10^{23} T_e^{1/2} F\ (\mathrm{H}\beta)\ln(-E/kT_e) \qquad (2)$$

where V , T_e, E and k are the volume occupied by electron, temperature of the circumstellar gases, ionization energy of HI and Boltzmann constant, respectively (Richards et al. 1999). F (Hβ) is defined by

$$F\ (\mathrm{H}\beta)=4\pi r^2 F_s W \qquad (3)$$

where r is the radius of an emission region, F_s the flux per unit wavelength of the star which is given by Kurucz(1979) and W is the equivalent width of the emission component 2 which is given in Table 1 (Richards et al. 1999). The F (Hβ) value calculated by Kurucz(1979) is about 3 erg/cm^2 sec Å.

The electron densities in CH Cygni are in the range of $n_e \simeq 10^4 - 10^5$ cm^{-3} (Hack et al, 1986, Mikolajewka et al. 1988, and Sokoloski 2003) n_e is a volume density. At present phase(2004 April) if n_e is about 1.4 $\times$ 10^3 and $T_e \simeq 10^4$ K, the distance from white dwarf up to the head of jet stream which is given by 2.2×10^{12}km$\simeq 3.1 \times 10^6$ solar radius. In 1999 September, the length of jet estimated by Croket et al. 2001 was about 10^5 solar radius which is larger value than that of the present.

4.2 Mass Transfer Rate

The mass loss rate of the matters (dM/dt) from the white dwarf is exoressed in terms of electron densities n_e (particles cm^{-3})and the distance l from the white dwarf is given by

$$dM/dt = n_e l^2 \mu m_H v_H \qquad (4)$$

where μ is the mean molecular weight, m_H is the mass of the hydrogen and v_H is the velocity of jet stream. If we use $l \simeq r$ and N_e values calculated above and v_H is substituted by the value in the Table 2 for the emission component 2, and using μ = 1/2, dM./dt $\approx$ 5x10^{-8} m$_\odot$ /yr. This value is reasonable as pointed by Skopal et al. (2002). If the dynamical scale is about 0.5 days (Sokoloski and Keyon 2003b), for the variations in U-band, the mass of a billion ton might have disappeared from the white dwarf during 0.5 days.

4.3 Variations of N_e in Time

In the 1984-1985 outburst phase, the initial radio structure grew to 0.3" - 0.4"(Taylor et al. 1986). The distance of the system is assume to be 250 pc and the effective radius of the disk is about 0.1 R$_\odot$ (Sokoloski and kenyon 2003a,b), using $W \propto \Omega\ N_e$, where Ω is a solid angle(Ezuka et al. 1998), $\Delta n_e \simeq$ -10$^{4-5}$ n_e, with Δ meaning dfference. It indicates that the electron densities decrease by an order of 4-5 with the expansion of the circumstellar matters.

CH Cygni is one of the most prominent objects in the sky. However, until now the proposed models are not sufficient to explain the special behaviors of CH Cygni. To understand such changes in its light and spectrum etc, observations in future are needed.

5. SUMMARY

Through this study the conclusions we have derived from two nights high resolution spectroscopic observations for CH Cygni using the BOES on April 2004 at the BOAO are summarized as follows.

1. CH Cygni seems to be again in a quiescent phase at the time of April 2004.
2. Double-peaked profiles of the Hβ line with a weak absorption component cutting the broad emission profile were observed. The intensity of red component of the Hβ line is stronger than that of blue one.
3. The variations of the Hβ line were detected during two nights and the cause of variations in the Hβ line might be due to the interaction between the matters in the way of the mass accreting onto the white dwarf.
4. The profiles of the Hβ line could be deconvolved into three emission and one absorption components. The FWHM in unit of Å of Gaussian fitting to the Hβ line components are 7.0, 3.0, 2.6 and 1.4 for emission and 1.8 for absorption. Their radial velocities corrected to the sun are -49, -70, -7 and -190 km/sec respectively.
5. The size of jet stream measured from white dwarf up to the head of the jet stream is estimated as 3.1 $\times 10^6$ solar radius with the assumption of n_e $\approx$ 1.4 $\times$ 10^3 cm^{-3} and $T_e \approx 10^4$ K.
6. The mass transfer rate of the matters *dM/dt* from the white dwarf is estimated as about 5x10^{-8} m$_\odot$/yr and this value is in good agreement with that by Skopal et al. (2002).

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