MASS EJECTION FROM THE SYMBIOTIC PROTOTYPE Z And DURING ITS 2006 OUTBURST

N. A. Tomov¹, M. T. Tomova¹ and D. V. Bisikalo²

¹ *Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Science, P.O. Box 136, 4700 Smolyan, Bulgaria; tomov@astro.bas.bg*

² *Institute of Astronomy of the Russian Academy of Science, 48 Pyatnitskaya Str., 119017 Moscow, Russia; bisikalo@inasan.rssi.ru*

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Abstract. High-resolution spectroscopic observations in the region of the Balmer H α and H γ lines of the symbiotic binary Z And were performed during its major eruption in 2006. The H α line had additional satellite high-velocity components situated on either side of its central peak which indicated bipolar collimated outflow from the compact object. The H γ line presented three components, consisting of a central narrow emission, a broad emission component with low intensity indicating an optically thin stellar wind with a velocity of about 500 km s⁻¹ from the compact object and a blueshifted P Cyg absorption with a multi-component structure occupying a broad velocity range. These data are explained in light of a model where a disk-like envelope surrounding the accretion disk collimates the stellar wind on the compact object and gives rise to bipolar outflow. The mass-loss rate of the accretor was derived at several epochs after outburst. We conclude that the mass-loss rate has decreased probably from $4\text{--}5 \times 10^{-7} (d/1.12\text{kpc})^{3/2} M_{\odot} \text{yr}^{-1}$ at the time of maximum light to about $2 \times 10^{-7} (d/1.12\text{kpc})^{3/2} M_{\odot} \text{yr}^{-1}$ in 2006 December.

Key words: stars: binaries: symbiotic – stars: activity, mass-loss, winds, outflows – stars: individual (Z And)

1. INTRODUCTION

Symbiotic stars are long-period interacting binaries consisting of a cool visual primary and a hot compact secondary component accreting matter from the atmosphere of its companion. The nature of collimated jets from symbiotic stars is the subject of intensive theoretical investigation and the view that they represent outflow from an accreting compact object is widely accepted (Zanni et al. 2007). The collimated bipolar outflow, however, could arise due to a stellar wind, if the mechanism of collimation is available in the system. Such a mechanism can be related to disk-like formation surrounding the white dwarf which provides a small opening angle of the outflowing jets.

The system Z And is considered as a prototype of the classical symbiotic stars. Its last active phase began at the end of 2000 August (Skopal et al. 2000) and continues up to now including six (or seven?) optical eruptions. During the historical 2006 eruption optical collimated bipolar outflow was well observed along

with other mass-loss mechanisms (Burmeister & Leedjrv 2007; Tomov et al. 2007; Skopal et al. 2009; Tomov et al. 2010).

According to the modern theory, the existence of bipolar collimated jets is supposed to be due to the presence of a magnetic disk which transforms the potential energy of the accreting material into kinetic energy of the outflowing gas. This means that the accreting material provides the jet outflow. However, different indications of stellar wind were present along with satellite emission components implying a collimated bipolar outflow in the spectrum of Z And during its 2006 outburst. Therefore, accretion and stellar wind from the compact object must happen at the same time. To avoid this difficulty we propose another model for the interpretation of the spectrum, namely one with collimated stellar wind.

A model of collimated stellar wind was suggested in the works of Tomov et al. (2010, 2011) to explain the basic spectral features of Z And during its 2000, 2002 and 2006 eruptions. The main aim of our present work is to propose an explanation for the $H\alpha$ and $H\gamma$ lines during the major 2006 eruption of Z And in the framework of this model.

2. OBSERVATIONS AND REDUCTION

The region of the $H\alpha$ and $H\gamma$ lines of the spectrum of Z And was observed on fourteen nights during 2006 July – December covering its major eruption with a Photometrics CCD camera mounted on the Coude spectrograph of the 2 m Ritchey-Chretien-Coude (RCC) telescope of the National Astronomical Observatory Rozhen. The spectral resolution was 0.2 Å/pixels on all occasions. When more than one exposure was taken per night, the spectra were coadded with the aim of improving the signal-to-noise ratio. The IRAF package was used for the data reduction as well as for obtaining the dispersion curve, calculating the radial velocities and equivalent widths.

The absolute fluxes in the $H\alpha$ and $H\gamma$ lines were calculated by using their equivalent widths and the continuum fluxes at their positions. The continuum flux at the position of the $H\gamma$ line was obtained using a linear extrapolation of the B and V photometric fluxes taken on the same, or close, nights (Skopal et al. 2007). To obtain the $H\alpha$ flux we used the Cousins R_C photometric flux from the same paper accepting that it is practically equal to the continuum flux at the position of $H\alpha$. The B and V fluxes were not corrected for the intensive emission lines of Z And because of the strong increase of the stellar and nebular continua and the relative decrease of emission lines. The uncertainty of the continuum flux is not more than 10%. All fluxes were also corrected for the interstellar reddening $E_{B-V} = 0.30$ using the extinction law of Cardelli et al. (1989).

We assumed $\text{Min (vis)} = \text{JD } 2\,442\,666.0 [\text{d}] + 758.8 [\text{d}] \times E$ (Tomov et al. 2010, 2011), where the orbital period is calculated from both the photometric and spectral data, and the epoch of the orbital photometric minimum coincides with that of the spectral conjunction (Formigini & Leibowitz 1994; Mikolajewska & Kenyon 1996; Fekel et al. 2000).

3. A MODEL OF THE FLOW STRUCTURE IN THE SYSTEM

To interpret the line spectrum of Z And we used the model from Tomov et al. (2010, 2011). They concluded that as a result of accretion of the stellar wind from the giant star, a thin accretion disk located in the orbital plane is formed around

the compact object in the quiescent state of the system. The estimates of the size and mass of the disk show that its innermost part in the quiescent state can be optically thick. During the active phase an accretion disk with mass of 50–80 % of its initial mass continues to exist (Tomov et al. 2010 and references therein).

During the first outburst the outflowing material with a high velocity collides with the accretion disk. As a result, the ejecta velocity decreases in the region of the orbital plane and does not change at higher stellar latitudes. The decrease of the velocity leads to an increase of the density and the level of the observed photosphere resides further away from the star. At higher stellar latitudes the level of the photosphere is located closer to the star. In this way an optically thick disk-like shell appears in the orbital plane, which plays the role of the observed photosphere. This shell occults the hot compact object and, since the shell has a lower effective temperature (Tomov et al. 2003; Skopal et al. 2006, 2009), it is responsible for redistribution of the continuum energy and a growth of the optical flux of the star. The observed P Cyg absorption is related to this shell. The collision of the wind with the accretion disk is equivalent to collision of two stellar winds and leads to appearance of a region of shock waves whose temperature can reach 10^6 K (Nussbaumer & Walder 1993; Bisikalo et al. 2006).

During the active phase the wind of the compact object strips the accretion disk and ejects some part of its mass. At the end of each outburst some part of the ejected mass locates in the potential well of the compact object. After the cessation of the wind it begins to accrete again. Because of conservation of the initial angular momentum a disk-like envelope forms surrounding the disk which is located at a greater distance from the orbital plane than the accretion disk itself. The existence of centrifugal barrier leads to the appearance of two hollow cones with a small opening angle (15° – 30°) around the rotation axis (Figure 1, left panel) (Icke 1981; Blandford & Begelman 2004).

During the first outburst, the disk-like envelope does not exist. During the following outbursts, the extended disk-like envelope can collimate the wind, which in this case occupies only the two hollow cones and bipolar outflow forms (Figure 1, left panel). This outflow is observed as the high velocity satellite components, situated on either side of the main peak of the emission line. Their presence in the spectrum depends on the density of both the disk-like envelope and the outflowing material. These components will appear only if the density of the disk-like envelope is high enough to provide collimation and the mass-loss rate of the outbursting component is also high. According to our model they are expected to be observed during outbursts accompanied by mass loss at high rates and preceded by a similar strong outburst.

The observed broad emission components indicating an optically thin stellar wind with a high velocity appear close to the compact object, where the outflowing material moves in all directions. The gas outflowing close to the surface of the cone, whose velocity is lower than that along the cone axis, can contribute to these emission components too. Depending on the inclination angle of the orbit and the opening angle of the cone, the outflow close to the cone surface can have a radial velocity, which makes it able to emit at wavelengths outside the satellite emission.

The question on the nature of the collimated outflow is related to the important point about the inclination angle of the system. If the outflow is related to radiatively accelerated wind, its velocity cannot be higher than 3000 km s^{-1} . The highest observed velocity during the 2006 eruption is 1500 km s^{-1} . One prelim-

Fig. 1. *Left panel.* Schematic model of the region around the hot component during recurrent strong outbursts. *Right panel.* The same but in the plane perpendicular to the orbital plane where the emission regions are shown. From Tomov et al. (2010, 2011).

inary result of the reduction of our spectra taken at the end of 2009 December proposes velocity of $1700\text{--}1800\text{ km s}^{-1}$. Correcting the velocity for the inclination angle and bearing in mind the upper limit of the velocity, in this case of 3000 km s^{-1} , we can determine the maximum inclination angle of the system as 55° . There are two points of view about the inclination angle of Z And: (i) the inclination angle is rather high, supported by optical and UV data (Skopal 2003; Skopal et al. 2006), (ii) the inclination angle of $47^\circ \pm 12^\circ$ has been derived based on polarimetric orbits (Schmid & Schild 1997). The model proposed by us can be used only if the inclination angle does not exceed 55° and thus the answer to the question on the nature of the collimated outflow can permit us to define more accurately the inclination angle.

4. ANALYSIS OF THE BALMER LINES

4.1. $H\alpha$ line

The first eight of our spectra taken around the $H\alpha$ line were considered in Tomov et al. (2007). According to these data the line consisted of strong central narrow emission component (core), located around the reference wavelength, a broad emission component with low intensity (wings) and additional absorption and emission features on both sides of the central component (Figure 2). The central component presented shoulder(s) on its short-wavelength side, which was not visible in the spectra taken in September. A weak peak component on the short-

Fig. 2. Time evolution of the H α (left panel) and H γ (right panel) lines.

wavelength side of the central component is seen in the spectrum of August 8 and the dip feature between them indicates a moderate velocity of about 100 km s^{-1} . The other spectra (Figure 2) show that at the rest of the time of our observations the line consisted of the same components. Very weak peak component on the short-wavelength side of the central component was seen again from October 31. The high-velocity satellite emission components were fitted with a Gaussian and the other part of the line (the core together with the wings) – with two or three Lorentzians. The uncertainty of the equivalent width of the satellite emissions was not more than 30% and that of the whole line – about 2%.

The high resolution H α data taken in quiescent before the 2000–2011 active phase were analyzed by Tomov et al. (2008) and was concluded that the broad wings of the line, extending to velocities not smaller than about 2000 km s^{-1} from its center, are formed mainly through Raman scattering of Ly β photons by atomic hydrogen in the wind of the giant. It was also concluded that radiation damping has probably some contribution in these wings too. In 2006 July the red wing of the broad component was appreciably stronger than the blue one. Skopal (2006) suggested that the H α wings of the symbiotic stars during their active phases are formed in the high velocity wind of their compact component. Based on this suggestion, Skopal et al. (2009) concluded that the H α wings of Z And during its 2006 brightening also originate in the stellar wind. However, attention should be paid to the fact that the FWZI of the H α wings of Z And was the same both in the quiescent and the active stages of the system, maintaining its value of about 4000 km s^{-1} . This fact gives us some reason to suppose that during the 2006 brightening the FWZI of the wings was determined mainly from the radiation damping like in the quiescent state of the system, and the stellar wind emitted at a smaller distance from the line center. The problem on the nature of the H α wings needs to be considered further.

Table 1. The H α line data. $F(t)$ is the total H α flux and $\dot{M}_{\text{cw}}$ is sum of the mass-loss rates based on the satellite line components. All fluxes are in units of $10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, the mass-loss rates – in units of $10^{-7} (d/1.12 \text{ kpc})^{3/2} M_{\odot} \text{ yr}^{-1}$ and the radial velocities – in units of km s^{-1} .

Date	$F(t)$	Blue			Red			$\dot{M}_{\text{cw}}$
		RV	F	$\dot{M}$	RV	F	$\dot{M}$	
Jul 19	332.527	−1196	1.675	1.03	1445	1.675	0.85	1.88
Aug 8	279.490	−1087	2.883	1.17	1346	3.244	1.27	2.44
Aug 12		−1260	4.407	1.54	1201	3.526	1.03	2.57
Sept 7	262.478	−1245	2.642	0.50	1178	2.936	0.61	1.11
Sept 8	257.047	−1262	2.496	0.42	1196	3.083	0.78	1.20
Oct 3	264.773	−1050	4.071	1.27	1112	3.053	0.54	1.81
Oct 4	270.444	−1070	4.071	1.15	1099	3.053	0.61	1.76
Oct 31	241.650	−1054	2.295	0.60	1132	1.620	0.38	0.98
Dec 1	251.334	−1214	1.577	0.75	1174	1.092	0.54	1.29
Dec 2	250.484				1185	1.092	0.70	>0.70
Dec 30	279.816							

Together with the central narrow and broad components, the H α line presented additional satellite components with velocity of more than 1000 km s^{-1} situated on either side of the central component (Figure 2). The view that they are an indication of bipolar collimated outflow from the compact object is commonly accepted (Burmeister & Leedjr 2007; Tomov et al. 2007; Skopal et al. 2009). We associated these components with the collimated stellar wind.

The first of our spectra, taken in July, show one pronounced absorption with a velocity of 1400 km s^{-1} on the short-wavelength side of the central component of the line and a weak emission component, irregularly shaped and having velocity of about 1500 km s^{-1} on its long-wavelength side. The absorption indicates mass outflow which projects onto the observed photosphere of the outbursting compact object (its disk-like shell). As is seen from the evolution of the spectrum, the absorption component disappears and emission appears. Thus two emission components on the two sides of the central peak were formed after the middle of July and were visible until December. The disappearance of the blueshifted absorption component and the development of emission are most probably due to a decrease of the mass-loss rate of the compact object and/or increase of the number of emitting atoms in that area of the wind which does not project onto the observed photosphere. The evolution of the spectrum (Figure 2, Table 1) shows also that the line flux of the satellite components after the beginning of October decreases with time, which is due to decrease of the mass-loss rate of the compact object too.

4.2. H γ line

During the 2006 brightening the H γ line presented a broad emission component with low intensity and FWZI of about 1000 km s^{-1} in addition to its central narrow component with a nebular profile. The broad component is best seen on the spectra taken after 2006 October 31 (Figures 2 and 3). The data obtained in this period of time show that the energy flux of the broad component decreased when the light have weakened after its maximum, whereas the behaviour of the central narrow emission was different (Table 2). The broad component was analyzed by fitting

Fig. 3. Left panel. The profile of the $H\gamma$ line on July 9 and October 31. The Gaussian fit of the broad component is also shown. The level of the local continuum is marked by a dashed line. *Right panel.* The profile of the $H\alpha$ and $H\gamma$ lines on July 9. The level of the local continuum is marked by a dashed line.

Table 2. The $H\gamma$ line data. N denotes narrow component and B – broad component. F is in units $10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, $\dot{M}$ and $\dot{M}_w$ are in units $10^{-7} (d/1.12 \text{ kpc})^{3/2} M_\odot \text{ yr}^{-1}$, $\dot{M} = \dot{M}_w + \dot{M}_{cw}$.

Date	FWHM(N) (km s^{-1})	$F(N)$	FWHM(B) (km s^{-1})	FWZI(B) (km s^{-1})	v_w (km s^{-1})	$F(B)$	$\dot{M}_w$	$\dot{M}$
Oct 31	85.6	20.174	340 ± 40	746	370	7.834	1.05	2.03
Dec 1	82.9	20.003	430 ± 40	981	490	6.209	1.14	2.43
Dec 2	82.9	20.074	480 ± 50	1022	510	6.280	1.20	> 1.90

with a Gaussian function (Figure 3, left panel), and its parameters obtained with this procedure are listed in Table 2. The error of the equivalent width due to the uncertainty of the continuum level reaches up to 10%. On the spectra taken in July – September the blue wing of the broad component was not seen because of blending with the P Cyg absorption component (see below and Figure 2, left panel). In the spectra taken in October and December the blue wing appeared to be less extended than the red one due to blending with the P Cyg absorption. We consider that the broad emission component indicates an optically thin stellar wind with a high velocity of about 500 km s^{-1} from the compact object in the system.

In the spectra taken during 2006 July – September the central narrow component of the line had positive radial velocity, which was due to the presence of a blueshifted P Cyg absorption (Figures 2 and 3). In July this absorption presented a multi-component structure and occupied a velocity range from about 100 to $1500\text{--}1600 \text{ km s}^{-1}$. After that it gradually weakened and converted into a low velocity absorption present in the spectrum until the beginning of 2006 October (Figure 2). The residual intensity of this absorption was minimal in the middle of July at 0.4. As the cool giant’s continuum, at the same time, was less than 9% of the total continuum of the system at the wavelength position of the B photometric band (Skopal et al. 2009) which is close to the $H\gamma$ line, the P Cyg absorption may be related to the optically thick mass outflow from the outbursting compact object. The comparison of the spectra taken on July 9 and October 31 shows that the red wing of the broad component on the two spectra coincides (Figure 3),

which suggests that the $H\gamma$ line has also three components, consisting of a central narrow emission component, a broad emission component of low intensity and a multi-component P Cyg absorption occupying a broad region of velocities of the outflowing material – from about 100 to 1500–1600 km s^{-1} .

In the framework of our model the three-component line can be interpreted in the following way. The high velocity wind indicated by the broad emission component collides with the disk and disk-like envelope and after the collision the outflowing material moves close to the surface of the cone. This part of the material, which is located between the observed photosphere of the outbursting compact object (the disk-like shell) and the observer, gives rise to the P Cyg absorption.

The position of the most blueshifted component of the $H\gamma$ absorption was very close to the position of the $H\alpha$ absorption, which suggests the $H\gamma$ component arises in the same velocity region. The $H\gamma$ absorption, however, has presented additional components with lower velocities which arise probably closer to the compact object (Figure 3).

5. MASS-LOSS RATE

According to the model we suggested, the wind of the outbursting compact object associated with the broad emission component of the $H\gamma$ line is collimated by the disk-like envelope, and the collimated outflow is observed as the satellite emission components of the $H\alpha$ line. These two lines appear in different regions of the outflow but both of them indicate mass-loss. The total mass-loss rate of the compact object is obtained as a sum of the mass-loss rates, based on each of these lines. The mass-loss rate was determined from the energy flux of the lines assuming that the outflow was constant using the nebular approach (Vogel & Nussbaumer 1994).

The mass-loss rate based on the broad $H\gamma$ emission component was calculated from the spectra obtained from October 31, since in the period before the blue wing of the $H\gamma$ line was absorbed by the wind outflow responsible for the P Cyg absorption (Table 2). In the spectra used, the broad $H\gamma$ component was not symmetric as its blue wing was partly absorbed by the P Cyg type wind outflow with low velocity. Having in mind this absorption we consider the $H\gamma$ wind velocity and the corresponding mass-loss rate as a lower limit.

The particle density in the wind is expressed via the continuity equation. In our calculations, we adopted a value of the electron temperature in the wind of 30 000 K like during the first outburst (Tomov et al. 2008). We used the parameter $\mu = 1.4$ (Nussbaumer & Vogel 1987), determining the mean molecular weight μm_H in the wind and a helium abundance of 0.1 (Vogel & Nussbaumer 1994). We adopted a distance to the system $d = 1.12$ kpc (Fernandez-Castro et al. 1988, 1995) to compare the results with our previous paper on Z And more easily. It is supposed that the line is emitted by a spherical layer, and the radii of integration must be estimated. We assumed optically thin medium, and the inner radius in this case is thought to be the photospheric radius. The photospheric radius was estimated from the bolometric luminosity and the effective temperature of the outbursting compact object at the time of each observation. We used a bolometric luminosity of $10^4 L_\odot$ (Sokoloski et al. 2006) and Zanstra temperature from Burmeister & Leedjrv (2007) and Burmeister (2010). The outer radius of integration was $14 R_\odot$ (see below). We used a recombination coefficient for case B (Storey & Hummer

1995) corresponding to a temperature of 30 000 K and the density at the level of the photosphere at the time of each observation. The results are presented in Table 2. The mass-loss rate based on the H α satellite emission components was calculated for each observation. The wind outflow was considered to occupy a spherical sector with opening angle θ and solid angle Ω . These angles were calculated using the approach of Skopal et al. (2009). With an upper limit of the inclination angle of the system of 55° , we obtained average values of the lower limit of the opening angle of the spherical sector of $\theta(f) = 18.4^\circ \pm 1.1^\circ$ for the front wind component and $\theta(b) = 16.8^\circ \pm 0.7^\circ$ for the back wind component.

The next step is to estimate the radii of integration. The broad component of the H γ line and the satellite H α components are emitted in regions with different velocity fields. We assume that the satellite H α components are emitted in the region of the wind where the velocity is at maximum. The inner radius of this region was determined in the next way. The absorption satellite component is an indication of mass outflow which is projected onto the observed photosphere of the outbursting compact object (its disk-like shell). The radius of this photosphere according to Skopal et al. (2009) is $12 \pm 4 R_\odot$ at a distance to the system of 1.5 kpc. Baring in mind the error on the observations, a radius of $10 R_\odot$ at a distance of 1.12 kpc is acceptable. Assuming a diameter of the disk-like shell of $20 R_\odot$ and the inclination angle of 55° , for the inner radius of the region of the collimated wind we obtain $14 R_\odot$. We adopted outer radius of the region of the collimated wind as infinity. We used a recombination coefficient for case B (Storey & Hummer 1995) corresponding to a temperature of 30 000 K and density at a distance of $14 R_\odot$ from the compact object at the time of each observation. The results are presented in Table 1.

The total mass-loss rate, which is the sum of the mass-loss rates based on the two lines, is listed in Table 2. The data in Table 1 show that the mass-loss rate based on the satellite H α components decreases with the optical light of the system. It is about $2 \times 10^{-7} (d/1.12 \text{ kpc})^{3/2} M_\odot \text{ yr}^{-1}$ at the time of the light maximum and decreases to about $1 \times 10^{-7} (d/1.12 \text{ kpc})^{3/2} M_\odot \text{ yr}^{-1}$ in 2006 December. The mass-loss rate based on the H γ data from October to December is equal to the H α rate at the same time. This result proposes that the rate based on H γ probably has been close to that of H α at the time of maximum light, and has been decreasing at the same rate. Therefore, we can conclude that the total mass-loss rate of the compact object has been $4\text{--}5 \times 10^{-7} (d/1.12 \text{ kpc})^{3/2} M_\odot \text{ yr}^{-1}$ at the time of maximum light and has decreased to about $2 \times 10^{-7} (d/1.12 \text{ kpc})^{3/2} M_\odot \text{ yr}^{-1}$ in 2006 December.

6. DISCUSSION

The data in Tables 1 and 2 show the energy flux of the H α satellite components decreasing when the flux of the H γ broad component also decreases, which imply that the collimated outflow emitted most of its material when the wind was strongest. Tight correlation between the strength of the H α satellite components and the He I P Cyg absorption imply stellar wind from the compact object in the system Hen 3-1341 as observed by Munari et al. (2005) during the phase of activity between 1989 and 2004. The authors wrote “The jets were most prominent when the wind was strongest, and declined in parallel with the decrease of wind intensity.” They came to the conclusion that the wind plays a role in feeding

the mechanism for collimating the outflow. The spectral behavior of Hen 3-1341 during its active phase was identical to that of Z And. In light of our model of Z And the wind plays a role of feeding mechanism for the collimated outflow too.

7. CONCLUSIONS

We present the results of high-resolution observations of the $H\alpha$ and $H\gamma$ lines of the symbiotic prototype Z And carried out during maximum light and after it. The profile of the $H\alpha$ line was a multi-component, consisting of an intense central narrow emission located around the reference wavelength, a broad emission component with low intensity (wings) and additional high-velocity absorption and emission features on both sides of the central emission indicating bipolar collimated outflow from the compact object in the system.

The line profile of $H\gamma$ was three-component, consisting of central narrow emission, a broad emission component with low intensity and a blueshifted absorption of the type P Cyg. The broad emission component was present in the spectrum during the whole time of our observations – from July until December 2006. In July the P Cyg absorption had multi-component structure being situated in a broad velocity range from about 100 km s^{-1} to $1500\text{--}1600 \text{ km s}^{-1}$. After that it gradually weakened towards low-velocity absorption seen in the spectrum until the beginning of October 2006. In July the velocity position of the most blueshifted component of the $H\gamma$ absorption was quite close to the position of the $H\alpha$ absorption.

The behaviour of the lines is considered in the framework of a model suggested for interpretation of the line spectrum of Z And during the 2000–2011 active phase. It is supposed that the high-velocity wind from the compact object observed in the broad emission component of the $H\gamma$ line collides with the accretion disk and the disk-like envelope, which plays the role in collimating the outflow. After the collision the wind is collimated and is observed in both groups of lines, the high-velocity satellite $H\alpha$ components and the $H\gamma$ P Cyg absorption.

The mass-loss rate of the compact object was estimated at several epochs of the eruption. The rate was found to decrease from $4\text{--}5 \times 10^{-7} (d/1.12\text{kpc})^{3/2} M_{\odot} \text{ yr}^{-1}$ at the time of maximum light to about $2 \times 10^{-7} (d/1.12\text{kpc})^{3/2} M_{\odot} \text{ yr}^{-1}$ in 2006 December.

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