UNUSUAL ACCRETION DISK IN AN ALGOL - TYPE BINARIES - KU Cyg

T. Szymański[1], S. Zola[1,2], M. Siwak[3], W. Ogłoza[2]

[1] Astronomical Observatory of the Jagiellonian University
ul. Orla 171, 30-244 Cracow, Poland
[2] Mt. Suhora Observatory, Pedagogical University
ul. Podchorążych 2, 30-084 Cracow, Poland
[3] Department of Astronomy and Astrophysics, University of Toronto
50 St. George Street, M5S 3H4 Toronto, Canada

ABSTRACT. We present new results obtained from analysis of Hα double peaked emission line observed at several phases. We confirm the results that KU Cyg harbours an eccentric shape, precessing accretion disk. The system mass ratio q = 0.13 may indicate that the 3:1 resonance can be responsible for changes in the accretion disk.

Key words: binaries: eclipsing stars: individual: KU Cyg.

1. Introduction

KU Cyg is a well studied Algol-type eclipsing binary. It has been observed both photometrically and spectroscopically since 1964 by Popper (1964,1965), Olson (1988,1991) and Olson et al. (1995). The first attempt to classify the components, resulting in F4p and K5 III spectral types, was made by Popper (1965). He suggested that the primary (the hotter) star was surrounded by gaseous matter of a relatively low temperature, creating a disk – like structure. He also pointed out that the secondary component likely fills its Roche lobe.

KU Cyg belongs to the group of long period Algol – type binaries, its orbital period derived from spectroscopic and photometric studies is $P = 38^d.4$. The radius of the primary, probably a Main Sequence star, is small enough and for such configuration the matter lost from the secondary star can not directly hit the primary but an accretion disk must be formed.

The spectroscopic results published by Olson and Etzel (1991) and Olson (1991) revealed in KU Cyg a double – peaked, hydrogen emission line, visible throughout the orbital cycle, confirming the hypothesis of a disk presence in this system (Smak 1984).

The main difficulty to obtain reliable orbital parameters of KU Cyg is due to uncertain properties of the primary component. Its mass and radius make it a Main Sequence star with the expected spectral type around B7 V and the effective temperature of about 13 300 K. However, the observed spectral type of the primary is F4p (Popper 1964), resembling a supergiant, and its colours appear to indicate an effective temperature of only 7500 K (Olson 1988). On the other hand, the photometric solution by Zola (1992) gave $T_{e,1} = 10330K$. The discrepancy between those results could be due to absorption arising in a shell surrounding a star of earlier type (Popper 1964).

Smak(1997) calculated the orbital parameters from the analysis of the observed H_α emission line profile originated from the disk. Though the analysis was based on only a single spectrum, he found that accretion disk is eccentric and determined the deformation of the disk from the circular shape: $a_d = 0.48 \pm 0.01$ (the major semi – axis of disk), $e_d = 0.31 \pm 0.07$ (the disk eccentricity) and $i = 86.0 \pm 0.1$ (the orbital inclination).

2. Spectroscopic Data

Spectroscopic observations of KU Cyg were collected at the David Dunlap Observatory (DDO), University of Toronto. The first observing run was done on 4^{th} ($\phi \sim 0.220$), 10^{th} ($\phi \sim 0.377$) and 12^{th} ($\phi \sim 0.429$) December 2002 (Fig. 1), while the second one is more recent, data were taken on 1^{st} ($\phi \sim 0.171$) and 2^{nd} ($\phi \sim 0.197$) July 2008 (Fig. 1). The 1.9 m telescope and the Cassegrain focus spectrograph with dispersion of 10.8 $\AA$ mm^{-1}, corresponding to about 0.2 $\AA$ pixel^{-1} or about $12 kms^{-1}$ pixel^{-1} , were used for most observations.

The spectra were reduced with IRAF, the standard procedures were employed, which consist of calibrating the frames for bias, flat field, cosmic rays removal, extraction of one-dimensional spectra, wavelength calibration and rectification. After reduction, spectra were

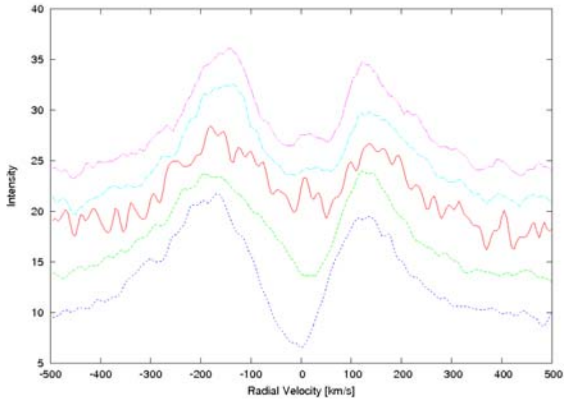

Figure 1: Double peak of Hα emission line. Spectra correspond to the phases, from the top to phases 0.171, 0.197, 0.220, 0.377, 0.429 respectively. All data were shifted to show Hα profile.

corrected by removing the γ velocity of whole binary system.

At the final result the observed velocity were corrected for the Earth rotation, the motion of the Earth around the Earth-Moon barycenter, and the orbit of the barycenter around the Sun.

Finally IRAF task (splot) were used to made Gauss fit to Hα peak. From that task, peak velocity were collected (Table 1).

Table 1: Radial velocity of the center of Gauss fit for blue and red peak of Hα

phases	blue peak	red peak
0.1707	-146.337	125.735
0.1711	-152.081	134.435
0.1967	-146.739	131.662
0.1971	-160.126	152.730
0.2204	-176.138	132.317
0.2207	-154.897	144.711
0.2212	-146.488	153.262
0.3774	-183.379	113.590
0.3518	-182.319	112.744
0.4291	-162.919	99.308
0.4296	-163.547	99.365

3. Model

In our model we use well know situation where in the circular, Keplerian disk, the observed peak velocities are almost the same as the Keplerian rotational velocities, at the outer edge of the disk (Smak 1981). We assumed that, it is also true in the case of an eccentric disk. In our work the disk is supposed to be restricted in the region close to the equatorial plan of the star. Therefore we may simplify this problem to a two – dimensional case. In the calculations we use a polar coordinate system (r, ϕ) with its pole at the center of the primary star. We define the position angle θ_0 of the semi-major axis of the disk as follows: θ_0 equal 0° when the periastron is located between the two stars and θ_0 equal 90° when the periastron is locate between the primary and the observer, at the phase $\phi = 0.75$. For that model the radial velocity of a point placed by the angle θ in the orbit of disk semi – major axis a_d, disk eccentricity e_d and phases ϕ is given by well-know equation (e.g. Huang 1973)

$$V_r = C[\cos(\phi + \theta_0 + \theta) + e_d \sin(\phi + \theta_0)]$$

The constant C is equal to:

$$C = (GM_1/A_{ORB})^{(1/2)}[a_d(1 - e_d^2)] \sin i$$

For example the peaks velocity, corresponding to $\theta = \pm\ \pi/2$ - ($\phi\ + \theta_0$), are:

$$V_{r,peak} = C[\pm + e_d \sin(\phi + \theta_0)]$$

where ± 1 corresponds to the red and the blue peak respectively (Smak 1997).

To compare radial velocity of the blue and red components of the emission line, coming from an eccentric disk with data of our model, the orbital motion K1 were taken into account.

Figure 2 shows variation of radial velocity curves at different parameters with ($\phi + \theta_0$)

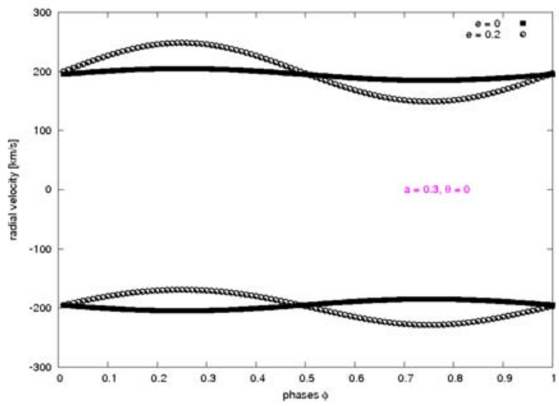

Figure 2: Variation of radial velocities of the blue and the red peaks at the different values of a_d, e_d , θ_0

4. Conclusion

The results of our model for the new spectra confirm the Smak's hypothesis that the disk shape is not circular. The resulting parameters are: inclination i = 85.6 ± 0.8, the disk major semi – axis

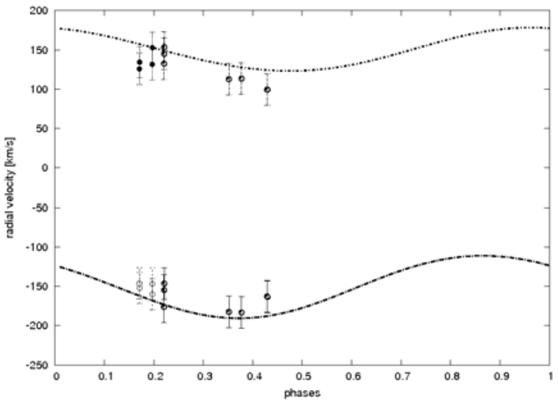

Figure 3: Observed points and theoretical velocity curves.

$a_d = 0.43 \pm 0.05$, disk eccentricity: $e_d = 0.21 \pm 0.08$, and the position angle $\theta_0 = 122 \pm 12$. The comparison of the theoretical versus observed velocities for all phases are shown in Figure 3. We were able to obtain a reasonable fit to the peak velocities for data taken in 2002 and 2008. It means that the disk size was similar in 2002 and 2008. The time scale of perturbation responsible for the growth of disk eccentricity is near 6 years, the same as in King (1994).

Using the inclination obtained from our model we determine the remaining system parameters (Table 2).

The mass ratio near 0.14 from our solution confirms another suggestion made by Smak(1997) about important role of the effects of 3:1 resonance. It can take the main role in the dynamic changes in the disk structure of the accretion disk. Further high precision spectral observations of the whole phases of this binary system are needed to resolve this problem.

Table 2: System Parameters of KU Cyg

$i[^\circ]$	=	85.6 ± 0.8
$q = M_2/M_1$	=	0.136 ± 0.01
$r_1 = R_1/A_{orb}$	=	0.041 ± 0.004
$M_1/M_\odot$	=	3.88 ± 0.07
$M_2/M_\odot$	=	0.53 ± 0.07
$A[10^{10}$ m$]$	=	5.46 ± 0.004

References

Hoang, S.-S.: 1973, *Astrophys. J.*, **183**, 541

Kreiner J.M.: 2004, *Acta Astron.* **54**, 207-210

King, A.R.: 1994, *in: "The Evolution of X-Ray Binaries"*, ed. S.S.Holt, AIP Conf. Series, **308**, 515

Olson E.C.: 1988, *AJ*, **96**, 1439

Olson E.C.: 1988, *AJ*, **102**, 1423

Olson E.C., Etzel P.B., Dewey M.R.: 1995, *AJ*, **110**, 2378

Popper D.M.: 1964, *ApJ*, **139**, 143

Popper D.M.: 1965, *ApJ*, **141**, 314

Robinson E.L., Marsh T.R., and Smak J.: 1993, *in:"Accretion Disk in Compact Stellar System"*, ed. J.C. Wheeler (Singapore: World Scientific), p.75

Smak J.: 1981, *Acta Astron.*, **31**, 395

Smak J.: 1984, *Acta Astron.*, **34**, 161

Smak J.: 1997, *Acta Astron.*, **47**, 345

Zola S.: 1992, *Acta Astron.*, **42**, 355