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Is there an accretion disc, envelope, or torus in the YY Her binary?

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Abstract. A set of extensive long-term photometric observations of the symbiotic star YY Her covering the period of (JD 2 451 823 – 2 453 880) is presented. We explain the periodic variations of the brightness of YY Her by the eclipses of the components in the symbiotic system. A model with a deformed (non-homogeneous) envelope, surrounding the white dwarf is discussed. The open question is the nature of the envelope - is it a spherical envelope, torus or thick accretion disk?

Key words. Stars: cataclysmic variables, photometry, eclipses

1. Introduction

YY Her belongs to the classical symbiotic binaries with nova-like outbursts. Tatarnikova et al. (2000) suggested from the duration of the eclipse in 1997 that the cool component of YY Her fills its Roche lobe. Munari et al. (1997) analysed all the available data and concluded that eclipses should be excluded as the cause of the light variability. Hric et al. (2001) published the long-term monitoring of the YY Her and discovered that secondary minima were also present in the light curves. Mikolajewska et al. (2002) explained the light variability of YY Her by a combination of the ellipsoidal changes and sinusoidal variations of the nebular continuum and line emission. Hric et al. (2006) summarised the results from two photometric campaigns and proposed the eclipsing model of the binary. Recently Formiggini and Leibowitz (2006) proposed to explain the secondary minimum by dark spots on the surface of the rotating red giant.

2. The eclipsing model

Our new data revealed the shape of the primary and the secondary minimum with a high accuracy. The first inspection of the light curves of YY Her casts doubts on the model by Mikolajewska et al. (2002). Nevertheless, we constructed the model curves in particular colours with parameters by Mikolajewska et al. (2002). These curves are depicted by dashed lines in Figs. 1 and 2. It is clear that this phenomenological model does not fit the new B, V, R and I data. We tested the interpretation by means of the reflection and ellipsoidal effects using the code Binary Maker 2.0. We assumed a simplified binary model: the white dwarf (WD) and the cool giant (c) at or

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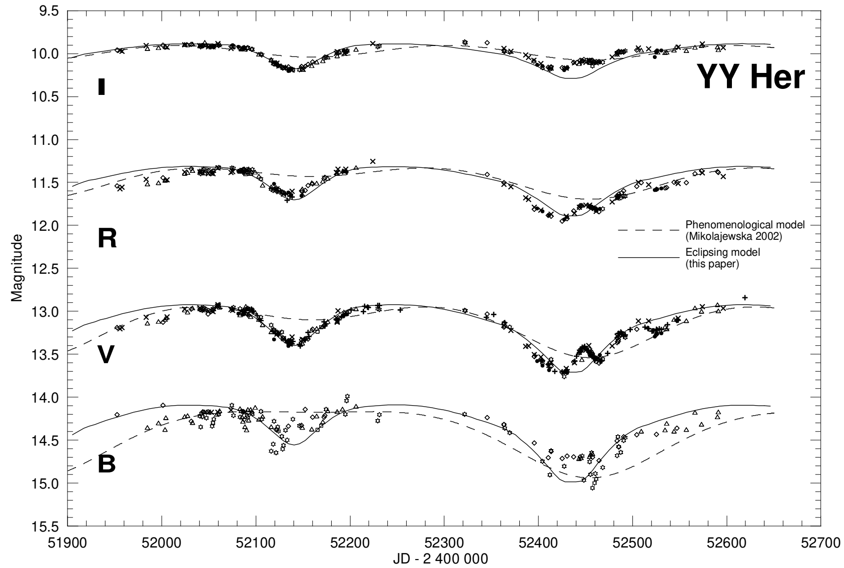

Fig. 1. The B, V, R and I light curves of YY Her covering one orbital cycle.

near its Roche lobe. The starting parameters were set as follows: $T_{\rm WD} = 100\,000\,{\rm K}, T_{\rm c} = 3\,500\,{\rm K}, q = M_{\rm c}/M_{\rm WD} = 2$. In this case, the reflection effect was so pronounced that the ellipsoidal effect was suppressed, one minimum was absent and the light curve had a sinusoidal shape (doted line in Fig. 1). Because the white dwarf can be embedded in a circumstellar nebula that dramatically changes its radiating characteristics, we decreased the temperature of the white dwarf during the next steps and traced the changes of the synthetic light curves. The second minimum appeared for $T_{\rm WD} < 53\,000K$ (dot-and-dashed line in Fig. 1). For $T_{\rm WD} \approx 35\,000K$ (solid line in Fig. 1), both minima had the same depth and for the lower temperatures the secondary minimum was deeper than the primary one.

In the next step, we attempted to explain the observed light variations by the eclipsing model (Fig. 2 - solid line). Optically thick envelope around white dwarf is able to eclipse the red giant. The envelope can be described by the model of stellar atmosphere. The white dwarf was substituted by a normal star and the parameters of the system were optimised to fit the observed light curves by the synthetic ones. The result of this optimisation process is the model with the red giant near to its Roche lobe and the white dwarf embedded in the envelope (en) with the temperature $T_{\rm en} = 4\,000\,{\rm K}$. The envelope lies inside its Roche lobe. The eclipses of the red giant and the envelope occur during the orbital cycle because the inclination of the orbital plane is $i \approx 85°$ The course of the light curve of YY Her can enable us to derive the radius of the envelope around the accretor. As the duration of the secondary minimum we determined the value of 96 days. We have adopted the radius of the giant $R_{\rm g} = 110\,{\rm R}_\odot$ as well as the radius of the circular orbit $A_{\rm circ} = 403\,{\rm R}_\odot$ by Skopal (2005). Afterwards the radius of the envelope is $R_{\rm en} = 100\,{\rm R}_\odot$ for $i \approx 85°$.

The derived values of radius and the temperature lead to the envelope luminosity $L_{\rm en} = 2\,290\,{\rm L}_\odot$, which corresponds to $M_{\rm en}(bol) = -3.65$ mag. Using the $BC_{\rm en} = -0.88$ mag we can derive the absolute magnitude of the envelope $M_{\rm en}(V) = -2.77$ mag and the apparent magnitude $m_{\rm en}(V) = 11.22$ mag for the distance d = 6.3 kpc (Skopal, 2005). The observed apparent magnitude in the secondary minimum is $m_{\rm en}(V) = 13.38$ mag. If we take into account the interstellar reddening we get the corrected

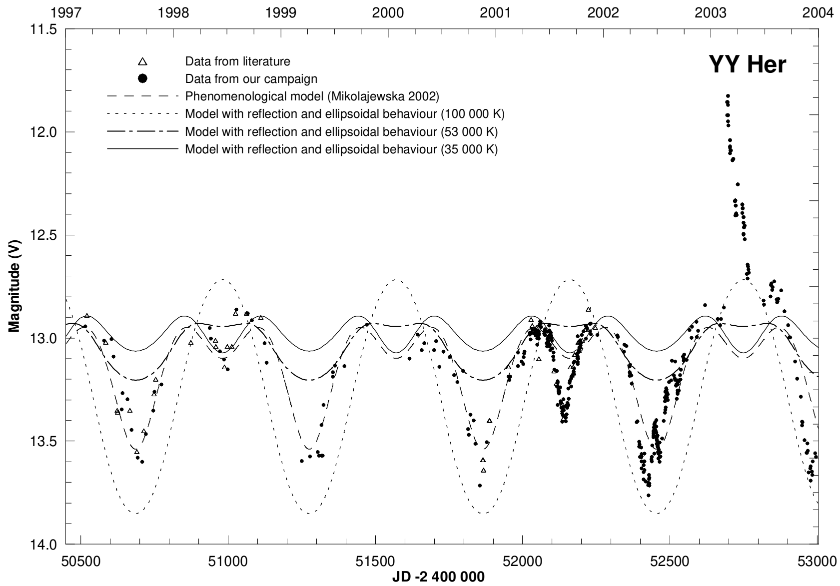

Fig. 2. The V light curve of YY Her with particular models.

apparent magnitude $m_{\mathrm{en}}(V)$ = 12.66 mag. This magnitude is by 1.44 mag less than the value computed on the base of the luminosity of the envelope. The possible explanation of this difference is in a disk-like structure of the envelope around the white dwarf.

If we turn the mentioned process we can try to assume the asymmetry rate of disk-like structure envelope. To the modified apparent magnitude of the envelope $m_{\mathrm{en}}(V)$ = 12.66 mag corresponds for the distance d = 6.3 kpc (Skopal, 2005) $M_{\mathrm{en}}(V) = -1.34$ mag and $M_{\mathrm{en}}(bol) = -2.22$ mag. We compare this value with one derived according to assumption of its asymmetric shape. We take the surface flux in both cases as equal. In this case the ratio of symmetric and asymmetric face of envelope is 3.73 what responds to the envelope thickness of 0.27 times of its radius, i. e. $H_{\mathrm{en}} = 27\,\mathrm{R}_{\odot}$ in our case. The question is if the eclipses are caused by envelope, torus or accretion disk.

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