Boletim da Sociedade Astronômica Brasileira, **32**, no. 1, 161-162

Time evolution of the quiescent accretion disc of the dwarf nova OY Carinae

Wagner Schlindwein & Raymundo Baptista

[1] Universidade Federal de Santa Catarina (UFSC)
e-mail: `wagner.schlindwein@astro.ufsc.br, raybap@gmail.com`

Abstract. OY Car was observed in quiescence with SOI/SOAR in 2014 February-April. An outburst was detected during the epoch of our observations, 6 days after/4 days before our first/second run and at least 30 days before the remaining three runs. We revised its binary parameters, combining our measurements with those in the literature, to find a mass ratio of $q = 0.098 \pm 0.003$. We used 3D eclipse mapping techniques to trace the evolution of the surface brightness distribution of the accretion disc + rim along the interoutburst phase. Our measurements show that the accretion disc radius and integrated flux decrease exponentially along the interoutburst phase, while there is marginal evidence for white dwarf cooling after outburst.

Resumo. OY Car foi observada em quiescência com o SOI/SOAR entre fevereiro-abril de 2014. Uma erupção foi detectada durante a época das nossas observações, 6 dias depois/4 dias antes da nossa primeira/segunda monitoria e pelo menos 30 dias antes das outras três monitorias. Nós revisamos os parâmetros de OY Car, combinando as nossas medidas com as da literatura, para encontrar uma razão de massa de $q = 0.098 \pm 0.003$. Usamos técnicas de mapeamento por eclipse 3D para traçar a evolução da distribuição superficial de brilho do disco de acréscimo + borda ao longo da fase entre erupções. Nossas medidas mostraram que o raio e o fluxo integrado do disco de acréscimo diminuem exponencialmente ao longo da fase entre erupções, enquanto há evidência marginal de resfriamento da anã branca depois da erupção.

Keywords. Stars: dwarf novae – binaries: eclipsing – novae, cataclysmic variables

1. Introduction

In dwarf novae, a a solar-like star (secondary) transfers matter to a white dwarf companion (WD, primary) via an accretion disc (Warner 1995). Dwarf novae show recurrent outbursts on a days-months timescales, where the accretion disc increases in brightness by factors 20 – 100. A subtype of the dwarf novae is the SU UMa systems, which show not only outbursts but also superoutbursts, which are brighter and last about 5 times longer than common outbursts. During superoutbursts, superhumps are observed, which a brightness modulation at a period slightly different from orbital.

OY Carinae is a short period dwarf nova ($P_{\rm orb} \simeq 91\,$min) of the SU UMa type. Its light curves show deep eclipses ($\sim 2.5\,$mag), which last $\sim 9\,$min, as well as outbursts and superoutbursts on a days-months time scale.

Two models compete for the explanation of these outbursts. The disc instability model (DIM, Lasota 2001; Cannizzo 1993) assigns the outbursts to a thermo-viscous instability on the disc which causes it to cyclically transition between a cold and low viscosity (quiescence) state and a hot and high viscosity (outburst) state. On the other hand, the mass transfer instability model (MTIM, Bath 1972, 1975; Bath & Pringle 1981) assigns the outbursts to the response of a disc with constant (and high) viscosity to sudden increases in the mass transfer rate from the secondary.

2. Analysis and results

OY Car was observed in quiescence with SOI/SOAR in 2014 February-April. An outburst was detected during the epoch of our observations, 6 days after/4 days before the first/second runs and more than 30 days before the other three runs.

We combined white dwarf and bright spot ingress/egress phases from our data and literature measurements to revise the binary parameters. The mass ratio (q) is determined by assuming that the bright spot originates at the intersection of the ballistic gas stream trajectory with the disc rim. As a bonus, this procedure yields an estimate of the disc radius ($R_{\rm D}$). We find $q = 0.098 \pm 0.003$, consistent with value of Littlefair et al. (2008) within the 1σ confidence level.

We separated the data into three sets according to morphology of their light curves: high (4 days after the outburst), intermediate (more than 30 d after the outburst) and low (6 days before the outburst). We apply eclipse mapping techniques (Baptista 2016) to the three data sets in order to trace the evolution of the surface brightness of the accretion disc + rim along the interoutburst phase (Fig. 2).

Disc brightness distributions (Fig. 1) have a pronounced central emission, from the WD + boundary layer, plus an asymmetric emission along the stream trajectory, which may be evidence of gas stream overflow/penetration. The asymmetric source elongated in azimuth at the outer disc traces the bright spot emission. The time evolution shown in Fig. 2 reveal that the WD, the disc and the bright spot emission decrease in brightness along the interoutburst phase. The increase in bright spot intensity along the interoutburst phase is due to the decrease in disc radius and consequent increase in gravitational energy released in the impact at disc rim.

We can estimate $\dot{M}_2$ from the luminosity of the bright spot. For this, we estimate the temperature of the bright spot ($T_{\rm BS}$) along with its radius ($R_{\rm BS}$) from the brightness distribution at disc rim of Fig. 1. Thus,

$$\dot{M}_2 = \frac{2\pi\sigma R_{\rm D}}{G M_1}\left(1 - \frac{R_{\rm D}}{R_{\rm L_1}}\right)^{-1} R_{\rm BS}^2 T_{\rm BS}^4 \qquad (1)$$

where σ is the Stefan-Boltzmann constant, G is the gravitational constant, M_1 is the primary mass, and $R_{\rm L_1}$ is the distance from the disc center to the inner Lagrangian point.

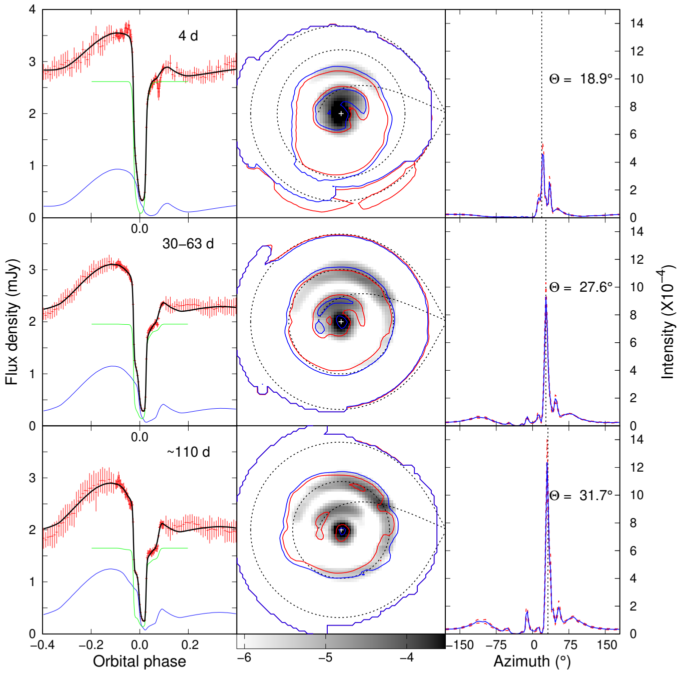

FIGURE 1. Ellipse mapping result for OY Car curves in the high (upper panels), intermediate (center panels) and low (lower panels) brightness states. *Panels on the left:* Data (red crosses with error bars) and model (black line) light curves. The green/blue solid line depicts the model disc/rim eclipse light curve. *Center panels:* Surface brightness distribution of the disc map in a logarithmic grayscale. Regions inside the red/blue contour lines are above the 3- and 5-σ confidence levels, respectively. Dashed lines depict the primary Roche lobe, the radius of the disc in each of the states, and the ballistic stream trajectory. The horizontal bar shows the logarithmic intensity grayscale; brighter regions are darker. *Panels on the right:* Brightness distribution at disc rim (blue curves) and its uncertainty (red dashes). The dotted line indicates the azimuthal position of the bright spot as measured by the intersection of the ballistic gas stream trajectory with the disc rim.

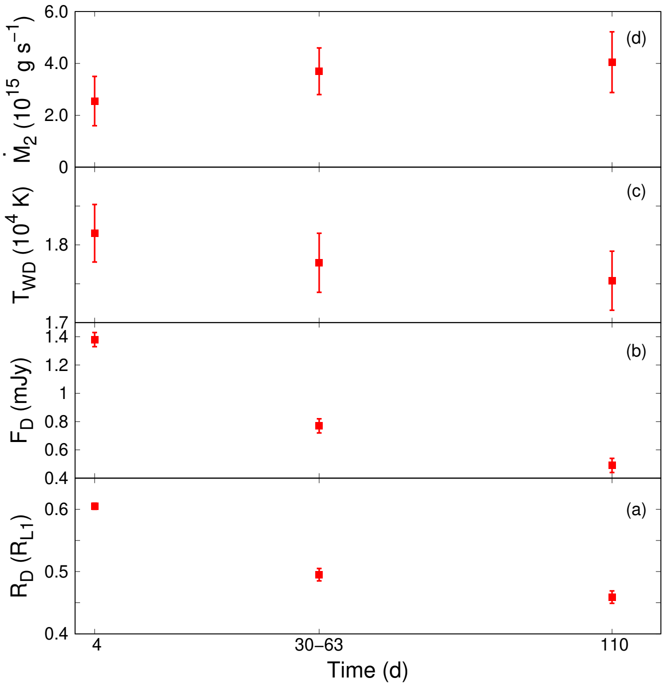

FIGURE 2. Variation of mass transfer rate ($\dot{M}_2$), white dwarf temperature ($T_{\rm wd}$), disc flux ($F_{\rm D}$) and accretion disc radius ($R_{\rm D}$) versus time since last outburst.

The evolution along the interoutburst phase of 4 quantities of interest are shown in Fig. 2:

- The accretion disc radius ($R_{\rm D}$) and integrated disc flux ($F_{\rm D}$) decrease exponentially along the interoutburst phase, in good agreement with MTIM expectations (Ichikawa & Osaki 1992). The monotonic decrease in disc flux along the interoutburst phase is in clear disagreement with the basic DIM prediction that the whole quiescent disc should increase in brightness as matter accumulates and the next outburst aproaches (Schreiber et al. 2005).
- There is marginal evidence for white dwarf cooling after outburst. The episode of increased accretion of matter during outbursts should heat the WD, leading to an expected exponential cooling along the following interoutburst phase (e.g., Sion 1999). Our data is consistent with a small $\Delta T = 820\,$K post-outburst WD cooling on a timescale of $\tau_{\rm WD} = 68$ days.
- The mass transfer rate ($\dot{M}_2$) derived from the bright spot luminosity ($L_{\rm bs}$) seems to be reduced by a factor 1.5 right after the outburst. This variation is not predicted by the DIM neither by MTIM. This may imply that a sizeable fraction of the disc mass input at that phase evades collision at disc rim and proceeds along the stream trajectory to release its gravitational energy at inner disc regions (i.e., stream overflow or penetration). The fact that there is increased emission along the gas stream at the same epoch supports this idea.

3. Conclusion

The fact that an outburst occurred during the epoch of our observations enabled us to study the temporal evolution of OY Car along the interoutburst phase. This study shows that (1) the accretion disc radius and integrated disc flux decrease exponentially along the interoutburst phase, in disagreement with predictions of the DIM, (2) there is marginal evidence for white dwarf cooling after outburst, and (3) the mass transfer rate derived from the bright spot luminosity seems to be reduced by a factor 1.5 right after the outburst.

Acknowledgements. We thank CNPq/Brazil and CAPES/Brazil for financial support through scholarships.

References

Baptista R., 2016, in Astronomy at High Angular Resolution, Astroph. and Space Science Library, eds. H.M.J. Boffin, G. Hussain, J.-P. Berger, L. Schmidtobreick (Springer: Switzerland), p. 155
Bath, G. T. 1972, ApJ, 173, 121
Bath, G. T. 1975, MNRAS, 171, 311
Bath, G. T., & Pringle, J. E. 1981, MNRAS, 194, 967
Cannizzo, J. K. 1993, ApJ, 419, 318
Ichikawa, S., & Osaki, Y. 1992, PASJ, 44, 15
Lasota, J.-P. 2001, New A Rev., 45, 449
Littlefair, S. P., Dhillon, V. S., Marsh, T. R., et al. 2008, MNRAS, 388, 1582
Schreiber, M. R., Hameury, J.-M., & Lasota, J.-P. 2005, The Astrophysics of Cataclysmic Variables and Related Objects, 330, 207
Sion, E. M. 1999, PASP, 111, 532
Warner, B. 1995, Camb. Astrophys. Ser. Vol. 28, Cataclysmic Variable Stars, Cambridge Univ. Press, Cambridge