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Short-period cataclysmic variables at Observatorio Astronomico Nacional IA UNAM.

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Abstract. We present results of time-resolved spectroscopy and photometry of faint (∼17-19 mag) Cataclysmic Variable stars with periods around the minimum orbital period (∼80 min). In this work we concentrated to our results of study of CVs systems which have evolved beyond the period minimum (so-called bounce-back systems). Using various instruments attached to 2.1m, 1.5m and 0.84m telescopes of OAN SPM of IA UNAM we explored conditions and structure of accretion disks in those short-period Cataclysmic Variables. We showed that the accretion disk in a system with an extremely low mass ratio ($\leq$0.05) grows in the size reaching 2:1 resonance radius and is relatively cool. The disk in such systems also becomes largely optically thin in the continuum, contributing to the total flux less than the stellar components of the system. In contrast, the viscosity and the temperature in spiral arms formed at the outer edge of the disk are higher and their contribution in continuum plays an increasingly important role. We model such disks and generate light curves which successfully simulate the observed double-humped light curves in the quiescence. Thanks to support of our programs by the Time Allocation Commission of OAN SPM, the perfect astroclimate in the observatory, and the phase-locked method of spectroscopic observations, the significant progress in the study of bounce-back systems using a small size telescope was reached.

Key words: cataclysmic variables: the period minimum — cataclysmic variables: time-resolved spectroscopy and photometry

1. Introduction

A widely accepted evolutionary theory of cataclysmic variables (CV), as presented in Kolb & Baraffe (1999, and references therein), predicts a significant accumulation of CV systems around the orbital period minimum (Paczynski 1981). It also envisions that ∼70% of the current CV's population have evolved past the orbital period minimum and formed so-called bounce-back systems. Figure 1 illustrates the current concept of CV evolution at the orbital period turn-around point on the mass-transfer rate and mass-ratio to orbital period diagrams. Cataclysmic Variables with orbital periods close to the 80 min orbital period minimum that undergo infrequent (years to decades) super-outbursts are called WZ Sge-type stars. Objects with short periods that have not been

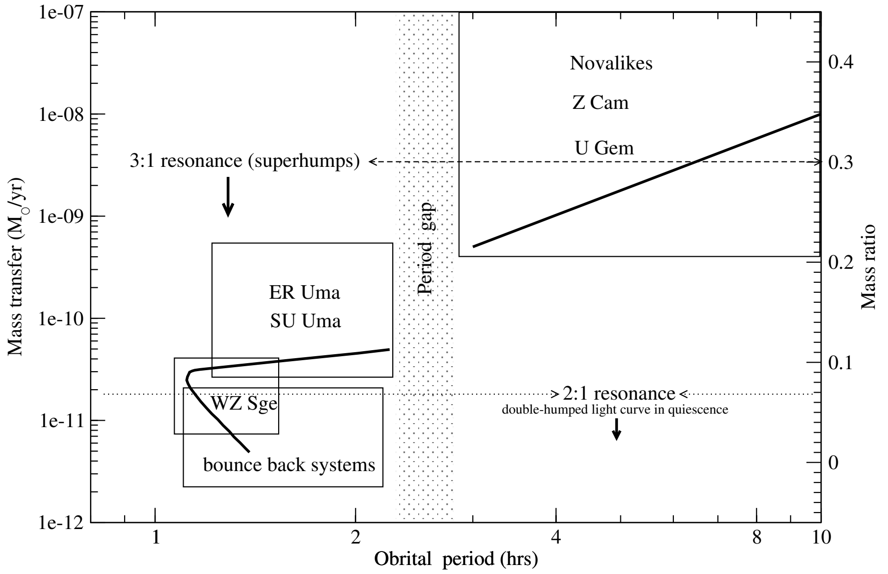

Figure 1. Schematic distribution of CV-types on the plot of the mass ratio and mass transfer rate vs. the orbital period.

observed in outbursts or super-outbursts but have spectral characteristics similar to WZ Sge are listed also as WZ Sge-type candidates. Those systems are dominating at the period minimum. The bounce-back systems are CVs that have evolved beyond the minimum period limit, which is reached when the secondary star becomes of a substellar mass (brown dwarf) and partially degenerate. Bounce-back systems are expected to float within the 80 - 100 min orbital period range. Bounce- back systems are spectroscopically similar to these, but not every WZ Sge-type object has necessarily passed through the turning point. Figure 1 also displays the expected position of the bounce-back systems.

The OAN is a facility of the Instituto de Astronomía of the Universidad Nacional Autónoma de México (IA-UNAM). OAN-SPM is located at San Pedro Mártir, Baja California, Mexico at 31^o of north latitude. It is situated at 2890m above sea level. The site is characterized by low humidity, excellent seeing conditions, and the dark sky. There are 3 telescopes in operation currently: 2.1, 1.5, and 0.84 meter with different type spectroscopic and photometric equipments[1]. Thanks to support of our programs by the Time Allocation Commission of OAN SPM and use of the phase-locked method (Zharikov, S., et al. 2013) used during spectroscopy, and with simultaneous spectroscopic and photometric observations, significant progress in the study of short period CVs ($\leq$ 90min) and bounce-back systems with these small telescopes has been achieved (Zharikov, S., et al. 2008 & 2013, Aviles, A., et al. 2010)

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[1] http://haro.astrossp.unam.mx/indexspm.html

2. Short-period cataclismic variables

2.1. WZ Sge-type stars

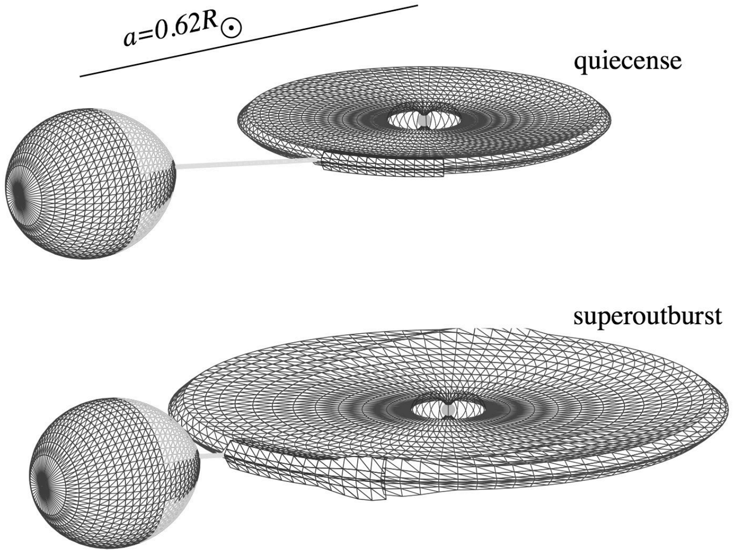

Figure 2. The current conception about WZ Sge- type systems which have not passed yet the period minimum.

WZ Sge is the prototype star of the class of short-period cataclysmic variables (named WZ Sge-type stars). It is a high inclination (~77^o; Steeghs et al. 2007) cataclysmic variable with a late M-type dwarf secondary star ($0.078M_\odot < M_2 < 0.13M_\odot$) orbiting at 81.6 min the fastest-spinning (~ 28 sec, Robinson et al.1978) white dwarf ($0.88M_\odot < M_1 < 1.53M_\odot$). The distance to WZ Sge is only 43.5 pc. For most of its life it is in quiescence with a $V \sim 15$, corresponding to $M_V \sim 12$. Below the main characteristics of WZ Sge are summarised:

• A short orbital period of 81.6 min, close to the predicted period minimum of CVs ~ 77min with a main sequence secondary.

• A spectrum in quiescence shows strong double-peaked Balmer emission lines from the accretion disk surrounded by broad absorptions, formed by the primary white dwarf (see for an example Howell et al. (2008)).

• Infrequent ~20-30yr and large-amplitude (~ 8mag; 1913, 1946, 1978, 2001) super-outbursts followed by echo outbursts, absence of a normal (as in SU UMa-type stars) outbursts. In order to avoid an earlier occurrence of normal outburst in WZ Sge-type systems, it can be accepted as an extreme low viscosity parameter a ~0.01-0.001 in accretion disks (Smak (1993), Osaki (1994)).

• The light curve during a super-outburst shows long-lasting super-humps (Patterson, et al. 2002).

- The optical light curve are double-humped sometimes during a super-outburst and in quiescence (Patterson, et al. 1998; Patterson, et al. 2002).
- There is evidence of forming spiral arms in the disk during super-outburst (Baba et al. 2002, Howell et al. 2003).
- In quiescence the accretion disk is asymmetric, and the bright spot region is shown to be extended along the mass transfer stream (Skidmore et al. 2000, Mason et al. 2000).
- The outer layers of the accretion disk must be of low density and low temperature ∼3000K (Howell et al. 2004).
- A cavity most likely formed in the inner part of the disk during quiescence implying an annulus-shaped accretion disc (Kuulkers et al. 2011).
- The outer radius of the disk is about a 3:1 resonance radius ($r_{disk} \leq R_{3:1}$) in quiescence and it can reach the 2:1 resonance radius ($r_{disk} \leq R_{2:1}$) during a super-outburst.

There are about ∼100 objects proposed or confirmed as WZ Sge-type systems. Most of them were suggested based on features of spectra or the amplitude of the super-outbursts. Figure 2 summarise current conception about WZ Sge-type systems which have not passed yet the period minimum.

2.2. Bounce-back systems

After reaching the period minimum the CVs should evolve back toward longer periods and form so-called bounce-back or post-period minimum systems. The increasing of orbital periods of bounce-back systems is accompanied by decline in the mass transfer rate about an order of magnitude according to the existing models of CVs evolution (Kolb & Barrafe 1999, Sirotkin & Kim 2010). The list of the bounce back candidates are given in Zharikov et al. 2013. The optical spectra in quiescence of proposed candidates are similar to WZ Sge. All those systems include a massive and relatively cool ($\sim 12000K$) white dwarf primary and a M_2/M_1 mass ratio less than 0.075. Such low mass ratio implies a Jupiter-size secondary (a late type M-dwarf or a brown dwarf) and with a 2:1 resonance radius is within of the Roche lobe of the primary. Also, similar to WZ Sge, the bounce back candidates do not show normal outbursts which implies an extremely low $\alpha \sim 0.01 - 0.001$ viscosity parameter (Smak (1993), Osaki (1994). This together with the low $\sim 10^{-11} M_{\odot}/year$ mass transfer rate, allows the accretion disk to expand in bounce back systems up to a 2:1 resonance radius and form a two spiral wave structure in those systems (Lin & Papaloizou, 1979).

The large size of the disk and domination of white dwarf radiation in the optical range, and the secondarys radiation in the JHK bands in bounce back candidates SDSS0804 and SDSS1238 (Zharikov et al 2013, Aviles et al 2010) lead to the conclusion that the standard accretion disk model (Frank et al. 2002) does not apply to bounce-back systems. Cannizzo & Wheeler (1984) studied the vertical structure of a steady-state, α-model thin-accretion disk for an accreting object of 1 $M_{\odot}$. They found that, for low accretion rates, the disk structure is optically thin and can be double-valued with high- (∼5000 K) and low- (∼2000 K) temperature branches. For $\alpha > 0.1$ a warm solution is possible in the inner region of the accretion disk, but disk annuli at larger radii will be in a cold state with $T < 2000$ K. Only the low-temperature solution exists for $\alpha \approx 0.1$. As α decreases with temperature, the tendency to develop cold solutions in quiescence is enhanced. Therefore, accretion disk in bounce back systems are most probably cool (∼2500 K).

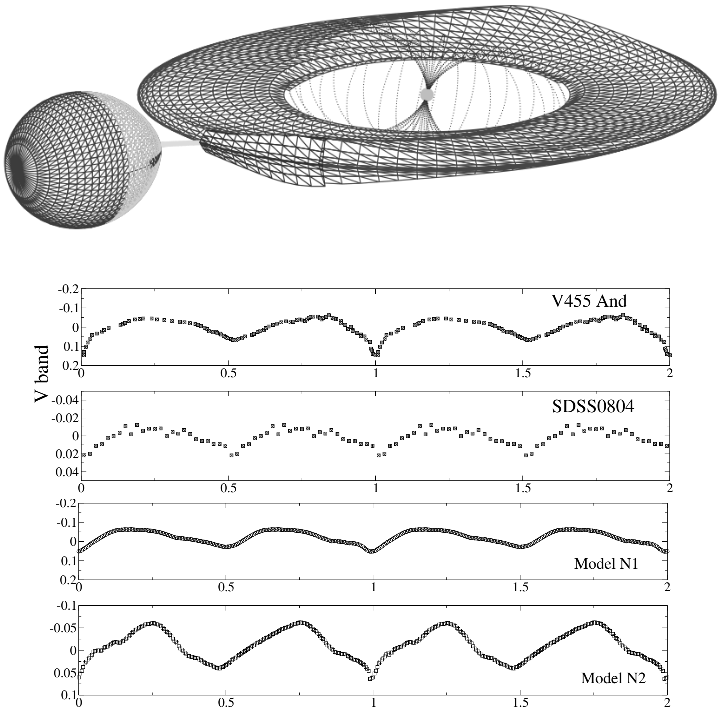

Figure 3. Top panel: model configuration used to calculate the light curves of bounce-back systems. Middle panels: examples of double-humped light curve. Bottom panels: examples of the light curve generated by the model.

The optical light curve of the high inclination bounce back candidates shows permanently a double-humped light shape. The spiral arm structures were found from Doppler tomography mapping in quiescence in two well studied example of bounce back candidates SDSS1238 (Aviles et al. 2010) and SDSS0804 (Zharikov et al. 2013). At very low mass transfer rate (see. Fig.1), even a relatively weak magnetic field strength of 1 MG is sufficient to form a cavity in inner regions of these accretion disks (Zharikov et al 2013). Taking into account all these features a geometrical model of bounce back system was constructed to explain the observed double-humped light curve in quiescence. The model takes into account the positions of the bright structures in the Doppler maps, the large size of the accretion disk, and the description of the spiral density waves in Hachisu et al. (2004). Figure 3 presents the geometry used in the model (top panel). We calculated a variety of models using the typical average parameters of bounce-back systems and found that the double-hump-shape light curve (Fig. 3, middle panels) is easily reproduced by such models (Fig. 3, bottom panels).

3. Conclusion

Using various instruments attached to 2.1m, 1.5m and 0.84m telescopes of OAN SPM of IA UNAM we explored conditions and structure of accretion disks in short-period CVs. The data from those telescopes give a strong contribution to significant progress in our understanding of the physics of CVs systems around the period minimum.

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