WZ SGE STARS

E.P. Pavlenko[1,2]

[1] Crimean astrophysical observatory
Nauchny 98409 Crimea, Ukraine, *pavlenko@crao.crimea.ua*
[2] Tavrida national university

ABSTRACT. The WZ Sge type stars is a rare subclass of the cataclysmic variables (CVs). It possesses the properties of both dwarf novae and recurrent novae. The WZ Sge stars have the shortest orbital periods (typically 80 - 90 minutes) known among the dwarf novae, and the long (decades) recurrent time of outbursts never displayed by the dwarf novae but that is typical for the recurrent novae. At the same time the WZ Sge stars show their own unique peculiarities and are the promising objects for search for the brown dwarfs in close binaries. The brief review of the main characters of the known WZ Sge stars is given including the last results of the newly discovered and investigated binaries of this type.

Key words: Stars: binary: cataclysmic; stars: individual: WZ Sge, SDSS J0804, V455 And, ASAS J002511+1217.2

1. Introduction

The cataclysmic variable stars (CVs) are the close binaries suffering the late stage of their evolution. They consist from the late type star filling its Roshe Lobe and loosing material through the inner Lagrangian point onto the compact primary (white dwarf/neutron star/Black Hole). This class of variables displays the outbursts of different amplitudes and different recurrent time. Basing on the variety of these parameters, the CVs are divided onto several subclass: 1) classical novae: the recurrent time of outbursts presumably is 10^4 - 10^5 years, amplitude - more than 6^m (in the case of the Nova V1500 Cyg (1975) the amplitude of the outburst was 19 mag!), 2) dwarf novae: The recurrent time of the outbursts is weeks and amplitude is mostly less than 6 magnitudes (Warner, 1995); 3) recurrent novae: time between outbursts is decades of years. The last subclass however covers both close and wide binaries (one could find recurrent novae among symbiotic stars).

WZ Sge stars were extracted into separate subclass last time because of the large ($\sim 8^m$) amplitudes (Bailey, 1979; Downes, Margon, 1981; Patterson et al., 1981; O'Donoghue et al., 1991; Kato et al., 2001a) and specyfic combination of the orbital periods and recurrent time of the outburst: the shortest orbital periods (80 - 90 min.), that is typical to the SU UMa type subclass of the dwarf novae, but contrary to them, the long recurrent time of the outbursts (decades). It is possible to consider the WZ Sge stars as recurrent novae as well. Furthermore, while the symbiotic stars bound the recurrent novae at the longest orbital periods (years or decades) among interacting binaries, the WZ Sge type stars bound this subclass at the shortest orbital periods.

The physics of the classical novae and dwarf novae is principally different. While the nature of the classical nova explosion according to the morden conceptions, is the thermonuclear event in the upper layers of the white dwarf, the nature of the dwarf novae is the thermal-viscous instability that occurs in accretion disc in which the viscosity is given by the alpha-prescription (Warner, 1995; Shakura & Sunyaev, 1973). The outburst in the dwarf novae starts happens when the disc becomes partially ionized and the opacities vary steeply with temperature; this occurs when the disk material reaches temperatures of order of 8000 K (Lasota, 2001). The origin of the WZ Sge type binaries outbursts means also the termal instability of accretion disc.

There is a tendency of growing of the WZ Sge stars number last time not only due to the developed net of the amator monitoring of the outbursts, but, also, due to the possibility to select some candidates aside the outburst on the base of the modern surveys (for example, such as the SDSS, HS, ASAS).

2. Types of the outbursts

It is possible to distingwish four types of the outbursts among the WZ Sge type stars.

1. Perhaps the majority of the WZ Sge stars shows single outburst. The examples are: HV Vir(Kato et al., 2001b), WX Cet (Kato et al., 2001a).

2. Outburst with one rebrightening. That is typical to the normal (but not to all!) SU UMa type of the dwarf nova. For example: RZ Leo (Ishioka et al.,

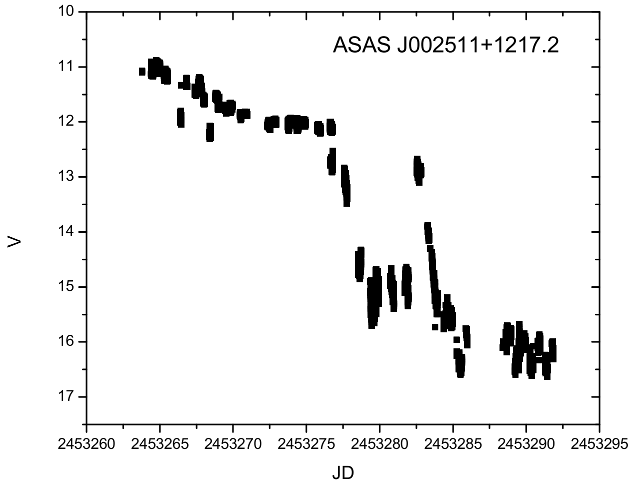

Figure 1: Light curve of the ASAS J002511+1217.2 outburst with single rebrightening (from Golovin et al., 2005).

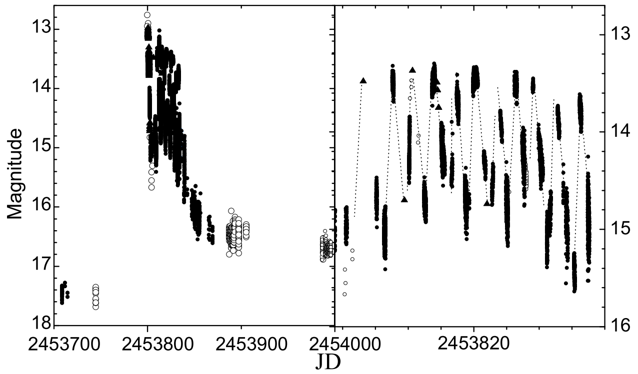

Figure 2: Left: Light curve of the J0804 outburst (from Pavlenko et al., 2007a) with eleven rebrightenings. Right: Detail view of rebrightenings.

2001); ASAS J002511+1217.2 (Golovin et al., 2005). For illustration of such type of the outbursts the light curve of the ASAS J002511+1217.2 is given in Fig.1.

3. The outburst with series of rebrightenings (one could find in literature also another sinonima: reflares, or echo-outbursts). That is a unique fenomena that was observed ONLY in WZ Sge type stars, namely WZ Sge itself -12 rebrightenings (Patterson et al., 2002), SDSS J0804 -11 rebrightenings (Pavlenko et al., 2007), and EG Cnc - 6 rebrightenings (Patterson et al., 1998a). Fig. 2 shows the light curve of SDSS J0804. Several competing points of view try to explain the phenomenon of rebrightenings, for example:

The rebrightenings are triggered while the mass transfer rate is still high after the superoutburst (Buat-Menard and Hameury, 2002).

The heating waves reflected from the cooling waves accompanying the decline from the last outburst (Patterson et al., 1998a).

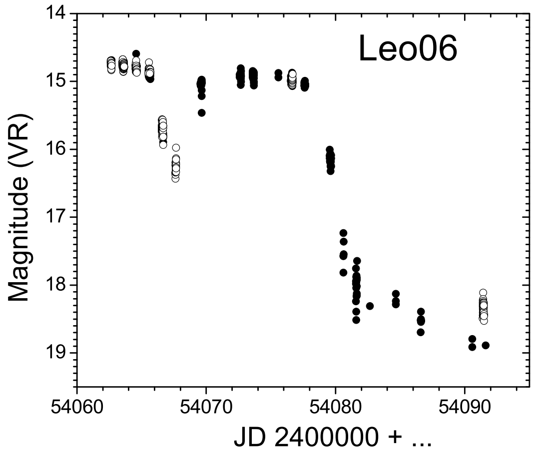

Figure 3: Light curve of the Leo06 = SDSS J102146.44+234926.3 outburst with dip (from Uemura et al., 2007.)

4. Outburst with no rebrightenings but with 1.5^m - 2^m dip that lasts a few days. Such kind of the outburst could also be called as the outbursts with long-lived plateau (Uemura et al., 2007): AL Com (Nogami et al., 1997), CG CMa (Kato et al., 1999); Leo06 = SDSS J102146.44+234926.3 (Golovin et al., 2007); TSS J0222 (Imada et al., 2006b); V2176 Cyg (Novak et al., 2001). The example of the Leo06 outburst light curve is given in Fig. 3.

3. Superhumps and "early" superhumps

Similar to the SU UMa dwarf novae, the WZ Sge binaries also display during the outburst the light variations (superhumps) that a few minutes differ from the orbital period. these variations often appear at the ~ 10th day of the superoutburst (main outburst). The basic origin of the superhump light is the extra heating associated with periodic deformation of the disk shape (Lubow 1992; Murray 1996 etc.): An eccentric instability grows at the 3:1 resonance in the accretion disk, and perturbation by the secondary forces it to precess (Whitehust 1988, Hirose and Osaki 1990, Lubow 1991).

The ordinary superhumps display the one-peaked profile that could be slightly distorted through the course of the outburst. The $q = M_2/M_1$ plays a key role: superhumps produced only below a critical ratio, $q_{crit} \sim 0.3$. During the cource of the main outburst, O-C for the superhumps maxima display the parabolic change that is consistent with period increase for the WZ Sge (Andronov et al., 2002; Patterson et al., 2002), RZ Leo (Ishioka et al., 2001), EG Cnc (Kato et al., 2006), V592 Her (Kato et al., 2007), ASAS J002511+1217.2 (Templeton et al., 2006), AL Com

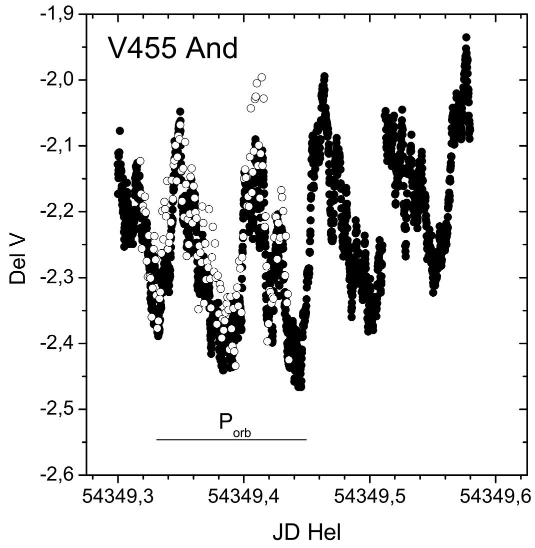

Figure 4: Left: The Early "orbital" humps of the V455 And. Filled circles denotes data obtained with Zeiss-600 telescope (Terskol) while the open circles are the data obtained simultaneously with K-380 telescope (CrAO).

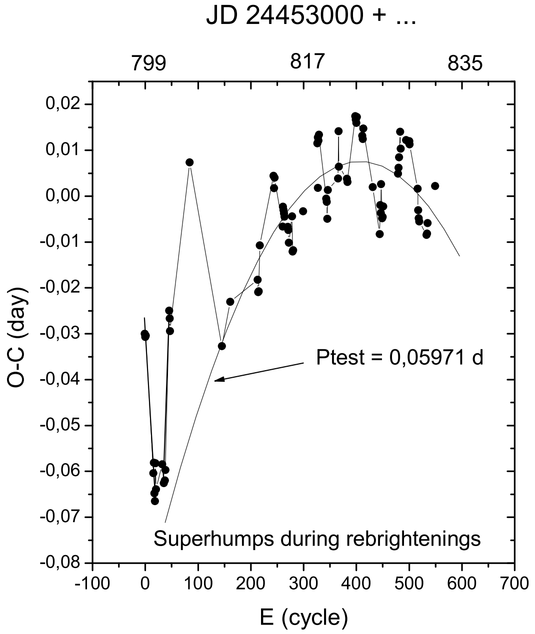

Figure 5: The O-C of superhumps behavior during the rebrightenings for SDSS J0804.

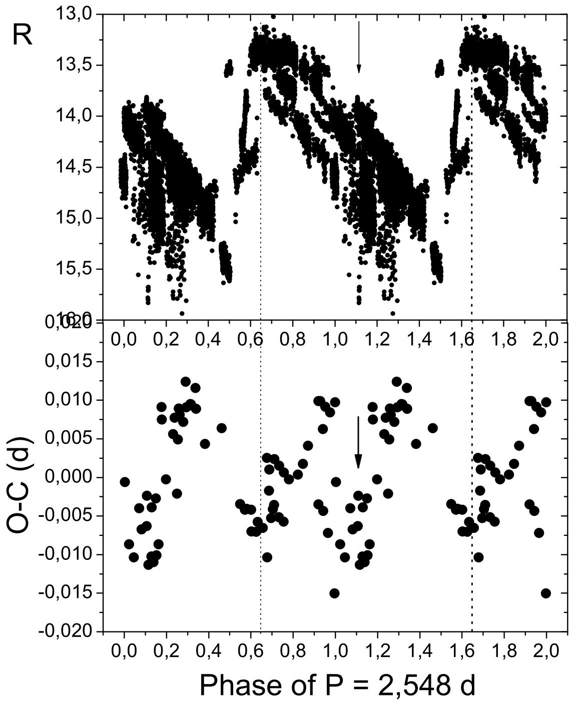

Figure 6: The mean rebrightening profile (upper frame) and superhump maximum O-C for SDSS J0804 folded on the rebrightening cycle (lower frame). The dotted lines plotted through the rebrightenings maxima and O-C minima. Arrow points to the small bump on the rebrightening profile and correspondent O-C minimum. For clarity data are plotted twice.

(Nogami et al., 1997), SDSS J0804 (Pavlenko et al., 2006).

Among the WZ Sge stars only 8 binaries show the double-peaked humps ("early superhumps"), that could appear even on the rising branch of the outburst (Andronov et al., 2002). Contrary to the superhumps, the early superhumps profile shows the strong two-picked humps modulated by orbital period.

These binaries are:
ASAS 160048-4846.2 (Imada et al., 2007); AL Com (Patterson etal., 1996); EG Cnc (Patterson et al., 1996); RZ Leo (Ishioka et al., 2001); HV Vir (Ishioka et al., 2003); Var Her 04 (Price 2004); WZ Sge (Andronov et al., 2002; Patterson et al., 2002; Kato et al., 2004); V455 And = HS 2331+3905 (newly discovered in September, 2007 (AAVSO alert, 2007). The nightly light curve that relates to the early part of the outburst is presented in Fig.4. It demonstrates the clear double-peacked humps wich repeat with known orbital periodicity found by Araujo-Betancor et al. (2007) in minimum.

The nature of the two-humped orbital profile is still unclear. Several suggestions connect such profile with:

a) enhanced hot spot caused by a sudden increase of the mass-transfer (Patterson et al., 1981; Patterson et al., 2002);

b) excitation of the 2:1 tidal resonance in the expanding accretion disc (Osaki and Meyer, 2002; Kato, 2002);

c) geometrical effect with a two-arm spiral wave modifying our view of the inner accretion disc (Wheatley and Mauche, 2004).

4. Superhumps during rebrightenings

It was shown that during the rebrightenings (reflares, echo-outbursts) superhumps are still present. The O-C of the superhumps display the parabolic change that is consistent with period decrease for the WZ Sge (Patterson et al., 2002), EG Cnc (Kato et al., 2006), SDSS J0804 (Pavlenko et al., 2006). For the J0804 it was first found the complex O-C variations (Pavlenko et al., 2008). In addition to the parabolic change corresponding to the superhump period decrease, the O-C show more frequent cyclic variations (Fig. 5). These variations strongly correlate with rebrightening phase: The O-C reach the minimal values twice the rebrightening cycle (see Fig. 6). The first O-C minimum coincides with rebrightening maximum, and the second minimum happens at the small and not prominent bump on the ascending branch of the rebrightening profile. The O-C variations reflect the complex precession phenomenon of the accretion disc. Despite of the overall decay of precession, it tends to enhance from one rebrightening to another.

5. Orbital humps

While the superhumps are observing during the outburst plateau and rebrightenings, the orbital humps begin to appear already soon after rebrightenings finish during the long-term return to the pre-outburst state. It could be seen in Fig. 7, where the dependence of the photometrical period on time for the SDSS J0804 is shown (Pavlenko et al., 2007). The orbital profile in minimum of some WZ Sge type stars is also two-peaked. For example in Fig. 8 the nightly light curve of the SDSS J0804 obtained approximately in a year after the outburst is presented. Araujo-Betancor et al. (2004) suggested for the case of V455 And as explanation that we are seeing some sort of symmetrical structure, such as two bright spots existence.

6. White dwarf

The white dwarfs of some WZ Sge type stars exibit the fast light variability in the range of tens - hundreds seconds that could be connected with white dwarf: either with ZZ Ceti-like pulsations or with

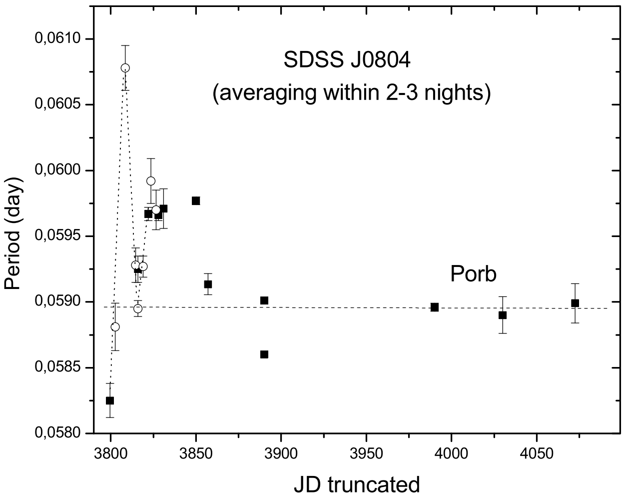

Figure 7: Dependence of photometrical period on time for the SDSS J0804 during the cource of the outburst (Pavlenko et al., 2007b). The dramatical change of the period correspond to the end of the main outburst and rebrightenings era. Later - at least in ~ 150 days after the end of rebrightenings - the photometrical light modulation is close to the orbital period (marked by dotted line) known from spectroscopy of Szcody et al. (2006) in minimum.

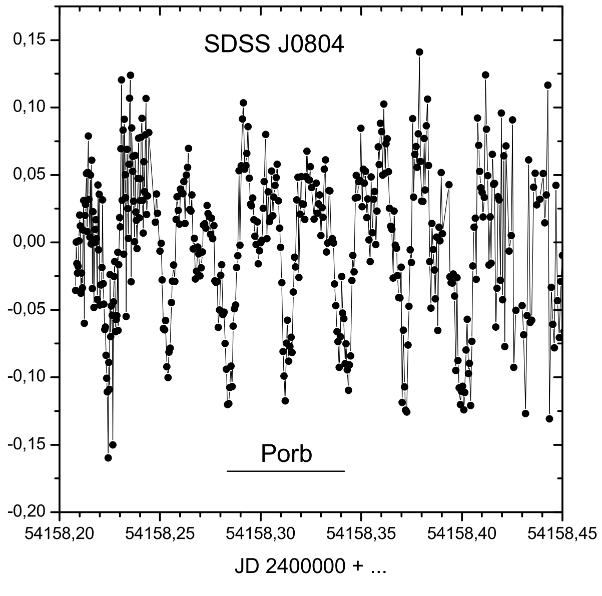

Figure 8: The nightly light curve of the SDSS J0804 obtained with high time resolution with 2.6-m mirrow Shajn telescope of CrAO. The two-peaked structure of the orbital hump with mean amplitude 0.25^m is clearly seen. Note the additional splitting of the maxima with less amplitude.

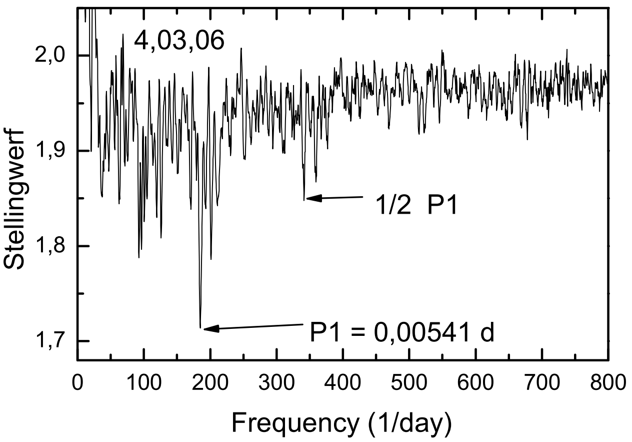

Figure 9: Periodogram for the SDSS J0804 obtained for the data at the main outburst. The most significant peak points to the 0.00541 d light variations (from Pavlenko et al., 2007a).

white dwarf spin period. The WZ Sge itself displays the 27.9-sec optical and X-ray light variations that believed to be the white dwarf spin period (Patterson, 1998), that, however, is not detecting all the time. The photometric variations with period 72 sec. were recently found by Araujo-Betancor et al.(2007)in V455 And = HS 2331+3905 during its low state and interpreted as its rotational period. This period was not confirmed by Gansicke (2007), instead he found another spin period 67.62 sec. Araujo-Betancor et al. also suggested that there are 5 - 6 min white dwarf nonradial pulsations of V455 And. Gansicke (2007) confirmed the existence of these pulsations. Evidence of probably nonradial pulsations with period 8-9 min. and amplitude ∼ 0.02^m were found for SDSS J0804 during one night in the outburst by Pavlenko et al., 2007a (see Fig. 9 and Fig. 10) and were not found by Szkody et al. (2005) in qiiescence. The fast white dwarf rotation could be explain within the model of the magnetic rotator Patterson (1998b). He suggested that a weak magnetic field can allow the very long outburst times by carving out a central cavity in the accretion disc. However this model meets difficulties in specific cases. Also not all quasy-periodical oscillations could be explained as the nonradial pulsations. For example, the white dwarf temperature in V455 And in minimum was 11 000K (Araujo-Betancor et al., 2004) that is well within the instability strip for ZZ Ceti pulsators, so observed 5 - 6 min light oscillations could be the white dwarf pulsations, while the 15-sec light oscillations of WZ Sge during outburst decline could't, because of the current dwarf temperature ∼ 25 000K that is far beyond the blue end of the instability strip.

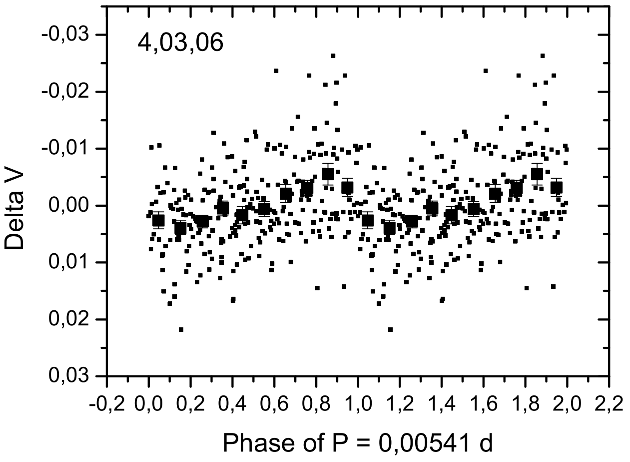

Figure 10: The data of the SDSS J0804 from one night for the main outburst folded on the 0.00541 d period., probably connected with non-radial pulsation of the white dwarf (from Pavlenko et al., 2007a). For clarity data are plotted twice.

7. Red dwarf

According to the current standard model of cataclysmic variable evolution (King 1988) the close binary evolvs to the shorter orbital periods, reach the shortest (∼ 70 min) period and then evolve back to longer orbital periods. These "bouced" systems are these with brown dwarf. Practically the brown dwarf could be found by several ways. The direct way is the radial velocities measure or modeling the spectral-energy distribution. However the white dwarf and accretion disc contribution make the process highly uncertain. The indirect way demands knoledge of the orbital and superhump periods, that could be measured photometrically during the superoutburst (superhump light modulation) and in quiescence (orbital light modulation). The knowledge of these periods leads to the secondary component mass estimation due to the empirical relationship between mass ratio and superhump period excess (Patterson, 1998)

$\epsilon = 0.23 \times q/(1 + 0.27 \times q)$

where the superhump period excess

$\epsilon = (P_{sh} - P_{orb})/P_{orb}$

Together with assumed (or measured) value of the primary mass, this relationship allows one to calculate the mass of secondary star for eny system with known superhump and orbital period.

As far as WS Sge stars have the orbital period close to the period minimum, they are very promissing candidates to the white dwarf + red dwarf binaries. These binaries with brown dwarfs show the "bounce" on the "q-Porb" diagramme. While cataclysmic variables approaches the minimum period, the mass of the secondary component - the red dwarf - decreases until it can no longer sustain hydrogen burning. Such secondary becomes increasingly degenerate, entering the browm dwarf regime. Kolb (1993) estimated that 70% of all cataclysmic variables should include such "substellar" secondaries. Despite this theoretical prediction only a few cataclysmic variables (or "stars-bouncers" following the Patterson's terminology) with mass of secondary less than 0.08 of Sollar masses (brown dwarfs) are known. The best candidates are WZ Sge, EG Cnc, EF Eri, DI UMa (Littlefair et al., 2003, Patterson et al., 1998b, Buermann et al., 2000). The first two are the WZ Sge type stars. The descripency of the theory and observations may be caused by both the selection effect (the rarity of the outbursts and faitness of binaries in minimum) or by the incorrectness of theory.

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