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Systematic search for post period-minimum cataclysmic variables: A short review

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Standard evolutionary theory suggests that cataclysmic variables (CVs) evolve from longer to shorter orbital periods. CVs that have passed beyond the period minimum and are evolving back towards longer periods are called the period bouncers. CVs of the WZ Sge-type have been long considered as potential period-bounce candidates. However, only very few of recently discovered WZ Sge-type stars were observed spectroscopically in quiescence due to their faintness. The lack of information on many of WZ Sge-type stars does not allow us to put restrictions on their system parameters and to confirm or deny their period bounce nature. Here we present a novel, simpler yet equally valuable approach based on multicolour broadband photometry to reveal the best period bounce candidates. By adopting such an approach, we performed a pilot study of a sample of WZ Sge-type stars and accreting WDs and have found solid evidence for very low luminosity donor stars in several of them.

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1. Introduction

Cataclysmic variables (CVs) are interacting binary stars consisting of a white dwarf (WD) as primary and a low-mass main-sequence star or a brown dwarf as donor (secondary) component. Standard evolutionary theory suggests that CVs evolve from longer to shorter orbital periods. At some point which is called the period minimum, the mass-losing donor star reaches a substellar mass and degenerates into a brown dwarf-like object. As a result, the binary begins to evolve towards longer orbital periods [1]. CVs that have passed beyond P_{min} and are evolving back towards longer periods are called the period bouncers. This has been predicted to be the current state of 70% of all CVs [2], however only about two dozens of more or less robust candidates for such period bouncer systems have been identified until now, out of a thousand of known CVs [3, 4, 5]. Moreover, direct (spectral) evidence for brown-dwarf secondaries exists only for very few CVs; the cleanest example of a spectroscopically confirmed and characterized sub-stellar donor is represented by SDSS J143317.78+101123.3 [6].

Characteristics of CVs change as they approach the period minimum. As the mass-transfer rate decreases towards shorter orbital periods, the accretion discs can suffer a thermal instability caused by hydrogen ionisation. This results in outbursts. Dwarf novae are an important subset of CVs, which undergo such outbursts. WZ Sge-type stars are an extreme subgroup of short-period dwarf novae ($P_{orb}\lesssim$120 min), in which accretion rates are so low that they undergo outbursts only every several years or even decades. It was shown that the distribution of the mass-ratio $q=M_2/M_1$ of the components in WZ Sge-type stars shows a peak between 0.07 and 0.08 [7]. The CVs with such small mass ratios are of a special interest because they should have a very low mass donor stars, and accordingly a significant amount of period bouncers should be present among them. Patterson [3] showed that the period bounce seems to occur in the mass ratio range q=0.065–0.080, with a corresponding secondary mass in the range 0.05–0.07 $M_\odot$. Indeed, most of known period-bounce candidates are of the WZ Sge-type, or they are accreting WDs which have never been observed in outbursts, but whose spectral properties show close similarity between them and the prototype dwarf nova WZ Sge. Here we report on results of a pilot study aiming to reveal solid period bounce candidates among WZ Sge-type stars.

2. SEDs of WZ Sge-type stars

Until recently, the WZ Sge-type stars were rare objects. There has been a dramatic increase of their number since mid of 2000s, approaching now to ∼150 objects [7]. Most of them were observed in detail during their superoutbursts, but only very few of recently discovered WZ Sge-type stars were observed spectroscopically in quiescence due to their faintness (19–22 mag). Thus, the lack of information on many of WZ Sge-type stars does not allow us to put restrictions on their system parameters and to confirm or deny their period bounce nature. The determination of system parameters requires many hours of observations with very large telescopes. Such observing time is difficult to obtain, which explains why the nature of the donor star has been directly confirmed by the detection of absorption lines/bands only for very limited number of short-period CVs. In order to distinguish CVs with normal and brown-dwarf-like donors — the latter can be considered as solid candidates for the period bouncers — we present a novel, simpler yet equally valuable

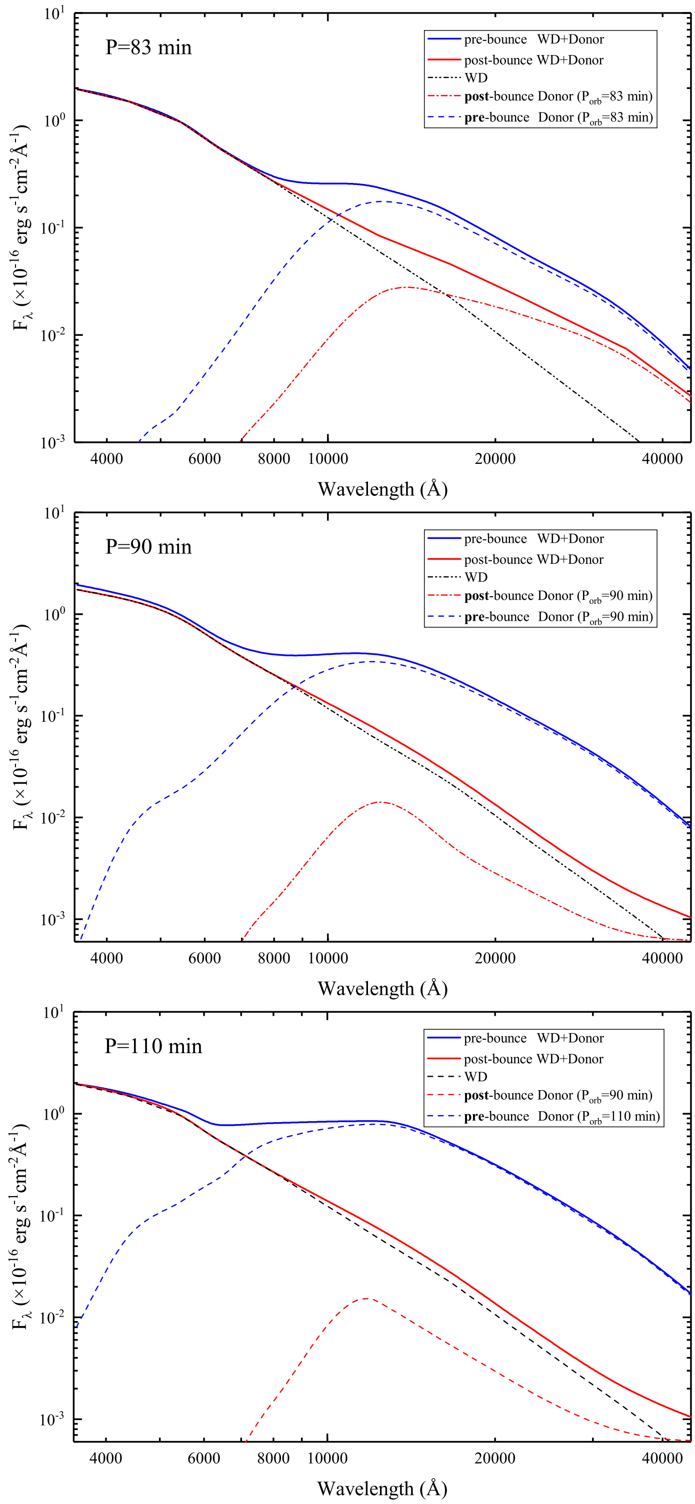

Figure 1: Theoretical SEDs of pre- and post-period-minimum CVs with the orbital periods of P_{orb}=83 min (upper panel), 90 min (middle) and 110 min (bottom) shown together with the SEDs of the WD and the donor star. The SEDs are scaled to the distance of 275 pc.

approach based on multicolour broadband photometry with optical and near-infrared (NIR) filters, without the recourse to spectroscopy. Instead of a brute-force search, only such candidates should be targeted for the following detailed study by means of spectroscopy.

The proposed classification scheme is based on an analysis of the spectral energy distribution (SED) of CVs. Indeed, the SED of a CV encodes a wealth of information concerning its components. It has the potential to inform us of the temperatures of the WD and the secondary star, and also a contribution of the disc to the optical-NIR flux, and hence test evolutionary models of CVs. The most important factor behind this idea is that the donor photometric properties along the CV evolution sequence change dramatically. It is expected that a NIR flux of the donor star drops by several times during a period turn, and a luminosity difference between pre- and post-period-minimum donors is larger for longer orbital-period CVs [8]. Thus, the presence of a notable red-NIR excess in the spectrum should indicate a pre-bounce donor in the system (Fig 1).

It is important to note that although in many ordinary CVs there is still a substantial contamination of the NIR luminosity by the accretion process, which can make the detection of their donor stars difficult [9], sometimes the donor can indeed be directly recognized even in such CVs by observing the red-NIR hump in the SED [10]. In CVs in which a contamination of the NIR luminosity by the accretion disc is less significant, the NIR hump is more pronounced. The WZ Sge-type CVs are ideal targets for studying the nature of their donor stars because the contribution of their discs to the continuum is quite low due to a low mass-transfer rate, as evident from clearly seen absorption spectral lines of the WD. Thus, the optical continuum in these objects is dominated by the WD, whereas a normal donor star should produce a hump in the NIR wavelengths. In period-bouncers, by contrast, a very low-luminosity brown-dwarf donor of very late spectral type (L/T) is expected, resulting in very insignificant contribution of the donor even to the NIR spectrum [11].

This qualitative approach can be turned into a quantitative one by means of comparing an observed optical-NIR SED with theoretically calculated SEDs of a CV at different evolutionary stages. For this, the models of Knigge et al. [8] can be used. These models utilize a semi-empirical CV evolution track based on the observed mass-radius relationship of their donor stars and provide the predicted absolute magnitudes in different optical and NIR filters of both the donor star and the WD of CVs of different orbital periods before and after the period minimum. The combined fluxes of the donor and the WD can then be scaled to the distance of the target. The just released Gaia DR2 provides a considerable improvement in accuracy of the distances to a significant fraction of the WZ Sge-type stars. The distance can also be estimated, for example, by utilizing the empirical relationships between absolute magnitude and orbital period of dwarf novae at the superoutburst plateau [3]. Although P_{orb} is not accurately known for most of recently discovered WZ Sge-type stars, its value is expected to be very close to the superhump period which is well known for most of these stars [7].

The applicability of this approach was recently demonstrated by Neustroev et al. [12]. They compared the SEDs of two WZ Sge-type systems, SSS J122221.7$-$311525 and RZ Leo, which both have a very similar orbital period ($\sim$110 min) and share many other observational properties. In particular, the disc contribution to the spectra of both the objects is very small. However, RZ Leo is a confirmed pre-bounce system (the donor star of M5 spectral type is clearly seen in its spectrum [13, 14]), whereas SSS J122221.7$-$311525 is a solid period bounce candidate [4]. Neustroev et al. found that the observed SEDs of both the objects show a close resemblance in the optical

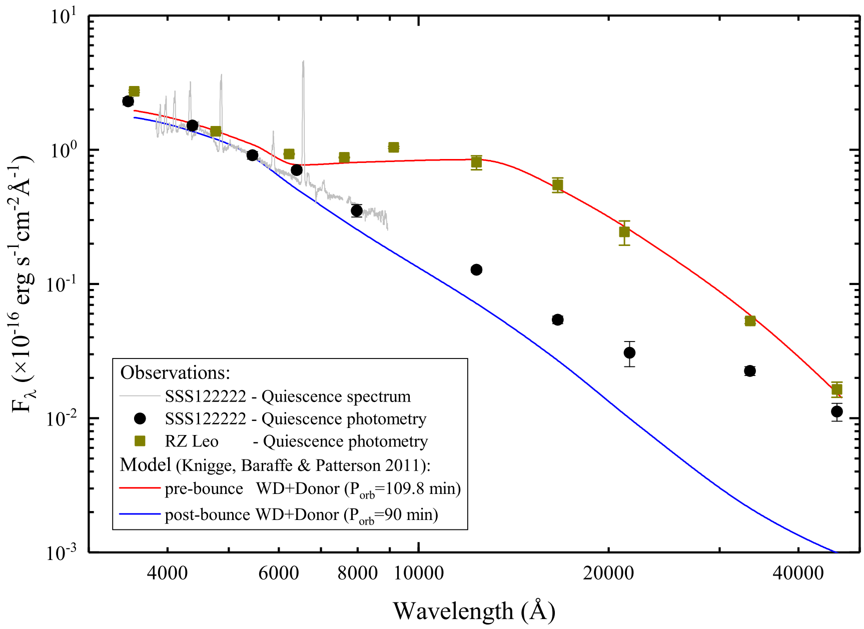

Figure 2: Theoretical SEDs of pre- and post-bounce CVs, shown together with the photometric data of RZ Leo and the photometric and spectroscopic data of SSS J122221.7−311525 (SSS122222). These WZ Sge-type objects have similar orbital periods (∼109.8 min) and they both share many other observational properties. However, RZ Leo is a confirmed pre-bounce CV [13, 14]), representing thus a good test case for comparing the observed and calculated SEDs, whereas SSS122222 is the best period-bounce candidate known today [12]. For the pre-bounce case, the theoretical SED is calculated for a CV with P_{orb} = 109.8 min. For the post-bounce case, the longest calculated period in [8] is 90 min. Thus, we used the component fluxes of a CV with this P_{orb}. The calculated SEDs are scaled to the distance of SSS122222, 275 pc.

wavelengths, but a significant difference in the NIR (Fig. 2). RZ Leo follows the predicted pre-bounce SED surprisingly well, whereas the observed NIR flux of SSS J122221.7−311525 is much lower (7–10 times in the *JHKs* bands) than expected from a CV with a normal donor star; therefore, a main-sequence donor in SSS J122221.7−311525 is excluded.

3. A pilot study of a larger sample of WZ Sge type stars

In order to test further this approach on a larger sample, we performed a pilot study of the SEDs of the best period-bouncer candidates from Patterson's scorecard [3], and of a few other, recently discovered CVs, in which the donor nature is still unknown. This sample of the WZ Sge-type stars and accreting WDs with orbital periods from ∼79 min to ∼120 min includes MT Com (P_{orb}=120 min), GD 552 (P_{orb}=103 min) and EG Cnc (P_{orb}=86 min), MASTER J004527.52+503213.8 (P_{orb}=115 min), ASASSN-16eg (P_{orb}=111 min), V1838 Aql (P_{orb}=84 min), PNV J21095047+1348396 (P_{orb}=82 min), FL Psc and V455 And (both P_{orb}=81 min), and HO Cet (P_{orb}=79 min). The observations were taken with the 2.56 m Nordic Optical Telescope (NOT) located in the Observatorio de Roque de los Muchachos (ORM, La Palma, Spain), and with the ESO/NTT telescope at La Silla, Chile. Optical data were obtained using the NOT/ALFOSC and

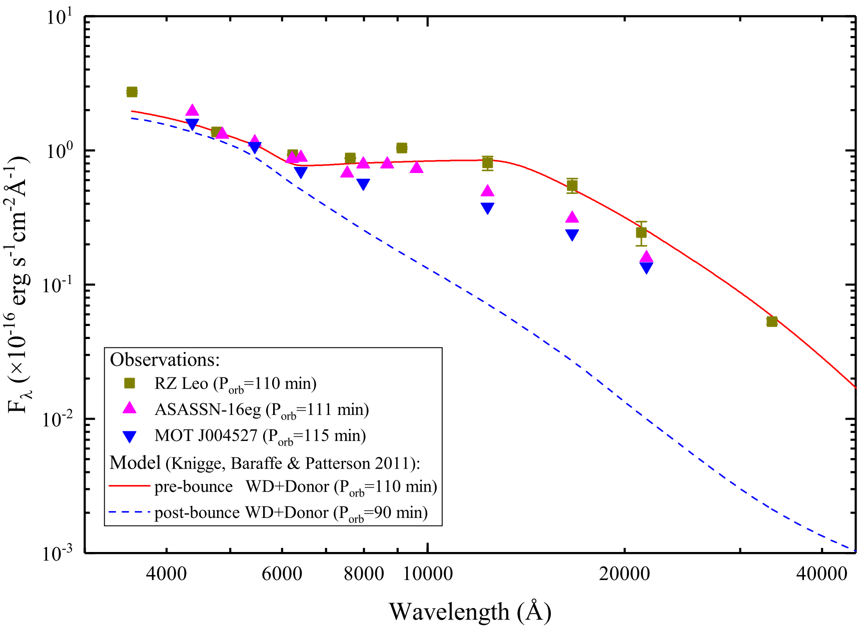

Figure 3: Theoretical SEDs of long-period pre- and post-bounce CVs, shown together with the photometric data of ASASSN-16eg, MASTER J004527.52+503213.8 (MOT J004527) and RZ Leo. All three objects are pre-bounce dwarf novae.

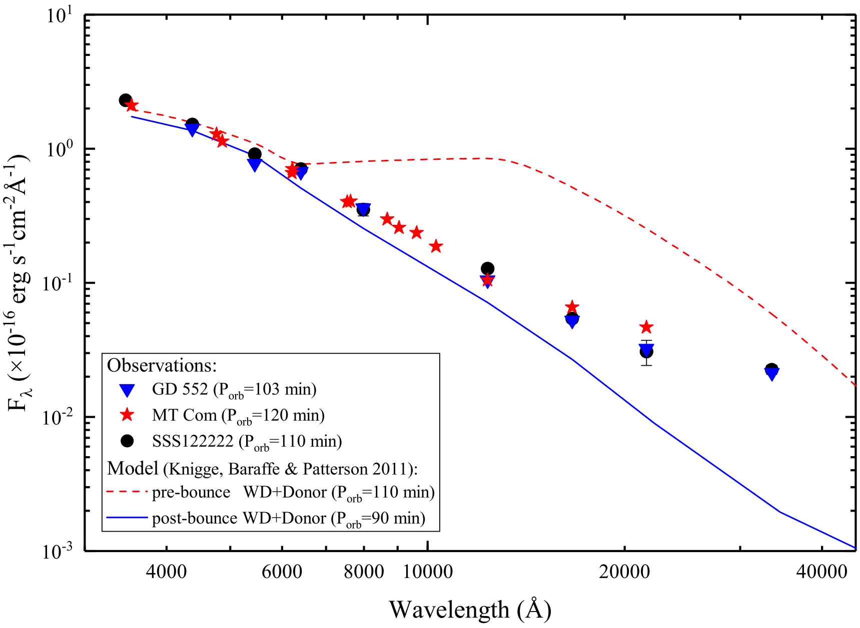

Figure 4: Theoretical SEDs of long-period pre- and post-bounce CVs, shown together with the photometric data of GD 552, MT Com and SSS J122221.7−311525 (SSS122222). All three objects are very solid period-bouncer candidates.

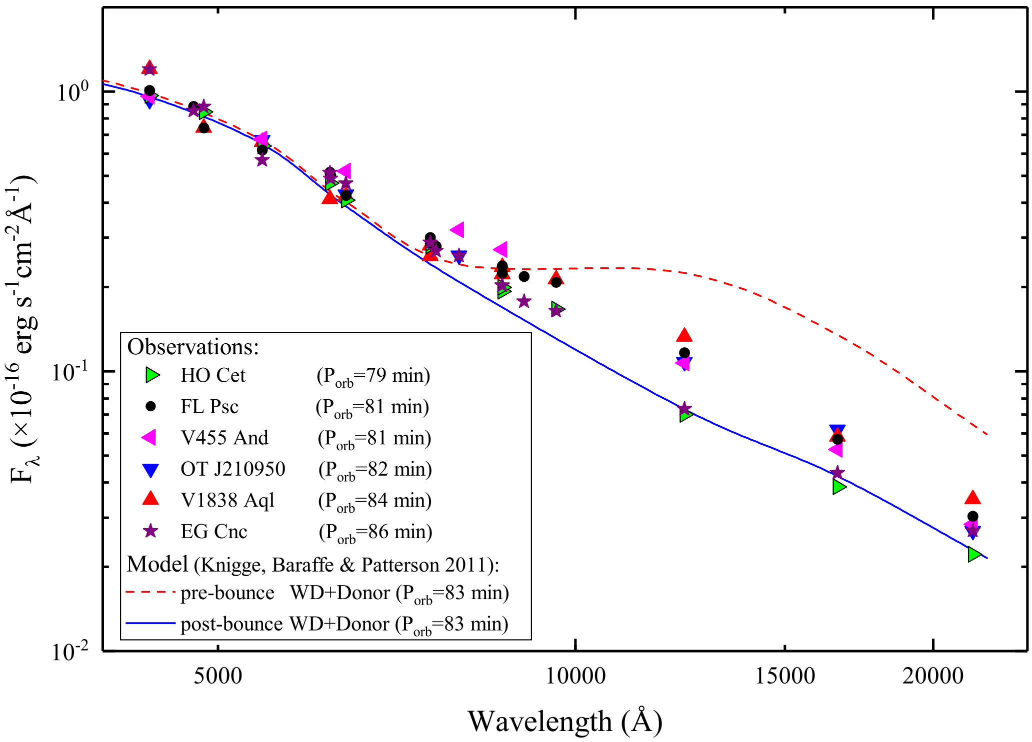

Figure 5: Theoretical SEDs of short-period pre- and post-bounce CVs, shown together with the photometric data of HO Cet, FL Psc, V455 And, PNV J21095047+1348396 (OT J210950), V1838 Aql and EG Cnc. All these objects show the NIR flux lower than that expected from a normal donor star and thus can be considered as period bounce candidates. Of them, EG Cnc appears to be the best candidate as it has the longest orbital period and the lowest NIR luminosity.

ESO/EFOSC2 instruments in imaging mode with the *BVRI* and *BVRiz* filters, respectively. NIR data were taken using NOTCam and ESO/SOFI with the JHK_s filters.

The observed stars can be roughly divided into two groups: the long-period objects (P_{orb}>100 min) and the short-period objects (P_{orb}<86 min). The observed SEDs of the long-period group were compared with the theoretical SEDs of a CV with P_{orb}=109.8 min, whereas the short-period stars were compared with a CV with P_{orb}=83 min. The observed long-period objects can be well separated according to the shape of their SEDs. ASASSN-16eg and MASTER J004527.52+503213.8 exhibit a prominent NIR excess resembling the one in the SED of RZ Leo (Fig. 3). All these objects are pre-bounce CVs. In contrast, MT Com and GD 552 show no sign of a NIR excess, and their SEDs resemble strongly the one of SSS J122221.7−311525 (Fig. 4). This analysis supports their period-bouncer classification proposed in earlier papers (see [3] and references therein).

All the observed short-period WZ Sge-type stars show the NIR flux lower than that expected from a normal donor star and thus can be considered as period bounce candidates, Of them, HO Cet and EG Cnc have the lowest NIR luminosity. Moreover, EG Cnc has the longest orbital period among objects of this group, meaning that the contribution of its donor star to the total flux is expected to be the largest in the pre-bounce case. Thus, EG Cnc appears to be the best period-bounce candidate from the observed sample of short-period WZ Sge-type stars.

4. Summary and concluding remarks

In order to reveal the best period bounce candidates, we proposed a novel approach based on multicolour broadband photometry. By adopting such a method, we performed a pilot study of a sample of WZ Sge-type objects and accreting WDs, a part of which were already referred to as solid period-bounce candidates. Our observations have confirmed that these candidates (MT Com, GD 552 and EG Cnc) do not exhibit an emission excess in the NIR part of the spectrum as would be expected in the case of a normal donor star. In contrast to them, ASASSN-16eg and MASTER J004527.52+503213.8 show a notable NIR excess indicating the pre-bounce nature of these two stars. The properties of V1838 Aql, PNV J21095047+1348396, FL Psc, V455 And, and HO Cet also indicate the presence in them of low-luminosity, probably degenerated donors. To confirm their period-bounce status, time-resolved spectroscopic observations in the NIR wavelengths are needed to detect photospheric absorption lines/bands from brown-dwarf donors. Unfortunately, most of the WZ Sge-type stars are hardly accessible even to the largest telescopes. In addition to the presented approach, the confirmation of the period-bounce nature of these stars should be based on other indirect methods such as radial velocity studies and/or mass-ratio measurements (based e.g. on measuring superhump excesses [15]).

Acknowledgments

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QUESTIONS:

Ryoko Ishioka: Is there a possibility that a WD and a brown dwarf just happen to become semi-detached at the given P_{orb}?

Vitaly Neustroev: Indeed, alternative evolutionary scenarios leading to brown-dwarf donors in CVs directly from detached WD/brown-dwarf binaries are possible. We discussed this alternative in our paper [12] and came to the conclusion that at the present time we cannot unambiguously discriminate between different evolutionary channels.

Anna Pala: What is the WD temperature in the WZ Sge-type stars, for which you showed the SED?

Vitaly Neustroev: For most objects we used the predicted WD temperature from [8]. However, for a few other stars we used the WD temperature derived from observations. For example, for the WD in SSS J122221.7−311525 we adopted T_{eff}=14000 K [12].

Natalia Katysheva: Have you measured the temperature of accretion discs in quiescence? How low is it? 5000 K?

Vitaly Neustroev: In our calculations we assumed that the contribution of the accretion disc to the continuum is very low, and thus no contribution from the disc was taken into account. On the other hand, our preliminary analysis shows that the disc temperature in quiescence is very low indeed, possibly as low as 3000 K.

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