OBSERVATIONAL RESULTS AND INDICATIONS OF ACTIVE STATES IN TWO SU UMA STARS

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Abstract: *In this work, we present observational results that give indications of active states over several time-intervals of two SU UMa stars: V368 Per (Perseus) and V521 Peg (Pegasi). We use observational data from the TESS (The Transiting Exoplanet Survey Satellite) mission and the AAVSO (American Association of Variable Star Observers) international database. Fluctuations in brightness are detected in the light curves of the two objects, obtained from both astronomical facilities. The results show that the stars pass through different types of activity, which we identify as outbursts, superhumps and flickering. Based on a theoretical approach and applying data from observations, we calculate the accretion efficiency for both objects. Then, we compare the behavior of the disc efficiency throughout the targets' rising brightening events and estimate the level of their accretion activity.*

НАБЛЮДАТЕЛНИ РЕЗУЛТАТИ И ИНДИКАЦИИ ЗА АКТИВНИ СЪСТОЯНИЯ В ДВЕ SU UMA ЗВЕЗДИ

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Ключови думи: *Звезди: Двойни звезди; Акреция: акреционни дискове*

Резюме: *В настоящата работа представяме резултати от наблюдения за няколко времеви интервала, които показват наличието на активни състояния при две звезди от типа SU UMa: V368 Per (Персей) и V521 Peg (Пегас). Използвани са данни от мисията TESS (The Transiting Exoplanet Survey Satellite) и международната база данни на AAVSO (American Association of Variable Star Observers). В кривите на блясъка на двата обекта, получени от двата астрономически източника, са открити вариации в яркостта. Резултатите показват, че звездите преминават през различни видове активност, които идентифицираме като избухване, суперхъмп и фликеринг. Въз основа на теоретичен подход и прилагане на данни от наблюдения изчисляваме ефективността на акрецията за двата обекта. Това дава възможност да сравним поведението на ефективността на диска по време на нарастваща яркост на обектите и да оценим нивото на тяхната акреционна активност.*

Introduction

In many astrophysical objects, the states of activity are usually related to some detected observational effects. They should be short- or long-lasting variations in brightness, on time-scales from seconds to days and months. In binary star systems we could recognize fluctuations in their light curves with amplitudes of 0.1–5 (even more) magnitudes, delimited as flickering, flares, superhumps, burst and outbursts.

Flickering is defined as a non-periodic, irregular variation in brightness with amplitudes of a few x 0.1 to 1 magnitudes, seen in the light curves with a duration of seconds to few minutes [2, 20]. Periodic variations in brightness, with periodicity of a few (2–6) percent longer than the orbital period of the studied objects and with low amplitudes in magnitudes, are accepted as a manifestation of superhumps [8, 18]. The sudden fluctuations with a higher magnitudes, > 2 mag, are known as bursts and outbursts [19] that could last from days to months. Flickering could appear during the high states of

the objects, with active outbursts or also in the low quiescent state, whereas superhumps are usually active during the outbursts.

All these events of activity in brightness could be observed in many Cataclysmic variable stars (CVs). Cataclysmic variable stars (CVs) are binary systems that consist of a white dwarf primary star, accreting matter from a main-sequence companion via Roche lobe overflow [19]. As a subclass of CVs, dwarf novae (DNe) manifest outbursts, which last a few days, as well as superoutbursts that prolong for approximately two weeks to several months [12, 15].

One of the subgroups of dwarf novae, SU UMa stars, also exhibits both normal outbursts and superhumps, which typically occur within the duration of long-lasting superoutbursts [4]. We choose to study here two members of the SU Uma stars group that are found to have such brightness activities: V368 Per (Perseus) and V521 Peg (Pegasi).

V368 Per is discovered by Richter (1969) [14], as he reported for the outburst in 1968-10-22 21:36 UTC that prolongs for ≈ 2 days. Later, several outbursts, superoutbursts and superhumps are detected for this object [3]. The average superhump period is found to be Psh ≈ 0.078946 ± 0.000050 days, where the orbital period of the binary is determined as Porb ≈ 0.0762 days [9].

The second object V521 Peg is initially studied only as a dwarf nova star. It is found that the object has outbursts with long recurrent time, detected by (Pojmański, 2001 and Rodríguez-Gil et al. 2005) [13, 16]. A detection of superhumps is reported with periods Psh ≈ 0.061006 ± 0.000029 days, while the orbital period of the binary is estimated as Porb ≈ 0.0599 days [16]. Some of the parameters are calculated in their paper, as mass of the white dwarf M_1 ≈ 0.7 MΘ and the white dwarf radius is $R_1 = 8.7 \times 10^8$ cm ≈ 0.012 RΘ.

In this paper we present observational data for the two SU UMa stars, V368 Per and V521 Peg, obtained both from TESS (The Transiting Exoplanet Survey Satellite) and AAVSO (American Association of Variable Star Observers), by which to indicate the brightness activity in their light curves (reported in the next Section). The accretion efficiency and an estimation of the dominant accretion modes in the objects are given in the third section, followed by the Discussion.

Observational data and results for V368 Per and V521 Peg

In this section, we apply photometric observational data obtained from two different facilities, TESS and the AAVSO international database. The results from both of them could allow us to analyze more data and for a longer observational time-intervals. We use the time format in UTC: yyyy-mm-dd.

- Observational data and results from TESS

In the TESS field of view, except from transiting exo-planets, observations of over 200 000 objects, including bright stars, are provided too [6]. The light curves constructed by TESS photometric data are analyzed with a 120 s cadence [5].

In this work, we use data from the TESS observations of V368 Per, obtained in the time-interval: 2024-10-27 01:29–2024-11-15 22:50 UTC (2460610.5618 – 2460630.4513 JD (Julian date)) from sector number 85, with an exposure time-length of 200 s.

The data for V521 Peg are obtained in two time-intervals: 2022-09-02 18:12:19–2022-09-30 15:25:02 UTC (2459825.2585–2459853.1423 JD) from the sector number 56, with an exposure time 200 s and 2024-09-05 22:23:41–2024-09-30 21:06:22 UTC (2460559.4331–2460584.3794 JD) from the sector number 83.

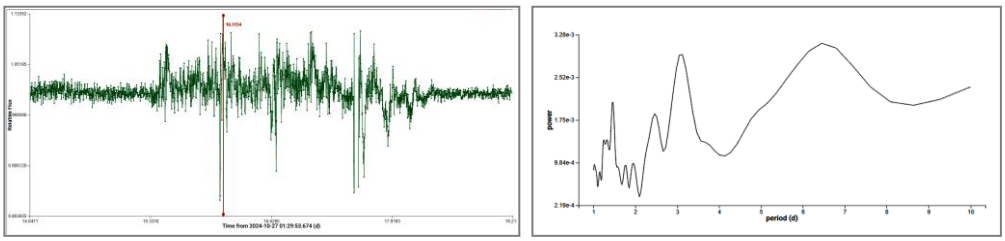


Fig.1. Light curve of V368 Per, created with the data obtained from TESS for the observational interval 2460610.56–2460630.45 JD (a, left panel). The time of the peak in the relative flux is marked with a red vertical line. (b, Right panel): a power-period diagram of V368 Per, obtained by the frequency analysis with data for the same observational time.

The data were downloaded and reduced from the Mikulski Archive for Space Telescopes (MAST, https://archive.stsci.edu). The light curves for both objects (Fig. 1a and Fig. 2a, c) were constructed as Flux-rate [e-/s] (electrons/second) vs. time in [days]. The Simple Aperture Photometry (SAP) Flux data were used for the light curves analysis.

Irregular variations in the flux-rates are observed in the light curve of V368 Per with amplitudes of increase in values between minimum and maximum in the range: 0.094–1.112 e-/s. The duration is different for each of the events and it is: 0.0077, 0.0118, 0.0187, and 0.0285 days. The maximum value of the relative flux is ~ 1.13 e-/s, marked with a red line in the figure.

Then, we could suggest that these types of variations are close to the flickering nature of activity.

Frequency analysis of the obtained data for the same time-intervals is represented as power-period diagrams (Figs. 1b and 2b, d) with different periods in [days]. To determine the period, the Lomb-Scargle method is applied [11, 17].

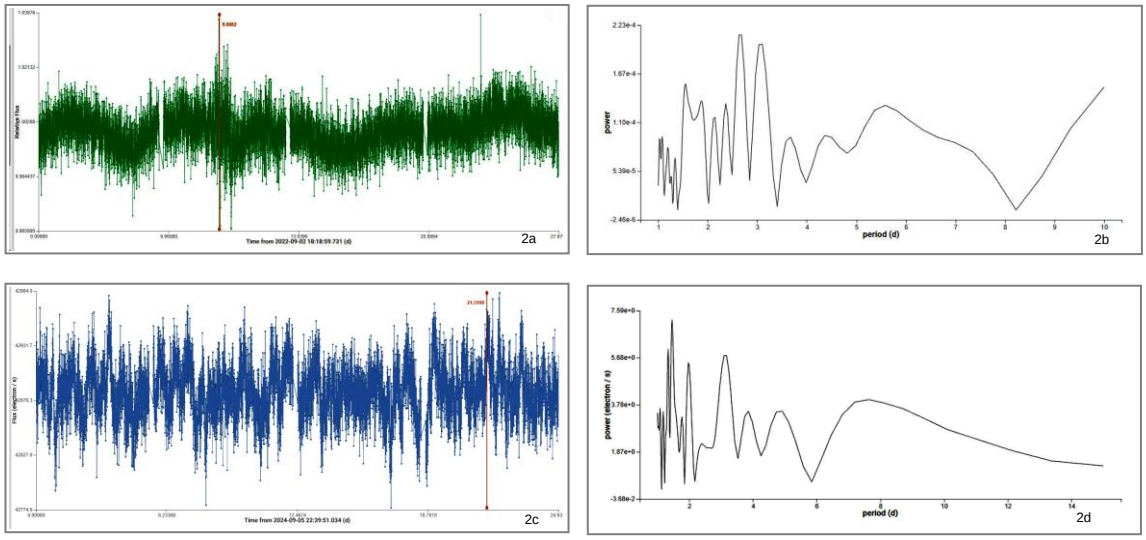


Fig. 2. Light curves of V521 Peg, created with the data obtained from TESS for the observational intervals 2459825.25–2459853.14 JD and 2460559.43–2460584.37 JD (a, c – left panels). The time of the peaks in the flux variation is marked with a red vertical line. (Right panels – b, d): power-period diagrams of V521 Peg, obtained by the frequency analysis data for the same observational times.

In both time-intervals of the V521 Peg light curves, fluctuations in the flux-rate of different types are observed.

The maximum values of these light variations for the first time-interval, in relative flux-rates, are (1.027 ± 0.002) e-/s with an average amplitude between minimum and maximum of (0.043 ± 0.002) e-/s. The highest peak in power detected in the periodogram (Fig. 2b) has periodicity of (2.5 ± 0.2) days, although the duration is ~ 4.5–5 days. Our suggestion for the type of these variations is that they are some-kind of a periodic wave modulation in brightness.

During the second interval, the maximum observed flux-rates vs. time is estimated as (4.29 ± 0.002) $\times 10^4$ e-/s, with an average amplitude between minimum and maximum values of (0.013 ± 0.004) $\times 10^2$ e-/s. The time length-scale of these variations is less than a day and it varies between 15 and 20 hours. The power-period diagram for this interval depicts the power peak at the period of ~ 1.2 ± 0.02 days, which is in correlation with the duration of each of the events.

- Observational data from AAVSO

The obtained observational data for V368 Per in V band cover a six-years observational time-interval in the range: 2455400–2457500 JD (Julian dates) (2010-07-22–2016-07-30 Calendar dates). In the light curve (Fig. 3a) we see irregular variations of brightness with amplitudes of 3–3.5 magnitudes that prolonged 14–20 days. We could determine these sudden increases in brightness as outbursts. The maximum in brightness during the outbursts reaches ~ 15.3 ± 0.046 mag in V band. To better distinguish the brightening events, a detailed view of a shorter time-interval 2456130–2456375 JD, within the whole observational interval, is presented (Fig. 3b). The same activity in brightness could be also seen during a second shorter time-interval 2456500 2456720 JD. The period between these outbursts are estimated to be 35–40 days for both short time-intervals.

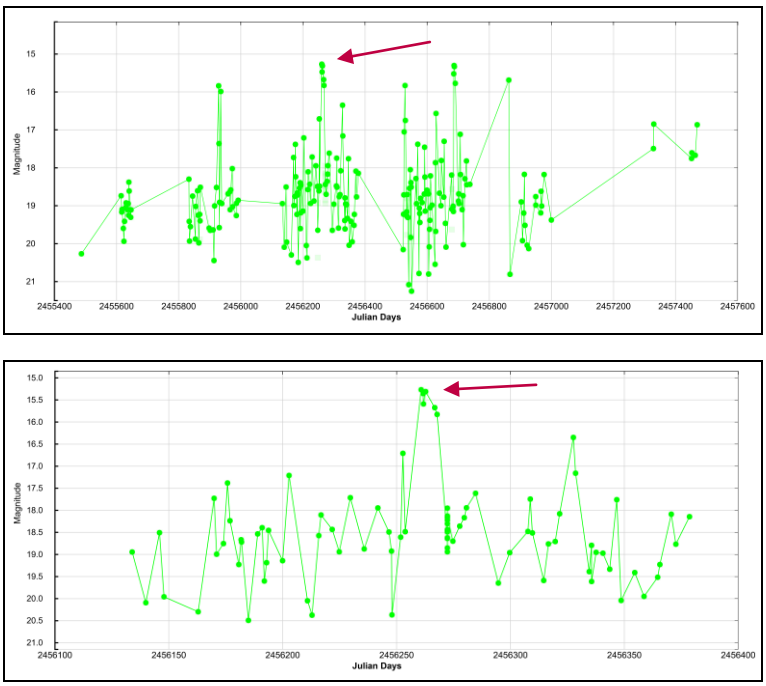
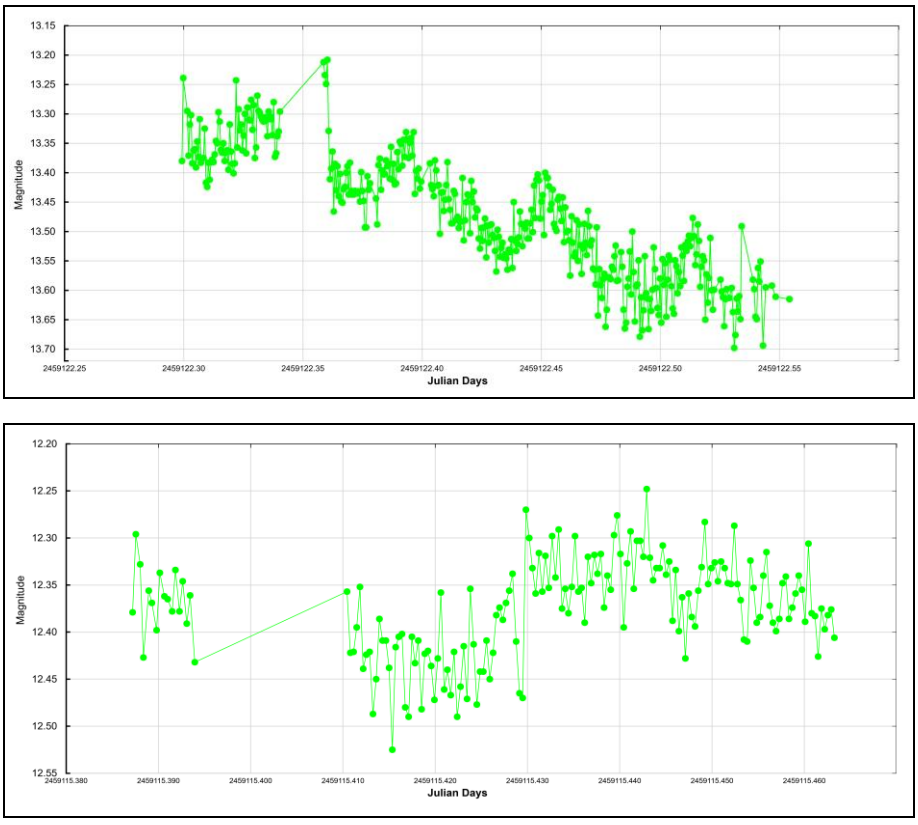


Fig. 3. Light curves of V368 Per in the V band for the intervals of time: 2010-07-22–2016-07-30 (3a, upper panel) and the shorten time-interval within 2012-09-29–2013-03-30 Calendar dates (3b, lower panel). Outbursts are detected with amplitudes 3–3.5 mag (the red arrows mark the maximums). The observational times in the figures are in JD (Julian dates). The data are taken from AAVSO.

For the second object V521 Peg, the eligible observational data that indicate activity of the object were in three short time-intervals. We obtained data for: 2459122.29–2459122.57 JD (2020-09-29 18:30–2020-09-30 01:40 UTC); 2459115.385–2459115.465 JD (2020-09-22 21:10 – 2020-09-22 23:20 UTC); 2458325.38–2458325.62 JD (2018-07-25 20:50–2018-07-26 03:20 UTC). During the first interval, a trend of slightly decrease in brightness is seen, with an average amplitude of 0.35 ± 0.002 mag (Fig.4a). Within this time, variations with min to max amplitudes of 0.162–0.168 mag that prolong for 78–90 min are observed.



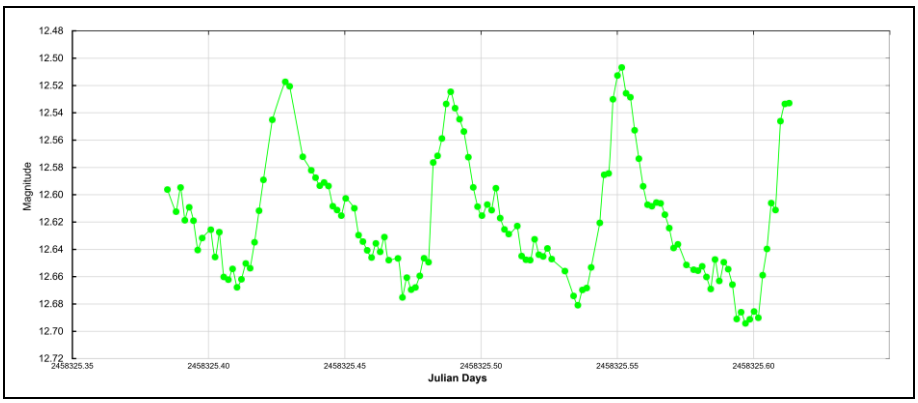


Fig. 4. Light curves of V521 Peg in the V band for the intervals of time: 2020-09-29 – 2020-09-30 (4a, upper panel), 2020-09-22–2020-09-22 (4b, mid panel) and 2018-07-25–2018-07-26 (4c, lower panel) Calendar dates. The observational times in the figures are in JD (Julian dates). The data are taken from AAVSO.

The second time-interval shows very short-period variations in brightness with a duration of 2–3 min and amplitudes of 0.114–0.117 mag. They look more like irregular, non-periodic oscillations. The third interval manifests regular or periodic variations with an average amplitude of increase in brightness of 0.165 ± 0.003 mag. We determined the periodicity of 87–93 min, which is very close or with a few percent higher than the value of the object's orbital period Porb ≈ 0.059 d ≈ 86.25 min. According to the definitions in the Introduction, we can suggest that these variations in brightness are superhumps, which is in agreement with the obtained by Rodríguez-Gil et al. (in [16]) results and a superhump period of Psh ≈ = 89.05 min.

Theoretical approach and accretion activity

In Cataclysmic variable stars, during the mass-transfer process between the two binary components, an accretion disc is formed around the white dwarf object.

It is widely accepted that the instabilities (as thermal) in the disc are responsible for the outbursts in DNe and indirectly tidal, by causing an eccentricity of the disc, for the superhumps production in SU UMa stars [7, 21]. It is evident that the flickering activity is also coming from the processes of instability at outer part of the accretion disc.

In this section, we relate these activities to estimate how efficiently the mass energy of the accreted material is converted into radiation. This gives the parameter of an accretion efficiency.

We calculate average accretion efficiency values for the two objects, by using the formula of Kolb [10]: $\xi = GM_1/R_1c^2$. It is obtained by the expression of accretion luminosity for both: spherical $L_{sph} = \xi \dot{M}_{sph} c^2$ and disc accretion $L_d = \eta \dot{M}_d c^2$. We apply for the luminosity the observational data from the previous section.

M_1 and R_1 are the mass and radius of the central object, in current case of the white dwarf component. Their values are pointed in the Introduction.

The term **ξ** depicts the spherical accretion efficiency. We calculate the disc accretion efficiency **η** by the relation $\eta = \xi(4\,H/R_d)^{-1}$. **Rd** is the disc radius (see the details of the expression in (Boneva and Yankova 2021, [1])).

The calculations give the next results for both types of accretion efficiency (see Table 1):

Table 1. Accretion efficiency values, calculated for V521 Peg and V368 Per.

Object/parameter x 10^{-4}	η_0	η_{a1}	η_{a2}	η_{a3}	%
V521 Peg	3.25	3.5	3.8	4.3	~ 25
V368 Per	4.5			6.2	~ 37

Here, η_0 depicts the disc efficiency in quiescent state, while η_{a1}, η_{a2}, η_{a3} express the efficiency in active states with outbursts and superhumps. It is seen from the table that during the outbursts the disc efficiency increases by ~ 25 % in V521 Peg and by ~ 37 % in V368 Per.

Conclusion

In this paper, we presented observational results of two SU UMa stars V368 Per and V521 Peg, using data from two observational facilities, TESS and AAVSO. In the resulting light curves from both and in the power-period diagrams from TESS, manifestation of different types of activity in brightness was detected. During the objects observational time-intervals, outbursts, flickering and superhumps are identified. From the TESS light curves, we can compare the relative flux rate of both objects and we realize that the amplitude of variations of V368 Per have larger value than that of V521 Peg with a factor of ≈ 2. In the obtained light curves from AAVSO, outbursts activity is detected for V368 Per with amplitude between minimum and maximum of 3–3.5 mag. Manifestations of superhumps and short-interval light oscillations are found in the data and light curves of both time-intervals of the second object V521 Peg, with an average amplitude of brightness variations for the superhumps of ≈ 0.16 mag and the superhump period Psh ≈ 90.2 ± 0.02 min.

Since all these brightening events are related to the disc accretion processes, we estimated the accretion efficiency for both objects. We applied the luminosity from the obtained observational data in the calculations. The results of disc accretion efficiency, show that disc of V368 Per is more active, and its efficiency increases nearly twice as much as that of the V521 Peg.

By comparing the results of both objects, we can suppose that the star V368 Per exhibits more powerful processes in regards to its brightness and the structure of its accretion disc.

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