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BRIGHTNESS VARIABILITY AT DIFFERENT SCALES OF DETECTION IN THREE BINARY STAR SYSTEMS

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Keywords: *Stars: Binary stars; Stars: cataclysmic variables; Stars: symbiotic binaries*

Abstract: *We present a periodic and quasi-periodic variability in brightness of three binary stars: MV Lyr (Lyrae), ER Del (Delphinus) and FU Ori (Orion).*

The brightening events occur both at different time- and amplitude- scales in the magnitude. According to this, we define the events' types as flickering and flares. On the base of the observational data, we calculate the color indices during the nights of the three objects high states. Using the B-V index, the color temperatures are calculated. The results show, the color in the selected observational intervals of MV Lyr and ER Del is rather red and the corresponding objects' temperatures are not very high.

We compare the properties of the brightness variability events for the three objects. We conclude that it partially depends on the physical nature of the each of the objects, due to their different types of stars.

ПРОМЕНЛИВОСТИ В БЛЯСЪКА ПРИ РАЗЛИЧНИ СКАЛИ НА ОЦЕНКА В ТРИ ДВОЙНИ ЗВЕЗДНИ СИСТЕМИ

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Ключови думи: *Звезди: Двойни звезди; Звезди: симбиотични; Променливости в блясъка*

Резюме: *В тази статия ние представяме периодична и квазипериодична променливост в яркостта на три двойни звезди: MV Lyr (Lyrae), ER Del (Delphinus) и FU Ori (Orion).*

Промените в блясъка се случват както в различни времеви, така и в амплитудни скали. Според това, ние дефинираме типовете на събитията като просветвания и изхвърляния. Въз основа на данните от наблюденията, ние изчисляваме цветовите индекси по време на високите състояния на трите обекта. С помощта на индекса B-V се изчисляват цветовите температури. Резултатите показват, че цветът в избраните интервали на наблюдение на MV Lyr и ER Del е по-скоро червен и температурите на съответните обекти не са много високи.

Ние сравняваме свойствата на промените в яркостта за трите обекта и правим извод, че те зависят от физическите характеристики на всеки от обектите, произтичащи от различните типове на изследваните звезди.

Introduction

1. The problem

Brightness variations are usually associated with fluctuations in a light curve that appeared in numerous variable stars. These variations are characterized with amplitude of a few 0.1 to 5 and more magnitudes on different time-scales from seconds to days. In depends on these characteristics, they could be delimited as flickerings, flares, bursts, outbursts.

The flickering and flares are known as small-scale amplitude events, of 0.01 to 1 mag (Warner (1995) and Babtista & Bortoletto (2004)). They usually appeared in type of binaries as cataclysmic variables (CVs), supersoft X-ray binaries, and symbiotic stars (Sokoloski 2003). The higher amplitude

fluctuations of the bursts and outbursts, >2 mag, have been detected in various of objects, as well (Warner 1995, Bisikalo et al. 2003).

The study of various types of brightness variation is important. The results give an information needed for further calculation of luminosity, stellar masses, radii and temperatures.

2. Targets' details

For the purpose of this paper, the objects of different types are selected. In this subsection, we give some details of MV Lyr (Lyrae), ER Del (Delphinus) and FU Ori (Orion).

MV Lyr is a member of VY Scl subclass of Nova-likes stars (NLs). It exhibits a high rate of accretion with existence of hot white dwarf (≈ 50000K). MV Lyr has an orbital period of P = 3.19hr and a mass ratio of q = 0.4 (Skillman et al. 1995). The system inclination is found to be in a range: i = 10 ÷13◦. Short-periods drops in brightness are observed, as MV Lyr displays "quasi-orbital" light variations. The typical time scale of the observed fast quasi-periodic oscillations is approximately tens of minutes.

ER Del belong to the Symbiotic variables of the Z Andromedae type. They are known as close binaries that consist a hot star primary star, usually a white dwarf and a red giant secondary star. Their combined brightness displays irregular variations with amplitudes up to 4 mag. in V. For ER Del, it is found that its cool companion is a giant of S5.5/2.5 spectral class (Ake 1979). The estimated effective temperature of ER Del is Teff ≈ 3470 – 3500 K (Boffin et al. 2014). The spectrum bands indicate for mass transfer from the red giant companion (Van Eck & Jorissen 1999). The ER Del orbital period is ≈ 2089 days and its eccentricity is e ≈ 0.17 – 0.22 (Jorissen et al. 2012, Boffin et al, 2014).

The third object FU Ori is a variable young stellar object, which belongs to type of FU Orionis, a class with exceptional increases in optical brightness within 5 magnitudes or more (Herbig 1977). These occasional sudden increases in their brightness (Hartmann & Kenyon 1996) could be caused by the variability in the accretion rate. The mass of the FU Ori's primary star is calculated to be M1= 1.1M⊙ (Solar masses) and the mass of the FU Ori itself M2= 0.5M⊙ (Hartmann & Kenyon 1996). The FU Ori discs are found to be quite massive and compact (Liu et al. 2018), about 10 − 20 of the stellar masses and radii of tens of AU (Astronomical unit). The disc inclination angle i= 55◦.

In this paper we aim to compare the variability in brightness of the three described above binary stars. In section Results: observational data of the three objects are presented; color indices and the temperatures are calculated. For the purpose of this paper, we use data from AAVSO (American Association of the Variable Star Observers).

Results

1. Observational data and light curves

MV Lyr: The observational period of a year and a half, from 2011/03/29 to 2012/11/18 (fig.1a), was chosen according to the active state period during the long time of brightness variability. The light curve in figure 1 indicates the transition between the low and high state, as the magnitude increases with 3.5 – 5 in V, in ≈ 8 months: 2011/09/15 – 2012/05/02. To track the small amplitude variations in the magnitude, we select one night during the high state of this period (fig.1b). The non-periodic variations in brightness with 0.15 – 0.3 mag in the frame of 40 – 90 min are probably a manifestation of flickering.

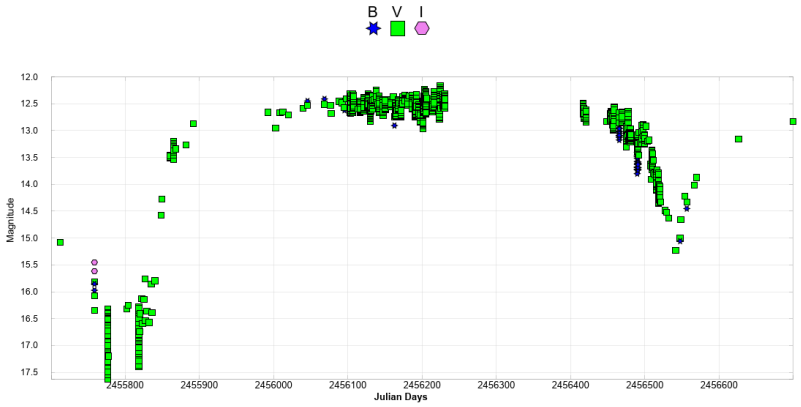

Fig. 1. Light curve of MV Lyr in B and V bands: Observational period: 2011/03/29 - 2012/11/18. (AAVSO data, Observers' Codes WGR, PVEA, LMJ.)

The variations in the light curve, zoomed from the later period of fig. 1a, when the brightness starts to decrease are represented in Figure 1c. Here, we see the difference in data in B and V bands.

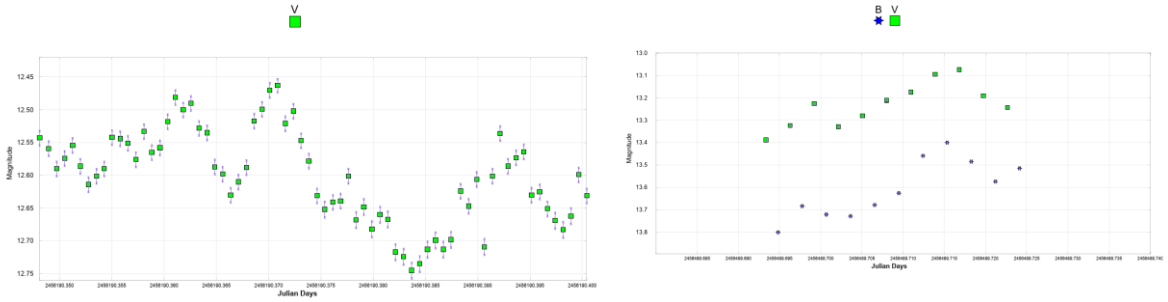

Fig. 1b (left). Light curve of MV Lyr. A close up view of the figure 1a. The figure shows the brightness variability in one night, in V band. Observational period: UTC 2012/09/19 20:21:16 - 2012/09/19 21:36:37 (AAVSO data, Observer's Code ATE.). Fig. 1c (right). Light curve of MV Lyr in B and V bands. The figure shows brightness variations in B and V bands during one night. (AAVSO data, Observer's Code ATE).

The brightness of ER Del changes with up to 0.5 mag in a frame of three months, during the chosen observational period of ≈ four years: 2016/07/30 to 2020/05/30 (fig. 2).

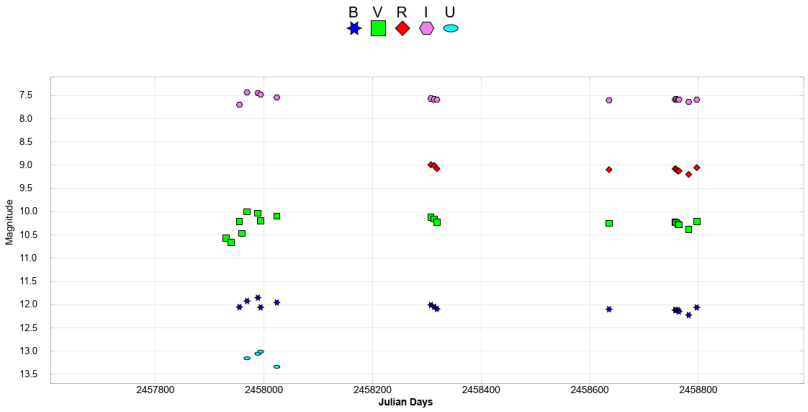

Fig. 2. Light curve of ER Del in UBVRI bands. Three months variability: JD 2457920 – 2458040. The entire observational period: 2016/07/30 to 2020/05/30. (AAVSO data, Observer's Code GCO, SRIC, AAUA.)

FU Ori: The time scales of the FU Ori's irregular variability are much larger. The small amplitude variability duration is less than a year, while the outbursts could prolong from ten to hundreds of years. The rise time of the outburst is from year to ten years.

It is difficult to track-out the so long observational period. The selected observational period is ≈ 3 years. We suggest the light curve of FU Ori (fig. 3) is mostly likely an exhibition of a small-amplitude variability in the magnitude during its outburst state.

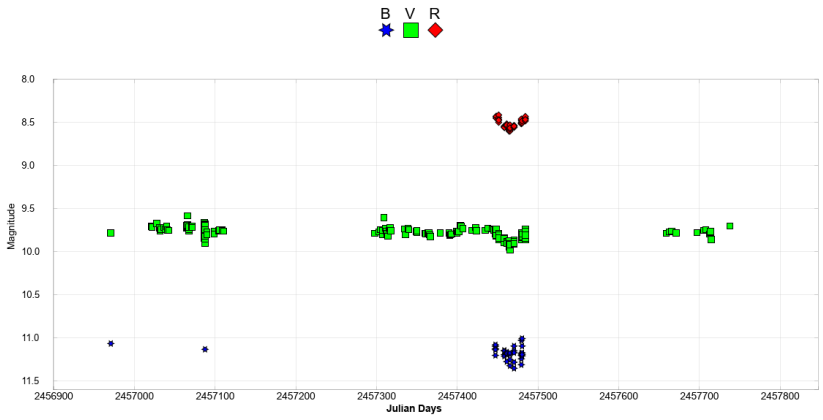

Fig. 3a. Light curve of FU Ori. Variations in BVR bands. Observational period: 2014/07/11 to 2017/04/06. (AAVSO data, Observer's Codes DKS, DUBF, HBB, SAH)

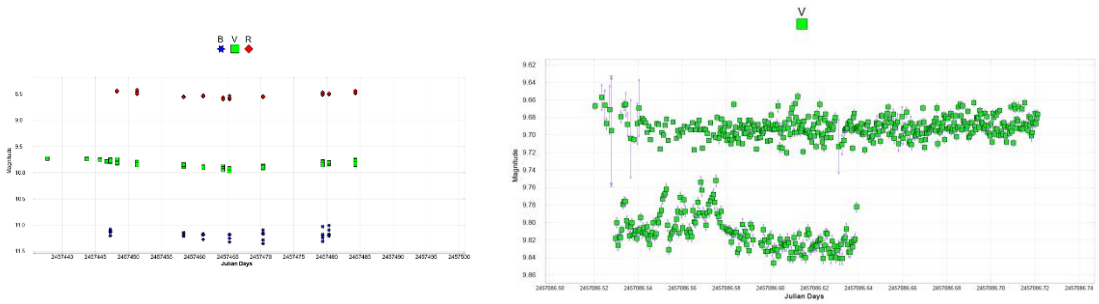

Fig. 3b (left). Light curve of FU Ori. A close up view of the variations in BVR bands. Observational period: 2016-02-21 12:00 - 2016-04-16 12:00 UTC. Fig. 3b (right). Light curve of FU Ori. A close up view of the variations in V bands. Observational time during the night: 2015/03/05 00:28 – 2015/03/05 05:45 UTC. (AAVSO data, Observer's Codes DKS, DUBF, HBB, SAH)

Figures 3b and 3c present the much extended time scale the shorter periods of the whole observational period of fig.3a. We can see in detail the brightness variations of FU Ori in intervals of two months (fig.1b) and five hours (fig.1c). Figure 3b clearly shows short-period variability with small-amplitude variations in V, with ~ 0.05 to 0.1 mag. They appear to be quasi-periodic variations.

2. Color index and temperature

The observational data in B and V bands allow us to estimate the color index or the color of the studied objects, for the time of observations. Following the data from previous subsection, we obtain the next values of the B-V index for the three objects.

MV Lyr at high state on JD 2456489.69 (UTC 2013/07/16): B-V ≈ 0.32 ± 0.005 at its maximum brightness and B-V ≈ 0.41 ± 0.005 at minimum brightness.

ER Del on JD 2457988.87 (UTC 2017/08/23): B-V ≈ 1.92 ± 0.1 at maximum brightness; B-V ≈ 1.56 ± 0.12 at minimum brightness.

FU Ori on JD: 2457480.31987 (2016/04/01): B-V ≈ 1.21 ± 0.07 at its maximum brightness and B-V ≈ 1.37 ± 0.07 at minimum brightness. On this date, the color index of FU Ori is slightly larger than zero. The color tends to be reddening.

Using the B-V index, we could estimate the color temperature (Tcol) during the minimum and maximum brightness of the three objects. We use the formula of Ballesteros (2012):

$$T = 4600K \times \frac{1}{(0.92(B-V)+1.7)} + \frac{1}{(0.92(B-V)+0.62)}$$

Then, for the color temperature values of the three objects, we obtain:

Tcol (MV Lyr min) = 6827K ± 0.0006

Tcol (MV Lyr max) = 7337 K ± 0.0005

Tcol (ER Del min) = 3254 K ± 0.002

Tcol (ER Del max) = 3705 K ± 0.0009

The color temperature of ER Del, obtained in our calculation is very close to the value, in a range of the effective temperature (Teff = 3500K ±160), obtained in (Boffin et al. 2014).

Tcol (FU Ori min) = 4000 K ± 0.0006

Tcol (FU Ori max) = 4289 K ± 0.0006

The obtained temperature of FU Ori is lower than the expected one. A reason of this result could be found in the possible source. Another explanation is the insufficient amount of data that we have, which leads to the larger value of the error in the estimation.

The dates of the calculated temperatures correspond to the dates used in the B-V index estimation. The parameters are listed in the Table 1:

Table 1. Color index and temperature of the three objects: MV Lyr, ER Del, FU Ori.

Parameter / Object	B-V (min) [mag]	B-V (max) [mag]	Tcol (min) [K]	Tcol (max) [K]
MV Lyr	0.41 ± 0.005	0.32 ± 0.005	6827K ± 0.0006	7337 K ± 0.0005
ER Del	1.56 ± 0.12	1.92 ± 0.1	3254 K ± 0.002	3705 K ± 0.0009
FU Ori	1.37 ± 0.07	1.21 ± 0.07	4000 K ± 0.0006	4289 K ± 0.0006

Conclusion

In this paper, we presented a periodic and quasi-periodic variability in brightness of the three binary stars: the Nova-likes star MV Lyr; the symbiotic variable ER Del and the variable young stellar object FU Ori.

Our aim was to distinguish each of the three stars in the way their light curves exhibit.

The brightening events occur both at different time- and amplitude- scales in the magnitude. In depend on this, we defined the events as flickering and flares.

The different observational periods of the three objects are considered in accordance with their activity states. The dissimilarity in the manifestation of their brightness variability is coming from the physical properties due to the objects' classes and types.

On the base of the observational data, we calculated the color indices during the nights of the three objects high states. Using the B-V index the color temperatures are calculated. The results show the color in the selected observational intervals is rather red and the corresponding objects' temperatures are not very high.

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