Short time-scales burst activity in three binary star systems and the related accretion efficiency

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Highlights

- ❑ Gamma-ray events such as bursts are among the most energetic events in the Universe. Dissimilar to bursts, gamma flares are events with lower energy and magnitude.
- ❑ We present our results of short burst activity in three binary stars systems of different types. Data from different astronomical sources (Swift observatory (BAT and XRT), Fermi/LAT (Large Area Telescope) data) are used. We identify signatures of X-ray and optical events in the three objects. Gamma flares in different energy ranges at the position of the selected target are detected.
- ❑ We estimate an accretion efficiency in these binaries, based on the obtained from the observational data luminosity. We define the type of accretion for each of the studied in this work objects and its relevance to the mass transfer properties. The importance of accretion processes onto compact objects to power-up gamma-ray and X-ray events is discussed.
- ❑ Swift/XRT details: Swift energy band total = 0.3 ≤ E ≤ 10 keV; Following the separation of the energy band (Evans 2013): Soft = 0.3 ≤ E < 1 keV ; Medium = 1 ≤ E < 2 KeV; Hard = 2 ≤ E < 10 keV. Two reading-out basic modes at the XRT: The Windowed Timing (WT) mode operates at high count rates; Photon Counting (PC) mode, which is used at lower count rates (Evans et al. 2009, Evans et al. 2014). All processing was performed using HEASOFT v6.22.
- ❑ FAVA (Fermi All-sky Variability Analysis) details: based on the data of Large Area Telescope (LAT) on board the Fermi Satellite. The events detections with the significance threshold: > 5.5 σ (or < -5.5 σ) (Ackermann et al. 2013; Abdolahi et al. 2017) are considered only.

Objects details

MWC148 (Monoceros, = HD 259440)

Binary system: HMXB; Be/X-ray star (Jaschek & Egret 1982).

- B0 Vpe star [4];
- γ-ray source, at very high energy bands (TeV) [4, 7];
- Its average apparent magnitude is 9.12 in the V band (Tycho-2);
- the distance to it is estimated as: 1.4 kpc [8];
- Orbital period: 321 days [8].

Gamma Cas (Cassiopeia)

Binary system: Be star (by Secchi in 1867) [16]

- Its optical magnitude is in the range 1.5 – 2.5 in V (AAVSO data);
- spectral type of γ Cas is B0.5 IV [14, 22];
- X-ray luminosity $L_x = 10^{32}–10^{33}$ erg s^{-1} [17];
- effective temperature Teff = 25000 K [19];
- Orbital period: 203.5 days; rotational period ≈ 1.215 days [18, 21].

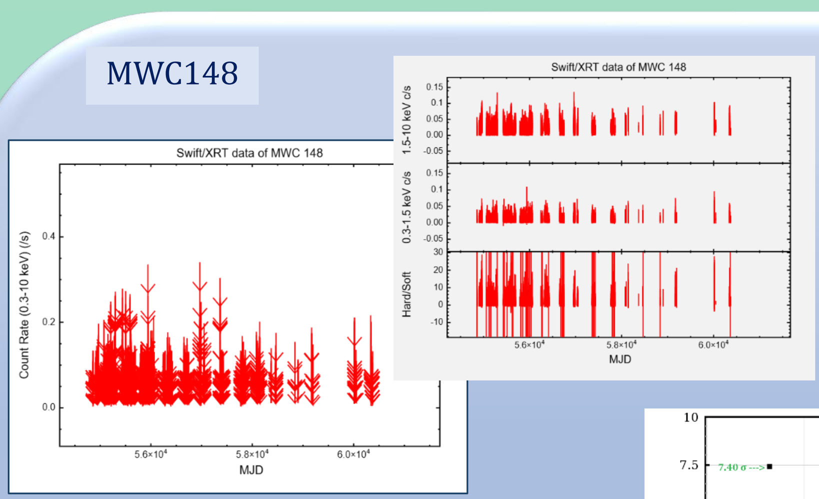
V2436 Cyg (Cygnus)

Binary system: BY Dra Variable

- Spectral type - K2.5V
- Magnitudes: 8.694 in B; 7.714 in V (AAVSO data; Tycho-2 catalogue)
- Orbital period: 10.526 d (Gaia DR3);
- effective temperature Teff =4819 K (Gaia DR3);
- Distance to the object: 19.6 pc (Gaia DR3).

Observational results from Swift/XRT and FAVA

MWC148



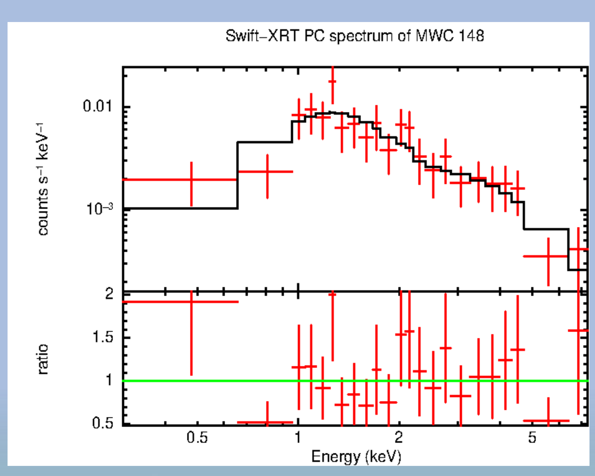


Figure 1. Swift-XRT light curves (up) and energy spectrum (down) of MWC 148. The light curves data are binned by time. The σ[min] = 3; bin length: WT - 20, PC - 100. The count rate maximum: 0.25 – 0.35 c/s with average 0.07±0.0001 c/s in 1.5 – 10 keV. The values of Normalized counts reach their maximum up to ~ 10^{-2} s^{-1} keV^{-1} in medium energy band 1 - 2 keV.

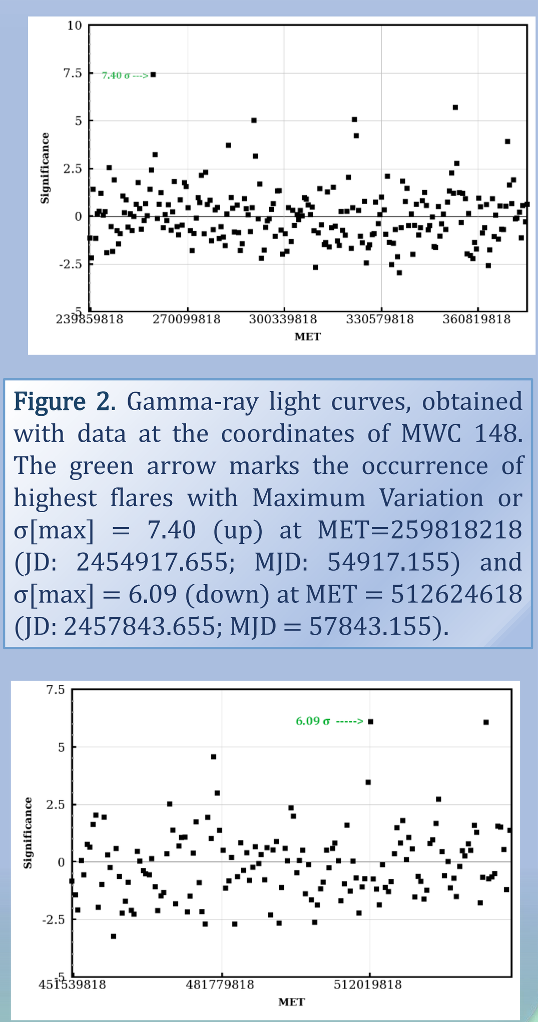


Figure 2. Gamma-ray light curves, obtained with data at the coordinates of MWC 148. The green arrow marks the occurrence of highest flares with Maximum Variation or σ[max] = 7.40 (up) at MET=259818218 (JD: 2454917.655; MJD: 54917.155) and σ[max] = 6.09 (down) at MET = 512624618 (JD: 2457843.655; MJD = 57843.155).

gam Cas

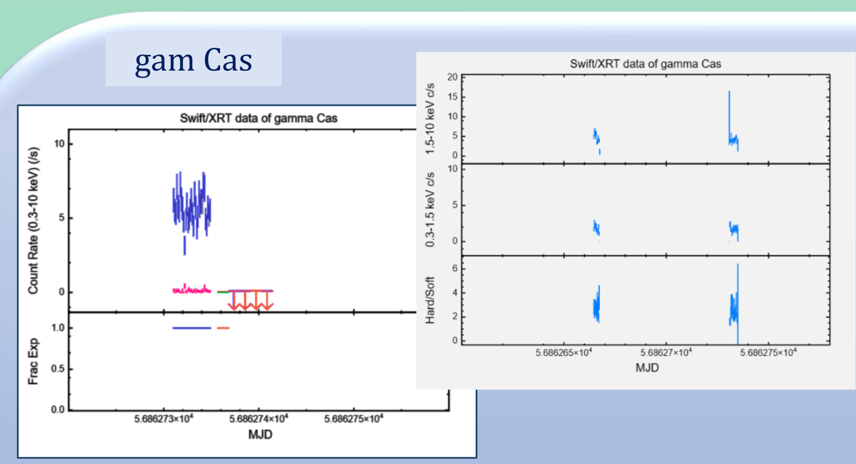
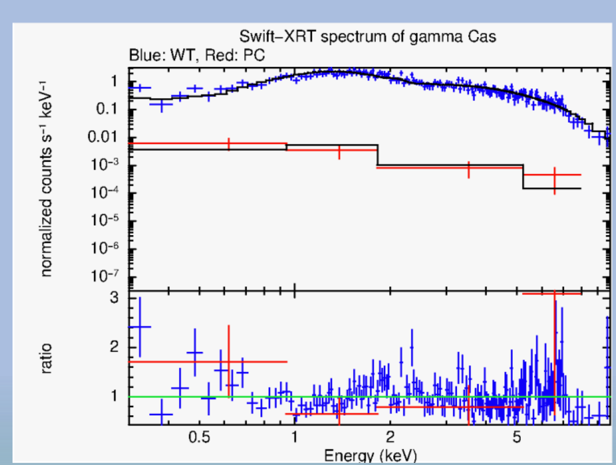


Figure 3. Swift-XRT light curves (up) and energy spectrum (down) of gamma Cas. The light curves data are binned by time. The σ[min] = 3; bin length: WT - 20, PC - 100. The count rate maximum: 0.35 – 0.55 c/s in PC mode (red); 4.7 – 6.5 c/s in WT mode (blue) with average 5.70±0.001 c/s in 1.5 – 10 keV and 2.5±0.003 c/s in 0.3 – 1.5 keV. The values of Normalized counts reach their maximum up to ~ 10^0 s^{-1} keV^{-1} in medium to hard energy bands 1 - 2 keV and 4 – 10 keV.



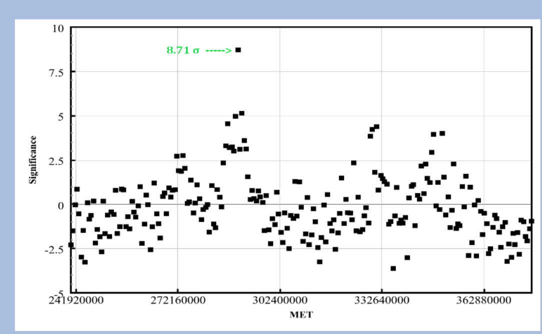


Figure 4. Gamma-ray light curves, obtained with data at the coordinates of gamma Cas. The green arrow marks the occurrence of highest flares with Maximum Variation or σ[max] = 8.71 (up), MET=290058218 (JD:2455267.655; MJD: 55267.155).

V2436 Cyg

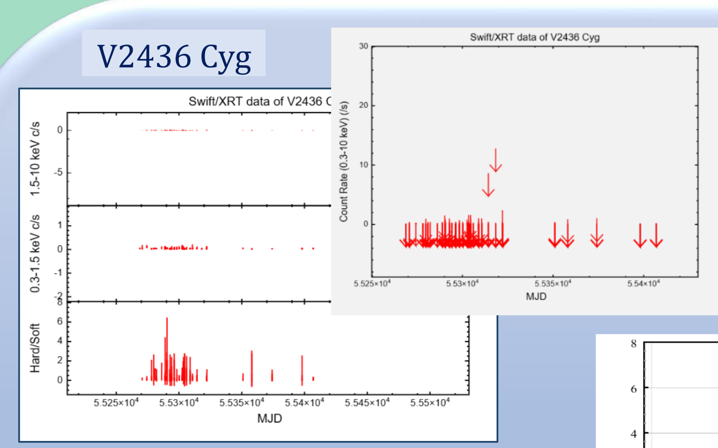
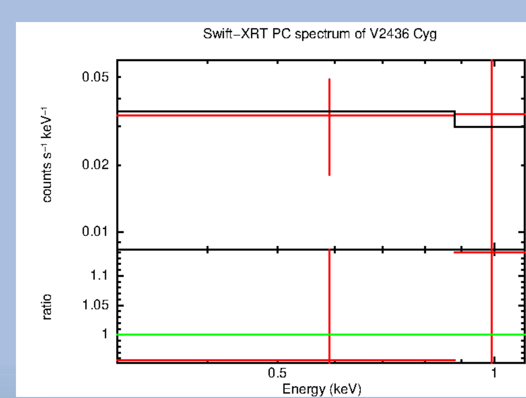


Figure 5. Swift-XRT light curves (up) and energy spectrum (down) of gamma Cas. The light curves data are binned by time. The σ[min] = 3; bin length: WT - 20, PC - 100. The count rate maximum: 0.03 – 0.04 c/s in PC mode (red) with average 0.25±0.005 c/s in 0.3 – 1.5 keV. The values of Normalized counts reach their maximum up to ~ 3 x 10^{-2} s^{-1} keV^{-1} in soft energy band 1 ÷ 2 keV.



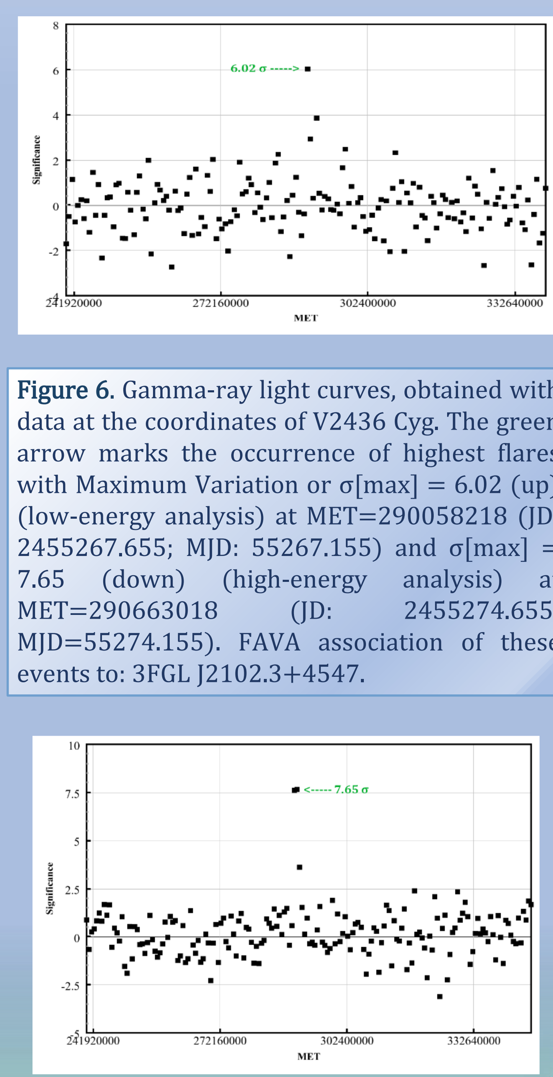


Figure 6. Gamma-ray light curves, obtained with data at the coordinates of V2436 Cyg. The green arrow marks the occurrence of highest flares with Maximum Variation or σ[max] = 6.02 (up) (low-energy analysis) at MET=290058218 (JD: 2455267.655; MJD: 55267.155) and σ[max] = 7.65 (down) (high-energy analysis) at MET=290663018 (JD: 2455274.655; MJD=55274.155). FAVA association of these events to: 3FGL J2102.3+4547.

Accretion efficiency and comparison of the targets' emission profiles

- It is important to know an accretion efficiency values, since it gives the measurement of how efficiently the mass energy of the accreted material is converted into radiation.
- We calculate average accretion efficiency values ηacc for the three objects, by using the expression of (Kolb 2010): $\eta_{acc} = GM_1/R_1c^2$, obtained by the expression of accretion luminosity: $L_{acc} = \eta_{acc}\dot{M}c^2$. We use the maximum values of luminosity, based on the obs. data.
- $\boldsymbol{\eta_{acc}}$ depicts the disc accretion; We evaluate the spherical accretion efficiency **ξ** in order to estimate the dominant accretion mode in each of the objects (see Table).

Parameter / Object	η	ξ	*Mco* [M⊙]	*Rco* [R⊙]
MWC 148	(6 ± 0.12) x 10^{-2}	(1.2 ± 0.02) x 10^{-2}	5	16 km
γ Cas	(4 ± 0.1) x 10^{-4}	(8 ± 0.18) x 10^{-5}	0.9	0.009
V2436 Cyg	(9 ± 0.14) x 10^{-3}	(1.8 ± 0.03) x 10^{-3}	1.35	0.003

Table: The mean values of accretion efficiency calculated for the three objects in the two suggested accretion modes: η - for disc accretion, ξ - for spherical accretion. ***Mco*** is the mass of the compact companion; ***Rco*** – radius of the compact companion.

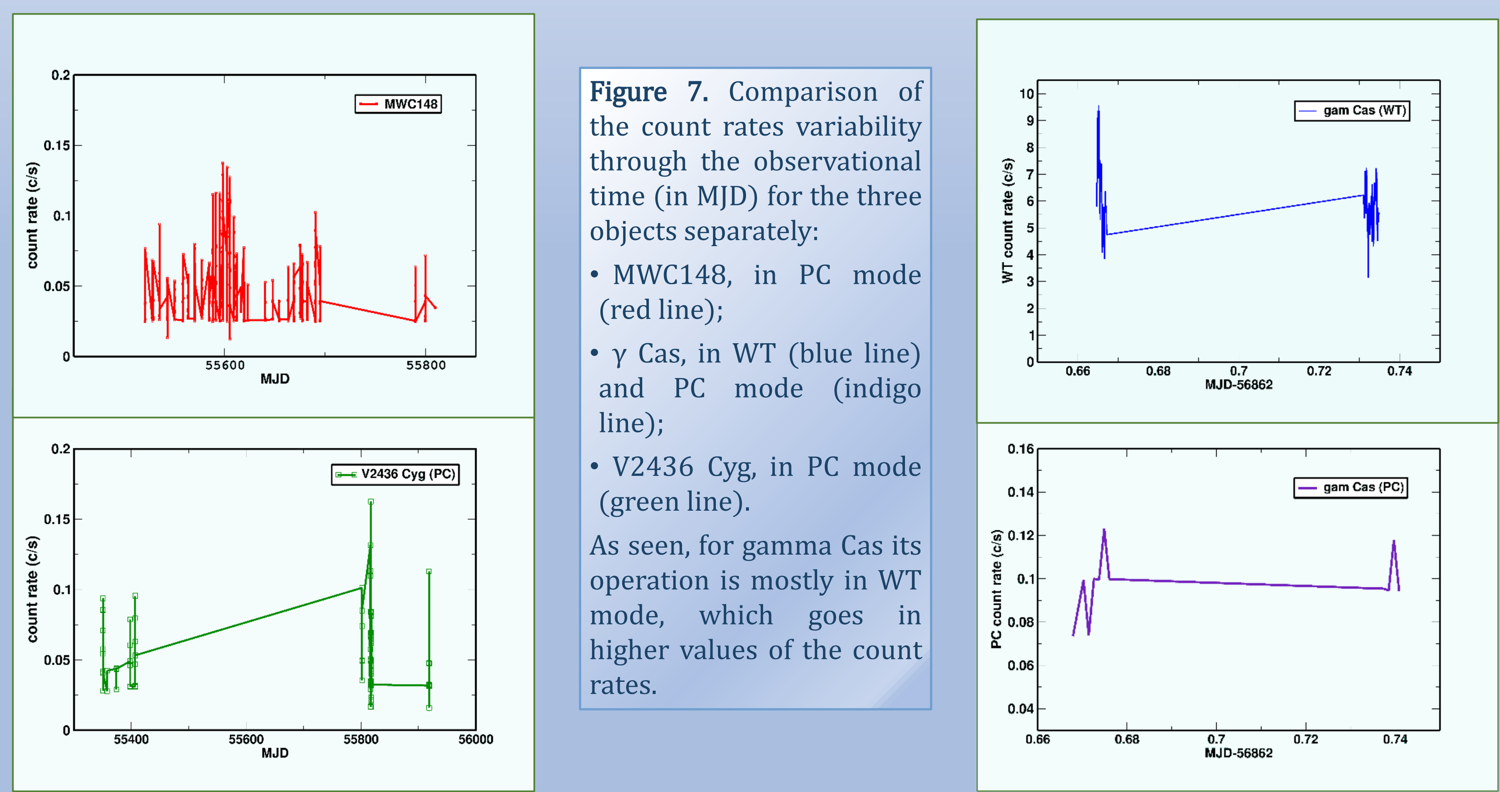


Figure 7. Comparison of the count rates variability through the observational time (in MJD) for the three objects separately:

- MWC148, in PC mode (red line);
- γ Cas, in WT (blue line) and PC mode (indigo line);
- V2436 Cyg, in PC mode (green line).

As seen, for gamma Cas its operation is mostly in WT mode, which goes in higher values of the count rates.

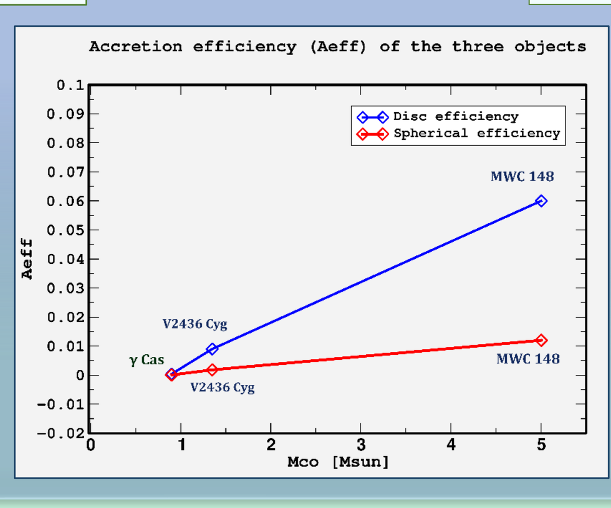


Figure 8. This figure shows the increase in accretion efficiency (*Aeff*) in relation to the mass of the compact object (*Mco*) for the three targets. The two curves depict the changes in two types of efficiency, disc η (blue line) and spherical ξ (red line). The corresponding efficiency values are pointed for each star (see squares).

Discussion and Concluding remarks

❑ The accretion of matter onto compact objects in binaries with neutron stars or black holes, as MWC 148, releases sufficient gravitational energy that could be able to power gamma-ray processes (Diehl 2001). The obtained data from Swift/XRT for this object show its maximum activity operates at medium energy band 1 ÷ 2 keV during the time-interval in Figs. 1 and 2, which is unexpected moderate behavior for this class of stars.

❑ No coincidence in the time of gamma events for the three objects, detected by FAVA and Swift, is observed.

❑ The γ-events, in the current survey, detected by FAVA are sporadic. They are not as energetic as the typical Gamma-Ray Bursts. The registered flares fade rapidly, within a day.

❑ Despite the detected gamma emissions are localized in the targets coordinates, we do not have strong evidence that they originate precisely from the objects, even for the gamma-ray emitter MWC148. One assumption we could make about the sources of such gamma events is that their position is out of the three examined objects [6].

❑ As expected, the accretor in the MWC148 system has larger accretion efficiency with approximately two orders of magnitude than that of the compact objects in the other two systems. As a black hole, it has two independent but complementary effects on the accretion flows around it:

<> It acts as a more massive accretor; <> It functions as a more powerful compact object.

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Acknowledgments:

This work made use of data supplied by the UK Swift Science Data Centre at the University of Leicester.
We acknowledge the project "Accretion flows in binary stars" KP-06-H98/8 (Bulgarian National Science Fund).

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