Detection of possible gamma emission flares in three interacting binary stars

D. Boneva[1] & R. Zamanov[2]
[1] Space Research and Technology Institute - Bulgarian Academy of Sciences, BG-1113,Sofia
[2] Institute of Astronomy and NAO, Bulgarian Academy of Sciences, BG-1784, Sofia
danvasan@space.bas.bg
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Abstract. Using the Fermi All-sky Variability Analysis tool (FAVA), we search for gamma flare events from 15 binary stars. We detected flares in the coordinates of three objects: the symbiotic stars AG Peg and ER Del, and the high mass X-ray binary MWC 148. The period of monitoring toward the regions of the targets' coordinates includes about 10 years of observations. The light curves from the FAVA generator show that these three objects manifest 3 to 9 individual gamma flares in the low energy band 100 - 800 MeV. The lifetime of each event lasts within one day. The possible origin of the detected gamma flares is briefly discussed.
Key words: Stars:binaries - Stars: flare - Accretion, accretion disks - Stars: individual: AG Peg, ER Del, MWC148

1 Introduction

Gamma-ray events such as bursts are among the most energetic events in the Universe. Unlike gamma-ray bursts, gamma flares are events with lower energy and magnitude. We search for gamma flares in the energy range > 100 MeV and < 800 MeV. These values are chosen in accordance with the Fermi All-sky Variability Analysis (FAVA) - based on the data of Large Area Telescope (LAT) on board the Fermi Satellite. FAVA is positioned to search for transient gamma-ray emission in all sky directions. In a specified time interval, the detected number of counts are compared to the expected one, averaged for a long-period (Abdolahi et al. 2017). It receives data both from positive and negative flux variations.

Since the background emission properties and its diffusivity are different along the axes in different directions, the sensitivity of FAVA varies with the position on the sky. Its sensitivity also depends on the energy spectrum of the flaring gamma source (Nolan et al. 2012). To improve the sensitivity of detection by FAVA and to search for transients in the gamma-ray sky that does not require a diffuse emission model, a new method is developed by Ackermann et al. (2013). It is independent of any model of the diffuse gamma-ray emission of the temporal variations of the gamma-ray sky measured by the LAT on board the Fermi Satellite. The number of detected variable gamma-ray sources in our Galaxy is too low so far. The search for gamma-ray events, produced from the regions of binary stars, by employing the FAVA (or LAT) instruments has already given a lot of results. Loh et al. (2017) have investigated the gamma-ray events of binary star DG CVn by using LAT on board of the Fermi satellite and BAT (Burst Alert Telescope) on board of the Swift satellite. They have detected a gamma-ray excess, but they attributed to another source, which is close to the position of this binary. The Fermi LAT is also successfully used to detect gamma-rays, coming from the Crab Nebula (Abdo et al. 2011a) during a continuous monitoring of this object. The discovery of γ-rays from the binary system PSR B1259-63/LS 2883 (binary system consisting of a Be star and radio pulsar)has been reported using the LAT again (Abdo et al. 2011b).

In the current paper, we aim to search for of possible gamma emission among selected 15 binary stars. Section 2 presents a description and some observational details of the objects. The results of FAVA are given in Section 3. In the final section, a short discussion about the gamma flares activity is included.

2 Targets details

We have checked for the existence of gamma flares in 15 binary stars, previously defined as X-ray sources: AG Dra, AG Peg, DD Mic, CH Cyg, Draco C1, EG And, ER Del, V615 Cas, MWC 656, MWC 148, X Per, V2116 Oph, HM Sge, RR Tel, V1329 Cyg (Luna et al. 2013). Most of them manifest no significant level of gamma activity, producing just one flare for the whole observational period. We have found presence of gamma activity in 3 of them: AG Peg, ER Del and MWC 148.

AG Peg consists of an M3 III giant and a hot component - most probably a white dwarf with mass $06 - 0.7\,M_\odot$ (Tomov & Tomova 1992, Fekel et al. 2000). The binary's orbital period is 818.2 ± 1.6 d and the eccentricity of the orbit is 0.11 (Fekel et al. 2000). The behaviour of AG Peg shows some characteristics of the R-stars (Zamora et al. 2009), a sub-group of the "carbon stars". The light curves have a shape close to the sinusoidal one and the light varies with the P_{orb}. The maximum brightness occurs, when the hot star is in front of the companion.

Regarding the symbiotic binary ER Del, it is found that its cool companion is a giant of S5.5/2.5 spectral class (Ake 1979) - a class of peculiar red giants (Merrill 1959).

The orbital period of ER Del is $\approx 2089\,d$ and the eccentricity of its orbit is $e = 0.17$ (Jorissen et al. 2012). Its spectrum displays hydrogen emission lines, as well as UV emissions (Belczyński et al. 2000). These features are typical for symbiotic binaries to which class ER Del belongs (Luna et al. 2013).

The high mass X-ray binary MWC 148 (Roeser et al. 1991, Nesterov et al. 1995) consists of a Be star (Jaschek & Egret 1982) similar to the classical Be star γ Cas. The compact companion is probably a ~ 5 $M_\odot$ black hole (Casares et al. 2012; Zamanov et al. 2017). It is identified as a γ -ray binary, detected at very high energy bands (TeV) (Aharonian et al. 2007, Hinton et al. 2009, Bongiorno et al. 2011). The orbital period derived from the X-ray data is $P_{orb} = 315$ d (Aliu et al. 2014).

3 Detection of gamma events with FAVA

To examine the gamma flare events of AG Peg, ER Del and MWC 148, we employ the online data base and light curve generator FAVA, which we have already described in Section 1.

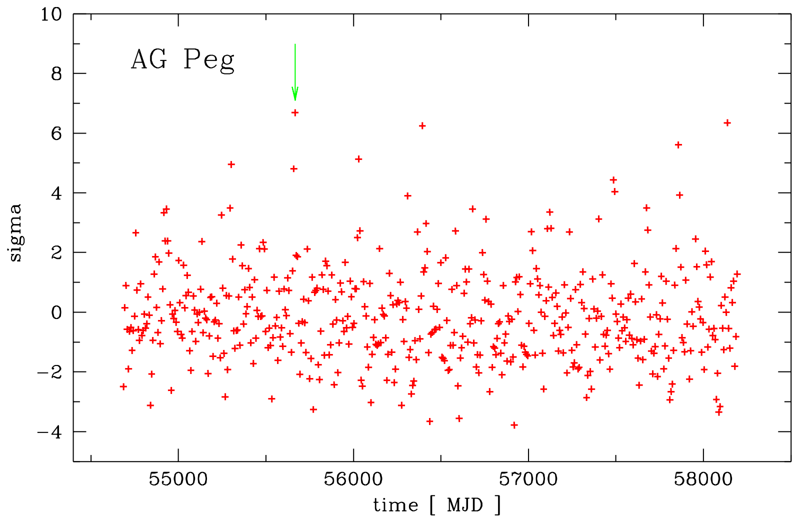

Fig. 1. Gamma-ray LC of a source with coordinates at the position of AG Peg. The green vertical arrow marks the highest flare with $\sigma[max] = 6.85$ at MET=324531818 (JD 2455666.655; MJD 55666.155; Calendar date 2011.04.15)

Ackermann et al. (2013) and Abdolahi et al. (2017) apply the units of Gaussian sigmas (σ) to visualize the significance of the probabilities that the observed counts are a statistical fluctuation of the expected one. According to their papers, only the events with $\sigma \geq 5.5$ and $\sigma \leq -5.5$ should be considered. To limit the false flares, authors of the online FAVA catalog eliminated those within this range in advance. The sensitivity of

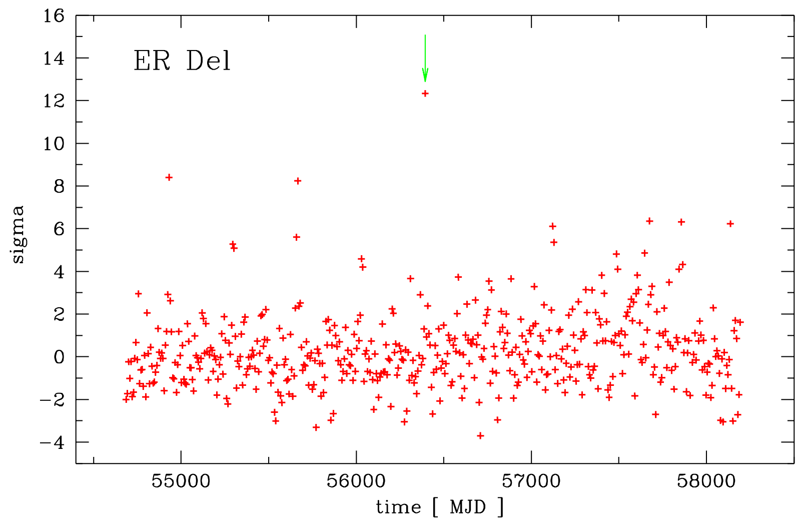

Fig. 2. Gamma-ray LC of a source with coordinates at the position of ER Del. The green vertical arrow marks the highest flare with $\sigma[max]$ = 12.34 at MET= 387431018 (JD 2456394.655; MJD 56394.155; Calendar date 2013.04.12)

FAVA data also depends on the energy spectrum of the flaring gamma-ray source. Typically gamma-ray sources have photon index between 1.5 and 2.5 in the Fermi-LAT energy range (Nolan et al. 2012). To compute the set of the flaring source, a power-law spectra is assumed, as well as the values for the photon index Γ: 1.5 and 3.5. Since the receiving data are separated for high- and low- energy bands, the harder ($\Gamma \leq 2$) and the softer ($\Gamma \geq 2.5$) flares are respectively detected for each of the two bands.

For the significance threshold of $\sigma > 5.5 - 6$, the sensitivity maps of FAVA are in relation to the weekly exposure of the expected counts. If FAVA detections are in one of the two energy bands (low energy map: $100 - 800MeV$, as an example), the flare flux needs to reach the threshold of 6σ. When there are detections in both energy bands at the same time (low: $100 - 800MeV$ and high: $> 800MeV$), 4σ is enough. We chose to examine the flares in the low energy band with FAVA detections of the significance threshold: $> 5\sigma$, calling them "gamma flares" or "gamma events". Employing the FAVA light curve generator, we have obtained the gamma light curves of sources with the coordinates of the binary stars AG Peg, ER Del and MWC 148 (Figures 1,2,3). The data of AG Peg and ER Del are downloaded in April 2018 and those of MWC 148 in March 2018.

The light curves of the sources at these positions manifest individual 4 to 9 gamma-flares during the period of observations. They are sporadic events with magnitudes 2 to 3 times above the average ones and different σ values larger than 5σ. The period of monitoring is chosen automatically by the light curve generator and it reaches approximately 10 years of observations with Starting Time: 239859818 [MET] and End Time: 542864618 [MET]. The input time format for the light curve generator is MET (Mission Elapsed Time) - Fermi seconds since 2001.0 UTC (decimal). The corresponding dates in JD (Julian Date), MJD (Modified Julian Date) and Calendar Date (yyyy.mm.dd) are calculated as: JD 2454686.655 - JD 2458193.655, MJD 54686.155 - MJD 58193.155 and Calendar date 2008.08.08 - 2018.03.16. The values for each of the observed objects are presented in Table 1.

Table 1. Data from FAVA for the 3 objects, during the same observational periods. Range of $\sigma[max]$, number of gamma events n and energy range Δ E.

Object	$\sigma[max] \geq 5$	n	$\Delta E(MeV)$
AG Peg	5.3 - 6.85	5	100 - 800
ER Del	5.5 - 12.34	9	100 - 800
MWC 148	5.8 - 7.40	4	100 - 800

We summarize the data for the 3 objects (from figs. 1,2,3, Table 1). The maximum values of σ are as follows: AG Peg - 6.85σ; ER Del - 12.34σ;

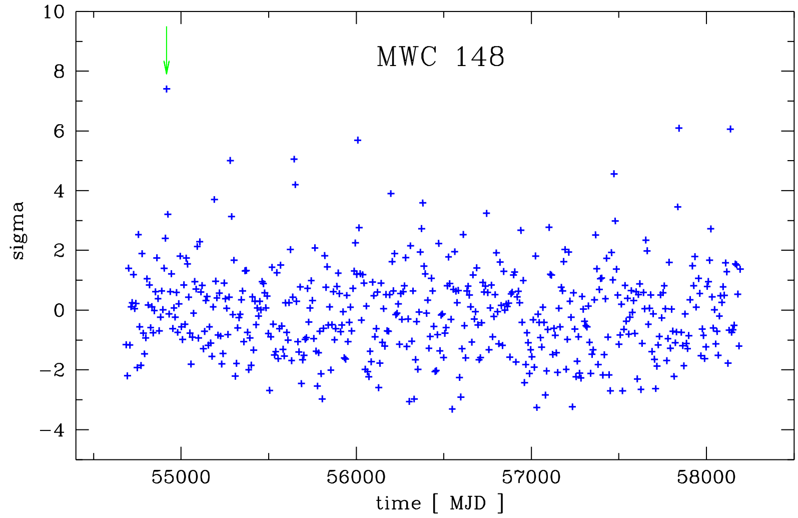

Fig. 3. Gamma-ray LC of a source with coordinates at the position of MWC 148. The green vertical arrow marks the highest flare with $\sigma[max] = 7.40$ at MET=259818218 (JD 2454917.655; MJD 54917.155; Calendar date 2009.03.27)

MWC 148 - 7.40σ. The next most indicative values above the threshold of 5σ, detected for the same period of the FAVA monitoring are listed below:
AG Peg - 6.34σ - MJD 58137.155 (Calendar date 2018.01.19); 6.24σ - MJD 56394.155 (Calendar date 2013.04.12);
ER Del - 8.40σ - MJD 54931.155 (Calendar date 2009.04.10); 6.31σ - MJD 57857.155 (Calendar date 2017.04.14);
MWC 148 - 6.09σ - MJD 57843.155 (Calendar date 2017.03.31); 6.05σ - MJD 58137.155 (Calendar date 2018.01.19).

These results give indications of gamma-ray excesses from the submitted to FAVA coordinates, associated with the three objects.

The detected γ events are occasional and not so high-energetic as the typical Gamma Ray Bursts. The registered flares fade rapidly, within a day. Each of the targets has produced more than two flares. The origins of such activity could have different sources, some of them are still unexplored.

4 Discussion

Gamma rays are produced by the hottest and most energetic objects in the Universe (Butcher et al. 2016). During the 8 years of observations, Fermi-LAT has detected more than 5000 sources of gamma emission above 100 MeV (Abdolahi et al. 2017, Ackermann et al. 2012). The known astrophysical sources of γ-rays in our Galaxy are pulsars, pulsar wind nebulae, supernova explosions, supernova remnants, neutron stars in binary systems, and the regions around black holes (Butcher et al. 2016). Very often the emissions come from the Extra-galactic regions, usually from Active Galactic Nuclei. The cosmic-ray interactions with interstellar matter and photon fields are the origin of the Galactic diffuse emission, which is an effective gamma-ray source above 100 MeV (Ackermann et al. 2012). They could be some decaying remnant from the higher energy bursts, as well.

The most commonly suggested and discussed by the authors mechanisms of gamma-ray emissions are the processes related to the synchrotron radiation (Méeszáros et al. 1994; Ravasio et al. 2018) and the inverse Compton scattering (Shen, & Berkey 1968, Ghisellini et al. 2000). Most of the 15 objects (see Sect. 2) investigated in this paper are far from the typical gamma ray sources.

The accretion of matter onto compact objects in binaries with neutron stars or black holes releases sufficient gravitational energy that could be able to power gamma-ray processes (Diehl 2001).

In the previous section, we presented the results from FAVA and the dates of maximal values of σ for each of the objects separately. For AG Peg, it is $\sigma = 6.85$ on MJD 55666.15 (Calendar date 2011.04.15). In reference to the optical activity of this star, on this date AG Peg is still in its quiescent state, staying in almost the same brightness level between 1997 to June 2015 (Skopal et al. 2007, 2012, 2017). In June 2015, AG Peg has produced a powerful burst (Skopal et al. 2017) that increased its brightness from ~ 8.5 in V to ~ 6 mag. in V, raising the luminosity of the hot component to $8 \times 10^{37} ergs^{-1}$. Otherwise, there is no FAVA detection of significant gamma-ray emission, associated with the optical flares of this star in the period of optical eruptions.

Although the detected gamma emissions are localized in the targets coordinates, we do not have strong evidence that they are coming precisely from the objects. The data are inadequate to make such a conclusion even for the gamma-ray emitter MWC 148.

We have noticed the following coincidences in the obtained data of the gamma events: there is one flare production from each of the positions of AG Peg and ER Del in the same date, but with different σ values. The same is observed from the coordinates of AG Peg and MWC 148 (see the data in Section 3). According to these remarks, one of the assumptions we could make about the sources of such gamma events is to consider their position to be out of the three examined objects.

The Gamma-rays are also found to originate from the diffuse parts of our Galaxy (De Angelis & Mallamaci 2018) and more distant regions as well. It is possible that the gamma-ray emission is coming not from the fitted to the coordinates object, but from a nearby location of the mapped background region. Therefore, according to the FAVA analysis, we should be careful with the interpretation of the emission excesses at the specific positions of the sky, as we have set the coordinates of the 3 objects. Since the emission of the flares is detected throughout the vast sky area, it is recommended to take into account the close surroundings flares and then to check the location again. This will be considered in our future work.

5 Concluding remarks

We have searched for γ-ray flares from 15 binary stars: AG Dra, AG Peg, DD Mic, CH Cyg, Draco C1, EG And, ER Del, V615 Cas, MWC 656, MWC 148, X Per, V2116 Oph, HM Sge, RR Tel, V1329 Cyg AG Peg, ER Del and MWC 148. Using the FAVA light curve generator we detected individual sporadic gamma events at low energy (100 MeV - 800 MeV) at the positions of MWC 148, AG Peg and ER Del. Above 5 sigma level we detected 5 gamma events in AG Peg, 9 in ER Del and 4 in MWC 148. The results are based on 10 years of observations of Fermi-LAT at the coordinate's positions of these systems.

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