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A GAMMA-RAY TRANSIENT AT THE POSITION OF DG CVN

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Abstract. Solar flares are regularly detected by the Large Area Telescope (LAT) on board the *Fermi* satellite, however no gamma-ray emission from other stellar eruptions has ever been captured. A recent *Swift* detection of a powerful outburst originating from the nearby binary star DG CVn, with optical and radio counterparts, gave us an opportunity to measure the 0.1–100 GeV emission from this kind of objects for the first time. We performed a deep LAT study over the past six years of the *Fermi* mission and we report a significant gamma-ray excess in November 2012, at a position consistent with this binary at a 2σ confidence level. Since no multi-wavelength coverage was available in 2012 and because no high-energy emission was detected during the recent X-ray superflare, we discuss the possible origin of this gamma-ray transient.

Keywords: Acceleration of particles, stars: flare, gamma-rays: stars, stars: individual (DG CVn).

1 Introduction

Wide-field surveys and rapid response capabilities have offered the keys to discover unanticipated classes of transient sources. The high-energy sky above 100 MeV proves to be intensely variable and the *Fermi* satellite is at the forefront of detecting such events. Indeed, its main instrument, the Large Area Telescope (LAT, Atwood et al. 2009), combines a high sensitivity, a wide field of view, a large energy range, and operates in a sky-survey mode most of the time. This nearly complete mapping and continuous monitoring of the sky led to the discovery of new and sometimes unexpected gamma-ray source classes such as microquasars (Fermi LAT Collaboration et al. 2009) or Galactic novae (Ackermann et al. 2014).

The hard X-ray transient monitor Burst Alert Telescope (BAT) on board *Swift* detected on 2014 April 23 a powerful and rare outburst (Drake et al. 2014) from the DG Canum Venaticorum system (hereafter DG CVn, also known as GJ 3789 or G 165−8AB). DG CVn is a M-dwarf binary whose components are separated by $0\farcs2$ (Mason et al. 2001; Beuzit et al. 2004) in rapid rotation ($v \sin i = 55.5\,\mathrm{km\,s^{-1}}$, Delfosse et al. 1998; Mohanty & Basri 2003). Riedel et al. (2014) indicate that the system lies at 18 pc from the Earth and that it is relatively young (~ 30 Myr, confirmed by estimations from Caballero-García et al. 2015), explaining its intense activity.

The brightness of this event was high enough so that *Swift* triggered an automatic follow-up with the Arcminute Microkelvin Imager radio telescope at 15 GHz (Fender et al. 2015). Radio observations started within 6 minutes after the trigger and captured a bright 100 mJy flare. Some additional smaller flares occurred during the next four days before the return at a quiescent radio level (2–3 mJy, as detected by Bower et al. 2009). DG CVn's radio detection suggests production of synchrotron emission from electrons accelerated during the initial phase of the stellar flare. These non-thermal particles are thought to deposit their energy in the lower stellar atmosphere where the density is higher, heating the medium and possibly producing X-ray thermal radiation from the plasma (e.g. Neupert 1968). Caballero-García et al. (2015) measured a delay between hard X-ray and optical emissions, that can be attributed to this Neupert effect. The accelerated particles could also lose their energy via pion decay or Bremsstrahlung processes depending on their leptonic or hadronic nature. This would result in high-energy emission that may be detectable by the LAT.

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2 Search for high-energy gamma-ray emission with the LAT

We report here the analysis of the P302 LAT data from *Fermi* launch in August 2008 to September 2014, six years later. The reduction and analysis of the LAT products were performed with the *Fermi* Science Tools (version 10-00-02) using the Instrument Response Functions `P8R2_SOURCE_V6` and the corresponding diffuse models for the Galactic and isotropic emissions. The source model file used to constrain the diffuse and nearby point-source emissions is based on the Third *Fermi*-LAT Source Catalog (3FGL, Acero et al. 2015). We added the model of DG CVn at the position (RA = 202.°94, Dec. = 29.°28, J2000) with a power-law spectrum.

As the binary star lies far away from the Galactic plane, the likelihood analysis over the full LAT data set easily converged and we used the Test Statistic (defined as $\mathrm{TS} = 2\Delta \log L$, where the difference compares the likelihood functions L with and without the addition of DG CVn) to quantify the statistical significance of the presence of the point-source with respect to the background. Including the DG CVn source model does not seem essential for the fitting procedure over six years as its derived TS value is about 19.7 (approximatively just over 4σ for 2 degrees of freedom, Mattox et al. 1996) with a mean gamma-ray flux of $(3.9 \pm 1.6) \times 10^{-9}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$. A low TS value over a large time scale could mean that either the steady gamma-ray flux, if present, is lower than the LAT sensitivity or the gamma-ray emission is transient (e.g. during an outburst).

2.1 Long-term variability

The binary star's light-curve was built using 4-day time bins (Fig. 1) over the entire range of *Fermi* observations to identify time periods where a gamma-ray emission is significantly detected at the position of DG CVn. We computed 95 per cent upper-limits on the high-energy flux when the TS value was below 25 ($\sim 5\sigma$) using the (semi-)Bayesian method of Helene (1991) as implemented in the `pyLikelihood` module provided with the Science Tools. Otherwise, we provide integrated gamma-ray fluxes along with 1σ statistical error bars.

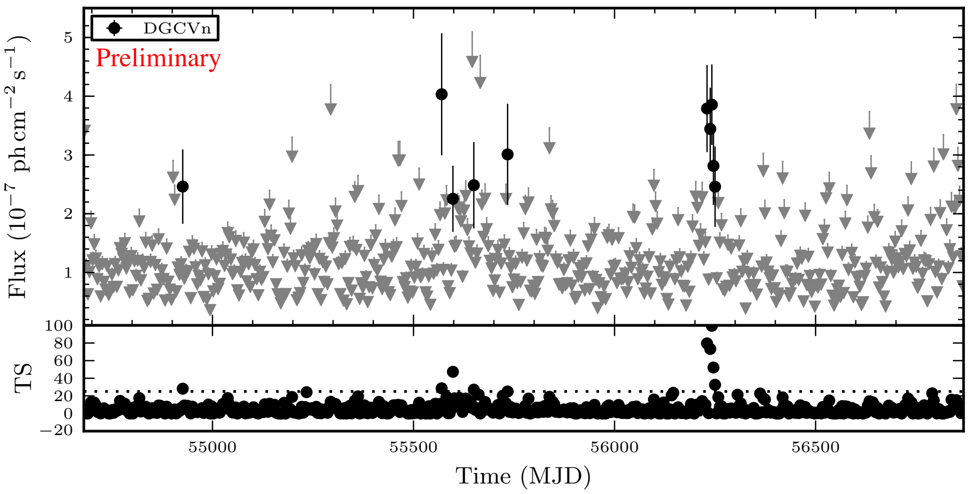

Fig. 1. 4-day exposure LAT light-curve (0.1–100 GeV) obtained by fitting a point-source at DG CVn position. Upper-limits (grey arrows) or gamma-ray fluxes given with 1σ statistical errors (black dots) are derived whether the Test Statistic (bottom panel) falls below or above the defined threshold value of 25 (horizontal dotted line) respectively.

Most of the time, including a point-source at DG CVn's position does not improve the fitting of the region (i.e. TS < 25), thus we are only able to provide upper-limits on the binary star flux for the corresponding periods. However, a few data points exceed the TS threshold. We identified the spurious detections related to local fluctuations or outbursts originating from nearby sources. For instance, the gamma-ray excess around MJD 55600, which reaches a 47 TS value, is time-coincident with a flaring episode of the nearby blazar 3FGL J1332.8+2723 and has been detected by the weekly *Fermi All-Sky Variability Analysis* (FAVA, Ackermann et al. 2013a) between 2011 February 7 and 14. Due to the large PSF of the instrument, some of its softest photons may have been included during the model fitting of DG CVn, resulting in an artificial TS excess for the latter source, although situated 1.°9 away (Ackermann et al. 2013b).

Apart from these spurious detections, one can clearly distinguish a significant excess around MJD 56240 (2012 November 9) where five measurements present a TS value between 32 and 99. Again, this gamma-ray flare has been previously reported by the FAVA. The automatic analysis detected a significant transient event lasting for about three weeks (from 2012 October 29 to November 19) and incorrectly associated it with the blazar 3FGL J1332.8+2723 responsible for the outburst previously mentioned (see Sec. 2.2).

We also note the absence of any gamma-ray counterpart for the X-ray/radio superflare which occurred on 2014 April 23 (MJD 56770.88). 40 days encompassing the outburst were investigated in details but no significant gamma-ray emission can be associated with a point-source at the position of DG CVn. A single 1-day measurement presents a TS value just above 9 with a mean flux of $(2.0 \pm 1.2) \times 10^{-7}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ eight days before the X-ray flaring episode but this could be due to a statistical fluctuation.

2.2 November 2012 outburst

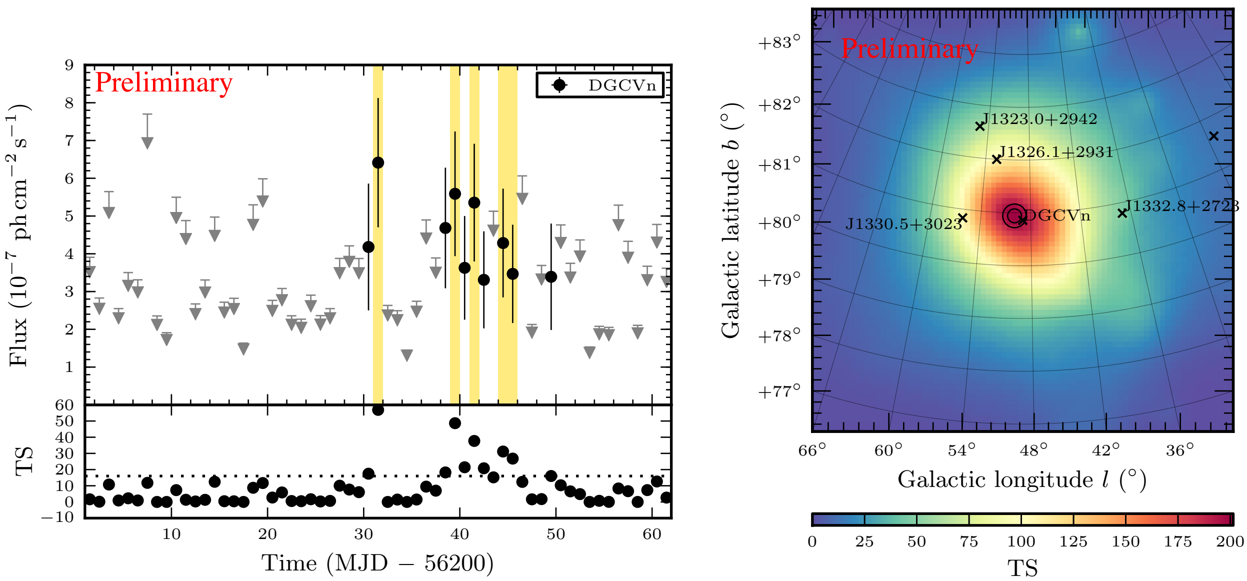

Fig. 2. Left: One-day bin light-curve built over the 61-day interval encompassing the most significant gamma-ray excess in Fig. 1. Black data points correspond to TS > 16 measurements. Yellow shaded periods represent the daily measurements for which the TS value is above 25. **Right:** $8^\circ \times 8^\circ$ residual TS map computed over the stacked TS > 25 period. 68 and 95 per cent containment regions of the *Fermi* source localisation are overplotted.

The 1-day bin light-curve over 61 days encompassing the MJD 56240 flare (Fig. 2, left) unveils a gamma-ray flare evolving over several days. The addition of a point-source at the position of DG CVn seems significant with a TS value up to 57. It starts on MJD 56230 with a peak flux of $(6.4 \pm 1.7) \times 10^{-7}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ one day later before a six day quenching. We detect a re-ignition around MJD 56238 followed by a slow decrease of the gamma-ray flux over eight days. A hint for another small hump two days after can be distinguished although associated with a lower TS.

We stacked the data corresponding to the days when DG CVn's model addition significantly improve the sensitivity (i.e. 2012 October 31, November 8, 10, 13, 14, all yellow shaded in Fig 2 left). The likelihood analysis yields a TS of about 197 for a mean gamma-ray flux of $(4.9 \pm 0.7) \times 10^{-7}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ and a power-law index of -2.42 ± 0.14. Fig. 2 (right) displays the residual TS map during the excess. The best-fit is at the position (RA = 202.°81, Dec. = 29.°41, 0.°18 from DG CVn) with 68 and 95 per cent containment radii r68 = 0.°13 and r95 = 0.°22. There is thus a 2σ significance agreement between DG CVn and the gamma-ray peak positions.

3 Discussion and conclusion

Regarding the TS map (Fig. 2, right) and the localisation, we can rule out the FAVA association of the November 2012 flare with the blazar 3FGL J1332.8+2723. Moreover, the TS peak displayed on the bottom panel of the Fig. 1 is clearly above the TS distribution. This feature has not been found in the other analyses that we performed at the position of several active stars. Besides, the flare is spread over several consecutive days, which ensures an unlikely statistical noise origin.

Without any known counterpart and considering the localisation uncertainty, it is not clear whether or not the binary star DG CVn is responsible for the observed transient event. Active stars are indeed not known to produce such high-energy and long-lasting outbursts. On the other hand, the April 2014 superflare (Drake et al. 2014) as well as the radio counterpart (Fender et al. 2015) were totally unexpected, indicating that DG CVn may be an extreme system. It is possible that a major outburst happened and remained unnoticed by a lack of simultaneous monitoring at other wavelength. Such unique and interesting behaviour would require further investigations.

If not originating from DG CVn system, the flare could come from an Active Galactic Nucleus (AGN) since AGNs account for the vast majority of high-latitude ($|b| > 10°$) *Fermi*-LAT sources (more than 71 per cent according to Ackermann et al. 2015, 3LAC catalogue). Among them, 98 per cent are blazars (either Flat Spectrum Radio Quasars FSRQs or BL Lacertae objects). Blazar light-curves are known for their variability on a wide range of time scales and display strong flares due to internal shocks or sporadic increases of the accretion flow feeding the jets. We have listed three association candidates. Two quasars are located within the containment region (namely J133059.8+293005 and J133031.5+292854, Véron-Cetty & Véron 2010, respectively $0.^\circ10$ and $0.^\circ17$ away from the best fit position). The flat-spectrum radio source GB6 J1331+2932 (with a 19.6 ± 0.2 mJy flux density, Muñoz et al. 2003), $0.^\circ13$ away from the *Fermi*-LAT localisation, may also be worth investigating since this high-Galactic latitude source is likely to be an AGN (either a blazar or a compact radio galaxy core).

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References

Acero, F., Ackermann, M., Ajello, M., et al. 2015, ApJS, 218, 23
Ackermann, M., Ajello, M., Albert, A., et al. 2013a, ApJ, 771, 57
Ackermann, M., Ajello, M., Albert, A., et al. 2014, Science, 345, 554
Ackermann, M., Ajello, M., Allafort, A., et al. 2013b, ApJ, 765, 54
Ackermann, M., Ajello, M., Atwood, W. B., et al. 2015, ApJ, 810, 14
Atwood, W. B., Abdo, A. A., Ackermann, M., et al. 2009, ApJ, 697, 1071
Beuzit, J.-L., Ségransan, D., Forveille, T., et al. 2004, A&A, 425, 997
Bower, G. C., Bolatto, A., Ford, E. B., & Kalas, P. 2009, ApJ, 701, 1922
Caballero-García, M. D., Šimon, V., Jelínek, M., et al. 2015, MNRAS, 452, 4195
Delfosse, X., Forveille, T., Perrier, C., & Mayor, M. 1998, A&A, 331, 581
Drake, S., Osten, R., Page, K. L., et al. 2014, The Astronomer's Telegram, 6121, 1
Fender, R. P., Anderson, G. E., Osten, R., et al. 2015, MNRAS, 446, L66
Fermi LAT Collaboration, Abdo, A. A., Ackermann, M., et al. 2009, Science, 326, 1512
Helene, O. 1991, Nuclear Instruments and Methods in Physics Research A, 300, 132
Mason, B. D., Wycoff, G. L., Hartkopf, W. I., Douglass, G. G., & Worley, C. E. 2001, AJ, 122, 3466
Mattox, J. R., Bertsch, D. L., Chiang, J., et al. 1996, ApJ, 461, 396
Mohanty, S. & Basri, G. 2003, ApJ, 583, 451
Muñoz, J. A., Falco, E. E., Kochanek, C. S., Lehár, J., & Mediavilla, E. 2003, ApJ, 594, 684
Neupert, W. M. 1968, ApJ, 153, L59
Riedel, A. R., Finch, C. T., Henry, T. J., et al. 2014, AJ, 147, 85
Véron-Cetty, M.-P. & Véron, P. 2010, A&A, 518, A10