Gamma-ray transients as seen by the Fermi LAT

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Abstract

We have performed the search for gamma-ray transients using the Fermi-LAT data for the five years of observations (2008-2013). The search is performed blindly without a priori information on the sources for the time scales of 1-100 seconds and energies greater than 1 GeV. We propose a technique which is complementary to the established burst and flare advocates. A number of transient events is found, some belonging to the known sources and some indicate high confidence level candidates of the new sources.

1 Introduction

Fermi LAT is the primary instrument on board of the Fermi satellite that was launched on the August 2008 [1]. It possesses the unprecedented sensitivity in the 100 MeV–500 GeV energy range and has already greatly contributed to a wide array of various astrophysical researches [2, 3, 4] .

Transient searches are also in the focus of the Fermi LAT science – there are two real-time activities, so-called burst and flare advocates, aimed at detection of gamma-ray bursts with the time scales ∼seconds and longer and more general flares with time scales hours and days [5, 6, 7]

In this work we have performed blind search for 1-100 s long transients in 3 selected intervals 1,10,100 s at energies higher than 1 GeV in more than 5 years of the Fermi LAT data.

2 Data and method

In this work we used the LAT Pass 7 Reprocessed weekly all-sky data publicly available at Fermi mission website[1]. The analysis spans the time period of 275 weeks from August 04, 2008 to November 09, 2013, corresponding to mission elapsed time (MET) from 239557417 s to 405721950 s. We used the 'Pass 7 Reprocessed Source' event class photons with $E > 1$ GeV and impose an Earth relative zenith angle cut of 100° and rocking angle cut of 52°.

This energy threshold selection comes as a compromise between ample statistics that is still available at these energies and decent angular resolution of the instrument ($1-2^\circ$). At lower energies, like 100 MeV almost any possible signal would be swamped by a huge background coming from the large region of ~ 100 sq.deg., and at higher energies, > 10 GeV a number of gamma-photons is drastically reduced thus precluding us from any meaningful transient searches.

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[1] http://fermi.gsfc.nasa.gov/ssc/data/access/

Our aim was to find some new transients in a blind search in the long span of data. That could be advantageous, comparing to the real-time analysis because of the better estimation of the background thay would result in more accurate estimation of the statistical significance of any detected transient. Our search was performed in several steps:

- First, we employ a space-time clustering algorithm We have defined certain metric and corresponding distance between any two events i, k:

$$D = \sqrt{\alpha_{ik}^2/(\theta_i^2 + \theta_k^2) + (t_i - t_k)^2/\tau_0^2}, \tag{1}$$

  where θ_i, θ_k are the point spread function (PSF) widths for the i, k events, α_{ik} is the angular distance between these two events, t_i, t_k are the times of the photon arrival and τ_0 is the characteristic time scale (1,10,100 seconds). Note, that the point spread function width is considered to be a function of energy only. We use PSFs corresponding to the case of normal incidence, not accounting for unknown increase of the PSF at other angles of incidence. If the resulting distance is smaller than some initially chosen threshold, say $D_0 = 2$, the events are added to the j-th cluster at this timescale τ_0.

- The second step – discard obviously coincidental clusters. It was done as following: all photons in the triplet or quadruplet (we have not found any larger multiplets leaving aside bright GRBs like GRB130427A) should have at least one common point inside their respective PSFs:

$$\alpha_{ik} < \theta_i + \theta_k,$$

  for all i, k belonging to the same cluster. This procedure allowed to get rid of 'chain-like' clusters that could be produced at the first step.

- (the most cumbersome task) Whether it could still have been a fluctuation? Some additional checks are badly needed.

There are several possible ways to estimate probability of a false detection-some very bright source could occasionally produce several photons in a row. Of course it would not be a genuine transient but rather a quirk of a Poissonian statistics. We have performed a full Monte Carlo simulation of gamma-ray sky using *gtobssim* utility from the standard Science Tools package (ScienceTools-v9r32p5) provided by the Fermi LAT collaboration. Refinement of the simulation parameters allowed us to reach a high level of precision ($\sim 5\%$), number of photons was controled in a large amount (> 10) of patches located in different parts of the sky. Thus, comparison of the simulation with the real data could provide us with some crude estimation of the transient significance. The results was largely negative, e.g. despite large number of triplets and quadruplets from such bright sources as Vela or Geminga observed in the real data, we have found the corresponding amount in the simulated data as well.

Another possible way of estimating the significance is to employ relevant additional previously unused information, namely events at lower energies – we could uncover results in 100-1000 MeV energy range, previosly unused. One could expect that the flare at energies larger than 1 GeV would be accompanied with some excess at lower energies –if it is there then we have a genuine transient. The significance of number of observed photons could be quantified following analysis method for GRB searches developed in [8]:

(a) find all photons that fall in PSF 95% around suspicious direction in selected time interval (-1000–1000s) around the transient candidate and during whole mission;

(b) Calculate 2 corresponding exposures using the *gtexpcube2* utility;

(c) Obtain the background estimate and the corresponding significance.

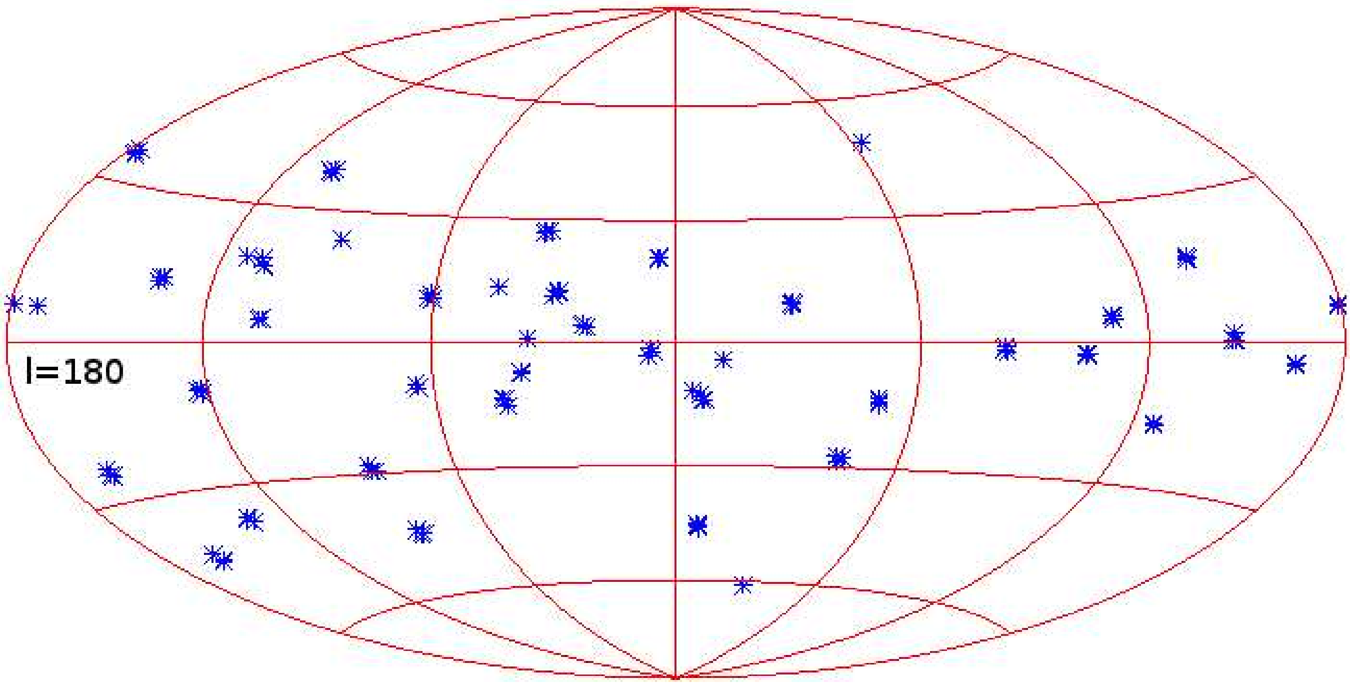

Figure 1: Locations of the centers of the clusters with the 100 s characteristic time scale in Galactic coordinates.

3 Results

We have found more than 200 genuine transients, mostly GRBs, AGN flares and even solar flares. For unidentified candidate we perform an additional test using lower energy photons. To estimate the significance of the burst at lower energies we define Σ as follows:

$$\Sigma = \frac{N_{\rm obs}(100-1000) - N_{\rm bg}(100-1000)}{\sqrt{N_{\rm bg}(100-1000)}},$$

and number of expected photons $N_{\rm bg}(100-1000)$ was estimated as described above. There are 10 'suspects' that crossed $2-\sigma$ threshold ($\Sigma > 2$). This significance estimation is replaced with Poissonian probability for the cases when the number of the events is small.

There are several final caveats – our method discriminates against very hard bursts, if the burst has quite standard spectrum $dN/dE \propto E^{-2}$ we would have around 10 additional photons in the low-energy range, however, in case of really hard burst, $dN/dE \propto E^{-1.5}$ there would be only 3-4 of them producing rather meagre significance in 'σs'. And of course our analysis is handicapped in the regions of low galactic latitude b – the background is so strong there that it could easily dilute all the transients besides the brightest ones.

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References

[1] W. B. Atwood *et al.* [LAT Collaboration], Astrophys. J. **697**, 1071 (2009) [arXiv:0902.1089 [astro-ph.IM]].

[2] A. A. Abdo *et al.* [Fermi LAT Collaboration], Astrophys. J. Suppl. **187**, 460 (2010) [Erratum-ibid. **193**, 22 (2011)] [arXiv:0910.1608 [astro-ph.HE]].

[3] M. Ackermann, M. Ajello, K. Asano, M. Axelsson, L. Baldini, J. Ballet, G. Barbiellini and D. Bastieri *et al.*, Astrophys. J. Suppl. **209**, 11 (2013).

[4] [Fermi-LAT Collaboration], Astrophys. J. **743**, 171 (2011) [arXiv:1108.1420 [astro-ph.HE]].

[5] J. Chiang, AIP Conf. Proc. **906**, 11 (2007).

[6] S. Ciprini [Fermi-LAT Collaboration], AIP Conf. Proc. **1505**, 697 (2012).

[7] M. Ackermann *et al.* [Fermi-LAT Collaboration], Astrophys. J. **771**, 57 (2013) [arXiv:1304.6082 [astro-ph.HE]].

[8] G. I. Rubtsov, M. S. Pshirkov and P. G. Tinyakov, Mon. Not. Roy. Astron. Soc. Lett. **421**, L14 (2012) [arXiv:1104.5476 [astro-ph.HE]].