A search for gravitational lensing effects in Fermi GRB data

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Abstract

As GRBs trace the high-z Universe, there is a non-negligible probability of a lensing effect being imprinted on the lightcurves of the bursts. We propose to search for lensed candidates with a cross-correlation method, by looking at bursts days to years apart coming from the same part of the sky. We look for similarities and hypothesize a Singular Isothermal Sphere (SIS) model for the lens. A lensed pair would enable us to constrain the mass of the lensing object. Our search did not reveal any gravitationally lensed events.

Lensing basics

The detected gravitationally lensed quasar images have a separation which is smaller than the resolution of current gamma-ray detectors. The time resolution of gamma-ray instruments however is superior in many aspects to the optical instruments. The time-delays we are looking for come in two flavours that define two types of searches. We can compare the shape and spectra of two bursts coming from the same part of the sky or we can look for similarly shaped pulses in a single GRB's stream of photons. In this work we focus on the first scenario. We just mention the second case for its simplicity. The equation from Krauss & Small (1991) defines the characteristic mass scale of the point lens up to a factor $(1+z)$.

$$M(1+z_{\mathrm{LENS}}) = \frac{\Delta\tau c^3}{2G}\left(\frac{1-f}{\sqrt{f}} + \ln f\right)^{-1}$$

$\Delta\tau$ is the time delay between the pulses, $f(<1)$ is the ratio of the peak counts. This model is deemed accurate for time delays of $\sim 10^{-5}$ to ~ 100 s with lens masses ranging from $\sim M_\odot$ to $\sim 10^7 M_\odot$. For time delays of days to months we use the a single isothermal sphere model. In this case it is impossible to ascertain the lens mass, only a combination if the angular diameter distances (lens-source (D_{ds}), observer-lens (D_d) and observer-source (D_s)) and the velocity dispersion (σ_v):

$$\frac{\Delta\tau(1-f)}{2(1+f)} = \frac{(1+z_{\mathrm{LENS}})}{c}\frac{D_d D_{ds}}{D_s}\left(\frac{4\pi\sigma_v^2}{c^2}\right)^2$$

How to find a lensed burst?

We used the bursts in the Fermi/GBM burst table. We imposed an upper limit on the error radius of $6°$. We selected pairs of bursts closer than two-times their positional errors (2σ). The next step was creating pairs of lightcurves and their cross-correlation curve on the same timescale for comparison. Each of the resulting **179** figures was inspected for similarities with the aid of the cross-correlation curve at two timescales (**0.064** and **0.512** s). If the burst was deemed interesting, we proceeded to compare the spectral parameters by fitting for the spectrum. Simultaneously we check if the early burst is brighter than the later. This is a necessary condition for the time delays (Mao, 1992).

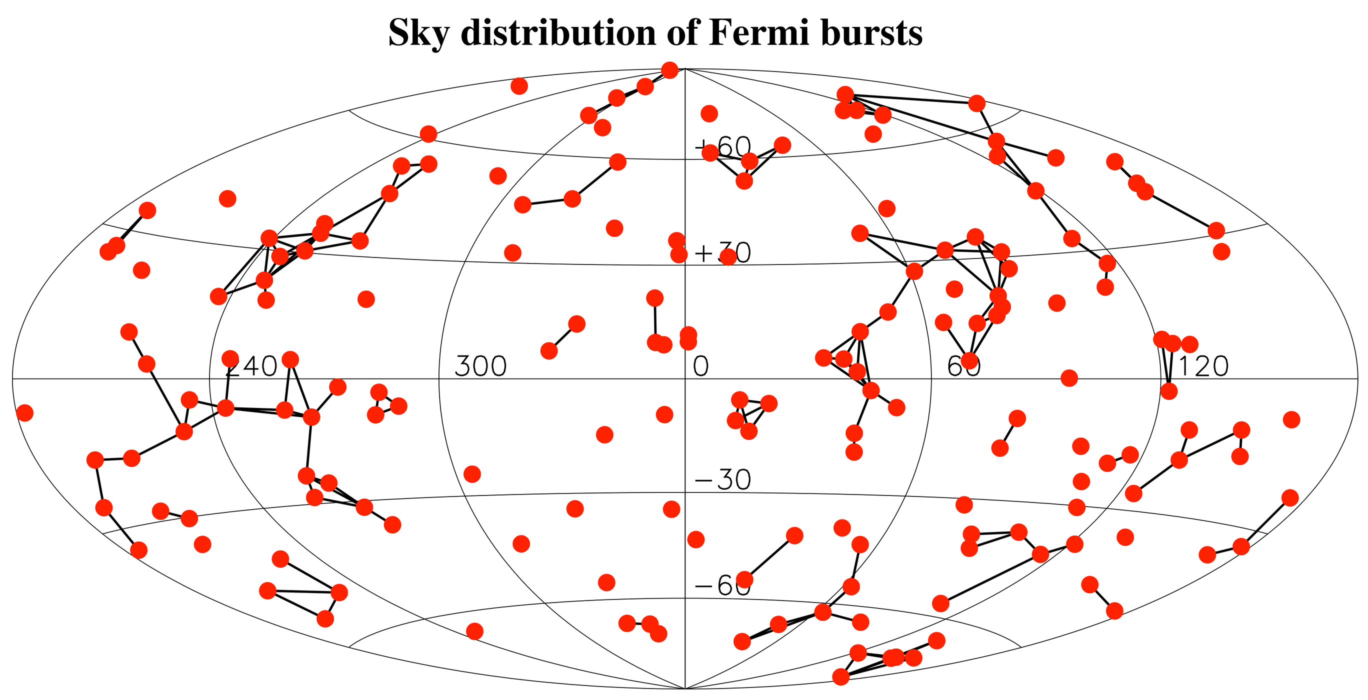

Figure 1: Figure showing all the GRBs closer than 2 times their position errors.

The typical echo timescale is from days to months but no longer than $\sim$ **14** months (the elapsed time from the first Fermi trigger).

Candidate events

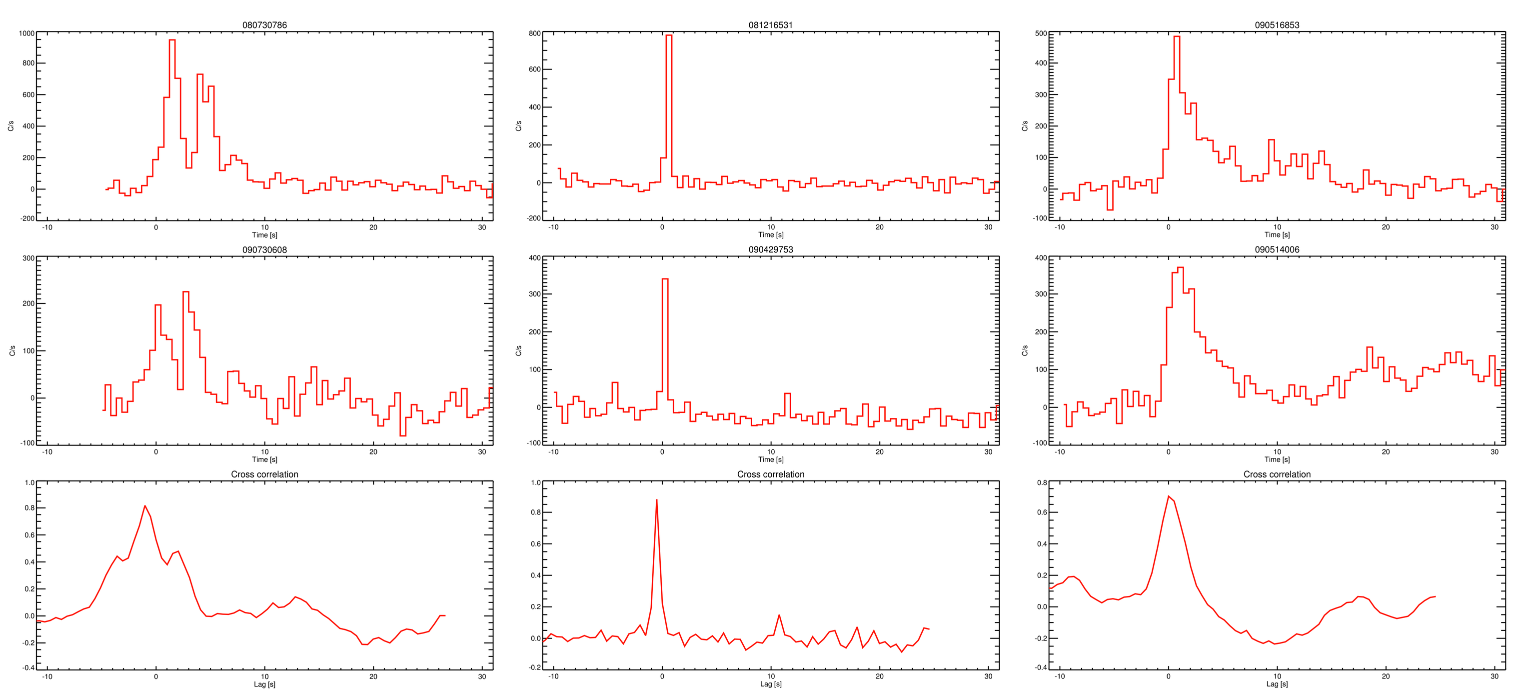

Figure 2: Candidate pairs shown here with their most luminous detector and the cross-correlation. The resolution is **0.512** s.

Triggers		Distance	$\Delta\tau$[days]	f
080730.786	090730.608	$5.5°(0.9\sigma)$	364.8	0.29
081216.531	090429.753	$4.8°(0.5\sigma)$	134.2	0.44
090516.853	090514.006	$4.3°(0.5\sigma)$	2.9	$\lesssim 1$

Discussion - analysis

As in Nemiroff et al. (1994), a list of close calls was established. Examples can be seen in the table below. None of these pairs passed the spectral inspection convincingly. We have relaxed our 2σ criterion to 3σ and checked the resulting **270** pairs, but found no candidates.

080730.786 and 090730.608: Both of these bursts have three peaks, with roughly the same time between them. It is curious that the elapsed time between them is roughly one year. We fitted a Band spectrum for the first two peaks. We compare the low-energy spectral indices(α) as both bursts have most of their emission in this range and not all of the other spectral parameters could be constrained. While for 080730 α decreases slightly from -0.53 ± 0.1 to -0.56 ± 0.1, for 090730 α decreases (from -0.74 ± 0.2 to -0.63 ± 0.3). Even though the indices have some overlap, we feel it is hard to put forward convincing arguments for a lensing scenario in this pair.

081216.531 and 090429.753: These short bursts were also put forward as worthy for a spectral inspection. It turned out that 090429 has a significantly higher peak energy ($E_p = 1235 \pm 264$ keV *vs.* $E_p = 152.8 \pm 92.4$ keV), though the spectral indices agree fairly well ($\alpha_1 = -0.66 \pm 0.53$, $\alpha_2 = -0.70 \pm 0.09$ and $\beta_1 = -1.88 \pm 0.32$, $\beta_2 = -2.17 \pm 0.21$) (McBreen & von Kienlin, 2008; Bhat, 2009)

090516.853 and 090514.006: There is no detector response matrix (DRM) available for 090516.853 and no GCN was published for this trigger. This prevented us from spectral fitting and from determining the burst-detector angle, hence the uncertainty on f. In spite of a visible extended emission region unique to the lightcurve of 090514.006, we considered this a good candidate based on the similarities of the profile of the main event. We are waiting for the release of the DRMs complete the analysis.

Conclusion

We carried out a search for lensing signatures in an up-to-date burst sample. We selected bursts closer than 2σ and found three presentable candidates for a lensing events that occurred at long timescales (days to months). Inspection of the spectra casted doubts on the viability of the lensing scenario in two cases and we need more data to decide in a third case.

Acknowledgements

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