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Observations of GRBs with the Fermi Large Area Telescope

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Summary. — Fermi Gamma-ray Space Telescope successfully detected high-energy emission from 20 GRBs so far. Thanks to its unprecedented very wide energy coverage of Large Area Telescope (LAT: from 25 MeV to > 300 GeV) and Gamma-ray Burst Monitor (GBM: from 8 keV to 40 MeV), Fermi provided new observational pictures of GRBs. Here we review some of the GRB properties seen by the LAT instrument such as the delayed onset and longer durations of high-energy emission compared with low-energy emission of the GBM. An extra spectral component in high and low energy is detected in some GRBs and moreover for the first time a cut-off in the spectral extra component is seen. These temporal and spectral distinct behaviors inspire many implications on the emission mechanism, including leptonic, hadronic and afterglow origin. Fermi also placed constraints both on the bulk Lorentz factor of the relativistic jet, larger than 1000 for bright LAT GRBs, and on outside-GRB topics such as quantum gravity.

PACS 98.70.Rz – γ-ray sources; γ-ray bursts.

1. – Introduction

The Gamma-Ray Bursts (GRBs) were first discovered by the Vela satellites in 1969. Since then many discoveries were made, but still there is no clear evidence on the GRB progenitors and the emission mechanisms that can produce high-energy photons up to tens of GeV.

The high-energy detector EGRET on board of the CGRO satellite detected 5 GRBs with energy > 50 MeV seen also by the other detector on board: BATSE. Two important discoveries were made: a very late emission of high-energy photons (up to 90 min) in the GRB 940217 [1] and a spectral extra component at energies > 100 MeV lasted for more than 200 s in the GRB 941017 [2]. Both these properties are inconsistent with a pure electron synchrotron model. More recently, also the Astro-rivelatore Gamma ad Immagini LEggero (AGILE) detected four GRBs with energy > 30 MeV: 080514B [3] with a high-energy delayed component, 090401B (GCN 9069), 090510 [4] which shows an extended high-energy emission and the brightest 100224B (GCN 1096).

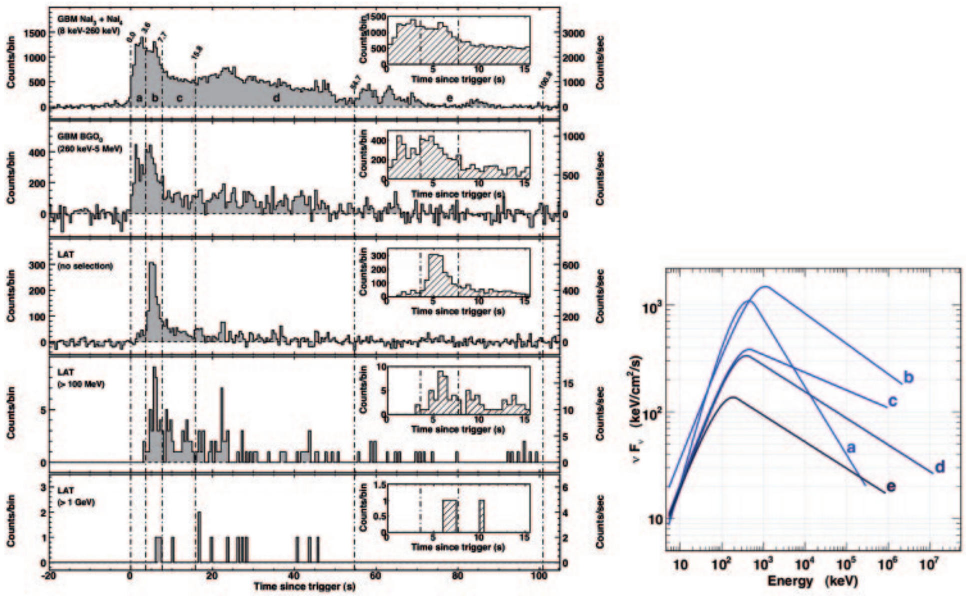

Fig. 1. – Left: multi-detector light curve of GRB 080916C. The insets are a zoom of the first 15 seconds after the GBM trigger. Right: time-resolved spectral fits in the 5 time bins. Both the delayed onset (time bin a) and the long-lived emission (time bin d) are present in other bursts detected by Fermi-LAT.

Eight years after the end of the CGRO mission, Fermi was launched on June 11th 2008. The Fermi/LAT instrument has an effective area 10 times larger than the EGRET one and together with a larger field of view and a smaller dead time it collects more statistics to perform a detailed temporal-spectral analysis [5]. The possibility to repoint itself autonomously when a bright GRB happens and the synergy with the GBM instrument dedicated to the GRBs monitoring, make the LAT a perfect instrument to investigate the problems opened by EGRET on the GRB high-energy emission.

In the first two years of science operations more than 500 bursts were detected with the Gamma-ray Burst Monitor also on board of the Fermi satellite. Among those, 18 were detected also by the LAT instrument (as of August 2010), both long and short with at least 10 photons $> 100\,\mathrm{MeV}$, but only few GRBs have also photons at energies $> 1\,\mathrm{GeV}$.

2. – Properties from the Fermi-LAT data

Thanks to the Fermi-LAT large field of view and its timing capabilities a new feature of GRB was discovered: a delayed onset of the $> 100\,\mathrm{MeV}$ component. In almost all the bursts the delay onset is clearly detected as shown in fig. 1. In the first 3 seconds of GRB 080916C the light curve from the GBM detectors shows a first peak, instead there are no photons in the LAT light curve, when the $> 100\,\mathrm{MeV}$ "transient" [5] events are selected. In this first time interval also the spectrum shows a different behavior with respect the others time bins as shown in fig. 1 (right panel) there is a soft-to-hard evolution from bin a to bin b, but a hard-to-soft evolution later on [6].

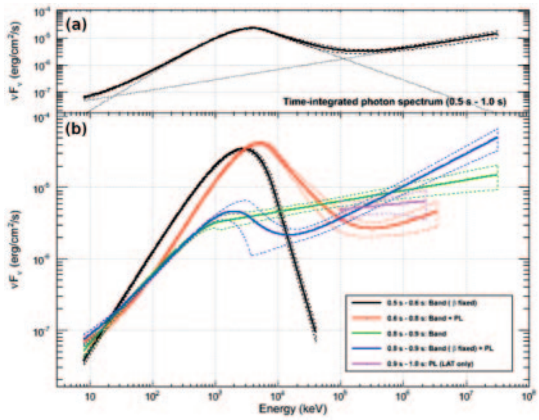

Fig. 2. – The time-integrated and time-resolved spectra for GRB 090510 [8]. Panel (a): best-fit spectral model (Band+PL) for the time-integrated spectrum. Panel (b): spectral evolution. The spectral extra component is clearly present in the time-integrated spectrum and all but one (the first time bin) the time-resolved spectra.

The first GBM peak is missing in the LAT > 100 MeV events also in the short GRB 081024B (GCN 8407). The emission in the GBM lasts for less than 1 second and the LAT data still shows a signal 3 seconds after the trigger. As for the burst 080916C the spectrum of this first peak has a softer high-energy spectral index with respect to later spectra and the spectra of the later emission are hardening [7].

A feature the EGRET GRBs already showed is the presence of an extra component in the spectrum, so far among the LAT sample only thee bursts clearly show it, for two it is statistically disfavored, while for the other bursts the extra-component hypothesis is not statistically significant.

The GRBs 090510 (GCN 9334) and 090902 (GCN 9867) are, respectively, a short and a long burst but they have very similar characteristics. With more than 150 photons above 100 MeV and more than 20 above 1 GeV, they are two of the three brightest GRBs seen so far by the Fermi/LAT. For both the highest-energy photon is ~ 30 GeV but emitted at different times: in the short one, this photon comes in the first second when the GBM emission is still present, while for the long burst, this photon is received 82 seconds after the trigger when the GBM emission is no more present. As well as other bursts also these two have an extended emission lasting longer than the GBM emission, but the feature that is clearly detected in these bursts is the spectral extra components shown in fig. 2. This component is present not only in the highest energies (> 100 MeV), but also in the lowest GBM energy band (8–20 keV) [8, 9].

A cut-off of the extra component was not measured so far, but the GRB 090926A shows a clear cut-off at 1.4 GeV with 5σ significance. This long GRB is one of the three brightest bursts detected by the LAT with more than 150 photons with energy > 100 MeV and more than 50 photons with energy grater than 1 GeV. If the cut-off is due to the changing of the optical depth and pair production, this lets the first direct measurement of Γ of ~ 630 [10].

The extended emission is another GRB property identified by EGRET and confirmed from most of the Fermi/LAT GRBs. It is still present after several tens of seconds from the trigger when the low-energy component is returned to the background level. This property is not ubiquitous for all the bursts: for example 081215 (GCN 8684) and 090217 (GCN 8903) do not show this feature. For the first one, 081215, not many studies were possible, because it was detected at large incident angle and no spatial or spectroscopic information are therefore available. The "featureless" burst 090217 instead has a temporal coincidence between the low energy detected by GBM and the high energy in the LAT data, as well as it shows no spectral extra component and no photons above 1 GeV [11]. The GRBs 090323 (GCN 9021) and 090328 (GCN 9077), on the contrary, show a very long-lasting high-energy tail still present 3 hours after the trigger. The studies on these bursts will be presented into an upcoming paper.

3. – Conclusion

After a few months from its launch, the LAT telescope has detected around 10 gamma-ray bursts per year above 100 MeV. The high-energy emission is, indeed, not common for GRBs: the long ones have a fluence from few percent to few tens percent in the band 100 MeV–10 GeV with respect to the band from 20 keV to 2 MeV. There are common trends in the bursts observed so far, some already seen by EGRET and some discovered by Fermi/LAT. We believe that the understanding of these properties is needed for the overall understanding of gamma-ray burst phenomena. As proposed in [6], the delayed onset can occur if the pulses originate in two distinct physical regions, with different physical conditions. In the framework of internal shocks, this naturally happens as the two emission episodes are related to different sets of shells. This could be explained as an additional hard component that arises later and lasts longer than the GBM emission. This component emerges distinctly in the late part of the LAT signal, where the GBM flux has decreased below detectability. The existence of an extra component was firmly detected by Fermi in both long and short bursts, suggesting analogies between these two classes of objects. Different interpretations span from synchrotron emission from internal shocks [12], to Self-Synchrotron Compton in internal shocks [12], or to high-energy emission from an external shock [12-14]. Hadronic models are also proposed [15], as well as thermal emission from the jet photosphere combined with non-thermal emission [16]. Temporally extended emission also appears to be common in LAT gamma-ray bursts, suggesting that the high-energy emission mechanism lasts longer than previously believed. Future detections will enlarge our high-energy GRB sample, this will allow us to study deeply the properties illustrated and maybe to discover new ones. These studies on the detected GRBs might or not confirm the proposed acceleration and emission mechanisms, providing new elements to distinguish among those.

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