The $E_{\text{p},\text{i}} - E_{\text{iso}}$ Correlation and Fermi Gamma–Ray Bursts

L. Amati

Italian National Institute for Astrophysics (INAF) – IASF Bologna, via P. Gobetti 101, 40129 Bologna, Italy

Abstract

The $E_{\text{p},\text{i}} - E_{\text{iso}}$ correlation is one of the most intriguing properties of GRBs, with significant implications for the understanding of the physics and geometry of the prompt emission, the identification and investigation of different classes of GRBs, the use of GRBs as cosmological probes. The Fermi satellite, by exploiting the high accuracy of the GBM instrument in the measurement of $E_{\text{p},\text{i}}$, the simultaneous detection of GRBs with Swift, and the detection and localization of GRBs in the GeV energy range by the LAT instrument, is allowing us to enrich the sample of GRBs with known redshift and reliable estimate of $E_{\text{p},\text{i}}$ and, thus, to further test the robustness, reliability and extension of this correlation. Based on published results and preliminary spectral data available as of the end of 2009, it is found that the locations in the $E_{\text{p},\text{i}} - E_{\text{iso}}$ plane of Fermi long and short GRBs with measured redshift, including extremely energetic events, are consistent with the results provided by previous / other experiments.

1 Introduction

Since 1997, the measurements of the redshift of a significant fraction of events (more than 200 nowadays) is giving us the possibility of performing systematic investigations of the intrinsic properties of Gamma–Ray Bursts (GRBs). Among these, the correlation between the photon energy, $E_{\text{p},\text{i}}$, at which the $\nu F_{\nu}$ spectrum (in the cosmological rest–frame of the source) of
the prompt emission peaks, and the isotropic–equivalent radiated energy, $E_{\text{iso}}$, is one of the more intriguing and debated \[1, 2\]. Indeed, several observational and theoretical studies have shown the relevance of the existence and properties (namely, the slope and the dispersion) of the $E_{\text{p,i}} - E_{\text{iso}}$ correlation for the models of the GRB prompt emission, whose physics and geometry are still to be settled \[3, 2, 4\]. Furthermore, it was found that short GRBs do not follow the correlation, as is true for the peculiarly sub–energetic and close GRB 980425, the proto–type of the GRB/SN connection (see Figure 1). These evidences suggest that the $E_{\text{p,i}} - E_{\text{iso}}$ plane can be used to distinguish between different classes of GRBs and to understand the differences in the physics / geometry of their emission \[5, 6, 7\]. The $E_{\text{p,i}} - E_{\text{iso}}$ correlation, together with other ”spectral–energy” correlation derived from it by adding more observables or substituting $E_{\text{iso}}$ with the average peak luminosity, were also investigated as a promising tool for the estimate of cosmological parameters \[8, 9, 10\].

Thus, the enrichment of the sample of events with known redshift and $E_{\text{p,i}}$, together with the investigation of the impact of selection and instrumental effects on the correlation, is of key importance for this field of research. Under this respect, the Fermi satellite, thanks to the unprecedentedly broad energy band ($\sim$8 keV – $\sim$50 MeV) of its GRB Monitor (GBM) is expected to provide a significant contribution. This is particularly true in the present ”golden era”, in which the Swift satellite, thanks to its fast and accurate location of the early afterglow emission, is allowing prompt follow–up of GRBs with optical telescopes and, consequently, a significant increase of the number of redshift estimates. In addition, the Fermi/LAT can detect and localize those bright GRBs with emission extending up to the GeV energy range, thus allowing the investigation of the spectral–energetic properties of peculiarly energetic events and to further test the robustness and extension to the $E_{\text{p,i}} - E_{\text{iso}}$ correlation.

2 The $E_{\text{p,i}} - E_{\text{iso}}$ correlation: observational status

Figure 1 shows the location in the $E_{\text{p,i}} - E_{\text{iso}}$ plane of those GRBs with measured redshift and spectral peak energy, as of the end of 2009. The sample of long GRBs includes 108 events. For the 95 events up to April 2009, the data are taken from \[10\] and \[11\]. For the remaining 13 GRBs (090516, 090618, 090715B, 090812, 090902B, 090926, 090926B, 091003, 09103, 091020, 091029, 091127, 091208B) the values of $E_{\text{p,i}}$ and $E_{\text{iso}}$ were calculated based on the redshift, fluences and spectral parameters reported
in the GCNs (gcn.gsfc.nasa.gov) and following the method described, e.g., in [2]. The values for short GRBs are from [5, 11, 7].

As can be seen, the $E_{p,i}$ and $E_{iso}$ values of all long GRBs, with the already mentioned exception of the peculiar GRB 980425, are strongly correlated (Spearman’s $\rho = 0.86$ for 108 events). The $E_{p,i} - E_{iso}$ correlation, as reported also in previous works [10, 11], can be modeled with a power–law with index $\sim 0.5$ and an extrinsic dispersion (i.e., the scatter of the data in excess to that expected based on Poissonian fluctuations only) $\sigma(\log E_{p,i}) \sim 0.2$. As discussed above, even if the sample is still small, there is clear evidence that short GRBs do not follow the correlation holding for long ones. This fact gives further clues on the different emission mechanisms at work in the two classes of events and makes the $E_{p,i} - E_{iso}$ plane a useful tool to distinguish between them [12]. A natural explanation for the short/long dicotomy and the different locations of these classes of events in the $E_{p,i} - E_{iso}$ plane is provided by the ”fireshell” model of GRBs [13].

The impact of selection and instrumental effects on the $E_{p,i} - E_{iso}$ correlation of long GRBs was investigated since 2005, mainly based on the large sample of BATSE GRBs without known redshift. Different authors came to different conclusions [14, 15, 16]. In particular, [16] showed that BATSE
events potentially follow an $E_{p,i} - E_{iso}$ correlation and that the proper question is not if the correlation is real but if, and how much, its measured dispersion is biased. There were also claims that a significant fraction of Swift GRBs is inconsistent with the correlation [17]. However, as can be seen in Figure 1, when considering those Swift events with peak energy measured by broad–band instruments like, e.g., Konus–WIND or the Fermi/GBM (see next Section) or reported by the BAT team in their catalog [18] or GCNs, it is found that they are all consistent with the $E_{p,i} - E_{iso}$ correlation as determined with previous/other instruments [11, 19]. In addition, [11] also found that the slope and normalization of the correlation based on the single data sets provided by GRB detectors with different sensitivities and energy bands are very similar. These evidences further support the reliability of the correlation.

3 Fermi GRBs in the $E_{p,i} - E_{iso}$ plane

As discussed above, in the last five years, thanks to the unprecedented capabilities of the the Swift satellite, the fraction of GRBs with redshift estimate increased significantly. However, due to the limited energy band (15–150 keV) of the BAT GRB monitor, Swift can estimate $E_p$ only for 15–20% of the events. Indeed, for most of the Swift GRBs that can be placed in the $E_{p,i} - E_{iso}$ plane (Figure 1), the peak energy could be measured thanks to the simultaneous detection by other detectors with better spectral capabilities (e.g., Konus–WIND). In this context, with its wide field of view and unprecedentedly broad energy band, the Fermi/GBM is expected to provide an important contribution by significantly increasing the number and accuracy of the estimates of $E_{p,i}$ for GRBs with measured redshift.

In Figure 2, I show the location in the $E_{p,i} - E_{iso}$ plane of those GRBs for which the spectral parameters were provided by the GBM, with the only exception of GRB 090323 (also detected by the LAT), for which the spectrum of the whole event was reported only by the Konus–WIND team [20]. The red dashed line is the best fit power–law of this sample, whereas the continuous line show the best–fit power–law and ±2σ dispersion region of the $E_{p,i} - E_{iso}$ correlation as determined by [10] based on a sample of 75 GRBs not including Fermi events. As can be seen, Fermi GRBs follow the $E_{p,i} - E_{iso}$ correlation, with a slope and dispersion well consistent with those determined based on measurements by other satellites.

Figure 2 also shows that, as already pointed out and discussed by [11], the extremely energetic events with GeV emission detected and localized by
the LAT, GRB 080916C and GRB 090323, are consistent with the correlation and extend it to higher energies. Pushed by the extension of the spectrum of GRB 080916C up to several GeVs without any significant deviation from the Band function describing the soft gamma–rays emission, these authors also investigated the impact of the extension from 10 MeV up to 10 GeV of the energy band on which $E_{\text{iso}}$ is computed, finding no significant changes in the slope and dispersion of the $E_{\text{p,i}} - E_{\text{iso}}$ correlation.

Finally, Fermi provided the most accurate estimate of $E_{\text{p,i}}$ for a short burst with measured redshift, GRB 090510. The apparent deviation of this event from the $E_{\text{p,i}} - E_{\text{iso}}$ correlation is a further confirmation of results obtained by previous satellites.

It has to be cautioned that the spectral parameters and fluences published in the GCNs by the GBM team are still preliminary. However, the results coming from a more refined analysis are not expected to be so different to drastically change the above conclusions.
References

[1] AMATI L. ET AL., Astron.Astrophys, 390 (2002) 81.
[2] AMATI L., Mont.Not.R.Astron.Soc., 372 (2006) 233.
[3] ZHANG B. AND MÉSZÁROS P, Astrophys.J., 581 (2002) 1236.
[4] AMATI L., AIPC Proc., 966 (2008) 3.
[5] AMATI L., N.Cim.B., 121 (2006) 1081.
[6] AMATI L. ET AL., Astron.Astrophys, 463 (2007) 913.
[7] PIRANOMONTE S. ET AL., Astron.Astrophys, 491 (2008) 183.
[8] GHIRLANDA G., GHISELLINI G. AND FIRMANI C., New J. Phys., 8 (2006) 123.
[9] SCHAEFER B.E., Astrophys.J., 660 (2007) 16.
[10] AMATI L. ET AL, Mont.Not.R.Astron.Soc., 391 (2008) 277.
[11] AMATI L., FRONTERA F. AND GUIDORZI C., Astron.Astrophys, 508 (2009) 173.
[12] ANTONELLI A.L. ET AL., Astron.Astrophys, 507 (2009) L45.
[13] RUFFINI R., AIPC Proc., 1111 (2009) 325.
[14] NAKAR E. AND PIRAN T., Astrophys.J., 360 (2005) L73.
[15] BAND D. AND PREECE R.D., Astrophys.J., 627 (2005) 319.
[16] GHIRLANDA G., GHISELLINI G. AND FIRMANI C., Mont.Not.R.Astron.Soc., 361 (2005) L10.
[17] BUTLER N.R. ET AL., Astrophys.J., 671 (2007) 656.
[18] SAKAMOTO T. ET AL., Astrophys.J.Supp., 175 (2008) 179.
[19] KRIMM H.A. ET AL., Astrophys.J., 704 (2009) 1405.
[20] GOLENETSKII H. ET AL., GCN Circ., 9030 (2009).