View metadata, citation and similar papers at core.ac.uk
brought to you by CORE

Acta Polytechnica **53**(Supplement):687–692, 2013
doi:10.14311/AP.2013.53.0687
© Czech Technical University in Prague, 2013
available online at http://ojs.cvut.cz/ojs/index.php/ap

INVESTIGATING THE $E_{p,i} - E_{iso}$ CORRELATION

Lorenzo Amati[a,*], Simone Dichiara[b]

[a] *Istituto Nazionale di Astrofisica – IASF Bologna, Via P. Gobetti 101, I-40129 Bologna, Italy*
[b] *University of Ferrara, Department of Physics, via Saragat 1, 44100 Ferrara, Italy*
[*] corresponding author: amati@iasfbo.inaf.it

Abstract. The correlation between the spectral peak photon energy, E_p, and the radiated energy or luminosity (i.e., the "Amati relation" and other correlations derived from it) is one of the central and most debated topics in GRB astrophysics, with implications for physics and the geometry of prompt emission, the identification and understanding of various classes of GRBs (short/long, XRFs, sub-energetic), and GRB cosmology. Fermi is exceptionally suited to provide, also in conjunction with Swift observations, a significant step forward in this field of research. Indeed, one of the main goals of Fermi/GBM is to make accurate measurements of E_p, by exploiting its unprecedented broad energy band from ~ 8 keV to ~ 30 MeV; in addition, for a small fraction of GRBs, the LAT can extend the spectral measurements up to the GeV energy range, thus allowing a reliable estimate of the bolometric radiated energy/luminosity. We provide a review, an update and a discussion of the impact of Fermi observations in the investigation, understanding and testing of the $E_{p,i} - E_{iso}$ ("Amati") relation.

Keywords: gamma-rays: observations, gamma-rays: bursts.

1. Introduction

Despite the huge observational advances and theoretical efforts of the last 20 years, the gamma-ray bursts (GRB) phenomenon is still far from being fully understood. Open issues include the fraction and peculiar characteristics (mass, rotational speed, metallicity, core collapse physics) of highly energetic type Ic SNe ("hyper-novae") producing long GRBs, the progenitors of short GRBs (coalescence of NS–NS or BH–NS binary systems, magnetars, etc.); the mechanisms through which the gravitational energy of the central engine is converted into an ultra-relativistically expanding plasma, and the kinetic (or magnetic) energy of this "fireball" (or "firejet") is converted into X- and gamma-rays; the explanation of the early afterglow phenomenology (steep decay, plateau, flares) and of the properties of the GeV emission; the degree of collimation of the emission and the structure of the jet; and other topics. After several years of deep investigations of the multi-wavelength properties of early and late afterglow emission, following the discoveries of *Beppo*SAX and *Swift*, the focus of the community is getting back to the physics of the prompt emission, prompted by the very high-energy measurements by *Fermi* and based on refined re-analysis of the BATSE, *Beppo*SAX, HETE-2 and Konus/WIND data.

In this respect, one of the most intriguing and most investigated pieces of observational evidence is the correlation between the photon energy at which the νF_ν spectra of GRBs peak, $E_{p,i}$, and their radiated energy, E_{iso} (or other GRB intensity indicators, e.g. average luminosity or peak luminosity). Indeed, this correlation can provide useful constraints to the models for prompt emission physics and geometry. It can also be used to identify and understand the different sub-classes of GRBs (short/long, sub-energetic, X-Ray Flashes) and to standardize these sources for cosmological investigations. Thanks to its unprecedented capability to measure the GRB prompt emission from ~ 8 up to ~ 30 MeV for hundreds of GRBs and up to tens of GeV for a few GRBs per year, the *Fermi* satellite is making a major contribution to this field of research.

In this paper, after reviewing the basic properties, implications and uses of *Fermi* we show how its measurements are confirming and extending the $E_{p,i} - E_{iso}$ correlation in GRBs, providing further evidence of its reliability.

2. The $E_{p,i} - E_{iso}$ correlation in GRBs

2.1. Observations

GRB spectra are typically described by the empirical smoothed broken-power-law introduced by [1], with parameters α (low-energy index), β (high-energy index), E_0 (break energy). In terms of νF_ν, they show a peak at the photon energy $E_p = E_0 \times (2 + \alpha)$. This quantity is a relevant parameter in most of the models for GRB prompt emission, see, e.g., [2]. Presently, more than 250 GRBs have measured redshift, and about $40 \div 50\,\%$ of them have well-measured spectra. From the measured spectrum and the measured redshift it is then possible to compute two fundamental quantities in the cosmological rest-frame of these sources: the intrinsic spectral peak energy, $E_{p,i}$, and the radiated energy in the assumption of isotropic emission, E_{iso}. Both $E_{p,i}$ and E_{iso} span several orders

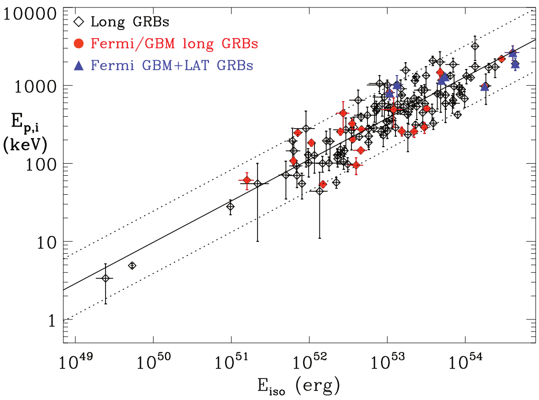

Figure 1. Location of long GRBs in the $E_{\rm p,i}-E_{\rm iso}$ plane as of July 2011. *Fermi* GRBs are marked with red (GBM detection) and blue (GBM + LAT detection) color. The continuous line and the dotted line show the best fit power–law of the $E_{\rm p,i}-E_{\rm iso}$ correlation and its $\pm 2\sigma$ limits, respectively, as determined by Amati et al. [6].

of magnitude and a distribution which can be described by a Gaussian plus a low–energy tail (intrinsic XRFs and sub-energetic events).

In 2002, based on a small sample of BeppoSAX GRBs with known redshift, it was discovered [3] that a very significant correlation exists between $E_{\rm p,i}$ and $E_{\rm iso}$ (Fig. 1). The $E_{\rm p,i}-E_{\rm iso}$ correlation for GRBs with known redshift was then confirmed, and was extended in the subsequent years by measurements of all other GRB detectors with spectral capabilities [4–6]. These include the $E_{\rm p,i}$ values for *Swift* GRBs measured by Konus/WIND, Suzaku/WAM, *Fermi*/GBM and *Swift*/BAT itself (only when $E_{\rm p}$ is inside or close to $15 \div 150$ keV).

Despite its strength, this correlation is characterized by a significant dispersion of the data around the best-fit power-law; the distribution of the residuals can be fitted by a Gaussian with $\sigma(\log E_{\rm p,i}) \sim 0.2$. This extra-Poissonian scatter of the data can be quantified by performing a fit with a maximum likelihood method which accounts for the sample variance and the uncertainties on both X and Y quantities [7]. This method, by expressing $E_{\rm p,i}$ in keV and $E_{\rm iso}$ in units of 10^{52} erg, provides an extrinsic scatter $\sigma_{\rm ext}(\log E_{\rm p,i})$ of 0.19 ± 0.02 and an index of 0.54 ± 0.03 [6, 8]. In recent years, definite evidence has been found that short GRBs do not follow the $E_{\rm p,i}-E_{\rm iso}$ correlation, thus showing that the $E_{\rm p,i}-E_{\rm iso}$ plane can be used as a tool for distinguishing between short and long events and for getting clues on their different nature [5, 9]. Finally, the only long GRB outlier to the correlation is GRB 980425, an event which is peculiar in several respects: it has a very low redshift ($z = 0.0085$), it is sub-energetic, and it is inconsistent with most other GRB properties.

2.2. Implications and uses

The physics of the prompt emission of GRBs is still not settled, and various scenarios have been proposed: synchrotron emission in internal shocks (SSM, Inverse Compton (IC) dominated internal shocks), external shocks, photospheric emission dominated models, kinetic energy/Poynting flux dominated fireballs, and more. The existence and properties of the $E_{\rm p,i}-E_{\rm iso}$ correlation can be used to discriminate among different models and to constrain the physical parameters within each model [2]. In addition, the extension of the correlation over several orders of magnitude from the brightest events to the softest XRFs provides challenging evidence for models in which the observed properties of GRBs depend strongly on the jet structure and the viewing angle [4, 10]. An $E_{\rm p,i}-E_{\rm iso}$ correlation with properties consistent with the observed properties is also predicted by alternative scenarios like the “cannonball” model [11], the “fireshell” model [12] and the “precessing jet” model [13].

As mentioned above, the $E_{\rm p,i}-E_{\rm iso}$ plane is also a useful tool for identifying sub-classes of GRBs, first of all short and long GRBs. Only very recently, redshift estimates for short GRBs became available, thanks to the observational progress. The estimates and limits on $E_{\rm p,i}$ and $E_{\rm iso}$ for short GRBs show that they are inconsistent with the $E_{\rm p,i}-E_{\rm iso}$ correlation holding for long GRBs. In addition, a long weak soft emission following the short spike has been observed in some cases. Intriguingly, this component is consistent with the correlation, showing that the $E_{\rm p,i}-E_{\rm iso}$ plane can be used to identify and understand not only short and long GRBs but also “hybrid” GRBs. Another issue concerns sub-energetic GRBs. Indeed, the only long GRB not following the correlation is GRB 980425, which is not only a prototype event of GRB/SN connection but is also the closest GRB ($z = 0.0085$) and a very sub-energetic event ($E_{\rm iso} \sim 10^{48}$ erg). Moreover, GRB 031203, which is the most similar case to GRB 980425, being very close ($z = 0.105$), associated to a bright type Ic SN (SN2003lw) and sub-energetic, may also be inconsistent with the correlation (however, only an upper limit to $E_{\rm p,i}$ is available for this burst). The most common explanations for the (apparent?) sub-energetic nature of GRB 980425 and GRB 031203 and their violation of the $E_{\rm p,i}-E_{\rm iso}$ correlation is that they are “normal” events seen very off-axis [10]. GRB 060218, very close ($z = 0.033$, second only to GRB 9809425), with a prominent association with SN2006aj, and very low $E_{\rm iso}$ (6×10^{49} erg) is very similar to GRB 980425 and GRB 031203, but, contrary to these two events, it is consistent with the $E_{\rm p,i}-E_{\rm iso}$ correlation. This provides evidence that it is a truly (and not apparent) sub-energetic GRB, pointing to the likely existence of a population of under-luminous GRB detectable only in the local universe.

Finally, the $E_{\rm p,i}-E_{\rm iso}$ correlation can also provide clues to a better understanding of the GRB–SN connection. Except for the peculiar sub-energetic GRBs

980425 and 031203, associated with SN1998bw and SN2003dh, respectively, GRB 060218 and other GRBs with the firmest evidence of association with an SN are consistent with the $E_{p,i} - E_{iso}$ correlation. In particular, the location of these GRBs in the $E_{p,i} - E_{iso}$ plane seems to be independent from the magnitude of the associated SN. Furthermore, GRB 060614, a long GRB with a very deep lower limit to the magnitude of an associated SN, is also consistent with the correlation. These pieces of evidence support the hypothesis that the GRB properties are not, or are only weakly, linked to those of the SN explosion which produced them. Recently, *Swift* detected an X-ray transient associated with SN 2008D at $z = 0.0064$, showing a light curve and duration similar to GRB 060218. The properties of this event gave rise to a debate: are we facing a very soft/weak GRB or an SN shock breakout? Based on *Swift* XRT and UVOT data, it can be found that the peak energy limits and energetics of this transient (also named XRF 080109) are consistent with a very low energy extension of the $E_{p,i} - E_{iso}$ correlation. This provides evidence that the transient may really be a very soft and weak GRB, thus confirming the existence of a population of sub-energetic GRBs.

2.3. GRB cosmology

An interesting aspect of the $E_{p,i} - E_{iso}$ correlation is that it can be used to infer limits or ranges of redshift for long GRBs. Redshift estimates available only for a small fraction of GRBs have occurred in the last 15 years, based on optical spectroscopy. Pseudo--redshift estimates for the large number of GRBs without measured redshift would provide us with fundamental insights into the GRB luminosity function, the star formation rate evolution up to $z > 6$, etc. In addition, in some cases the optical measurements provide more than one possible value for the redshift. The most straightforward method for using the $E_{p,i} - E_{iso}$ correlation for pseudo-redshift estimates or for disentangling different possible redshifts from optical spectroscopy/photometry, is to study the track in the $E_{p,i} - E_{iso}$ plane as a function of z, i.e., to compute, based on the measured fluence and spectral parameters, the values of $E_{p,i}$ and E_{iso} for each possible value of the redshift and see for which range of redshift the GRB would be consistent with the correlation. This method often does not provide precise z estimates, but it is anyway useful for low-z GRB and in general when combined with optical measurements. An outstanding case is that of GRB 090429B, for which photometric analysis pointed to a redshift of ~ 9.4, but also provided a very small probability that the GRB was at very low redshift [14]. The consistency of this GRB with the $E_{p,i} - E_{iso}$ correlation only for $z > 1$ further supported the very high redshift estimate from the photometric analysis.

However, one of the most intriguing, debated and investigated issues about the $E_{p,i} - E_{iso}$ correlation and other spectrum–energy correlations derived from it is their use for GRB cosmology. All GRBs with measured redshift (~ 250 up to now, including a few short GRBs) lie at cosmological distances ($z \sim 0.033 \div 9.4$) (except for the peculiar GRB 980425, at $z = 0.0085$). This fact, combined with the huge radiated power of these events, would make them very powerful cosmological probes. Nevertheless, the isotropic luminosities and radiated energies of GRBs span several orders of magnitude, thus these sources are not standard candles (unfortunately). Given that it links a quantity, $E_{p,i}$, which can be derived from the observables based only on the redshift, and a quantity, E_{iso}, whose computation requires the assumption of a cosmology, the $E_{p,i} - E_{iso}$ correlation can, in principle, be used to "standardize" GRBs. Indeed, it can be found [8, 15] that a fraction of the extrinsic scatter of the correlation is due to the cosmological parameters used to compute E_{iso}. In particular, by assuming, e.g., a standard ΛCDM flat universe, it can be found that the scatter minimizes for $\Omega_M \sim 0.25 \div 0.3$, in very good agreement with the estimate coming from other cosmological probes (SN Ia, CMB, BAO, clusters). More in general, this simple analysis provides evidence, independent from SN Ia and other cosmological probes, that, if we are in a flat ΛCDM universe, as resulting from CMB analysis, Ω_M is lower than 1. By using a maximum likelihood method, the extrinsic scatter can be parametrized and quantified. For example, [8] found Ω_M constrained to $0.04 \div 0.43$ (68 %) and $0.02 \div 0.71$ (90 %) for a flat ΛCDM universe ($\Omega_M = 1$ excluded at 99.9 % c.l.), and that significant constraints on both Ω_M and Ω_Λ are expected from sample enrichment. And, indeed, the analysis of an updated sample of 109 GRBs shows significant improvements in the constraints on Ω_M ($0.06 \div 0.36$ at 68 % and $0.03 \div 0.59$ at 90 %) with respect to the sample of 70 GRBs ($0.06 \div 0.36$ at 68 % and $0.03 \div 0.59$ at 90 %), providing evidence of the reliability and perspectives of the use of the $E_{p,i} - E_{iso}$ correlation for estimating of cosmological parameters.

2.4. Reliability

Different GRB detectors are characterized by different detection and spectroscopy sensitivity as a function of the GRB intensity and spectrum, see, e.g., [16]. This may introduce relevant selection effects/biases in the observed $E_{p,i} - E_{iso}$ and other correlations. In the past, there were claims that a high fraction ($70 \div 90$ %) of BATSE GRBs without redshift would be inconsistent with the correlation for any redshift [17]. However, this would imply unreliable huge selection effects in the sample of GRBs with known redshift. In addition, other authors [9, 18, 19] have shown that most BATSE GRBs with unknown redshift are consistent with the $E_{p,i} - E_{iso}$ correlation. Moreover, [6] showed that the normalization of the correlation varies only marginally using GRBs measured by individual instruments with different sensitivities and energy bands,

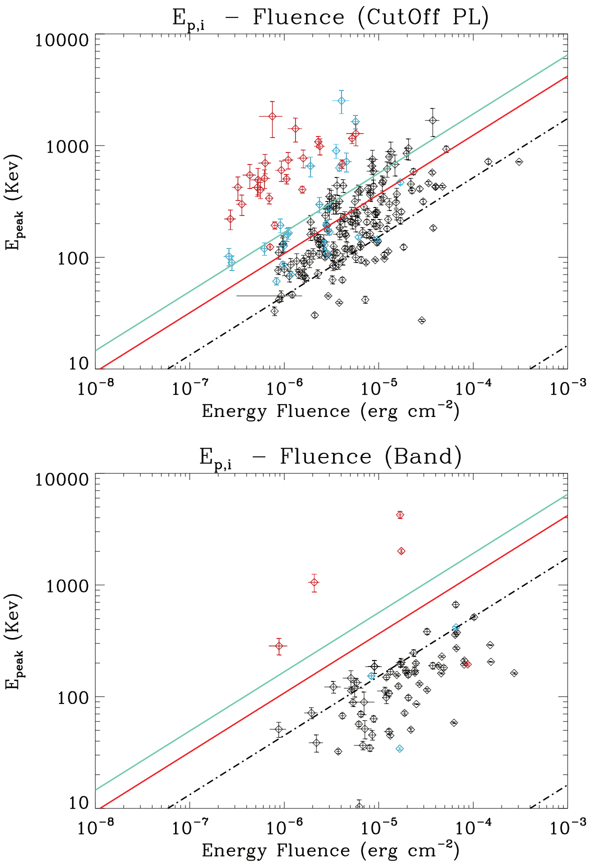

FIGURE 2. Location of *Fermi* GRBs in the E_p – fluence plane based on the analysis reported by Nava et al. [21]. In the left and right panels we show those GRBs for which the spectral parameters and the fluence were derived by fitting the data with a cut-off power-law and with the Band function, respectively. GRBs have been divided according to their durations: short (red points), intermediate (cyan points) and long (black points). The red and blue lines represent the limits above which a GRB would be inconsistent with the $E_{p,i} - E_{iso}$ correlation at 2σ or 3σ, respectively, for any redshift.

which provides further evidence that the instrumental limits do not have a significant impact.

Selection effects in the process leading to the redshift estimate may also play a role. Thanks to its capability of providing quick and accurate localization of GRBs, *Swift* is reducing selection effects in the sample of GRB with measured redshift. Thus, Swift GRBs are expected to provide a robust test of the $E_{p,i} - E_{iso}$ correlation. By considering the $E_{p,i}$ of *Swift* GRBs measured by Konus-WIND, Suzaku/WAM, *Fermi*/GBM and *Swift*/BAT (only when E_p is inside or close to $15 \div 150$ keV and the values provided by the Swift/BAT team, it can be found that they are consistent with the $E_{p,i} - E_{iso}$ correlation.

Finally, based on time-resolved analysis of BATSE, *Beppo*SAX and *Fermi* GRBs, it was found that the $E_{p,i} - L_{iso}$ correlation holds also within a good fraction of GRBs [20], which is robust evidence for a physical origin, also providing clues to its explanation.

3. THE *Fermi* CONTRIBUTION

The key features of *Fermi* for the study of GRBs are: detection, arcmin localization and study of GRBs in the GeV energy range through the Fermi/LAT instrument, with dramatic improvement w/r CGRO/EGRET; detection, rough localization (within a few degrees) and accurate determination of the shape of the spectral continuum of the prompt emission of GRBs from 8 keV up to 30 MeV through the *Fermi*/GBM instrument. The investigated $E_{p,i} - E_{iso}$ correlation with Fermi can thus be done under the following respects:

a) location in the $E_{p,i} - E_{iso}$ plane of GRBs with known z (most of which were detected and localized by *Swift*) and with E_p accurately measured by GBM (direct test);

b) testing the $E_{p,i} - E_{iso}$ correlation by analyzing the location of hundreds of GBM GRBs in the E_p–Fluence plane (as done with BATSE GRBs);

c) exploiting joint analysis of GBM and LAT spectra to investigate the impact of the extension from 10 MeV up to > 1 GeV of the spectral–energetic analysis.

3.1. *Fermi* GRBs IN THE $E_{p,i} - E_{iso}$ PLANE

Up to now, GBM has detected several hundreds of GRBs, providing accurate E_p estimates for $\sim 90\,\%$ of them. However, only $\sim 15\,\%$ of these events were simultaneously detected by *Swift*, leading to a final $\sim 5\,\%$ with E_p and z estimates. GRB fluences and spectral data of *Fermi* GRBs are presently available from four main data sets: GCNs (preliminary results for most GRBs by the *Fermi* collaboration); [21] (430 GRBs); [22] (52 bright GRBs by the Fermi collaboration); [23] (32 GRBs with known redshift by the *Fermi* collaboration). Based on GCN data, [6] showed that all *Fermi*/GBM long GRBs with known z are fully consistent with the $E_{p,i} - E_{iso}$ correlation, as determined by previous experiments (Fig. 1): further confirmation of non relevant instrumental effects. In addition, the analysis of the *Fermi*/GBM GRB 090510 further confirms that short GRBs do not follow the correlation. Very recently, [23] (an official *Fermi* team) performed a refined analysis of the updated sample of *Fermi*/GBM GRBs with known z, confirming that long ones are consistent with $E_{p,i} - E_{iso}$ correlation, while short GRBs are not. The slightly higher normalization and dispersion of the $E_{p,i} - E_{iso}$ correlation found by them with respect to previous analysis is possibly due to the use, for some GRBs, of the cut-off power-law model, instead of the Band model, which leads to an overestimate of $E_{p,i}$ and an underestimate of E_{iso}).

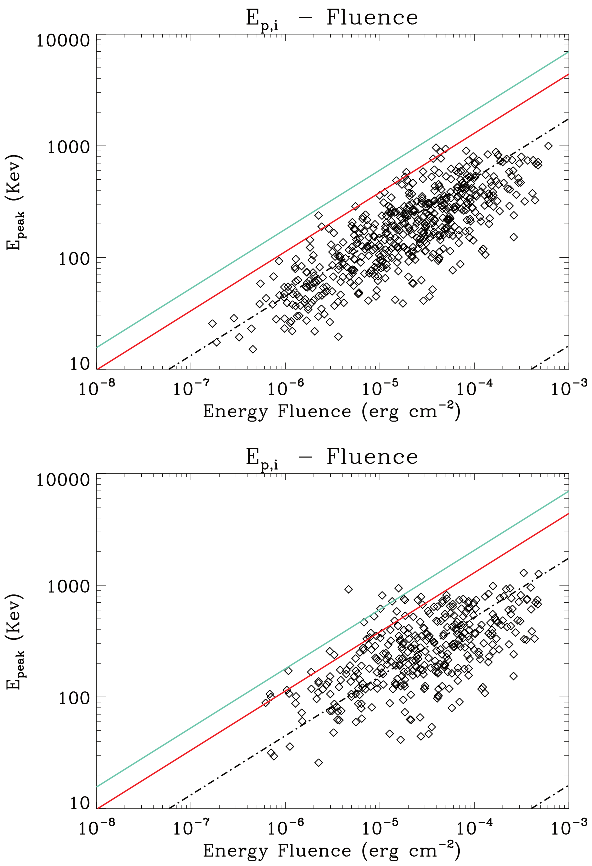

Figure 3. Location in the E_{p}–fluence plane of GRBs simulated by assuming the existence of the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation and the sensitivity limits of the *Fermi*/GBM. In the right panel we have also included in the simulations the effect of the spectral evolution $E_{\mathrm{p,i}} \propto L^{0.5}$ observed for most GRBs. The red and blue lines represent the limits above which a GRB would be inconsistent with the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation at 2σ or 3σ, respectively, for any redshift.

3.2. *Fermi* GRBs without redshift

As mentioned above, besides the small sample of GRBs with measured redshift, *Fermi*/GBM is providing a large sample of hundreds of GRBs without redshift but with accurate measurements of the spectral peak energy E_{p} and fluence F. This sample can be used to test the reliability of the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation. This is similar to what was done in the past with BATSE GRBs, but it takes advantage of the better accuracy in the spectral parameters allowed by the unprecedented wide energy band of this instrument (8 keV ÷ 30 MeV). Given that we are considering GRBs without measured redshift, this analysis requires a conversion from the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation in the cosmological rest-frame plane to an $E_{\mathrm{p}} - F$ correlation in the observer plane. By considering the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation in the form $E_{\mathrm{p,i}} = K \times E_{\mathrm{iso}}^m$ and taking into account that $E_{\mathrm{p,i}} = E_{\mathrm{p}} \times (1+z)$ and $E_{\mathrm{iso}} = F \times (4\pi D_L^2)/(1+z)$, where D_L is the luminosity distance to the source, we obtain $E_{\mathrm{p}} = f(z) \times K \times F^m$, where $f(z) = (4\pi D_L^2)^m/(1+z)^{m+1}$. Given that $f(z)$ shows a maximum for $z \sim 4$, we can convert the best-fit and 2σ or 3σ upper limits of the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation into lines in the logarithmic $E_{\mathrm{p}} - S$ plane above which a GRB would be inconsistent with the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation at the corresponding confidence level for any redshift (see Figs. 2 and 3).

We applied the above method to *Fermi* GRBs, using the different resources described above for the spectral parameters and fluence. In all cases, we have found that most (90 ÷ 95 %) of the long GRBs are potentially consistent with the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation, whereas most short ones are not. In addition, we have found that, when considering only those GRBs with well measured spectral parameters and fluence, properly modeled with the Band function instead of the cut-off power-law, and with integration times not shorter than 75 % of the total duration of the event, all long *Fermi* GRBs are potentially consistent with the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation. As an example, we show in Fig. 2 the impact of the fitting model (Band function vs. cut-off power-law) for the sample by [21].

In addition, we performed Monte Carlo simulations aimed at evaluating the impact on the location of GRBs in the $E_{\mathrm{p}} - S$ plane of the combination of spectral evolution with detector sensitivity. Indeed, time resolved analysis of GRBs generally shows, that E_{p} is correlated with the flux: the higher the flux, the higher the spectral peak energy. This means that if we detect only the brightest part of a GRB, we will overestimate E_{p} and underestimate the fluence. In order to evaluate this effect, we generated thousands of fake GRBs by assuming the existence and the measured parameters of the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation, accounting for the observed distributions of relevant parameters (E_{iso}, z, E_{iso} vs. z). We also attributed to each GRB a specific light curve and a spectral evolution of the type $E_{\mathrm{p,i}} \propto L^n$, where n is between 0.4 and 0.6, as observed in several GRBs [20]. Then by accounting for cosmological effects and Fermi/GBM instrumental sensitivity as a function of $E_{\mathrm{p,i}}$ [16, 24], we computed for each GRB the E_{p} and fluence that would be measured by the GBM. As can be seen in Fig. 3, when accounting for the spectral evolution, the observed small fraction of outliers in the $E_{\mathrm{p}} - S$ plane is reproduced.

3.3. Extremely energetic *Fermi* GRBs

Thanks to its sensitivity and its huge energy band, *Fermi* is detecting and characterizing from $\sim$ 10 keV up to several GeVs the sub-class of very energetic GRBs also detected by LAT. As pointed out by [6], GRB 080916C, the most energetic GRB ever ($E_{\mathrm{iso}} \sim 10^{55}$ erg in the 1 keV ÷ 10 GeV band), and the other extremely energetic GRBs 090323 and 090902B are fully consistent with the $E_{\mathrm{p,i}} - E_{\mathrm{iso}}$ correlation (Fig. 1). Thus, *Fermi* is providing a further extension of the correlation and evidence that the physics behind the X-ray and soft gamma-ray emission of extremely energetic events with GeV emission is similar to the physics of normal events. In addition, based on the fact that GRB 080916C showed a spectrum extending up to tens of GeV without any excess or cut-off, [6] investigated the impact on the correlation of the extension of the energy range over which $E_{\rm iso}$ is computed from the canonical upper bound of 10 MeV up to 10 GeV, finding no significant change in the slope and dispersion of the correlation. It also has to be cautioned that, given that for a few events GBM plus LAT spectral fitting shows an additional power-law component with respect to the simple Band function, the extrapolation of the spectrum at energies higher than 10 MeV is not straightforward.

4. Conclusions

The $E_{\rm p,i}-E_{\rm iso}$ correlation in long GRBs is one of the most robust pieces of observational evidence in the GRB field. Implications and uses of the $E_{\rm p,i}-E_{\rm iso}$ correlation include: prompt emission physics and geometry, identification and understanding of sub-classes of GRBs (e.g., short, sub-energetic), GRB cosmology. Refined analysis of large samples of GRBs without redshifts, combined with simulations, further support the reliability of the correlation. The *Fermi* observatory is providing a significant contribution to investigations of the property and reliability of this correlation. First of all, GBM is significantly increasing the number and the accuracy of $E_{\rm p,i}$ estimates for GRBs with known redshift. It is found that GBM long GRBs in the $E_{\rm p,i}-E_{\rm iso}$ plane follow the same correlation as measured by previous/other instruments; as expected short GRBs do not. Furthermore, the analysis of the spectral peak energy and the fluences of hundreds of GBM GRBs without redshift, joined with Monte Carlo simulations, confirm that the $E_{\rm p,i}-E_{\rm iso}$ correlation is not significantly affected by instrumental effects. Finally, extremely energetic Fermi long GRBs with significant GeV emission detected by LAT (e.g., 080916c, 090323) further confirm and extend the correlation.

References

[1] Band, D., et al.: 2002, ApJ 413, 281

[2] Zhang, B., & Meszaros, P.: 2002, ApJ 581, 1236

[3] Amati, L., et al.: 2002, A&A 390, 81

[4] Lamb, D.Q., Donaghy, T.Q., & Graziani, C.: 2005, ApJ 620, 355

[5] Amati, L.: 2006, MNRAS 372, 233

[6] Amati, L., Frontera, F., & Guidorzi, C.: 2009, A&A 508, 173

[7] D'Agostini, G.: 2005, arXiv:physics/0511182

[8] Amati, L., et al.: 2008, MNRAS 391, 577

[9] Ghirlanda, G., et al.: 2008, MNRAS 387, 319

[10] Yamazaki, R., Yoka, K., & Nakamura, T.: 2004, ApJ 606, L33

[11] Dado, S., Dar, A., & De Rujula, A.: 2007, ApJ 663, 400

[12] Guida, R., et al.: 2008, A&A 487, L37

[13] Fargion, D., & D'Armiento, D.: 2010, Mem. SAIT 81, 44

[14] Cucchiara, A., et al.: 2011, ApJ 736, 7

[15] Amati, L.: 2012, Int.J.Mod.Phys.S 12, 19

[16] Band, D.: 2003, ApJ 588, 945

[17] Nakar, E., & Piran, T.: 2005, MNRAS 360, L73

[18] Ghirlanda, G., Ghisellini, G., & Firmani, C.: 2005, MNRAS 361, L10

[19] Bosnjak, Z., et al.: 2008, MNRAS 384, 599

[20] Ghirlanda, G., Nava, L., & Ghisellini, G.: 2010, A&A 511, 43

[21] Nava, L., et al.: 2011, A&A 530, 21

[22] Bissaldi, E., et al.: 2011, ApJ 733, 97

[23] Gruber, D., et al.: 2011, A&A 528, A15

[24] Band, D., et al.: 2009, ApJ 701, 1673