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A universal scaling for short and long gamma-ray bursts: $E_{X,iso} - E_{\gamma,iso} - E_{pk}$

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The comprehensive statistical analysis of *Swift* X-ray light-curves, collecting data from six years of operation, revealed the existence of a universal scaling among the isotropic energy emitted in the rest frame $1-10^4$ keV energy band during the prompt emission ($E_{\gamma,iso}$), the rest frame peak of the prompt emission energy spectrum (E_{pk}), and the X-ray energy emitted in the rest frame $0.3-30$ keV observed energy band ($E_{X,iso}$). We show that this scaling is shared by long, short, and low-energetic GRBs, and thus reflects the existence of some properties which are shared by the GRB class as a whole. A simpler and more physically intuitive form the relation could be expressed is as a two-parameter correlation between the GRB efficiency and E_{pk}.

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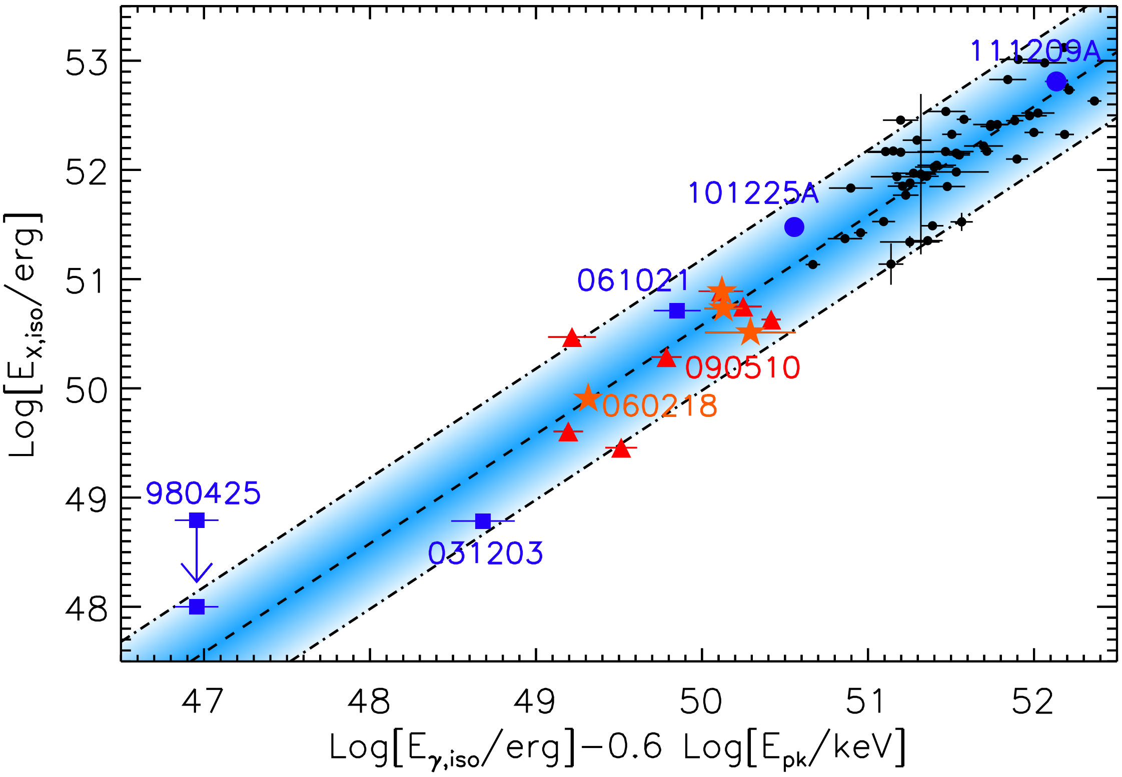

Figure 1: $E_{X,iso} - E_{\gamma,iso} - E_{pk}$ correlation for the sample of 54 LGRBs (black points) and 7 SGRBs (red triangles). The orange stars correspond to low-energetic GRBs (GRB050416A, GRB060218, GRB060614, GRB081007). The blue squares correspond to GRB090425, GRB031203, and GRB061021, outliers of the $E_{\gamma,iso}$-E_{pk} correlation. The blue circles correspond to GRB101225A and GRB111209A. The black dashed line is the best-fitting function $y = 1.06(x - 0.7z) - 2.36$ and the blue area marks the $2 - \sigma$ region.

During the comprehensive statistical analysis of *Swift* X-ray light-curves, collecting data from six years of operation of the *Swift*/X-ray Telescope (XRT), we proved that a universal scaling exists among the isotropic energy emitted in the rest frame $1 - 10^4$ keV energy band during the prompt emission $E_{\gamma,iso}$, the rest frame peak of the prompt emission energy spectrum E_{pk}, and the X-ray energy emitted in the rest frame $0.3 - 30$ keV observed energy band $E_{X,iso}$ [1, 2] (see also Margutti et al., this volume):

$$Log\left[\frac{E_{X,iso}}{erg}\right] = (1.00 \pm 0.06) Log\left[\frac{E_{\gamma,iso}}{erg}\right] - (0.60 \pm 0.10) Log\left[\frac{E_{pk}}{keV}\right] - (0.58 \pm 0.25)\,, \qquad (1)$$

with $\sigma_i = (0.30 \pm 0.03)$. This three-parameter correlation is not dependent on our definition of $E_{X,iso}$ [2]. Several peculiar GRBs as the outliers of the $E_{\gamma,iso} - E_{pk}$ relation are consistent with the correlation (see Fig. 1 and [2] for further details).

The main advantage in introducing a third variable relies in the possibility to combine long (LGRBs) *and* short GRBs (SGRBs) in a common scaling (see Fig. 1). Thus, this correlation reflects some physical property that characterises the GRB class as a whole. It is a new piece of information that allows one to explore what SGRBs and LGRBs have in common (as the outflow properties), and is likely independent of the progenitors and environment since both are thought to be different.

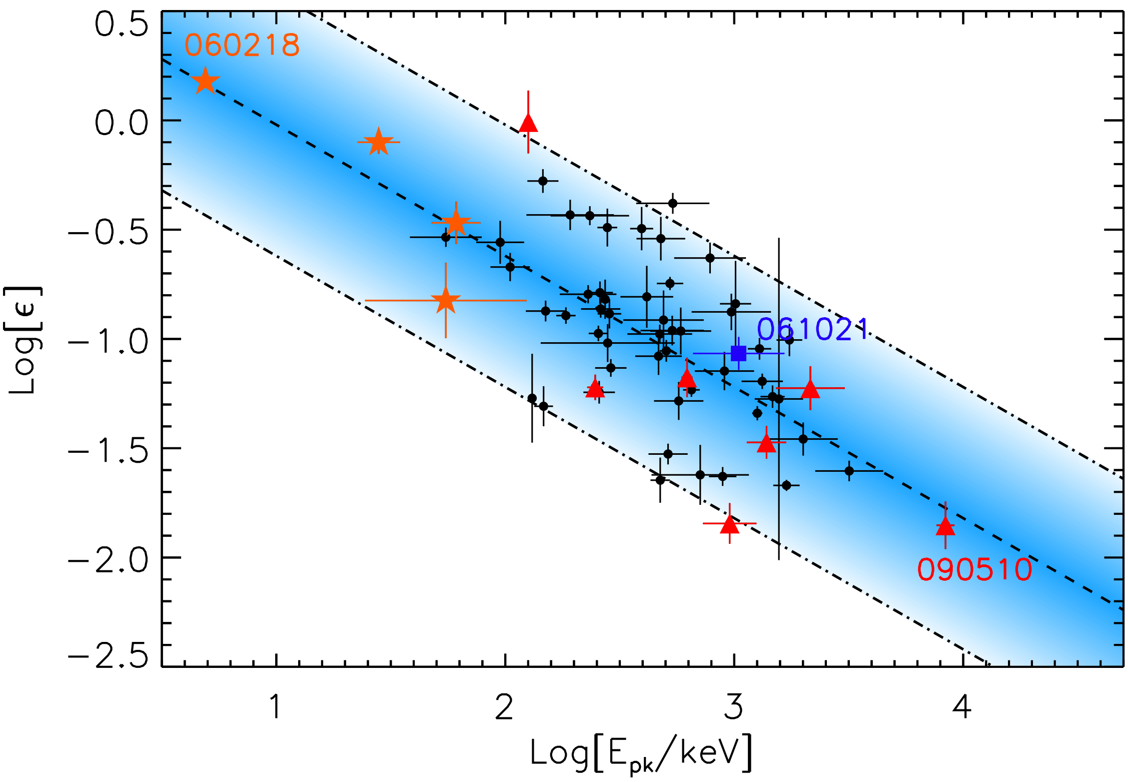

Figure 2: $\varepsilon = E_{X,iso}/E_{\gamma,iso}$ vs E_{pk} correlation for the sample of 54 LGRBs (black points) and 7 SGRBs (red triangles). The orange stars correspond to the low-energetic GRBs and the blue square to GRB061021. The black dashed line is the best-fit function $y = -(0.58 \pm 0.40)x + (0.60 \pm 0.15)$ and the blue area marks the $2 - \sigma$ region, with $\sigma_i = (0.30 \pm 0.06)$.

A physical way to interpret the three-parameter correlation is in the form of a two-parameter correlation between the GRB efficiency and E_{pk}. We rewrite Eq. 1 by introducing the ratio between the X-ray and the prompt emission energies: $\varepsilon \equiv E_{X,iso}/E_{\gamma,iso}$. Since ε is inversely proportional to the GRB efficiency, defined as the ratio between the prompt emission energy and the outflow kinetic energy, we conventionally define highly efficient GRBs those that have a low ε, meaning that the majority of energy is emitted during the prompt phase. The efficiency depends, to a first approximation, only on E_{pk}, since $\varepsilon \propto E_{pk}^{-0.6}$ (see Fig. 2).

Ghirlanda et al. [3] showed that a linear correlation exists between E_{pk} and Γ, where Γ is the Lorentz factor of the outflow, and concluded that different Γ factors are responsible for the observed correlations in the prompt emission. As a direct consequence, it results $\varepsilon \propto \Gamma^{-\alpha}$, with $\alpha \sim 0.6$: the Lorentz factor may be the ultimate parameter ruling the GRB efficiency.

The photospheric model identifies E_{pk} with the thermal peak of the photospheric emission (see [4] for a recent summary of the main results of the photospheric model and relevant references). Its value in this interpretation is coupled to the main properties of the outflow, as the luminosity and the Lorentz factor. The dependency of the efficiency on E_{pk} is a natural outcome of this model (see Lazzati, this volume). Fan et al. [5] derived analytically the relation we find between the efficiency and E_{pk} within the photospheric model, and retrieved the same scaling as well as the one between

E_{pk} and Γ.

The three-parameter correlation can be retrieved also in the cannonball model framework, resulting from the strong dependence of the observed radiations on the bulk motion Lorentz and Doppler factors of the jet of highly relativistic plasmoids that produces these radiation by interaction with the medium through which it propagates [6].

References

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