The maximum isotropic energy of long GRBs

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GRB jets

- GRBs are extremely efficient lighthouses!
 - The most luminous GRBs are visible up to $z \ge 8$.
 - However, GRBs require very special conditions:
 - Highly relativistic outflows: $\Gamma \sim 100 \rightarrow$ Doppler boost
 - Beamed outflows \rightarrow All the jet energy in a small solid angle
 - Radio calorimetry & afterglow jet breaks constrain the energy of the jet: $E_{\rm jet} \le 10^{51}~erg$



The isotropic equivalent energy E_{iso}

- Lacking information on the jet beaming for most GRBs, we cannot compute the energy radiated by the jet during the prompt emission, instead we compute the *isotropic equivalent* energy E_{iso} .
- E_{iso} is the energy released during the prompt phase assuming isotropic emission. E_{iso} is a proxy for the *energy radiated in our direction*. This is our imperfect view to GRB energetics!
- The true energy radiated in $\gamma\text{-rays}$ is E_{rad} = E_{iso}/f_b -- f_b = $4\pi/\Omega$ \approx $10^2\text{--}10^3$

Goal of this work: Verify if there a limit to E_{iso} .

Calculating E_{iso}

• E_{iso} is computed according to the formulae:

$$E_{\rm iso} = \frac{4 \pi D_l^2 S_{\rm bol}}{1+z} \qquad S_{\rm bol} = S_{\gamma} \frac{\int_{\frac{1}{1+z}}^{\frac{10^4}{1+z}} E N(E) dE}{\int_{E_{\rm min}}^{E_{\rm max}} E N(E) dE}$$

- S_γ is the fluence measured in the detector energy range, from E_{min} to E_{max}.
- N(E) describes the shape of the spectrum.
- E_{iso} is computed in the range [1-10⁴] keV *in source frame*.

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The sample

- To compute E_{iso}, we need GRBs with redshifts and reliable spectral parameters:
 - Spectra from *Fermi*/GBM (Gruber et al. 2014, von Kienlin et al. 2014) & *Wind*/Konus (Tsvetkova et al. 2017)
 - Redshifts from optical follow-up of Swift GRBs
- 95 GRBs with redshift $1 \le z \le 5$
 - 69 GRBs detected by *Wind*/Konus (K):
 - Sample threshold: $P_f \ge 3.5 \text{ ph.cm}^{-2}.\text{s}^{-1}$ in [50-200] keV
 - $P_{med} = 7.3 \text{ ph.cm}^{-2} \cdot \text{s}^{-1} z_{med} = 1.77$
 - 52 GRBs detected by *Fermi*/GBM (G):
 - Sample threshold: $P_f \ge 1.05 \text{ ph.cm}^{-2}.\text{s}^{-1}$ in [50-300] keV
 - $P_{med} = 5.4 \text{ ph.cm}^{-2} \cdot s z_{med} = 1.85$
 - 26 events in common

The observed E_{iso} distribution

• Eiso is in the range $[2 \ 10^{52} - 4 \ 10^{54}]$ erg



Correcting the Eiso distribution

- 1. For every GRB in our reference volume $(1 \le z \le 5)$, we compute its *horizon* z_{max} , the redshift at which its peak flux becomes fainter than the sample limiting peak flux.
- 2. Assuming a *GRB world model*, we compute Nz_{max} , the number of GRBs in the volume $1 \le z \le z_{max}$ and N_5 , the number of GRBs in the volume $1 \le z \le 5$.

w = N₅/Nz_{max} is the *weight* of this GRB, used to correct the E_{iso} distribution. If $z_{max} \ge 5$, w = 1.



The corrected E_{iso} distribution

- The correction does not change the bright end of the distribution (as expected).
 - The correction is stronger for Konus, which is less sensitive, with a closer horizon.
 - GBM detects GRBs with $E_{iso} \ge 10^{53}$ erg up to $z \ge 5$.



Existence of a maximum E_{iso}

• We compare the data with various GRB models having different redshift distributions (SFR plus density or luminosity evolution).

We find that an energy cutoff around $E_{iso} = 3 \ 10^{54}$ erg is required at the level of 99.9%, for all models.

(more details in ApJ 2017, 837, 119 (arXiv:1711.06122)

• This energy cutoff must not be confused with the break of the luminosity function found by various authors in the range $10^{51} - 10^{52}$ erg.



Interpretation?

- GRBs are very luminous lighthouses... up to some limit!
- An upper limit on E_{iso} *does not* indicate a limit on the energy of GRB jets: the most energetic GRBs may not have the largest E_{iso} .
 - The geometry of the jet may change.
 - The energy may be radiated outside the keV/MeV energy range.
 - The energy may be emitted outside the electromagnetic spectrum.

• ...

• The E_{iso} limit could be associated with the activity of the central engine (e.g. energy reservoir, energy extraction, Lorentz factor), with the beaming of the jet, or with the energy dissipation or radiation processes in the jet.

Conclusions and perspectives

- The GRB isotropic energy seems limited to $E_{iso} \approx 3 \ 10^{54}$ erg, and there is no indication of a class of very energetic GRBs.
- Energetic GRBs are rare, our study is based on 8 years of observation with Fermi/GBM and 22 years with Wind/Konus.
 - We estimate the rate of GRBs with $E_{iso} \ge 2 \ 10^{54}$ to be ~5 yr⁻¹.
 - Most of them have no redshift!
 - Swift, Fermi and Wind are planned to operate for several more years.
 - In 2022+ SVOM will contribute (cf. talk of C. Lachaud).
- The Eiso limit may be associated with the activity of the central engine or with the physics of the jet.
- If we find a way to identify GRBs close to E_{iso} limit, we'll have very luminous standard candles, visible to $z \ge 10!$
- Should do the same work with L_{iso}.

The most energetic GRBs

- Our sample contains 8 *energetic* GRBs with $E_{iso} \ge 2.3 \ 10^{54}$ erg (arbitrary limit):
 - 080916C, 090323, 120624B, 160625B → K+G (and *Fermi*/LAT)
 - 090902B, 140206A → G only (and *Fermi*/LAT)
 - 130505A, 130907A → K only
- These energetic GRBs are not special
 - z = 4.35, 3.60, 2.20, 1.41, 1.82, 2.73, 2.27, 1.24
- Outside our redshift range, we found one energetic GRB:
 - GRB 110918A at z=0.984, with Eiso = $2.3 \ 10^{54}$ erg detected by Konus
 - We found no energetic GRB beyond z=5, despite 1500 Gpc³ in $5 < z \le 10$
- We estimate the rate of energetic GRBs to be ~5/yr/sky.









