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The GRB variability/peak luminosity correlation: New results(*)

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Summary. — We test the correlation between time variability and isotropic-equivalent peak luminosity found by Reichart *et al.*(*ApJ*, **552** (2001) 57) using a set of 26 Gamma-Ray Bursts (GRBs) with known redshift. We confirm the correlation, though with a larger spread around the best-fit power-law obtained by Reichart *et al.* which in turn does not provide an acceptable description any longer. In addition, we find no evidence for correlation between variability and beaming-corrected peak luminosity for a subset of 14 GRBs whose beaming angles have been taken from Ghirlanda *et al.*(*ApJ*, **616** (2004) 331). Finally, we investigate the possible connection for some GRBs between the location in the variability/peak luminosity space and some afterglow properties, such as the detectability in the optical band, by adding some GRBs whose redshifts, unknown from direct measurements, have been derived assuming the Amati *et al.*(*A&A*, **390** (2002) 81) relationship.

PACS 95.75.Wx – Time series analysis, time variability.
PACS 98.70.Rz – γ-ray sources; γ-ray bursts.
PACS 01.30.Cc – Conference proceedings.

1. – The GRB sample

We tested the correlation found by [1] between time variability and isotropic-equivalent peak luminosity for a larger set of GRBs with known redshift. The GRB sample includes 26 GRBs: 16 GRBs detected with the *BeppoSAX* Gamma-Ray Burst Monitor

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TABLE I. – *Variability vs. Peak Luminosity for* 26 *GRBs with known redshift. Uncertainties reported are* 1 σ*.*

GRB Name	z Redshift	Mission[(a)]	$T_{f=0.45}$ (s)	$V_{f=0.45}$	Peak Lum. $L^{(b)}$ (10^{50} erg s^{-1})
970228	0.695	BS/U/K	2.2	$0.223^{+0.018}_{-0.017}$	48.7 ± 9.9
970508	0.835	B/BS/U/K	2.4	$0.023^{+0.013}_{-0.013}$	9.43 ± 1.89
970828	0.958	B/U/K/S	12.9	$0.101^{+0.002}_{-0.002}$	120.0 ± 40.0
971214	3.418	BS/B/U/K/N/R	4.4	$0.110^{+0.012}_{-0.012}$	$360. \pm 65.$
980425	0.0085	B/BS/U/K	4.7	$0.049^{+0.048}_{-0.048}$	0.0007 ± 0.0002
980703	0.966	BS/B/U/K/R	3.2	$0.044^{+0.007}_{-0.007}$	26.4 ± 5.6
990123	1.6	BS/B/U/K	12.8	$0.112^{+0.002}_{-0.002}$	$840. \pm 121.$
990506	1.3	BS/B/U/K/R	8.6	$0.270^{+0.005}_{-0.005}$	$583. \pm 121.$
990510	1.619	B/BS/U/K/N	3.2	$0.214^{+0.005}_{-0.008}$	$300. \pm 50.$
990705	0.86	BS/U/K/N	8.0	$0.178^{+0.003}_{-0.003}$	$134. \pm 21.$
990712	0.434	BS/U/K	4.1	$0.042^{+0.017}_{-0.017}$	5.4 ± 1.0
991208	0.706	K/U/N	5.1	$0.082^{+0.003}_{-0.003}$	$290. \pm 100.$
991216	1.02	BS/B/U/N	2.6	$0.193^{+0.002}_{-0.002}$	$1398. \pm 200.$
000131	4.5	B/U/K/N	8.0	$0.187^{+0.005}_{-0.005}$	$3600. \pm 900.$
000210	0.846	BS/U/K	1.59	$0.026^{+0.002}_{-0.002}$	$480. \pm 50.$
000911	1.058	U/K/N	5.2	$0.077^{+0.034}_{-0.034}$	$360. \pm 60.$
010222	1.477	BS/U/K	6.62	$0.201^{+0.003}_{-0.003}$	$801. \pm 119.$
010921	0.45	BS/H/U/K	5.3	$0.038^{+0.016}_{-0.016}$	8.0 ± 2.0
011121	0.36	BS/U/K/O	8.3	$0.049^{+0.002}_{-0.002}$	19.9 ± 3.1
020124	3.198	H/U/K	8.8	$0.203^{+0.031}_{-0.032}$	$300. \pm 60.$
020405	0.69	BS/U/K/O	9.9	$0.168^{+0.007}_{-0.007}$	71.4 ± 11.2
020813	1.25	H/U/K/O	17.4	$0.248^{+0.007}_{-0.007}$	$340. \pm 70.$
030226	1.98	H/K/O	26.6	$0.042^{+0.015}_{-0.015}$	25.0 ± 5.0
030328	1.52	H/U/K	24.9	$0.051^{+0.005}_{-0.005}$	$90. \pm 18.$
030329	0.168	H/U/K/O/RH	4.9	$0.105^{+0.007}_{-0.007}$	6.1 ± 1.2
041006	0.712	H/K/RH	8.0	$0.052^{+0.002}_{-0.002}$	$66. \pm 10.$

[(a)] Mission: BS (*BeppoSAX*), B (BATSE/*CGRO*), K (Konus/*WIND*), H (*HETE-II*), U (*Ulysses*), S (*SROSS-C*), N (*NEAR*), R (*RossiXTE*), O (*Mars Odyssey*), RH (*RHESSI*): the data used are taken from the first mission mentioned.

[(b)] Isotropic-equivalent peak luminosity in 10^{50} erg s^{-1} in the rest-frame 100–1000 keV band, measured on a 1 s timescale, $H_0 = 65$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$.

(GRBM) [2] (8 out of which have been detected with BATSE too), 2 by *CGRO*/BATSE, 6 by the *HETE-II* FREGATE, 1 by Konus/*WIND* and 1 by *Ulysses*. We used the following public data: BATSE([1]), *HETE-II*([2]), and Konus/*WIND*([3]). Table I reports the list of the GRBs in our sample with mentioned the spacecraft that detected it.

We calculated the variability using the following time binnings in the energy bands, both depending on the instrument: 7.8125 ms for the GRBM data (40–700 keV), 64 ms for BATSE (110–320 keV), 164 ms for *HETE-II* (30–400 keV), 64 ms for Konus/*WIND*

([1]) `ftp://cossc.gsfc.nasa.gov/compton/data/batse/ascii_data/64ms/`
([2]) `http://space.mit.edu/HETE/Bursts/Data/`
([3]) `http://lheawww.gsfc.nasa.gov/docs/gamcosray/legr/bacodine/konus_grbs.html`

(50–200 keV), 31.25 ms for *Ulysses* (25–100 keV).

We ignored some GRBs with known redshift (980613, 011211, and 021004) because of their low total counts or because of a too coarse time binning with respect to the entire GRB duration (*HETE-II* GRB 021211) or because public data do not cover the entire GRB profile like for the Konus GRBs 000301C, 000418, 000926.

2. – Variability and peak luminosity measures

Variability V_f has been calculated according to the expression given by [1] with two small corrections due to instrumental dead time and a small non-Poisson noise affecting the GRBM background data. It can be expressed heuristically by eq. (1a):

$$V_f = \frac{\sum_{i=1}^{N}\left[\left(\langle C_i\rangle_{(1+z)^\beta} - \langle C_i\rangle_{T_f}\right)^2 - r_{\rm np}\, S_{{\rm P},i}\right]}{\sum_{i=1}^{N}\left[\langle C_i\rangle_{(1+z)^\beta} - B_i\right]^2} \qquad (1a)$$

C_i and B_i are the total and background counts in the i-th bin, respectively, and $\langle C_i\rangle_{(1+z)^\beta}$ are the counts smoothed by a box car function with a width of $(1+z)^\beta$ (z is the redshift, β is 0.6). $\langle C_i\rangle_{T_f}$ are the counts smoothed over a timescale T_f, with $f = 0.45$: T_f is the shortest cumulative time in which a fraction f of the total counts of the GRB is collected [1]. $S_{{\rm P},i}$ is the Poisson variance of the term $(\langle C_i\rangle_{(1+z)^\beta} - \langle C_i\rangle_{T_f})$; $r_{\rm np}$ is the small non-Poisson correction. Peak Luminosities have been calculated in the 100–1000 keV source-frame energy band similarly to [1]. We verified the mutual consistency for a subset of 13 common GRBs between our values (both variability and peak luminosity) and those obtained by [1], except for three GRBs with significantly different values for variability (see [3] for details).

3. – Results

Figure 1 shows variability *vs.* peak luminosity for the sample of 26 GRBs with known redshift considered. Apparently the correlation is confirmed, although the best-fit power law parameters obtained by [1] ($L \propto V^m$, $m = 3.3^{+1.1}_{-0.9}$) are not consistent with our results ($m = 1.4^{+0.9}_{-0.6}$). The correlation coefficients found have the following significances: 0.2% and 0.3% for the Spearman's rank-order coefficient r_s and the Kendall's coefficient τ, respectively, whilst 1.3% for the linear correlation.

3·1. *Variability vs. beaming-corrected peak luminosity.* – We selected a subset of 14 GRBs for which [4] provide the beaming angles. We compared the correlation coefficients for this subset obtained in two cases: i) with the beaming-corrected peak luminosity, ii) with the isotropic-equivalent peak luminosity. While the correlation still survives in the latter case ($\sim$ 0.5% confidence level), in the former it is less statistically significant ($\sim$ 5%).

4. – GRBs with unknown redshift

We tentatively added 25 more GRBs with no measured redshift detected with *BeppoSAX* GRBM: for them we assumed redshifts estimated assuming the Amati relationship [5] between the rest-frame peak energy $E_{\rm p}^{\rm rest}$ of the $E\,F(E)$ energy spectrum and the total isotropic released energy $E_{\rm rad}$. It turns out that the above correlation between

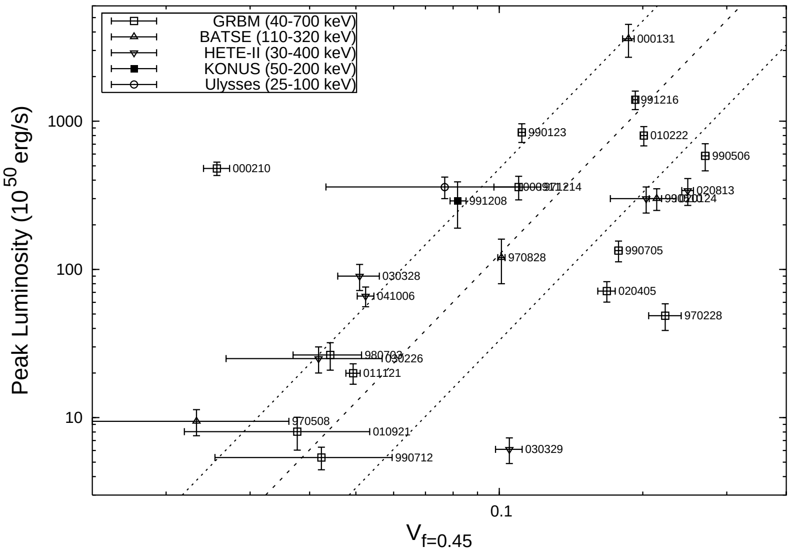

Fig. 1. – $V_{f=0.45}$ *vs.* peak luminosity for 26 GRBs with known redshift. Dashed lines mark the best-fit power law relationship found by [1] and $\pm 1\sigma$ widths.

$V_{f=0.45}$ and L is no longer significant. The fact that one of the most notable outliers is the dark burst 000210 [6] motivated us to search for possible connections for some GRBs between their location in the $V_{f=0.45} - L$ space and the detectability of their optical afterglow counterpart. For a subset of 29 GRBs we found possible evidence that GRBs with intermediate-to-bright optical afterglows show a better correlation between $V_{f=0.45}$ and L than dark and faint-afterglow GRBs. Actually, it must be pointed out that this possible connection relies on the assumption of the validity of the Amati relationship.

* * *

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