IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10092-6

General properties of X-Ray Riches and X-Ray Flashes in comparison with Gamma-Ray Bursts(*)

V. D' Alessio and L. Piro

IASF, INAF-CNR - str. Fosso del Cavaliere, 00113 - Rome, Italy

(ricevuto il 23 Maggio 2005; pubblicato online il 22 Settembre 2005)

Summary. — The X-Ray Flashes (XRFs) and X-Ray Riches (XRRs) are two subclasses of Gamma-Ray Bursts (GRBs), which have respectively no detection in the gamma-ray energy and very faint gamma to X-ray fluence. To investigate their nature we compiled a sample of 54 events observed by *BeppoSAX* and *HETE-2*, available in literature and from the web. To classify XRRs/XRFs for those two experiments, we adopted the same spectral hardness ratio. We studied their prompt emission in the X and γ range and their spectral parameters and compared them with those of GRBs. We find XRRs/XRFs are characterized by a significantly smaller value of E_{peak} while the spectral slopes α and β are quite similar. We analysed also the optical and X-ray afterglow fluxes and their ratio and compared them with that obtained for GRBs. We find that the distribution of X-ray flux of XRR/XRF afterglow is consistent with that of GRBs, which is incompatible with the off-axis model. For example, in the inhomogeneous jet model it implies that the observer angle for an XRR/XRF is at most 2°. It is also not explained by the high redshift scenario.

PACS 95.85.Nv – X-ray.
PACS 95.85.Kr – Visible (390–750 nm).
PACS 98.70.Rz – γ-ray sources; γ-ray burts.

1. – Introduction

The XRRs and XRFs are a class of GRBs characterized by strong emission in the range of 2–30 keV. Several studies have been carried out about spectral properties of XRRs/XRFs and various theories have been proposed to explain their origin. In this work, we studied the properties of XRRs/XRFs in comparison with those of GRBs. Our results are then discussed in the framework of the high redshift scenario, where XRFs could be GRBs at $z \geq 5$, and in the framework of off-axis scenario, where XRFs are the result of a highly collimated GRB jet viewed off axis [1, 2].

(*) Paper presented at the "4th Workshop on Gamma-Ray Burst in the Afterglow Era", Rome, October 18-22, 2004.

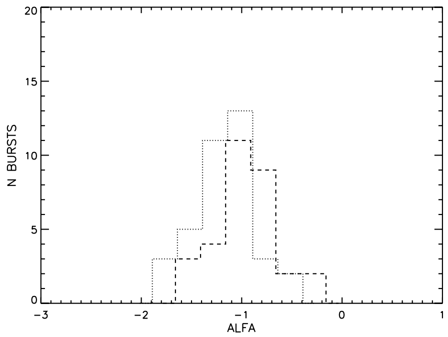

Fig. 1

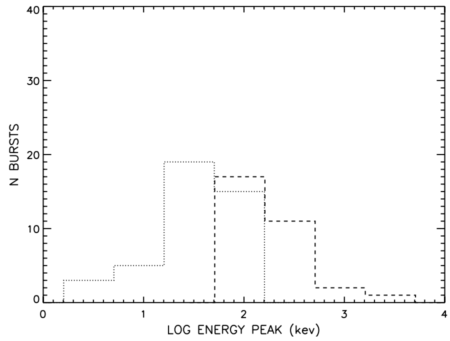

Fig. 2

Fig. 1. – Distribution of spectral slope α for 37 XRRs/XRFs (dotted line) and 31 GRBs (dashed line).
Fig. 2. – Distribution of logarithm of E_{peak} for 42 XRRs/XRFs (dotted line) and 31 GRBs (dashed line).

2. – Distribution of spectral parameters of X-Ray Riches and X-Ray Flashes

We compiled a sample of 54 events, 17 observed by *BeppoSAX* and 37 by *HETE-2* and originally classified either XRR or XRF, available in literature and from the web. The criterions to classify a burst as GRB, XRR, XRF depend by the energy range and the instrument which observes the bursts. To classify the XRRs/XRFs as observed by *BeppoSAX* and *HETE-2*, we adopted the same hardness ratio and classified as XRRs/ XRFs all the bursts which have $H = S(2,30)/S(30,400) \geq 0.32$, where $S(E_1, E_2)$ is the fluence in the energy range E_1–E_2 [3]. We calculated H for these bursts using their spectral parameters, available in literarure and find that all these 54 events are consistent with our XRRs/XRFs definition. Several studies have been made about spectral properties of XRRs/XRFs; Kippen *et al.* [4] analysed a sample of 9 XRFs observed by *BeppoSAX* and from *BATSE* off-line data and found that the photon index α and β of XRFs are similar to those of GRBs, while E_{peak} is less than 10 keV for most XRFs, suggesting XRRs/XRFs are the same phenomena of GRBs.This result has been confirmed by Sakamoto *et al.* [5] with the analysis of 42 XRRs/XRFs observed by *HETE-2*. We studied the spectral parameters of the prompt emission of our XRR/XRF sample, considering not only events fitted by Band law but also events whose spectral data are adeguately fitted by a power law exponential model, where α is spectral slope at low energy and $E_{peak} = (2+\alpha) \times E_o$, with E_o the break energy. We built up the distribution of α and E_{peak} for the bursts which have these parameters well constrained and compared them with those of a sample of 21 GRBs repoted in [6] and 10 GRBs in [5] (figs. 1, 2). We calculated also the mean value for α, β and E_{peak} distributions (table I). For XRRs/XRFs α is compatible with that of the GRBs within 3σ and the mean value of β is consistent within 1σ. Instead the value of E_{peak} is significantly smaller by a factor ~ 7, confirming the *soft* nature of these events. The result obtained is compatible with the high redshift scenario for XRRs/XRFs, because the spectral slope are similar between these two classes and only the E_{peak} is shifted to lesser values, and reinforces the idea that XRRs and XRFs are the same phenomenon of GRBs.

3. – The optical and X-ray flux of the afterglow

We analysed optical and X-ray [1.6-10 keV] fluxes at 11.1 h after burst trigger and their correlation for a sample of 34 XRRs/XRFs: there are 12 XRRs/XRFs with X-ray

Table I. – *Mean value of spectral parameters for XRRs/XRFs and GRBs.*

CLASS(number)	$\langle\alpha\rangle$	CLASS(number)	$\langle\beta\rangle$
XRRs+XRFs (37)	$-(1.20 \pm 0.05)$	XRRs+XRFs (19)	$-(2.83 \pm 0.22)$
GRB (31)	$-(0.98 \pm 0.07)$	GRB (25)	$-(2.86 \pm 0.23)$
CLASS (number)	$\langle E_{peak}\rangle$		
XRRs+XRFs (42)	47 ± 5		
GRB (31)	348 ± 150		

afterglow observations and 27 with optical observations. There are 15 XRRs/XRFs which have not an optical counterpart and for them we obtained upper limits for the optical flux. When the value for optical and X-ray fluxes were not available in literature, we extracted them at 11.1 h from the observations of the afterglow at different time, with the best temporal slope between the prompt and afterglow observations. We built up the distribution of these parameters an compared them with those of 27 GRBs [7] (fig. 3). We calculated the mean value and variance of these parameters (table II). We find that the ratio between GRB and XRR/XRF optical flux is ~ 1.4, and for X flux is $R = 1.18 \pm 0.54$.

Analysing optical to X-ray flux ratio we find a value for XRRs/XRFs consistent with that of the classical GRBs, even if there are three events with a very small value of this ratio: XRF981226, XRF990704 and XRR 020410. Only the second is dark and can be at $z \geq 5$. A hypothesis to explain the lack of optical emission, alternative to the very high redshift scenario, may be strong absorption, caused by environments rich of dust, which extinguishes efficiently the optical and UV light. There are some indications that XRRs/XRFs take place in dense environments, like the giant molecular clouds (GMCs), confirming this hypothesis.

4. – Implications on the high redshift and off-axis model

We find that the ratio between GRBs and XRRs/XRFs X-ray afterglow flux is $R = 1.18 \pm 0.54$. If XRRs/XRFs were at $z = 5$ and GRBs at $z = 1$ we would expect a ratio

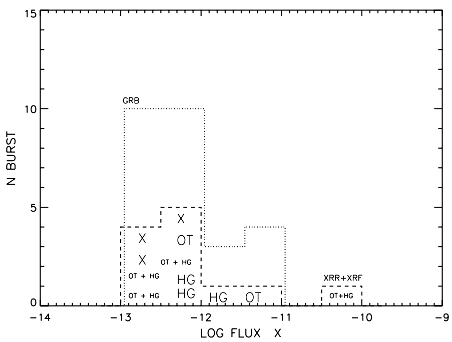

Fig. 3. – Distribution of logarithm of X flux at 11.1 h from burst trigger in erg cm^{-2} s^{-1} for 12 XRRs/XRFs (dashed line) and 27 GRBs (dotted line): OT = XRRs/XRFs with Optical transient, HG = XRRs/XRFs with host galaxy, X = XRRs/XRFs without OT and HG.

TABLE II. – *Mean value and σ of the logarithm of X (in erg $cm^{-2}s^{-1}$) and Optical (in W $m^{-2}Hz^{-1}$) flux of the afterglow at 11.1 h and of their ratio for XRR/XRF and GRB samples. In the catalogue we included the bright event 030329, but we excluded it in this analysis.*

CLASS (number)	$\langle \log F_x \rangle$	$\langle \sigma(\log F_x \rangle$
XRRs+XRFs (11)	$-(12.31 \pm 0.17)$	0.57
GRB (27)	$-(12.24 \pm 0.10)$	0.51
CLASS (number)	$\langle \log F_o \rangle$	$\langle \sigma(\log F_o) \rangle$
XRRs+XRFs (26)	$-(30.98 \pm 0.12)$	0.53
GRB (26)	$-(30.85 \pm 0.12)$	0.62
CLASS (number)	$\langle \log F_{o/X} \rangle$	$\langle \sigma(\log F_{o/X}) \rangle$
XRRs+XRFs (11)	(0.31 ± 0.28)	0.94
GRB (26)	(0.37 ± 0.11)	0.55

of $R \sim 7$. Moreover, 7 events in the sample have redshift known with a mean value $z = 0.66 \pm 0.27$. However, 55% of XRRs/XRFs examinated does not show any optical emission. Of course it is not possible to explain the whole class of XRRs/XRFs with an high redshift scenario, but we can not exclude that a significant partion of them is at $z \geq 5$. In order to study the afterglow property for an off-axis GRB we have adopted the computation made by Rossi *et al.* [8]; the X-ray afterglow flux is expected to decrease as the observed angle increases. The value of R obtained by our analysis is used to estimate the observing angle ϑ_o for an XRR/XRF in the inhomogeneous jet model and the ϑ_o/ϑ_j where $2\vartheta_j$ is the open angle of the jet, in the homogeneous jet model. For the homogeneous jet model we find that ϑ_o/ϑ_j is of the order of few degrees and for the inhomogeneous jet model, assuming $\vartheta_o \sim 1$ for a GRB, $\vartheta_o = (1.5 \pm 0.5)°$. These values are consistent with those found for the classical GRBs: thus the average properties of the whole sample are not consistent with an off-axis scenario.

5. – Conclusion

We found that the whole class of XRRs/XRFs cannot be explained neither in the GRB high redshift scenario, nor in the GRB off axis theory. It is possible that the class is composed by objets of different type, like GRBs at high redshift, GRBs viewed off axis and intrinsically faint events. More confirmations of these results will be possible with more observations of XRRs/XRFs, presently detected by *HETE-2* and *SWIFT*.

REFERENCES

[1] YAMAZAKI R. *et al.*, *ApJ*, **571L** (2002) 31.
[2] YAMAZAKI R. *et al.*, *ApJ*, **593L** (2003) 941.
[3] LAMB D. Q *et al.*, *AAS*, **202** (2003) 12.
[4] KIPPEN R. M., WOODS P. M. *et al.*, *Comparing prompt emission from X-ray flashes and gamma-ray bursts*, in *Gamma-Ray Burst in the Afterglow Era*, edited by COSTA E., FEROCI M. and HJORTH J. (Springer, Heidelberg) 2001.
[5] SAKAMOTO T., LAMB D., GRAZIANI C. *et al.*, submitted to *ApJ*, (astro-ph 049128).
[6] KIPPEN R. M. *et al.*, *Gamma-Ray Bursts: 30 Years of Discovery, Santa Fe, 8-12 Sep. 2003 AIP Conf. Proc*, **727** (2004) 119.
[7] DE PASQUALE M., PIRO L. *et al.*, *ApJ*, **592** (2003) 1018.
[8] ROSSI E., LAZZATI D. and REES M. J., *MNRAS*, **332** (2002) 945.