Temporal and Spectral Studies of SWIFT/BAT Detected Gamma Ray Burst (GRB)-111228A

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Abstract— We report timing (lag-luminosity relation, energy bands versus lag, flux and luminosity) and spectral studies of the GRB11228A using data from the SWIFT observatory. The observation used in the present work was carried out in 2011 December 28. We extracted temporal lags by cross-correlating different energy band light curves. Data analysis was performed for all combinations of the standard Swift hard X-ray energy bands: 15-25 keV, 25-50 keV, 50-100 keV and 100-150 keV. The temporal lags between these energy channels are presented as a function of the peak luminosity of the GRB. The results of our timing and spectral analysis of SWIFT/BAT data of GRB111228A are presented in this paper.

Index Terms— gamma rays: bursts: individual (GRB111228A): timing studies: cross-correlations: energy lag, energy-flux, energy-luminosity and lag-luminosity; spectral studies

1 INTRODUCTION

GRBs are among the most fascinating phenomena in the universe. They are powerful flashes of gamma rays with spectral energy distribution peaking in the gamma ray band.GRBs were first discoverd in 1967 by vela satellite [2] but it was greatly stimulated by the launch of the Swift Satellite [5] in 2004. The bursts last from a few milliseconds to roughly 100 s. GRBs are classified into two classes- short duration and long duration GRBs. The short duration bursts are defined as those lasting less than 2 sec while long duration burst last more than 2 sec. Lag is common features of GRBs. The lag is defined as the difference in the time of arrival of high and low energy photons and is considered positive when high energy photons arrives earlier than the low energy ones [13].

In recent works, some of the authors have described the phenomenon of the gravitational collapse of a neutron star induced by a Super explosion. They have proposed the scenario of a binary system composed of a massive star (an evolved C+O core) and a neutron star. The massive star explodes as a SN Ib/c, ejecting material that reaches the NS and inducing its collapse to a black hole. Immediately after, a GRB is produced. We believe that GRB111228A could been produced in these circumstances. The GRB111228A is very bright source and was detected on 2011 December 28 by BAT instrument on board Swift Mission. In addition, GRB111228A was detected by KonusWind [6] and also by the Fermi GBM (Briggs et al. 2011).
The gamma ray light curve shows that GRB 111228A is multi-peak GRB, with an emission lasting approximately 100 sec. The fluence of GRB in the range 15-150 keV is $8.5 \pm 0.2 \times 10^{-6}$ erg cm^{-2}. The spectroscopic redshift of the burst is ~0.714 [4], [3], [11], [14], [12]. In this paper we report timing properties and spectral studies of the GRB111228A.

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2 OBSERVATIONS AND DATA ANALYSIS

BAT triggered (Trigger number 510649) on GRB 111228A at 15:44:43 UT [13]. Swift slewed immediately to the burst. This was a 16.82 σ rate-trigger on a burst with $T_{90} = 101.20 \pm 5.42$ sec. GRB111228 has been detected by Swift (BAT, XRT and UVOT), Fermi and KonusWind. There have been also observations in the optical band by GROND, NOT, TAROT and TNG among others. The BAT light curve presents two main episodes, the first one starting ~20 s before the trigger and lasting ~60 s. The second one starts ~90 s after the trigger and lasts ~20 s.
Data reduction was done with available SWIFT software and FTOOLs package whereas the data analysis was performed using heasoft (version-6.12). We used specially the following package: batbinevt-v1.48, crosscor-v1.0 (xronos-5.22) and GNUPLOT-v4.4 patch level 3 for timing analysis.

For spectral analysis we used XSPEC (version-12.7.1), CALDB (version-1.0.1), batmaskwtevt (version-1.22), batbinevt (version-1.48), batfftimage (version-1.20), batcelldetect (version-1.85), battblocks (version1.18), batphasyserr (version-1.6), batupdatephakw (version-1.4), batdrmgen (version-3.6). We found five different pulses for GRB111228A. The timing lags were found using improved cross-correlation function (CCF) analysis method. A Gaussian curve was fitted to the CCF to extract the timing lag.
The light curves with time bin size 64 ms were generated of BAT data for energy range 15-150 keV thereafter they were

extracted. We extracted five different pulses separately for energy range 15-150 keV and then divided each pulse into four energy bands 15-25 keV, 25-50 keV, 50-100 keV and 100-150 keV. Last three energy band light curves were cross correlated with first one and found lag as described by Band [1]. Using CCF lag we established relations between energy-flux, energy-lag, energy-luminosity and lag-luminosity variables. Since the signal was strong enough that clear pulses could be unambiguously extracted with consistent characteristics across all energy bands. Every pulse was characterized by its own lag under the limit of uncertainty. Performing the analysis across four different intervals allowed us to address the question of evolution of CCF lag. The lag was measured by Gaussian fitting in the region near CCF main peak. The Gaussian profile was modeled as:

$$I(t) = I_o \exp[-(t-t_0)^2 / 2\sigma^2]$$

Here σ is the variance.
Luminosity is obtained from the following relation

$$L = 4\pi d_L^2 F$$

Where F is flux and d_L is luminosity distance.
Pulse properties of the source are shown in table 1.

Table 1 : Pulse properties of GRB111228A

Pulse	Energy bands (keV)	Lag (sec)	Lag error (sec)	Flux(10^{-9}erg /sec/ cm^2)	Flux error (10^{-9}erg/sec/ cm^2)	Luminosity (10^{50}erg/sec)	Luminosity error (10^{50}erg/sec)
1	15-25	0	0	69.02	18.41	4.49	1.20
	25-50	-0.06	0.054	74.24	25.79	4.83	1.68
	50-100	-0.06	0.11	115.014	36.12	7.48	2.35
	100-150	0.30	0.25	112.38	58.09	7.31	3.78
2	15-25	0	0	103.82	21.50	6.75	1.40
	25-50	-0.02	0.034	125.91	26.25	8.19	1.71
	50-100	-0.02	0.050	128.86	43.03	8.38	2.80
	100-150	0.15	0.19	140.19	62.19	9.12	4.05
3	15-25	0	0	143.56	21.99	9.34	1.43
	25-50	-0.04	0.028	314.78	33.004	20.48	2.15
	50-100	-0.0006	0.06	357.32	49.69	23.24	3.23
	100-150	0.08	0.09	212.71	64.64	13.84	4.20
4	15-25	0	0	172.86	22.70	11.24	1.48
	25-50	0.0008	0.023	263.73	30.46	17.15	1.98
	50-100	0.0005	0.03	320.47	49.50	20.85	3.22
	100-150	0.012	0.08	143.24	65.90	9.32	4.29
5	15-25	0	0	173.76	15.04	11.30	.98
	25-50	-0.084	0.014	224.83	20.01	14.62	1.31
	50-100	-0.15	0.017	220.65	28.0002	14.35	1.82
	100-150	0.03	0.045	117.76	36.60	7.66	2.38

3 RESULTS AND DISCUSSION:

3.1 TIMING ANALYSIS:

Energy vs flux: The number of sources emitting radiation of specific energy band per second per unit area is a measure of flux. Figure 1 and 2 represent plot (with error bars) of the observed flux and luminosity for five peaks: pulse 1 (black colour), pulse 2 (red colour), pulse 3 (green colour), pulse 4 (blue colour) and pulse 5 (sea green colour) of GRB111228A as a function of mid point of energy bands 15-25 keV, 25-50 keV, 50-100 keV and 100-150 keV respectively.

Photon flux is higher for higher energy bands and continuously increases for pulse I (black color) but photon flux decreases for higher energy band (Expect first peak, last four peaks flux and luminosity do not rise in high energy bands (100-150 keV). Although it was emitted by high density inner matter, loosing large gravitational energy but must have been stopped by incoming bulk matter as shown in figure 1. Variations among peaks flux and luminosity is minimum in the energy band (15-25 keV) and maximum for 50-100 keV whereas for 25-50 keV and 100-150 keV, it is more or less same. These features reveal that as soon as GRB episode begins the photon flux and luminosity are more intense but later succession time of burst gradually decline, which is in good agreement with earlier studies [7]. Pulse 1 does not show that type of trend because the large gravitational energy is not stopped by incoming matter. Collapsar exhibited almost similar trend for luminosity as shown in figure 2.

Energy vs lag: figure 3 shows the energy dependence of lag for GRB. II and III energy band are at almost same lag, but IV band shows rather large lag with respect to I energy band. This trend is common for all pulses expect fourth pulse is GRB which is little less delayed III band as compared to II and IV.

Lag vs luminosity: As indicated by Hakkila the anti-correlation between luminosity and lag is ubiquitous in almost all observed GRBs. Lag between bands of GRB shows unclear anti-correlation with luminosity for five pulses and shown in figure 4. There is no definite trend as expected to be inversely proportional as reported by Hakkila [7].

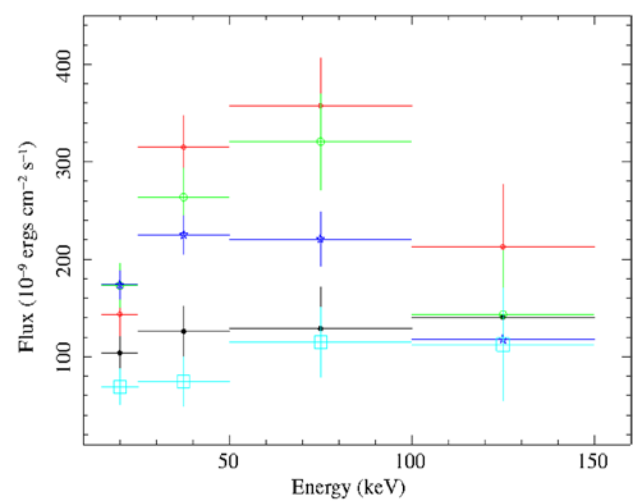

Figure: 1 Presents energy vs flux for 64 ms timing for five different peaks in pulse GRB 111228A

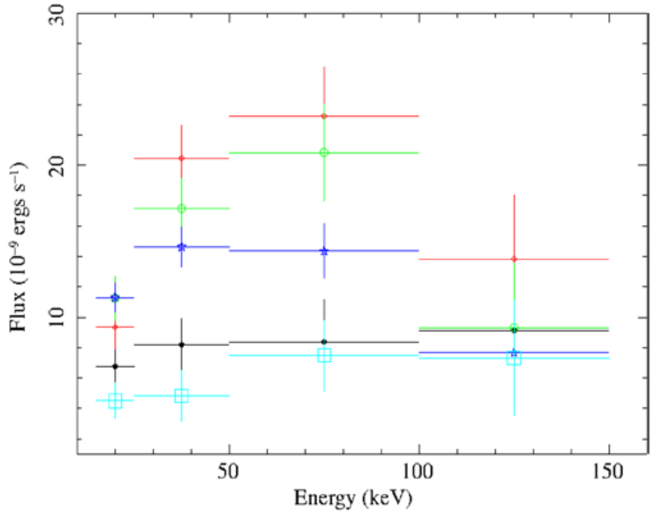

Figure: 2 Presents energy vs luminosity for 64 ms timing for five different pulses for GRB 111228A

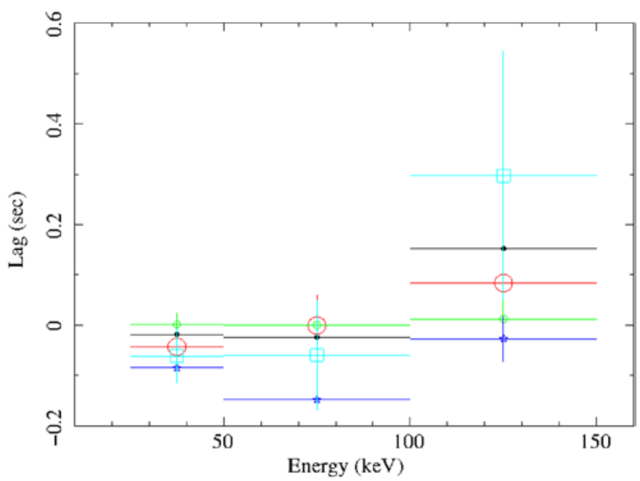

Figure: 3 Presents energy vs lag for 64 ms timing for five different pulses for GRB 111228A

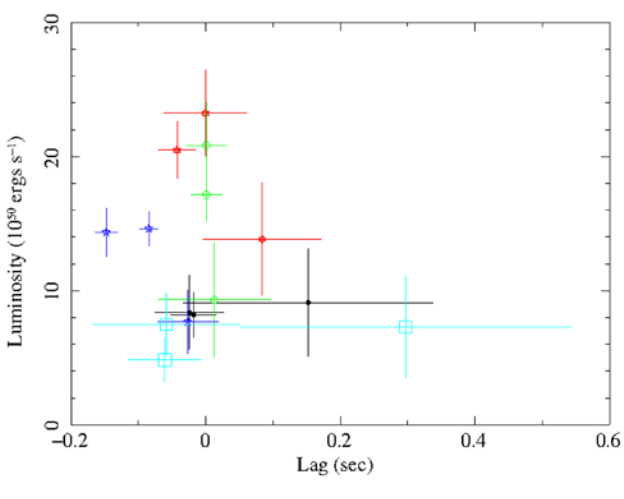

Figure: 4 Presents lag vs luminosity for 64 ms timing for five different pulses for GRB 111228A.

3.2 SPECTRAL ANALYSIS

We performed model fitting to the spectra employing negative and positive power laws with exponential (NPEX) model as a featureless continuum [10], [9].
It is modeled as

$$NPEX\,(E) = (A_1E^{-\alpha 1} + A_2{}^{+\alpha 2})\ \exp^{(-E/kT)}$$

Where E is the X-ray photon energy.
A_1 and $\alpha_1 > 0$ are the normalization and photon index of negative power law that dominates the low-energy band and A_2 and $\alpha_2 > 0$ are those of the positive power law and KT is the e-floding energy that represents the high energy cut off.

The fitted spectrum (as shown in figure 5) showed photon index = 6.64 ± 2.62 and we found high energy cut off at 15.08 keV (E_0 = 15.0864± 3.03). The central energy for the modeled data is found to be 36.79±1.38. Reduced chi-square = 0.8734 for 48 degrees of freedom.

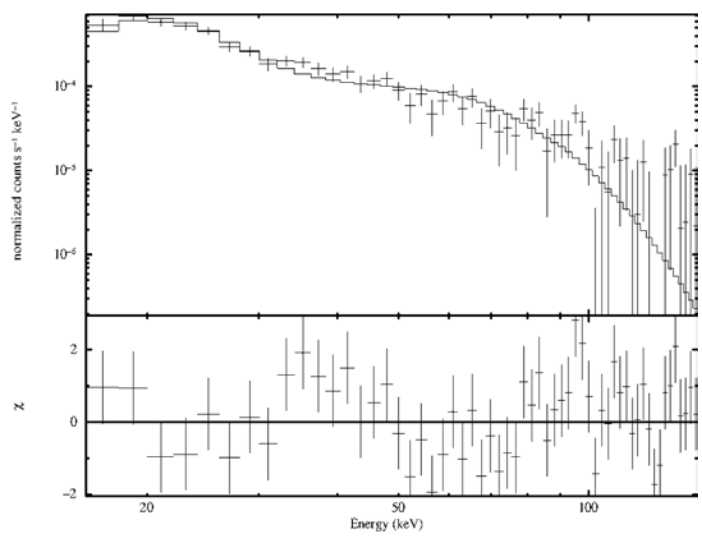

Figure: 5 Presents spectrum with residuals fitted with NPEX Model for GRB111228A.

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