GRB SPECTRAL LAGS IN THE SOURCE FRAME: AN INVESTIGATION OF FERMI-GBM BURSTS

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Spectral lag (difference between arrival times of high-energy and low-energy photons and considered positive when high-energy photons arrive earlier than low-energy ones) is a common feature in long GRBs. There exists an anti-correlation of Luminosity with Lag (Norris et al. 2000; Schaefer, Deng & Band 2001; Gehrels et al. 2006; Hakkila et al. 2008; Ukwatta et al. 2010; Arimoto et al. 2010). In this work, we have extracted spectral lags of Fermi GBM bursts in eight source-frame energy bands to probe wide source frame energy range compared to the Swift analysis. Our sample contains 37 GRBs with measured redshifts in the range 0.49 - 8.26. The source-frame energy bands were obtained by projecting variable observer-frame bands to the source-frame (Ukwatta et al. 2012).

LIGHT CURVE EXTRACTION

Using only the brightest combinations of NaI and BGO detectors in which the GRBs are seen, we created background-subtracted light curves from the High Time-resolution Time-Tagged Event (TTE) data. The background was subtracted by fitting a segment of a pre-burst region and one segment at the end of each light curve (post-burst region) using low-order polynomials for various time bins. IDL codes were used to extract background subtracted light curves for various observer-frame energy bands depending on redshift of each burst. The fixed source-frame energy bands were selected based on the detectable energy ranges of the NaI and BGO detectors of the Fermi - GBM Instrument (see Table 1).

Band	Energy keV
Band 1	100 - 150; 200 - 250
Band 2	350 - 450; 550 - 650
Band 3	850 - 1050; 1250 - 1450
Band 4	1850 - 2250; 2650 - 3050
Band 5	3850 - 4650; 5450 - 6250
Band 6	7850 - 9450; 11050 - 12650
Band 7	15850 - 19050; 22250 - 25450
Band 8	31850 - 38250; 44650 - 51050

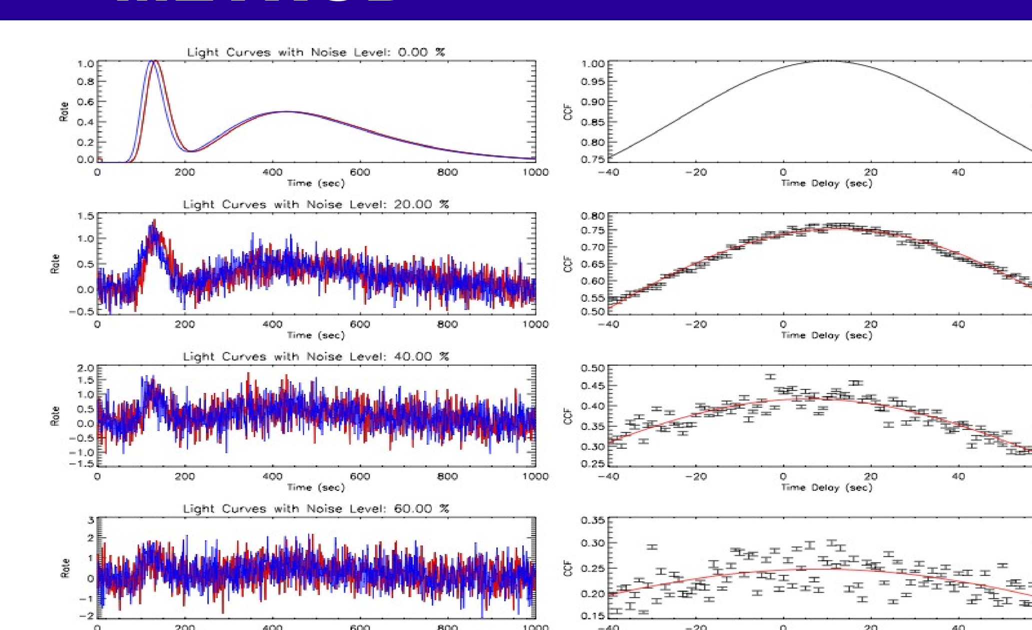
Table 1. The source frame energy bands for bursts in the sample

METHOD

The CCF method, described in Ukwatta et al. (2010), was used to calculate spectral lags. In this method, spectral lags are determined by fitting the global maximum of the cross correlation function by a Gaussian function. The CCF is defined as;

$$CCF(d,x,y) = \frac{\sum_{i=max(1,1-d)}^{min(N,N-d)} x_i y_i + d}{\sqrt{\sum_i x_i^2 \sum_i y_i^2}}$$

where, time delay is given by τ = d × time bin size and x ¯ and y ¯ are the average counts of x and y respectively.



Using Band function parameters α, β, E_p, and observed flux, f_{obs}, in a given energy band, Emin and Emax, we also calculated Luminosities for 34 long and 3 short GRBs. Uncertainties were calculated using Monte Carlo simulations.

RESULTS

We have obtained positive lag values for 12 long and one short GRBs. The short GRB (GRB 090510A) has a small lag value for bands 1 and 2 as previously reported by (Norris & Bonnell 2006; Zhang et al. 2006). Spectral lags and isotropic peak luminosities are plotted in a log–log scale. Black circles represent the lags calculated between Fermi/GBM source frame energy bands 100 - 150; 200 - 250 keV, 350 – 450; 550 – 650 keV, 850 – 1050; 1250 – 1450 keV respectively in Figure1, 2, 3 and red circles represent the spectral lags between Swift source-frame energy bands 100 - 150; 200 - 250 keV calculated by Ukwatta et al. 2012.

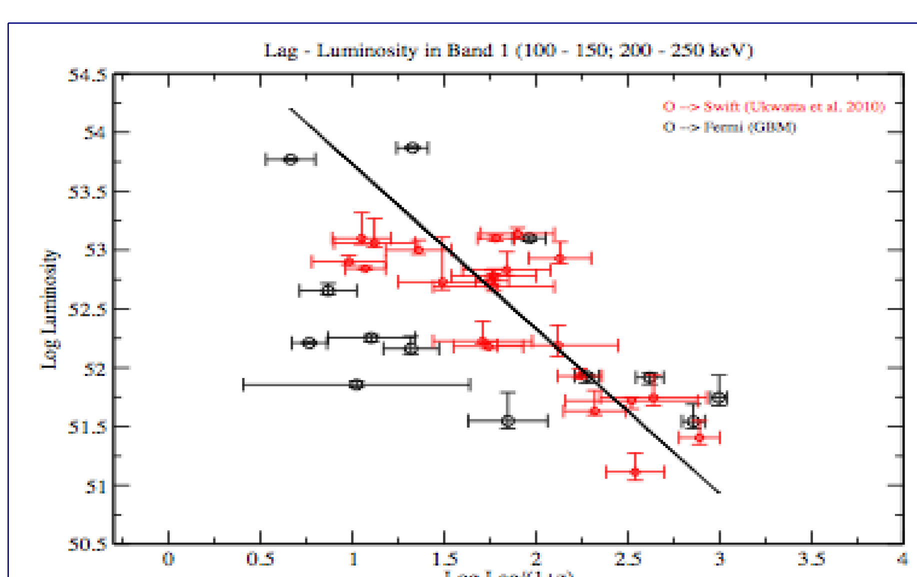


Figure 1.

The solid line shows the best-fit power - law for band 1 as follows

$$\log\left(\frac{L_{iso}}{ergs^{-1}}\right) = (55.13 \pm 0.13) - (1.4 \pm 0.06)\log\frac{lag/ms}{1+z}$$

The values of best-fit power - law indices for each band are consistent with source frame results obtained by (Ukwatta et al. 2012).

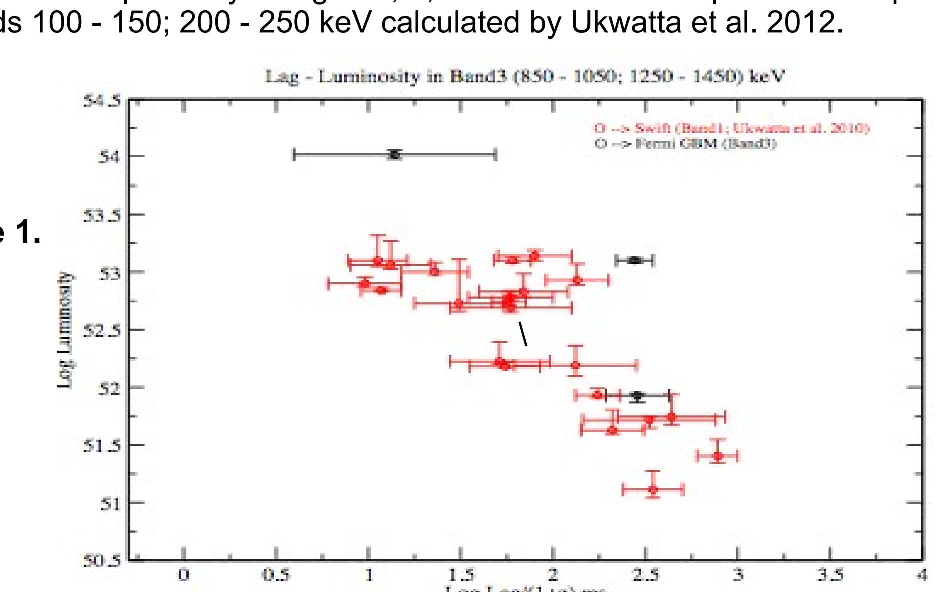


Figure 3.

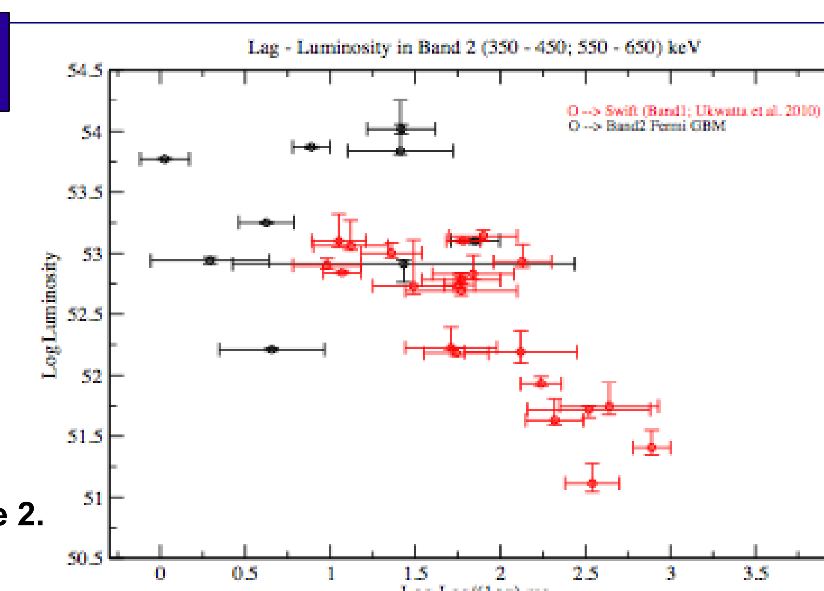


Figure 2.

Evolution of Lag vs Energy

We have selected five bright GRBs from the sample in order to see the evolution of lag versus source frame energies. The energy bands that we used to extract light curves cover both NaI and BGO ranges. We projected them to the observer frame energy bands using the redshift of each burst. Then, we calculated spectral lags of first band with respect to the other bands (Figure 5).

According to prediction of the curvature model by Lu et al. (2006), the value of spectral lag is expected to be either constant or zero beyond the value of E_{pk}. While GRB 080916009, GRB 090926181, GRB 0900510016 seem to be consistent with this prediction, GRB 081222204, and GRB 080916353 appear to contradict it.

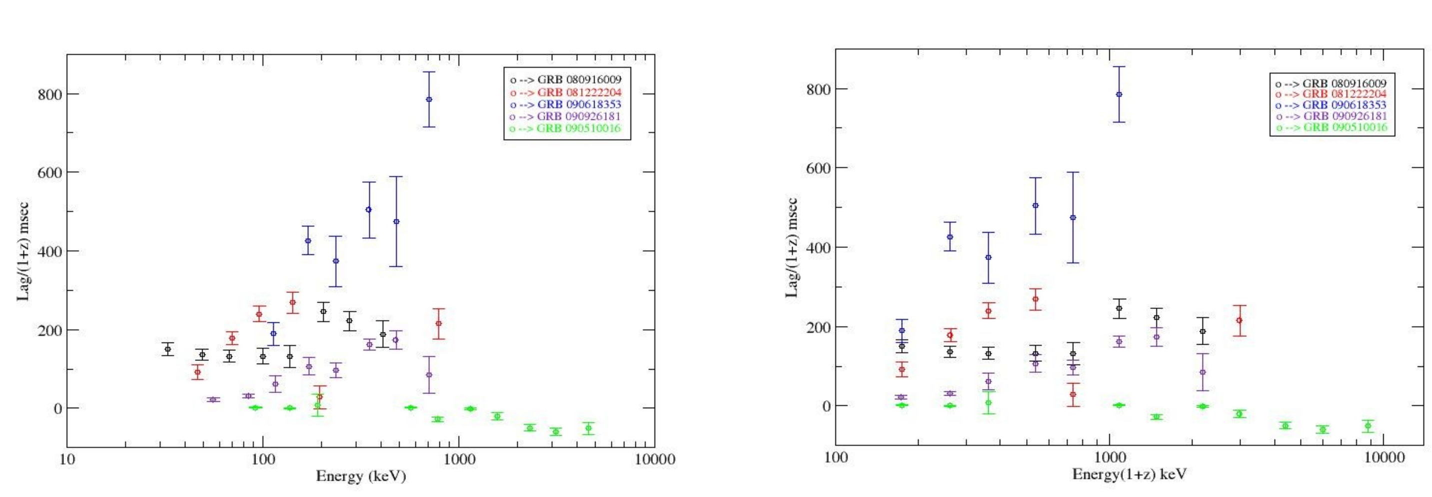


Figure 5. (a) (b)

Lag – Epk Relation

Spectral lags and source frame peak energy (E_{pk} (1+z)) are plotted in a log - log plot shown in Figure 4. The lags calculated between Fermi/GBM source frame energy bands 100-150; 200-250 keV, 350-450; 550-650 keV, 850-1050; 1250-1450 keV. The solid line represents the best fit. Source frame E_{pk} values were taken from (Gruber et al. 2011)

The best-fit gives the following relation between E_{pk}(1+z) and Lag/(1+z) for band 1:

$$\log\left(\frac{E_{pk}(1+z)}{keV}\right) = (3.57 \pm 0.05) - (0.49 \pm 0.02)\log\frac{lag/ms}{1+z}$$

The best-fit slope of -0.49 ± 0.02 for Band 1 is consistent with the results of (Ukwatta et al. 2012).

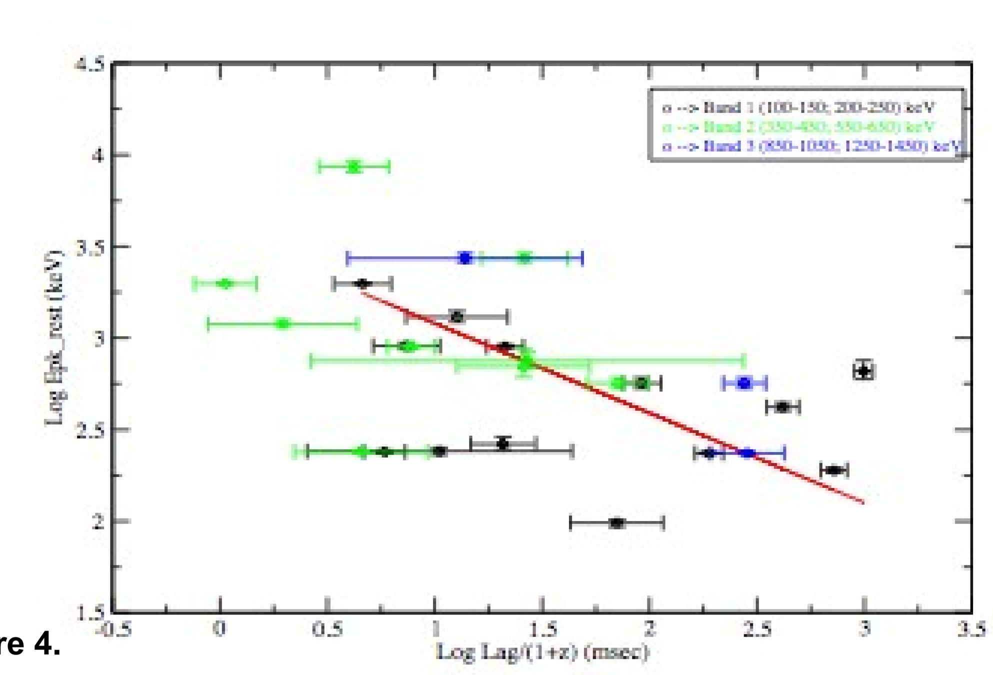


Figure 4.

Lag – Variability Relation

Employing a fast wavelet technique, MacLachlan et al. 2012, obtained a minimum variability timescale (MVT) for a sample of long and short GRBs. Using this timescale, we investigated the lag-variability relation in the source frame for band1 (Fig. 6).

Schaefer et al. (2001) tested the lag-variability relation using 112 BATSE bursts between channels 1 and 3. They found a correlation with *r =-0.45*. Our results show that there is a positive correlation between MVT and spectral lag (see Figure 6).

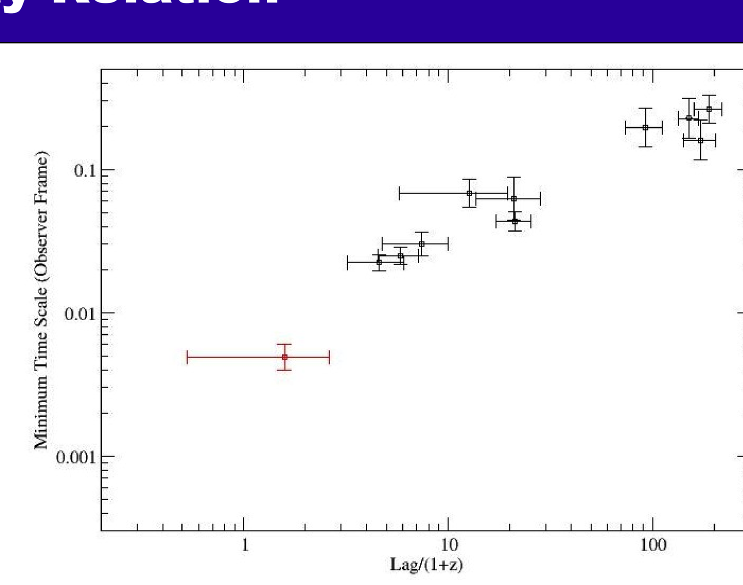


Figure 6.

CONCLUSIONS

We have analyzed the prompt emission for a sample of GBM bursts. The extracted spectral lags, in fixed source-frame energy bands, show features that are consistent with those exhibited by the bursts detected by Swift in the lower energy bands, i.e., the lag-luminosity relation appears to hold. We also notice that Epeak seems to indicate an anti-correlation with the spectral lag.

The evolution of spectral lag in long GRBs as a function of energy is of considerable interest theoretically. Our preliminary results show a number bursts to be consistent with the curvature model, and a number that appear to contradict the model. Further analysis is clearly warranted.

Finally, we exploit the minimum variability timescale extracted by MacLachlan et al 2012 to explore the lag-variability relation. Our results point to a positive correlation between these two temporal features of the prompt emission.

We plan on investigating possible energy dispersion effects as they relate to the extraction of lightcurves and the evolution of spectral lags.

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