Search for Millisecond Flares in INTEGRAL and RHESSI GRBs — towards probing Quantum Gravity with GRBs

Cornelia B. Wunderer, Eric Bellm, Steven E. Boggs and Kevin Hurley

Space Sciences Laboratory, UC Berkeley

Abstract. Since the discovery of the cosmological origin of GRBs there has been growing interest in using these transient events to probe the Quantum Gravity energy scale in the range 10^{16}–10^{19} GeV, up to the Planck mass scale. This energy scale can manifest itself through a modification in the electromagnetic radiation dispersion relation, specifically, an energy-dependence of the velocity of light. To impose stringent limits on a possible modification, a flare within a GRB must be both short and significant over a wide energy band to provide a sufficient baseline for determining dt/dE, the difference in the arrival times of photons of different energies. To approach the Planck mass scale, we must measure arrival time differences on the order of 0.5 ms from soft to hard (∼10 MeV) photons within a flare for a GRB at a redshift of a few. We have searched INTEGRAL- and RHESSI-observed GRBs for suitable flares, requiring a 5σ trigger on a 2 ms, 10 ms, or 100 ms time scale using only photons above 1 MeV. We present methods for automated determination of $\Delta t/\Delta E$ from GRB flares. GLAST's LAT will significantly expand the energy band accessible to GRB-based quantum gravity studies. GBM will provide more GRB flare data in the MeV regime, contributing to a systematic study of their properties.

Keywords: GRB, millisecond variability, quantum gravity, Lorentz invariance, INTEGRAL, RHESSI, GLAST
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INTRODUCTION

Some Quantum Gravity (QG) theories predict a violation of Lorentz Invariance manifesting itself in a slight dependence of the speed of light c on the photon energy [1, 2]. The magnitude of the variation depends on the QG energy scale E_{QG}. For some theories the propagation of electrons is also affected, others predict this energy dependence for photons only. Therefore the effect might not be visible in processes involving electrons/positrons as well as photons. Also, while polarization changes are a very sensitive probe of some QG theories (namely loop quantum gravity) which predict birefringence, this phenomenon is not predicted by all QG theories.

We aim to find 'flares' in a GRB lightcurve that extend to MeV energies and last on the order of a few milliseconds for a GRB at high redshift. If all flare photons are emitted at the source at the same time, a difference in arrival times between lower and higher energy photons — with lower-energy photons arriving earlier — allows determination of lower limits on E_{QG}. Given the 'right' GRB, the lower limit could be pushed to the Planck mass scale ($z = 2$, ΔE baseline 10 MeV, flare peak time shift of ∼0.5 ms). The simultaneous emission of all flare photons at the source, however, has not been established at MeV energies and on the timescales of interest; there may well be source-intrinsic spectral lags. A systematic study of GRB flare time-lag properties at these timescales and energies is needed to disentangle source-intrinsic lags from the z-dependent lags that would be induced by QG effects.

The RHESSI observation of GRB021206 has established that flares extending to MeV energies on millisecond timescales do occur [3]. The lack of a firmly established redshift, and the relatively low pseudoredshift derived from spectral characteristics, limited the exclusion power of the observation. The resulting upper limit on E_{QG}, $1.8\cdot10^{17}$GeV, nevertheless is quite stringent, reaching within 2 orders of magnitude of the Planck mass.

OBSERVATIONS

ESA's **INTEGRAL** observatory [4], launched in 2002, carries two complementary gamma-ray telescopes: IBIS and SPI. Single-event lists with precise enough photon timing for this search are available in the IBIS Compton-mode as well as all SPI data. At energies above one MeV where we concentrate our search for millisecond-timescale flares, SPI sees many more photons than IBIS in its Compton mode. We have only investigated GRBs in INTEGRAL's FoV; among the 29 GRBs seen through 2005 none resulted in a convincing flare trigger. The search of INTEGRAL data has been severely hampered by SPI electronic noise in the 1.4-1.6 MeV regime; a more detailed discussion of the INTEGRAL analysis can be found in [5].

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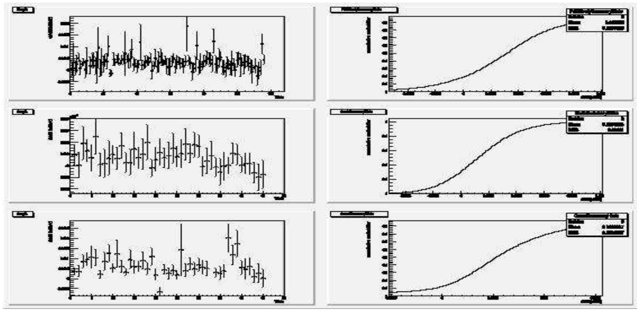

Top: gaussian + constant fit to light curve in each energy bin, with constraints on width derived from energy-integrated light curve >1 MeV;
Middle: centroid of photon arrival times calculated within a time window encompassing the full GRB flare;
Bottom: Kolmogorov-Smirnov-based matching of lightcurves — photon arrival history in each energy bin is matched with overall arrival of photons >1 MeV to determine most likely arrival time shift.

FIGURE 1. Sum of integrated probability of dt/dE value determined in the individual evaluations, separate for the 3 methods.

RHESSI [6] was launched by NASA in 2002. Its Ge detector volume is similar to SPI's, but without heavy shielding and thus views the full sky. We have applied the GRB flare trigger algorithms developed for INTEGRAL to selected RHESSI GRBs that exhibit significant emission above 1 MeV over the whole flare. (A more exhaustive search of all – currently $\sim$430 – RHESSI GRBs is planned.) As RHESSI data are tagged by time, energy, and detector, and at MeV energies photons can Compton-scatter between detectors, finding and combining such multiple events is part of our analysis. The approaches to this used in this work differ slightly from [3]. We note the presence of a higher fraction of short GRBs in *this* RHESSI sample, compared to that seen in *all* INTEGRAL FoV GRBs.

METHODS

Once a significant flare (5σ excess above 1 MeV in a 2 ms, 10 ms, or 100 ms time bin relative to a 40-bin average) is found, the challenge is to derive dt/dE and associated error bars from the often sparse data.

The choice of time bins, time bin edges, and energy bins can influence the result of dt/dE evaluations. Consequently, we used a range of time bin widths, time binning start times, and energy binnings on each GRB flare candidate. We use three different approaches to determining dt/dE described in Fig. 1; the first two were used in [3]. We then determine an overall best-fit dt/dE and overall errors from the range of dt/dE values and errors obtained in the individual evaluations. We sum the individual cumulative probability functions derived from best fit and error; the result is shown in Fig. 1.

For GRB021206 we obtain results that in all cases are consistent within one sigma with each other and with the dt/dE derived in our earlier analysis [3]. For all but the Kolmogorov-Smirnov test, the dt/dE derived is also consistent with dt/dE=0 within 1σ; for the KS-test dt/dE=0 lies well within 1.5σ.

SUMMARY AND OUTLOOK — GLAST

We have developed a partially automated, relatively bias-free method to determine dt/dE from GRB flare data. Future improvements will include energy binning dependent on the individual GRB flare statistics. GLAST's MeV-to-GeV coverage will provide significantly larger energy baselines, enabling more powerful constraints on dt/dE. MeV observations, also from GBM, will be invaluable in constraining intrinsic flare properties.

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REFERENCES

1. G. Amelino-Camelia, J. Ellis, N. E. Mavromatos, D. V. Nanopoulos, and S. Sarkar, *Nature* **393**, 763–765 (1998).
2. G. Amelino-Camelia, *Int. J. Mod. Phys. D* **12**, 1633–1639 (2003).
3. S. E. Boggs, C. B. Wunderer, K. Hurley, and W. Coburn, *Astrophys. J., Lett.* **611**, L77–L80 (2004).
4. C. Winkler, et al., *Astron. Astrophys.* **411**, L1–L6 (2003).
5. C. Wunderer, S. Boggs, and K. Hurley, in *Proc. 6th INTEGRAL Workshop*, ESA, 2007, vol. SP-, in press.
6. R. P. Lin, et al., *Sol. Phys.* **210**, 3–32 (2002).