A unified constraint on the Lorentz invariance violation from both short and long GRBs

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Based on the work arXiv: 1201.3413, to appear in Astroparticle Physics.

Fermi satellite observation

- Gamma-Ray Burst Monitor (GBM) : 8 KeV – 40 MeV,
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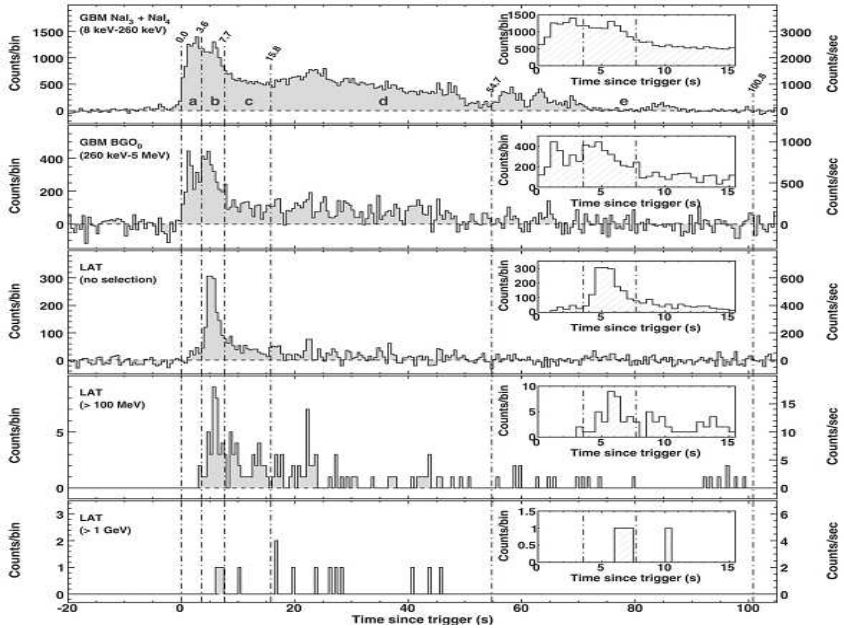

Figure: GRB 080916, The Fermi LAT and GBM Collaborations, Science, **323**:1688

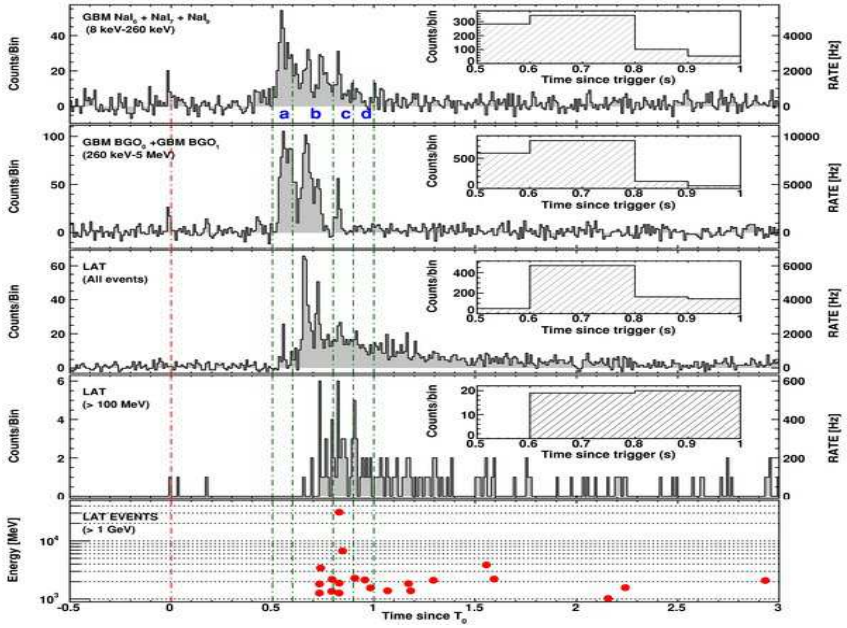

Figure: GRB 090510, Ackermann et al. ApJ, **716**:1178

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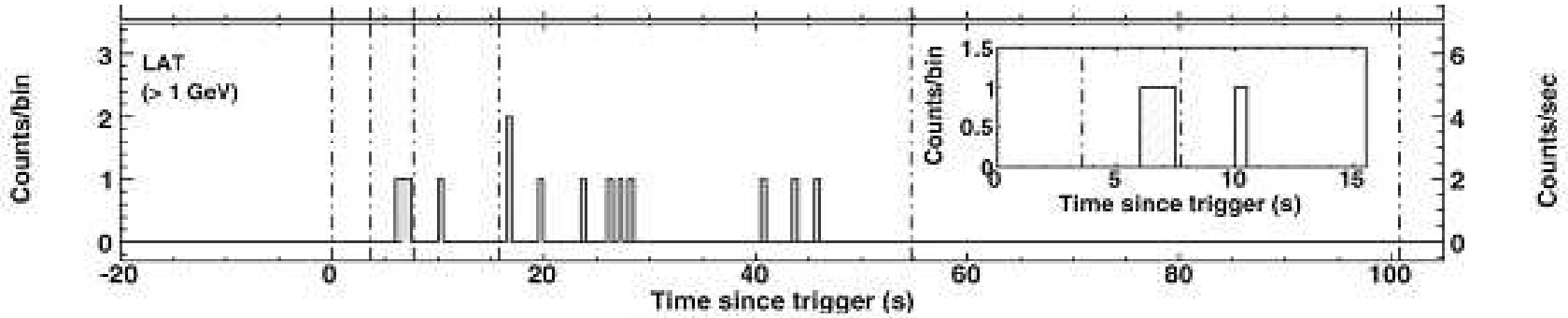

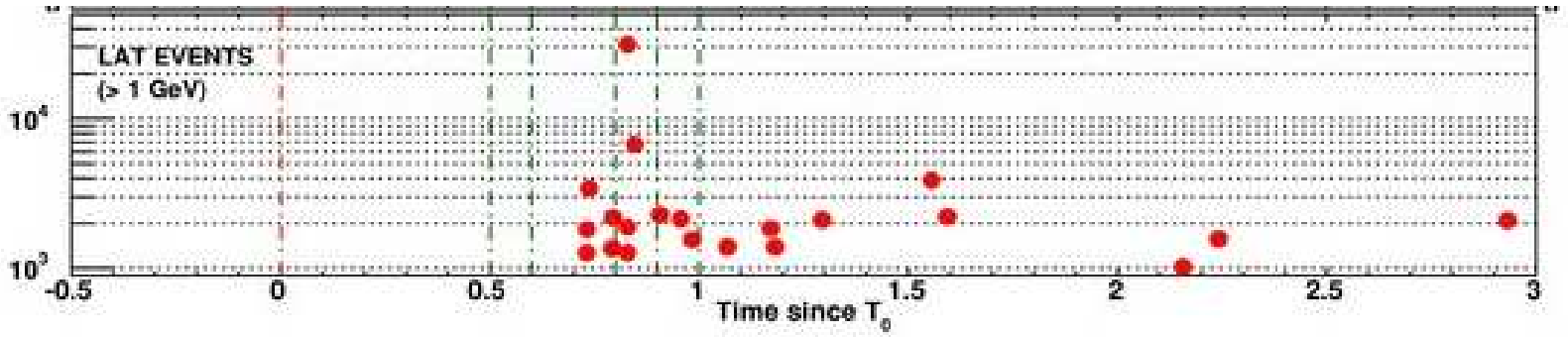

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- Our Recipe (Chang&Jiang&Lin, arXiv:1201.3413)

$$\Delta t_{\rm obs} = \Delta t_{\rm LIV} + \Delta t_{\rm int}.$$

Magnetic jet model, Bośnjak & Kumar

- Bulk Lorentz factor

$$\Gamma(r) \approx \begin{cases} (r/r_0)^{1/3} & \text{for} \quad r_0 \lesssim r \lesssim r_s, \\ \eta & \text{for} \quad r \gtrsim r_s. \end{cases}$$

- Optical depth

$$\tau_T(r) = \int_r^\infty \frac{dr'}{2\Gamma^2} \sigma_T n \Gamma,$$

where $n \simeq L/4\pi r^2 m_p \Gamma c^3 \sigma_0$.

- MeV emission

$$\frac{r_p}{r_0} \approx 1.36 \times 10^5 L_{52}^{3/5} \sigma_{0,3}^{-3/5} r_{0,7}^{-3/5},$$

where $L_{52} \equiv L/10^{52}\ \mathrm{erg \cdot s^{-1}}$, $\sigma_{0,3} \equiv \sigma_0/10^3$, and $r_{0,7} \equiv r_0/10^7$ cm.

Magnetic jet model

- Spectra of background photons:

$$n'_\gamma(>E) = \frac{1}{4\pi r^2 \Gamma c}\left(\frac{\beta-2}{\beta-1}\right)\left[\frac{E_p}{E}\right]^{\beta-1}\frac{L_{>p}}{(1+z)E_p},$$

- Optical depth of High Energy photons

$$\tau_\pm(E_0, r) = \left(\frac{\beta-2}{\beta-1}\right)\frac{\sigma_{\gamma\gamma}}{4\pi r\Gamma^2}\frac{L_{>p}}{(1+z)^{3-2\beta}E_p c}\left[\frac{E_p E_0}{\Gamma^2 m_e^2 c^4}\right]^{\beta-1}.$$

- GeV emission radius

$$\frac{r_{\gamma\gamma}(E_0)}{r_0} \approx 4.13\times 10^6 L_{>p,52}^{0.41} E_{p,-6}^{0.08} E_{0,-4}^{0.49} r_{0,7}^{-0.41}(1+z)^{0.57}$$

- Intrinsic time delay

$$\Delta t = \frac{3r_0(1+z)}{2c}\left[\left(\frac{r_{\gamma\gamma}(E_0)}{r_0}\right)^{1/3} - \left(\frac{r_p}{r_0}\right)^{1/3}\right].$$

LIV Effects

- LIV induced time delay

$$\Delta t_{\rm LIV} = \frac{1+n}{2c}\left(\frac{\Delta E}{M_n c^2}\right)^n D_n,$$

$$D_n \equiv \frac{c}{H_0}\int_0^z \frac{(1+z')^n dz'}{\sqrt{\Omega_M(1+z')^3+\Omega_\Lambda}}.$$

- For $n=1$,

$$M_1 c^2 = \frac{\Delta E}{\Delta t_{\rm LIV}}\frac{D_1}{c}.$$

- A statistical method

$$\frac{\Delta t_{\rm obs}}{1+z} = a_{\rm LIV} K(z) + b, \qquad K(z) \equiv \frac{\Delta E}{(1+z)}\frac{D_1}{c}$$

LIV Effects

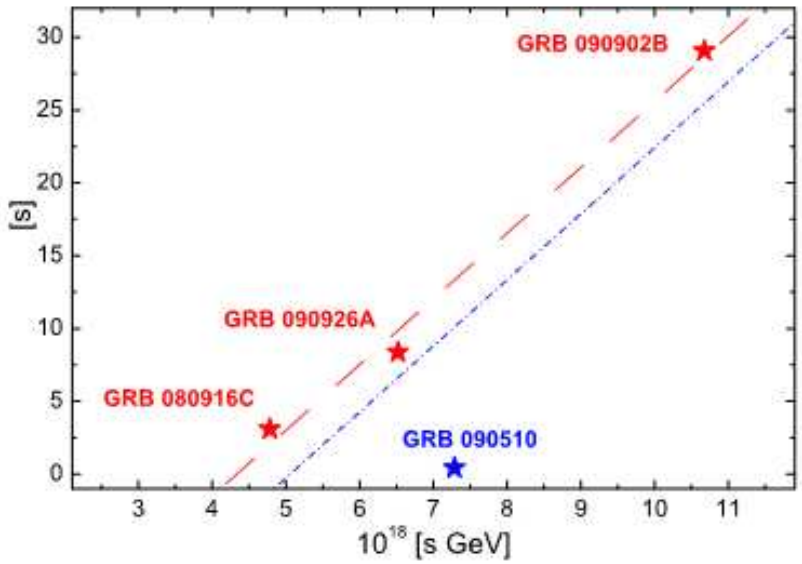

Figure: Linear fit of GRBs, $E_{\rm QG} = (2 \pm 0.2) \times 10^{17}$ GeV. Shao & Xiao, & Ma, arXiv:0911.2276

Questions:

- Dependence of GeV photons selection.
- GeV photons are emitted earlier.

LIV effects and GRB models

- Considering the GRB models

$$\Delta t_{\rm LIV} = \Delta t_{\rm obs} - \Delta t_{\rm int},$$

- Estimation of $b \sim \Delta t_{\rm int}/(1+z)$,

$$b \simeq 0.08\, r_{0.7}^{0.86} L_{>p,52}^{0.14} E_{p,-6}^{0.03} E_{0,-4}^{0.16} (1+z)^{0.19}$$

GRB	$E_{\rm low}$ MeV	$E_{\rm high}$ GeV	$\Delta t_{\rm obs}$ s	$\Delta t_{\rm LIV}$ s	$K(z)$ s·GeV	$M_1 c^2$ GeV
080916c	100	13.22	12.94	0.24	4.50×10^{18}	10.02×10^{19}
090510	100	31	0.20	0.14	7.02×10^{18}	9.73×10^{19}
090902b	100	11.16	9.5	0.10	3.38×10^{18}	9.94×10^{19}
090926	100	19.6	21.5	0.20	6.20×10^{18}	9.59×10^{19}

Table: $r_{0,7}$ is chosen as 16.7, 0.1, 28.7 and 55.0 for GRB 080916c, GRB 090510, GRB 090902b and GRB 090926, respectively.

LIV effects and GRB models

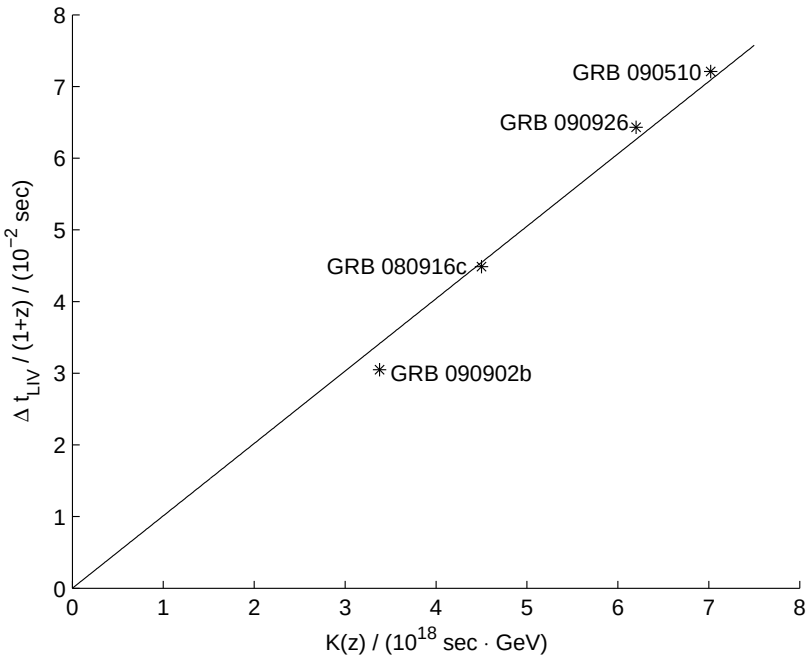

Figure: The plot of $\Delta t_{\rm LIV}/(1+z)$ vs. $K(z)$ for four *Fermi*-detected GRBs.

- Quantum gravity scale

$$M_1 c^2 \sim 1.0 \times 10^{20}\, GeV$$

Discussion and conclusion

- Without GRB models, the LIV effects are not conclusive.
- The quantum energy scale is 10^{20} GeV.
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- Quantum gravity theories are ruled out?
- Are GRB models trustable?

Thank you!