



Light Speed Variation from Gamma Ray Bursts

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In collaboration with Zhi Xiao, Lijing Shao, Shimin Yang, Zhou Lingli, Haowei Xu, Yunqi Xu, Nan Qin, Shu Zhang.....

Principles of Special Relativity

- **Principle of Relativity:** the equations describing the laws of physics have the same form in all admissible frames of reference.
- **Principle of constant light speed:** the speed of light is the same in all directions in vacuum in all reference frames, regardless whether the source of the light is moving or not.

Triumphs of Einstein's Relativity

- One of the foundations of modern physics.
- Proved to be valid at very high precision.

Lorentz Invariance, the basic theoretical foundation of relativity, states that

the equations describing the laws of physics have the same form in all admissible reference frames.

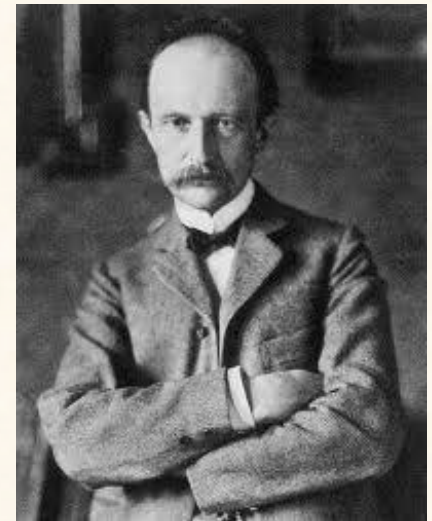
So is there any reason that we seek for

Lorentz Violation ?

Planck's *God-Given Unit System*

(Planck, 1899)

c , G , \hbar , k_B , and $1/4\pi\epsilon_0$



Planck, 1900

units of length, mass, time, and temperature that would, independently of special bodies and substances, necessarily retain their significance for all times and all cultures, even extraterrestrial and extrahuman ones, and which may therefore be designated as natural units of measure. (Planck 1899, pp. 479–480)

Planck, M.: Über irreversible Strahlungsvorgänge. Sitzungsberichte der Königlich Preussischen Akademie der Wissenschaften zu Berlin **5**, 440 (1899)

Basic units of the universe: Planck Units

$$l_P = \sqrt{\frac{G\hbar}{c^3}} = 1.61624(8) \times 10^{-35} \text{ m}$$

$$t_P \equiv \sqrt{G\hbar/c^5} \simeq 5.4 \times 10^{-44} \text{ s}$$

$$M_P = \sqrt{\frac{\hbar c}{G}} = 1.22089(6) \times 10^{19} \frac{\text{GeV}}{c^2} = 2.17644(11) \times 10^{-8} \text{ kg}$$

$$E_P \equiv \sqrt{\hbar c^5/G} \simeq 2.0 \times 10^9 \text{ J}$$

$$T_P \equiv \sqrt{\hbar c^5/Gk_B^2} \simeq 1.4 \times 10^{32} \text{ K}$$

A physical argument of discrete space-time

Y.Xu & B.-Q.Ma, MPLA 26 (2011) 2101, arXiv: 1106.1778

- From two known entropy constraints:

$$S_{\text{matter}} \leq 2\pi ER, \quad S_{\text{matter}} \leq \frac{A}{4},$$

- Combined with black-body entropy

$$S = \frac{4}{45}\pi^2 T^3 V = \frac{16}{135}\pi^3 R^3 T^3.$$

- We arrive at a minimum value of space

$$R \geq \left(\frac{128}{3645\pi}\right)^{\frac{1}{2}} l_{\text{P}} \simeq 0.1 l_{\text{P}},$$

We reveal from physical arguments that space-time is discrete rather than continuous.

Proposal of a **new fundamental length scale** instead of the Newtonian constant

L.Shao & B.-Q.Ma, *Sci.China Phys. Mech. Astro.* 54 (2011) 1771, arXiv: 1006.3031

- If gravity is emergent, a new fundamental constant should be introduced to replace G .
- It is natural to suggest a fundamental length scale.
- Such constant can be explained as the smallest length scale of quantum space-time.
- Its value can be measured through searches of Lorentz violation.

LV as Window on the Nature of Space-Time

- The typical scale of quantum gravity is Planck scale

$$l_P = \sqrt{\frac{G\hbar}{c^3}} = 1.61624(8) \times 10^{-35} \text{ m}$$

$$t_P \equiv \sqrt{G\hbar/c^5} \simeq 5.4 \times 10^{-44} \text{ s}$$

$$E_P \equiv \sqrt{\hbar c^5/G} \simeq 2.0 \times 10^9 \text{ J}$$

Lorentz Violation could be a relic probe for the nature of space-time & quantum gravity

Many possible ways for Lorentz violation

- spacetime foam [Ellis et al.'08, PLB]
- loop gravity [Alfaro et al.'00, PRL]
- backgrounds in general gravity [Ni'75, PRL; Yan'83, TP,]
- vacuum condensate of antisymmetric tensor fields in string theory [Kostelecky & Samuel'89 & '91, PRL]
- double special relativity [Amelino-Camelia'02, Nature & '02 IJMPD]

A New Theory: the replacement of basic principle in Special Relativity

- Principle of Relativity: the equations describing the laws of physics have the same form in all admissible frames of reference.



- Principle of physical invariance :
the equations describing the laws of physics have the same form in all **admissible mathematical manifolds.**

A new theory of Lorentz violation

- a replacement of the common derivative operators by covariant co-derivative ones

$$\partial^\alpha \rightarrow M^{\alpha\beta} \partial_\beta, \quad D^\alpha \rightarrow M^{\alpha\beta} D_\beta,$$

- The effective minimal Standard Model

$$\mathcal{L}_{SM} = \mathcal{L}_G + \mathcal{L}_F + \mathcal{L}_{HG} + \mathcal{L}_{HF},$$

$$\mathcal{L}_G = -\frac{1}{4} F^{a\alpha\beta} F_{\alpha\beta}^a,$$

$$\mathcal{L}_F = i\bar{\psi}\gamma^\alpha D_\alpha\psi,$$

$$\mathcal{L}_{HG} = (D^\alpha\phi)^\dagger D_\alpha\phi + V(\phi),$$

- A new standard model with supplementary terms

$$\mathcal{L}_{SMS} = \mathcal{L}_{SM} + \mathcal{L}_{LV},$$

$$\mathcal{L}_{LV} = \mathcal{L}_{GV} + \mathcal{L}_{FV} + \mathcal{L}_{HFV}$$

Zhou Lingli and B.-Q. Ma, *MPLA* 25 (2010) 2489, arXiv:1009.1331 ; *CPC* 35 (2011) 987, arXiv: 1109.6387

The Lorentz invariance violation matrix

$$M^{\alpha\beta} = g^{\alpha\beta} + \Delta^{\alpha\beta},$$

$$\Delta^{\alpha\beta} = \begin{cases} 0 & \text{LI exact} \\ \rightarrow 0 & \text{LV small} \\ \text{otherwise LV big} \end{cases} .$$

The Lorentz violation for protons from GZK cut-off

A special case is

$$\Delta^{\alpha\beta} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & \xi & 0 & 0 \\ 0 & 0 & \xi & 0 \\ 0 & 0 & 0 & \xi \end{pmatrix},$$

$$E^2 = (1 - \delta)\vec{p}^2 + m^2,$$

$$\delta = -\xi^2 + 2\xi.$$

$$\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 10^{-23} & 0 & 0 \\ 0 & 0 & 10^{-23} & 0 \\ 0 & 0 & 0 & 10^{-23} \end{pmatrix},$$

LV from energetic photon emissions from GRBs

Z.Xiao and B.-Q.Ma, PRD 80 (2009) 116005, arXiv:0909.4927

L.Shao, Z.Xiao and B.-Q.Ma, APP 33 (2010) 312, arXiv:0911.2276

S.Zhang, B.-Q.Ma, APP 61 (2015) 108, arXiv:1406.4568

H.Xu, B.-Q.Ma, APP 82 (2016) 72, arXiv: 1607.03203

H.Xu, B.-Q.Ma, PLB 760 (2016) 602, arXiv: :1607.08043

H.Xu, B.-Q.Ma, JCAP 1801 (2018) 050, arXiv: 1801.08084

.....

Modified photon dispersion relation from LV

$$v(E) = c_0 \left(1 - \xi \frac{E}{M_{\text{P}} c^2} - \zeta \frac{E^2}{M_{\text{P}}^2 c^4} \right)$$



$$\sqrt{\hbar c / G} \simeq 1.22 \times 10^{19} \text{ GeV} / c^2$$

Z.Xiao and B.-Q.Ma, PRD 80 (09) 116005, arXiv:0909.4927

See also, e.g.,

Jacobson et al.'06, Ann. Phys.

Kostelecky & Mewes'09, PRD

Mattingly'05, Living Rev. Rel.

Amelino-Camelia & Smonlin'09, PRD

Gammy-ray Bursts (GRBs)

- the most energetic astrophysical process except the Big Bang
- 2 types [[Piran'05, Rev. Mod. Phys.](#)]
 - long GRBs: duration > 2 s; collapses of massive rapidly rotating stars
 - short GRBs: duration < 2 s; coalescence of two neutron stars or a neutron star and a black hole
- use GRBs to test LV [[Amelino-Camelia et al.'98, Nature](#)]



Formulas in our analysis of LV parameter

linear and quadratic energy dependence

$$v(E) = c_0 \left(1 - \frac{E}{M_{\text{QG}} c^2} \right)$$

$$v(E) = c_0 \left(1 - \frac{E^2}{M_{\text{QG}}^2 c^4} \right)$$

- L.Shao, Z.Xiao and B.-Q.Ma, APP 33 (2010) 312, arXiv:0911.2276
- S.Zhang, B.-Q.Ma, APP 61 (2015) 108, arXiv:1406.4568
- H.Xu, B.-Q.Ma, APP 82 (2016) 72, arXiv: 1607.03203
- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602
- H.Xu, B.-Q.Ma, JCAP 1801 (2018) 050

Time lag by LV effect

- expansion universe [Jacob & Piran'08, JCAP]

$$\Delta t_{\text{LV}} = \frac{1+n}{2H_0} \left(\frac{E_h^n - E_1^n}{M_{\text{QG}}^n c^{2n}} \right) \int_0^z \frac{(1+z')^n dz'}{h(z')}$$

$$M_{\text{QG,L}} = |\xi|^{-1} M_{\text{P}} \quad \text{and} \quad M_{\text{QG,Q}} = |\zeta|^{-1/2} M_{\text{P}}$$

$$h(z) = \sqrt{\Omega_{\Lambda} + \Omega_{\text{M}}(1+z)^3}$$

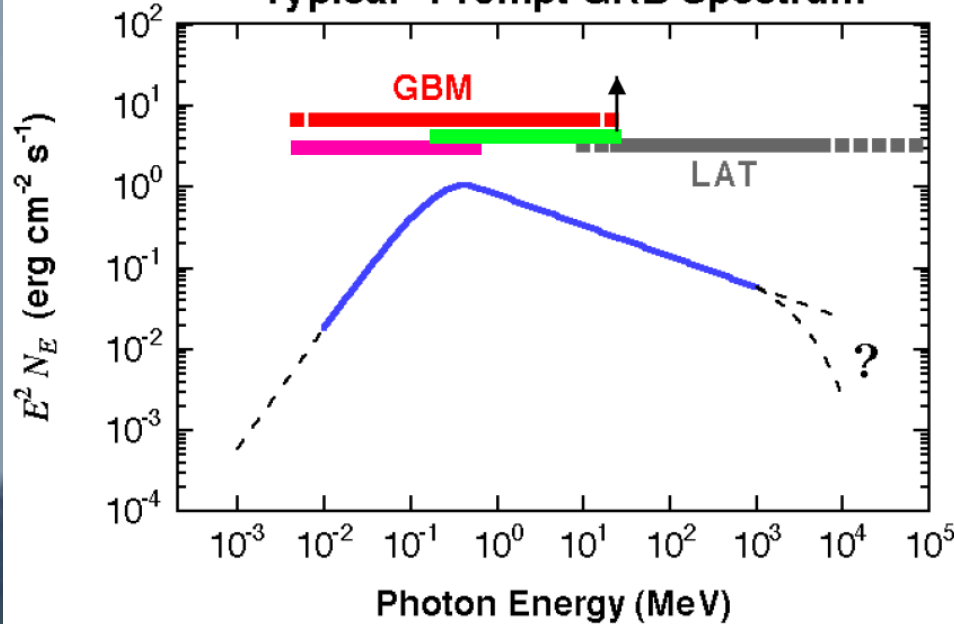
$$H_0 \simeq 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$\Omega_{\Lambda} \simeq 0.73 \quad \Omega_{\text{M}} \simeq 0.27$$

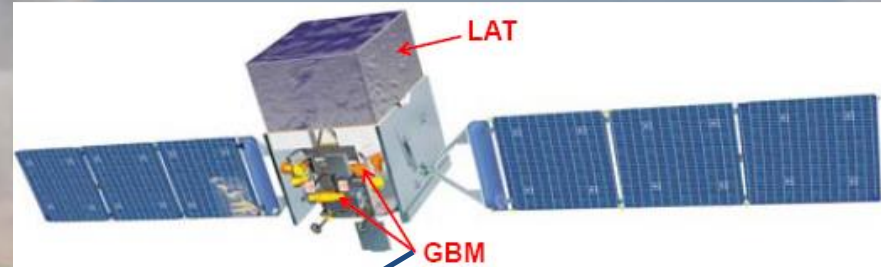
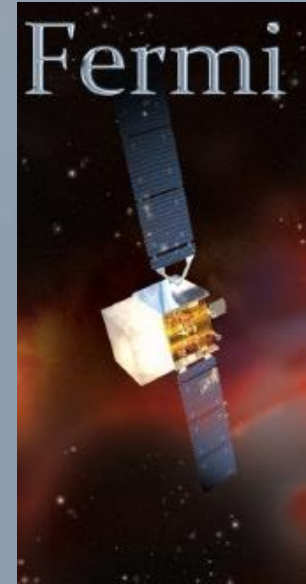
June 11, 2008

Fermi instruments

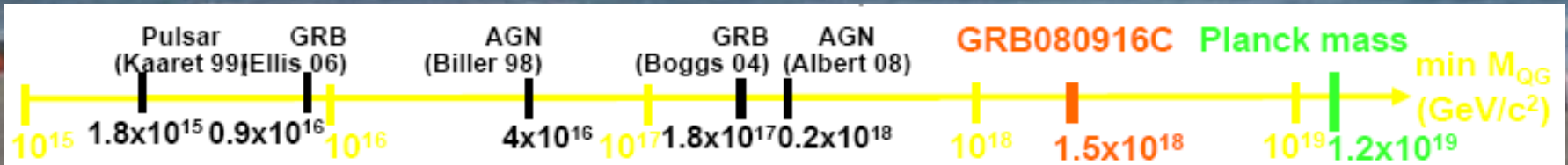
"Typical" Prompt GRB Spectrum



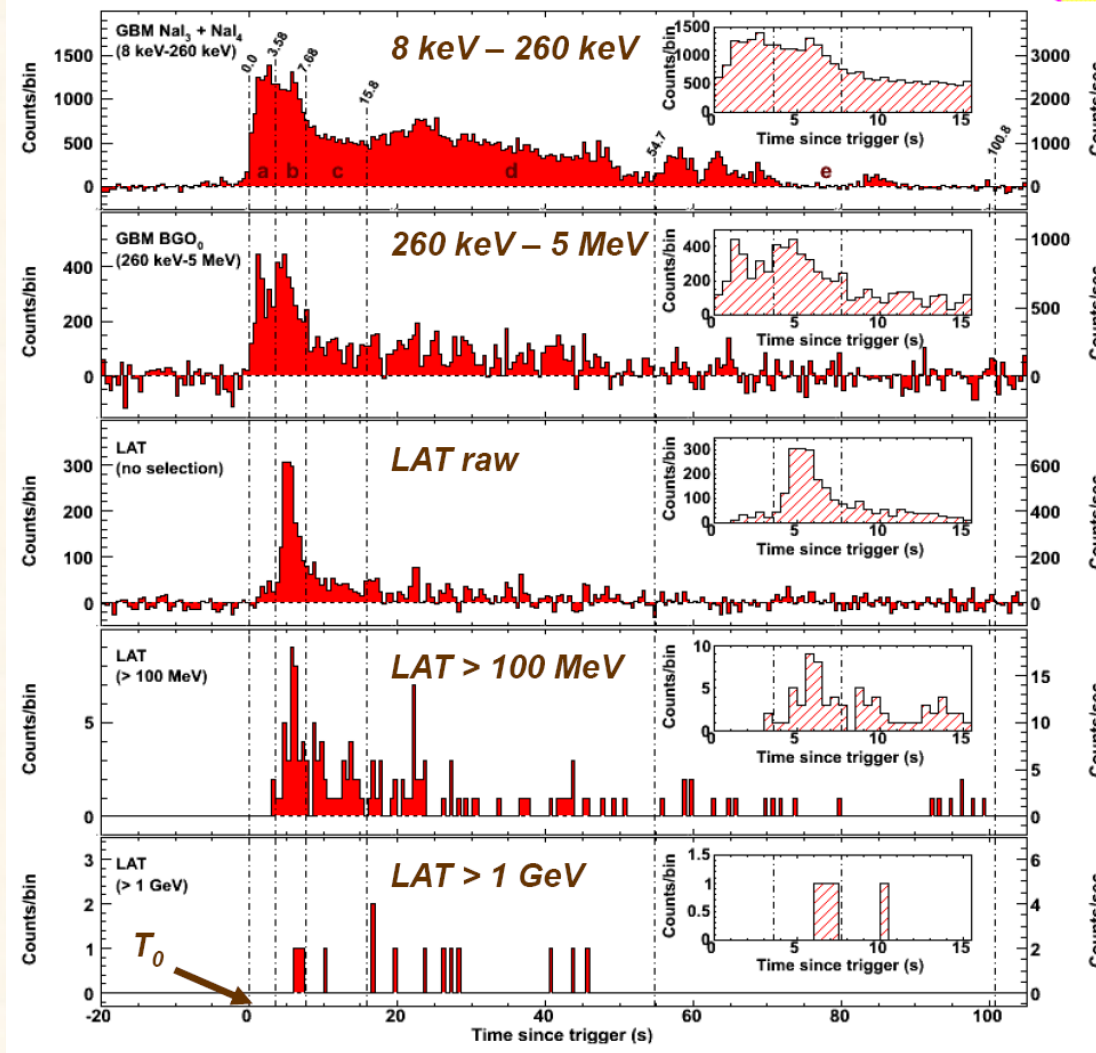
~ 300 GeV



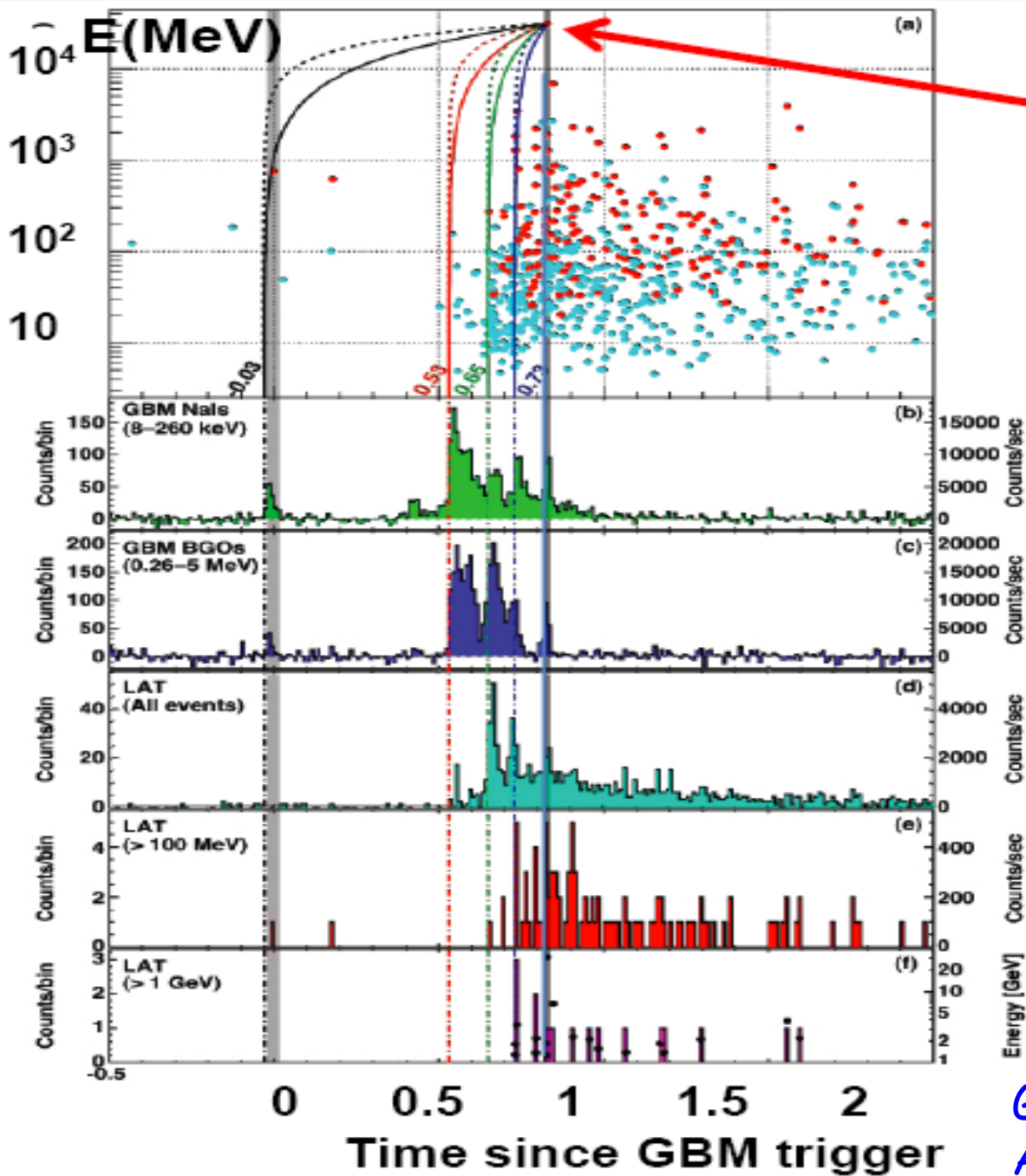
trigger photons ~ 0.1 MeV



Lag determinations



GRB080916C -- Abdo et al.'09, Science



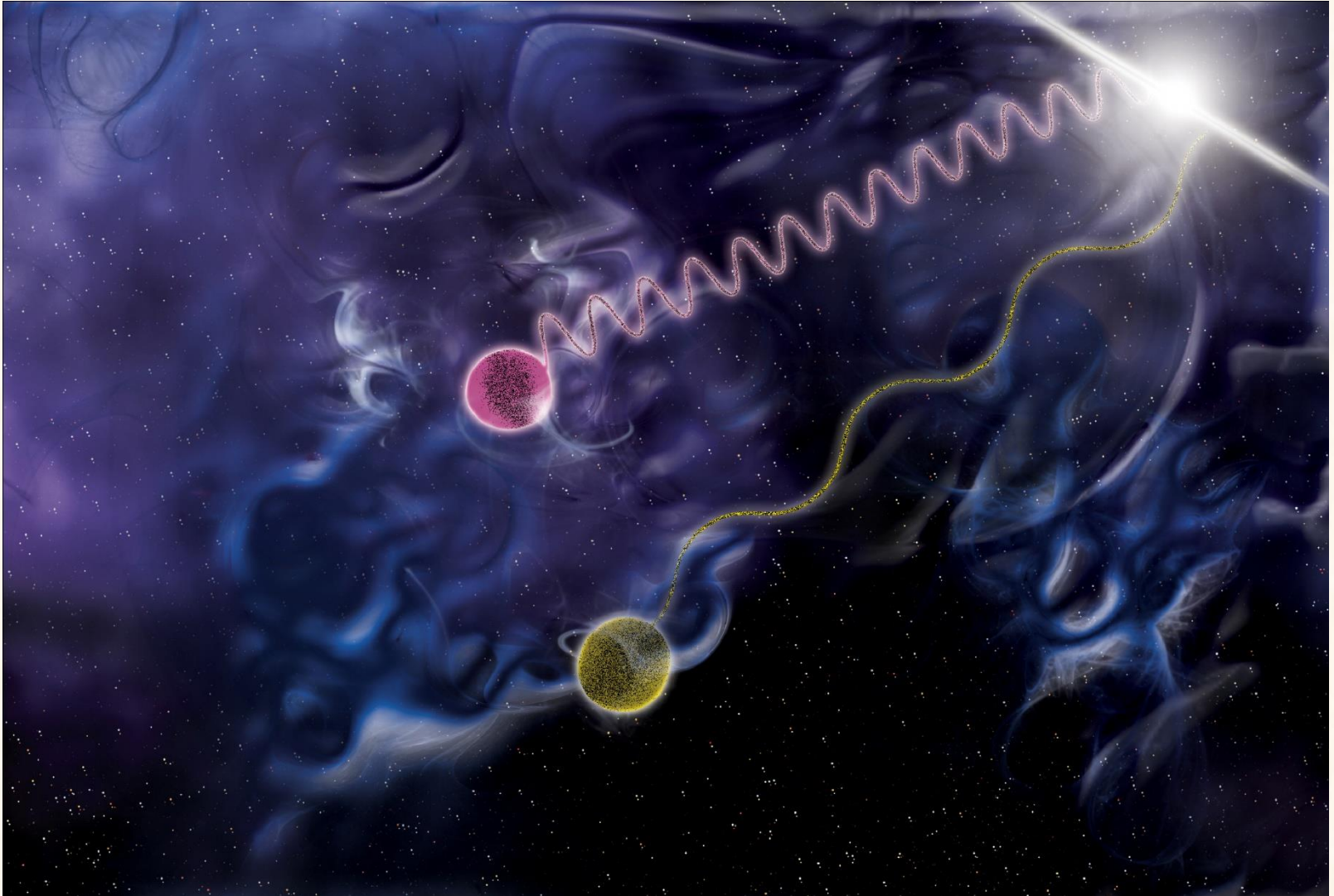
31 GeV

Time lags are affected both artificially and instrumentally

GRB090510


Abdo et al.'09, Nature

Time-lag by GRB




Four Fermi observations

the arrival of the highest energy photon to GBM trigger



GRBs	z	E (GeV)	Δt_{obs} (s)	$M_{\text{QG,L}}$ (GeV/c ²)	$M_{\text{QG,Q}}$ (GeV/c ²)
080916C [19]	4.35 [21]	13.22	16.54	1.5×10^{18}	9.7×10^9
090510 [20]	0.903 [22]	31	0.829	1.7×10^{19}	3.4×10^{10}
090902B [23]	1.822 [24]	33.4	82	3.7×10^{17}	5.9×10^9
090926A [25]	2.1062 [26]	19.6	26	7.8×10^{17}	6.8×10^9


$$\Delta t_{\text{obs}} = \Delta t_{\text{LV}}$$

$$M_{\text{QG,L}} \sim (4.9 \pm 8.1) \times 10^{18} \text{ GeV}$$

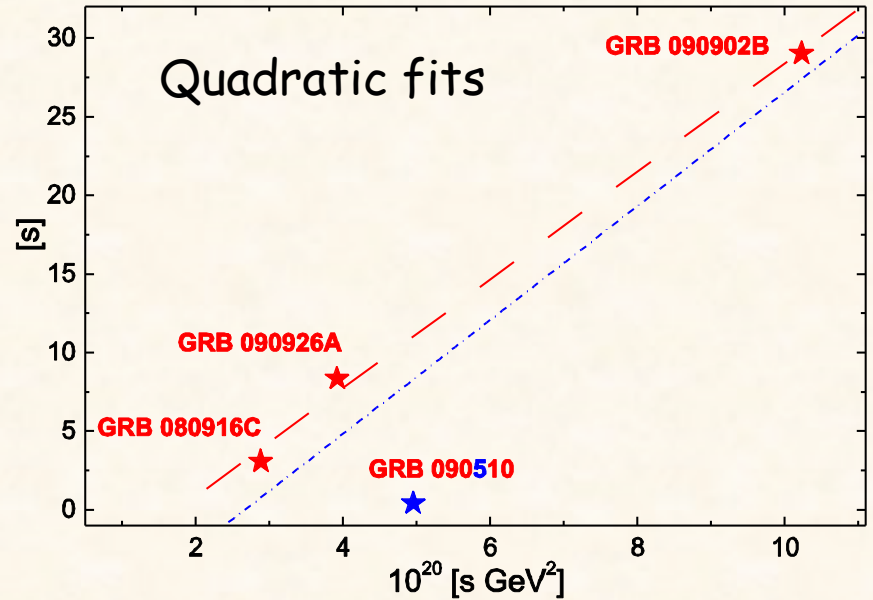
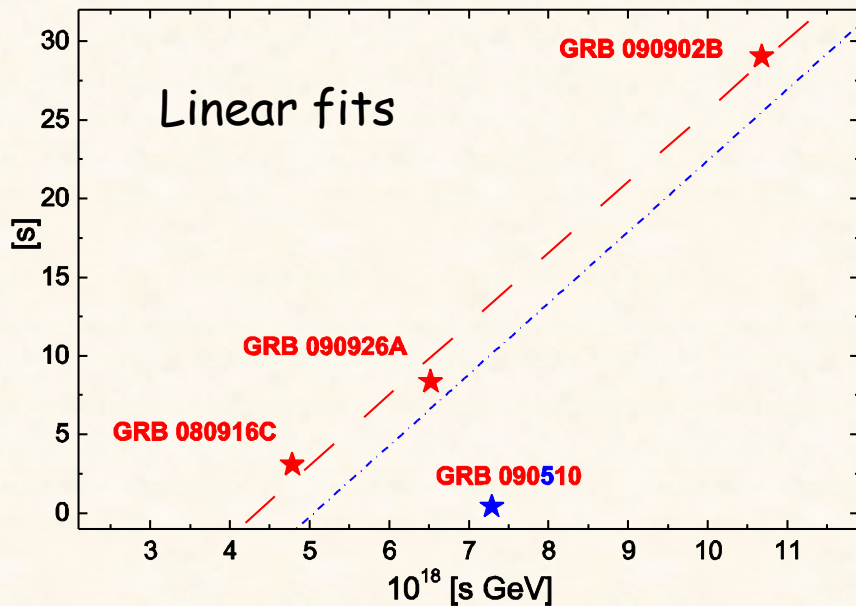
$$M_{\text{QG,Q}} \sim (1.4 \pm 1.3) \times 10^{10} \text{ GeV}$$

Separation of astrophysical time lags from LV delay

- imperfect knowledge of radiation mechanism of GRBs
- a survey of GRBs at different redshifts
 - the time lag induced by LV accumulates with propagation distance
 - the **intrinsic source** induced time lag is likely to be a distance independent quantity
- A robust survey [Ellis et al.'06 & 08, *Astropart. Phys.*]

$$\Delta t_{\text{LV}} = \frac{1+n}{2H_0} \left(\frac{E_h^n - E_l^n}{M_{\text{QG}}^n c^{2n}} \right) \int_0^z \frac{(1+z')^n dz'}{h(z')}$$

$$\Delta t_{\text{obs}} = \Delta t_{\text{LV}} + \Delta t_{\text{in}}(1+z)$$



$$M_{\text{QG,L}} = (2.2 \pm 0.2) \times 10^{17} \text{ GeV}/c^2 \text{ and } M_{\text{QG,Q}} = (5.4 \pm 0.2) \times 10^9 \text{ GeV}/c^2$$

$$M_{\text{QG,L}} = (2.2 \pm 0.9) \times 10^{17} \text{ GeV}/c^2 \text{ and } M_{\text{QG,Q}} = (5.3 \pm 0.8) \times 10^9 \text{ GeV}/c^2$$

the $\Delta t_{\text{obs}}/(1+z)$ - K_n plot

An intuitive way to perform analysis

$$\frac{\Delta t_{\text{obs}}}{1+z} = s_n \frac{K_n}{E_{\text{LV},n}^n} + \Delta t_{\text{in}}$$

$$K_n = \frac{1+n}{2H_0} \frac{E_{\text{high}}^n - E_{\text{low}}^n}{1+z} \int_0^z \frac{(1+z')^n dz'}{\sqrt{\Omega_m(1+z')^3 + \Omega_\Lambda}}$$

S.Zhang, B.-Q.Ma, APP 61 (2015) 108, arXiv:1406:4568

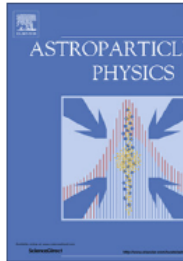
further development

Astroparticle Physics 61 (2015) 108–112

Contents lists available at [ScienceDirect](#)

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart



Lorentz violation from gamma-ray bursts

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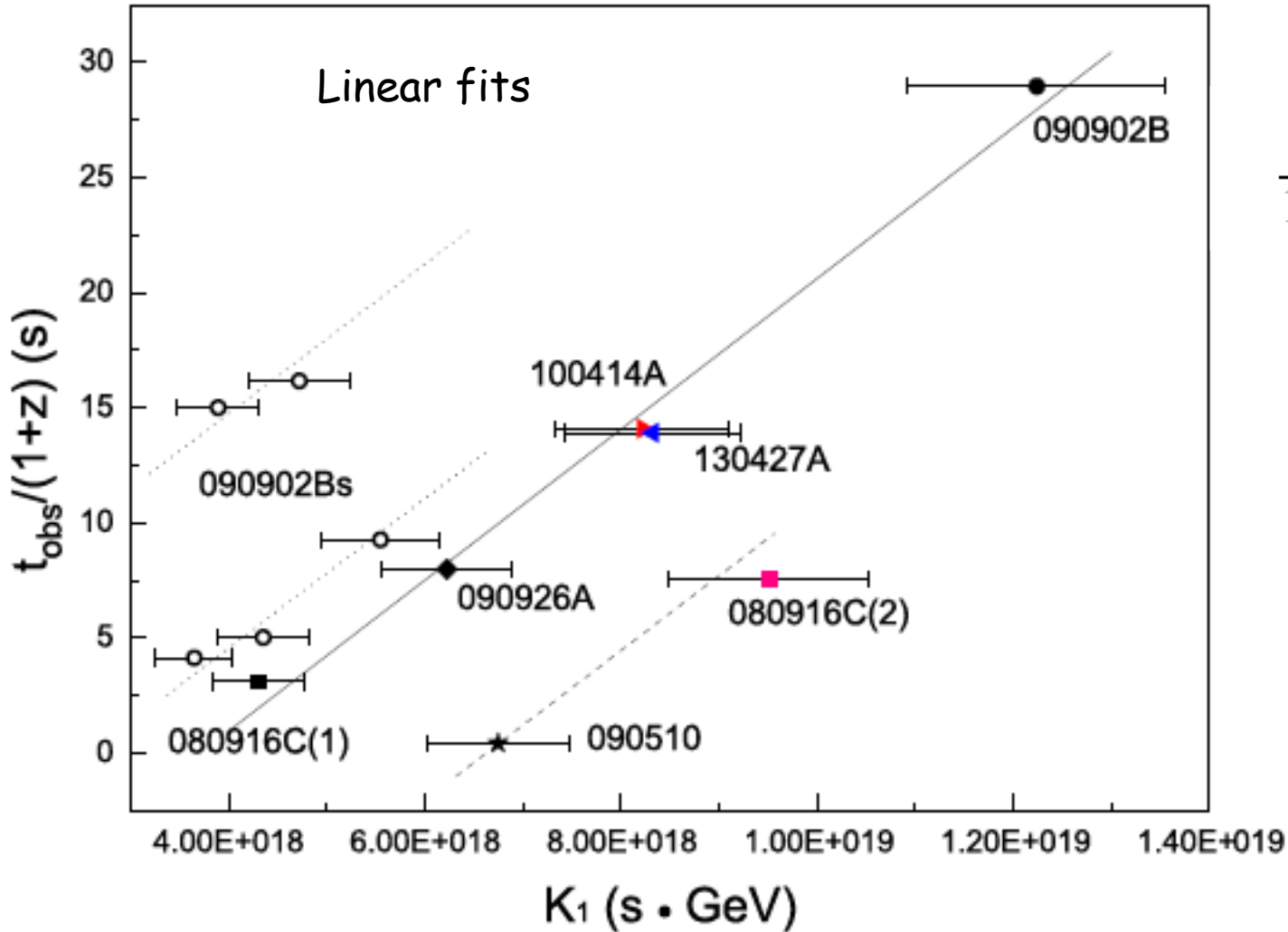
Added data

Table 1: The data of the GRBs with high energy photons and known redshifts.

GRB	z	t_{obs} (s)	E_{obs} (GeV)	E_{in} (GeV)	$E_{\text{LV},1}$ ($\times 10^{17}$ GeV)	$\frac{t_{\text{obs}}}{1+z}$ (s)	K_1 ($\times 10^{18}$ s \cdot GeV)
080916C(1)	4.35 ± 0.15	16.545	12.4	66.3	13.9 ± 1.7	3.092	4.30
090926A	2.1071 ± 0.0001	24.835	19.5	60.6	7.8 ± 0.8	7.993	6.23
100414A	1.368	33.365	29.7	70.3	5.8 ± 0.6	14.090	8.22
130427A ^a	0.3399 ± 0.0002	18.644	72.6	97.3	6.0 ± 0.7	13.915	8.32
090902B	1.822	81.746	39.9	112.6	4.2 ± 0.5	28.967	12.24
090510	0.903 ± 0.003	0.828	29.9	56.9	155 ± 17	0.435	6.75
080916C(2)	4.35 ± 0.15	40.509	27.4	146.6	12.6 ± 1.4	7.572	9.51
		11.671	11.9	33.6	8.8 ± 1.0	4.136	3.65
		14.166	14.2	40.1	8.7 ± 1.0	5.020	4.36
090902Bs	1.822	26.168	18.1	51.1	6.0 ± 0.7	9.273	5.55
		42.374	12.7	35.8	2.6 ± 0.3	15.016	3.90
		45.608	15.4	43.5	2.9 ± 0.3	16.162	4.72

^aThe data of this GRB are from the Pass 7 LAT reconstruction. The references for the redshifts of the GRBs are [18](GRB 080916C), [22](GRB 090510), [21](GRB 090902B), [19](GRB 090926A), [20](GRB 100414A), and [17](GRB 130427A). t_{obs} is the arrival time after the onset of the GRBs, E_{obs} is the measured energy of the photon, E_{in} is the intrinsic energy at the source of the GRBs, and $E_{\text{LV},1}$ is the Lorentz violation parameter of the linear LV model without considering the intrinsic time lag. The standard errors of $E_{\text{LV},1}$'s are calculated with the consideration of the energy resolution of LAT [25] and the uncertainties of the cosmological parameters and the redshifts. K_1 is the Lorentz violation factor with a unit as (s \cdot GeV)

further development



$$\frac{t_{\text{obs}}}{1+z} = \frac{K_n}{E_{\text{LV},n}^n} + t_{\text{in}}$$

$$n=1$$

$$E_{\text{LV},1} = (3.05 \pm 0.19) \times 10^{17} \text{ GeV}$$

Benchmark of low energy photons: trigger or peak?

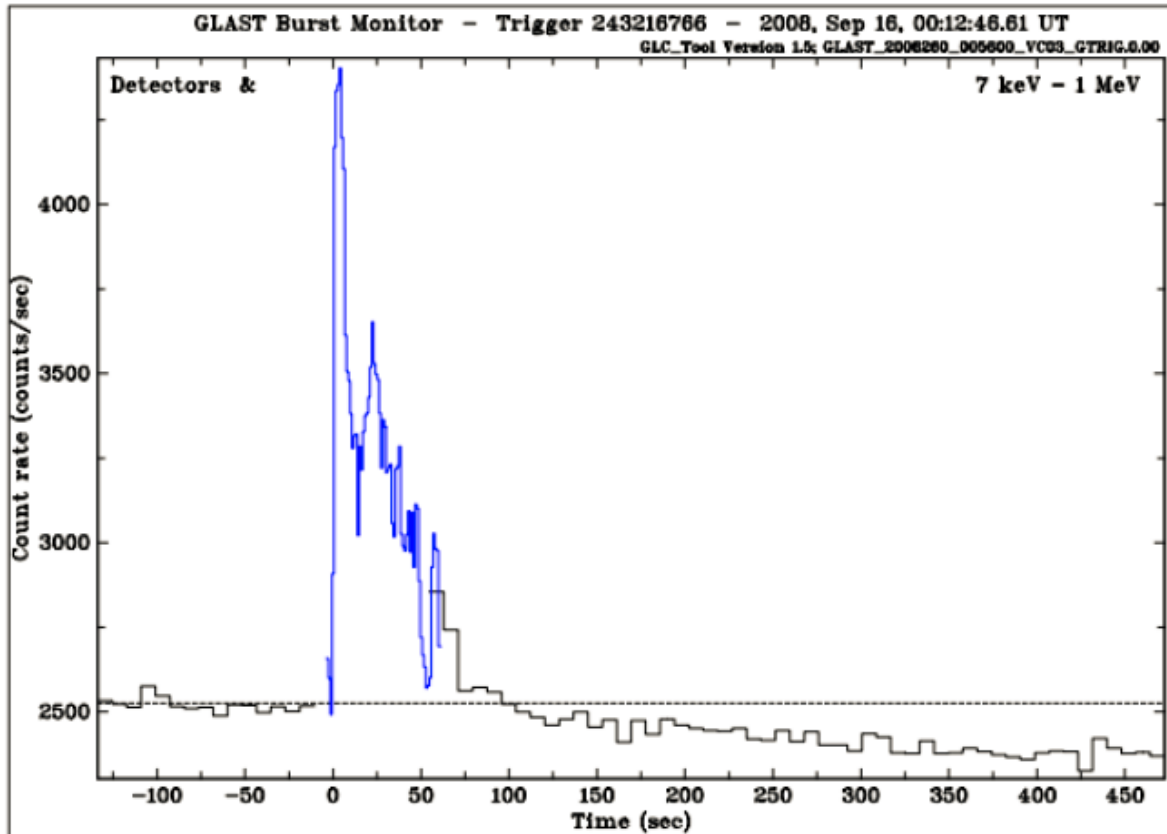
Trigger:

- L.Shao, Z.Xiao and B.-Q.Ma, APP 33 (2010) 312, arXiv:0911.2276
- S.Zhang, B.-Q.Ma, APP 61 (2015) 108, arXiv:1406.4568

The peak of low energy photons:

- H.Xu, B.-Q.Ma, APP 82 (2016) 72, arXiv: 1607.03203
- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602

Benchmark of low energy photons: trigger or peak?



- H.Xu, B.-Q.Ma, APP 82 (2016) 72, arXiv: 1607.03203
- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602

- H.Xu, B.-Q.Ma, APP 82 (2016) 72, arXiv: 1607.03203

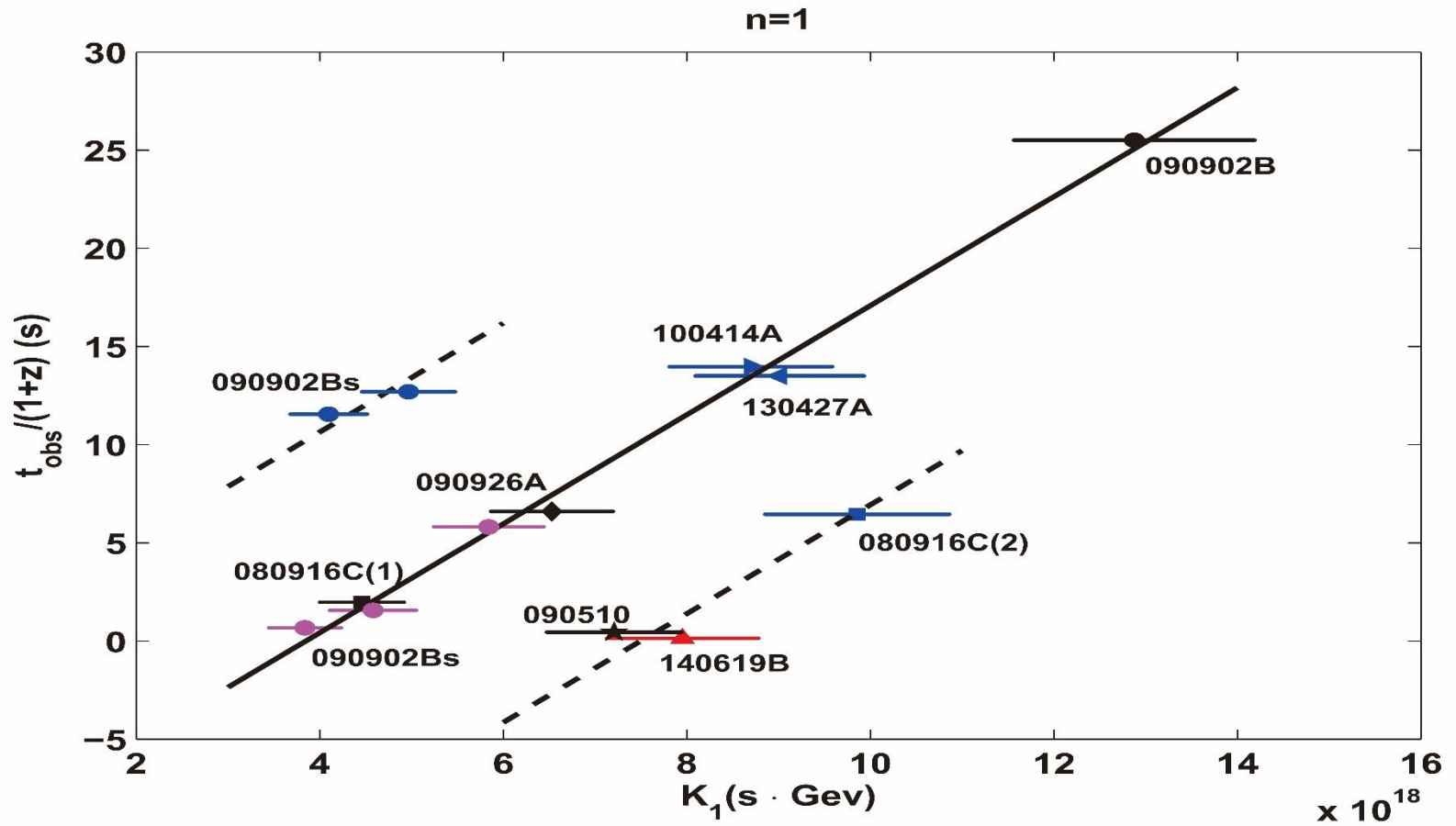
New Analysis of Data

Table 1: The data of high energy photon events from GRBs with known redshifts.

GRB	z	t_{high} (s)	t_{low} (s)	E_{obs} (GeV)	E_{source} (GeV)	$\frac{\Delta t_{\text{obs}}}{1+z}$ (s)	K_1 ($\times 10^{18}$ s · GeV)
080916C(1)	4.35 ± 0.15	16.545	5.984	12.4	66.3	1.974	4.46 ± 0.45
080916C(2)	4.35 ± 0.15	40.509	5.984	27.4	146.6	6.453	9.86 ± 0.99
090510	0.903 ± 0.003	0.828	-0.032	29.9	56.9	0.452	7.21 ± 0.73
090902B	1.822	81.746	9.768	39.9	112.6	25.506	12.9 ± 1.3
		11.671		11.9	33.6	0.674	3.84 ± 0.39
		14.166		14.2	40.1	1.559	4.58 ± 0.47
090902Bs	1.822	26.168	9.768	18.1	51.1	5.812	5.84 ± 0.59
		42.374		12.7	35.8	11.554	4.10 ± 0.42
		45.608		15.4	43.5	12.700	4.97 ± 0.51
090926A	2.1071 ± 0.0001	24.835	4.320	19.5	60.6	6.603	6.53 ± 0.66
100414A	1.368	33.365	0.288	29.7	70.3	13.968	8.70 ± 0.88
130427A	0.3399 ± 0.0002	18.644	0.544	72.6	97.3	13.509	9.02 ± 0.91
140619B	2.67 ± 0.37	0.613	0.096	22.7	83.5	0.141	7.96 ± 0.82

- H.Xu, B.-Q.Ma, APP 82 (2016) 72, arXiv: 1607.03203

New Results



- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602

New GRB: 160509A

Physics Letters B 760 (2016) 602–604



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www.elsevier.com/locate/physletb



Light speed variation from gamma ray burst GRB 160509A



Haowei Xu^a, Bo-Qiang Ma^{a,b,c,d,*}

A B S T R A C T

It is postulated in Einstein's relativity that the speed of light in vacuum is a constant for all observers. However, the effect of quantum gravity could bring an energy dependence of light speed. Even a tiny speed variation, when amplified by the cosmological distance, may be revealed by the observed time lags between photons with different energies from astrophysical sources. From the newly detected long gamma ray burst GRB 160509A, we find evidence to support the prediction for a linear form modification of light speed in cosmological space.

- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602

New GRB: 160509A

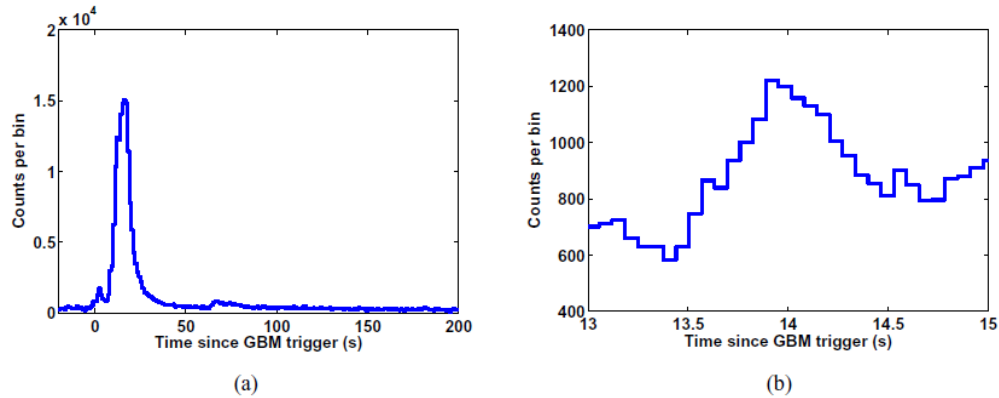


Figure 1: Light curves of the two brightest trigger detectors combined (GBM NaI-n0 and NaI-n3, 8 ~ 260 keV) for GRB 160509A. In the left panel (a), photon events are binned in 1 second intervals. In the right panel (b), photon events are binned in 0.064 seconds intervals to determine the peak of the main pulse as $T_{\text{peak}} = 13.920$ s.

Table 1: Photons with energy higher than 1 GeV from GRB 160509A

$E_{\text{obs}} / \text{GeV}$	$t_{\text{arri}} / \text{s}$	(RA, Dec)
51.9	76.506	(310.3, 76.0)
2.33	24.258	(313.2, 75.9)
1.85	87.039	(308.3, 73.9)
1.52	50.570	(328.8, 72.5)
1.26	49.155	(311.3, 75.8)

- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602

New GRB: 160509A

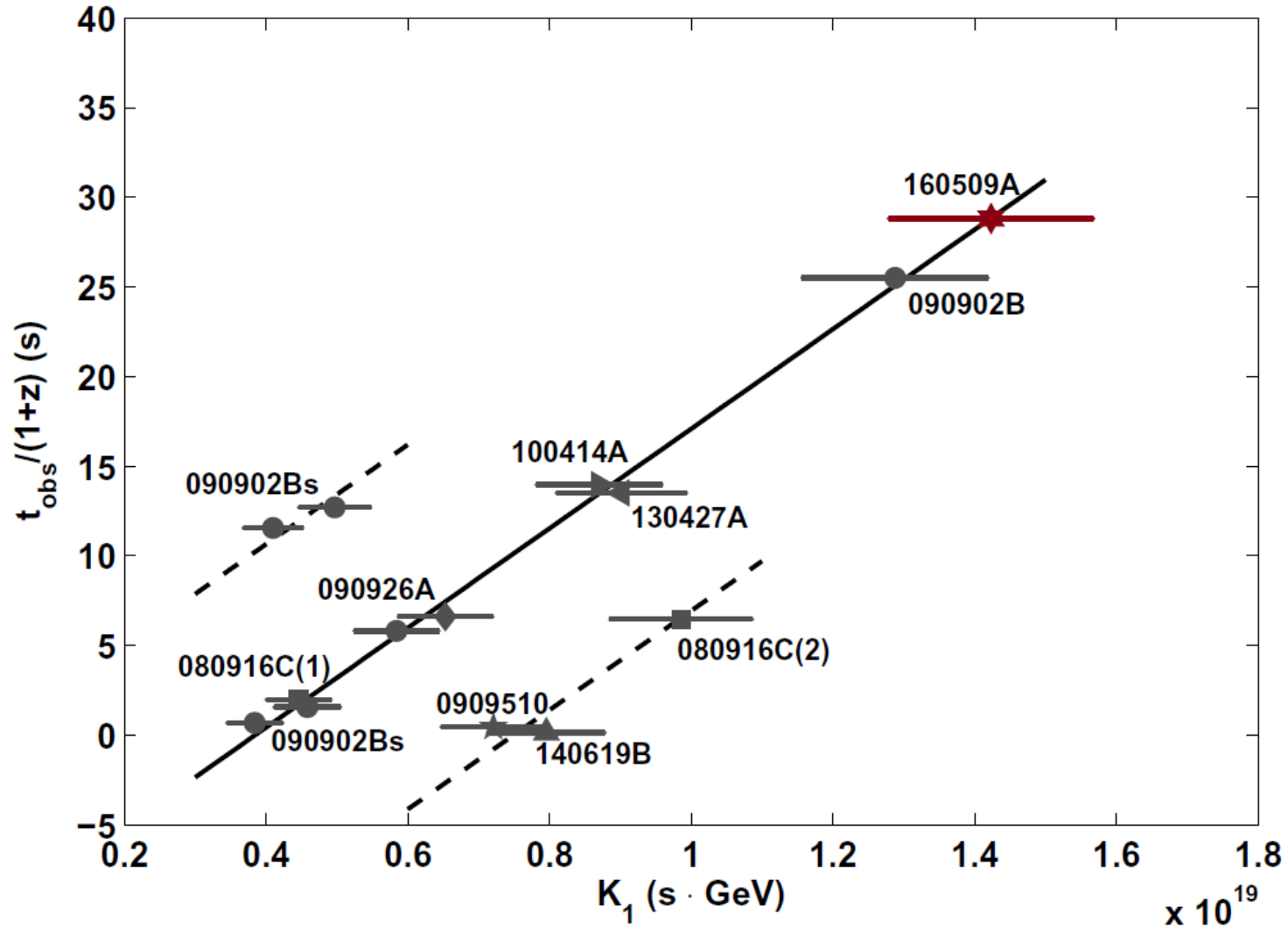
Table 2: Data of high energy photon event from GRB 160509A

GRB	z	t_{high} (s)	t_{low} (s)	E_{obs} (GeV)	E_{source} (GeV)	$\frac{\Delta t_{\text{obs}}}{1+z}$ (s)	K_1 ($\times 10^{18}$ s · GeV)
160509A	1.17	76.506	13.920	51.9	112.6	28.812	14.2

Data of GRB 160509A. t_{high} and t_{low} denote the arrival time of the high energy photon event and the peak time of the main pulse of low energy photons respectively, with the trigger time of GBM as the zero point. E_{obs} and E_{source} are the energy measured by Fermi LAT and the intrinsic energy at the source of GRBs, with $E_{\text{source}} = (1 + z)E_{\text{obs}}$. K_1 is the Lorentz violation factor with a unit of (s · GeV) for $n = 1$.

- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602

New GRB: 160509A



- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602

New GRB: 160509A

we find evidence

to support the prediction for a linear form modification of light speed

$$v(E) = c(1 - E/E_{LV})$$

$$E_{LV} = 3.60 \times 10^{17} \text{ GeV}$$

A B S T R A C T

It is postulated in Einstein's relativity that the speed of light in vacuum is a constant for all observers. However, the effect of quantum gravity could bring an energy dependence of light speed. Even a tiny speed variation, when amplified by the cosmological distance, may be revealed by the observed time lags between photons with different energies from astrophysical sources. From the newly detected long gamma ray burst GRB 160509A, we find evidence to support the prediction for a linear form modification of light speed in cosmological space.

new development

Journal of **C**osmology and **A**stroparticle **P**hysics
An IOP and SISSA journal

Regularity of high energy photon
events from gamma ray bursts

Haowei Xu^a and Bo-Qiang Ma^{a,b,c,d,1}

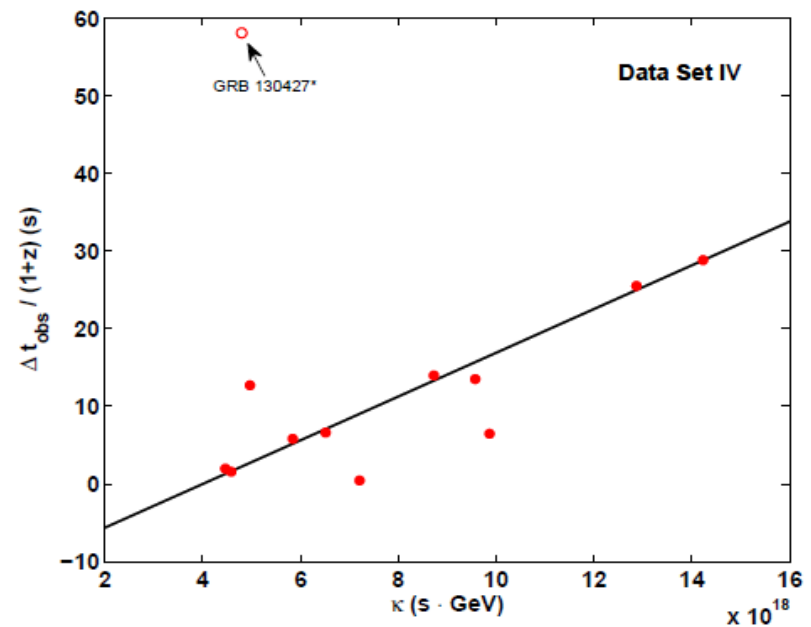
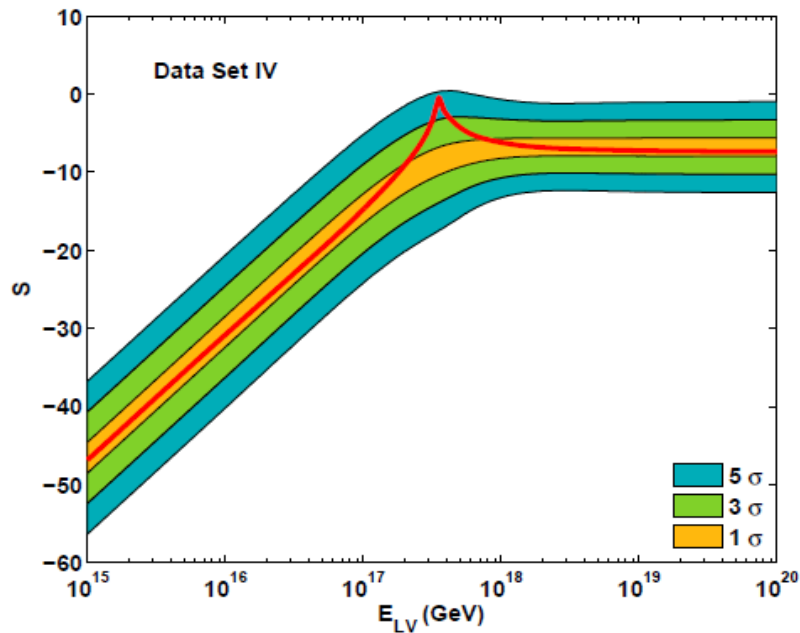
H.Xu, B.-Q.Ma, JCAP 1801 (2018) 050

- A general analysis on the data of 25 bright GRBs
- Allow a completed scan over all possibilities without bias
- The regularity exists at a significance of 3-5 σ

new development

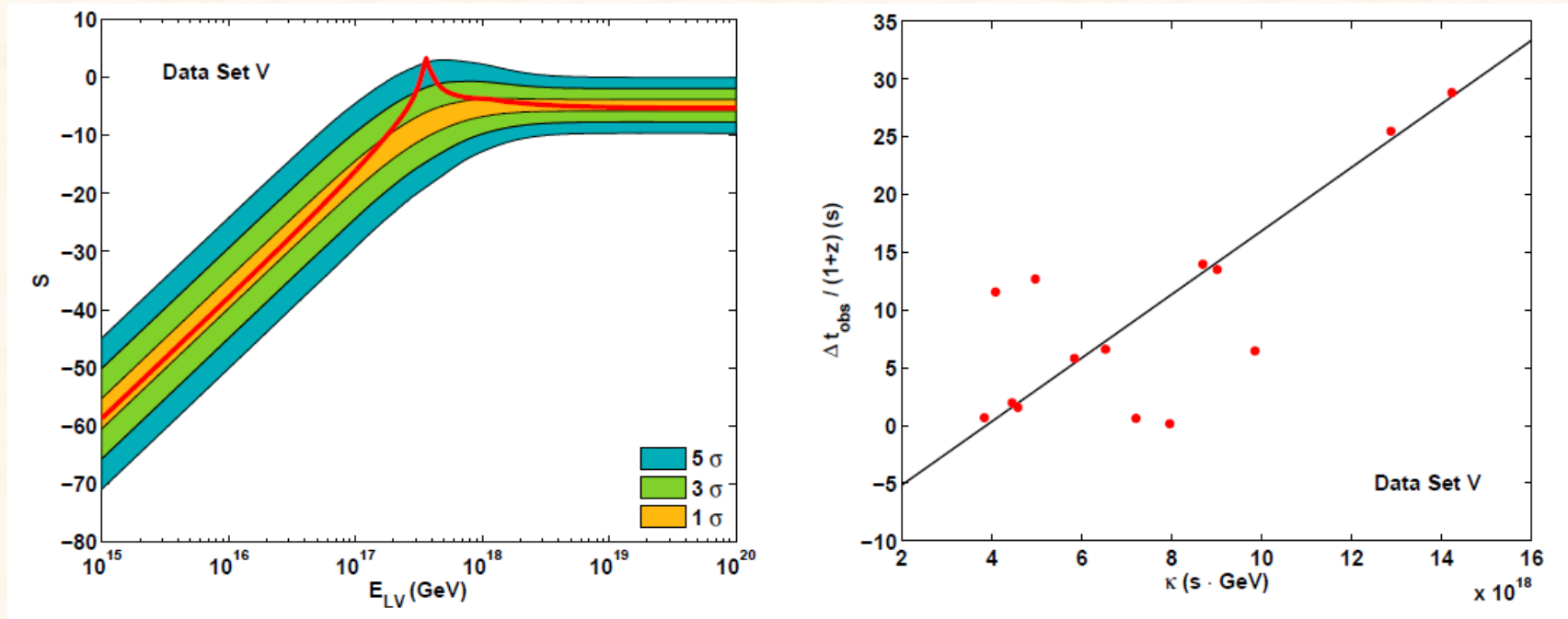
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$$\mathcal{S}(E_{LV}) = \sum_{i=1}^{N-\rho} \log \left(\frac{\rho}{t_{i+\rho} - t_i} \right)$$



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In conclusion, we use a general method to analyze the data of 25 bright GRBs detected by FGST. The results suggest that for photons with energy higher than 40 GeV, the regularity of high energy photon events from different GRBs exists at a significance of 3–5 σ with $E_{LV} = 3.6 \times 10^{17}$ GeV determined by the GRB data.

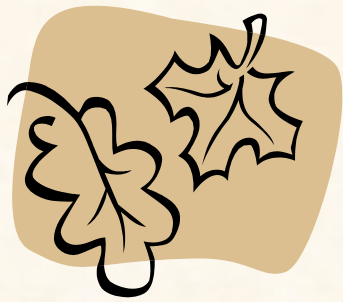
Two options for light speed variation

- A consequence of the matter effect in space: cosmological medium.
- An observation of the Lorentz violation effect at

$$E_{LV} = 3.60 \times 10^{17} \text{ GeV}$$

$$\text{Planck scale } (E \sim E_{Pl} = \sqrt{\hbar c^5 / G} \simeq 1.22 \times 10^{19} \text{ GeV})$$

The exact parameter for quantum gravity or Lorentz violation should be determined from experimental evidence rather than a priori assumption.

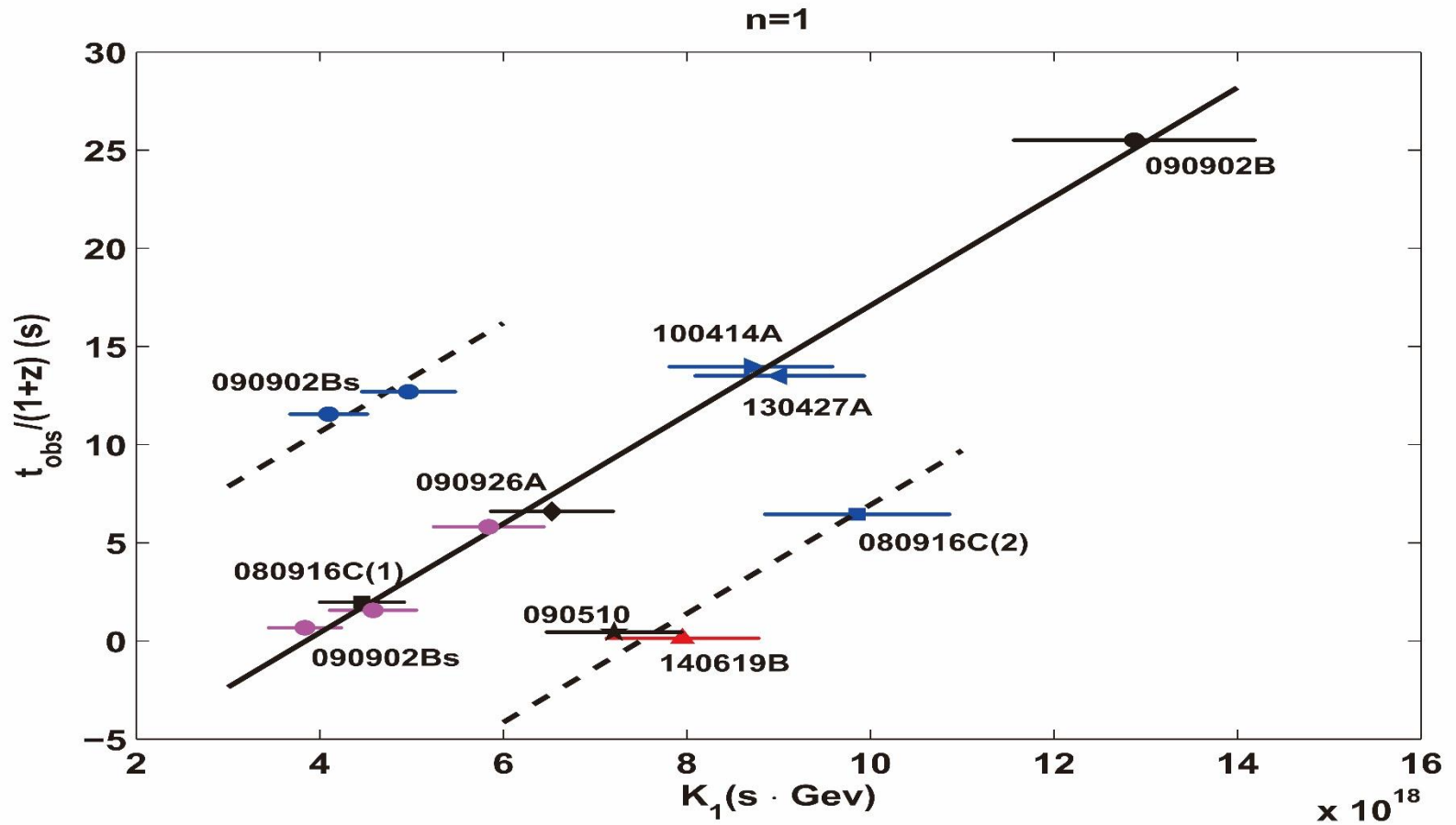


Summary

- We analyse the data of the energetic photons from the gamma-ray bursts (GRBs).
- We unveil a surprising regularity behind the data of these energetic photons.
- We find events to support the energy dependence of the light speed.
- The predictions from such scenarios are strongly supported by new GRB 160509A.
- **A general analysis suggests a significance of 3-5 σ .**

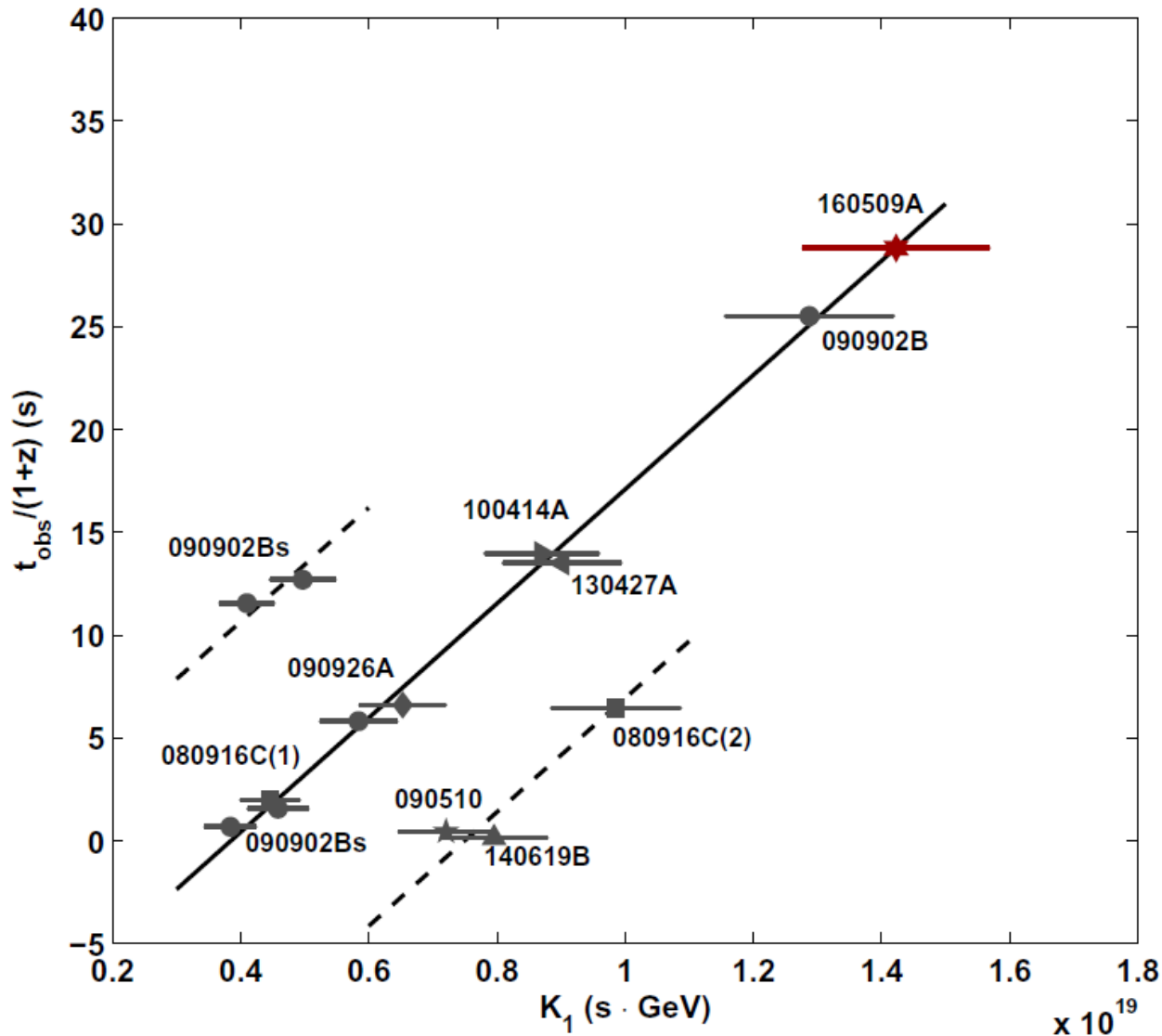
- H.Xu, B.-Q.Ma, APP 82 (2016) 72, arXiv: 1607.03203

Results from previous GRBs



- H.Xu, B.-Q.Ma, Phys.Lett.B 760 (2016) 602, arXiv:1607.08043

New GRB: 160509A





Thanks 谢谢!