Lorentz Invariance and CPT Violation Studies with MeV Blazars and GRBs

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1.) Motivation and Status of Observations.

2.) Theoretical Framework (the Standard Model Extension).

3.) The Next Frontier: Polarimetry at >20 MeV Energies.

Krawczynski+2013: arXiv:1307.6946.

Search for New Physics at the Planck Energy Scale

General Relativity

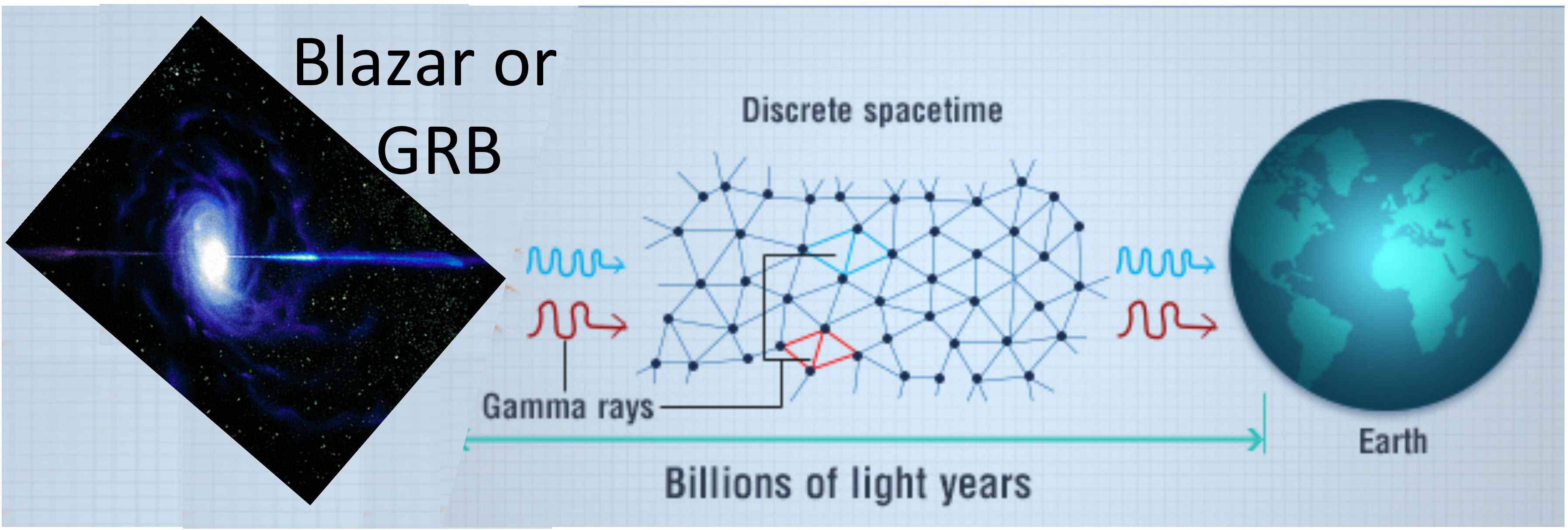
Quantum
Field Theories

Quantum Gravity
(avoid singularities of GR)

Observable Consequences:

$$\Rightarrow \quad E_P = \sqrt{\hbar c^5 / G} \approx 10^{19}\,\mathrm{GeV}$$

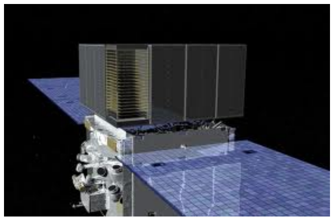
Probe Physics at the Planck Energy Scale with Astronomical Observations



- Effects are suppressed by $(E_\gamma/E_P)^n$ with $n \geq 1$.
- Tiny Effects accumulate over cosmological distances (Colladay & Kostelecky 1997, Amelino-Camelia+ 1998) ➔ sensitive tests with optical/UV to gamma-ray photons.

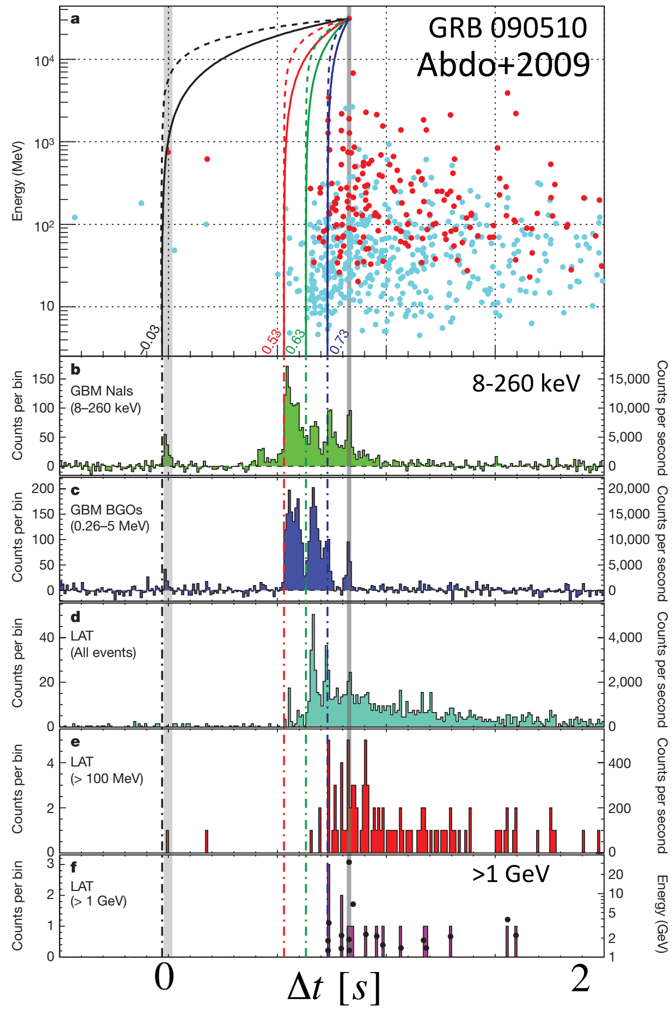
Gamma-Ray Time of Flight Measurements

Constrain time dispersion of photons with energies E_1 & E_2:



Fermi/AGILE

VERITAS, MAGIC, HESS, CTA.



$$\delta v < \zeta^{(5)0} \frac{E}{E_P}$$

GRB 090510 (Fermi):

$$\zeta^{(5)0} < 0.13$$

(Vasileiou+2013)

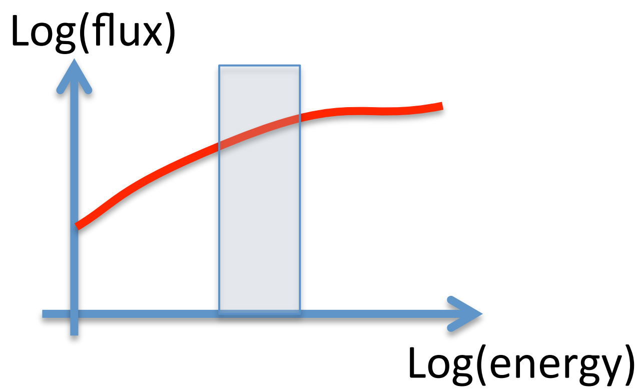
Accuracy depends on:

- Photon statistics.

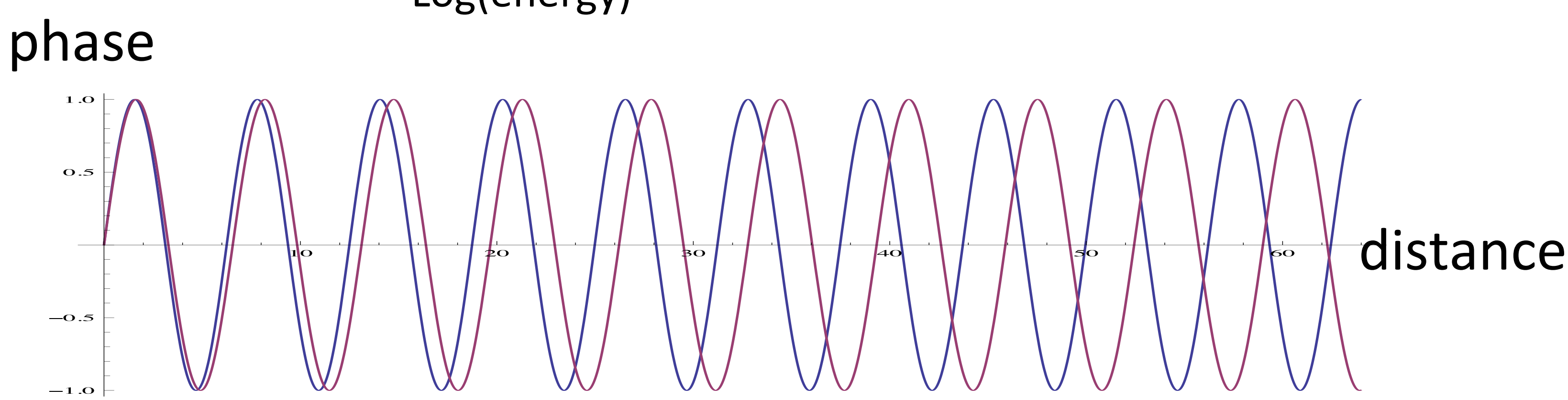
- Time scale of flares (msec to min).

Polarimetric Measurements

Group velocity depends on photon energy and helicity.



Time scale probed by observed linear polarization at frequency f: T=1/f.



Polarized UV/optical: $\delta v < \zeta^{(5)0} \dfrac{E}{E_P}$ $\zeta^{(5)0} < 2 \times 10^{-7}$ (Fan+2007)

Limit from Polarimetry is by a factor ~10^6 "better"!

Theoretical Framework: Standard Model Extension (SME)

Kostelecký et al. *(Colladay & Kostelecký 1997,1998, Kostelecký & Mewes 2002, Kostelecký 2004, Kostelecký & Mewes 2009)*:

• The action of the Standard Model is the 0^{th}-order term in an expansion approximating a more complete quantum gravity theory.

• Astronomical observations can constrain the non-zero contributions of non-standard-model operators in the Lagrangian.

$$S_{(d)} = \int d^4x \, \mathcal{K}_{(d)}^{\alpha_1\alpha_2\alpha_3\ldots\alpha_d} A_{\alpha_1} \partial_{\alpha_3} \ldots \partial_{\alpha_d} A_{\alpha_2}$$

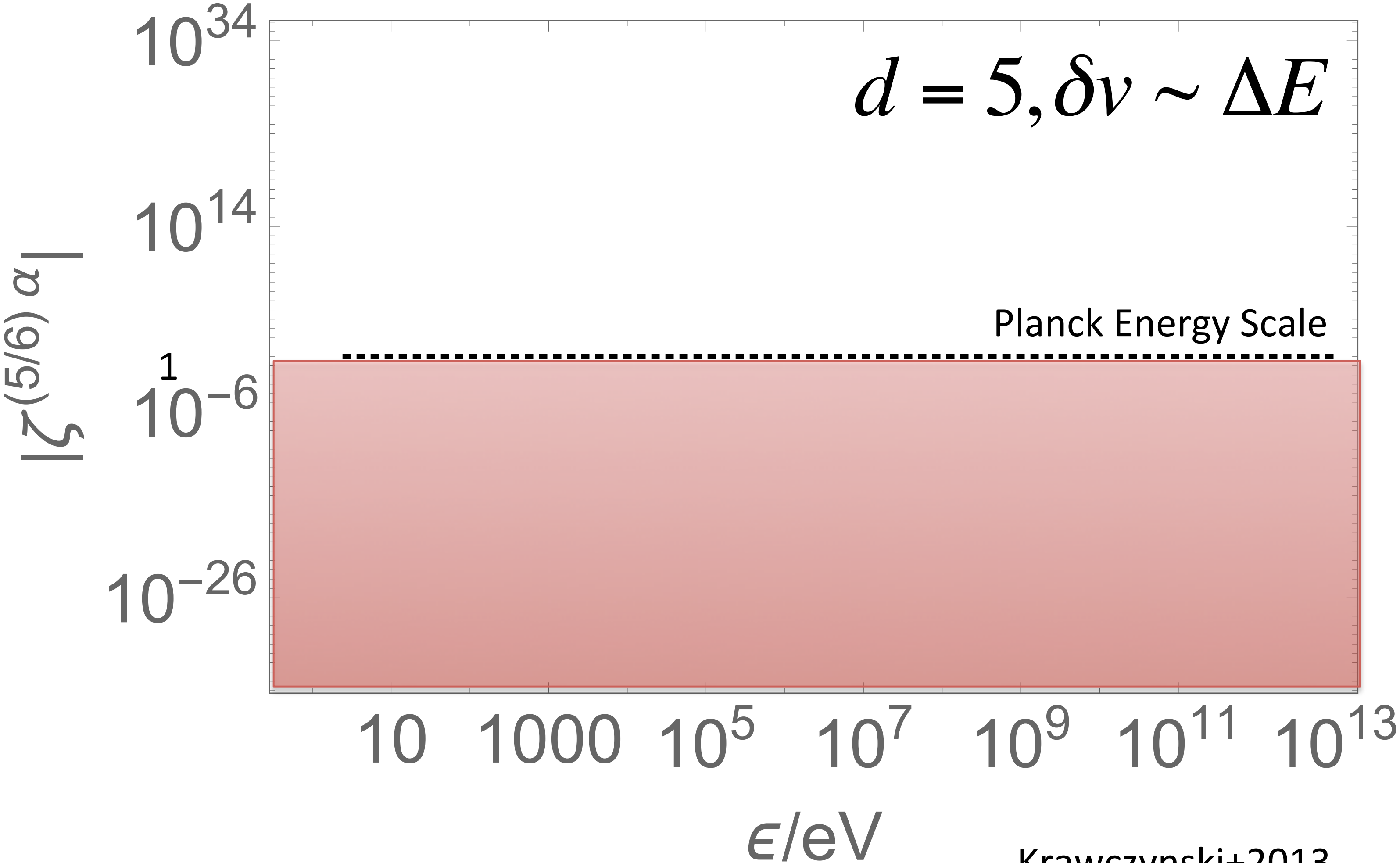
Results:

Mass Dimension	Lor. Inv. Violation?	CPT Violation?	Photon Group Vel.
d=5	~~Yes~~	~~Yes~~	$\cancel{\delta v < \Delta E}$
d=6	Yes	No	$\delta v < \Delta E^2$

Polarization obs. constrain ***all*** expansion coefficients.

How good can we get?

Assumptions: (i) Detect GRBs at z=1; (ii) Measure difference of arrival times of photons with energies 0.1E and E with 1msec accuracy.



Krawczynski+2013
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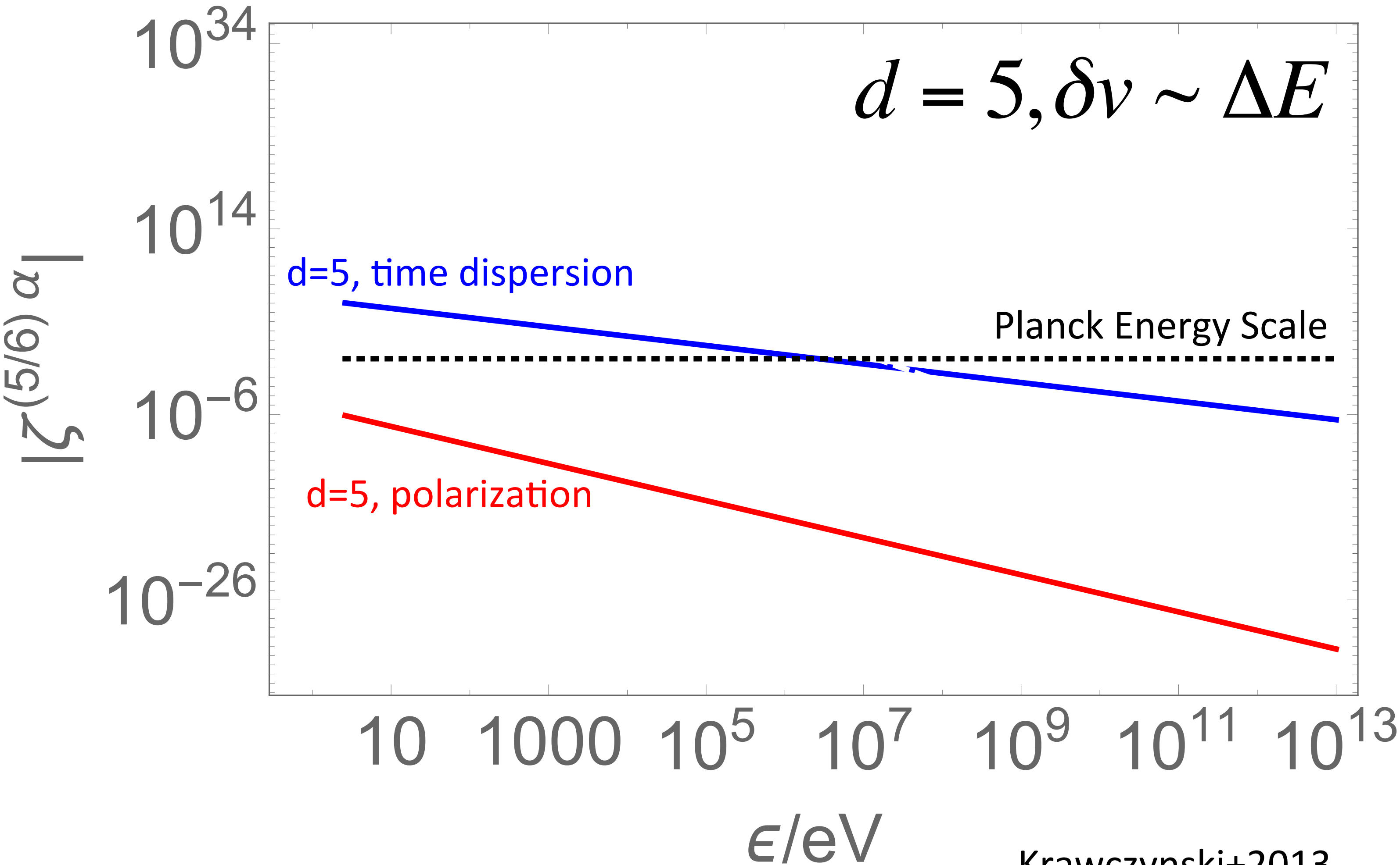

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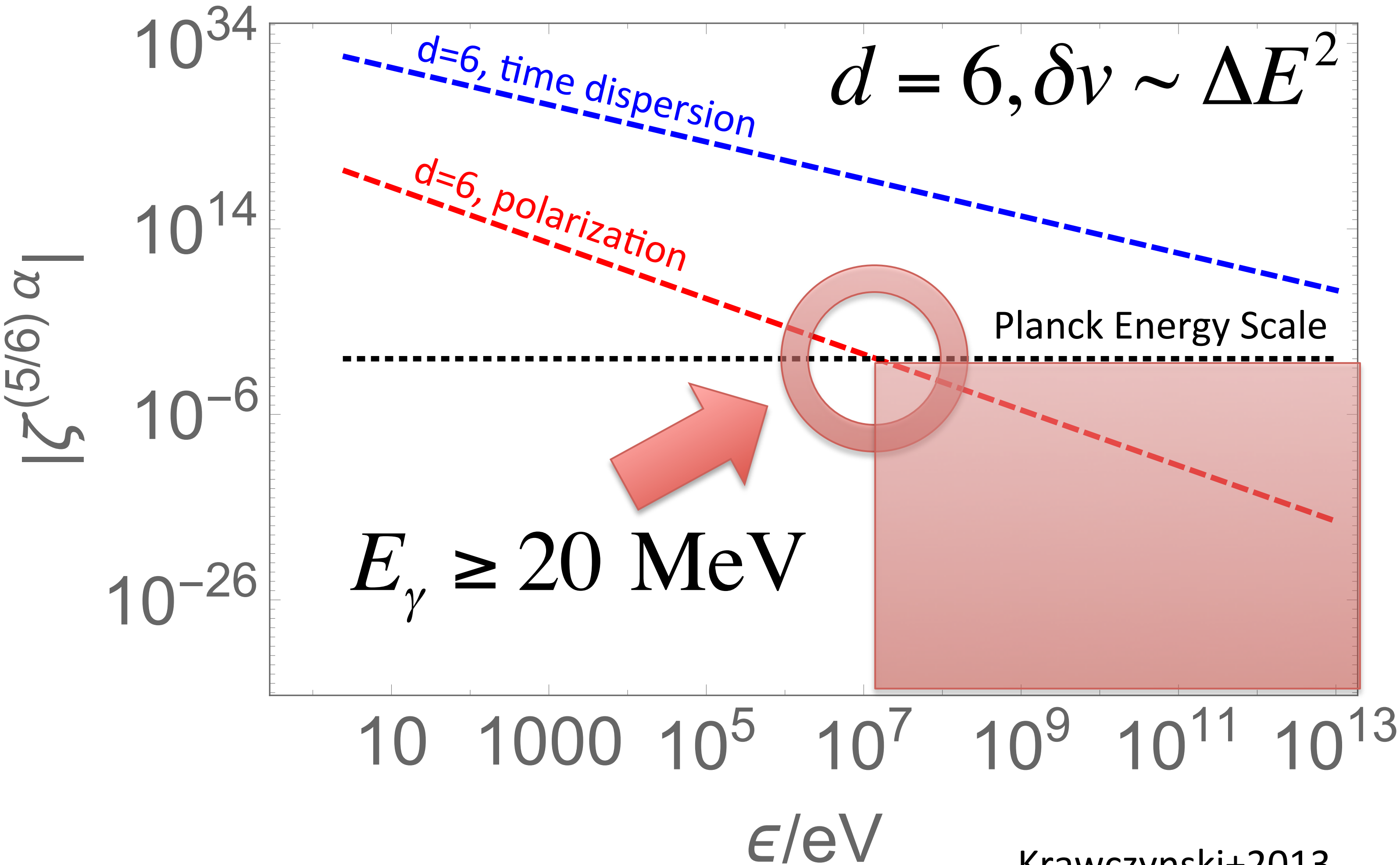

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Summary

- X-ray and gamma-ray *timing and polarimetry* observations *have already been used* to search for new physics at the Planck energy scale.
- The Standard Model Extension (SME) gives us a theoretical framework to parameterize the results and to relate different types of measurements to each other.
- Polarimetry gives the most sensitive constraints on the coefficients of mass-dimension 5 operators.
- *The next frontier:* polarimetric observations of blazars and GRBs at cosmological distances at >20 MeV energies can constrain the *coefficients of mass-dimension 6 operators*.
- *Requirement*: detection of ~20% polarization degrees of Blazars and/or GRBs at z~1.