Lorentz-invariance violation studies with blazars: A cautionary tale

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10th Hel.A.S. meeting: Monday 5th to Thursday 8th September 2011, Ioannina, Greece

Light Propagation

“Light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body.”

Einstein.A, Ann.Phys., **322**, 891, (1905)

Light Propagation

“Light is always propagated in empty space with a definite velocity c_0 which is independent of the state of motion of the emitting body.”

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Light Propagation

Dispersion: The phase velocity of a wave depends on its frequency i.e. energy E.

$$u(E) = \frac{c_0}{n(E)}$$

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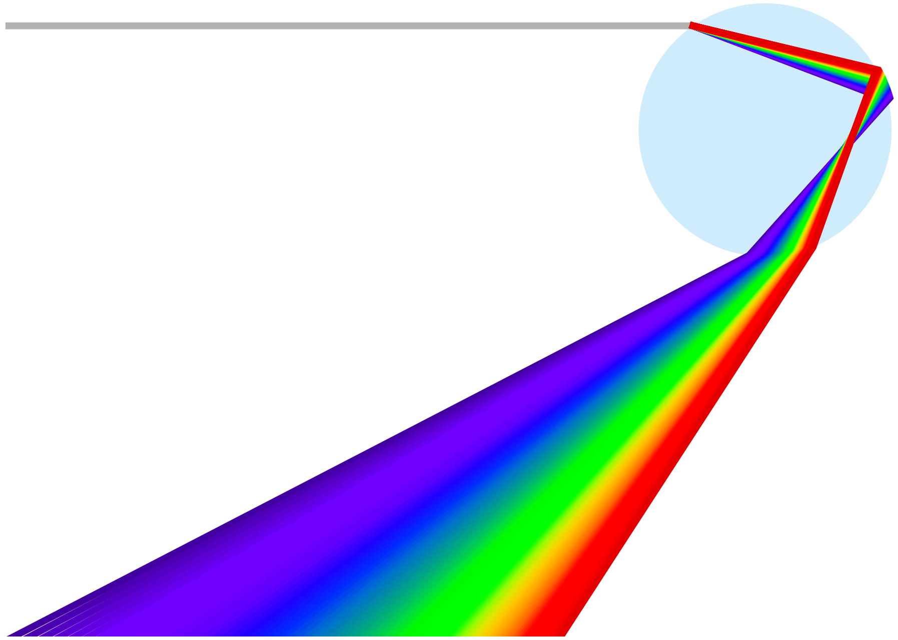

Light Propagation

$$c(E) = c_0 \left[1 + \xi \frac{E}{E_{\mathrm{P}}} + \zeta \left(\frac{E}{E_{\mathrm{P}}} \right)^2 + \mathcal{O} \left(\frac{E}{E_{\mathrm{P}}} \right)^3 \right]$$

Amelino-Camelia, G. et al., Nature, **393**, 763, (1998)

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Scales:

- Energies

$$E_{\mathrm{P}} = \sqrt{\frac{\hbar c^5}{G}} \simeq 1.22 \times 10^{19} \ \ \mathrm{GeV}$$

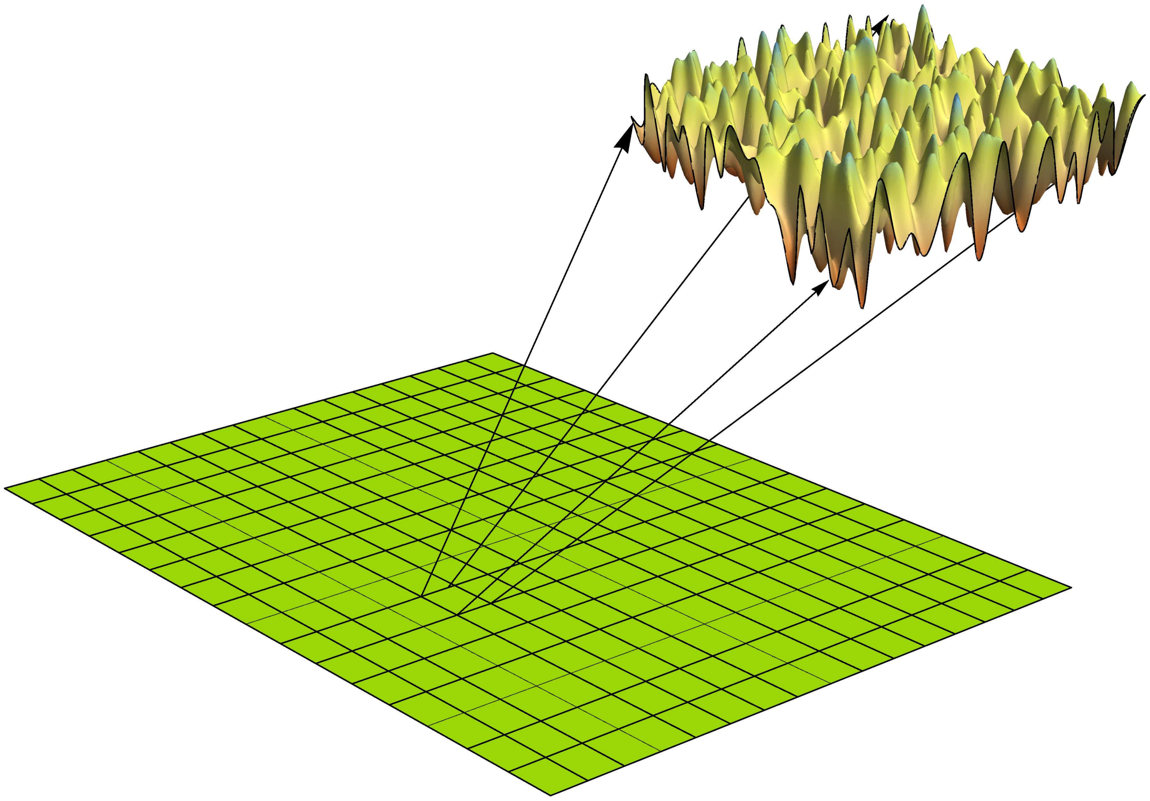
- Lengths

$$l_{\mathrm{P}} = \sqrt{\frac{\hbar G}{c^3}} \simeq 1.61 \times 10^{-33} \ \ \mathrm{cm}$$

- Times

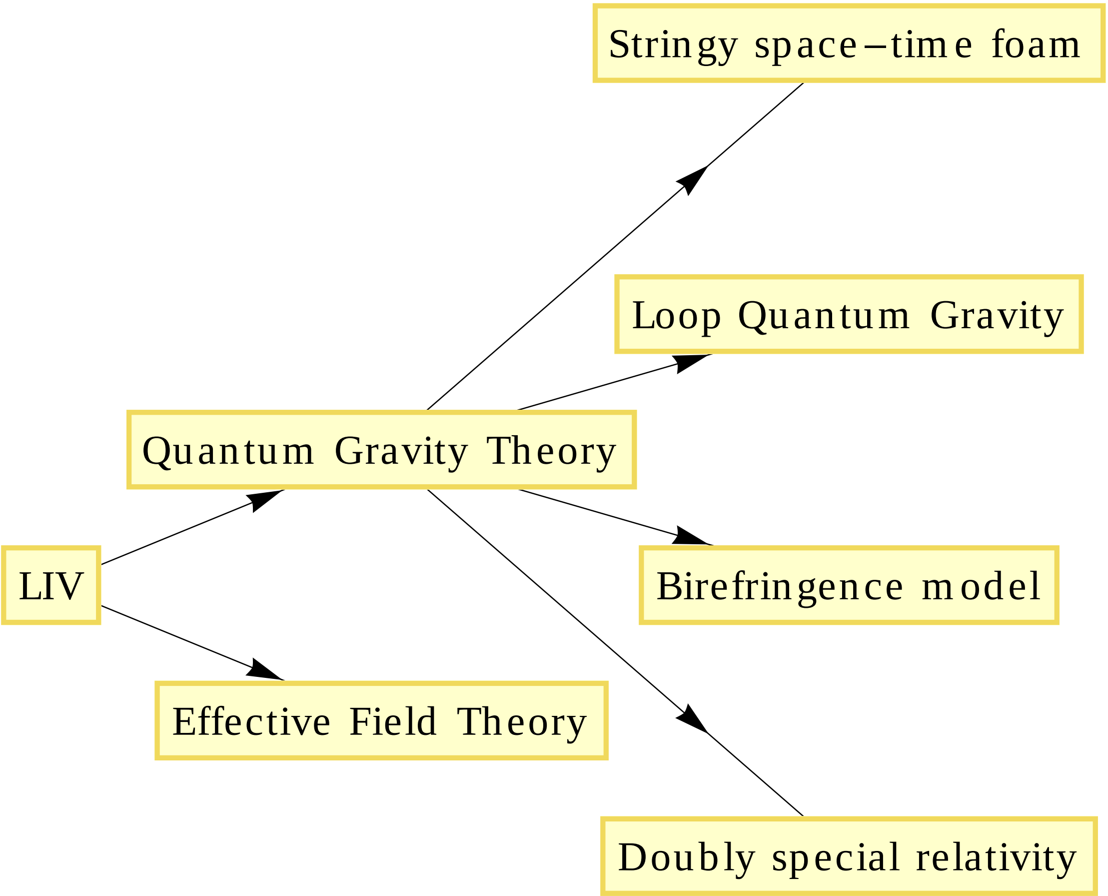
$$t_{\mathrm{P}} = \sqrt{\frac{\hbar G}{c^5}} \simeq 5.39 \times 10^{-44} \ \ \mathrm{s}$$

Light Propagation



What is Quantum-Gravity?

Theoretically numerous models



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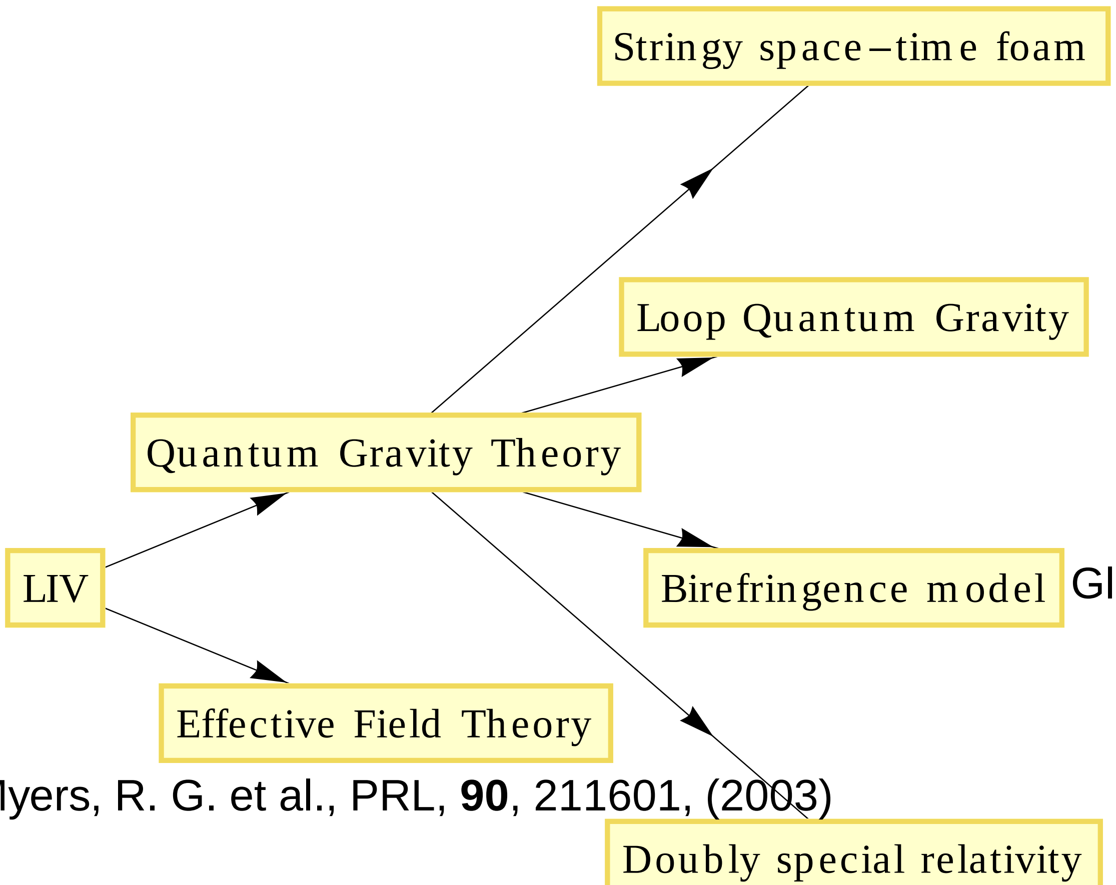

Ellis, J. et al., Phys.Lett.B, **665**, 412, (2008)

Alfaro, J. et al., Phys.Rev.D, **65**, 103509, (2002)

Gleiser, R. J. et al., Phys.Rev.D, **64**, 083007, (2001)

Myers, R. G. et al., PRL, **90**, 211601, (2003)

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$$\Delta t \approx \xi \left(\frac{\Delta E}{E_{\mathrm{P}}} \right) \frac{L}{c_0}$$

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Problem: Phenomena on very small length scales (10^{-33} cm) and very high energies (10^{19} GeV)

What is Quantum-Gravity?

Theoretically numerous models

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Solution: Distant VHE astrophysical sources

-Blazars-

Why to use blazars?

Advantages

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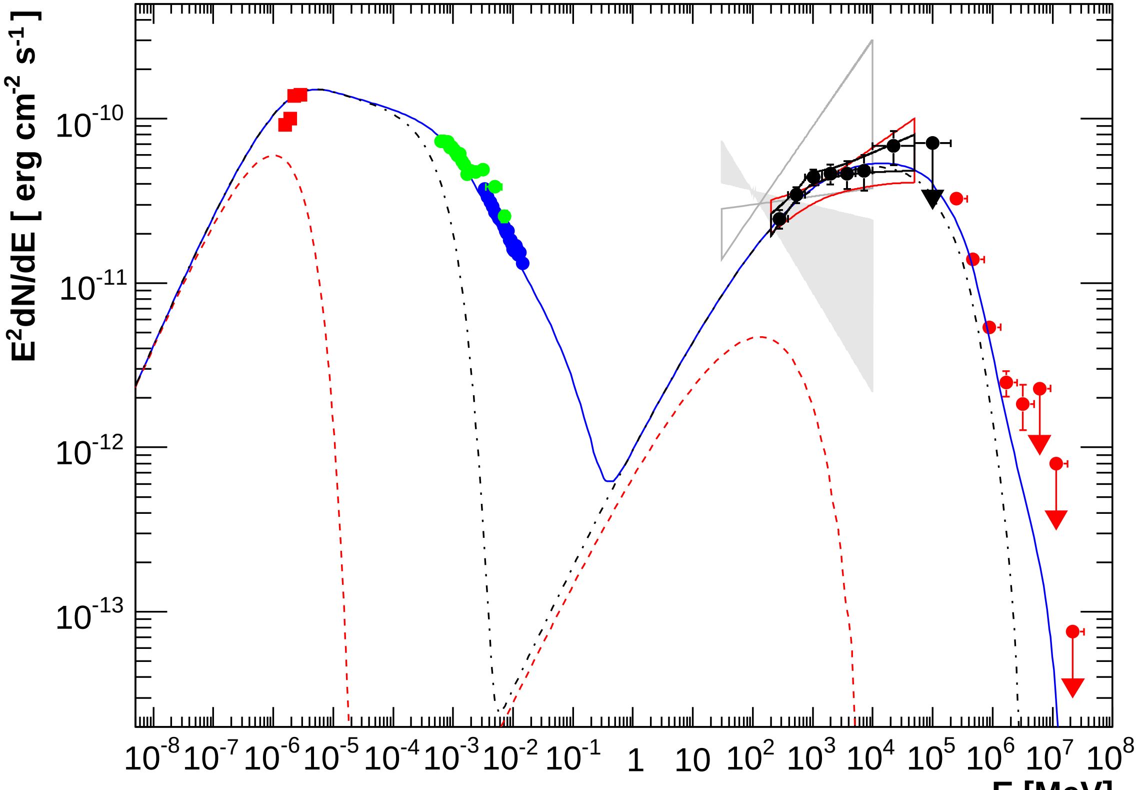
Advantages

- They produce VHE photons

PKS 2155-304 (z=0.117)



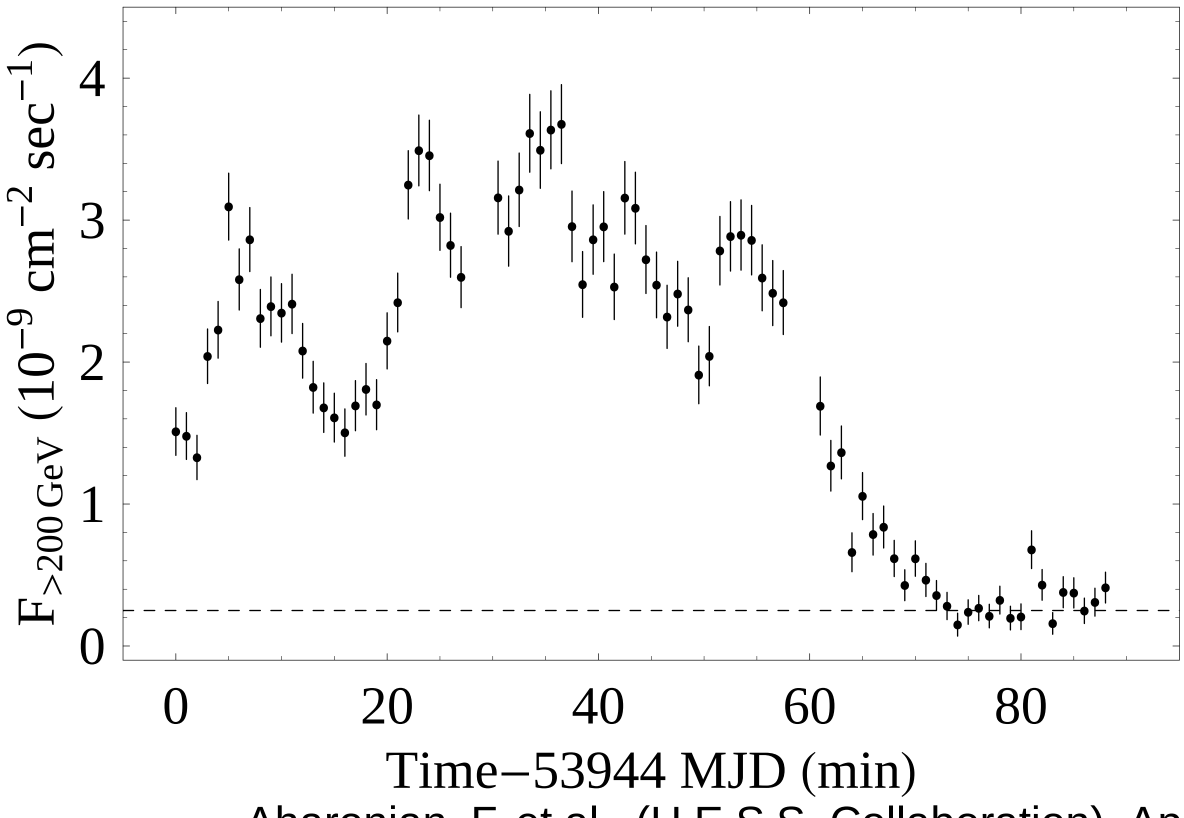
Aharonian, F. et al., (H.E.S.S. Collaboration), ApJ, **969**, 2, L150, (2009)

Why to use blazars?

Advantages

- The are highly variable in minutely time scales

PKS 2155-304



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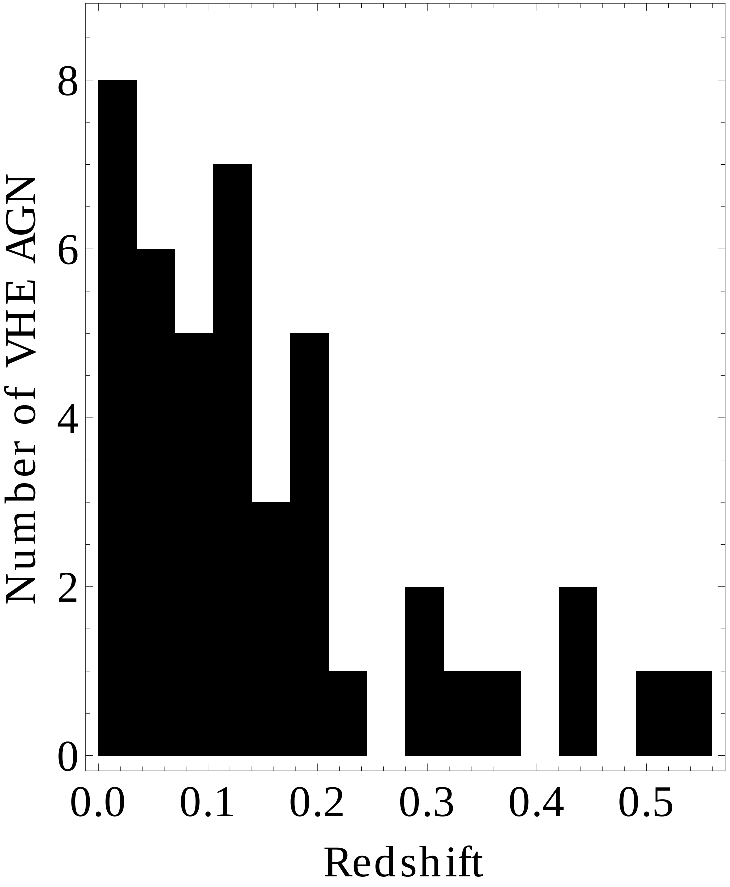
Why to use blazars?

Advantages

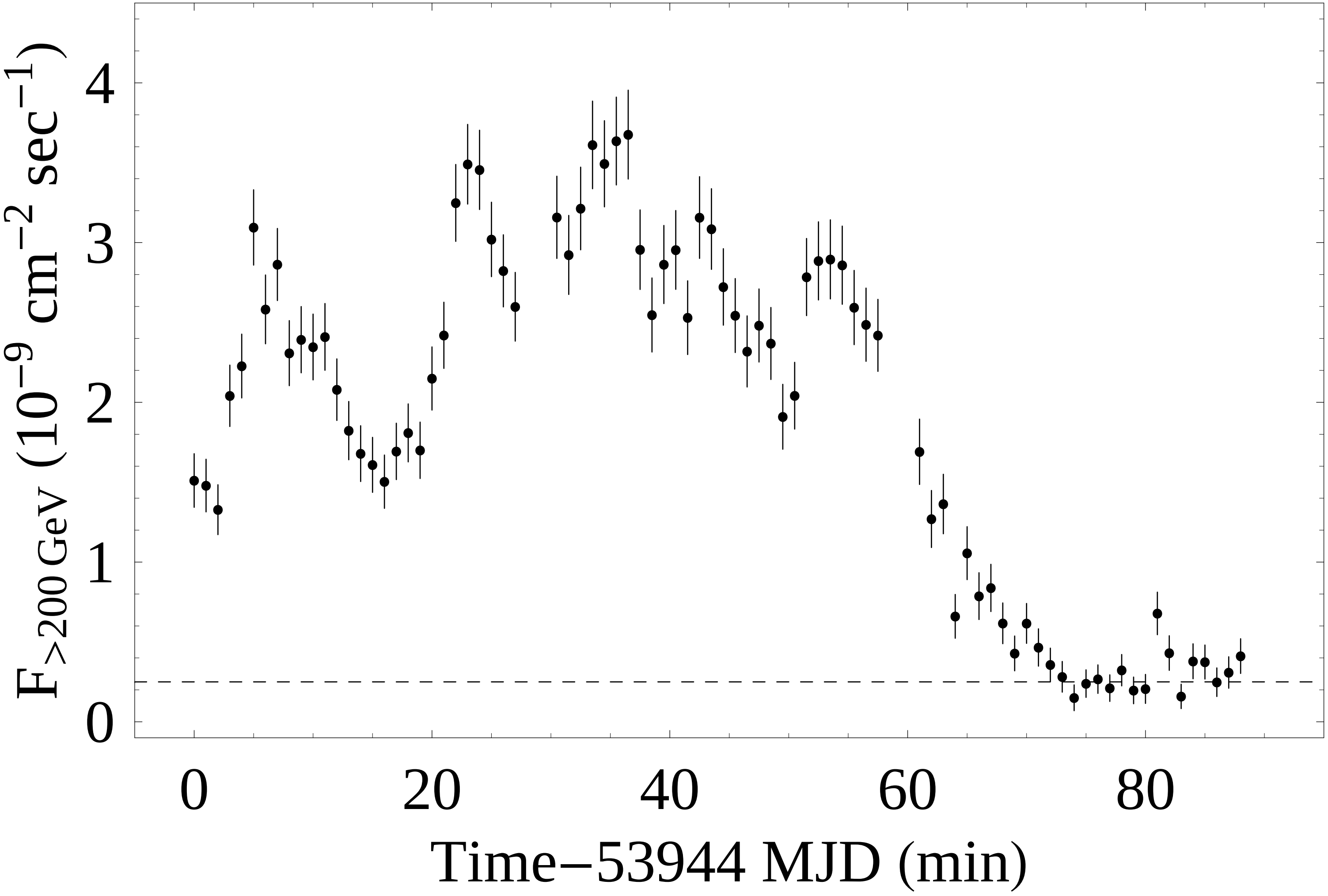
- They are in relatively cosmological distances

48 extragalactic ojects



Results

PKS 2155-304 (July 2006)



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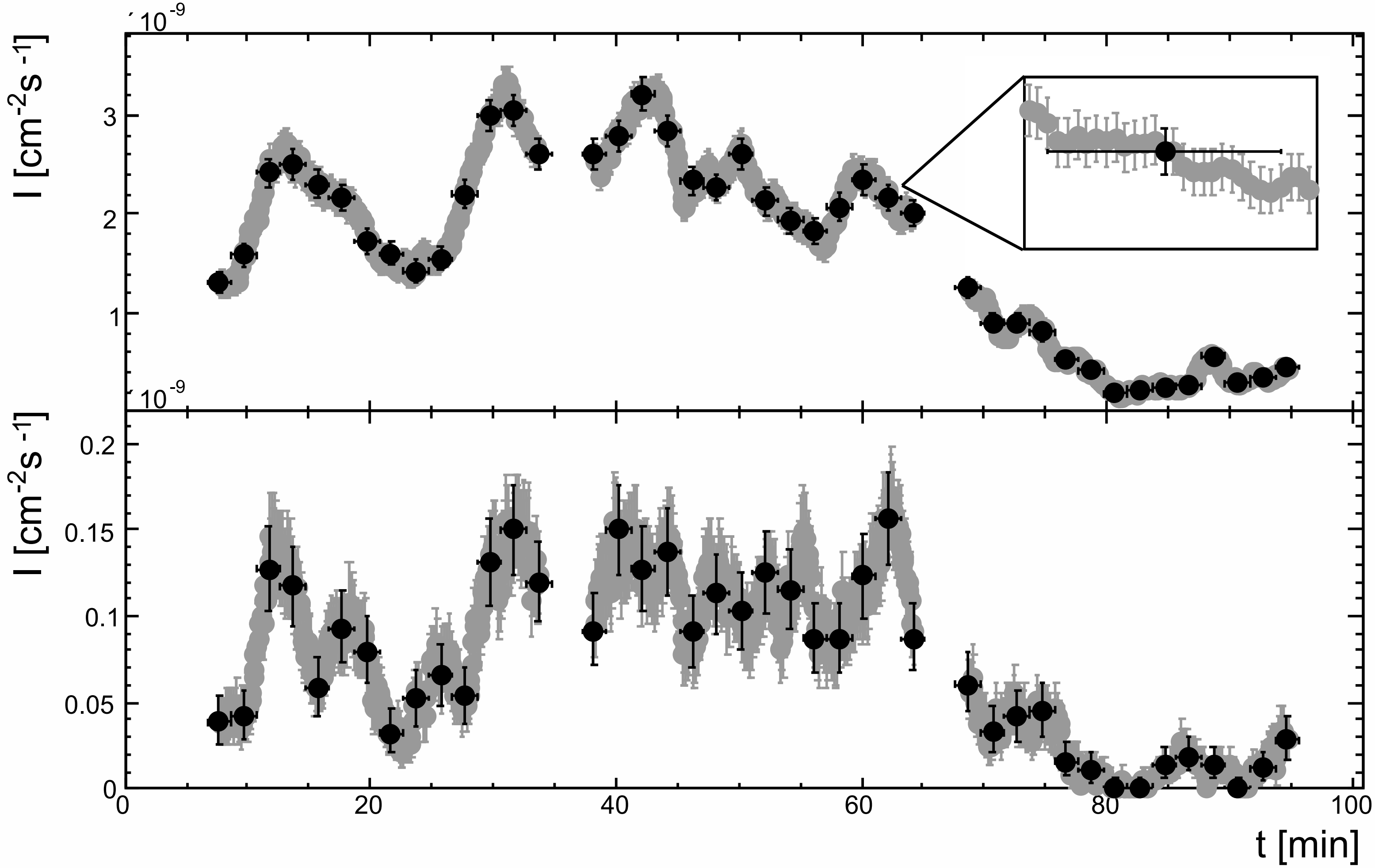
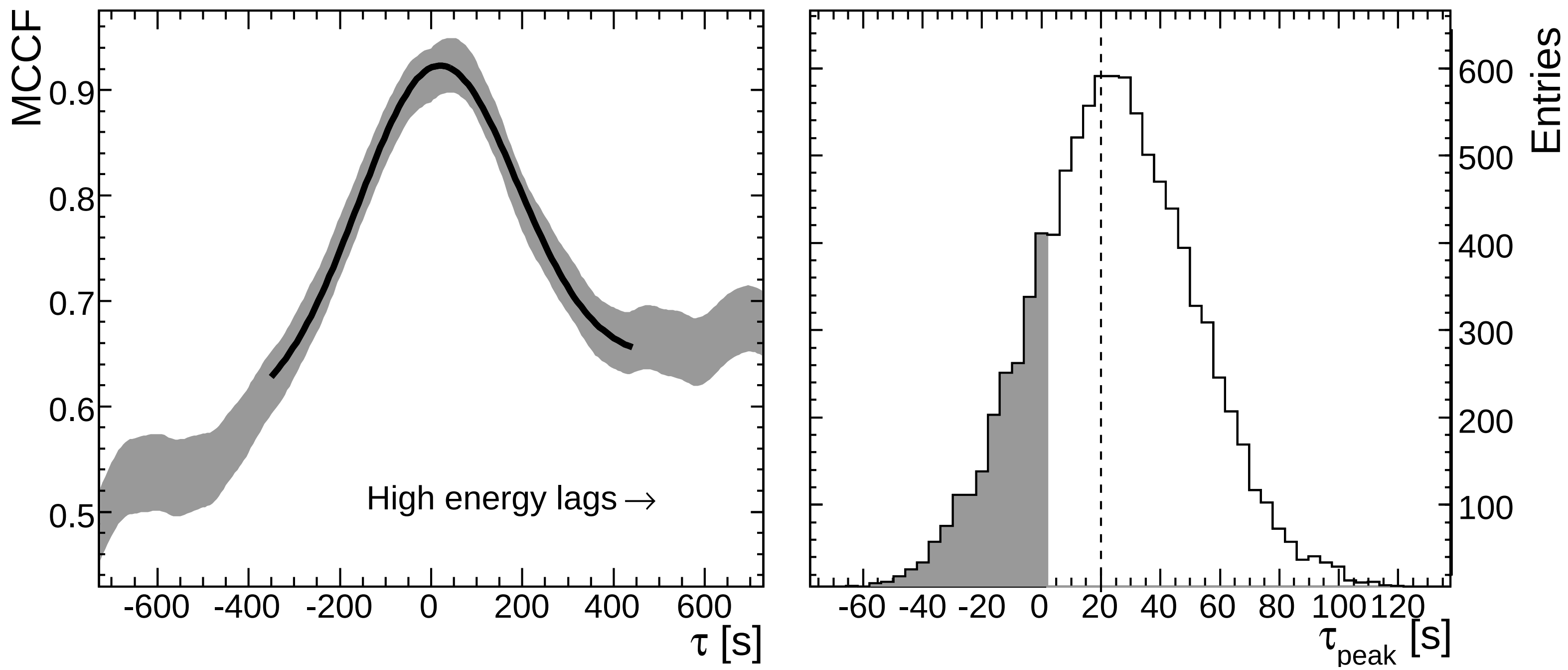


200–800 GeV

>800 GeV

Results



$$t_{\text{peak}} = (20 \pm 28)\text{sec} \xrightarrow{\Delta t \approx \xi \left(\frac{\Delta E}{E_{\text{P}}}\right) \frac{L}{c_0}} \xi < 17$$

Aharonian, F. et al., (H.E.S.S. Collaboration), PRL, **101**, 170402 (2008)

Results

Methodologies: Cross-correlation, wavelets, energy cost function, maximum likelihood

- $\xi < 300$ from Mrk 421 (z=0.030)

  Biller, S. D. et al., (WHIPPLE Collaboration), PRL, **83**, 2108, (1999)

- $\xi < 60$ from Mrk 501 (z=0.034)

  Albert, J. et al., (MAGIC Collaboration), Phys. Lett. B, **668**, 253, (2008)

- $\xi < 17$ from PKS 2155-304 (z=0.117)

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  Abramowski, A. et al., (H.E.S.S. Collaboration), Astropart. Phys. **34**, 738, (2011)

What about GRBs?

- $\xi < 8$ from GRB 080916C (z=4.35)

  Abdo, A. A. et al., (Fermi LAT Collaboration), Science, **323**, 5922, 1688, (2009)

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BUT

$$\xi = \frac{E_{\mathrm{P}}}{E_{\mathrm{QG},1}} \gtrsim 1$$

Ellis, J. et al., Phys.Lett.B, **665**, 412, (2008)

Zloshchastiev, K. G., arXiv:0906.4282, (2009)

Current LIV status

Collecting all the AGN, GRBs results and ...

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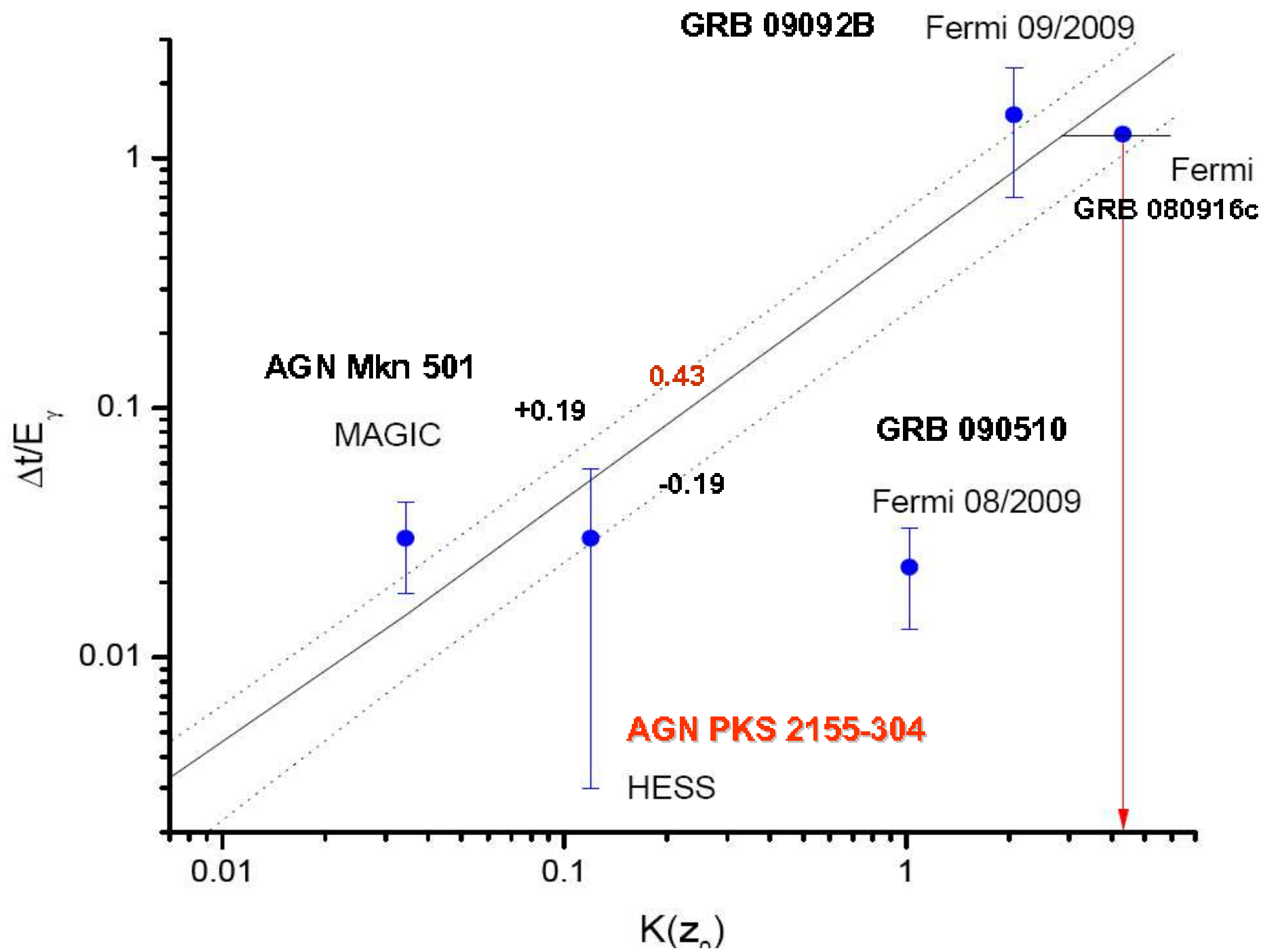
$$\Delta t \approx \xi \left(\frac{\Delta E}{E_{\mathrm{P}}}\right) \frac{L}{c_0} \Rightarrow \frac{\Delta t}{\Delta E} \approx \xi \frac{1}{E_{\mathrm{P}}} \frac{L}{c_0}$$

Current LIV status

Collecting all the AGN, GRBs results and ...

Current LIV status



Mavromatos N.E., J.Phys.:Conf.Ser., **283**, 012022, (2011) or (arXiv:1010.5399)

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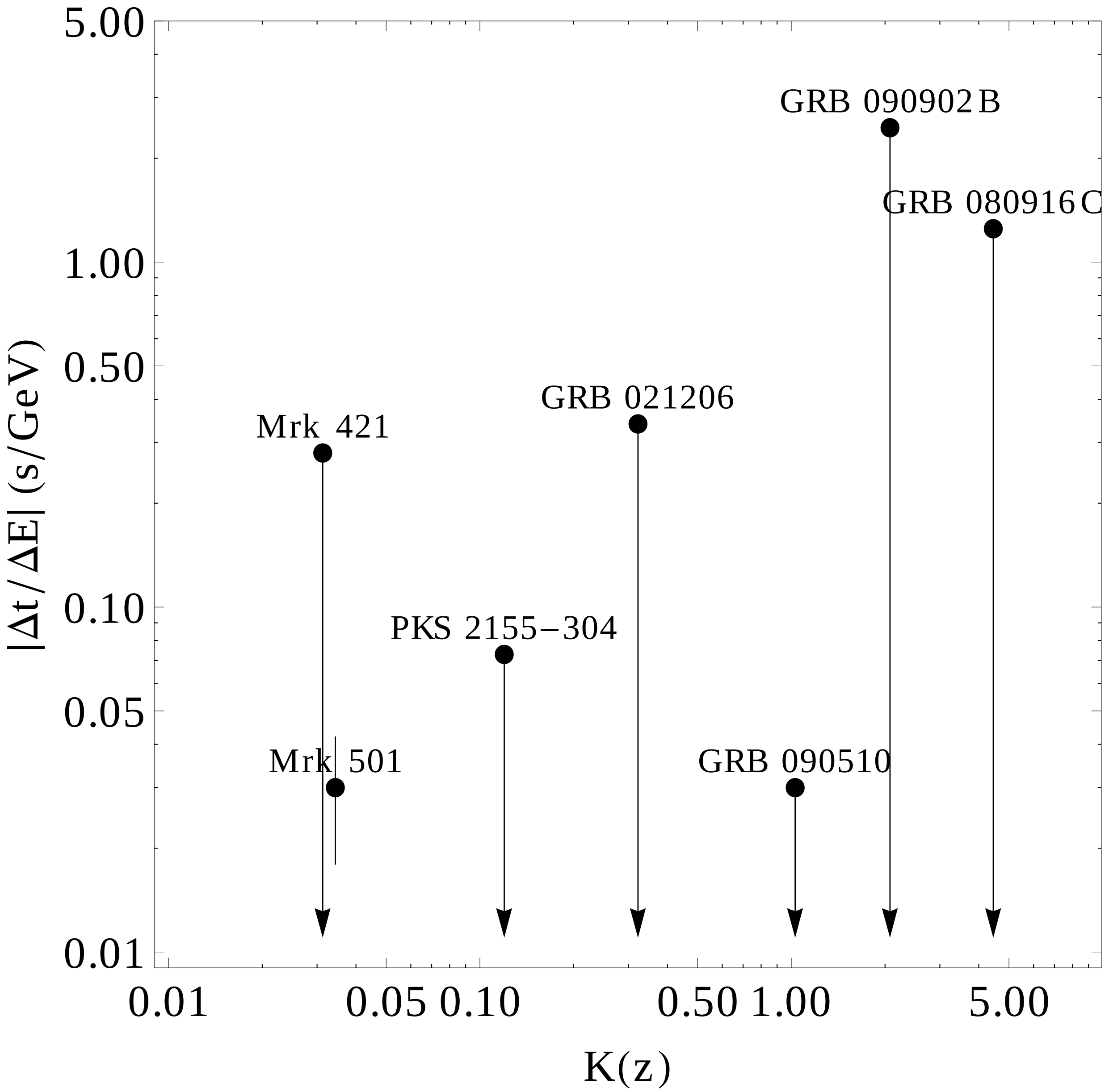

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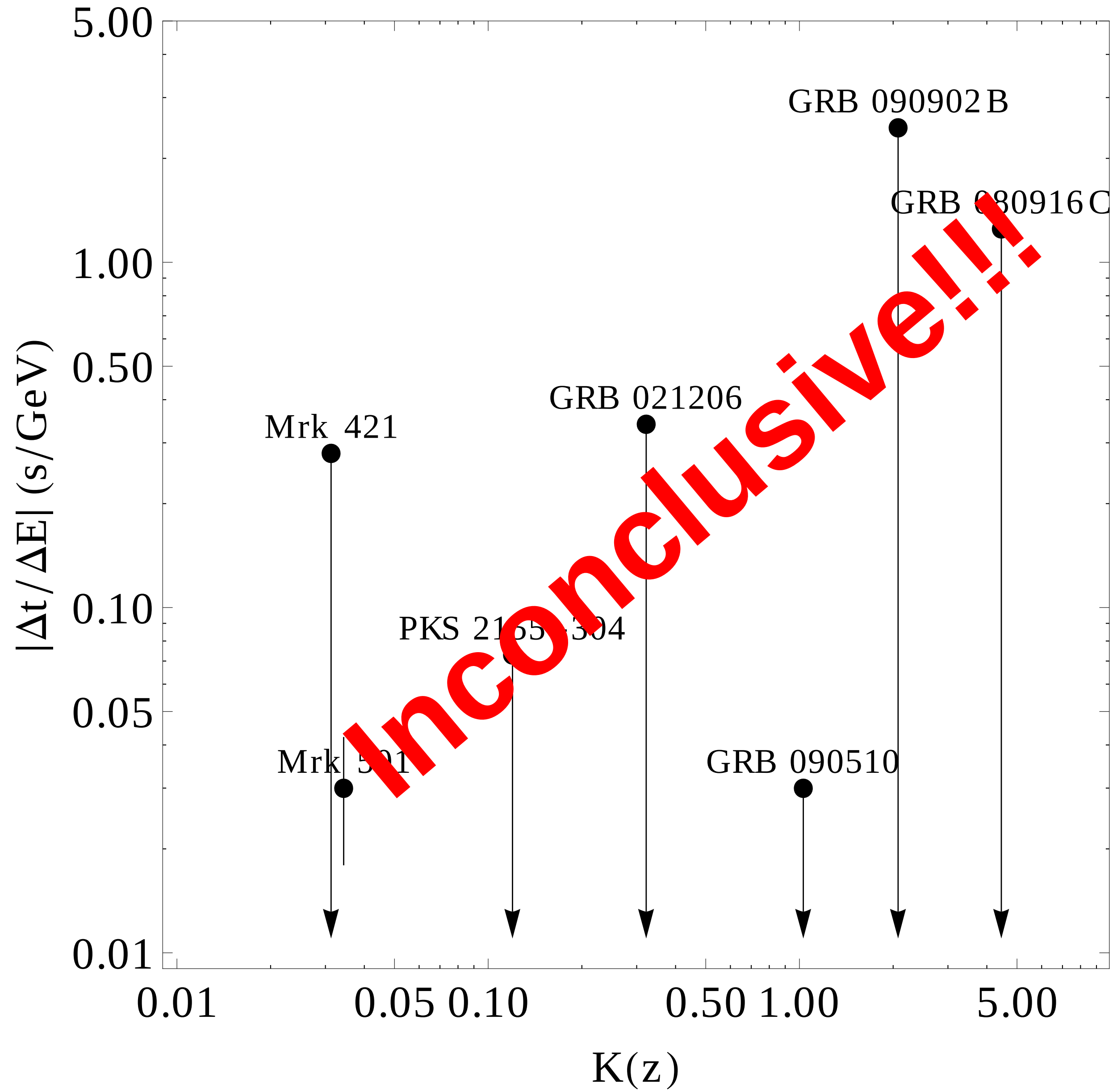

Cautions

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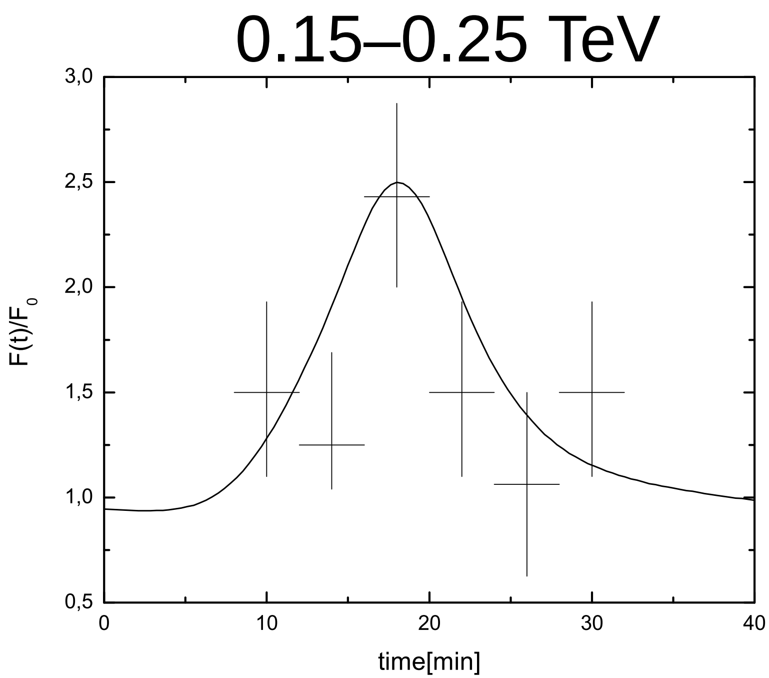
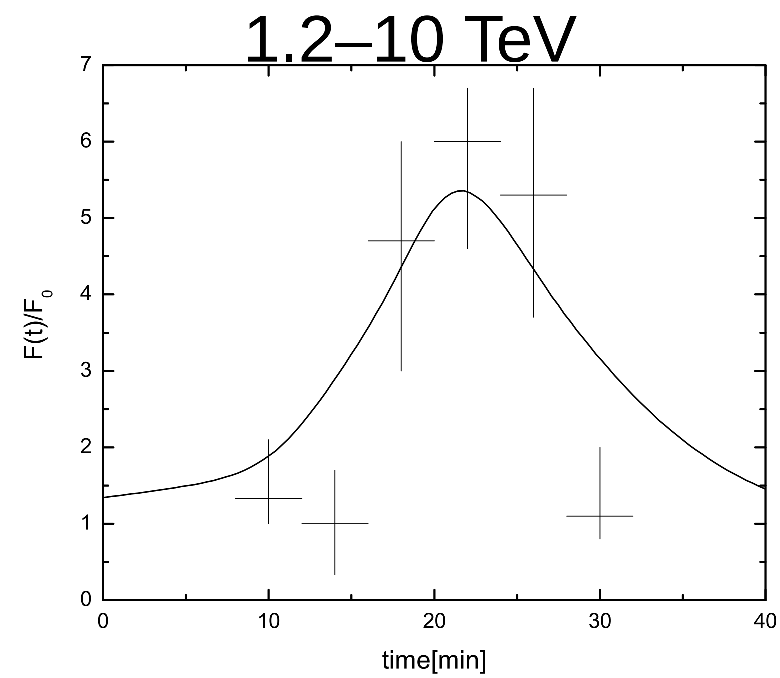
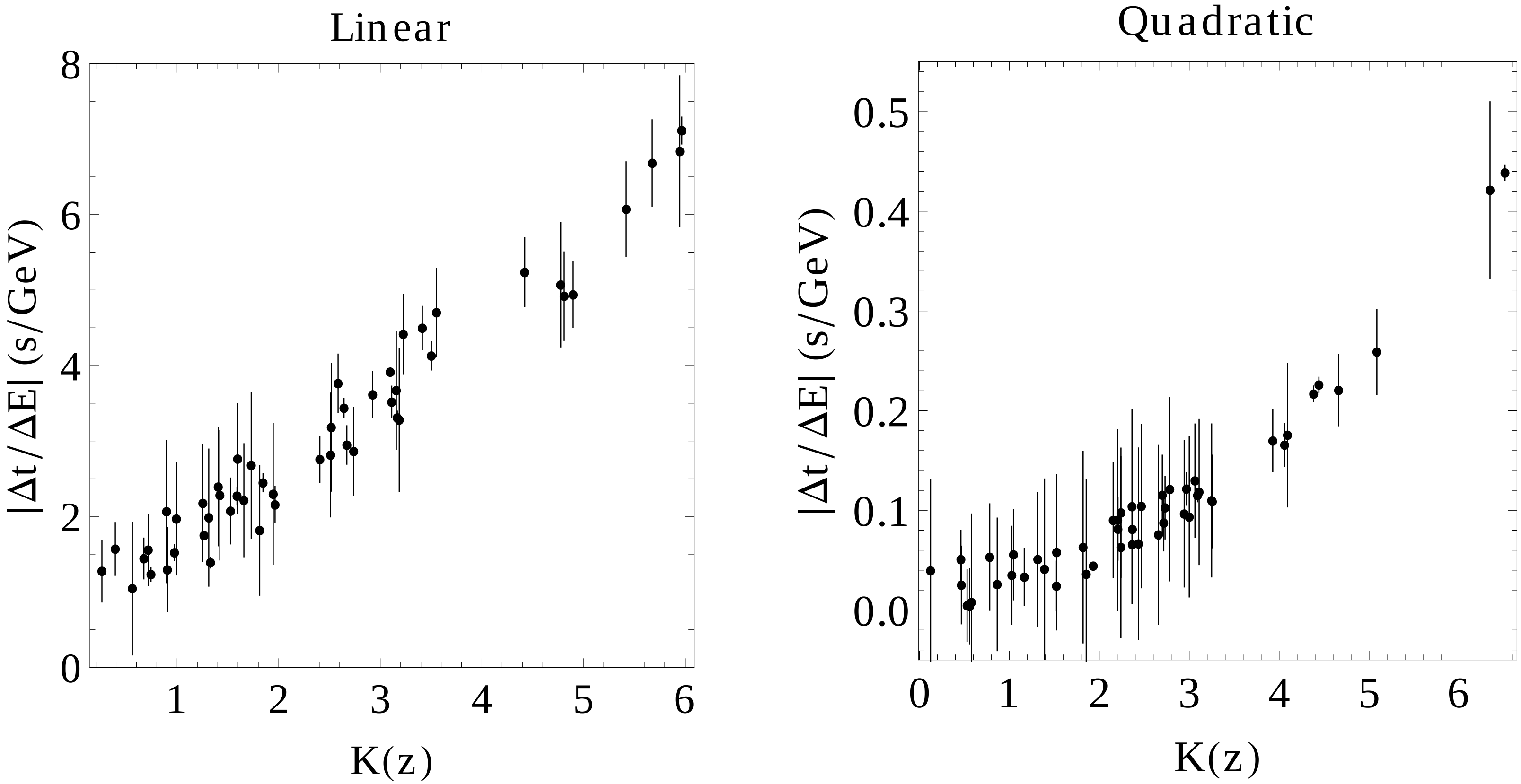




Mastichiadis, A. et al., A&A, **491**, 2, L37–L40, (2008)

Keep in mind...

- Energy dependent time-lags can be induced intrinsically in the source.
- Population studies are necessary: $\Delta t(z)$



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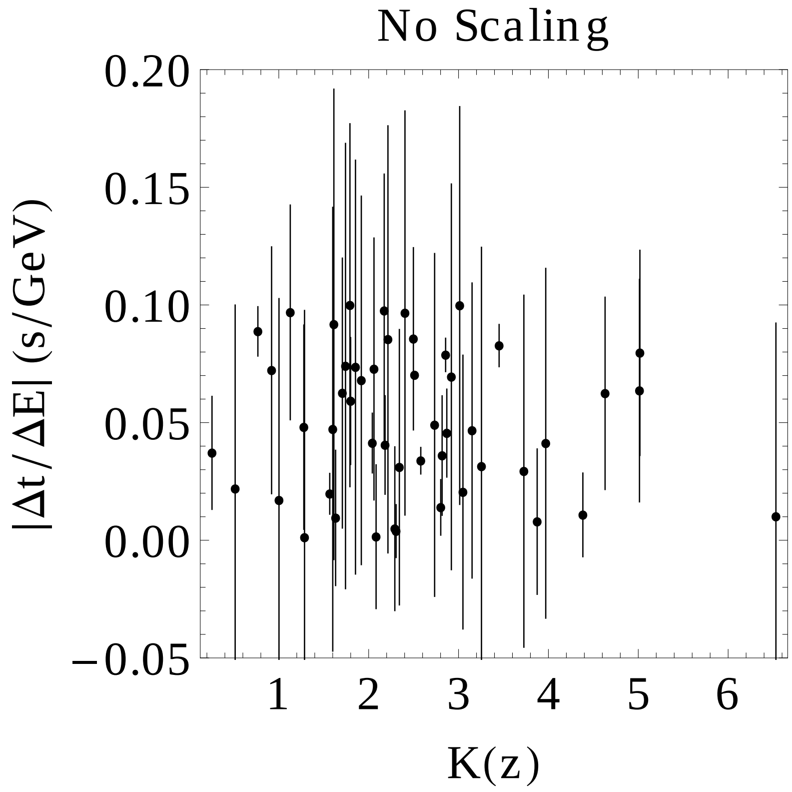

Keep in mind...

- Energy dependent time-lags can be induced intrinsically in the source.
- Population studies are necessary: $\Delta t(z)$
- Main emphasis on blazars: They are always there!!!

Recap

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- Several theories predict that vacuum may exhibit light-dispersional effects in Planck scales.
- Tiny variations in photon speed, accumulated over cosmological distances, can be unveiled from variable VHE objects.
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Recap

- Several theories predict that vacuum may exhibit light-dispersional effects in Planck scales.
- Tiny variations in photon speed, accumulated over cosmological distances, can be unveiled from variable VHE objects.
- Up to now, there is <u>no robust evidence</u> from an astrophysical point of view.
- Energy dependent time-lags can be produced in the source.
- Large source samples needed to reject or determine the existence of possible LIV.