High-Energy Astrophysics and Transplanckian Dispersion Relation

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Outline

- What is a transplanckian dispersion relation ?
- Motivations
- Possible Effects
- Are we observing something new?
- Conclusions

Transplanckian Dispersion Relation

- One of the basis of the SR is the invariance of the speed of light
- SR predicts a dispersion relation for the photon
- Considering a FRW metric we have:

$$ds^2 = -c^2\,dt^2 + a(t)^2 d\vec{x}^2.$$

$$\mathcal{H} = \sqrt{m^2\,c^4 + \frac{p^2\,c^2}{a^2}}\,,$$

$$x(t,p) = \int \frac{p\,c^2}{a^2} \frac{dt}{\sqrt{m^2\,c^4 + \frac{p^2\,c^2}{a^2}}} \quad , \quad p = \text{constant}\,.$$

$$a\,\dot{x} = c\,.$$

So, we can have a transplanckian too...

- A possible modification of the hamiltonian could be written as:

$$E^2 = p^2 - \sum f^{(n)} \frac{E^n}{E_{Pl}^{(n-2)}}$$

- That can be read as the classical one plus some corrections!

- This leads to Lorentz Invariance Violation! (LIV)

$$v \simeq 1 - \frac{n-1}{2} \cdot f^{(n)} \left(\frac{E}{E_{Pl}}\right)^{(n-2)} + \mathcal{O}\left(\frac{E}{E_{Pl}}\right)^{(n-1)}$$

Motivations...

- Examples of motivations are:
  - String Theory
  - Loop Quantum Gravity
- Einstein Lagrangian allows for large fluctuations of the metric and the topology of space-time (Wheeler, 1957 and Hawking, 1978)
- LIV will be a consequence of the foam of the space-time structure caused by quantum fluctuations. But what about the energy scale ?
- DSR: Adds a postulate in SR, Planck length is invariant.

$$E_{Pl} = \sqrt{\frac{\hbar c^5}{G}} \simeq 1.22 \cdot 10^{19}\ GeV.$$

If LIV is true…

- Photon decay: forbidden in LI physics, but possible in LIV formulation (corrections act as an effective mass).

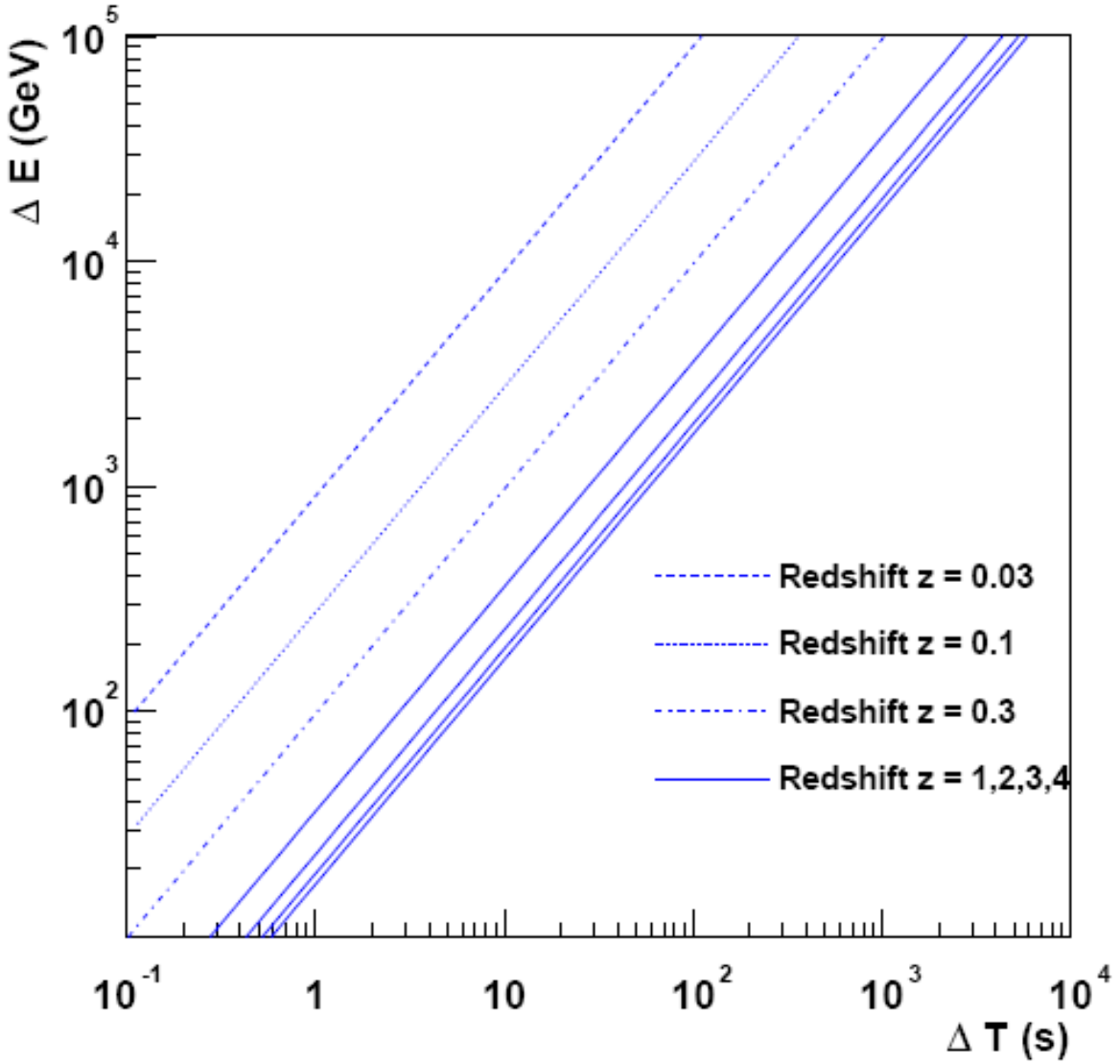
$$(\gamma \rightarrow e^{+}\, e^{-})$$

- Vacuum Cherenkov: spontaneous emission of photons by a charged particle in vacuum.

$$(A^{\pm} \rightarrow A^{\pm}\, \gamma)$$

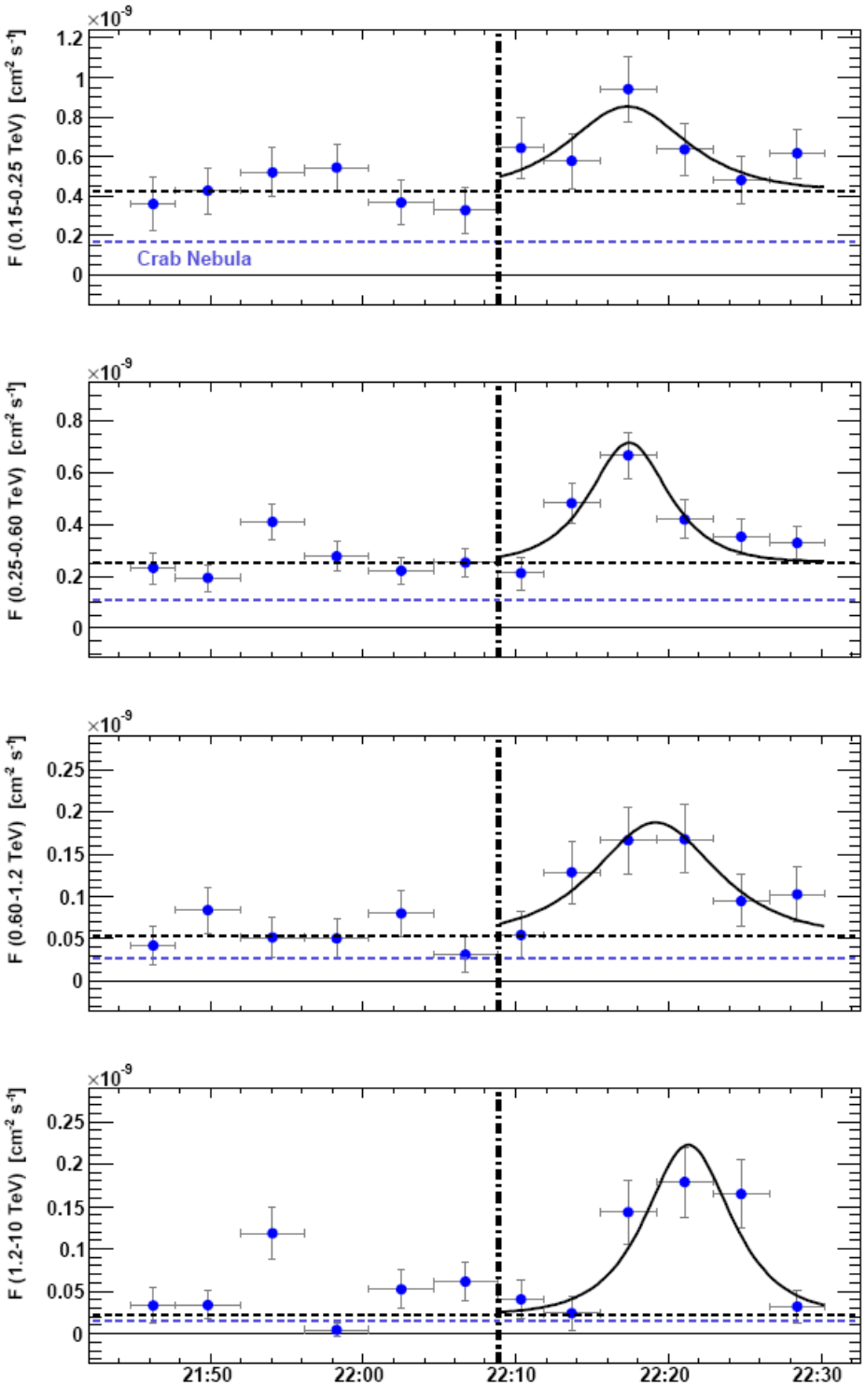
About evidences or detection ...

- GZK cutoff
  - Protons interacting with the CMB produce pions. If the proton energy increase, he can interact with lower energy CMB photons. If the energy is too high he can interact with any CMB photon in a short lenght decreasing until the GZK limit.
- Synchroton radiation
  - e^+ or e^- have a maximal synchroton frequency independent of the energy. Above this...Synchroton Self Compton?
- Birefringence
  - linearly polarized wave rotates the direction of polarization during propagation
- Time of Flight (TOF)
  - if we have a transplanckian, the velocity for two photons emitted by the same source, at the same time will be different resulting in a time delay for the observer


Δ E (GeV)
10^5
10^4
10^3
10^2
10^-1
1
10
10^2
10^3
10^4
Δ T (s)
Redshift z = 0.03
Redshift z = 0.1
Redshift z = 0.3
Redshift z = 1,2,3,4

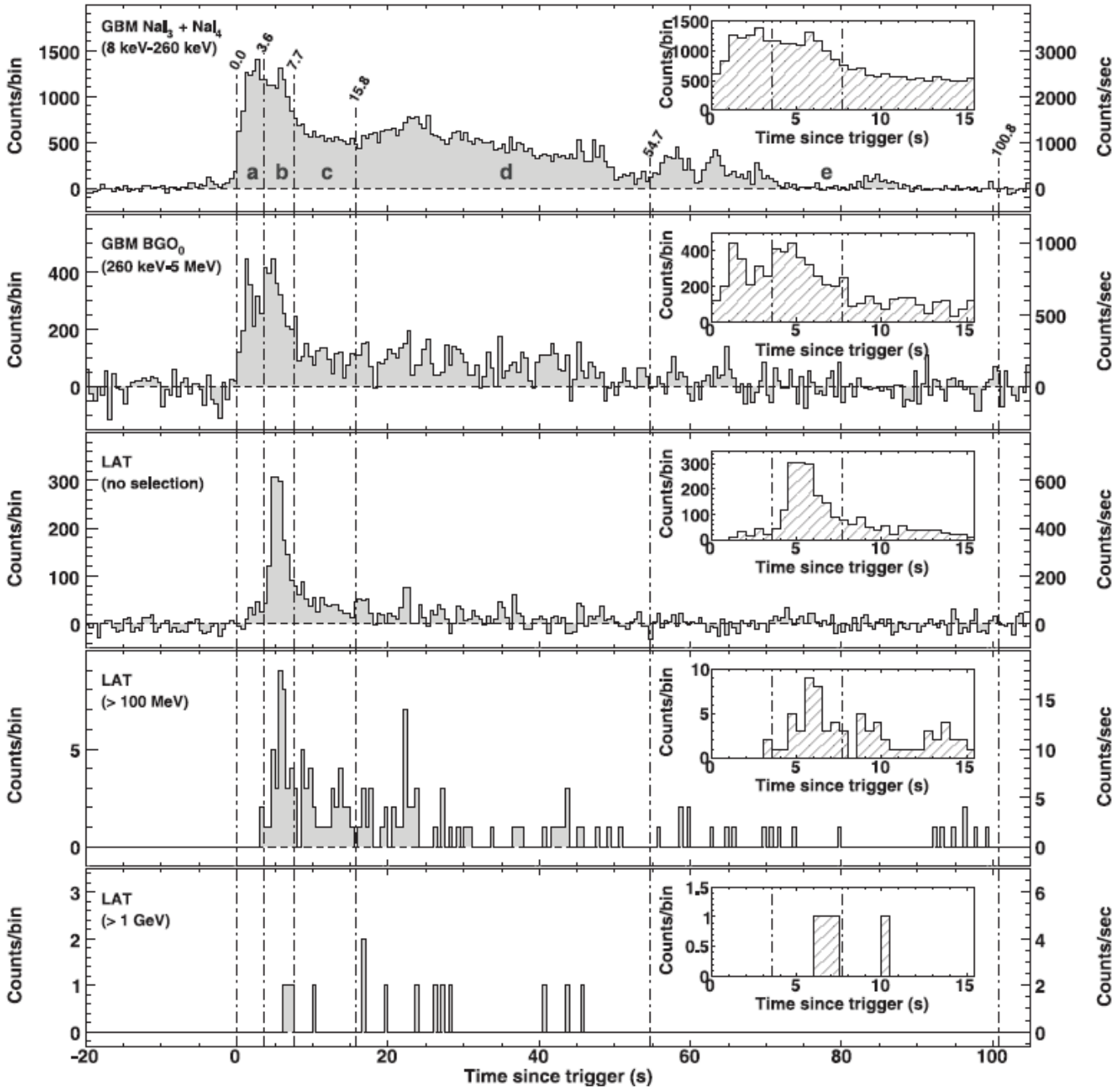
Observations

- MAGIC = Major Atmospheric Gamma-ray Imaging Telescope
  - July 9th 2005 observed flare in Mkn 501 source (AGN)
  - Redshift z=0.034
  - Energies up to the order of 10TeV
  - 4 minutes of time delay between highest and lower (0.6 TeV)
  - Source Effect or LIV?


×10⁻⁹
F (0.15-0.25 TeV) [cm⁻² s⁻¹]
Crab Nebula
F (0.25-0.60 TeV) [cm⁻² s⁻¹]
F (0.60-1.2 TeV) [cm⁻² s⁻¹]
F (1.2-10 TeV) [cm⁻² s⁻¹]
21:50
22:00
22:10
22:20
22:30

Observations

- FERMI (formerly known as GLAST)
- GRB080916c
- Compatible with HESS observations
- Energies up to 10 GeV
- Observed delays (seconds)
- Redshift z=4.35


GBM NaI3 + NaI4
(8 keV-260 keV)
GBM BGO0
(260 keV-5 MeV)
LAT
(no selection)
LAT
(> 100 MeV)
LAT
(> 1 GeV)
Counts/bin
Counts/sec
Time since trigger (s)
0.0
3.6
7.7
15.8
54.7
100.8
a
b
c
d
e

Instead of Conclusions

Mavromatos, N.
astro-ph/.HE 0903.0318

- Take it easy!!!
  - We are not saying that LIV occurs!
  - But is possible...
  - Quantum gravity laboratories
  - But we don’t know the astrophysics of the environment
  - These results need confirmation of other sources like MAGIC, WHIPPLE and FERMI
  - Continues...