

ON THE TRANSPARENCY
OF THE UNIVERSE
TO HIGH ENERGY PHOTONS
IN "QUANTUM GRAVITY"

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TeV

NEUTRINOS FROM GRB,

DELAYED BY 1 hour /
Gpc

... IN SOME APPROACHES
TO QUANTUM GRAVITY

TeV γ ASTRONOMY IS A WELL-ESTABLISHED FIELD.

> 3 SOURCES: CONFIRMED BY INDEPENDENT INSTRUMENTS - i.e. DIFFERENT ATMOSPHERIC \checkmark CERENKOV TELESCOPES AGREE

• CRAB (& other pulsars)

\geq 2 "MARKARIANS" (EXTRAGALACTIC)

BLAZARS - NOT THE BRIGHTEST

"EGRET" (i.e. GeV) SOURCES

MRK 421

MRK 501

$z = 0.03$

BUT THE CLOSEST.

\swarrow
ARE TeV photons absorbed?



or
TeV
PeV IR
 CMB

ABSORPTION OF VHE γ BY INTERGALACTIC
INFRARED RADIATION FIELD

STECKER, DE JAGER, SALAMON 1996

ApJ Lett 473, L75

STECKER, DE JAGER 1997, ApJ 496, 712

MALKAN, STECKER 1998, ApJ 496, 13

STECKER, DE JAGER 1988, AA 334, 685

COPPI, AHARONIAN 1999, Texas Conf

in press

J. PRIMAKOFF et al 1999, astro-ph

RECENT OBSERVATIONS $E > 20 \text{ TeV}$

PUSH THE ENVELOPE

(UNCONFIRMED) REPORTS OF TeV

γ 's from a few GRBs.

Note Mark very variable

QUANTUM GRAVITY ?

FUNDAMENTAL LENGTH $L \sim E_Q^{-1}$
or time

\Rightarrow LORENTZ INVARIANCE BROKEN

See AMELINO-CAMBIA et al 1998
Nature 393, 763

& references therein

e.g. GONZALES physics 9705031
9712015

also Group theoretical approach:

(K-DEFORMED POINCARÉ GROUP)

LUKIERSKI et al ANN PHYS 243,
90

1/2

$$pc = E \left(1 + \frac{E}{2E_Q} \right) + \dots$$

e.g. $\frac{\text{GeV}}{E_{pl}} \sim 10^{-19} \ll 1$

but $10^{-19} (\text{GeV})^2 \approx 10^{-1} \text{ eV}$

OBSERVABLE ?

AMELINO CAMELIA et al 1998:

Hamiltonian formalism

$$v = c \left(1 - \frac{E}{E_Q} \right)$$

BILLER et al 1998

MvK flare

$\tau \lesssim$ few minutes

NO DISPERSION OBSERVED ($E < 1 \text{ TeV}$
 $E > 2 \text{ TeV}$)

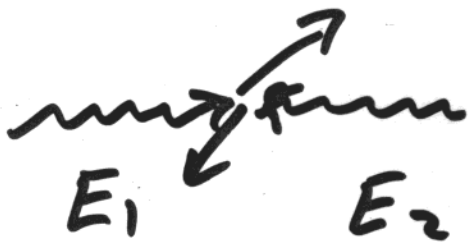
$d \approx 300\,000\,000 \text{ L.y.} \Rightarrow$

$$E_Q \geq 2 \times 10^{16} \text{ GeV}$$

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TRANSPARENCY OF THE UNIVERSE
TO VHE PHOTONS

$$\gamma + \gamma \rightarrow \text{matter}$$

e.g. $\gamma + \gamma \rightarrow e^+ + e^-$



$$E_1 = E_2 \Rightarrow \text{OK}$$

ZERO MOMENTUM

$$E_1 \neq E_2$$

DOES ZERO MOMENTUM
FRAME EXIST?

NOT IF $E_2 \gtrsim \sqrt{E_1 E_0}$
 $\gg E_1$

DO CALCULATIONS IN "FRAME OF GALAXIES"

EXAMPLE 1.

$$p^2 = E^2 + E^3/E_0$$

$$m_e^2 + p_e^2 = E_e^2$$

$\gamma + \gamma \rightarrow e^+ + e^-$

ONLY IF $E_1 E_2 \geq m_e^2 + \frac{(E_1 - E_2)^2 (E_1 + E_2)}{4 E_0}$

i.e. $\frac{m_e^2 c^4}{E_1} \leq E_2 \leq 2 \sqrt{E_1 E_0}$

EXAMPLE 2.

$$m^2 + p^2 = E^2 + E^3/E_0$$

$$E_e = \frac{E_1 + E_2}{2}$$

$\begin{matrix} \rightsquigarrow \\ E_1 \end{matrix} \quad \begin{matrix} \rightsquigarrow \\ E_2 \end{matrix}$

$\gamma + \gamma \rightarrow e^+ + e^-$

ONLY IF

$$E_2 \leq 2 \sqrt{2 E_1 E_0}$$

$$E_2 \leq 3 \sqrt{E_1 E_Q}$$

$$E_1 < 1 \text{ eV} \Rightarrow$$

UNIVERSE TRANSPARENT TO

PHOTONS OF $E > 10 \text{ TeV} \left(\frac{E_Q}{10^{16} \text{ GeV}} \right)^{1/2}$

$$\text{IF } p_\gamma^2 = E_\gamma^2 + E_\gamma^3 / 2E_Q$$

GKZ cutoff \rightarrow similar idea

$$p + \gamma \rightarrow \pi's$$

Glashow hep-ph 9808446

Q. GRAVITY WILL AFFECT
KINEMATICS OF HE INTERACTION.

HE NOT SO HIGH!