Astrophyiscal Limits on Lorentz Invariance Violation At the Planck Scale

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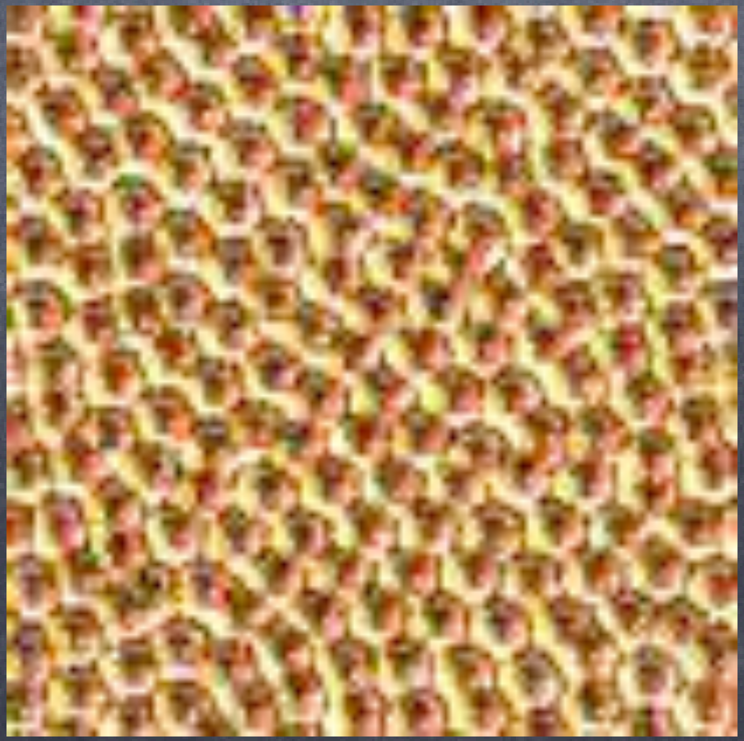
Moriond 2012

Quantum Gravity Effect at low energies (Amelino-Camelia et al., 98)

Lorentz Violation (or deformation) appears in various Quantum Gravity Theories.

Energy dependent dispersion and speed of light.



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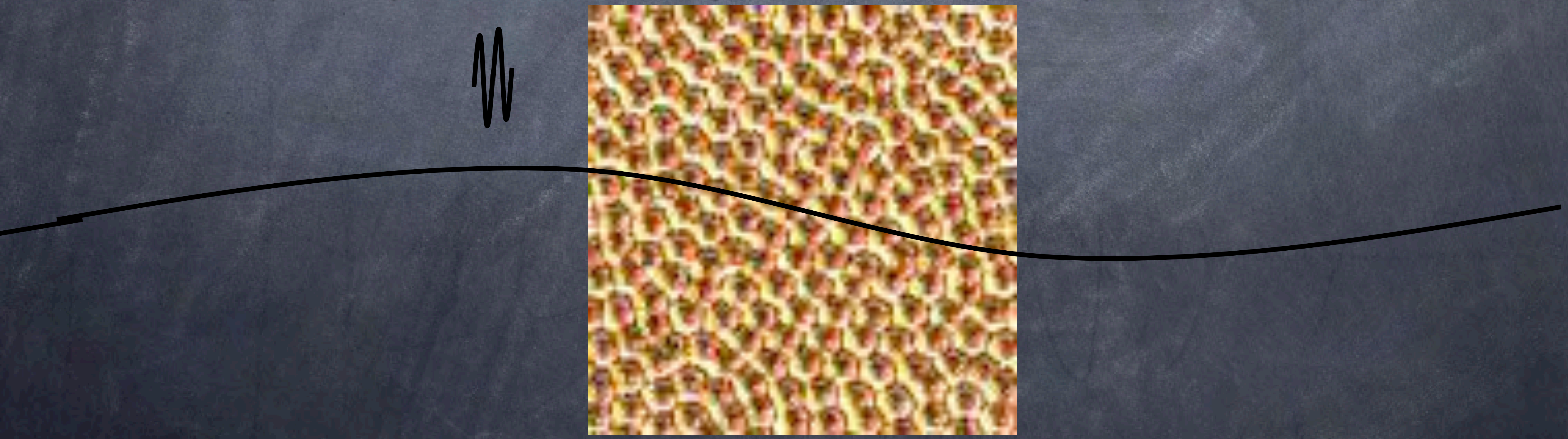

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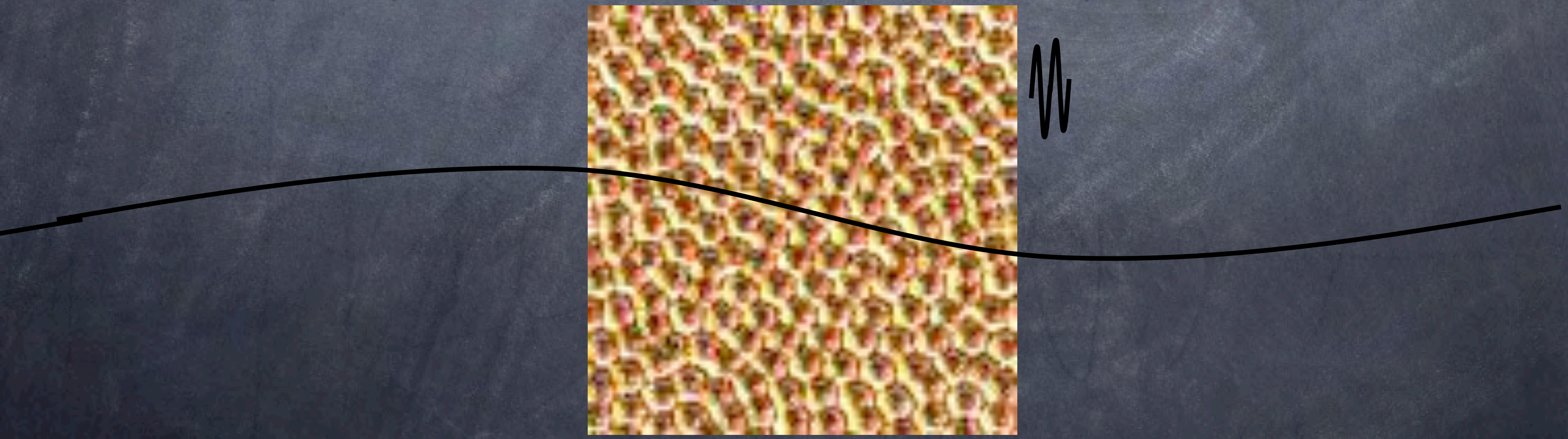

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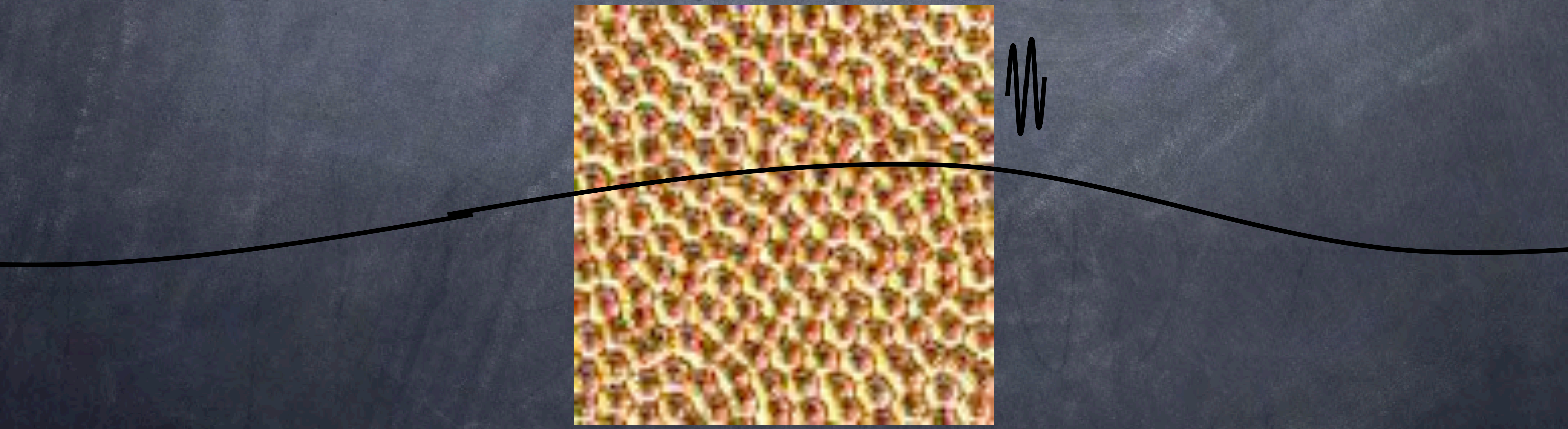
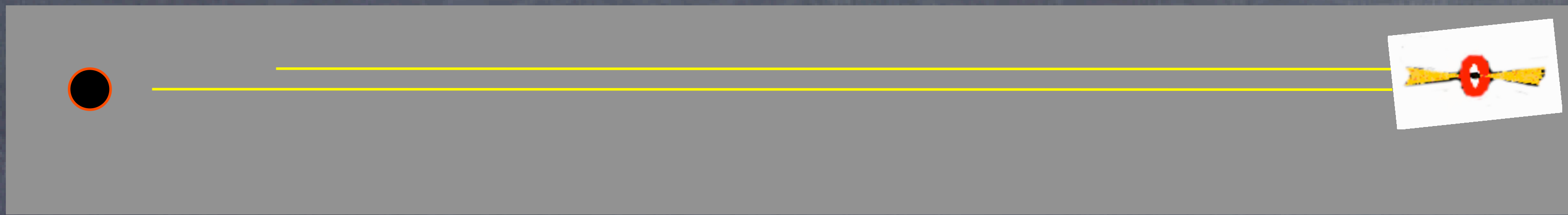


A phenomenological approach

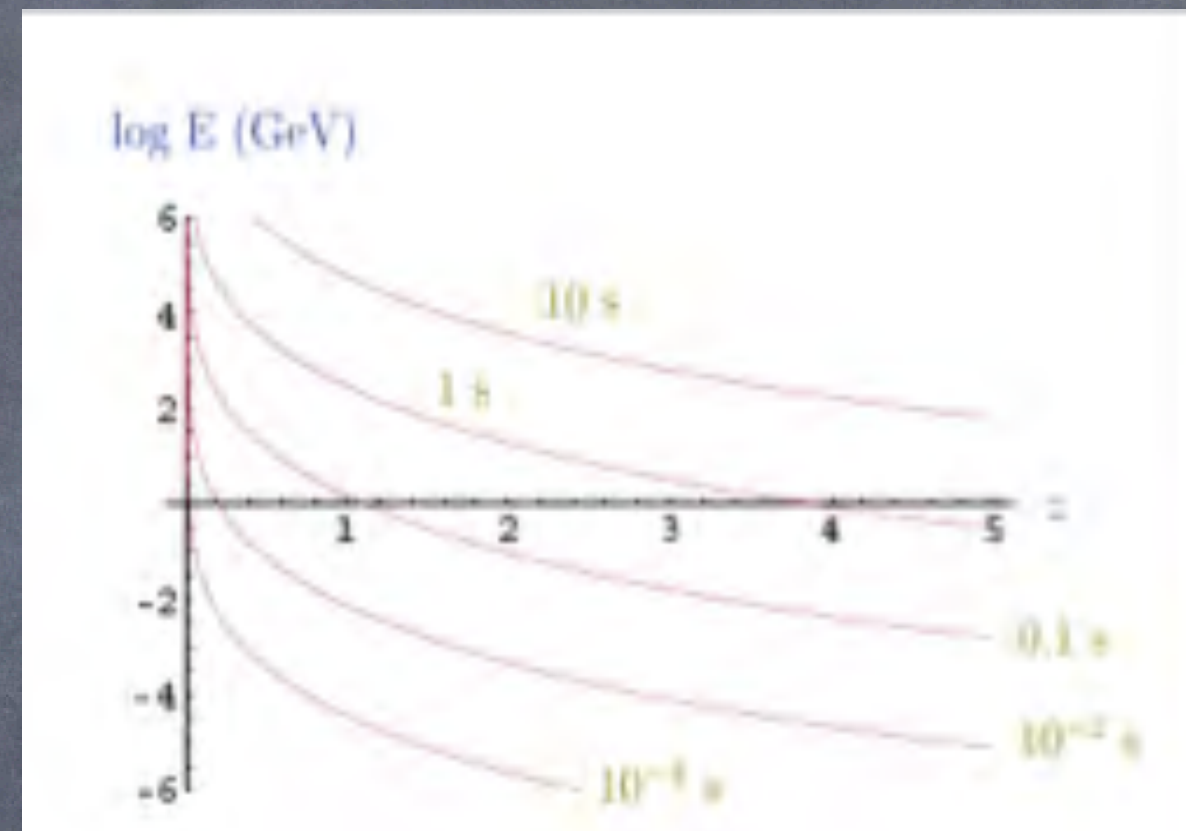
The simplest leading order low-energy approximation of any theory that breaks Lorentz Invariance at a very high energy scale: ξm_{pl}, for the deformed dispersion relation is:

$$E^2 - p^2 - m^2 \approx \pm \left(\frac{E}{\xi_n m_{pl}} \right)^n$$

$$v \approx c \left[1 \pm \frac{(1+n)}{2} \left(\frac{E}{\xi_n m_{pl}} \right)^n \right]$$



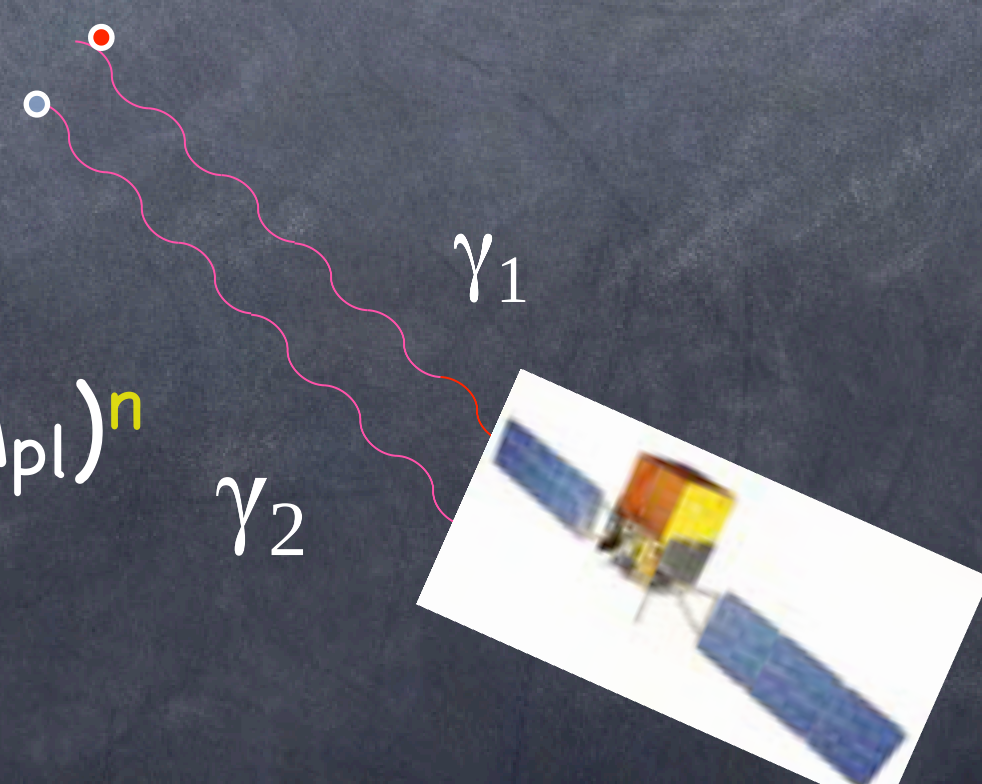
$$E^2 \approx (pc)^2 \left[1 + \left(\frac{E}{\xi m_{pl}}\right)^n\right]$$



$$v \approx c\left[1 + \frac{(1+n)}{2}\left(\frac{E}{\xi m_{pl}}\right)^n\right]$$

$$dt \approx \pm \frac{d}{c}\left(\frac{E}{\xi_n m_{pl}}\right)^n \approx 10^{-2-(n-1)19}\,\mathrm{sec}\left(\frac{E}{\xi_n \mathrm{GeV}}\right)^n$$

Energy dependent arrival time (Amelino-Camelia et al., 1998)



$$E^2 = p^2c^2 + E^2(E/\xi M_{pl})^n$$

$$E_{QG} \equiv \xi M_{pl}$$

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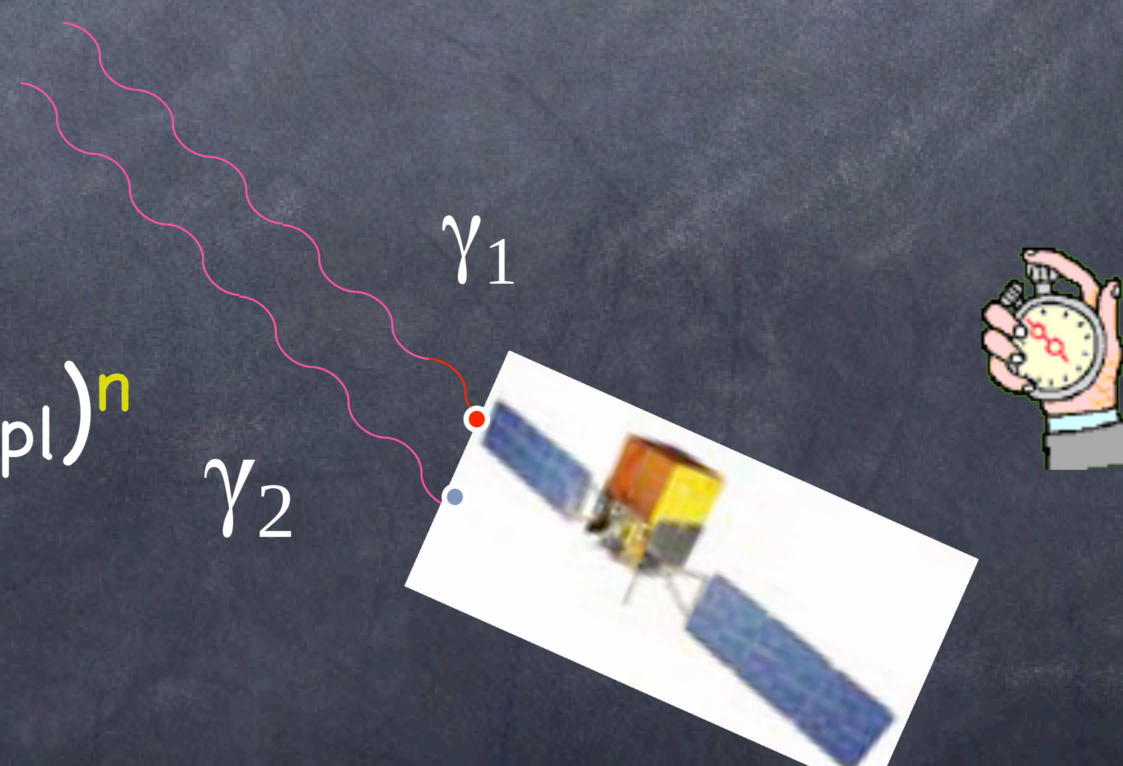

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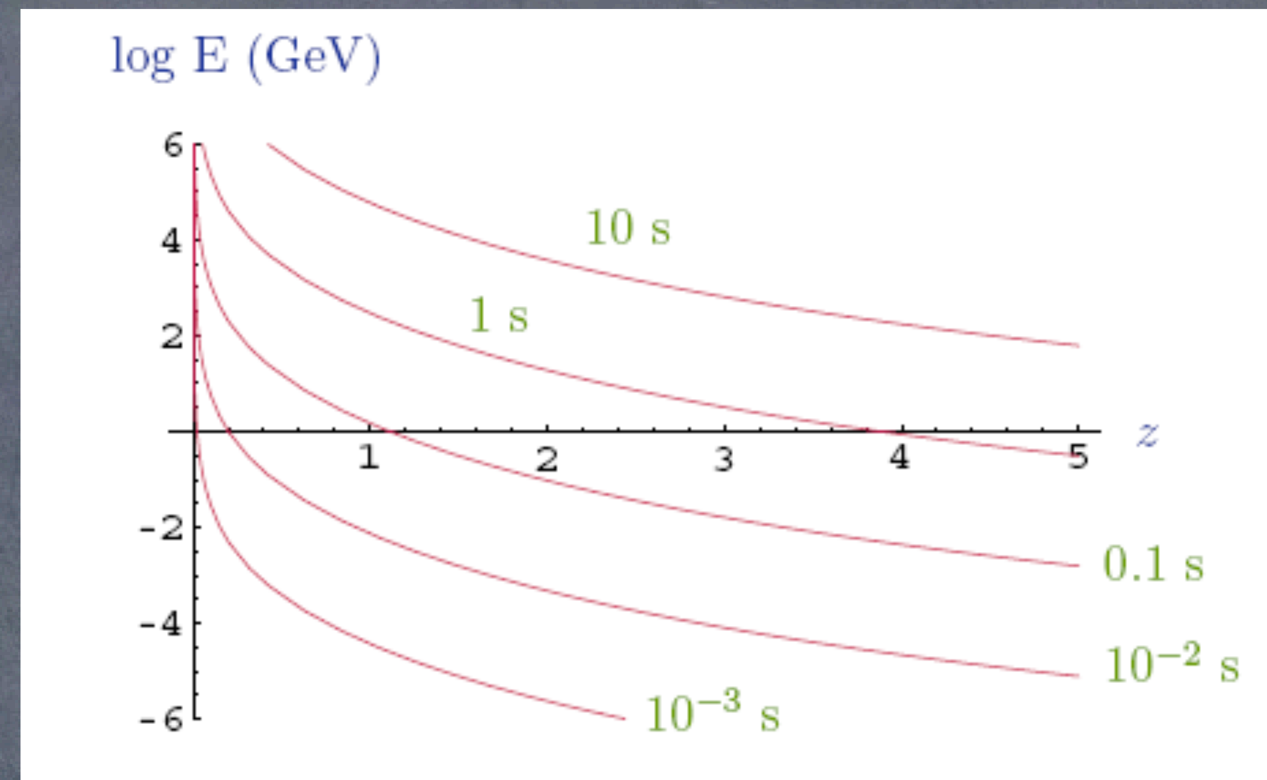

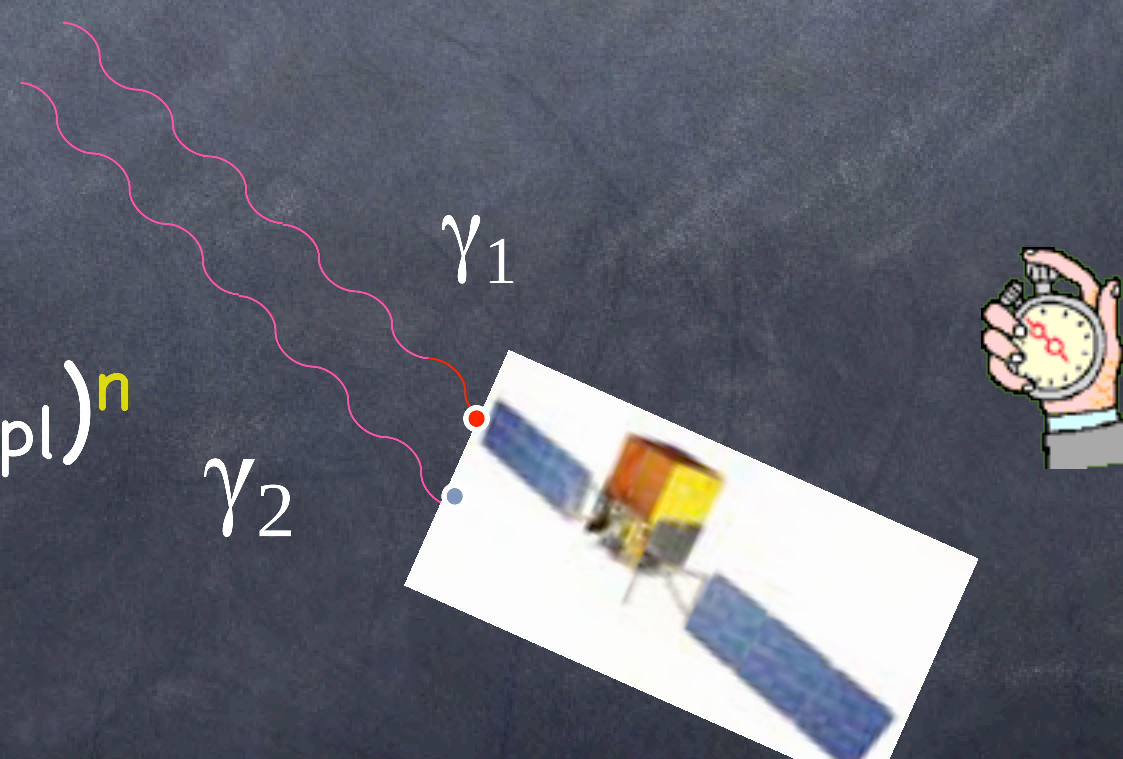

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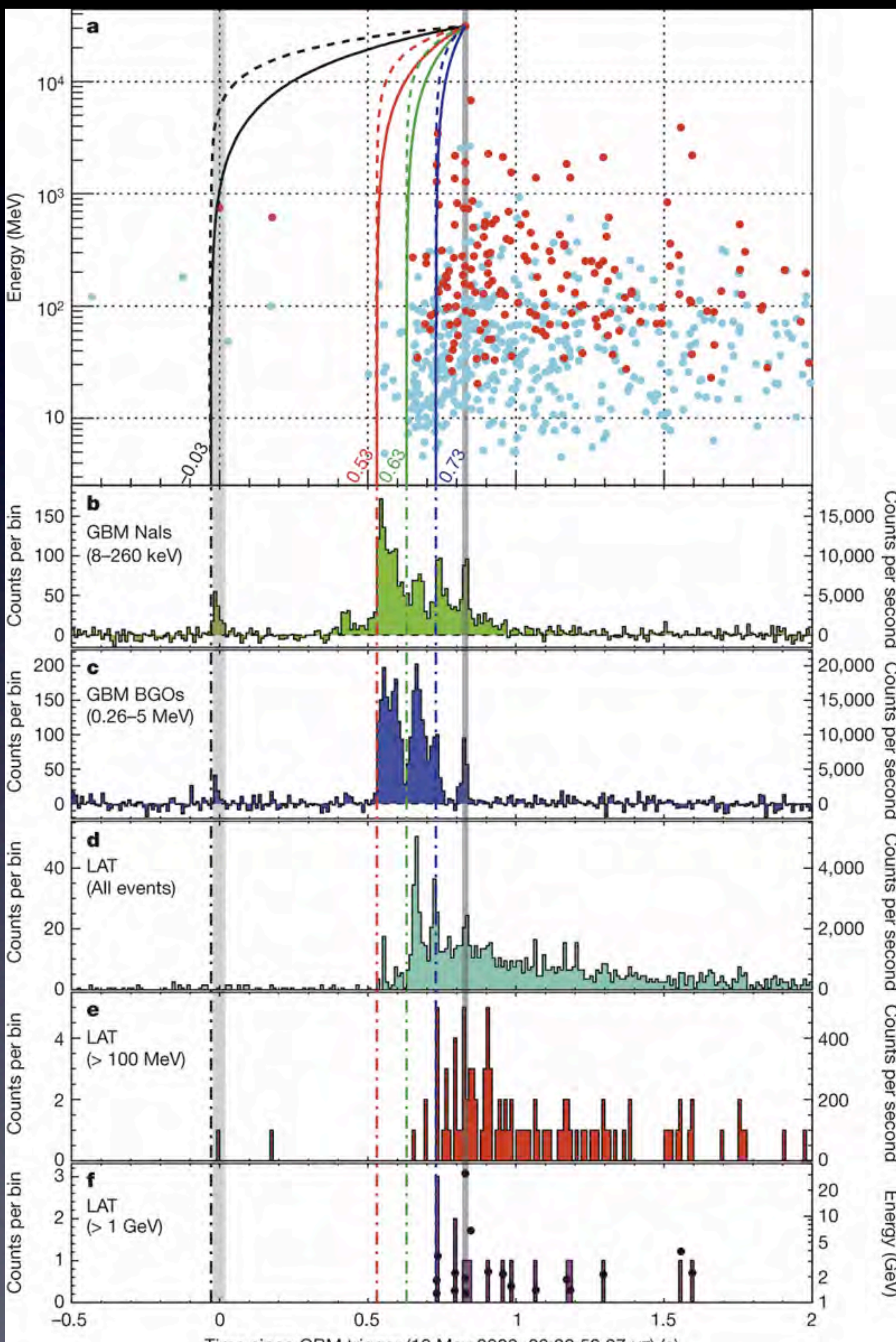
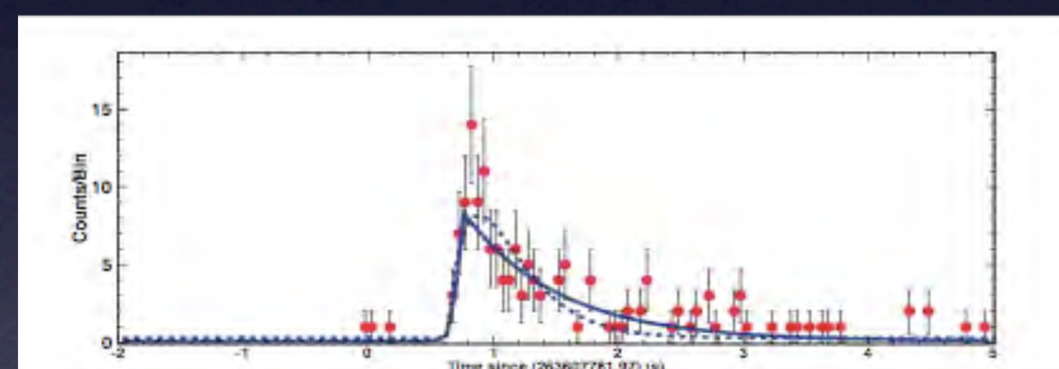
Fermi's observations of GRB 050910



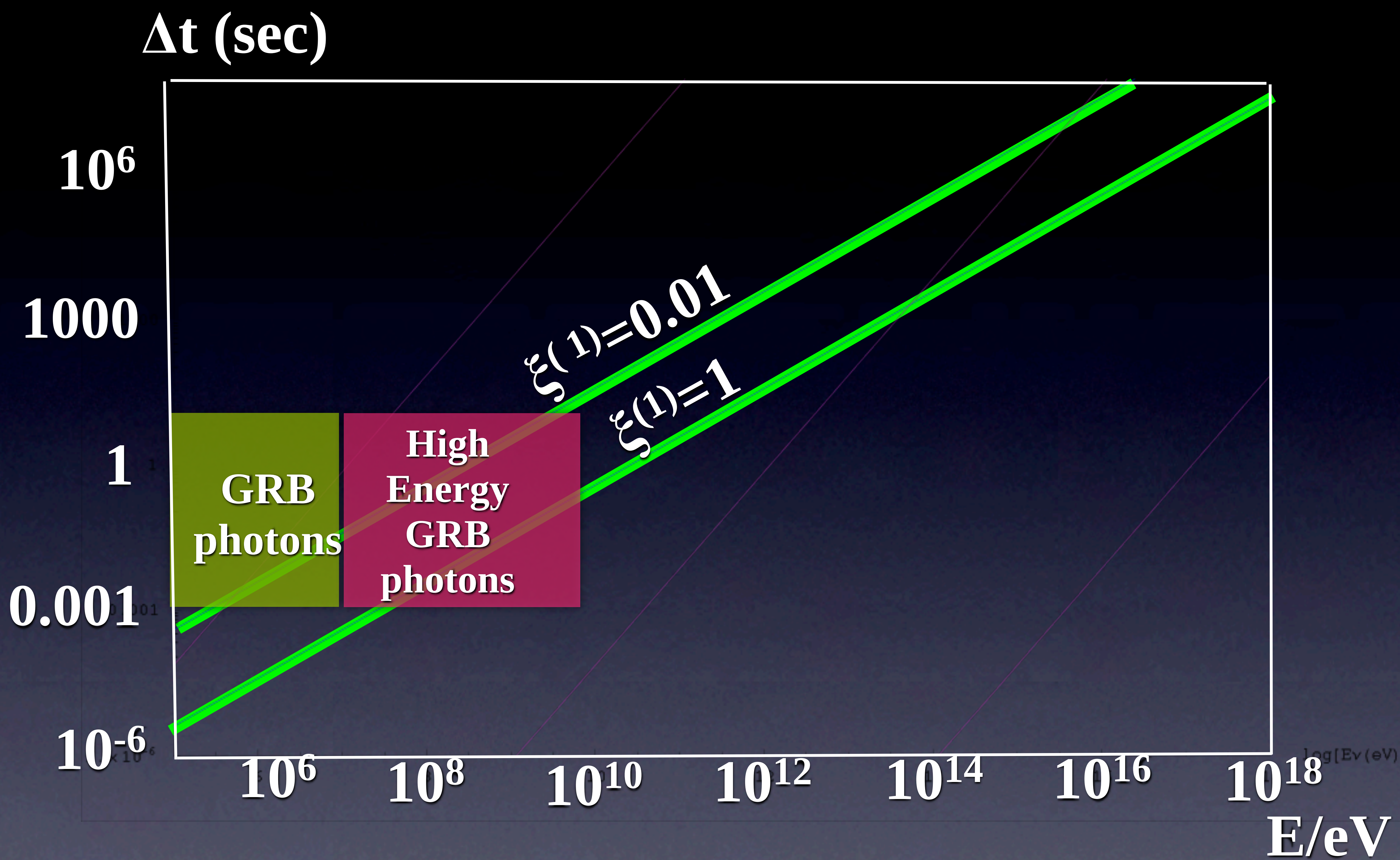
Z=0.903

$\Delta t_{0.1MeV-30GeV} < 0.9sec$

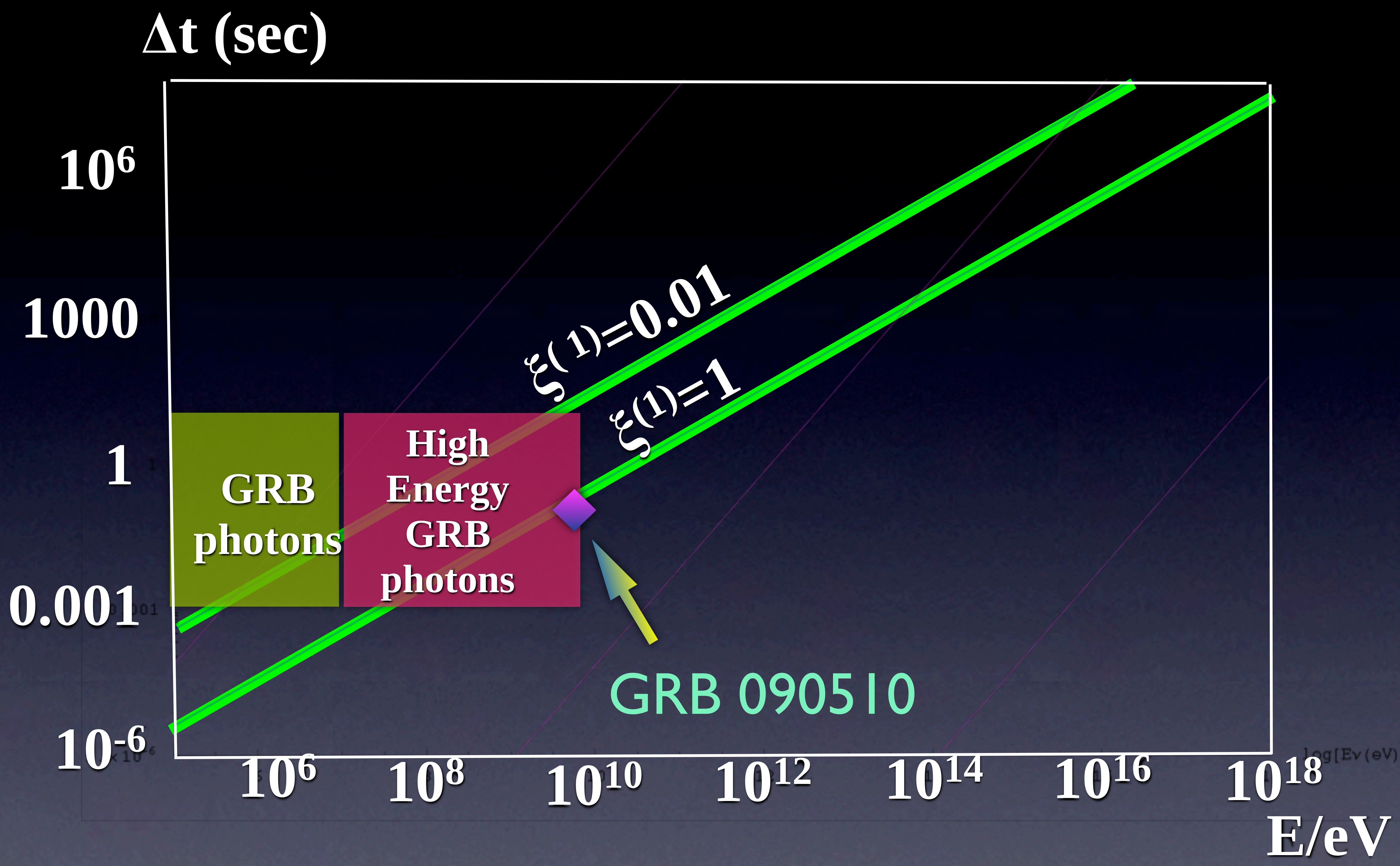
$\Rightarrow E^{(1)}_{QG} > 1.2 \cdot 10^{19}$ GeV $= 1.2\ m_{pl}$



t_{start} (ms)	limit on $\lvert\Delta t\rvert$ (ms)	Reason for choice of t_{start} or limit on Δt	E_l (MeV)	valid for s_n	lower limit on $M_{QG,1}/M_{Planck}$	limit on $M_{QG,2}$ in 10^{10} GeV/c^2
−30	< 859	start of any observed emission	0.1	1	**> 1.19**	> 2.99
530	< 299	start of main < 1 MeV emission	0.1	1	**> 3.42**	> 5.06
630	< 199	start of > 100 MeV emission	100	1	**> 5.12**	> 6.20
730	< 99	start of > 1 GeV emission	1000	1	**> 10.0**	> 8.79
—	< 10	association with < 1 MeV spike	0.1	±1	**> 102**	> 27.7
—	< 19	if 0.75 GeV γ is from 1st spike	0.1	−1	**> 1.33**	> 0.54
$\lvert\Delta t/\Delta E\rvert$ < 30 ms/GeV		lag analysis of all LAT events	—	±1	**> 1.22**	—



$\xi^{(1,2)} = E_{LIV}/m_{pl}$



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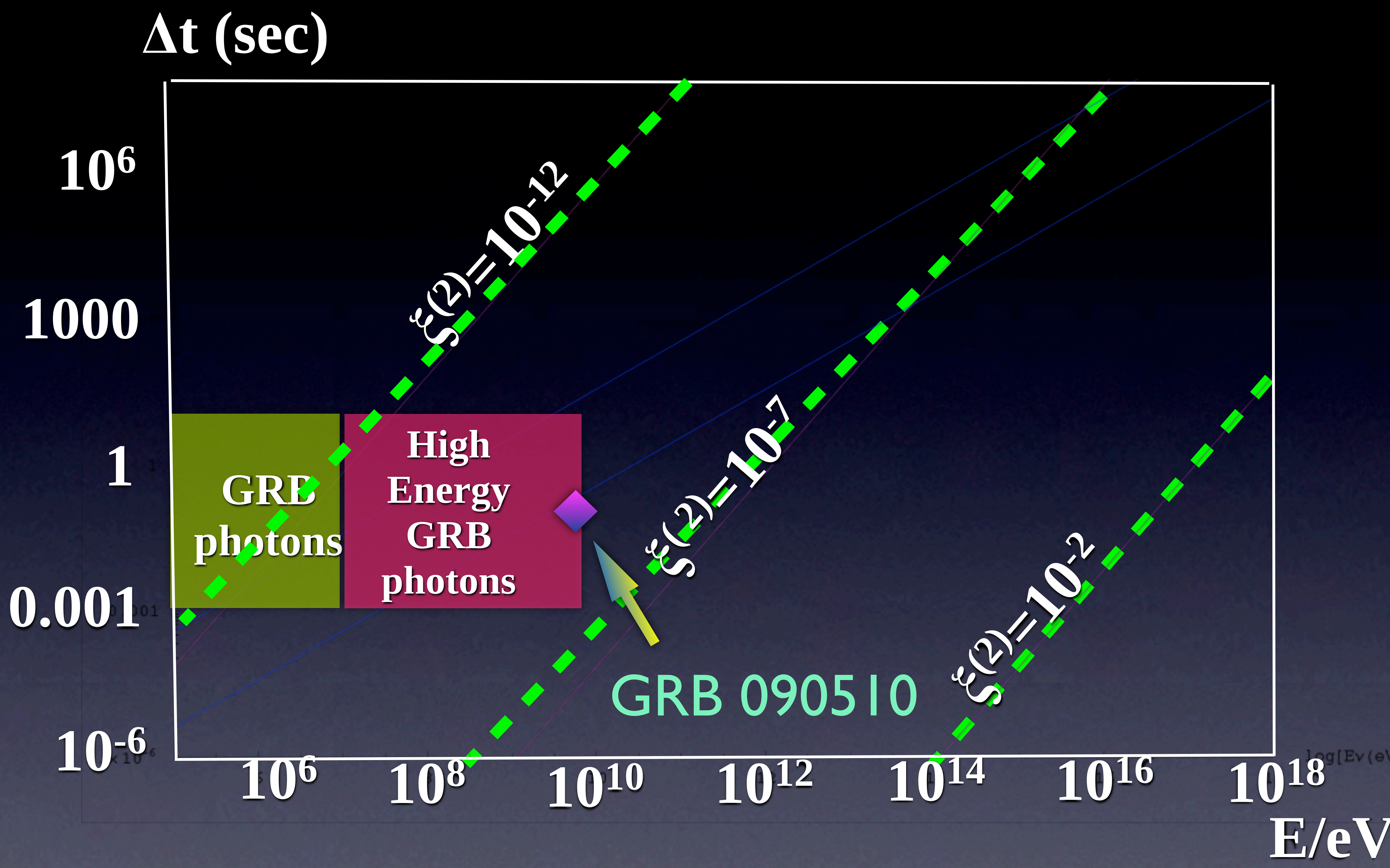

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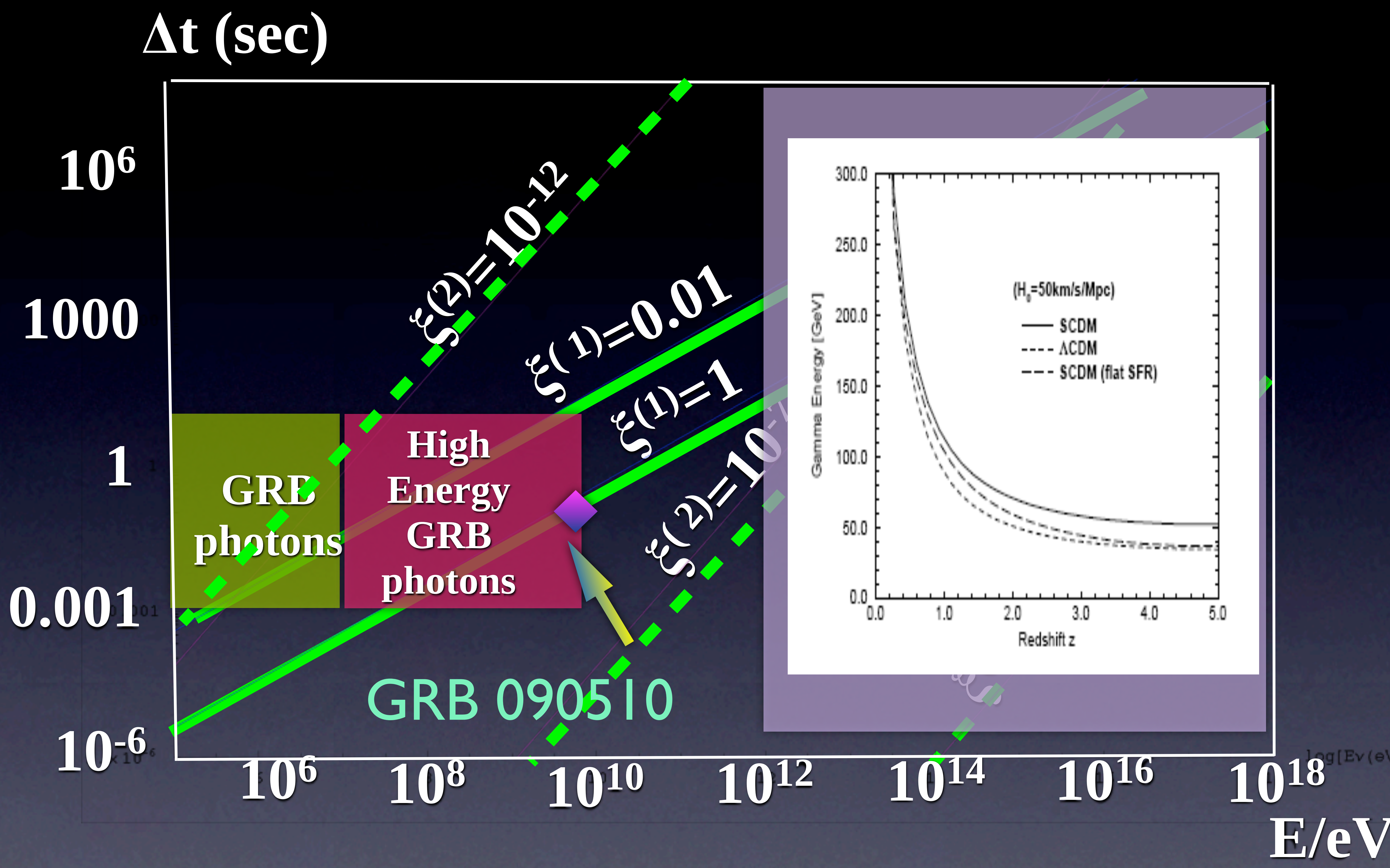

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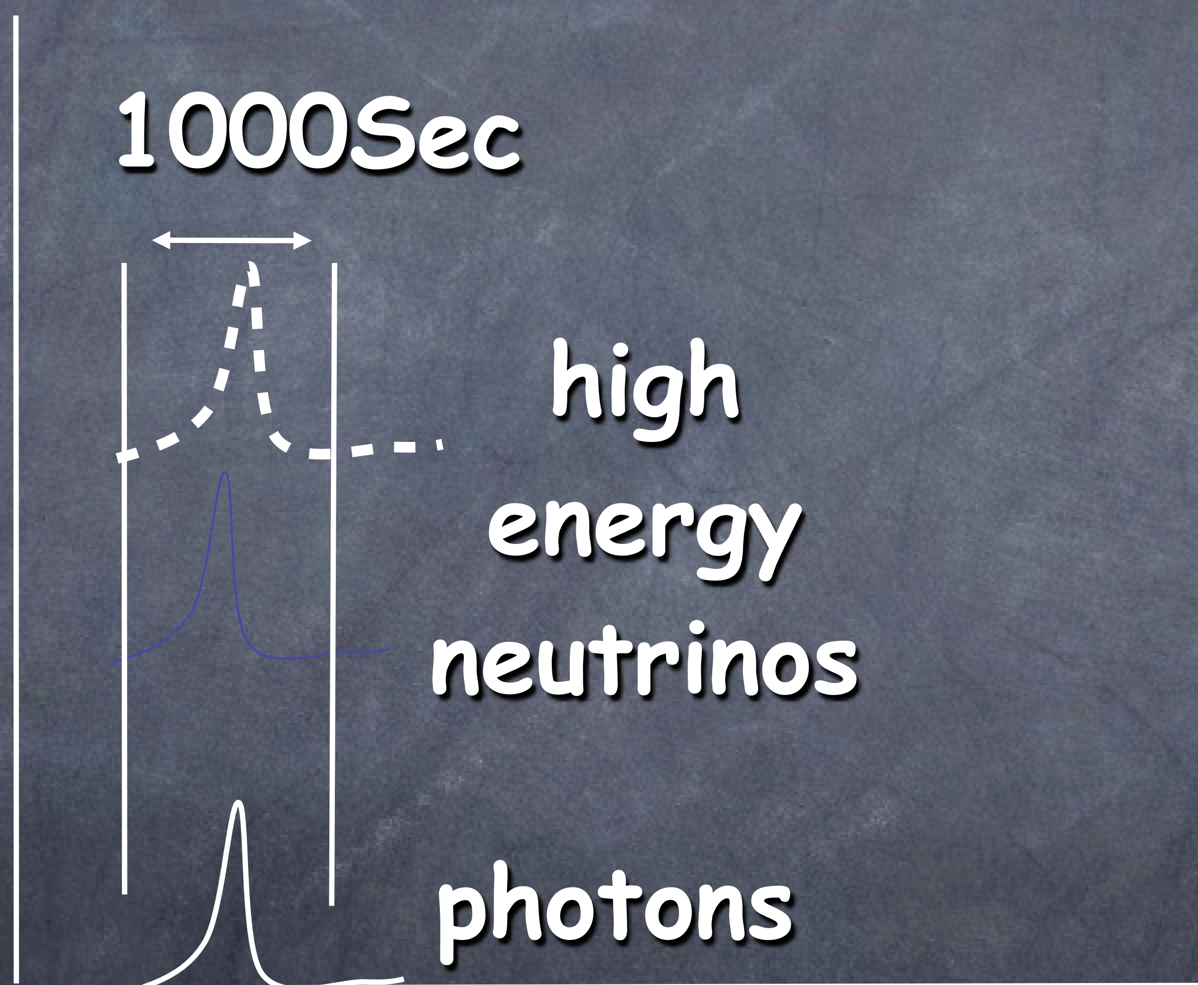
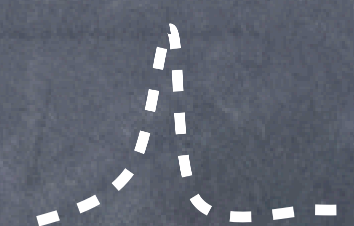
GRB photons & high energy neutrinos

Expect 10 neutrinos detected in a km^3 detector per 1000 GRBs





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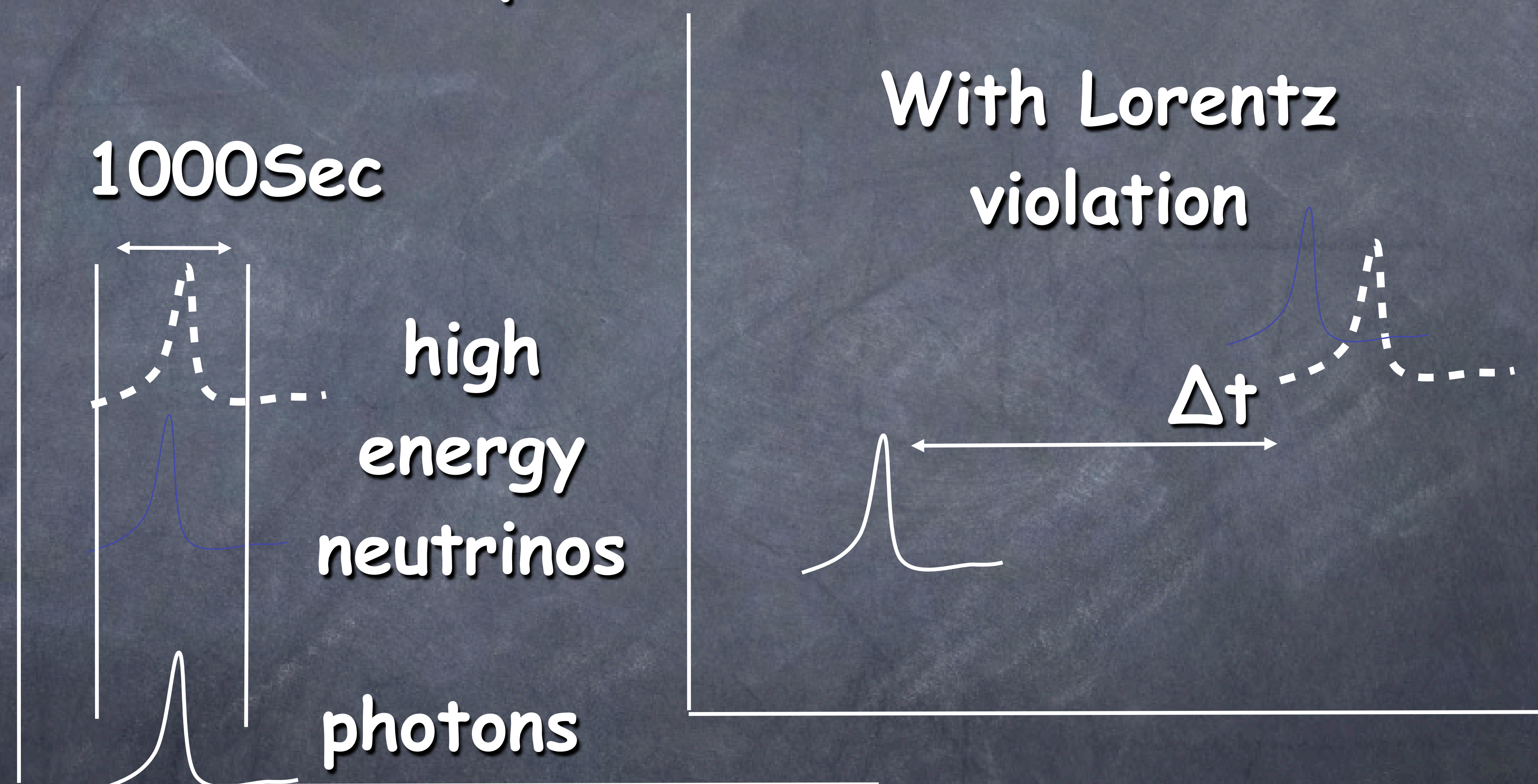

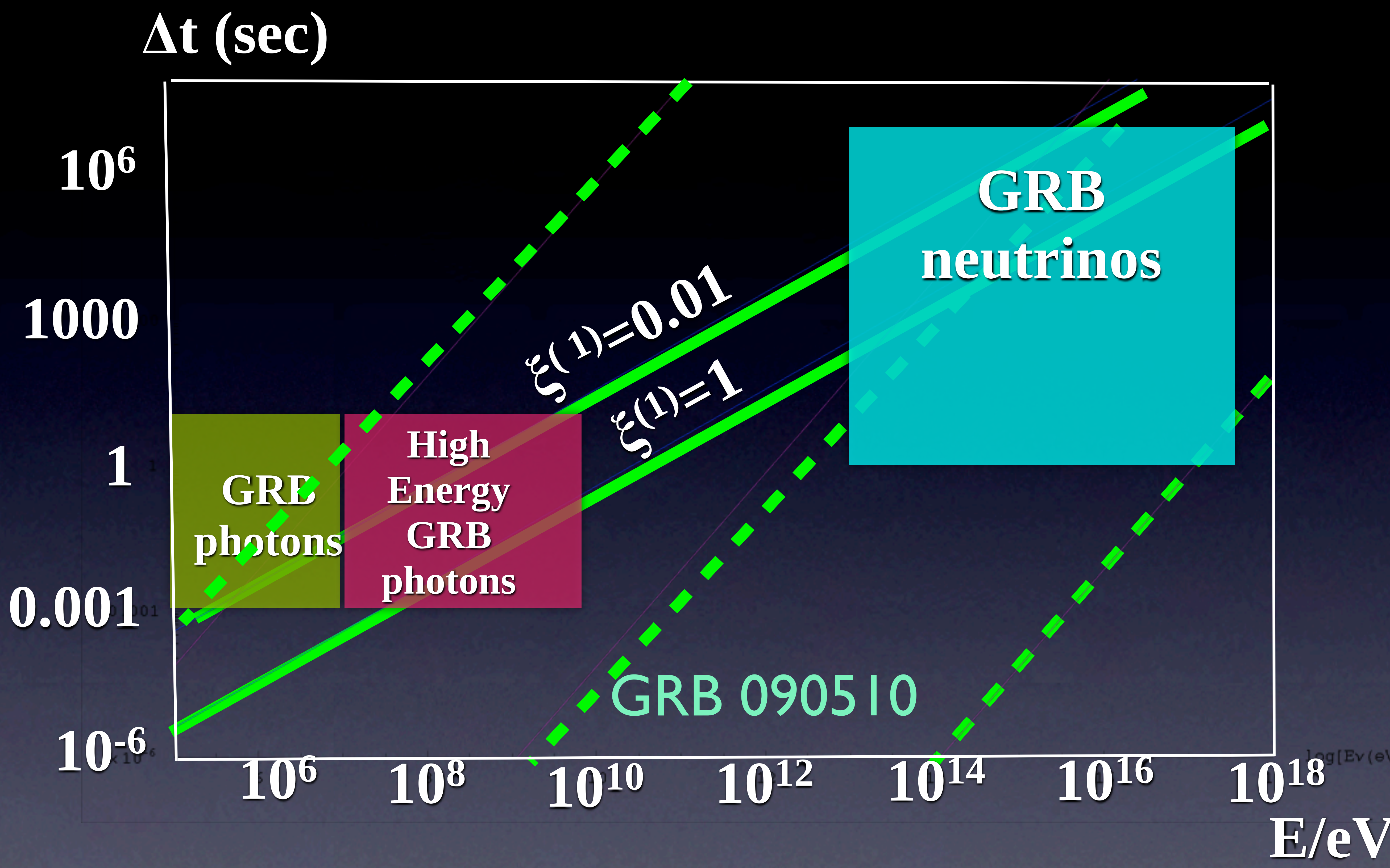

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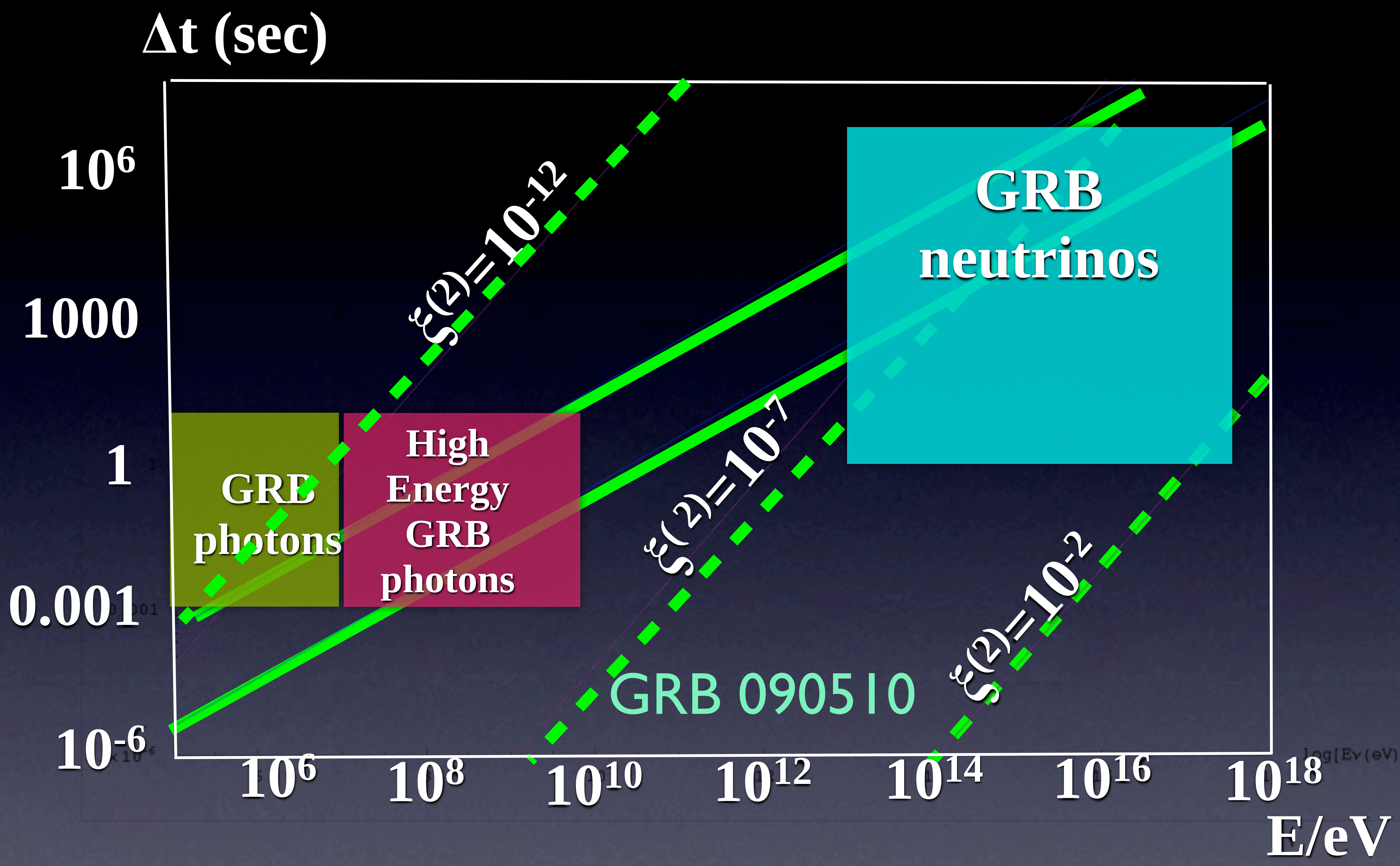

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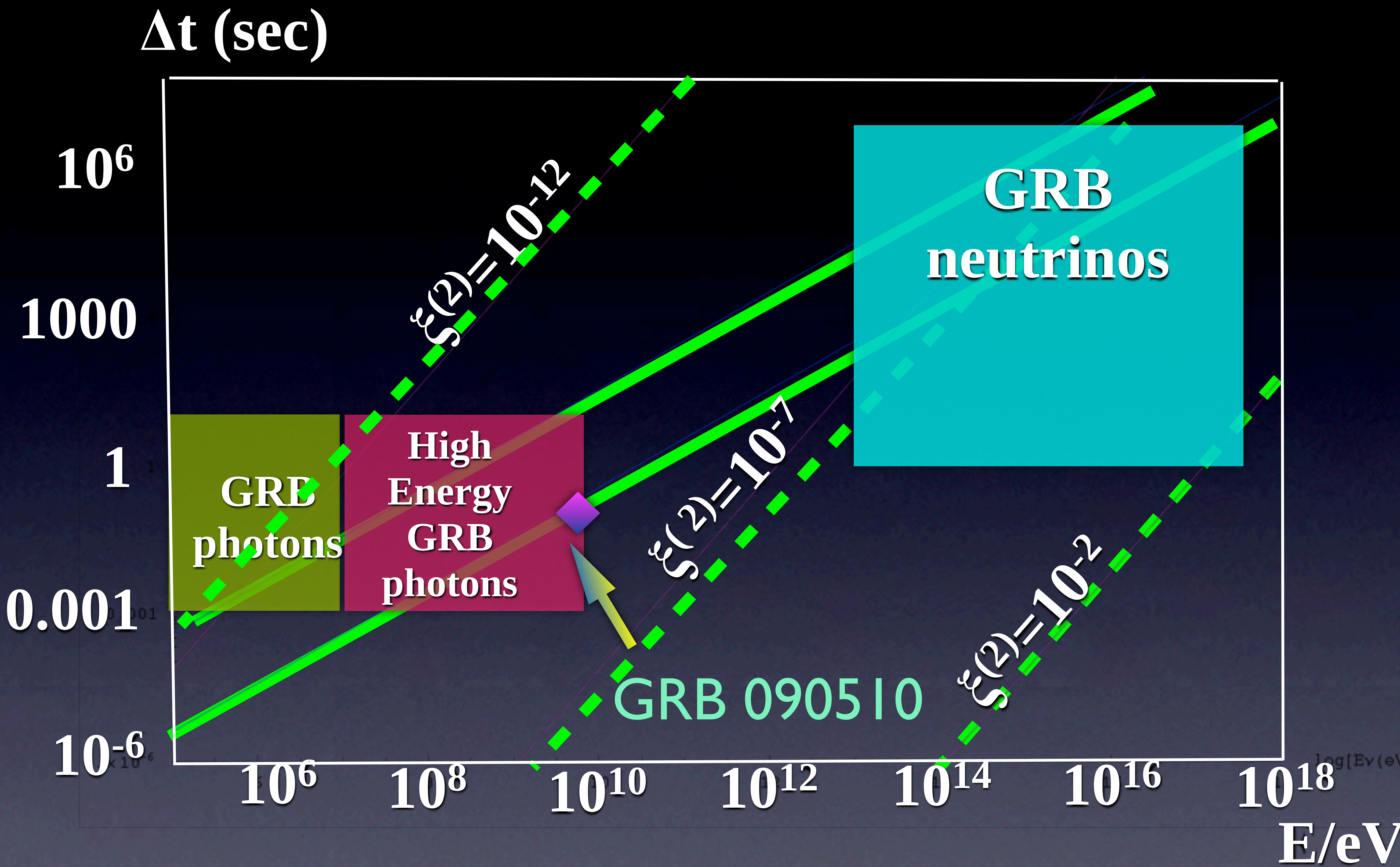

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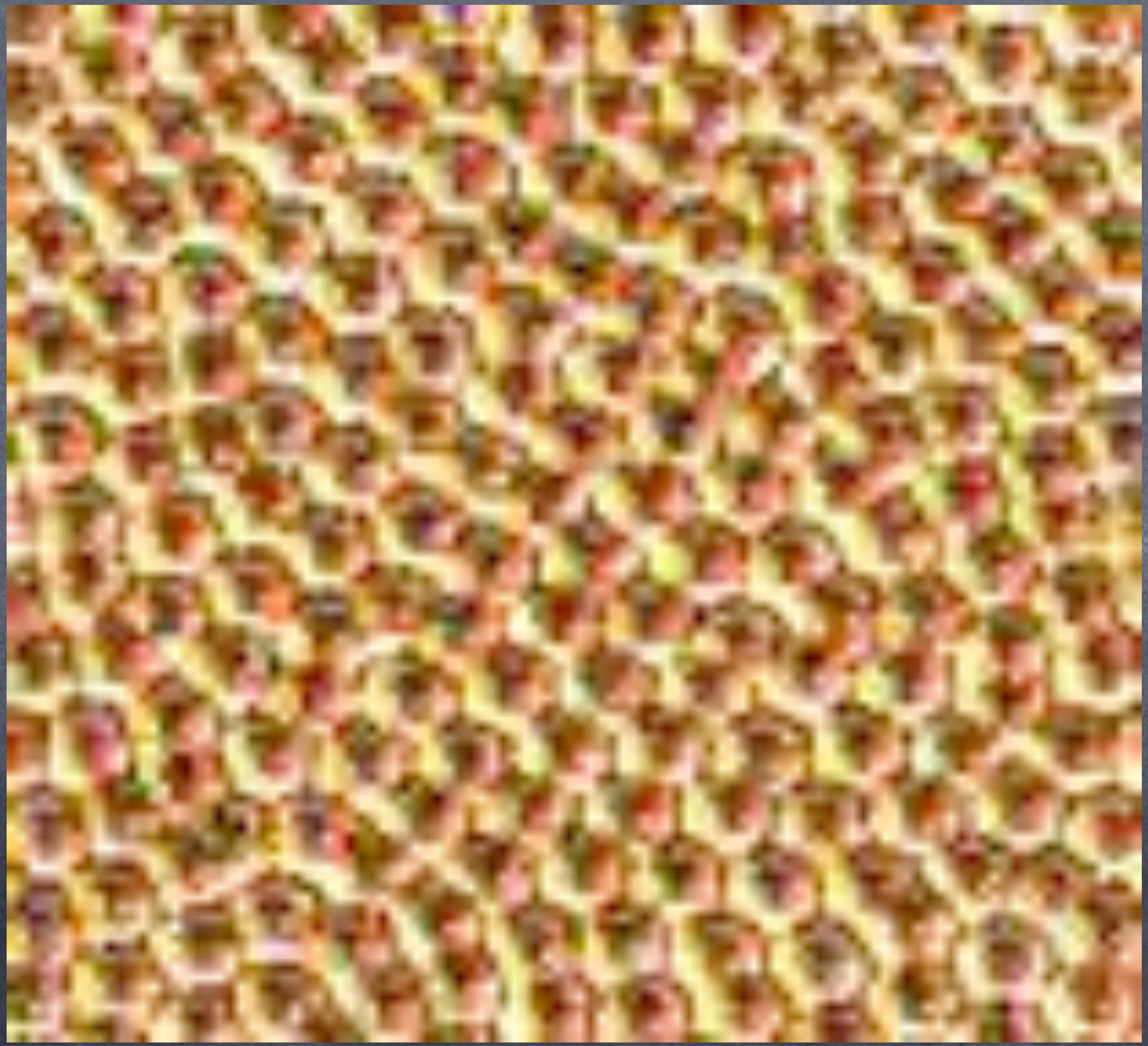
Stochastic (fuzzy) photon motion



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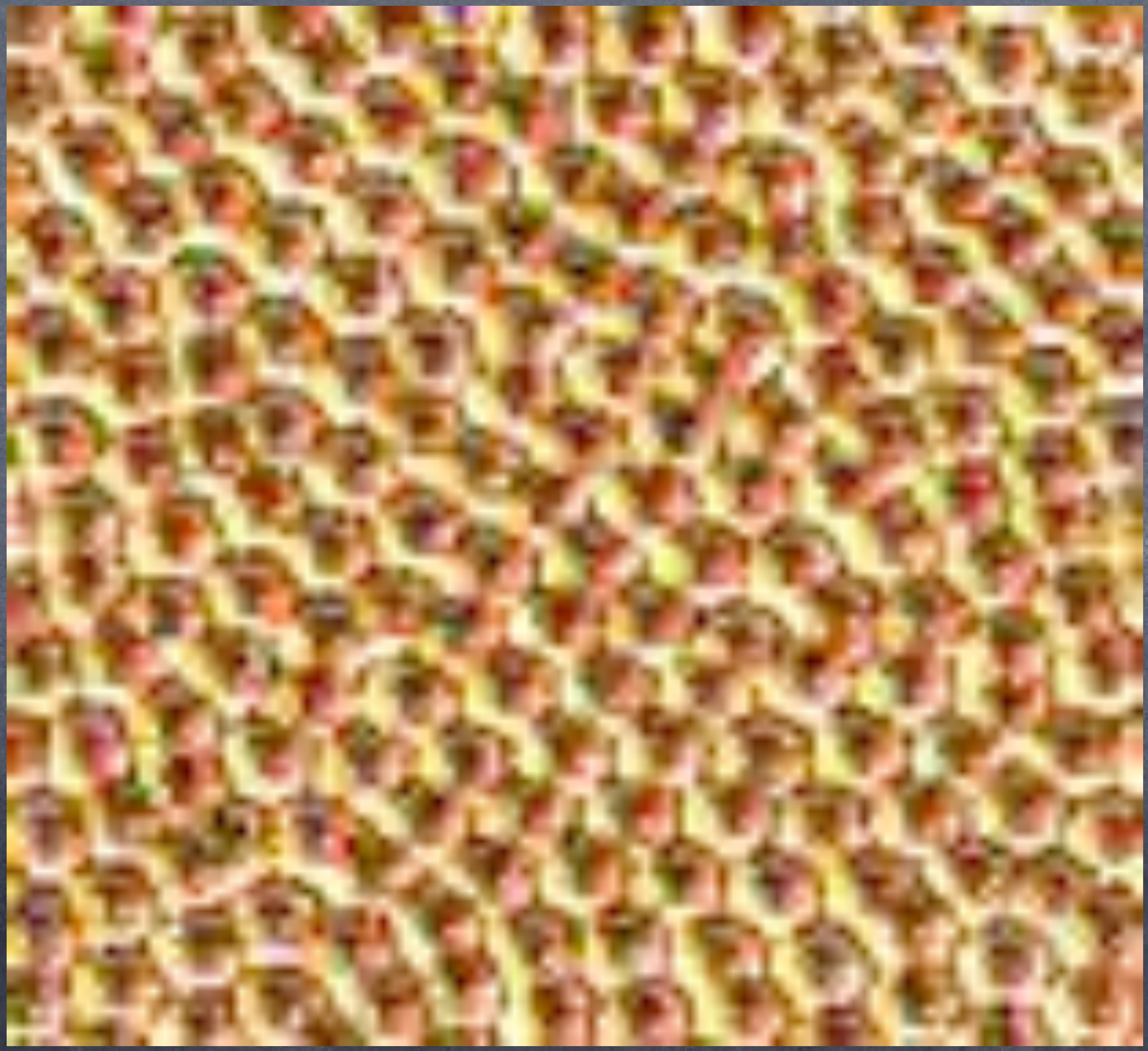
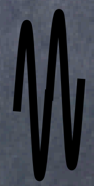


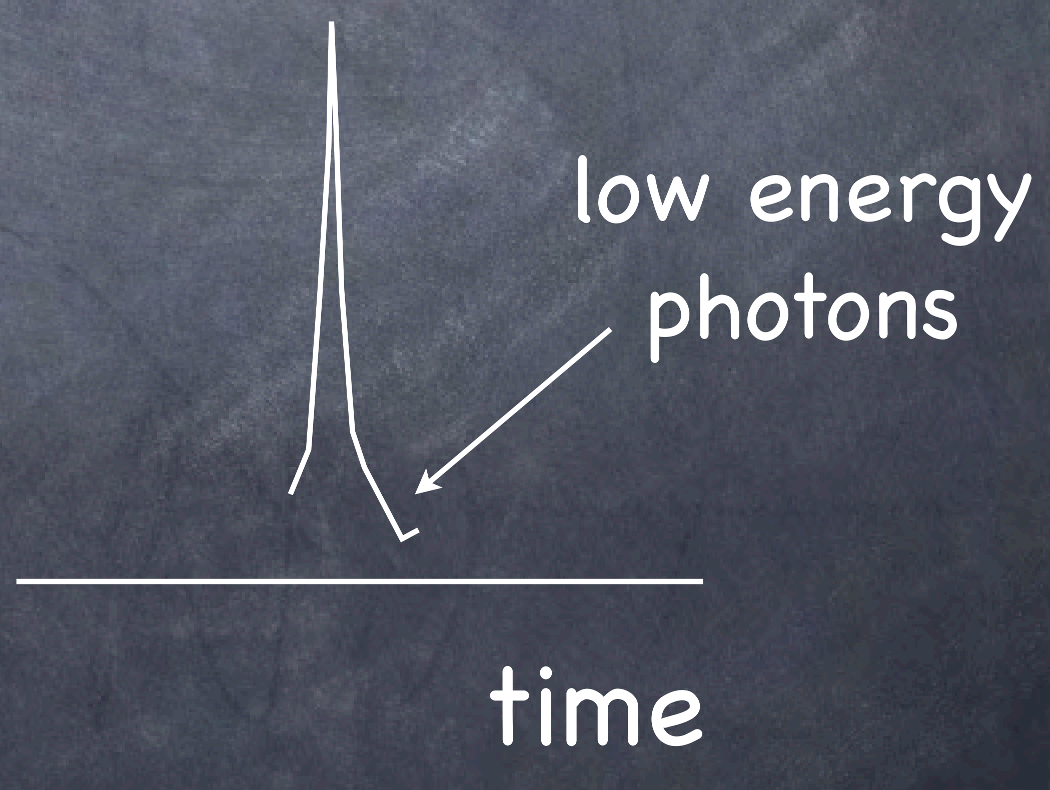


Stochastic (fuzzy) photon propagation

Amelino Camelia & Smolin 08

$$\delta v(E) = \left(\frac{E}{\xi_f M_{pl}} \right)^n$$

$$\delta T(E) = \delta v(E) T$$



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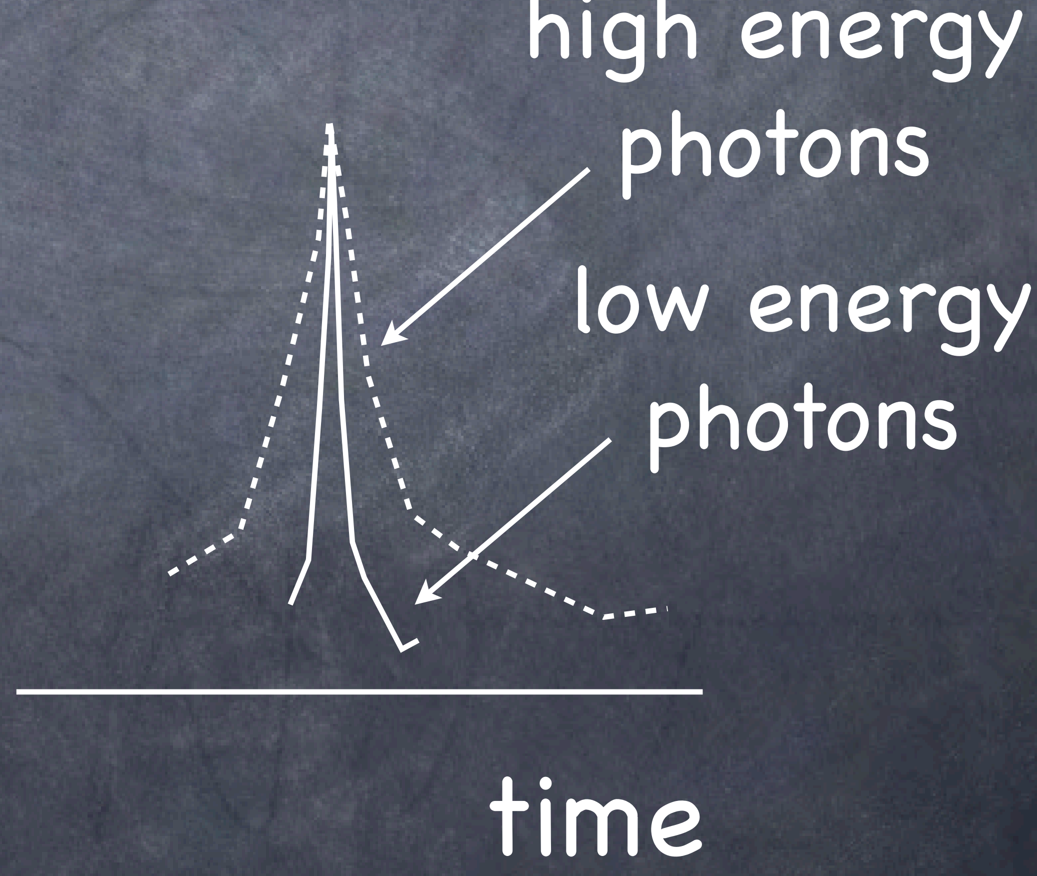
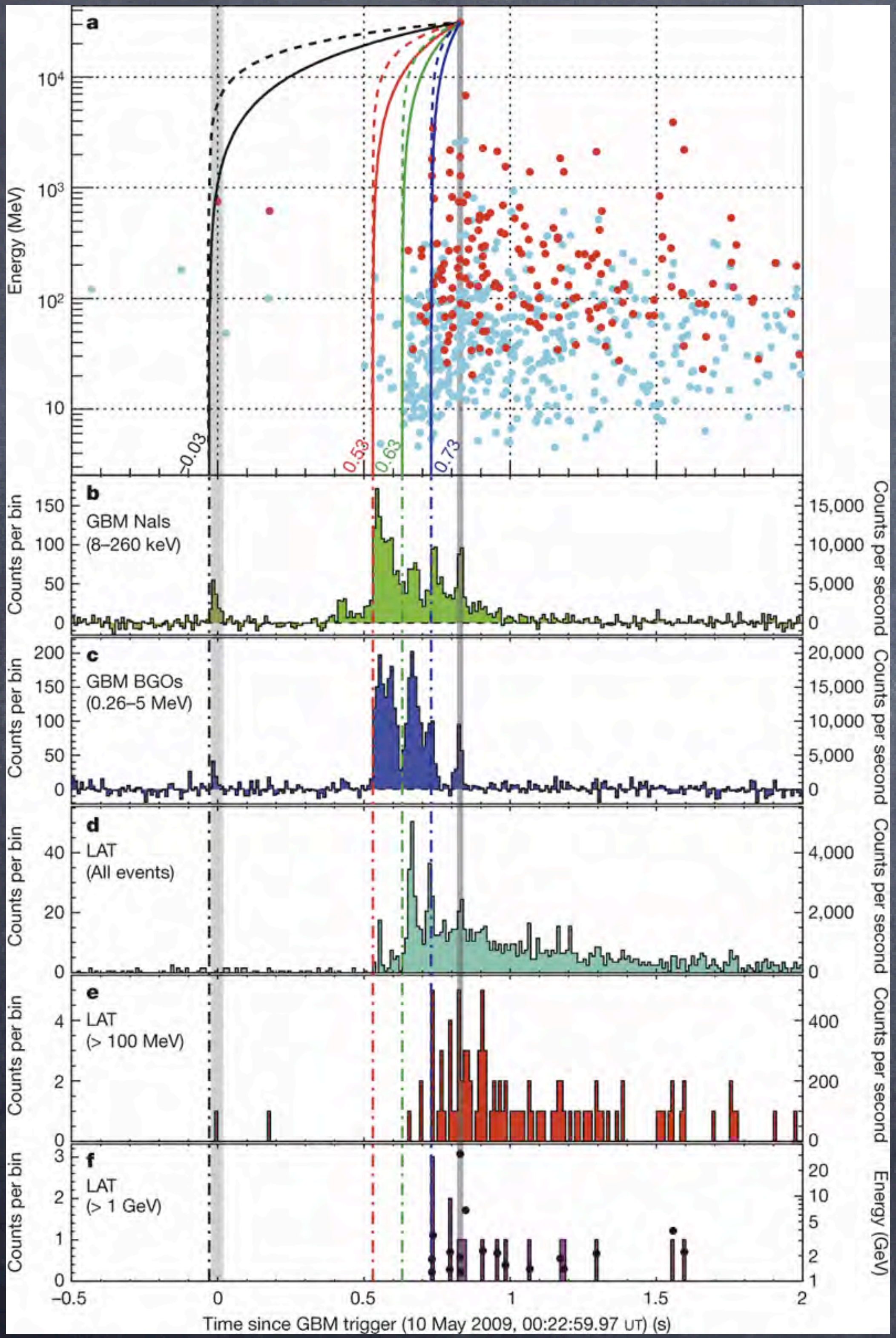


GRB 090510



$t = t_{em} + (\Delta t/dE)_s E + f(\delta T/dE)_f E$

f is a random Gaussian variable

We find a preliminary limit $(\delta T/dE)_f < 0.4$ sec/GeV.

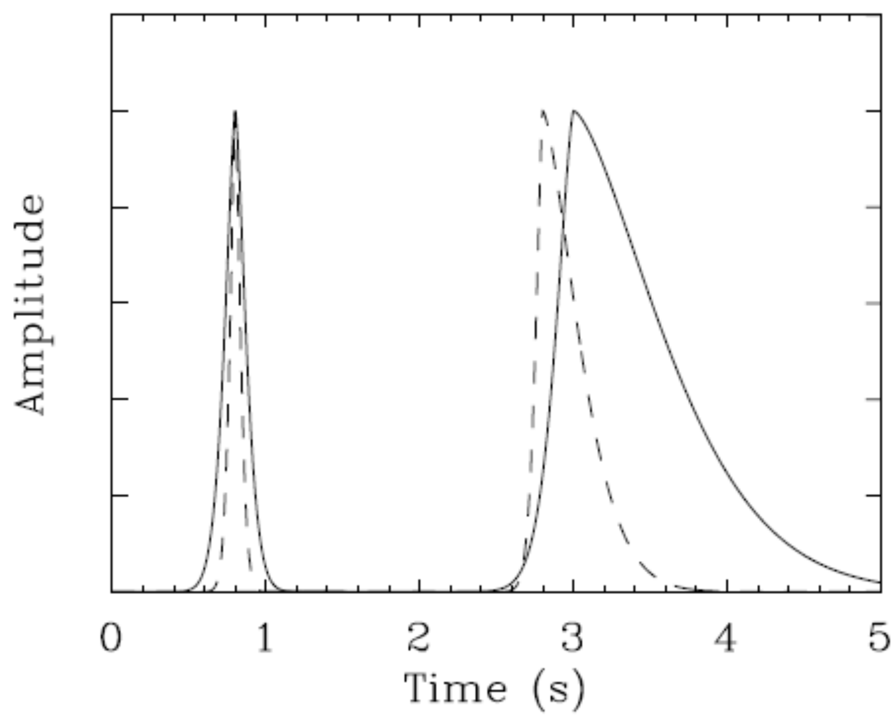
This should be compared with the limit $(\Delta t/dE)_s < 0.01$ sec/GeV for the systematic shift.

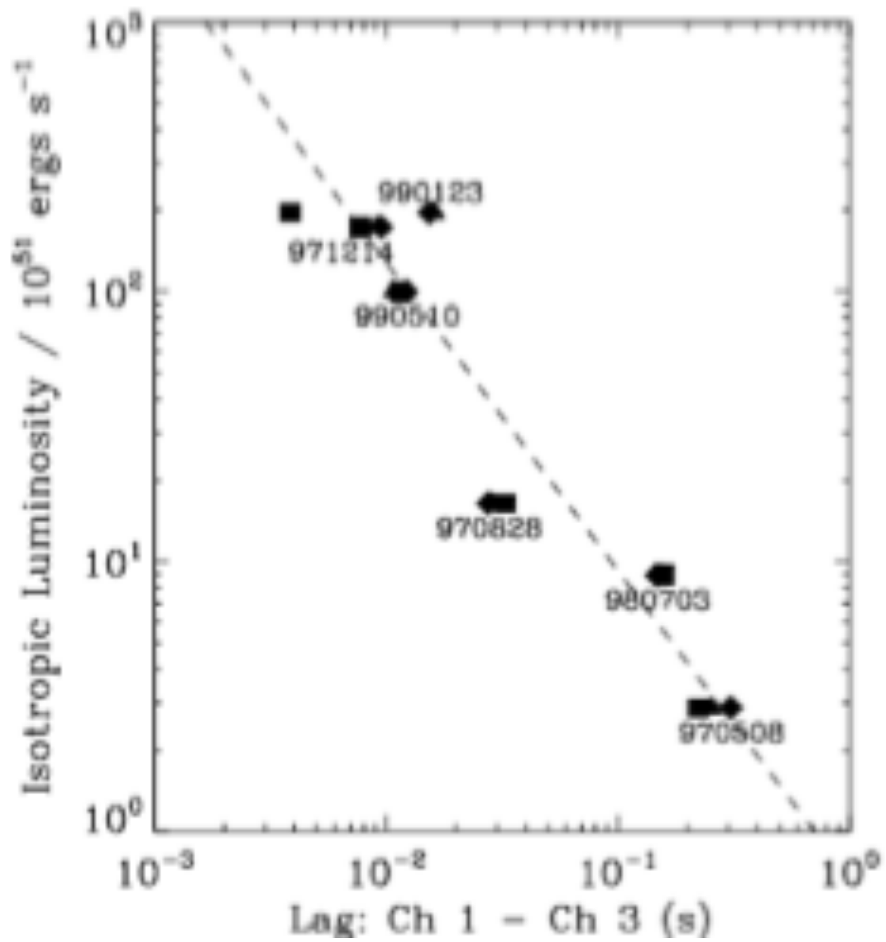
Conclusions

- GRBs timing gives the best limits on the scale of possible Lorentz violation: $E^{(1)}_{LV} > 10^{19}$ GeV
- High energy neutrinos are essential for $n \geq 2$.
- GRB neutrinos provide the best venue for detecting of setting upper limits on Loretnz violation with any $n \geq 2$.
- GRB photons can also serve to put a limit on models with stochastic (fuzzy) motion of the photons. Our <u>preliminary</u> limit is $E_{LV,f} > 0.5\ 10^{18}$ GeV

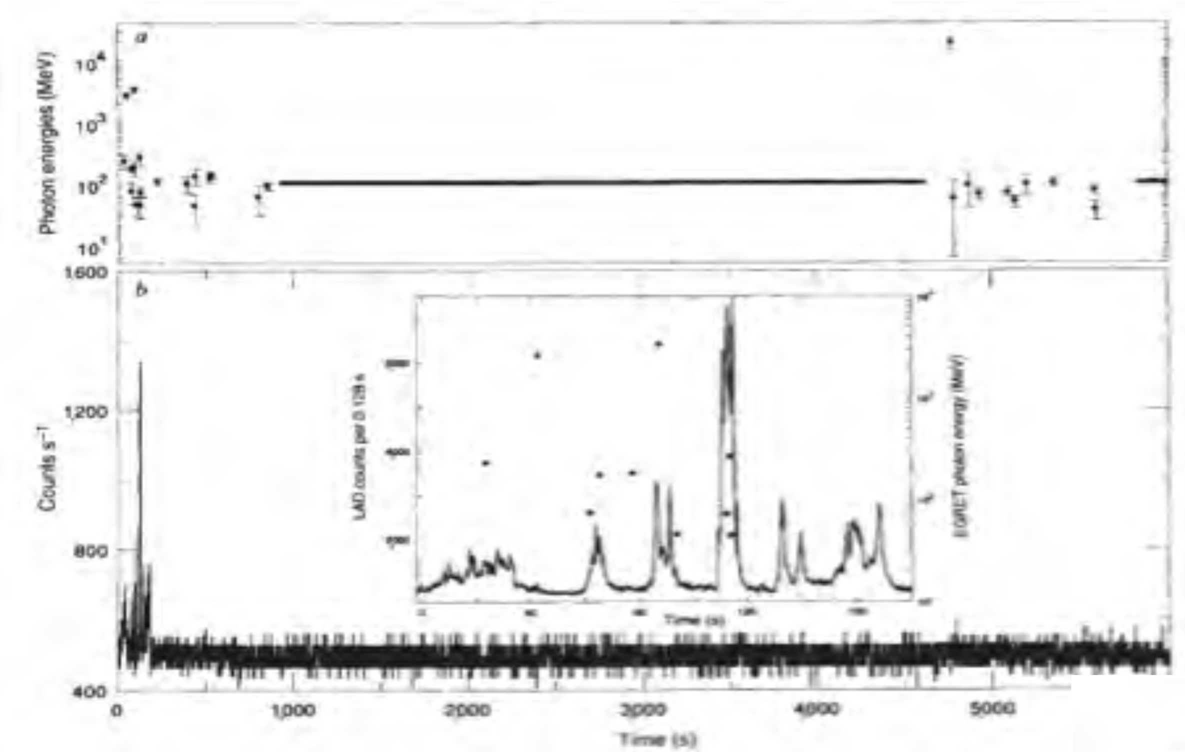
Spectral Lags

(Norris, Marani & Bonnel, 99)





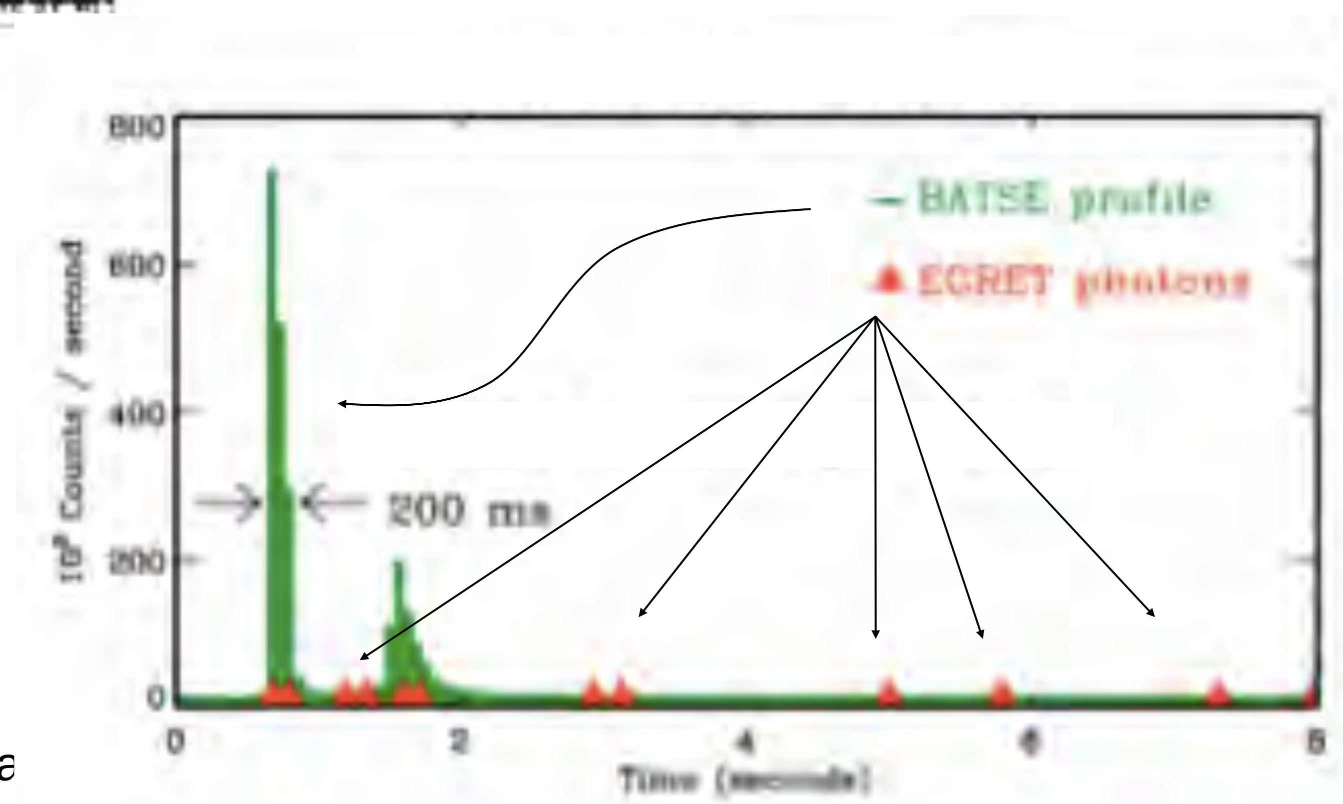
High Energy Emission from GRBs (EAGRET)



GRB 940217

(Hurley et al. 1994)

GRB 930131 (Superball Burst)



Tsvi Pira

This can be viewed as a random motion