quantum-gravity phenomenology, farther and slower

Stockholm 16.4.2010
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University of Rome "La Sapienza"

1. **tests of in-vacuo dispersion could use data from GRBs at z>1**
   but do we have test theories to handle spacetime expansion?
   open issues for LSB scenario
   a definite picture for DSR scenario

   GAC+ Marciano+Matassa+Rosati, arXiv:1006.2126

2. **nonlocality in DSR**

   GAC+ Matassa+Mercati+Rosati, arXiv:1006.0007

3. **precision of 1 part in 10^9 in the measurement of the d220 lattice spacing of the WASO04 silicon crystal might have implications for QG phenomenology**

   Massa+Mana+Kuetgens+Ferroglio, New J. Phys 11 (2009) 053013

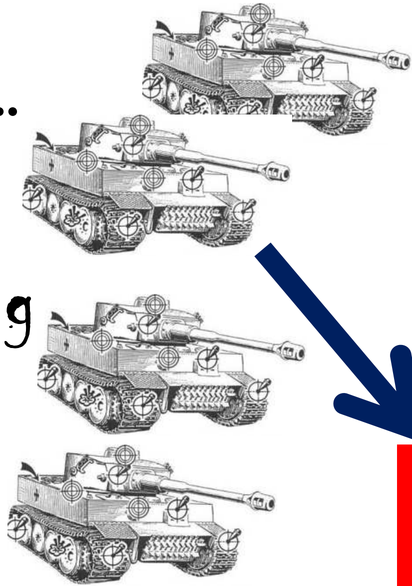
   GAC+Mercati, arXiv:1004.3352

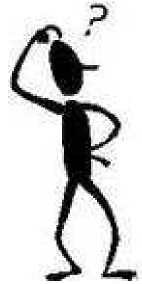
traditional strategy

“wanna be like Einstein”...

........we’ll get ourselves a

Theory Of Everything





quantum-gravity problem

[traditional strategy]

"wanna be like Einstein"...

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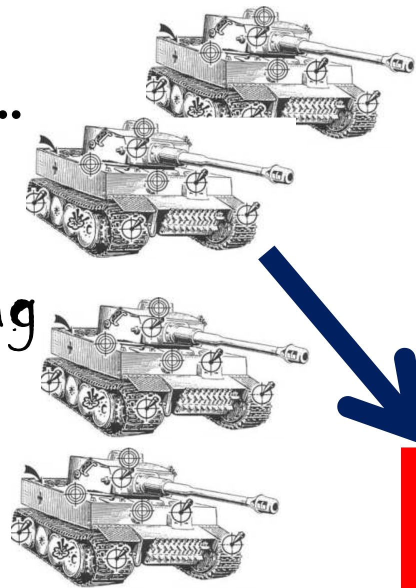
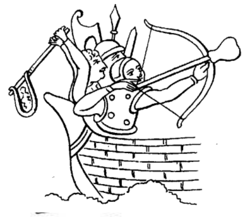
Theory Of Everything



quantum-gravity problem



but we evidently need
an "old quantum-gravity theory strategy":
....QG clearly requires a totally new paradigm...

“searching for the Old Quantum Gravity Theory”

several research programmes within QG phenomenology could stumble on the first item in the “old quantum-gravity theory puzzle”.....but are we really ready?

much work on momentum dependence of the speed of photons....

GAC+Ellis+Mavromatos+Nanopoulos+Sarkar, Nature393,763(1998)

but nearly all analyses and arguments only apply to flat (Minkowski-like) spacetime

now we have "good" data and of course z>1
is going to be a key player
but are we ready? how does the expansion
of a spacetime affect the momentum
dependence of speed of light ?

pioneering work by
Ellis+Mavromatos+Nanopoulos+Sakharov+Sarkisyan
and by Jacob+Piran
which eventually led to the adoption
of a description based on (for <u>dS spacetime</u> in <u>conformal coordinates</u>)

$$ds^2 = \frac{1}{(1-H\eta)^2}\left(d\eta^2 - dx^2\right)$$

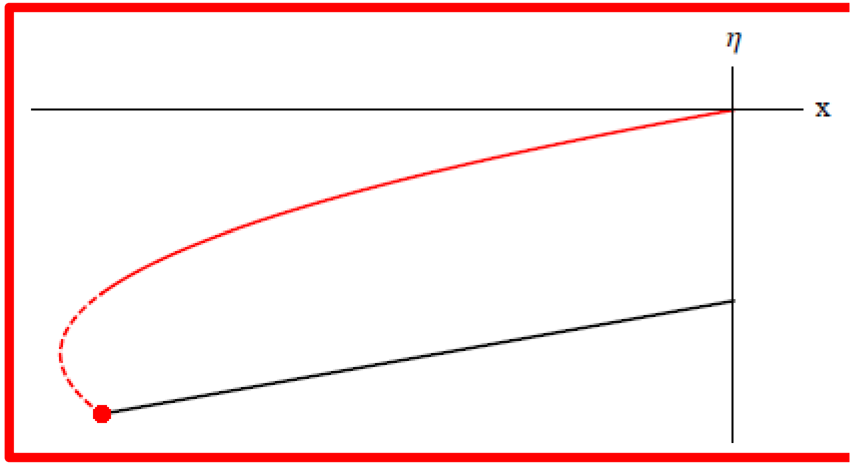
$$m^2 = (1-H\eta)^2(\Omega^2 - \Pi^2 + \lambda(1-H\eta)\Pi^3)$$

"canonical energy" **"canonical momentum"**

$$v_\gamma \simeq 1 - \lambda(1-H\eta)\Pi$$

<u>all this ASSUMES "LSB" (or "LIV"),</u>
<u>i.e. requires a preferred frame</u>

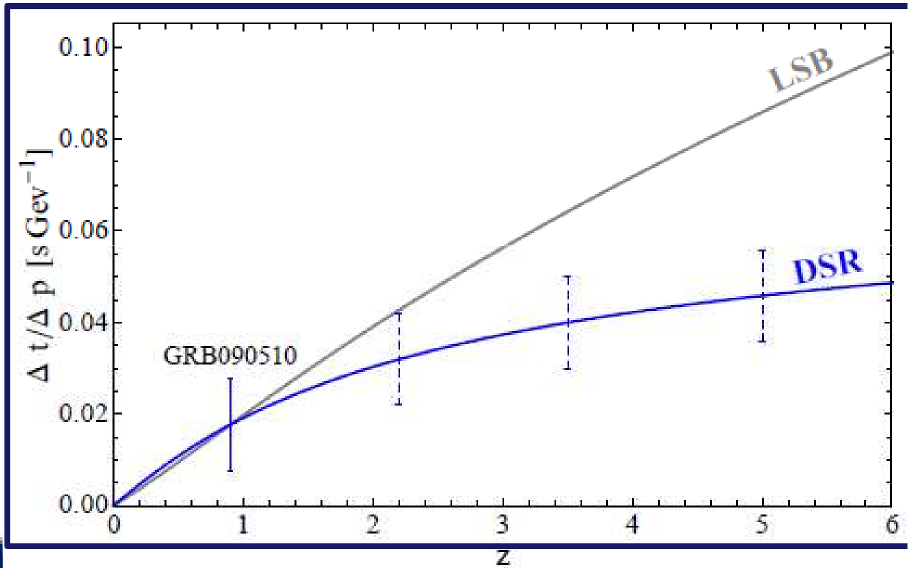
$$m^2 = (1 - H\eta)^2(\Omega^2 - \Pi^2 + \lambda(1 - H\eta)\Pi^3)$$



$$v_\gamma \simeq \quad 1 - \lambda(1 - H\eta)\Pi$$

λ_{LSB}

$$\boxed{\Delta t = \frac{\lambda_{\mathrm{LSB}}}{H_0}\Delta\Pi_p K_e \int_0^z \frac{(1+z')dz'}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}}$$



coordinate artifact?

artifact of leading-order truncation?

<u>a “feature” due to preferred frame?</u>

let us see if this is found in a DSR setup

we showed that <u>there is no</u> deformed deSitter boost compatible with the invariance of

$$m^2 = (1 - H\eta)^2(\Omega^2 - \Pi^2 + \lambda(1 - H\eta)\Pi^3)$$

<u>a DSR framework compatible with spacetime expansion</u>
arXiv:1006.0007
GAC+Marciano+Matassa+Rosati)

a DSR framework compatible with spacetime expansion
GAC+Marciano+Matassa+Rosati, arXiv:1006.0007

DSR idea: departures from Special Relativity
but without a preferred frame

GAC, PLB(2001)
IJMPD(2002)
Nature(2002)
Kowalski-Glikman,PLB(2001)
Magueijo+Smolin, PRL(2002)

much studied prototype: deformed Lorentz invariance of energy-momentum space, with EXPLICIT DESCRIPTION of deformed boost generators that leave invariant on-shell relationships of the type, e.g.,

$$m^2 = \Omega^2 - \Pi^2 + \lambda \, \Omega \Pi^2$$

invariant in the sense that λ is the same in the entire family of observers connected by deformed boosts

for nearly a decade we had no idea how to generalize this setup to expanding spacetimes but that is not satisfactory when we have data from z=4

a DSR framework compatible with spacetime expansion

GAC+Marciano+Matassa+Rosati, arXiv:1006.0007

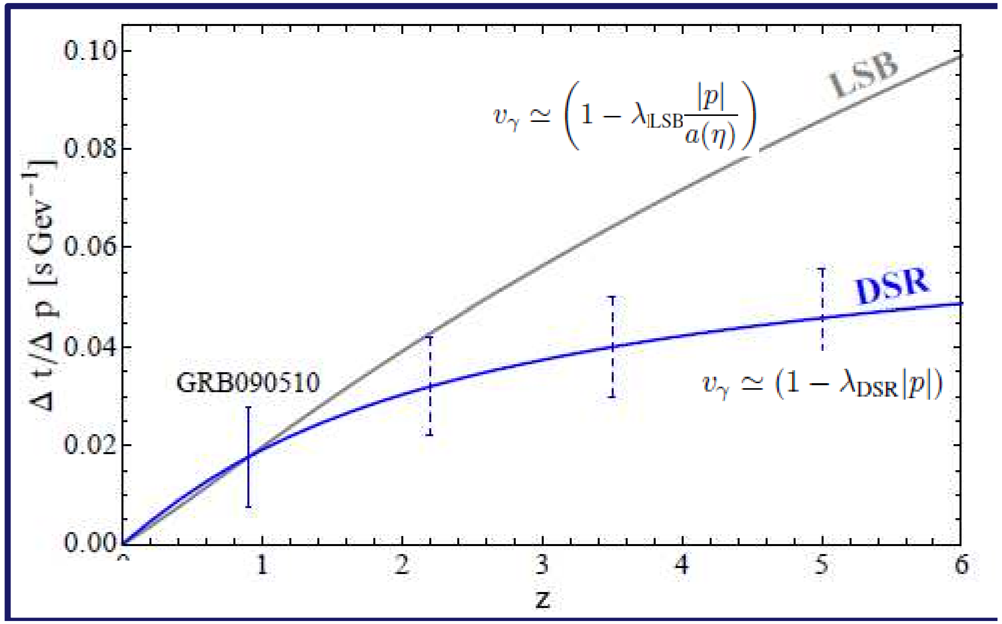
$$\{\Pi, x\} = -1 \,, \qquad \{\Omega, \eta\} = 1$$

$$\boxed{m^2 = (1 - H\eta)^2(\Omega^2 - \Pi^2 + \lambda\Omega\Pi^2)}$$

$$G_N = x(1 - H\eta)\partial_\eta + \left(\frac{1 - (1 - H\eta)^2}{2H} - \frac{H}{2}x^2\right)\partial_x + \\ + \lambda_{\mathrm{DSR}}\left(\frac{1 + H\eta}{2}\, x\,\partial_x - (1 - H\eta)\,\eta\,\partial_\eta + \frac{H\eta}{2}\right)\partial_x$$

$$\boxed{v_\gamma \simeq (1 - \lambda_{\mathrm{DSR}}|p|)}$$

$$\Delta t \simeq \frac{1}{H_0}\lambda_{\mathrm{DSR}}\Delta p \int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z')^3 + \Omega_\Lambda}}$$



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$$G_N = x(1-H\eta)\partial_\eta + \left(\frac{1-(1-H\eta)^2}{2H} - \frac{H}{2}x^2\right)\partial_x + \\ + \lambda_{\rm DSR}\left(\frac{1+H\eta}{2}\, x\,\partial_x - (1-H\eta)\,\eta\,\partial_\eta + \frac{H\eta}{2}\right)\partial_x$$

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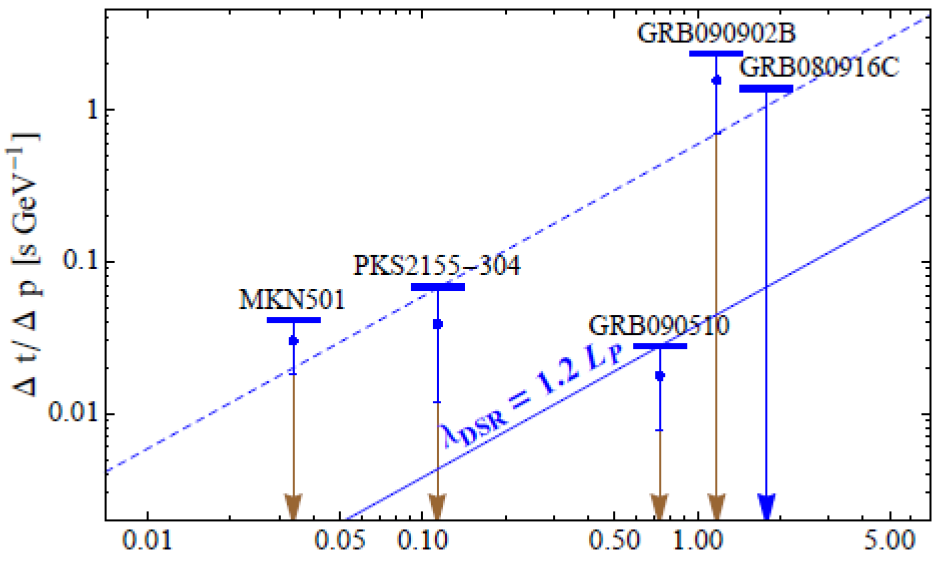

$$K_{\rm DSR}(z) = \int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z')^3 + \Omega_\Lambda}}$$

a DSR framework compatible with spacetime expansion

GAC+Marciano+Matassa+Rosati, arXiv:1006.0007

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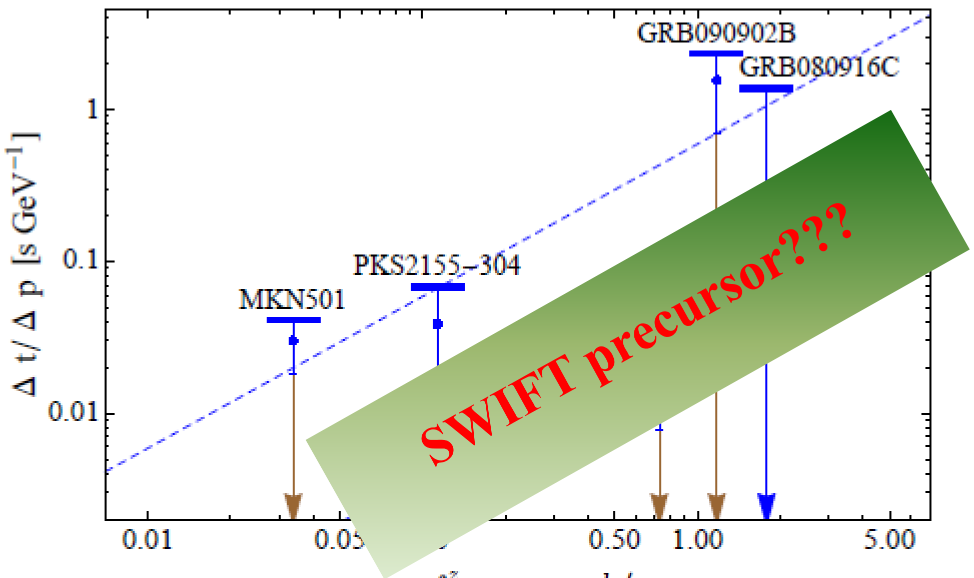
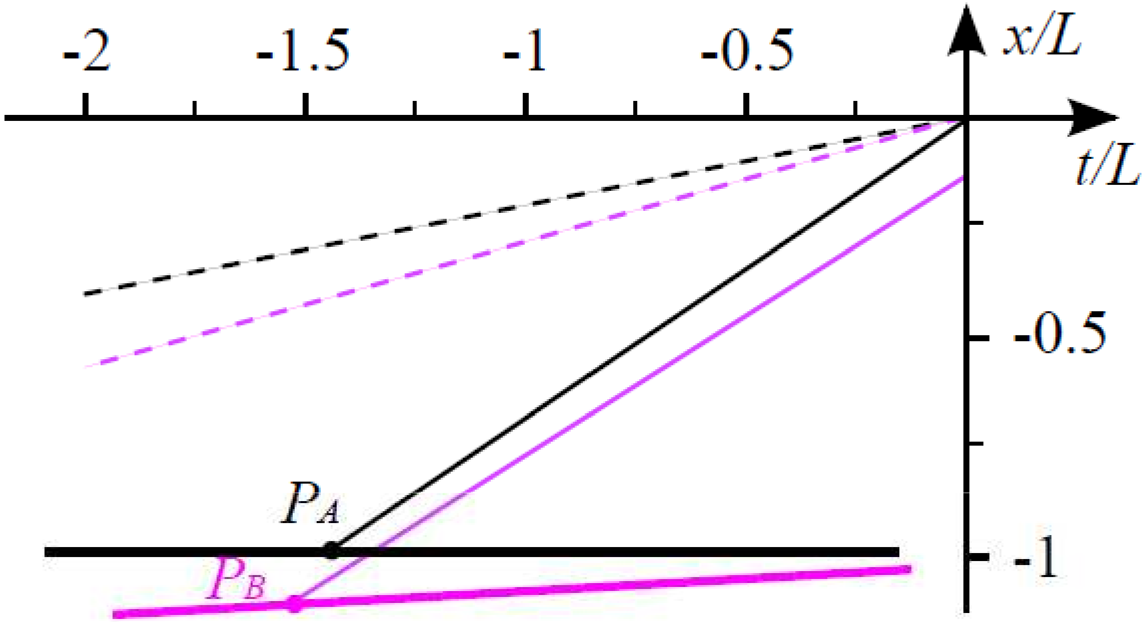
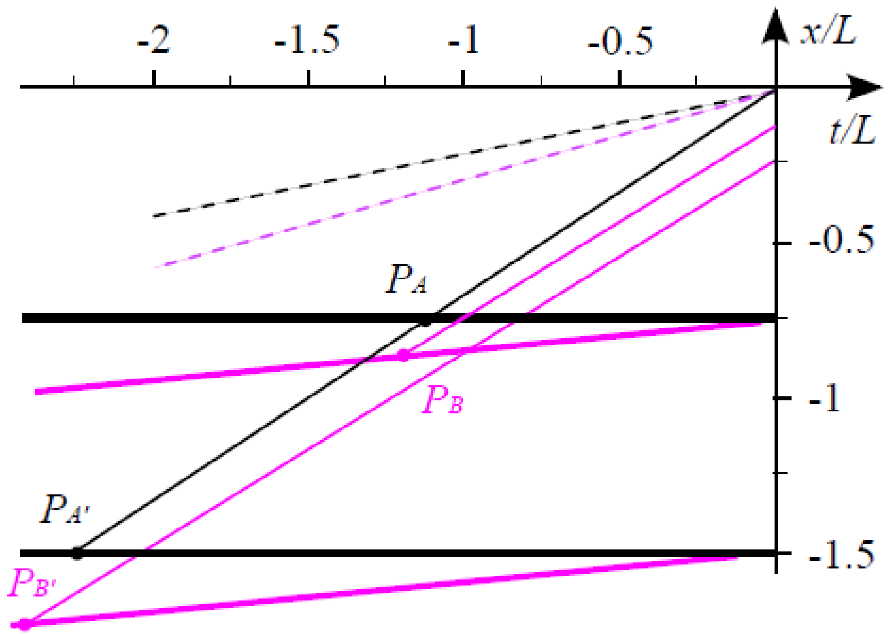


$$K_{\rm DSR}(z) = \int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z')^3 + \Omega_\Lambda}}$$

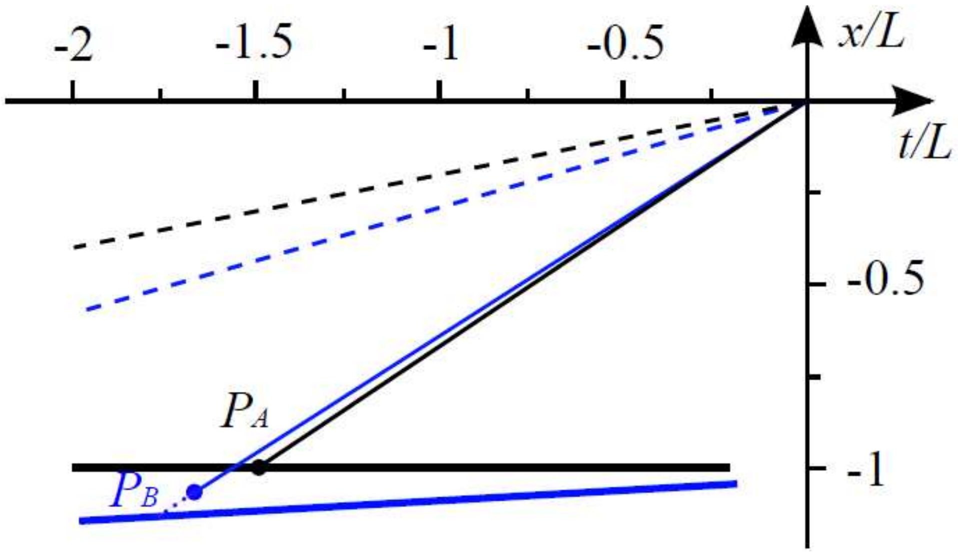
2. nonlocality in DSR



Sabine's nonlocality....not obtained imposing covariance of worldlines under any of the EXPLICIT deformations of boosts in use in the DSR literature....



one of the implications of not relying on covariance of worldlines under deformed boosts...



For definiteness we specialize some formulas and all of our figures to the case of

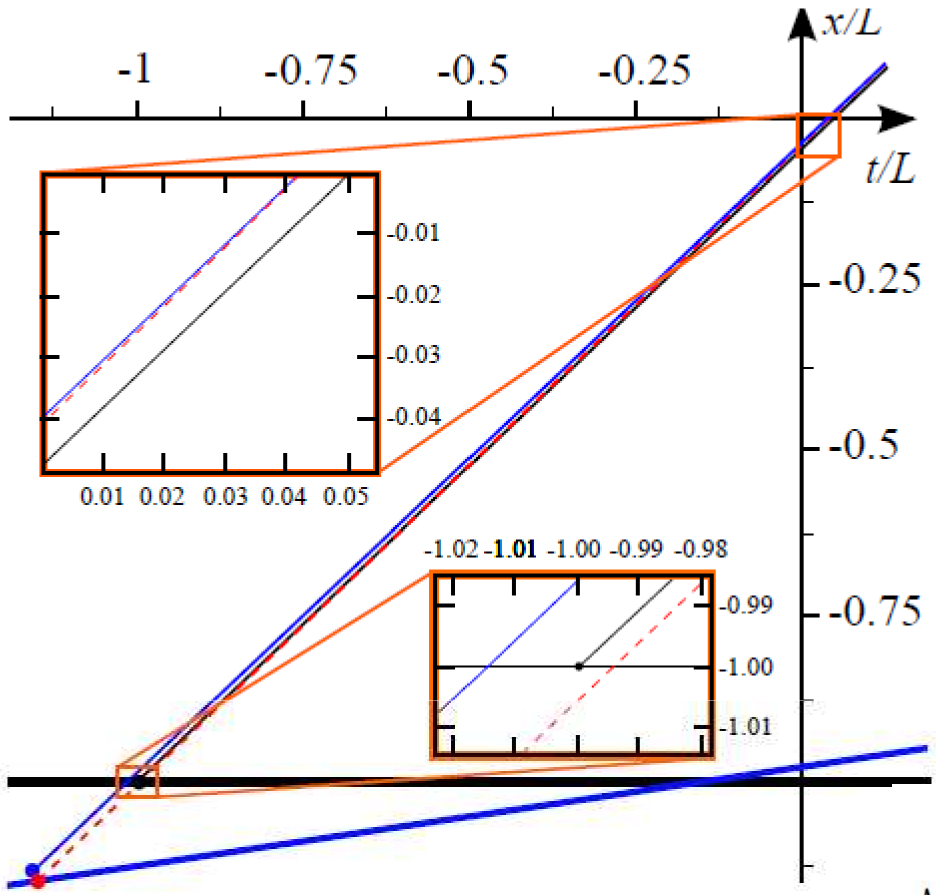
$$\{\Pi, x\} = -1, \{\Omega, t\} = 1$$

$$\mathcal{N} = x\Omega - t\Pi + \lambda t\Omega\Pi + \frac{\lambda}{2}x\Pi^2 \,. \qquad m^2 = \Omega^2 - \Pi^2 + \lambda\,\Omega\Pi^2$$

With this description of boosts one finds that under a boost of small rapidity ξ the coordinates of points on a worldline and the canonical momentum Π transform as follows:

$$\boxed{\begin{aligned} x' &= x + \xi\, t - \lambda\,\xi(x\,\Pi + t\,\sqrt{m^2 + \Pi^2}) \,, \\ t' &= t + \xi\, x + \lambda\xi\, t\,\Pi \,, \\ \Pi' &= \Pi + \xi\,\sqrt{m^2 + \Pi^2} \,. \end{aligned}}$$

$$x(t) = x_0 + \left(\frac{\Pi}{\sqrt{\Pi^2 + m^2}} - \lambda\Pi\right)(t - t_0)$$



$$\mathcal{C} = \Omega^2 - \Pi^2 + \lambda\left(\gamma_1\Omega\Pi^2 + \gamma_2\Omega^3\right)$$

$$\mathcal{N} = -t(\Pi + \lambda\alpha_1\Pi\Omega) + x(\Omega + \lambda\alpha_2\Pi^2 + \lambda\alpha_3\Omega^2)$$

$$\mathcal{C}_{\alpha_2} = \Omega^2 - \Pi^2 + \lambda\left(2\alpha_2\Omega\Pi^2 + (1-2\alpha_2)\Omega^3\right)$$

$$\mathcal{N}_{\alpha_1,\alpha_2} = x\Omega - t\Pi + \lambda\left[\alpha_2 x\Pi^2 - \alpha_1 t\Pi\Omega + \left(\frac{3}{2}+\alpha_1-\alpha_2\right)x\Omega^2\right]$$

FIG. 3: We here compare the DSR worldline of a rather generic hard-photon (missing the origin by a fair amount) as seen by Alice (black) and Bob (blue). And in order to assess the significance of the differences between the DSR boost and the standard boost we also show (dashed-red) the worldline that would be obtained by a standard (special-relativistic) boost of the black worldline. Of course the same rapidity is used both for the standard boost and for the DSR boost, and it is noteworthy that (in spite of assuming for the plot the unrealistically huge $\lambda p = 0.05$) the solid-blue and dashed-red lines are nearly indistinguishable near the origin.

1. The claim that there is a bound from existing experiments on the parameters of DSR theories rests on the claim that the satellite frame would see macroscopic non-local effects at the detector.

2. What the satellite frame sees can be found by making a pure lorentz boost from the lab frame. In the framework of κ-Poincare, this Lorentz boost is completely specified by the condition that the origins of the lab and satellite frames coincide, and coincide with the event at which their two world lines intersect, as it would be in special relativity. The correct lorentz transformation in this case is the pure boost that fixes that unique event where worldlines of the two detectors intersect.

3. When this Lorentz transformation is computed explicitly in κ-Poincare there is no macroscopic non-locality in the satellite frame's description of the detector. This is the case in both the commuting and non-commuting spacetime coordinates. Computations in other formulations of DSR agree [22].

4. The potential non-localities that are produced by Lorentz boosts at the detector are on distance scales of the order of vLE^2/cE_p^2, (11). This disagrees with the prediction of [6], by a factor of $E/E_p \approx 10^{-18}$. It is much smaller than the Compton wavelength of an electron in the detector and therefor unobservable.

5. Therefore the claim in [6], of an experimental bound on the α in (1), does not apply to DSR theories in general, because the prediction on which it is based, of a macroscopic non-locality at the detector, does not appear in at least one formulation of DSR. Hence, the experiments testing the consequences of (1) need to be done, and the results of current observations by Fermi and other astrophysical detectors cannot be predicted in advance based on the knowledge we have now as to the fate of lorentz invariance at the Planck scale.

6. The reason the calculation of [6] disagrees with that done here is that it makes the assumption that the fixed point of the lorentz transformation from the detector to the satellite frome is at the emission event. This is equivalent to C, which is that there is no ambiguity in the coordinates of the emission event. But when one defines the fixed point of the boost to the satellite frame to be the unique event where the worldlines of the two observers coincide, at the detector, explicit calculations show that there are ambiguities in the definition of the coordinates of the emission event. Hence, C is not satisfied. This in an example of a general phenomena in which lorentz boosts can produce energy dependent ambiguities in the coordinates of events very distant from the origin of coordinates of an inertial frame.

7. We can mention also that assumptions A and D are critiqued in [26] and discussed further in [30].

text from Smolin, arXiv:1007.0718

text from
Smolin,
arXiv:1007.0718

In closing, we note that an issue of a macroscopic non-locality at the detector, seen by an observer located there, would be very different from the issue of a possible macroscopic non-locality that arises only at a cosmological distance from the observer. To establish that a cosmologically distant event is afflicted by a physical non-locality, rather than a coordinate artifact, one would have to be assured that the coordinates defined by a process of synchronization with the clock of a local observer are unambiguously defined arbitrarily far from that clock. Here we have examined whether this is the case for κ-Minkowski spacetime, and found that there are ambiguities in the sychronization procedure coming from either the energy dependence of the speed of light or the commutation relations (3).

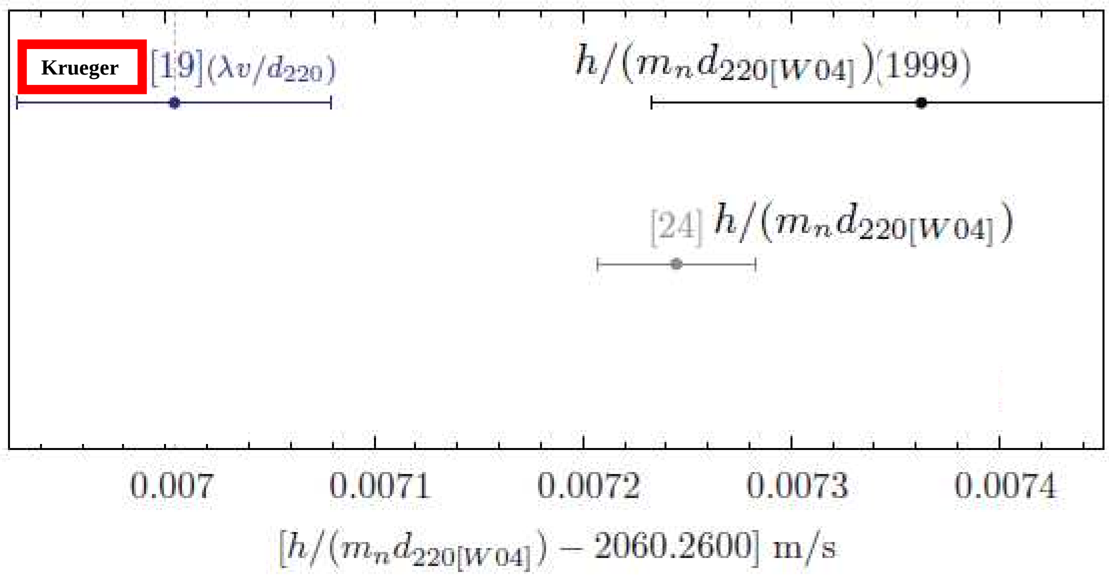
3. QG-deformed deBroglie relation

GAC+Mercati, arXiv:1004.3352

- deformations of the deBroglie relation are "natural" (naturally considered) in quantum gravity…..e.g. can be used to introduce a minimum wavelength principle…

•we have good data on this from cold neutrons and of course deBroglie relation for cold neutrons is $\lambda v = \frac{h}{m_n}$

•measurement of Krueger et al (done between 1995 and 1999) determined λv/d220 which can be compared to independent measurements of $h/(m_n d_{220[W04]})$



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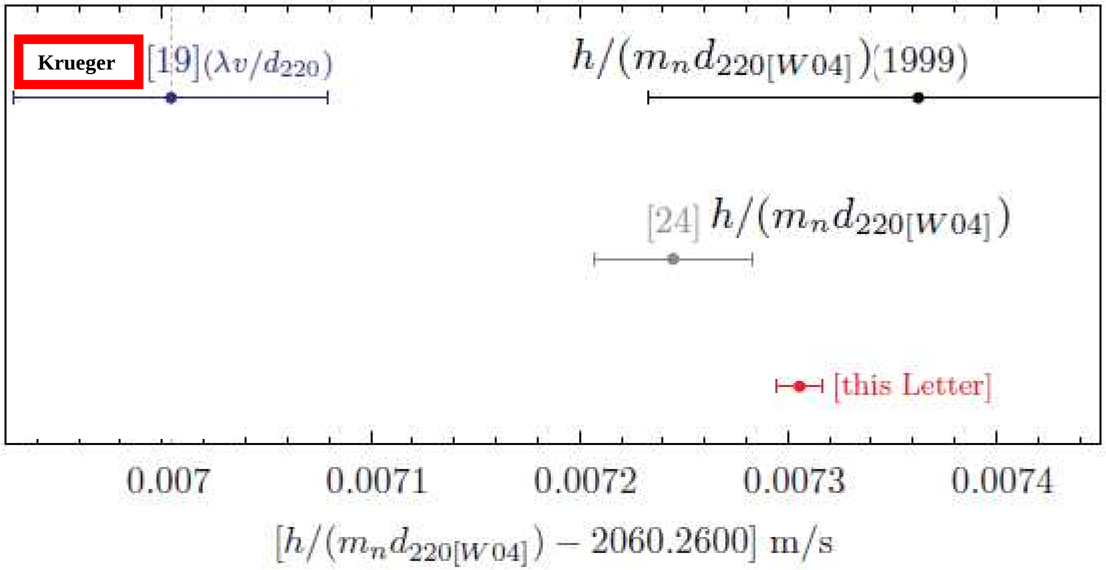
which can be compared to independent measurements of $h/(m_n d_{220[W04]})$

and now (2009) we have a much improved measurement of d220[W04]



Massa+Mana+Kuetgens+Ferroglio,
New J. Phys 11 (2009) 053013

4 standard deviation significance!!!

- **Mercati and I went looking for this because of**
  - **– desire to test accurately the deBroglie relation**
  - **-- intuition that IR/UV mixing should be there**

- **but what did we find?**

hypothesis 1: NOTHING (4 σ → 99% no effect…systematics?)

hypothesis 2: something else (no quantum gravity)

hypothesis 3: quantum gravity…surely unlikely…but we must be ready!!
considering this is with cold neutrons it would have to be IR/UV mixing

GAC+Mercati, arXiv:1004.3352

Fuzziness

$$[x_\mu, x_\nu] = i\theta_{\mu\nu}(\{x_\alpha\}) \quad \Rightarrow$$

points are not "point-like"…..
roughly like position in phase space….

very general <u>prediction of QG problem</u>….
more general than dispersion(!!)….
and "seen" in most QG formalisms…
but how big is this fuzziness??
an ansatz

$$v_\gamma(p) \simeq 1 - \frac{p}{M_{QG}} \pm \eta_f \frac{p}{M_{QG}}$$

GAC,ModPhysLettA(1994)
Ng+VanDam,ModPhysLett(1994)
Garay,IntJournModPhysA(1995)
Ford,PhysRevD(1995)
GAC,PhysLettB(1997)←with kappaMinkowski

GAC+Smolin,PhysRevD(2009)

N.B. dispersion $\Rightarrow$ fuzziness (but not necessarily same order)
but fuzziness <u>does not imply dispersion</u>, so it is possible

$$v_\gamma(p) \simeq 1 \pm \eta_f \frac{p}{M_{QG}}$$

surely testable with bursts of γ-rays…
can't say if it can compete with other
bound-setting strategies

Lieu+Hillman, Astrophys.Journ.(2003)
Ng+VanDam+Christiansen, Astrophys.Journ.(2003)

absorption of TeV photons

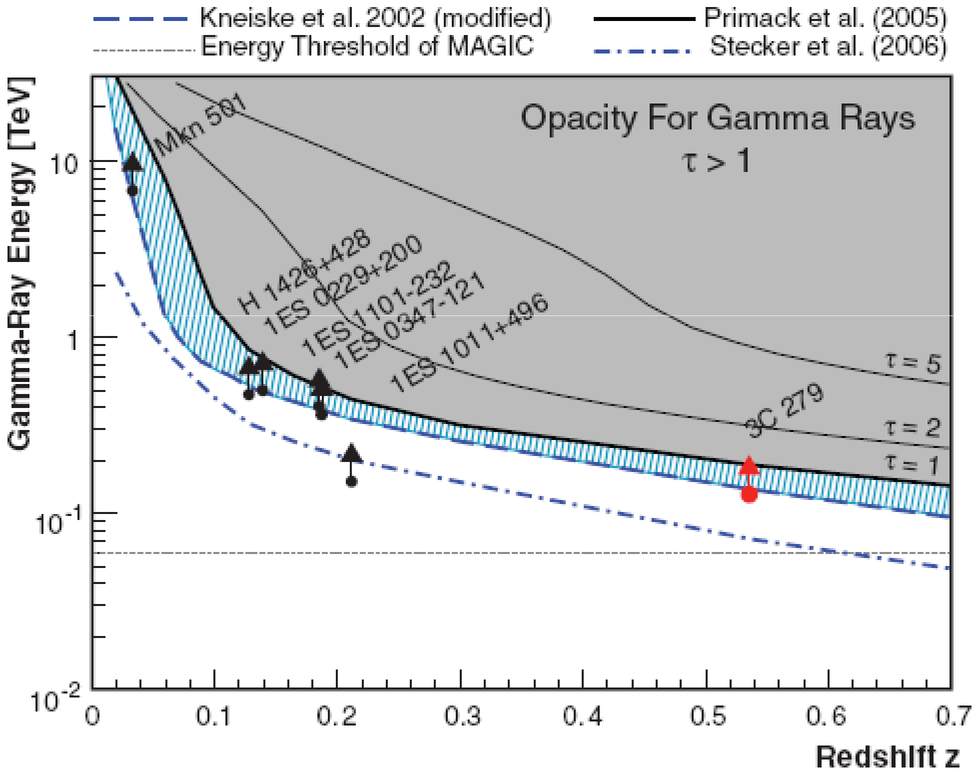


Fig. 3. The gamma-ray horizon. The redshift region over which the gamma-ray horizon can be constrained by observations has been extended up to $z = 0.536$. The prediction range of EBL models is illustrated by (*8*) (thick solid black line) and (*11*) (dashed-dotted blue line). The tuned model of (*14*) (dashed blue line) represents an upper EBL limit based on our 3C 279 data, obtained on the assumption that the intrinsic photon index is ≥1.5 (red arrow). Limits obtained for other sources are shown by black arrows, most of which lie very close to the model (*14*). The narrow blue band is the region allowed between this model and a maximum possible transparency (i.e., minimum EBL level) given by (*8*), which is nearly coincident with galaxy counts. The gray area indicates an optical depth $\tau > 1$, i.e., the flux of gamma rays is strongly suppressed. To illustrate the strength of the attenuation in this area, we also show energies for $\tau = 2$ and $\tau = 5$ (thin black lines), again with (*8*) as model.

Albert et al,
Science 320, 1752 (2008)

absorption of TeV photons

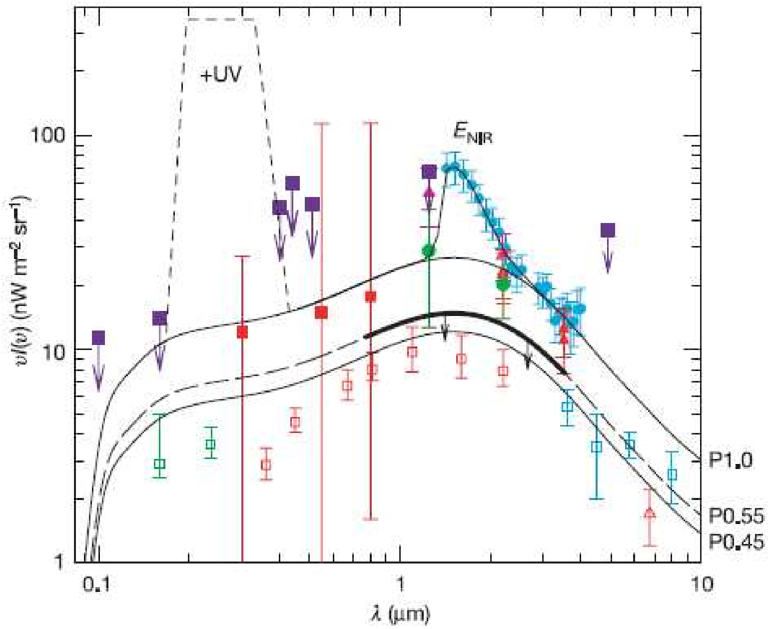


Figure 1 | SED of the EBL in the wavelength band most affecting these HESS data (0.1–10 µm). The EBL data are from a review compilation[1] (errors 1σ), unless otherwise stated. Open symbols correspond to the integrated light from galaxy counts, and thus must be considered lower limits for the EBL: in the UV–O range, from Hubble data (green, red[8]); in the NIR, from Spitzer (blue[28]) and ISO data. We note that these data are also lower limits for the total emission from galaxies, because of various observational and selection effects in the detection and counting of faint galaxies. The possible missed light in the the UV–O band has been estimated[29] to be $\lesssim$(2–3) nW m^{-2} sr^{-1}. The upper limits (purple) are 2σ estimates[1]. Direct measurements are shown as filled symbols: IRTS data from the NIR spectrometer[16] (blue), and data from COBE/DIRBE (green[15], magenta[17] and red triangles). Red squares correspond to tentative detections in the optical[26] with corrections according to ref. 30. The curves show the EBL shapes used to reconstruct the intrinsic spectra. P1.0 gives 26, 23 and 14 nW m^{-2} sr^{-1} at 1.25, 2.2 and 3.5 µm, respectively. The thick line shows the range most effectively constrained by the HESS data.

Aharonian et al
Nature 440, 1018 (2006)

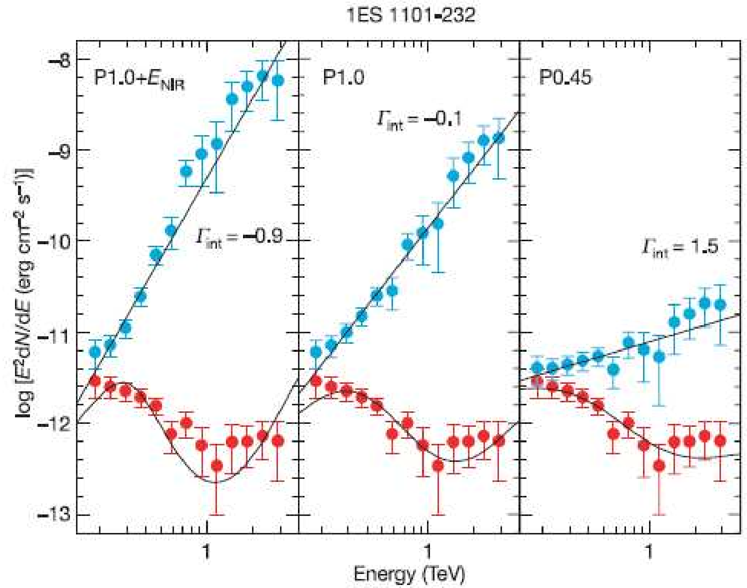


Figure 2 | The HESS spectra of 1ES 1101−232, corrected for absorption with three different EBL SED values, as labelled in Fig. 1. Red, observed data; blue, absorption-corrected data. The data points are at the average photon energy in each bin, also used to calculate the optical depth for reconstruction. For the calculation, a flat Λ-dominated cosmology was adopted, with $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$. Error bars are 1σ s.d., statistical errors only. Between 1.3 and 3.3 TeV, the overall detection is 4σ. The lines show the best-fit power laws to the reconstructed spectrum ($dN/dE = N_0 E^{-\Gamma_{int}}$), where E is measured in TeV, and the corresponding shapes after absorption. The χ^2_{red}/d.o.f. (calculated by integrating the

Therefore, the conservative and self-consistent assumptions of both not-unusual blazar spectra ($\Gamma_{int} \geq 1.5$) and a galaxy-like EBL spectrum allow the EBL flux around 1–2 µm to be constrained at the level of $\lesssim$(14 ± 4) nW m^{-2} sr^{-1} (that is, $\lesssim$0.55 ± 0.15 × P1.0). This corresponds to P(0.45 + 0.1) to allow for galaxy evolution effects. Coupled with the lower limits derived from galaxy counts given by the Hubble Space Telescope[8] ($\sim 9.0 - 9.7^{+3.0}_{-1.9}$ nW m^{-2} sr^{-1}), the HESS spectra lead us to conclude that more than two-thirds of the EBL in the O–NIR band is resolved into single sources. This result is independent of any 'direct' measurement of the EBL. Remarkably, it is in severe conflict with the claims of high EBL flux at NIR wavelengths[16,17] and, to a lesser extent, with the reported detections at 2.2 and 3.5 µm (refs 1, 15). The HESS upper limits agree instead with the most recent theoretical calculations[23] of the EBL, as well as with recent theoretical arguments[24,25] against high EBL fluxes due to population III stars.

CONCLUSIONS:

we are in the (slow but certain) process of starting to understand noteverything

Einstein's theory-of-everything utopia :
"I would like to state a theorem…: there are no arbitrary constants ... that is to say, nature is so constituted that it is possible logically to lay down such strongly determined laws that within these laws only rationally completely determined constants occur…"