Title: Fermi's lazy photon, the GEO600 anomaly, and the no-Riemann-no-pie theorem

Date: Mar 25, 2009 04:00 PM

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Abstract: I comment on rather significant recent developments that are relevant for proposals I had presented in previous PI seminars. The Fermi/GLAST space telescope has reported observations that would naturally fit previous formalizations of Planck-scale-induced in-vacuo dispersion (but also quite a few other things). And the unexplained excess noise found at the GEO600 interferometer is just of the type that had been previously described in terms of phenomenological models of spacetime foam (but may well be caused by quite a few other things). On the pure-theory side I can finally keep my promise to show that spacetime noncommutativity is a valuable tool of exploration of nonclassicality of spacetime, allowing the derivation of discretized spectra of distance, area, volume, and also providing a completely new overall geometric picture, in which amusingly the number Pi looses some of its privileges.

25.3.2009

Giovanni AMELINO-CAME
Univ. of Rome "LA SAPIEN
& INFN sez. ROMA1

an update on the QGphenomenology side:

- Planck-scale-induced in-vacuo dispersion,
  and "Fermi's lazy photon"

- Excess interferometric noise as manifestation of spacetime foam,
  and "GEO600's mystery excess noise"

and, if time allows, something new on the pure-theory side

- Discretization of distances and areas in noncommutative space,
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in-vacuo dispersion

(nearly generic feature?)

"quantum" spacetime

↓

broken/deformed symmetries

↓

modified dispersion relations

E_p

Minkowski limit:
*Lorentz Invariance Violatio
*Doubly-Special Relativity

$$p^2 = f(m,E;\lambda) \approx E^2 - m^2 + \lambda_{P,n}\, E^{2+n}$$

where $|\lambda_{P,n}| \approx E_P^{-n}$

GAC,PhysLettB(1997)
GAC+Ellis+Mavromatos+Nanopoulos, IJMPD (19
GAC+Ellis+Mavromatos+Nanopoulos+Sarkar, Nature(1998)
Gambini+Pullin,PhysRevD(1999)
Kifune, Astr.Journ.Lett.(1999)

slide from a couple (GLAST…many delays…) of previous PI seminars:

in-vacuo dispersion

$$p^2 \approx E^2 - m^2 + \lambda^n E^{2+n} \Rightarrow v_\gamma = \frac{dE}{dp} \approx 1 - \lambda_{P,n} E^n$$

wavelength-dependent speed for photon

This would mean that two (nearly-)simultaneously-emitted photons would reach the detector with a relative time-of-arrival difference of $\Delta t = T \lambda_{P,n} E^n$ **where T is the overall time travelled**

gamma-ray bursts

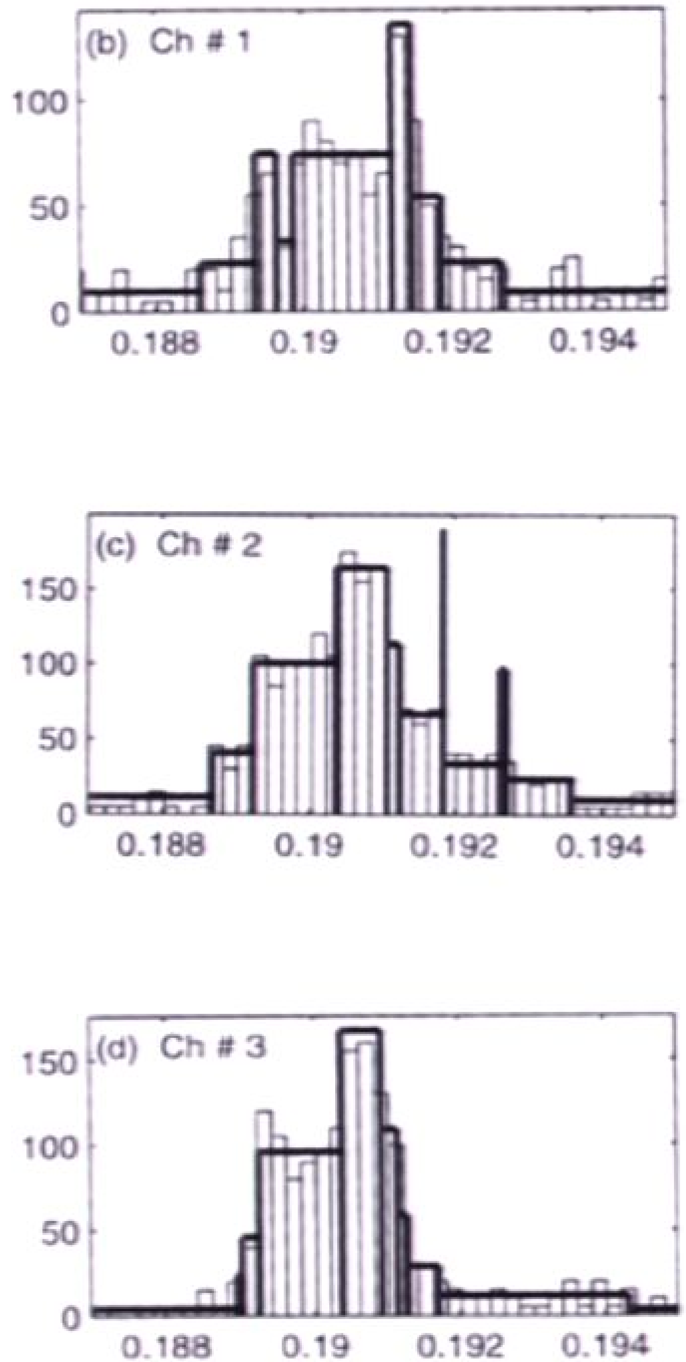
- **travel distances of order 10^{10} light years**
- **microbursts within a burst have duration 10^{-3} seconds and arrived simultaneously (within available sensitivity) in all BATSE channels**
- **large ΔE (10 MeV... 100 MeV...possibly a few GeV...)**

next-generation γ-ray telescopes (GLAST) will have sensitivity to $\lambda_{P,1} \approx 1/E_P$

Concerning the relation $v = dE/dp$ it may be useful to stress that it can be obtained assuming that a Hamilton description is still available, $v = dx/dt \sim [x, H(p)]$, and that the Heisenberg uncertainty principle still holds exa ($[x, p] = 1 \rightarrow x \sim \partial/\partial p$).

Another slide from previous PI seminars:

20 to 300 KeV



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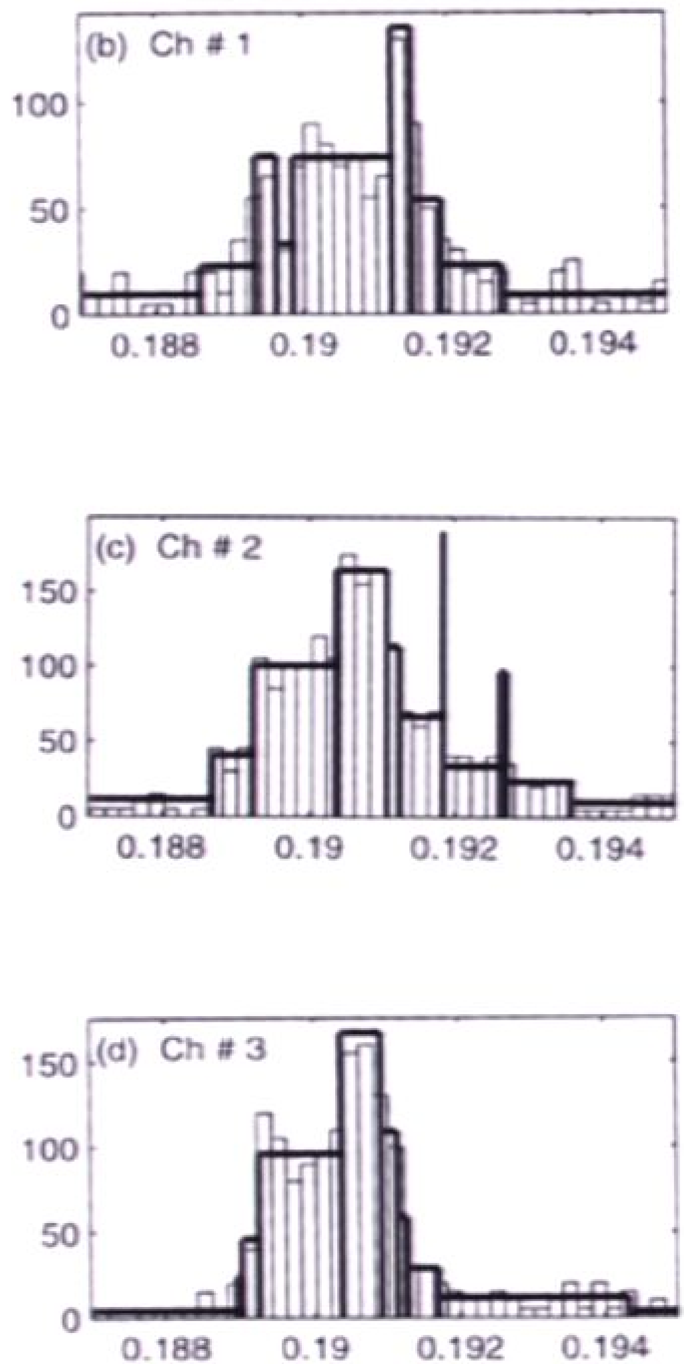


GRB 080916C: notable firsts about this burst

- Largest number, ≈ 200, of high-energy, >100 MeV photons (second is GRB 940217, with 28), allowing time-resolved spectral studies
- **Significant ≅4.5s delay between onset of >100 MeV and 100 keV radiation**
- First high-energy 100 MeV – GeV detection of a GRB with known redshift
- Redshift z = 4.2±0.3 from GROND photometry on 2.2 m in La Silla, Chile (Greiner et al. 2008)

– **Highest energy, ≅ 13.2 GeV photon, detected 16.5 sec after GBM trigger**

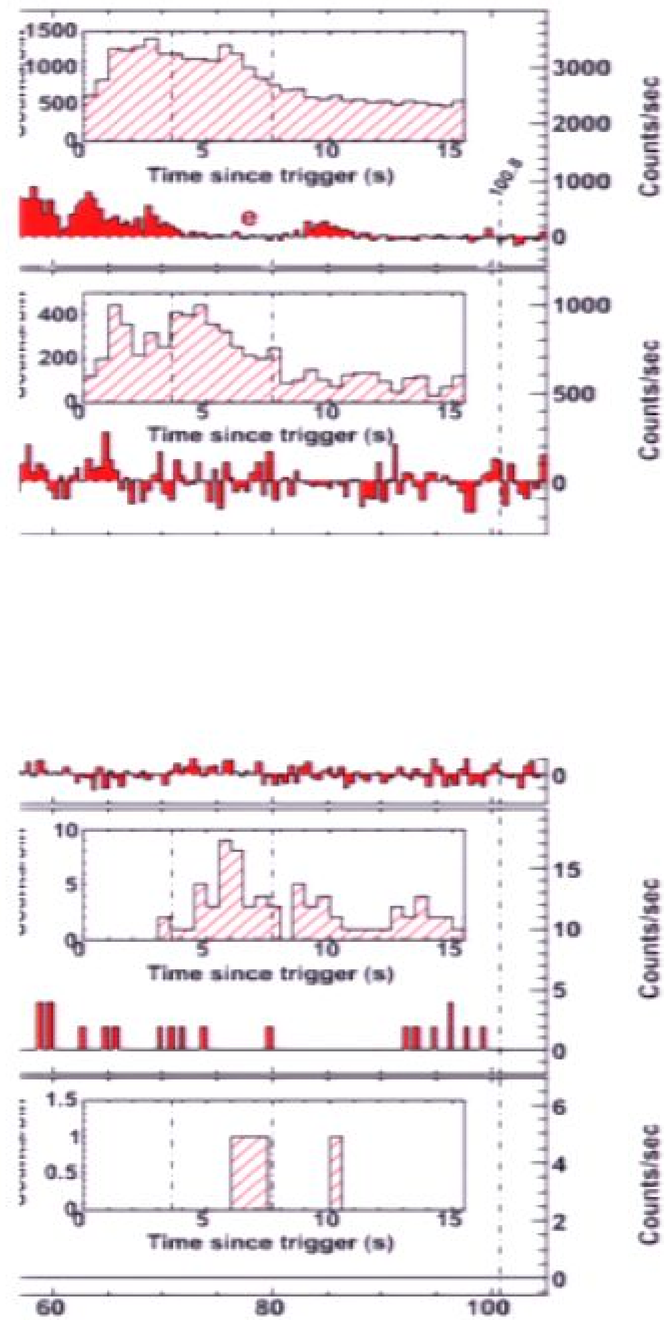
Charles D. Dermer, On behalf of the Fermi Collaboration,January 7, 2009

8-260 keV

0.26-5 MeV

>100 MeV

>1 GeV



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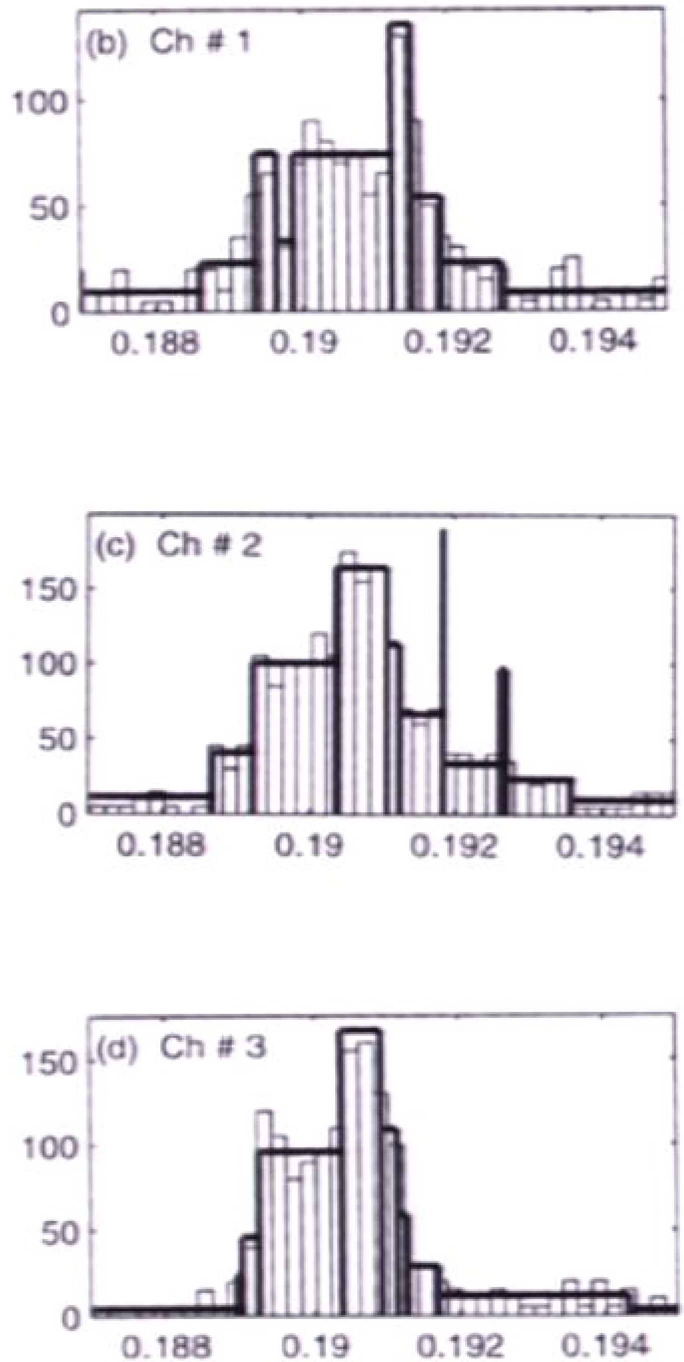

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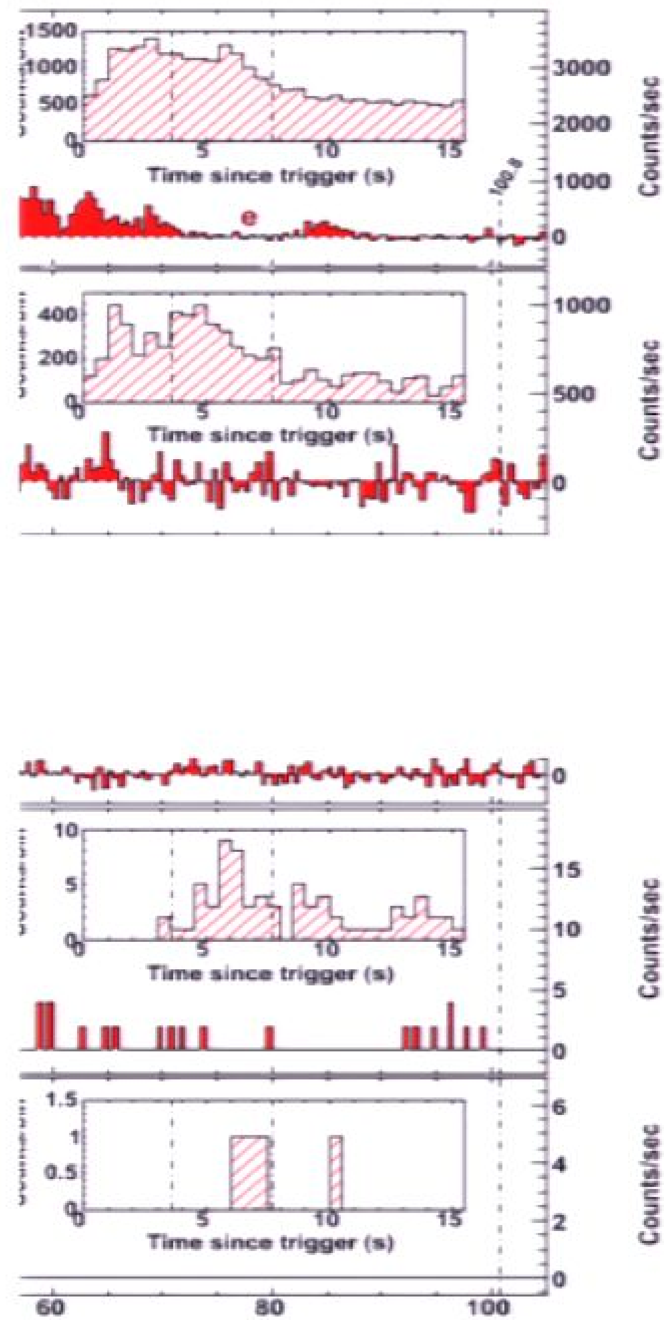

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   Fermi acceleration limits: cannot gain a significant fraction of energy on timescale shorter than Larmor time

High energy emission is delayed with respect to the lower energy emission

Could be due to the time to accelerate protons and ions, and to develop the electromagnetic shower

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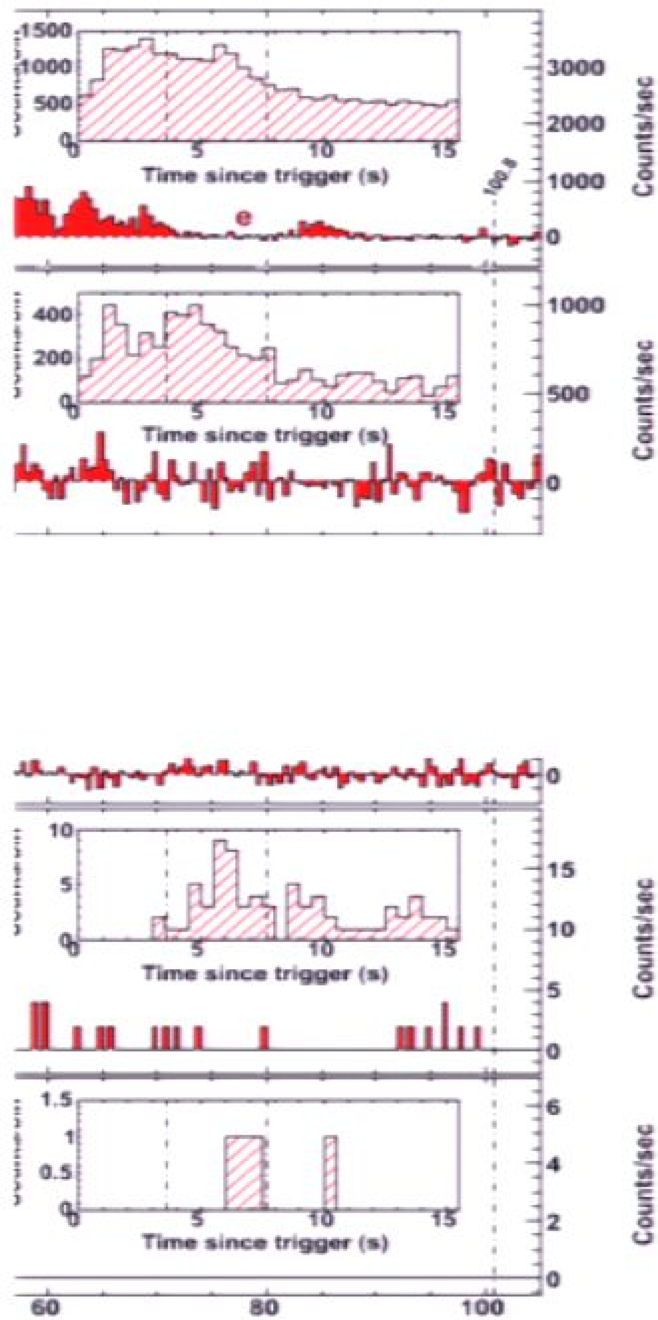

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My perspective:

* in 1997 there was no way to imagine a 13GeV "lazy" photon arriving 16 seconds late ...... 13 GeV,16s $\leftrightarrow$ Planck scale !!!

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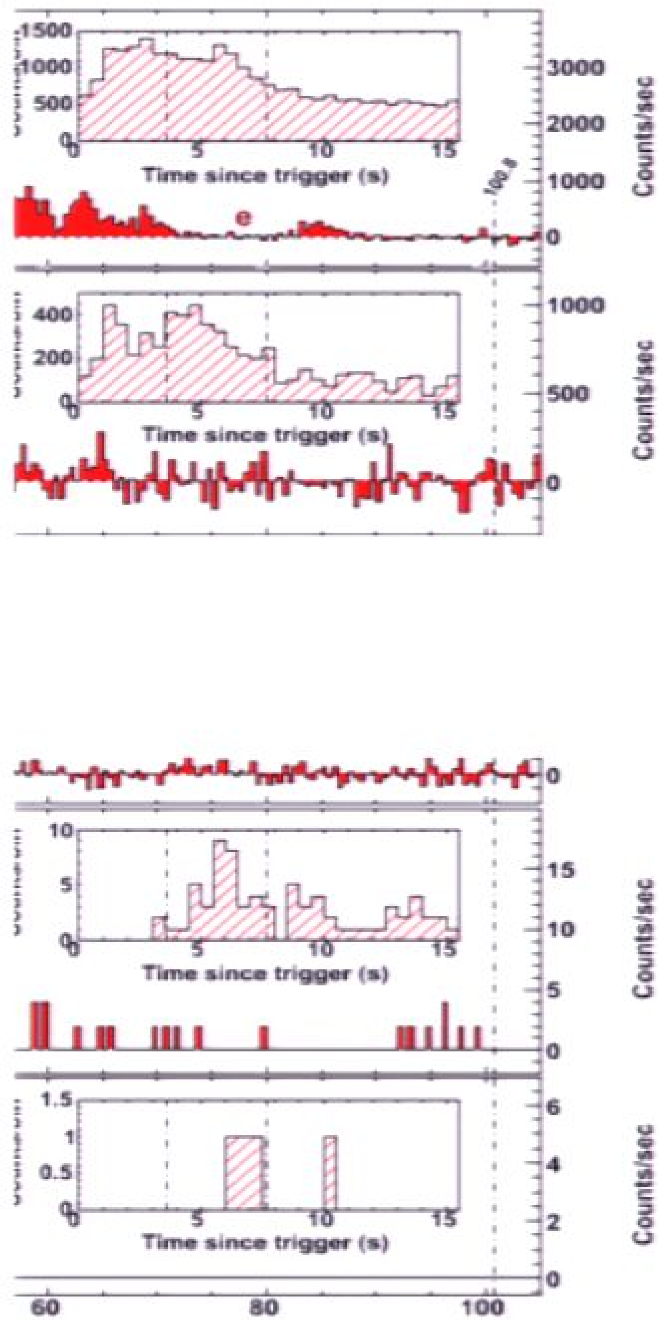

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excess noise in interferometry

(absolutely generic feature!!!)

GAC, Nature 398(1999)2

interferometers are sensitive to anything that makes distances/lengths not sharp

all of physics is coded in interferometric noise!!!
(the classical mechanics of thermal and seismic effects...
the quantum mechanics that goes into analysis of photon shot noise and radiation pressure noise)

If any sort of quantization of spacetime is actually present (think of the "spacetime foam" picture) there will be a Planck-scale contribution to noise

Another tentative estimate can be based on heuristic arguments for the measurability of distances, suggesting that

GAC, ModPhysLett(1994)

$$\sigma_L^2 \propto \sqrt{T} \approx \sqrt{L}$$

and it is well known that standard deviation going like square root of T is manifestation of random-walk noise

Modelling of spacetime foam effectively in terms of random-walk stochastic process would be reasonable in light of plausible expectations for the application of the fluctuation-dissipation theorem in a spacetime foam environment. GAC, PhysRevD62(2000)0240

And if indeed it is random-walk noise the spectrum would be of the type

$$S(f) \approx \frac{\alpha}{f^2}$$

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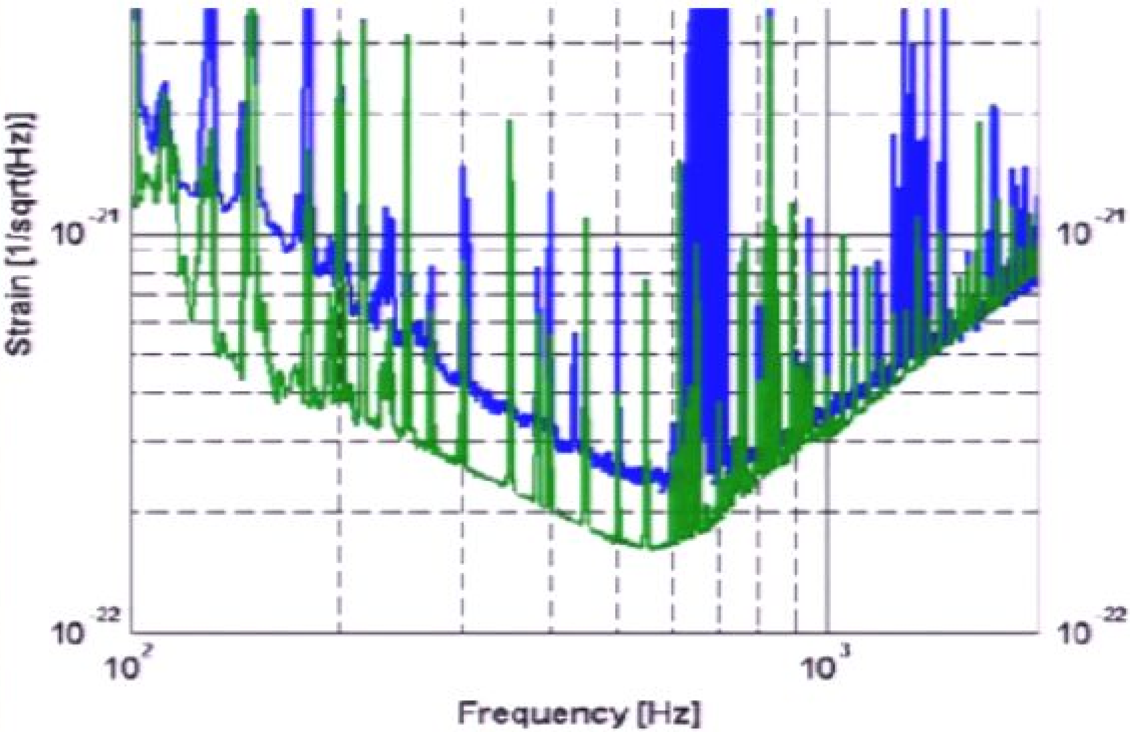
With a time scale α characteristic of the specific interferometric setup (which however should be determined within a given spacetime-foam picture....a task which is at least presently impossible....)

.....was ready to give up.....but......

…..but the much-discussed "GEO600 mistery noise" provides some Motivation to keep wondering



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ILIAS WG1, March 2008

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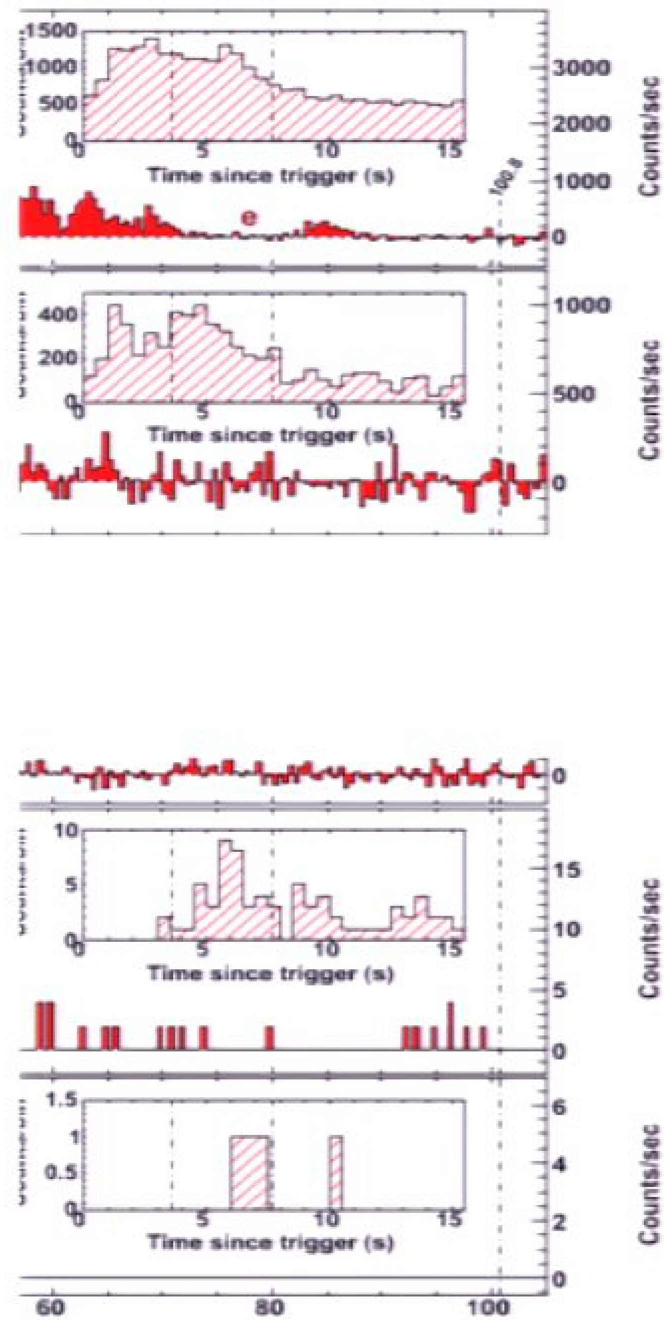

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PhysRevD62(2000)024(
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Noise in interferometers characterized through the "strain noise power spectrum"

$$\sigma_L^2 = \int df\, S(f)$$

Rough characterization of sensitivities achievable with this generation of interferometers (used for gravity-wave detection):

$$S(\approx 100\ Hz) \approx 10^{-44}\ Hz^{-1}$$

It appears inevitable that the strain noise power spectrum receives some contribution from Planck-scale effects.
But it is difficult to estimate it....no symmetry (or symmetry breaking) principles appear to be able to guide us...
Still noteworthy: if QG noise is "white" a natural guess would be

$$S(f) \approx \frac{L_p}{c} \approx 10^{-44}\ Hz^{-1}$$

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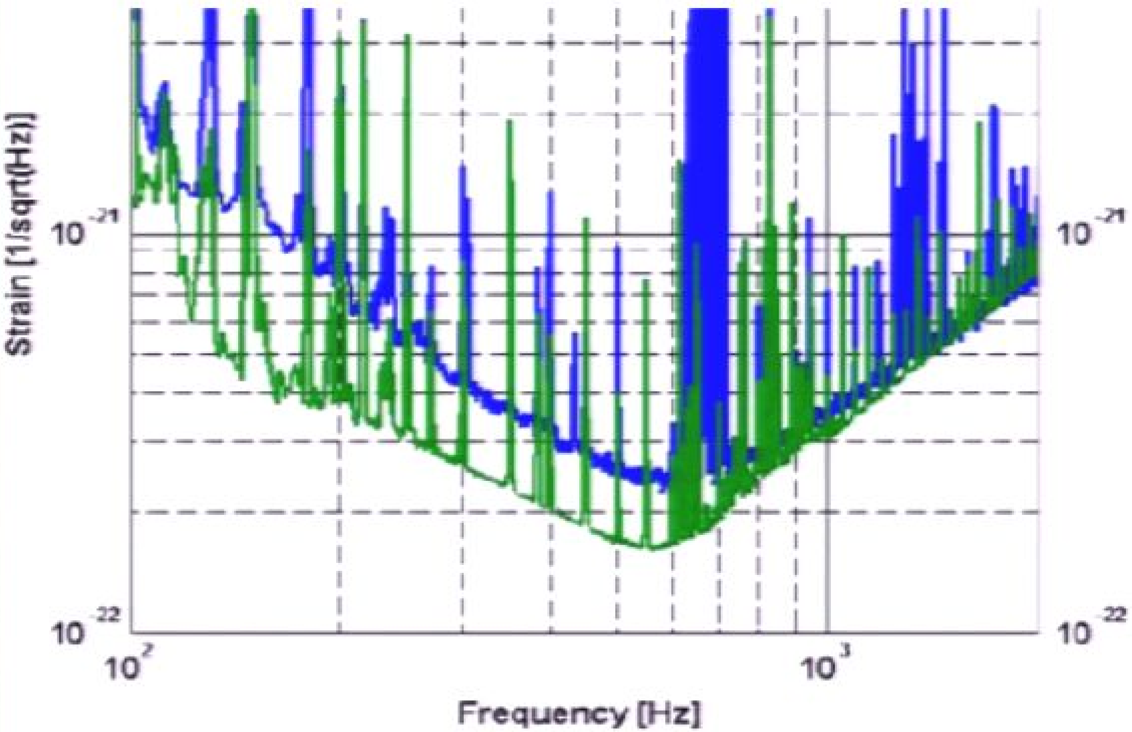

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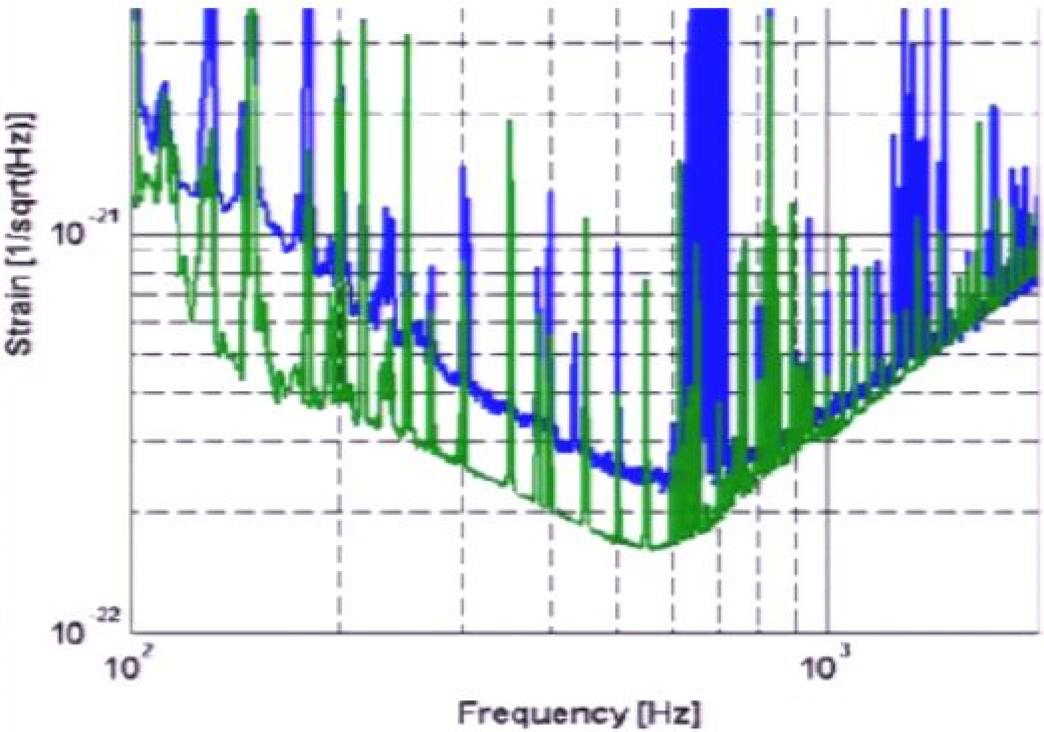

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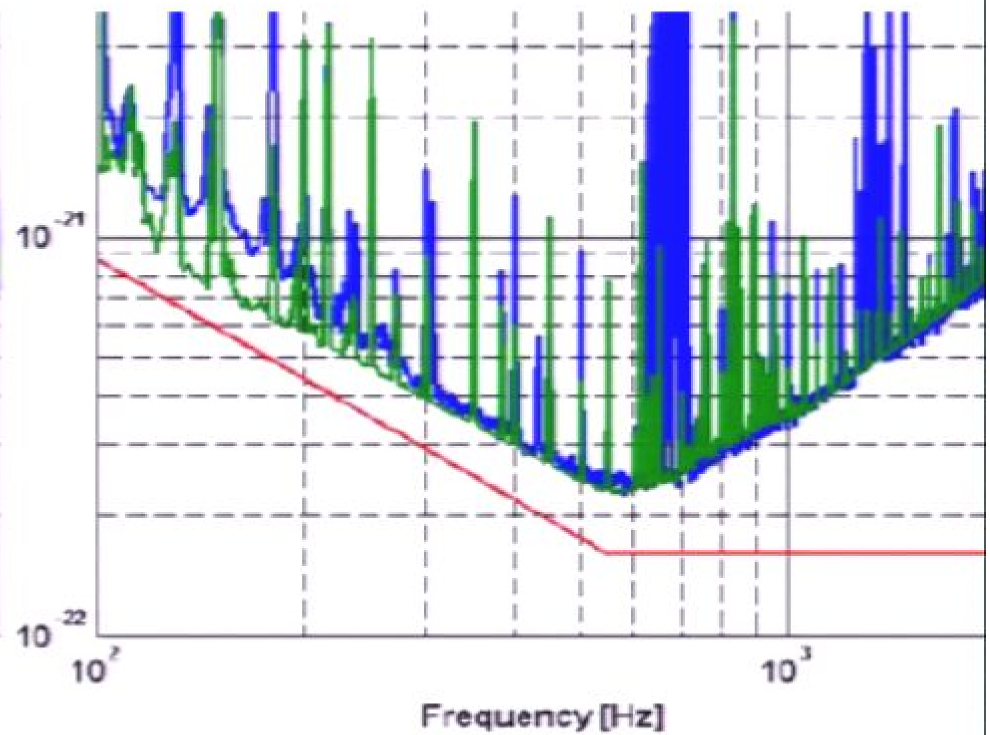

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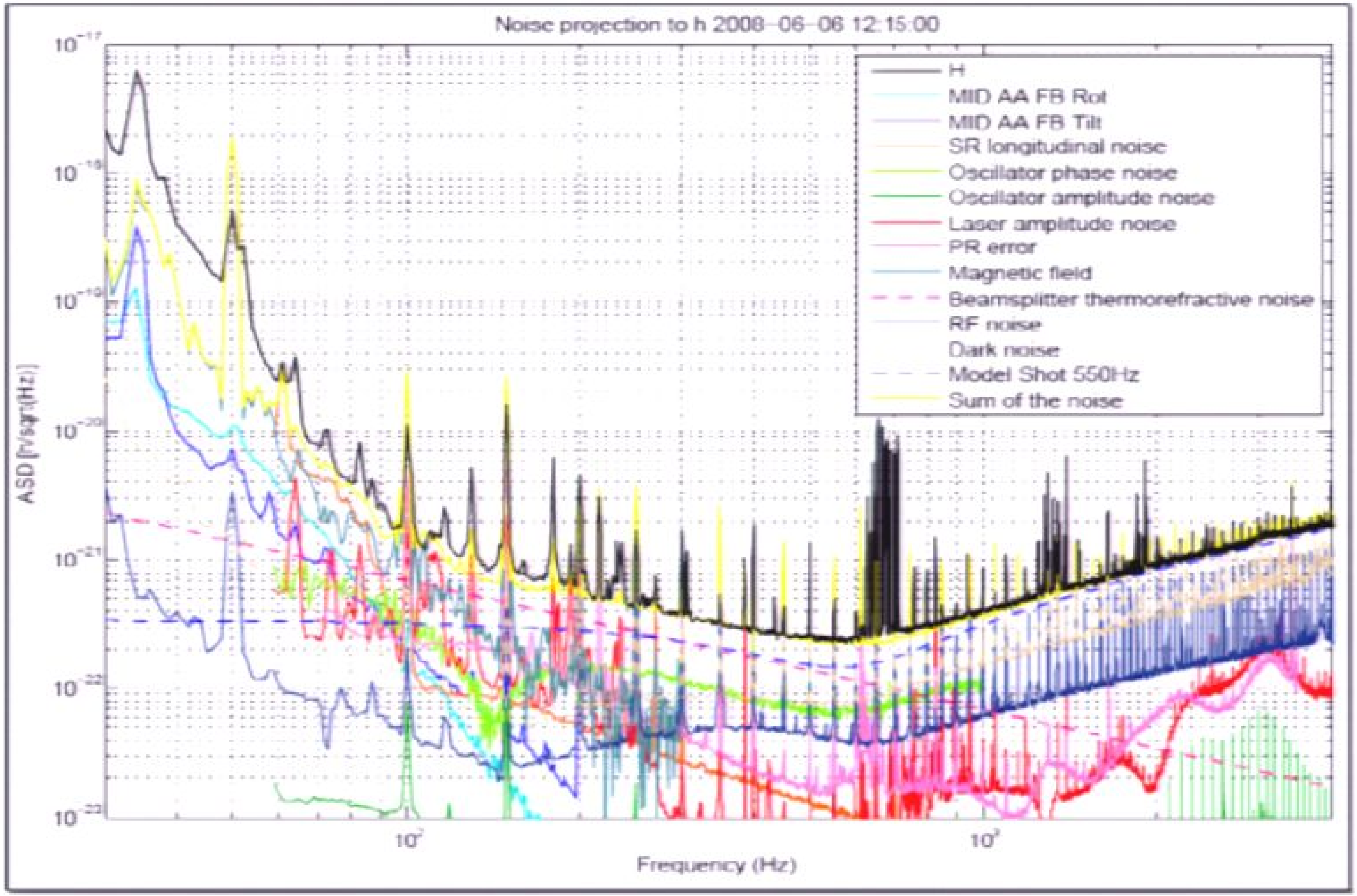
Hogan PhysRevD78(2008) 0875

Projection including increased BS thermo refractive noise



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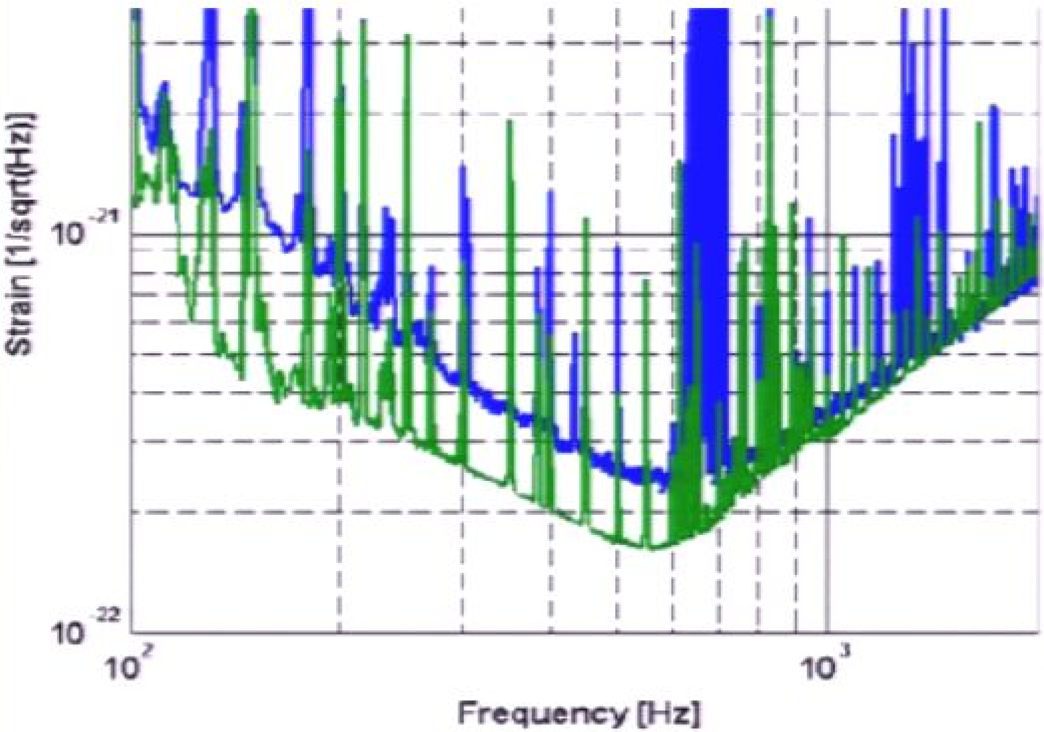

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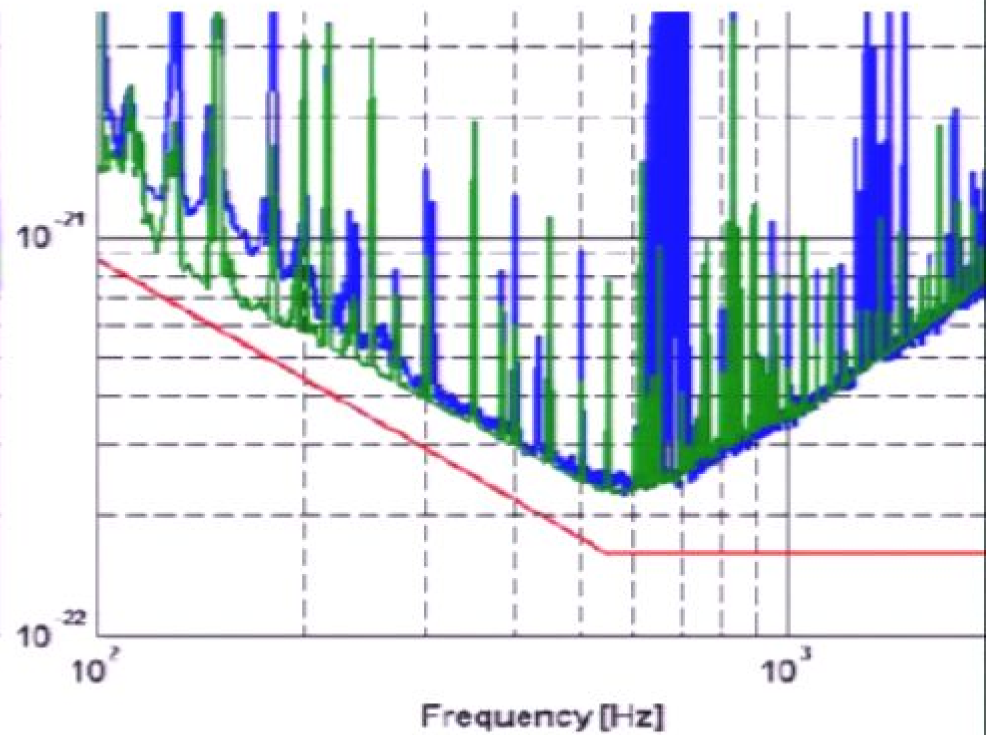

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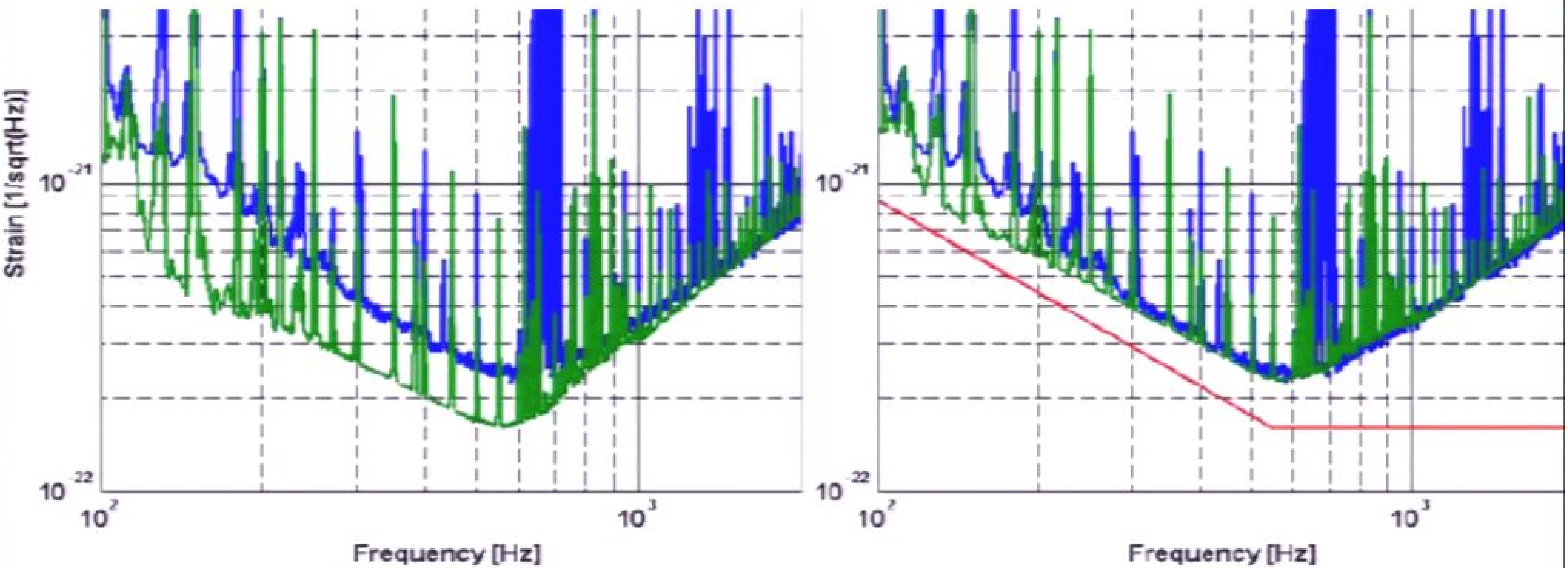

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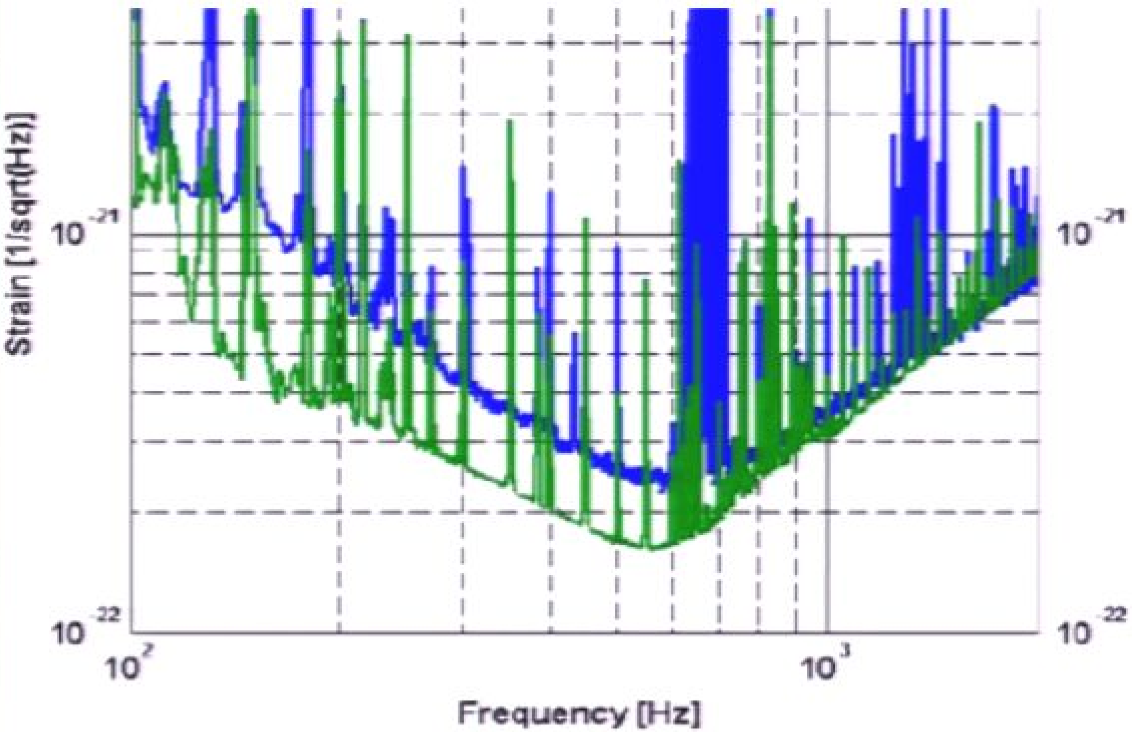

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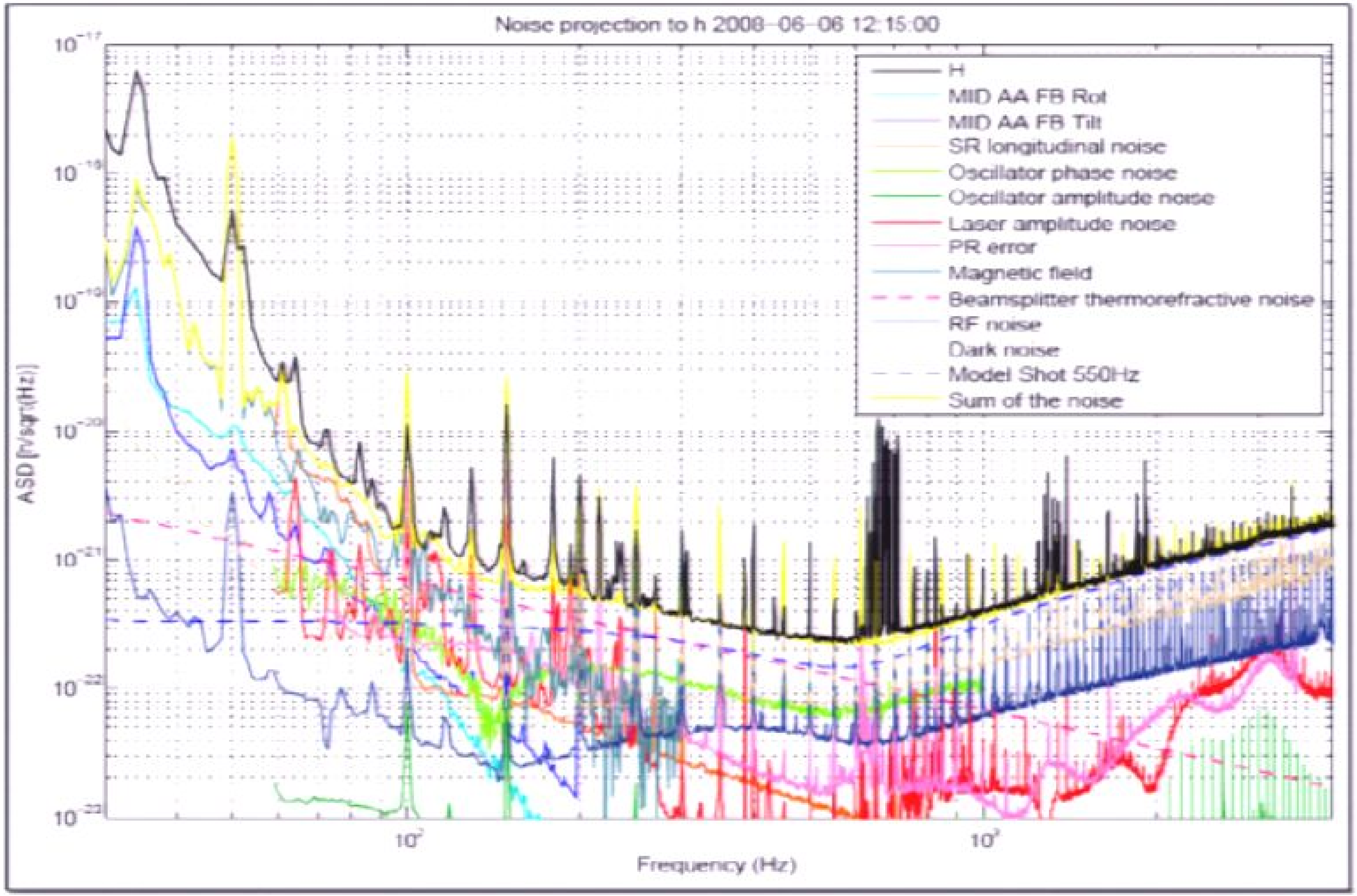

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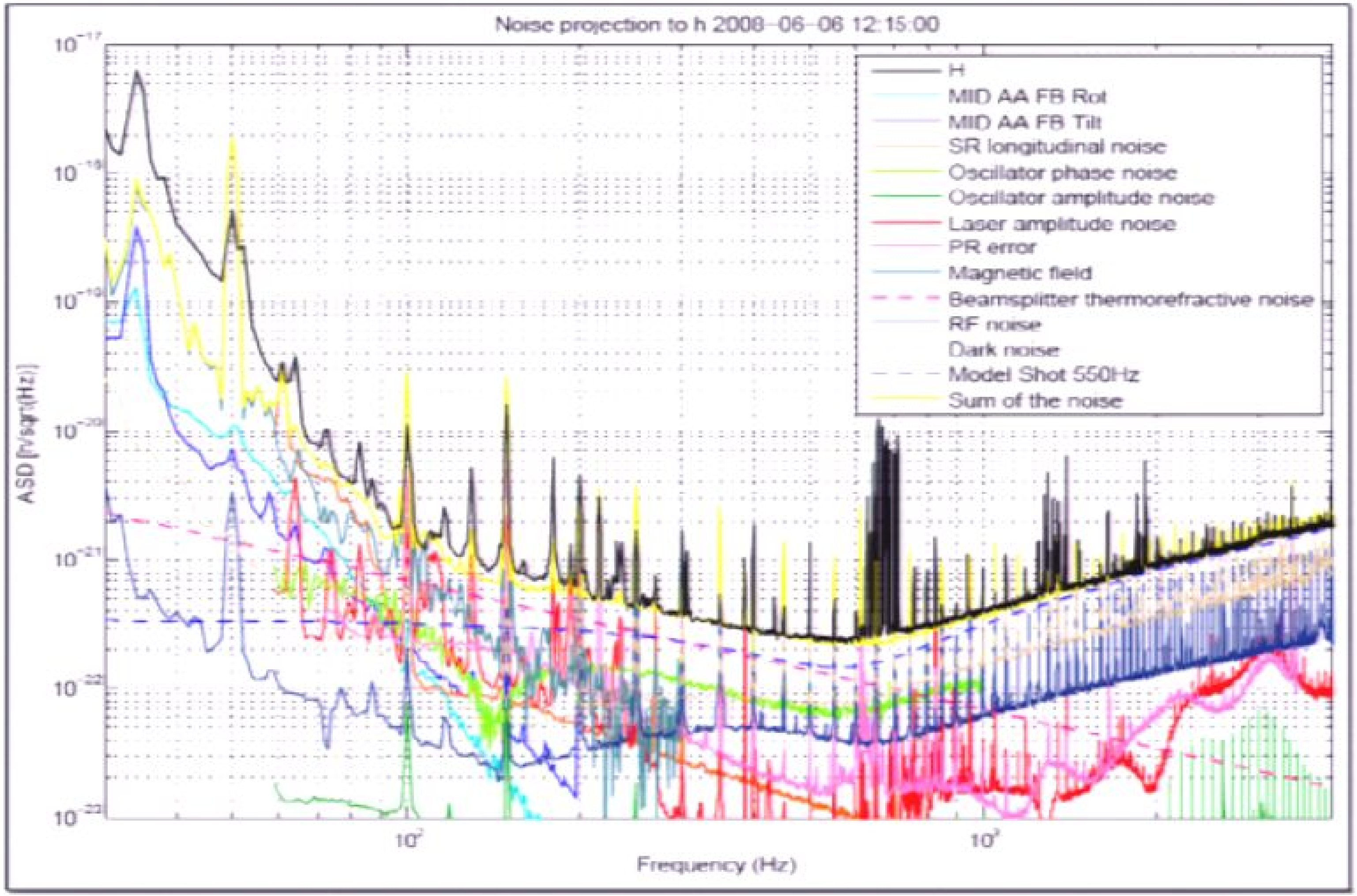

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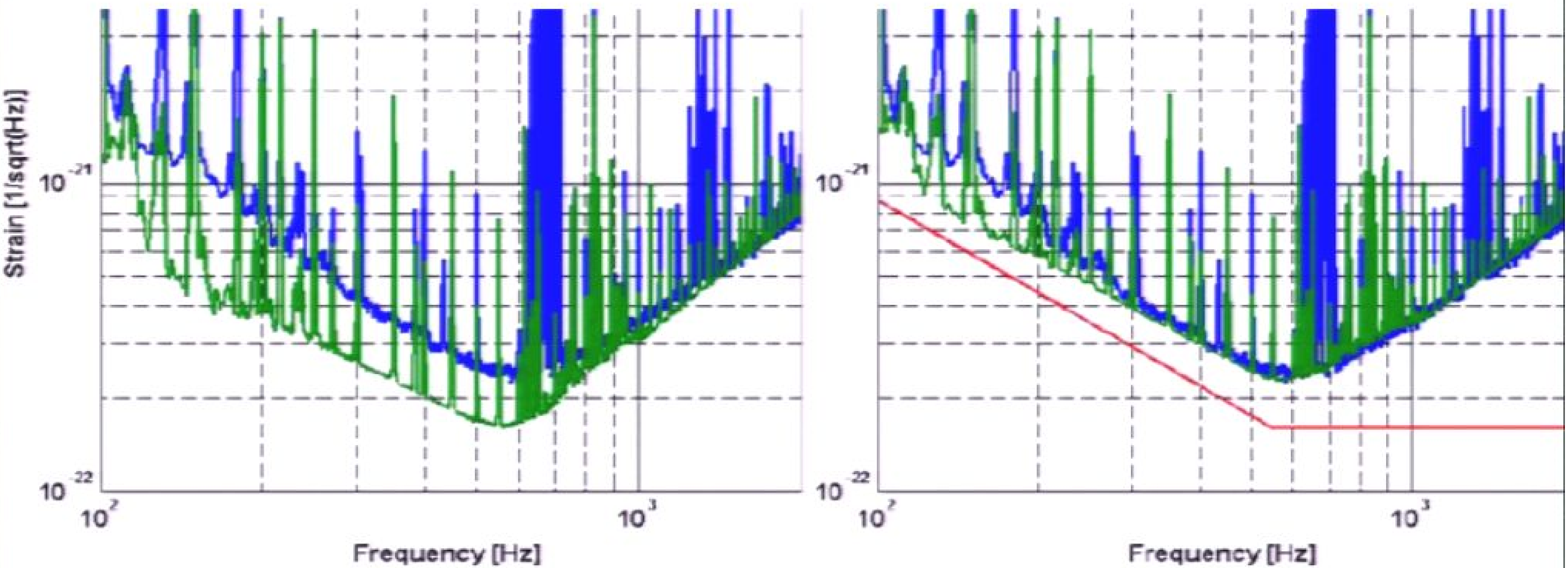

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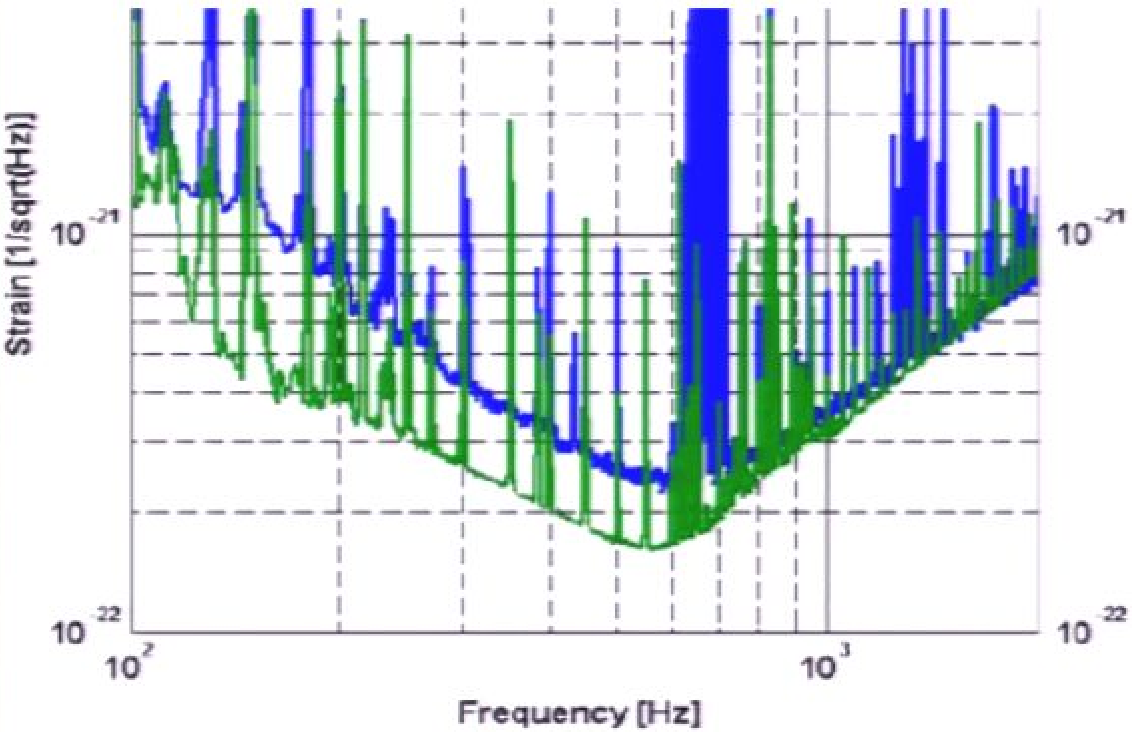

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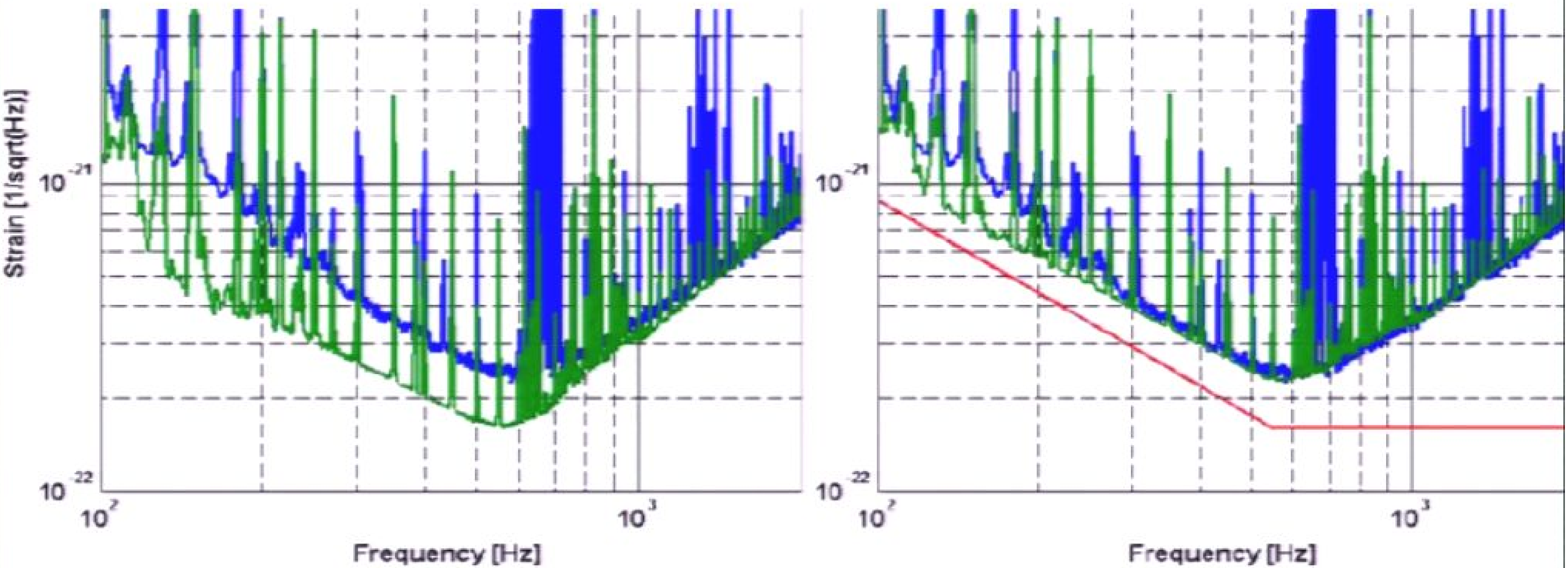

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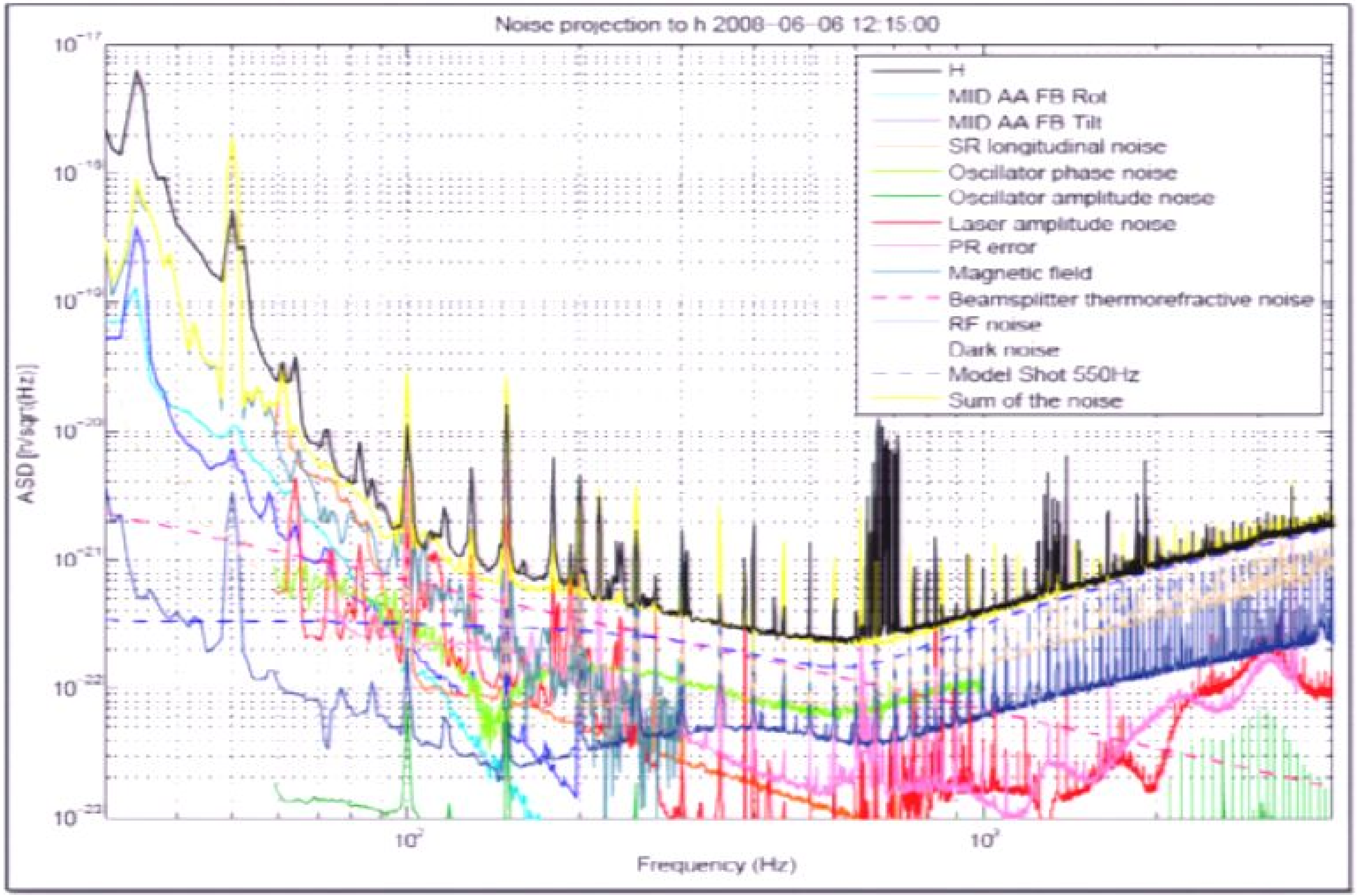

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Quantum Gravity Phenomenology:

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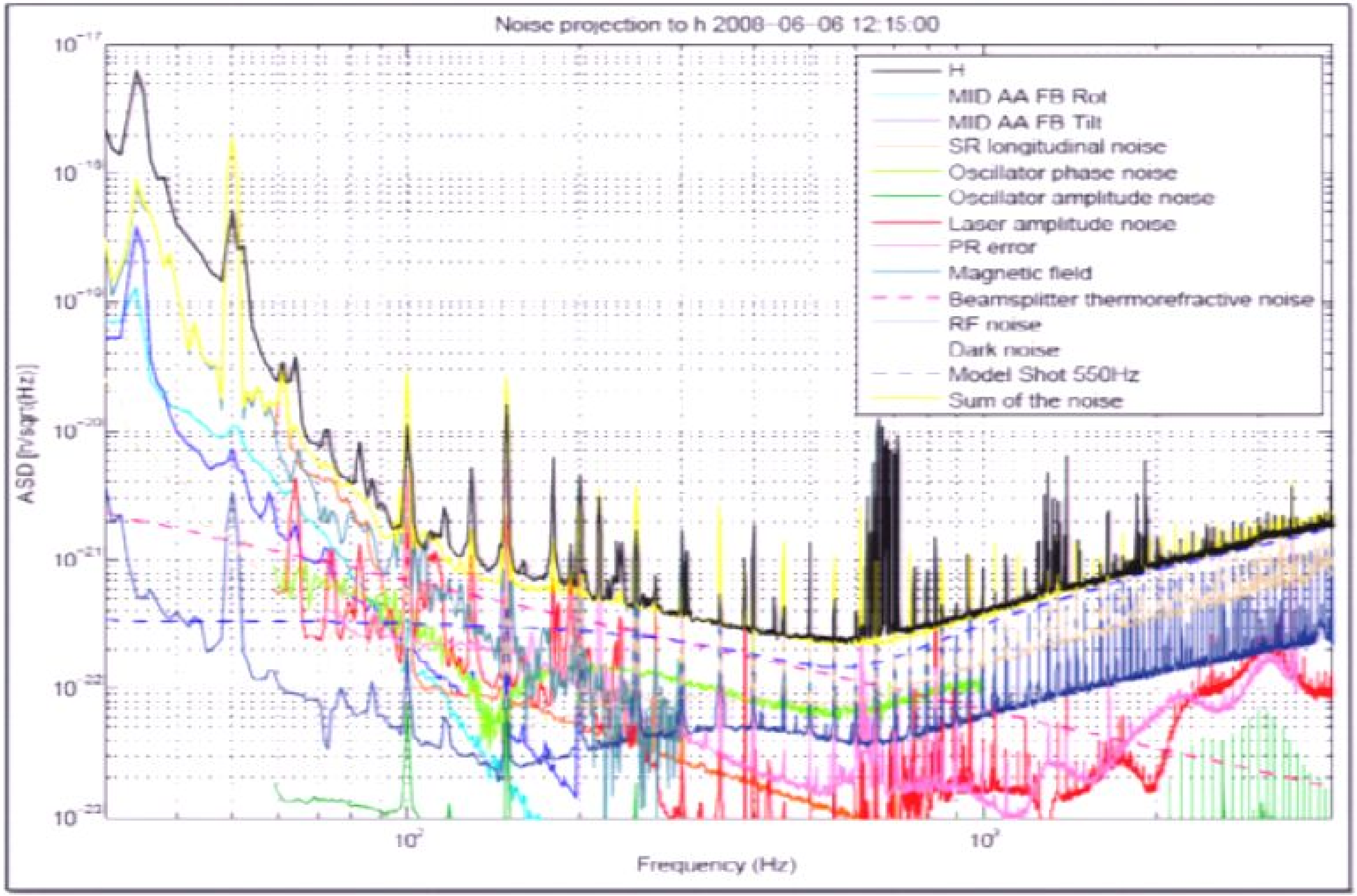

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But focus on properties of field theories in these spaces might not be the only way to get intuition on the implications of spacetime quantization

Should we not ask what happens to key "geometric observables" like distances, areas, volumes ??
No work on this!!!!

theory side: Discreteness of area in noncommutative space

studies of noncommutative spacetimes as a way to gain intuition on what "spacetime quantization" might bring about...(what could be characteristic experimental signatures?)

Typical papers: field theories in either "canonical spacetimes" $[x_\mu, x_\nu] = i\theta_\mu$

or kappa-Minkowski spacetime

$$[x_j, x_m] = 0 \quad [x_j, t] = i\lambda x_j$$

Main physics result:

symmetries are described by Hopf algebras...might be a way to formalize conc of "deformed Poincare' symmetries", in the Doubly-Special-Relativity sense

Hopf-algebra description fully established only with results on Noether analysis of these field theories which I reported in previous PI seminar

PLB671(2009)298, PRD78(2008) 025005 ,MPLA22(2007)1779
(with Arzano,Gubitosi,Marciano',Martinetti,Mercati)

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Well, here is our analysis of distances and areas in the "Moyal plane":

arXiv:0812.2675 PhysLettB (in pre
(with Gubitosi and Mercati)

$$\left[\hat{X}_1, \hat{X}_2\right] = i\theta$$

First a few notions of the "pregeometric description" of noncommutative spaces and particularly of the Moyal plane

$\hat{X}_1$ and $\hat{X}_2$ can be described as operators on a Hilbert space with structure that exactly reproduces the Hilbert space of a particle in nonrelativistic quantum mechanics.
Denoting the "state of the point" by $|\psi>$, so that the "wave functions" of the first coordinate of the point is $\psi(x_1) =< x_1|\psi$
we can prescribe that $\hat{X}_1$ and $\hat{X}_2$ act as follows

$$\hat{X}_1 \triangleright \psi(x_1) = x_1 \, \psi(x_1) \ ,$$

$$\hat{X}_2 \triangleright \psi(x_1) = -i\theta \frac{\partial}{\partial x_1} \psi(x_1$$

arXiv:0812.2675 PhysLettB (in pr
(with Gubitosi and Mercati)

Analysis of (squared-)distance observable is rather simple:

$$\hat{d}^2 \equiv \left(\hat{X}_1^{(1)} - \hat{X}_1^{(2)}\right)^2 + \left(\hat{X}_2^{(1)} - \hat{X}_2^{(2)}\right)^2 \ ,$$

where $\hat{X}_i^{(1)} \equiv \hat{X}_i \otimes \mathbb{1}$, $\hat{X}_i^{(2)} \equiv \mathbb{1} \otimes \hat{X}_i$.

and one easily finds the spectrum (this observable pregeometrically gives the Hamiltonian of an harmonic oscillator):

$$d_N^2 = 4\theta \left(N + \frac{1}{2}\right) \ .$$

with N integer and nonnegative.

NOTE THAT:

- **equal spacing**
- **minimum distance (d=0 not possible)**

arXiv:0812.2675 PhysLettB (in pr
(with Gubitosi and Mercati)

areas:

....we find that triangles have a special role but would not be able to explain it clearly now...

The area of a triangle obtained from the coordinates of its 3 vertices:

$$\hat{A}(\vec{\hat{X}}^{(1)}, \vec{\hat{X}}^{(2)}, \vec{\hat{X}}^{(3)}) \equiv \frac{1}{2}\, det \begin{bmatrix} \hat{X}_1^{(1)} & \hat{X}_2^{(1)} & \mathbb{1} \\ \hat{X}_1^{(2)} & \hat{X}_2^{(2)} & \mathbb{1} \\ \hat{X}_1^{(3)} & \hat{X}_2^{(3)} & \mathbb{1} \end{bmatrix}$$

- its modulus should give area of triangle
- the overall sign gives the orientation of the vertices (clockwise, anticlockwise)
- pregeometrically described as an observable on the Hilbert space of 3 pregeometric particles

Not as easy as the Hamiltonian of an harmonic oscillator but it is still rather easy to find the spectrum

$$A_n^{(triangle)} = \frac{\sqrt{3}}{2}\theta\ M\ .$$

with M integer and nonnegative.

NOTE THAT: ....equal spacing....but no minimum area!!!!

no-Riemann-no-π:

amusing to contemplate a disc in the Moyal plane...
boundary can't be given by points equidistant from an "origin" (no point can be the origin with sharp coordinates 0,0)...
and boundary can't be given by points equidistant from a certain "center" point because a relation like AB=BC cannot be sharp in any state of the geometry...
more soon....

Quantum Gravity Phenomenology:

from simple estimates to show that it could be done (it definitely can be done!!!)

to the availability of data and the need to perform robust delicate difficult analyses…..but we are finally walking the Planck (scale)….

slide from a couple (GLAST…many delays…) of previous PI seminars:

in-vacuo dispersion

$$p^2 \approx E^2 - m^2 + \lambda^n E^{2+n} \Rightarrow v_\gamma = \frac{dE}{dp} \approx 1 - \lambda_{P,n} E^n$$

wavelength-dependent speed for photon

This would mean that two (nearly-)simultaneously-emitted photons would reach the detector with a relative time-of-arrival difference of $\Delta t = T \lambda_{P,n} E^n$ where T is the overall time travelled

gamma-ray bursts

- travel distances of order 10^{10} light years
- microbursts within a burst have duration 10^{-3} seconds and arrived simultaneously (within available sensitivity) in all BATSE channels
- large ΔE (10 MeV... 100 MeV...possibly a few GeV...)

next-generation γ-ray telescopes (GLAST) will have sensitivity to $\lambda_{P,1} \approx 1/E_P$

Concerning the relation $v = dE/dp$ it may be useful to stress that it can be obtained assuming that a Hamilton description is still available, $v = dx/dt \sim [x, H(p)]$, and that the Heisenberg uncertainty principle still holds exa ($[x, p] = 1 \rightarrow x \sim \partial/\partial p$).

GRB 080916C: notable firsts about this burst

- Largest number, ≈ 200, of high-energy, >100 MeV photons (second is GRB 940217, with 28), allowing time-resolved spectral studies
- **Significant ≅4.5s delay between onset of >100 MeV and 100 keV radiation**
- First high-energy 100 MeV – GeV detection of a GRB with known redshift
- Redshift z = 4.2±0.3 from GROND photometry on 2.2 m in La Silla, Chile (Greiner et al. 2008)

– **Highest energy, ≅ 13.2 GeV photon, detected 16.5 sec after GBM trigger**

Charles D. Dermer, On behalf of the Fermi Collaboration,January 7, 2009

in-vacuo dispersion

(nearly generic feature?)

"quantum" spacetime

↓

broken/deformed symmetries

↓

modified dispersion relations

E_p

Minkowski limit:
*Lorentz Invariance Violatio
*Doubly-Special Relativity

$$p^2 = f(m,E;\lambda) \approx E^2 - m^2 + \lambda_{P,n} E^{2+n}$$

where $|\lambda_{P,n}| \approx E_P^{-n}$

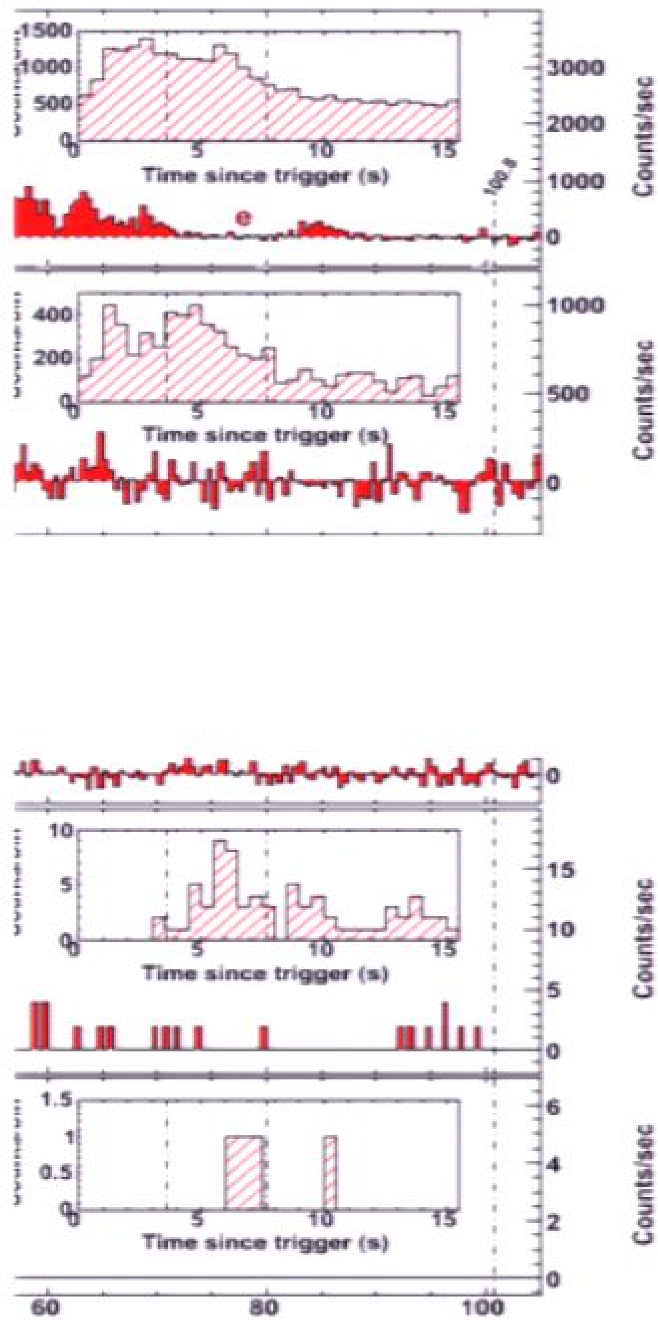
GAC,PhysLettB(1997)
GAC+Ellis+Mavromatos+Nanopoulos, IJMPD (19
GAC+Ellis+Mavromatos+Nanopoulos+Sarkar,
Nature(1998)
Gambini+Pullin,PhysRevD(1999)
Kifune, Astr.Journ.Lett.(1999)

8-260 keV

0.26-5 MeV

>100 MeV

>1 GeV



Charles D. Dermer, On behalf of the Fermi Collaboration,January 7, 20(