Falsifiable Planck-scale theories of NOT everything

traditional "strategy" for the "study" of the QG problem:

beautiful Theories Of Everything

- problem must be solved in one single (10^{16}) big jump: must find a beautiful (?) perfect(??) solution of the whole QG problem

- impossible to compare to data, but if the theory is "really perfectly beautiful" it will be "natural"(?) to assume it is "true"(????)

[String theory main candidate for many years (but now..."landscape"... "anthropic principle"....basically giving up on serious QG applications....)]

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new strategy:

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- **we presently need theories of the type of Fermi's description of weak interactions in terms four-fermion interactions....partial solutions stepping stones on the way to a gradual improved description of the QG realm**
- **must desperately seek guidance from data**
- **might have some useful "theories of not everything" within a decade or two but QG problem is here to stay**

GAC, MPLA(1994) LectNotesPhys(2000) arXiv:0806.0339(LivingReviewsRelativity,in press)

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the new strategy is presently adopted by at least 20 research groups internationally.

In Italy also at SISSA([Jacobson+]<u>Liberati</u>+…) and LNGS (<u>Grillo</u>+[Aloisio+]…)

<u>nearly</u> the standard strategy used in physics...
...e.g. development of description of weak interactions....

problem arises because of accidental discovery by experiment

↓

first data-inspired theories

↓

experimental searches of effects predicted by the new theories

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"better" theories are proposed

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Experiment inspired by such crude theories stumbles upon charateristic effect

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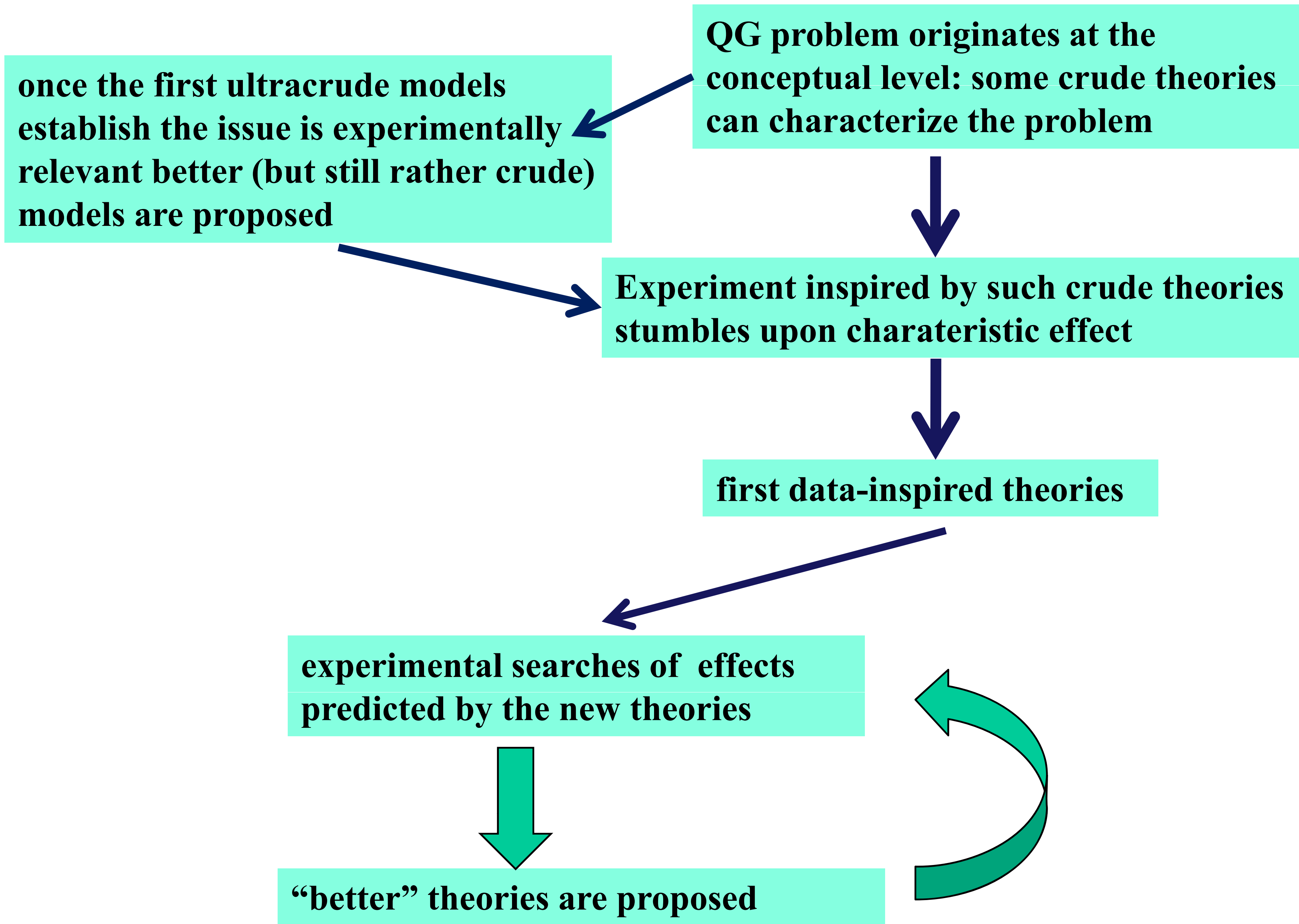
QG problem originates at the conceptual level: some crude theories can characterize the problem
once the first ultracrude models establish the issue is experimentally relevant better (but still rather crude) models are proposed
Experiment inspired by such crude theories stumbles upon charateristic effect
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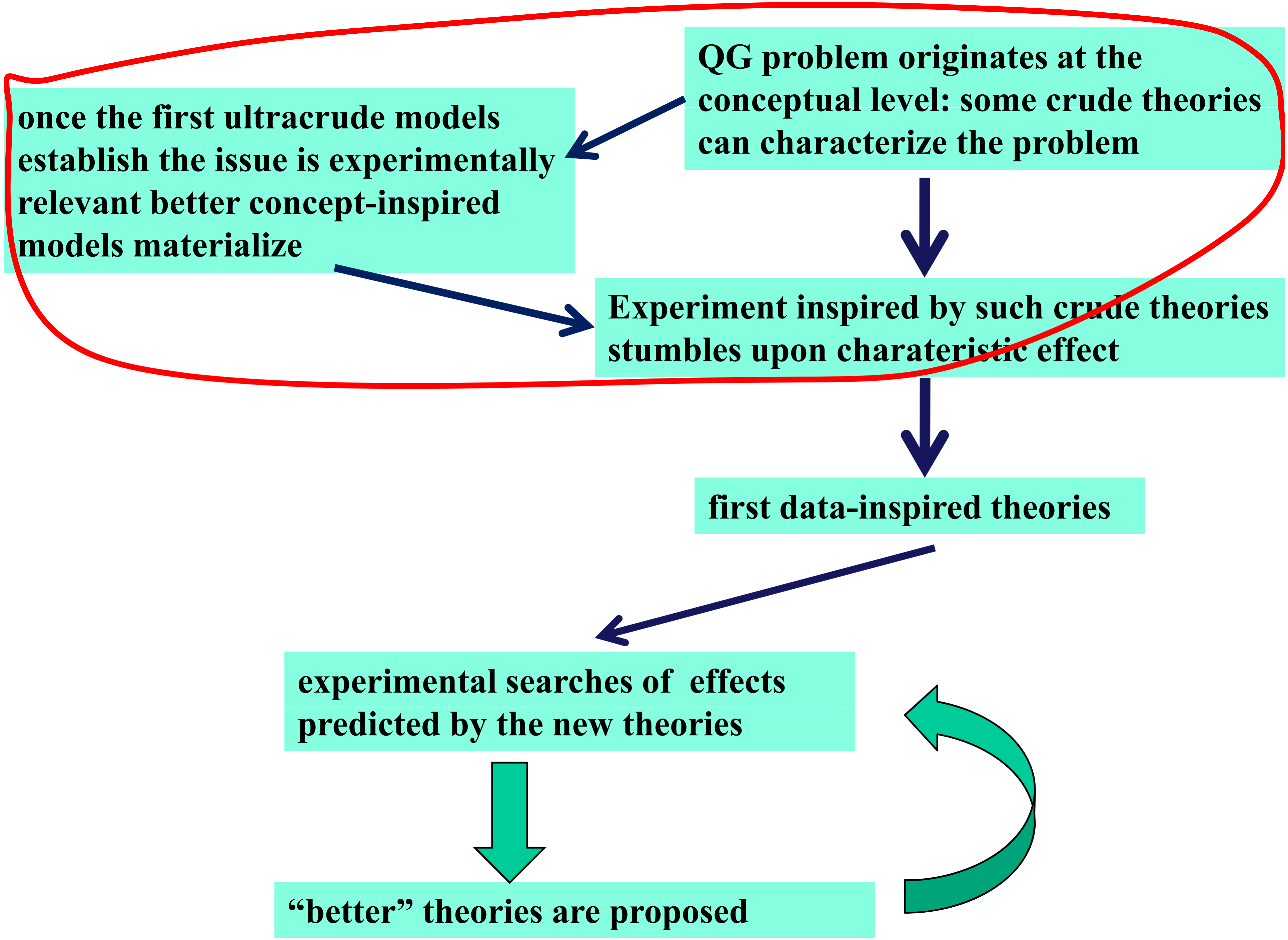
QG problem originates at the conceptual level: some crude theories can characterize the problem
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“QG problem” still completely open, but we have strong “theoretical evidence” that the Planck scale (~10^{16}TeV) is the characteristic scale
(noteworthy counter-example in the “large extra dim” scenario….)

well recognized that Planck-scale effects could be “striking” (“test of zero”)

- **(small) extra dimensions (Witten...)**
- **violations of EP (very many authors...even in Sakurai’s book..)**
- **violations of Poincarè/Lorentz symmetry (t’Hooft....)**
- **violations of CPT symmetry (Alvarez-Gaume,Peskin....)**

***modifications of Heisenberg Uncertainty Principle (Veneziano...)**

- **loss of quantum coherence (Hawking,Penrose....)**

these effects would indeed be very small because $E_P \approx 10^{16}$ TeV is much greater than energies accessible to us…but….

over the last decade it has been shown that the smallness of effects introduced at the Planck scale does not necessarily render unobservable the effects...
strategy similar to analyses of brownian motion or the study proton decay from the granunification perspective....could not possibly be any different from doing granunification research!!!!

A review of this, now rather sizeable, literature:
GAC, arXiv:0806.0339, Living Reviews in Relativity (to appear)

main objective today: a couple of examples of how the strategy works

modified "dispersion" relation

some "exploratory papers" then led to developments both on the experiment side and the theory side

situation toward the end of the 1990s:

"quantum" spacetime

Ep

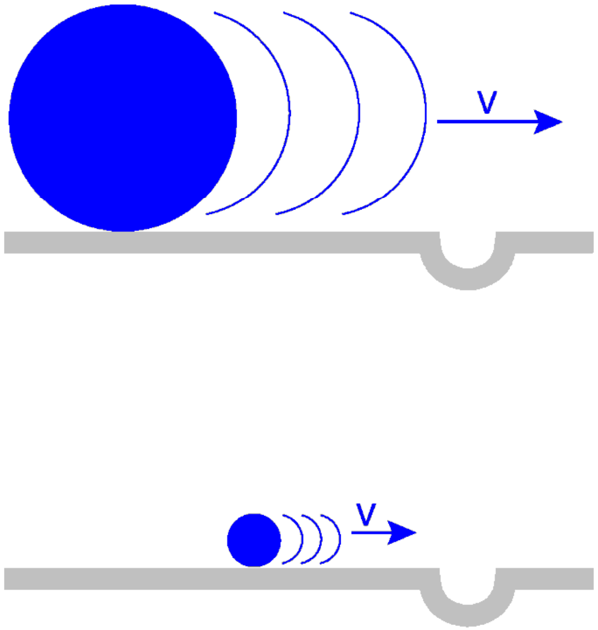
departures from classical symmetries

modified dispersion relations

$$p^2 \approx E^2 - m^2 + \frac{E^n}{E_p^n} p^2 + \ldots$$

GAC,PhysLettB(1997)
GAC+Ellis+Mavromatos+Nanopoulos+Sarkar, Nature(1998)
Gambini+Pullin,PhysRevD(1999)
Kifune, Astr.Journ.Lett.(1999)
GAC,Nature(2000)
Alfaro+Morales+Urrutia,PhysRevLett(2000)
GAC+Piran, PhysRevD (2001)

first attempts to formalize a quantum spacetime to some extent in analogy with a material medium



Situation a decade ago on the pure-theory side:

•“theoretical evidence” of modifications of dispersion relation emerging from quantization of spacetime was rather weak

*what happens to classical Poincare’ symmetry? Is there some weird “QG ether”?

Situation a decade ago on the phenomenology side:

IF (and this is not guaranteed in QG…see Veneziano+….)
the Heisenberg Principle is not modified

$$(\text{so that } x \rightarrow \partial/\partial p)$$

THEN modificationof disp rel implies modified dependence of speed on energy

$$\dot{x} = \frac{\partial E}{\partial p}$$

***Planck-scale-modified dispersion relations could lead to "in vacuo dispersion", observably large for certain studies of gamma-ray bursts**

GAC+Ellis+Mavromatos+Nanopoulos+Sarkar, Nature(1998)
Biller et al, PhysRevLett(1999)
Gambini+Pullin,PhysRevD(1999)
Kifune, Astr.Journ.Lett.(1999)
Alfaro+Morales+Urrutia,PhysRevLett(2000)
GAC,Nature(2000)
GAC+Piran, PhysRevD (2001)

***Planck-scale-modified dispersion relations could lead to anomalous particle-production thresholds, observably large in certain types of observation of cosmic rays and TeV gamma rays**

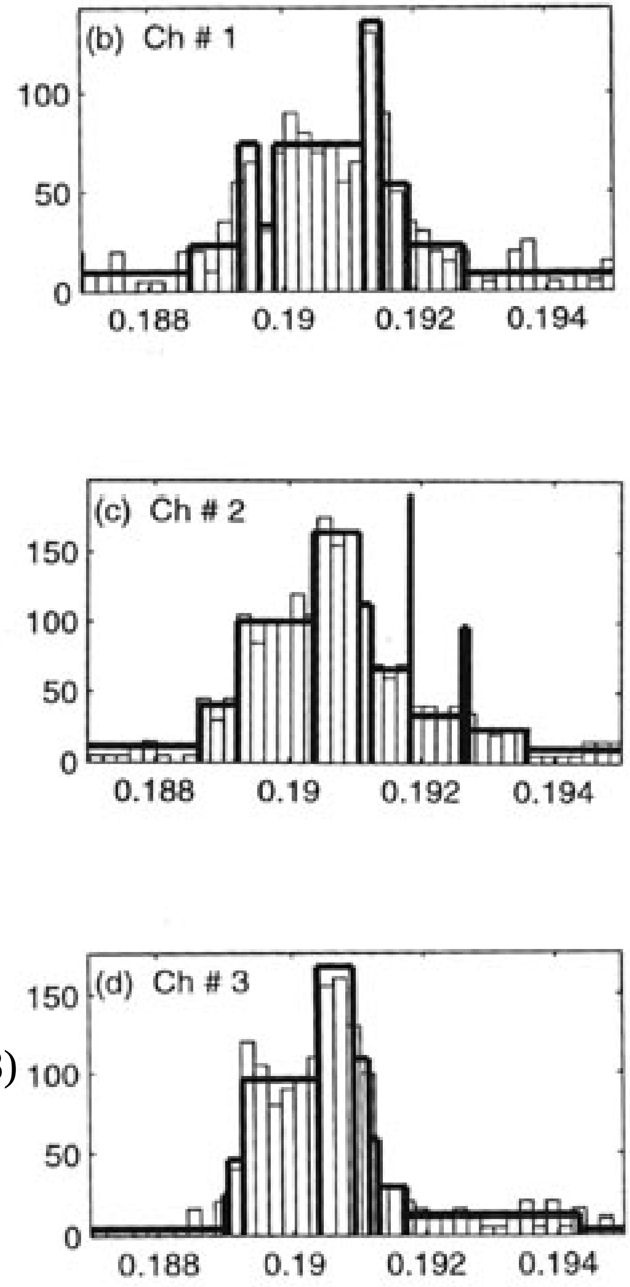
IF (and this is not guaranteed in QG) the modificationof disp rel is the only modification of the kinematics THEN it is for example easy to show that there is a shift of the threshold for

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

and similar effects for other thresholds

slide from “old” seminars:

20 to 300 KeV



BEPPO-SAX afterglow observation

Costa et al., Nature (*1997)*

allowed to show sensitivity to in-vacuo dispersion, if suppressed only by one power of Planck scale

GAC+Ellis+Mavromatos+Nanopoulos+Sarkar, Nature(1998)

Biller et al, PhysRevLett(1999)

Alfaro+Morales+Urrutia,PhysRevLett(2000)

GAC,Nature(2000)

GAC+Piran, PhysRevD (2001)

Present situation on the pure-theory side:

• modifications of dispersion relation established rather rigorously for spacetime noncommutativity

• growing "evidence" (as far as they can see) of modifications of dispersion relation in Loop Quantum Gravity ("weave states", "coherent states", Kodama state) and rigorously established in some 2+1D applications of the LoopQG approach

*growing evidence that these results do not provide a manifestation of some weird QG "ether", but rather the result of a symmetry deformation of the type I envisaged in raising the possibility of a "Doubly Special Relativity", with both "c " and "E_p" as nontrivial relativistic invariants

GAC, PLB(2001)
Magueijo+Smolin, PRL(2002)
GAC,Nature(2002)
Rovelli,arXiv:0808.3505

• both in LoopQG and with spacetime noncommutativity the possibility of Hopf-algebra spacetime symmetries is emerging as a strong candidate for the formalization of the symmetry deformation….Hopf-ST-symm for several years only vaguely defined physics concept…..but now Noether analysis generalized to the case of Hopf-algebra spacetime symmetries….

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

Present situation on the phenomenology side:

• it is now understood that observably-large modification of particle production thresholds require broken Lorentz symmetry (preferred frame!), and are instead not allowed with deformation of Lorentz Symmetry while in-vacuo dispersion is admissible (though of course not necessarilly present) both with broken and with deformed LS

GAC,Nature(2002)
Heyman+Hinteleitner+Major, PhysRevD(2004)

*natural context for study of in-vacuo dispersion at order L_p is observation of gamma-ray bursts

GAC+Ellis+Mavromatos+Nanopoulos+Sarkar, Nature(1998)
Biller et al, PhysRevLett(1999)

*observatories of neutrinos of ultra-high energies should provide opportunities for probing in-vacuo dispersion at order L_p^2

Piran+Jacob, NaturePhys(2007)
GAC, NaturePhys(2007)

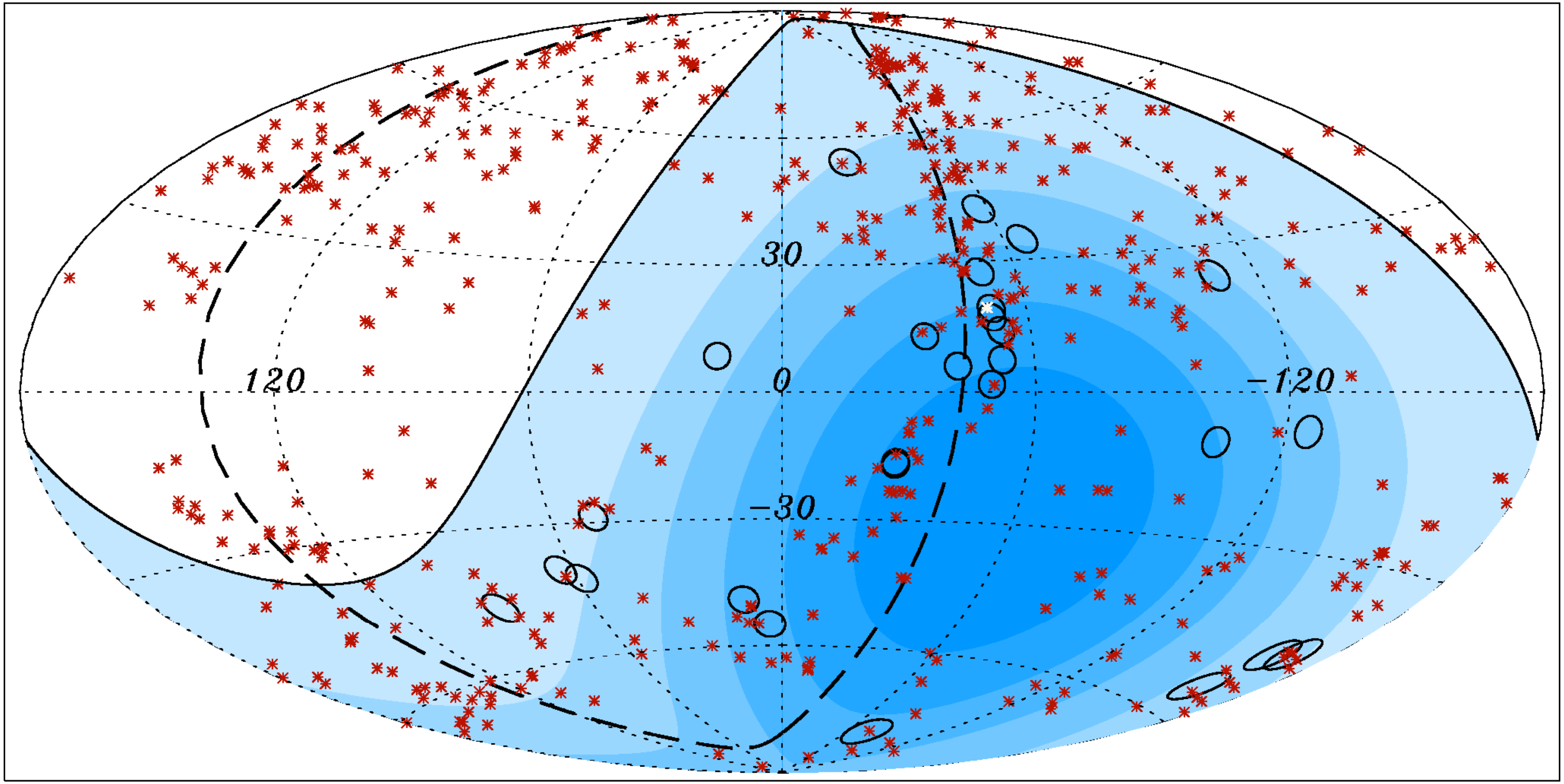
*natural context for study of modification of particle-production thresholds at order L_p is observation of TeV gamma rays from Blazars

Protheroe+Meyer, PLB(2000)
Grillo et al, PhysRevD(2000)

*natural context for study of modification of particle-production thresholds at order L_p^2 is study of spectrum of cosmic rays in a neighborhood of GZK scale

GAC+Piran, PhysRevD(2001)
Jacobson+Liberati+Mattingly,PhysRevD(2003)

concerning modification of particle-production thresholds….



The celestial sphere in galactic coordinates…showing the arrival directions of the 27 highest energy cosmic rays detected by Auger. The energies are greater than 57 x 10^{18} eV (57 EeV). These are shown as circles of radius 3.1°. The positions of 472 AGN within 75 megaparsecs are shown as red *'s. The blue region defines the field of view of Auger; deeper blue indicates larger exposure. The solid curve marks the boundary of the field of view, where the zenith angle equals 60°. The closest AGN, Centaurus A, is marked as a white *. Two of the 27 cosmic rays have arrival directions within 3° of this galaxy. The supergalactic plane is indicated by the dashed curve. This plane delineates a region where large numbers of nearby galaxies, including AGNs, are concentrated.

concerning in-vacuo dispersion….

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

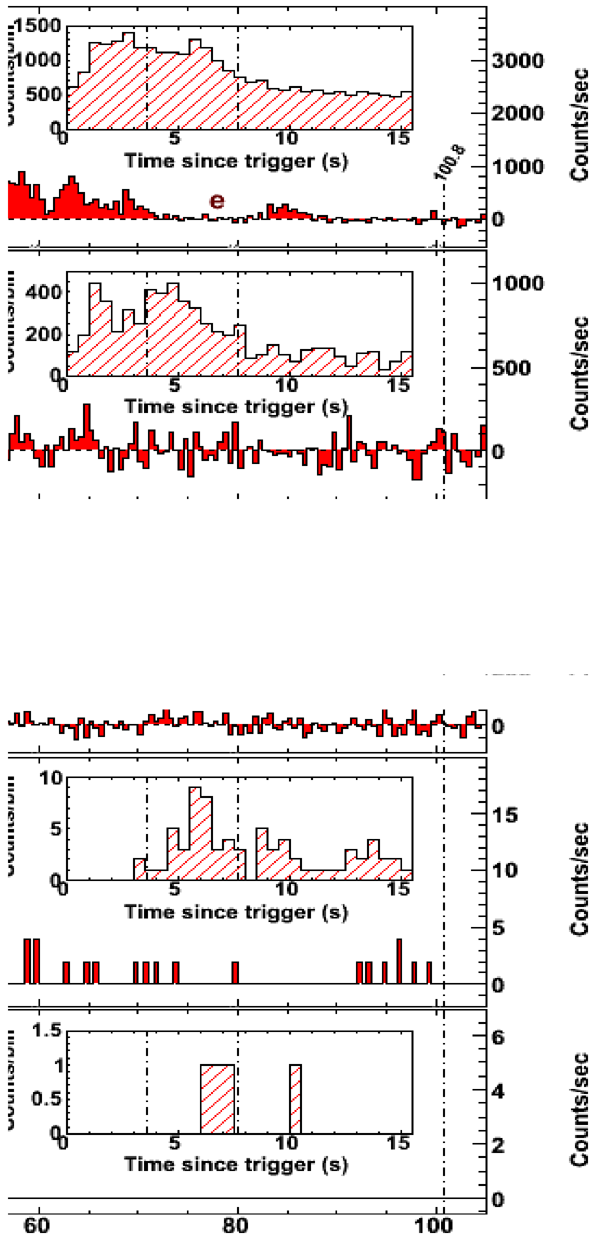
Charles D. Dermer, On behalf of the Fermi Collaboration,January 7, 2009

8-260 keV

0.26-5 MeV

>100 MeV

>1 GeV



GAC, Nature 398(1999)216
PhysRevD62(2000)024015
Nature410(2001)1065

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

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

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)024015**

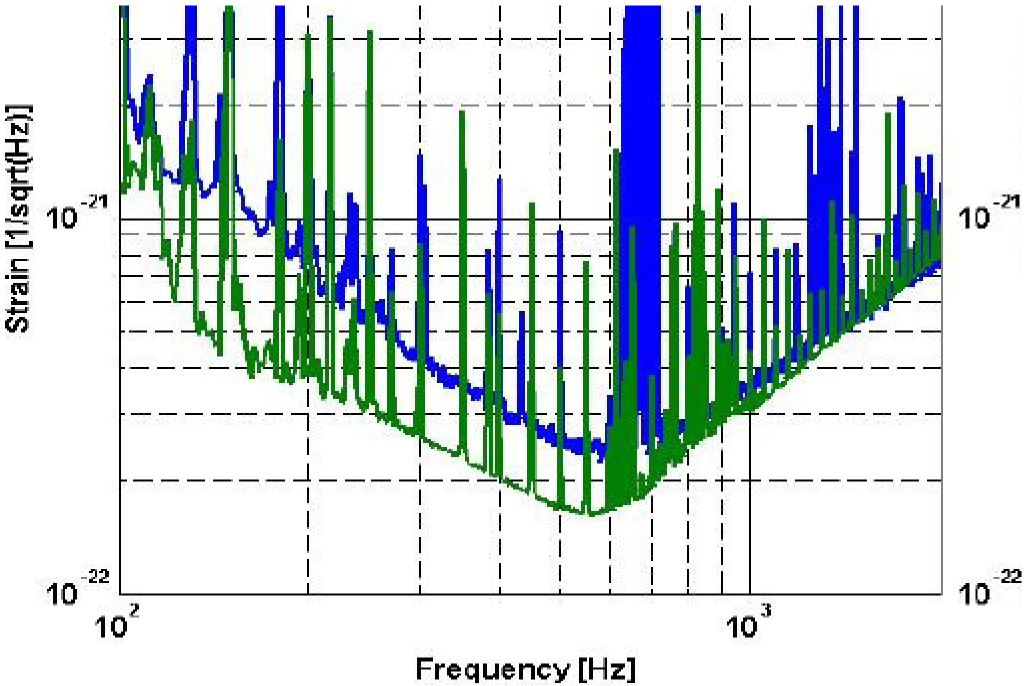
And if indeed it is random-walk noise the spectrum would be of the type

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

GAC, Nature 398(1999)216

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....)

proposed in 1998 when no report of peculiar excess noise was available……for the last couple of years we have had the much-discussed "GEO600 mystery noise"…
Hagen [PhysRevD(2007)] recently argued that this could be well described by the type of random-walk noise I had envisaged in 1998



Stefan Hild

ILIAS WG1, March 2008

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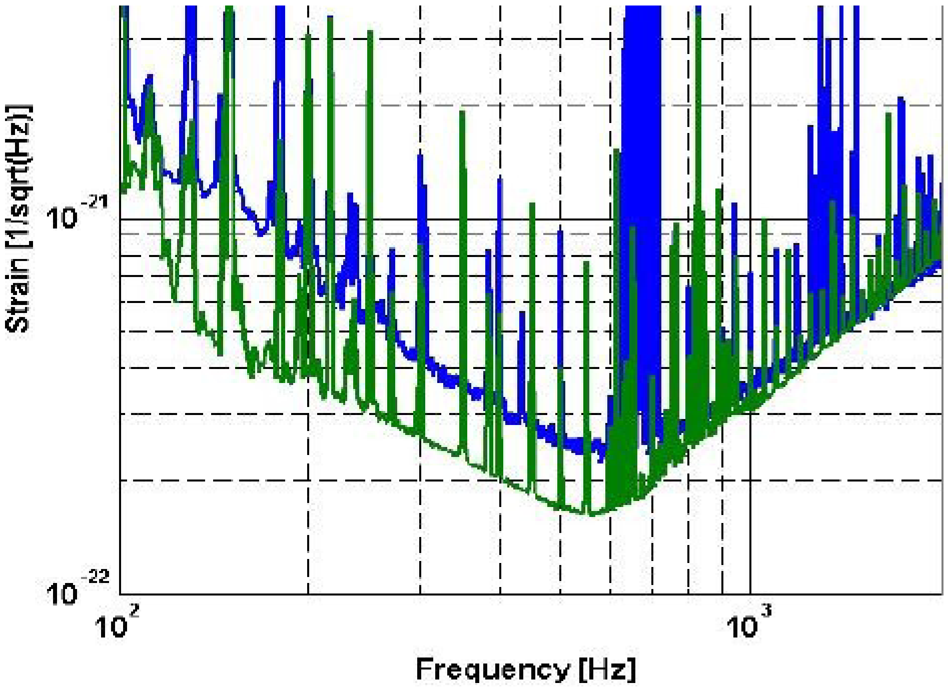

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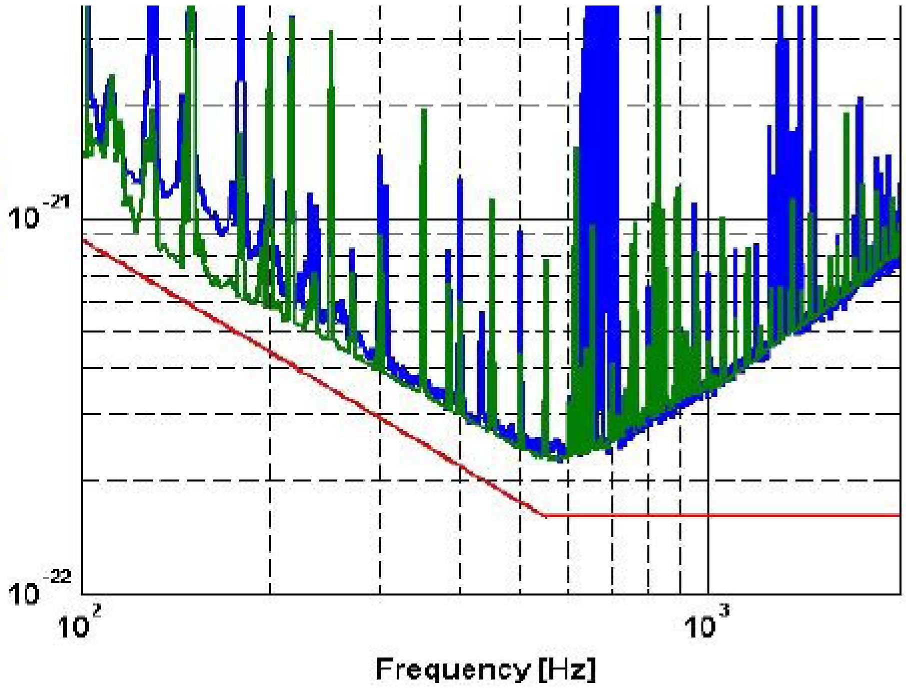

ILIAS WG1, March 2008

CONCLUSIONS:

we are in the (slow but certain) process of starting to understand <u>noteverything</u>

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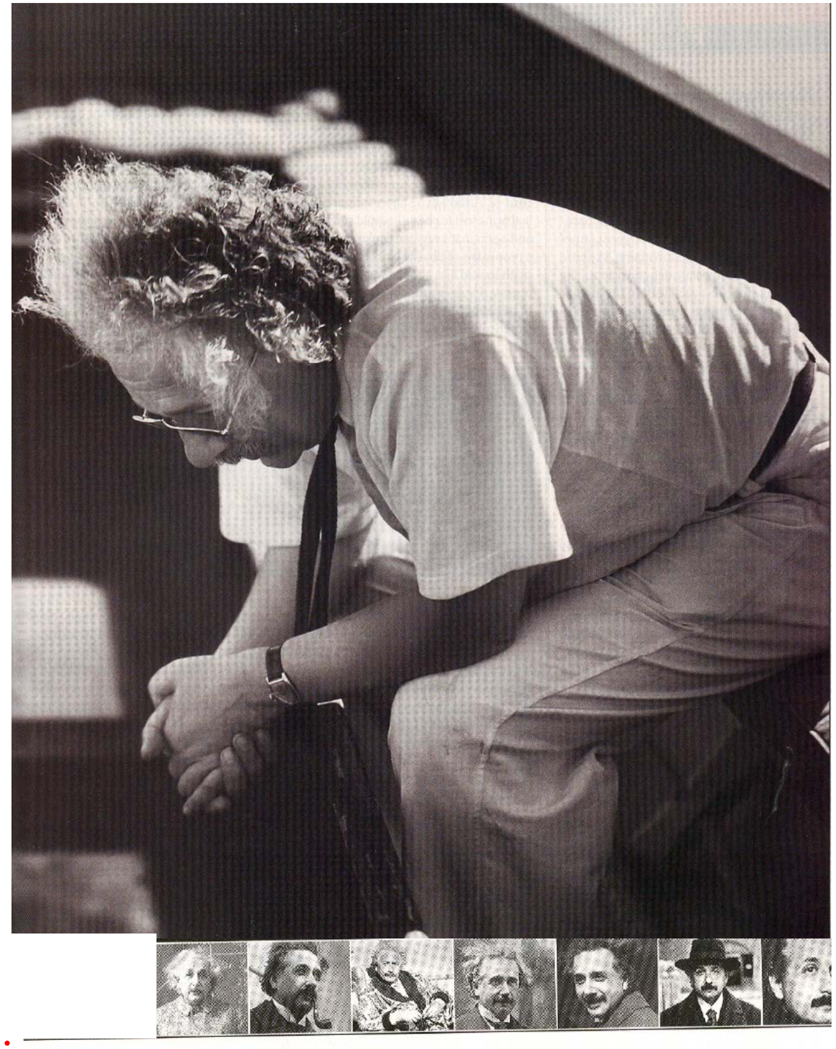

Einstein's theory-of-everything utopia :

"<u>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…</u>"