Proposal for Quantum Gravity Phenomenology without Lorentz Symmetry Violation

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Contents

Motivation

- QG theory is unknown, we are looking for QG Phenomenology.
- Through Lorentz Symmetry Violations?
  - Serious experimental bounds.
  - A preferential frame (space-time discreetness) + QFT radiative corrections $\Rightarrow$ observable LSV's effects (Collins et al., 2004).
- Assuming some granular structure of space-time, by which other ways (besides LSV) can QGP manifest?

The proposal

- The metric is NOT the only fundamental object of space-time.

- We consider a space-time with *some* granular structure whose building blocks are Lorentz Invariant.

- The only way of proceeding is by using symmetry principles.

Analogy with solid state physics

Macroscopic symmetry = microscopic symmetry

$\Rightarrow$ the microscopic symmetry doesn't manifest through a symmetry violation.

Macroscopic symmetry $\neq$ microscopic symmetry

$\Rightarrow$ there is chance to detect the microscopic symmetry through the roughness in its surface.

Analogy with solid state physics

Cubic crystal	Space-time
Cubic cells	Granular unit of space-time
Cubic symmetry	Lorentz Symmetry
Cubic crystal's surface	$R_{\mu\nu\rho\sigma} = 0$ (g.s. is not manifest through LSV)
Spherical crystal's surface	$R_{\mu\nu\rho\sigma} \neq 0$ (g.s. sensed by matter fields)

$R_{\mu\nu}(x)$ is locally determined by $T_{\mu\nu}^{fields}(x)$. Thus, coupling $R_{\mu\nu}$ to the fields looks like self-interaction $\Rightarrow$ we focus on Weyl.

Non-minimal coupling of Weyl tensor with matter fields

- We seek the coupling terms of Weyl with fermion matter fields that are minimally suppressed by M_{Pl}.
- The must obvious coupling terms are proportional to $W_{\mu\nu\rho\sigma}\gamma^{\mu}\gamma^{\nu}\gamma^{\rho}\gamma^{\sigma}$ which vanish identically.
- Other "obvious" coupling terms are suppressed by higher orders of M_{Pl}.
- What can we do?

Non-minimal coupling of Weyl tensor with matter fields

- Let $\mathcal{S}$ be the 6-dimensional space of 2-forms. The $(2,2)$ Weyl tensor is a self-adjoint map $\mathcal{S} \to \mathcal{S}$, therefore it can be diagonalized:

$$W_{\mu\nu}{}^{\rho\sigma}\Xi^{(s)}_{\rho\sigma} = \lambda^{(s)}\Xi^{(s)}_{\mu\nu}.$$

- Solution: we can construct coupling terms using $\lambda^{(s)}$ and $\Xi^{(s)}_{\mu\nu}$. In addition, $\mathcal{S}$ has a metric $G_{\mu\nu\rho\sigma}$ that can be used to normalize the non-null eigenbivectors according to

$$G^{\mu\nu\rho\sigma}\Xi^{(s)}_{\mu\nu}\Xi^{(s)}_{\rho\sigma} = \pm 1.$$

The problem of degeneration

- The proposal requires a unique way to choose among the normalized eigenbivectors $\Xi^{(s)}_{\mu\nu}$.
- A degeneracy in the Weyl eigenvalue equation is a problem because any linear combination of the degenerated eigenbivectors has the same eigenvalue.
- Unfortunately

$$\epsilon_{\mu\nu}{}^{\rho\sigma} W_{\rho\sigma}{}^{\alpha\beta} \left(\epsilon^{-1}\right)_{\alpha\beta}{}^{\gamma\delta} = W_{\mu\nu}{}^{\gamma\delta},$$

implies that $\Xi^{(l)}_{\mu\nu}$ and $\widetilde{\Xi}^{(l)}_{\mu\nu} \equiv \epsilon_{\mu\nu}{}^{\rho\sigma}\Xi^{(l)}_{\rho\sigma}$ correspond to the same eigenvalue $\lambda^{(l)}$ $(l = 1, 2, 3)$.

The problem of degeneration

- Solution: choose those linear combinations $\chi^{(l)}_{\mu\nu} = \alpha \Xi^{(l)}_{\mu\nu} + \beta \widetilde{\Xi}^{(l)}_{\mu\nu}$ satisfying

$$\epsilon^{\mu\nu\rho\sigma} \chi^{(l)}_{\mu\nu} \chi^{(l)}_{\rho\sigma} = 0.$$

- The proposal calls for the use of the space-time volume form $\Rightarrow$ QG may violate the P symmetry. (Recall that the weaker the interaction, less symmetries respects. Einstein's gravity brakes this pattern).

The coupling term

A natural way of writing the less-suppressed coupling term of Weyl and the fermionic matter fields (taking into the account a possible flavor dependence) is

$$\mathcal{L} = \sum_{a,l} \sqrt{\lambda^{(l)}} \left\{ \xi_a^{(l)} \left(\frac{\sqrt{\lambda^{(l)}}}{M_{\text{Pl}}} \right)^r \chi_{\mu\nu}^{(l)} + \widetilde{\xi}_a^{(l)} \left(\frac{\sqrt{\lambda^{(l)}}}{M_{\text{Pl}}} \right)^{\widetilde{r}} \widetilde{\chi}_{\mu\nu}^{(l)} \right\} \bar{\Psi}_a \gamma^\mu \gamma^\nu \Psi_a$$

where...

Phenomenology

In the linearized regime...

$$g_{\mu\nu} \quad = \quad \eta_{\mu\nu} + \gamma_{\mu\nu}.$$

If $\partial^\mu \bar{\gamma}_{\mu\nu} = 0$, neglecting $\mathcal{O}(\frac{1}{c})$ and considering $T_{\mu\nu} = \rho u_\mu u_\nu$, the only non-zero components of Weyl are

$$W_{0i}{}^{0j} = \partial_i \partial^j \Phi_N$$
$$W_{ij}{}^{kl} = -4\delta^{[k}_{[i} \partial_{j]} \partial^{l]} \Phi_N$$

where Φ_N is the Newtonian potential. (Same matrix).

Non-relativistic Hamiltonian

In order to obtain the non-relativistic Hamiltonian...
1. Solve the eigenvalue equation

$$(\partial_i \partial^j \Phi_N) q_j^{(l)} = \lambda^{(l)} q_i^{(l)}$$

2. Construct

$$D_i = \sum_l \left\{ \xi^{(l)} \left(\frac{\sqrt{\lambda^{(l)}}}{M_{\text{Pl}}} \right)^r + \tilde{\xi}^{(l)} \left(\frac{\sqrt{\lambda^{(l)}}}{M_{\text{Pl}}} \right)^{\tilde{r}} \right\} \sqrt{\lambda^{(l)}} q_i^{(l)}.$$

3. The non-relativistic Hamiltonian (using the work of Kostelecky and Lane, 1999) takes the form

$$\mathcal{H}_{NR} = \vec{\sigma} \cdot \vec{D} + \left(\vec{\sigma} \cdot \frac{\vec{P}}{M} \right) \left(\vec{D} \cdot \frac{\vec{P}}{M} \right) - \left(1 - \frac{1}{2} \frac{P^2}{M^2} \right) \frac{\vec{P}}{M} \cdot \vec{\sigma} \times \vec{D}.$$

where...

Experimental Outlook

- Due to the tidal forces, we must take care when comparing experiments carried out in different places.
- Polarized matter is needed $\Rightarrow$ many existing experiments don't work.
- Hughes-Drever experiments also fail (here the "field" is not ether-like, is produced by the Earth).

In order to conclude

- This is a concrete proposal for possible manifestations of QG which is based on the idea that space-time may have a granular structure that respect Lorentz Symmetry.

- Bounds for the free parameters can be obtained.

- The model suggests new types of experiments.