Lorentz Violating Supersymmetric Quantum Electrodynamics

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Lorentz Violation

There are many known examples in the history of physics when a symmetry of nature, which was assumed to be exact, has fallen under experimental scrutiny.
Lorentz symmetry is used as a crucial ingredient in the construction of fundamental theories of nature.
There is a number of seemingly unrelated motives to study Lorentz violating theories:

- Time evolution of dark energy (quintessence) creates a preferred frame which could be detected as a LV background, provided that it couples to the Standard Model.
- Low-energy limits of string theory contain a number of gauge fields with condensed fieldstrengths (fluxes) which carry open Lorentz indices.
- There are some conjectures that a theory of Quantum Gravity can manifest itself at low energies through LV modifications of particle dispersion relations.

Direct experimental constraints on modifications of dispersion relations come from *astrophysical processes* and terrestrial *clock comparison* and *torsion balance* experiments.

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Lorentz Violating EFT

One of the most straightforward ways to study the effects of new physics is to parametrize all our ignorance into a small number of new parameters.
Lorentz Violation is created at a high UV scale $M \sim M_{\rm Pl}$, and at lower scales we have an *effective theory*.
In QED, the generic expansion in terms of the gauge invariant operators starts at dimension three:

$$\mathcal{L}^{(3)}_{\rm QED} = \; - \; a_\mu \, \bar{\Psi}\gamma_\mu\Psi \; - \; b_\mu \, \bar{\Psi}\gamma^\mu\gamma_5\Psi \; - \; \frac{1}{2}H_{\mu\nu}\bar{\Psi}\sigma^{\mu\nu}\Psi \; - \; k_\mu \, \epsilon^{\mu\nu\kappa\lambda}A_\nu\partial_\kappa A_\lambda \; .$$

Naive power counting:

$\mathcal{L}^{(3)} \sim M$ — *enhanced* by a UV scale

$\mathcal{L}^{(4)} \sim 1$

$\mathcal{L}^{(5)} \sim \; 1/M$ — *suppressed* by a UV scale

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Dimension three operators create a problem: from dimensional counting one expects $a_\mu \sim M n_\mu$, where n_μ is a unit vector, and M is the scale of New Physics. That creates *disastrous* effects.
Dimension *five* operators are naturally suppressed. One of the solutions is if such dimension three and four operators are suppressed by a symmetry.

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Supersymmetry

Supersymmetry (SUSY) has been introduced a few decades ago and is known to have salutary properties for QFT.

In particular, it removes quadratic divergencies.

It appears to be beneficial for LV theories too!

In particular in the Minimal Supersymmetric Standard Model, LV operators of dimensions three and four are prohibited by the requirements of supersymmetry and gauge invariance.

Lorentz-violating interactions start only at dimension five.

Once Supersymmetry is softly broken, dimension three LV operators can be induced, with coefficients controlled by the soft-breaking mass scale, $m_s \sim 1 \text{ TeV}$.

Dimension three operators are now pure quantum effects, and effectively, the divergencies are stabilized at the supersymmetric threshold:

$$[LV]_{\rm dim\ 3} \;\sim\; (\text{loop factor})\ m_s^2 \;\times\; [LV]_{\rm dim\ 5}\,.$$

$\Rightarrow$ This might lead to a solution of the naturalness problem: why the lower dimensional LV operators are so much suppressed as compared to their natural scale.

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Lorentz-violating in SQED at dimension five

SQED — supersymmetric extension of QED — is the simplest gauge supersymmetric theory.

At dimension five level there are only *three* LV interactions (whereas in ordinary QED there are about *ten* of them).

Upon SUSY breaking LV SQED *does* generate dimension *three* interactions:

Very strigent constraints on the *Standard Model* Lorentz violation come from astrophysical observations, as LV modifies dispersion relations — this might cause birefridgence of light and vacuum Čerenkov radiation.

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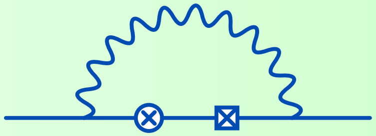

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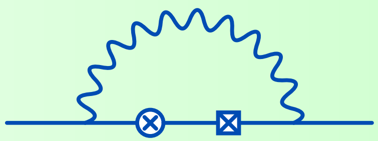

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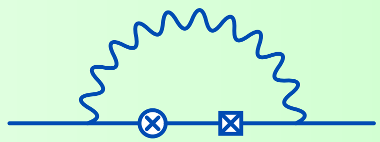

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Conclusions

- Analysis of low energy effective behavior shows that LV in SQED leads to detectable effects, being limited at the level of $10^{-10} - 10^{-12}$.
- Thus, theories predicting LV at dimension five level have a potential naturalness problem.
- This might be healed also by symmetry arguments, *e.g. CPT*, which could *prohibit* dimension five interactions.
- Dimension *six* LV interactions are CPT-invariant and *not yet* excluded by experiment.
- The next stage to consider is a *Dimension six LV extension of the Minimal Supersymmetric Standard Model* (MSSM).

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