

Using Effective Field Theory to test Lorentz invariance

Self-consistency tests in curved spacetime

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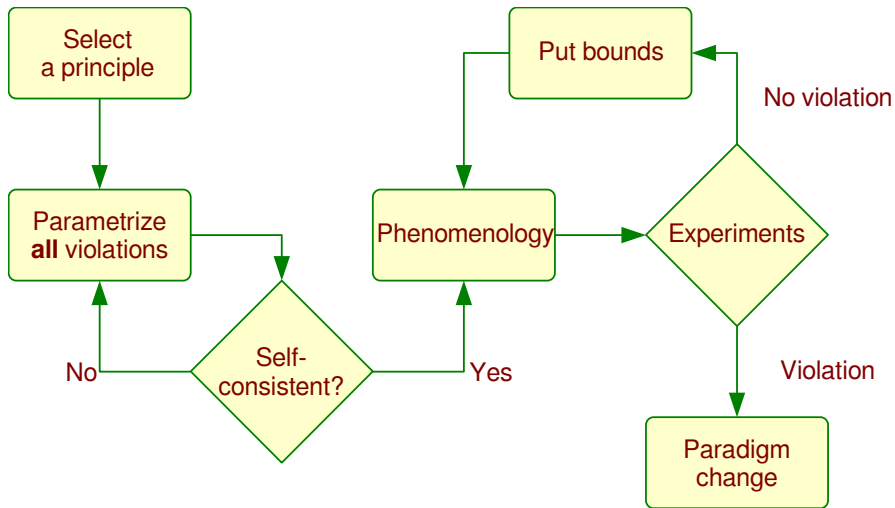
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Theoretical physics status

- Fundamental physics = GR + QM.
- Accurate empirical description (where we have access).
- Theoretically inconsistent.
- Need a new theory (QG).
- Towards QG: top down vs. bottom up.



(Idealized) phenomenologists' workflow



- Often, steps 2 and 3 not considered.
- Main point: these are crucial steps!
- Parametrization serves as a guide for theory and experiment.

Lorentz invariance

- Lorentz invariance = *all* local inertial frames are equivalent.
- No preferred (nondynamical) spacetime directions.
- Test: perform the same experiment in different frames.
- Motivation:
 - LI is fundamental for both GR and QFT.
 - LV implies CPT violation¹.
 - Accommodated by most QG candidates (*e.g.*, ST, LQG).
 - Possible discovery of new interactions.
 - Clear phenomenology.

¹Greenberg PRL 2002

Effective field theory

- EFT is useful when the fundamental d.o.f. are unknown.
- Requires knowing the field content and symmetries.
- Field content = standard physics;
symmetries = standard physics without LI.
- Result: Most general parametrization!
Lagrange density¹

$$\mathcal{L} = \mathcal{L}_{\text{GR}} + \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{LV}}.$$

where \mathcal{L}_{LV} contains *all* possible LV additions to SM + GR.

- Naive expectation: \mathcal{L}_{LV} is suppressed by $E_{\text{EW}}/E_{\text{P}} \sim 10^{-17}$.
- Terms of every dimensionality (higher dimensions are more suppressed).

¹“Standard Model Extension”: Colladay+Kostelecký PRD 1997; PRD 1998; Kostelecký PRD 2004;...

Self-consistency checks

- Field redefinitions: some LV effects can be removed, other moved to different sectors.
- Bianchi identities¹: the divergence of the modified Einstein equation places severe restrictions on LV \Rightarrow spontaneous LV.
- Standard vs. Palatini and boundaries²: generically inequivalent approaches and no Gibbons–Hawking boundary term.
- Dirac algorithm and Cauchy problem³: in the archetypal spontaneous LV model, there is a Hamilton density compatible with the constraints but the evolution is not uniquely determined by the initial data.

¹Kostelecký PRD 2004

²Bonder PRD 2015

³Bonder+Escobar PRD 2016

Conclusions

- EFT provides the general parametrization of LV.
- Such a parametrization allows us to test the possibility of having LV experimentally and theoretically.
- Several theoretical restrictions, mainly in curved spacetime.