Space-time Defects

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Phys. Rev. D 88, 124030 + 124031 (2013), [arXiv:1309.0311] + [arXiv:1309.0314]

Discrete or continuous?

- One of the central questions of quantum gravity is whether space-time is fundamentally discrete or continuous
- But the Planck length is tiny and direct signatures of a fundamental discreteness are hard if not impossible to find
- Plan: Do not search for direct evidence of a Planck scale structure, but for defects in that structure that represent deviations from the smooth space-time of GR
- These space-time defects can affect the propagation of particles and become indirectly noticeable
- But to make quantitative statements one needs a model. That's what this talk is about.
- Space-time defects do not have worldlines.

What about Lorentz-invariance?

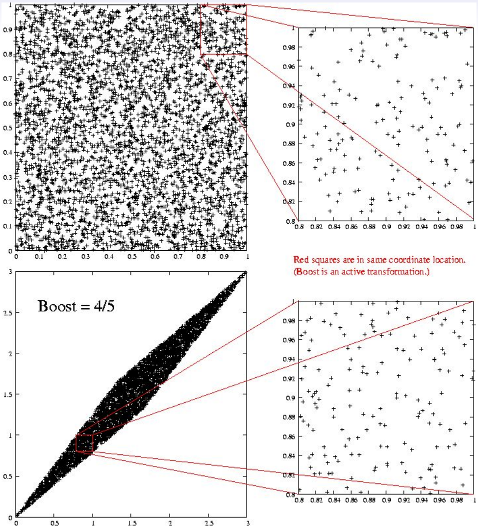
- I've gotten very, very tired of deviations and violations of Lorentz-invariance
- I will show you that it is possible to maintain Lorentz-invariance on the average
- That, maybe not so surprisingly, severely constraints what defect one can possibly put into space-time
- To my best knowledge this is the only existing model of defects in space-time that maintains Lorentz-invariance on the average

What do defects do?

There are two types of space-time defects

- Violate locality: Non-local defects cause a translation in position space
- Violate momentum-conservation: Local defects cause a translation in momentum space
- To model these defects we need two ingredients:
  - The distribution of defects
  - What happens at the defect

Causal Sets: Sprinkling



Picture credits: David Rideout `www.phy.syr.edu/řideout/`

Defect distribution

- We will assume the defects are distributed according to the CS sprinkling
- This distribution is Lorentz-invariant on the average.
- This introduces one parameter, $\rho := 1/L^4$, which is the (space-time) density of the defect sprinking. $\varepsilon = l_{\mathrm{P}}/L$.
- We will assume the defects to me much sparser than a Planck-length sprinking.
- We will for now only consider flat space, but extension to more general backgrounds should be possible
- The interaction probability is a function of the world-volume swept out by the particle, *not* of the duration of travel.

Local Defects

- We assume that local defects violate momentum conservation locally.
- They effectively modify the covariant derivative, ie their coupling is of the type $\partial + \Gamma$.
- The defects do not carry quantum numbers.
- Then Lorentz-invariance does the rest.
- Call the ingoing momentum $\mathbf{p}$ and the outgoing momentum $\mathbf{p}'$, then there's two free parameters, $\mathbf{p} \cdot \mathbf{p} := M$ and $\mathbf{p} \cdot \mathbf{p}' := aM$.
- The distribution of the momentum added at the defect must be a function of these two parameters.
- For simplicity, further assume gaussian distribution with mean values $\langle a \rangle, \langle M \rangle$ and variances Δa, ΔM.
- The particle must be off-shell after scattering, otherwise the probability distribution is not normalizable.

Local Defects

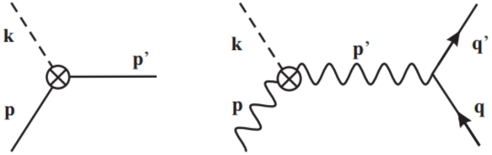


Figure 1: Assignment of momentum notation. Left: Simple vertex for scattering on local defect (dotted line). Right: Photon (wavy line) decays into a fermion pair (solid line) enabled by scattering on local defect (dotted line).

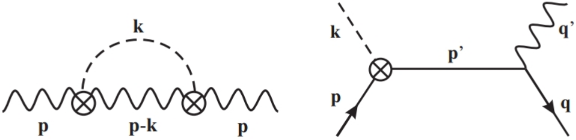
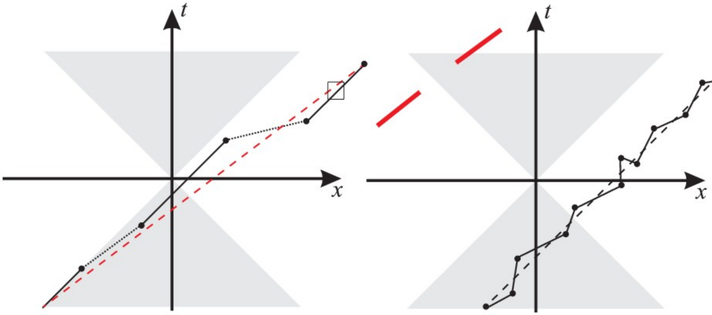


Figure 2: Left: Contribution to photon mass from twice scattering on a defect. Right: Vacuum Cherenkov radiation, enabled by scattering on a defect.

Non-Local Defects

- Non-local defects do in position space what local defects do in momentum space.
- Call the ingoing momentum $\mathbf{p}$ and the translation $\mathbf{y}$, then there's two free parameters, $\mathbf{p} \cdot \mathbf{y} := \Lambda$ and $\mathbf{y} \cdot \mathbf{y} := \alpha^2$.
- The distribution of the momentum added at the defect must be a function of these two parameters.
- Assume gaussian distribution with $\langle \alpha^2 \rangle, \langle \Lambda \rangle$ and $\Delta\alpha^2$, $\Delta\Lambda$.



Local Space-time defects: Constraints

- Photon decay: CMB distortion, vacuum opacity
- Vacuum Cherenkov radiation: CMB heating
- Effective photon mass

Local Space-time defects: Constraints

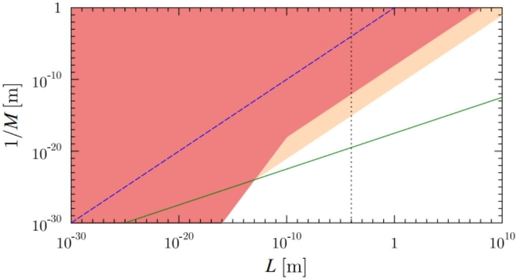


Figure 3: Summary of constraints. The coral (dark) shaded region is excluded. The peachpuff (light) shaded region indicates the stronger constraint from photon decay with the ad-hoc assumption that the typical distance between defects increases with the cosmological scale factor. The dotted (black) line indicates the length scale associated with the cosmological constant. The dashed (blue) line is the case $LM = 1$ and the solid (green) line is the case $LM = 1/\epsilon$.

Reduce parameters by assuming $a \sim 1$, $\langle . \rangle \sim \Delta$

Non-local Space-time defects: Constraints

- Loss of closely monitored particles
- GZK cutoff not so cut off because particles don't see part of the distance traveled
- Quasar blurring due to random deviations

Non-Local Space-time defects: Constraints

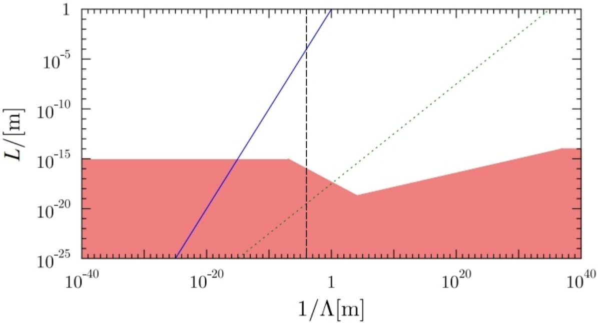


Figure 7: Summary of constraints. The red shaded region is excluded. The dashed (black) line indicates the value of the cosmological constant. The dotted (green) line depicts the case $\Lambda L = \epsilon$ and the solid (blue) line the case $\Lambda L = 1$.

Reduce parameters by assuming $\alpha \sim L$, $\langle . \rangle \sim \Delta$

Your 7 Items

1. We are in Stockholm!
2. Space-time defects don't have worldlines, they are events.
3. There are two types of defects: local and nonlocal ones.
4. Space-time defects can maintain Lorentz-invariance on the average.
5. Local defects cause a translation in momentum space, non-local defects cause a translation in position space
6. A particle that scatters off a local defect is off-shell.
7. The probability to hit a defect depends on the world-volume swept out by the particle. It will generically be *larger* for low energies (wide wave-packets).