UNITARITY VIOLATION IN DYNAMICAL SPACETIMES

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Background and Validity:

- Free QFT in curved spacetimes
 - \Rightarrow Assume backreactions are negligible.
 - \Rightarrow 1. Semiclassical framework
 - 2. Weak quantum fluctuations.
- \therefore Strong fluctuations \Rightarrow Breakdown of perturbative framework.

Questions:

• Connection between unitarity violation & validity loss?

• Develop an *Effective Field Theory* inspired approach:

- 1. Respect semiclassical assumptions.
- 2. Systematic unitarity analysis.
- 3. Connect unitarity violation & validity loss.
- 4. Explore phenomena triggering unitarity violation.

METHODOLOGY AND RESULTS

I. Setup Physical Configuration Space

 $\mathcal{C}_{\mathrm{phy}} = \mathcal{R} \setminus (\mathcal{C}_H \cup \mathcal{D})$

• Naive Space \mathcal{R} :

Contains all possible field configurations.

• Dismissed Space C_H : $\forall \phi \in C_H$ contradicting assumptions.

• Detector Resolution Space \mathcal{D} : $\forall \phi \in \mathcal{D}$ unresolvable by detector.

II. Time Evolution and Norm

• Physical norm measures unitarity. $\|\Psi\|_{\Sigma(t)}^2 = \int_{\mathcal{C}_{phy}} \mathcal{D}\phi \ |\Psi_t[\phi]|^2$

• $\Psi_t[\phi]$ = Ground state wave functional.

• Functional Schrodinger equation:

 $i\partial_t \Psi_t[\phi] = \hat{H}_t[\Pi, \Phi] \Psi_t[\phi]$

• Physical norm/probability is not conserved for quantum fields in dynamical spacetimes.

III. RESULTS

• Non-unitarity caused by fluctuations enhancement/suppression by gravitational field.

• Phenomenlogical examples in FLRW:

1. Particle creation (asymptotically static).

2. Unitarity loss to fluctuation unresolvable by detector.

 $\mathcal{C}_{H} = \mathcal{J}[\phi]|_{B(\mathcal{C}_{\text{phy}})}$

 $\mathcal{C}_{\mathrm{phy}}$

 $^{\circ}\mathcal{D}$

Figure 1: Probability current flow in the configuration space.

∂_t ||Ψ||²_{Σ(t)} = J[φ]|_{B(C_{phy})}
J[φ] ≠ 0 for any dynamical spacetimes.



Figure 2: Enhancement of quantum fluctuations by gravity.

||Ψ||²_{Σ(t)} = Erf(φ/σ)|_{B(C_{phy})}
Enhancement increases DOF in C_H.

CONCLUSIONS

• Unitarity violation is inevitable in any dynamical spacetimes for semiclassical framework.

• QFTCS is an open system in the configuration space.

WHAT NEXT?

• Breakdown of the semiclassical framework near classical singularity formation in a gravitational collaspe.

• Validity analysis for inflationary models.

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