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On the breakdown of space-time in General Relativity

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Drawing upon the canonical quantization of general relativity (GR) in dimensions higher than two, using the Dirac constraint formalism, we propose the loss of covariance as an intrinsic property of the theory. This loss manifests in the first-order Einstein–Hilbert action, where besides first-class constraints, second-class constraints emerge, giving rise to non-standard ghost fields that disrupt the covariance of the path integral. We explore canonical quantization via the path integral calculation for the equivalent Hamiltonian formulation of GR, where only first-class constraints are present. Despite this, covariance is still compromised due to the loss of diffeomorphism invariance and the introduction of non-covariant constraints in the path integral. However, we find that covariance is restored as a symmetry in the weak limit of the gravitational field, allowing for perturbative calculations. Consequently, we establish that the breakdown of space–time is inherent to GR itself, suggesting its characterization as an effective field theory (EFT). Moreover, we propose that this breakdown occurs non-perturbatively in the strong field limit of the theory. While covariance is preserved in the constraint quantization of non-Abelian gauge theories like the Yang–Mills theory, our results indicate a unique departure in the context of canonical gravity formalism and EFT approach. These findings align with GR singularity theorems, extending their scope to imply breakdowns at the strong field limit, such as those encountered in black holes. In contrast to the asymptotic safety program, our findings support emergent theories of space–time and gravity without necessitating thermodynamics, such as the entropic gravity program. Through the lens of EFT, our results underscore the necessity of new degrees of freedom or principles in the non-perturbative sector of the full theory, where covariance as a symmetry is breached in the high-energy (strong field) regime of GR.

Keyword-1

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Keyword-2

Quantization

Keyword-3

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