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En route to Background Independence: Broken split-symmetry, and how to restore it with bi-metric average actions

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HIGHLIGHTS

- The Asymptotic Safety scenario in quantum gravity is explored.
- A bi-metric generalization of the Einstein–Hilbert truncation is investigated.
- We find that Background Independence can coexist with Asymptotic Safety.
- RG trajectories restoring (background-quantum) split-symmetry are constructed.
- The degree of validity of single-metric truncations is critically assessed.

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ABSTRACT

The most momentous requirement a quantum theory of gravity must satisfy is Background Independence, necessitating in particular an ab initio derivation of the arena all non-gravitational physics takes place in, namely spacetime. Using the background field technique, this requirement translates into the condition of an unbroken split-symmetry connecting the (quantized) metric fluctuations to the (classical) background metric. If the regularization scheme used violates split-symmetry during the quantization process it is mandatory to restore it in the end at the level of observable physics. In this paper we present a detailed investigation of split-symmetry breaking and restoration within the Effective Average Action (EAA) approach to Quantum Einstein Gravity (QEG) with a special emphasis on the Asymptotic Safety conjecture. In particular we demonstrate for the first time in a non-trivial setting that the two key requirements of Background Independence and Asymptotic Safety can be satisfied simultaneously. Carefully disentangling fluctuation and background fields, we employ a 'bi-metric' ansatz

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for the EAA and project the flow generated by its functional renormalization group equation on a truncated theory space spanned by two separate Einstein–Hilbert actions for the dynamical and the background metric, respectively. A new powerful method is used to derive the corresponding renormalization group (RG) equations for the Newton- and cosmological constant, both in the dynamical and the background sector. We classify and analyze their solutions in detail, determine their fixed point structure, and identify an attractor mechanism which turns out instrumental in the split-symmetry restoration. We show that there exists a subset of RG trajectories which are both asymptotically safe and split-symmetry restoring: In the ultraviolet they emanate from a non-Gaussian fixed point, and in the infrared they loose all symmetry violating contributions inflicted on them by the non-invariant functional RG equation. As an application, we compute the scale dependent spectral dimension which governs the fractal properties of the effective QEG spacetimes at the bi-metric level. Earlier tests of the Asymptotic Safety conjecture almost exclusively employed 'single-metric truncations' which are blind towards the difference between quantum and background fields. We explore in detail under which conditions they can be reliable, and we discuss how the single-metric based picture of Asymptotic Safety needs to be revised in the light of the new results. We shall conclude that the next generation of truncations for quantitatively precise predictions (of critical exponents, for instance) is bound to be of the bi-metric type.

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1. Introduction

One of the key requirements every candidate for a quantum theory of the gravitational interaction and spacetime geometry should satisfy is *Background Independence*. The theory's basic kinematical rules and dynamical laws should be formulated without reference to any distinguished spacetime such as Minkowski space, for instance. Rather, the possible states of a 'quantum spacetime' should be a prediction of the theory. In addition, it must provide us with a set of special observables which, by means of their expectation values in a given state, 'interpret' this state in terms of classical geometry, or a generalized notion thereof. Among them the expectation value of the metric would play a significant role. If non-degenerate, smooth and approximately flat, on large length scales at least, the underlying state might appear like a classical spacetime macroscopically, possibly similar to the real Universe we live in. We can then try to match the predictions against concrete measurements and observations [1–7].

However, in general one would also expect states without any interpretation in terms of concepts from classical General Relativity, Riemannian geometry in particular. A simple example are situations in which the metric has an expectation value which is degenerate, identically vanishing, for instance. While the gravitational physics implied by such states is certainly very different from the one we know, they might realize a 'symmetric phase' of gravity which arguably is easier to understand than the broken phase we live in. In the latter, diffeomorphism symmetry is broken down to the stability group of the metric expectation value, the Poincaré group in the flat case.

There exist two fundamentally different approaches to deal with the requirement of Background Independence. They differ in particular in the way they deal with the rather severe conceptual and technical difficulties which are caused by this requirement and are of a kind never encountered in conventional matter field theories on Minkowski space:

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