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Absence of cosmological constant problem in special relativistic field theory of gravity

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ABSTRACT

The principles of quantum field theory in flat spacetime suggest that gravity is mediated by a massless particle with helicity ± 2, the so-called graviton. It is regarded as textbook knowledge that, when the self-coupling of a particle with these properties is considered, the long-wavelength structure of such a nonlinear theory is fixed to be that of general relativity. However, here we indicate that these arguments conceal an implicit assumption which is surreptitiously motivated by the very knowledge of general relativity. This is shown by providing a counterexample: we revisit a nonlinear theory of gravity which is not structurally equivalent to general relativity and that, in the non-interacting limit, describes a free helicity ± 2 graviton. We explicitly prove that this theory, known as Weyl-transverse gravity (unimodular gravity with explicit Weyl invariance), can be understood as the result of self-coupling in complete parallelism to the well-known case of general relativity. We discuss the absence of cosmological constant problem in this theory, highlighting that it provides a particular realization of previous arguments formulated in studies of the emergence of the gravitational interaction from condensed-matter-like models. Overall, we conclude that the consideration that gravity is medi-

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ated by a massless particle with helicity ±2 does not inextricably lead to the cosmological constant problem.

1. Introduction

The lack of gravitating properties of vacuum zero-point energies of matter can be considered as the only available glance to the realm of quantum gravity with which we have been experimentally rewarded up to now. However, the application of effective field theory arguments to the combination of the standard model of particle physics and general relativity strongly suggests that what is reasonable from the theoretical perspective is, indeed, the contrary [1–3]. The cosmological constant problem [1–4] is usually defined as the problem of finding a mechanism that forbids these energies to gravitate (or, more formally, prevents semiclassical radiative corrections to modify the value ultimately taken by the cosmological constant) while, at the same time, respects the low-energy physics in order to guarantee that no contradictions arise with the stringent experimental tests on deviations from general relativity.

It is generally expected that this problem can only be solved within a theoretical framework that combines the principles of general relativity and quantum mechanics. At the same time, any quantum gravity theory must reproduce the known classical laws of physics, and hence lead to general relativity in the long-wavelength limit [5]. This has led to several attempts to find mechanisms that can avoid this problem, while maintaining the structure of general relativity intact. It is fair to say that, after decades of research, there is no completely satisfactory model that satisfies these requirements; moreover, any of these attempts includes unknown physics [2]. The spirit of the present discussion is different. Here, we start from the well-established principles of quantum field theory in flat spacetime, namely the observation that gravity is mediated by gravitons, as well as the equivalence principle as reformulated by Weinberg [6], and follow these principles to their ultimate consequences. The starting point for our discussion is then the special relativistic setting pioneered by Feynman and others in their investigations about the quantum properties of the gravitational interaction [7].

In this work we point out that there is a loophole in the chain of arguments that assert that the only possible consistent theory of self-interacting gravitons (particles with helicity ±2) is general relativity. This has nontrivial consequences: there exists an alternative nonlinear theory of gravity that arises due to the self-interactions of such a particle as well. To the best of our knowledge, it is the first time that this has been solidly argued. This theory is similar in spirit to unimodular gravity and it is denominated Weyl-transverse gravity in order to highlight its symmetries. The interpretation of its nonlinear character as the result of self-coupling makes this theory a legitimate candidate to describe the long-wavelength limit of a hypothetical quantum gravity theory. This position is strengthened by the fact that it does not present the cosmological constant problem [8]: the (effective) cosmological constant is rendered stable against radiative corrections, while the remaining phenomenological aspects of the standard model and general relativity are respected.[1]

What makes this proposal attractive is that it involves only assumptions which are natural in quantum field theory. One could have reached it without previous knowledge of general relativity. In fact, being accustomed to the geometric description of gravity even hinders its obtention: as we point out, this prior knowledge caused previous approaches such as [9,10] to overlook this theory. The lesson to be drawn is that the issue of vacuum zero-point energies is no longer a problem if one takes the principles of special relativity and quantum mechanics seriously, considering that general relativity is just an effective theory valid at sufficiently low energies.

A few sentences may be useful in order to properly place this paper with respect to previous work in the subject. It represents a continuation of the research reported in [11], where it was discussed how unimodular gravity can be obtained as a solution to the self-coupling problem. To reach this result

[1] Contrary to other proposals, based in some form of scale invariance, which imply constraints on the matter sector even classically. This is of central importance for our discussion.