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Absence of the fifth force problem in a model with spontaneously broken dilatation symmetry

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Abstract

A scale invariant model containing dilaton ϕ and dust (as a model of matter) is studied where the shift symmetry $\phi \to \phi + \text{const.}$ is spontaneously broken at the classical level due to intrinsic features of the model. The dilaton to matter coupling "constant" f appears to be dependent of the matter density. In normal conditions, i.e. when the matter energy density is many orders of magnitude larger than the dilaton contribution to the dark energy density, f becomes less than the ratio of the "mass of the vacuum" in the volume occupied by the matter to the Planck mass. The model yields this kind of "Archimedes law" without any especial (intended for this) choice of the underlying action and without fine tuning of the parameters. The model not only explains why all attempts to discover a scalar force correction to Newtonian gravity were unsuccessful so far but also predicts that in the near future there is no chance to detect such corrections in the astronomical measurements as well as in the specially designed fifth force experiments on intermediate, short (like millimeter) and even ultrashort (a few nanometer) ranges. This prediction is alternative to predictions of other known models.

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Keywords: Fifth force; Spontaneously broken dilatation symmetry; Coupling depending on the matter density

1. Introduction

Possible coupling of the matter to a scalar field can be the origin of a long range force if the mass of the scalar particles is very small. It is well known since the appearance of the

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Brans–Dicke model [1] that such "fifth" force could affect the results of tests of general relativity (GR). In more general cases it may entail a violation of the Einstein's equivalence principle. A possible existence of light scalar particles interacting to matter could also give rise to testable consequences in an intermediate or submillimeter or even shorter range depending on the scalar mass. Numerous, many years lasting, specially designed experiments, see for example [2–10], have not revealed so far any of possible manifestations of the fifth force. This fact, on each stage of the sequence of experiments, is treated as a new, stronger constraint on the parameters (like coupling constant and mass) with hope that the next generation of experiments will be able to discover a scalar force modifying the Newtonian gravity. This is the essence of the fifth force problem in the "narrow sense".[1]

In this paper we demonstrate that it is quite possible that the fifth force problem in such narrow sense does not exist. Namely we will present a model where the strength of the dilaton to matter coupling measured in experimental attempts to detect a correction to the Newtonian gravity turns out so small that at least near future experiments will not be able to reveal it. On the other hand, if the matter is very diluted then its coupling to the dilaton may be not weak. But the latter is realized under conditions not compatible with the design of the fifth force experiments.

The idea of the existence of a light scalar coupled to matter has a well known theoretical ground, for example in string theory [11] and in models with spontaneously broken dilatation symmetry [12,13]. The fifth force problem has acquired a special actuality in the last decade when the quintessence [14] and its different modifications, for example coupled quintessence [15], *k*-essence [16], were recognized as successful models of the dark energy [17]. If the amazing observational fact [18] that the dark energy density is about two times bigger that the (dark) matter density in the present cosmological epoch is not an accidental coincidence but rather is a characteristic feature during long enough period of evolution, then the explanation of this phenomenon suggests that there is an exchange of energy between dark matter and dark energy. A number of models have been constructed with the aim to describe this exchange, see for example [15,19–26] and references therein. In the context of scalar field models of the dark energy, the availability of this energy exchange implies the existence of a coupling of the scalar field to dark matter. Then immediately the question arises why similar coupling to the visible matter is very strongly suppressed according to the present astronomical data [10]. Thus the resolution of the fifth force problem in its modern treatment should apparently consist of simultaneous explanations, on the ground of a fundamental theory, of both the very strong suppression of the scalar field coupling to the visible matter and the absence of similar suppression of its coupling to the dark matter.

One of the interesting approaches to resolution of the fifth force problem known since 1994 as "the least coupling principle" based on the idea [27] to use non-perturbative string loop effects to explain why the massless dilaton may decouples from matter. In fact it was shown that under certain assumptions about the structure of the (unknown) dilaton coupling functions in the low energy effective action resulting from taking into account the full non-perturbative string loop expansion, the string dilaton is cosmologically attracted toward values where its effective coupling to matter disappears.

[1] As is well known, other implications of the light scalar generically may be for cosmological variations of the vacuum expectation value of the Higgs field, the fine structure constant and other gauge coupling constants. However in this paper we study only the strength of the fifth force itself.