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Kinetic scalar curvature extended $f(R)$ gravity

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Abstract

In this work we study a modified version of vacuum $f(R)$ gravity with a kinetic term which consists of the first derivatives of the Ricci scalar. We develop the general formalism of this kinetic Ricci modified $f(R)$ gravity and we emphasize on cosmological applications for a spatially flat cosmological background. By using the formalism of this theory, we investigate how it is possible to realize various cosmological scenarios. Also we demonstrate that this theoretical framework can be treated as a reconstruction method, in the context of which it is possible to realize various exotic cosmologies for ordinary Einstein–Hilbert action. Finally, we derive the scalar–tensor counterpart theory of this kinetic Ricci modified $f(R)$ gravity, and we show the mathematical equivalence of the two theories.

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1. Introduction

Modified gravity in its most general forms, serves as a formal theoretical framework which can potentially harbor in a consistent way both cosmological and astrophysical phenomena [1–8]. For example, in the context of the most sound and simple modified gravity, $f(R)$ gravity, it is possible to provide a unified description of the late-time acceleration and of inflation as it was demonstrated firstly in Ref. [9]. Also generalized modified gravities, like for example Gauss–Bonnet modified gravities [10–17], teleparallel gravity [18–26] and extensions of these [27–29], can also describe a plethora of cosmological and astrophysical phenomena. Now the question is, which theory provides the most correct description of our Universe, and this question can be answered only by confronting each modified gravity with the observational data. It is possible that the answer is simple, however most of the theories can be compatible with the observations, so in principle, all possible modified gravities should be scrutinized in order to reveal the phenomenology these suggest.

In this line of research, recently the $f(R)$ gravity framework was extended to include first and higher derivatives of the Ricci scalar in the $f(R)$ gravity action [30]. It was shown that the resulting theory is free from ghost, under an appropriate choice of the functional form of the Lagrangian. Later on several studies in this framework were performed, see for example [31–39].

In the present work, we shall investigate an extended $f(R)$ gravity model which contains first derivatives of the Ricci scalar in the standard $f(R)$ gravity action. We shall derive the gravitational field equations and we shall emphasize to cosmological applications of the model at hand. Particularly, we firstly demonstrate in a formal way how to obtain the gravitational field equations, and we introduce appropriate variables in order to cast the field equations in a convenient and compact way. We specialize the field equations for a spatially flat spacetime metric, and we study how it is possible to realize various cosmological evolutions. As we demonstrate, the realization of specific cosmological evolutions results to a system of ordinary linear coupled differential equations, and the general case can be quite tedious, so we focus our study on specific limiting cases of the theory, which have some physical significance. Also we demonstrate that the field equations can be used as a reconstruction method, in which by providing the cosmological evolution and the $f(R)$ gravity (or the kinetic term related $X(R)$ function) it is possible to find which $X(R)$ (or $f(R)$) gravity, may realize such an evolution. Interestingly enough, it is possible to realize several cosmological evolutions even in the case $f(R) = R$, such as bouncing cosmologies and even inflationary evolutions of some sort, which in standard vacuum $f(R)$ gravity was possible to realize for only specific forms of the $f(R)$ gravity. Finally, we shall demonstrate that the kinetic Ricci modified $f(R)$ gravity is equivalent with a multi-tensorial scalar–tensor theory of gravity.

This paper is organized as follows: In section 2 we present the theoretical framework of kinetic scalar curvature-corrected $f(R)$ gravity, and we derive the gravitational equations for a general metric. In section 3, we focus our study on cosmological applications, by using a spatially flat metric. We investigate various cosmological evolutions of physical interest and we find the approximate form of the kinetic scalar curvature-corrected $f(R)$ gravity which may realize such an evolution. We also show how to treat the theory at hand as a reconstruction method for realizing various cosmological evolutions, by specifying the $f(R)$ gravity and the cosmological