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ORIGINAL ARTICLE

The plane symmetric vacuum solutions of modified field equations in metric $f(\mathrm{R})$ gravity

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Abstract The $f(\mathrm{R})$ theories of gravity have been interested in recent years. A considerable amount of work has been devoted to the study of modified field equations with the assumption of constant Ricci scalar which may be zero or nonzero. In this paper, the exact vacuum solutions of plane symmetric spacetime are analyzed in $f(\mathrm{R})$ theory of gravity. The modified field equations are studied not only for $\mathrm{R} = \text{constant}$ but also for general case $\mathrm{R} \neq \text{constant}$. In particular, we show that the Novotný-Horský and anti-de Sitter spacetimes are the exact solutions of the field equations with the non-zero constant Ricci scalar. Finally, the family of solutions with $\mathrm{R} \neq \text{constant}$ is obtained explicitly which includes the Novotný-Horský, Kottler-Whittaker, Taub and conformally flat spacetimes.

Keywords Plane symmetric vacuum solutions · Metric $f(\mathrm{R})$ gravity · Exact solutions

1 Introduction

Different data from the recent astrophysical observations such as Super-Nova Ia (Riess et al. 1998, 2004; Knop et al. 2003), Cosmic Microwave Background Radiations (Spergel et al. 2003, 2007; Komatsu et al. 2009), Wilkinson Microwave Anisotropy Probe (Bennett et al. 2003), Sloan Digital Sky Survey (Tegmark et al. 2004; Seljak et al. 2005) and Baryon Acoustic Oscillations (Eisenstein et al. 2005; Percival et al. 2007) have indicated that the universe is flat and the expansion of universe is currently accelerating. The standard general theory of relativity can not describe the accelerated expansion. Based on these data, physicists now believe that the most part of universe contains dark energy with negative pressure, in which this energy constrain the cosmic expansion (Carroll 2001; Padmanabhan 2003; Copeland et al. 2006). One of the seriously approaches which may help to explain the origin of dark energy is to modify the general theory of relativity. The modified theories of gravity, such as $f(\mathrm{R})$ gravity, scalar-tensor theories (see e.g. Setare 2008), scalar-tensor vector theories (see e.g. Bruneton and Esposito-Farese 2007), brane-world gravity (see e.g. Setare 2006) and Gauss-Bonnet dark energy (see e.g. Sadeghi et al. 2009), have gained a lot of interest in recent years. Nojiri and Odintsov (2006, 2007a) showed that the modified theories of gravity provide a natural gravitational alternative way for dark energy. In these theories, the geometrical part of Einstein-Hilbert action is modified by adding the higher-order curvature invariants (Schmidt 2007). Stelle (1977) showed that the higher-order actions are renormalizable. Hence, the modifying of Einstein-Hilbert action is a possible approach to make a renormalized theory of gravity (Birrell and Davies 1982). Among the modified theories, the $f(\mathrm{R})$ gravity seems to be an attractive model which is relatively simple but has many applications in gravity, cosmology and high energy physics (Elizalde et al. 2004). In this theory, a general function of Ricci scalar as $f(\mathrm{R})$ is replaced instead of R in the Einstein-Hilbert action, first discussed by Buchdahl (1970). Nojiri and Odintsov (2003, 2007b, 2008) and Faraoni (2006) have shown that the some $f(\mathrm{R})$ theories can pass the Solar System tests. Also, it has been shown that there exists a mathematically equivalent between $f(\mathrm{R})$ gravity and scalar-tensor theory of gravity (Chiba et al. 2007). A brief review of literature which describe the exact solutions in $f(\mathrm{R})$ gravity is presented below.

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