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ORIGINAL ARTICLE

Vacuum solution of a quadratic red-shift based correction in $f(R)$ gravity

Mozhgan Masoudi · Reza Saffari

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Abstract In the present paper, using action derivative with respect to Ricci scalar and its expansion relative to red-shift, to the second-order and consequently without needing dark energy, the history of cosmos expansion is reconstructed in vacuum. Then, employing supernova data, free parameters of the model which are the expansion coefficients, are calculated. It will be seen that if the free parameters of the model are zero, action of general relativity, which is a boundary mode of the gravity, is found. Also the cosmic age for this model in vacuum is calculated. Finally, it is attempted to reconstruct the reference action in terms of its Taylor expansion. Thus, it will be found that the reconstructed action and their actions definitely pass the Solar system tests.

Keywords Modified gravity · Cosmology · Semi-inverse method

1 Introduction

The results of current cosmological observations indicate that the standard model of cosmology besides its dramatic achievements has been confronted with some problems in describing some phenomena. Such results are associated with observing supernovae type *Ia* and cosmic microwave background radiation (Perlmutter et al. 1999; Riess et al. 1998; Cole et al. 2005; Spergel et al. 2007; Seljak et al. 2005; Eisenstein et al. 2005; Jain and Taylor 2003). Such observational data show that the current universe has been located at an accelerated expansion phase. It also states that the total density of universal energy is currently too close to the critical density and as a result the geometry of the universe is flat.

Now this question raises that which component of the cosmos has caused such accelerated expansion? Several efforts have been conducted to improve the standard model of cosmology. Being responsible for this expansion, several approaches such as positive cosmological constant, Dark Energy, and modified gravity have been introduced. The positive cosmological constant would be defined either geometrically as modifying the left hand side of Einstein equations or as a kinematic term on the right hand side with the equation of state parameter $\omega = -1$. However, the fine tuning problem causes some difficulties (Copeland et al. 2006; Sami 2009; Sahni and Starobinsky 2000; Padmanabhan 2003; Linder 2008; Frieman et al. 2008; Caldwell and Kamionkowski 2009; Silvestri and Trodden 2009). There are various scalar field models of Dark Energy (Bamba et al. 2008, 2012). Indeed, these models are the outcomes of modifying the right hand side of the Einstein equations, $G_{\mu\nu} = \chi T_{\mu\nu}$, by considering a source term with an equation of state parameter $\omega < -1/3$ which is recognized as Dark Energy.

In modified gravity, the right hand side is left unchanged and we modify the left hand side of Einstein field equations, so we have a large class of theories of gravity. Particularly, we are interested in fourth order theories (Demianski et al. 2006; Thakur et al. 2011; Capozziello 2002; Capozziello et al. 2003, 2005; Carloni et al. 2005; Kleinert and Schmidt 2002; Nojiri and Odintsov 2003a, 2003b, 2003c, 2007a; Carroll et al. 2004; Allemandi et al. 2004) based on replacing the scalar curvature R in the Hilbert-Einstein action by a generic analytic function $f(R)$ which should be reconstructed starting from data and physically

M. Masoudi · R. Saffari (✉)
Department of Physics, University of Guilan,
P.O. Box 41335-1914, Rasht, Iran
e-mail: rsk@guilan.ac.ir