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ORIGINAL ARTICLE

Oscillatory Universe, dark energy and general relativity

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Abstract The concept of oscillatory Universe appears to be realistic and buried in the dynamic dark energy equation of state. We explore its evolutionary history under the framework of general relativity. We observe that oscillations do not go unnoticed with such an equation of state and that their effects persist later on in cosmic evolution. The 'classical' general relativity seems to retain the past history of oscillatory Universe in the form of increasing scale factor as the classical thermodynamics retains this history in the form of increasing cosmological entropy.

Keywords Oscillatory Universe · Dark Energy · General Relativity

1 Introduction

Although, the belief in Cyclic model related to *Oscillatory Universe* dates back to the ancient times (Kanekar et al. 2001 and references cited therein), a scientific model for it could only be proposed during the first half of the twentieth century (Friedman 1922). At a stage, cosmological model of oscillatory Universe that combines both the Big Bang and the Big Crunch as part of a cyclical event, was considered as one of the main possibilities of cosmic evolution (Dicke et al. 1965). However, Durrer and Laukenmann (1996) showed it as a viable alternative to inflation. Throughout the past century, the idea has been of scientific importance rather than of mere belief, which has been a focus of many theoretical investigations till date as summarized in the Sect. 2.

Various observations (Riess et al. 1998; Perlmutter et al. 1998; Spergel et al. 2003; Tegmark et al. 2004) suggest that our Universe has been accelerating from 7 Gyr ago. The reason behind this phenomenon is believed to be a mysterious *dark energy*, a term coined recently in 1999 but its history traces back as late as Newton's time (Calder and Lahav 2008). The cosmological constant Λ, first adopted and then abandoned by Einstein for his static model of the Universe (Einstein 1917, 1918, 1931), is considered as one of the candidates for the dark energy. It is, however, speculated that Λ is a dynamical term rather than a constant. The other candidate is a scalar field often referred to as quintessence (Watterich 1988; Ratra and Peebles 1988; Caldwell et al. 1998).

The dark energy may be described as a perfect fluid through the equation of state (EOS) relating the fluid pressure and matter density of the physical system through the relation

$$p = \omega\rho, \tag{1}$$

where $\omega \equiv \omega(t)$ is the barotropic dark energy EOS parameter. It plays a significant role in the cosmological evolution. This is in general a function of time and may be a function of scale factor or redshift (Chervon and Zhuravlev 2000;

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