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Robertson–Walker model universe interacting with electromagnetic field and Brans–Dicke field in presence of hybrid scale factor

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ABSTRACT

We discuss Robertson–Walker model universe with Hybrid Scale factor for two cases Flat and Open model interacting with Brans–Dicke field and electromagnetic field. Some exact solutions are obtained and the different characteristics and phenomena of the dark energy contained in it are discussed.

1. Introduction

Accelerated expansion of the present day universe is described and supported by recent cosmological observations [1–12]. The Brans–Dicke (B-D) theory [13] is one of the simplest scalar-tensor theory used by different authors to study about accelerated expansion of the universe. Using the B-D theory Banerjee and Beesham [14] discussed exponential and power-law solutions for the flat Robertson–Walker cosmological model. Ahmadi-Azar and Riazi [15], Etoh et al. [16], Singh and Beesham [17], Banerjee and Pavon [18], Chakraborty et al. [19] discussed different cosmological models in the context of B-D theory in different scenario. Singh et al. [20–22] studied different problems of interaction of gravitational field and Brans–Dicke field in R/W universe. Singh and Usham, Reddy and Rao, Bohra and Mehra [23–25] are some authors who discussed a field of charged distribution in Brans–Dicke field. Also, the presence of electromagnetic field was discussed in many papers by various authors [26–33]. El-Nabulsi discussed about relation concerning the dependence of the Hubble parameter with the scalar field in his number of papers [34–43]. These works have played a crucial role in this paper for taking power law relation between scale factor and scalar field. There have been lots of work done by authors [44–50] on hybrid scale factor in cosmological models. The work of Bohra and Mehra [25] in charged B-D field are the motivation behind this paper. In this paper, we studied isotropic cosmological model with hybrid scale factor interacting with the electromagnetic field and Brans–Dicke field considering Robertson–Walker metric.

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2. Metric and field equations

The spherically symmetric Robertson–Walker metric is

$$ds^2 = dt^2 - R^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + sin^2\theta d\varphi^2)\right], \tag{1}$$

where k is the curvature index which can take values $-1, 0, 1$.

The Brans–Dicke (B-D) theory of gravity is described by the action (in units $h = c = 8\pi G = 1$)

$$S = \int d^4x\sqrt{|g|}\left[\frac{1}{16\pi}\left(\phi R - \frac{\omega}{\phi}g^{sl}\phi_{,l}\phi_{,s}\right) + L_m\right], \tag{2}$$

where R represents the curvature scalar associated with the 4D metric g_{ij}; g is the determinant of g_{ij}; ϕ is a scalar field; ω is a dimensionless coupling constant; L_m is the Lagrangian of the ordinary matter component. In the absence of the potential V (or the case of a nearly massless field with the potential V) the BD parameter is constrained to be greater than 4.0×10^4 from solar system experiments [54].

The Einstein field equations in the most general form are given by

$$R_{ij} - \frac{1}{2}Rg_{ij} + \Lambda g_{ij} = -\frac{\kappa}{\phi}T_{ij} - \frac{\omega}{\phi^2}\left[\phi_{,i}\phi_{,j} - \frac{1}{2}g_{ij}\phi^{,s}\phi_{,s}\right] - \frac{1}{\phi}(\phi_{,ij} - g_{ij}\phi^{;s}_{;s}), \tag{3}$$

where

$$(3 + 2\omega)\phi^{;s}_{;s} = \kappa T, \tag{4}$$

where $\kappa = 8\pi$, T is the trace of T_{ij}, Λ is the cosmological constant, R_{ij} is Ricci-tensor, g_{ij} is metric tensor, $\Box\phi = \phi^{;s}_{;s}$, $\Box$ is the Laplace-Beltrami operator and $\phi_{,\,i}$ is the partial differentiation with respect to x^i coordinate.

The energy-momentum tensor is

$$T_{ij} = M_{ij} + E_{ij}, \tag{5}$$

where

$$M_{ij} = (p + \rho)u_i u_j - pg_{ij}, \tag{6}$$

and

$$E_{ij} = -F_{il}F^l_j + \frac{1}{4}g_{ij}F_{lm}F^{lm}, \tag{7}$$

with $u_1 = u_2 = u_3 = 0$, $u_4 = 1$, u_i is four velocity vector satisfying $g^{ij}u_i u_j = 1$, p is the pressure and ρ is the energy density. A comma (,) or semicolon (;) followed by a subscript denotes partial differentiation or a covariant differentiation respectively. T_{ij} is the energy-momentum tensor for matter and E_{ij} is the electromagnetic energy-momentum tensor. The velocity of light is taken to be unity.

Then, the non-vanishing components of the electromagnetic energy-momentum tensor E^i_j are

$$E^1_1 = -E^2_2 = -E^3_3 = E^4_4 = -\frac{1}{2}g^{11}g^{44}F^2_{14} = \frac{1}{2}\frac{1-kr^2}{R^2}F^2_{14}. \tag{8}$$

Shear scalar is defined as

$$\sigma^2 = \frac{1}{2}\left(\sum_{i=1}^{3}H_i^2 - 3H^2\right). \tag{9}$$

The average anisotropy parameter Δ is defined as

$$\Delta = \frac{1}{3}\sum_{i=1}^{3}\left(\frac{H_i - H}{H}\right)^2, \tag{10}$$

where $H_i, i = 1, 2, 3$ represent the directional Hubble parameters in x,y,z directions respectively and $\Delta = 0$ corresponds to isotropic expansion.

Gravitational variable [51] is defined as

$$G = \frac{1}{\phi}\left(\frac{4 + 2\omega}{3 + 2\omega}\right). \tag{11}$$

The deceleration parameter q is defined as

$$q = -\frac{R\ddot{R}}{\dot{R}^2}, \tag{12}$$

where q is the measure of the cosmic acceleration of the universe in cosmology.

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