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RESEARCH ARTICLE

LRS BIANCHI TYPE-I COSMOLOGICAL MODEL IN F(R,T) GRAVITY WITH STIFF FLUID

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ABSTRACT

Field equations in a modi ed theory of gravitation proposed by Harko *et al.* (Phys. Rev. D 84: 024020, 2011) are obtained with the aid of a spatially homogeneous and anisotropic LRS Bianchi type-I metric. Cosmological models corresponding to stiff uid obtained. Some physical and kinematical properties of each of the models are also studied.

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1. INTRODUCTION

In recent years there has been an increasing interest in modified theories of gravity in view of the direct evidence of late time acceleration of the universe and the existence of the dark matter and dark energy (Reiss *et al*., 1980; Permutter *et al*., 1999; Bennet *et al*., 2003). In particular, f(R) theory of gravity formulated by Nojiri and Odinstov (2003a) and f(R,T) theory of gravity proposed by Harko *et al*. (2011) are attracting more and more attention. It has been suggested that cosmic acceleration can be achieved by replacing Einstein-Hilbert action of general relativity with a general function f(R) (R being the Ricci Scalar curvature). Carroll *et al*. (2004), Nojiri and Odinstov, (2003b, 2004, 2007) and Chiba *et al*. (2007) are some of the authors who have investigated several aspects of f(R) gravity. Very recently, Adhav, (2012), Reddy *et al.* (2012a, 2012b) have investigated Bianchi type-I and III and Kaluza-Klein perfect fluid cosmological model in f(R,T) theory of gravity. Also we have investigated LRS Bianchi type-I universe, by using a special law of variation for Hubble's parameter which represents cosmological model with a constant deceleration parameter in f(R,T) gravity. Motivated by the above investigations we study spatially homogeneous LRS Bianchi type-I anisotropic cosmological models corresponding to physically important matter distribution namely stiff fluid in f(R,T) gravity. These models are very important in the discussion of large scale structure and to realize real picture of the universe in its early stages. They are also necessary to study the evolution of the universe.

This chapter is organized as follows: In the section 2, the field equations of f(R,T) gravity are derived with the help of Bianchi type - I metric in the presence of perfect fluid distribution. Section 3, is devoted to the solution of the field equations. Cosmological models corresponding to stiff fluid is studied. The last section contains some conclusions.

2. METRIC AND FIELD EQUATIONS

We consider a homogeneous LRS Bianchi type–I space–time given by

$$ds^2 = dt^2 \quad A^2dx^2 \quad B^2(dy^2 + dz^2) \qquad (1)$$

where A and B are functions of cosmic time t.

The field equations of f(R,T) gravity are

$$f(R,T)R_{ij} \quad \tfrac{1}{2}f(R,T)g_{ij} + \left(g_{ij} \quad \nabla_i\nabla_j\right)f_R(R,T) = 8\pi T_{ij} \quad f_T(R,T)\,T_{ij} \quad f_T(R,T)\,\theta_{ij} \qquad (2)$$

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Here $\theta_{ij} = \quad 2\,T_{ij} + g_{ij}L_m \quad 2g^{lk}\frac{\partial^2 L_m}{\partial g^{ij}\partial g^{lm}}$ (3)

Here $f_R = \frac{\delta f(R,T)}{\delta R}$, $f_T = \frac{\delta f(R,T)}{\delta T}$ $= \nabla^i\nabla_i$, $\nabla_i$is the co-variant derivative and$T_{ij}$is the standard matter energy-momentum tensor derived from the LagrangianL_m. It may be noted that when f(R,T) ≡f(R) the equation (2) yield the field equations of f(R) gravity. The problem of the perfect fluids described by an energy density ρ, pressure p and four velocity$u^i$is complicated since there is no unique definition of the matter Lagrangian. However, here, we assume that the stress energy tensor of the matter is given by

$T_{ij} = (\rho + p)u_i u_j \quad p g_{ij}$ (4)

and the matter Lagrangian can be taken as$L_m = \quad p$and we have

$u^i\nabla_j u_i = 0, \quad u^i u_i = 1$ (5)

Then with the use of Equations (5) we obtain for the variation of stress-energy of perfect fluid the expression

$\theta_{ij} = \quad 2T_{ij} \quad p g_{ij}$ (6)

Generally, the field equations also depend through the tensor θ_{ij}, on the physicsl nature of the matter field. Hence in the case of f(R,T) gravity depending on the nature of the matter source, we obtain several theoretical models corresponding to each choice of f(R,T). Assuming

$f(R,T) = R + 2f(T)$ (7)

as a first choice where f(T) is an arbitrary function of the trace of stress-energy tensor of matter, we get the gravitational field equations of f(R,T) gravity from Eq. (2) as

$R_{ij} \quad \frac{1}{2}Rg_{ij} = 8\pi T_{ij} \quad 2f'(T)\,T_{ij} \quad 2f'(T)\theta_{ij} + f(T)\,g_{ij}$
(8)

where the prime denotes differentiation with respect to the argument.

If the matter source is a perfect fluid,

$\theta_{ij} = \quad 2T_{ij} \quad p g_{ij}$

then the field equations become

$R_{ij} \quad \frac{1}{2}g_{ij}R = 8\pi T_{ij} + 2f'(T)\,T_{ij} + [2pf'(T) + f(T)]\,g_{ij}$
(9)

Using co-moving coordinates and equations (4)-(6) f(R, T) gravity field equations (8) with the particular choice of the function (Harko *et al.*, 2011)

$f(T) = \lambda T$,λ is constant for the metric (1) take the form

$2\left(\frac{B}{B}\right) + \left(\frac{B}{B}\right)^2 = (8\pi + 3\lambda)p \quad \lambda\rho$ (10)

$\frac{B}{B} + \frac{A}{A} + \frac{A\,B}{A\,B} = (8\pi + 3\lambda)p \quad \lambda\rho$ (11)

$\left(\frac{B}{B}\right)^2 + 2\frac{A\,B}{A\,B} = \quad (8\pi + 3\lambda)\rho + \lambda p$ (12)

where an over head dot denotes differentiation with respect to cosmic time t.

The spatial volume for the metric (1) is given by
$V = A^2B(13)$

We define $a = (A^2B)^{\frac{1}{3}}$as the average scale factor of the space-time (1) so that the Hubble's parameter is

$H = \frac{a}{a} = \frac{1}{3}\left(2\frac{A}{A} + \frac{B}{B}\right)$ (14)

We define the generalized Hubble's parameter H as

$H = \frac{1}{3}\left(H_x + H_y + H_z\right)$ (15)

Where $H_x = \frac{A}{A}, H_y = \frac{B}{B}$, $H_z = H_x$ are the directional Hubble's parameters in the direction of x,y,z respectively. The scalar expansion θ, shear scalar σ^2 and the average anisotropy parameter A_α are defined by

$\theta = 2\frac{A}{A} + \frac{B}{B}$ (16)

$\sigma^2 = \frac{1}{3}\left(\frac{A}{A} \quad \frac{B}{B}\right)^2$ (17)

$A_\alpha = \frac{1}{3}\sum_{i=1}^{3}\left(\frac{H_i}{H}\right)^2$ (18)

Where $H_i = H_i \quad H(i = 1,2,3)$

3. SOLUTIONS AND THE MODELS

When $\rho = p$(Stiff fluid Model or Zeldovich Model)

The field equations (10)-(12) are a system of three independent equations in four unknowns A,B, $p$and ρ. Hence to obtain determinate solutions, we consider the following physically important cases and discuss the corresponding cosmological models. In this particular case, the field equations (10 +12) reduce to

$\frac{A}{A} + \frac{B}{B} + \frac{B^2}{B^2} + 3\frac{A\,B}{A\,B} = 0$ (19)

Eq.(19) being highly non-linear, we use the condition that the scalar expansion θ is proportional to shear scalar $\sigma$of the space-time so that

$A = B^m$ (20)

where m>1 is a constant (Collins *et al.*1980)

Now, using Eq.(20) in(19) we get the metric coefficients as

$$A=\left[\frac{(m^2+6m+1)}{m}(C_1t+C_2)\right]^{\frac{m^2}{(m^2+6m+1)}}, B=\left[\frac{(m^2+6m+1)}{m}(C_1t+C_2)\right]^{\frac{m}{(m^2+6m+1)}} \qquad (21)$$

where C_1 and C_2 are constants of integration. By a suitable choice of integration constants (i.e., C_1=1,C_2=0) the metric(1) with the help of (21) can, now, be written as

$$ds^2=dt^2 \quad (Mt)^{\frac{2m}{M}}dx^2 \quad (Mt)^{\frac{2}{M}}(dy^2+dz^2) \qquad (22)$$

where $M=\frac{(m^2+6m+1)}{m}$

Eq.(22) represents Bianchi type-I stiff fluid (Zeldovich fluid) cosmological model in f(R,T) gravity with the following physical and kinematical parameters which are important in the discussion of cosmological models.

Spatial volume in the model is

$$V=(Mt)^{\frac{m+1}{M}} \qquad (23)$$

Hubble's parameter is

$$H=(\frac{2m+1}{3M})(\frac{1}{t}) \qquad (24)$$

The scalar expansion is

$$\theta=(\frac{2m+1}{M})(\frac{1}{t}) \qquad (25)$$

The shear scalar is

$$\sigma^2=\frac{1}{3}\left[\frac{m-1}{M}\right]^2\frac{1}{t^2} \qquad (26)$$

The anisotropy parameter is

$$A_\alpha=\frac{4}{3} \qquad (27)$$

Also $\lim_{t\to\infty}\frac{\sigma^2}{\theta^2}=\frac{1}{3}\left[\frac{m-1}{2m+1}\right]^2\neq 0 \qquad (28)$

The pressure and density in the model is

$$\rho=p=\frac{1}{(8\pi+2\lambda)}\left[\frac{(2M-1)}{(Mt)^2}\right] \qquad (30)$$

From the above results, we observe that the volume scale factor of the universe increases with the growth of cosmic time. In the beginning of the universe, i.e., at t=0, the Hubble parameter, the scalar expansion, the shear scalar, pressure and density assumed infinitely large values whereas with the growth of cosmic time (i.e. as $t\to 0$) they decrease to null values as $t\to\infty$. Also stiff fluid model plays a vital role in the discussion of early stages of evolution of the universe. However, in view of the major development in modern cosmology our universe will make a transition from decelerating phase to accelerating one as confirmed by anisotropic cosmic microwave background radiation (CMBR). This is possible by cosmic re collapse.

4. Conclusions

Here we have investigated LRS Bianchi type-I cosmological model in f(R,T) gravity. In particular, we have studied stiff fluid, and anisotropic models in the modified f(R,T) gravity. It is well known that anisotropic models represent cosmos in its early stage of evolution and isotropic FRW models represent present day universe. It is observed that all the above models in f(R,T) gravity have stability and have no initial singularity. It may also be noted that even though the early universe in f(R,T) theory of gravity decelerates in the standard way, it will accelerate in finite time thus establishing with the present day accelerated expansion of the universe. This is possible by cosmic recollapse of the universe in finite future as the universe in turns inflates, decelerates and then accelerates (Nojiri and Odintsov, 2003).

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