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ROTATIONAL PERTURBATION OF HOT BIG BANG VISCOUS FLIUD MODEL UNIVERSES COUPLED WITH SCALAR FIELD

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Keywords

Big Bang Model, Radiation-dominated, Cosmological Constant, Roberstson-Walker Metric, Comic Fluid, Energy-Momentum Tensor, Newtonian Limit, Perfect Dragging.

Abstract

We will focus on standard hot Big-Bang models involving rotating viscous fluid leading to new interesting solutions. Their properties will be studied from various respective thereby obtaining new idea and information's regarding the evolutions of the universe. Investigation will also be made as to when the universe ceased to be radiation-dominated and become matter – dominated, pointing out the advantages of our model over the Friedman model.

Introduction

It is commonly accepted that no real astrophysical object is composed of a perfect-fluid. Moreover, it is known that a scalar field plays an important role in the evolution of the universe and some theories had already exists to that effect. The most commonly accepted model of the universe is Big Bang Model with this view in fact, proposing a modification of the cosmological constant introduced by Einstein and assuming Λ as a function of the "cosmical time" the evolution of the universe according to "standard hot bing-bang model "is being studied using the modified field equations obtained there from. As object of our study, we take up slowly rotating viscous fluid distribution coupled with zero-mass scalar field as it will be very stimulating to make investigations on such models is try to obtain new informations concerning rotating astrophysical objects in this universe and we can draw many conclusions for realistic universe from such studied and also, it will be great interest to find out explicitly solved models of expanding as well as rotating objects so that the information about the behaviour of the universe can be obtained from such models. The study of rotational perturbation of standard hot big-bang models are made in order to substantiate the possibility that the universe is endowed with slight rotation , in course of presentation of several analytic solutions. In this problem, it is assumed that any deviation which many exist is very small; and we neglect terms of the higher than the first appearing in the rotation as we are considering slow rotation.

FIELD EQUATIONS:

Here we consider the Robertson-Walker metric

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

where k is the curvature index and takes the values +1, -1 or 0 when universe is closed , open or flat respectively . R(t) is the scale factor form measuring distances in the non-static universe . This metric is applicable to all homogenous and isotropic model universes with the condition that the cosmic fluid is at rest relative to the commoving observer hence u_i = (0, 0, 0, 1) .

The energy-momentum tensor for the “cosmic fluid “ may be taken as

$$T_{\mu\lambda} = \rho u_\mu u_\lambda + (p+\xi\theta)H_{\mu\lambda} - 2\eta\sigma_{\mu\lambda} + \frac{1}{\varphi}\left(\varphi_\mu\varphi_\lambda - \frac{1}{2}g_{\mu\lambda}\varphi^k\varphi_k\right) \quad [2]$$

where ρ is the density ; p is the isotropic pressure,φ is the zero mass scalar field, η& ξ is the co-efficients of shear and bulk respectively and u_μ is the four –velocity vector of the cosmic fluid which satisfied the relation

$$g_{\mu\lambda}u_\mu u_\lambda=1,$$

[3] $H_{\mu\lambda}$ is the projection tensor defined by

$H_{\mu\lambda}$ = $u_\mu u_\lambda$ - $g_{\mu\lambda}$, [4]

And $$\sigma_{\mu\lambda} = \frac{1}{2}\left(u_{\mu;\beta}H^\beta_\lambda + u_{\lambda;\beta}H^\beta_\mu\right) - \frac{1}{3}\theta H_{\mu\lambda}$$

is the shear tensor where θ = $u_{;\alpha}^{\alpha}$ is the expansion factor

φ is the scalar field satisfies the relation

$$\frac{\delta}{\delta x^\lambda}\left(\varphi_\alpha\sqrt{-g}.g^{\alpha\lambda}\right) - \frac{\varphi_\lambda\varphi_\alpha}{\varphi}\sqrt{-g}g^{\alpha\lambda} = 0 \quad [5]$$

The modified Einstein's field equations are given by

$$R_{ij} - \frac{1}{2} R g_{ij} + \Lambda g_{ij} = -8\pi G T_{ij} \quad (i,j=1,2,3,4) \qquad [6]$$

where Λ_{ij} are different functions of the " comical time " for i,j = 1,2,3 (space components) are constants.

The invariant nature of the quantities Λ_{ij} and the symmetric property of the field equations suggest that

$$\Lambda_{ij} = \Lambda_{ji} = \Lambda_j{}^i = \Lambda_i{}^j = \Lambda^{ij} = \Lambda_{ji} \quad (i,j=1,2,3,4) \qquad [7]$$

Taking into consideration the special theory the field equation (6) yield the diagonal values of Λ_{ij} as (Chandra , 1977)

$$\Lambda_{ij} = A(t) > 0 \quad (i.\, j = 1,2,3,4) \qquad [8]$$

and $\Lambda_{ij} = -B = \text{constant} < 0$ [9]

Under these conditions the Newtonian limit of the field equations (6) is given by

$$\nabla^2\varphi + [\, A(t) + B\,] = 8\pi G\rho \qquad [10]$$

which gives a variable density

$$\rho = \left[\frac{A(t)+B}{8\pi G}\right], \qquad [11]$$

In the presence of homogeneous matter , namely φ = constant.

FIELD EQUATIONS AND THEIR SOLUTIONS:

$$8\pi G(p - \xi\theta) = -4\pi G\left(\frac{\dot{\varphi}}{\varphi}\right)^2 - 4\pi G\left(\frac{1-kr^2}{R^2}\right)\left(\frac{\varphi'}{\varphi}\right)^2 - 2\frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} - \frac{k}{R^2} + A(t) \qquad [12]$$

$$8\pi G(p - \xi\theta) = -4\pi G\left(\frac{\dot{\varphi}}{\varphi}\right)^2 + 4\pi G\left(\frac{1-kr^2}{R^2}\right)\left(\frac{\varphi'}{\varphi}\right)^2 - 2\frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} - \frac{k}{R^2} + A(t) \qquad [13]$$

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$$8\pi G\rho = -4\pi G\left(\frac{\dot{\varphi}}{\varphi}\right)^2 - 4\pi G\left(\frac{1-kr^2}{R^2}\right)\left(\frac{\varphi'}{\varphi}\right)^2 - 3\left(\frac{\dot{R}^2}{R^2} + \frac{k}{R^2}\right) + B \qquad [14]$$

$$3\frac{\dot{R}}{R}\Omega' + \dot{\Omega}' = -16\pi G\eta\omega' \qquad [15]$$

and

$$\frac{1}{2}\left(1-kr^2\right)\Omega'' + \frac{2}{r}\left(1-\frac{5kr^2}{4}\right)\Omega' - \left(R\ddot{R} + 2\dot{R}^2 + 2k\right)\Omega$$
$$= 8\pi G\left[\left(\frac{3}{2}\Omega - \omega\right)(p-\xi\theta) + \left(\frac{\Omega}{2} - \omega\right)\rho\right]R^2 \qquad [16]$$

Equation (12) and (13) gives

$$\frac{\varphi'}{\varphi} = 0 , \qquad [17]$$

Using equation (17) in equation (5) , we get

$$\frac{\dot{\varphi}}{\varphi} = cR^{-3} \qquad [18]$$

where c is arbitrary constant.

By virtue of (18), equations (12) and (14) become

$$8\pi G(p-\xi\theta) = -4\pi Gc^2R^{-6} - 2\frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} - \frac{k}{R^2} + A(t) , \qquad [19]$$

$$\frac{8\pi G\rho}{3} = -\frac{4\pi Gc^2R^{-6}}{3} + \frac{\dot{R}^2}{R^2} + \frac{k}{R^2} + \frac{B}{3} , \qquad [20]$$

Equation (19) is a dynamic equation that gives the second derivative of the scale factor and thereby governs the dynamic evolution away from the initial moment of time . On the other hand , equation (20) may be taken as initial value equation which gives the relation of $\dot{R}$ with R and ρ at the origin of the epoch of time . From these two equation, we get

$$\left[-8\pi G(p-\xi\theta) + A(t) + B\right]R^2\dot{R} = \frac{d}{dt}\left(\frac{8\pi G}{3}\rho R^3\right)$$

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Thus taking for granted that the variation of A(t) and the equation of the state for the cosmic fluid are known, equations (20) and (21) together will give the dynamics evolution of the "standard hot big – bang models".

By using of equations (19) and (20) assuming A(t) as constant , equation (16) becomes

$$\left(1-kr^2\right)\Omega'' + \left(\frac{4}{r} - 5kr\right)\Omega' = \left(4k - 8\pi Gc^2R^{-4} + 2\dot{R}^2 - 2R\ddot{R}\right)(\Omega - \omega) \quad [21]$$

In what follows, we shall now discuss three cases.

Case . I

In this case we take

$$\Omega - \omega = \left[1 - \dot{N}(t)\right]\Omega \,, \quad [22]$$

where N(t) is an arbitrary function of time .

Then from (15) we get

$$\Omega = \frac{L(r)}{R^3}\exp\left[-16\pi G\eta N(t)\right] + F(t) \,, \quad [23]$$

where L(r) is the function of r and F(t) is the function of time which is set equal to zero for our problem.

Now, from equation (21), (22) and (23) , we get

$$\left(1-kr^2\right)\frac{L''}{L} + \left(\frac{4}{r} - 5kr\right)\frac{L'}{L} = \left(4k - 8\pi Gc^2R^{-4} + 2\dot{R}^2 - 2R\ddot{R}\right)\times\left[1 - \dot{N}(t)\right]$$

Since the left hand side of this equation is a function of r only whereas the right hand side depends only on "t" , we can take

$$\left(1-kr^2\right)\frac{L''}{L} + \left(\frac{4}{r} - 5kr\right)\frac{L'}{L} = s \,, \quad [24]$$

$$\left(4k - 8\pi Gc^2R^{-4} + 2\dot{R}^2 - 2R\ddot{R}\right)\times\left[1 - \dot{N}(t)\right] = s \,, \quad [25]$$

where s is a separation constant.

For a given cosmological model, R(t) is known, hence, N(t) solved from (26). Using the substitution y = kr^2 in equation (24) we get

$$y(1-y)L_{yy} + \left(\frac{5}{2} - 3y\right)L_y - \frac{s}{4k}L = 0 \,, \quad [26]$$

SUB-CASE I(a)

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For open and close model, we have k = ± 1, equation (26) is similar to the hypergeometric equation

$$y(1-y)F_{yy}+[\gamma-(1+\alpha+\beta)y]F_y-\alpha\beta F=0$$

of which the general solution is given by

$$F=A_0F(\alpha,\beta;\gamma;y)+A_1y^{1-\gamma}F(1-\gamma+\alpha,1-\gamma+\beta;2-\gamma;y)$$

where A_0 and A_1 are the arbitrary constants and

$$F(\alpha,\beta;\gamma;y)=\sum_{n=0}^{\alpha}\frac{(\alpha)_n(\beta)_n}{(\gamma)_n\,n!}$$

Thus in this case we get the general solution of equation (26) as

$$L(r)=A_0\sum_{n=0}^{\alpha}\frac{(\alpha)_n(\beta)_n}{\left(\frac{5}{2}\right)_n n!}y^n+A_1y^{\frac{-3}{2}}\sum_{n=o}^{\alpha}\frac{\left(\alpha-\frac{3}{2}\right)_n\left(\beta-\frac{3}{2}\right)_n}{\left(\frac{-1}{2}\right)_n n!}y^n$$

[27]

since the second term is not regular at y = 0, we take $A_1 = 0$. Then get

$$L(r)=A_0\sum_{n=0}^{\alpha}\frac{(\alpha)_n(\beta)_n}{\left(\frac{5}{2}\right)_n n!}y^n \qquad [28]$$

Or $$L(r)=\sum_{n=0}^{\alpha}A_0(1-y)^{\frac{5}{2}-\alpha-\beta}\sum_{n=o}^{\alpha}\frac{\left(\frac{5}{2}-\alpha\right)_n\left(\frac{5}{2}-\beta\right)_n}{\left(\frac{5}{2}\right)_n n!}y^n$$

Now we give some of the explicit solutions:

(i) If $\alpha = -\frac{1}{2}$, $\beta = 5/2$, then we have s = -5k and

$$F\left(\frac{-1}{2},\frac{5}{2},\frac{5}{2};y\right)=(1-y)^{\frac{1}{2}}$$

In this case , we get

$$\Omega(r,t)=A_0\left(1-kr^2\right)^{\frac{1}{2}}R^{-3}\exp[-16\pi G\eta N(t)]$$

(ii) If $\alpha = 9/2$, $\beta = -5/2$, then we have s = - 4sk and

$$F\left(\frac{9}{2},\frac{-5}{2},\frac{5}{2};y\right)=(1-y)^{\frac{1}{2}}\left(1-4y+\frac{24}{7}y^2\right)$$

In this case, we get

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$$\Omega(r,t) = A_0\left(1-kr^2\right)^{\frac{1}{2}}\left(1 - 4kr^2 + \frac{24}{7}k^2r^4\right)$$
$$\times R^{-3}\exp[-16\pi G\eta N(t)]$$

(iii). If $\alpha = -1, \beta = 3$ then $s = -12k$ and

$$F\left(-1,3,\frac{5}{2};y\right) = 1 - \frac{6}{5}y$$

Therefore

$$\Omega(r,t) = A_0\left(1-kr^2\right)^{\frac{1}{2}}\left(1 - \frac{6}{5}kr^2\right)R^{-3}\exp[-16\pi G\eta N(t)]$$

SUB-CASE .I (b)

For $k = 0$ (flat model), equation (25) becomes

$$L'' + \frac{4}{r}L' = sL$$

Which gives

$$L(r) = a_1\left[1 + \frac{sr^2}{2.5} + \frac{s^2r^4}{2.4.5.7} + \ldots\ldots\ldots\ldots\right]$$
$$+ b_1 r^{-3}\left[1 - \frac{sr^2}{2.1} - \frac{s^2r^4}{2.4} + \ldots\ldots\ldots\ldots\right] \quad [29]$$

Where a_1 and b_1 are constants.

$$\therefore \quad \Omega(r,t) = \left[a_1\left\{1 + \frac{sr^2}{2.5} + \frac{s^2r^4}{2.4.5.7} + \ldots\right\} + b_1 r^{-3}\left\{1 - \frac{sr^2}{2.1} - \frac{s^2r^4}{2.4} + \ldots\right\}\right]$$
$$\times R^{-3}\exp[-16\pi G\eta N(t)] \quad [30]$$

CASE-II

We assume that

$\Omega = \omega,$ [31]

which is perfect dragging .

Then equation (15) becomes

$$3\frac{\dot{R}}{R} + \frac{\dot{\Omega}'}{\Omega} = -16\pi G\eta$$

which gives

$$\Omega(r,t) = L_1(r)R^{-3}\exp[-16\pi G\eta N(t)] + A(t), \quad [32]$$

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where $L_1(r)$ is an arbitrary function of r , and A(t) is an arbitrary function of t which is set equal to zero for our problem.

Then equation (21) becomes

$$\left(1-kr^2\right)\Omega'' + \left(\frac{4}{r} - 5kr\right)\Omega' = 0 \quad , \qquad [33]$$

From equation (32) and (33) , we get

$$\left(1-kr^2\right)L_1'' + \left(\frac{4}{r} - 5kr\right)L_1' = 0$$

which gives

$$L_1 = \frac{c}{3} r^{-3}\left(1-kr^2\right)^{\frac{1}{2}}\left(1+2kr^2\right) + c_1 \quad , \qquad [34]$$

where c and c_1 are arbitrary constants.

CASE . III

In this case, we take

$$\Omega - \omega = N(t)\Omega'' R^3 \quad , \qquad [35]$$

Equation (21) becomes

$$\left(1-kr^2\right)\Omega'' + \left(\frac{4}{r} - 5kr\right)\Omega' = R^3\left(4k - 8\pi G c^2 R^{-4} + 2\dot{R}^2 - 2R\ddot{R}\right)N(t)\Omega'' \qquad [36]$$

Making use of equation (23), we get

$$\left(1-kr^2\right) + \left(\frac{4}{r} - 5kr\right)\frac{L'}{L''} = R^3\left(4k - 8\pi G c^2 R^{-4} + 2\dot{R}^2 - 2R\ddot{R}\right)N(t) \qquad [37]$$

Separation of equation (37) , we have

$$\left(1-kr^2\right) + \left(\frac{4}{r} - 5kr\right)\frac{L'}{L''} = s_1 \quad , \qquad [38]$$

and

$$R^3\left(4k - 8\pi G c^2 R^{-4} + 2\dot{R}^2 - 2R\ddot{R}\right)N(t) = s_1 \quad , \qquad [39]$$

From equation (38), we get

$$L = c\int r^{\frac{-4}{z}}\left(z - kr^2\right)^{\frac{4-5z}{z}} dr$$

where $z = 1 - s_1$ and c are the arbitrary constants.

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$$\therefore \Omega(r,t) = cR^{-3} \int r^{\frac{-4}{z}} \left(z - kr^2\right)^{\frac{4-5z}{z}} dr + N(t), \qquad [40]$$

CASE .IIIa

If we choose

$$N(t) = \frac{s_1}{4k} R^{-3}$$

Then equation (39) becomes

$$4\pi Gc^2 R^{-4} - \dot{R}^2 + R\ddot{R} = 0, \qquad [41]$$

which gives

$$R = \left[a \sinh\left(bt + c_1\right)\right]^{\frac{1}{3}}$$

where a, b,c are arbitrary constant such that

$$a^2 b^2 = 12\pi Gc^2$$

$$\therefore \Omega(r,t) = c\left[a \sinh\left(bt + c_1\right)\right]^{-1} \int r^{\frac{-4}{z}} \left(z - kr^2\right)^{\frac{4-5z}{z}} dr + N(t)$$

DISCUSSION OF THE RESULTS

In case I, the rotational velocity decays with an increase of time where N(t) and R(t) are increasing functions as well as expanding of time, We get a rotational model which can be thought of as one of the realistic models.

In case II, the perfect dragging, we see that the rotational velocity decreases with the increase of r as well as with the increase of the time if N(t) is a decreasing function of time. In this case of perfect dragging the matter rotation ω(r,t) as well as the rotational Ω(r,t) is independent of scalar field.

In case III, both for the open and closed models the rotational velocities decay with the increase of r and t if N(t) is a decreasing function of time, but in case of the closed model the solution is realistic only for $-1 \le r \le 1$ .For flat model the rotational velocity is found to be an increasing function of r . In case III(a) , the open, close and flat models behave almost in the same manner . The results of our investigation here show the possibility of the existence of slowly rotating astrophysical objects coupled with scalar fields.

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CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

PLAGIARISM POLICY

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