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BIANCHI TYPE – VIII INFLATIONARY UNIVERSE WITH FLAT POTENTIAL AND CONSTANT DECELERATION PARAMETER IN GENERAL RELATIVITY

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Abstract

In present paper we havestudied Bianchi type – VIII inflationary universe with constant deceleration parameter in presence of massless scalar field and flat potential. It is also observed that the ratio of shear and expansion is non-zero for all values of T. Thus the universe remains anisotropic throughout the evolution.In order to obtain a deterministic solution of the field equations we have assumed thata condition between metric potentials A_1 and A_2 as $A_1 = A_2{}^n$ where n is the constant.For the two different constant value of deceleration we have obtained two different cosmological models. The behaviour ofboth models from physical and geometrical aspects in presence of bulk viscosity is discussed in detail.

Keywords: Bianchi Type-VIII, deceleration parameter, Inflationary, General relativity.

1. INTRODUCTION

Bianchi type VIII model is one of the important anisotropic cosmological models and hence it is widely studied in general relativity. The anisotropy plays a significant role in the early stage of evolution of the universe and hence the study of anisotropic and homogeneous cosmological models becomes important.Sancheti, M. M. and Hatkar, S. P.[20] presented Bianchi type VIII space time with perfect fluid in theory of gravitation and observed that the universe is anisotropic with early acceleration and late deceleration.A number of explicit, rotating and expanding cosmological solutions of the Einstein field equations for homogeneous hyper-surfaces of Bianchi type VIII cosmological models are discussed by Bradley, J. M. and Sviestins, E.[9].Also the study of Bianchi types VIII universes is important because familiar solutions like FRW universe with positive curvature, the de Sitter universe, and the Taub-Nut solutions.

Bianchi Type VIII cosmological models are the most general ever-expanding Bianchi cosmologies and are therefore of special interest. Bianchi models have been studied by several authors to achieve better understanding of the observed small amount of anisotropy in the universe. Bali, R. and Singh, S.[7] investigate inflationary scenario in Bianchi Type VIII space-time for a massless scalar field with flat potential using the condition that shear is proportional to expansion and found that the model represents accelerating universe. Bianchi types VIII, IX and II, string cosmological models are obtained in a scalar tensor theory of gravitationby Rao, V. U. M. and Santhi, M. V.[19].Argyris, P. J., et. al.[4] proposed a study on the influence of noise on chaotic phenomena as arising in the Bianchi VIII and IX cosmological models and examined the effects on various cosmological models for a number of alternative parameters in the presence of a noise.

The long-term behavior of Bianchi-type VIII models with three different types of stress-energy tensors are examined by Halpern, P.[10], also he discussed the existence of chaotic behavior and transitions to chaotic behavior. In Bianchi type-VIII, type-IXandtype-II cosmological models within the frame work of $f(R,T)$ theory of gravity for the role of dark energy in the form of wet dark fluid studied by Adhav, K. S., et. al.[2]. Kuvshinova, E. V. et. al.[16] have built non-stationary Bianchi type VIII cosmological models with rotation. The sources of gravity are in a comoving perfect fluid along with non-comoving dust, in a comoving perfect fluid and pure radiation and in a comoving anisotropic fluid.

An inflationary stage is a very general property of the solutions concluded by Belinskii and the concept of quantum "creation" of the universe.The state of accelerated expansion of the universe is termed as Inflation. It was first proposed in the beginning of the 1980s and now a days receives a great deal of attention.Linde, A. D.[17] was shown that the theory of the very early stages of evolution of the universe may differ considerably from the usual hot universe theory. It became clear that the universe at very large scales may consist of many locally isotropic and homogeneous mini-universes the properties of elementary particles, the vacuum energy may be very different.Yuanjie, L. and Zhijun, W.[25] discussed two inhomogeneousR^2 inflationary models, a spherically symmetric model and a Szekers class II model, and theyanalyzed the behaviour of inflation in these systems and found the exact solutions.Inflationary cosmological model for Bianchi type VI_0 with flat potential in General Relativity, is investigated by Bali, R. and Poonia, L. [6].A five-dimensional inflationary cosmological model in the presence of massless scalar field with a flat potential in general relativity presented by Katore, S. D. et. al.[14].Tinker, S. [24] have been studied an inflationary framework in spatially homogeneous and anisotropic Bianchi Type-II space-time and they also tried to describe that inflationary framework can be proposed for an anisotropic and homogeneous metric with exponential potential.

Following the inflationary period, the universe continued to expand but at a slower rate. In particular, self-interacting scalar fields play a central role in the study of inflationary cosmology. Recently Jat, L. L., et. al.[11] have investigated the Bianchi Type-I inflationary cosmological models with perfect fluid distribution in the presence of massless scalar field with a flat region in which potential is constant.Abbott, L. F. and Wise, M. B.[1] consider cosmologies having an inflationary period during which the Robertson-Walker scale factor is an arbitrary function of time satisfying $\ddot{R} > 0$ and showed that any such inflationary period will produce long-wavelength gravitational waves whichcan affect present observations of the microwave background. Exact analytical solutions of Einstein's equations are found for a spherically symmetric inhomogeneous metric in the presence of a massless scalar field with a flat potential. The process of isotropization and homogenization is studied by Stein-Schabes, J. A.[23]. Bulk viscous inflationary model with flat potential under framework of LRS Bianchi type II metric for relativistic solution of the field equations derived by Poonia, L. and Sharma, S. [18].

For the constant deceleration parameter, a spatially homogeneous anisotropic LRS Bianchi type-I cosmological modelin $f(R,T)$ gravity with a special form of Hubble's parameterstudied by Bishi, B. K. et. al. [8]. Kandalkar, S.,et. al.[12]have discussed the variation law for Hubble's parameter, average scale factor in spatially homogenous anisotropic Bianchi Type V space-time that yields a constant value deceleration parameter and investigated a number of solutions with constant and time varying cosmological constant together with variable and constant bulk viscosity. The expansion history of the Universe in power-law cosmology essentially depends on two crucial parameters, namely the Hubble constant H_0 and Deceleration parameter q observed by Kumar, S.[15]. The Hubble parameter and the deceleration parameter are analysed for a group of anisotropic homogeneous solutions of the Petrov type-D Studied by Alvarado, R.[3] and constructed a representative average value of the Hubble constant and the deceleration parameter.

Inflationary universe scenario with constant deceleration parameter in the presence of massless scalar field and flat potential taking Bianchi Type VI_0 space time as a source is discussed by Bali, R. and Kumari, P.[5]. Katore, S.D.[13] have studied Bianchi type-III inflationary universe with constant deceleration parameter in general relativity in the presence of mass less scalar field with a flat potential. Singh, C. P. and Kumar, S.[22] constructed Bianchi Type-II inflationary models with constant deceleration parameter in general relativity in presence of a massless scalar field with a scalar potential.Sharma, S. and Poonia, L.[21] constructed locally symmetric Bianchi Type I space time undertaken in framework of massless scalar field with flat potential and solvedEinstein field equations by using suitable transformation yields negative deceleration parameter represent accelerating phase of universe.

In this paper we have investigated Bianchi type – VIII inflationary universe with constant deceleration parameter in presence of massless scalar field and flat potential. It is also observed that the ratio of shear and expansion is non-zero for all values of T. Thus the universe remains anisotropic throughout the evolution.In order to obtain a deterministic solution of the field equations we have assumed thata condition between metric potentials A_1 and A_2 as $A_1 = {A_2}^n$ where n is the constant.For the two different constant value of deceleration we have obtained two different cosmological models.

2. THE METRIC AND FIELD EQUATIONS

We consider Bianchi type-VIII line element in form

$$ds^2 = dt^2 - {A_2}^2 dx^2 - {A_1}^2 dy^2 - [{A_1}^2 sinh^2 y + {A_2}^2 cosh^2 y]dz^2 + 2{A_2}^2 \cosh y \; dxdz \quad (1)$$

where A_1 and A_2 are metric potentials and functions of 't' alone.

The unit time like vector satisfying the following condition:

$$v_i v^i = -1$$

The co-moving coordinate system is chosen as

$$v^1 = v^2 = v^3 = 0, \;\; v^4 = 1$$

The Lagrangian is that of gravity minimally coupled to Higgs scalar field (ϕ) with effective potential $V(\phi)$ given by Stein-Schabes.

$$S = \int \sqrt{-g}\, [R - \tfrac{1}{2} g^{ij} \partial_{ij}\phi \partial_{ij}\phi - V(\phi)] d^4x \quad (2)$$

The Einstein's field equations (in the gravitational unit $8\pi G = c = 1$) in case of massless scalar field ϕ with potential $V(\phi)$ are given by

$$R_{ij} - \tfrac{1}{2} R g_{ij} = -T_{ij} \quad (3)$$

with energy momentum tensor (T_{ij}) for scalar field in presence of viscosity is given by

$$T_{ij} = (\rho + p) v_i v_j - p g_{ij} + \partial_i \phi \partial_j \phi - \left[\tfrac{1}{2} \partial_\rho \phi \partial^\rho \phi + V(\phi)\right] g_{ij} + \xi\theta\left(g_{ij} + v_i v_j\right) \quad (4)$$

where V is the effective potential, ϕ is Higgs field, ξ is the coefficient of bulk viscosity and θ is the expansion in the model.

The energy conservation law coincides with the equation of motion for ϕ and we have

$$\frac{1}{\sqrt{-g}} \partial_\mu\left(\sqrt{-g}\, \partial^\mu \phi\right) = -\frac{dV}{d\phi} \quad (5)$$

where scalar field ϕ is the function of t-alone.

The Einstein field equation (3) for the metric (1) and energy momentum tensor (4) leads to the following system of equations

$$2\ddot{A}_1/A_1 + {\dot{A}_1}^2/{A_1}^2 - 1/{A_1}^2 - 3{A_2}^2/4{A_1}^4 = -\dot{\phi}^2/2 - V(\phi) - (p - \xi\theta) \quad (6)$$

$$\ddot{A}_1/A_1 + \ddot{A}_2/A_2 + \dot{A}_1\dot{A}_2/A_1A_2 + {A_2}^2/4{A_1}^4 = -\dot{\phi}^2/2 - V(\phi) - (p - \xi\theta) \quad (7)$$

$$2\dot{A}_1\dot{A}_2/_{A_1A_2} + \dot{A}_1{}^2/_{A_1{}^2} - 1/_{A_1{}^2} - {A_2}^2/_{4{A_1}^4} = \rho + \dot{\phi}^2/_2 - V(\phi) \qquad (8)$$

The equation (5) for scalar field (ϕ) leads to

$$\ddot{\phi} + \left[2\dot{A}_1/_{A_1} + \dot{A}_2/_{A_2}\right]\dot{\phi} = -{}^{dV}/_{d\phi} \qquad (9)$$

where the overhead symbol dot$(\cdot)$ with A_1 and A_2 indicates derivative with respect to time t.

3. SOLUTION OF FIELD EQUATIONS

We are interested in inflationary solution so flat region is considered. Thus we have $V(\phi)$ is constant.

i.e. $V(\phi) = K$ (10)

From equations (9) and (10), we get

$$\ddot{\phi} + \left[2\dot{A}_1/_{A_1} + \dot{A}_2/_{A_2}\right]\dot{\phi} = 0 \qquad (11)$$

above equation leads to

$$\dot{\phi} = {}^{l}/_{{A_1}^2A_2} \qquad (12)$$

where l is constant of integration.

The average scale factor (R) for line element (1) is given by

$$R^3 = {A_1}^2A_2 \qquad (13)$$

To find the deterministic solution, we assume two conditions as follows:

(i) The shear $(\sigma)$is proportional toExpansion (θ)as considered by Throne (1967) which leads to the condition between metric potential

$$A_1 = {A_2}^n \qquad (14)$$

(ii) The deceleration parameter q is constant (α), thus we have

$$q = -{}^{\ddot{R}/R}/_{\dot{R}^2/R^2} = \alpha\ (constant) \qquad (15)$$

Thus two cases arises (1) $\alpha > 0$ and (ii) $\alpha < 0$

Case (1): $\alpha > 0$ i.e. $\alpha = a > 0$

Now by equations (13), (14) and (15), we have

$$\left(\ddot{A}_2/_{A_2}\right) = -b_1\left(\dot{A}_2{}^2/_{{A_2}^2}\right) \qquad (16)$$

where $b_1 = \frac{a(2n+1)+2(n-1)}{3}$

Equation (16) leads to

$$\left(\ddot{A}_2/_{\dot{A}_2}\right) = -b_1\left(\dot{A}_2/_{A_2}\right) \qquad (17)$$

After solving the above equation, we have

$$A_2 = [\gamma t + \delta]^{1/_{b_1+1}} \qquad (18)$$

where $\gamma = (b_1 + 1)m_1$& $\delta = (b_1 + 1)m_2$

After suitable transformation of co-ordinates, the metric (1) leads to the form

$$ds^2 = \frac{dT^2}{\gamma^2} - T^{2/b_1+1}dX^2 - T^{2n/b_1+1}dY^2 - \left[T^{2n/b_1+1}sinh^2Y + T^{2/b_1+1}cosh^2Y\right]dZ^2 - 2T^{2/b_1+1}\cosh Y\, dXdZ \quad (19)$$

Where $(\gamma t + \delta) = T,\quad x = X,\quad y = Y$ and $z = Z.$

Case (2): $\alpha < 0$ i.e. $\alpha = -a < 0$

Now by equations (13), (14) and (15), we have

$$\left(\ddot{A_2}/A_2\right) = b_2\left(\dot{A_2}^2/A_2^{\,2}\right) \quad (20)$$

where $b_2 = \frac{a(2n+1)-2(n-1)}{3}$

Equation (20) leads to

$$\left(\ddot{A_2}/\dot{A_2}\right) = b_2\left(\dot{A_2}/A_2\right) \quad (21)$$

After solving the above equation, we have

$$A_2 = [\lambda t + \beta]^{1/1-b_2} \quad (22)$$

where $\lambda = (1 - b_2)m_3$& $\beta = (1 - b_2)m_4$

After suitable transformation of co-ordinates, the metric (1) leads to the form

$$ds^2 = \frac{d\tau^2}{\lambda^2} - \tau^{2/1-b_2}dX^2 - \tau^{2n/1-b_2}dY^2 - \left[\tau^{2n/1-b_2}sinh^2Y + \tau^{2/1-b_2}cosh^2Y\right]dZ^2 - 2\tau^{2/1-b_2}\cosh Y\, dXdZ \quad (23)$$

where $(\lambda t + \beta) = \tau,\quad x = X,\quad y = Y$ and $z = Z.$

4. PHYSICAL AND GEOMETRICAL ASPECTS

The Higgs field(ϕ), and the pressure(p), Energy density(ρ), the spatial volume(R^3), the expansion(θ), shear(σ), the directional Hubble parameter(H_x, H_y, H_z), Hubble parameter(H), the anisotropic parameter(Δ), the deceleration parameter$(q)$for the model (19) are given by

$$\phi = l\left\{b_1 + 1/\gamma(b_1 - 2n)\right\}T^{(b_1-2n)/b_1+1} + L_1 \quad (24)$$

where L_1 is constant of integration.

$$R^3 = A_2^{\,2n+1} = T^{(2n+1)/b_1+1} \quad (25)$$

$$H_x = H_y = \dot{A_1}/A_1 = n\,\dot{A_2}/A_2 = n\gamma/(b_1 + 1)T$$

and $H_z = \dot{A_2}/A_2 = \gamma/(b_1 + 1)T$

The average Hubble parameter (H) is found to be

$$H = {[H_x + H_y + H_z]}/{3} = [2n + 1/3]\left[{\gamma}/{(b_1 + 1)T}\right] \quad (26)$$

$$\theta = 3H = (2n + 1)\left[{\gamma}/{(b_1 + 1)T}\right] \quad (27)$$

$$\Delta = (1/3)\sum_{i=3}^{3}\left[{H_i}/{H} - 1\right]^2 = {2(n-1)^2}/{(2n+1)^2} \quad (28)$$

The shear scalar $\sigma^2$is given by

$$\sigma^2 = (3/2)\Delta H^2 = \left[{(n-1)^2}/{3}\right]\left[{\gamma^2}/{(b_1+1)^2T^2}\right] \quad (29)$$

$$\sigma/\theta = {(n-1)}/{\sqrt{3}(2n+2)} \neq 0\ (constant) \quad (30)$$

The energy density ρ is given by Einstein field equation (8)

$$\rho = V(\phi) - {\dot{\phi}^2}/{2} + {2\dot{A}_1\dot{A}_2}/{A_1A_2} + {\dot{A}_1{}^2}/{A_1{}^2} - {1}/{A_1{}^2} - {A_2{}^2}/{4A_1{}^4}$$

$$\Rightarrow \rho = K - \left({l^2}/{2}\right)T^{{-2(2n+1)}/{b_1+1}} + \left[{n(n+2)\gamma^2}/{(b_1+1)^2}\right]T^{-2} - T^{{-2n}/{b_1+1}} - (1/4)T^{{2(1-2n)}/{b_1+1}} \quad (31)$$

Now the pressure $(p - \xi\theta)$ is given by Einstein field equation (7)

$$(p - \xi\theta) = -V(\phi) - {\dot{\phi}^2}/{2} - {\ddot{A}_1}/{A_1} - {\ddot{A}_2}/{A_2} - {\dot{A}_1\dot{A}_2}/{A_1A_2} - {A_2{}^2}/{4A_1{}^4}$$

$$\Rightarrow (p - \xi\theta) = -K - \left({l^2}/{2}\right)T^{{-2(2n+1)}/{b_1+1}} + \left[{\{(n+1)b_1 - n^2\}\gamma^2}/{(b_1+1)^2}\right]T^{-2} - T^{{2(1-2n)}/{b_1+1}} \quad (32)$$

The Higgs field(ϕ), and the pressure(p), Energy density(ρ), the spatial volume(R^3), the expansion(θ), shear(σ), the directional Hubble parameter(H_x, H_y, H_z), Hubble parameter(H), the anisotropic parameter(Δ), the deceleration parameter$(q)$for the model (23) are given by

$$\phi = l\left[{(b_2 - 1)}/{\lambda(b_2 + 2n)}\right]\tau^{{(b_2+2n)}/{1-b_2}} + L_2 \quad (33)$$

where L_2 is constant of integration.

$$R^3 = A_2{}^{2n+1} = \tau^{{2n+1}/{1-b_2}} \quad (34)$$

$$H_x = H_y = {\dot{A}_1}/{A_1} = n\,{\dot{A}_2}/{A_2} = {n\lambda}/{(1-b_2)\tau}$$

and $H_z = {\dot{A}_2}/{A_2} = {\lambda}/{(1-b_2)\tau}$

The average Hubble parameter (H) is found to be

$$H = {[H_x + H_y + H_z]}/{3} = [2n + 1/3]\left[{\lambda}/{(1-b_2)\tau}\right] \quad (35)$$

$$\theta = 3H = (2n+1)\left[{\lambda}/{(1-b_2)\tau}\right] \quad (36)$$

$$\Delta = (1/3)\sum_{i=3}^{3}\left[{H_i}/{H} - 1\right]^2 = {2(n-1)^2}/{(2n+1)^2} \quad (37)$$

$$\sigma^2 = \left(\frac{3}{2}\right)\Delta H^2 = \left[\frac{(n-1)^2}{3}\right]\left[\frac{\lambda^2}{(1-b_2)^2\tau^2}\right] \tag{38}$$

$$\frac{\sigma}{\theta} = \frac{(n-1)}{\sqrt{3}(2n+2)} \neq 0\ (constant) \tag{39}$$

The energy density ρ is given by Einstein field equation (8)

$$\rho = V(\phi) - \frac{\dot{\phi}^2}{2} + \frac{2\dot{A}_1\dot{A}_2}{A_1A_2} + \frac{\dot{A}_1^{\,2}}{A_1^{\,2}} - \frac{1}{A_1^{\,2}} - \frac{A_2^{\,2}}{4A_1^{\,4}}$$

$$\Rightarrow \rho = K - \left(\frac{l^2}{2}\right)\tau^{-2(2n+1)/1-b_2} + \left[\frac{n(n+2)\lambda^2}{((1-b_2)^2}\right]\tau^{-2} - \tau^{-2n/1-b_2} - \left(\frac{1}{4}\right)T^{2(1-2n)/1-b_2} \tag{40}$$

Now the pressure $(p - \xi\theta)$ is given by Einstein field equation (7)

$$(p-\xi\theta) = -V(\phi) - \frac{\dot{\phi}^2}{2} - \frac{\ddot{A}_1}{A_1} - \frac{\ddot{A}_2}{A_2} - \frac{\dot{A}_1\dot{A}_2}{A_1A_2} - \frac{A_2^{\,2}}{4A_1^{\,4}}$$

$$\Rightarrow (p-\xi\theta) = -K - \left(\frac{l^2}{2}\right)\tau^{-2(2n+1)/1-b_2} + \left[\frac{\{(n+1)b_1 - n^2\}\gamma^2}{(b_1+1)^2}\right]\tau^{-2} - \tau^{2(1-2n)/1-b_2} \tag{41}$$

5. CONCLUSION

The spatial volume (R^3) for the models (19) and (23) increases with time representing inflationary scenario is observed in Bianchi Type VIII space time in presence of massless scalar field with flat potential. The Higgs field (ϕ) for both models evolves slowly but the universe expands.The rate of expansion slows down with the increase of time and finally drops to zero when $T \to \infty$ for model (19) and when $\tau \to \infty$ for model (23). It is also observed that the ratio of shear and expansion is non-zero for all values of time. Thus universe remains anisotropic throughout the evolution. The Hubble parameter (H) is initially large but decreases with time. Both the models have Point type singularity at $T = 0$ for model (19) and $\tau = 0$ for model (23). The models describe the unified expansion history of universe which starts with decelerating and accelerating phases of universe.

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