Wet Dark Fluid Cosmological Model in Self- Creation Theory

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Abstract : *In this paper, we have studied Bianchi type-VI_0 cosmological model with wet dark fluid in Self -Creation theory formulated by Barber (1982) . Exact cosmological model in the theory are obtained with the help of relation between metric coefficient and equation of state. Various physical features of the model are also discussed.*

Keyword : *Wet Dark fluid, Barber self-creation theory, Bianchi type VI_0 space time.*

2010 Mathematics Subject Classification: 92C10

1. Introduction :

Barber (1982) has proposed two self-creation theories modifying the Brans - Dicke (1961) and Brans (1987) theory of gravitation and Einstein theory of general relativity. In 1987 Brans has pointed out that the first theory of Barber is not satisfactory because of violation of equivalence principle. According to Brans, Barber's first theory is not in disagreement with experimental observations and is also not consistent in general. His second self-creation theory is a modification of Einstein's general theory of gravitation to variable G-theory which predicts local effect and is within the observational limit. In his postulate, the gravitational coupling of the Einstein field equations is allowed to be a variable scalar on the space time so that this scalar couples to the trace of energy momentum tensors.

The Barber field equation in second self-creation theory can be expressed as

$$R_{ij} - \frac{1}{2} R g_{ij} = -8\pi \phi^{-1} T_{ij} \qquad (1)$$

And

$$\Box \phi = \phi^{;k}_{;k} = \frac{8\pi u}{3} T \qquad (2)$$

Where $\Box\phi$ is the Barber's scalar, T_{ij} is the energy momentum tensor, ϕ is the invariant D'Alembertian, T is the trace of energy momentum tensor T_{ij}, u is a coupling constant to be determined from experiment

and $0 \prec |u| \prec 1/10$. In the limit $u \to 0$, this theory approaches the Einstein's theory in every respect. Due to the nature of the space time Barber's scalar ϕ is a function of 't'. Pinental (1985), Venkateswaru et.al (1989), Shanti and Rao (1991), Mohanty et al (2002), Adhav et al (2008), Katore (2011) and Pawar et al (2014) are some of the authors who have investigated the various aspects of Barber's second self-creation theory by using various cosmological models.

The nature of the dark energy component of the universe as one of the deepest mysteries of cosmology. The wet dark fluid (WDF) as a model for dark energy. This model is in the spirit of the generalized Chaplygin gas Gorini *et al* (2004), where a physically motivated equation of state is offered with properties relevant for the dark energy problem. Here the motivation stems from an empirical equation of state proposed by Tait(1988) and Hayward (1967).

The equation of state for WDF is very simple.

$$P_{WDF} = \gamma\left(\rho_{WDF} - \rho_*\right) \qquad (3)$$

The pressure p and ρ_* are taken to be positive and we restrict ourselves to $0 \le \gamma \le 1$

To find the WDF energy density, we use the energy conservation equation

$$\rho_{WDF} = \frac{\gamma}{1+\gamma}\rho_* + \frac{c}{v(1+v)} \qquad (4)$$

Where *c* is the constant of integration and *v* is the volume expansion WDF naturally includes two components , a piece that behaves as a cosmological constant as well as a standard fluid with an equation of state $p = \gamma\rho$. We can show that if we take $c > 0$, this fluid will not violate the strong energy condition $p + \rho \ge 0$.

$$\mathrm{p}_{\mathrm{WDF}} + \rho_{WDF} = (1+\gamma)\rho_{WDF} - \gamma\rho_*$$
$$= (1+\gamma)\frac{c}{v^{(1+v)}} \ge 0 \qquad (5)$$

The wet dark fluid has been used as dark energy in the homogeneous, isotropic FRW case by Holman. Adhav *etal (2011),*, Mishra etal (2014), Nimkar etal (2015) ,Chirde etal (2016) , Dagwal (2020) are some of the researchers who have investigated various aspects of wet dark fluid.

The purpose of the present work is to obtain Bianchi type-VI_0 cosmological model in presence of wet dark fluid. Our paper is organized as follows. In section 2, we drive

the Metric and field Equations in self creation theory of gravitation**.** Section 3, contain solutions of wet dark fluid. .Section 4, is mainly concerned with the physical and Kinematical properties of the model The last section contains conclusion.

2. Metric and Field Equations:

We consider the Bianchi type VI_0 space time in the form,

$$ds^2 = -dt^2 + A^2dx^2 + B^2e^{2x}dy^2 + C^2e^{-2x}\,dz^2$$

(6)

Where A, B, C are functions of 't' only.

The energy-momentum tensor for wet dark fluid is given by,

$$T_{ij} = (\rho_{WDF} + p_{WDF})u_iu_j + p_{WDF}g_{ij} \qquad (7)$$

$$u_iu^i = -1 = -x_ix^i$$

From equation (2) we get,

$$T_1^1 = T_2^2 = T_3^3 = p_{WDF}, T_4^4 = -\rho_{WDF} \qquad (8)$$

The field equations in Barber second self creation theory are given by,

$$\frac{B_{44}}{B} + \frac{C_{44}}{C} + \frac{B_4C_4}{BC} + \frac{1}{A^2} = -8\pi\phi^{-1}\,p_{WDF}$$

(9)

$$\frac{A_{44}}{A} + \frac{C_{44}}{C} + \frac{A_4C_4}{AC} - \frac{1}{A^2} = -8\pi\phi^{-1}\,p_{WDF}$$

(10)

$$\frac{A_{44}}{A} + \frac{C_{44}}{C} + \frac{A_4C_4}{AC} + \frac{1}{A^2} = -8\pi\phi^{-1}\,p_{WDF}$$

(11)

$$\frac{A_4B_4}{AB} + \frac{A_4C_4}{AC} + \frac{B_4C_4}{BC} - \frac{1}{A^2} = 8\pi\phi^{-1}\rho$$

(12)

$$\frac{B_4}{B} - \frac{C_4}{C} = 0$$

(13)

$$\phi_{44}\left(\frac{A_4}{A} + \frac{B_4}{B} + \frac{C_4}{C}\right)\phi_4 = \frac{8\pi\upsilon}{3}(3p_{WDF} - \rho_{WDF})$$

(14)

Where suffixes 4 denotes ordinary differentiation with respect to time t.

3. Solutions of Field Equations :

The equations (9) to (14) is a system of six independent equations with seven unknown $A, B, C, \phi, \upsilon, p_{WDF}$ and ρ_{WDF} .In order to get

deterministic solution we use the condition for radiation

$$3p_{WDF} - \rho_{WDF} = 0 \qquad (15)$$

From equation (13) we get,

$$B = \mu C \qquad \mu = 1 \qquad (16)$$

Also the power law is given by

$$B = A^n \qquad (17)$$

We get ,

$$\frac{A_{44}}{A} + k_1 \frac{A_4^{\,2}}{A^2} - \frac{2}{A^2} = 0 \qquad (18)$$

Integrating equation (18) we get,

$$A = k_3 t + k_4 \qquad (19)$$

$$B = (k_3 t + k_4)^n \qquad (20)$$

$$C = (k_3 t + k_4)^n \qquad (21)$$

Using equations (19)-(21) cosmological model in equation (6) takes the form,

$$ds^2 = -dt^2 + (k_3 t + k_4)^2 dx^2 + (k_3 t + k_4)^{2n} e^{2x} dy^2 + (k_3 t + k_4)^{2n} e^{-2x} dz^2 \qquad (22)$$

From equation (14) we get

$$\phi = \frac{k_7}{(k_3 t + k_4)^{2n}} + k_6 \qquad (23)$$

From equation (9 -12),

$$p_{WDF} = \frac{k_8}{8\pi (k_3 t + k_4)^2} \left(\frac{k_7}{(k_3 t + k_4)^{2n}} + k_6 \right) \qquad (24)$$

$$\rho_{WDF} = \frac{k_9}{8\pi (k_3 t + k_4)^2} \left(\frac{k_7}{(k_3 t + k_4)^{2n}} + k_6 \right) \qquad (25)$$

4. Physical and Kinematic Properties :

In this section we discuss some physical and kinematical properties of wet dark fluid

The wet dark fluid cosmological model in Barber self creation theory is represented by (22) when $3p_{WDF} - \rho_{WDF} = 0$. The physical quantities that are important in cosmology are spatial volume ,the scalar expansion, shear scalar and Hubble's parameters and have the following expressions for the model given by (22).

Spatial Volume

$$v = (k_3 t + k_4)^{2n+1} \quad (26)$$

Scalar Expansion

$$\theta = \frac{1}{3}\frac{(2n+1)k_3}{k_3 t + k_4} \quad (27)$$

Hubble Parameter

$$H = \frac{(2n+1)k_3}{k_3 t + k_4} \quad (28)$$

Shear Scalar

$$\sigma^2 = \frac{3}{54}\left(\frac{(2n+1)k_3}{k_3 t + k_4}\right)^2 \quad (29)$$

Deceleration parameter

$$q = \frac{-2n}{2n+1} \quad (30)$$

Graphical representation of spatial volume,expansion scalar, shear scalar and Hubble parameters are -

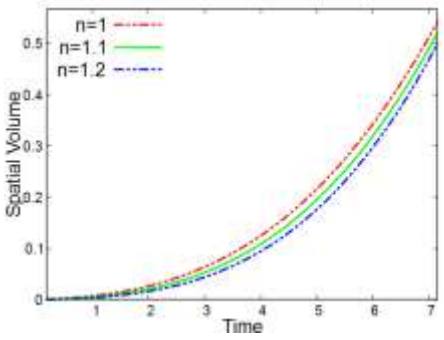

Figure 1: spatial volume vs time

Here we observed that at the initial point t=0, the spacial volume become zero and it becomes infinitely large.

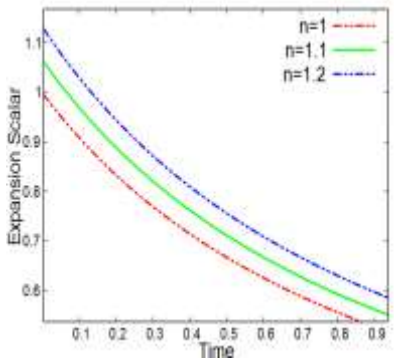

Figure 2: Expansion scalar vs time

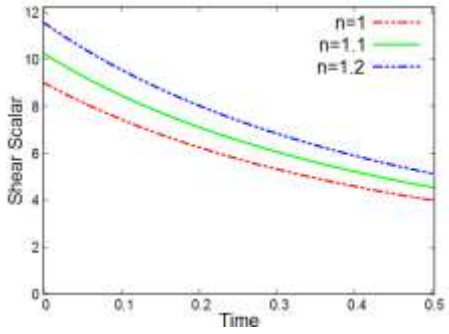

Figure 3: shear scalar vs time

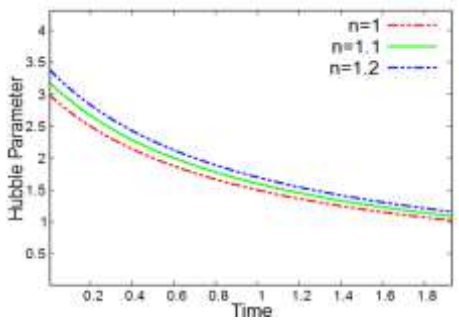

Figure 4: Hubble parameter vs time

The expression for the scalar field ,pressure and energy density for the wet dark fluid model in Barber self creation theory are given by (23) – (25). It may be observed that at initial moment ,when t=0, the spatial volume will be zero while energy density and pressure diverge. When t tends to zero, then the expansion scalar , shear scalar and Hubble's parameters tends to infinity. For large value of t, we observe that expansion scalar, shear scalar and Hubble parameters become zero.

Also, $\lim_{t\to\infty}\left(\frac{\sigma}{\theta}\right)\neq 0$

The model does not approach isotropy for large value of t.

Conclusion:-

In this paper, we have obtained Bianchi type-VI_0 cosmological model in Barber second self-creation theory of gravitation in presence of wet dark fluid . Wet dark fluid model studied here will be useful for a better understanding of scalar-tensor cosmology and structure formation of the universe. The model is free from singularities and it is expanding in the standard way. Also, we find all the physical quantities like pressure and density diverges at the initial moment.

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