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C-Field Model of Cosmos with Variable Newton's Gravitatinal Constant G and Non Zero Curvature index

by
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Abstract

Regarding Flat FRW space-time, an investigation is conducted on a creation field cosmological model with a time dependent Newton's constant G. We have investigated the possibility that there is a barotropic perfect fluid distribution throughout the universe. We made the assumption that $G = \alpha\dot{H} + \beta H^2$, where H is the Hubble parameter, in order to arrive at the deterministic model. We discover that because new matter is continuously being created, the density of the matter stays constant even though the creation field changes over time. In the absence of a particle horizon, G is found to vary as $\frac{1}{t^2}$. According to Riess et al.[30] and Perlmutter et al.[31], the model's representation of a universe that is expanding quickly is consistent with observations.

Mathematics Subject Classification 2020: 83C05,83C15,83F05

Keyword: Newton Constant ,Flat FRW, Creation field,Horizon.

1 Introduction

The conventional understanding of gravity as a fundamental force that is constant in strength throughout space and time is called into question by the theory of a changing gravitational constant. A stable gravitational constant (G) is necessary for both Albert Einstein's general theory of relativity and Isaac Newton's law of universal gravitation. According to other theories of gravity, G might vary based on circumstances or space-time regions. These alternative theories emerge either as extensions of general relativity to explain phenomena like the universe's fast expansion, or as attempts to reconcile discrepancies in cosmological data without resorting to dark matter or dark energy. For instance, fundamental constants like G could have changed across cosmic timescales according to changing speed of light (VSL) hypotheses.

Extra scalar fields in scalar-tensor theories affect the strength and, thus, the value of gravity.It is important to stress that, despite their interesting nature, these alternative theories remain theoretical and have not gained widespread acceptance among the scientific community. Based on experimental evidence, it is highly suggested that G stays constant within the current measurement accuracy.

The gravitational constant G appears in physics literature for the first time in Newton's law of gravitation.

$$F = \frac{Gm_1 m_2}{a^2}$$

There are two masses m_1 and m_2 that are separated by distance a , under the influence of the forces of attraction F.

There is confidence that the above law is correct, at least as a first approximation, because Newtonian gravity can explain gravitational events in our local area (the Earth and the Solar System).

For this reason, when he wrote down his gravity field equations in order to find the constant K, Einstein's law had to decrease to $F = \frac{Gm_1 m_2}{a^2}$ in the weak-field approximation, or $R_{ik} - \frac{R}{2} g_{ik} = -KT_{ik}$. The answer, which was determined by applying Newtonian mechanics, as $K = \frac{8\pi G}{c^4}$,where c is the speed of light.

Regardless of whether it is named after Einstein or Newton, gravity is a long-range force that is essential to cosmology and the universe's large-scale structure. Nevertheless, cosmic considerations pose deeper questions. The physical principles governing the construction of the cosmos are also included because, by definition, everything exists in the universe. In other words, rather than existing independently of the cosmos, laws are a fundamental component of it. So how much is the cosmos determining the law of gravity itself? transforms the law alter in form if the universe transforms as well? Evidently, if we are obliged to deal with a law of gravitation that varies with time and space as a result of the aforementioned concerns, the cosmological problem becomes considerably more challenging.

Gravitation is significant on a large scale because of the limited range of the strong and weak forces as well as the fact that electromagnetic force lessens due to the general neutrality of matter, as mentioned by Dicke and Peebles in their [1]. Dicke [2] highlighted that using Earth as a source of evidence for or against the existence of temporal fluctuation of the gravitational constant would be difficult. Dirac [3] mentioned a theory with a variable gravitational constant based on the assumption that high numbers occur often. Researchers Pochoda and Schwarzschild, Ezer and Cameron, and Gamow studied how the sun altered over time when a variable gravitational constant was present.

The solar development was examined by Pochoda and Schwarzschild [4], Ezer and Cameron [5], and Gamow [6] in the presence of a time-varying gravitational constant. If the Dirac theory had been correct, they concluded, the Sun would have burned off its initial nuclear fuel by now. This is the outcome of the Poisson equation, which states that an increase in the gravitational constant is equal to an increase in the density of stars. Demarque and colleagues [7] examined an ansatz where $G \propto t^{-n}$ and demonstrated that $|n| < 0.1$ is equivalent to $|\frac{\dot{G}}{G}| < 2 \times 10^{-11} yr^{-1}$. Gaztanaga et al. [8] considered the effect of a variation of the gravitational constant on the cooling of white dwarfs and on their luminosity function and concludes that $|\frac{\dot{G}}{G}| < 3 \times 10^{-11} yr^{-1}$.Barrow [9] assumed that $G \propto t^{-n}$ and obtained from helium abundances for $-5.9 \times 10^{-3} < n < 7 \times 10^{-3}$, $|\frac{\dot{G}}{G}| < (2 \pm 9.3) h \times 10^{-12} yr^{-1}$ by assuming a flat universe.

In order to extend Einstein's general theory of relativity by incorporating variable G and meeting the conservation equation, alternative theories of gravity that are mathematically well posed were subsequently created. Many proposals have been made for the potential extension of general relativity with time-dependent G in an effort to unify gravitation and elementary particle physics or to include Mach's principle into the theory [10]–[13].

All studies pertaining to the physical events in the early cosmos employ a universe model, sometimes referred to as the "big-bang model." Nonetheless, it is well known that the big-bang paradigm has shortcomings in the following areas: (i) There is a singularity in the model's history and perhaps a future one. Both physical incompleteness and mathematical inconsistency are shown by the singularity. (ii) The big-bang concept defies the law of conservation of energy. In contrast, the energy density in the big-bang scenario is positive-definite, as the left-hand side of Einstein's field equation has zero divergence. Therefore, matter cannot exist without going against the principle of energy conservation. (iii) In the early epochs of the cosmos, the big-bang theories based on plausible equations of state result in an extremely narrow particle horizon. The universe's "horizon problem" is a result of this reality. (iv) There isn't a single coherent scenario that fits the framework of the big bang model to explain the genesis, development, and characteristics of small-scale structures in the universe. (v)Problem of flatness.

The horizon and flatness issues that plagued the big-bang model have been resolved by the C-field, a negative energy field. In the usual big-bang scenario, inflation has provided a solution to these issues. Using inflationary theory within the framework of the big bang, the difficulties of the universe's flatness and isotropy have been resolved (Guth [14]). Numerous authors, including Linde [15], Grön [16], Barrow [17], Rothman and Ellis [18], Madsen and Coles [19], Linde [20], Bali and Jain [21], Chervon [22], Reddy and Naidu [23], have discussed how inflation has also provided a basis for understanding the origin of large structures resulting from quantum fluctuations during the inflationary period.

A certain amount of freedom that functions as a negative energy mode is required if a model is able to explain the production of positive-energy matter without going against energy conservation. Such a "negative energy mode" originating from the scale degree of freedom of gravity is employed by all quantum gravitational models that explain creation consistently [14]. Thus, the natural process of matter production is enabled by a negative-energy field.We are aware that when positive of energy density is not assured, the classical singularity theorems stop working. To explain the formation of matter, Hoyle and Narliker [24] used a field theoretic method that included a massless and chargeless scalar field. The C-field theory does not contain a big-bang type singularity, unlike Bondi and Gold's steady-state theory [25]. Narlikar [26] has highlighted that the production of matter occurs at the cost of the negative energy C-field. Einstein's field equations have been solved by Narlikar and Padmanabhan [27], which allows radiation and a massless scalar creation field with negative energy as a source. It has been demonstrated that a cosmological model grounded on this solution meets all empirical requirements, serves as a strong substitute for the conventional big-bang model, is devoid of singularity and particle horizon, and offers a rationale for the flatness issue. According to several writers, including Caldwell [28], Gibbons [29], Singh et al. [30], Giocomini and Lara [31], and Paul and Paul [32], the phantom field is also the resuscitation of the C-field. In their paper [33], Vishwakarma and Narlikar address modelling repulsive gravity with creation. In FRW space-time with a variable gravitational constant, Bali and Tikekar [34], Bali and Kumawat [35],and many other authors [38]-[41] have recently studied C-field cosmological models .

Inspired by the aforementioned, we have examined C-field cosmological models within the framework of flat FRW space-time for barotropic perfect fluid distributions with variable G. We have assumed $G = \alpha\dot{H} + \beta H^2$ to obtain the deterministic solution, where H is the Hubble parameter and over dot indicates derivative with regard to time. Additionally, we have spoken about a cosmological model for certain values of constants in terms of cosmic time. There is also discussion of the physical factors associated with the astronomical observations.

2 Metric and Basic Field Equations

Robertson-Walker characterizes cosmological space-time as homogeneous and isotropic in the type

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

Where $k = 0, 1, -1$curvature index.

By adding the C-field, Hoyle and Narlikar [11] alter Einstein's field equations as

$$R_i^j - \frac{R}{2} g_i^j = -8\pi G[{T_m}_i^j + {T_c}_i^j] + \Lambda g_i^j \quad (2)$$

The perfect fluid energy momentum tensor (${T_m}_i^j$) and creation field tensor (${T_c}_i^j$) are defined as

$${T_m}_i^j = (\rho + p)v_i v^j - p g_i^j \quad (3)$$

$${T_c}_i^j = -f(C_i C^j - \frac{1}{2} g_i^j C^\alpha C_\alpha) \quad (4)$$

where matter and the creation field are coupled with a coupling constant $f > 0$ and $C_i = \frac{dC}{dx^i}$. The modified Einstein field equation for FRW metric with $\Lambda = 0$ gives

$$\frac{3\dot{R}^2}{R^2} + \frac{3k}{R^2} = 8\pi G[\rho - \frac{1}{2} f \dot{C}^2] \quad (5)$$

$$\frac{2\ddot{R}}{R} + \frac{\dot{R}^2}{R^2} + \frac{k}{R^2} = 8\pi G[\frac{1}{2} f \dot{C}^2 - p] \quad (6)$$

3 Solution of The Field Equations

vanishing divergence of Einstein Tensor leads to energy conservation equation with $\Lambda = 0$.

$$[8\pi G T_i^j]_{;j} = 0$$

This takes

$$8\pi\dot{G}[\rho - \frac{1}{2} f\dot{C}^2] + 8\pi G[\dot{\rho} - f\dot{C}\ddot{C} + 3\rho\frac{\dot{R}}{R} - 3f\dot{C}^2\frac{\dot{R}}{R} + 3p\frac{\dot{R}}{R}] = 0 \quad (7)$$

Where Hoyle and Narlikar's consideration of the isotropic pressure $p = \omega\rho$ and the gravitational constant G as a function of time are taken into account. Furthermore, $C^i_{;j} = 0$ in the source field equation This demonstrates that $\dot{C} = 1$ with the condition $\dot{C} = 1$ above equations (5) and (6), as well as that $C = t$ for large values of r.

$$\frac{3\dot{R}^2}{R^2} + \frac{3k}{R^2} = 8\pi G[\rho - \frac{1}{2}f] \tag{8}$$

$$\frac{2\ddot{R}}{R} + \frac{\dot{R}^2}{R^2} + \frac{k}{R^2} = 4\pi G f - 8\pi G\omega\rho \tag{9}$$

These two equation together give

$$\frac{2\ddot{R}}{R} + (1+3\omega)\frac{\dot{R}^2}{R^2} = (1-\omega)4\pi G f - \frac{(1+3\omega)k}{R^2} \tag{10}$$

To obtain a deterministic solution, we assume

$$G = 2\alpha\frac{\ddot{R}}{R} + \beta\frac{\dot{R}^2}{R^2} \tag{11}$$

Where α and β are constants and R is the scale factor.
Equation (10) can be written as

$$\frac{2\ddot{R}}{R} + (1+3\omega)\frac{\dot{R}^2}{R^2} = (1-\omega)4\pi f(2\alpha\frac{\ddot{R}}{R} + \beta\frac{\dot{R}^2}{R^2}) - \frac{(1+3\omega)k}{R^2} \tag{12}$$

$$2[4(1-\omega)\pi f\alpha - 1]\frac{\ddot{R}}{R} + [(1-\omega)4\pi f\beta - (1+3\omega)]\frac{\dot{R}^2}{R^2} = \frac{(1+3\omega)k}{R^2} \tag{13}$$

Which can be written as

$$2\frac{\ddot{R}}{R} + \frac{[(1-\omega)4\pi f\beta - (1+3\omega)]}{[4(1-\omega)\pi f\alpha - 1]}\frac{\dot{R}^2}{R^2} = \frac{(1+3\omega)k}{[4(1-\omega)\pi f\alpha - 1]}\frac{1}{R^2} \tag{14}$$

Where $4(1-\omega)\pi f\alpha - 1 \neq 0$ and let $\epsilon = \frac{[(1-\omega)4\pi f\beta]-(1+3\omega)}{[4(1-\omega)\pi f\alpha-1]}$ and $\delta = \frac{(1+3\omega)k}{[4(1-\omega)\pi f\alpha-1]}$ Now above equation take the following form

$$2\ddot{R} + \epsilon\frac{\dot{R}^2}{R} = \delta\frac{1}{R} \tag{15}$$

$$\dot{R}^2 R^\epsilon = \delta\frac{1}{\epsilon}R^\epsilon + M \tag{16}$$

Where M is constant of integration.For deterministic solution, we considered $M = 0$.

This gives

$$\dot{R}^2 = \frac{\delta}{\epsilon} \tag{17}$$

On integration this gives

$$R = \sqrt{\frac{\delta}{\epsilon}t + c} \tag{18}$$

Where c is constant of integration . for deterministic we take $c = 0$ then above equation take the form

$$R = \sqrt{\frac{\delta}{\epsilon}t} \tag{19}$$

Now Newton's constant G becomes

$$G = \frac{\beta}{t^2} \tag{20}$$

Energy density can be given as

$$\rho = \frac{3(\delta + \epsilon k)}{8\pi\beta\delta} + \frac{f}{2} \tag{21}$$

The isotropic pressure becomes

$$p = \omega\rho = \omega[\frac{3(\delta + \epsilon k)}{8\pi\beta\delta} + \frac{f}{2}] \tag{22}$$

By putting barotropic equation of state $p = \omega\rho$ in equation (7)

$$8\pi\dot{G}[\rho - \frac{1}{2}f\dot{C}^2] + 8\pi G[\dot{\rho} - f\dot{C}\ddot{C} + 3\rho\frac{\dot{R}}{R} - 3f\dot{C}^2\frac{\dot{R}}{R} + 3\omega\rho\frac{\dot{R}}{R}] = 0 \tag{23}$$

Equation (23) after using (19),(20),(21) becomes

$$\frac{d\dot{C}^2}{dt} + (\frac{\dot{G}}{G} + 6H)\dot{C}^2 = \frac{2\rho}{f}[\frac{\dot{G}}{G} + 3H(1 + \omega)] \tag{24}$$

Integrating above we get

$$\dot{C}^2t^4 = [\frac{(1 + 3\omega)}{2\pi f(\beta - \alpha)} + (1 + 3\omega)]\int t^3dt + M \tag{25}$$

For deterministic solution we considered integration constant $M = 0$

$$\dot{C}^2t^4 = [\frac{(1 + 3\omega)}{2\pi f(\beta - \alpha)} + (1 + 3\omega)]\frac{t^4}{4} \tag{26}$$

$$\dot{C}^2 = \frac{(1 + 3\omega)}{8\pi f(\beta - \alpha)} + \frac{(1 + 3\omega)}{4} \tag{27}$$

In order to get deterministic solution we take $\frac{1}{2\pi f} = \frac{\omega}{1+\omega}(\alpha - \beta)$ Which take the form

$$\dot{C}^2 = 1 \tag{28}$$

On integration this gives

$$C = t \tag{29}$$

This shows that creation field increases with cosmic time.
Now the metric take the form

$$ds^2 = dt^2 - (\sqrt{\frac{\delta}{\epsilon}}t)^2[\frac{dr^2}{1-kr^2} + r^2d\theta^2 + r^2sin^2\theta d\phi^2] \tag{30}$$

Since $\epsilon = \frac{[(1-\omega)4\pi f\beta-(1+3\omega)]}{[4(1-\omega)\pi f\alpha-1]}$
and $\delta = \frac{(1+3\omega)k}{[4(1-\omega)\pi f\alpha-1]}$.
Hence $\frac{\delta}{\epsilon} = \frac{[(1+3\omega)k]}{[(1-\omega)4\pi f\beta-(1+3\omega)]}$
Now above equation take the following form

$$ds^2 = dt^2 - \left[\frac{[(1+3\omega)k]}{[(1-\omega)4\pi f\beta-(1+3\omega)]}\right]t^2[\frac{dr^2}{1-kr^2} + r^2d\theta^2 + r^2sin^2\theta d\phi^2] \tag{31}$$

4 Physical and Geometrical behaviour of the model

Now the metric take the form

$$ds^2 = dt^2 - (\sqrt{\frac{\delta}{\epsilon}}t)^2[\frac{dr^2}{1-kr^2} + r^2d\theta^2 + r^2sin^2\theta d\phi^2] \tag{32}$$

Since $\epsilon = \frac{[(1-\omega)4\pi f\beta-(1+3\omega)]}{[4(1-\omega)\pi f\alpha-1]}$
and $\delta = \frac{(1+3\omega)k}{[4(1-\omega)\pi f\alpha-1]}$.
Hence $\frac{\delta}{\epsilon} = \frac{[(1+3\omega)k]}{[(1-\omega)4\pi f\beta-(1+3\omega)]}$

Now above equation take the following form

$$ds^2 = dt^2 - \left[\frac{[(1+3\omega)k]}{[(1-\omega)4\pi f\beta-(1+3\omega)]}\right]t^2[\frac{dr^2}{1-kr^2} + r^2d\theta^2 + r^2sin^2\theta d\phi^2] \tag{33}$$

Cosmic Scale Factor

$$R=\sqrt{\frac{\delta}{\epsilon}}t$$

Newton's Constant G

$$G=\frac{\beta}{t^2}$$

Energy Density

$$\rho=\frac{3(\delta+\epsilon k)}{8\pi\beta\delta}+\frac{f}{2}$$

The Isotropic Pressure

$$p=\omega\rho=\omega[\frac{3(\delta+\epsilon k)}{8\pi\beta\delta}+\frac{f}{2}]$$

Hubble Parameter

$$H=\frac{\dot{R}}{R}=\frac{1}{t}$$

Decceleration Parameter

$$q=-1-\frac{H\dot{H}}{H^2}=-1+\frac{1}{t}$$

5 Conclusions

For the model (30), the matter density (ρ)is constant with time.In cosmology, the cosmic energy density refers to the total amount of energy contained within a given volume of the universe. It's a crucial concept in understanding the dynamics and evolution of the universe.In the early universe, when densities and temperatures were extremely high, various forms of energy, such as radiation and relativistic particles, exerted isotropic pressure. This pressure was an essential component in determining the evolution of the universe, including processes like cosmic inflation and the formation of the cosmic microwave background radiation. The scale factor (R) increases with time.As the universe evolves over time, the scale factor changes. When the scale factor increases, distances between galaxies and other objects in the universe increase as well, indicating the expansion of the universe. Conversely, if the

scale factor decreases, distances between objects decrease, indicating a contracting universe.Newton's constant is a fundamental constant of nature, and its value determines the strength of the gravitational force between objects.As it is function of cosmic time and $|\frac{\dot{G}}{G}| = 2H.G \to \infty$ when $t \to 0$ and $G \to 0$ when $t \to \infty$.The deceleration parameter, often denoted as q, is a dimensionless quantity used in cosmology to describe the rate at which the expansion of the universe is slowing down or speeding up. It characterizes the acceleration or deceleration of the universe's expansion. The deceleration parameter $q \neq 0$ indicates that the model (30) represents accelerating universe. Thus, an inflationary scenario exists in the model (30).The Hubble parameter, denoted as $H(t)$ or $H(z)$, depending on whether it's expressed as a function of time or redshift, is a measure of the rate of expansion of the universe. It quantifies how quickly objects in the universe are moving away from each other as a result of the expansion of space.The value of the Hubble parameter is not constant over cosmic time but changes as the universe evolves. Observationally, it's often expressed in terms of the Hubble constant, denoted as H_0, which represents its present-day value. The Hubble constant is typically measured in units of kilometers per second per megaparsec (km/s/Mpc).The Hubble parameter and its variations provide essential information about the age, size, and expansion history of the universe. The creation field (C) increases with time and $\dot{C} = 1$ which agrees with the value taken in source equation. When $t = 0$ then $\rho = constant$. This result may be interpreted as: Referring to Narlikar [36], Hawking and Ellis[37], the matter is supposed to move along the geodesic normal to the surface t = constant. As the matter moves further apart, it is assumed that more matter is continuously created to maintain the matter density at constant value.
The coordinate distance to the horizon $r_H(t)$ is the maximum distance a null ray could have travelled at time t starting from the infinite past i.e.

$$r_H(t) = \int_{\infty}^{t} \frac{1}{R(t)} dt$$

We could extend the proper time t to $(-\infty)$ in the past because of the nonsingular nature of the space-time. Now

$$r_H(t) = \int_{0}^{t} \frac{1}{\sqrt{\left[\frac{[(1+3\omega)k]}{[(1-\omega)4\pi f\beta-(1+3\omega)]}\right]t}} dt$$

This integral diverges at lower limit, showing that the models (30) is free from horizon.

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