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FRW DOMAIN WALLS IN MODIFIED $f(G)$ THEORY OF GRAVITATION

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In this paper, we have studied Friedmann-Robertson-Walker space-time in the presence of domain walls in the framework of $f(G)$ theory of gravitation. We propose the generalization of linearly varying deceleration parameter. It is observed that the universe is accelerating and expanding. The values of state finder parameters are close to ΛCDM model. Some physical parameters of the obtained models are discussed in detail.

Keywords: *Domain walls: FRW, $f(G)$ gravity*

1. *Introduction.* Einstein's general theory of relativity (GR) laid foundation of theoretical cosmology whereas observational cosmology is boosted by the work of Hubble. Hubble has pointed out that galaxies are moving away from each other i.e. the universe is expanding. The present observational data indicate that the expansion of the universe is accelerating. The accelerated expansion of the universe could not be explained in the background of general relativity. In addition to this general theory of relativity has singularity problem. Hence, modified theories of gravitation are proposed by replacing R in the Einstein-Hilbert action. When R is replaced by $f(R)$ in Einstein-Hilbert action, the resulting theory is known as $f(R)$ theory of gravitation [1]. Very recently Harko et al. [2] have constructed a generalized $f(R,T)$ gravity where the gravitational Lagrangian is given by an arbitrary function of the Ricci scalar R and of the trace T of the stress energy tensor. The $f(G)$ is another modified theory of gravitation which is obtained by introducing the Gauss-Bonnet curvature invariants G. In the framework of the $f(G)$ theory, one can construct viable and consistent models with local constraints of General Relativity. The curvature invariant G can avoid ghost contribution and contribute to the regularization of the gravitational action [3]. Recently, various cosmological models have been constructed in the $f(G)$ theory for various physical fluid. Capozziello et al. [4] have discussed Noether symmetry approach in the context of the $f(G)$ cosmology. Myrzakulov et al. [5] have studied cosmological solution on the ΛCDM model in the $f(G)$ gravity. Dadhich [6] has coupled four dimensional space time with Gauss-Bonnet gravity. Bamba et al. [7] have

explored bouncing cosmology in the $f(G)$ gravity. Kang et al. [8] have obtained static spherically symmetric star in Gauss-Bonnet gravity. Katore et al. [9] have discussed string bulk viscous cosmological models in the $f(G)$ theory of gravitation.

Early stages of evolution of the universe has been an active field of investigation in recent days. It is assumed that, the universe has gone through the various phases of transition. In the phase of vacuum domain walls are formed which may possibly have survived to the present day. Topological defects play an important role in the formation of the large scale structure of the universe. Recently, domain walls have been received considerable interest. Katore et al. [10-12] have studied domain walls in various context. Reddy et al. [13] have studied domain walls and cosmic string in Bimetric theory. Press et al. [14] have investigated dynamical evolution of domain walls in an expanding universe. Tiwari [15] have obtained transition of the 5D perfect fluid universe in $f(R,T)$ theory of gravitation.

In view of high energy physics, string theory is a valid modification of GR. Gauss-Bonnet (GB) is correction to GR where GB terms in four dimenions has no dynamics. In order to affect the GB terms on the Friedmann equation, we require that couple GB term with matter field or to add it by a non-linear form $f(G)$ [16]. In $f(G)$ theory the 6 primary constraints coming from the higher derivative modes in the action generates only 5 secondary constraints and the Hamiltonian still remain linear in the trace momentum. The Ostrogradsky mode possesed by the $f(G)$ theory is removed by adding kinetic term for the scalar field in the action which result in generation of 6 secondary constraints and total number of degree of freedom remain same. This makes $f(G)$ is classically equivalent to some Horndeski Theory [17-19]. In the literature, it is found that $f(G)$ has ability to describe the inflationary era, transition from deceleration to acceleration epoch and crossing of phantom divide line [20,21].

The above discussion motivated us to study domain walls in the $f(G)$ theory of gravitation. The main purpose of this work is to present generalization of linearly varying deceleration parameter proposed by Akarsu and Dereli [22]. The paper is organized as follows: in section 2, we present metric and field equations. In section 3 and 4 we obtain the solutions of the field equations. In section 5, we conclude our discussion.

2. *Metric and field equations*. Recently, the detection of gravitational wave by the LIGO-VIRGO placed the constraints on higher order gravitational theories. Jana and Mohanty [23] have been obtained bounds on $f(R)$ such that $|f'(R_0)-1|<3\cdot 10^{-3}$ where R_0 is the curvature of the universe at present. In the light of the GW170817, the constraints for $f(G)$ gravity are $\rho_G \geq 0$, equation of motion and $f_{GG}>0$ [24]. Besides it was shown that there are some viable $f(G)$ models that can pass the solar system test [25-26]. The action of the $f(G)$ gravity

is given by the following equation

$$S_1 = \frac{1}{2L}\int\left[R + f(G)\right]\sqrt{-g}\,d^4x + s_\varphi\left(g^{ij},\varphi\right), \tag{1}$$

where g is the determinant of the metric tensor g_{ij}, $L^2 = 8\pi G_n$, G_N is the constant of Newtonian, s_φ is the action of matter. The matter is minimally coupled to the metric tensor g_{ij} which means $f(G)$ is a purely metric theory of gravity, φ represents the matter field. The $f(G)$ is an arbitrary function of G which is given by

$$G = R^2 - 4R_{ij}R^{ij} + R_{ij\mu\nu}R^{ij\mu\nu}, \tag{2}$$

where R is the Ricci scalar, R_{ij} stands for Ricci tensor and $R_{ij\mu\nu}$ denotes Riemannian tensors. Varying the action (1) with respect to the metric g_{ij} we obtain the field equations as

$$\begin{aligned} R_{ij} - \frac{1}{2}Rg_{ij} + \delta\Big[&R_{i\mu j\nu} + R_{\mu j}g_{\nu i} - R_{\mu\nu}g_{ji} - R_{ij}g_{\nu\mu} + R_{i\nu}g_{j\mu} \\ &+ \frac{1}{2}R\left(R_{ij}g_{\mu\nu} - g_{i\nu}g_{j\mu}\right)\Big]\nabla^\mu\nabla^\nu + \left(Gf_G - f\right)g_{ij} = LT_{ij}, \end{aligned} \tag{3}$$

here ∇_μ denotes the covariant derivative and f_G stand for the derivative of f with respect to G. Many cosmological issues like cosmological inflation, late time acceleration of the universe are explained in the framework of scalar field. However, modified gravity models with geometry-matter coupling play a vital role in completer explaining the late time acceleration not only from geometrical contribution but it is also depended on the matter content of the universe. Moreover, they can provide alternative explanation of dark energy. These models describe gravitational dynamics that usually assumed and are useful for connecting the classical and the quantum worlds. The stress energy tensor T in the gravitational action may be due to quantum effects or of some imperfect quantum fields [2,27]. Friedmann-Robertson-Walker is the simplest homogeneous and isotropic model of the universe. It is a good approximation of the present day. We consider the Friedmann-Robertson-Walker (FRW) cosmological model in the following form;

$$ds^2 = dt^2 - S^2\left(\frac{dr^2}{1-kr^2} + r^2\left(d\theta^2 + \sin\theta^2\,d\phi\right)\right). \tag{4}$$

In FRW space time, the angles $0 \le \theta \le \pi$ and $0 \le \phi \le 2\pi$ are the usual azimuthal and polar angles of spherical coordinates. The k represents the curvature of the space. It has three different values. When $k=1$ the radius is finite and the universe is closed. When $k=0$, the universe is flat and when $k=-1$ the radius is infinite or imaginary corresponding to open universe [28]. Pradhan et al. [29] have presented general solutions for domain walls in Lyra geometry. Khadekar et al.

[30] have studied Kaluza-Klein type FRW cosmological model with domain walls. The Ricci tensor and Gauss-Bonnet invariant are obtained as:

$$R = -6\left[\frac{k}{S^2} + \frac{\dot{S}^2}{S^2} + \frac{\ddot{S}}{S}\right], \tag{5}$$

$$G = 12k\frac{\dot{S}^2}{S^4} + 24k\frac{\ddot{S}}{S^3} + 24\frac{\dot{S}^2\ddot{S}}{S^3}, \tag{6}$$

where over dot denotes differentiation with respect to *t*. The energy momentum tensor of domain walls is given as

$$T_{ij} = \rho\left(g_{ij} + \mu_i\mu_j\right) + P\mu_i\mu_j\,. \tag{7}$$

Based on the standard model of particle physics, it is believed that when the hot early universe cooled and expanded, the field would have settled down to single values within extended regions. The boundaries of those different regions would be the domain walls. The T_{ij} of domain walls contain normal matter ρ_m and pressure P_m as well as tension σ_d with the relation $P = P_m - \sigma_d$, $\rho = \rho_m + \sigma_d$ satisfying $P_m = (\gamma - 1)\rho_m$, $1 \le \gamma \le 2$. For the line element (4) with the help of euations (3) and (7) we have the following set of field equations.

$$\frac{k}{S^2} + \frac{\dot{S}^2}{S^2} + 2\frac{\ddot{S}}{S} + 16\frac{\dot{S}\ddot{S}}{S^2}\dot{f}_G - 8\left[\frac{k}{S^2} + \frac{\dot{S}^2}{S^2}\right]\ddot{f}_G + Gf_G - f = L\rho \tag{8}$$

$$3\frac{k}{S^2} + 3\frac{\dot{S}^2}{S^2} - 24\left[\frac{k}{S^2} + \frac{\dot{S}^2}{S^2}\right]\ddot{f}_G + Gf_G - f = -LP. \tag{9}$$

Very recently, Houndjo et al. [31] have presented solutions for cylindrically symmetric metric in $f(G)$ theory of gravitation. Sharif and Ikram [32] have explored warm inflation in the background of $f(G)$ theory of gravitation. Atazadeh and Darabi [3] have studied the viability of an alternative gravitational theory $f(R,G)$. Sharif and Fatima [33] have discussed role of Gauss Bonnet term for the early and late time acceleration phase of the universe in $f(G)$ theory. Garcia et al. [34] have studied $f(G)$ gravity and the energy conditions. Here, we have two equations in four unknown. Now, two more conditions are required to solve the system of equations. Firstly we assume that

$$f(G) = \alpha G^{\beta+1} \tag{10}$$

where α, β are arbitrary constants. Secondly, we assume varying deceleration parameter as

$$q = -\frac{S\ddot{S}}{\dot{S}^2} = -b(t) - 1. \tag{11}$$

The law of variation for the Hubble parameter that yield a constant value of the deceleration parameter is proposed by Berman [35]. Akarsu and Dereli [22] have presented generalized linearly varying deceleration parameter (LVDP) which is generalization of Berman [35] law. In this work, we generalize the linearly varying deceleration parameter given in equation (11). If we take $b(t)=\alpha t-m$, we get the LVDP proposed by Akarsu and Dereli [22]. Equation (11) further leads to

$$\frac{\dot{S}}{S}=-\frac{1}{\int b(t)dt}. \tag{12}$$

Akarsu et al. [36] also proposed hybrid law of expansion to obtain the solution of the field equations. In this paper we investigate state finders defined as follows:

$$r^{*}=\frac{\dddot{S}}{SH^{3}} \tag{13}$$

$$s=\frac{r-1}{3\left(q-\frac{1}{2}\right)}. \tag{14}$$

Sahni et al. [37] have introduced a new geometrical diagnostic pair for dark energy. It is called state finder pair r^{*}, s. It is constructed from scale factor S and its derivatives up to the third order. In this pair r^{*} is natural extension of Hubble parameter and deceleration parameter q whereas s is a linear combination of r^{*} and q. For spatially flat universe in the LCDM the pair corresponds to a fixed point $(S, r^{*})=(0,1)$. In this paper we would like to discuss physical parameters such as lookback time, proper distance etc. The time travel of photon from the source at instant r^{*} and destination at time t_0 is given by $t - t_0$ and we call it as photon travel time or look back time. It is defined as

$$t-t_0=\int_{S_0}^{S}\frac{ds}{\dot{S}} \tag{15}$$

where S_0 is the present value of the scale factor of the universe. The redshift Z can be given by the equation

$$1+Z=\frac{S_0}{S}. \tag{16}$$

The distance travelled by photon from a source to receiver is a proper distance and is defined by

$$D=S_0\int_{t}^{t_0}\frac{dt}{S}. \tag{17}$$

3. *Case I.* In this case we assume the following form of the function $b(t)$

$$b(t)=-\mathrm{sech}^{2}\, t. \tag{18}$$

The deceleration parameter and scale factor are obtained as

$$q = \text{sech}^2 t - 1 \tag{19}$$

$$S = \sinh t\,. \tag{20}$$

It should be noted that the sign of the deceleration parameter indicate whether the universe is accelerating or decelerating. Positive sign corresponds to decelerating universe whereas negative sign indicate accelerating universe. It is clear that the deceleration parameter vary from positive to negative values. The universe was decelerating in the past and accelerating at the present (see Fig.3). The scale factor is increasing function of time. The Gauss-Bonnet invariant G is found to be

$$G = \frac{12k}{\sinh^2 t}\left[\coth^2 t + 2\right] + 24\coth^2 t\,. \tag{21}$$

The energy density ρ, Pressure P and tension of the domain walls σ_d have the following expressions

$$\begin{aligned} L_\rho = d_1 + l_3 G^{\beta-1}&\left[\frac{d_2\sinh t - d_3\cosh t}{\sinh^6 t} - \frac{96\cosh^2 t + 48 l_2\left(3 + 2\sinh^2 t\right)}{\sinh^4 t}\right] \\ &+ \alpha\beta\, G^{\beta+1} - d_4 G^{\beta-2}\left[-\frac{d_5}{\sinh^{16} t} + \frac{d_6}{\sinh^8 t} + \frac{d_7}{\sinh^6 t}\right] \end{aligned} \tag{22}$$

$$LP = -3l_2 - 3l_2 l_3 G^{\beta-1}\left[\frac{12\,kl_1\cosh t}{\sinh^6 t} + \frac{48\cosh^2 t}{\sinh^4 t}\right] - \alpha\beta\, G^{\beta+1} \tag{23}$$

$$\begin{aligned} L\sigma_d = d_8 + d_4 G^{\beta-1}&\left[\frac{(\gamma-1)\left(d_2\sinh t - d_3\cosh t\right) + 36\,kl_1 l_2\cosh t}{\gamma\sinh^6 t} + \frac{d_9 + d_{10}\sinh^2 t}{\sinh^4 t}\right] \\ &+ \alpha\beta\, G^{\beta+1} + d_6 G^{\beta-2}\left[\frac{(\gamma-1)d_5}{\gamma\sinh^{10} t} + \frac{(\gamma-1)d_6\cosh t}{\gamma\sinh^8 t} + \frac{(\gamma-1)d_7\cosh^2 t}{\gamma\sinh^6 t}\right] \end{aligned} \tag{24}$$

where

$$l_1 = 1 + 2\cosh t + 3\sinh^2 t\,,\quad l_2 = \frac{k}{\sinh^2 t} + \cosh^2 t\,,\quad l_3 = 8\alpha\beta(\beta+1),$$
$$d_1 = 2 + l_2\,,\quad d_2 = 24\,kl_1 l_2\,,\quad d_3 = l_1(24k + l_2),\quad d_4 = l_3(\beta-1),$$
$$d_5 = 144\,kl_1 l_2\,,\quad d_6 = 1152\,kl_1 l_2\,,\quad d_7 = 2304\,l_2\,,\quad d_8 = 2\frac{\gamma-1}{\gamma} + \frac{l_2(\gamma+2)}{\gamma},$$
$$d_9 = 96(1-\gamma) + 144k(2-\gamma),\quad d_{10} = 240\,l_2 + 96 - 96\gamma - 96\,l_2\,\gamma\,.$$

From Fig.1, it is observed that energy density is positive only for $k = 1$. It is zero for $k = 0$ and negative for $k = -1$. The tension of the domain walls is positive in the early stages for $k = 1$, -1 which tends to zero at later time and therefore the domain walls will be vanished in the far future (see Fig.2), which is as per the expectations of Zeldovich et al. [38]. The σ_d is zero throughout the evolution

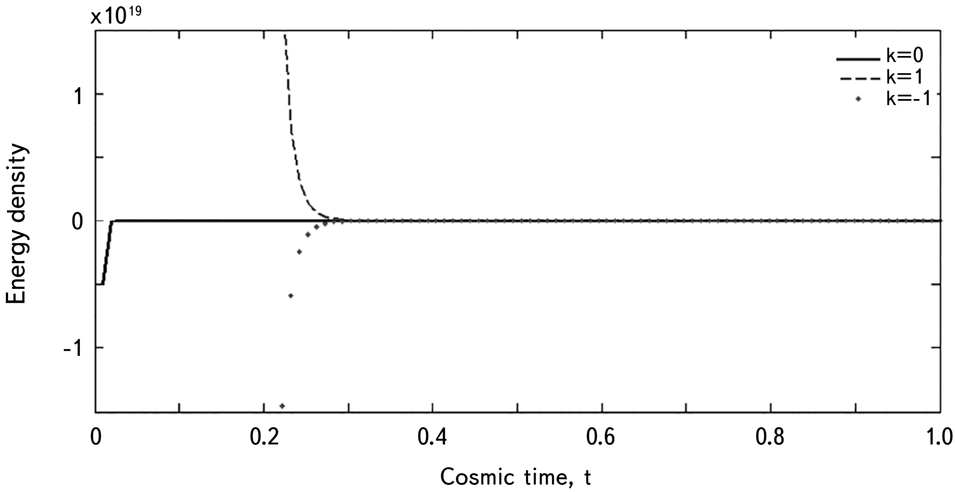

Fig.1. Plot of energy density with cosmic time.

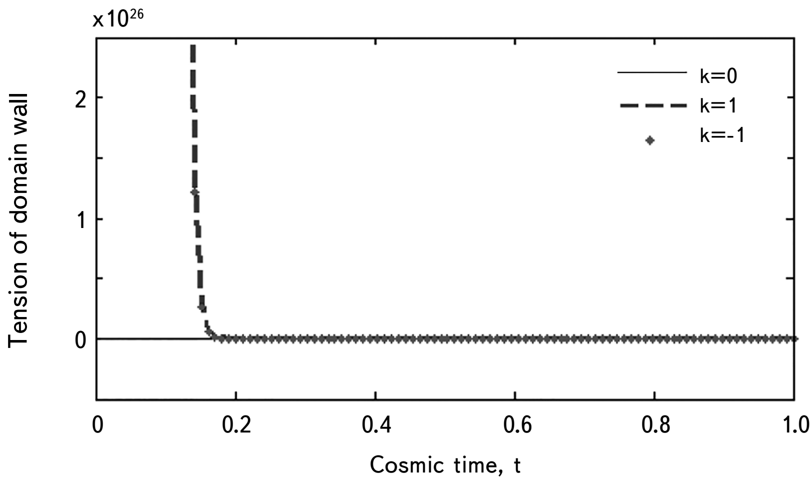

Fig.2. Plot of tension of domain wall with cosmic time.

for $k=0$. Since energy density is negative for $k=-1$. We are not interested in this case. The model is in favor of closed universe. It is important to note that in our earlier study of domain walls in $f(R,T)$ theory we found that the possibility of closed universe model is declined and model is in favor of flat and or open universe [10]. In self creation theory in case of FRW space time, it is found that the energy density tends to constant at large time [39].

3.1. *Physical parameters*. The look back time, Hubble parameter, proper distance, luminosity distance, and a pair of state finders are obtatained as follows:

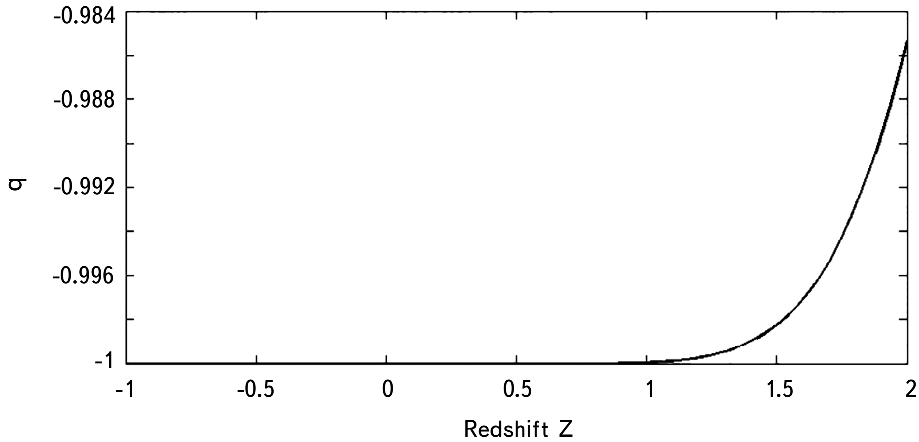

Fig.3. Plot of deceleration parameter with redshift.

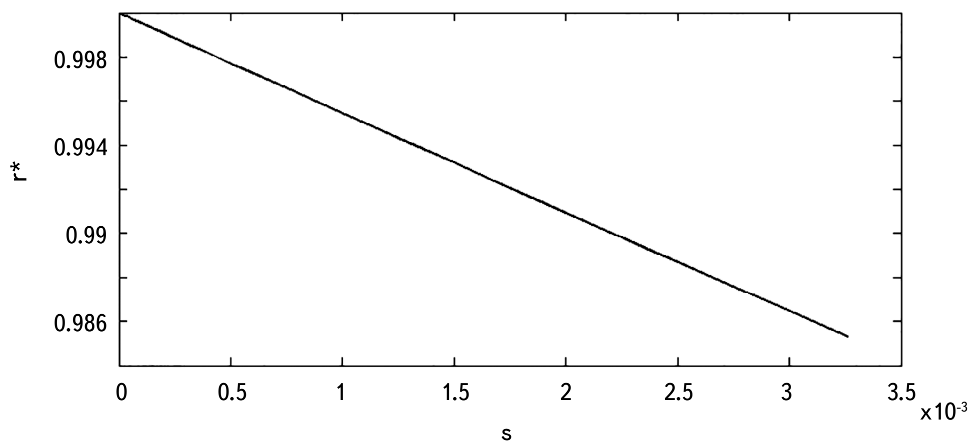

Fig.4. Plot of r* with s.

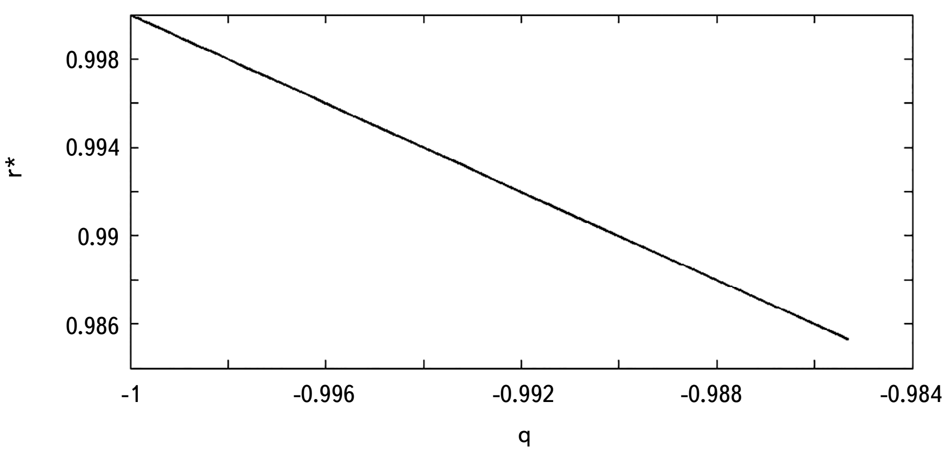

Fig.5. Plot of r* with q.

$$t - t_0 = \sinh^{-1}\left(\frac{\sinh t_0}{1+Z}\right) - \coth^{-1}(H_0) \tag{25}$$

$$H = \coth t \tag{26}$$

$$D = \sinh t_0 \log \frac{\tanh \frac{t_0}{2}}{\tanh \frac{t}{2}} \tag{27}$$

$$d_L = \frac{\sinh^2 t_0}{\sinh t} \log \frac{\tanh \frac{t_0}{2}}{\tanh \frac{t}{2}} \tag{28}$$

$$r^* = \tanh^2 t \tag{29}$$

$$s = -\frac{2}{3\left(2 - 3\cosh^2 t\right)}. \tag{30}$$

The Hubble parameter is decreasing function of time t. The rate of expansion of the universe was large in the early stages of evolution of the universe and at the present the rate of expansion is decreasing. The r^* start from zero and tends to 1 with increasing time whereas s is negative throughout the evolution of the universe. From Fig.4 we see that (s, r^*) varies from (0.003, 0.98) to (0, 1) which corresponds to flat ΛCDM model in state finder plane. From Fig.5, it is clear that (q, r^*) varies from (-0.98, 0.98) to (-1, 1) which corresponds to steady state universe.

4. *Case II.* In this case we assume the $b(t)$ in the following form

$$b(t) = -\frac{1}{2}. \tag{31}$$

The scale factor and deceleration parameter are obtained as

$$S = t^2 \tag{32}$$

$$q = -\frac{1}{2}. \tag{33}$$

The deceleration parameter is negative i.e. the universe is accelerating. The scale factor is increasing function of the time. The Gauss-Bonnet invariant have the following expression

$$G = \frac{24k}{t^7} + \frac{48k}{t^6} + \frac{192}{t^4}. \tag{34}$$

The energy density, pressure and tension of the domain walls have the following expressions

$$L_\rho = \frac{8}{t^2} + \frac{k}{t^4} + \alpha\beta G^{\beta+1} + \alpha\beta(\beta+1)G^{\beta-2}\left[\frac{k_1}{t^{18}} + \frac{k_2}{t^{17}} + \frac{k_3}{t^{16}} - \frac{k_4}{t^{15}} + \frac{k_5}{t^{14}} - \frac{k_6}{t^{13}} - \frac{k_7}{t^{12}} - \frac{k_8}{t^{10}}\right] \tag{35}$$

$$LP = -3k\frac{1}{t^4} - \frac{12}{t^2} - \alpha\beta G^{\beta+1} - 6\alpha\beta(\beta+1)TG^{\beta-1}\left[\frac{148k}{t^9} + \frac{288k}{t^8} + \frac{768}{t^6}\right] \tag{36}$$

$$\begin{aligned} L\sigma_d &= \frac{4(2\gamma+1)}{\gamma t^2} + \frac{k(\gamma+2)}{\gamma t^4} + \alpha\beta G^{\beta+1} \\ &+ \alpha\beta(\beta+1)G^{\beta-1}\frac{\gamma-1}{\gamma}\left[\frac{k_1}{t^{18}} + \frac{k_2}{t^{17}} + \frac{k_3}{t^{16}} - \frac{k_4}{t^{15}} - \frac{k_6}{t^{13}} - \frac{k_7}{t^{12}} - \frac{k_8}{t^{10}}\right] \\ &+ 6\alpha\beta\frac{\gamma-1}{\gamma}(\beta+1)TG^{\beta-1}\left[\frac{148k}{t^9} + \frac{288k}{t^8} + \frac{768}{t^6}\right] \end{aligned} \tag{37}$$

where

$$T = 8\left(\frac{k}{t^4} + \frac{4}{t^2}\right), \quad k_1 = (-227828 - 21904T\beta + 20904T)k^2,$$

$$k_2 = k^2(85248T(1-\beta) - 897024), \quad k_3 = (5428 - 82944\beta)k^2T - 884736k^2,$$

$$k_4 = (2998272 + 103488kT)k, \quad k_5 = 227328kT - 96768k^2T - 227328k\beta T - 5898240,$$

$$k_6 = 91392kT + 221184k\beta T, \quad k_7 = 571398kT + 9437184, \quad k_8 = 589824\beta T + 147456T.$$

From Fig.6, 7 we found that the energy density was large in the past and it is tends to constant at the present for $k = 1$, -1. It is similar to the result obtained by Caglar and Aygun [39]. The universe may be steady state in the future. The domain wall tension was positive and large in the past which conforms the existence of the domain walls in the early universe. The term σ_d tends to zero as $Z \to -1$ which is as per expectation of Zeldovich et al. [38].

4.1. *Physical parameters*. We obtain look back time, Hubble parameter, proper distance, luminosity distance, and a pair of state finders as follows:

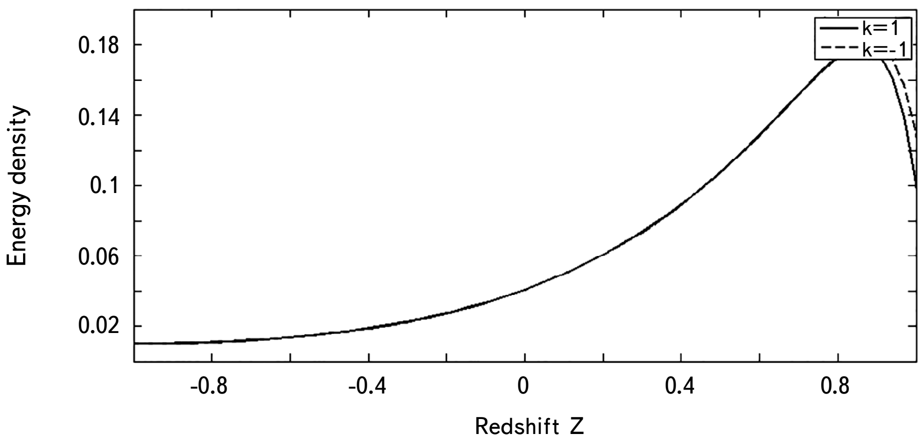

Fig.6. Plot of energy density with redshift.

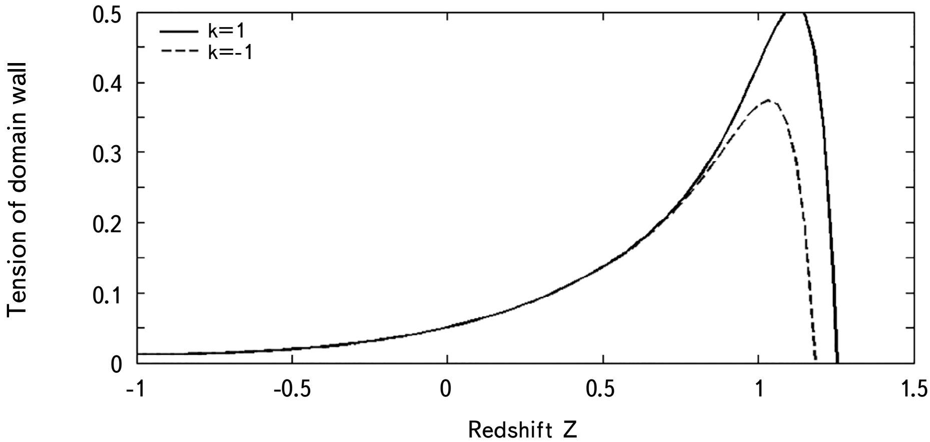

Fig.7. Plot of tension of domain wall with redshift.

$$t - t_0 = \frac{2}{H_0}\left[(1+Z)^{-1/2} - 1\right] \tag{38}$$

$$H = \frac{2}{t} \tag{39}$$

$$D = -t_0^2\left[\frac{1}{t_0} - \frac{1}{t}\right] \tag{40}$$

$$d_L = \frac{t_0^4}{t^2}\left[\frac{1}{t_0} - \frac{1}{t}\right] \tag{41}$$

$$r^* = 0 \tag{42}$$

$$s = \frac{1}{3} \tag{43}$$

The Hubble parameter is decreasing function of time. Therefore, the rate of expansion of the universe is slowing down with increasing time. The state finder pair has fixed value i.e $(r^*, s) = (0, 1/3)$ which is the quiessence model of the universe.

5. *Conclusion*. In this paper we have studied Friedmann-Robertson-Walker space time with domain walls in the context of $f(G)$ theory of gravitation. We have investigated two different cases in which we have following observations:

1. In the case I, the model is in favor of closed universe. The behavior of term σ_d indicate that the domain walls exists in the early epoch of the universe which vanish at the present. The value of a statefinder pair (r^*, s) indicate that

the universe is at like ΛCDM model whereas the pair (r^*, q) indicate the steady state universe.

2. In the case II, we find that the energy density as well as tension of domain wall behave alike. The universe may be closed or open. The energy density was large in the past and tends to constant in the future whereas tension of domain walls was large in the past and tends to zero as $Z \to -1$. Thus, domain walls exist in the past and will be zero in the future. We have $\rho \to \text{const}$ when $Z \to -1$. The universe may be steady state in the future. The statefinder pair (r^*, s) is constant which shows the quiessence model of the universe.

3. The Hubble parameter is decreasing function of time i.e. the rate of expansion is decreasing with increasing time.

4. It is important to note that in both the cases we have q is negative therefore the universe is accelerating

5. The look back time, proper distance, luminosity distance have also been calculated.

In the summary of two cases we found that the universe may be steady state in the future. The domain walls was exist in the past and vanish at the present. The universe is expanding and accelerating.

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FRW ДОМЕННЫЕ СТЕНКИ В МОДИФИЦИРОВАННОЙ ТЕОРИИ ГРАВИТАЦИИ f(G)

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В статье исследуется пространство-время Фридмана-Робертсона-Уокера при наличии доменных стенок в рамках $f(G)$-теории гравитации. Предлагается обобщение линейно изменяющегося параметра замедления. Отмечается, что Вселенная ускоряется и расширяется. Значения параметра $\{r, s\}$ близки к модели ΛCDM. Подробно обсуждаются некоторые физические параметры полученных моделей.

Ключевые слова: *доменные стенки: FRW: гравитация* $f(G)$

REFERENCES

1. *H.A.Buchdahl*, Mon. Not. Roy. Astron. Soc., **150**, 1, 1970.
2. *T.Harko*, *F.S.N.Lobo*, *S.Nojiri et al.*, Phys. Rev. D, **84**, 024020, 2011.
3. *K.Atazadeh*, *F.Darabi*, Gen. Relat. Gravit., **46**, 1664, 2014.
4. *S.Capozziello*, *M. De Laurents*, *S.D.Odintsov*, Mod. Phys. Lett. A, **29**, 30, 2014.
5. *R.Myrzakulov*, *D.S.Gomez*, *A.Tureanu*, Gen. Relat. Gravit., **43**, 1671, 2011.
6. *N.Dadhich*, in Math. Phys., Proc. 12th Regional Conf. Pakistan, eds. M.J.Aslam, A.Qadir, H.Salem, p.331, 2007.
7. *K.Bamba*, *A.N.Makarenko*, *A.N.Myagky et al.*, Phys. Lett. B, **732**, 149, 2014.
8. *Z.Kang*, *Y.Z.Ying*, *Z.D.Cheng et al.*, Chin. J. Phys. B, **21**, 020401, 2012.
9. *S.D.Katore*, *S.P.Hatkar*, *S.V.Gore*, Int. J. Geom. Meth. Mod. Phys., **15**, 1850116, 2018.
10. *S.D.Katore*, *S.P.Hatkar*, *R.J.Baxi*, Chin. J. Phys., **54**, 563, 2016.
11. *S.D.Katore*, *S.P.Hatkar*, Prog. Theoret. Exp. Phys., 033E01, 2016.
12. *S.D.Katore*, *S.P.Hatkar*, Astrophys. Space Sci., **357**, 55, 2015.
13. *D.R.K.Reddy*, *R.L.Naidu*, *U.M.V.Rao*, Int. J. Theoret. Phys., **47**, 1594, 2008.
14. *W.H.Press*, *B.S.Ryden*, *D.N.Spergel*, Astrophys. J., **347**, 590, 1989.
15. *R.K.Tiwari*, *A.Beesham*, *A.Pradhan*, Gravit. Cosmol., **23**, 302, 2017.
16. *G.Abbas*, *D.Momeni*, *M.A.Ali et al.*, Astrophys. Space Sci., **357**, 158, 2015.
17. *M.Crisostomi*, *K.Noui*, *C.Charmousis et al.*, Phys. Rev. D., **97**, 044034, 2018.
18. *M.Crisostomi*, *M.Hull*, *K.Koyama et al.*, J. Cosmol. Astropart. Phys., 038, 2016.
19. *T.Koboyashi*, *M.Yamaguchi*, *J.Yokoyama*, Prog. Theoret. Phys., **126**, 511, 2011.
20. *B.M.Leith*, *I.P.Neupane*, J. Cosmol. Astropart. Phys., **05**, 019, 2007.
21. *S.Nojiri*, *S.D.Odintsov*, *S.Ogushi*, Int. J. Mod. Phys. A, **17**, 4809, 2002.
22. *O.Akarsu*, *T.Dereli*, Int. J. Theoret. Phys., **51**, 612, 2012.
23. *S.Jana*, *S.Mohanty*, Phys. Rev. D, **99**, 044056, 2019.
24. *S.Karimi*, *K.Karami*, Astrophys. Space Sci., **365**, 26, 2020.
25. *S.C.Davis*, arXiv:0709.4453, 2008.
26. *A. De Felice*, *S.Tsujikawa*, Phys. Rev. D, **80**, 063516, 2009.
27. *M.X.Xu*, *T.Harko*, *S.D.Liang*, Europ. Phys. J. C, **76**, 449, 2016.
28. *H.Saadat*, Int. J. Theoret. Phys., **50**, 1769, 2011.

29. *A.Pradhan*, *K.K.Rai*, *A.K.Yadav*, Braz. J. Phys., **37**, 3b, 2007.
30. *G.Khadekar*, *R.Wanjari*, *C.Ozel*, Int. J. Theoret. Phys., **48**, 2550, 2009.
31. *M.J.S.Houndjo*, *M.E.Rodrigues*, *D.Momeni et al.*, Canad. J. Phys., **92**, 1528, 2014.
32. *M.Sharif*, *A.Ikram*, J. Exp. Theoret. Phys., **123**, 40, 2016.
33. *M.Sharif*, *H.I.Fatima*, Int. J. Mod. Phys. D, **25**, 1650011, 2016.
34. *N.M.Garcia*, *F.S.N.Lobo*, *J.P.J.Mimoso*, J. Phys. Conf. Ser., **314**, 012056, 2011.
35. *M.S.Berman*, Il Nuovo Cimen. B, **74**, 182, 1983.
36. *O.Akarsu*, *S.Kumar*, *R.Myrzakulov et al.*, J. Cosmol. Astropart. Phys., 022, 2014.
37. *V.Sahni*, *T.D.Saini*, *A.A.Starobinsky et al.*, JETP Lett., **77**, 201, 2009.
38. *B.Zeldovich*, *I.Y.Kobzarev*, *L.B.Okun*, Soc. Phys. JETP, **40**, 1, 1975.
39. *H.Caglar*, *S.Aygun*, Chin. J. Phys. C, **40**, 045103, 2016.