Astrophys Space Sci (2016) 361:85
DOI 10.1007/s10509-016-2669-4

ORIGINAL ARTICLE

Do neutrinos contribute to total dark energy

Koijam Manihar Singh[1] **· K.L. Mahanta**[2]

Received: 12 January 2016 / Accepted: 21 January 2016 / Published online: 27 January 2016

Abstract From a critical study of our present universe it is found that dark energy, and of course, dark matter are there in the universe from the beginning of its evolution manifesting in one form or the other. The different forms contained in our model are found to be generalized Chaplygin gas, quintessence and phantom energy; of course, the generalized Chaplygin gas can explain the origin of dark energy as well as dark matter in our universe simultaneously. However the more beauty in our study is that there is high possibility of the energy produced from the neutrinos might contribute to the dark energy prevalent in this universe.

Keywords Dark energy · Dark matter · Neutrinos · Generalized Chaplygin gas · Quintessence · Phantom energy · Evolution of the universe

1 Introduction

To explain the accelerated expansion of the universe different investigators studied the existence of the so-called dark energy in the framework of general relativity. On the other hand, to explain such accelerated expansion some other researchers suppose that gravity is modified on the large scale. The forms of dark energy studied by different authors are quintessence (Urena-Lopez and Matos 2000; de Ritis and Marino 2001; Rubano and Seudellaro 2002; Bludman and Roos 2002; Sen and Seshadri 2003), K-essence (Armendariz-Picon et al. 2001; Chiba 2002; Malquarti et al. 2003; Chimanto and Feinstein 2004; Scherrer 2004), f-essence (Myrzakulov 2011), cosmological constant (Deinberg 1989; Carroll et al. 1992; Sahni and Starobinsky 2000; Padmanabhan 2003, 2005a,b; Ellis 2003; Copeland et al. 2006), tachyon field (Choudhury et al. 2002; Gibbons 2002; Padmanabhan 2002a,b; Sen 2005; Bagla et al. 1996; Jassal 2004; Gorini et al. 2001), phantom fields (Caldwell 2002; Hao and Li 2003; Gibbons 2003; Gonzalez-Diaz 2003; Elizalda et al. 2004; Nojiri et al. 2005; Bronnikov and Starobinsky 2007), Chaplygin gas and its generalizations (Gorini et al. 2001; Bento et al. 2002; Dev et al. 2003; Sen and Scherrer 2005; Srivastava 2005), branes (Gonzalez-Diaz 2000; Uzawa and Soda 2001; Jassal 2003; Milton 2003; Sahni and Shtanov 2003; Sahni et al. 2008), cosmological nuclear energy (Gupta and Pradhan 2010). Yadav and Yadav (2011), Pradhan et al. (2011), Adhav et al. (2011a), Kumar and Singh (2011), Yadav (2011), Shamir and Bhatti (2012), Reddy et al. (2012, 2013), Pradhan (2013), Sahoo and Mishra (2014) studied various dark energy models using different metrics.

Dark energy models with variable equation of state parameters were studied by Yadav et al. (2011), Ray et al. (2011), Pradhan et al. (2012), Rao et al. (2012), Rao and Neelima (2013), Katore et al. (2012), Saha and Yadav (2012), Sahoo and Mishra (2014). Cosmological models with wet dark fluid as the candidate for dark energy were studied by Adhav et al. (2011b,c), Jain et al. (2012), Samanta (2013), Samanta et al. (2013, 2014), Mishra and Sahoo (2014). Modeled universes containing dark energy based on bulk viscosity have been studied by some authors (Singh and Singh 2011; Katore et al. 2011; Saadat 2012; Bali and Singh 2012; Verma et al. 2012; Samanta et al. 2013). Tade and Sambhe (2012), Mahanta et al. (2014) also studied a few dark energy models of the universe. Manihar

✉ K.L. Mahanta
mahantakamal@gmail.com

K. Manihar Singh
drmanihar@rediffmail.com

1 National Institute of Technology, Imphal, Manipur, India

2 C.V. Raman College of Engineering, Bidya Nagar, Mahura, Janla, Bhubaneswar, India

and Priyokumar (2014) obtained a model universe consisting partly of quintessence form of dark energy and partly of cosmological constant form of dark energy and studied the present state of the universe. In one of their papers (Manihar et al. 2015a) they obtained the possibility of cosmic time going back in some universe dominated by dark energy. Manihar et al. (2015b), Manihar and Priyokumar (2015), Priyokumar et al. (2016) obtained also some models of the universe containing dark energy with interesting results and properties.

But unlike the universe models investigated by the different authors, we obtain here a universe which seems to contain dark energy from the beginning of its existence throughout its evolution, towards the pseudo big crunch, manifesting in one or other form, namely, in the form of generalized Chaplygin gas in the beginning, then as quintessence, and then as the phantom form of dark energy, which will be a very interesting model of the universe giving us a chance to study very deeply the inter relation between dark energy and our universe. Moreover taking into account the period of the universe dominated by the generalized form of Chaplygin gas fluid it will be advantageous also for us to study about the dark matter contained in this universe, as such a fluid (Chaplygin gas) model can explain the origin of dark energy as well as dark matter.

Again the ΛCDM (cosmological constant type dark energy with cold dark matter) model is successful in describing our universe on large scales (Bahcall 1984). But it faces challenges from results obtained from observations on small scales that investigate into the innermost regions of dark matter halos. The predictions of ΛCDM on galaxy scales disagree with observed properties of galaxies. From this point of view, the warm dark matter is an acceptable dark matter model which can solve the small scale controversies though on large scales it bears resemblance with cold dark matter model. Interestingly enough, the keV scale sterile neutrinos are believed to contribute to warm dark matter particles (Kumar and Xu 2014). Because the only known non-baryonic particle was neutrinos, thus it is natural that neutrinos were considered as dark matter particle candidates, as controversies with observational data can be solved if non-baryonic elementary particles, such as massive neutrinos are taken as candidates for forming dark matter (Einasto 2013).

Similarly there is high possibility of the energy produced from neutrinos to contribute to dark energy. In neutrino oscillations the three types of neutrinos, namely, electron neutrino, muon neutrino and tau neutrino continuously change their form from one to another. It is amazing that about 60 billion neutrinos pass through every square centimeter of our body in every second, and they are neither seen nor felt. Our universe is abundant with neutrinos which have mass and produce huge amount of energy. Taking an example, during the supernova explosion seen on 23rd February 1987 the energy released was 3×10^{53} ergs, out of which two-third of the energy was carried by neutrinos and roughly the remaining one- third by the anti-neutrinos that were produced during the event of explosion. In that supernova explosion the total number of neutrinos produced are estimated to be 10^{58}. Neutrinos hardly interact with any other matter. Since they have no charge and are very small in size they can pass from one side of the earth to another side very easily and it is very difficult to detect them. Trillions of them pass through our body in a day. Thus neutrinos must be pressure less and even might have negative pressure as in the case of dark energy. Moreover as in the case of the dark energy model universe we are studying now, dark energy can oscillate or change its form from one form to another, namely in this model, from modified Chaplygin gas form to quintessence form, then again to phantom form of dark energy, and vice versa according to the oscillation theory we have introduced in one of our papers (Manihar et al. 2015b). Thus from these characteristics and behaviors of neutrinos and dark energy it is believed that there is possibility for the energy produced from neutrinos to contribute to the total dark energy prevailing in this universe in the same way as neutrinos are believed to account for warm dark matter.

2 A model universe with different manifestations of dark energy

Let us consider the metric

$$ds^2 = dt^2 - a^2(t)\left[dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2\right] \tag{1}$$

with energy momentum tensor

$$T_{ij} = \rho u_i u_j + p(u_i u_j - g_{ij}) \tag{2}$$

where p is the fluid pressure, ρ the fluid density, u_i the four flow vector satisfying the relation

$$g_{ij} u^i u^j = 1 \tag{3}$$

Then the Einstein's field equations

$$R_{ij} - \frac{1}{2} g_{ij} R = -8\pi G T_{ij} \tag{4}$$

give

$$8\pi G p = -2\frac{\ddot{a}}{a} - \frac{\dot{a}^2}{a^2} \tag{5}$$

and

$$8\pi G \rho = 3\frac{\dot{a}^2}{a^2} \tag{6}$$

The equation of state for generalized Chaplygin gas may be taken as

$$p = -\frac{A}{\rho^{\frac{1}{z}}} \tag{7}$$

where $1 \le z < \infty$. On the other hand the equation of state for the barotropic fluid is

$$p = \omega\rho \tag{8}$$

with $\omega < -1$. Thus from (7) and (8) we have

$$\omega = -\frac{A}{\rho^{\frac{z+1}{z}}} \tag{9}$$

Again making use of the hydrodynamic equation

$$\dot{\rho} = -3\frac{\dot{a}}{a}(\rho + p) \tag{10}$$

in Eq. (7) we get

$$\dot{\rho} = -3\frac{\dot{a}}{a}\left(\rho - \frac{A}{\rho^{\frac{1}{z}}}\right) \tag{11}$$

Integrating it we obtain

$$\rho^{\frac{1+z}{z}} = A + \left(\rho_p^{\frac{1+z}{z}} - A\right)\left[\frac{a_p}{a}\right]^{\frac{3(1+z)}{z}} \tag{12}$$

where ρ_p and a_p are the values of ρ and a at present time t_p. From (9) we have

$$A = -\omega_p \rho_p^{\frac{1+z}{z}} \tag{13}$$

where $\omega_p = \omega(t_p)$, t_p being the present time. Now (12) and (13) give

$$\rho = \rho_p\left[-\omega_p + (1+\omega_p)\left(\frac{a_p}{a}\right)^{\frac{3(1+z)}{z}}\right]^{\frac{z}{1+z}} \tag{14}$$

In the homogeneous model of the universe, we have

$$p = \frac{1}{2}\dot{\phi}^2 - V(\phi) \tag{15}$$

and

$$\rho = \frac{1}{2}\dot{\phi}^2 + V(\phi) \tag{16}$$

where $V(\phi)$ is the potential of the scalar field $\phi(t)$. From (15), (7) and (13) we have

$$\dot{\phi}^2 = 2\frac{\omega_p \rho_p^{\frac{1+z}{z}}}{\rho^{\frac{1}{z}}} + 2V(\phi) \tag{17}$$

Now using (16) in (17) we get

$$\dot{\phi}^2 = \frac{\rho^{\frac{1+z}{z}} + \rho_p^{\frac{1+z}{z}}\omega_p}{\rho^{\frac{1}{z}}} \tag{18}$$

Then (14) and (18) give

$$\dot{\phi}^2 = \frac{(1+\omega_p)\rho_p(\frac{a_p}{a})^{\frac{3(1+z)}{z}}}{[-\omega_p + (1+\omega_p)(\frac{a_p}{a})^{\frac{3(1+z)}{z}}]^{\frac{1}{1+z}}} \tag{19}$$

For $\omega_p > -1$ we see that $\dot{\phi}^2 > 0$ which gives positive kinetic energy. Thus in this case the form of the dark energy will be quintessence. And for $\omega_p < -1$ we see that $\dot{\phi}^2 < 0$, in which case the kinetic energy is negative; thereby the form of dark energy in this case will be phantom.

Thus the scalar field we have taken manifests the three different forms of dark energy, namely, generalized Chaplygin gas, quintessence and phantom energy. In the case of this dark energy fluid, the Einstein-Friedmann equation gives

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho \tag{20}$$

i.e.

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho_p^{(c)}\Omega_p}{3}\left[-\omega_p + (1+\omega_p)\left(\frac{a_p}{a}\right)^{\frac{3(1+z)}{z}}\right]^{\frac{z}{1+z}} \tag{21}$$

where $|\omega_p| > 1$ and

$$\Omega_p = \frac{\rho_p}{\rho_p^{(c)}} \tag{22}$$

with

$$\rho_p^{(c)} = \frac{3H_p^2}{8\pi G} \tag{23}$$

Thus (21) can be written as

$$\frac{\dot{a}}{a} = H_p\Omega_p^{\frac{1}{2}}\left[|\omega_p| + (1-|\omega_p|)\left(\frac{a_p}{a}\right)^{\frac{3(1+z)}{z}}\right]^{\frac{z}{2(1+z)}} \tag{24}$$

where H_p is the present value of the Hubble's constant given by

$$H_p^2 = \frac{8\pi G}{3}\rho_p^{(c)} \tag{25}$$

where $\rho_p^{(c)}$ is the critical energy density. Now expanding (24) up to the second term we get

$$\frac{\dot{a}}{a} \approx H_p\Omega_p^{\frac{1}{2}}|\omega_p|^{\frac{z}{2(1+z)}}\left[1 + \frac{z(1-|\omega_p|)}{2(1+z)|\omega_p|}\left(\frac{a_p}{a}\right)^{\frac{3(1+z)}{z}}\right] \tag{26}$$

Integrating (26) we get

$$a(t)=\frac{a_p}{[2(1+z)|\omega_p|]^{\frac{z}{3(1+z)}}}\times\Big[\big(z+2(1+z)|\omega_p|\big)e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big]^{\frac{z}{3(1+z)}} \tag{27}$$

Thus from (14) we obtain

$$\rho=\rho_p\Big[-\omega_p+2(1+z)(1+\omega_p)|\omega_p|\Big\{\big(z+2(1+z)|\omega_p|\big)\times e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big\}^{-1}\Big]^{\frac{z}{(1+z)}} \tag{28}$$

And from (7) and (13) we have

$$p=-\omega_p\rho_p^{\frac{1+z}{z}}\Big[\omega_p-2(1+z)(1+\omega_p)|\omega_p|\times\Big\{\big(z+2(1+z)|\omega_p|\big)e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big\}^{-1}\Big]^{\frac{-1}{(1+z)}} \tag{29}$$

Volume V is given by

$$V=\frac{a_p^3}{[2(1+z)|\omega_p|]^{\frac{z}{1+z}}}\Big[\big(z+2(1+z)|\omega_p|\big)\times e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big]^{\frac{z}{(1+z)}} \tag{30}$$

Hubble parameter H is given by

$$H=\left(\frac{8\pi G}{3}\right)^{\frac{1}{2}}\rho_p^{\frac{1}{2}}\Big[-\omega_p+2(1+z)(1+\omega_p)|\omega_p|\times\Big\{\big(z+2(1+z)|\omega_p|\big)e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big\}^{-1}\Big]^{\frac{z}{2(1+z)}} \tag{31}$$

Shear scalar $\sigma=0$ and anisotropic parameter $\triangle=0$. Hubble's directional parameters are $H_x=H_y=H_z$, where

$$H_x=\left(\frac{8\pi G}{3}\right)^{\frac{1}{2}}\rho_p^{\frac{1}{2}}\Big[-\omega_p+2(1+z)(1+\omega_p)|\omega_p|\times\Big\{\big(z+2(1+z)|\omega_p|\big)e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big\}^{-1}\Big]^{\frac{z}{2(1+z)}} \tag{32}$$

The scalar of expansion is given by

$$\Theta=3\left(\frac{8\pi G}{3}\right)^{\frac{1}{2}}\rho_p^{\frac{1}{2}}\Big[-\omega_p+2(1+z)(1+\omega_p)|\omega_p|\times\Big\{\big(z+2(1+z)|\omega_p|\big)e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big\}^{-1}\Big]^{\frac{z}{2(1+z)}} \tag{33}$$

The deceleration parameter q is obtained as

$$q=-1-6\left(\frac{8\pi G}{3}\right)^{\frac{-1}{2}}\rho_p^{\frac{-3}{2}}\Big[-\omega_p+2(1+z)(1+\omega_p)|\omega_p|\times\Big\{\big(z+2(1+z)|\omega_p|\big)e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big\}^{-1}\Big]^{\frac{-3z}{2(1+z)}}\Big[-\omega_p+2(1+z)(1+\omega_p)|\omega_p|\times\Big\{\big(z+2(1+z)|\omega_p|\big)e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}-z(1-|\omega_p|)\Big\}^{-1}\Big]^{\frac{z}{(1+z)}-1}\times(1+\omega_p)|\omega_p|z\big(z+2(1+z)|\omega_p|\big)\times e^{6H_p(t-t_p)\sqrt{\Omega_p}|\omega_p|^{\frac{z}{2(1+z)}}}H_p|\omega_p|^{\frac{z}{2(1+z)}}\sqrt{\Omega_p} \tag{34}$$

3 Interpretations and conclusion

Here the volume and the scale factor of the universe are found to increase rapidly with time thus complying with the accelerated expansion of the universe. As also the pressure is negative here it helps in the accelerated expansion of this universe, because a negative pressure stimulates a repulsive gravity and inflates the universe by overwhelming the usual gravitational effects of matter.

In this model, the directional Hubble parameters, anisotropy parameter and shear tensor come out to be constants. Here the equation of state is found to be negative, but a decreasing function of time. Thus our universe starts first as a universe containing the dark energy in the form of modified Chaplygin gas, then the dark energy taking the form of quintessence, and finally our model becoming a universe filled with dark energy in the form of phantom energy. At time t_s given by

$$[z+2(1+z)|\omega_0|]e^{6H_0|\omega_0|^{\frac{z(t_s-t_0)\sqrt{\Omega_0}}{2(1+z)}}}=z(1-|\omega_0|)^{\frac{z}{3(1+z)}}$$

there is a singularity or bounce, perhaps which is an instant of changing from one form of dark energy to another form of dark energy. At other times there is accelerated expansion as a_t tends to ∞ as $t\to\infty$. At very large time the energy density of this universe is negative which implies from (16) that the kinetic energy is negative for the scalar field, showing that the universe contains, at this stage, phantom type of dark energy.

Here the scalar expansion θ is found to be an increasing function of time which agrees with the accelerated expansion of the universe. On the other hand the pressure and density of this model are found to have finite values at infinite time. As also the anisotropic parameter of this universe is found to be zero, we see that our model is an isotropic one.

Moreover from the isotropic behavior of ρ of the model universe we have obtained here, we can conclude as follows. In the early universe, that is, when $a \leq 1$, we find that $\rho \approx (1+\omega_0)a_0^{3(1+\beta)}a^{-3}$ and in the late universe, that is, when $a > 1$, we find that $\rho \approx (-\omega_0)^{\frac{1}{1+\beta}}$. These results imply that in the early universe, the energy density behaves as $\rho \approx a^{-3}$ which is the same as in the case of non-relativistic matter such as dark matter. And in the case of the late universe the energy density behaves in the form $\rho \to (-\omega_0)^{\frac{1}{1+\beta}}$ showing that the energy density tends to a constant which means that it can play the role of dark energy. Here the generalized Chaplygin gas model can explain the origin of dark energy as well as dark matter simultaneously, the forming of dark matter preceding the forming of dark energy. Moreover from our study we see the possibility of the existence of a fluid, in our universe, which is originally in the form of generalized Chaplygin gas and later on behave as quintessence and then as the phantom form of dark energy. Thus we can conclude that dark energy and, of course, the dark matter are there in our universe from the beginning of its evolution till the pseudo big crunch manifesting in one form or the other. On the other hand, neutrinos change their forms, namely electron neutrino, muon neutrino and tau neutrino, from one to another frequently. Their properties are not yet all explored. But who knows there might have been neutrinos which have negative pressure as we know that though millions of neutrinos pass through our body every second we never feel them! Taking into account the known properties of the neutrinos we see the similarity of them with the dark energy contained in the universe we have studied above. Thus we are instigated to think whether the energy due to the neutrinos contribute to dark energy. If it is so there is high hope for finding out the exact behavior, property and characteristics of dark energy.

References

Adhav, K.S., Bansod, A.S., Dankhade, P., Ajmire, H.G.: Cent. Eur. J. Phys. **9**, 919 (2011a)
Adhav, K.S., Dawande, M.V., Thakare, R.S., Raut, R.B.: Int. J. Theor. Phys. **50**, 339 (2011b)
Adhav, K.S., Mete, V.G., Thakare, R.S., Pund, A.M.: Int. J. Theor. Phys. **50**, 164 (2011c)
Armendariz-Picon, C., Mukhanov, V., Steinhardt, P.J.: Phys. Rev. D **63**, 103510 (2001)
Bagla, J.S., Padmanabhan, T., NArlikar, J.V.: Comments Astrophys. **18**, 275 (1996). astro-ph/9511102
Bahcall, J.N.: Astrophys. J. **287**, 926 (1984)
Bali, R., Singh, P.: Int. J. Theor. Phys. **51**, 772 (2012)
Bento, M.C., Bertolami, O., Sen, A.A.: Phys. Rev. D **66**, 043507 (2002)
Bludman, S.A., Roos, H.: Phys. Rev. D **65**, 043503 (2002)
Bronnikov, K.A., Starobinsky, A.A.: JETP Lett. **85**, 1 (2007)
Caldwell, R.R.: Phys. Lett. B **545**, 23 (2002)
Carroll, S.H., Press, D.H., Turner, E.L.: Annu. Rev. Astron. Astrophys. **30**, 499 (1992)
Chiba, T.: Phys. Rev. D **66**, 063514 (2002)
Chimanto, L.P., Feinstein, A.: Mod. Phys. Lett. A **19**, 761 (2004)
Choudhury, D., Ghosal, D., Jatkar, D.P., Panda, S.: Phys. Lett. B **544**, 231 (2002)
Copeland, E.J., Sami, H., Tsujikawa, S.: Int. J. Mod. Phys. D **15**, 1753 (2006)
de Ritis, R., Marino, A.A.: Phys. Rev. D **64**, 083509 (2001)
Deinberg, S.: Rev. Mod. Phys. **61**, 1 (1989)
Dev, A., Jain, D., Alianiz, J.S.: Phys. Rev. D **67**, 023515 (2003)
Einasto, J.: arXiv:1308.2534v1 (2013)
Elizalda, E., Nojiri, S., Odintsov, S.D.: Phys. Rev. D **70**, 043539 (2004)
Ellis, J.: Philos. Trans. R. Soc. Lond. A **361**, 2607 (2003)
Gibbons, G.W.: Phys. Lett. B **537**, 1 (2002)
Gibbons, G.W.: Class. Quantum Gravity **20**, 5321 (2003)
Gonzalez-Diaz, P.F.: Phys. Lett. B **481**, 353 (2000)
Gonzalez-Diaz, P.F.: Phys. Rev. D **68**, 021303 (2003)
Gorini, V., Kamenshchik, A.Y., Moschella, U., Pasquier, V.: Phys. Lett. B **511**, 265 (2001)
Gupta, R.C., Pradhan, A.: Int. J. Theor. Phys. **49**(4), 821 (2010)
Hao, J., Li, X.: Phys. Rev. D **67**, 107303 (2003)
Jain, P., Sahoo, P.K., Mishra, B.: Int. J. Theor. Phys. **51**, 2546 (2012)
Jassal, H.K.: arXiv:hep-th/0312253 (2003)
Jassal, H.K.: Pramana **62**, 757 (2004)
Katore, S.D., Shaikh, A.Y., Kapse, D.V., Bhaskar, S.A.: Int. J. Theor. Phys. **50**, 2644 (2011)
Katore, S.D., Adhav, K.S., Sancheti, M.M.: Astrophys. Space Sci. **337**, 393 (2012)
Kumar, S., Singh, C.P.: Gen. Relativ. Gravit. **43**, 1427 (2011)
Kumar, S., Xu, L.: Phys. Lett. B **737**, 244 (2014)
Mahanta, K.L., Biswal, A.K., Sahoo, P.K.: Can. J. Phys. **92**, 295 (2014)
Malquarti, H., Copeland, E.J., Liddle, A.R., Trodden, M.: Phys. Rev. D **67**, 123503 (2003)
Manihar, S.K., Priyokumar, S.K.: Int. J. Theor. Phys. **53**, 4360 (2014)
Manihar, S.K., Priyokumar, S.K.: Prespacetime J. **6**(12), 1400 (2015)
Manihar, S.K., Priyokumar, S.K., Dewri, M.: Int. J. Phys. **3**(5), 213 (2015a)
Manihar, S.K., Priyokumar, S.K., Dewri, M.: Glob. J. Sci. Front. Res. **15**(7), 15 (2015b)
Milton, K.A.: Gravit. Cosmol. **9**, 66 (2003)
Mishra, B., Sahoo, P.K.: Astrophys. Space Sci. **349**, 491 (2014)
Myrzakulov, R.: Phys. Rev. D **84**, 024020 (2011)
Nojiri, S., Odintsov, S.D., Tsujikawa, S.: Phys. Rev. D **71**, 063004 (2005)
Padmanabhan, T.: Phys. Rev. D **66**, 021301 (2002a). arXiv:hep-th/0204150
Padmanabhan, T.: Class. Quantum Gravity **19**, 5387 (2002b). arXiv:hep-th/0204019
Padmanabhan, T.: Phys. Rep. **380**, 235 (2003). arXiv:hep-th/0212290
Padmanabhan, T.: Curr. Sci. **88**, 1057 (2005a). arXiv:astro-ph/0411044
Padmanabhan, T.: Phys. Rep. **49**, 406 (2005b). arXiv:gr-qc/0311036
Pradhan, A.: Res. Astron. Astrophys. **13**, 139 (2013)
Pradhan, A., Amirhashchi, H., Saha, B.: Astrophys. Space Sci. **333**, 343 (2011)
Pradhan, A., Jaiswal, R., Jotania, K., Khare, R.K.: Astrophys. Space Sci. **337**, 401 (2012)
Priyokumar, S.K., Manihar, S.K., Dewri, M.: Astron. Astrophys. (2016, accepted)
Rao, V.U.M., Neelima, D.: Eur. Phys. J. Plus **128**, 35 (2013)

Rao, V.U.M., Sreedevi Kumari, G., Neelima, D.: Astrophys. Space Sci. **337**, 499 (2012)
Ray, S., Rahaman, F., Mukhupadhyay, U., Sarkar, R.: Int. J. Theor. Phys. **50**, 2687 (2011)
Reddy, D.R.K., Santikumar, R., Naidu, R.L.: Astrophys. Space Sci. **342**, 249 (2012)
Reddy, D.R.K., Kumar, R.S., Kumar, T.V.P.: Int. J. Theor. Phys. **52**, 239 (2013)
Rubano, C., Seudellaro, P.: Gen. Relativ. Gravit. **34**, 307 (2002)
Saadat, H.: Int. J. Theor. Phys. **51**, 1317 (2012)
Saha, B., Yadav, A.K.: Astrophys. Space Sci. **341**, 651 (2012)
Sahni, V., Shtanov, Y.: J. Cosmol. Astropart. Phys. **0311**, 014 (2003)
Sahni, V., Starobinsky, A.A.: Int. J. Mod. Phys. D **9**, 373 (2000)
Sahni, V., Shafieloo, A., Starobinsky, A.: Phys. Rev. D **78**, 103502 (2008)
Sahoo, P.K., Mishra, B.: Eur. Phys. J. Plus **129**, 196 (2014)
Samanta, G.C.: Int. J. Theor. Phys. **52**, 2303 (2013)
Samanta, G.C., Dhal, S., Mishra, B.: Astrophys. Space Sci. **346**, 233 (2013)
Samanta, G.C., Jaiswal, S., Biswal, S.K.: Eur. Phys. J. Plus **129**, 48 (2014)
Scherrer, R.J.: arXiv:astro-ph/0402316 (2004)
Sen, A.: Phys. Scr. T **117**, 70 (2005). arXiv:hep-th/0312153
Sen, A.A., Scherrer, R.J.: Phys. Rev. D **72**, 063511 (2005)
Sen, S., Seshadri, T.R.: Int. J. Mod. Phys. D **12**, 445 (2003)
Shamir, M.F., Bhatti, A.A.: Can. J. Phys. **90**, 193 (2012)
Singh, K.P., Singh, N.L.: Int. J. Theor. Phys. **50**, 1382 (2011)
Srivastava, S.K.: Phys. Lett. B **619**, 1 (2005)
Tade, S.D., Sambhe, M.M.: Int. J. Theor. Phys. **51**, 447 (2012)
Urena-Lopez, L.A., Matos, T.: Phys. Rev. D **32**, 081302 (2000)
Uzawa, K., Soda, J.: Mod. Phys. Lett. A **16**, 1089 (2001)
Verma, M.K., Singh, M.K., Ram, S.: Int. J. Theor. Phys. **51**, 1729 (2012)
Yadav, A.K.: Astrophys. Space Sci. **335**, 565 (2011)
Yadav, A.K., Yadav, L.: Int. J. Theor. Phys. **50**, 218 (2011)
Yadav, A.K., Rahaman, F., Ray, S.: Int. J. Theor. Phys. **50**, 871 (2011)