РУХАНИ ЖАҢҒЫРУ

20 АСТАНА

ЕУРАЗИЯ ҰЛТТЫҚ УНИВЕРСИТЕТІ

Студенттер мен жас ғалымдардың
«ҒЫЛЫМ ЖӘНЕ БІЛІМ - 2018»
XIII Халықаралық ғылыми конференциясы

СБОРНИК МАТЕРИАЛОВ

XIII Международная научная конференция
студентов и молодых ученых
«НАУКА И ОБРАЗОВАНИЕ - 2018»

The XIII International Scientific Conference
for Students and Young Scientists
«SCIENCE AND EDUCATION - 2018»

12[th] April 2018, Astana

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ БІЛІМ ЖӘНЕ ҒЫЛЫМ МИНИСТРЛІГІ
Л.Н. ГУМИЛЕВ АТЫНДАҒЫ ЕУРАЗИЯ ҰЛТТЫҚ УНИВЕРСИТЕТІ

Студенттер мен жас ғалымдардың «Ғылым және білім - 2018» атты XIII Халықаралық ғылыми конференциясының БАЯНДАМАЛАР ЖИНАҒЫ

СБОРНИК МАТЕРИАЛОВ XIII Международной научной конференции студентов и молодых ученых «Наука и образование - 2018»

PROCEEDINGS of the XIII International Scientific Conference for students and young scholars «Science and education - 2018»

2018 жыл 12 сәуір

Астана

УДК 378

ББК 74.58
Ғ 96

Ғ 96

«Ғылым және білім – 2018» атты студенттер мен жас ғалымдардың XIII Халықаралық ғылыми конференциясы = XIII Международная научная конференция студентов и молодых ученых «Наука и образование - 2018» = The XIII International Scientific Conference for students and young scholars «Science and education - 2018». – Астана: http://www.enu.kz/ru/nauka/nauka-i-obrazovanie/, 2018. – 7513 стр. (қазақша, орысша, ағылшынша).

ISBN 978-9965-31-997-6

Жинаққа студенттердің, магистранттардың, докторанттардың және жас ғалымдардың жаратылыстану-техникалық және гуманитарлық ғылымдардың өзекті мәселелері бойынша баяндамалары енгізілген.

The proceedings are the papers of students, undergraduates, doctoral students and young researchers on topical issues of natural and technical sciences and humanities.

В сборник вошли доклады студентов, магистрантов, докторантов и молодых ученых по актуальным вопросам естественно-технических и гуманитарных наук.

УДК 378

ББК 74.58

ISBN 978-9965-31-997-6

4. Yesmakanova K. R, Shaikhova G. N. , Bekova G.T., Myrzakulova Zh. R. Determinant Reprentation of Dardoux Transformation for the (2+l)-Dimensional Schrodinger-Maxwell-Bloch E quation // Advances in Intelligent Systems and Computing, № 441, 2016, P.183-198.

UDC 524.834

INVESTIGATION OF COSMOLOGICAL MODELS OF NONLOCAL F(T) GRAVITY VIA NOETHER SYMMETRY

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Most of cosmological observations convince that the expansion of the universe is accelerating. These experiments include Type Ia Supernovae, cosmic microwave background (CMB) radiation, large scale, baryon acoustic oscillations (BAO). There are many promising explanations of the dark energy (DE). But the DE sector remains still unknown [1,2].

As an alternative to standard general relativity (GR), there are some possibilities for the modification theory. One of them is teleparallel gravity. In this kind of gravity, the use of torsion is basically realized contrary to the case of GR. Levi-Civita connection of teleparallel gravity is concerned. The torsion scalar T represents the Lagrangian density of teleparallel gravity. The extension of this case is similar to f(R) gravity, where R is scalar curvature. The resulting theory is called f(T) gravity, where f(T) is a function of T. In f(T) gravity inflationary behavior and the late time cosmic acceleration can be realized.

There has been considered another way of modifying gravitation, called nonlocal teleparallel gravity. It is argued that nonlocal teleparallel formalism is the best tool to study quantum gravitational effects. The nonlocal f(T) gravity can be considered as an extension of nonlocal general relativity to the Weitzenbock spacetime [3, 4]. The purpose of the present study is to analyse the dynamics of the field in the nonlocal f(T) Gravity through the Noether symmetry technique. We will start by making a short review of nonlocal f(T) theory of gravity.

Let us first develop the formalism of nonlocal modified gravity with torsion T. Total action for gravity and matter can be written as

$$S = \frac{1}{2k}\int d^4xeT\left(f\left(\Pi^{-1}T\right)-1\right)+\int d^4xeL_m \, . \tag{1}$$

Here $k = 8\pi G$ is the gravitational coupling, speed of light $c = 1$, G is gravitational constant and $\Box$ is d\`Alembert operator, it is defined as $\Box = e^{-1}\partial_\alpha\left(e\partial^\alpha\right)$. We use $e = \sqrt{-g} = \det\left(e_a^\mu\right) = \sqrt{-\det\left(g_{\alpha\beta}\right)}$, torsion scalar is defind by $T = S_\rho^{\mu\nu}T_{\mu\nu}^\rho$. Components of the torsion tensor

$$T_{\mu\nu}^\rho = e_i^\rho\left(\partial_\mu e_\nu^i - \partial_\nu e_\mu^i\right), \tag{2}$$

$$S_\rho^{\mu\nu} = \frac{1}{2}\left(K_\rho^{\mu\nu} + \delta T_\theta^\nu\right), \tag{3}$$

$$K_\rho^{\mu\nu} = -\frac{1}{2}\left(T_\rho^{\mu\nu} - T_\rho^{\nu\mu}\right). \tag{4}$$

It is illustrative to find a scalar-tensor reduction for action (1) using a pair of auxiliary fields $\phi = \frac{1}{T}$ and $\varepsilon = -\frac{1}{T}\left(f'(\phi)T\right)$, the new form for the reduced action will be written as

$$S = \frac{1}{2k}\int d^4xe\left[Tf(\phi-1) - \partial_\mu \varepsilon \partial^\mu \phi - \varepsilon T\right] + \int d^4xeL_m \, . \tag{5}$$

We are interested in studying systems where the Lagrangian of the system is $L \equiv L(q_i, \dot{q}_i; t)$, $1 \le i \le N$. Noether symmetry is the existence of a vector $\vec{X}$

$$X = \sum_{i=1}^{N} \alpha^i(q)\frac{\partial}{\partial q^i} + \alpha^i(q)\frac{\partial}{\partial \dot{q}^i} \, . \tag{6}$$

If we adjust a set of functions $\alpha_i(q_j)$, in a such manner that the Lie derivative of Lagrangian vanishes

$$L_X L = 0 \, , \tag{7}$$

$$L_X L = XL = \sum_{i=1}^{N} \dot{\alpha}^i(q)\frac{\partial L}{\partial q^i} + \dot{\alpha}^i(q)\frac{\partial L}{\partial \dot{q}^i} \, . \tag{8}$$

Applying Euler-Lagrange equations to (8) leads to

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}^i} + \dot{\alpha}^i(q)\frac{\partial L}{\partial \dot{q}^i} \, . \tag{9}$$

We suppose that the nonsingular, physical metric of spacetime is characterized by a Friedman-Lemaitre-Robertson-Walker (FLRW) metric given by $ds^2 = dt^2 - a(t)^2\left(dx^b dx_b\right)$, where $b = 1,2,3$ is spatial coordinate and $a(t)$ is a scale factor. The set of FLRW equations of equation (2) can be obtained as follows

$$3H^2\left(1 + \xi - f(\phi)\right) = \frac{1}{2}\dot{\phi}\dot{\xi} + k\left(\rho_m + \rho_\Lambda + \rho_r\right), \tag{10}$$

$$(2\dot{H} + 3H^2)(1 + \xi - f(\phi)) = -\frac{1}{2}\dot{\phi}\dot{\xi} + 2H(\dot{\xi} - \dot{f}(\phi)) - k(p_\Lambda - p_r) \, . \tag{11}$$

Adding the these equations together, we obtain

$$2H\left(\dot{\xi} - \dot{f}(\phi)\right) = \left(2\dot{H} + 6H^2\right)\left(1 + \xi - f(\phi)\right) - k\rho_m \, . \tag{12}$$

The point-like Lagrangian for the action (1) in the FLRW background in configuration spaces (a, ϕ, ξ), with matter Lagrangian $L_m = \rho$, takes the form:

$$L(a, \phi, \xi, \dot{a}, \dot{\phi}, \dot{\xi}) = -\frac{1}{2k}(-6\dot{a}^2a(f(\phi) - 1) - \dot{\phi}\dot{\xi}a^3 + 6\dot{a}^2a\xi) + \rho a^3 \, . \tag{13}$$

From Eq.(13) we obtain the Euler-Lagrange (EL) equations

$$\ddot{\phi}+3H\dot{\phi}+6H^{2}=0, \tag{14}$$

$$\ddot{\xi}+3H\dot{\xi}-6H^{2}f'(\phi)=0, \tag{15}$$

$$\frac{\ddot{a}}{a}\left(1+\varepsilon-f(\phi)\right)+(\dot{H}+5H^{2})(1+\varepsilon-f(\phi))-k\rho_{m}=0. \tag{16}$$

The infinitesimal generator of the Noether symmetry is

$$\overrightarrow{X}=\alpha\frac{\partial}{\partial a}+\beta\frac{\partial}{\partial\phi}+\gamma\frac{\partial}{\partial\xi}+\dot{\alpha}\frac{\partial}{\partial\dot{a}}+\dot{\beta}\frac{\partial}{\partial\dot{\phi}}+\dot{\gamma}\frac{\partial}{\partial\dot{\xi}}. \tag{17}$$

Here α,β,γ are in general functions of $\{a,\phi,\xi\}$, and $\dot{f}\equiv\dot{a}\frac{\partial f}{\partial a}+\dot{\phi}\frac{\partial f}{\partial\phi}+\dot{\xi}\frac{\partial f}{\partial\xi}$. The Lie derivative of Lagrangian L vanishes, provides us the following system of the differential equations

$$(a+2a\frac{\partial\alpha}{\partial a})(1+\xi-f(\phi))+a(\gamma-\beta f'(\phi))=0, \tag{18}$$

$$a^{2}\frac{\partial\gamma}{\partial a}-12\frac{\partial\alpha}{\partial\phi}(1+\xi-f(\phi))=0, \tag{19}$$

$$a^{2}\frac{\partial\beta}{\partial a}-12\frac{\partial\alpha}{\partial\xi}(1+\xi-f(\phi))=0, \tag{20}$$

$$3\alpha+a\left(\frac{\partial\gamma}{\partial\xi}+\frac{\partial\beta}{\partial\phi}\right)=0, \tag{21}$$

$$\frac{\partial\gamma}{\partial\phi}=0, \tag{22}$$

$$\frac{\partial\beta}{\partial\xi}=0, \tag{23}$$

$$a\rho'+3\rho=0. \tag{24}$$

Let us discuss some solutions of one class. We start sorting out the solutions by considering (19-21). We find first particular solutions as follows:

$$\alpha(a)=-\frac{c_{1}a}{3}+c_{2}, \tag{25}$$

$$\gamma(\varepsilon)=c_{1}\xi+c_{3}, \tag{26}$$

$$\beta = c_4 , \tag{27}$$

$$f(\phi) = c_5 e^{\frac{c_1 \varphi}{c_4}} + c_6 , \tag{28}$$

Here $c_i s$ are constants. Noether conserved charge for these solutions is defined as follows

$$Q = \alpha \frac{\partial L}{\partial \dot{a}} + \beta \frac{\partial L}{\partial \dot{\phi}} + \frac{\partial L}{\partial \dot{\xi}} . \tag{29}$$

Using solutions given in Eqs.(25-28), we obtain solutions

$$Q_1 = \frac{1}{k}(2\dot{a}a(-c_1 a + 3c_2)(1 - c_5 e^{\frac{c_1 \phi}{c_4}} - c_6 + \xi) - \frac{c_4}{2}(\dot{\xi}a^3) - \frac{1}{2}(c_1 \xi + c_3)(\dot{\phi}a^3)) . \tag{30}$$

However, with the de Sitter case $H = H_0$, the particular solutions can be obtained. In this circumstance, we find for $f(\phi) = c_5 e^{\frac{c_1 \phi}{c_4}} + c_6 \equiv A e^{n\phi} + c_6$

$$\ddot{\phi} + 3H_0 \dot{\phi} - 6H_0^2 = 0 , \tag{31}$$

$$\ddot{\xi} + 3H_0 \dot{\xi} - 6nAH_0^2 e^{n\phi} = 0 , \tag{32}$$

where the constrained values of A and n are given above. We obtain the solution as the following:

$$\phi(t) = -\frac{k_1 e^{-3H_0 t}}{3H_0} - 2H_0 t + k_2 , \tag{33}$$

where $k_i s$ are integration constants. We use the standard method to solve and the solution reads

$$\xi(t) = \xi_h(t) + \xi_i(t) , \tag{34}$$

where ξ_h is a general solution of the corresponding homogeneous equation given by

$$\xi_h(t) = p_2 - \frac{p_1 e^{-3H_0 T}}{3H_0} , \tag{35}$$

where $p_i s$ are integration constants. To specify $\xi_i(t)$ that satisfies the nonhomogeneous equation, the solution can be written in the form:

$$\xi_1(t) = F(e^{n\phi(T)}) , \tag{36}$$

where F is a function depends on $e^{n\phi(T)}$.

We found that the scalar factor $a(t)$ mimics de Sitter solution. For the fields $\{\phi(t), \xi(t)\}$, we observed that ϕ is not monotonic increasing or decreasing form. There is a local minima after that the field ϕ is monotonically increasing. For the field ξ, we discovered that it is increasing till the late time $t \to \infty$. Spacetime in this class is asymptotically considered as de Sitter for $t \to \infty$.

In this work we considered a formal framework of nonlocal f(T) theory of gravity and investigated the nonlocal f(T) theory through the Noether symmetry. We derived the Noether equations of the nonlocal f(T) theory in FLRW universe. We analysed the dynamics of the field in nonlocal f(T) gravity using the Noether symmetry. In summary, we observed classes of solutions that there exists the transition from a deceleration phase to the acceleration one in our present analysis.

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UDC 532.5; 519.95

CONSERVATION LAWS FOR THE INHOMOGENEOUS HIROTA AND THE MAXWELL-BLOCH SYSTEM

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Introduction. In recent years, nonlinear science has emerged as a powerful subject for explaining the mystery present in the challenges of science and technology today. Among nonlinear science, the interplay between dispersion and nonlinearity gives rise to several important phenomena in optical fibers, including parametric amplification, wavelength conversion, modulational instability(MI), soliton propagation and so on. Among all concepts, solitons, positons and rogons have been not only the subject of intensive research in oceanography [1, 2] but also it has been studied extensively in several areas, such as Bose-Einstein condensate, plasma, superfluid, finance, optics and so on [3-9].

An important ingredient in the development of the theory of soliton and of complete integrability has been the interplay between mathematics and physics. In 1973, Hasegawa and Tappert [10] modeled the propagation of coherent optical pulses in optical fibres by nonlinear Schrodinger (NLS) equation without the inclusion of fibre loss. They showed theoretically that generation and propagation of shape-preserving pulses called solitons in optical fibres is possible by balancing the dispersion and nonlinearity. The H-MB system has been shown to be integrable and also admits the Lax pair and other required properties for complete integrability [11].

In this paper, we will concentrate on the inhomogeneous Hirota and the Maxwell-Bloch (H-MB) system as following specific form [12, 13],

$$q_z = -\left(a_1(z)q_t + a_2(z)q + ia_3(z)q_{tt} + a_4(z)q_{ttt} + a_5(z)|q|^2 q_t + ia_6(z)|q|^2 q + a_7(z)p\right), \tag{1}$$

$$p_t = 2b_1(z)q\eta - 2ib_2(z)\omega p, \tag{2}$$

$$\eta_t = -b_1(z)\left(qp^* + q^* p\right), \tag{3}$$