Physics Letters B 678 (2009) 423–426

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Accelerating Universe with spacetime torsion but without dark matter and dark energy

A.V. Minkevich [a,b,*]

[a] Department of Theoretical Physics, Belarussian State University, Minsk, Belarus
[b] Department of Physics and Computer Methods, Warmia and Mazury University in Olsztyn, Poland

ARTICLE INFO

Article history:
Received 24 April 2009
Received in revised form 23 June 2009
Accepted 25 June 2009
Available online 26 June 2009
Editor: S. Dodelson

PACS:
98.80.Jk
95.35.+d
95.36.+x

Keywords:
Dark matter
Dark energy
Accelerating Universe
Riemann–Cartan spacetime continuum

ABSTRACT

It is shown that cosmological equations for homogeneous isotropic models deduced in the framework of the Poincaré gauge theory of gravity by certain restrictions on indefinite parameters of gravitational Lagrangian take at asymptotics the same form as cosmological equations of general relativity theory for ΛCDM-model. Terms related to dark matter and dark energy in cosmological equations of standard theory for ΛCDM-model are connected in considered theory with the change of gravitational interaction provoked by spacetime torsion.

1. Introduction

As it is well known, the notions of dark matter (DM) and dark energy (DE) were introduced in order to explain observational cosmological and astrophysical data in the framework of the general relativity theory (GR). According to obtained estimations the contribution of these invisible components to the energy of the Universe is approximately equal to 96%. The origin problem of hypothetical kinds of gravitating matter – DM and DE – is one of the most principal problems of modern cosmology and gravitation theory. Many attempts have been proposed with the purpose of solving this problem (see [1–7] and references herein). In the frame of GR the DE (or quintessence) as gravitating matter with negative pressure provoking accelerating cosmological expansion at present epoch is associated in many works with vacuum energy leading to cosmological constant in cosmological equations that is expressed in the title "ΛCDM-model". In other works the quintessence is related to some hypothetical fields. The DM is considered usually as connected with some massive particles (WIMP), which appear in elementary particles theory including various generalizations of Standard Model and the search for which is realizing in many experimental projects (see review [7]). At the same time there is another treatment that explains effects associated in the framework of the standard theory with DE and DM. This treatment is connected with the search for some generalization of Einstein gravitation theory, where there is no DE and DM, and the corresponding effects are connected with the change of gravitational interaction. At present there are different approaches in this direction connected, in particular, with extradimensional theories, $f(R)$ gravity, MOND, etc. Not always such theories are based on acceptable fundamental physical principles.

The present Letter is devoted to the discussion of possible a solution of DE- and DM-problems in the frame of the Poincaré gauge theory of gravity (PGTG) (see [8–11]), which is a natural generalization of GR and which offers opportunities that can solve the principal problems of Einstein gravitational theory (see [12,13] and references herein). The PGTG is based on well-known and acceptable physical principles including the local gauge invariance principle, and it is the gravitation theory in 4-dimensional physical spacetime with the structure of the Riemann–Cartan continuum. Note that the PGTG is a necessary generalization of GR, if one supposes that the Lorentz group, which is fundamental group in physics, is included to gauge group corresponding to gravitational

* Correspondence address: Department of Theoretical Physics, Belarussian State University, Minsk, Belarus.
E-mail addresses: minkav@bsu.by, awm@wmii.uwm.edu.pl.

0370-2693
doi:10.1016/j.physletb.2009.06.050

interaction. At the first time the simplest PGTG – the Einstein–Cartan theory [14] – was applied with the purpose to solve one of the problems of GR, the problem of cosmological singularity in Refs. [15,16]. However, the possibilities of the Einstein–Cartan theory are limited. As a natural generalization of Einstein–Cartan theory is the PGTG based on gravitational Lagrangian $\mathcal{L}_{\rm g}$ including not only scalar curvature but invariants quadratic in gravitational field strengths – curvature $F_{\alpha\beta\mu\nu}$ and torsion $S_{\alpha\mu\nu}$ tensors. By using sufficiently general expression of $\mathcal{L}_{\rm g}$ regular isotropic cosmology including inflationary cosmology was built and investigated in the frame of PGTG (see [17–20] and references herein). As it was shown, the character of gravitational interaction by certain physical conditions in the frame of PGTG is changed, and in the case of usual gravitating matter with positive values of energy density and pressure the gravitational interaction can be repulsive [13,17,19] that offers opportunities to solve principal problems of GR, in particular, the problem of the beginning of the Universe in time in the past (problem of cosmological singularity). The possible solution of DE-problem in the frame of PGTG was discussed in [20]. Below we will show that the PGTG offers opportunity to solve also the DM-problem together with the DE-problem. In Section 2 the cosmological equations for homogeneous isotropic models (HIM) of PGTG are given. In Section 3 the restrictions on indefinite parameters of $\mathcal{L}_{\rm g}$ leading to a possible solution of DM- and DE-problems in cosmology are obtained. In conclusion some physical problems in connection with proposed solution are discussed.

2. Cosmological equations of isotropic cosmology in PGTG

We will consider the PGTG based on sufficiently general following expression of gravitational Lagrangian (definitions and notations of [20] are used below):

$$\begin{aligned}\mathcal{L}_{\rm g} = \big[&f_0 F + F^{\alpha\beta\mu\nu}(f_1 F_{\alpha\beta\mu\nu} + f_2 F_{\alpha\mu\beta\nu} + f_3 F_{\mu\nu\alpha\beta})\\ &+ F^{\mu\nu}(f_4 F_{\mu\nu} + f_5 F_{\nu\mu}) + f_6 F^2\\ &+ S^{\alpha\mu\nu}(a_1 S_{\alpha\mu\nu} + a_2 S_{\nu\mu\alpha}) + a_3 S^{\alpha}{}_{\mu\alpha} S_{\beta}{}^{\mu\beta}\big]. \qquad (1)\end{aligned}$$

The Lagrangian (1) includes the parameter $f_0 = (16\pi G)^{-1}$ (G is Newton's gravitational constant, the light velocity $c = 1$) and a number of indefinite parameters: f_i ($i = 1, 2, \ldots, 6$) and a_k ($k = 1, 2, 3$). Physical consequences of PGTG depend essentially on restrictions on indefinite parameters f_i and a_k. Some such restrictions will be given below by investigation of HIM.

In the framework of PGTG any HIM is described by three functions of time: the scale factor of Robertson–Walker metrics R and two torsion functions S_1 and S_2 [21,22]. Gravitational equations for HIM filled with spinless matter with two torsion functions corresponding to gravitational Lagrangian (1) were analyzed in [20]. These equations allow to obtain cosmological equations generalizing Friedmann cosmological equations of GR and equations for torsion functions. Unlike metric theories of gravity terms of $\mathcal{L}_{\rm g}$ quadratic in the curvature tensor do not lead to higher derivatives in cosmological equations. Higher derivatives can appear because of terms of $\mathcal{L}_{\rm g}$ quadratic in the torsion tensor. In order to exclude higher derivatives from cosmological equations we have to put the following condition for indefinite parameters a_k: $2a_1 + a_2 + 3a_3 = 0$ [23]. Besides this condition the following restriction on f_i was used in [20]: $f_2 + 4f_3 + f_4 + f_5 = 0$; by this restriction gravitational equations take a more symmetric form. Then the cosmological equations for HIM include three following indefinite parameters: the parameter $\alpha \equiv f/(3f_0^2)$ ($f = f_1 + \frac{f_2}{2} + f_3 + f_4 + f_5 + 3f_6$) with inverse dimension of energy density, the parameter $b = a_2 - a_1$ with the same dimension as f_0 and dimensionless parameter $\varepsilon = (2f_1 - f_2)/f$. Explicit form of cosmological equations is the following [20]:

$$\begin{aligned}&\frac{k}{R^2} + (H - 2S_1)^2\\ &\quad= \frac{1}{6f_0 Z}\left[\rho + 6(f_0 Z - b)S_2^2 + \frac{\alpha}{4}\left(\rho - 3p - 12bS_2^2\right)^2\right]\\ &\qquad- \frac{3\alpha\varepsilon f_0}{Z}\left[(HS_2 + \dot S_2)^2 + 4\left(\frac{k}{R^2} - S_2^2\right)S_2^2\right], \qquad (2)\end{aligned}$$

$$\begin{aligned}&\dot H + H^2 - 2HS_1 - 2\dot S_1\\ &\quad= -\frac{1}{12f_0 Z}\left[\rho + 3p - \frac{\alpha}{2}\left(\rho - 3p - 12bS_2^2\right)^2\right]\\ &\qquad- \frac{\alpha\varepsilon}{Z}\left(\rho - 3p - 12bS_2^2\right)S_2^2\\ &\qquad+ \frac{3\alpha\varepsilon f_0}{Z}\left[(HS_2 + \dot S_2)^2 + 4\left(\frac{k}{R^2} - S_2^2\right)S_2^2\right], \qquad (3)\end{aligned}$$

where $H = \dot R/R$ is the Hubble parameter (a dot denotes the differentiation with respect to time), ρ is the energy density, p is the pressure and $Z = 1 + \alpha(\rho - 3p - 12(b + \varepsilon f_0)S_2^2)$. According to gravitational equations the torsion function S_1 take the following form:

$$S_1 = -\frac{\alpha}{4Z}\left[\dot\rho - 3\dot p + 36\varepsilon f_0 H S_2^2 - 12(2b - \varepsilon f_0)S_2\dot S_2\right]. \qquad (4)$$

Derivatives of the energy density and pressure can be excluded from (4) by using the conservation law, which in the case of spinless matter minimally coupled with gravitation takes the same form as in GR:

$$\dot\rho + 3H(\rho + p) = 0. \qquad (5)$$

The torsion function S_2 satisfies the differential equation of the second order:

$$\begin{aligned}&\varepsilon\left[\ddot S_2 + 3H\dot S_2 + \left(3\dot H - 4\dot S_1 + 12HS_1 - 16S_1^2\right)S_2\right]\\ &\quad- \frac{1}{3f_0}\left(\rho - 3p - 12bS_2^2\right)S_2 - \frac{(1 - b/f_0)}{3\alpha f_0}S_2 = 0. \qquad (6)\end{aligned}$$

Cosmological equations (2)–(3) together with Eqs. (4) and (6) for torsion functions describe the evolution of HIM by given equation of state for gravitating matter.

3. Accelerating Universe without dark energy and dark matter

Now we will analyze the following question: by what restrictions on the indefinite parameters cosmological equations of PGTG for HIM describe the evolution of the Universe in agreement with actual observations without using notions of dark matter and dark energy. By taking into account that various parameters of HIM have to be small at the asymptotics, when values of energy density are sufficiently small, we see from (6), that if $|\varepsilon| \ll 1$, the torsion function S_2 has at asymptotics the following value:

$$S_2^2 = \frac{1 - b/f_0}{12\alpha b} + \frac{\rho - 3p}{12b}. \qquad (7)$$

Then we have at asymptotes: $Z \to (b/f_0)$, $S_1 \to 0$ and the cosmological equations (2)–(3) at asymptotics take the following form:

$$\frac{k}{R^2} + H^2 = \frac{1}{6f_0}\left[\rho(f_0/b) + \frac{1}{4}\alpha^{-1}(1 - b/f_0)^2(f_0/b)\right], \qquad (8)$$

$$\begin{aligned}\dot H + H^2 = -\frac{1}{12f_0}\Big[&(\rho + 3p)(f_0/b)\\ &- \frac{1}{2}\alpha^{-1}(1 - b/f_0)^2(f_0/b)\Big]. \qquad (9)\end{aligned}$$

Effective cosmological constant in cosmological equations (8)–(9) is induced by spacetime torsion function (7). According to (8)–(9) the evolution of HIM at the asymptotics depends on two indefinite parameters: α and b. Let us to compare (8)–(9) with Friedmann cosmological equations of GR:

$$\frac{k}{R^2}+H^2=\frac{1}{6f_0}\rho_{\rm tot}, \tag{10}$$

$$\dot{H}+H^2=-\frac{1}{12f_0}(\rho_{\rm tot}+3p_{\rm tot}), \tag{11}$$

where $\rho_{\rm tot}$ and $p_{\rm tot}$ are total values of energy density and pressure including contributions of three components: baryonic matter, dark matter and dark energy: $\rho_{\rm tot}=\rho_{\rm BM}+\rho_{\rm DM}+\rho_{\rm DE}$, $p_{\rm tot}=p_{\rm BM}+p_{\rm DM}+p_{\rm DE}$. In the case of standard ΛCDM-model one uses at present epoch for baryonic and dark matter the equation of state of dust ($p_{\rm BM}=p_{\rm DM}=0$), and for dark energy $p_{\rm DE}=-\rho_{\rm DE}$. According to observational data, the Universe evolution is in agreement with Friedmann cosmological equations (10)–(11) for flat model ($k=0$), if one supposes that the contribution of dark matter and dark energy to energy density of the Universe approximately is the following: $\rho_{\rm DM0}=0.23\rho_{cr}$, $\rho_{\rm DE0}=0.73\rho_{cr}$, where $\rho_{cr}=6f_0H_0^2$ and values of physical parameters at present epoch are denoted by means of the index "0". By comparing cosmological equations (8)–(9) with (10)–(11) we see that cosmological equations of PGTG at asymptotics have quasi-Friedmannian structure and lead to the same consequences as Friedmann cosmological equations of GR, if one supposes that the energy density ρ in (8)–(9) corresponds to all physical matter in the Universe, which is practically equal to baryonic matter (by suppsing that the contribution of invisible non-baryonic matter in the form of neutrino etc is sufficiently small), by certain values of parameters b and α, namely if $b=f_0(\rho_0/(\rho_0+\rho_{\rm DM0}))$ and $\alpha=\frac{1}{4}\rho_{\rm DE0}{}^{(-1)}(1-b/f_0)^2(f_0/b)$. Obtained estimation of α corresponds to energy density of order of average energy density in the Universe at present epoch and differs from estimation of α used in our previous papers [17–20, 23], where the value of α corresponds to the scale of extremely high energy densities at the beginning of cosmological expansion. Previous estimation of α was obtained by investigation of HIM with the only torsion function S_1, and it was introduced in order to satisfy the correspondence principle with GR by description of such HIM at asymptotics, where values of energy density are sufficiently small. However, as follows from our consideration given above, such estimation is not necessary in the case of HIM with two torsion functions. Moreover, in the case of obtained estimation for parameters b and α the fine tuning problem of defining of b in [20] disappears. Note that terms in cosmological equations containing the parameter b describe the change of gravitational interaction provoked by spacetime torsion. When effective cosmological constant in (8)–(9) was small in comparison with the first term in the right-hand side of (8)–(9), gravitational attraction was larger in comparison with GR and Newton's theory of gravity. This fact could play the important role by formation of the large scale structure of the Universe ensuring additional gravitational attraction, which is provoked in the frame of standard theory by the dark matter. However, now when effective cosmological constant dominates, gravitational interaction has the repulsive character and leads to acceleration of cosmological expansion. Note that if some non-baryonic invisible matter exists and gives certain contribution to energy density ρ in cosmological equations (8)–(9), in this case obtained estimation for parameters b and α will be changed.

Cosmological equations (8)–(9) are valid only in the zeroth approximation with respect to small parameter ε. It is interesting to analyze observational cosmological data by taking into account corrections connected with ε in order to estimate more precisely the role of spacetime torsion at present epoch of cosmological evolution. By using obtained estimation for parameters α and b it is interesting also to study HIM at the beginning of cosmological expansion with the purpose to build totally regular Big Bang scenario. However, these problems will be object of our further investigations.

4. Conclusion

We see that the PGTG leads to essential changes of gravitational interaction not only at extreme conditions (extremely high energy densities and pressures) in the beginning of cosmological expansion, but also at present epoch. These changes allow us to explain the cosmological observational data associated in the frame of GR with the notions of "dark matter" and "dark energy" without using these notions. From the point of view of considered PGTG, the notions of "dark matter" and "dark energy" play the role similar to that of "ether" in physics before the creation of special relativity theory by A. Einstein. Unlike GR, in the frame of PGTG Newton's law of gravitational attraction is not applicable at cosmological scale. If we remember that the "dark matter" notion was introduced by applying Newton's law of gravitational attraction at the galactic scales, the problem of the investigations of inhomogeneous gravitating systems at galactic scales in the framework of PGTG becomes very actual. Although the vacuum Schwarzschild solution for the metrics with vanishing torsion is an exact solution of PGTG for any values of indefinite parameters of the gravitational Lagrangian (1) that allows us to explain the usual gravitational phenomena in the Solar system, for the above mentioned restrictions on indefinite parameters of $\mathcal{L}_g$ the Birkhoff theorem [24] is not valid. This means that there are other solutions in this case, and possibly we have to use in the Solar system the solution, which deviates from the vacuum Schwarzschild solution. (In connection with this let us to remind about the problem of Pioneer anomaly). The search for the criteria that allow us to be able to choose physically acceptable solutions is warranted and also important for PGTG.

Acknowledgements

The author is very grateful to Prof. Jaan Einasto for discussions of problems presented in this Letter.

References

[1] J. Frieman, M.S. Turner, D. Huterer, arXiv:0803.0982 [astro-ph].
[2] V. Sahni, A. Starobinsky, Int. J. Mod. Phys. D 15 (2006) 2105, astro-ph/0610026.
[3] T. Padmanabhan, AIP Conf. Proc. 861 (2006) 179, astro-ph/0603114.
[4] A.D. Chernin, Phys. Usp. 51 (2008) 253.
[5] V.N. Lukash, V.A. Rubakov, Phys. Usp. 51 (2008) 282, arXiv:0807.1635 [astro-ph].
[6] S. Nojiri, S.D. Odintsov, arXiv:0807.0685 [hep-th].
[7] V.A. Ryabov, V.A. Tsarev, A.M. Tskhovrebov, Phys. Usp. 51 (11) (2008).
[8] T.W.B. Kibble, J. Math. Phys. 2 (1961) 212.
[9] F.W. Hehl, Four lectures on Poincare gauge field theories, in: Cosmology and Gravitation, Plenum Press, New York, 1980.
[10] K. Hayashi, T. Shirafuji, Progr. Theor. Phys. 64 (1980) 866;
K. Hayashi, T. Shirafuji, Progr. Theor. Phys. 64 (1980) 1435;
K. Hayashi, T. Shirafuji, Progr. Theor. Phys. 64 (1980) 2222.
[11] M. Blagojević, Gravitation and Gauge Symmetries, IOP Publishing, Bristol, 2002.
[12] A.V. Minkevich, Ann. Fond. Louis de Broglie 32 (2007) 253, arXiv:0709.4337 [gr-qc].
[13] A.V. Minkevich, Acta Phys. Pol. B 40 (2) (2009) 229, arXiv:0808.0239 [gr-qc].
[14] A. Trautman, Einstein–Cartan theory, in: J.-P. Francoise, et al. (Eds.), Encyclopedia of Math. Physics, Elsevier, Oxford, 2006, pp. 189–195, gr-qc/0606062.
[15] W. Kopczynski, Phys. Lett. A 39 (1972) 219.
[16] A. Trautman, Nature (Phys. Sci.) 242 (1973) 7.
[17] A.V. Minkevich, Gravit. Cosmol. 12 (2006) 11, gr-qc/0506140.

[18] A.V. Minkevich, A.S. Garkun, Class. Quantum Grav. 23 (2006) 4237, gr-qc/0512130.
[19] A.V. Minkevich, Acta Phys. Pol. B 38 (2007) 61, gr-qc/0512123.
[20] A.V. Minkevich, A.S. Garkun, V.I. Kudin, Class. Quantum Grav. 24 (2007) 5835, arXiv:0706.1157 [gr-qc].
[21] V.I. Kudin, A.V. Minkevich, F.I. Fedorov, On spacetime symmetries in gauge theory of gravity (1979), 12 p., Preprint No. 3794-79 VINITI Akad. Nauk SSSR.
[22] M. Tsamparlis, Phys. Lett. A 75 (1979) 27.
[23] A.V. Minkevich, Phys. Lett. A 80 (1980) 232.
[24] R. Rauch, H.T. Nieh, Phys. Rev. D 24 (1981) 2029.