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THE PROPER MASS OF THE UNIVERSE

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A modification of the covariant theory based on the concept of the proper mass (mass distribution) of the system is proposed. The proper mass is a special dynamic quantity that forms a fundamental frame of reference for measuring proper time and spatial shifts without violating the theory's covariance. A simple model of an ingomogeneous system (universe, string) with two proper time parameters, whose constraint algebra is isomorphic to SL2, is considered.

Keywords: universe, time, mass, covariance, reference frame, algebra of constraints

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СОБСТВЕННАЯ МАССА ВСЕЛЕННОЙ

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Предложена модификация ковариантной теории, основанная на понятии собственной массы (распределение масс) системы. Собственная масса является особой динамической величиной, которая образует фундаментальную систему отсчета для измерения собственного времени и пространственных сдвигов без нарушения ковариантности теории. Рассмотрена простая модель неоднородной системы (Вселенная, струна) с двумя параметрами собственного времени, алгебра связей которой изоморфна SL2.

Ключевые слова: Вселенная, время, масса, ковариантность, система обсчета, алгебра связей

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Introduction

The quantization of covariant theories, to which we include gauge theories with constraints linear in momenta, as well as the theory of gravity and string theory with quadratic in momenta (Hamiltonian) constraints, makes it necessary to expand their phase space by including Lagrange multipliers and ghosts along with the corresponding canonical momenta [1 – 6]. However, in the simplest case of the reparametrization-invariant theory of a relativistic particle, all this construction is reduced to introducing the particles proper time parameter into the initial action, followed by integrating the wave function over this parameter within [0, ∞) [7]. The result is a representation of the Feynman propagator of a particle, which was first proposed by V.A. Fock [8] and J. Schwinger [9]. Based on this, a simplified procedure for quantizing the covariant theory was proposed in Ref. [10], in which the parameters of finite symmetry transformations (including the proper time in reparameterization-invariant theories) are introduced into the classical theory as additional coordinates.

The equations of constraints in quantum theory with this modification take the form of evolution equations on a group space, and the invariant propagator is obtained after integrating the wave function over the group parameters over the entire area of their variation (for proper time, these are the functional space (FS) integrals within [0, ∞)) with a simple measure equal to 1. However, in contrast to gauge theories with linear momentum constraints, FS integrals are not removed by delta functions from Hamiltonian constraints. This means that in quantum theory there is no time parameter. In Ref. [11], to solve the problem of time in the case of a homogeneous isotropic model of the universe, the second stage of modification is proposed, in which an additional condition is imposed on the dynamics of proper time as an independent dynamic variable. It consists in adding to the initial action its small variation generated by the infinitesimal shift of proper time. As a result, a new quantity arises in the theory – mass-energy, which corresponds to its own time. In a homogeneous universe, this quantity is an integral of motion and must be added to the original set of constants of the universe. In Ref. [11], it was also suggested that the mass of the universe, taking into account the multi-turnaround of time in the general case [12], will have the character of a distribution, which should be supplemented by the corresponding mass flux density. The purpose of this work is to substantiate this assumption by the example of a simple dynamical system with two proper time parameters and with the algebra of constraints identical to SL (2, *R*). In this case, we will have two components of its own mass and a flow between them. These three parameters are not integrals of motion. They are present in the energy-momentum balance of the system (constraint equations), and should be considered as observable quantities. Their equations of motion, together with the equations of constraints, make it possible to remove integration over the parameters of proper time and thereby solve the problem of time in the quantum theory.

The first stage of modification of SL (2, *R*)-model

The initial Lagrange function of the considered dynamic system has the form:

$$L=\frac{1}{2N_1}\left(\dot{u}-N_3u\right)^2+ \\ +\frac{1}{2N_3}\left(\dot{v}+N_3v\right)^2+\frac{N_1}{2}v^2+\frac{N_2}{2}u^2, \tag{1}$$

where the dot denotes derivatives with respect to an arbitrary parameter τ; N_1, N_2 are the lapse functions, N_3 is the shift function [12].

Minkowski indices u_μ, v_ν, $\mu, \nu = 0, 1, 2, 3$ are implied and abbreviated notation for the invariants of the Minkowski space are used.

Hamilton's function is reduced to a linear combination of constraints

$$h=N_1H_1+N_2H_2+N_3D, \tag{2}$$

where

$$H_1=\frac{1}{2}\left(p^2-v^2\right),\quad H_2=\frac{1}{2}\left(\pi^2-u^2\right), \\ D=pu-\pi v. \tag{3}$$

The Poisson brackets of these constraints form the algebra SL(2, *R*) [13]:

$$\left\{D,H_1\right\}=2H_1,\quad \left\{D,H_2\right\}=-2H_2, \\ \left\{H_1,H_2\right\}=D. \tag{4}$$

This algebra will serve us as the simplest analogue of the algebra of constraints of the theory of gravity (and string [14]). The constraints are generators of infinitesimal symmetry transformations of the canonical variables, which are compensated by the transformation of the lapse and shift functions [1],

$$\delta N_\alpha = \dot{\varepsilon}_\alpha - C_{\beta\gamma\alpha} N_\beta \varepsilon_\gamma, \tag{5}$$

which ensures the invariance of the action (in this case $C_{311} = 2$, $C_{322} = -2$, $C_{123} = 1$).

At the first stage of the modification of the dynamic theory, as additional generalized coordinates, we introduce the parameters of finite symmetry transformations that arise as a result of the integration of the system of functional differential equations:

$$N_\beta = \dot{s}_\alpha \Lambda_{\alpha\beta}, \tag{6}$$

where the functions $\Lambda_{\alpha\beta}$ obey the system of differential equations [10]:

$$\frac{\partial \Lambda_{\alpha\beta}}{\partial s_\gamma} - \frac{\partial \Lambda_{\gamma\beta}}{\partial s_\alpha} + \Lambda_{\alpha\delta}\Lambda_{\gamma\omega}C_{\delta\omega\beta} = 0. \tag{7}$$

The modified theory is obtained by substituting (6) into the original Lagrange function (1).

The modified Hamilton function reduces to a linear combination of modified constraints

$$p_{s_\alpha} - \Lambda_{\alpha 1} H_1 - \Lambda_{\alpha 2} H_2 - \Lambda_{\alpha 3} D = 0, \tag{8}$$

which form a closed algebra with trivial Poisson brackets.

It is these constraints, in quantum theory that have the form of evolution equations on a group space with coordinates s_α. Since these coordinates are not observable, one should take additional integrals over them of the wave function over the entire range of their variation on the manifold of the group. For the parameters of proper time, these are the integrals of the FS within $[0, \infty)$. As a result of this integration, the wave function loses its dynamic meaning. It is necessary to take the next step in modifying the original theory [11], which will remove additional integrals.

Second stage of the theory modification

Considering the coordinates on the group space as independent dynamic variables, we take their classical equations of motion as additional conditions. The latter are obtained as a result of the infinitesimal shift of these variables $s_\alpha \to s_\alpha + \varepsilon_\alpha$ in the action.

Thus, the finally modified Lagrange function takes the form:

$$\begin{aligned}\tilde{L} = &\frac{1}{2}\left[\frac{(\dot{u} - N_3 u)^2}{N_1} + v^2 N_1\right]^2 + \\ &+ \frac{1}{2}\left[\frac{(\dot{v} + N_3 v)^2}{N_2} + u^2 N_2\right] - \\ &- \frac{1}{2}\left[\frac{(\dot{u} - N_3 u)^2}{N_1^2} + v^2\right]\delta N_1 - \\ &- \frac{1}{2}\left[\frac{(\dot{v} + N_3 v)^2}{N_2^2} + u^2\right]\delta N_2 - \\ &- \left[u\frac{(\dot{u} - N_3 u)}{N_1} - v\frac{(\dot{v} + N_3 v)}{N_2}\right]\delta N_3.\end{aligned} \tag{9}$$

Below we will see that this modification significantly changes the theory in the right direction – the removal of the integrals of the FS over its group evolution parameters.

We turn to the Hamiltonian form of the modified theory. Let's find the canonical momenta:

$$p = \frac{(\dot{u} - N_3 u)}{N_1}\left(1 - \frac{\delta N_1}{N_1}\right) - u\frac{\delta N_3}{N_1}, \tag{10}$$

$$\pi = \frac{(\dot{v} + N_3 v)}{N_2}\left(1 - \frac{\delta N_2}{N_2}\right) + v\frac{\delta N_3}{N_2}, \tag{11}$$

$$p_{s_\alpha} = -H_1 \Lambda_1^\beta - H_2 \Lambda_2^\beta -$$

$$-H_1\frac{\partial\Lambda_1^\beta}{\partial s_\gamma}\varepsilon_\gamma-H_2\frac{\partial\Lambda_2^\beta}{\partial s_\gamma}\varepsilon_\gamma-$$
$$-D\frac{\partial\Lambda_3^\beta}{\partial s_\gamma}\varepsilon_\gamma+$$
$$+\frac{(\dot u-N_3u)^2}{N_1^2}\frac{\delta N_1}{N_1}\Lambda_1^\beta+ \quad (12)$$
$$+\frac{(\dot v+N_3v)^2}{N_2^2}\frac{\delta N_2}{N_2}\Lambda_2^\beta+$$
$$+u\frac{(\dot u-N_3u)}{N_1}\frac{\delta N_3}{N_1}\Lambda_1^\beta-$$
$$-v\frac{(\dot v+N_3v)}{N_2}\frac{\delta N_3}{N_2}\Lambda_2^\beta,$$

$$P_{\varepsilon_\beta}=-H_1\Lambda_1^\beta-H_2\Lambda_2^\beta-D\Lambda_3^\beta. \quad (13)$$

The Hamilton function, as expected, is reduced to a linear combination of new constraints, which are here used by Eqs. (12).

In these equations, velocities should be eliminated by expressing them in terms of canonical momenta. First, eliminate the variation δN_1, δN_2, δN_3. To do this, we use the old constraints that are contained in Eqs. (13) together with the new dynamic variables, which are the two components of the mass distribution in our model universe and the mass flow. We express the old connections through new dynamic variables by solving Eqs. (13) using a triple of 3-vectors $\Omega_\beta^1,\Omega_\beta^2,\Omega_\beta^3$, each of which is orthogonal to the corresponding additional pair of column vectors $\Lambda_1^\beta,\Lambda_2^\beta,\Lambda_3^\beta$:

$$H_1=-\frac{(P_\varepsilon,\Omega^1)}{(\Omega^1,\Lambda_1)},\quad H_2=-\frac{(P_\varepsilon,\Omega^2)}{(\Omega^2,\Lambda_2)},$$
$$D=-\frac{(P_\varepsilon,\Omega^3)}{(\Omega^3,\Lambda_3)}. \quad (14)$$

We find the variations δN_1, δN_2 from the Hamiltonian constraints:

$$1-\frac{\delta N_1}{N_1}=\frac{\sqrt{\left(p+u\frac{\delta N_3}{N_1}\right)^2}}{\sqrt{H_1+v^2}},$$
$$1-\frac{\delta N_2}{N_2}=\frac{\sqrt{\left(\pi-v\frac{\delta N_3}{N_2}\right)^2}}{\sqrt{H_2+u^2}}, \quad (15)$$

and for the variations δN_3 the momentum constraint remains:

$$D=\frac{u\left(p+u\frac{\delta N_3}{N_1}\right)}{1-\frac{\delta N_1}{N_1}}-$$
$$-\frac{v\left(\pi-v\frac{\delta N_3}{N_2}\right)}{1-\frac{\delta N_2}{N_2}}. \quad (16)$$

which we cannot solve explicitly.

We only note that the variation δN_3 is a homogeneous function of the first degree of the canonical momenta, as well as Eqs. (15), which contain square roots. After that, we can substitute the velocities (10), (11) in Eqs. (12) and obtain the required equations of new constraints.

Leaving these constraints in the same implicit form, we write the modified action in the canonical form:

$$\tilde I\doteq\int d\tau\left[p\dot u+\pi\dot v+p_{s_\alpha}\dot s_\alpha-\right.$$
$$\left.-\dot P_{\varepsilon_\alpha}\varepsilon_\alpha-\tilde N_\alpha\left(p_{s_\alpha}-\tilde h_\alpha\right)\right], \quad (17)$$

where $\tilde h_\alpha$ denotes the right hand side of the Eqs. (12).

Here we consider infinitesimal shifts as canonical momenta. We will see the solution to the problem of time in our "universe" when we exclude momenta in this canonical form of action and write it again in Lagrangian form. We can do this explicitly.

Proper time

We will be the first to exclude the momenta p_{s_α} conjugated to the group parameters s_α. As a result, we get $\tilde{N}_\alpha = \dot{s}_\alpha$. Next we exclude infinitesimal shifts. This gives the equations of motion in the form of the law of the change in time of new dynamic variables:

$$Q_\gamma = \dot{P}_{\varepsilon_\alpha} + \\ + \frac{(P_\varepsilon, \Omega^1)}{(\Omega^1, \Lambda_1)} \frac{\partial \Lambda_1^\beta}{\partial s_\gamma} \dot{s}_\beta + \frac{(P_\varepsilon, \Omega^2)}{(\Omega^2, \Lambda_2)} \frac{\partial \Lambda_2^\beta}{\partial s_\gamma} \dot{s}_\beta + \\ + \frac{(P_\varepsilon, \Omega^3)}{(\Omega^3, \Lambda_3)} \frac{\partial \Lambda_3^\beta}{\partial s_\gamma} \dot{s}_\beta = 0. \quad (18)$$

The last ones we exclude the canonical momenta corresponding to the "physical" degrees of freedom – the Minkowski coordinates u_μ, v_ν. Here the difficulty remains associated with the absence of an explicit solution of the constraint equations with respect to variations δN_1, δN_2, δN_3. However, it is easy to see that the resulting dependence of the modified Hamiltonian on the canonical momenta is a homogeneous function of the first degree. The consequence is that all terms in the canonical action (17), depending on the canonical momenta, disappear.

Thus, the dependence of the modified action on all velocities disappears, except for the one contained in the equations of motion (18), as well as in the old constraints (4), which we must now remember and add to the action as additional conditions. We also recall that the implicit solution of these constraints involves the operation of extracting a square root with a choice of the sign of this root. We must perform the same operation under additional conditions, writing down the Hamiltonian constraints with square roots of the kinetic energies of the physical degrees of freedom. As a result, we get the modified action in the form

$$\tilde{I} \doteq \int d\tau \times \\ \times \Bigg\{ \varepsilon_\beta Q_\beta + \lambda_1 \left[\sqrt{(\dot{u} - N_3 u)^2} - N_1 \sqrt{v^2 - \frac{(P_\varepsilon, \Omega^1)}{(\Omega^1, \Lambda_1)}} \right] + \\ + \lambda_2 \left[\sqrt{(\dot{v} + N_3 v)^2} - N_2 \sqrt{u^2 - \frac{(P_\varepsilon, \Omega^2)}{(\Omega^2, \Lambda_2)}} \right] + \\ + \lambda_3 \left[\sqrt{\frac{N_2}{N_1}} u (\dot{u} - N_3 u) - \right. \\ \left. - \sqrt{\frac{N_1}{N_2}} v (\dot{v} + N_3 v) - \sqrt{N_1 N_2} \frac{(P_\varepsilon, \Omega^3)}{(\Omega^3, \Lambda_3)} \right] + \\ + N_1 \left[\frac{(P_\varepsilon, \Omega^1)}{(\Omega^1, \Lambda_1)} - v^2 \right] + N_2 \left[\frac{(P_\varepsilon, \Omega^2)}{(\Omega^2, \Lambda_2)} - u^2 \right] \Bigg\}, \quad (19)$$

where additional conditions are included with the corresponding Lagrange multipliers λ_1, λ_2, λ_3. Infinitesimal shifts ε_β also fulfill their original function of the Lagrange multipliers.

Note that the modified Lagrange function is a homogeneous first-order velocity function, so that the theory remains explicitly reparameterization-invariant.

In the quantum theory, in the representation of a propagator in the form of a functional integral, integration over the Lagrange multipliers gives the product of the corresponding functional delta functions that remove functional integration over group parameters s_α, as well as over additional parameters P_{ε_α}. The dynamics of the latter, considered by us as observables, serves to measure their proper time in the universe. If we do not allow the introduction of new observables and set $P_\varepsilon = 0$, the additional equations of motion for them also disappear. Then the FS integrals are removed by δ-functions from the initial constraints, which have the same meaning as the first integral,

$$\int \frac{dq}{\sqrt{E - U(q)}} = t, \quad (20)$$

defining time in mechanics.

Any physical degree of freedom can play the role of proper time in this case.

Conclusions

A modification of the covariant dynamical theory with constraint algebra SL2 is inspired by the problem of time in quantum theory. The usual practice in this case of imposing additional gauge conditions violating the covariance has been replaced by a modification of the original theory at the classical level, which does not violate the covariance of the dynamics of the physical degrees of freedom. Additional conditions in it are imposed on the physically unobservable parameters of symmetry transformations – proper time (for each point of the "universe" its own) and the spatial shift between points. However, the modification turns out to be deeper, adding new dynamical variables to the balance of energy and momentum of physical degrees of freedom, which should be considered observable. The dynamics of these observables can serve to measure proper time and spatial shifts, forming the fundamental frame of reference in the universe.

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REFERENCES

1. **Faddeev L.D., Slavnov A.A.,** Gauge fields: An introduction to quantum theory, 2nd edition, Westview Press, 1993.

2. **Fradkin E.S., Vilkovisky G.A.,** Quantization of relativistic systems with constraints, Phys. Lett. B. 55 (2) (1975) 224–226.

3. **Batalin I.A., Vilkovisky G.A.,** Relativistic *S*-matrix of dynamical systems with boson and fermion constraints, Phys. Lett. B. 69 (3) (1977) 309–312.

4. **Henneaux M.,** Hamiltonian form of the path integral for theories with a gauge freedom, Phys. Rep. 126 (1) (1985) 1–66.

5. **Kugo T., Ojima I.,** Local covariant operator formalism of non-Abelian gauge theories and quark confinement problem, Progr. Theor. Phys. Suppl. 66 (February) (1979) 1–130.

6. **Ore F.R., van Nieuwenhuisen P.,** Local {BRST} symmetry and the geometry of gauge-fixing, Nucl. Phys. B. 204 (2) (1982) 317–332.

7. **Govaerts J.,** A note on the Fradkin – Vilkovisky theorem, CERN-TH 5010/88 (1988).

8. **Fock V.A.,** The eigen-time in classical and quantum mechanics, Phys. Zs. Sowjet. 12 (4) (1937) 404–425 (in German).

9. **Schwinger J.,** On gauge invariance and vacuum polarization, Phys. Rev. 82 (5) (1951) 664–679.

10. **Gorobey N., Lukyanenko A.,** Time and observables in covariant quantum theory, arXiv:2001.09003[gr-qc], 2020.

11. **Gorobey N., Lukyanenko A., Goltsev A.,** Feynman propagator for a system of interacting scalar particles in the Fokker theory, arXiv.2002.03607v1[quant-ph], 2020.

12. **Misner C.W., Thorne K. S., Wheeler J.A.,** Gravitation, Princeton University Press, New Jersey, USA, 2017.

13. **Montesions M., Rovelli C., Thiemann T.,** SL (2, R) model with two Hamiltonian constraints, Phys. Rev. D. 60 (4) (1999) 044009.

14. **Green M.B., Schwarz J.H., Witten E.,** Superstring theory, Vol. 1: Introduction, Cambridge University Press, 1987.

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1. **Славнов А.А., Фаддеев Л.Д.** Введение в квантовую теорию калибровочных полей. 2-е изд. М.: Наука. 1988. 272 с.

2. **Fradkin E.S., Vilkovisky G.A.** Non-perturbation methods in 2 dimensional quantum field theory // Phys. Lett. B. 1975. Vol. 55. No. 2. Pp. 224–226.

3. **Batalin I.A., Vilkovisky G.A.** Relativistic *S*-matrix of dynamical systems with boson and fermion constraints // Phys. Lett. B. 1977. Vol. 69. No. 3. Pp. 309–312.

4. **Henneaux M.** Hamiltonian form of the path integral for theories with a gauge freedom // Phys. Rep. 1985. Vol. 126. No. 1. Pp. 1–66.

5. **Kugo T., Ojima I.** Local covariant operator formalism of non-Abelian gauge theories and quark confinement problem // Progr. Theor. Phys. Suppl. 1979. Vol. 66. February. Pp. 1–130.

6. **Ore F.R., van Nieuwenhuisen P.** Local {BRST} symmetry and the geometry of gauge-fixing // Nucl. Phys. B. 1982. Vol. 204. No. 2. Pp. 317–332.

7. **Govaerts J.** A note on the Fradkin – Vilkovisky theorem // CERN-TH 5010/88, 1988. 21 p.

8. **Фок В.А.** Собственное время в классической и квантовой механике // Известия АН СССР. Серия физическая. 1937. № 4–5. С. 551–568.

9. **Schwinger J.** On gauge invariance and vacuum polarization // Phys. Rev. 1951. Vol. 82. No. 5. Pp. 664–679.

10. **Gorobey N., Lukyanenko A.** Time and observables in covariant quantum theory// arXiv:2001.09003 [gr-qc] (2020).

11. **Gorobey N., Lukyanenko A.** Feynman propagator for a system of interacting scalar particles in the Fokker theory // arXiv:2002.03607v1 [quant-ph] (2020).

12. **Misner C.W., Thorne K.S., Wheeler J.A.** Gravitation. New Jersey, USA: Princeton University Press, 2017. 1279 p.

13. **Montesions M., Rovelli C., Thiemann T.** SL(2, R) model with two Hamiltonian constraints // Phys. Rev. D. 1999. Vol. 60. No. 4. P. 044009.

14. **Green M.B., Schwarz J.H., Witten E.** Superstring theory. Vol. 1. Introduction. Cambridge: Cambridge University Press, 1987. 469 p.

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