# General Ether Theory — A Metric Theory of Gravity with Condensed Matter Interpretation

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**Abstract**

Starting with simple assumptions about an "ether" in a Newtonian framework with Galilean coordinates $(X^i(x), T(x))$ we obtain a metric theory of gravity defined by

$$L = L_{GR} + \Xi g^{\mu\nu}\delta_{ij}X^i_{,\mu}X^j_{,\nu} - \Upsilon g^{\mu\nu}T_{,\mu}T_{,\nu}.$$

We compare this theory with general relativity and Logunov's "relativistic theory of gravity". The equations have a GR limit $\Xi, \Upsilon \to 0$, nonetheless there are remarkable differences even for small $\Upsilon > 0$: a big bounce instead of the big bang singularity, stable frozen stars instead of black holes.

## 1. Introduction

The purpose of the present work is to present a metric theory of gravity which, in addition to giving agreement with observation, provides an interesting conceptual and philosophical framework.

Of course, there is already a theory of gravity with these properties — general relativity. What is the motivation to develop another theory of gravitation? Different motivations have been given by other authors of alternative theories of gravity: Lightman and Lee [8] have considered the following questions: "(i) if such theories exist, how complex and contrived are their formulations? (ii) Do such theories have anything in common and in what respect do they differ from GR outside the PN limit?". Rosen's [13] problem was "whether one can set up a theory of gravitation which will give agreement with observation without permitting black holes". These are interesting questions which justify the consideration of our theory of gravity too.

Instead, our main motivation was quantum gravity. GR seems incompatible with quantum theory mainly because of the absence of an absolute framework. Our initial hypothesis was that such an absolute framework exists in quantum gravity, but remains unobservable in the classical limit. But in the theory of gravity we present here, the preferred frame remains in principle observable.

From mathematical point of view, the theory is a metric theory of gravity, the Lagrangian contains the GR Lagrangian with additional terms, which depend on the "preferred coordinates" $X^i, T$:

$$L = (R - \Lambda)\sqrt{-g} + L_{matter}(g_{\mu\nu}, \psi^m) + \Xi g^{\mu\nu}\delta_{ij}X^i_{,\mu}X^j_{,\nu}\sqrt{-g} - \Upsilon g^{\mu\nu}T_{,\mu}T_{,\nu}\sqrt{-g}.$$

But the philosophical framework is completely different from GR. We start with assumptions very close to old "ether theory": an Euclidean space with absolute time, filled with an ether. The speed of sound of this ether is the speed of light. The ether is described as usual matter by density, velocity, stress and other, inner steps of freedom. A new point is that there is nothing except the ether — the usual "matter fields" are steps of freedom of the ether too, not external matter. The restriction that we, together with all our measurement devices, are part of the ether, is sufficient to explain relativistic symmetry.

It is important to understand that "general ether theory" considers only general properties — properties of a whole class of possible ether theories: basic steps of freedom, conservation laws, existence of a Lagrange formalism. It does not specify the "inner steps of freedom" and the "material laws" of the ether. The complete ether model, which specifies them, will be the "theory of everything".

For $\Lambda < 0$ the Lagrangian of the theory coincides with the Lagrangian of the "relativistic theory of gravity" of Logunov et al. [9] [10] [11] with massive graviton. For $\Xi > 0, \Upsilon < 0$ the Lagrangian coincides with GR with four scalar "dark matter" fields. The differences between these theories are not only metaphysical, they have different empirical content.

The values of $\Xi, \Upsilon, \Lambda$ should be obtained from observation. The values of $\Xi$ and $\Lambda$ influence the age of the universe. Current observation seems to favour positive values. The choice $\Upsilon > 0$ leads to remarkable qualitative effects: we obtain a counter-force which prevents horizon formation during the gravitational collapse and big bang singularity. Even for arbitrary small $\Upsilon$ this solves the cosmological horizon problem.

## 2. General Ether Theory

The reason to name the theory "ether theory" is that some properties of our theory closely remember classical ether theory: absolute time, Euclidean space filled with some "ether" so that the speed of sound of the ether is the speed of light. It seems to be more than a nice similarity — we can choose this interpretation as to justify basic properties of the theory: "ether density" should be positive, conservation laws for ether mass and momentum. Therefore, the interpretation has essential explanatory power.

But this does not mean that we provide a mechanical model for the ether. Instead, we consider only *general properties* of the ether, that means, common properties of a whole class of theories — *complete ether models*. This is similar to the way we learn condensed matter theory: first, we consider common properties, especially the conservation laws. Only later we consider material-specific properties like the "material equations".

Our theory describes only the general part — that's why I have named it *general ether theory*. This part consists of the definition of basic variables — ether density, ether velocity, stress tensor — and the basic equations — the conservation laws. These general variables define the gravitational field. What is left for the "complete ether model" are the inner steps of freedom of the ether — all matter fields (gauge fields, fermions) — and the related "material equations". Therefore, the complete ether model should be a theory of everything. There is nothing except the ether.

An essential point is that our general ether theory does not define the matter Lagrangian itself, but nonetheless derives a very important property of this Lagrangian — its relativistic invariance. $L_{matter}$ should not depend on the preferred coordinates $X^i, T$ of the Newtonian background. Thus, to explain relativistic symmetry we do not need the complete ether model. Instead, we need only general assumptions — especially that "matter fields" describe inner steps of freedom of the ether.

## 2.1 Basic variables and equations

Let's now consider the mathematics. We have a Newtonian framework (absolute Euclidean space, absolute time) described by "preferred" orthonormal coordinates $X^i, T$. This space is filled with an ether. The general variables of GET are "ether density" $\rho(X,T)$, "ether velocity" $v^i(X,T)$ and a symmetric "stress tensor" $\sigma^{ij}(X,T)$. We assume that there are "inner steps of freedom" $\psi^m(X,T)$ of the ether without defining them — this has to be done by a complete ether model.

Basic assumptions (axioms) are: "ether density" $\rho(X,T) > 0$, "stress tensor" $\sigma^{ij}(X,T)$ is positive definite, the ether fulfils classical conservation laws:

$$\begin{aligned} \partial_t \rho + \partial_i(\rho v^i) &= 0, && (1) \\ \partial_t(\rho v^j) + \partial_i(\rho v^i v^j - \sigma^{ij}) &= 0. && (2) \end{aligned}$$

Note that the conservation laws do not contain terms for momentum exchange with other matter. This is the mathematical expression for our axiom that "there is nothing except the ether".

The basic formula is the definition of the physical metric $g^{\mu\nu}$ as a function of the basic ether variables:

$$\begin{aligned} \hat{g}^{00} = g^{00}\sqrt{-g} &= \rho, && (3) \\ \hat{g}^{i0} = g^{i0}\sqrt{-g} &= \rho v^i, && (4) \\ \hat{g}^{ij} = g^{ij}\sqrt{-g} &= \rho v^i v^j - \sigma^{ij}. && (5) \end{aligned}$$

This formula allows to translate properties of the ether into properties of the metric. We obtain: The signature of $g_{ij}$ is $(3,1)$, T is a time-like coordinate, the metric is harmonic:

$$\square X^i = \square T = 0.$$

## 2.2 Covariant Lagrange mechanism

Let's observe that instead of the original variables $\rho, v^i, \sigma^{ij}, \psi^m$ in the preferred coordinates $X^i, T$ we can use the variables $g_{ij}(x), X^i(x), T(x), \psi^m(x)$ for a covariant description of the ether. What depends on the preferred frame may be described as depending on the fields $X^i(x), T(x)$ in a covariant way. The conservation laws are already described by a covariant equation. Thus, we assume that the other equations are covariant too without restricting generality.

Now let's introduce another axiom of GET — that there exists a Lagrange formalism. For simplicity, let's leave the "axiomatic" way and try to find a simple Lagrangian. We have to obtain covariant equations. Therefore, the simplest way is to assume that the Lagrange density is covariant too. We have to obtain the equations for $X^i$ and $T$. There is a simple way to do this — the standard GR Lagrangian for scalar fields $X^i, T$. Using the Euclidean symmetry of the space, we can reduce the four constants for the four scalar fields $X^1, X^2, X^3, T$ to two constants $\Xi, \Upsilon$ and obtain:

$$L = \Xi g^{\mu\nu}\delta_{ij}X^i_{,\mu}X^j_{,\nu}\sqrt{-g} - \Upsilon g^{\mu\nu}T_{,\mu}T_{,\nu}\sqrt{-g} + L_{rem}.$$

Now, the remaining part should not modify the equations for $X^i$ and $T$. And there is a very simple and natural way to reach this — it is sufficient to require that the remaining part does not depend on the preferred coordinates $X^i$ and $T$. But this is simply the requirement for the GR Lagrangian. Therefore, we have found a simple class of Lagrangians which fulfils our requirements:

$$L = \Xi g^{\mu\nu}\delta_{ij}X^i_{,\mu}X^j_{,\nu}\sqrt{-g} - \Upsilon g^{\mu\nu}T_{,\mu}T_{,\nu}\sqrt{-g} + L_{GR},$$

where $L_{GR}$ is a classical GR Lagrangian with matter fields $\psi^m$:

$$L_{GR} = (R + \Lambda)\sqrt{-g} + L_{matter}(g_{\mu\nu}, \psi^m).$$

Of course, this is not a strong derivation of the Lagrangian based on our axioms — it cannot be because the Lagrangian itself is not uniquely defined by the equations. In full agreement with the modern concept of QFT as an effective field theory there is no reason to restrict the Lagrangian to the lowest order terms R and $\Lambda$. There may be also other ways to obtain the harmonic equations for $X^i, T$ in the Lagrange formalism (using other variables, Lagrange multipliers). The Lagrange density should not be covariant for giving covariant equations. Especially it seems reasonable to replace R by the (non-covariant) Rosen Lagrangian which does not depend on higher order derivatives of $g_{ij}$.

Nonetheless, the explanation of relativistic symmetry is independent of this uncertainties of the Lagrange formalism. If there exists a Lagrange density, then we have a symmetry requirement for the equations: they have to be "self-adjoint". And this is what we really need to explain relativistic symmetry: once the equations for $X^i, T$ do not depend on the matter fields $\psi^m$, the equations for $\psi^m$ do not depend on the preferred coordinates $X^i, T$ too. The only way we can observe the preferred coordinates is as "dark matter" — via its interaction with the gravitational field. The equations for matter fulfil the Einstein equivalence principle.

## 3. Quantization

The preferred Newtonian framework avoids most conceptual problems (problem of time [5], topological foam, information loss problem) of GR quantization, allows to define uniquely local energy and momentum density for the gravitational field as well as the Fock space and vacuum state in semi-classical theory.

What remains are the ultraviolet problems. But they may be cured by explicit, physical regularization if we accept an "atomic hypothesis" for the ether. Unlike in renormalized QFT, the relationship between bare and renormalized parameters obtains a physical meaning.

Similar ideas are quite old and in some aspects commonly accepted among particle physicists [6]. Usually it is expected that the critical cutoff length is of order of the Planck length $a_P \approx 10^{-33} cm$ [6],[16]. But an atomic hypothesis for our condensed matter interpretation predicts a different cutoff: Once we interpret $\rho$ as the number of "atoms" per volume, we obtain the prediction

$$\rho(x)V_{cutoff} = \text{cons.}$$

Considering this prediction for the homogeneous universe, we find that the cutoff length seems to expand together with the universe. More accurate, our rulers shrink compared with the cutoff length.

## 4. Why absolute space and time?

While the reintroduction of absolute space and absolute time solves serious conceptual problems of GR quantization (problem of time, topological foam, information loss problem) and allows the generalization of Bohmian mechanics [2] into the relativistic domain, it may be (and has been) criticized as ad hoc. This is unjustified, because a fixed background manifold and a preferred foliation may be derived from completely different axioms.

To derive a preferred foliation we simply use the EPR criterion of reality [3] and causality. Then the violation of Bell's inequality [1] proves the existence of real, causal influences which propagate faster than light. The only way to make this compatible with causality is a preferred foliation with classical causality.

A fixed background manifold we obtain from quantum gravity. We consider the interaction of a superposition of gravitational fields $|g^1\rangle + |g^2\rangle$ with a test particle $|\varphi\rangle$. The assumption is that the transition probability $|g^1\rangle + |g^2\rangle \to |g^1\rangle - |g^2\rangle$ is observable. It depends on a scalar product between the resulting states of the test particle $\langle\varphi^1|\varphi^2\rangle$, which therefore should be well-defined. But this scalar product may be used to transfer position measurement from one state of the gravitational field to another. Thus, starting with a position measurement for a reference state (say, the vacuum), we obtain a similar one for all states. This common position measurement defines the common background manifold. For more details, see [14].

Note that in above cases it is already known that the axioms are in contradiction with relativistic principles (no preferred frame, no absolute background manifold). The point is that to use them is sufficient to obtain a fixed background manifold with preferred foliation. The choice of Newtonian space-time may be justified by Occam's razor.

Of course, this justification depends on a certain metaphysical decision: we consider these assumptions as fundamental and use them as axioms. Relativists prefer to reject them because they contradict relativistic philosophy. But, of course, we cannot reject relativity without making such a metaphysical decision: to falsify the meta-rule "all laws of nature are local Lorentz-invariant" we need not only a law of nature which is not Lorentz-invariant — we also have to decide that it is really a law of nature, despite the violation of local Lorentz-invariance.

## 5. Comparison with other theories of gravity

For a certain choice of cosmological constants, the equations of GET are identical with the equations of another alternative theory of gravity — the "relativistic theory of gravity" proposed by Logunov et al. [11]. For another choice, they are equivalent with classical GR with some additional scalar "dark matter" fields. Nonetheless, equations are not all. The comparison of these theories provides an interesting example — there are other physical important things, like global restrictions, boundary conditions, causality restrictions, quantization concepts which are closely related with the underlying "metaphysical" assumptions.

### 5.1 Comparison with RTG

The "relativistic theory of gravity" (RTG) proposed by Logunov et al. [11] has Minkowski background metric $\eta_{\mu\nu}$. The Lagrangian of RTG is

$$L = L_{Rosen} + L_{matter}(g_{\mu\nu}, \psi^m) - m_g^2(\frac{1}{2}\eta_{\mu\nu}g^{\mu\nu}\sqrt{-g} - \sqrt{-g} - \sqrt{-\eta}).$$

Instead of the preferred coordinates $X^i, T$ in GET, we vary the metric $\eta_{\mu\nu}$ in RTG. But this does not change the equations. Variation over $\eta_{\mu\nu}$ of the RTG Lagrangian gives the harmonic equation for $g_{\mu\nu}$ too [11]. Variation over $g_{\mu\nu}$ gives the same equation because the Lagrangians as functions of $g_{\mu\nu}$ are equivalent for appropriate choice of the constants: $\Lambda = -m_g^2 < 0$, $\Xi = -\eta^{11}m_g^2 > 0$, $\Upsilon = \eta^{00}m_g^2 > 0$.

The metaphysical context of RTG is completely different. It is a special-relativistic theory, therefore incompatible with EPR-realism and Bohmian mechanics. Another difference is the causality condition: In RTG, only solutions where the light cone of $g_{ij}$ is insider the light cone of $\eta_{ij}$ are allowed. A comparable but weaker condition exists in GET too: $T(x)$ should be a time-like function, or, $\rho(X, T) > 0$. Note also that GET suggests a different way of quantization: the GET suggestion for $l_{cutoff}$ is not Lorentz-covariant.

### 5.2 Comparison with GR plus dark matter

The Lagrangian is also equivalent to GR with some dark matter — four scalar fields $X^\mu$. In this theory they are no longer preferred coordinates, but simply fields. Such "clock fields" in GR have been considered by Kuchar [7]. Usual energy conditions require $\Xi > 0, \Upsilon < 0$. Nonetheless, the choice $\Xi > 0, \Upsilon > 0$ does not look completely unreasonable — it is similar to the diagonal Lagrangian for EM.

Now, this GR variant allows a lot of solutions where the fields $F^\mu(x)$ cannot be used as global coordinates. Especially, all solutions with non-trivial topology are of this type. They may also violate the condition that $F^0(x) = T(x)$ is time-like. Such solutions are forbidden in GET and would falsify this theory. On the other hand, the boundary values of GET solutions are very strange, incompatible with usual boundary conditions for matter fields — they go to infinity instead of remaining finite.

Therefore, despite having the same equations, the two theories remain essentially different. The differences become especially important during quantization: in GET we can use the preferred coordinates to apply canonical quantization, while in GR with dark matter we have the full beauty of GR quantization problems.

## 6. Observable effects

Using small enough values $\Xi, \Upsilon \to 0$ leads to GR equations. Therefore it is not problematic to fit observation. It is much more problematic to find a way to distinguish GET from GR by observation.

### 6.1 A dark matter candidate

Let's consider the influence of the new terms on the expansion of the universe. In GET a homogeneous universe is flat. The the usual ansatz $ds^2 = d\tau^2 - a^2(\tau)(dx^2 + dy^2 + dz^2)$ gives

$$\begin{aligned} 3(\dot{a}/a)^2 &= -\Upsilon/a^6 + 3\Xi/a^2 + \Lambda + \varepsilon \\ 2(\ddot{a}/a) + (\dot{a}/a)^2 &= +\Upsilon/a^6 + \Xi/a^2 + \Lambda - p. \end{aligned}$$

We see that $\Xi$ influences the expansion of the universe similar to dark matter with $p = -\frac{1}{3}\varepsilon$.

### 6.2 Big bounce instead of big bang singularity

$\Upsilon$ becomes important only in the very early universe. But for $\Upsilon > 0$, we obtain a qualitatively different picture. We obtain a lower bound $a_0$ for $a(\tau)$ defined by

$$\Upsilon/a_0^6 = 3\Xi/a_0^2 + \Lambda + \varepsilon.$$

The solution becomes symmetrical in time, with a big crash followed by a big bang. For example, if $\varepsilon = \Xi = 0, \Upsilon > 0, \Lambda > 0$ we have the solution

$$a(\tau) = a_0 \cosh^{1/3}(\sqrt{3\Lambda}\tau).$$

In time-symmetrical solutions of this type the horizon is, if not infinite, at least big enough to solve the cosmological horizon problem (cf. [12]) without inflation.

### 6.3 Frozen stars instead of black holes

The choice $\Upsilon > 0$ influences also another physically interesting solution — the gravitational collapse. There are stable "frozen star" solutions with radius slightly greater than their Schwarzschild radius. The collapse does not lead to horizon formation, but to a bounce from the Schwarzschild radius. Let's consider an example. The general stable spherically symmetric harmonic metric depends on one step of freedom m(r) and has the form

$$ds^2 = (1 - \frac{m}{r}\frac{\partial m}{\partial r})(\frac{r-m}{r+m}dt^2 - \frac{r+m}{r-m}dr^2) - (r+m)^2 d\Omega^2.$$

Let's consider the ansatz $m(r) = (1-\Delta)r$. We obtain

$$
\begin{aligned}
ds^2 &= \Delta^2 dt^2 - (2-\Delta)^2(dr^2 + r^2 d\Omega^2), \\
0 &= -\Upsilon\Delta^{-2} + 3\Xi(2-\Delta)^{-2} + \Lambda + \varepsilon, \\
0 &= +\Upsilon\Delta^{-2} + \Xi(2-\Delta)^{-2} + \Lambda - p.
\end{aligned}
$$

Now, usually the cosmological terms $\Upsilon, \Xi, \Lambda$ may be ignored and we obtain only the trivial solution $\varepsilon = 0$. But for very small $\Delta$ even a very small $\Upsilon$ becomes important, and we obtain a non-trivial stable solution for $p = \varepsilon = \Upsilon g^{00}$. Thus, the surface remains visible, with time dilation $\sqrt{\varepsilon/\Upsilon} \sim M^{-1}$.

A radiation of this type from objects which should be black holes according to GR would be strong evidence for GET. On the other hand, for small enough $\Upsilon$ this radiation becomes invisible in comparison with the background radiation.

**References**


[1] J.S. Bell, Speakable and unspeakable in quantum mechanics, Cambridge University Press, Cambridge, 1987.

[2] D. Bohm, Phys. Rev. 85, 166-193, 1952.

[3] A. Einstein, B. Podolsky, N. Rosen, Phys. Rev. 47, 777-780, 1935.

[4] V. Fock, Theorie von Raum, Zeit und Gravitation, Akademie-Verlag Berlin, 1960.

[5] C. Isham, gr-qc/9210011.

[6] F. Jegerlehner, hep-th/9803021.

[7] K.V. Kuchar, C.G. Torre, Physical Review D, vol. 44, nr. 10, pp. 3116-3123, 1991.

[8] A.P. Lightman, D.L. Lee, New two-metric theory of gravity with prior geometry, Phys.Rev. D 8, 10, 3293-3302 (1973).

[9] A.A. Logunov, M.A.Mestvirishvili, Yu.V.Chugreev, Graviton mass and evolution of a Friedman universe, Theor.Math.Phys. 74, 1-20 (1988).

[10] A.A. Vlasov, A.A. Logunov, Bouncing from the Schwarzschild sphere in the relativistic theory of gravity with non-zero graviton mass, Theor.Math.Phys. 78, 229-233 (1989).

[11] S.S. Gershtein, A.A. Logunov, M.A. Mestvirishvili, The upper limit on the graviton mass, hep-th/9711147.

[12] J.R. Primack, astro-ph/9707285.

[13] N. Rosen, A theory of gravitation, Ann. Phys. 84, 45-473 (1974).

[14] I. Schmelzer, gr-qc/9811033.

[15] M. Visser, Mass for the graviton, gr-qc/9705051.

[16] G.E. Volovik, Induced gravity in superfluid $^3He$, cond-mat/9806010.