A Metric Theory of Gravity with Condensed Matter Interpretation

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Abstract

We consider a classical condensed matter theory in a Newtonian framework where conservation laws

\[ \partial_t \rho + \partial_i (\rho v^i) = 0 \]
\[ \partial_t (\rho v^j) + \partial_i (\rho v^i v^j + p^{ij}) = 0 \]

are related with the Lagrange formalism in a natural way. For an “effective Lorentz metric” \( g_{\mu\nu} \) it is equivalent to a metric theory of gravity close to general relativity with Lagrangian

\[ L = L_{GR} - (8\pi G)^{-1}(\Upsilon g^{00} - \Xi(g^{11} + g^{22} + g^{33})\sqrt{-g}) \]

We consider the differences between this theory and general relativity (no nontrivial topologies, stable frozen stars instead of black holes, big bounce instead of big bang singularity, a dark matter term), quantum gravity, and the connection with realism and Bohmian mechanics.

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1 Introduction

General relativity is a very beautiful and successful theory of gravity. Nonetheless, the consideration of alternative theories of gravity remains to be legitimate part of science. Even if the purpose is only “to play devil’s advocate”, as in the case of some interesting theories of gravity (Lightman and Lee [12], Ni [14]) or to answer Rosen’s [16] question “whether one can set up a theory of gravitation which will give agreement with observation without permitting black holes”.

The current research was motivated by the conceptual conflict between general relativity and quantum theory. The basic idea was that the Einstein equations may appear in a completely different metaphysical framework, which is better compatible with quantum principles than relativistic spacetime. This idea is in itself in full agreement with “the present educated view on the standard model, and of general relativity, ... that these are leading terms in effective field theories” [21]. The simplest choice would be a classical Newtonian framework with absolute time. This is a known way to solve the “problem of time” in quantum gravity, usually rejected for metaphysical reasons: “... in quantum gravity, one response to the problem of time is to ‘blame’ it on general relativity’s allowing arbitrary foliations of spacetime; and then to postulate a preferred frame of spacetime with respect to which quantum theory should be written. Most general relativists feel this response is too radical to countenance: they regard foliation-independence as an undeniable insight of relativity.” [5].

Nonetheless, following this “too radical to countenance” way, we have found a surprisingly simple and beautiful scheme which allows to derive a variant of the Einstein equations based not only on the classical Newtonian framework, but also on classical condensed matter theory – in other words, an ideal realization of the last century “ether” concept. In this derivation, we do not need any conspiracy to explain the Einstein equivalence principle. All we need are classical conservation laws and their connection with the Lagrange formalism. The point is the combination of the symmetry of the Lagrange formalism (self-adjoint equations) with the special character of the conservation laws (their relation with the preferred coordinates).

The mere existence of a viable theory of gravity with preferred frame is of great importance for other foundational problems. A preferred frame is, for example, required for compatibility of the EPR criterion of reality [3] with
the violation of Bell’s inequality \[1\]. Bell himself concludes \[3\]: “the cheapest resolution is something like going back to relativity as it was before Einstein, when people like Lorentz and Poincare thought that there was an aether — a preferred frame of reference — but that our measuring instruments were distorted by motion in such a way that we could no detect motion through the aether.” The theory presented here is strong support for this “cheapest resolution”. A closely related question is the extension of Bohmian mechanics \[4\] into the domain of relativistic gravity which requires a preferred frame too.

The resulting theory differs from general relativity in an interesting way. It contains additional terms which depend on the preferred frame. These additional terms allow the definition of local energy and momentum densities of the gravitational field. But they don’t violate the Einstein equivalence principle — the theory remains to be a metric theory of gravity. They influence only the gravitational field itself, similar to dark matter.

The close analogy between condensed matter theory and gravity is well-known. It has been recognized that “effective gravity, as a low-frequency phenomenon, arises in many condensed matter systems” \[20\]. This has been used to study Hawking radiation and the Unruh effect \[19\] \[18\] \[4\] \[20\] and vacuum energy \[20\] for condensed matter examples. Wilczek \[22\] mentions the general exchange of ideas with high energy physics, which “includes global and local spontaneous symmetry breaking, the renormalization group, effective field theory, solitons, instantons, and fractional charge and statistics”. This analogy has suggested the idea of a “Planck ether” \[10\]. Our theory fits very well into this general context, and suggests interesting modifications: the critical length should not be Planck length.

2 The Theory

Our theory describes a classical medium in a Newtonian framework — Euclidean space and absolute time. The medium is described by steps of freedom typical for condensed matter theory. The gravitational field is defined by a positive density \( \rho \), a velocity \( v^i \), and a negative-definite symmetrical tensor field \( p^{ij} \) which we name “pressure”. The effective metric \( g_{\mu\nu} \) is defined algebraically by
\[ \hat{g}^{00} = g^{00} \sqrt{-g} = \rho \]
\[ \hat{g}^{0i} = g^{0i} \sqrt{-g} = \rho v^i \]
\[ \hat{g}^{ij} = g^{ij} \sqrt{-g} = \rho v^i v^j + p^{ij} \]

This decomposition of \( g^{\mu \nu} \) into \( \rho, v^i \) and \( p^{ij} \) is a variant of the ADM decomposition. The signature of \( g^{\mu \nu} \) follows from \( \rho > 0 \) and negative definiteness of \( p^{ij} \).

The theory does not specify all properties of the medium, but only a few general properties – the conservation laws and their relation to the Lagrange formalism. The “material properties” of the medium, denoted by \( \varphi^m \), remain unspecified. They become the matter fields. The complete specification of the medium – which includes the material laws of the medium – gives the theory of everything. The few general properties fixed here define a theory of gravity similar to GR. While it leaves the matter steps of freedom and the matter Lagrangian unspecified, it derives the Einstein equivalence principle.

For the derivation of the Lagrange formalism we prefer a formalism where the non-covariant terms are disguised as covariant, with the preferred coordinates considered formally as scalar fields \( X^\mu(x) \).\footnote{It is well-known that every physical theory may be described in a covariant way. But usually this is done in another way (for example, by Fock for SR): a flat background metric \( \gamma_{\mu \nu} \) is described by vanishing curvature \( R^\mu_{\nu \lambda \rho} = 0 \).} It is easy to transform a non-covariant Lagrangian \( L = L(T^{\ldots \ldots}, \partial_\mu T^{\ldots \ldots}) \) into a (formally) covariant form \( L = L(T^{\ldots \ldots}, \partial_\mu T^{\ldots \ldots}, X^\mu) \). For example, the non-covariant component \( a^0 \) of a vector \( a^\mu \) will be written as \( a^\mu X^0_{\mu} \). Here \( X^0 = T \) is no longer a spatial index, but enumerates one of the four “scalar fields” \( T, X, Y, Z \).

This formalism is interesting in itself. Especially the question how to distinguish “truly covariant” theories from theories made covariant using this formalism is a very interesting one. The most interesting point of the formalism is the relation between conservation laws and the preferred coordinates. The conservation laws may be defined as the Euler-Lagrange equations for the preferred coordinates. The related energy-momentum tensor

\[ T^\nu_\mu = -\frac{\partial L}{\partial X^\mu_{\nu}} \]
is not the same as in Noether’s theorem, but is equivalent: if the Lagrangian does not depend on the $X^\mu$ them-self, we obtain immediately conservation laws in the form

$$\partial_\nu T^\nu_\mu = 0$$

Now, the main postulate of the theory is that these conservation laws are identified with the classical conservation laws we know from condensed matter theory. First, the Euler-Lagrange equation for the preferred time $T$ we identify with the classical continuity equation for the medium:

$$\partial_t \rho + \partial_i (\rho v^i) = 0 \quad (1)$$

The equations for the preferred spatial coordinates $X^i$ we identify with the Euler equation:

$$\partial_t (\rho v^i) + \partial_i (\rho v^j v^i + p^{ij}) = 0 \quad (2)$$

Note that the Euler equation contains an important physical assumption: there is no momentum exchange with other materials, because there are no other materials. We have only one, universal, medium. All usual “matter fields” $\varphi^m$ are material properties of this universal medium.

The four conservation laws transform into the harmonic condition for the metric $g_{\mu\nu}$. Thus, they really look like equations for the preferred coordinates:

$$\Box X^\nu = \partial_\mu (g^{\mu\nu} \sqrt{-g}) = 0$$

Therefore, the main postulate transforms into the following relation between the the Euler-Lagrange equations for $S = \int L$ and the preferred coordinates $X^\mu$:

$$\frac{\delta S}{\delta X^\mu} \equiv -(4\pi G)^{-1} \gamma_{\mu\nu} \Box X^\nu$$

We have introduced here a constant diagonal matrix $\gamma_{\mu\nu}$ and a common factor $-(4\pi G)^{-1}$ to obtain appropriate units below. Euclidean symmetry gives $\gamma_{11} = \gamma_{22} = \gamma_{33}$. Thus, we have two coefficients $\gamma_{00} = \Upsilon, \gamma_{ii} = -\Xi$. Now, we can derive the general form of the Lagrangian. First, we have the particular Lagrangian
\[ L_0 = -(8\pi G)^{-1}\gamma_{\mu\nu} X_{\alpha}^\mu X_{\beta}^\nu g^{\alpha\beta} \sqrt{-g} \]

which fulfils this property. For the difference \( L - L_0 \) we obtain

\[ \frac{\delta \int (L - L_0)}{\delta X^\mu} \equiv 0 \]

Thus, the remaining part is not only covariant in the weak, formal sense enforced by our decision to handle the preferred coordinates as fields. It does not depend on the preferred coordinates \( X^\mu \). But this is the original “strong” covariance, the classical requirement for the Lagrangian of general relativity. Thus, we can identify the difference \( L - L_0 \) with the most general classical Lagrangian of general relativity. In the preferred coordinates we obtain

\[ L = -(8\pi G)^{-1}\gamma_{\mu\nu} g^{\mu\nu} \sqrt{-g} + L_{GR}(g_{\mu\nu}) + L_{\text{matter}}(g_{\mu\nu}, \varphi^m). \]

Note that this Lagrangian fulfils the Einstein equivalence principle in its full beauty. That means, we have derived this principle starting with few general assumptions about a medium in a classical Newtonian framework.

This derivation of exact relativistic symmetry in the context of a classical condensed matter theory is the main result of this paper. To improve our understanding, let’s consider how this has happened, and what has been really used to derive the EEP. The derivation is extremely simple, but given in an unusual formalism.

But how relativistic symmetry appears may be explained without reference to this formalism. There are three principles involved: first, the inherent symmetry of the Lagrange formalism – the equations should be self-adjoint, or “action equals reaction”. Next, there is the relation between preferred coordinates and conservation laws in the Lagrange formalism well-known from Noether’s theorem. And, last not least, we have the independence of the conservation laws from the material properties of the medium enforced by our choice of variables. As a consequence of these principles, the Euler-Lagrange equations for the material properties do not depend on the preferred coordinates. But this is already the EEP:

\[ \frac{\delta}{\delta X^\mu} \frac{\delta S}{\delta \phi^m} = \frac{\delta}{\delta \phi^m} \frac{\delta S}{\delta X^\mu} = \frac{\delta}{\delta \phi^m} [\text{cons. laws}] = 0 \]
The following heuristic, informal picture may be useful for the understanding: The medium is universal. All usual matter fields (gauge fields, fermions) are material properties of this medium, something like defect densities in a crystal. In this picture human beings consist of crystal defects and interact only with other crystal defects. It seems quite obvious that such beings have only restricted observational possibilities. This restriction of observational possibilities leads to relativistic symmetry – we cannot distinguish by observation states which are really different. Thus, there is nothing strange in the appearance of relativistic symmetry in usual condensed matter. It is a natural consequence of the special nature of matter fields in this theory – they are all material properties of a single universal medium.

2.1 Equations and Energy-Momentum Tensor

After the derivation of the theory, the “covariant formalism” has done its job, and we can return to a form more appropriate for the comparison with other theories of gravity. We obtain the following equations:

\[ G_{\mu}^{\nu} = 8\pi G (T_{m})_{\mu}^{\nu} + (\Lambda + \gamma_{\kappa\lambda}g^{\kappa\lambda})\delta_{\mu}^{\nu} - 2g^{\mu\kappa}\gamma_{\kappa\nu}. \]

The harmonic condition

\[ \partial_{\mu}(g^{\mu\kappa}\sqrt{-g}) = 0 \]

is a consequence of these equations and one form of energy-momentum conservation in the theory. Remarkably, there is also another form – the basic equation may be simply considered as a decomposition of the full energy-momentum tensor \( g^{\mu\kappa}\sqrt{-g} \) into a part which depends on matter fields and a part which depends on the gravitational field:

\[ (T_{g})_{\mu}^{\nu} = (8\pi G)^{-1} \left( \delta_{\mu}^{\nu}(\Lambda + \gamma_{\kappa\lambda}g^{\kappa\lambda}) - G^{\mu}_{\nu} \right) \sqrt{-g} \]

Thus, instead of no local conservation law in GR we obtain even two equivalent forms of local conservation laws. The first is equivalent to classical conservation laws from condensed matter theory and, in our variables, to the harmonic condition. The other is equivalent to the conservation law in Noether’s theorem, and splits into a part which depends on the “matter fields” \( \varphi^{m} \) and a purely gravitational part.
3 Predictions

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

3.1 A dark matter candidate

Let’s consider the influence of the new terms on the expansion of the universe. In our theory a homogeneous universe should be flat. Solutions with non-zero curvature may be solutions of our theory too, but they cannot be homogeneous. The the usual ansatz $ds^2 = d\tau^2 - a^2(\tau)(dx^2 + dy^2 + dz^2)$ gives

\[
3(\ddot{a}/a)^2 = -\Upsilon/a^6 + 3\Xi/a^2 + \Lambda + \varepsilon
\]
\[
2(\dot{a}/a) + (\dot{a}/a)^2 = +\Upsilon/a^6 + \Xi/a^2 + \Lambda - p
\]

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

3.2 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. [15]) without inflation.
3.3 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

$$ds^2 = \Delta^2 dt^2 - (2 - \Delta)^2 (dr^2 + r^2 d\Omega^2)$$

$$0 = -\Upsilon \Delta^{-2} + 3\Xi (2 - \Delta)^{-2} + \Lambda + \varepsilon$$

$$0 = +\Upsilon \Delta^{-2} + \Xi (2 - \Delta)^{-2} + \Lambda - p$$

Now, 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 $\sqrt{\varepsilon/\Upsilon} \sim M^{-1}$.

4 Relativity Principle, Realism and Bohmian mechanics

As we have shown, we have relativistic symmetry for all observable effects (relativity principle for observables). On the other hand, reality itself does not have this relativistic symmetry (no relativity principle for reality).

But this distinction is meaningful only if we have a realistic theory. Here we define realism in the following classical way: Assume we have an experiment described by observables $X$ with the observable probability distribution $\rho_X(\mathcal{X}, x) d\mathcal{X}$, which depends on a set of control parameters $x$ (the decisions of experimenters). In a realistic theory this is described by some reality $\lambda \in \Lambda$ with observer-independent probability distribution $\rho_\lambda(\lambda) d\lambda$ which explains the observations $X$ with a function $X(x, \lambda)$ so that for a test function $f$ we have:
\[ \int f(X) \rho_X(X, x) dX = \int f(X(x, \lambda)) \rho(\lambda) d\lambda \]

This definition is appropriate to define causality in a natural way: The decision of the experimenter x has a causal influence on X if this function \( X(x, \lambda) \) depends on x.

These definitions are sufficient to prove Bell’s inequality following \([2]\). Therefore, the violation of Bell’s inequality \([1]\) defines a contradiction between realism, causality and the relativity principle for reality. If we want to preserve the full relativity principle, we have to reject realism or causality, and the usual decision is the rejection of realism. But in our theory the relativity principle is automatically restricted to observable effects. Therefore, no contradiction appears. We cannot prove Bell’s inequality for space-like separated events and, therefore, have no conflict with Aspect’s experiment.

This solution of the puzzle has been preferred by Bell \([3]\): “the cheapest resolution is something like going back to relativity as it was before Einstein, when people like Lorentz and Poincare thought that there was an aether — a preferred frame of reference — but that our measuring instruments were distorted by motion in such a way that we could not detect motion through the aether. Now, in that way you can imagine that there is a preferred frame of reference, and in this preferred frame of reference things go faster than light.”

In this context, Bohmian mechanics (BM) \([4]\) is very important. BM is a realistic, even deterministic, theory which makes in a “quantum equilibrium” the same predictions as quantum theory. In the relativistic context it requires a preferred frame. This is usually considered as a decisive argument against BM. But in the context of our theory this argument no longer holds: our theory shows the way how to extend BM into the domain of relativistic gravity.

Let’s add a few additional arguments in favour of realism: In our definition, realism is not related with a particular spacetime theory, it does not even depend on the notion of spacetime. This makes realism more fundamental than spacetime theory, and, moreover, more fundamental than a particular spacetime theory like relativity. In the case of conflict, the natural decision is to reject the less fundamental theory. In our case, it is the relativity principle for reality, and not realism. Moreover, there is no independent
evidence against realism – this is proven by the existence of BM for all quantum effects. Instead, the problems related with quantum theory, especially the problem of time [8], may be interpreted as independent evidence against relativity. And, last not least, we loose essentially nothing if we reduce the relativity principle to observable effects. If we reject realism, the relativity principle essentially reduces to observable effects too.

As we see, the relation between our theory, realism, and BM is mutual support. On one hand, compatibility with realism and BM are strong arguments in favour of our theory. On the other hand, our theory weakens the most serious arguments against realism and BM – incompatibility with relativistic principles.

5 Quantization

Most workers would agree that “at the root of most of the conceptual problems of quantum gravity” is the idea that “a theory of quantum gravity must have something to say about the quantum nature of space and time” [4]. These problems obviously disappear for a theory of gravity with fixed Newtonian background. Especially this holds for the “problem of time”: “... in quantum gravity, one response to the problem of time is to ‘blame’ it on general relativity’s allowing arbitrary foliations of spacetime; and then to postulate a preferred frame of spacetime with respect to which quantum theory should be written.” [4]. In this way, in our theory the problem of time simply disappears. Now, “most general relativists feel this response is too radical to countenance: they regard foliation-independence as an undeniable insight of relativity.” [4]. That means, this rejection is based on metaphysical preference for the GR spacetime concept only.

It should be noted that together with black holes another quantization problem disappears – the information loss problem. The frozen stars are stable and do not evaporate. Most problems related with energy and momentum conservation disappear too – the Hamiltonian is no longer a constraint.

To solve the ultraviolet problems, we have to make an additional assumption, but a very natural one for a condensed matter theory: an “atomic hypothesis”. After this, the theory is in ideal agreement with “the present educated view on the standard model, and of general relativity, ... that these are leading terms in effective field theories” [21] – an idea introduced by
Sakharov [17]. An interpretation of $\rho$ as the number of “atoms” per volume leads to an interesting prediction for the cutoff:

$$\rho(x)V_{cutoff} = 1.$$  

It is non-covariant. For a homogeneous “expanding” universe, it seems to expand together with the universe. Thus, the cutoff differs in a principal way from the usual expectation that the cutoff is the Planck length $a_P \approx 10^{-33} cm$ (cf. [10], [20]).

### 6 Comparison with other theories of gravity

Because of the simplicity of the additional terms it is no wonder that they have been already considered. Two other theories have a similar Lagrangian for appropriate signs of the cosmological constants: the “relativistic theory of gravity” proposed by Logunov et al. [13] and classical GR with some additional scalar “dark matter” fields. Nonetheless, equations are not all. There are other physical important things which makes the theories different as physical theories, like global restrictions, boundary conditions, causality restrictions, quantization concepts which are closely related with the underlying “metaphysical” assumptions.

#### 6.1 Comparison with RTG

The “relativistic theory of gravity” (RTG) proposed by Logunov et al. [13] has Minkowski background metric $\gamma_{\mu\nu}$. The Lagrangian of RTG is

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

which de facto coincides with our theory for $\Lambda = -m_g^2 < 0$, $\Xi = -\gamma^{11} m_g^2 > 0$, $\Upsilon = \gamma^{00} m_g^2 > 0$.

The metaphysical concept of RTG is completely different. It is a special-relativistic theory, therefore incompatible with classical realism and Bohmian mechanics because of the violation of Bell’s inequality. Another difference is the causality condition: In RTG, only solutions where the light cone of $g_{ij}$ is inside the light cone of $\gamma_{ij}$ are allowed. A comparable but weaker condition exists in our theory too: $T(x)$ should be a time-like function, or, $\rho(X, T) > 0$. 

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The metaphysical differences become physical if we consider quantization. Indeed, RTG suggests quantization following standard QFT schemes. Instead, our theory suggests to quantize an atomic model. These ways are conceptually incompatible. Indeed, the prediction for the cutoff length $l_{\text{cutoff}}$, which is based on the interpretation of $g^{00}\sqrt{-g}$ as the atomic density, is not Lorentz-covariant and therefore incompatible with RTG.

6.2 Comparison with GR plus scalar fields

In the formalism where the preferred coordinates are handled as scalar fields, the Lagrangian of our theory looks equivalent to GR with some dark matter – four scalar fields $X^\mu$. Similar “clock fields” in GR have been considered by Kuchar [11]. Usual energy conditions require $\Xi > 0$, $\Upsilon < 0$. To obtain the most interesting effects (no black holes, no big bang singularity) we have to choose $\Upsilon > 0$, which violates the usual GR energy conditions.

Nonetheless, even if the Lagrangian seems to be the same, the theories are completely different as physical theories. In a typical solution of GR with scalar fields the fields $X^\mu(x)$ cannot be used as global coordinates. Especially this holds for all solutions with non-trivial topology. Even if they may be used as global coordinates, the field $T(x)$ may be not time-like. All these solutions are forbidden in our theory.

But the remaining solutions – that means, solutions of our theory which may be interpreted as solutions of GR with scalar fields too – are very unnatural from point of this theory. They have very strange boundary values – the fields $X^\mu(x)$ are unbounded. Thus, if we consider boundary conditions of type $|X^\mu(x)| < C$ as part of GR with scalar fields, then we have no common solutions for above theories.

As we see, to handle preferred coordinates like scalar fields is justified only in a very restricted domain. It does not make our condensed matter theory on a preferred background equivalent to a general-relativistic theory, even if the Lagrangian has the same form. Preferred coordinates and scalar fields remain to be very different things.

Of course, above theories differ also in their metaphysical principles and their quantization concepts. Especially it is incompatible with classical re-

\footnote{That means, their observation falsifies our theory, but does not falsify GR with scalar fields. According to Popper’s criterion of empirical content this means higher empirical content for our theory.}
alism and Bohmian mechanics. Similarly, we have a completely different quantization approach, the cutoff length $l_{\text{cutoff}}$ is not Lorentz-covariant and therefore incompatible with GR metaphysics. In our theory the $X^\mu$ are not fields, but fixed background coordinates and therefore should not be quantized, while the “fields” $X^\mu(x)$ in GR with scalar fields should be quantized.

7 Conclusions

We have started with postulates for a medium in a classical Newtonian world: classical conservation laws and their connection with the Lagrange formalism. We have obtained a viable theory of gravity which, in a certain limit $\Xi, \Upsilon \to 0$, leads to the classical Einstein equations. We have derived the Einstein equivalence principle from these first principles.

The resulting theory is compatible with classical realism and Bohmian mechanics. This is not only an argument in favour of this theory, but removes serious arguments against realism and Bohmian mechanics, making them viable in the domain of relativistic gravity.

The theory has a lot of other interesting advantages in comparison with general relativity: well-defined local energy and momentum densities, a classical Hamilton formalism, no black hole and big bang singularities, no cosmological horizon problem, a natural dark matter candidate, no problem of time in quantum gravity, no information loss problem, no problems with non-trivial topologies, a natural “atomic ether” quantization concept compatible with modern effective field theory.

Are there serious disadvantages? The relativity principle is restricted to observable effects, but the rejection of realism related with relativistic quantum theory has a similar effect in relativity. SF authors probably don’t like that non-trivial topologies and causal loops are forbidden. Nonetheless, it is an advantage according to Popper’s criterion of empirical content. Is our theory less beautiful than GR? That’s, of course, a matter of taste. But many beautiful aspects of GR appear in our theory too, and some very beautiful concepts often used but of no fundamental importance in GR (ADM decomposition, harmonic gauge) play a fundamental role in our theory. The situation with conservation laws is certainly more beautiful in our theory.

But, even if you nonetheless decide to prefer relativistic theory – the mere existence of a theory which, based on first principles, predicts a variant of
the Einstein equations is an interesting fact. As a consequence, the strong empirical evidence in favour of the Einstein equations themselves (Solar system observations, binary pulsars) are no longer support for general-relativistic spacetime concepts. The choice between relativistic spacetime and classical ether should be justified in a different way.

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