A GENERALIZATION OF THE LORENTZ ETHER TO GRAVITY WITH GENERAL-RELATIVISTIC LIMIT

I. SCHMELZER

Abstract. We define a class of condensed matter theories in a Newtonian framework with a Lagrange formalism so that a variant of Noether's theorem gives the classical conservation laws:

$$\begin{aligned} \partial_t\rho + \partial_i(\rho v^i) &= 0 \\ \partial_t(\rho v^j) + \partial_i(\rho v^i v^j + p^{ij}) &= 0. \end{aligned}$$

We show that for the metric $g_{\mu\nu}$ defined by

$$\begin{aligned} \hat{g}^{00} = g^{00}\sqrt{-g} &= \rho \\ \hat{g}^{i0} = g^{i0}\sqrt{-g} &= \rho v^i \\ \hat{g}^{ij} = g^{ij}\sqrt{-g} &= \rho v^i v^j + p^{ij} \end{aligned}$$

these theories are equivalent to a metric theory of gravity with Lagrangian

$$L = L_{GR} + L_{matter}(g_{\mu\nu}, \varphi^m) - (8\pi G)^{-1}(\Upsilon g^{00} - \Xi\delta_{ij}g^{ij})\sqrt{-g}.$$

with covariant L_{matter}, which defines a generalization of the Lorentz ether to gravity. Thus, the Einstein equivalence may be derived from simple condensed matter axioms. The Einstein equations appear in a natural limit $\Xi, \Upsilon \to 0$.

keywords: gravity, alternative theories.

1. Motivation

To revive the concept of an ether – a concept which has been rejected more than hundred years ago – is an extraordinary proposal which requires some justification.

First, the existence of a viable ether theory of gravity is interesting already in itself, even if only for playing devil's advocate. In any case, we should reevaluate the arguments against the ether. At least one argument against the ether – non-existence of a viable ether theory of gravity – should be thrown away. Some other arguments against the old Lorentz ether are also no longer valid, if we consider the theory proposed here: Relativistic symmetry is no longer ad hoc: In our theory, we derive the Einstein equivalence principle from independent simple axioms. Then, the violation of the "action equals reaction" principle by the static, incompressible Lorentz ether no longer holds in the generalized theory, which has a classical Lagrange formalism.

The initial motivation for the author has been very different: It was the quantization of gravity. Last not least, we know how to quantize usual condensed matter theories. Thus, if we succeed to put gravity into a framework of classical condensed

ilja.schmelzer@gmail.com, ilja-schmelzer.de.

matter theory, we obtain a new way to quantize it. While string theory claims to have solved this problem, the current problems of string theory are sufficiently serious to search for alternatives.

Then, in [37] the author has proposed a surprisingly simple ether model which gives all fermions of the standard model (without mass terms) and allows, essentially, to compute the gauge group of the standard model as well as its action on the fermionic sector, as a maximal gauge group which fulfills some natural set of axioms. In this model, the three generations, the three colors, and the three generators of weak interactions have been associated with directions in the three-dimensional space. Combined with an ether theory of gravity, as we want to propose here, this defines a new, ether-based alternative for the unification of particle physics with gravity. It should be noted that the ether theory we present here seems compatible with the ether model proposed in [37]: We do not specify the material properties of the ether (which have to be defined by a special model like [37]), but consider only the most important general fields of condensed matter theory (density, velocity, and pressure tensor). Nonetheless, this allows to derive an extremely important property of the fields which describe the other, unspecified material properties of the ether – the fields which should describe the matter fields in a complete theory: We derive the Einstein equivalence principle for these other fields.

Independent motivation comes from the foundations of quantum theory. There are nice and simple hidden variable theories – the de Broglie - Bohm pilot wave interpretation, as well as Nelsonian stochastics – but their generalizations into the relativistic domain need a preferred frame. The violation of Bell's inequality shows that this is not a particular problem of these two hidden variable theories. Instead, any realistic hidden variable theory needs (hidden) violations of Einstein causality. To preserve causality, any hidden variable theory has to return to absolute causality related with a preferred frame. As far as we consider special-relativistic field theories, this is not a problem – such a frame can always be introduced, moreover, it is used in canonical approaches to quantization. The situation is different in general relativity, where it is not possible to introduce a preferred foliation into all solutions (say, into solutions with closed causal loops). Thus, a modification of general relativity which is compatible with a (possibly hidden) preferred frame would be important and useful for generalizations of Bohmian mechanics as well as Nelsonian stochastics to gravity.

Last not least, different from the Lorentz ether, which cannot be distinguished from special relativity by any observation, our ether theory of gravity leads, at least in principle, to some different predictions. Of course, to decide between GR and our theory based on observations is hard: In a natural limit of our theory we obtain the Einstein equations of GR. Nonetheless, some interesting differences exist: GLET predicts a flat universe, inflation (in the technical meaning of $\ddot{a}(\tau) > 0$ for very dense states of the universe), a stop of the gravitational collapse immediately before horizon formation, and a homogeneous dark energy term with $p = -(1/3)\varepsilon$. Especially, we have no black hole and big bang singularities.

2. Introduction

Thus, the aim of this paper is to propose a generalization of the classical Lorentz ether to gravity. The theory, which we have named "General Lorentz Ether Theory" (GLET), is a metric theory of gravity, with a Lagrangian, which has the GR Lagrangian as a limit $\Xi, \Upsilon \to 0$:

$$L = L_{GR} + L_{matter}(g_{\mu\nu}, \varphi^m) - (8\pi G)^{-1}(\Upsilon g^{00} - \Xi\delta_{ij}g^{ij})\sqrt{-g}. \tag{1}$$

On the other hand, the theory is defined like a classical ether theory, that means, a classical condensed matter theory in a Newtonian framework $\mathbb{R}^3 \otimes \mathbb{R}$: We assume classical condensed matter variables (density ρ, velocity v^i, pressure tensor p^{ij}), which follow classical conservation laws (Euler and continuity equations):

$$\begin{aligned} \partial_t\rho + \partial_i(\rho v^i) &= 0 \\ \partial_t(\rho v^j) + \partial_i(\rho v^i v^j + p^{ij}) &= 0, \end{aligned}$$

together with Lagrange formalism and a connection between them as required by Noether's theorem. The only "strange" assumption is that the pressure tensor p^{ij} should be negative definite.

The transformation of this theory into a metric theory of gravity is defined by the following simple definition of the effective gravitational field $g_{\mu\nu}$:

$$\hat{g}^{00} = g^{00}\sqrt{-g} = \rho, \tag{2a}$$

$$\hat{g}^{i0} = g^{0i}\sqrt{-g} = \rho v^i, \tag{2b}$$

$$\hat{g}^{ij} = g^{ij}\sqrt{-g} = \rho v^i v^j + p^{ij}. \tag{2c}$$

Matter fields φ^m have to be identified with other degrees of freedom (material properties) of the ether. The axioms of the theory, as far as considered here, do not specify the material properties of the ether. Therefore, they do not fix the matter degrees of freedom and the matter Lagrangian. There may be different ether models, which lead to theories with different matter fields. Nonetheless, the general axioms considered here are not only sufficient to derive the gravitational part of the general Lagrangian (1), but also allow to derived the Einstein equivalence principle (EEP) for the matter fields. Moreover, we have well-defined conservation laws with local energy and momentum densities for the gravitational field.

While we focus our attention on the presentation of an ether theory of gravity, the main technical results – the derivation of a metric theory with GR limit from condensed-matter-like axioms – may be, possibly, applied also in a completely different domain: Search for classical condensed matter theories which fit into this set of axioms as analog models of general relativity. This possibility we discuss in app. I.

Once the aim of this paper is to define the theory in an axiomatic way and to derive the Lagrangian of the theory, the paper is organized as follows. We start with the description of the explicit formalism which is used in the formulation of the axioms. Then we define and discuss the axioms of our class of condensed matter theories. After this, we derive the general Lagrangian and prove the EEP for internal observers. We also consider the GR limit.

Then we have added a lot of appendices. On one hand, they seem necessary to address common arguments against the ether concept. On the other hand, a short consideration of various questions which are beyond the scope of this paper seems necessary to motivate the reintroduction of the ether. Some of these appendices, especially the parts about analog models, quantization, realism and Bohmian mechanics, and predictions, have to be considered in separate papers in more detail.

3. Conservation Laws as Euler-Lagrange Equations for Preferred Coordinates

Below we consider classical condensed matter theories with Lagrange formalism and classical conservation laws as known from condensed matter theory (continuity and Euler equations). We know from Noether's theorem that translational invariance of the Lagrange density leads to conservation laws. It seems natural to identify the conservation laws obtained via Noether's theorem from the Lagrange formalism with the conservation laws as known them from condensed matter theory. The problem with this identification is that the conservation laws are not uniquely defined. If a tensor $T^{\alpha\beta}$ fulfills $\partial_\alpha T^{\alpha\beta} = 0$, then the tensor $T^{\alpha\beta} + \partial_\gamma \psi^{\alpha\beta\gamma}$ fulfills the same equation if ψ is an arbitrary tensor which fulfills the condition $\psi^{\alpha\beta\gamma} = -\psi^{\gamma\beta\alpha}$.

We solve this problem by proposing a variant of Noether's theorem which seems privileged because it is especially simple, natural and beautiful. Then this especially beautiful variant we identify with the known, also especially simple, classical conservation laws.

3.1. Explicit Dependence on Preferred Coordinates.

As the Lagrangian of a classical condensed matter theory in a classical Newtonian framework $\mathbb{R}^3 \otimes \mathbb{R}$, our Lagrange density is not covariant, does depend on the preferred coordinates X^μ. Now, there are various possibilities to express a given dependence on preferred coordinates. For example, we have $u^0 \equiv u^\mu X^0_{,\mu}$. But on the right hand side $u^\mu X^0_{,\mu}$ the dependence on the preferred coordinates in given in a way we name *explicit*. This explicit expression is, in some sense, more informative. Especially, in $u^\mu X^0_{,\mu}$ we have a manifest dependence on X^0, we can see that there is no dependence on the other coordinates X^i for $i > 0$. This is not obvious in the implicit form u^0 — indeed, the similarly looking expression u_0 depends on all four coordinates X^μ, not only on X^0.

Let's define now explicit dependence on the preferred coordinates in a formal way:

Definition 1. *A dependence of an expression $F(\phi^k, \phi^k_{,i}, \ldots, X^\alpha, X^\alpha_{,\mu}, \ldots)$ on the coordinates X^α is* explicit *if the expression $F(\phi^k, \phi^k_{,i}, \ldots, U^\alpha, U^\alpha_{,\mu}, \ldots)$, where the coordinates $X^\alpha(x)$ have been replaced by four independent scalar fields $U^\alpha(x)$, is covariant.*[1]

Indeed, if the second expression is covariant, no implicit dependence on the preferred coordinates X^μ has been left. Now, it may be asked if every dependence on preferred coordinates can be made explicit. In this context, we propose the following

[1]This includes the case of covarinace – no dependence on the coordinates at all.

Thesis 1. *For every physically interesting function* $F(\phi^k, \phi^k_{,i}, \ldots)$ *there exists a function* $\hat{F}(\phi^k, \phi^k_{,i}, \ldots, X^\alpha, X^\alpha_{,\mu}, \ldots) = F(\phi^k, \phi^k_{,i}, \ldots)$ *so that any dependence on the preferred coordinates* X^α *is explicit.*

Note that the thesis is not obvious. The definition of explicit dependence already requires that we know how to transform the other fields ϕ^k. For a non-covariant theory this is possibly not yet defined (see app. B). In this sense, this thesis may be considered as analogous to Kretschmann's thesis [21] that every physical theory allows a covariant formulation. In the following, we do not assume that this thesis holds. If it holds, the assumption of axiom 2 is less restrictive.

3.2. **Euler-Lagrange Equations for Preferred Coordinates and Noether's Theorem.** Now, if the dependence of the Lagrangian on the preferred coordinates is explicit, we can vary not only over the fields, but also over the preferred coordinates. The point is that, despite the special geometric nature of coordinates we can apply the Lagrange formalism as usual and obtain Euler-Lagrange equations for the preferred coordinates X^α:

Theorem 1. *If the Lagrange density* $L(\phi^k, \phi^k_{,i}, \ldots, X^\alpha, X^\alpha_{,\mu}, \ldots)$ *explicitly depends on the preferred coordinates* X^μ*, then for the extremum of* $S = \int L$ *the following Euler-Lagrange equation holds:*

$$\frac{\delta S}{\delta X^\mu} = \frac{\partial L}{\partial X^\mu} - \partial_\nu \frac{\partial L}{\partial X^\mu_{,\nu}} + \partial_\nu \partial_\lambda \frac{\partial L}{\partial X^\mu_{,\nu\lambda}} - \cdots = 0$$

For the proof, see appendix C. This does not mean that the special geometric nature of the X^α is not important. We see in appendix G that a theory with "the same" Lagrangian but usual scalar fields $U^\alpha(x)$ instead of coordinates $X^\alpha(x)$ is a completely different physical theory.

We know from Noether's theorem that symmetries of the Lagrangian lead to conservation laws. Especially, conservation of energy and momentum follows from translational symmetry in the preferred coordinates. Now, in the case of explicit dependence on the preferred coordinates X^α, translational symmetry $X^\alpha \to X^\alpha + c^\alpha$ has an especially simple form. We obtain the conservation laws automatically as Euler-Lagrange equations for the coordinates! Indeed, translational symmetry immediately gives the Lagrangian does not depend on the X^α them-self, only on their partial derivatives $X^\mu_{,\nu}, X^\mu_{,\nu\lambda} \ldots$. Therefore the Euler-Lagrange equations for the X^α *already have the form of conservation laws*.

Theorem 2. *If a Lagrangian with explicit dependence on the preferred coordinates has translational symmetry* $X^\alpha \to X^\alpha + c^\alpha$*, then the Euler-Lagrange equations for the preferred coordinates* X^α *are conservation laws:*

$$\frac{\delta S}{\delta X^\alpha} = \partial_\mu T^\mu_\alpha = 0 \tag{3}$$

We know that in agreement with Noether's second theorem these conservation laws disappear if we have general covariance. Again, in our formulation we do not have to do much to see this – if there is no dependence on the X^α, the Euler-Lagrange equation for the X^α, which are the conservation laws, disappear automatically:

Theorem 3. *If L is covariant, then*

$$\frac{\delta S}{\delta X^\alpha} \equiv 0 \tag{4}$$

In above cases, the proof is an obvious consequence of theorem 1. Of course, there is not much to wonder about, we have simply used a set of variables X^α appropriate for the symmetries we have considered – translational symmetry.

Based on these theorems we identify the Euler-Lagrange equation $\frac{\delta S}{\delta X^0}$ with the *energy conservation law* and $\frac{\delta S}{\delta X^i}$ with the *momentum conservation law*. Note also that the most general GR Lagrangian is given by the conditions (4). [2]

It seems worth to note that until now we have only considered a quite general formalism which is in no way restricted to the application in condensed matter theory below.

4. Axioms for General Lorentz Ether Theory

Let's define now our set of axioms for the class of condensed-matter-like theories we call "Lorentz ether theories". It looks quite natural, nonetheless, it should be noted that it is in some essential points an unorthodox formalism for condensed matter theories. Especially it remains open if there exist classical condensed matter theories which fit into this set of axioms.

Axiom 1 (independent variables)**.** *The independent variables of the theory are the following fields defined on a Newtonian framework $\mathbb{R}^3 \otimes R$ with preferred coordinates X^i, T: a positive density $\rho(X^i,T)$, a velocity $v^i(X^i,T)$, a symmetric pressure tensor $p^{ij}(X^i,T)$, which form the classical energy-momentum tensor $t^{\mu\nu}(X^i,T)$:*

$$\begin{aligned} t^{00} &= \rho \\ t^{i0} &= \rho v^i \\ t^{ij} &= \rho v^i v^j + p^{ij} \end{aligned}$$

Moreover, there is an unspecified number of "inner degrees of freedom" (material properties) $\varphi^m(X^i,T)$ with well-defined transformation rules for arbitrary coordinate transformations.

That we use a pressure tensor p^{ij} instead of a scalar p is a quite natural and known generalization. Instead, the use of p^{ij} as an independent variable is non-standard. Usually pressure is defined as an algebraic "material function" of other independent variables.

---

[2] "Most general" means that higher order derivatives of the metric and non-minimal interactions with matter fields are allowed. This is in agreement with the modern concept of effective field theory, as, for example, expressed by Weinberg [44]: "I don't see any reason why anyone today would take Einstein's general theory of relativity seriously as the foundation of a quantum theory of gravitation, if by Einstein's theory is meant the theory with a Lagrangian density given by just the term $\sqrt{g}R/16\pi G$. It seems to me there's no reason in the world to suppose that the Lagrangian does not contain all the higher terms with more factors of the curvature and/or more derivatives, all of which are suppressed by inverse powers of the Planck mass, and of course don't show up at energy far below the Planck mass, much less in astronomy or particle physics. Why would anyone suppose that these higher terms are absent?" We follow this point of view.

Axiom 2 (Lagrange formalism)**.** *There exists a Lagrange formalism with explicit dependence of the Lagrange density on the preferred coordinates:*

$$L = L(t^{\mu\nu}, t^{\mu\nu}_{,\kappa}, \ldots, \varphi^m, \varphi^m_{,\kappa}, \ldots, X^\alpha, X^\alpha_{,\kappa}, \ldots)$$

The existence of a Lagrange formalism is certainly a non-trivial physical restriction (it requires an "action equals reaction" symmetry) but is quite common in condensed matter theory. Instead, the requirement of explicit dependence on the X^μ is non-standard. In appendix B we argue that this additional requirement is not really a restriction: Every physical theory with Lagrange formalism can be transformed into this form. But this remains a general thesis which cannot be proven in a strong way, only supported by showing how this can be done in particular cases.

Axiom 3 (energy conservation law)**.** *The conservation law related by theorem 2 with translational symmetry in time $X^0 \to X^0 + c^0$ is proportional to the continuity equation:*

$$\frac{\delta S}{\delta X^0} \sim \partial_t \rho + \partial_i(\rho v^i). \tag{5}$$

Axiom 4 (momentum conservation law)**.** *The conservation laws related by theorem 2 with translational symmetry in space $X^i \to X^i + c^i$ are proportional to the Euler equation:*

$$\frac{\delta S}{\delta X^j} \sim \partial_t(\rho v^j) + \partial_i(\rho v^i v^j + p^{ij}). \tag{6}$$

These axioms also look quite natural and are well motivated by our version of Noether's theorem. But it should be noted that this is not the only possibility to connect continuity and Euler equations with the Lagrange formalism. The energy-momentum tensor is not uniquely defined. The main purpose of the introduction of our "explicit dependence" formalism was to motivate this particular choice as the most natural one.[3] Thus, by our choice of axioms 3, 4 we fix a particular, even if especially simple, relation between Lagrange formalism and continuity and Euler equations.

Despite the non-standard technical features of these axioms, none of them looks like being made up to derive the results below. And we also have not fixed anything about the inner structure of the medium: The inner degrees of freedom (material properties) and the material equations are not specified. From point of view of physics, the following non-trivial restrictions have been made:

- The existence of a Lagrange formalism requires a certain symmetry – the equations are self-adjoint (the principle "action equals reaction").
- This medium is conserved (continuity equation).
- There is only one, universal medium. There are no external forces and there is no interaction terms with other types of matter (as follows from the Euler equation).

Last not least, there is one additional axiom which sounds quite strange:

Axiom 5 (negative pressure)**.** *The pressure tensor $p^{ij}(X^i, T)$ is negative definite*

[3] If a tensor $T^{\alpha\beta}$ fulfills $\partial_\alpha T^{\alpha\beta} = 0$, then the tensor $T^{\alpha\beta} + \partial_\gamma \psi^{\alpha\beta\gamma}$ fulfills the same equation if ψ is an arbitrary tensor which fulfills the condition $\psi^{\alpha\beta\gamma} = -\psi^{\gamma\beta\alpha}$.

Instead, for most usual matter pressure is positive. On the other hand, the Euler equation defines pressure only modulo a constant, and if we add a large enough negative constant tensor $-C\delta^{ij}$ we can make the pressure tensor negative definite. The physical meaning of this axiom is not clear.

These are all axioms we need. Of course, these few axioms do not define the theory completely. The material properties are not defined. Thus, our axioms define a whole class of theories. Every medium which meets these axioms we name "Lorentz ether".

5. The Derivation of the General Lagrangian

The technical key result of the paper is the following derivation:

Theorem 4. *Assume we have a theory which fulfills the axioms 1-5.*

Then there exists an "effective metric" $g_{\mu\nu}(x)$ of signature $(1,3)$, which is defined algebraically by $\{\rho, v^i, p^{ij}\}$, and some constants Ξ, Υ so that for every solution $\{\rho(X,T), v^i(X,T), p^{ij}(X,T), \varphi^m(X,T)\}$ the related fields $g_{\mu\nu}(x), \varphi^m(x)$ together with the preferred coordinates $X^\alpha(x)$ are also solutions of the Euler-Lagrange equations of the Lagrangian

$$L = -(8\pi G)^{-1}\gamma_{\alpha\beta}X^\alpha_{,\mu}X^\beta_{,\nu}g^{\mu\nu}\sqrt{-g} + L_{GR}(g_{\mu\nu}) + L_{matter}(g_{\mu\nu}, \varphi^m) \tag{7}$$

where L_{GR} denotes the general Lagrangian of general relativity, L_{matter} some general covariant matter Lagrangian compatible with general relativity, and the constant matrix $\gamma_{\alpha\beta}$ is defined by two constants Ξ, Υ as $diag\{\Upsilon, -\Xi, -\Xi, -\Xi\}$.

Proof: The metric $g_{\mu\nu}$ defined by equation (2) has signature $(1,3)$. This follows from $\rho > 0$ (axiom 1) and negative definiteness of p^{ij} (axiom 5). Equation (2) allows to express ρ, v^i, p^{ij} in terms of $g^{\mu\nu}$, so that the Lagrangian $L(\rho(x), v^i(x), p^{ij}(x), \varphi^m(x), X^i(x), T(x))$ may be expressed as a function of the metric variables $L(g^{\mu\nu}(x), \varphi^m(x), X^i(x), T(x))$. Now, the key observation is what happens with our four classical conservation laws during this change of variables. They (essentially by construction) become the harmonic condition for the metric $g_{\mu\nu}$:

$$\partial_\mu(g^{\alpha\mu}\sqrt{-g}) = \partial_\mu(g^{\beta\mu}\sqrt{-g})\partial_\beta X^\alpha \equiv \Box X^\alpha = 0 \tag{8}$$

where $\Box$ denotes the harmonic operator of the metric $g_{\mu\nu}$. We define now the constants Υ, Ξ as the proportionality factors between the energy and momentum conservation laws and the continuity resp. Euler equations (axioms 3, 4). For convenience a common factor $(4\pi G)^{-1}$ is introduced:

$$\frac{\delta S}{\delta T} = -(4\pi G)^{-1}\Upsilon\Box T \tag{9}$$

$$\frac{\delta S}{\delta X^i} = (4\pi G)^{-1}\Xi\Box X^i \tag{10}$$

Defining the diagonal matrix $\gamma_{\alpha\beta}$ by $\gamma_{00} = \Upsilon, \gamma_{ii} = -\Xi$, we can write these equations in closed form as [4]

[4]Note that the coefficients $\gamma_{\alpha\beta}$ are only constants of the Lagrange density, the indices enumerate the scalar fields X^α. They do not define any fundamental, predefined object of the theory. Instead, variables of the Lagrange formalism, by construction, are only $g_{\mu\nu}$, φ^m and X^α.

$$\frac{\delta S}{\delta X^\alpha} \equiv -(4\pi G)^{-1}\gamma_{\alpha\beta}\Box X^\beta \tag{11}$$

Let's find now the general form of a Lagrangian which gives these equations. Its easy to find a particular solution L_0:

$$L_0 = -(8\pi G)^{-1}\gamma_{\alpha\beta}X^\alpha_{,\mu}X^\beta_{,\nu}g^{\mu\nu}\sqrt{-g} \tag{12}$$

Then, let's consider the difference $L - L_0$. Together with L and L_0 it's dependence on the preferred coordinates is explicit. Moreover we obtain:

$$\frac{\delta\int(L - L_0)}{\delta X^\alpha} \equiv 0 \tag{13}$$

But that means covariance, and is our condition for the most general Lagrangian of general relativity. So we obtain:

$$L = -(8\pi G)^{-1}\gamma_{\alpha\beta}X^\alpha_{,\mu}X^\beta_{,\nu}g^{\mu\nu}\sqrt{-g} + L_{GR}(g_{\mu\nu}) + L_{matter}(g_{\mu\nu}, \varphi^m). \tag{14}$$

qed.

6. Lorentz Ether Theory as a Metric Theory of Gravity

Now, the explicit formalism has been quite useful to formulate the axioms of GLET and to derive the effective Lagrangian in theorem 4. But it is only a technical formalism. Once theorem 4 has been proven, we can as well return to the usual, implicit non-covariant formulation of the theory.

Theorem 5. *Assume we have a theory which fulfills axioms 1-5. Then formula (2) defines an isomorphism between solutions of this theory and the solutions of the (non-covariant) metric theory of gravity defined by the Lagrangian*

$$L_{GLET} = L_{GR} + L_{matter} - (8\pi G)^{-1}(\Upsilon g^{00} - \Xi\delta_{ij}g^{ij})\sqrt{-g} \tag{15}$$

and the additional "causality condition" $g^{00} > 0$.

Indeed, the Lagrangian L_{GLET} is simply the Lagrangian L of theorem 4 written in the preferred coordinates X^α. It follows from (2) and $\rho > 0$ that for solutions of GLET the causality condition $g^{00} > 0$ is fulfilled. For a given solution of GLET formula (2) also allows to define the pre-image solution in terms of ρ, v^i, p^{ij}. **qed**.

Thus, our class of condensed matter theories is equivalent to a metric theory of gravity with a Newtonian framework as a predefined background. As equations of the theory in the preferred coordinates we obtain the Einstein equations of general relativity with two additional terms:

$$G^\mu_\nu = 8\pi G(T_m)^\mu_\nu + (\Lambda + \gamma_{\kappa\lambda}g^{\kappa\lambda})\delta^\mu_\nu - 2g^{\mu\kappa}\gamma_{\kappa\nu} \tag{16}$$

as well as the harmonic equations – the conservation laws

$$\partial_\mu(g^{\mu\alpha}\sqrt{-g}) = 0. \tag{17}$$

Note that the "energy-momentum tensor of matter" $(T_m)^\mu_\nu$ should not be mingled with the classical energy-momentum tensor t^μ_ν of the ether defined in axiom 1 which is the full energy-momentum tensor. There is also another form of the conservation laws. The basic equation may be simply considered as a decomposition of the full energy-momentum tensor $g^{\mu\kappa}\sqrt{-g}$ into a part $(T_m)^\mu_\nu$ which depends on matter fields and a part $(T_g)^\mu_\nu$ which depends on the gravitational field. Thus, for

$$(T_g)^\mu_\nu = (8\pi G)^{-1}\left(\delta^\mu_\nu(\Lambda + \gamma_{\kappa\lambda}g^{\kappa\lambda}) - G^\mu_\nu\right)\sqrt{-g} \tag{18}$$

we obtain a second form of the conservation law

$$\partial_\mu((T_g)^\mu_\nu + (T_m)^\mu_\nu\sqrt{-g}) = 0 \tag{19}$$

Thus, we have even two equivalent forms for the conservation laws, one with a subdivision into gravitational and matter part, and another one where the full tensor depends only on the gravitational field. In the covariant formalism, the equations are

$$\begin{aligned} G^\mu_\nu(x) &= 8\pi G(T_m)^\mu_\nu(x) + (\Lambda + \gamma_{\alpha\beta}X^\alpha_{,\kappa}(x)X^\beta_{,\lambda}(x)g^{\kappa\lambda}(x))\delta^\mu_\nu \\ &\quad - 2g^{\mu\kappa}(x)\gamma_{\alpha\beta}X^\alpha_{,\kappa}(x)X^\beta_{,\nu}(x) \end{aligned} \tag{20}$$

and

$$\Box X^\alpha(x) = \partial_\mu(g^{\mu\beta}(x)\sqrt{-g})\partial_\beta X^\alpha(x) = 0. \tag{21}$$

7. Internal Observers and the Einstein Equivalence Principle

The explicit form of the Lagrangian is, if we replace the preferred coordinates X^μ with scalar fields U^μ, formally equivalent to the Lagrangian of "general relativity with clock fields" (GRCF) considered by Kuchar and Torre [22] in the context of GR quantization in harmonic gauge:

$$L_{GRCF} = -(8\pi G)^{-1}\gamma_{\alpha\beta}U^\alpha_{,\mu}U^\beta_{,\nu}g^{\mu\nu}\sqrt{-g} + L_{GR}(g_{\mu\nu}) + L_{matter}(g_{\mu\nu}, \varphi^m). \tag{22}$$

The only difference is that in GRCF we have scalar fields $U^\alpha(x)$ instead of preferred coordinates $X^\alpha(x)$. But this makes above theories completely different as physical theories. We show this in detail in app. G. Despite these differences, internal observers of our condensed matter theories have a very hard job to distinguish above theories by observation:

Corollary 1. *In GLET internal observers cannot falsify GRCF by any local observation.*

Indeed, internal observers are creatures described by field configurations of the fields $\left(\rho(X,T), v^i(X,T), p^{ij}(X,T), \varphi^m(X,T)\right)$. Whatever they observe may be described by a solution $\left(\rho(X,T), v^i(X,T), p^{ij}(X,T), \varphi^m(X,T)\right)$. Now, following theorem 4, they can describe all their experiments and observations also as local solutions of GRCF for some "fields" $g^{\mu\nu}, \varphi^m(x), U^i(x), U^0(x)$. **qed.** [5]

[5] Note that in the reverse direction the corollary doesn't hold: There are local solutions of GRCF where the fields $U^\mu(x)$ cannot be used as coordinates even locally.

Based on this observation we can prove now the Einstein Equivalence Principle. For this purpose we have to clarify what is considered to be a matter field. This question is theory-dependent, and there are two possibilities for this: First, the internal observers of GLET may believe into GRCF. In this case, they consider the four special scalar fields $X^{\alpha}(x)$ as non-special scalar matter fields together with the other matter fields $\varphi^m(x)$. Second, they may believe into GLET. Then they consider only the fields $\varphi^m(x)$ as non-gravitational matter fields. This gives two different notions of non-gravitational experiments and therefore different interpretations of the EEP. But in above interpretations of the EEP it holds exactly:

Corollary 2. *For internal observers of a condensed matter theory GLET which fulfills axioms 1-5 the Einstein Equivalence Principle holds in above interpretations.*

Indeed, GRCF is a variant of general relativity where the EEP holds exactly. Because the EEP is a local principle (it holds if it holds for all local observations) and internal observers cannot falsify GRCF by local observations, they cannot falsify the EEP by observation. Thus, in the first interpretation the EEP holds. In the second case, only the φ^m are interpreted as matter fields. Nonetheless, we have also a metric theory of gravity coupled with the matter fields φ^m in the usual covariant way, and therefore the EEP holds.**qed.**

8. The GR Limit

In the limit $\Xi, \Upsilon \to 0$ we obtain the Lagrangian of general relativity. Thus, we obtain the classical Einstein equations. Nonetheless, some points are worth to be discussed here:

8.1. **The Remaining Hidden Background.** In this limit the absolute background becomes a hidden variable.

Nonetheless, the theory remains different from general relativity even in this limit. The hidden background leads to some important global restrictions: Non-trivial topologies are forbidden, closed causal loops too. There always exists a global harmonic time-like function. [6]

8.2. **The Absence of Fine Tuning in the Limit.** Note that we need no fine-tuning to obtain the GR limit $\Xi, \Upsilon \to 0$. All non-covariant terms depend only on the metric $g^{\mu\mu}\sqrt{-g}$, not on its derivatives $\partial_\kappa g_{\mu\nu}$. That means, in a region where we have well-defined upper and lower bounds $0 < c^{\mu}_{min} < |g^{\mu\mu}\sqrt{-g}| < c^{\mu}_{max}$ (in the preferred coordinates) all we have to do is to consider low distance high frequency effects. In comparison with global cosmology, solar system size effects obviously fit into this scheme. Thus, the non-covariant terms may be reasonably considered as cosmological terms, similar to Einstein's cosmological constant Λ.

On the other hand, there may be effects in solar-system-like dimension where these cosmological terms cannot be ignored: In the preferred coordinates, the terms

[6] There is a general prejudice against such hidden variables. It is sometimes argued that a theory without such restrictions should be preferred as the "more general" theory. But this prejudice is not based on scientific methodology as described by Popper's criterion of empirical content. If this limit of GLET is true, an internal observer cannot falsify GR in the domain of applicability of this limit. On the other hand, if GR is true, GLET is falsifiable by observation: If we observe non-trivial topology, closed causal loops, or situations where no global harmonic time exists, we have falsified GLET. In this sense, the GR limit of GLET should be preferred by Popper's criterion of predictive power in comparison with GR.

$g^{\mu\mu}\sqrt{-g}$ may become large. An example is the region near horizon formation for a collapsing star. As shown in app. L, in the case of $\Upsilon > 0$ this term prevents black hole formation, and we obtain stable "frozen star" solutions.

8.3. **Comparison with Other Approaches to GR.** Part of the beauty of GR is that there many different ways to general relativity. First, there are remarkable formulations in other variables (ADM formalism [3], tetrad, triad, and Ashtekar variables [1]) where the Lorentz metric $g_{\mu\nu}$ appears as derived. Some may be considered as different interpretations of general relativity (like "geometrodynamics"). On the other hand we have theories where the Lorentz metric is only an effective metric and the Einstein equations appear in a limit (spin two field in QFT on a standard Minkowski background [16] [43] [13], string theory [31]), Sakharov's approach [35].

In this context, the derivation of GLET, combined with the limit $\Xi, \Upsilon \to 0$, may be considered as "yet another way to GR". In this interpretation, it should be classified as part of the second group of derivations: The metric is, as in these approaches, not fundamental. Moreover, a flat hidden background remains.

9. The No-Gravity Limit

Last not least, let's consider shortly the no gravity limit of GLET. For a metric theory of gravity, it is the Minkowski limit $g_{\mu\nu}(x) = \eta_{\mu\nu}$. In this limit, the additional terms of GLET in comparison with GR no longer vary, therefore, may be omitted. Thus, the no gravity limit of GLET coinsides with the no gravity limit of GR, and is, therefore, equivalent to SR.

In this limit, we have

$$\begin{aligned} \rho(x) &= \rho_0 \\ v^i(x) &= 0 \\ p^{ij}(x) &= p_0\delta^{ij} \end{aligned}$$

with constants $\rho_0 > 0, p_0 < 0$. Thus, the ether is static and incompressible. It follows from the properties of the no gravity limit of the matter Lagrangian, which is identical in GR and GLET, that clocks and rulers behave as they behave in SR.

Thus, in the no gravity limit we obtain a static and incompressible ether in a Newtonian framework. The remarkable property of the Lagrangian of the remaining fields, which describe the remaining material properties of the ether, is, that, nonetheless, the Einstein equivalence principle for them holds. As a consequence, the Lagrangian has to follow the general rules for Lagrangians in special relativity, in particular, has to be Lorentz-covariant.

The consequence of the Lorentz-covariance of the matter Lagrangian is that clocks and rulers constructed from matter show time dilation and length contraction in agreement with the formulas of special relativity. Especially moving clocks have to be slower, and moving rulers have to be contracted, in such a way that the preferred time coordinate T remains unobservable. These properties of the no gravity limit of GLET are the properties of the classical Lorentz ether. This justifies the interpretation of GLET as a generalization of Lorentz ether theory to gravity.

Nonetheless, it seems worth to note a minor but important difference: In the classical ether theories, the ether has been considered only as a substance which explains electromagnetic waves. Usual matter has been considered to be something different. In GLET, a key point of the derivation is that all fields – including the fields which describe fermionic particles – describe degrees of freedom of the ether itself. Thus, there is no type of matter which "interacts with the ether". There is only a single universal ether, and nothing else. To talk about matter interacting with the ether is as meaningless as to talk about water waves interacting with water.

10. Conclusions

We have presented a new metric theory of gravity starting with a set of axioms for a classical condensed matter theory in a Newtonian background. Relativistic symmetry (the Einstein equivalence principle) is derived here: Internal observers of the medium (called "general Lorentz ether") are unable to distinguish all properties of their basic medium. All their local observations fulfill the Einstein equivalence principle.

While we have used an unorthodox formalism – explicit dependence of a non-covariant Lagrangian on the preferred coordinates – the basic principles we have used in the axioms are well-known and accepted: continuity and Euler equations, Lagrange formalism, and Noether's theorem, which relates them with translational symmetries.

The differences between GR and our theory are interesting: The new theory predicts inflation and a stop of the gravitational collapse, preventing black hole and big bang singularities. As a condensed matter theory in a Newtonian framework, classical canonical quantization concepts known from quantum condensed matter theory may be applied to quantize the theory.

The new theory is able to compete with general relativity even in the domain of beauty: It combines several concepts which are beautiful already by them-self: Noether's theorem, conservation laws, harmonic coordinates, ADM decomposition. Instead of the ugly situation with local energy and momentum of the gravitational field in GR, we have nice, local conservation laws. Moreover we have no big bang and black hole singularities.

To establish this theory as a serious alternative to general relativity, this paper may be only a first step. We have to learn more about the predictions of GLET which differ from GR, experimental bounds for Ξ, Υ have to be obtained, the quantization program has to be worked out in detail. The methodological considerations related with such fundamental notions like EPR realism have to be worked out too. Nonetheless, the results we have obtained are already interesting enough, and the new theory seems able to compete with general relativity in all domains we have considered – cosmology, quantization, explanatory power, and even simplicity and beauty.

Appendix A. About some common misunderstandings

Many common misunderstandings of the theory are related with the nature of the equations which define the gravitational field:

$$\begin{aligned}
\hat{g}^{00} = g^{00}\sqrt{-g} &= \rho \\
\hat{g}^{i0} = g^{i0}\sqrt{-g} &= \rho v^i \\
\hat{g}^{ij} = g^{ij}\sqrt{-g} &= \rho v^i v^j + p^{ij}
\end{aligned}$$

The equation itself is often misrepresented as if it is a physical equation, which describes the interaction of the usual spacetime metric $g_{\mu\nu}(x)$ with the ether, which is something like usual condensed matter. This is wrong. There is no separate gravitational field $g_{\mu\nu}(x)$ which interacts with the ether. Instead, there are two possible sets of fields we can use to describe one and the same thing – the ether. One set of variables consists of $\rho(x), v^i(x), p^{ij}(x)$ and other material properties $\varphi_m(x)$, a set which we know from condensed matter physics as an appropriate choice for the description of condensed matter. The other set of fields consists of $g_{\mu\nu}(x)$ and the $\varphi_m(x)$. The equation describes how these two sets of variables are connected with each other: It is an algebraic transformation of variables.

The ether density ρ_{ether} has to be clearly distinguished from densities of usual matter ρ_{matter}, which appear on the right-hand side of the Einstein equations in the energy-momentum tensor of matter. They are as different as, for comparison, the density of water from the density of waves on its surface, or the density of air from the density of sound waves in it.

In relation with this definition of the ether density, the question of units may arise. Naively, one may think about the ether density as having the unit g/cm^3. The expression on the other side of the equation has the unit cm^3/s. Thus, a factor containing appropriate units seems to be missed.

But the density of the ether ρ is a qualitatively new entity. We have nothing to compare it with: We cannot take one peace of ether and measure its weight in g. Therefore, to assume that the ether density is measured in g/cm^3 is physically nonsensical. We also don't know (yet) the size of the ether atoms, so we cannot count their number in a given volume to measure the ether density in $atoms/cm^3$. What is, in this case, the appropriate unit to measure the ether density in our theory? Physical units should be defined in connection with a way to measure them. But the only way to measure ρ of the ether in our theory is to measure the metric $g_{\mu\nu}$ and then to compute ρ according to the definition $\rho = g^{00}\sqrt{-g}$. Thus, it is the definition, without any additional unit factor, which provides us with a way (the only way) to measure the ether density, and, therefore, allows a definition of a natural unit for the ether density.

The situation would be different if, say, we would know the critical length of some atomic structure of the ether. In this case, there would be a natural unit for the ether density, in $atoms/cm^3$ of the ether. Correspondingly we would need, in this case, an additional coefficient for the transformation between these two natural units for the ether density, which, in analogy to the Avogadro number, could be named "ether Avogadro number". But, even in this case, the unit for the ether density given by the definition $\rho = g^{00}\sqrt{-g}$ could survive as well as the unit mol has survived in chemistry. Moreover, even in this case there would be no need to introduce a constant into the definition itself.

Once the unit of ρ is defined appropriately, corresponding units for the ether momentum vector ρv^i and the ether pressure tensor p^{ij} follow automatically.

Appendix B. Can every Lagrangian be rewritten in explicit form?

In axiom 2 we assume that the Lagrangian is given in explicit form. Now, the question we want to discuss here is if this is a non-trivial restriction or not. If it is not, then our thesis 1 holds.

In some sense, this can be considered as a corollary to Kretschmann's [21] thesis that every physical theory may be reformulated in a general covariant way. We would have to reformulate a given theory with Lagrangian F into a general covariant form, and when, as far as possible, try to replace all objects used to describe the absolute Newtonian framework in this covariant description by a description which depends explicitly on the preferred coordinates $X^\alpha(x)$. [7]

In this sense, let's try to describe how the classical geometric objects related with the Newtonian framework may be described in an explicit way:

- The preferred foliation: It is immediately defined by the coordinate $T(x)$.
- The Euclidean background space metric: A scalar product $(u,v) = \delta_{ij}u^iv^j$ may be presented in explicit form as $(u,v) = \delta_{ij}X^i_{,\mu}X^j_{,\nu}u^\mu v^\nu$.
- Absolute time metric: Similarly, the (degenerate) metric of absolute distance in time may be defined by $(u,v) = T_{,\mu}T_{,\nu}u^\mu v^\nu$.
- The preferred coordinates also define tetrad and cotetrad fields: $dX^\alpha = X^\alpha_{,\mu}dx^\mu$, for the vector fields $\partial/\partial X^\alpha = (J^{-1})^\mu_\alpha(X^\beta_{,\nu})\partial/\partial x^\mu$ we need the inverse Jacobi matrix J^{-1}, which is a rational function of the $X^\beta_{,\nu}$.
- Arbitrary upper tensor components $t^{\alpha_1,\ldots\alpha_n}$ may be transformed into $X^{\alpha_1}_{,\mu_1}\cdots X^{\alpha_n}_{,\mu_n}t^{\mu_1,\ldots\mu_n}$. For lower indices we have to use again the inverse Jacobi matrix J^{-1}.
- Together with the background metrics we can define also the related covariant derivatives.

Now, these examples seem sufficient to justify our hypothesis. Of course, if we want to transform a given non-covariant function into explicit form, we have no general algorithm. For example, a scalar in space in a non-relativistic theory may be a spacetime scalar, the time component of a four-vector, and so on for tensors. But uniqueness is not the problem we have to solve here. For our hypothesis it is sufficient that there exists at least one way.

Let's note again that our hypothesis is not essential for our derivation. Simply, if the hypothesis is false, our assumption that the Lagrangian is given in explicit form (which is part of axiom (2)) is a really non-trivial restriction. This would be some loss of generality and therefore of beauty of the derivation, but in no way fatal for the main results of the paper. The considerations given here already show that the class of theories which allows an explicit formulation is quite large.

Appendix C. Justification of the Euler-Lagrange Equations for the Preferred Coordinates

In the Euler-Lagrange formalism for a Lagrangian with explicit dependence on the preferred coordinates we propose to handle the preferred coordinates like usual fields. Of course, every valid set of coordinates $X^\alpha(x)$ defines a valid field configuration. But the reverse is not true. To define a valid set of coordinates, the functions

[7] Remember that there has been some confusion about the role of covariance in general relativity. Initially it was thought by Einstein that general covariance is a special property of general relativity. Later, it has been observed that other physical theories allow a covariant description too. The classical way to do this for special relativity (see [17]) is to introduce the background metric $\eta_{\mu\nu}(x)$ as an independent field and to describe it by the covariant equation $R^\mu_{\nu\kappa\lambda}[\eta] = 0$. For Newton's theory of gravity a covariant description can be found in [28], §12.4. The general thesis that every physical theory may be reformulated in a general covariant way was proposed by Kretschmann [21].

$X^\alpha(x)$ have to fulfill special local and global restrictions: the Jacobi matrix should be non-degenerated everywhere, and the functions should fulfill special boundary conditions. In app. G we find that this makes the two theories different as physical theories.

Here we want to prove theorem 1 that nonetheless the Lagrange formalism works as usual. The description of the Lagrange function in explicit form is, in comparison with an implicit description, only another way to describe the same minimum problem. To solve this minimum problem we can try to apply the standard variational calculus. Especially we can also vary the preferred coordinates X^α, which are, together with the other fields, functions of the manifold. But there is a subtle point which has to be addressed. The point is that not all variations $\delta X^\alpha(x)$ are allowed – only the subset with the property that $X^\alpha(x)+\delta X^\alpha(x)$ defines valid global coordinates. Therefore, to justify the application of the standard Euler-Lagrange formalism we have to check if this subset of allowed variations is large enough to give the classical Euler-Lagrange equations.

Fortunately this is the case. To obtain the Euler-Lagrange equations we need only variations with compact support, so we don't have a problem with the different boundary conditions. Moreover, for sufficiently smooth variations ($\delta X^\alpha \in C^1(\mathbb{R}^4)$ is sufficient) there is an ε so that $X^\alpha(x)+\varepsilon\delta X^\alpha(x)$ remains to be a system of coordinates: indeed, once we have an upper bound for the derivatives of δX^α (because of compact support), we can make the derivatives of $\varepsilon\delta X^\alpha$ arbitrary small, especially small enough to leave the Jacobi matrix of $X^\alpha+\varepsilon\delta X^\alpha$ non-degenerated. Such sufficiently smooth variations are sufficient to obtain the Euler-Lagrange equations.

Now, to obtain the Euler-Lagrange equations we need only small variations. Thus, the geometrical restrictions on global coordinates do not influence the derivation of the Euler-Lagrange equations for the $X^\alpha(x)$. For the preferred coordinates we obtain usual Euler-Lagrange equation, as if they were usual fields, despite their special geometric nature.

Appendix D. Discussion of the Derivation

The extremely simple derivation of exact general-relativistic symmetry in the context of a classical condensed matter theory looks very surprising. It may be suspected that too much is hidden behind the innocently looking relation between Lagrange formalism and the condensed matter equations, or somewhere in our unorthodox "explicit formalism". Therefore, let's try to understand on a more informal, physical level what has happened, and where we have made the physically non-trivial assumptions which lead to the very non-trivial result – the EEP.

A non-trivial physical assumption is, obviously, the classical Euler equation. This equation contains non-trivial information – that there is only one medium, which has no interaction, especially no momentum exchange, with other media. This is, indeed, a natural but very strong physical assumption. And from this point of view the derivation looks quite natural: What we assume is a single, universal medium. What we obtain with the EEP is a single, universal type of clocks. An universality assumption leads to an universality result.

From point of view of parameter counting, all seems to be nice too. We have explicitly fixed four equations, and obtain an independence from four coordinates. All the effective matter fields are by construction fields of a very special type – inner degrees of freedom, material properties, of the original medium. Therefore it is also not strange to see them closely tied to the basic degrees of freedom (density, velocity, pressure) which define the effective gravitational field.

The non-trivial character of the existence of a Lagrange formalism seems also worth to be mentioned here. A Lagrange formalism leads to a symmetry property of the equation – they should be self-adjoint. This is the well-known symmetry of the "action equals reaction" principle. It can be seen where this symmetry has been applied if we consider the second functional derivatives. The EEP means that the equations for effective matter fields φ^m do not depend on the preferred coordinates X^α. This may be formally proven in this way:

$$\frac{\delta}{\delta X^\mu}\frac{\delta S}{\delta \varphi^m} = \frac{\delta}{\delta \varphi^m}\frac{\delta S}{\delta X^\mu} = \frac{\delta}{\delta \varphi^m}[\text{cons. laws}] = 0 \tag{23}$$

Thus, we have applied here the "action equals reaction" symmetry of the Lagrange formalism and the property that the fundamental classical conservation laws (connected with translational symmetry by Noether's theorem) do not depend on the material properties φ^m.

Our considerations seem to indicate that the relativistic symmetry (EEP) we obtain is explained in a reasonable way by the physical assumptions which have been made, especially the universality of the medium and the special character of the "effective matter" degrees of freedom – assumptions which are implicit parts of the Euler equation – and the "action equals reaction" symmetry of the Lagrange formalism.

It seems also necessary to clarify that the states which cannot be distinguished by local observation of matter fields are not only different states, they can be distinguished by gravitational experiments. The EEP holds (we have a metric theory of gravity) but not the Strong Equivalence Principle (SEP). The SEP holds only in the GR limit. For the definitions of EEP and SEP used here see, for example, [45].

Appendix E. What Happens During Evolution with the Causality Condition?

We have proven that solutions of $GRCF$ which are images of solutions of GLET fulfill some restrictions (time-like $T(x)$, $X^\alpha(x)$ are coordinates). Now, it is reasonable to ask if these restrictions are compatible with the evolution equations of GRCF. Assume that we have a solution of GRCF which fulfills all necessary restrictions for some time $T(x) < t_0$. This solution now evolves following the evolution equations of GRCF. Is there any warranty that these global restrictions remain to be fulfilled also for $T(x) \geq t_0$? The answer is no. There is not such general warranty. But, as we will see, there is also no necessity for such a warranty.

For a given Lorentz ether theory (with fixed material Lagrangian) such a warranty would follow from a global existence and uniqueness theorem. Indeed, having such a theorem for the condensed matter theory, it would be sufficient to consider the image of the global solution. [8]

[8] In this context it seems not uninteresting to note that the famous local existence and uniqueness theorems for GR given by Choquet-Bruhat [12] are based on the use of harmonic gauge. That means, they may be interpreted as local existence and uniqueness theorems for the limit $\Xi, \Upsilon \to 0$ of $GLET$, combined with considerations that local existence and uniqueness for this limit (in this gauge) is the same as local existence and uniqueness for general relativity.

But in such a general class of theories as defined by our axioms 1-5 where is no hope for general global existence theorems and, as a consequence, for a warranty that the restrictions remain valid for $T(x) > t_0$. Moreover, theories without global existence theorems are quite reasonable as condensed matter theories. It happens in reality that some material tears. In this case, the continuous condensed matter theory which is appropriate for this material should have a limited domain of application, and there should be solutions which reach $\rho = 0$ somewhere. But according to equation (2) $\rho = 0$ corresponds to a violation of the condition that $T(x)$ is time-like. Thus, if such a material is described by a theory which fulfills our axioms, and a solution describes a state which at some time starts to tear, the restriction that $T(x)$ is time-like no longer holds.

Appendix F. Reconsideration of Old Arguments Against The Ether

The generalization of Lorentz ether theory we have presented here removes some old, classical arguments against the Lorentz ether – arguments which have justified the rejection of the Lorentz ether in favor of relativity:

- There was no viable theory of gravity — we have found now a theory of gravity with GR limit which seems viable;
- The assumptions about the Lorentz ether have been ad hoc. There was no explanation of relativistic symmetry, the relativistic terms have had ad hoc character — the assumptions we make for our medium seem quite natural, and we *derive* the EEP instead of postulating it.
- There was no explanation of the general character of relativistic symmetry, the theory was only electro-magnetic — in the new concept the "ether" is universal, all matter fields describe properties of the ether, which explains the universality of the EEP and the gravitational field;
- There was a violation of the "action equals reaction" principle: there was influence of the ether on matter, but no reverse influence of matter on the stationary and incompressible ether — we have now a Lagrange formalism which guarantees the "action equals reaction" principle and have a compressible, instationary ether;
- There were no observable differences in the predictions of the Lorentz ether and special relativity — there are important and interesting differences between our theory and general relativity (see appendix L).

Appendix G. Non-Equivalence of General Lorentz Ether Theory and General Relativity with Clock Fields

In theorem 4 we have proven that solutions of GLET also fulfill the equations of general relativity with four additional scalar fields $X^\alpha(x)$ which do not interact in any way with the other matter. In the context of GR quantization in harmonic gauge, this Lagrangian has been considered by Kuchar and Torre [22]. Following them, we name it "general relativity with clock fields" (GRCF).

Now, a very important point is that, despite theorem 4, GLET is not equivalent to GRCF as physical theories. Indeed, what we have established in theorem 4 is only a very special relationship: for solutions of GLET we obtain "image solutions" which fulfill the equations of GRCF. But there are a lot of important differences which make above theories different from physical point of view:

- Different notions of completeness: A complete, global solution of GLET is defined for all $-\infty < X^i, T < \infty$. It is in no way required that the effective metric $g_{\mu\nu}$ of this solution is complete. Therefore, the image of this solution in GRCF is not necessarily a complete, global solution of GRCF.
- Global restrictions of topology: GRCF has solutions with non-trivial topology. Every image of a solution of GLET has trivial topology.
- Global hyperbolicity: GRCF has solutions which are not globally hyperbolic, especially solutions with closed causal loops. Every image of a solution of GLET is globally hyperbolic. Moreover, there exists a global harmonic time-like function: $T(x)$ on images.
- Special character of X^i, T: GRCF contains a lot of solutions so that the fields $X^i(x), T(x)$ do not define a global system of coordinates. For every image of a solution of GLET the fields $X^i(x), T(x)$ have this property.
- Unreasonable boundary conditions: Physically reasonable solutions of GRCF are only solutions with reasonable boundary conditions in infinity. For example, it seems reasonable to require that physical fields have some upper bounds. This leads to $|X^i(x)|, |T(x)| < C$ for some constant C. In this case, no image of a solution of GLET defines a global physically reasonable solution of GRCF.

Therefore, the two theories are conceptually very different theories. They only look similar if we ignore the very special geometric nature of the preferred coordinates X^i, T of GLET.

Appendix H. Comparison with RTG

There is also another theory with the same Lagrangian – the "relativistic theory of gravity" (RTG) proposed by Logunov et al. [23]. In this theory, we have a Minkowski background metric $\eta_{\mu\nu}$. The Lagrangian of RTG is

$$L = L_{Rosen} + L_{matter}(g_{\mu\nu}, \psi^m) - \frac{m_g^2}{16\pi}(\frac{1}{2}\eta_{\mu\nu}g^{\mu\nu}\sqrt{-g} - \sqrt{-g} - \sqrt{-\eta})$$

If we identify the Minkowski coordinates in RTG with the preferred coordinates in GLET, the Lagrangians are equivalent as functions of $g_{\mu\nu}$ for the following choice of constants: $\Lambda = -\frac{m_g^2}{2} < 0$, $\Xi = -\eta^{11}\frac{m_g^2}{2} > 0$, $\Upsilon = \eta^{00}\frac{m_g^2}{2} > 0$. In this case, the equations for $g^{\mu\nu}$ coincide. The harmonic equation for the Minkowski coordinates hold in RTG [23]. As a consequence, the equations of the theories coincide. This holds despite the fact that different fields are considered as physical fields, so that, at a first look, the covariant versions seem to be different. In the covariant RTG version, we have equations for the metric $\eta_{\mu\nu}(x)$, while in our theory we have equations for the coordinates $X^\mu(x)$, while the $\eta_{\mu\nu}$ appear only as coefficients. But the two versions are connected by the standard formula for the metric in different coordinates: $\eta_{\mu\nu}(x) = \eta_{\alpha\beta}X^\alpha_{,\mu}(x)X^\beta_{,\nu}(x)$.

The two theories are much closer to each other – above theories are metric theories of gravity with a preferred background. Nonetheless, there remain interesting differences even in this case. First, in above theories we have additional restrictions related with the notion of causality – causality conditions. In GLET, causality is related with the Newtonian background – the preferred time $T(x)$ should be a time-like function. This is equivalent to the condition $\rho > 0$. In RTG, causality is defined by the Minkowski background. The light cone of the physical metric $g_{\mu\nu}$ should be inside the light cone of the background metric $\eta_{\mu\nu}$. The RTG causality condition is, therefore, much more restrictive. Interesting solutions of our theory which violate the RTG causality condition and are, therefore, not acceptable as solutions of RTG, exist. Especially we have oscillating homogeneous universe solutions without matter (see appendix L.1), while only the trivial solution $g_{\mu\nu}(x) = \eta_{\mu\nu}$ is compatible with the RTG causality condition.

Second, the derivation of GLET does not lead to the restrictions for the sign of Ξ, Υ, Λ. Especially the restriction for Λ may be important: The cosmological constant Λ in RTG leads to deceleration, which (in combination with the big bounce caused by $\Upsilon > 0$) leads to an oscillating universe [25]. Instead, observation suggests an acceleration of the expansion, thus, the "wrong" sign of Λ.

But the more important differences are the differences which are metaphysical at the classical level. RTG, with its completely different metaphysics, leads to a completely different quantization program.

Appendix I. Analog Models of General Relativity

In this paper, we propose an ether theory of gravity, starting from condensed-matter-like axioms and deriving a metric theory of gravity with GR limit. But this connection between condensed matter axioms and a metric theory with GR limit may be, possibly, applied also in another direction: Search for classical condensed matter theories which fit into this set of axioms as analog models of general relativity. In this appendix we consider the possibility of such applications.

I.1. **Comparison With Analog Gravity Research.** The observation that curved Lorentz metrics appear in condensed matter theories is currently attracting considerable attention. Though it is not a priori expected that all features of Einstein gravity can successfully be carried over to the condensed matter realm, interest has turned to investigating the possibility of simulating aspects of general relativity in analog models. Domains of research in "over a hundred articles devoted to one or another aspect of analog gravity and effective metric techniques" have been dielectric media, acoustics in flowing fluids, phase perturbations in Bose-Einstein condensates, slow light, quasi-particles in superfluids, nonlinear electrodynamics, linear electrodynamics, Scharnhorst effect, thermal vacuum, "solid state" black holes and astrophysical fluid flows [5]. Asking whether something more fundamental is going on, Barcelo et al [5] have found that linearization of a classical field theory gives, for a single scalar field, a unique effective Lorentz metric. As observed by Sakharov [35], quantization of the linearized excitations around this background gives a term proportional to the Einstein-Hilbert action in the one-loop effective action. But this approach has serious limitations: It is not clear how to obtain the Einstein equivalence principle for different types of excitations which, in general, "see" different effective metrics. The Einstein-Hilbert action appears only in the quantum domain. The most serious question is how to suppress the non-covariant terms.

Now, the approach presented here may be used to solve these problems. If we are able to find some real condensed matter which fits into our set of axioms, this matter defines an ideal analog model of general relativity. Thus, we have reduced the search for analog models for general relativity to a completely different question – the search for Lagrange formalisms for condensed matter theories which fit into our set of axioms. While we have not been able to find such Lagrange formalisms yet, there are some points which seem worth to be mentioned:

- Our metric has been defined independent of any particular linearization of waves. It's definition is closely related to the energy-momentum tensor:

$$T^{\mu}_{\alpha} = -(4\pi G)^{-1}\gamma_{\alpha\beta}g^{\beta\mu}\sqrt{-g} \tag{24}$$

  It is in no way claimed that some or all excitations which may be obtained by various linearizations follow this metric. Such a claim would be false even in the world of standard general relativity. Indeed, we know particular excitations which have different speeds – like light on the background of a medium. The EEP allows to distinguish "fundamental" excitations (which use its basic metric) and "less fundamental" excitations (like light in a medium). But starting with arbitrary waves in a medium described phenomenologically or obtained by some linearization of approximate equations, without knowing the EEP-related metric, we have no base to make this distinction.

  Once we do not define the metric as an effective metric of some excitations, it is not a problem for our approach if different excitations follow different effective metrics. The metric is uniquely defined by the energy-momentum tensor, which is closely related to translational symmetry. Therefore it is not strange that this metric is the metric related with the EEP.
- The general-relativistic terms appear already in the classical domain. Their origin is not quantization, but the general restrictions for non-covariant terms which follow from our axioms. Whatever additional terms we add to the Lagrangian – if the modified theory does not violate the axioms and does not renormalize $\gamma_{\alpha\beta}$, the difference between old and new Lagrangian should be covariant.
- The non-covariant terms in our approach are uniquely defined and easy to control: they do not depend on matter fields, they do not depend on derivatives of $g_{\mu\nu}$.

It remains to find interesting condensed matter theories which fits into our axioms.

I.2. **How to Find Analog Models.** Let's shortly consider how difficult it is to find such matter. The continuity and Euler equations are common. The negative definiteness of the pressure tensor p^{ij} seems uncommon. But pressure is defined by the Euler equation only modulo a constant. This constant should be fixed by the Lagrange formalism. Thus, the real point is the Lagrange formalism. Unfortunately, Lagrange formalisms are not uniquely defined, and there is a similar uncertainty in the definition of the energy-momentum tensor. Moreover, usually the pressure p^{ij} is not used as an independent variable. Because of such problems, it is not straightforward to obtain a Lagrange formalism which fits into our axioms starting with known condensed matter Lagrangians (as described, for example, in [42]).

One idea to find Lagrange formalisms which fit into our scheme may be reverse engineering: we start with a typical GLET Lagrangian, see how it looks in the condensed matter variables, and try to interpret them. The background-dependent part of the GLET Lagrangian obtains a quite simple form:

$$L = L_{GR} + L_{matter} - (8\pi G)^{-1}(\Upsilon\rho - \Xi(\rho v^2 + p^{ii})) \quad (25)$$

I.3. **Condensed Matter Interpretation of Curvature.** The physical meaning of the general-relativistic Lagrangian can be understood as related with inner stress. If at a given moment of time all spatial components of the curvature tensor vanish, then there exists a spatial diffeomorphism which transforms the metric into the Euclidean metric. Such diffeomorphisms are known as transformations into stress-free reference states in elasticity theory. If no such transformation exists, we have a material with inner stress. This understanding is in agreement with a proposal by Malyshev [26] to use of the 3D Euclidean Hilbert-Einstein Lagrangian for the description of stress in the presence of dislocations.

The physical meaning of the components which involve time direction is less clear. It seems clear that they describe modifications of inner stresses, but this has to be better understood. Nonetheless, our approach suggests a generalization of Malyshev's proposal – to use the full Hilbert-Einstein Lagrangian instead of its 3D part only.

I.4. **Condensed Matter Interpretation of Gauge Fields and Fermions.** Of course, search for analog models requires a better understanding of the matter part of the theory. It would be helpful to have a similar understanding of gauge and fermion fields. It seems natural to interpret the analog of the harmonic condition, the Lorenz gauge condition

$$\partial_\mu A^\mu = 0, \quad (26)$$

as a conservation law. Then, gauge symmetry will be no longer a fundamental symmetry. Instead, it should be derived in a similar way as the EEP, describing the inability of internal observers to distinguish states which are different in reality.

The example of superfluid $^3He - A$ seems to be of special interest: "the low-energy degrees of freedom in $^3He - A$ do really consist of chiral fermions, gauge fields and gravity" [40].

Another proposal for an ether interpretation of the standard model fermions and gauge fields has been made by the author [37].

Appendix J. Quantization of Gravity Based on Ether Theory

The most important open problem of fundamental physics is quantization of gravity. Here, an ether theory suggests an alternative quantization concept which at least solves some of the most serious problems of GR quantization. Indeed, we already know one simple way to quantize classical condensed matter theories in a Newtonian framework: It would be sufficient to use classical Schrödinger quantization of some discrete (atomic) model of these field theories. Once we have a classical condensed matter theory with Newtonian framework as the fundamental theory of everything, the analogy with classical condensed matter theory suggests a quantization program along the following lines:

- As a first step we have to switch from Euler (local) coordinates to Lagrange (material) coordinates. It is known that a Lagrange formalism in Euler coordinates gives a Lagrange formalism in Lagrange coordinates and that this transformation gives a canonical transformation of the related Hamilton formalisms [8].

This essentially changes the situations with the constraints. The condensed matter is no longer described by ρ, v^i but by $x^i(x_0^i, t)$. The continuity equation disappears, the Euler equation becomes a second order equation.

- Next, we have to find atoms, that means, to discretize the problem. The density ρ should be identified with the number of nodes inside a region, and for functions defined on the nodes we obtain

$$\int_A f(x)\rho(x)dx \to \sum_{x_k \in A} f_k. \tag{27}$$

The density ρ does not appear as a discrete variable at all. Of course, instead of discretizing the equations them-self, we discretize the Lagrangian and define the discrete equations as exact Euler-Lagrange equations for the discretized Lagrangian.

It would be helpful if it would be possible to discretize the Lagrangian so that the discrete Lagrangian L_d fulfills our axioms too. Then it would be sufficient to discretize only the lowest order parts L_0 of L, that means, not the Einstein-Hilbert Lagrangian itself. Following our derivation, we obtain that $L_0 - L_d$ should be covariant but non-zero. Then the Einstein-Hilbert term appears as the lowest order term of the discretization error automatically. On the other hand, the discrete Lagrangian itself would be only a simple discretization of the lowest order terms.

- Note that in this approach we are not forced to quantize in a way which preserves local symmetry groups like the group of diffeomorphisms or gauge groups. Instead, we believe that these symmetry groups appear only as large distance approximations, moreover not as fundamental symmetry groups but as groups which describe the restricted possibilities of internal observers to distinguish different states – but such symmetry groups are irrelevant for quantization. Of course, we have to develop yet a similar understanding of gauge symmetry (see app. I.4).
- The last step is canonical quantization. We have to derive the Hamilton formalism from the Lagrange formalism. Then we can apply some canonical ordering (Weyl quantization or normal ordering) to obtain a well-defined quantum theory.

Note that this quantization approach is closely related to the consideration of analog models (app. I). If we have an analog model, we can use this model as a guide for quantization. Nonetheless, the general scheme described here may work even if we do not find any real analog models.

J.1. **Comparison with Canonical Quantization.** It is worth to note that this quantization program is completely different from the program of canonical quantization of general relativity: Space and time remain a classical background and are not quantized. We have a different number of degrees of freedom: States which are different but indistinguishable for internal observers are nonetheless handled as different states. That means, in related path integral formulations their probabilities have to be added. No ghost fields have to be introduced. There is also no holography principle: the number of degrees of freedom of the quantum theory is, for almost homogeneous ρ, proportional to the volume.

The problems which have to be solved in this quantization program seem to be not very hard in comparison with the problems of canonical GR quantization. This suggests, on the other hand, that quantization of gravity following this scheme will not lead to non-trivial restrictions of the parameter space of the standard model: There will be a lot of quantum theories of gravity with very different material models.

That a preferred frame is a way to solve the "problem of time" in quantum gravity is well-known: "... 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." [11]. This way to solve the problem is rejected not for physical reasons, but because of deliberate metaphysical preference for the standard general-relativistic spacetime interpretation: "most general relativists feel this response is too radical to countenance: they regard foliation-independence as an undeniable insight of relativity." [11]. These feelings are easy to understand. 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" [11]. The introduction of a Newtonian background "solves" them in a very trivial, uninteresting way. It does not tell anything about quantum nature of space and time, because space and time do not have any quantum nature in this theory – they have the same classical nature of a "stage" as in non-relativistic Schrödinger theory. The hopes to find something new, very interesting and fundamental about space and time would be dashed. But nature is not obliged to fulfill such hopes.

Appendix K. Compatibility with Realism and Hidden Variables

An important advantage of a theory with preferred frame is related with the violation of Bell's inequality [6]. It is widely accepted that experiments like Aspect's [2] show the violation of Bell's inequality and, therefore, falsify Einstein-local realistic hidden variable theories. Usually this is interpreted as a decisive argument against hidden variable theories and the EPR criterion of reality. But it can as well turned into an argument against Einstein locality. Indeed, if we take classical realism (the EPR criterion [15]) as an *axiom*, the violation of Bell's inequality simply proves the existence of superluminal causal influences. Such influences are compatible with a theory with preferred frame and classical causality, but not with Einstein causality.

This has been mentioned by Bell [7]: "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. 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."

Note that at the time of the EPR discussion the situation was quite different. People have accepted the rejection of classical realism under the assumtion that realistic hidden variable theories for quantum theory do not exist, and that this is a theorem proven by von Neumann. Today we know not only that EPR-realistic, even deterministic hidden variable theories exist – we have Bohmian mechanics (BM) [9], [10] as an explicit example. Thus, quantum theory alone does not give any argument against classical realism, as was believed at that time. Therefore, the only argument against classical realism is its incompatibility with Einstein causality — thus, the reason why we mention it here as support for our ether theory.

We use here the existence of Bohmian mechanics as an argument for compatibility of classical realism with observation. Therefore, some remarks about the problems of Bohmian mechanics are useful. First, the main "problem" of Bohmian mechanics is that it needs a preferred frame. This is already a decisive argument for many scientists, but cannot count here because it is the reason why we mention it as support for ether theory. But there have been other objections. Problems with spin, fermions, and relativistic particles are often mentioned. But these problems have been solved in modern presentations of BM [10] [14]. It seems useful to mention here that BM is a quite general concept which works on quite arbitrary configuration spaces. Thus, it does not depend on a particle picture. Once a quantum theory starts with fields, the natural "Bohmianization" of it is a Bohmian field theory.

Thus, we can use BM here as support for our ether theory. Reversely, our ether theory defines a program for Bohmian gravity. Indeed, following the quantization program described in app. J we end with canonical quantization of a discrete theory, which fits into the domain of applicability of the classical scheme of Bohmian mechanics.

Appendix L. Cosmological Predictions

It is not the purpose of this paper to consider the various experimental differences between GR and our theory in detail. Nonetheless, we want to give here a short description of some differences to support the claim that such differences exist and lead to observable effects. It is clear that the predictions have to be worked out in detail.

In general, because the Einstein equations appear as the limit $\Xi, \Upsilon \to 0$, the overwhelming experimental evidence in favor of the EEP and the Einstein equations (Solar system tests, binary pulsars and many others) as described by Will [45] can give only upper bounds for the parameters Ξ, Υ. It is not the purpose of this paper to obtain numerical values for these bounds.

Some qualitative differences have been already mentioned: non-trivial topologies and closed causal loops are forbidden. There should exist a global time-like harmonic coordinate. Additional predictions require reasonable guesses about the preferred coordinates. But this is easy. For the global universe, we obtain such natural guesses based on obvious symmetry considerations. For local situations (gravitational collapse) we have the requirement that the preferred coordinates have to fit the global solution and need reasonable initial values. Together with the harmonic equation, this is enough to define them.

Note that all the differences between GLET and GR considered below depend on the assumptions about the special geometric nature of the preferred coordinates. Especially the GLET solutions have the boundary conditions appropriate for coordinates, but not for scalar matter fields. Therefore, the difference between GR with scalar fields and GLET is not only a purely theoretical one, it leads to really observable differences.

L.1. **The Homogeneous Universe.** The background-dependent terms of GLET lead to interesting observable effects. Let's consider at first the homogeneous universe solutions of the theory. Because of the Newtonian background frame, only a flat universe may be homogeneous. An appropriate harmonic ansatz for the flat homogeneous universe is

$$ds^2 = a^6(t)dt^2 - \beta^4 a^2(t)(dx^2 + dy^2 + dz^2). \tag{28}$$

For proper time $d\tau = a^3 dt$ this gives the usual FRW-ansatz for the flat universe with some scaling factor $\beta > 0$:

$$ds^2 = d\tau^2 - \beta^4 a^2(\tau)(dx^2 + dy^2 + dz^2). \tag{29}$$

This leads to ($p = k\varepsilon$, $8\pi G = c = 1$):

$$3\left(\frac{\dot a}{a}\right)^2 = -\frac{\Upsilon}{a^6} + 3\frac{\Xi}{\beta^4 a^2} + \Lambda + \varepsilon \tag{30}$$

$$2\frac{\ddot a}{a} + \left(\frac{\dot a}{a}\right)^2 = +\frac{\Upsilon}{a^6} + \frac{\Xi}{\beta^4 a^2} + \Lambda - k\varepsilon \tag{31}$$

The Υ-term influences only the early universe, its influence on later universe may be ignored. But, if we assume $\Upsilon > 0$, the qualitative behavior of the early universe changes in a remarkable way. We obtain a lower bound a_0 for $a(\tau)$ defined by

$$\frac{\Upsilon}{a_0^6} = 3\frac{\Xi}{\beta^4 a_0^2} + \Lambda + \varepsilon \tag{32}$$

The solution becomes symmetrical in time – a big bounce. Note that this solves two problems of cosmology which are solved in standard cosmology by inflation theory: the flatness problem and the cosmological horizon problem.[9] The question what the theory predicts about the distribution of fluctuations of the CMBR radiation requires further research: It depends on reasonable initial conditions before the bounce. The bounce itself is too fast to allow the establishment of a global equilibrium, thus, the equilibrium should exist already before the bounce.

Instead, the Ξ-term gives a dark energy term. For $\Xi > 0$ it behaves like homogeneously distributed dark matter with $p = -(1/3)\varepsilon$. The additional term has the same influence on $a(\tau)$ as the classical curvature term. On the other hand, the universe should be flat. [10]

---

[9]About these problem, see for example Primack [30]: First, "the angular size today of the causally connected regions at recombination ($p^+ + e^- \to H$) is only $\Delta\theta \sim 3^o$. Yet the fluctuation in the temperature of the cosmic background radiation from different regions is very small: $\Delta T/T \sim 10^{-5}$. How could regions far out of causal contact have come to temperatures that are so precisely equal? This is the 'horizon problem'." (p.56) Even more serious seems the following problem: In the standard hot big bang picture, "the matter that comprises a typical galaxy, for example, first came into causal contact about a year after the big bang. It is hard to see how galaxy-size fluctuations could have formed after that, but even harder to see how they could have formed earlier" (p.8).

[10]This makes the comparison with observation quite easy: as long as $a(\tau)$ is considered, the prediction of a ΞCDM theory with $\Lambda = 0, \Xi > 0$ is the same as for OpenCDM. Therefore, the SNeIa data which suggest an accelerating universe are as problematic for ΞCDM as for OpenCDM. The 2000 review of particle physics [18], 17.4, summarizes: "the indication of $\Omega_\Lambda \neq 0$ from the SNeIa

The case of a universe without matter $\varepsilon(\tau) = 0$ is interesting for comparison with RTG [23]. We obtain a vacuum solution with $a^4(\tau)\Xi = \beta^4\Upsilon$, $a(\tau)^6\Lambda = 2\Upsilon$. The RTG causality condition gives $a^4(\tau)\Xi \le \beta^4\Upsilon$, so that this is also a valid RTG solution. But we also obtain oscillating solutions for smaller values of β, and these oscillating solutions already violate the RTG causality condition.

L.2. **Gravitational Collapse.** Another domain where $\Upsilon > 0$ leads to in principle observable differences to GR is the gravitational collapse. Let's consider for this purpose a stable spherically symmetric metric in harmonic coordinates. For a function $m(r), 0 < m < r, r = \sqrt{\sum (X^i)^2}$, the metric

$$ds^2 = (1 - \frac{m\partial m/\partial r}{r})(\frac{r-m}{r+m}dt^2 - \frac{r+m}{r-m}dr^2) - (r+m)^2 d\Omega^2 \tag{33}$$

is harmonic in X^i and $T = t$. For constant m this is the Schwarzschild solution in harmonic coordinates. For time-dependent $m(r,t)$ the X^i remain harmonic but t not. T has to be computed by solving the harmonic equation for Minkowski initial values before the collapse.

Now, a non-trivial term $\Upsilon > 0$ becomes important near the horizon. Indeed, let's consider as a toy ansatz for the inner part of a star the distribution $m(r) = (1-\Delta)r$. This gives

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

We can ignore the cosmological terms Ξ, Λ in comparison to the matter terms ε, p, but for very small Δ even a very small $\Upsilon > 0$ becomes important. Our ansatz gives a stable "frozen star" solution for ultra-relativistic $p = \varepsilon$ and $\Xi = \Lambda = 0$. The surface time dilation is $\Delta^{-1} = \sqrt{\varepsilon/\Upsilon} \sim M^{-1}$ for mass M. In general, it seems obvious that the term $\Upsilon > 0$ prevents $g^{00}\sqrt{-g}$ from becoming infinite in harmonic coordinates. Therefore, the gravitational collapse stops and leads to some stable frozen star with a size very close to the Schwarzschild radius.

In principle, this leads to observable effects. The surface of the objects considered as black holes in GR should be visible but highly redshifted. Astronomical observations like described by Menou et al. [27] would be in principle able to observe such effects. Unfortunately, surface time dilation should be very large for cosmological reasons: To preserve the standard big bang scenario (see above), we obtain very small upper bounds for Ω_Υ today. For small enough Υ we obtain a large enough redshift and the surface remains invisible in comparison to the background radiation.

Are there effects which may distinguish a stable frozen star with very small $\Upsilon \ll 1$ from a GR black hole? At least in principle, yes. A GR black hole will

Hubble diagram is very interesting and important, but on its own the conclusion is susceptible to small systematic effects. On the other hand small scale CBR anisotropy confirming a nearly flat universe ... strongly suggests the presence of Λ or other exotic (highly negative pressure) form of dark mass-energy." The fit with the farthest SN 1997ff can be seen in in figure 11 of [32] – the figure for $\Omega_M = 0.35, \Omega_\Xi = 0.65$ is the same as for the $\Omega_M = 0.35, \Omega_\Lambda = 0$ open universe given in this figure. Thus, while not favored by the SNeIa results, ΞCDM may be nonetheless a viable dark energy candidate, better than OpenCDM because it requires a flat universe.

Hawking radiate, a stable frozen star (as every stable star in semiclassical theory) not. This leads to observable differences for very small black holes. A difference appears also if we look at radiation going through a transparent star [11]. For a GR black hole we will see nothing (exponentially redshifted radiation), while in the case of a stable frozen star we see non-redshifted radiation. In above cases this is caused by the same difference: For an external observer, the GR black hole always looks like a collapsing, non-static solution. Instead, a collapsing star in our theory becomes a stable frozen star after quite short time. This time depends on Υ only in a logarithmic way, therefore, the prediction does not depend on the value of Υ.

In a completely symmetric situation, an ideal point-like elastic infalling body would bounce back from the surface of a frozen star. This has been found for RTG in [24] and remains correct for $\Upsilon > 0$ in our theory. If this leads to easily observable effects is another question. Real infalling matter will not remember an ideal elastic body in such an extremal situation.

L.3. **Ether Sound Waves and Gravitational Waves.** In fluids described by continuity and Euler equations there are sound waves. This seems to be in contradiction with the situation in general relativity. They cannot correspond to gravitational waves as predicted by general relativity, which are quadrupole waves.

Now, in the Lorentz ether these waves are gravity waves. Because general-relativistic symmetry is broken by the additional background-dependent terms, the gravitational field has more degrees of freedom in the Lorentz ether. In some sense, these additional degrees of freedom are the four fields which appear in GRCF discussed in app. G. Now, these additional degrees of freedom interact with the other degrees of freedom only via the background-dependent term. That means, they interact with matter only as dark matter. Second, in the limit $\Xi, \Upsilon \to 0$ they no longer interact with usual matter at all. Thus, in this limit they become unobservable for internal observers. That's why in this limit they may be removed from considerations as hidden variables.

On the other hand, for non-zero Ξ, Υ they nonetheless interact with matter. And this interaction leads, in principle, to observable effects. Nonetheless, we have not considered such effects, because we believe that the restrictions which follow from cosmological considerations are much stronger. This belief is qualitatively justified by our considerations about the GR limit: We have argued that the GR limit is relevant for small distance high frequency effects, and if the total variation of the $g_{\mu\nu}$ remains small. This is exactly the situation for gravitational waves.

On the other hand, there may be other factors which override these simple qualitative considerations. For example the ability of gravity waves to go over large distances which leads to integration of these small effects over large distances, or for measurements of energy loss as done for binary pulsars, which allows integration over many years. For the range of gravity waves in theories with massive graviton such considerations have been made in [23], and their results agree with our expectation that the upper bounds coming from cosmological considerations are nonetheless much stronger.

[11] Note in this context that for neutrinos all usual stars are transparent.

13. Acknowledgements

I would like to thank A.A. Logunov, V.A. Petrov and A.B. Shabat for interesting and helpful conversations.

References

[1] A. Ashtekar, Phys.Rev.Lett. 57, 2244, 1986 Phys.Rev. D the Ashtekar variables
[2] A. Aspect, J. Dalibard, G. Roger, Experimental test of Bell's inequalities using time-varying analysers, Phys. Rev.Lett. 49, 1801-1807, 1982
[3] R. Arnowitt, S. Deser, C. Misner, Quantum theory of gravitation: General formalism and linearized theory, Phys. Rev. 113, 745–750, 1959
[4] J.L. Anderson, Principles of relaivity physics, Academis Press, New York 1967
[5] C. Barcelo, S. Liberati, M. Visser, Analog gravity from field theory normal modes?, gr-qc/0104001 (2001)
[6] J.S. Bell, On the Einstein-Podolsky-Rosen paradox, Physics 1, 195-200, 1964
[7] J.S. Bell, in Davies, P.C.W. and Brown,J.R., eds., The Ghost in the Atom, Cambridge: Cambridge University Press 1986
[8] L.F.J. Broer, J.A. Kobussen, Conversion from material to local coordinates as a canonical transformation, Appl. Sci.Res. 29, 419-429, 1974
[9] D. Bohm, Phys. Rev. 85, 166-193, 1952
[10] D. Bohm, B.J. Hiley, The undivided universe: an ontological interpretation of quantum theory, Routledge, London 1993
[11] J. Butterfield, C.J. Isham, Spacetime and the philosophical challenge of quantum gravity, gr-qc/9903072
[12] Y. Choquet-Bruhat, Theoreme d'existence pour certain systemes d'equations aux derivees partielles non lineaires, Acta Math., 88, 141 (1952)
[13] S. Deser, Gen. Rel. and Grav 1, 9, 1970
[14] D. Dürr, S. Goldstein, N. Zanghi, Bohmian mechanics as the foundation of quantum mechanics, quant-ph/9511016, (1995)
[15] A. Einstein, B. Podolsky, N. Rosen, Phys. Rev. 47, 777-780, 1935
[16] R.P. Feynman, Lectures on gravitation, Calif. Inst. of Technol. 1963
[17] V. Fock, Theorie von Raum, Zeit und Gravitation, Akademie-Verlag Berlin, 1960
[18] D.E. Groom et al., 2000 Review of Particle Physics, The European Physical Journal C15 (2000) 1, available on the PDG WWW pages (URL: http://pdg.lbl.gov/)
[19] T. Jacobson, Thermodynamics of spacetime: the Einstein equation of state, gr-qc/9504004
[20] T. Jacobson, Spontaneously broken Lorentz symmetry and gravity, gr-qc/0007031
[21] E. Kretschmann, Ann. Phys. 53, 575, 1917
[22] K.V. Kuchar, C.G. Torre, Harmonic gauge in canonical gravity, Physical Review D, vol. 44, nr. 10, pp. 3116-3123, 1991
[23] A.A. Logunov et.al., Theor.Math.Phys. 69 Nr 3, 1986
A.A. Logunov, Theor.Math.Phys. 70 Nr 1, 1987
S.S. Gershtein, A.A. Logunov, M.A. Mestvirishvili, The upper limit on the graviton mass, hep-th/9711147
[24] A.A. Vlasov, A.A. Logunov, Bouncing from the Schwarzschild sphere in the relativistic theory of gravity with nonzero graviton mass, Theor.Math.Phys. 78, 229-233 (1989)
[25] A.A. Logunov, M.A.Mestvirishvili, Yu.V.Chugreev, Graviton mass and evolution of a Friedman universe, Theor.Math.Phys. 74, 1-20 (1988)
[26] C. Malyshev, cond-mat/9901316
[27] K. Menou, E.Quataert, R. Narayan, Astrophysical evidence for black hole event horizons, gr-qc/9803057
[28] C. Misner, K. Thorne, J. Wheeler, Gravitation, Freedman, San Francisco, 1973
[29] E. Nelson, Derivation of the Schrödinger Equation from Newtonian Mechanics, Phys.Rev. 150, 1079–1085, 1966
[30] J.R. Primack, astro-ph/9707285
[31] J. Polchinski, String theory, Cambridge University Press, Cambridge (1998)
[32] A.G. Riess et al, The farthest known supernova: support for an accelerating universe and a glimpse of the epoch of deceleration, astro-ph/0104455

[33] N. Rosen, Ann. of Phys. vol. 22, nr. 1, pp. 1-11, 1963
[34] H. C. Rosu, Hawking-like effects and Unruh-like effects: toward experiments? gr-qc/9406012
[35] A.D. Sakharov, Sov.Phys.Doklady 12, 1040 (1968)
[36] I. Schmelzer, General ether theory – a metric theory of gravity with condensed matter interpretation, Proc. of the XXII international workshop on high energy physics and field theory, Protvino, June 23-25, 1999
[37] I. Schmelzer, A Condensed Matter Interpretation of SM Fermions and Gauge Fields, Foundations of Physics, vol. 39, nr. 1, p. 73 (2009)
[38] W.G. Unruh, Phys Rev Lett **46** 1351 (1981)
[39] M. Visser, Acoustic black holes: horizons, ergospheres, and Hawking radiation, gr-qc/9712010
[40] G.E. Volovik, Induced gravity in superfluid ^3He, cond-mat/9806010
[41] G.E. Volovik, Field theory in superfluid ^3He, cond-mat/9812381
[42] H.-J. Wagner, Das inverse Problem der Lagrangeschen Feldtheorie in Hydrodynamik, Plasmaphysik und hydrodynamischem Bild der Quantenmechanik, Universität Paderborn, 1997
[43] S. Weinberg, Phys.Rev. B138, 988 (1965)
[44] S. Weinberg, What is quantum field theory, and what did we think it is, hep-th/9702027
[45] C.M. Will, The confrontation between general relativity and experiment, gr-qc/9811036