Abstract

The paper is an introduction into General Ether Theory (GET). We start with few assumptions about an universal "ether" in a Newtonian space-time which fulfils

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

For an "effective metric" $g_{\mu\nu}$ we derive a Lagrangian where the Einstein equivalence principle is fulfilled:

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

We consider predictions (stable frozen stars instead of black holes, big bounce instead of big bang singularity, a dark matter term), quantization (regularization by an atomic ether, superposition of gravitational fields), related methodological questions (covariance, EPR criterion, Bohmian mechanics).

General Ether Theory

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1 Introduction

The purpose of the present work is to present an alternative metric theory of gravity. The Lagrangian of the theory

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

is very close to the GR Lagrangian, and in the limit $\Xi, \Upsilon \to 0$ we obtain the classical Einstein equations.

The key point is that this Lagrangian may be *derived* starting with a few assumptions about the "ether" – a classical medium in a classical Newtonian background with Euclidean space and absolute time $\mathbb{R}^3 \otimes \mathbb{R}$. We need only a few general principles: a Lagrange formalism and its relation with standard conservation laws. The gravitational field $g^{\mu\nu}$ is defined by the "general" steps of freedom of the ether – density ρ, velocity v^i, pressure p^{ij}.[1] The matter fields describe its material properties. What explains the Einstein equivalence principle is that the ether is universal: all fields describe properties of the ether, there is no external matter. Therefore, observers are also only excitations of the ether, unable to observe some of the ether properties. This explains that we are unable to observe all steps of freedom of the ether. We need no artificial conspiracy or highly sophisticated model to obtain relativistic symmetry in an ether theory.

[1] As usual, we use latin indices for three-dimensional indices and greek indices for four-dimensional indices. We also use the notation $\hat{g}^{\mu\nu} = g^{\mu\nu}\sqrt{-g}$.

The only difference to GR are two additional terms which depend on the preferred coordinates X^i, T. In "weak" covariant formulation (with the preferred coordinates handled as "fields" $X^i(x), T(x)$) we obtain:

$$L = L_{GR} - (8\pi G)^{-1}(\Upsilon g^{\mu\nu}T_{,\mu}T_{,\nu} - \Xi g^{\mu\nu}\delta_{ij}X^i_{,\mu}X^j_{,\nu})\sqrt{-g}$$

Instead of no equation for the preferred coordinates, we obtain a well-defined general equation for these coordinates: the classical conservation laws, which appear to be the harmonic coordinate condition.

But this changes a lot. It is, essentially, a paradigm shift as described by Kuhn [44]. We revive the metaphysics of Lorentz ether theory in its full beauty. This requires the reconsideration of the whole progress made in fundamental physics in this century. Therefore, after derivation of the theory and their comparison with existing theories of gravity we reconsider different domains of science from point of view of the new paradigm. Of course, this may be only a raw overview, a program for future research instead of a summary of results. But this raw overview does not suggest serious problems for the new paradigm, while essential problems of the relativistic paradigm disappear.

The preferred background leads to well-defined local energy and momentum conservation laws. Moreover, the additional terms seem to be useful to solve cosmological problems. The Ξ-term defines a nice homogeneous dark matter candidate. The Υ-term is even more interesting: it avoids the big bang singularity and leads instead to a bounce. Such a bounce makes the cosmological horizon much larger and therefore solves the cosmological horizon problem without inflation. This term stops also the gravitational collapse immediately before horizon formation. Because of the underlying Euclidean symmetry, the flat universe is the only homogeneous universe. Therefore, GET is not only in agreement with observation, but allows to solve some serious cosmological problems solved today by inflation theory.

A very strong argument in favour of GET is the violation of Bell's inequality. In our opinion, it is a very simple and decisive proof of the existence of a preferred foliation – as simple and decisive as possible in fundamental physics. Only if we try to avoid this simple conclusion, the issue becomes complicate – we have to reject simple fundamental principles like the EPR criterion of reality or causality. In our opinion, there is a lot of confusion in this question. For example, it is often assumed that the EPR criterion is in contradiction with quantum theory. But the existence of Bohmian mechanics proves that there is no such contradiction.

In quantum field theory the reintroduction of a preferred frame does not lead to problems. Instead, it allows to generalize Bohmian mechanics into the relativistic domain and clarifies the choice of the Fock space in semiclassical field theory.

The "ether hypothesis" suggests also a simple solution for the problem of non-renormalizability. Technically, this solution is already known as "effective field theory". In this concept, it is assumed that below a certain cutoff scale the theory becomes really different. This concept has two features where GET suggests modification: First, in the standard concept the nature of the theory below this cutoff remains completely unspecified. Instead, GET suggests a well-defined framework: canonical quantum theory, Newtonian space-time, and some "atomic ether theory". Second, the cutoff length is supposed to be the Planck length. Instead, GET makes a prediction which is inconsistent with Planck length – the cutoff is defined by $g^{00}\sqrt{-g}V_{cutoff} = 1$. As a consequence, the cutoff length seems to increase in a homogeneous "expanding" universe.

Remarkably, all these results are only side-effects. It was not the original intention of the author to revive old ether theory. Instead, the author shares the common admiration for the beauty of GR. It was also not the intention to solve cosmological problems – they have been considered only after the derivation of the Lagrangian. We also have not tried to save the EPR criterion or to generalize Bohmian mechanics.

The original motivation was different. It was a quantum gravity thought experiment which has convinced the author that a Newtonian framework is necessary. The question is if a "one world theory" as GR is sufficient to describe superpositions of different gravitational fields, or if such a superposition depends on relations between the superposed fields, their "relative position". To decide this question, we consider a simple interaction of a superposition of quasiclassical fields with a test particle. We observe a transition probability which depends on such relative information. To describe such transition probabilities in quantum gravity it seems necessary to introduce a common background.

Last not least, it seems necessary to criticize some aspects of the relativistic paradigm for quantum gravity. "Because of the lack of data, quantum gravity is strongly influenced by philosophical prejudices of the researchers"

[20], therefore, these prejudices have to be considered. We use Rovelli [63] as a base for this consideration. It includes an excellent methodological part we agree with. We criticize his relativistic argumentation and argue that our consideration is in much better agreement with the proposed methodology.

2 General Ether Theory

Let's now define general ether theory. We have a Newtonian framework – absolute Euclidean space with orthonormal coordinates X^i and absolute time T. We have also classical causality – causal influence $A \to B$ between events A and B is possible only if $T(A) \le T(B)$.

The ether is described by steps of freedom which are usual in condensed matter theory: there is an "ether density" $\rho(X,T)$, an "ether velocity" $v^i(X,T)$ and an "ether pressure" $p^{ij}(X,T)$. As usual for a density, $\rho > 0$.

These steps of freedom define the gravitational field. The theory is a metric theory of gravity, and the metric $g_{\mu\nu}$ is defined algebraically by the following formula:

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

This formula is a variant of the ADM decomposition. Especially, v^i is the ADM shift vector.

Because the density ρ is always positive, this formula defines a Lorentz metric if and only if the tensor p^{ij} is negative definite. Therefore, we make the additional assumption that p^{ij} is negative definite.

2.1 The material properties of the ether

These are not all steps of freedom of the ether. Instead, there are other steps of freedom, the "material properties" $\varphi^m(X,T)$ of the ether. But these steps of freedom are not defined by GET. Instead, GET is a general theory only, it describes only a few general properties, not all properties of the ether. It is, therefore, a meta-theory, a general scheme for an ether theory. Different ether theories can fit into this scheme. Ether theories with well-defined material properties and material laws we name “complete ether models”.

This is in no way strange for a theory of gravity. All metric theories of gravity are general schemes in the same sense. They do not specify the matter steps of freedom and the matter Lagrangian. Nonetheless, they specify an essential and very important property of the matter Lagrangian – that it fulfils the Einstein equivalence principle. Thus, the meta-theoretical character is a common feature of theories of gravity.

GET in some sense explains this subdivision into a universal gravitational field and matter fields. Indeed, there is a similar subdivision in condensed matter theory – the subdivision between the few basic steps of freedom (like density, velocity, pressure) which are common for very different materials and the “material properties” which differ for different materials. In GET this subdivision fits with the subdivision into gravity and matter fields: Density, velocity and pressure are used to describe the gravitational field, while the other material properties describe the matter fields.

This is an essential difference to classical ether theory. In the classical concept, the ether is assumed to be something different from usual matter. In GET, usual matter is described by continuous fields, and these fields describe various properties of the ether.

But we not only assume that there are material properties of the ether described by some matter fields. We assume more: all matter fields describe material properties of the ether. There is no ethr-external matter:

Axiom 1 (universality) *There is nothing except the ether. All fields describe steps of freedom of the ether.*

Thus, the complete ether model is the theory of everything.

2.2 Conservation laws

In our covariant formalism, the conservation laws are the Euler-Lagrange equations for the preferred coordinates X^{μ} (see (A.2)). Now, let's try to find these conservation laws. The main hypothesis is that these conservation laws coinside with the classical conservation laws we know from condensed matter theory.

Axiom 2 (continuity equation) *The mass of the ether is conserved. This conservation is described by the classical continuity equation:*

$$\partial_t \rho + \partial_i(\rho v^i) = 0 \tag{1}$$

The other important equation of classical condensed matter theory is the Euler equation. It is the conservation law for momentum:

Axiom 3 (Euler equation) *The momentum of the ether is conserved. This conservation is described by the classical Euler equation:*

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

Note that we have no terms for external forces or interaction with external matter. The reason is that we have already incorporated here the universality axiom – there is no momentum exchange with external matter, there are no external forces. All "matter fields" are "material properties" of the ether.

These are already all ether equations specified by GET. All other equations are "material laws" of the ether, they depend on the "material properties" φ^m which have to be defined only by the complete ether model. GET does not specify them.

Now, a key observation is what happens if if we rewrite the classical conservation laws as equations for the effective metric $g_{\mu\nu}$. We obtain a well-known equation – the harmonic condition:

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

2.3 Lagrange formalism

A major assumption is that we have a Lagrange formalism. We use the covariant formulation of the theory: the preferred coordinates X^μ are considered as fields, the Lagrangian depends on the fields $X^\mu(x)$ in a covariant way (see §A.1). In this formalism, the conservation laws are the Euler-Lagrange equations for the preferred coordinates (see (A.2)).

On the other hand, we have already found the conservation laws and observed that they may be written as equations for the preferred coordinates. Thus, it seems reasonable to assume that they are proportional:

$$\frac{\delta S}{\delta X^{\mu}} = \gamma_{\mu}\Box X^{\mu}$$

Now, the coefficients γ_μ may be different. We can use Euclidean symmetry to argue that $\gamma_1 = \gamma_2 = \gamma_3$, but there is no reason to suppose a relation between γ_0 and the γ_i.

Instead of the γ_μ we introduce introduce a diagonal matrix $\gamma_{\mu\nu}$ with $\gamma_{\mu\mu} = -4\pi G\gamma_\mu$. The factor $4\pi G$ is well-known from GR, and it seems natural to introduce it here: in this case, the two constants $\Upsilon = \gamma_{00}$, $\Xi = -\gamma_{ii}$ appear in a similar way as Einstein's cosmological constant Λ. Now we can formulate the

Axiom 4 (Lagrange formalism) *There exists a "weak covariant" Lagrange formalism so that the Euler-Lagrange equations for the preferred coordinates X^μ and the classical conservation laws for the ether $\Box X^\mu = 0$ are related in the following way:*

$$\frac{\delta S}{\delta X^{\mu}} = -(4\pi G)^{-1}\gamma_{\mu\nu}\Box X^{\nu} \tag{3}$$

Now, let's find the general Lagrangian which fulfils this assumption.

Theorem 1 *The general Lagrangian for GET is*

$$L = -(8\pi G)^{-1}\gamma_{\mu\nu}g^{\mu\nu}\sqrt{-g} + L_{GR}(g_{\mu\nu}) + L_{matter}(g_{\mu\nu}, \varphi^m) \tag{4}$$

Proof: First, we find a Lagrangian which fulfils the condition (3):

$$L_{GET} = -(8\pi G)^{-1}\gamma_{\mu\nu}X^{\mu}_{,\alpha}X^{\nu}_{,\beta}g^{\alpha\beta}\sqrt{-g}$$

For the difference we obtain

$$\frac{\delta \int (L - L_{GET})}{\delta X^{\mu}} = 0$$

Thus, the remaining part is "strong" covariant, that means, it is not only covariant, but does not depend on the preferred coordinates X^μ too. But this is the classical requirement for the Lagrangian of general relativity. Thus, we can identify the difference with the classical Lagrangian of general relativity.

$$L = L_{GET}(g_{\mu\nu}, X^\mu) + L_{GR}(g_{\mu\nu}) + L_{matter}(g_{\mu\nu}, \varphi^m)$$

In the preferred coordinates L_{GET} may be rewritten as

$$L_{GET} = -(8\pi G)^{-1}(\Upsilon g^{00} - \Xi(g^{11} + g^{22} + g^{33}))\sqrt{-g}$$

or in a more compact form as

$$L_{GET} = -(8\pi G)^{-1}\gamma_{\mu\nu} g^{\mu\nu}\sqrt{-g}$$

This proves the theorem.

It should be noted that we have no theoretical reason to fix the signs for the cosmological constants Ξ, Υ, Λ. Their values should be fixed by observation.

3 Simple properties

Now we have defined GET and can describe its properties.

First, let's write down the other Euler-Lagrange equations. As equations for $g^{\mu\nu}$ we obtain the Einstein equations with two additional non-covariant terms:

$$G^\mu_\nu = 8\pi G(T_m)^\mu_\nu + (\Lambda + \gamma_{\kappa\lambda} g^{\kappa\lambda})\delta^\mu_\nu - 2g^{\mu\kappa}\gamma_{\kappa\nu} \quad (5)$$

As in GR, the equations for the matter fields φ^m depend on the matter Lagrangian and remain unspecified.

The expression of the GET Lagrangian in terms of the original ether variables is quite nice:

$$4\pi G\Xi^{-1} L_{GET} = \frac{1}{2}(\rho|v|^2 + p^{ii} - \Upsilon\Xi^{-1}\rho)$$

3.1 Energy-momentum tensor

Now, we have derived the GET Lagrangian using assumptions about the conservation laws. Therefore, to write dowm the energy-momentum tensor is easy:

$$T^{\mu}_{\nu} = (4\pi G)^{-1}\gamma_{\nu\kappa}g^{\kappa\mu}\sqrt{-g}$$

In this form, the tensor does not depend on the material properties φ^m of the ether. But how is this energy-momentum tensor related with the usual energy-momentum tensor for the matter fields? Now, the answer is simple. We have to multiply the GET variant of the Einstein equation (5) with $\sqrt{-g}$ and obtain the following decomposition of the full energy-momentum tensor:

$$T^{\mu}_{\nu} = (T_m)^{\mu}_{\nu}\sqrt{-g} + (8\pi G)^{-1}\left((\Lambda + \gamma_{\kappa\lambda}g^{\kappa\lambda})\delta^{\mu}_{\nu} - G^{\mu}_{\nu}\right)\sqrt{-g}$$

Thus, we obtain immediately what is missed in GR: an energy-momentum tensor for the gravitational field.

3.2 Constraints

If we want to formulate an initial value problem for GR as well as GET, we cannot simply define the initial values $g^0_{\mu\nu}(x) = g_{\mu\nu}(x,0)$ and $k^0_{\mu\nu}(x) = \partial_t g_{\mu\nu}(x,t)|_{t=0}$. Instead, we obtain the problem that the four equations

$$G^0_{\mu} = \ldots$$

do not contain second order derivatives in time, that means, they define constraints for the initial values. This is a common property in above theories, because the additional terms of GET do not add second order derivatives of the $g_{\mu\nu}$. Moreover, in GET the four conservation laws are also only first order in time.

Nonetheless, their character is completely different. In GR, these constraints play a very special role in the ADM Hamilton formalism – the energy H itself is a constraint. This is a consequence of the covariance of the GR Lagrangian. In GET, as we have already seen, we have a well-defined local energy and momentum density.

Even if the constraints are much more harmless in GET, they remain to be constraints, which is not very nice. But there is some interesting insight into the nature of the constraints in GET which has been found for GR in harmonic coordinates by Choquet-Bruhat [22]. This insight was important for his proof of local existence and uniqueness theorems for GR. It is remarkable in itself that this proof has been done in harmonic coordinates.

First, as has been observed by Lanczos [46], the Ricci tensor essentially simplifies in harmonic coordinates:

$$R^{(h)}_{\mu\nu} = -\frac{1}{2} g^{\alpha\beta} \frac{\partial^2 g_{\mu\nu}}{\partial x^\alpha \partial x^\beta} + H_{\mu\nu}$$

where $H_{\mu\nu}$ does not contain second derivatives of the metric. Now, in GET we have the harmonic condition $\Gamma^\mu = \partial_\nu (g^{\mu\nu}\sqrt{-g}) = 0$ as an equation. Therefore, for the initial values we have

$$\Gamma^\mu(0,x) = 0 \qquad \partial_t \Gamma^\mu(0,x) = 0$$

The second condition contains a second order time derivative. But this is true also for the Ricci tensor in harmonic coordinates. Now, if we use the appropriate combination of this second initial condition and the equation in harmonic coordinates, we obtain the four other first order constraints (see [30], Lemma 22). Thus, all constraints are closely related to the harmonic condition.

The ether interpretation gives additional insight. The point is that in this interpretation the components $\rho v^i = g^{0i}\sqrt{-g}$ are already velocities. A second order equation for these components would be a third order equation for the ether particles them-self. Therefore, it is very natural that there are no such third order terms in the equations them-self.

4 Derivation of the Einstein equivalence principle

The Einstein equivalence principle (EEP) is an immediate consequence of the GET Lagrange density: the matter Lagrangian is covariant in the strong sense, does not depend on the preferred coordinates X^μ. The question we want to consider here is if there are generalizations of the GET axioms so that the EEP remains correct.

At first we have to formulate the EEP in an appropriate way. The equations for matter do not depend on the preferred coordinates. In our covariant formalism there is a natural way to do formulate this property. The "equations for the matter" we identify with the Euler-Lagrange equations for φ^m, and the property that they do not depend on the preferred coordinates X^μ can be written as

$$\frac{\delta}{\delta X^\mu}\frac{\delta S}{\delta \varphi^m} = 0$$

To obtain a proof, let's look how this property may be proven for the GET Lagrangian:

Theorem 2 (Einstein equivalence principle) *Let L be a weak covariant Lagrangian with the conservation laws*

$$\partial_\mu T^\mu_\nu = 0.$$

If the conservation laws do not depend on the variables φ^m, then the Einstein equivalence principle holds for these variables.

Proof: The conservation laws in the weak covariant formalism are defined as

$$\frac{\delta S}{\delta X^\mu} = \partial_\nu T^\nu_\mu = 0$$

The EEP follows immediately:

$$\frac{\delta}{\delta X^\mu}\frac{\delta S}{\delta \varphi^m} = \frac{\delta}{\delta \varphi^m}\frac{\delta S}{\delta X^\mu} = \frac{\delta}{\delta \varphi^m}\partial_\nu T^\nu_\mu = 0$$

As we see, the first property we need is that the material properties are not used in the conservation laws. This property depends on our choice of p^{ij} as an independent variable. But this is only a technical question. More important is the universality axiom – that the matter fields φ^m describe only "material properties" of the ether. External steps of freedom, that means other, non-ether fields which interact with the ether have some momentum exchange with the ether. Therefore, there will be some interaction terms in the momentum conservation laws.

But this may be partially weakened. If some steps of freedom ψ^n are external forces or external matter, while other steps of freedom φ^m describe material properties of the ether, than the EEP does not hold for the external steps of freedom, but remains valid for the material properties. The proof remains the same.

The other property is that the conservation laws are the Euler-Lagrange equations for the preferred coordinates:

$$\frac{\delta S}{\delta X^\mu} = \partial_\nu T^\nu_\mu$$

Now, this may be generalized for the case where we have explicit dependencies on the preferred coordinates, and, therefore, no conservation laws. All we need is that the equation does not depend on the material properties φ^m.

Therefore, we conclude that the EEP holds for material properties φ^m even in more general situations, if we have other external fields, external forces, even explicit dependencies of the Lagrangian from the coordinates. Let's summarize: *The EEP holds for a step of freedom φ^m only if it describes a material property of the ether. The universality axiom explains why the EEP holds for all matter fields.*

4.1 Higher order approximations in a Lagrange formalism

Let's consider now another possibility for generalization. We consider the situation where we have to consider different approximations for a Lagrange formalism. All we assume is that all approximations are consistent. For a condensed matter theory that means that the conservation laws are valid. Let's compare now two approximations. For the approximation $S = S_0 + S_1$ we have

$$\frac{\delta S_0}{\delta X^\mu} = \partial_\nu T^\nu_\mu$$

as well as

$$\frac{\delta S}{\delta X^\mu} = \partial_\nu T^\nu_\mu$$

Now, in this situation we do not even need that these conservation laws do not depend on some fields φ^m. All we need now is that the two approximations of the conservation laws are identical. This leads immediately to the Einstein equivalence principle for the additional part of the Lagrangian:

$$\frac{\delta S_1}{\delta X^\mu} = 0$$

This consideration suggests that it may be even easier to detect relativistic symmetry in the higher order approximations. Sequences S_n of approximations appear in effective field theory.

4.2 Weakening the assumptions about the Lagrange formalism

We have obtained the conservation laws with reference to condensed matter theory. Then we have identified them with the conservation laws from the weak covariant formalism. This is a quite natural, but non-trivial identification. There are many different variants of the conservation laws, and even if they are equivalent if the equations of motion are fulfilled, their functional dependencies differ. Therefore, it would be nice to weaken this assumption.

Unfortunately, it seems impossible to prove something without an explicit assumption which relates a certain conservation law with the Euler-Lagrange equations. The property "there exists a Lagrange formalism" for some equivalent system of equations is too weak. The problem is that there are various methods of transformation of a given system of equations – multiplying them with "integrating factors", Lagrange multipliers, replacement of fields by potentials. That's why a general method which allows to decide if a given set of equations is equivalent to a system of Euler-Lagrange equations is not known [77]. That means, we are not even able to find all Lagrange formalisms for a given set of equations.

It seems natural to assume that the equations already have the form of Euler-Lagrange equations. Such systems of equations are "self-adjoint" and have been considered in detail [66]. Especially there exist standard methods to construct Lagrange densities which are also tests if the system is self-adjoint [77]. Thus, let's assume that the conservation laws are part of such a self-adjoint system of equations, that means, are Euler-Lagrange equations for some variables c^μ:

$$\frac{\delta S}{\delta c^\mu} = \partial_\nu T^\nu_\mu$$

This allows to derive a similar symmetry property of the equations for φ^m:

$$\frac{\delta}{\delta c^\mu}\frac{\delta S}{\delta\varphi^m} = \frac{\delta}{\delta\varphi^m}\frac{\delta S}{\delta c^\mu} = \frac{\delta}{\delta\varphi^m}\partial_\nu T^\nu_\mu = 0$$

Thus, we have a symmetry group with four continuous parameters, only the relation between these parameters and the coordinates has been lost.

4.3 Explanatory power of the derivation

Last not least, it should be noted that the derivation of the EEP has very high explanatory power. First, as we have seen, it is based on a few very general principles. We do not need any special assumptions about the ether, no "mechanical explanation", no strange "mechanism", no "conspiracy". We make non-trivial assumptions, but these non-trivial assumptions are very natural for a condensed matter theory.

Evidence for the high explanatory power is that we can describe the proof in a simple verbal way: The conservation laws can be understood as equations for the preferred coordinates. Now, the conservation laws do not depend on the material properties. Therefore, because of the principle "action equals reaction", the equations for the material properties do not depend on the preferred coordinates.

5 Does usual matter fit into the GET scheme?

If we compare the Einstein equations with usual hydro-dynamical equations, they look very different. The Einstein equations depend on second order derivatives of the $g_{\mu\nu}$. At a first look, there seems to be no chance to unify them.

GET suggests such a way. Indeed, in the derivation of GET we have used only a few general properties of the ether. None of these assumptions is obviously wrong for usual condensed matter theory. The material properties of the GET ether remain unspecified. We cannot even tell if the ether is solid or liquid.[2] This suggests that usual condensed matter may be described by a GET-like Lagrangian.

5.1 The role of the Einstein Lagrangian

The problem with the second derivatives which appear in the Einstein equations can be easily solved: we have identified the "remaining part" of the GET Lagrangian with the Einstein Lagrangian because of its strong covariance. None of the GET axioms requires to include the Einstein-Hilbert term $L_{GR} = R\sqrt{-g}$ into the GET Lagrangian. It is simply a possible term in the GET Lagrangian, not a necessary one. The same holds for covariant terms with higher order.[3] Moreover, in comparison with the three "cosmological terms" $g^{00}\sqrt{-g}, g^{ii}\sqrt{-g}, \sqrt{-g}$ of GET the Einstein-Hilbert term is a higher order term. Therefore, in the first approximation for usual condensed matter the Einstein-Hilbert term may be simply omitted. In this case, the GET equation becomes an algebraic relation between the gravitational field defined by ρ, v^i, p^{ij} and the material properties φ^m. This is already much more close to usual condensed matter theory.

On the other hand, GET suggests that the Einstein-Hilbert Lagrangian should be used in higher order approximations of condensed matter theory. The physical meaning of curvature-dependent term in condensed matter theory is easy to understand: if curvature is zero, then there exists an undistorted reference state which remains unchanged in time. Therefore, curvature describes inner stress and its change in time.

5.2 The role of Lorentz symmetry

Another property seems to be much more in contradiction with usual hydrodynamics – the Lorentz invariance of the GET Lagrangian. The physical meaning of this Lorentz invariance is not clear.

[2]It may be assumed that the condition that the pressure tensor p^{ij} is negative definite tells something about the ether – that the ether is a material with negative pressure. But the only reason for naming the tensor field p^{ij} "pressure" is that it appears like usual pressure appears in the usual Euler equation. And this allows to identify p^{ij} with usual pressure only modulo a constant.

[3]As described by Weinberg [78] "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".

One possibility is that it has none, and it simply as a consequence of the fact that there are not very much possibilities for quadratic Lagrangians, therefore, symmetries appear more or less by accident. With another choice of the constants, especially $Xi < 0$, we would obtain an SO(4) symmetry, also without any physical meaning.

Nonetheless, a consequence is that we cannot describe with GET a Galilean-invariant theory. On the other hand, we can use GET to describe special-relativistic condensed matter. The reverse method would be to describe a Galilean invariant theory as the limit $\Xi \to 0$ of a GET theory.

5.3 Existing research about the similarity

Considering the mentioned problem to obtain a Galilean invariant theory it is no wonder that the usual Lagrange formalisms for non-relativistic fluid dynamics in Euler coordinates (as far as considered in Wagner [77]) do not fit into our scheme. Remarkably, to use the three-dimensional Einstein-Hilbert Lagrangian to describe dislocations has been proposed by Malyshev [51].

On the other hand, it is widely acknowledged in the condensed matter community that phonons in various matter move in an effective Lorentz metric $g_{\mu\nu}$ which is usually curved. Various aspects have been considered here. Katanaev and Volovich [43] compare wedge dislocation with cosmic strings. See also Guenther [35]. A lot of research has been related with the idea of "dumb holes" – an analog of "black holes" in acoustics. These "dumb holes" may be used to study quantum gravity effects like Unruh radiation in usual condensed matter (Unruh [69], Jacobson [40], Rosu [62], Visser [74]).

The most interesting example of usual condensed matter is superfluid ^3He. Here not only a curved Lorentz metric has been identified, but also chiral fermions and non-abelian gauge fields (Volovik [76], Jacobson and Volovik [41]).

Of course, the amount of research which connects condensed matter theory and fundamental field theory is much greater. As noted by Wilczek [79], "the continuing interchange of ideas between condensed matter and high energy theory, through the medium of quantum field theory, is a remarkable phenomenon in itself. A partial list of historically important examples includes global and local spontaneous symmetry breaking, the renormalization group, effective field theory, solitons, instantons, and fractional charge and statistics."

6 Comparison with RTG

There is also another theory with almost the same Lagrangian – the "relativistic theory of gravity" (RTG) proposed by Logunov et al. [49]. 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 GET, 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 [49]. As a consequence, the equations of the theories coincide.

Nonetheless, the Euler-Lagrange equations are not all. In above theories we have additional restrictions related with the notion of causality – causality conditions. In GET, 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 $\eta_{\mu\nu}$.

Once RTG is a special-relativistic theory, it is also incompatible with the EPR criterion of reality and Bohmian mechanics. This question should be considered as the most serious difference.

There is also a difference in the quantization concept. RTG suggests to apply standard quantum field theory on a Minkowski background, while GET suggests to understand quantum field theory as an effective field theory. The GET prediction about the cutoff length depends on the interpretation of $g^{00}\sqrt{-g}$ as the density of the ether and is not Lorentz-invariant.

RTG has a completely different metaphysical background. Therefore, RTG has a completely different justification of the Lagrangian. While such metaphysical differences are often considered to be unimportant in physics, we do not agree. Metaphysical interpretations and esthetic feelings often influence preferences for theories. Because the simplicity and beauty of the explanation of the Einstein equivalence principle is one of the main advantages of GET, this question should not be underestimated.

7 Comparison with GR with four dark matter fields

There is also another theory with the same Lagrangian – GR with four scalar "dark matter fields" $X^\mu(x)$[4]. Let's denote it as GRDM. The Lagrangian is

$$L_{GRDM} = -(8\pi G)^{-1}\gamma_{\mu\nu}X^\mu_{,\alpha}X^\nu_{,\beta}g^{\alpha\beta}\sqrt{-g} + L_{GR}(g_{\mu\nu}) + L_{matter}(g_{\mu\nu},\varphi^m)$$

and therefore formally equivalent to GET. But we have completely forgotten the physical meaning of the fields $X^\mu(x)$ as coordinates. In GRDM, they are really only scalar fields.

We have to consider here the usual GR energy conditions. They require the following signs: $\Upsilon < 0$ and $\Xi > 0$.

There is another difference between GET and GRDM which is essential and important to understand. In GET, we have additional global restrictions:

- First, the fields $X^\mu(x)$ are global coordinates in GET. In GRDM, there will be many solutions where the dark matter fields do not define a global system of coordinates. Moreover, it will be even the typical solution of GRDM. Indeed, solutions which define global coordinates have unusual boundary conditions. Moreover, complete classes of solutions are excluded: all solutions with non-trivial topology are forbidden.

- Second, the coordinate $T(x) = X^0(x)$ is a global time-like function. This is equivalent to $\rho > 0$. Again, a whole class of solutions of GRDM is excluded: all solutions with closed time-like curves.

- We have also other, unusual boundary conditions for the fields $X^\mu(x)$: their boundary values go to infinity.

These properties do not follow from the Euler-Lagrange equations. Instead, we have to remember that the original axioms are axioms about an ether in a Newtonian space-time. The Lagrange formalism with the "fields" $X^\mu(x)$ is only derived, not fundamental.

Therefore, it is in no way a weakness of GET that the additional global restrictions do not follow from the GET equations. Instead, this proves

[4]Kuchar [45] has considered similar scalar fields in GR as "clock fields".

additional predictive power of GET in comparison with GRDM. Indeed, if we observe a solution of GRDM which does not fulfill the additional global restrictions we have falsified GET, but not GRDM. Thus, in GET we have additional possibilities for falsification, therefore, higher empirical content.

This difference is of principal, conceptual character – similar global restrictions are impossible in general-relativistic theories. Therefore, it helps to understand the difference between general-relativistic theories and theories with preferred frame. We consider this question also in appendix B.

8 Comparison with General Relativity

Let's consider now the differences between the predictions of GET and GR itself. There are, first, the differences between GET and the variant of GR with four dark matter fields we have already considered. This restricts GET to global hyperbolic solutions with trivial topology, moreover, of a special type – with global harmonic coordinates and global harmonic time-like function.

8.1 Dark matter and energy conditions

The other part of the difference between GET and GR can be understood as the difference between GRDM and GR. First, the additional terms define "dark matter" in the sense that the scalar fields $X^\mu(x)$ do not interact with usual matter.

To understand the most interesting property of this new type of "dark matter" we have to consider the energy conditions. GET does not yet relate energy conditions with general properties of the ether. But because GR does not provide an explanation too, this is unproblematic. We can introduce them – as in GR – as additional, yet unexplained, properties of the matter Lagrangian. But if we introduce it in this way, as a property of the matter fields, the energy conditions do not restrict the sign of Ξ and Υ. Therefore, without violating the GET version of the energy condition, it is possible to set $\Upsilon > 0$. And, because of the interesting predictions which follow from this choice, we really set $\Upsilon > 0$.

From point of view of GRDM, this choice violates all energy conditions. Therefore, GRDM contains a very special, strange type of "dark matter" which violates all energy conditions of GR. Therefore, all general theorems about GR which use various energy conditions fail. Especially the theorems about big bang and black hole singularities fail.

8.2 Homogeneous universe: no big bang singularity

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. Thus, we make the ansatz:

$$ds^2 = d\tau^2 - a^2(\tau)(dx^2 + dy^2 + dz^2)$$

Now, we see that in this ansatz the spatial coordinates x^i are already harmonic. It remains to find the harmonic time. The equation for harmonic time is $dT/d\tau = 1/a^3$. The metric in harmonic coordinates is therefore:

$$ds^2 = a^6(t)dT^2 - a^2(t)\delta_{ij}dX^i dX^j$$

Note that $\rho = g^{00}\sqrt{-g} = 1$, thus, in this ansatz the ether has constant density, and the universe does not expand. The observable expansion is an effect of shrinking rulers. In GR this would be only one of the possible interpretations, without physical importance. Instead, in GET this is the preferred interpretation because of symmetry reasons. Thus, if the universe is homogeneous, the universe does not expand, but our rulers are shrinking. But, as in GR, the global universe looks like expanding.

Below we use standard relativistic language and usual proper time τ (that means,$\dot{a} = \partial a/\partial\tau$). Using some matter with $p = k\varepsilon$ we obtain the equations $(8\pi G = c = 1)$:

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

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

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

The solution becomes symmetrical in time. Therefore, before the big bang there was a big crush, and the whole story can be named big bounce. For some simple situations, analytical solutions are possible. For example, if $\varepsilon = \Xi = 0, \Upsilon > 0, \Lambda > 0$ we have the solution

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

8.3 Is there independent evidence for inflation theory?

Now, such a big bounce scenario solves the problems of the big bang scenario with the small horizon. For the description of these problems and their current solution in inflation theory we follow Primack [60]. There are two such problems with a small horizon: 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).

Last not least, there is the "flatness problem". In GR, the assumption that the universe is flat does not seem to be natural. But for a curved universe, the initial curvature has to be extremely small in comparison to a natural dimensionless constant for curvature.

Now, these three problems seem sufficient to rule out the standard Big Bang model without inflation. But all three problems are solved in GET without inflation: the two variants of the horizon problem are solved because the horizon in a universe with big bounce is much larger, if not infinite. And the flat universe is certainly preferred as the only homogeneous universe, therefore, there is no flatness problem.

Therefore, it seems reasonable to question the necessity for inflation in GET cosmology. There are some other problems solved by inflation: that it "dilutes any preceding density of monopoles or other unwanted relics", and predictions about a "nearly constant curvature spectrum δ_H = constant of adiabatic fluctuations" (p.59). If these will be serious problems for a GET universe without inflation is hard to say. If such "relics" are really necessary because of particle theoretical reasons, it seems possible to use a large enough Υ. Then the critical temperature which causes the creation of the various "relics" may not be reached during the Big Bounce. What GET allows to predict about the spectrum of adiabatic fluctuation will be a question for future research, but it seems not unreasonable to assume that the simplest imaginable spectrum – the constant one – may be compatible with GET.

Another question is if inflation is a necessary consequence of particle theory. This seems to be not the case. To obtain inflation, we have to make non-trivial assumptions about this phase transition.[5] Particle theory does not give independent evidence in favor of inflation. Thus, it seems that GET cosmology with $\Upsilon > 0$ is a viable theory without inflation, while GR requires inflation.

The existing evidence for a hot state of the universe may be used to obtain upper bounds for Υ.

[5] "In the first inflationary models, the dynamics of the very early universe was typically controlled by the self-energy of the Higgs field associated with the breaking of a Grand Unified Theory (GUT) into the standard 3-2-1 model: $GUT \to SU(3)_{color} \otimes [SU(2) \otimes U(1)]_{electroweak}$. ... Guth (1981) initially considered a scheme in which inflation occurs while the universe is trapped in an unstable state (with the GUT unbroken) on the wrong side of a maximum in the Higgs potential. This turns out not to work ... The solution in the 'new inflation' scheme ... is for inflation to occur after barrier penetration (if any). It is necessary that the potential of the scalar field controlling inflation ('inflaton') be nearly flat (i.e. decrease very slowly with increasing inflaton field) for the inflationary period to last long enough. This nearly flat part of the potential must then be followed by a very steep minimum, in order that the energy contained in the Higgs potential be rapidly shared with the other degrees of freedom ('reheating'). A more general approach, 'chaotic' inflation, has been worked out ... However, ... it is necessary that the inflaton self-coupling be very small ... This requirement prevents the Higgs field from being the inflaton." [60], p. 57. This consideration suggests that inflation is in no way a necessary consequence of the phase transition related with a GUT.

8.4 A new dark matter term

The influence of the Ξ-term on the age of the universe is easy to understand. For $\Xi > 0$ it behaves like homogeneously distributed dark matter with $p = -(1/3)\varepsilon$. It influences the age of the universe. A similar influence on the age of the universe has a non-zero curvature in GR cosmology.

It seems not unreasonable that a non-zero value for Ξ may be part of the solution of the dark matter problem. According to Primack [60], there seems to be a large amount of "cold dark matter" (CDM), but this is not sufficient to fit the data. The models favored in this paper have some additional homogeneous component: some "hot dark matter" part (CHDM) or a non-zero cosmological constant (ΛCDM). Now, the "dark matter" term proposed here is also homogeneous, and something between homogeneous "hot dark matter" and a cosmological constant.

Thus, the Ξ-term defines a reasonable candidate for dark matter. Current observation seems to favor $\Xi > 0$.

8.5 Stable frozen stars instead of black holes

Let's consider now spherical symmetric stable solutions. Of course, for symmetry reasons, we want to have static preferred coordinates too. For the preferred coordinates X^i the metric should be harmonic. Of course, we describe this metric using the "preferred radius" $r = \sqrt{\delta_{ij}X^iX^j}$. Fortunately, there is a simple general formula for the harmonic metric. For a given function $m(r), 0 < m < r$, the metric

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

is harmonic in X^i. For constant m, this formula reduces to the Schwarzschild metric in harmonic coordinates. Therefore, m(r) defines the (harmonic) Schwarzschild radius of the mass inside the radius r.

Now this general solution of the harmonic equation may be used to construct various partial solutions for special matter equations. We start with an arbitrary distribution of mass m(r) with $0 < m < r, \partial m/\partial r \geq 0$. The Einstein equations define $\varepsilon(r)$ and $p(r)$, and we obtain a solution for some material law which depends on the radius: $p = k(r)\varepsilon$. As a simple example, let's consider the ansatz $m(r) = (1 - \Delta)r$. We obtain

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

Now, in GR we obtain only the trivial solution $\varepsilon = p = 0$. Once the cosmological constants are sufficiently small, nothing changes for moderate values of Δ. But for sufficiently small $\Delta \ll 1$ the situation changes – we obtain a stable solution $p = \varepsilon = \Upsilon\Delta^{-2}$. This is a stable star with a radius very close to the Schwarzschild radius, with time dilation $\Delta^{-1} = \sqrt{\varepsilon/\Upsilon} \sim M^{-1}$ for a frozen star of mass M.

It is seems obvious that this is not a special property of this solution, but a rather general effect. Even a very small Υ-term becomes important close enough to the horizon size and allows to obtain stable solutions. For a collapsing star this term defines a counter-force which stops the collapse immediately before horizon formation and leads to a subsequent explosion. This explosion does not follow immediately, because near the bounce the movement is time-dilated too.

Thus, we obtain very interesting differences for the gravitational collapse. For the outside observer, we can fit the GR predictions making Υ small enough. But even for arbitrary small $\Upsilon > 0$ we have remarkable qualitative differences – there is no region "behind the horizon", no singularity, and every infalling observer can observe this difference.

9 General-relativistic quantization problems

The quantization of gravity is usually considered as one of the major problems of fundamental physics. But, it seems, this problem should be named instead "quantization of general relativity". Indeed, Butterfield and Isham [20] note that "... most workers would agree on the following ... diagnosis of what is at the root of most of the conceptual problems of quantum gravity. Namely: general relativity is not just a theory of the gravitational field – in an appropriate sense, it is also a theory of spacetime itself; and hence a theory of quantum gravity must have something to say about the quantum nature of space and time."

Now, in GET the theory of gravity is not a theory of space-time itself, instead, it is a theory of a medium in a classical Newtonian space-time. This problem is, obviously, much easier – the most serious problems simply disappear. On the other hand, it is much less interesting – we do not learn anything new about "the quantum nature of space and time", instead, the classical Newtonian space-time defines the fixed stage for quantization. While the Newtonian background is very simple, it is also not very interesting and remains as unexplained as in Newton's theory. The really hard, conceptual, interesting problems of relativistic quantum gravity disappear into nothing. What remains seem to be only a few technical problems as complex as the quantization of usual condensed matter.

Once these conceptual problems disappear, they can be considered as additional fundamental support for GET and are therefore worth to be considered in this context. In appendix D we consider in more detail a problem related with superposition of gravitational fields which I have named the "scalar product problem". This problem has several nice properties: it suggests a simple solution – a fixed space-time background which is common for different gravitational fields. Moreover, it is based on an interesting quantum observable – a transition probability. And this transition probability may be computed in the non-relativistic limit – multi-particle Schrödinger theory.

The notorious "problem of time" is mainly a conceptual problem. It appears if we make a deliberate theoretical decision: that the time measured with clocks – the time of general relativity – has to be unified with the notion of time of quantum mechanics. We discuss these metaphysical questions in § C.

Nonetheless, some other well-known problems of quantum GR which do not exist in quantum GET are also worth to be considered: the problem of causality, and the information loss problem.

9.1 Causality

The problem of time is also closely related with causality: "General relativity accustoms us to the ideas that (i) the causal structure of spacetime depends on the metric ... and (ii) the metric and causal structure are influenced by matter ... In general relativity, these ideas are 'kept under control' in the sense that in each model, there is of course a single metric tensor $g_{\mu\nu}$, representing a single metric and causal structure. But once we embark on constructing a quantum theory of gravity, we expect some sort of quantum fluctuations in the metric, and so also in the causal structure. But in this case, how are we to formulate a quantum theory with a fluctuating causal structure?" [20]

This conceptual problem has also technical aspects. "For example, a quantum scalar field satisfies the micro-causal commutation relations

$$\left[\hat{\phi}(X), \hat{\phi}(Y)\right] = 0$$

whereby fields evaluated at space-like separated spacetime points commute. However, the concept of two points being space-like separated has no meaning if the spacetime metric is probabilistic or phenomenological. In the former case, the most likely scenario is that [the commutator] never vanishes, thereby removing one of the foundations of conventional quantum field theory."

9.2 Information loss problem

Another problem which disappears is the "information loss problem" proposed by Hawking [38]. The problem is that the black hole contains information. But the Hawking radiation cannot take away this information because it is determined only by the geometry of the black hole outside the horizon, and the black hole has no hair that records any detailed information about the collapsing body. The key constraint comes from causality – once the collapsing body is behind the horizon, it is incapable of influencing the radiation. Now, suppose the black hole evaporates. That means, the black hole has been replaced by the radiation completely. It is a familiar fact of life that information is often lost in practice. But here the information is lost in principle. It seems that an initially pure state becomes after evaporation a mixed state. And this is in contradiction with the fundamental principles of quantum mechanics.

Preskill [58] in a review of the problem writes that initially he "was inclined to dismiss Hawking's proposal as an unwarranted extrapolation from an untrustworthy approximation". But as "I have pondered this puzzle, it has come to seem less and less likely to me that the accepted principles of quantum mechanics and relativity can be reconciled with the phenomenon of black hole evaporation."

Now, it is hard for me to judge about the seriousness of this problem. Personally I'm convinced that the correct black hole evaporation scenario in GR is different from the usually accepted one. In my opinion it is the scenario of black hole evaporation proposed by Gerlach [32]. In this scenario, no black hole horizon is formed. As far as I understand, relativists do not like this scenario because it seems to prefer the coordinates of the outside observer. But I don't think this argument is justified – the preference is predefined by the preference for the Minkowski vacuum state in the initial situation before the collapse. In Gerlach's scenario we have no information loss problem because no horizon is formed.

Anyway, in GET the information loss problem disappears together with the black holes. We have stable frozen stars which do not radiate Hawking radiation once they have reached a stable state. We also have not to be afraid of some similar situations – there is always a global absolute time, and this global time has to be used in quantum GET to define an unitary evolution.

10 Atomic ether theory

With the Newtonian background only the conceptual problems related with relativistic space-time quantization disappear. The problem with non-renormalizability remains. But there is a natural solution for this problem in the context of a condensed matter theory – an atomic hypothesis. Therefore, we assume that our medium has an atomic structure. This leads to an explicit cutoff. The regularization becomes physical. The concept of gravity as an effective field theory is well-known and goes back to Sakharov [65]. [6]

One property of this widely accepted effective field theory picture is that it makes a certain assumption about the cutoff length. It is assumed to be the Planck length $a_P \simeq 10^{-33}$cm. This property has even used to name this concept: "Planck ether", "Planck solid" [42] or "Planck condensed matter" [76]. But this is de facto the only property of the "Planck ether" which is known. [7]

[6] Jegerlehner notes that ideas that "the relationship between bare and renormalizes parameters obtains a physical meaning ... are quite old and in some aspects are now commonly accepted among particle physicists" [42]. Weinberg describes this as "the present educated view on the standard model, and of general relativity, ... that these are leading terms in effective field theories" [78].

[7] "The curvature of space-time is relevant and special relativity is modified by gravita-

The "atomic ether hypothesis" differs from this concept in everything except the fact that current field theory should be replaced by another one below some cutoff. First, a well-defined space-time concept has been fixed – the classical Newtonian background with Euclidean space, absolute time and classical causality. Moreover we have well-defined conservation laws. We have also fixed the quantization concept – classical canonical quantization for a theory with a discrete number of steps of freedom. Momentum quantization is part of this concept. Moreover, the number of ether atoms will not vary in this scheme too. Thus, we fix an extremely simple, very special class of underlying microscopic theories. [8]

Another property of atomic ether theory is especially interesting: the interpretation of the "ether density" $\rho = g^{00}\sqrt{-g}$ as the number of "ether atoms" per volume. This leads to an interesting prediction for the cutoff:

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

The point is that this prediction is different from the usual Planck length a_P. This can be illustrated with the example of the "homogeneous universe" solution (see § 8.2). In this solution, ρ remains constant in time. Therefore, the cutoff length remains constant in time too. On the other hand, our rulers shrink. Thus, the cutoff length is not constant in our cm scale, it cannot be the Planck length. From point of view of our rulers, the cutoff length is expanding. For $\Upsilon < 0$ or small enough Υ the cutoff was below Planck scale in the past, for $\Lambda > 0$ or small enough Λ it will be greater than Planck scale, but even greater than the cm scale, in future. Thus, in this case we will be able to observe in a far away cosmological future the effects of the atomic ether.

tional effects. One expects a world which exhibits an intrinsic cutoff corresponding to the fundamental length $a_P \simeq 10^{-33}$cm. But not only Poincare invariance may break down, also the laws of quantum mechanics need not hold any longer at Λ_P." [42]

[8] It may be argued that we are unable to do experiments in this domain, therefore, it is also unreasonable to make a hypothesis about nature in this domain. All we can do is to describe their universality class. Nonetheless, even if we are unable to do experiments, we can use general principles as Ockham's razor to make a choice. Moreover, there is no need to make a definite choice. A situation where we have several metaphysically completely different models which are all in ideal agreement with experiment would be satisfactory too – it gives a clear account about the boundaries of scientific research.

11 Canonical atomic ether quantization

Ether theory suggests to solve the ultraviolet problems with explicit, physical regularization, based on the idea of an atomic ether. This idea leads to the following *canonical atomic ether quantization scheme*:

1. First, we need the full continuous ether theory, that means, a continuous "theory of everything" (TOE) which describes the complete ether. This in no way implies that we need some "grand unification" to obtain this TOE. There is no requirement that there should be only one unified force. We can as well try to start with GET + SM.

2. Then, we have to find an atomic ether model which gives the TOE in the large scale limit. There are obviously many of them, because the large scale limit fixes only the universality class. This uncertainty remains as long as there is no experimental evidence in the short distance domain. Therefore simple standard models would be sufficient.

   The possibly critical problem is to prove that the large scale limit of the discrete model is indeed the original theory.

3. Then, this classical atomic ether theory has to be quantized in the canonical way. If the atomic model is close enough to usual atomic models of usual condensed matter, this step will be unproblematic. Note that in this case we can apply also Bohmian mechanics. Once this step has been finished, we have quantized gravity.

4. Now, for actual quantum computations it is necessary to derive the large scale limit of the quantum atomic ether theory, which will be quantum field theory.

   Note that this step is already purely phenomenological and not necessary for the theory itself. That mean, problems which appear in this last step are problems of large scale approximations in classical quantum theory, but not fundamental problems of quantum gravity.

Now, for this quantization program we have to distinguish different problems. The first problem is if this scheme works at all. Here, we are in a very good situation. We have an example in reality where the the whole quantization scheme is realized – superfluid $^3He - A$. In the theory of $^3He - A$, we obtain in the large scale limit the most important ingredients of the current standard model. Volovik writes: "In this sense the superfluid phases of ^3He, especially $^3He - A$, are of most importance: the low-energy degrees of freedom in $^3He - A$ do really consist of chiral fermions, gauge fields and gravity" [76]. Thus, if we do not have an (uncommon among physicists) desire for mathematical rigor, for at least one field theory with gravity, fermions and gauge fields an atomic ether quantization scheme works. Moreover, it works in reality.

This is very important – the existence of such a model in reality gives certainty that the program may be realized, and it provides suggestions how this has to be done.

11.1 Regularization using a moving grid

Let's see how this works on the example of our second step – the derivation of an atomic model for a given continuous ether theory.

Without the ether interpretation, it would be natural to try to regularize the theory with a regular lattice, following lattice gauge theory. Based on the space-time interpretation, we would try to develop a discrete variant of geometry – something like the Regge calculus or dynamical triangulations [50].

The ether interpretation suggests something different – a discretization which remains as close as possible to the real atomic grid. That means, we do not have to use a regular, static lattice. Instead, we have to use a grid with the following properties:

- The grid node density is the "ether density" ρ:

$$\sum_{x_k \in V} 1 \approx \int_V \rho d^3x$$

- The grid moves, with "ether velocity" $v^i(x_k)$;

Without additional information about the other material properties of the ether we cannot say anything reasonable about their discretization. But in the case of the Minkowski space-time, this prescription reduces to a homogeneous, static grid. Therefore, we can use the lectures of lattice gauge theory [36] to understand how to discretize them.

Let's consider shortly some details: as a first step to obtain an atomic model we have to switch from Euler (local) coordinates to Lagrange (material) coordinates. Once GET is defined by a Lagrange formalism, the first interesting problem is if this transformation is possible in the Lagrange or Hamilton formalism too. This is known to be possible in hydrodynamics. In the Hamilton formalism this can be done with a canonical transformation [19], [64], [34]. In the following we assume that this is possible in GET too.

The next important step is the discretization. Here, it is useful to have in mind that we want to quantize the theory later. Therefore, to be able to use canonical quantization, we need a Lagrange or Hamilton formalism for the discrete theory. For this purpose, it is not reasonable to discretize the equations them-self. Instead, it is much more reasonable to discretize the Lagrange function and to define the discrete equations as Euler-Lagrange equations for the discrete Lagrangian.

The usual method to obtain a discrete function on a grid is the finite element method. In this method, we define functions on the grid as a subspace of the space of all functions. In the simplest case, this is the space of piecewise linear function on the simplices. These functions are uniquely defined by their function values on the grid nodes: $f(x_k) = f_k$. This defines an embedding of the grid functions into the space of all functions. In the other direction, we can use orthogonal projection of this subspace to define the discrete image of a continuous function. Thus, the function values in the nodes f_k are not defined by the function values of the original continuous functions, but by integral formulas: $f_k = \int f(x)\chi_k(x)dx$, where $\chi_k(x)$ is the piecewise linear function defined by $\chi_k(x_l) = \delta_{kl}$.

In our case, we have an interesting modification of this method: the density $\rho(x)$ should not be described by a variable grid function ρ_i. Instead, an integral containing ρ should be interpolated on the grid in another way. The simplest way would be

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

Therefore, in the discrete Lagrange formalism the density simply disappears. Now, there are various variants of this method, and which is the best one depends on the material properties of the ether. Therefore, further specification of the scheme in this general context does not seem to be justified and has to be left to future research.

11.2 Constraints and conservation laws in a moving grid

Now, it is reasonable to ask about the advantage of this type of discretization, for example in comparison with a regular, static lattice. As far, the only argument was that this looks more natural from point of view of the atomic ether interpretation.

But, if we look at the remaining problems, we observe that they become essentially simplified. Indeed, once we have a well-defined discrete Lagrange formalism, the most serious remaining quantization problem are constraints. Unfortunately, without specification of the material properties we cannot say anything about possible constraints related with these material properties. But there are well-known constraints in GR, and as we have seen in § 3.2, they remain to be constraints in GET. Moreover, the conservation laws themself are constraints too.

Now, these constraints essentially change their character. The continuity equation simply disappears. It is no longer an equation of the discrete theory. The density ρ is no longer part of the equations. Instead, the continuity equation becomes a tautology – the number of grid nodes remains constant. Moreover, the Euler equations become second order equations: the first order derivative of $g^{0i}\sqrt{-g}$ becomes a second order derivative of the grid node position:

$$\partial_t(g^{0i}\sqrt{-g}) = \partial_t(\rho v^i) \to m\ddot{x}^i$$

Moreover, we have seen in § 3.2 that the other constraints also may be explained by the requirement that there are no second order equations for ρ and ρv^i.

Therefore, the constraint problem essentially simplifies. Closely related with the constraints is the question how the conservation laws are realized. The conservation of ether particles in this approach is realized automatically, as the conservation of the number of grid nodes. Therefore, we have no "quantum fluctuations" of the ether particle number.

Note that this property holds in the fundamental, atomic ether theory. We do not make any claim about the large scale quantum field theory approximation and the behavior of a field operator $\hat{\rho}(x)$ which fulfills an operator version of the continuity equation. This approximation is nothing we have to care as long as we consider fundamental questions.

11.3 Universality

Now, considering the previously discussed program, it seems to suggest that almost every ether theory may be quantized in this way. But a completely different question is how a typical ether theory looks like. For this question, the consideration of long distance universality is important.

The first point of long distance universality is that very different atomic theories can have the same large scale limit. "Long distance universality is a well-known phenomenon from condensed matter physics, where we know that a ferromagnet, a liquid-gas system and a super-conductor may exhibit identical long range properties (phase diagram, critical exponents, etc.)" [42].

This point is important for the justification of the "moving grid" method – it suggests that it is not very meaningful to search for the "true" atomic theory without experimental evidence in this domain. All we can do is to search for a theory which is sufficiently simple and natural in comparison with their competitors. Even without experimental evidence Ockham's razor may be used to choose between theories.

The other side of large scale universality is that the theories which appear as large scale approximations have some very typical properties. Existing research in this domain has already given important and interesting results: "The extraction of the leading low energy asymptote is equivalent to the requirement of renormalizability of S-matrix elements, and this has been shown to be necessarily be a non-Abelian gauge theory which must have undergone a Higgs mechanism if the gauge bosons are not strictly massless. ... only a renormalizable field theory can survive as a tail, the possible renormalizable theories on the other hand are known and are easy to classify" [42].

At a first look, this seems to be in conflict with our atomic ether quantization scheme. There seems to be no point where similar restrictions appear. But there is no contradiction – these are simply different questions. One question is if a quantization in this way is possible in principle. Another question is if a theory has the *typical* properties of a large scale limit of an atomic ether theory. The answer for the first question may be very well a positive one, but the related atomic ether theory may require a very strange conspiracy of their coefficients.

But, if we have seen, for the basic ingredients of the SM – fermions and gauge fields – the situation is very nice. It is well understood in theory why such renormalizable theories appear as large scale limits of a typical atomic ether theory, and we have observed them in reality in condensed matter, in $^3He - A$.

Considering all these facts, it seems likely that this scheme works, and that problems which appear on this way may be solved. Instead, the problem of canonical GR quantization we discuss in § D suggests that a quantization without a fixed background fails in principle.

12 Comparison with canonical quantization of general relativity

It is interesting to compare our canonical program for GET quantization with the real way of development of quantization programs for general relativity, especially the canonical program. The point is that the progress of the canonical quantization program is much more in agreement with ether philosophy than with general relativistic philosophy. Let's consider the different steps in the standard canonical quantization approach:

12.1 ADM formalism

The ADM decomposition [1] is essentially the decomposition of $g_{\mu\nu}$ into ρ, v^i, p^{ij}. Therefore, it is an essential part of the GET approach.

This decomposition is in obvious disagreement with relativistic philosophy. Space and time are no longer considered as a unit, they are separated. We have a special time coordinate t(x). Moreover, the general spacetime manifold becomes subdivided into a product $S \otimes \mathbb{R}$, that means, changes of topology in time are excluded. This modification of relativistic metaphysics is so important that the ADM formalism is often considered as a different interpretation of general relativity – geometrodynamics. In this interpretation, GR no longer describes a spacetime, but the evolution of three-dimensional geometries.

Of course, the Hamilton formalism of general relativity and that of ether theory remain quite different. In GET, the Hamiltonian is not a constraint. We have equations for the preferred coordinate $T(x)$ used to define the foliation. And we have additional physical steps of freedom: density and velocity of the ether.

12.2 Tetrad and triad formalism

The next important step is the introduction of the tetrad formalism. In this formalism, the metric $g^{\mu\nu}$ becomes derived. We have a tetrad field – four vector fields $e^{\mu}_{a}(x)$ which form an orthonormal basis in each point, so that

$$g^{\mu\nu} = e^{\mu}_{a} e^{\nu}_{b} \eta^{ab}.$$

This is necessary for the incorporation of fermions into general relativity. Obviously this step is also a gross violation of relativistic ideology. Indeed, according to this ideology the field $g^{\mu\nu}$ has already a fundamental interpretation, it defines spacetime. The other argument in favor of this procedure is that GR becomes a gauge theory, with the gauge group SO(3,1).

The next step on this way is the combination of above approaches: The time coordinate of the ADM composition is used to fix the time-like tetrad vector. After this "time gauge" we have a triad – three vector fields in space, with compact gauge group SO(3). The technical problems with non-compact gauge groups are a main argument for this choice.

Now, a triad field looks very natural from point of view of ether theory. If we imagine the ether as a crystal, the three triad vector fields may be considered as defining locally the orientation of the crystal structure. Thus, to introduce triad variables may be an interesting possibility for canonical GET quantization. Of course, as in the case of the ADM variables, we cannot take the formulas as they are, because we have a different Hamiltonian and different steps of freedom.

Instead, to consider this triad formalism as something natural from point of view of relativistic ideology seems impossible.

12.3 Ashtekar variables

The next step is a canonical transformation to Ashtekar variables [4] which simplifies the constraints. There are two variants of the Ashtekar formalism: the first was a complex formalism. In this complex formalism, an additional simplification of the Hamiltonian constraint happens. For this advantage it is necessary to pay with the problem of "reality conditions". But the problem with these reality conditions was too hard, that's why following Barbero [8] the real version of the Ashtekar formalism is preferred now. This seems to be a good idea from point of view of the ether approach – the real variant of the formalism clearly better fits into ether ideology in comparison with a complex formalism.

The physical meaning of the Ashtekar variables is not obvious at all in the relativistic approach. On the other hand, we already know that we have to do something similar, with similar results, but with clear physical interpretation in canonical ether quantization: the transformation from Euler to Lagrange coordinates. As we have already mentioned, this is a canonical transformation, and it results in a simplification of the constraints.

12.4 Discrete models of geometry

An important part of existing attempts to quantize gravity are discrete models. In some sense, discrete models are also not in ideal fit with classical spacetime ideology. It would be much more natural to have a continuous spacetime for all distances. But the problems with non-renormalizability suggest to use discrete regularizations.

On the other hand, the consideration of discrete models is a natural part of canonical ether quantization, with clear physical motivation: an atomic ether theory. Of course, the grids used in ether theory are three-dimensional grids in a standard Newtonian space, moving in continuous time. The position of the grid nodes are steps of freedom of the ether. These steps of freedom do not exist in the purely geometrical approaches. Nonetheless, we can learn from these approaches how to discretize the geometric steps of freedom.

For example, it seems quite natural to use the basic ideas of Regge calculus [61] to discretize the pressure p^{ij}. We obtain a discretization where the pressure p^{ij} is described by a scalar on each edge between neighbor nodes. This discretization has a natural interpretation as the force between neighbor atoms.

12.5 Summary

The interesting observation is that, while searching for a way to quantize general relativity, most success has been reached in a direction which is in no way close to standard GR ideology:

- introduction of a preferred time and a Hamilton formalism;

- introduction of other variables so that the metric $g_{\mu\nu}$ no longer fundamental;
- canonical transformations to simplify the constraints;
- discretization of the theory;

Instead, all these steps are quite natural in the ether approach. We have formulated most of them in our canonical ether quantization program. The steps of freedom in GET are different from the steps of freedom in canonical GR, and the formulas for the GET approach have yet to be worked out. Nonetheless, our observation suggests that the canonical ether quantization concept is on the right way.

13 Quantum field theory

Now, the question how to quantize an ether theory is conceptually completely different from the quantization of GR. The main question we want to consider here is if this leads to differences in semi-classical QFT.

In principle, the way we have to quantize continuous ether theory is to quantize a discrete atomic ether model in a canonical way and then to consider the large scale limit. Thus, we have to quantize gravity similar to the quantization of hydrodynamics by extrapolation of the microscopic theory, as done by Landau [47]. But it has been found (Davydov [25]) that the same result may be obtained by canonical quantization, without using microscopic theory. Therefore, without having reasonable microscopic models, it is reasonable to apply canonical quantization to the continuous GET equations. To consider microscopic models seems necessary only for a better understanding of the way we have to regularize the infinities. For example, we can learn why the renormalization of the vacuum energy is justified. This can be seen using superfluid ^3He as a model (Volovik [76]).

Once we use canonical quantization, it is no wonder that we obtain the same formulas as usual in quantum field theory. Nonetheless, some remarks seem to be interesting.

First, even if in our covariant formulation the preferred coordinates formally appear as fields $X^\mu(x)$, this does not mean that they should be quantized as scalar fields. This would be a serious misunderstanding about the purpose of the covariant formulation. Instead, the X^μ remain classical preferred coordinates. This is an immediate consequence of the basic idea for quantization: to quantize a microscopic atomic model in a canonical way, using classical Schrödinger theory.

13.1 Semi-classical quantization of a scalar field

Let's consider as an example the canonical quantization of a scalar field on a classical GET background. We have the Lagrangian

$$\mathcal{L} = \frac{1}{2}\sqrt{-g}(g^{\mu\nu}\phi_{,\mu}\phi_{,\nu} - m^2\phi^2)$$

We have a well-defined preferred frame defined by the coordinates X^μ, and we quantize the field in this frame. Note that canonical quantization is a very artificial procedure from point of view of general relativity - it destroys its covariance ideology. Instead, it is a very natural procedure from point of view of ether theory. Using the standard formalism of canonical quantization, we obtain

$$\pi = \frac{\partial \mathcal{L}}{\partial \phi_{,0}} = \hat{g}^{0\mu}\phi_{,\mu}$$

$$\mathcal{H} = \pi\phi_{,0} - \mathcal{L} = \frac{1}{2}(\hat{g}^{00})^{-1}(\pi - \hat{g}^{0i}\phi_{,i})^2 - \frac{1}{2}\hat{g}^{ij}\phi_{,i}\phi_{,j} + \frac{m^2}{2}\phi^2\sqrt{-g}$$

Note that these expressions look beautiful in the original ether variables too:

$$\pi = \rho\phi_{,0} + \rho v^i\phi_{,i}$$

$$\mathcal{H} = \frac{1}{2}(\rho^{-1}\pi^2 - 2\pi v^i\phi_{,i} - p^{ij}\phi_{,i}\phi_{,j}) + \frac{m^2}{2}\phi^2\sqrt{-\rho|p^{ij}|}$$

As we see, our ADM-like decomposition is in good agreement with the canonical formalism. We define now ϕ and π as operators with the standard commutation rules ($\hbar = 1$):

$$[\phi(x), \pi(y)] = i\delta(x - y)$$

As we see, this definition does not depend on the gravitational field. This is an important observation. The background space, its affine symmetry, the related Hilbert space for the field $\phi(x)$, the commutation relations and the algebra of observables on this Hilbert space do not depend on the gravitational field. This does not seem to be important in semi-classical theory, but it becomes very important if we consider superpositions of gravitational fields (see appendix D). In this case, the definition of the Hilbert space may be used as it is, and scalar products between states defined for different gravitational fields are well-defined.

This is a very important difference between quantization of GR and GET. In GR, the spacetime points and therefore the Hilbert spaces for the fields $\varphi(x)$ have no independent meaning.

13.2 Particle operators and vacuum state

One of the main lectures of quantum field theory is that the fundamental object are the fields, not the particles. The notion of particles is derived, secondary. [9] GET does not question this insight. Instead, in the canonical GET quantization scheme this becomes exceptionally obvious. The classical continuous ether is described by continuous fields – properties of the ether. The fields are fundamental. Their description does not depend on the gravitational field – as we have seen, the Hilbert space for the quantum field $\varphi(x)$ is defined independent of the gravitational field. On the other hand, the notion of particles and the vacuum state do not appear in a gravity-independent way. For the vacuum state we have a natural definition: it is the state with minimal energy. But the Hamilton operator depends on the gravitational field, therefore, the definition of the vacuum state and the notion of particles too. In the case of a constant metric $g^{\mu\nu}$ particle operators are defined by the formulas:

[9] "In its mature form, the idea of quantum field theory is that quantum fields are the basis ingredients of the universe, and particles are just bundles of energy and momentum of the fields" [78]. What "quantum field theory uniquely explains is *the existence of different, yet indistinguishable, copies of elementary particles.* Two electrons anywhere in the Universe, whatever their origin and history, are observed to have exactly the same properties. We understand this as a consequence of the fact that both are excitations of the same underlying ur-stuff, the electron field. The electron field is thus the primary reality" [79].

$$
\begin{aligned}
\phi_k &= \int e^{ikx}\phi(x)dx \\
\pi_k &= \int e^{ikx}\pi(x)dx \\
a_k^+ &= \frac{1}{\sqrt{2\omega_k}}(\pi_k - i(\hat{g}^{0i}k_i - \omega_k)\phi_k), \\
a_k &= \frac{1}{\sqrt{2\omega_k}}(\pi_k - i(\hat{g}^{0i}k_i + \omega_k)\phi_k), \\
\omega_k^2 &= \hat{g}^{00}(-\hat{g}^{ij}k_ik_j + m^2\sqrt{-g})
\end{aligned}
$$

with

$$
\begin{aligned}
H = \int \mathcal{H}dx &= \frac{1}{2}\int \pi_k^2 + \omega_k^2\phi_k^2 dk \\
[a_k, H] &= \omega_k a_k \\
a_k|0\rangle &= 0
\end{aligned}
$$

Now, in the case of a non-trivial gravitational field, these particle states are no longer eigenstates of the the Hamilton operator. They interact with the gravitational field. Nonetheless, they remain to be an approximation. We can introduce wave packets:

$$
\begin{aligned}
\phi_{kx} &= \int e^{iky-\sigma(y-x)^2}\phi(y)dy \\
\pi_{kx} &= \int e^{iky-\sigma(y-x)^2}\pi(y)dy \\
a_{kx}^+ &= \frac{1}{\sqrt{2\omega_{kx}}}(\pi_{kx} - i(\hat{g}^{0i}k_i - \omega_{kx})\phi_{kx}) \\
a_{kx} &= \frac{1}{\sqrt{2\omega_{kx}}}(\pi_{kx} - i(\hat{g}^{0i}k_i + \omega_{kx})\phi_{kx}) \\
\omega_{kx}^2 &= \hat{g}^{00}(-\hat{g}^{ij}k_ik_j + m^2\sqrt{-g})
\end{aligned}
$$

We obtain

$$
\begin{aligned}
[a_{kx}, H] &\approx \omega_{kx} a_{kx} \\
a_{kx}|0\rangle &\approx 0
\end{aligned}
$$

Here the vacuum state $|0\rangle$ remains to be defined as the state with minimal energy, it's expression using the local particle operators becomes an approximation.

This local definition of particle is useful for comparison with existing semi-classical field theory (cf. [13]). In this theory, we have the problem how to define the vacuum state and the Fock space. It is usually solved by definition of a set of observers. For these observers, the vacuum state is the state where they do not observe particles.

Now, a similar problem does not appear in our canonical scheme. for our scalar field we have a natural choice – the vacuum state as the state with minimal energy. But this choice may be understood in a similar way as the definition of a set of preferred observers – the observers which are in rest compared with the preferred frame. Now, our local particle operators may be interpreted as the particle operators which are important for the local observers and their particle detectors. In the vacuum state they do not observe particles. Therefore, our definition of the vacuum is in agreement with the definition of the vacuum state related with the set of preferred observers which are in rest.

13.3 Different representations

The major technical problem in quantum field theory on a curved background $(M, g_{\mu\nu})$ is the existence of infinitely many unitarily inequivalent representations of the canonical commutation relations. Isham [39] describes it in the following way: "The real problems arise if one is presented with a generic metric $g_{\mu\nu}$, in which case it is not at all clear how to proceed. A minimum requirement is that the Hamiltonians $H(t)$, or the Hamiltonian densities should be well-defined. However, there is an unpleasant possibility that the representations could be t dependent, and in such a way that those corresponding to different values of t are unitarily inequivalent, in which case the dynamical equations are not meaningful."

Now, GET gives all what may be wanted to prove that this does not happen: we have a simple equation for the metric (the harmonic equation), conservation of some important quantities (ether mass and momentum), we can use inequalities for ρ and p of type $\varepsilon < \rho < R$ (which may be interpreted as boundaries for the validity of GET) if necessary. Possibly this will be sufficient to solve this technical problem.

On the other hand, this problem appears also in thermodynamics for states with different temperature – something which in reality sometimes changes in time. Therefore it would not be strange if the problem nonetheless remains. I consider it to be an artifact of the limit $l_{cutoff} \to 0$.

13.4 Gauge field quantization

Let's consider now questions related with the quantization of gauge fields, at first the simplest case of QED in flat space. There are different well-known quantization schemes which may be used to incorporate the gauge condition. In the variant of Bjorken and Drell [14] the gauge condition (Coulomb gauge) is incorporated into the configuration space:

$$[\dot{A}_i(\mathbf{x},t), A_j(\mathbf{x}',t)] = -i\delta^{tr}_{ij}(\mathbf{x}-\mathbf{x}')$$

The other possibility is to consider a large configuration space

$$[\dot{A}_\mu(\mathbf{x},t), A_\nu(\mathbf{x}',t)] = -i\delta_{\mu\nu}\delta(\mathbf{x}-\mathbf{x}')$$

and to incorporate the gauge condition as an additional restriction for the states:

$$(\partial_\mu A_\mu(x))_+|\Phi\rangle = 0$$

This scheme leads to a problem with the interpretation of the particle operators. We have

$$[c_{k\mu}c^\dagger_{k'\nu}] = \eta_{\mu\nu}\delta k - k'$$

therefore the role of c_{k0} is reversed: c_{k0} behaves like $c^\dagger_{kj}$. Now, there are two variants of the interpretation of these commutation relations. In the first, classical, Fermi-Dirac quantization [29], [26] we accept that the Lorentz symmetry is broken in the large space: the vacuum is defined by

$$c^\dagger_{k0}|\Phi_0\rangle = c_{ki}|\Phi_0\rangle = 0$$

In the other, explicitly relativistic variant introduced by Gupta and Bleuler [36], [15] we define the vacuum in the invariant way

$$c_{k\mu}|\Phi_0\rangle = 0$$

and obtain an indefinite Hilbert space:

$$\langle\Phi_0|c_{k0}c^{\dagger}_{k0}|\Phi_0\rangle < 0$$

Again, we have a conflict between relativistic symmetry and a fundamental physical principle – the definiteness of the Hilbert space. Of course, it is well-known that these differences do not lead to observable differences. Nonetheless, this particular quantization problem is further illustration of the general picture we have found in Bohmian mechanics as well as for the local energy and momentum of the gravitational field: every more fundamental description requires to break relativistic symmetry. It is obvious that in this case we prefer the definite Hilbert space. Therefore, GET suggests to reject the Gupta-Bleuler approach and to use, instead, the older, non-covariant Fermi-Dirac quantization scheme.

The choice between Fermi-Dirac quantization and the scheme used by Bjorken and Drell is more complicate. We prefer the Fermi-Dirac quantization scheme because it is based on the Lorenz condition

$$\partial_\mu A^\mu = 0.$$

This condition is interesting for GET because of the known analogy between gauge theory and gravity. Once GET modifies the understanding of gravity and the EEP, a similar modification of gauge symmetry would be natural. In this scenario, the Lorenz condition would be the natural candidate for a physical equation, similar to the harmonic condition in GET. It also allows a physical interpretation as a conservation law of some ether property.

The incorporation of exact conservation laws into a field theory is a subtle thing: while integrals over a finite domain very in time, the integral over the whole space should be exactly conserved, without any quantum fluctuations. An atomic ether model suggests natural ways to reach this property – if conservation laws are interpreted as conservation laws for numbers of atoms, and canonical multi-particle Schrödinger theory is used to quantize the theory, this number is conserved automatically. In field theory I don't know such a way. But it should be noted here again that if this is a problem, it is a problem of the field theory approximation and therefore not a fundamental problem of the ether approach. Field theory is only an approximation, their problems are therefore not fundamental problems, but problems of an inconsistent approximation.

13.5 Non-abelian gauge field quantization

We do not consider here the quantization of non-abelian gauge fields. The reason is not that this seems to be very hard. It is certainly not impossible, because they appear in real condensed matter (SU(2) in superfluid $^3He - A$ [76]). They may be justified as renormalizable theories which appear in a natural way in the large scale limit [42]. For the development of discrete atomic ether models we can also use the large amount of experience with lattice QCD [37]. The reason is simply that I have not considered this domain yet in sufficient detail.

13.6 Hawking radiation

For an instationary gravitational field the vacuum state and the particle operators depend on time. Therefore, the original vacuum becomes a state with particles. Once the basic concept remains unchanged, we obtain the same results:

Theorem 3 *Let $g_{\mu\nu}(X,T)$ be a background metric in preferred coordinates X^i, T and let's denote the set of observers in rest compared with the preferred coordinates the "preferred observers". Then in the canonical formalism we obtain the same results for Hawking radiation as in the usual formalism for the preferred set of observers.*

Indeed, the formalism does not depend on the question if the background metric is a solution of GET or GR. The only difference with the standard formalism is the well-defined choice of the preferred observers in every moment of time. But this is simply the application of the general formalism to this special choice of preferred observers.

But this does not mean that semi-classical GET predicts Hawking radiation similar to semi-classical GR. The equivalence holds only as long as we use the same metric $g_{\mu\nu}$. For usual configurations this can be done, the cosmological constants Υ and Ξ may be ignored. But for the interesting case of the gravitational collapse this is not the case. We obtain a stable "frozen star" without horizon (see §8.5).

Therefore, during the collapse we obtain Hawking radiation. But once the collapse has stopped, the radiation goes away and no new radiation appears, as for stable stars in GR too. The remarkable result is that this does not depend on the actual value of $\Upsilon > 0$. Even for very small Υ the collapsing star needs only a short time to reach the critical size of the frozen star. Once a stable state has been reached, the radiation disappears. Stable stars do not radiate.

Therefore, GET predicts no Hawking radiation from frozen stars. For small enough "frozen balls" this leads to observable differences between GR and GET. In GET they remain stable and don't evaporate.

14 Methodology

Because of the lack of data, in the domain of quantum gravity methodological and philosophical questions become much more important than in other domains of science. In some sense, they become decisive.[10] Does it mean that it is impossible to find agreement about methodological issues? Fortunately, the methodological concepts proposed by Rovelli [63] are in good agreement with the method used here. The key idea of his methodology is the following:

> ... confidence in the insight that came with some theory, or 'taking a theory seriously', lead to major advances that largely extended the original theory itself. Of course, far from me suggesting that there is anything simple, or automatic, in figuring

[10] Butterfield & Isham [20] describe this situation in the following words: "there are no phenomena that can be identified unequivocally as the result of an interplay between general relativity and quantum theory - a feature that arguably challenges the right of quantum gravity to be considered as a genuine branch of science at all! ... theory construction inevitably becomes much more strongly influenced by broad theoretical considerations, than in mainstream areas of physics. More precisely, it tends to be based on various prima facie views about what the theory should look like – these being grounded partly on the philosophical prejudices of the researcher concerned ... In such circumstances, the goal of a research programme tends towards the construction of abstract theoretical schemes which are compatible with some preconceived conceptual frameworks".

> out where the true insights are and in finding the way of making them work together. But what I am saying is that figuring out where the true insights are and finding the way of making them work together is the work of fundamental physics. This work is grounded on the *confidence* in the old theories, not on random search of new ones. ... The 'wild' scientist observes that great scientists had the courage of breaking with old and respected ideas and assumptions, and explore new and strange hypothesis. From this observation, the 'wild' scientist concludes that to do great science one has to explore strange hypotheses, and *violate respected ideas*. The wildest the hypothesis, the best. I think wilderness in physics is sterile. The greatest revolutionaries in science were extremely, almost obsessively, conservative.

Now, we are in full agreement with this "conservative" view on fundamental physics, against the popular "wilderness". Based on this common methodological background, we disagree mainly in one point: in the decisions what are the "true insights" of the old theories which should be taken seriously and extended into the domain of quantum gravity, and which should be explained, derived, and therefore not extended into quantum gravity.

Now, based on these methodological rules, we present the existence of a preferred frame as the deep insight of Bohmian mechanics. In other parts we criticize the usual "insights" of general relativity: the relativistic notion of "time" (§ C) and relationalism (§ B).

14.1 The insights of Bohmian mechanics

In some sense, the disagreement starts with the definition of the theories we want to unify in quantum gravity. Usually this is presented as the problem of unification of general relativity and special-relativistic quantum field theory. But it is completely ignored that there exists already a quantum theory of gravity – multi-particle Schrödinger theory for the Newtonian interaction potential. And, moreover, there is an interesting variant of this theory – Bohmian mechanics (BM). While it is in no way suggested that the interesting and important insights of quantum field theory should be ignored, the theories we really have to unify are general relativity and non-relativistic Bohmian mechanics.

We consider some details of BM in appendix F. This theory proves that vagueness, subjectivity, and indeterminism of the usual interpretations of quantum theory are not forced on us by the experimental facts. These are very interesting and important insights into the nature of quantum theory – in my opinion, insights of much more fundamental character in comparison with the domain of applicability of particular space-time symmetries.

The problem with BM is that it requires a preferred frame, in contradiction with the relativity principle. In this context, it seems useful to quote again Rovelli [63]: "So, Einstein *believed the two theories, Maxwell and Galileo*. He assumed that they would hold far beyond the regime in which they had been tested. ... If there was contradiction in putting the two together, the problem was ours: we were surreptitiously sneaking some incorrect assumption into our deductions."

Now, is there a possibility to believe above theories? If we require Lorentz invariance on the fundamental level, Bohmian mechanics should be simply rejected and does not give any insight. This certainly violates the recommendation to take above theories seriously. The choice of GET is to preserve Lorentz invariance for observable effects, but to accept a preferred frame on the fundamental level.

Now, the question is how much this weakens the insights of relativity. Obviously, we do not destroy the insights of relativity completely. Instead of "the stage does not exist" we obtain "the stage is not observable". This remains to be an important and non-trivial insight.

14.2 Relativity as a theory about observables

But we want to go farther. We argue that relativity is only a theory about observables. Therefore, nothing changes if we replace "the stage does not exist" with "the stage is not observable".

Indeed, if there would be a difference, then there should be a method to show the existence of unobservable objects. In classical realism, there are such methods – the EPR criterion of reality allows to prove the existence of such hidden objects. But this criterion has been rejected. Moreover, this is a necessity. Without the rejection of the EPR criterion relativity would be simply falsified. Thus, after the rejection of the EPR criterion we have no longer a chance to prove the existence of an unobservable stage. Lorentz invariance *is* only observable Lorentz invariance. The original principle "all laws of nature should be Lorentz-invariant" has been replaced by "all observable effects should be Lorentz-invariant" at least after Aspect's experiment.

Therefore, from point of view of relativity the statements "the stage does not exist" and "the stage is not observable" are simply identical. If we interpret the relativistic insight "the stage does not exist" as "the stage is not observable" we do not weaken relativity. Instead, we take the relativistic preference for observables seriously.

Thus, we conclude that the acceptance of a preferred frame is in natural agreement with the methodology recommended by Rovelli, which requires to take above theories seriously.

15 The violation of Bell's inequality

Before learning the details of the violation of Bell's inequality, I have thought that it gives some weak evidence in favour of a preferred frame. It was a real surprise for me that the evidence is, instead, very strong – its not an exaggeration to name it simply a falsification of relativity.

The whole problem is a very simple one. While relativity forbids any superluminal causal influence, the Lorentz ether allows them, as long as their observable consequences allow two explanations: ($A \to B$ or $B \to A$). In this case, they cannot be used to measure absolute time, which is forbidden in the Lorentz ether. Now, Bell's inequality may be violated only if ($A \to B$ or $B \to A$). And, because it is violated, relativity is falsified and we have to return to the Lorentz ether. A very nice, interesting but simple example of an indirect existence proof.

But, instead of accepting this elementary experimental falsification, the simple but fundamental principles used in this proof are questioned, even rejected. The argumentation used in this context is a classical example of immunization. Some arguments are nonsensical enough to describe the situation as a "flight from reason in science" (Goldstein [33]). Fortunately, reading Kuhn's "structure of scientific revolutions" [44] has recovered my optimism about the presence of reason in science. Kuhn observes that paradigms are never falsified by experiment alone. Their rejection always requires another paradigm for replacement. And, without GET, the ether paradigm was simply not a viable competitor.

But with GET the ether paradigm becomes a reasonable competitor of relativity. Now, with GET as the background, the violation of Bell's inequality should be reinterpreted. From point of view of competition between ether and relativity it becomes a simple and beautiful experimental falsification of relativity.

Of course, there seems no necessity to copy the well-known proofs of the various variants of Bell's inequality. Nonetheless, to explain some features (like the simplicity of the theorem itself, the classical character of the decisions and the observations and the existence of applications) the simplest way seems to be a simple "proof for schoolboys":

15.1 Bell's inequality for schoolboys

There are three cards, left, middle, right, with red or black color. I have to choose them so that:

- the left and middle cards have the same color;
- the middle and right cards have the same color;
- the left and right cards have different color.

Obviously, one of the three claims is wrong. Now, if you open two cards, you can test one of these claims. What's the probability p to detect a wrong claim? Obviously $p \geq 1/3$.

What if you win only with $p < 1/3$? Obviously, something is manipulated. What? That's easy: after you have chosen the first card, another card may be manipulated. For example, imagine one card is marked. If you open this card, you hand becomes marked. And the other card may be manipulated so that if touched by a marked hand it changes its color.

Let's try to avoid this possibility for manipulation. We use two rooms and assume that no information transfer between the two rooms is possible. In every room we have three cards, and your team has to choose one card in every room. How can you be sure that the cards in the two rooms are the same? Very simple, you can ask for the same card in above rooms as often as you like, and in this case these cards should always have the same color. Without information about the question in the other room your opponents cannot be sure if you ask about different cards or the same cards. They have no better strategy than to use the same predefined color for the same card.

Therefore, we are in the same situation as before, but without the possibility to manipulate based on the information about the other question. Therefore, we have again $p \geq 1/3$. And, if not, there is a hidden information transfer from one room to the other.

That's all – we have proven Bell's theorem. Let's formulate it in the following way:

Theorem 4 (Bell's theorem) *If Bell's inequality $p \geq 1/3$ is violated for measurements at A and B, then there exists a causal influence ($A \to B$ or $B \to A$).*

15.2 The difference between special relativity and Lorentz ether

As far, we have used only classical common sense, and proven that from the violation of Bell's inequality follows ($A \to B$ or $B \to A$). The question is now how relativity and ether theory are involved.

In special relativity, we have no absolute time. Instead, in pre-relativistic Lorentz-Poincare ether theory we have an absolute time, but we cannot measure it. Because of the ether, moving clocks are dilated and moving rulers contracted. Now, the formulas for SR and Lorentz ether are identical. Therefore, it is often said that above theories are identical in their predictions. But this is not true. The violation of Bell's inequality is an interesting difference.

In special relativity we have Einstein causality. This is a consequence of two axioms: that there are no causal loops, and that causality is a law of nature, and therefore has to be Lorentz invariant. Einstein causality is Lorentz-invariant, but a notion of causality which allows faster than light causal influences leads to causal loops. Therefore, any causal influence faster than light is forbidden. That means, as $A \to B$, as $B \to A$ is forbidden by Einstein causality. Therefore, ($A \to B$ or $B \to A$) is forbidden too.

But in the Lorentz ether the situation is different. We have classical causality. Therefore, causal influences faster than light are not forbidden. There is only one restriction: all observable effects should be Lorentz-invariant. Now, it seems to follow that such faster than light influences cannot have observable consequences. But that's wrong – observable effects between space-like separated events A and B may be very well Lorentz-invariant if they allow two explanations: ($A \to B$ or $B \to A$). If in absolute time

$t_A < t_B$, we use the explanation $A \to B$, but if $t_A > t_B$, we use explanation $B \to A$. Thus, ($A \to B$ or $B \to A$) is not forbidden in the Lorentz ether.

We conclude that there is an interesting difference in the predictions of special relativity and Lorentz ether theory: observable correlations between space-like separated events A and B which may be explained by causal influences ($A \to B$ or $B \to A$) are forbidden in special relativity, but allowed in Lorentz ether theory.

Bell's inequality is a simple example of an effect of this type. We have above explanations. If Alice is able to send information to Bob, they can always win. If Bob is able to send information to Bob, they can always win too. Thus, if they win with probability $p < 1/3$, we can explain this as ($A \to B$ or $B \to A$). Violations of Bell's inequality are obviously observable. We see that it is not correct to claim that special relativity and Lorentz ether are equivalent as physical theories. They are not. In special relativity, we can prove Bell's inequality for space-like separated events. In the Lorentz ether violations of Bell's inequality are allowed.

15.3 Aspect's device

Now, there is no need to understand how Aspect's device [5] works. It's sufficient to consider it as a black box, or, more accurate, a device consisting of two black boxes, one for each room. You can press one of three buttons – left, middle, right – and it gives the answer – red or black. And if Alice and Bob use this device, your probability to find the wrong answer is $p = 1/4$. That's all.

We conclude that we have to reject special relativity and to return to the Lorentz ether. Bell's conclusion was similar: "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 ether — 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 ether. 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." [11]

15.4 Should we question everything?

We have presented a very simple proof of Bell's inequality. Unfortunately proofs are certain only in mathematics. As far as we consider reality, nothing is certain. And, therefore, everything in this proof may be (and has been) questioned. This reaction is justified in a situation where relativity is an unquestioned paradigm of science. But it is no longer justified in a situation where we have a competition between two paradigms – relativity vs. ether theory.

In this situation, the previously justified search for explanations becomes a simple method of destruction – a method which may be applied to every experimental falsification of a physical theory: take an arbitrary sentence in the proof we have presented. Then, name it an "unproven hypothesis", explain that we "cannot be sure" that it holds, and that "far away from our everyday experience" this common sense assumption is possibly invalid. That's sufficient, you have found a "loophole" in the proof. Moreover, you will have a lot of fun if somebody tries to justify the statement you have questioned – especially because he cannot be successful. Whatever he presents, you have a simple counter-attack: take an arbitrary sentence from his reply, and ... you already know. This is the method described by Rovelli [63] as "wilderness":

> The 'wild' scientist observes that great scientists had the courage of breaking with old and respected ideas and assumptions, and explore new and strange hypothesis. From this observation, the 'wild' scientist concludes that to do great science one has to explore strange hypotheses, and *violate respected ideas*. The wildest the hypothesis, the best. I think wilderness in physics is sterile. The greatest revolutionaries in science were extremely, almost obsessively, conservative.

That we have to stop somewhere with the questioning is well-known in scientific methodology. Every test of a theory requires to stop questioning at some point. That's a well-known fact in scientific methodology. For example, Popper [57] writes:

> Every test or theory ... must stop at some basic statement or other which we *decide to accept*. If we do not come to any decision, ... then the test will have led nowhere.... Thus if the test is

to lead us anywhere, nothing remains but to stop at some point or other and say that we are satisfied, for the time being.

Note that this is not dangerous at all: we do not have to accept something forever, in a dogmatical way, we can remove our acceptance whenever we have reason to doubt. Now, the question may be only what are reasonable criteria to stop questioning some principles, at least for time. In our case, a simple rule seems to be that an objection should be justified by something more than the simple and trivial remark that it is an unproven hypothesis. Based on this basic rule let's reject now some well known objections against our resolution of the violation of Bell's inequality.

Thus, unjustified, pure doubt into some common sense principle, without reason, that means without independent evidence against the questioned principle, should be rejected. Let's look now at the common objections against the obvious resolution of the violation of Bell's inequality – the acceptance of a preferred frame.

15.5 No application for the violation

One common counter-argument is that we cannot use the violation of Bell's inequality for information transfer. This is really strange, because to use it for information transfer is forbidden in the Lorentz ether too. It is simply in contradiction with the requirement that two explanations of the violation are possible: ($A \to B$ or $B \to A$). If we use this device for information transfer $A \to B$ this is certainly in contradiction with the explanation $B \to A$. Therefore, we have the strange situation that it is considered to be an argument against a theory that the prediction of this theory holds.

A variant of this argument is that the violation of Bell's inequality cannot be applied. That's simply wrong. In our proof, we have described an application – Aspect's device allows Alice and Bob to improve their coordination and to win in the game with probability $p = 3/4$ instead of $2/3$. But to improve coordination in similar game-like situations is the classical application of information transfer. Therefore, even if pure communication is impossible – for known reasons – we can apply it in a similar way to improve coordination. Moreover, it should be noted that this objection, while common, is in no way an argument in favour of one of the competitors.

15.6 Objections against a preferred frame

One argument which was really justified in the past is that there was no theory of gravity with a preferred frame comparable with general relativity. Now, with the theory presented here this argument is obsolete. Of course, all other known arguments against the Lorentz ether may be presented in this context. Most of them, again, are obsolete in GET.

One specific argument is worth to be considered: It is argued that it is not natural to use two different explanations for the same observation. But two Lorentz-equivalent configurations are not "the same" in the Lorentz ether. That's the general situation in the Lorentz ether. In different but Lorentz-equivalent situations all other observable effects are explained in a different way. In this context it is natural to have different explanations for the violation of Bell's inequality too, much more natural than to have the same explanation.

Now, you may like or not like the properties of the Lorentz ether – the question is if ($A \to B$ or $B \to A$) is allowed in the Lorentz ether or not, if there are arguments against the experimental falsification of relativity. To count here metaphysical arguments against the other competitor is really strange. If we accept arguments about metaphysical beauty as decisive against an experimental falsification, this is simply the end of science.

15.7 No contradiction with quantum mechanics

Then where is a whole class of common objections: objections related with the strangeness of quantum theory. The strangeness of the double slit experiment or the quantum eraser seems to suggests that the preferred frame is not the problem, and that the common sense principles we have used in our proof are in contradiction with quantum theory. Of course, we can argue here that the burden of proof is on the side of the people who claim that there is such a contradiction. But we don't have to – instead, we can prove that there is no such contradiction.

Theorem 5 *There is no contradiction between the principles used in the proof of Bell's theorem and the predictions of non-relativistic quantum theory.*

The proof is given by Bohmian mechanics – a hidden variable theory of quantum mechanics found by David Bohm [16]. In a "quantum equilibrium", this theory makes the same predictions as non-relativistic quantum theory, therefore, no prediction of non-relativistic quantum theory is in contradiction with the predictions of Bohmian mechanics. But Bohmian mechanics is in full agreement with the common sense principles used in the proof of Bell's theorem. We consider Bohmian mechanics in appendix F.

Thus, "quantum strangeness" is not a reason to reject the proof. All arguments related with double slit experiments, spin, quantum erasers, the "wholeness" of quantum theory and so on are irrelevant. It gives no support for the thesis that something is wrong with the proof of Bell's theorem.

15.8 Objections in conflict with Einstein causality

There is another class of objections which may be rejected as a whole. It is based on the assumption that Einstein causality is considered as a prediction of relativity. The idea is a detailed consideration of an assumed faster than light phone line. Let's assume such a phone line exists. In this case, we obviously have to give up relativity as falsified. Nonetheless, let's consider the seemingly nonsensical question how we can prove this based on the observation. The point is that we can play here the same game of "questioning everything". Now, in this situation this looks certainly nonsensical. Surprisingly, we look at the details, we find that we have to use assumptions which may be and have been questioned in the discussion about Bell's inequality.

We propose the following criterion: *all assumptions and principles which have to be used to prove that a really working superluminal phone line falsifies Einstein causality should not be questioned in the proof of Bell's theorem.*

Now, let's look how to prove this. Let's consider the basic device which transfers one bit of information. The FTL phone consists of two black boxes. We make some decision and press a button on our box. Our friend makes a measurement on his side of the box and obtains a result. Then, we meet later and compare our decisions with his observations. If we observe a significant correlation we conclude that the phone works.

We see that the experimental situation is very close to the situation in the violation of Bell's inequality, and really includes parts which have been questioned:

- The device is a black box, we don't know how it works. This is similar to our presentation of Aspect's device as a black box. Therefore, every argumentation which requires some insight into this black box before accepting that some causal information transfer has happened should be rejected.

- We essentially use the free will of the experimenter. Of course, as in Bell's theorem, the experimenter may be replaced by various other random number generators to obtain certainty that the input – the decision of the experimenter – is not predefined. But that's enough. Every argument which does not accept this as sufficient to establish the independence of the decision of the experimenter should be rejected.

- We can verify the existence of a non-trivial correlation only after the experiment has finished, using other methods of information transfer. It is typical for "many world" explanations or explanations based on "superpositions of observers": nothing non-local happens, only if the observers meet again, with usual subluminal speed, something collapses and we obtain the correlations in a miraculous quantum way. These explanations should be rejected too.

- Note also the general objection what we observe only a correlation. Having only a correlation, we cannot conclude that there really exists a causal relation in reality. We need some principle which allows to make the step from observable correlations to the conclusion that there exists a real causal interaction. Every criticism which rejects the way this has been done in the proof of Bell's inequality but does not describe an alternative way to conclude from observation that a real, causal relation exists should be rejected.

- We know that as $A \to B$, as $B \to A$ is forbidden by Einstein causality. Therefore, ($A \to B$ or $B \to A$) is forbidden too. This is obvious. But there exists a well-known psychological bias known as "disjunction fallacy" [67]: if there are two alternatives, and above alternatives lead to the same conclusion (in our case: the falsification of relativity), but we are not sure which alternative happens, we tend not to make the conclusion. It seems, this fallacy is the base for arguments of type "we are unable to detect the direction of influence".

Again, our argumentation allows to reject a whole class of common objections. Of course, it works only if we want to defend Einstein causality as a physical prediction of relativity. It does not work against the idea of rejection of causality itself, for example following Price [59].

15.9 Discussion

Bell's inequality is a prediction of SR which does not hold in LET. Therefore the violation of Bell's inequality falsifies SR and requires to accept a preferred frame. The proof is indirect but so simple and straightforward that it is hard to imagine a stronger indirect falsification of a physical theory.

The consideration of the common counter-arguments has not given any serious loopholes. Instead, most of the common arguments are part of two classes we have rejected: objections based on assumed contradictions with quantum principles, and objections which, if accepted, would allow to immunize relativity even if we have working superluminal phone lines.

What remains is the possibility to question everything. Certain proofs exist only in mathematics, not in physics. Immunization of a physical theory is always possible. In principle, objections are always possible. Last not least, we are talking about reality, not about pure mathematics. But there is no independent evidence which suggests that some part of this proof should be questioned. Therefore, the rejection of the proof of Bell's inequality has to be qualified as an ad hoc immunization of relativity.

Nonetheless, in § E we consider the EPR criterion in more detail. We present there evidence for the thesis that the principles used in the proof of Bell's inequality – principles we denote as "EPR realism" – are of more fundamental character than space-time symmetries.

16 Conclusions

General ether theory proposes a paradigm shift back from relativity to a classical Newtonian background. It heals the main problems of the old Lorentz ether:

- relativistic symmetry is explained in a general, simple way;
- the ether is generalized to gravity;
- the ether is compressible, changes in time;

- there is no longer an action-reaction problem;

In various parts of fundamental physics we find advantages of the new approach:

- we obtain local energy and momentum density for gravity;
- the problem of time of quantum gravity is solved;
- singularities in physical important situations disappear;
- frozen stars instead of black holes solve the information loss problem of quantum gravity;
- we obtain a reasonable dark matter term;
- a big bounce instead of a big bang solves the cosmological horizon problem without inflation;
- the EPR criterion of reality holds;
- a generalization of Bohmian mechanics into the relativistic domain becomes unproblematic;

Even in the domain of beauty GET seems to be able to compete with GR: it seems that some of the most beautiful aspects of the mathematical apparatus of GR obtain a physical interpretation in the context of GET: harmonic coordinates, ADM decomposition, triad formalism, Regge calculus. Especially the beautiful relation between covariance and conservation laws has to be mentioned here: it gives in GET two nice expressions for the conservation laws, but in GR it makes energy conservation highly problematic.

Reconsidering the metaphysical foundations of relativity, we have found serious flaws:

- A reconsideration of the violation of Bell's inequality suggests its interpretation as a falsification of relativity; the rejection of the EPR criterion of reality should be interpreted as an immunization of relativity: except its contradiction with the relativity principle there is no independent evidence against the EPR criterion.

- A new quantization problem – named *scalar product problem* – suggests that a really relativistic covariant quantum theory fails to describe the non-relativistic limit.

- The consideration of the "insight" of relativity into the nature of time suggests that it is based on conflation of different physical notions – clock time and "true" time. All they have in common is that they have been named "time".

- The consideration of general covariance and relationalism shows that these are not advantages of relativity, but can always be reached – by forgetting valuable information.

On the other hand, we have been unable to detect serious difficulties of the new approach: there is no evidence that the introduction of a preferred frame is problematic in any part of modern physics.

But, of course, a lot of interesting questions remain open, especially the physical interpretation of gauge fields and fermions, Lagrange formalisms for condensed matter compatible with the GET scheme, the details of the related hidden relativistic symmetry in usual condensed matter. The unification of the geometrical methods developed for GR quantization with the canonical quantization schemes for condensed matter will be interesting for above domains: it defines how to regularize in quantum gravity, and it gives geometrical interpretation in condensed matter theory.

A Covariant description for theories with preferred coordinates

The covariant description we consider here is quite simple: we handle the preferred coordinates formally as "scalar fields" $X^\mu(x)$. This allows to describe a theory with preferred coordinates in a covariant way. An interesting point of this covariant description is that the Euler-Lagrange equations for the preferred coordinates are the conservation laws.

This is quite obvious and may be considered as a "folk theorem". Nonetheless, confusion about the physical meaning of "covariance" seems quite common, and it does not seem to be widely known. That's why it seems reasonable to describe the "weak covariant" description we use in more detail.

A.1 Making the Lagrangian covariant

We assume that we live in a Newtonian framework. That means, there is an absolute Euclidean space and absolute time. To describe this absolute background, we use preferred coordinates $X^i, T = X^0$. As usual, Latin indices vary from 1 to 3, Greek indices from 0 to 3. Of course, to use other coordinates x^μ is not forbidden, the coordinates X^i, T are only preferred – the laws of nature are simpler in these coordinates.

Now let's consider how to obtain a covariant description starting from a non-covariant one:

Theorem 6 *Let $S = \int L(T^{\cdots}_{\cdots}, \partial_\mu T^{\cdots}_{\cdots})$ be a functional which depend on components $T^{\cdots}_{\cdots}$ and first derivatives $\partial_\mu T^{\cdots}_{\cdots}$ of tensor fields T.*

Then there exists a covariant functional $S_c = \int L_c(T^{\cdots}_{\cdots}, \partial_\mu T^{\cdots}_{\cdots}, X^\mu_{,\nu})$ which depends on the components and first derivatives of the same tensor fields T and on the first derivatives $X^\mu_{,\nu}$ of four scalar fields $X^\mu(x)$ so that

$$S(T) = S_c(T, X^\mu_{,\nu})$$

for $X^\mu(x) = x^\mu$.

Proof: In L we replace the tensor components by expressions using the following replacement rules for all indices:

$$\begin{aligned}
T^{\cdots\mu\cdots}_{\cdots} &\rightarrow \frac{\partial X^\mu}{\partial x^\nu} T^{\cdots\nu\cdots}_{\cdots} \\
T^{\cdots}_{\cdots\mu\cdots} &\rightarrow \frac{\partial x^\nu}{\partial X^\mu} T^{\cdots}_{\cdots\nu\cdots} \\
T^{\cdots}_{\cdots,\mu} &\rightarrow \frac{\partial x^\nu}{\partial X^\mu} T^{\cdots}_{\cdots,\nu} \\
T^{\cdots\mu\cdots}_{\cdots,\cdot} &\rightarrow \frac{\partial X^\mu}{\partial x^\nu} T^{\cdots\nu\cdots}_{\cdots,\cdot} \\
T^{\cdots}_{\cdots\mu\cdots,\cdot} &\rightarrow \frac{\partial x^\nu}{\partial X^\mu} T^{\cdots}_{\cdots\nu\cdots,\cdot}
\end{aligned}$$

The matrix $\frac{\partial x^\nu}{\partial X^\mu}$ is the inverse matrix of $\frac{\partial X^\mu}{\partial x^\nu}$. We use this property to express all occurrences of $\frac{\partial x^\nu}{\partial X^\mu}$ by these rational functions of $X^\mu_{,\nu}$. For $X^\mu(x) = x^\mu$ these are obviously identical transformations. Moreover, each argument is now a covariant scalar. Indeed, the indices μ of the $X^\mu_{,\nu}$ are not tensor indices, but enumerate the scalar fields $X^\mu(x)$. But indices of this type are the only open indices in the expression. Therefore, being a function of covariant scalar expressions, the modified function L_c is a covariant scalar function, qed.

Covariant functions like L_c which do not depend on the fields $X^\mu(x)$ we name "strong covariant", to distinguish them from "weak covariant" functions which depend on the fields $X^\mu(x)$.

Of course, what is not part of this theorem is how to interpret something defined only in the preferred coordinates as a component of some tensor field. This is, essentially, the real problem if we have to make a theory covariant. There are usually different possibilities: a 3D scalar may be a 4D scalar as well as a component of a 4D vector or tensor field. But this is a question of the definition of the theory itself. We are interested here only in a special way to obtain a covariant description of a well-defined theory.

A.2 Conservation laws in the covariant formalism

This formalism raises two interesting questions. First, once we have a covariant formalism, we obtain the known problems with conservation laws – Noether's theorem does not give non-trivial conservation laws. Second, we have four new Euler-Lagrange equations for $S = \int L$ – the Euler-Lagrange equations for the preferred coordinates X^μ. What is their physical meaning? Now, the answer is simple and beautiful – the Euler-Lagrange equations for the preferred coordinates are the conservation laws. All we need is to look at the Euler-Lagrange equations for the preferred coordinates:

Theorem 7 *If a Lagrangian L does not depend explicitly on the coordinates, then the Euler-Lagrange equation of the related weak covariant Lagrangian L_c for the preferred coordinates X^μ defines conservation laws for the tensor*

$$T^\nu_\mu = -\frac{\partial L_c}{\partial X^\mu_{,\nu}}$$

If the original Lagrangian L is covariant, then $T^\nu_\mu = 0$.

If there was no explicit coordinate-dependence in the original Lagrangian, there is none in L_c too. Note also that for a covariant Lagrangian L we have $L \equiv L_c$ and does not depend on X^μ and $X^\mu_{,nu}$. This follows from the construction. The theorem now follows immediately from the the Euler-Lagrange equation for the X^μ:

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

The results about the existence of conservation laws are equivalent to Noether's theorem, but the energy-momentum tensor is not the same. The relation between preferred coordinates and conservation laws is a much more direct one in this formalism: de facto one line was sufficient for the proof. We have not used the other Euler-Lagrange equations. That's why we consider this variant of the conservation law as the more fundamental one.

We conclude: *the Euler-Lagrange equations for the preferred coordinates are the conservation laws.*

B Relationalism

The confusion about covariance has historical reasons. Initially covariance was believed to be a special, distinguishing property of GR. Later it has been recognized that every physical theory allows a covariant formulation. For example, Fock [31] has given a covariant formulation for special relativity. A simple way to do this is to use the curvature tensor of a metric g_{ij}. The equation $R^i_{jkl} = 0$ defines a flat metric in a covariant way. Once a flat background has been defined, all partial derivatives of the equations in the preferred frame may be replaced by covariant derivatives of this background metric. This method has been widely used to present theories of gravity with predefined geometries, for example [48], [52].

Nonetheless, this does not mean that this question is completely clear now. The situation is confusing. On one hand, every theory allows a covariant formulation, on the other hand, there is a non-trivial symmetry property – the property we have named "strong covariance" in GET. Rovelli [63] describes it using the notions "active vs. passive diff invariance":

> All this is coded in the active diffeomorphism invariance (diff invariance) of GR. Passive diff invariance is a property of a formu-

> lation of a dynamical theory, while active diff invariance is a property of the dynamical theory itself. A field theory is formulated in manner invariant under passive diffs (or change of coordinates), if we can change the coordinates of the manifold, re-express all the geometric quantities (dynamical *and non-dynamical*) in the new coordinates, and the form of the equations of motion does not change. A theory is invariant under active diffs, when a smooth displacement of the dynamical fields (*the dynamical fields alone*) over the manifold, sends solutions of the equations of motion into solutions of the equations of motion.

This is in agreement with our understanding. The problematic part is how to distinguish dynamical and non-dynamical fields. Rovelli continues:

> Distinguishing a truly dynamical field, namely a field with independent degrees of freedom, from a non-dynamical field disguised as dynamical (such as a metric field g with the equations of motion Riemann[g]=0) might require a detailed analysis (for instance, Hamiltonian) of the theory.

That means, it is assumed that an analysis of the equations of the theory – the dynamics – allows to distinguish the non-dynamical and the dynamical steps of freedom of the theory. The example of GET and its relation with general relativity with four scalar dark matter fields (GRDM) allows to proof that this is impossible:

Thesis: *It is impossible to distinguish a non-covariant theory with a "preferred frame in disguise" from a "truly" covariant physical theory by evaluation of the equations of motion and the Lagrange formalism.*

Indeed, in GET, the preferred coordinates X^μ are non-dynamical, and their presentation as "dynamical fields" $X^\mu(x)$ fits exactly with the description of a "non-dynamical field disguised as dynamical". As we have seen, the equation for the preferred coordinates $X^\mu(x)$ is simply the harmonic equation, thus, the usual general-relativistic equation for scalar fields. On the other hand, in GRDM the four scalar fields are dynamical. But the Lagrange formalism for GET is exactly the Lagrange formalism for GRDM.

A variant of this argument is the consideration of GET with the four "preferred coordinates in disguise" $X^\mu(x)$ and a few additional free scalar fields $\varphi^m(x)$. Then, looking at the equations and the Lagrangian, there is no way to tell what are the truly dynamical scalar fields $\varphi^m(x)$ and what are the coordinates in disguise $X^\mu(x)$. We need additional a-priori information, additional insight.

Once the equations are identical, even a "Hamiltonian analysis" (whatever this means in detail) cannot help. But there is an interesting point: the Hamilton formalism is different for GET and GRDM. In GRDM we have the typical problems of general-relativistic theories where the Hamiltonian is a constraint. Instead, in GET we have a classical Hamilton formalism, and the Hamiltonian is not a constraint. But we cannot derive the Hamilton formalism of GET without the additional information that the fields $X^\mu(x)$ are the preferred coordinates. Without this information we cannot decide which Hamilton formalism is the appropriate one.

Note that our thesis does not mean that there are no differences between GET and the "truly relativistic" theory GRDM. The differences we have considered in § 7. Our thesis is that we need additional insight – the insight that the fields X^μ are preferred coordinates – to be able to distinguish a theory with absolutes from a "truly relativistic" theory.

B.1 What is the true "insight" of general relativity?

This observation seems to destroy the whole concept described by Rovelli [63]:

> One of the thesis of this essay, is that general relativity is the expression of one of these insights, which will stay with us "forever". The insight is that the physical world does not have a stage, that localization and motion are relational only, that diff-invariance (or something physically analogous) is required for any fundamental description of our world ....
>
> In GR, the objects of which the world is made do not live over a stage and do not live on spacetime: they live, so to say, over each other's shoulders.

But, as we have seen, this is not an insight, but a tautological reformulation. If the theory has a stage, we can reformulate it and name the stage a dynamical field. Instead of "absolute motion" we talk about "motion relative to the stage field". Let's see how Rovelli describes Einstein's "insight":

> Of course, nothing prevents us, if we wish to do so, from singling out the gravitational field as "the more equal among equals", and declaring that location is absolute in GR, because it can be defined with respect to it. But this can be done within any relationalism: we can always single out a set of objects, and declare them as not-moving by definition. The problem with this attitude is that it fully misses the great Einsteinian insight: that Newtonian spacetime is just one field among the others.

The situation between GET and GRDM is the reverse one. The fields $X^\mu(x)$ are not just scalar fields among others. But this is a non-trivial insight. If we forget this insight, and the fields $X^\mu(x)$ are interpreted just as fields among others, we have lost important information and interesting predictions. In this way, by forgetting interesting information, a relational description is always possible. Therefore, the existence of a relational description is only an insight into the mathematical formalism of physical theories in general, not an insight of GR. Instead, in GET the existence of absolutes – the preferred coordinates $X^\mu(x)$ – is a non-trivial insight which leads to interesting predictions: the fields $X^\mu(x)$ may be used as global coordinates, the field $X^0(x)$ is time-like.

B.2 What are insights which are "forever"?

What would be an important insight is that a theory with a certain type of absolutes is impossible in nature. But for this insight general relativity is not enough. This can be, by its nature, only an impossibility proof for certain classes of theories. Such an insight may be based on certain observational facts, for example, observations of a worm-hole. This would be incompatible with a whole class of theories with flat background. Such an observation of a non-trivial topology, for example a worm-hole, would be really an insight which remains forever.[11] But we have not observed such non-trivial topology.

A lecture which can be learned from history of science is that metaphysical preferences like between relationalism and the existence of a predefined

[11]Another example of this type of insight is the violation of Bell's inequality, which excludes a whole class of theories – theories which allow the proof of Bell's inequality for space-like separated observations. This can be named also an "insight of quantum theory". But this would be a very sloppy description: the proof of Bell's is classical, and the violation of Bell's inequality has been observed in real experiments.

stage should not be justified based on the current physical theory. Rovelli himself has presented the best example of this type – Newton's insight, related with the famous rotating bucket, that there exists an absolute space. This insight, which was thought to remain forever too, was rejected by Einstein. In Einstein's theory, we have relationalism, no absolutes. But this insight may be as well superseded by another theory. GET proves that this is possible.

There is another example of an interesting metaphysical question where we tend to use current physical theory: probability versus determinism. Here we have even more switches between probabilistic chaos and determinism. Bohmian theory (deterministic), quantum theory (probabilistic), classical mechanics (deterministic), chaos in the many-particle situation (probabilistic), classical thermodynamics (deterministic), and chaos in its large scale predictions. Therefore, to base the metaphysical decision between chaos and determinism on current physical theory is highly speculative. To guess that this property remains forever is sufficiently falsified by historical evidence.

There are important insights of general relativity. For example that a special physical entity which was absolute in Newton's theory is not absolute in reality. It is the entity which defines inertial forces and causes the difference between a rotating bucket and a bucket in rest. This entity is the gravitational field. This insight into the nature of gravity and clock time will stay forever.

Another insight is the Einstein equivalence principle. Because this is an exact symmetry claim, we cannot be sure that it remains forever – but we can be sure that it survives at least as an approximative symmetry.

C The problem of time

It is well-known that the problem of time may be solved by the introduction of a preferred foliation as in GET: "in quantum gravity, one response to the problem of time is to 'blame' it on general relativity's allowing arbitrary foliations of spacetime; and then to postulate a preferred frame of spacetime with respect to which quantum theory should be written. Most general relativists feel this response is too radical to countenance: they regard foliation-independence as an undeniable insight of relativity." [20]

C.1 clock time vs. true time

To meet this argument, we have to consider the "insight of relativity" about the nature of time and the metaphysical aspects of the "problem of time" in more detail. In some sense, the problem of time may be discussed based on Newton's definition [53]. Newton distinguishes two notions of time:

> ... I do not define time, space, place, and motion as being well known to all. Only I observe, that the common people conceive these quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which it will be convenient to distinguish them into absolute and relative, true and apparent, mathematical and common.
>
> I. Absolute, true and mathematical time, of itself, and from its own nature, flows equable without relation to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year.

This definition is in agreement with GET. Here, we have an unobservable harmonic "true time" $T(x)$ together with the "apparent time" $\tau = \int \sqrt{g_{\mu\nu} dx^\mu dx^\nu}$ measured with clocks. These two notions of time may be roughly identified with "time of quantum theory" and "time of relativity":

Indeed, in quantum theory we have no self-adjoint operator for time measurement. Instead, it is closely related with the fundamental aspects of quantum theory: physical quantities have to be measured at a given time, the scalar product is conserved under time evolution. Thus, it ideally fits with Newtons "true time" and should be distinguished from "apparent time".

On the other hand, time in relativity is *defined* to be apparent time. General-relativistic time is the time measured by clocks – "measure of duration by means of motion". And its most interesting physical property is that it is unequable. The fit with Newton's definition of apparent time is simply ideal.

Therefore, if we deny Newton's insight into the different nature of true and apparent time, and try to develop quantum gravity without making this distinction, we are immediately faced with the problem to unify these two different notions of time. This is the metaphysical base of the notorious "problem of time" in quantum gravity.

C.2 About positivistic arguments against true time

The standard relativistic argumentation against this understanding of time is the rejection of "true time" based on positivistic arguments. The typical argument is that a physical notion needs an operational definition. If we cannot measure something, then it is not part of physics.

Now, this argumentation is based on positivistic methodology of science, which has been rejected by Popper [57]. According to Popper's "logic of scientific discovery" theory is prior to observation. Therefore, the fundamental objects of a theory are not based on observation, they do not need any operational definition. It is not the observation which decides about the fundamental notions of the theory. Instead, observation is always theory-laden. In Einstein's famous words, it is the "theory which decides what is observable". Positivism reverts the relation between theory and observation. All what is required in science is that the theory, as a whole, makes a lot of falsifiable predictions. An operational definition of some fundamental notions of the theory is a useful tool to obtain such predictions, but not more. Positivism is simply wrong. Again, in Einstein's words about Bohr's positivism: "Perhaps I did use such a philosophy earlier, and even wrote it, but it is nonsense all the same."

Moreover, in our case we do not have to rely on such methodological considerations. Instead, we have a beautiful example of a theory with unobservable "true time" – classical quantum theory. We have already mentioned that there is no self-adjoint operator for time measurement. As a consequence, no physical clock can provide a precise measure of time. There is always a small probability that a real clock will run backward with respect to it [70]. Nonetheless, the time of quantum theory is not only an important part of quantum theory. A lot of people have tried hard to remove time from quantum theory, without success.

The example of time in quantum theory is not only a powerful illustration of the failure of positivistic argumentation, but answers the question about the physical meaning of true time: the simple answer is "the same as in classical quantum theory". The advantage of this answer is that we do not need any vague metaphysical considerations about the nature of "true time".

C.3 Relativity as an insight about true time

On the other hand, positivistic argumentation against true time is not the only relativistic argumentation. It seems, a lot of relativistic scientists acknowledge very well that there is more behind the notion of time than simple clock measurement.

Indeed, let's for this argument accept the positivistic argumentation that there is nothing like "true time", and the only physically meaningful notion of time is clock time. What, in this case, is the physical meaning of the following – rather typical – relativistic argumentation [68]:

> One often hears that what General Relativity did was to make time depend on gravity ... Such a dependence of time on gravity would have been strange enough for the Newtonian view, but General Relativity is actually much more radical than that.[12] ... Rather the theory states that the phenomena we usually ascribe to gravity are actually caused by time's flowing unequable from place to place.... Most people find it very difficult even to imagine how such a statement could be true. ... That gravity could affect time, or rather could affect the rate at which clocks run, is acceptable, but that gravity is in any sense the same as time seems naively unimaginable.

As we see, the point is not that apparent time – time measurement with clocks – is influenced by gravity. This is only the part which is already "acceptable" to people who have not really understood relativity. The point which is considered to be the "naively unimaginable" insight of relativity is the identification with "time" – obviously not "apparent time", but "true time". Thus, the non-existing ghost of true time revives here in its full beauty, as an important, fundamental insight of relativity.

In my understanding we have here a conflict between two common relativistic argumentations. On one hand, the rejection of the notion of "true

[12] We have to disagree with this claim that a dependence of apparent time on gravity would have been strange for the Newtonian view. Last not least, a classical clock based on Newtonian theory – the pendulum clock – obviously depends on gravity.

time" and the reduction of time to clock time measurement, on the other hand the metaphysical identification of the same "true time" with time measurement, presented as an "insight of relativity". This contradiction shows that there is not much in support of this "insight" except methodological confusion:

Or we accept that there is nothing behind "time" except clock measurement. Then no non-trivial insight into the nature of "true time" exists. The (nonetheless very important) insight of relativity is about the influence of gravity on clocks.

Or we accept that time is more than clock measurement. Then there is no empirical base for the identification of clock time with this other notion of time. The identification is not only a purely metaphysical hypothesis without empirical support. Moreover, this metaphysical hypothesis is highly questionable, it seems to be based only on misunderstanding because the two notions are usually described with the same word – time. Simply two completely different notions of time which have been distinguished already by Newton have been mingled.

C.4 Technical aspects of the problem of time

The metaphysical choice to identify quantum true time with relativistic clock time leads to subsequent technical problems. In different approaches to quantum gravity the problem of time shows in different ways. It is not the purpose of this paper to consider them, we refer here to [20], [39], [6] for further details. But an example may be informative. In the canonical approach which seems to be the closest to our approach, some "internal coordinates" have to be chosen. But this leads to a "multiple choice problem" [39]:

> Generically, there is no geometrically natural choice for the internal spacetime coordinates and, classically, all have an equal standing. However, this classical cornucopia becomes a real problem at the quantum level since there is no reason to suppose that the theories corresponding to different choices of time will agree.
>
> The crucial point is that two different choices of internal coordinates are related by a canonical transformation and, in this sense, are classically of equal validity. However, one of the central properties/problems of the quantization of any non-linear

system is that, because of the well-known Van-Hove phenomenon [73], most classical canonical transformations *cannot* be represented by unitary operators while, at the same time, maintaining the irreducibility of the canonical commutation relations. This means that in quantizing a system it is always necessary to select some preferred sub-algebra of classical observables which is to be quantized.

D Quantum gravity requires a common background

In this section, we consider an interesting problem of the quantization of GR. This problem has been the starting point for the author. It strongly suggest that for successful quantization GR should be modified, especially that it is necessary to introduce a common background manifold.

The main difference between GR and other theories including SR is that GR is a "one world theory". It does not have a possibility to compare different gravitational fields. In other theories we have some common background. This allows to talk about values at "the same point" for different solutions. In GR, this is not possible. Another solution may be defined even on another manifold.

This is not problematic because a possibility to compare different solutions is not necessary in the classical domain. As long as we consider classical gravitational fields, there is only one solution we can observe, there is only "one world". Therefore, in the classical domain a "one world theory" does not cause problems. But what about quantum superposition? In a superpositional state we can consider different classical solutions in a single state. Is a "one world theory" sufficient to describe superpositions? Or is there more information hidden in a superpositional state? Especially, is there information about relative position between the states which are in superposition?

This simple question may be the key for the understanding of quantum theory. There seem to be only two ways to answer this question: yes or no. The relativistic answer is a clear no. Our answer is a clear yes. A nice way to formalize the two possible answers has been proposed by Anandan [3]: the notions of c-covariance and q-covariance. We consider superpositions of quasi-classical gravitational fields. Now, we have to look what happens if we apply diffeomorphisms. We have different fields, and this raises the question if we are allowed to use different diffeomorphisms for these different fields or not. This leads to two ways to generalize classical covariance: The first, weak generalization is c-covariance – it requires covariance only if we apply the same diffeomorphism. The second, strong generalization is q-covariance – it allows different diffeomorphisms for the different states in superposition.

Now, the relativistic answer is unique – the only appropriate generalization is q-covariance. The reason is that c-covariance requires an essential modification of classical GR. Indeed, the Einstein equations of classical GR defines a pair of solutions only modulo q-covariance. The GR Lagrangian is also q-covariant. Thus, to define the evolution of c-covariant but not q-covariant objects we simply do not have appropriate equations in classical GR. Moreover, even the notion of "the same diffeomorphism" is not appropriately defined in GR. Different GR solutions live on different manifolds, and there is no well-defined notion of "the same diffeomorphism" on another manifold. This is the solution which has been proposed by Anandan too.

We have chosen the other way. We think that the description of a superposition requires additional, non-q-covariant information. The purpose of this section is to justify this choice.

Let's start with a simple question – the superposition of a state with a shifted version of itself: $|g_{ij}(x)\rangle + |g_{ij}(x-x_0)\rangle$. Do you really think this may be simply the original state, not a non-trivial superposition? I'm not. But, of course, this simple argument does not seem to be sufficient.

Fortunately, we can present a much stronger argumentation. As we see, already a very simple scattering experiment on such superpositional states gives observables which depend on "relative position".

D.1 A non-relativistic quantum gravity observable

In the consideration of quantum gravity, people usually consider two basic theories: classical general relativity and relativistic quantum field theory on a fixed background. But these are not really the theories which have to be unified – the gravitational field is classical in above theories. The interesting point of quantum gravity is, of course, the consideration of superpositions of gravitational fields. It is, last not least, superposition which makes quantum theory different from classical statistics. And this difference will be the point of our experiment: what we want to measure is the transition probability which decides if a superposition has been destroyed by measurement or not. The problem with semi-classical QFT is that it does not give a base for such considerations.

On the other hand, it is not at all difficult to compute such transition probabilities in a reasonable approximation. For this purpose, we can use a well-known simple theory which allows to consider non-trivial superpositions of gravitational fields. This theory is simply non-relativistic quantum gravity – classical multi-particle Schrödinger theory with Newtonian interaction potential.

There is nothing ill-defined with this theory. From theoretical point of view it works as well as multi-particle Schrödinger theory with Coulomb interaction potential. The fact that we have no data is not really problematic. Indeed, the theory unifies classical quantum principles with classical gravity in an ideal way. If somebody tends to doubt simply because there are no data, quantum gravity is a forbidden area for him. Thus, to assume the correctness of Schrödinger theory in the non-relativistic limit is not problematic. But, of course, it is a non-trivial decision: *We assume that classical Schrödinger theory is the non-relativistic limit of quantum gravity.*

Now, based on this non-relativistic theory we can consider simple gravitational scattering. This gives some insight into features of superpositions of gravitational fields, even if the field itself is not quantized. We simply have to consider superpositional states of an otherwise neutral particle. We need the particle only as a source of gravity. Thus, let's consider a situation like a double slit experiment, with some superpositional state $|\psi^1\rangle + |\psi^2\rangle$ of a source of gravity. For the interaction with a test particle $|\varphi\rangle$ only the gravitational field of the source is important. Thus, it is possible to interpret the interaction also as an interaction of the test particle $|\varphi\rangle$ with a superpositional state of the gravitational field $|g^1\rangle + |g^2\rangle$.

Now, let's make some simplifying assumptions. First, let the mass M of the source particle be much greater than the mass m of the test particle: $M \gg m$. In this case, the state of the heavy particle is much less influenced by the interaction than the state of the test particle. Let's also assume that the state of the source particle is highly localized: $\psi^1(x) \approx \delta(x - x_1)$, $\psi^2 \approx \delta(x - x_2)$. In this case, we can use single particle theory to compute the result of the interaction. Let's denote with φ^1, φ^2 the solution of the Schrödinger equation for the source particle located in x_1 resp. x_2. Then, for the two-particle problem with the initial values $|\psi^1\rangle \otimes |\varphi\rangle$ resp. $|\psi^2\rangle \otimes |\varphi\rangle$ we obtain approximately a tensor product solution $|\psi^1\rangle \otimes |\varphi^1\rangle$ resp. $|\psi^2\rangle \otimes |\varphi^2\rangle$. For the superpositional state $(|\psi^1\rangle + |\psi^2\rangle) \otimes |\varphi\rangle$ we obtain the solution by superposition:

$$|\psi^1\rangle| \otimes |\varphi^1\rangle + |\psi^2\rangle| \otimes |\varphi^2\rangle.$$

But this is equivalent to

$$(|\psi^1\rangle + |\psi^2\rangle) \otimes (|\varphi^1\rangle + |\varphi^2\rangle) + (|\psi^1\rangle - |\psi^2\rangle) \otimes (|\varphi^1\rangle - |\varphi^2\rangle)$$

Now, we are interested in the transition probability $|\psi^1\rangle + |\psi^2\rangle \to |\psi^1\rangle - |\psi^2\rangle$. We obtain

$$p_{trans} = \frac{1}{2}(1 - Re\langle\varphi^1|\varphi^2\rangle)$$

To understand why we are very interested in this transition probability let's consider the limiting cases: if $\langle\varphi^1|\varphi^2\rangle = 1$, gravitational interaction is not important, the position of the source particle does not influence the state of the test particle. Thus, the superpositional state remains unchanged, the interaction with the test particle was not a measurement of position of the source particle. We have a tensor product state. Therefore, we can ignore the test particle and obtain a pure one-particle state for the source.

In the other limiting case, the resulting states are orthogonal, $\langle\varphi^1|\varphi^2\rangle = 0$, therefore, the transition probability is $\frac{1}{2}$. We do not have a product state. If we ignore the test particle, we do not obtain a pure source particle state. Instead, we obtain a classical mixed state:

$$\frac{1}{2}(|\psi^1\rangle\langle\psi^1| + |\psi^2\rangle\langle\psi^2|)$$

Thus, the transition probability defines if the interaction was a measurement which has destroyed the superposition or not. If there is something which allows to distinguish a superposition from a classical mixed state, than this "something" gives us information about the transition probability. If not, then we cannot distinguish the superposition from a mixed state.

D.2 The problem: generalization to relativistic quasi-classical gravity

Therefore, this transition probability is very important. If it is not observable, what distinguishes the theory from a classical statistical theory? Is a theory which does not allow to distinguish a superposition from a classical mixed state worth to be named "quantum theory"? This seems questionable. Thus, the assumption that this transition probability remains observable in full, relativistic quantum gravity seems to be a very natural one.

Now, to compute the transition probability, we need the scalar product $\langle\varphi^1|\varphi^2\rangle$. For the derivation of this formula, we have used only very few fundamental principles. Therefore, it seems reasonable to assume that this formula may be generalized. We make the following hypothesis: *The scalar product $\langle\varphi^1|\varphi^2\rangle$ is well-defined in relativistic quantum gravity.*

Now, let's consider how to generalize it into the relativistic domain. The basic states of the source particle $\psi^1(x) \approx \delta(x - x_1)$ resp. $\psi^1(x) \approx \delta(x - x_1)$ we generalize into relativistic gravitational fields $g^1_{ij}(x)$ resp. $g^2_{ij}(x)$. For $\varphi(x)$ we have to solve now, instead of the classical Schrödinger equation, a similar wave equation on these background metrics. We ignore the related field-theoretical problems with particle creation and so on and assume that the field equations may be solved without problems. Thus, we obtain two solutions $\varphi^1(x)$ resp. $\varphi^2(x)$ for the two gravitational fields.

Now let's consider the computation of the scalar product $\langle\varphi^1|\varphi^2\rangle$, using the following naive formula as a base:

$$\langle\varphi^1|\varphi^2\rangle = \int \bar{\varphi}^1(x)\varphi^2(x)dx^3$$

The point is that this integral simply cannot be defined from point of view of classical general relativity. Indeed, if $g^1_{ij}(x)$ is a solution of the Einstein equations, we may apply an arbitrary transformation of coordinates and obtain the same solution in other coordinates. Now, if we apply such a transformation to $g^1_{ij}(x)$, the same transformation has to be applied to $\varphi^1(x)$ too to obtain the same solution in the other coordinates. But nothing requires to apply the same transformation to $g^2_{ij}(x)$ and $\varphi^2(x)$. Now, if we apply a coordinate transformation to $\varphi^1(x)$, but not to $\varphi^2(x)$, the result of the integral changes in a completely arbitrary way.

The same result may be formulated in another way: the functions $\varphi^1(x)$ resp. $\varphi^2(x)$ are defined on different manifolds – the manifolds defined by the spacetime metrics $g^1_{ij}(x)$ resp. $g^2_{ij}(x)$. And scalar products between functions on different manifolds are simply undefined.

A third way to formulate this result is that this scalar product is only c-covariant but not q-covariant. Indeed, the integral does not change if we apply the same diffeomorphism to above configurations, but changes if we apply different diffeomorphisms to above configurations. Therefore, it cannot be observable in q-covariant quantum GR.

A consequence of this situation is that GR is completely unable to make predictions for the scalar product, even if the scalar product is given for some initial values. Indeed, assume we have fixed some initial values $g^1_{ij}(x)$, $\varphi^1(x)$, $g^2_{ij}(x)$, $\varphi^2(x)|_{x^0=0}$ and an appropriate number of derivatives. Thus, for the initial values we have restricted the freedom of choice of diffeomorphisms. But this does not help: there are diffeomorphisms which are identical for the initial values, with all derivatives. And the Einstein equations define the solution only modulo arbitrary diffeomorphisms.

What seems to be even more serious is that the problem appears already in the non-relativistic limit. In Schrödinger theory, the scalar product is well-defined. But the gravitational field may be as close as possible to the non-relativistic situation, the scalar product remains completely undefined in relativistic theory. It seems therefore highly problematic to obtain Schrödinger theory as the non-relativistic limit of a q-covariant theory of quantum gravity.

D.3 The solution: a fixed space-time background

Let's look now how this problem is solved in GET. We have some well-defined Newtonian background which is common for all field configurations. The additional term in the Lagrangian does not only give some additional term in the Einstein equations, but breaks relativistic diffeomorphism invariance. We have four additional equations – the harmonic coordinate equations. They define the solution uniquely, not only modulo diffeomorphism.

Of course, "uniquely" is also a relative notion, it means relative to the Newtonian background. We can use the covariant formulation of GET, with a covariant equation for the variables used to define the background. The conceptual difference is that this background is common for all solutions.

The resulting quantum theory is not q-covariant, but only c-covariant. The relative position between a general field configuration and the common Newtonian background defines relative positions between different field configurations. This allows to define scalar products as well as the notion "the same diffeomorphism" which is necessary to define c-covariance.

Are there other ways to define the evolution of these scalar products? No. By accepting the existence and observability of the scalar product we have de facto accepted a common background manifold with preferred coordinates for all semi-classical gravitational fields. Indeed, we need only a few number of simple and natural restrictions to obtain a common position measurement for all gravitational fields.

Assume as before that we have two configurations of gravitational fields $g^1_{ij}(x)$, $g^2_{ij}(x)$ on manifolds M_1 resp. M_2 and some Hilbert space of appropriate wave functions $H(M_1)$ and $H(M_2)$. Now, we assume the element $\varphi^1(x) \in H(M_1)$ has well-defined "scalar products" with all elements of $H(M_2)$. But in this case it defines a linear functional on $H(M_2)$. A linear functional on $H(M_2)$ uniquely defines an element of $H(M_2)$. This construction defines a map $H(M_1) \to H(M_2)$.

Now, this map seems to be the appropriate place to define additional natural requirements. First, we need transitivity. If there are three spaces, the map $H(M_1) \to H(M_3)$ should be the same as the composition $H(M_1) \to H(M_2) \to H(M_3)$. As a special case $M_1 = M_3$ we obtain that the map $H(M_2) \to H(M_1)$ is the inverse of $H(M_1) \to H(M_2)$. Another property is that they are norm-preserving. This is required to have a consistent probability interpretation. Above restrictions may be justified in the same way we have justified the existence of the scalar product itself: these properties are fulfilled in Schrödinger theory.

But, once we have a norm-preserving map $H(M_1) \to H(M_2)$, we can use it to transfer a measurement from M_2 to M_1. Especially, we can transfer the position measurement for the manifold M_2 to $H(M_1)$. Now, we can choose an arbitrary solution as a reference solution and transfer its position measurement to all other states as the common background. Thus, we obtain a common background manifold for all field configurations. We are de-facto back to the scheme we use in GET, with a fixed common space-time background.

Thus, if we follow the relativistic paradigm and develop a q-covariant quantum theory of gravity, important observables of non-relativistic quantum gravity remain undefined. If we assume that they are well-defined, we have to reject the relativistic paradigm and to introduce a common background manifold into the theory. This consideration justifies the introduction of a fixed space-time background into GET.

D.4 Comparison of Regge calculus and dynamical triangulation

It is interesting to compare two well-known discrete approaches to quantum gravity – the Regge calculus [61] and dynamical triangulations (DT) from point of view of scalar product. In the Regge calculus, we have a fixed grid and the geometry is described by the edge lengths of the grid. In contrast, in DT the edge lengths are fixed but the triangulation varies.

Now, if we have some discrete functions defined for different geometries in the Regge calculus, we can define their scalar product without problem – we have the same grid as the base, therefore, for each point of one geometry we have a well-defined notion of "the same point" on the other geometry. Therefore, the Regge calculus is a nice example of a discrete c-covariant theory. Instead, in DT we do not have such a possibility. The scalar product between discrete functions on different triangulations is meaningless. Therefore, it is an example of a discrete q-covariant approach.

Thus, according to the ideology presented here, DT should be the "correct" way to quantize geometry in a diffeomorphism-invariant way, but leads to problems with the classical limit, while it should be reverse for the Regge calculus. Indeed, the review [21] shows exactly these properties of the two approaches: the Regge calculus with fixed grid contains steps of freedom which are unphysical from point of view of relativity, especially modes corresponding to general coordinate transformations, but it "possesses a weak field expansion in which contact can be made with continuum perturbation theory".

It is also noted that, at least for 2D, "the DT method affords a good prescription for regulating quantum gravity". But "there is no weak coupling limit in which contact can be made with continuum perturbation theory. Indeed, the attractive feature of this formulation – that it is purely geometric, making no reference to coordinates and metric tensors also poses a problem; how do such classical quantities emerge from the model at large distance".

I hope, these remarks help to clarify my understanding of the role of the scalar product problem: it does not claim that q-covariant theories are impossible. Instead, DT provides an example of the regularized version of such a theory. It also does not claim that by accepting the existence of a scalar product we immediately end with ether theory: there is a certain difference between Regge QG and our ether approach, especially in our ether approach the grid is not fixed, but moves, and the position of the grid nodes are steps of freedom of the ether approach.

The point is that a q-covariant approach has to be rejected because of the failure to define a scalar product between functions defined on different solutions, because such scalar products are necessary in the non-relativistic limit.

E Realism as a methodological concept

In § 15 we have not considered the EPR criterion of reality. There was no necessity for this, because we have considered it as part of common sense. To separate one of the common sense principles used in this proof and to name it "EPR criterion" is not necessary in our approach. Instead, it is part of the destruction strategy we have considered in section § 15.4.

Unfortunately, this destruction strategy was already successful. Therefore, it seems necessary to consider the part of common sense which has been named "EPR criterion of reality" and questioned in more detail.

E.1 Principles of different importance

If we have a contradiction between theory and experiment, there are always different parts of the theory which may be blamed for the problem. But often it is not too difficult to find the critical part. Usually it is very helpful that different parts are not on the same level of fundamentality. We usually can distinguish more and less fundamental parts of the theory, and in case of conflict we usually blame the less fundamental parts to be the cause of the problem. Let's consider, for example, the dark matter problem. We observe a difference between the Einstein equations and observation:

$$G^{\mu\nu} \neq 8\pi G T^{\mu\nu}_{obs}$$

In this case, we do not reject GR because it's main equation is falsified by observation. Instead, we simply define the energy-momentum tensor of "dark matter" as

$$T^{\mu\nu}_{dark} = G^{\mu\nu} - 8\pi G T^{\mu\nu}_{obs}$$

and obtain that the Einstein equations are fulfilled. In this case, our existing theory of matter is considered to be less fundamental. In this case, this seems to be a reasonable choice.

We argue here that the situation is different for the violation of Bell's inequality. The other principles involved in the proof of Bell's inequality, which we denote here as the principles of realism and which include the EPR criterion of reality, are more fundamental than the particular assumption about space-time symmetry known as relativity. Especially, we argue that these other principles are fundamental methodological principles, part of the methodological foundations of science. Thus, they are important as in physics, as in other sciences.

Note that this argument is only additional support for our argumentation. There is already another argumentation which is completely sufficient for a unique decision in favor of realism: There is independent evidence against relativity – their problems with quantum gravity, especially the problem of time (appendix C). Moreover, there is a viable competitor of relativity – ether theory – which has been developed to solve these other problems. Instead, nobody has proposed a theory which, for independent reasons, rejects realism. Moreover, there is simply no independent evidence against realism: as we have seen, quantum theory is compatible with realism.

E.2 A definition of reality and causal influence

Let's try to define classical realism in a way which allows a strong mathematical proof of Bell's inequality based on this notion of realism. Realism in the common sense proposes the existence of an observer-external reality which *exists* independent of our observation. The results of observations may be results of complex interactions between reality and observer, nothing requires a possibility of direct observation. To define realism we need at least the following three entities: of course the **observables**, but also the **decisions** of the experimenters what to measure, and last not least the **reality**. But that's all we need:

Axiom 1 (reality) *Assume we have an experiment described by observables* X *with the observable probability distribution* $\rho_X(X, x)dX$. *It depends on a set of control parameters* x *which describe the experimental setup (the decisions of experimenters).*

A theory is realistic if it describes such probability distributions based on a notion of **reality** *– a space* Λ *(reality) with probability distribution* $\rho_\lambda(\lambda)d\lambda$ *– and a* **realistic explanation** *– a function* $X(x, \lambda)$ *– so that for a test function* f

$$\int f(X)\rho_X(X, x)dX = \int f(X(x, \lambda))\rho(\lambda)d\lambda$$

This formal definition is in quite good agreement with the common sense idea that reality λ exists independent of our decisions x: the probability distribution $\rho(\lambda)$ indeed does not depend on x. But it already incorporates the insight that there is no pure observation, that our observations are only the result of complex interactions between observer and reality. An argumentation that classical realism is invalid because observations are only the result of such interactions is, therefore, invalid: this possibility is already part of classical realism.

Note that already on this level, without any relation to space-time, we can define causal influences in a natural way:

Axiom 2 (causal influence) *If in a realistic theory an observable* X *depends on a control parameter* x *in the realistic explanation* $X(x, \lambda)$, *then we have a* **causal influence** *of* x *on* X.

E.3 Bell's inequality as a fundamental property

These definitions are already sufficient for the proof of Bell's inequality. In the case of Bell's inequality, the control parameters are the questions: your question a to Alice and your friends question b to Bob. The observables are their answers A and B. Using the definition of realism we obtain the existence of two functions:

$$A = A(a, b, \lambda) = \pm 1; \qquad B = B(a, b, \lambda) = \pm 1$$

We also obtain the expectation value for the product AB as

$$P(a,b) = \int \rho(\lambda)A(a,b,\lambda)B(a,b,\lambda)d\lambda.$$

Now we have to consider causality. If there is no causal influence of the decision b on the result A, then we have $A = A(a,\lambda)$ and resp. $B = B(b,\lambda)$. Thus, we obtain

$$P(a,b) = \int \rho(\lambda)A(a,\lambda)B(b,\lambda)d\lambda$$

which is simply formula (2) of [10]. After this, Bell's inequality follows as derived in [10].

As a consequence, we obtain the proof of Bell's inequality on a level where even the *existence* of something like space-time has not been mentioned, and therefore in a space-time independent form: if it is violated, this proves the existence of causal influences $(a \to B)$ or $(b \to A)$.

E.4 The methodological character of this definition

A remarkable property of this definition is its unfalsifiable character. Whatever we observe, it is possible to describe it using a probability distribution $\rho_X(X,x)dX$. Whatever this probability distribution is, we can always construct a realistic theory which leads to this distribution – all we have to do is to use a (sufficiently artificial) functional space to describe the reality. Especially, reality may be described simply by the measure $\rho_X(X,x)dX$ itself.[13]

The reasonable question is about the purpose of this definition if it is unfalsifiable. Now, there is a surprisingly simple answer: realism is simply a *methodological rule*. It *enforces* to describe certain parts of the theory as *really existing*. As well, the subsequent definition of a causal influence is also unfalsifiable. The purpose of this definition is, as well, to *enforce* to name some relations *causal influence*. In other words, this definition of realism and causality enforces ontological clarity. A realistic theory is a theory where we

[13]As the many worlds interpretation, as Bohmian mechanics may be considered as realistic theories obtained as variants of this "cheap" way – they simply accept the wave function as reality.

are forced to name some things real and some influences causal, even if this violates our metaphysical prejudices or principles of the theory we prefer.

Especially this *definition* of realism and causality, a definition already enforces that any violation of Bell's theorem should be explained by causal influences – or $a \to B$ or $b \to A$.

E.5 Causality requires a preferred frame

It does not follow from the *definition* that these causal influences happen in a preferred frame. To prove the existence of a preferred frame we need a little bit more. First, the connection between causality and space-time. Until now, even the existence of something like a space-time has not been mentioned. Only now we have to define causality on space-time as a relation $x \to y$ between space-time events x, y: $x \to y$ if there exists some $a \to A$ so that the decision a is localized at x and the observation A localized at y. Moreover, we need the most important property of causality: the causal order along a world line and the absence of causal loops.

Axiom 3 (space-time causality) *Causality defines a partial order $x \to y$ on space-time with the property that on time-like trajectories $\gamma(t)$ we have $\gamma(t_0) \to \gamma(t_1)$ if $t_0 < t_1$.*

Now, we can simply prove the existence of a preferred foliation: [14]

Theorem 8 (existence of a preferred foliation) *If for all pairs of events Bell's inequality may be violated, then there exists a preferred foliation. It is defined by the property that if $x \to y$ than $T(x) < T(y)$ for the function T(x) which defines this foliation.*

Proof: Let's define the foliation as a time-like function $T(x^i, t)$. For this purpose, we set $T(0, t_0) = t_0$ and define the points contemporary to $A =$

[14] That the existence of a preferred foliation follow is nothing new. Valentini [71] suggests "that a preferred foliation of spacetime could arise from the existence of nonlocal hidden-variables" [39]. Bell himself concludes [11]: "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."

$(0,0,0,t_0)$ on the line $B(t)=(x^1,x^2,x^3,t)$. We use the Dirichlet algorithm on the line $B(t)$. We start with a large enough interval (a_0,b_0) so that there exists causal influences $B(a_0)\to A\to B(b_0)$. Assume at step n we have found an interval $B(a_n)\to A\to B(b_n)$ with $|b_n-a_n|<2^{-n}|b_0-a_0|$. Now, we consider the element $B(h=(b_n+a_n)/2)$. Then we observe a violation of Bell's inequality between A and $B(h)$. It follows from Bell's theorem that there should be $A\to B(h)$ or $B(h)\to A$. In the first case, we set $a_{n+1}=a_n, b_{n+1}=h$, else $a_{n+1}=h, b_{n+1}=b_n$. In above cases we have found an interval with $B(a_{n+1})\to A\to B(b_{n+1})$ with $|b_{n+1}-a_{n+1}|<2^{-n-1}|b_0-a_0|$. Therefore, we have a limit $l=\lim a_n=\lim b_n$. This limit defines a function $T(x^1,x^2,x^3,t_0)=l$.

To prove that the function $T(x)$ is correctly defined, Lipschitz continuous, and that the definition of the foliation does not depend on the choice of coordinates is straightforward. What we need is that in every environment of $B(l)$ we have points a_n with $B(a_n)\to A$ as well as points b_n with $A\to B(b_n)$, the non-existence of causal loops, and the existence of causal ordering $B(a)\to B(b)\Leftrightarrow a<b$ on time-like trajectories $B(t)$.

E.6 Relation between our definition and the EPR criterion

Let's consider now the difference between this definition of realism and the EPR criterion of reality [28]:

> If, without in any way disturbing a system, we can predict with certainty ... the value of a physical quantity, than there exists an element of physical reality corresponding to this physical quantity.

Now, this is a natural consequence of our definition of realism: We have no "disturbance", thus, no dependence of A on b: $A=A(a,\lambda)$. If it is a prediction, because we have no influence backward in time, we have no dependence of B on a: $B=B(b,\lambda)$. It is a prediction with certainty, thus, these functions are identical as functions: $A(.,\lambda)=B(.,\lambda)$. Last not least, λ is the "element of reality" and the function $A(.,\lambda)$ describes the correspondence to the physical quantity A.

The advantages of our new definition are, in our opinion, the following: we have a general definition, while the EPR mentions a special situation –

a correlation which allows to predict something with certainty, and we do not depend on the notion of space-time, while the EPR criterion includes an implicit reference to time ("predict"). Moreover, the formal character of the definition allows to show its methodological character: it does not restrict physical theories, but restricts our way to talk about them.

E.7 Methodological principles as the most fundamental part of science

Once we defend realism as a fundamental methodological principle it seems useful to look how other fundamental principles of science may be defended. There is another such fundamental methodological principle – classical logic, especially the law that there should be no contradictions, nor in the theory, nor between theory and observation. As our definition of realism and causality these principles are unfalsifiable themself – simply because the principle of falsification itself relies on classical logic.[15] Therefore, other arguments have to be used to defend them. In this context, it is interesting how Popper defends classical logic against "dialectical logic" ([56], p.316):

> Dialecticians say that contradictions are fruitful, or fertile, or productive of progress, and we have admitted that this is, in a sense, true. It is true, however, only so long as we are determined not to put up with contradictions, and to change any theory which involves contradictions; in other words never to accept a contradiction: it is solely due to this determination of ours that criticism, i.e. the pointing out of contradictions, induces us to change our theories, and thereby to progress. It cannot be emphasized too strongly that if we change this attitude, and decide to put up with contradictions, then contradictions must at once lose any kind of fertility.

Thus, the point of the argumentation is not to prove that there can be no contradictions. The basic idea is that we have to consider not the hypothesis

[15] If they are false, then the method of falsification is false too, therefore, cannot be used. Even if the use of rational arguments, especially the "therefore" in the last sentence, is also unjustified, this argument seems to show that an experimental falsification of classical logic is impossible.

itself, but their influence on the future development of science. That means, Popper defends classical logic as a methodological rule of science.

The main advantage of this argumentation is that we do not have to rely on "common sense" – a notion which has a bad name in current science and is usually compared with flat Earth theory. Classical logic is not a particular common sense theory like flat Earth theory which may be false, but defines the scientific method, therefore, if we reject classical logic, we simply reject the scientific method.

Our notion of realism is fertile in the same sense as classical logic. It is the rule to search for realistic, causal explanations for observable correlations. A non-trivial, unexplained correlation plays the same role as the contradiction in logic: it defines a scientific problem. We have to include a realistic explanation into our theory. Nobody forces us to search for explanations, it is only our own *methodological decision* not to accept unexplained correlations, and to accept only a realistic explanation. If we give up the search for realistic explanations, we loose an important way to reach scientific progress.

E.8 The methodological role of Lorentz symmetry

The great importance of Lorentz symmetry in modern physics is often presented as if it is a decisive argument against a preferred frame. But this suggests that Lorentz symmetry would have been less important in the Lorentz ether. Is there any evidence for this claim? I have never seen any justification for this assumption. It is simply claimed, without justification, that people would have been less eager to search for relativistic symmetry. The reverse may be closer to truth. Instead, with the Lorentz ether as the leading ideology, people would have tried to detect hidden Lorentz symmetry in usual condensed matter theory.

Moreover, without doubt any part of the hidden variables which can be made Lorentz-covariant would have been made Lorentz-covariant. An example are the equations of GET presented here. The new equation for the preferred coordinates is a nice, well-known relativistic equation – the harmonic equation. Moreover, the thesis is in obvious contradiction to the history of the Lorentz ether. In the context of the Lorentz ether, by Poincare, the program to make all physical theories Lorentz-invariant has been proposed in general and realized for kinematics. The decision to reject the existence of a preferred frame made by Einstein was in no way necessary for the development of this program.

The point is that to require a particular symmetry is not a general methodological rule of scientific research. At best there is the related methodological rule to search for symmetries in general. But even this rule seems much less fundamental than classical logic and realism: last not least, we search for symmetries in reality. Symmetries are a powerful *tool* to study realistic theories, to detect contradictions in such theories or between theory and experiment – but only a tool, in no way a fundamental principle.

E.9 Discussion

As presented here, the preferred frame is the unavoidable consequence of the violation of Bell's inequality. Relativity is falsified by Aspect's experiment, and its current status should be rejected as an immunization. This is so obvious that it becomes problematic to explain the unreasonable decision of mainstream science to reject realism. But there are several factors which may be blamed here:

- The absence of a reasonable theory of gravity with preferred frame. This problem is solved now by GET.
- The widely accepted belief, based on von Neumann's [54] theorem, that hidden variable theories are impossible. This was justified at the time the EPR criterion was proposed, but many seem to believe it even today.
- The ignorance of Bohmian mechanics *because* it requires a preferred frame.
- The extreme positivism and subjectivism during the foundational period of quantum theory.
- The general ignorance of fundamental problems of quantum theory today.

But the most important explanation seems to be Kuhn's theory of paradigm shifts [44]. According to Kuhn, paradigms are never falsified by experiments. A paradigm may be rejected only if a new paradigm appears.

Until now, no alternative paradigm has been proposed, therefore, to preserve the relativistic paradigm was justified – in full agreement with Kuhn's paradigm shifts.

We propose here a new paradigm – a return to classical Newtonian spacetime and ether theory. With this paradigm as a competitor of the relativistic paradigm it is no longer necessary to reject realism or causality.

F Bohmian mechanics

An essential property of non-relativistic Schrödinger theory is the existence of a simple deterministic interpretation – Bohmian mechanics (BM). We refer to this theory in our proof that EPR realism is not in conflict with non-relativistic quantum theory. Unfortunately, BM is widely ignored. The main reason for this ignorance seems to be that it requires a preferred frame – thus, a feature which makes it particularly attractive in the context of GET. Therefore, it seems reasonable to consider the basic features of BM here.

F.1 Simplicity of Bohmian mechanics

BM may be considered as a straightforward way to complete quantum mechanics. In BM, we have two entities: the "guiding wave" $\Psi(q)$ defined on the configuration space which fulfills the classical Schrödinger equation

$$i\partial_t\Psi = H\Psi$$

and the configuration $Q(t)$ which fulfills the so-called "guiding equation". This guiding equation may be obtained in a straightforward way from quantum mechanics. The basic observation is the following: quantum mechanics provides us with a probability current $j^i(q)$ as well as with a probability density $\rho(q) = \Psi^*(q)\Psi(q)$. In classical mechanics they are related by $j^i(q) = \rho(q)v^i(q)$. Now it requires no great imagination to write the guiding equation

$$\frac{dQ}{dt} = v^i = \frac{j^i}{\rho}$$

This defines the evolution of the state. Now, if in initially the state is in the so-called "quantum equilibrium" $\rho(q)$, then it remains in this state. This follows from the continuity equation

$$\partial_t \rho(q,t) + \partial_i j^i(q,t) = 0$$

That's already all what is necessary. There is no need for further axioms. Therefore, all we need for the definition of Bohmian mechanics is the quantum probability current. For example, in non-relativistic multi-particle theory

$$H = -\sum_{k=1}^{N} \frac{\hbar^2}{m_k^2} \nabla_k^2 + V(q_1, \ldots, q_N)$$

this probability current is given by

$$j_k = \frac{\hbar}{m_k} \Im(\psi^* \nabla_k \psi)$$

Therefore, we obtain the guiding equation

$$\frac{dQ_k}{dt} = \frac{\hbar}{m_k} \Im \frac{\nabla_k \psi}{\psi}$$

F.2 Clarity of the interpretation

The first thing we have to note here is the ontological clarity. To quote Bell ([9], p.191):

> Is it not clear from the smallness of the scintillation on the screen that we have to do with a particle? And is it not clear, from the diffraction and interference patterns, that the motion of the particle is directed by a wave? ... This idea seems to me so natural and simple, to resolve the wave-particle dilemma in such a clear and ordinary way, that it is a great mystery to me that it was so generally ignored. ...

This solution of the wave-particle confusion not the main point: in BM there is also nothing strange with Schrödinger's cat. The wave function of the cat remains in its superpositional state, but the actual cat is in a well-defined state. "There is no need in this picture to divide the world into 'quantum' and 'classical' parts. For the necessary 'classical terms' are available already for individual particles (their actual positions) and so also for macroscopic assemblies of particles." ([9], p.192)

Another interesting question is worth to be mentioned: why are the states we observe in quantum equilibrium? This question has an interesting answer: decoherence. "One of the best descriptions of decoherence, though not he word itself, can be found in Bohm's 1952 'hidden variables' paper [16]. We wish to emphasize, however, that while decoherence plays a crucial role in the very formulation of the various interpretations of quantum theory loosely called decoherence theories, its role in Bohmian mechanics is of quite different character: For Bohmian mechanics decoherence is purely phenomenological – it plays no role whatsoever in the formulation (or interpretation) of the theory itself" [27].

The most important property of BM is it's compatibility with classical principles: the EPR criterion of reality, classical causality, determinism. Let's quote again Bell ([9], p.163):

> It is easy to find good reasons for disliking the de Broglie-Bohm picture. Neither de Broglie nor Bohm liked it very much; for both of them it was only a point of departure. Einstein also did not like it very much. He found it 'too cheap', although, as Born remarked, 'it was quite in line with his own ideas'. But like it or lump it, it is perfectly conclusive as a counter example to the idea that vagueness, subjectivity, or indeterminism, are forced on us by the experimental facts covered by non-relativistic quantum mechanics.

F.3 Relativistic generalization

Let's consider now the main point why many researchers dislike BM – its relativistic generalization. The same basic scheme works as well in relativistic theory and field theory. For example, for multiple Dirac particles Bohm [17] has proposed the following guiding equation:

$$\mathbf{v}_k = \frac{\psi^+ \alpha_k \psi}{\psi^+ \psi}$$

For the general case of quantum field theory, we have to accept the lectures of quantum field theory what is the appropriate notion of the wave function: “Certainly the Maxwell field is not the wave function of the photon, and for reasons that Dirac himself pointed out, the Klein-Gordon fields we use for pions and Higgs bosons could not be the wave functions of the bosons. In its mature form, the idea of quantum field theory is that quantum fields are the basis ingredients of the universe, and particles are just bundles of energy and momentum of the fields. In a relativistic theory the wave function is a functional of these fields, not a function of particle coordinates” [78]. Thus, it does not make sense to search for a guiding equations for particles in the general case, and we have to consider Bohmian field theory [17] where we obtain a guiding equation for generalized coordinates – the field configuration.

Thus, the generalization itself is not problematic. It is an essential property of this generalization – that it has an explicit preferred frame on the fundamental level. The predictions are nonetheless Lorentz-invariant. For example, $\psi^{+}\psi$ is an equivariant ensemble density *in the chosen reference frame.* It reproduces the quantum predictions in this frame. These predictions don't contain a trace of the preferred frame. Lorentz invariance holds on the observational, but not on the fundamental level. The 4-tuple $(\psi^{+}\psi, \psi^{+}\alpha_k\psi)$ is not a 4-vector for $N > 1$.

This is not an accident. “There does not in general exist a probability measure P on N-paths for which the distribution of crossing ρ^{Σ} agrees with the quantum mechanical distribution on all space-like hyper-planes Σ” [12]. This assertion is a more or less immediate consequence of Bell's inequality: by means of a suitable placement of appropriate Stern-Gerlach magnets the inconsistent joint spin correlations can be transformed to (the same) inconsistent spatial correlations for particles at different times [12]. Thus, we have the probability measure $\rho = |\psi|^2$ only in one frame. But this measure in just *one* frame is sufficient to derive the quantum mechanical predictions for observations at different times.

F.4 Discussion

The fact that Lorentz invariance does not hold on the fundamental level is often considered as a decisive argument against BM. But from point of view of ether theory this becomes a virtue rather than a vice: every argument in favour of BM becomes an argument in favour of the preferred frame we use in ether theory. To use the argument “there is no fundamental Lorentz-invariance" against BM in this context would be simply circular reasoning – a main concept of ether theory is as well that there is no fundamental Lorentz-invariance.

Thus, BM gives additional support for one of the main ingredients of GET – the preferred absolute time. One the other hand, GET gives support to BM – it shows a way to generalize BM to gravity. We do not have to try to find Lorentz-invariant versions of BM, as tried, for example, in [12]. Instead, we can apply BM as it is, with a preferred frame, in GET or, even better, in an atomic ether theory.

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