Abstract

We define a new paradigm — postrelativity — based on the hypothesis of a preferred hidden Newtonian frame in relativistic theories. It leads to a modification of general relativity with ether interpretation, without topological problems, black hole and big bang singularities. Semiclassical theory predicts Hawking radiation with evaporation before horizon formation. In quantum gravity there is no problem of time and topology. Configuration space and quasiclassical predictions are different from canonical quantization of general relativity. Uncertainty of the light cone or an atomic structure of the ether may solve ultraviolet problems. The similar concept for gauge fields leads to real, physical gauge potential without Faddeev-Popov ghost fields and Gribov copy problem.

Postrelativity — A Paradigm For Quantization With Preferred Newtonian Frame

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1 Introduction

"Postrelativity" is a new paradigm about space, time and causality alternative to the usual, relativistic paradigm of curved spacetime. The name should suggest that it revives pre-relativistic notions combined with incorporation of relativistic results. It is defined by the following principles:

1. Classical quantum framework: Quantum theory has to be based on the complete framework of standard, classical quantum theory.

2. Restricted relativity: Relativistic invariance is not required. Relativity remains to be a powerful guiding principle, but only in a restricted sense. A relativistic expression has to be chosen whenever possible without violation of the first principle.

The introduction of a new paradigm requires "postrelativization" of current physics — the development of postrelativistic versions of existing relativistic theories and reconsideration of relativistic quantization problems. The aim of this paper is to give an overview of the results, hypotheses and ideas we have obtained following this program.

At first, we give a justification for our choice of principles. Postrelativity may be understood as a reformulation of the known "preferred frame hypothesis" — the existence of a hidden Newtonian frame is the most interesting consequence of postrelativity. This reinterpretation as an alternative paradigm removes the main argument against this hypothesis — incompatibility with the relativistic paradigm.

Postrelativity already requires a modification of classical general relativity. We have to incorporate a Newtonian background frame as a hidden variable. This leads to minor but interesting differences like a different scenario for the black hole collapse without singularity and well-defined local energy and momentum conservation. This postrelativistic theory of gravity suggests an interpretation as an ether theory with dynamical ether described by deformation tensor, velocity and a scalar material property — the local speed of light. The tetrad formalism may be incorporated, reduces to a triad variant and suggests interpretation as crystal structure of the ether.

In scalar semiclassical theory we define the configuration space independent on the gravitational field via canonical quantization. The vacuum state and the Fock space structure appear only as derived notions, uniquely defined but dependent on the gravitational field and time. Hawking radiation is a necessary consequence of this approach. The black hole evaporates before horizon formation. The introduction of tetrad formalism allows to generalize this scheme to particles with spin. Using semiclassical considerations the Feynman diagram technique may be justified only for the first order tree approximation and for momentum below Planck scale.

In quantum theory, the Newtonian background frame remains fixed and certain. On the other hand, the gravitational field, especially the light cone, becomes uncertain. The uncertainty of the light cone may remove ultraviolet problems by regularization of the light cone singularities. Another possibility to remove ultraviolet problems may be the introduction of an atomic structure of the ether, without necessity of discretization of space or time required by the similar relativistic concept.

We consider canonical quantization and the path integral formulation as possibilities for quantization. We observe some essential simplifications compared with the canonical quantization of general relativity. Especially we have no problem of time and no topological foam. We also find a difference in the configuration space. This suggests that above approaches lead to quantum theories with different experimental predictions because of different definition of the Pauli principle.

For quasiclassical theory we consider a simple gedanken-experiment to find differences between the postrelativity and relativity. In postrelativity we are able to make predictions which coincide in the non-relativistic limit with Schrödinger theory. These predictions cannot be made in the relativistic approach because of symmetry reasons. This suggests that in the relativistic approach it is problematic if not impossible to derive Schrödinger theory as the non-relativistic limit.

Then we use the similarity between gauge theory and gravity to find a version of gauge theory which corresponds to postrelativistic gravity. In this postrelativistic gauge theory the gauge potential becomes a real, physical variable, the Lorentz condition has to be interpreted as a physical evolution equation. The configuration space of postrelativistic gauge theory contains different gauge-equivalent gauge potentials as different states. This leads to different experimental predictions at least for non-Abelian gauge theory. Because of the absence of a gauge-fixing procedure there will be no Faddeev-Popov ghost fields and no problems with Gribov copies. Similar to gravity, a quasiclassical gedanken-experiment suggests problems of the relativistic approach with the Schrödinger theory limit.

Last not least, we discuss some esthetic, metaphysical and historical questions related with the postrelativistic approach.

2 The Principles of Postrelativity

This may be considered as the diametrically opposite to Einstein's concept that general relativity is more fundamental compared with quantum theory.

It is known that some problems of relativistic quantum theory, especially the problem of time [19] and the violation of Bell's inequality [7] for realistic hidden variable theories allow a solution by assumption of a preferred but hidden Newtonian background frame.

This "preferred frame hypothesis" is usually not considered as a serious alternative. The reason is that it is not compatible with the relativistic paradigm — the philosophical and metaphysical ideas about space and time related with Einstein's special and general relativity. This obvious incompatibility is usually solved in favour of the relativistic paradigm. But we consider the problems solved by the preferred frame hypothesis — especially the problem of time — as serious enough to try the other way and to reject the relativistic paradigm. This requires to replace it by an alternative paradigm which is not in contradiction with the preferred frame hypothesis.

2.1 A Simple Fictional World

Let's consider at first a simple fictional world. This world is non-relativistic, with a classical Newtonian frame. By unspecified reasons, measurement is very restricted, especially for length to rulers of a single material. That means, length comparison of different materials cannot be used to built a thermometer. We assume that temperature is not observable by other methods too.

Nonetheless, a non-constant temperature distribution may be observed by length measurement. Indeed, it leads to nontrivial curvature of the metric defined by this length measurement. On the other hand, length measurement cannot be used to observe the Newtonian background. It would be no wonder if it would be able to derive a "theory of relativity" with temperature as an unobservable, hidden potential, which is able to explain all classical observations.

On the other hand, it is clear that it would not be possible to extend this relativistic theory to the quantum domain. The correct quantum theory is — per construction — classical quantum theory. An identification of states with identical metric but different Newtonian background would be wrong.

We see, that a situation where the preferred frame hypothesis is correct and the relativity principle valid in the classical limit but restricted in general is imaginable. It may be not an inherent problem, but only a restriction of our observation possibilities, which hides the Newtonian background frame. It would be not the first time in history we have to learn about the restricted possibilities of mankind.

In principle, postrelativity may be considered as an attempt to find out if we live in a similar situation. The two principles we have formulated for postrelativity can be considered as derived from the general idea of a hidden preferred frame, by analogy from this fictional world. Let's now consider these principles in detail.

2.2 Classical Framework

At first let's consider the first principle. It describes the general, metaphysical and philosophical foundations of the theory and an essential part of the mathematical apparatus. It is the apparatus of classical quantum theory. This apparatus in no way requires to reject relativistic field theories. As we will see below, we don't have to modify very much to incorporate them into the classical framework.

Thus, the general structure and the symmetry group of the theory is classical, relativistic properties follow only from the physics, from properties of the Schrödinger operator.

Of course, this general notion "framework" is a little bit uncertain yet. In some sense, this is natural — it is possible to modify or remove some parts from the notion "framework" if they cause problems in future without giving up the whole concept. Thus, the specification below is also a description of the state of the research which parts of the classical framework do not cause problems in the following.

2.2.1 Contemporaneity, Time and Causality

Absolute contemporaneity is the most important, characteristic part of the classical framework. Remark that this contemporaneity is not considered to be measurable with clocks. The impossibility of an exact measurement of time is known from quantum mechanics: Any clock goes with some probability even back in time [19]. Absolute contemporaneity leads also to absolute causality.

Together with contemporaneity we require symmetry of translations in time. But, because we have no time measurement, we have no natural unit. We have only an affine structure in time direction.

2.2.2 The General Principles of Quantum Mechanics

We require the standard mathematical apparatus of quantum mechanics, that means, the Hilbert space, states as self-adjoint, positive-definite operators with trace 1, observables as projective operator measures, and evolution as an unitary transformation. Any of the usual interpretations of this apparatus can be used.

We consider classical theory to be only the limit $\hbar \to 0$ of quantum theory. In this sense, quantization is an incorrect, inverse problem, and canonical quantization is considered only as a method to obtain a good guess. But, of course, for a given classical theory, the canonical quantization has to be tried at first.

We do not include into the classical framework any requirements about the Hamilton operator other than to be self-adjoint and time-independent.

2.2.3 Space, Translations and the Affine Galilee Group

The next required part of classical quantum theory is the three-dimensional space and the group of translations in space. This allows to define position and momentum measurement, the standard commutation relations and the related standard simplectic structure of the phase space.

Remark that we have not included a metric of space or time into the classical framework. Indeed, the metric occurs in the Hamilton formulation of classical mechanics only in the Hamilton function and is that's why not part of the framework. Thus, the symmetry group of the classical framework as we have defined it here is not the classical Galilee group, it but the affine variant of this group. This group contains the following subgroups:

- translations in space;
- translations in time;
- the classical Galilee transformations ($x'^i = x^i - v^i t$);
- linear transformations in space ($x^{i'} = a^{i'}_j x^j$);
- linear transformations in time ($t' = at$);
- and, of course, any compositions.

Remark that because of the absence of a distance in space there is no preferred subgroup of rotations. In the following we name this group the "affine Galilee group".

2.2.4 Configuration Space

The configuration space has to be defined in an affine-invariant way. Another requirement is locality. That means, field operators dependent on position for different positions have to be independent.

Another question is the independence between different fields in the same point. In classical quantum theory, the configuration space is a tensor product of the configuration spaces for different steps of freedom. The interaction is defined by the Hamilton operator, not by nontrivial configuration space structure.

Such a tensor product structure allows a simple operation — to ignore the state of another step of freedom. We don't have to specify a complete measurement for all steps of freedom, but can define such a complete measurement by the measurement of interest for one step of freedom and "some other measurement" for the other steps of freedom. To ignore other steps of freedom is a measurement of these steps of freedom which seems easy to realize, thus, it is a natural assumption that this is possible.

Thus, if for a given theory it is possible to find a formulation with tensor product structure of the configuration space, it is reasonable to prefer this variant, at least by Ockham's razor. Of special interest is of course the independence between gravity and matter. As we will see below, it is possible to introduce a tensor product structure into the configuration space of postrelativistic quantum gravity.

2.3 Restricted Relativistic Invariance

The second principle is formulated in a very weak form, but nonetheless remains very powerful. De-facto, all what has been done in the relativistic domain, with small exceptions, has to be incorporated because of this principle. The restriction leads usually only to one modification: An object which is not relativistic invariant has in relativity the status "not existent", in postrelativity it has the status "maybe not observable".

Roughly speaking, it can be said, that the first principle describes the framework, the second tells that we have to make the contents as relativistic as possible.

3 Classical Postrelativistic Gravity

At first, it may be assumed that our set of principles leads to contradictions already in the classical limit $\hbar \to 0$. This is not the case. We present here a theory which is in full agreement with the principles of postrelativity and in agreement with experiment named (classical) postrelativistic gravity (PG). It can be considered as a generalization of the Lorentz-Poincare version of special relativity [26] to general relativity. It may be interpreted also as a classical ether theory. It can also be considered as a minor modification of general relativity which de-facto is not distinguishable from general relativity by classical experiment.

PG can be derived from the postrelativistic principles at least in an informal way: There have to be an absolute affine time t and an absolute affine space like in classical theory because of the first principle. The evolution of the additional variables — like for all variables — has to be fixed by evolution equations. If possible, we have to use a relativistic equation because of the relativistic principle. The existence of such relativistic equations — the harmonic coordinate condition is a relativistic wave equation for the harmonic coordinates — shows that this is possible and that's why fixes the harmonic equation as the evolution equation.

3.1 The Equations of Classical Postrelativistic Gravity

In the classical formulation we have preferred coordinates - affine space coordinates and time. The gravitational field is described like in general relativity by the tensor field $g_{ij}(x,t)$. General-relativistic time measurement is described like in general relativity by proper time:

$$\tau = \int \sqrt{g_{ij}(x,t)\frac{dx^i}{dt}\frac{dx^j}{dt}}dt$$

The equations of the theory are the Einstein equations

$$R_{ik} - \frac{1}{2}g_{ik}R = \frac{8\pi k}{c^4}T_{ik}$$

and the harmonic conditions

$$\partial_i \left(g^{ik}\sqrt{-g}\right) = 0$$

As equations for the material fields we also use the same equations as general relativity. The coordinates are interpreted as affine coordinates of a hidden but real Newtonian frame. This defines an absolute contemporaneity and absolute causality as required by the first principle.

Local existence and uniqueness theorems can be easily obtained. Indeed, the existing results for general relativity use harmonic coordinates and can be interpreted as theorems for postrelativistic gravity combined with the derivation of the general-relativistic results from these theorems.

PG does not define distances for the background structure, nor in space, nor in time. Thus, the symmetry group of PG is the affine Galilee group.

3.1.1 Covariant Formulation

Of course, we can give also an equivalent covariant formulation of the theory. In this formulation, we introduce a covariant derivative $\tilde{\nabla}$ (different from the covariant derivative defined by the metrical tensor) and a global function t and describe them by the following equations:

$$\left[\tilde{\nabla}, \tilde{\nabla}]\right] = 0$$

$$\tilde{\nabla}_i \left(g^{ik}\sqrt{-g}\right) = 0$$

$$\tilde{\nabla}_i\tilde{\nabla}_j t = 0$$

Let's remark also that the preferred coordinates fulfil relativistic wave equations:

$$\Box x^i = 0; \ \Box t = 0;$$

3.2 Properties of the Theory

The background framework of PG is hidden from direct observation, but nonetheless modifies some properties of the theory. Indeed, the assumption of additional hidden but real variables can forbids solutions which do not allow the introduction of these variables, can modify the definition of completeness of a solution, can change the symmetry group of the theory and through the Noether theorem the conservation laws. All these effects we find in the relation between PG and GR. They are similar to the differences found by Logunov et.al. [24], [33] for their "relativistic theory of gravity", a similar theory but with a special-relativistic instead of Newtonian background.

But, at first, remark that for every solution of PG we can define an "image"-solution of GR simply by "forgetting" the hidden variables. That's why, the differences have only one direction: They allow falsification of PG without falsification of GR. Let's consider now the differences in detail. As we will see, PG removes some of the most complicate problems for quantization: The singularities of the black hole collapse and the big bang, nontrivial topologies, and the problems with local energy-momentum tensor.

3.2.1 Fixation of the Topology

In a hidden variable theory it may happen that some solutions of the original theory do not allow the introduction of the hidden variables. The related observable solutions are forbidden in the hidden variable theory. This defines one way to falsify the hidden variable theory: To observe in reality one of the forbidden solutions.

In the case of PG, GR solutions with nontrivial topology are forbidden. Thus, PG excludes a whole class of GR solutions as forbidden. Unfortunately, the observation of nontrivial topology, if it exists, is very nontrivial, because it cannot be restricted to local observations only. Indeed, it is sufficient to remove some parts of codimension 1 from the solution with nontrivial topology, and we have a solution with trivial topology which can be interpreted as a PG solution, even as a complete PG solution.

Thus, the difference is only of theoretical interest and cannot be used for a real falsification of PG. Nonetheless, the theoretical simplification is essential. In quantum PG, we have not to consider different topologies, thus, we have no topological foam.

3.2.2 Different Notion of Completeness

A solution in PG is complete if it is defined on the whole affine space and time. There is no requirement of completeness of the metric defined by the gravitational field g_{ij}.

The most interesting example of this effect is the black hole collapse. For a collapsing black hole, there are reasonable initial values of the harmonic coordinates defined by the Minkowski coordinates in the limit $t \to -\infty$. The resulting coordinates have the interesting property that they do not cover the complete GR solution. Indeed, in the domain outside the collapsing body the harmonic time coincides with the Schwarzschild time, thus does not cover the part behind the horizon.

This offers a possibility to falsify PG, which is unfortunately also only very theoretical. If an observer falls into a black hole created by collapse, and if he really reaches the part behind the horizon, he can be sure that PG is falsified. Unfortunately he cannot tell us about this observation.

Let's remark that the conceptual problems which may be related with the singularity, especially the possibility that conservation laws may be violated [34], are simply not present in PG. Thus, another quantum gravity problem has simply disappeared.

3.2.3 Different Symmetry Group

Above theories have different symmetry groups. Thus, a solution which may be considered as symmetrical in GR may not have this symmetry in PG. An example are the Friedman universes. Only the flat Friedman universe allows harmonic coordinates with the same symmetry group. The other, curved, solutions allow the introduction of harmonic coordinates (if we remove a single "infinite" world-line from the closed universe solution), but these solutions are no longer homogeneous. From point of view of the hidden coordinates, these solutions have a center.

Thus, PG prefers the flat universe solution as the only homogeneous one. The fact that the observed universe is at least very close to a flat universe speaks in favour of PG. But in our world where even P and CP symmetry is not observed, an inhomogeneous universe is not forbidden. Thus, observation of a curved universe would not be a falsification of PG, and that's why it is not possible to say that PG predicts a flat universe. Nonetheless, PG suggests an easy explanation why our universe is approximately flat — because it is approximately homogeneous.

3.2.4 Local Energy and Momentum Conservation

Different from GR, we have a preferred symmetry group of translations in space and time. This leads because of the Noether theorem to well-defined local conservation laws for energy and momentum of the gravitational field too.

This situation is different from general relativity. The general-relativistic pseudo-tensor t^{ik} is not a tensor, thus, cannot be observable in general relativity. This is not required in PG. Thus, the pseudo-tensor t^{ik} is in PG a well-defined object, of the same class of reality as the hidden background frame. Thus, the problems with the definition of local energy density are not present in PG. Physically different PG states usually have different energy even if their general-relativistic image is equivalent.

3.3 Triad Formalism

In general relativity we have some interesting variables known as tetrad variables. They are useful for the quantization of tensor and spinor fields on general-relativistic background, and they allow to replace the non-polynomial $\sqrt{-g}$ by a polynomial expression. The tetrad variables are four covector fields $e^i_\mu(x,t)$, they define the metric as

$$g_{\mu\nu}(x,t) = e^i_\mu(x,t)e^j_\nu(x,t)\eta_{ij}$$

In PG, the preferred foliation into space and time already splits the metric into separate parts. It is natural to require that the tetrad variables correspond with this splitting. Especially, consider the hyper-plane defined by constant time. The time-like tetrad vector can be defined uniquely by orthogonality to this plane and the direction of time. Thus, this vector field is already fixed in PG.

The remaining three vector fields now have to be in this plane. Thus, in PG the tetrad formalism naturally reduces to a triad formalism. If we consider these triad variables as the real steps of freedom of the gravitational field, this leads also to some internal advantages. The metric always remains space-like in the plane of constant time.

3.4 Ether Interpretation

PG may be easily interpreted as a dynamical ether theory. At least, the number of components of the gravitational field $g_{ij}(x)$ is in good agreement with the steps of freedom and the transformation rules for a material ether.

Remark that from point of view of PG the gravitational field $g_{ij}(x)$ splits into parts with separate transformation behavior. At first, considering the transformation behavior for pure Galilee transformations, we can identify the vector $v^i = -g^{0i}/g^{00}$ as the velocity of the ether. The scalar $\rho = g^{00}\sqrt{-g}$ can be identified as the density of the ether. This leads to an interpretation of the first harmonic equation as a conservation law for this density:

$$\partial_t \rho - \partial_i v^i \rho = 0$$

The space part of the metrical tensor g_{ij} describes the deformation tensor modulo a scalar factor which defines a scalar material property — the local speed of light.

The ether interpretation is in good correspondence with the triad formalism. The three three triad vector fields define some hidden preferred directions, which suggest an interpretation in terms of a crystal structure of the ether.

The ether interpretation can also give hints for quantization. For example, if the harmonic equation is a conservation law, it has to be fulfilled also for quantum configurations, thus, interpreted as a constraint, not an evolution equation.

But much more interesting is that it suggests that there may be an underlying atomic structure of the ether. Such an atomic variant highly probable allows to solve ultraviolet problems.

4 Semiclassical Postrelativity

Semiclassical theory considers quantum fields on a fixed, classical background solution for the gravitational field. Thus, we consider the quantum effects only as small and neglect the influence of the quantum effects on the gravitational field.

4.1 Canonical Quantization of the Scalar Field

Assume we have given a PG solution as the fixed background. Consider a scalar particle on this background with the standard relativistic Lagrangian (Greek indices from 0 to 3, Latin indices from 1 to 3):

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

Using the standard canonical formalism, we define ($\hat{g}^{\mu\nu} = g^{\mu\nu}\sqrt{-g}$)

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

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

We define now ϕ and π as operators with the standard commutation rules ($\hbar = 1$):

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

This already gives the guarantee that the first principle is fulfilled. We don't consider here the problem of ordering which occurs in the definition of the Schrödinger operator. We define the vacuum state as the state with minimal energy, which has to exist because the energy is nonnegative.

4.2 Special-Relativistic Quantum Field Theory

In the case of the Minkowski space $\hat{g}^{\mu\nu} = \eta^{\mu\nu}$ it is useful to introduce another basis:

$$\phi_k = \int e^{ikx}\phi(x)dx, \ \pi_k = \int e^{ikx}\pi(x)dx$$

which essentially simplifies the expression for the energy

$$H = \int \mathcal{H}dx = \frac{1}{2}\int \pi_k^2 + \omega_k^2\phi_k^2 dk, \omega_k = \sqrt{k^2 + m^2}$$

Now it is useful to define operators

$$a_k^+ = \frac{1}{\sqrt{2\omega_k}}(\pi_k + i\omega_k\phi_k)\ a_k = \frac{1}{\sqrt{2\omega_k}}(\pi_k - i\omega_k\phi_k)$$

with the well-known commutation relations with H:

$$[a_k, H] = \omega_k a_k$$

These operators allow to characterize the vacuum state, because for this state we have

$$a_k|0\rangle = 0$$

Any other constant gravitational field (a metric of the same signature as for the whole spacetime, as for the space only), can be transformed in PG to the standard Minkowski form within the PG symmetry group. Nonetheless, let's write down the related expression for the general constant field too:

$$a_k^+ = \frac{1}{\sqrt{2\omega_k}}(\pi_k - i(\hat{g}^{0i}k_i - \omega_k)\phi_k),$$

$$a_k = \frac{1}{\sqrt{2\omega_k}}(\pi_k - i(\hat{g}^{0i}k_i + \omega_k)\phi_k),$$

$$\omega_k^2 = \hat{g}^{00}(-\hat{g}^{ij}k_ik_j + m^2\sqrt{-g})$$

4.3 Nontrivial Gravitational Field

In the general case, it is not so easy to define such a basis. Nonetheless, let's try to characterize the vacuum state in a similar way at least approximately. Indeed, consider the wave packets

$$\phi_{kx} = \int e^{iky-\sigma(y-x)^2}\phi(y)dy,\ \pi_{kx} = \int e^{iky-\sigma(y-x)^2}\pi(y)dy;$$

Assume a sufficiently small σ, so that we have a good approximation of the momentum, but, on the other hand, assume σ big enough so that the gravitational field can be approximated by a constant field in the region there the function is not very small. In this approximation, we can define local particle operators

$$a_{kx}^{+} = \frac{1}{\sqrt{2\omega_{kx}}}(\pi_{kx} - i(\hat{g}^{0i}k_i - \omega_{kx})\phi_{kx}),$$

$$a_{kx} = \frac{1}{\sqrt{2\omega_{kx}}}(\pi_{kx} - i(\hat{g}^{0i}k_i + \omega_{kx})\phi_{kx}),$$

$$\omega_{kx}^2 = \hat{g}^{00}(-\hat{g}^{ij}k_ik_j + m^2\sqrt{-g});$$

We obtain

$$[a_{kx}, H] \approx \omega_{kx}a_{kx}$$

$$a_{kx}|0\rangle \approx 0$$

Thus, for gravitational fields which vary not very fast, the vacuum state looks locally like the Minkowski vacuum.

4.3.1 Hawking Radiation

In this way, semiclassical PG defines a natural vacuum state and Fock space structure dependent on the gravitational field and time. In general relativity we have no such natural Fock space definition. In the GR paradigm, this is explained in the following way: To define the notion of a particle, we have to choose a preferred set of particle detectors which are considered to be inertial. The vacuum would be the state where these particle detectors do not detect particles.

The previous considerations allow us to describe the vacuum state defined by PG in these words too. Indeed, the PG background structure defines a preferred set of observers which are considered as inertial observers. At a given moment of time, these local observers do not observe particles in the vacuum state.

It is essential that the vacuum state definition in PG depends on time. The state which is the vacuum at $t = t_0$ in general not become the vacuum state at $t = t_1$, but becomes a state with particles. This effect leads to Hawking radiation. Let's show this: Outside the collapsing body, the harmonic coordinates which initially coincide with the Minkowski coordinates are static, especially the harmonic time is simply Schwarzschild time. As we have shown, in the vacuum state at least far away from the surface an observer at rest does not detect any particles. Thus, this vacuum state will be close to the state known as Boulware vacuum state. The real state is of course the result of the evolution of the initial Minkowski vacuum. The evolution of this state - known as the Unruh state - coincides after the collapse with the Hartle-Hawking state. In this state, observers at rest relative to the black hole observe Hawking radiation.

Thus, Hawking radiation is a natural consequence of postrelativity for the Fock space definition described here. The conceptual problems with the uncertainty of the definition of the Fock space do not occur in postrelativity.

4.3.2 Scenario of Black Hole Evaporation

Because we have no horizon formation in classical PG, we already know that Hawking radiation starts before the horizon is formed. If we consider the classical background as fixed, we observe a small but constant loss of energy in Schwarzschild time. Because of energy conservation this has to be compensated by a modification of the energy-momentum tensor of the classical background solution at this Schwarzschild time, that means, before horizon formation.

This modification leads to a decreasing horizon, thus, if the unmodified surface hasn't reached the horizon, the modified hasn't reached it too. Thus, this modification does not lead to a modification of the property that the horizon will not be reached by the surface in PG. Combined with the known results about the time for evaporation for the outside observer, which is finite, it seems clear that the black hole evaporates in PG before the horizon is even formed. Of course, there may be modifications of this picture near Planck length, for example there may be a remaining black hole of Planck order size without Hawking radiation. Nonetheless, even in this state we have no singularity inside.

The answer of general relativity about the evaporation is not so certain. According to Birrell and Davies [8], there are different proposals, with exploding singularity or remaining singularity of Planck order, but also a similar proposal of evaporation before horizon formation [16].

4.4 Nonscalar Fields

4.4.1 The Dirac Field

Before considering the Dirac field, remark that we have been able to define the configuration space for the scalar field independent of the gravitational field. Such a property is suggested by our first principle, thus, it seems natural to try to get the same independence for the other fields too.

Let's try to do this for the Dirac field. In special-relativistic field theory, we have the definition

$$\left\{\psi^+_\alpha(x), \psi_\beta(y)\right\}_+ = \delta_{\alpha\beta}\delta(x-y)$$

which depends only on the metric $\delta_{\alpha\beta}$, but not on the Minkowski metric. If we try to use this as the definition of the configuration space, we immediately obtain a problem: We have to establish a relation between the operators γ^i and the partial derivatives ∂_i. If we fix such a relation, it defines a Minkowski metric in the space derived from the internal Minkowski metric. Thus, this relation cannot be independent from the gravitational field. That means, this relation cannot be part of a gravity-independent configuration space for the Dirac field.

Thus, it has to be part of the gravitational field. That means, the gravitational field has to define an isometric relation between a four-dimensional internal Minkowski space defined by the γ^i and the tangential Minkowski space. The metric $g_{ij}(x)$ alone does not allow to define such a relation.

This problem is solved by the tetrad formalism. Thus, to be able to describe the Dirac field with an independent configuration space, we have to introduce tetrad variables into postrelativistic gravity. After the introduction of tetrad variables we are able to define the configuration space of the Dirac field by the same definition as for the Minkowski space.

4.4.2 Other Fields and Interactions

The tetrad technique can be used for other spinor and tensor fields too. The problem is reduced in this way to the definition of the configuration space for a standard Minkowski frame. Gauge fields we consider separately below.

The introduction of interaction terms changes only the Schrödinger operator, thus, does not have any influence on the configuration space. Thus, nothing has to be changed compared with the situation for free fields. That means, it is possible to derive the Feynman diagram formalism.

But it has to be remarked that the semiclassical limit is only justified for momentum below Planck scale. Already the Fock space is defined only in this sense. Thus, it is not justified to consider any integral over the whole momentum space. That means, only the first, tree approximation is justified. Thus, it is clear that at Planck scale the semiclassical limit becomes wrong.

Thus, we have no reason to wonder about ultraviolet problems in such illegal integrals. Of course, on the other hand, the results obtained by renormalization are reasonable. It is reasonable to assume that the correct theory leads to finite terms based on some type of effective cutoff at the order of Planck scale with unknown details. Renormalization claims to be able to compute results which do not depend on these details, even on the order of magnitude of the cutoff.

4.4.3 Small Quantum Variations of the Gravitational Field

The semiclassical approximation may be applied to consider small modifications of the gravitational field too. This leads to a standard Feynman diagram scheme for general relativity in harmonic gauge.

The independence of the configuration spaces of matter from gravity is necessary to show the correctness of the consideration of small modifications of the gravitational field as an independent quantum field. Else, the consideration of any material field operator together with operators which describe the difference between the real gravitational field and the background metric would be meaningless.

Especially that means that this approach is meaningless in the context of general relativity. The difference between even very close solutions of the Einstein equation is not covariant, thus not defined. Applying different coordinate transformations for above fields we can make the difference arbitrary big and strange. This difference between the relativistic and the postrelativistic approach if different gravitational fields are involved is discussed below.

5 Ultraviolet Problems and Non-Renormalizability

It is known that quantum general relativity is non-renormalizable. We havn't modified anything which may change this fact, thus, postrelativistic gravity is non-renormalizable too. Many people consider this as a strong, even decisive argument against a theory. There are already arguments [4] which show that non-renormalizability it is not a decisive argument against a theory. But, on the other hand, it is considered as a serious conceptual problem.

In the context of postrelativity I consider non-renormalizability not as a conceptual, but only as a technical problem. Some of the following remarks to justify this are valid also for the relativistic approach, other not.

First, we have already seen that there is no reason to wonder about infinities. They simply show an obvious error — the attempt to apply the semiclassical limit outside it's possibilities. In this sense, the divergences of these integrals not a conceptual problem, because our concepts don't even suggest these integrals have to be finite.

They are also not a problem to justify the first order tree approximation. Our concepts also don't suggest a definition of quantum gravity via a formal power series based on a fixed classical background. We have derived the semiclassical limit based on some general assumptions about the correspondence between the unknown full theory and their semiclassical limit. Thus, the derivation of the first order tree approximation is based on these assumptions, not on the formal power series and the correct definition of the higher order terms. Thus, problems of computation of higher order approximations do not question the correctness of the first order tree approximation.

5.1 Light Cone Uncertainty

Second, let's consider a simple qualitative prediction about the properties of postrelativistic quantum gravity. This prediction is the uncertainty of the light cone.

Remark at first that such a prediction does not make sense from point of view of the relativistic paradigm, because this paradigm does not allow to compare different solutions. This property of the relativistic approach we consider in detail below. But in the postrelativistic approach we can compare the light cone of different solutions. From point of view of the postrelativistic paradigm, events are defined independent of the state of the gravitational field. It makes sense to compare different gravitational fields. And we observe easily that different gravitational fields usually have different light cones. That means, in quantum PG the light cone will be uncertain.

There is no possibility to avoid this effect in postrelativity. But we have also no reason to bother, because this uncertainty does not cause any problem. It is not dangerous nor for causality, nor for position, because above notions are defined independent of the state of the gravitational field.

Moreover, this uncertainty suggests that ultraviolet problems of the usual type are not present in quantum PG. Indeed, the ultraviolet problems in relativistic quantum theory are caused by the singularity of the propagator near the light cone. But, if the light cone is not defined exactly, where is no place left for a light cone singularity to survive.

This is in no way a proof of anything. But it nonetheless suggests that a correct computation of higher order approximation (different from the incorrect one which remains in the semiclassical approximation without justification) may not lead to infinities. Last not least, we have a new physical effect — the uncertainty of the light cone caused by the quantum character of the gravitational field.

5.2 The Atomic Ether

Third, the ether interpretation of PG suggest a simple way to avoid ultraviolet problems — the assumption of an atomic ether. Indeed, to make this assumption is even natural without having any ultraviolet problem, because of the same philosophical reasons which have justified the atomic hypothesis for usual matter.

If we make such an assumption, we obviously obtain an effective cutoff which depends on the typical distance between the atoms of the ether. Thus, the assumption of an atomic ether defines a simple emergency exit for the case that the previous ideas do not lead to a removal of the ultraviolet problems.

The idea to introduce a discrete structure to solve the ultraviolet problems is not new [4]. But the realization of this idea in the relativistic paradigm leads to a completely different concept — a discrete spacetime. It requires completely different mathematics and foundations. Compared with this idea, the atomic ether is a very simple idea. Of course, we may obtain a lot of difficult technical problems, but conceptually the atomic ether is as complicate as a deformed crystal material.

Nonetheless, it seems not yet the time to develop such a theory in detail, this would be too speculative.

5.3 The Status of the Ultraviolet Problem

Let's remark that the status of ultraviolet problems is different in relativistic and postrelativistic theory. I don't want to diminish the technical problems, but I reject to consider ultraviolet problems as a serious *conceptual* problem of the postrelativistic approach.

Indeed, GR claims to be a theory of space and time, that means about the most fundamental things in the universe. It claims to be able to predict the evolution even of the topology of our space. There is nothing more fundamental than space and time. Thus, an ultraviolet problem becomes a serious conceptual problem in our understanding of space and time if they occur in this theory.

The status is completely different in postrelativity. PG doesn't claim to be the ultimate theory about space and time, it is a continuous ether theory, with similarity to classical continuum mechanics. If ultraviolet problems occur in such a continuous ether theory, they only show that the ether has some different, probably atomic, microscopic structure which is not yet observable. Thus, as far as we do not pretend to have found the ultimate theory — which is not a very natural claim for a continuous ether theory — this does not even suggest that there is anything wrong with our continuous approximation, and is that's why not a conceptual flaw of this theory, but the only chance for future research to observe — at least in principle — the microscopic structure of the ether.

6 Canonical Quantization and Path Integral Formulation

We have seen that there is no reason to be afraid of ultraviolet problems — they do not occur immediately in the semiclassical approximation, there are reasons to suggest that they do not occur in higher order approximations too, and we have an emergency exit if they nonetheless occur.

Nonetheless, perturbative theory starting with a classical background solution does not suggest a way of rigorous definition of quantum PG. For this purpose, other methods have to be used.

Two methods may be considered for this purpose — Feynman path integral formulation and canonical quantization. For above concepts, postrelativity leaves some freedom. Nonetheless, we can compare our approach with the standard general-relativistic paradigm. We can show not only a difference, but also an essential technical and conceptual simplification.

6.1 Freedom of Choice for Further Quantization

For above methods our first principles leave some freedom of choice for the following steps. Indeed, above concepts require to fix the following:

- the configuration space and
- the Lagrange function.

The classical postrelativistic theory leaves here some freedom. We have different choices which lead to the same classical equations:

- We can consider the harmonic equation as an external constraint. In this case, only harmonic fields are valid field configurations. This would be natural if we interpret it as a conservation law.
- The other alternative would be to consider it as a classical evolution equation, and to add a penalty term to the Lagrange functional so that the Euler-Lagrange equations include not only the Einstein equations, but also the harmonic equation. In this case, all field configurations (inclusive non-harmonic) are valid. The gauge field correspondence considered below suggests this choice.
- Orthogonal to this question, we have the possibility to introduce other variables with another configuration space. We have already seen that the introduction of the triad formalism is reasonable. This formalism introduces some new hidden (gauge) steps of freedom.
- But, of course, also other variables like Ashtekar's variables [4] have to be considered.

- We also have some freedom how to choose the Lagrange function for gravity between the usual Lagrange density — the scalar R — and the Rosen Lagrangian. The first is covariant, the second not. On the other hand, the first includes second derivatives, the second not. Postrelativity suggests to use the second, because second derivatives will be a problem, non-covariance not.

- If we introduce delta-functions into the path integral, we have to bother about correct norm. Thus, we may have to include an appropriate normalization coefficient.

Because of the Pauli principle, at least different choices of the configuration space lead with high probability to different quantum theories. Thus, postrelativity does not fix quantum gravity uniquely. To find which is the best choice has been left to future research. My personal preference at the current moment is the Rosen Lagrange function, harmonic equation as a constraint, triad variables. But one in in no way forced in this direction.

6.2 Properties of Quantum Postrelativistic Gravity

Nonetheless, all these variants have common properties, which we will describe here as properties of quantum postrelativity.

- Postrelativistic gravity is the classical limit.

- The path integral is defined between arbitrary but fixed, finite moments of time t_0, t_1.

- The configuration space consists of functions defined on the three-dimensional affine space. Especially the functions $g_{ij}(x)$ are defined and describe the gravitational field.

- Configurations with different gravitational field $g_{ij}(x)$ are different, even if the configurations can be transformed into each other by diffeomorphism. For such configurations, the related probabilities have to be added, not the amplitudes.

- For canonical quantization, we obtain a well-defined evolution in time, different from the Wheeler-DeWitt equation in canonical quantization of general relativity.

6.3 Comparison With Relativistic Approach

On the classical level, the main difference between the relativistic approach and the postrelativistic approach is the consideration of configurations which can be transformed into each other with a diffeomorphism. In GR they are identified, in PG they are different.

This identification leads to conceptual problems even in the formulation of quantization. The first and most serious group of problems is connected with diffeomorphisms which change time. The related problems are known as the "problem of time". Only if we neglect this problem by considering only diffeomorphisms which don't change time, we are able to define a configuration space which may be compared with the PG configuration space. This comparison shows that the configuration spaces are essentially different. Thus, highly probable, the resulting quantum theories will be different too, simply because of the Pauli principle.

6.3.1 Problem of Time

According to the paradigm, configurations have to be identified if there is a diffeomorphism between the configurations.

In this sense, it is already a violation of the paradigm if we write down a path integral with finite, fixed boundaries for time t_0, t_1. Probably only path integrals with infinite limit or over compact solutions can fulfil the paradigm completely.

This occurs in the canonical quantization approach too. As the result, instead of a Hamiltonian evolution we obtain only a so-called Hamilton constraint. After quantization, this leads to the Wheeler-DeWitt equation

$$\hat{H}\psi = 0$$

instead of a usual Schrödinger equation. This equation is considered to describe only the diffeomorphism-invariant information about our world. Thus, similar to the problem in the path-integral formulation, we have no description of the evolution for any finite time, how to extract physically meaningful information is completely unclear.

Because we are not able to solve this problem, we ignore it and consider in the following only diffeomorphisms which leave the time coordinate invariant.

6.3.2 Topological Foam

A second problem is the topology of the space. The topology is usually not a problem in classical general relativity, because it is controlled more or less by the Einstein equation which usually does not change topology during the evolution. But in the quantum domain, we have to consider also non-classical configurations. Because for small distances we have to assume that quantum theory allows small variations of the field, inclusive small, local variations of the topology, this concept leads to the picture that at small distances the topology will be de-facto uncertain. This concept is known as "topological foam".

Because we are not able to solve this problem, we fix in the following the topology of the space, for simplicity we consider only trivial topology.

6.3.3 The Configuration Space of General Relativity

After these two simplifications we can at least define the configuration space of the general-relativistic approach in a form comparable with the postrelativistic configuration space. It is the result of factorization of the postrelativistic configuration space where diffeomorph configurations have been identified.

Thus, we see, that two essential simplifications have been necessary even to define a configuration space which may be compared with postrelativity. Moreover, the resulting configuration space is essentially different. This highly probable leads to a quantum theory with different experimental predictions, simply because in the path integral we have a different basic rule for the computation of probabilities. Indeed, if different but diffeomorph configurations are considered, we have to add the related probabilities in the postrelativistic approach, but the related amplitudes in the general-relativistic approach. Thus, already the Pauli principle is defined differently. Probably in some situation one theory will predict interference effects but the other not.

7 Quasiclassical Theory

In this section we compare the predictions of above theories in the quasiclassical situation. That means, we leave the semiclassical situation where the gravitational field is approximated by a classical field and consider the next step — superpositions of such states.

In this case, above concepts lead to different predictions. More accurate, the general-relativistic concept remains silent, we are not able to obtain predictions from this concept. Nonetheless, the prediction of postrelativity cannot be copied, because it is in contradiction with the symmetry principles of the approach. Thus, it is reasonable to say nonetheless that the predictions are different.

7.1 Non-Relativistic Description of a Simple Experiment

At first, let's describe our experiment in non-relativistic language. More accurate, we describe it using classical multi-particle Schrödinger theory with Newtonian interaction potential.

We consider a "heavy" particle in a simple superposition state

$$\psi = \delta(x - x_1) + \delta(x - x_2)$$

and it's gravitational interaction with a light test particle. The initial product state splits into a nontrivial two-particle state. To compute this state, we use quasiclassical approximation, thus, if the heavy particle is in the delta-state, we approximate the two-particle problem by a single-particle problem for the test particle in the classical gravitational field created by the heavy particle in this position:

$$i\partial_t \phi^{1/2} = H^{1/2} \phi^{1/2}$$

$$H^{1/2} = \frac{p^2}{2m} - \frac{k}{|x - x_{1/2}|}$$

Then we interpret this one-particle solutions as two-particle tensor product states and use standard superposition rules to compute the result:

$$\phi \otimes \psi \rightarrow \phi_1 \otimes \delta(x - x_1) + \phi_2 \otimes \delta(x - x_2)$$

After the interaction, we simply ignore the test particle, but measure, if the state of the heavy particle has changed or not. This is simple and can be done by an arbitrary interference experiment which tests if the state of the heavy particle is yet in a superposition state or not, or, in other words, if the interaction with the test particle was strong enough to be considered as a measurement of the position or not. The probability of observing the heavy particle unchanged is

$$\rho = \frac{1}{2}(1 + \mathcal{R}e\langle\phi_1|\phi_2\rangle)$$

The extremal case of scalar product 1 can be interpreted as no measurement by the interaction with the test particle, thus we observe interference, and the other extremal case of scalar product 0 as complete position measurement, thus we observe no more interference.

But the point of this consideration is that the real part of the scalar product is observable in non-relativistic Schrödinger theory.

7.2 Postrelativistic Description of the Experiment

Let's describe now the same experiment in the postrelativistic approach. In principle, we can use a similar, classical language. We need only small modifications. Instead of the one-particle Schrödinger equation with the operator $H^{1/2}$ we have to consider now the semiclassical theory for fixed classical background $g_{ij}^{1/2}(x,t)$. The functions $\phi^{1/2}(x,t)$ are replaced by states defined in the configuration space of semiclassical theory.

It becomes essential now that the definition of the configuration space itself was given in terms of the operators ϕ and π independent of the gravitational field, not in terms of the particle operators which depend on the field. Thus, the two states $|\phi^{1/2}\rangle$ are states in the same Hilbert space. Thus, we can define their scalar product without problem.

Thus, the postrelativistic approach makes clear predictions about the results of the experiment. It allows to compute the relativistic corrections. These predictions coincide in the non-relativistic limit with classical Schrödinger theory.

7.3 Non-Covariance of the Scalar Product

Consider now the situation in general relativity. Let's use the language introduced by Anandan [3] who has considered a similar superposition experiment.

If there is a superposition of gravitational fields, he distinguishes two types of diffeomorphism: a classical or c-diffeomorphism that is the same for all superposed gravitational fields, and a quantum or q-diffeomorphism which may be different for the different superposed fields. He postulates as the "principle of quantum general covariance" that all physical effects should be invariant under all q-diffeomorphisms.

As we can easily see, the scalar product cannot be observable in this approach. Indeed, the semiclassical theory allows to define the states $|\phi^{1/2}\rangle \otimes |g^{1/2}\rangle$ only as pairs $(\phi^{1/2}(x,t), g_{ij}^{1/2}(x,t))$ modulo arbitrary coordinate transformations $(x,t) \to (x',t')$:

$$(\phi^{1/2}(x,t), g_{ij}^{1/2}(x,t)) \to (\phi^{1/2}(x',t'), g_{ij}^{1/2}(x',t'))$$

The scalar product as defined in postrelativity

$$\int \phi^1(x,t)\bar{\phi}^2(x,t)dx$$

is obviously invariant only for c-diffeomorphisms, but not for q-diffeomorphisms.

Anandan's principle is a consequence of the Einstein equations and cannot be simply removed from quantum general relativity. Indeed, if we consider a superposition of semiclassical solutions, above solutions are only defined modulo an arbitrary diffeomorphism, thus, quasiclassical general relativity is automatically q-diffeomorphism-invariant, if we don't introduce some new non-q-diffeomorphism-invariant mechanism into the theory. Moreover, the configuration space and the path integral formulation which we have considered for the general-relativistic approach also requires that the resulting quantum theory is q-diffeomorphism-invariant.

Thus, the scalar product is not defined in the general-relativistic approach, observable results of this theory cannot depend on such scalar products. That means, we are not able to predict relativistic corrections of our simple experiment.

7.4 Remarks About the Seriousness of this Problem

In principle, this problem can be added to the list of already existing conceptual problems of the general-relativistic approach which do not occur in the postrelativistic approach, but nonetheless continue to hope for a solution of all these problems in future. But in my opinion it has to be considered as a decisive argument in favour of the postrelativistic approach. Some remarks in favour of this position:

Remark that it is not our personal inability to compute the predictions of the general-relativistic approach, but a clear symmetry requirement of general relativity which does not allow to define this scalar product.

Remark that the argument is present in full beauty in the classical limit. Indeed, we can rewrite the classical Schrödinger theory experiment in general-relativistic language, using the metric

$$g_{00} = 1 + \frac{2\phi}{c^2}$$

and restricting the consideration to small velocities. We already have different gravitational fields, thus, the full problem of q-diffeomorphism-invariance. That this is not an exact solution of the Einstein equations is not significant, because in quantum theory we have to be able to handle configurations which are not exact solutions. This suggests that a q-diffeomorphism-invariant theory will not have Schrödinger theory as the classical limit.

Remark that the problem is present already for very small modifications of the gravitational field.

Remark that if we are able to define scalar products between functions on different solutions, we have de-facto a diffeomorphism between the solutions. Indeed, we can simply consider the scalar products between delta-like functions. And having a diffeomorphism for any two solutions is very close to a coordinate condition. Indeed, a diffeomorphism between the Minkowski space and an arbitrary space defines a preferred coordinate system — affine Minkowski coordinates — on the other solution.

Remark that the idea to accept a break of the q-diffeomorphism-invariance temporary, as a gauge condition, does not help if we want to obtain the observable prediction of classical Schrödinger theory.

Remark that the idea to accept a break of the q-diffeomorphism-invariance but to make it as relativistic as possible is de-facto the postrelativistic approach. Indeed, we use a really beautiful relativistic wave equation to define the scalar product. In this sense, the postrelativistic approach can be considered as the simplest way to solve this problem.

Remark, that we have simply ignored the results of measurement of the test particle. The aim of this ignorance was to avoid the consideration of problems which are related with almost every measurement in the relativistic approach. In the postrelativistic approach, we are able to consider the results of some measurement, for example coordinate measurement, for the test particle too.

On the other hand, the result depends on assumptions about measurability in Schrödinger theory. It may be argued that this theory may be wrong or that these observables are not really observable, but observable only in the classical limit.

Such argumentation may be of course used to show that nonetheless this problem is not decisive. But, of course, a theory of quantum gravity has to be based on some assumptions which cannot be exactly proven. This leads to the question how a more decisive argument against the relativistic approach could look like.

8 Postrelativistic Gauge Theory

The postrelativistic principles do not define immediately what has to be done with gauge fields. But there is a close similarity between gauge theory and general relativity. This suggests that there has to be also a similar correspondence between gravity and gauge theory in postrelativity too.

Using this correspondence argument, we obtain a new approach for gauge theory. It seems natural to use the name "postrelativistic gauge theory" for this gauge-theoretical approach too. Nonetheless, it has to be recognized that postrelativistic gravity and postrelativistic gauge theory are different, independent theories. Failure or success of one of them does not immediately prove failure or success of the other. But, of course, the correspondence will be a strong correspondence argument.

The main property of postrelativistic gauge theory is that the gauge potential has to be considered as a hidden but real step of freedom. The Lorentz condition becomes a physical equation, not a gauge condition.

Classical postrelativistic gauge theory cannot be distinguished from the relativistic variant. In the quantum domain, they become different.

8.1 Standard Paradigm — No Gauge Freedom

Let's shortly remember the standard, usual paradigm, which corresponds to general relativity. In this paradigm, different but gauge-equivalent gauge potentials are identical. The gauge freedom is considered only as a mathematical construct which makes it easier to write down some formulas, not as a real freedom. In the path integral, the usual way to realize this is to use a gauge condition which defines a unique gauge potential for each class of gauge-equivalent potentials:

$$\int_{t_0}^{t^1} \exp i \int \mathcal{L} dt \prod_{x,t} \Delta(\mathcal{A}) \delta(f(\mathcal{A})) d\mathcal{A}$$

Every equivalence class has to occur in the integral only once. It would be even more beautiful if we could describe gauge fields immediately in gauge-invariant terms like Wilson loops.

The most interesting (because of their relativistic form) gauge condition — the Lorentz condition — solves only half of the problem of gauge fixing. Indeed, it fixes the gauge only for fixed boundary conditions, but doesn't fix the gauge for the boundary conditions. This remaining gauge freedom has to be fixed by other, additional boundary conditions. This type of gauge fixing leads to problems with unitarity of the S-matrix, if it is not compensated by additional terms. These compensation terms may be interpreted as terms describing particles known as Faddeev-Popov ghost particles. But in the general case even fixed boundary conditions may be not sufficient to fix the gauge with the Lorentz condition — there may be so called Gribov copies. The problem is that the Gribov copies occur in the path integral as different states, but have to be identical in the ideal theory.

8.2 Classical Postrelativistic Gauge Theory

The general correspondence between gauge theory and general relativity requires to consider the gauge freedom as the analog of the freedom of choice of coordinates in general relativity, gauge transformations as the analog of diffeomorphisms. The definition of the gravitational field in a given coordinate system is the analog of the gauge potential. Let's apply this correspondence scheme to the postrelativistic approach.

The configuration space of postrelativistic gravity consists of gravitational fields in given coordinates. The analog of this configuration space is obviously the space of all gauge potentials. Thus, in postrelativistic gauge theory the gauge potential is the real variable we have to use to describe the gauge field. Field configurations which are different but equivalent from point of view of the symmetry transformation of the relativistic theory are considered as different states in the postrelativistic theory.

Thus, as in postrelativistic gravity, we have to introduce new steps of freedom into the theory. They are not directly observable. To describe the evolution of these observables, we need a new equation.

For gravity we have used an equation known already as a very useful coordinate condition, the harmonic condition. The similarity to the Lorentz condition in gauge theory is obvious: Above conditions can be written as a first-order divergence-like condition for the variables we use to describe the fields, but also as a second order relativistic wave equation immediately for the hidden steps of freedom. That's why in postrelativistic gauge theory we consider the Lorentz condition as a physical evolution equation for the gauge potential.

8.3 Canonical Quantization

As suggested by general rules, let's try now canonical quantization of classical postrelativistic gauge theory. We have different possibilities to define a Lagrange formalism, let's consider here only one — the "diagonal gauge" Lagrange density:

$$\mathcal{L}_{diag} = -\frac{1}{2}\partial^\nu A_\mu \partial_\nu A^\mu$$

For this Lagrange density, we have no problems to derive the canonical momentum variables

$$\pi^\mu(x) = \frac{\partial \mathcal{L}_{diag}}{\partial A_{\mu,t}(x)} = -\partial_t A^\mu(x)$$

Canonical quantization leads to commutation relations

$$[A_\alpha(x), \pi^\beta(y)] = i\delta_\alpha^\beta \delta(x-y)$$

This defines the standard, canonical configuration space. It does not depend on the gravitational field, as suggested by semiclassical postrelativistic gravity.

8.3.1 Particle Interpretation

For a given tetrad field we can try to define now particle operators similar to the scalar field separately for each component. The only difference is that the energy for the component 0 is negative. We can define the vacuum state not as the state with minimal energy — such a state doesn't exist in the configuration space — but the state with maximal energy.

The configuration space now consists of four types of particles. All of them are considered as physical in postrelativity. For comparison, in relativistic gauge theory, only two of them are considered as physical.

8.3.2 The Incorporation of the Lorentz Condition

One of the two additional steps of freedom is defined by the Lorentz condition $\chi(x) = \partial_\nu A^\nu(x)$. In classical theory, this equation has the solution $\chi = 0$. If it is fulfilled for the initial conditions, it will be fulfilled always. Thus, the step of freedom may be removed simply by making an assumption about the initial values.

This type of incorporation of the Lorentz condition into classical postrelativistic gauge theory has to be preferred, because the definition of χ depends on the gravitational field, thus, this condition should not be used to restrict the configuration space.

In the case of quantum mechanics the situation becomes more complicate. For non-Abelian gauge fields and Minkowski background it is possible to define an invariant subspace with the property

$$\langle\phi|\chi(x)|\phi\rangle = 0.$$

For this purpose we use a splitting $\chi = \chi^+ + \chi^-$ into adjoint operators χ^+ and χ^- which allows to define the subspace by

$$\chi^-(x)|\phi\rangle = 0,\ \langle\phi|\chi^+(x) = 0.$$

Here $\chi^{\pm}$ is the part of the operator χ consisting of particle creation resp. destruction operators. This subspace is invariant even if we have interaction. Thus, the consideration can be restricted to this subspace. Such an invariant subspace is not available in general. But this does not create a conceptual problem, because such a restriction is nice, but not necessary for postrelativistic theory. The assumption $\langle\chi\rangle = 0$ will be only a classical approximation.

8.3.3 Infinite Scattering Matrix

For a fixed postrelativistic Minkowski background, the fixed subdivision into space and time allows to define the subspace

$$A_0 = 0;\ \nabla \underline{A} = 0$$

This subspace is useful for comparison with relativistic theory. If we consider our observation to be restricted to this subspace, we have to make additional assumptions about the initial state to be able to apply the theory. In our case, we have a natural choice — the absence of hidden particles. For the state after the scattering, this condition may be not fulfilled. We have to integrate over all possible states of the hidden steps of freedom.

This general rule allows to make predictions about scattering of transversal photons without being able to measure the hidden steps of freedom.

8.4 Comparison With Relativistic Theory

Comparison with relativistic theory has to be subdivided into two parts. At first, there is the comparison of terms which are considered as physical in above theories, especially the scattering matrix. The other question is if the relativistic position to claim non-covariant and non-gauge-invariant expressions to be non-physical is really justified.

8.4.1 S-Matrix of QED

There are different variants of relativistic QED. In the variant of Bjorken and Drell [9] the gauge condition is incorporated into the configuration space. Configuration space and commutation relations of postrelativistic QED are more close to the quantization scheme of Gupta and Bleuler [17] [10].

The main difference between this approach and postrelativistic QED is the scalar product in the configuration space. In the relativistic variant we have an indefinite Hilbert space structure. We obtain more relativistic invariance in this variant, but this is obviously a situation where postrelativism suggests to sacrifice relativistic invariance in favour of the fundamental principles of quantum mechanics. But this manipulation is restricted only to the gauge steps of freedom which are considered to be unobservable in the relativistic approach. That's why I suppose this manipulation has no influence on the resulting scattering matrix for the states considered as physical by above theories. Thus, probably the comparison of QED does not lead to different experimental predictions.

8.4.2 S-Matrix of Non-Abelian Gauge Theory

Postrelativistic gauge theory does not require a modification for the case of non-Abelian gauge theory. For χ we have now a more complicate equation with interaction with the other gauge steps of freedom:

$$\Box\chi + [A_\mu, \partial^\mu \chi] = 0$$

We have yet the classical solution $\chi = 0$, but nonetheless in quantum theory we cannot define an invariant subspace with $\langle\chi\rangle = 0$ as before. But the restriction of the gauge freedom is not required in postrelativistic gauge theory. To have an invariant subspace is of course a nice property, but it is in no way essential part of the theory, which is well-defined in the whole configuration space.

The Gupta-Bleuler approach cannot be generalized straightforward to non-Abelian gauge theory. The restriction to the subspace $\chi = 0$ leads to non-unitarity of the S-matrix. This problem can be removed by compensation terms known as Fadeev-Popov ghost fields [13]. Because this restriction is not required in postrelativistic gauge theory, such a compensation is not necessary. Thus, Faddeev-Popov ghost fields do not occur in postrelativistic gauge theory.

This modification already leads to observable differences in the scattering matrix. Indeed, in relativistic gauge theory we have (after introduction of the ghost fields) unitary evolution in the gauge steps of freedom which are considered as physical (transversal particles). In postrelativistic gauge theory we have unitarity only in the full space. I cannot judge about the possibility to verify this difference in real experiments, but obviously this will be much easier compared with the case of quantum gravity.

8.4.3 A Quasiclassical Experiment

The other question is if the restriction of physics to gauge-invariant results is really justified. Similar to the situation in quasiclassical gravity, we have to distinguish here two notions of gauge-invariance: c-gauge-invariance (invariance for common gauge transformation) and q-gauge-invariance (invariance of a superposition state for different gauge transformation on the basic states). In postrelativity, we have trivial c-gauge-invariance, which may be considered as fixed by fixing the state of the vacuum to be trivial. In relativistic gauge theory we have also q-gauge-invariance.

We can show that the concept of q-gauge-invariance leads to the same problems as the concept of q-diffeomorphism-invariance in quantum gravity with the classical Schrödinger theory limit. For this purpose, we consider a quasiclassical experiment similar to the experiment we have considered for gravity. The real part of the scalar product $\langle\psi^1|\psi^2\rangle$ defined for a pair of solutions $(A^1,\psi^1),(A^2,\psi^2)$ is of interest here. Without copying this description, let's describe the results:

- In Schrödinger theory (multi-particle theory with Coulomb potential for electricity), the real part of the scalar product is observable.
- Postrelativistic quantum gauge theory allows to compute this scalar product and to obtain the non-relativistic limit.
- The scalar product is not q-gauge-invariant. Thus, the relativistic approach does not allow to define the scalar product. Relativistic observable results cannot depend on this scalar product.

The classical Maxwell equations lead to q-gauge-invariance in the sense that they do not define the evolution of the scalar product even classically. They have to be combined with some gauge condition.

Thus, we see, that relativistic quantum gauge theory has a problem with the non-relativistic limit. Of course, this is only a purely theoretical problem. In real QED and QFT computations the same non-gauge-invariant terms as in postrelativity are used. Thus, the problem becomes obvious only if we consider the situation very careful.

Of course, we have used here assumptions about measurability in classical Schrödinger theory. Especially we need a possibility to create and measure a superposition.

9 Discussion

Last not least, let's discuss some other questions related with postrelativity.

9.1 Historical Context

The harmonic coordinate equation has been often used in GR, starting with Lanczos [23] and Fock [15]. The Isham-Kuchar approach [22] interprets harmonic space and time coordinates as gravity-coupled mass-less fields used to identify instants of time and points in space. But in the context of general relativity they cause problems like different solutions for the same metric and solutions which don't cover the whole solution. Especially, a "clock field" will be uncertain and measurable, different from quantum mechanical and postrelativistic time.

Logunov et.al. have introduced the harmonic coordinate equation as a physical equation into their *Relativistic Theory of Gravity* [24], [33]. They have found the related modification for the black hole and big bang scenario and the conservation laws. Different from postrelativity, they have introduced a Minkowski background. Moreover, their argumentation for the theory was based on incorrect criticism of general relativity [29]. This theory was the starting point for the development of classical postrelativistic gravity.

For some of the quantization problems solved by the postrelativistic concept, the introduction of a Newtonian background frame as a possible solution has been recognized. For the problem of time, theories like PG are described by Isham [19] as "GR forced into a Newtonian framework". Isham mentions the reduction of the symmetry group in such an approach we find in PG too. The reason for the rejection of this concept given there — "theoretical physicists tend to want to consider all possible universes under the umbrella of a single theoretical structure" — is not impressive. The theory defines which universes are possible. Thus, tautologically, PG describes all possible universes too.

Real hidden variable theories have to violate Einstein causality if they want to predict a violation of Bell's inequality. For such theories, it is natural to introduce a Newtonian background frame. Bell has classified them as "relativistic but not Lorentz-invariant". A relativistic variant of the Bohm interpretation also includes such a preferred frame.

A possible link between these two questions has been recognized too. Isham [19] refers to Valentini [32] as a "recent suggestion that a preferred foliation of spacetime could arise from the existence of nonlocal hidden-variables".

Aharonov and Albert [1] have proposed an argument against the existence of a preferred frame in special-relativistic context, which has been rejected by Cohen and Hiley [12]. Roughly speaking, the flaw in the argument was that they have compared quantum evolution in different Lorentz frames. But, if we adopt the preferred frame hypothesis, the description of the evolution of the quantum system is allowed only in the preferred frame.

Classical postrelativistic gravity and the gedanken-experiment for quasi-classical theory have been introduced by the author 1992 [28].

9.1.1 Reasons for Previous Failure

It may be asked why such a simple concept has not been tried out before. In another formulation, it may be assumed that it has been already tried, but has failed. Thus, to continue the consideration of this concept is loss of time.

Here we have to reject that non-renormalizability, which is present in this approach, has been widely accepted as a sufficient reason to reject a concept. Arguments which show that this is not necessary [4] are not very old. Some other technical ideas like tetrad/triad formalism (which allow to avoid non-polynomial expressions like $\sqrt{-g}$) and functional-analytical methods for rigorous quantization are of course necessary for rigorous quantization of postrelativistic gravity.

Moreover, even if we assume that this approach fails, it seems interesting to find out where it really fails, which parts of the approach cause the failure etc.

9.2 Esthetic Questions

Of course, esthetic questions play an essential role in the distinction between theories which cannot be compared directly by experiment. Some questions we have considered — the consideration of the correspondence to gauge theory and the derivation of postrelativity using first principles — are essentially esthetic arguments for postrelativity. Let's consider also some other questions:

9.2.1 Popper's Criterion of Potential Power

Popper [27] has proposed a criterion of potential power. This criterion prefers a theory which can be easier falsified as potentially more powerful.

In this sense, already classical PG is more powerful. If PG is correct, GR is correct too, thus, there cannot be any falsification of GR without falsification of PG. But, in the other direction, there are at least theoretical possibilities to falsify PG without GR. It starts with the observation of nontrivial topology and the reality of the part behind the horizon of the collapsing black hole.

If we include quantum theory into the consideration, we obtain a really different predictive power. As the predictions of the tree approximation, as the prediction of the results of the quasiclassical experiment are postrelativistic predictions, general relativity remains silent.

9.2.2 What Has Been Lost?

In discussions, a main argument against postrelativity is an unspecified "loss of beauty" compared with general relativity. Unfortunately, the opponents give usually wrong reasons, like references to covariance or to the number of variables combined with Occam's razor. But, of course, something really has been lost. To understand the issue it seems necessary to find out what has been really lost.

At first, let's remark that it is not covariance, because any theory, PG too, allows a covariant description. It is also not symmetry. As already remarked by Fock [15], there is no symmetry in general relativity.

It seems useful to compare PG with an approach inside GR which defines time as a physical clock field defined by the harmonic equation [22]. This clock field approach remains completely inside GR and that's why does not "loose their beauty". This comparison shows that it is also not the number of variables which makes the difference, and it is of course not the equation used for the variables.

9.2.3 A Predefined Framework

But what is it? The only difference between the clock field approach and PG is the metaphysical status of space and time. In PG we have an a-priori given framework consisting of space, time and the affine-Galilee symmetry group. GR — with or without harmonic clock fields — lives without such a framework. Thus, it is presence or absence of a framework which is independent of physics which makes the real difference.

From esthetic point of view the presence of an independent framework can be considered as an advantage — we obtain greater modularity. The modular structure of the postrelativistic theory is different from general relativity. We have clear modular parts: Hilbert space theory — time — space — configuration space — Schrödinger operator.

On the other hand, there are arguments for preference of a theory "without framework".

First, the abstract principle "action = reaction" requires that the dependence of matter from the framework leads to influence of matter on the framework too. We can argue that the harmonic equation $\Box t = 0; \Box x^i = 0$ has the form of a relativistic wave equation, thus, defines a specific, weak influence of matter on the framework which corresponds to the specific, weak action of the framework on matter. Nonetheless, GR is obviously a better realization of this principle.

9.2.4 No Final Theory of Everything

The other argument is the hope for a "theory of everything". It suggests a "unification" of matter and framework too. This points to another difference between relativity and postrelativity: The loss of hope for the final theory of everything.

Indeed, the nontrivial physical results of general relativity are no longer results about "spacetime", but results about some ether. This defines a loss of philosophical importance of these results, and reduces the hope that we are close to the understanding of the most fundamental structure of the universe. Postrelativity suggests that there is an atomic underlying structure of the ether which has as many rights to be considered as fundamental as the atoms of usual matter.

A unified theory of everything we know yet may be possible — it is known that gauge theory occurs naturally for the description of crystal defects, by analogy it may be that particles and gauge fields may be interpreted as different types of defects of the crystal structure of the ether. Nonetheless, this theory cannot have the metaphysical status of a final theory of everything, but simply reduces the current observation to a more fundamental level.

The experimental possibilities to observe this more fundamental level are de-facto zero, thus, we have to give up the dream to find the most fundamental, final theory of everything.

9.2.5 Simplicity and Common Sense

PG is obviously much closer to "common sense", that means, to the picture of the world which is natural for our everyday experience. This is simply shown by the ether interpretation. There is no necessity to establish "spacetime", moreover "curved spacetime".

In this sense, PG is simpler compared with general relativity.

The fact that many expression, starting with the Einstein equations, are essentially simpler in harmonic coordinates, also has to be mentioned in a discussion of esthetic questions.

9.2.6 Beauty of the Harmonic Equation

Another criterion for beauty is the preference of a theory which requires the existence of a certain beautiful mathematical structure, compared with a theory which does not require this structure, if this structure really exists, moreover if it is unique.

Applied to the harmonic equation, which is obviously required to define the evolution of the gravitational field relative to the background in PG, but completely unnecessary in general relativity, this is a clear argument in favour of PG. Similarly, the existence of the Lorentz condition is an argument for postrelativistic gauge theory.

9.3 The Question of Measurability

From point of view of the relativistic paradigm, the variables we consider as real, physical variables are not observable. The comparison of configuration spaces and of the quasiclassical experiment suggest that the introduction of these steps of freedom lead to observable consequences. Nonetheless, there seem to be no direct measurement.

Is this a conceptual problem for postrelativity? The answer is no. It may be a problem of comparison of the theory with real experiments. Indeed, if we are not able to measure some variables, we are also not able to create the pure states of the theory in the experimental setup.

But often this is not a real problem. Indeed, the assumption that these steps of freedom are physical at least often allows to define a simplest state using physical criteria for simplicity — minimal energy or number of particles, highest symmetry. In these situations, we can usually assume that we are in this simplest state. The evolution of these states gives unique predictions also for more complicate situations.

A nice example of this strategy is the black hole collapse. In the initial state — nearly Minkowski space — we have a simplest choice of coordinates, the affine coordinates. These initial conditions allow to make predictions about the affine background through the collapse.

For the comparison of the predictions about a known state with experiment there is simply no problem. The theory is and has to be able to predict the evolution of the measurable variables of their states. The theory has not to be unable to predict anything else. If further research shows that some parts of the theory may be omitted without observable consequences, this does not invalidate the theory.

In reality we are used to work with theories without possibility to measure all variables. We have no possibility to measure the color of a quark or to observe the state of the Faddeev-Popov ghost particles, but nonetheless use such theories successfully.

9.4 Metaphysical Interpretation of the Background Frame

The metaphysical interpretation of the background frame is a more or less obvious consequence of our initial picture. The background time describes past, present, future, and causality. As a philosophical concept, it has to be distinguished from time measurement with clocks. It is remarkable that the distinction between two notions of time — using the notions "true time" and "apparent time" — has been introduced already by Newton [25]. It was already mentioned in this definition, that they may be in principle different: "It may be, that there is no equable motion, whereby time may be accurately measured. All motions may be accelerated and retarded, but the flowing of absolute time is liable to no change."

A similar distinction has to be made between the metaphysical concept of position and distance. The notion "position" is defined by the background space, distance by length measurement. They become really different in the context of a superposition of two gravitational fields: The distance between identical positions depends on the gravitational field. Only the existence of the notion "position" independent on distance measurement allows to define the scalar product independent of the gravitational field.

9.5 Summary

As far as we have been able to verify, the postrelativistic principles do not lead to serious quantization problems. Moreover, many known problems of the standard relativistic approach do not occur in postrelativity:

- The problem of time, inclusive the problems related with the Hamilton constraint in the Wheeler-DeWitt approach.
- Problems related with nontrivial topologies.
- Problems which may be related with Einstein causality, like uncertainty of causality if the gravitational field is uncertain, the violation of Bell's inequality, possible superluminal tunneling speed.
- Problems related with handling of the space diffeomorphisms, inclusive the diffeomorphism constraints in the canonical relativistic approach.
- The problem of Gribov copies in relativistic gauge theory.
- Problems related with the impossibility to compare different solutions in general relativity, which is necessary for the scalar product computation in our semiclassical experiment, the semiclassical consideration of small modifications of the gravitational field on a classical background.

- Problems related with the definition of usual observables in quantum gravity, inclusive local energy and momentum density, which is not observable already in classical general relativity, the vacuum state and the number of particles which is problematic in semiclassical general relativity, and any usual classical measurement which becomes problematic if q-diffeomorphism-invariance is required.

- Problems related with the impossibility to avoid the black hole and big bang singularities in general relativity.

The status of the remaining known problems is not very serious from point of view of their conceptual status. Without diminishing the difficulty of the technical problems, it can be said that they have different, technical character, comparable in difficulty with the quantization of a classical deformed crystal with an unusual nonlinear behaviour, not conceptual problems like the problem of time.

The postrelativistic approach allows to make a lot of additional experimental predictions in a domain where the relativistic approach remains silent. It predicts the evolution of variables which are considered to be not measurable in general relativity, like time, position, energy and momentum densities for the gravitational field, vacuum state and number of particles in semiclassical quantum field theory, gauge potential in postrelativistic gauge theory. It allows to leave the limits of semiclassical quantum gravity (tree approximation results for gravity, superpositions of semiclassical states).

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