The Universal Arrow of Time IV: Quantum gravitation theory.

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Abstract

The paper is dealing with the analysis of quantum gravitation theory from the point of view of thermodynamic time arrow. Within this framework «informational paradox» for black holes and «paradox with the grandfather» for time travel "wormholes", black stars, Penrose's project of new quantum gravitation theory, anthropic principle are considered.

1. Introduction

The paper includes the analysis of quantum gravitation theory from the point of view of the thermodynamic time arrow [1-3]. Inside of this framework«informational paradox» for black holes and «paradox of the grandfather» for time "wormholes", black stars [4] and anthropic principle [5] are considered. It is shown, that wishes of Penrose [6-7] for the future theory of quantum gravitation need not creation of the new theory, and can be realized within a framework of already existing theories by the help of the thermodynamic approach.

2. Black holes

In general relativity theory, unlike the classical mechanics, two different states for *finite* time can give infinitesimally close states. It happens during formation of a black hole as a result of its collapse. It results in the well-known informational paradox **[**8**]**: the collapse leads to losses of the information in the black hole. It results in incompleteness of our knowledge of the system state. Hence, it can leads to unpredictability of the system dynamics. The information, which in classical and a quantum mechanics is always conserved, disappears in a black hole. Whether is it so? Usually only two answers to this problem are considered. Or the information really vanishes completely; or the information is conserved inside of the black hole and can be extracted. We will see that in quantum gravitation we have the same answer, as in general relativity theory - both answers are possible and true, because the difference is not observed experimentally.

For the semiclassical theory of gravitation where gravitation is featured by relativistic relativity theory, and fields is featured by quantum field theory, the paradox resolution is made with the help of Hawking radiation.

In quantum field theory the physical vacuum is filled by permanently born and disappearing "virtual particles". Close to the event horizon (but nevertheless outside) of a black hole the pairs of particle-antiparticle can be born from vacuum. It is possible the situation when an antiparticle total energy appears subzero, and a particle total energy appears plus. Falling to the black hole, the antiparticle reduces its total energy and mass while the particle is capable to fly away to infinity. For the remote observer it looks as Hawking radiation of the black hole.

Since this radiation incoherent after evaporation of the black hole all information accumulated inside of it disappears. It is an answer of the semiclassical theory. It would seem that this result contradicts to reversibility and unitarily of quantum mechanics where the information can not be lost. We would expect the same result in quantum gravitation theory. But whether is it so?

We have now no finished theory of quantum gravitation. However for a special case of the 5-dimentional anti-de-Sitter space this paradox is considered by many scientists to be resolved. The information is supposed to be conserved, because a hypothesis about AdS/CFT dualities, i.e.

hypotheses that quantum gravitation in the 5-dimensional anti-de-Sitter space (that is with the negative cosmological term) is equivalent mathematically to a conformal field theory on a 4-surface of this world [9]. It was checked in some special cases, but not proved yet in a general case.

Suppose that if this hypothesis is really true, as it automatically solves the information problem. The fact of the matter is that the conformal field theory is unitary. If it is really dual to quantum gravitation then the corresponding quantum gravitation theory is unitary too. So, the information in this case is not lost.

Let's note that it not so. Taking into account the influence of the observer makes inevitable information losses. Process of black hole formation and its subsequent evaporation happens on all surface of the anti-de-Sitter world (described by the conformal quantum theory) which includes as well the observer. The observer inevitably gravitational interacts with the black hole and its radiation. Unlike usual quantum mechanics all-pervading gravitational interaction exists in quantum gravitation. So influence of the observer already cannot be made arbitrary small under any requirements. Interaction with the observer makes the system not unitary similarly to the semiclassical case.

It would seem that we can solve the problem by including the observer in the system description. But the observer cannot precisely know the initial state and analyze the system when he is its part! So, he cannot experimentally verify the difference between unitary and not unitary evolution. It is necessary complete knowledge of the system state for such verification. But it is impossible at introspection.

In the anti-de-Sitter world Universe expansion is inevitably replaced by a collapse. But the same effect information losses are available also for the accelerated expansion of the Universe - there appear unobservable parts of Universe, whence we are not reached even by light. Hence, these parts are unobservable, and the information containing in them is lost. It again results in unpredictability.

Thus, the experimental verification of informational paradox again becomes impossible *in principle*! In case of quantum gravitation information conservation happens only on a paper in the ideal dynamics. In the real observable dynamics the difference is not observed experimentally in principle. It is possible to consider both answers to the problem to be correct. The two cases of conservation or not conservation of information experimentally are not distinguishable.

Principal difference between usual quantum theory and quantum gravitation theory happens because of inevitable gravitational interaction. In usual quantum theory interaction between an observer and an observed system can be made zero in principle at known initial conditions of the observed system. In quantum gravitational systems the small gravitational interaction with the observer is irremovable in principle: it creates principally inherent decoherence and converts evolution of any observable system into the nonunitary. Only for nonobservable ideal evolution on a paper it can be made formally unitary. But also it is possible not to make it unitary- here we have a freedom to choose. If we wish to feature real observable dynamics we can put the dynamics to be nonunitary. For macrobodies such observable dynamics is semiclassical theory. It is experimentally indistinguishable for the real macroscopic observer from unitary quantum gravitation dynamics of large black holes.

3. Time wormhole

Let's consider from the point of view of the entropy such paradoxical object of general relativity theory, as time "wormhole" **[10]**. We will consider at the beginning the most popular variant, offered by Morris and Thorne **[11].** Let we have space wormhole with the extremities laying nearby. By very simple procedure (we will ship one of the extremities on a spaceship, we will move it with a velocity close to light, and then we will return this extremity on the former place) space wormhole can be conversed into time wormhole (wormhole traversing space into one traversing time). It can be used as a time machine. Such wormhole demands the special exotic matter necessary for conserving its equilibrium. However there were models of a time machine which allow to be bypassed absolutely without exotic substance [12, 17]. Or, using an electromagnetic field, allow to be bypassed by its small amount [13]. Use of such time machine can lead to well-known «paradox of the grandfather» when the grandson, being returned in the past, kills his grandfather. How this paradox can be resolved?

Let's consider, what answer to this problem the semiclassical theory of gravitation gives. Suppose that the macroscopic topology of the space related to the time machine is unchanged. At the moment of the time machine formation (transformation of the space wormhole into time one) between its extremities there is a closed light ray. Its energy does not reach infinity, despite the infinite number of passes, because of a defocusing of the light [16]. Other situation however arises in the semiclassical theory with «vacuum fluctuations» radiation field [14]. Passing the infinite number of times through the wormhole and summing, these fluctuations reach the infinite energy which will destroy any traveler.

However a situation in quantum gravitation is the other. Quantum fluctuations contain large energies when they arise on short distances. So it is possible to find so small distance on which energy of fluctuation will be large enough for formation of a tiny black hole. Thus the horizon of the tiny black hole will be the same size, as well as this small distance. The space - time is not capable to remain homogeneous on such short distances. This mechanism ensures natural "blocking" of singular fluctuations formation, restricting them on a size - «maximum energy in the minimal sizes» [16].

Detailed calculations of quantum gravitation show [15], that this "blocking" to formation of singular fluctuations ensures very small, but not zero probability of unobstructed transiting of time "wormhole" for macroscopic object. How to prevent in this situation «paradox of the grandfather»? Here it is convenient for us to use the language of multiworld interpretation of quantum mechanics. To prevent paradox the traveller should penetrate to the parallel world where it can easily «kill the grandfather» without breaking a causality principle. Such parallel world will interfere quantum-mechanically with the worlds of "not killed grandfather" where the observer was unsuccessful to transit the time wormhole. However the probability amplitude of such world will be extremely small. Whether can the observer in the world where «the grandfather has not killed» discover the alternative world at least in principle, using quantum correlations between the worlds? Similarly to "paradox of the Schrodinger cat" he cannot because of the same reasons, as in usual quantum mechanics [2]. Observation of large effects of quantum correlations is impossible because of «observer's memory erasing» [1-2]. Penetration to the parallel world of quantum mechanics is experimentally indistinguishable from time wormhole fracture and penetration to the parallel world of general relativity theory [3, 17]. It means, that from the point of view of the external real macroscopic observer a situation when the traveler has perished in the wormhole or has penetrated in «other world», are observationally indistinguishable. It is equivalent to a situation when the traveler falls into a black hole. we do not know - whether he is crushed in the singularity or penetrated into «other world» through the white hole [18]. (Though this difference is observed and essential for the traveler. But he will carry away all these observations with himself into «other world».) We see, that as well as in a case of "informational paradox", the difference between quantum and semiclassical theories for macroscopic objects experimentally is not observed for the macroscopic observer which did not travel in the time wormhole.

3. Black stars.

Recently there appears an interesting theory of "black stars" [4]. Usually the collapse of a black hole is considered as fast process. However we don't know well a matter behavior under high pressures. We know that intermediate stages such as white dwarfs, neutron stars are possible before a black hole collapse. These intermediate stages make a collapse not avalanche, but gradual. Probably, on the way to a collapse will appear additional intermediate stages appear, for example, quark stars. These intermediate stages make this process to be gradual without a fast collapse at all. For classical gravitation it is incidental. The star becomes a black hole for gradual process also. But for semiclassical gravitation it is important. It can be shown that for such case at slow squeezing quantum fluctuations at a surface will prevent a star material to collapse to a singularity and to become a black hole. Outside this object would be similar to a black hole, but inside it would be different, conserving all information without singularity. It will allow for a traveler to penetrate its surface and to come back. It is worthy of note that against such picture there is an essential objection.

How much is such construction of a star stable with respect to the external perturbation imported by the traveler to inside of a star? Also how much is the traveler stable during such travel? The traveler is a macroscopic body. After penetration to a black star, he will increase its mass stepwise at finite value. It can results in its collapse to a black hole. Suppose that the process again goes "gradually" without collapse. Then the traveler "would be dissolved" into the star and cannot come back also. Thus, it seems that the difference between a black star and a black hole can not observe experimentally. So, it means that the difference between these objects exists only on a paper, i.e. in ideal dynamics.

4. Penrose's project of new quantum gravity theory.

In the nice books [6-7] Penrose gives the remarkable prediction of the future theory of quantum gravitation. In this theory:

1) Unlike usual quantum mechanics a wave packet reduction is fundamental property of the theory.
2) This reduction inseparably linked with gravitation appearance.
3) The reduction is ruled not only by probability law. It can be result in some more complex uncertain behavior that can not be predicted even by probability law.
4) Unlike remarkable coherent quantum systems, classical chaotic nonequilibrium systems are exposed to criticism. They are supposed to be not relevant for modeling of real complex systems. Describes above unpredictable systems must be only pure quantum system.

It is worthy of note, that for receiving all these properties we need not new theory. Let take into account an inevitable gravitational interaction of the macroscopic real observer and his thermodynamical time arrow. It results in all described above outcomes within framework of already existing theories of quantum gravitation. Besides, classical chaotic nonequilibrium systems possess all properties of quantum ones. For any «purely quantum effect» always it is possible to discover such classical analogue (Appendix A [2]). Namely:

1) We saw above, that an inevitable gravitational interaction of the macroscopic real observer with an unstable observable system inevitably makes evolution of the observable system nonunitary. The difference between the unitary and nonunitary theory exists only on a paper and experimentally is not observed in quantum gravitation theory.
2) Because of the reasons stated above the gravitation interaction results in the inevitable reduction and correspondent nonunitarity in framework of the current quantum gravitation theory. Moreover, for macroscopic objects the semiclassical theory is already possessing desirable fundamental property of nonunitary. It is experementally equvalent to the quantum gravitation theory.
3) Behavior of many macroscopic bodies, in spite of nonunitarity, it is possible to describe completely by set of macroparameters and laws of their evolution. There are, however, *unpredictable* systems, whose behavior can not be described completely even by probability laws.

For example, let us consider quantum computers. Suppose that some person started such quantum computer and knows its initial state. Its behavior is completely predicted by such person. However for the second person who is not present at start, its behavior is *uncertain* and *unpredictable*. Moreover, an attempt of the second person to observe some intermediate state of the quantum computer would result in destroying its normal operation.

In case of quantum gravitation even the person started quantum computer cannot predict its behavior. Indeed the inevitable gravitational interaction between the person and the quantum computer will make such prediction impossible. Thus, «the unpredictability which is distinct from a probability law» becomes fundamental property of any quantum gravitation theory.

4) Unstable classical systems in many aspects remind on the properties of the quantum system (Appendix A [2]). Moreover, mathematical models of classical analogues of quantum computers exists [19]. Some paradoxical properties of the life objects reminding quantum computers can be modeled by classical unstable systems [20].

Summing up, we can see that all wishes of Penrose are realizable within the framework of the existing paradigm and need not any new fundamental theory. Moreover, all properties of macroobjects are usually described by macroparameters to exclude influence of the macroscopic observer. That inevitably results in unobservability too small intervals of time and space. So it is possible to construct their observable dynamics on basis of "discrete model of space-time". But such dynamics would not be a new theory. For any macroscopic observer the dynamics would be experimentally indistinguishable from the current quantum theory of gravitation.

5. Anthropic principle in quantum gravity theory.

The number of the possible vacuum states in quantum gravitation theory is equal to a very large value. For a selection of suitable vacuums usually anthropic principle is used [5]. It means that system evolution should results in appearance of an observer which is capable to observe the Universe. But such formulation has too philosophical character. It is complex to use it in practice. We can formulate here more accurate physical principles which are equivalent to the anthropic principle:

The initial state of Universe should result in formation of its substance in the form of a set of many macroscopic nonequilibrium objects weakly interacting with each other. These objects should have entropy and temperature. They should have thermodynamic time arrows. Small local interaction between objects should results in alignment of thermodynamic time arrows. Though these objects consist of many particles and are described by a huge set of microparameters, evolution of these objects can be described by a set of macroparameters, except for rare instable state.

However these unstable states play a important role, forming a basis for origin of a observer in the Universe. There should be unstable global correlations between Universe parts, and nonequilibrium macrosystems with local interior correlations which are origin of the observer.

We can conclude. To get the situation described above, the initial state of the Universe should be highly ordered and has the low entropy.

I.e., in short, evolution should results in the world that can be described in the thermodynamical form [1-3, 21-23]. Only such world can be origin of an observer, which is capable to study this world.

6. Conclusions.

We see that the informational paradox and the paradox of the grandfather are resolved in the quantum gravitational theory very similarly to the nonquantum general relativity theory. It is realized by consideration of weak interaction of systems with the real nonequilibrium macroscopic observer. Moreover, this approach (similarly to usual quantum theory) allows to resolve the wave packet reduction problem. But this reduction in quantum gravitation becomes fundamental property of the theory, unlike usual quantum mechanics. Such approach allows to consider the other complicated questions of quantum gravitation - anthropic principle, black stars.

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