Brief Introduction to Quantum Gravity

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Abstract- Quantum gravity is a field of theoretical physics that seeks to describe gravity according to the principles of quantum mechanics, and where quantum effects cannot be ignored, as almost compact astrophysical objects where gravity effects are strong. The current understanding of gravity is based on Albert Einstein's general theory of relativity, which is formulated within the framework of classical physics. On the other hand, the other three fundamental forces of physics are described within the framework of quantum mechanics and quantum field theory, radically different formalisms for describing physical phenomena. It is sometimes argued that a description of quantum gravity is necessary based on the fact that a classical system cannot be consistently coupled with a quantum system. Although a quantum theory of gravity may be necessary to reconcile general relativity with the principles of quantum mechanics, difficulties arise when applying the usual prescriptions of quantum field theory to the force of gravity via gravitational bosons.

Indexed Terms- gravity, quantum, and general relativity.

I. INTRODUCTION

Quantum theory was born by questioning for experimental reasons the nature of the elemental constituents of no luminous matter. Quantum theory of matter supposed a revolution in the way we understand matter. Crucial to what follows(1), however, is to emphasize that in this quantum theory space and time remained the old acquaintances of the mechanistic model. The search for a relativistic theory of gravity took us much further than we might have suspected at first. This quest has become synonymous with completely rethinking the description of space and time. The space and time of the mechanistic world have effects on matter, but are unaffected by it. This unsatisfactory situation is modified in the theory of general relativity. Space and time leave from being external and unchanging to forming a dynamic system, space-time, in direct relation to the matter it contains. The gravitational phenomenon has been reduced to nothing less than understanding the geometric structure of space-time. Space-time is curved in the presence of matter in a precise manner specified by Einstein's equations. In areas far from matter, this curvature becomes zero, giving rise to the flat space-time of special relativity. Seen in this way, the desire is to make a theory(2) that contains both properly modified concepts of matter and space-time. It is also straightforward to intuit that since neither of these theories was made with the other in mind, combining them could not be easy.

II. A FIRST PROPOSAL

A first attempt (3) to approach relativity and quantum was made with the proposition of quantum theory of relativistic fields. In this sense, for each type of elementary constituent corresponds a field. The wave excitations of each of these fields correspond to the different elementary particles, either photons for light or different types of fermions (electrons, quarks, etc.). These fields are quantum, meaning that their form is not perfectly determined, that is, it is only established on a probabilistic level. This theory provides a very powerful explanatory framework about the structure of matter and is endorsed daily in high energy laboratories. Returning to gravity, in terms of the geometry of space-time, we see that it can also be considered a field. Therefore, it can be said that contemporary physics imagines the world as a series of interacting fields where one of them, the gravitational, plays the special role. The problem is that the gravitational field of general relativity is not quantum. As we have already pointed out, the ideas (4) of material quantum mechanics can be transferred from space and time used in the mechanistic description to a relativistic space-time, provided that this space-time is fixed and external to quantum theory. The crucial point is that in quantum mechanics, space-time is not quantum. General relativity tells us; however, that space-time owes its form to the distribution of the matter it contains. But then, how can it be compatible to have a perfectly determined space-time if the question that defines it is quantum and therefore not perfectly determined?

III. INCONSISTENCIES

In general, it seems that having classical and quantum entities in interaction lead to inconsistencies. These inconsistencies lead us to think about the need to quantify gravity or, what is the same, the structure of space-time. From the point of view it could be concluded [5] that avoiding inconsistencies requires the existence of either a classical theory of matter, which manages the principles of quantum mechanics, or a hybrid theory, in which there are neither purely classical nor quantum aspects. In terms of theorems that say you can't reduce the quantum to the classical. Moreover, the return to classical formulations for the subject seems outdated. On the other hand, the second way has been explored, but in a very minority way and does not yet have a precise and complete formulation. The most straightforward way to quantify gravity was to follow the rules of the rest of quantum field theories in a flat space-time. The quantization of perturbations, as it is called, has shown considerable difficulties when applied to gravity. For example, general relativity tells us that when a star collapses under its own gravity, there is a time when nothing can stop the collapse, which leads to the formation of a black hole. Inside an astrophysical black hole, huge amounts of matter would eventually compress into subatomic-sized regions. Quantum gravity must hold the key to unraveling the behavior of such phenomena, which can affect all black hole physics, especially its event horizon. To understand the embryonic development of the universe we need quantum gravity [6]. We can say that to date there is no completely satisfactory theory of quantum gravity. There is a central and recurring problem in the various attempts to construct a theory of quantum gravity. The geometry of space is discrete, having states where areas and volumes appear only in units of some elementary areas and volumes. It is not yet known to fully control the spatiotemporal version. There is a hypothesis that perhaps gravity does not have to be quantified, but only has classic meaning, and the ingredients that underlie quantum matter and space-time may have a very different nature than the fields we are used to dealing with. This approach to the problem includes [7] lessons on how different collective behaviors appear in condensed matter physics. Possibly much of the difficulty in constructing a theory of quantum gravity stems from the inaccessibility of gravitational quantum phenomena to observation and experimentation. On the other hand, the two theories are known to work very well when applied in the context in which they were created, but fail to be employed in each other's fields. It is as if there are two "rival" physicists trying to explain the same universe. And one of the great obstacles is precisely gravity, which describes the course of the heavenly bodies so well, but is unable to be applied at the atomic level.

IV. POSSIBLE CAUSES OF INCONSISTENCE

One of the causes of the inconsistency mentioned is that the theory obtained in this way is not renormalizable because it predicts infinite values for some observable properties, such as particle mass. Therefore, it cannot be used to make meaningful physical predictions. As a result [8], theorists have taken more radical approaches to the problem of quantum gravity, the most popular approaches being string theory and loop quantum gravity. While some theories of quantum gravity, such as string theory, attempt to unify gravity with the other fundamental forces, others, such as loop quantum gravity, make no such attempt. Instead, they make an effort to quantify the gravitational field while it is kept separate from the other forces. Much of the difficulty in merging these theories across energy scales comes from the different assumptions these theories make about how the universe works. General relativity models gravity as a curvature of space-time and, according to John Archibald Wheeler, "space-time tells matter how to move; matter tells space-time how to bend." On the other hand, quantum field theory is typically formulated in the plane. Space-time used in special relativity. No theory [9] has yet proved successful in describing the general situation in which the dynamics of matter, modeled on quantum mechanics, affect the curvature of space-time. If one tries to treat gravity simply as another quantum field, the resulting theory is not renormalizable. Even in the simplest case, where the curvature of space-time is fixed a priori, developing quantum field theory becomes more mathematically challenging, and many ideas that physicists use in quantum field theory in flat space-time do not are more applicable. It is widely expected that a theory of quantum gravity will allow us to understand very high energy problems and very small dimensions of space, such as the behavior of black holes and the origin of the universe. No concrete proof of gravitons exists, but quantized theories of matter need their existence. The observation that all fundamental forces except gravity have one or more known messenger particles leads researchers to believe that at least one must exist. This hypothetical particle is known as the graviton. The predicted finding would result in the classification of the graviton as a particle of force similar to the photon of electromagnetic interaction. The graviton mediates the gravitational force. If found, the graviton is expected to be mass less because it acts instantaneously over long distances and has spin 2 because gravity is a second order tensor field. Many of the accepted notions[6] of a unified theory of physics since the 1970s assume, and to some extent depend on the existence of the graviton. Graviton detection would validate these various lines of research to unify quantum mechanics and relativity theory. The main problem with experimentally testing any theory of quantum gravity is that the energy levels required observing conjectures are unattainable in current laboratory experiments. Even theoretically, quantum gravity faces serious problems. Gravitation is currently explained [10] through the theory of general relativity, which makes very different assumptions about the universe at the macroscopic scale than those made by quantum mechanics at the microscopic scale. Attempts to combine them often run into the "renormalization problem," in which the sum of all forces does not nullify and results in an infinite value. In quantum electrodynamics this happened occasionally, but it was possible to renormalize mathematics to remove these problems. This renormalization does not work on a quantum interpretation of gravity. If quantum gravity exists, it will be neither simple nor elegant, in which case these attempts are being approached with erroneous assumptions and would probably be inaccurate. Only time and experimentation will tell for sure. It is also possible that some of the possible theories predict that an understanding of quantum gravity not only consolidates them but introduces a fundamentally new understanding of space and time.

V. FINAL CONSIDERATIONS

As highlighted in this text, the great challenge of quantum gravity is to fuse Einstein's general relativity with quantum mechanics. The phenomenological obstacles [9] to this unification are not trivial, and the mathematical complexity is for few, even for physicists. If these impediments are overcome, these two powerful theoretical tools would come together in so-called quantum gravity, a kind of final theory. In a way, Einstein himself fought with this merger in the final two decades of his life. The crux of quantum gravity is to propose that space be quantized. While in Newtonian Physics, Space and Time are taken as completely distinct and non-dynamic concepts, used for mere description of an event, in General Relativity Theory [10] they are studied as fundamental entities in which each event is a point in a new variety called of space-time. The classical perspective of this theory axiomatically assumes that this new space is continuous and is mathematically based on the concept of metric, which in turn characterizes the inner product of spaces and surfaces. In parallel, the development of Quantum Mechanics has introduced new concepts that oppose relativistic determinism. Each physical state results from the overlap and contribution of several quantum states, being only possible to determine the probability of occurrence of each one of them. A first attempt to reconcile quantum phenomena by the Compton wavelength with gravity by means of the Schwarzschild radius results in the determination of a fundamental unit of time and distance. Due to the discretized properties of quantum mechanics and the continuity of space-time and hence the gravitational field, much of the attempt to develop a theory of quantum gravity has been a failure.

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