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RESEARCH ARTICLE

# QUANTUM GRAVITY AS A THEORY OF QUANTUM SPACETIME

*,1,2,3Nilo Serpa

[1]Civil Engineering Coordination, ICESP Colleges, DF, Brazil
[2]GAUGE-F Scientific Researches, DF, Brazil
[3]Pro-Rectory of Post-Graduation, Research and Extension, Santa Ursula University, RJ, Brazil

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ABSTRACT

This article presents and discusses, from an epistemological point of view, a quantum theory of spacetime based on principles built from infinite mathematics applied to natural philosophy, cosmology and Riemannian geometry. A cautious argument shows that there is no logical reason to suppose that the ultimate structure of the universe is discontinuous from the moment that one considers an expanding universe. General relativity and quantum mechanics are evoked by discussing the barriers that today hinder a theory of great unification. A brief explanation of Lyra's geometry is made under the application of singularity functions in the context of the proposed theory. In addition, a quick appreciation of the current state of the investigations is made, showing the role of the proposed theory in the scenario of modern research.



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## INTRODUCTION

In this work, an effort of philosophical reflection is manifested towards the elimination of the obstacles which slowed the progress of modern physics, an effort which is inspired on previous works like those of Butterfield and Isham (2000). After so many years of research in gravitation, I find myself working on different theoretical lines in a sort of exemption of choice, developing only theories that carry in them promises of elucidation. I do not see them as competing theories, but as systems of representation that can be complementary in a certain sense. In the current state of knowledge, I cannot affirm this complementarity, but I think it shall be the case in the future. I do not want to discuss the existing gravitational models here, but to clarify the main model I propose for what we would call, for lack of a better expression, "quantum gravity", understood here as a quantum theory of spacetime. This theory aims to model a single substratum constituting all the existing mater in its different forms. In other words, the theory aims to build a model that allows for a unified understanding of what exists beyond interactions and "observers". It is therefore not a theory of great unification, but a general phenomenological theory of the primordial structures of the universe, structures that permeate everything that exists, including elementary particles and quarks. Lastly, I would like to make it clear that this work goes beyond a speculative model at Planck scale, showing that many unresolved issues still need to be addressed before a complete and unified theory of gravitation can be achieved.

**Corresponding author:* *,1,2,3Nilo Serpa,
[1]Civil Engineering Coordination, ICESP Colleges, DF, Brazil
[2]GAUGE-F Scientific Researches, DF, Brazil
[3]Pro-Rectory of Post-Graduation, Research and Extension, Santa Ursula University, RJ, Brazil

### Phenomenological metaphysics

An old master told me in high school: "Physics is mathematics plus good-sense". It is, perhaps, a simplistic view, but in fact it seems to apply perfectly to the question of the definition of the spacetime quantum (if this definition brings a realistic sense). Another thing I learned is that one can never give up the great classics of scientific literature, in which the most basic concepts are presented in a simple and clear way. This is what happens with the writings of Lazare Carnot on the metaphysics of the infinitesimal calculus, from which I allow myself here to transcribe a first enlightening passage:

*Il n'est aucune découverte qui ait produit dans les sciences mathématiques une révolution aussi heureuse et aussi prompte que celle de l'analyse infinitésimale; aucune n'a fourni des moyens plus simples ni plus efficaces pour pénétrer dans la connaissance des lois de la nature. En décomposant, pour ainsi dire, les corps jusque dans leurs éléments, elle semble en avoir indiqué la structure intérieure et l'organisation; mais, comme tout ce qui est extrême échappe aux sens et à l'imagination, on n'a jamais pu se former qu'une idée imparfaite de ces éléments, espèces d'êtres singuliers, qui* *tantôt jouent le rôle de véritables quantités, tantôt doivent être traités comme absolument nuls, et semblent, par leurs propriétés équivoques, tenir le milieu entre la grandeur et le zero, entre l'éxistence et le néant*[1]. (Carnot, 1797).

Note the reader that there is a direct reference to the study of the nature of things. It is not a loose mathematics in abstract reveries, but a mathematics applied immediately to the knowledge of the world of external things. The mathematical approach of the infinitesimal calculus thus implies the ideas of movement and evolution.

By applying that good-sense of which I have spoken above to this truly physical mathematics, it is possible to imagine a part of the spacetime which shrinks continuously to a size as small as one wants. Conversely, we can think of the same portion expanding on a region as small as we want. Whatever the size of this portion, we can think that it is even smaller at infinity. No matter how much this part is enlarged, we can always think of that smaller and smaller *ad infinitum*. The smallness of its expansion is added to an infinite number of other infinitely small expansions, so that an observable global expansion occurs. Thus, these unique beings, with size as small as one wants, which sometimes play the role of true quantities, sometimes must be treated as absolutely null, bring in their intrinsic ambiguity the dynamic essence of the spacetime becoming. Is that clear? Not at all! For me it worked well, but we need to improve our language and our representations to arrive at a clear idea for everyone.

**The divisible and the indivisible in the representation of the universe**

At this moment, my theory of quantum gravity separates from that advocated by Rovelli (whom I admire a lot) and others, not in a contradictory way, but rather on how we understand the essence of the spacetime. For Rovelli, space would not be continuous, that is, divisible into infinity, but composed of tiny loops intertwined with each other (Rovelli, 2006, 2007, 2011, 2012). As far as I know, the theory goes very well, because it provides indications of a satisfactory explanation of phenomena beyond the "initial" moment of the universe. But there remains a question that seems to be at the root of the difficulty of reconciling quantum mechanics with general relativity. While cosmology seeks to understand the genesis of the universe, *inter alia*, from an expansion dynamic that, in principle, does not indicate any discontinuous character of spacetime, quantum mechanics reveals the discrete character of the microphysical structure of matter. In my opinion, this discrete image is only what is captured from interactions, and Rovelli is right when he emphasizes interaction as a key concept for understanding the world. But when one talks about the ultimate tapestry of the universe, about the most intimate content of all matter, it would be a philosophical contradiction to establish an indivisible matter, since the indivisible does not consist in parts, and what has no parts has, theoretically, the nature of a point. But the point is a pure mathematical abstraction; physically, since matter is ultimately made up of spacetime itself, the most logical way to conceive physical reality is to imagine a dynamic continuum (of contraction or expansion), not the static point but the infinitely small in expansion or contraction. Moreover, the notion of the divisible boundary is certainly related to the limits of experimental apprehension; determining the lowest detectable value of a quantity does not mean that one has reached the limit of reality. It would be affirming an anthropogenic universe. There is no logical reason to support this limitation, although phenomenological approaches can be restricted by maintaining a more empirical circumscription.

Thus, quantum mechanics - as well as quantum field theory and all supersymmetric theories - is a theory of microphysical interactions par excellence, and these interactions go through the primal concept of force. In general relativity, there is no force, except in a very metaphorical way. The "fourth interaction" is expressed by mutually induced deformations between massive bodies in a spacetime continuum from which these bodies are made; there is not a Newtonian continuum of space that contains things, but things that are made of the spacetime continuum. Everything happens as if massive bodies were condensations of this continuum, or, if you prefer, "blisters" in the tapestry of the universe. A blister is the result of infinite expansions and contractions that occur in a chaotic manner, each one continually connecting with others. The combined effect of these expansions and contractions is called "gravity". Therefore, the quantum of spacetime is defined by a contraction - or expansion - of the spacetime as small as one wants. These contractions and expansions form the global dynamics of the universe that we observe.

**Time-like geodesics and Friedmann equation**

Of course, we are in a phase where expansion is dominant at large scale. Locally, however, we find here and there a predominance of contractions in black-holes and other processes of collapse. A quantum theory of spacetime, therefore, must deal with the uncertainties of the state of the geodesic paths as small as one wants; these infinitesimal paths are expansions or contractions of the spacetime itself. The tiny geodesic paths have recently been described by singularity functions in Lyra geometry (Serpa, 2016), the infinitesimal quantities being differentials of arbitrary intervals of time and space taken from geodesics. These paths can be timelike or spacelike. It is therefore necessary to define a correlation function based on the state uncertainty of the geodesic path (if timelike or spacelike). This opens the door to the application of concepts derived from quantum mechanics. The geometry of Lyra is a generalization of Riemannian geometry (Lyra, 1951), considered by some authors as a candidate for the modification of contemporary cosmological models (Shchigolev, 2013). By introducing a scalar field, that is, a gauge function $\chi$ ($x^k$), so that the Levi-Civita-Christofell connection is $\chi$-gauged and added with a term referring to the vector shift of a given parallel transport, we obtain the general form of the geodesic in Lyra geometry, given in singularity functions,

$$\chi \frac{d^2 \langle x-\varepsilon \rangle_\alpha}{d\tau^2} + {}^\dagger \Gamma^\alpha_{\mu\sigma} \frac{\chi d\langle x-\varepsilon \rangle_\mu}{d\tau} \frac{\chi d\langle x-\varepsilon \rangle_\sigma}{d\tau} = 0;$$

[1] There is no discovery which has produced in the mathematical sciences a revolution as successful and prompt as that of the infinitesimal analysis; none has provided simpler or more effective means of penetrating the knowledge of the laws of nature. By decomposing, so to speak, bodies into their elements, it seems to have indicated the internal structure and organization; but, as all that is extreme escapes the senses and the imagination, it has never been possible to form a perfect idea of these elements, species of singular beings, which sometimes play the role of true quantities, sometimes must be treated as absolutely null, and seem, by their ambiguous properties, to hold the middle between greatness and zero, between existence and nothingness. (free author's translation).

$$\frac{d^2\langle x-\varepsilon\rangle_\alpha}{d\tau^2}+\left[\chi^{-1}\Gamma^\alpha_{\mu\sigma}-\frac{1}{2}\left(\delta^\alpha_\mu\phi_\sigma+\delta^\alpha_\sigma\phi_\mu-g_{\mu\sigma}\phi^\alpha\right)\right]$$
$$\times\frac{d\langle x-\varepsilon\rangle_\mu}{d\tau}\chi\frac{d\langle x-\varepsilon\rangle_\sigma}{d\tau}=0;$$
$$\frac{d^2\langle x-\varepsilon\rangle_\alpha}{d\tau^2}+\Gamma^\alpha_{\mu\sigma}\frac{d\langle x-\varepsilon\rangle_\mu}{d\tau}\frac{d\langle x-\varepsilon\rangle_\sigma}{d\tau}$$
$$-\frac{\chi}{2}\left(\delta^\alpha_\mu\phi_\sigma+\delta^\alpha_\sigma\phi_\mu-g_{\mu\sigma}\phi^\alpha\right)\frac{d\langle x-\varepsilon\rangle_\mu}{d\tau}\frac{d\langle x-\varepsilon\rangle_\sigma}{d\tau}=0. \qquad (1)$$

Quantum spacetime has been compared with the quantum Riemannian metric to obtain the correlation function

$$\langle 0\,|\,g_{\mu\sigma}d\langle x-\varepsilon\rangle_\mu\,d\langle x-\varepsilon\rangle_\sigma\,|0\rangle=-d\langle x-\varepsilon\rangle_0^2, \qquad (2)$$

considering a timelike geodesic. Differences between brackets refer to arbitrary intervals on geodesics. The reader will find a detailed explanation in Serpa, 2016. An important aspect of this theory is that the choice of the geodesic type depends on the choice of the reference interval constants with respect to the domain of the independent variables. For instance, using the properties of brackets, we can select a purely temporal interval simply by making the spatial coordinates of the geodesic lower than the values of the reference interval constants which express fixed geodesic frames. From what has been explained above, the applicability of certain stochastic operatorial techniques of quantum mechanics to the formalism of general relativity seems to remain feasible. Of course, the other formal considerations of general relativity are valid here. In particular, adopting the usual assumptions of homogeneity and isotropy, the Friedmann equation restricted to the temporal coordinate becomes

$$\left(\frac{\dot{R}}{R}\right)^2=\frac{8\pi G}{3}\left\langle\rho_{\langle t-\varepsilon\rangle_0}\right\rangle\left(1-\frac{\left\langle\rho_{\langle t-\varepsilon\rangle_0}\right\rangle}{\rho_{Pl}}\right), \qquad (3)$$

where the density between brackets is a function of the brackets of the time interval, and $\rho_{Pl}\sim 10^{96}Kg/m^3$ is the Planck density.

## Final considerations

As we see, if this dialectical argumentation prevails, the trajectory of the quantization of spacetime, and consequently of gravity, will prove very different from what is generally understood by quantization, although some fundamental techniques of quantum mechanics can remain valid. For the moment, in the light of the current impasses, I do not see that it is productive to insist on a complete unification of the two great theories that have changed our vision of the cosmos. We can think of a partial unification of methods, but always keeping in mind the great architectural differences of general relativity and quantum mechanics. Perhaps we should be less pretentious and more modest, accepting that certain limits of knowledge will stay with us for a long time, maybe forever. After all, what we have are good representations that work very well, each of them in his own field. Does this mean that we must abandon the supersymmetric corpuscular model? Not necessarily. Gravitons and gravitinos, if confirmed, would also be blisters of the cosmological tapestry and could be useful as representations in specific explanatory constructions. As I have said elsewhere, the epistemological question that mattersis how to talk about supersymmetry in gravity, even if there is no evidence of the existence of particles like gravitons and gravitinos. The most effective way that I understand is to establish *a priori* that knowing the symmetries we know the system. So, it is reasonable to construct the symmetries that must govern gravity, regardless of its actual structure, granular or any other. Thus, what is most relevant is the symmetry proposed as the background of the facts, symmetry that precedes all phenomenological materialization.

## Epilogue

We have arrived at a metaphysical position in the sense indicated by Margenau (1972). The methodology to which this metaphysics is summarized leads us to a dynamic definition of the quantum of spacetime. On the one hand, we arrive at a quantity as small as we want, contracting spacetime to arbitrarily small dimensions; on the other hand, we arrive at the same amount as small as we want, but now in an arbitrarily tiny expansion perspective. Let us conclude by trying to hold two truths together:

1) Today, there is not a complete unified theory that encompasses both general relativity and quantum mechanics; how far we are from such a theory we do not know.
2) The fact is that we do not even know if this unification shall be possible.

Contemporary physics is progressing slowly. This is largely due to technological constraints, but there are also constraints of conceptual and theoretical nature. Unfortunately, current criticism on physics often lacks considerations on conceptual and semantic structures. From my point of view, one of the difficulties that modern physics faces is the lack of a clear physical linguistic, which has led the research in theoretical physics more and more to a simple mathematical exercise. I do not think it's the right way. If we do not keep the focus on representation, the focus will be on mathematics, not on the representation which is, after all, the object of the theorist. In fact, throughout my university life, I met colleagues who said they did not see much of physics in physics graduate school while working on their theses. Here is a subject for which a deep philosophical intervention is necessary in the sense of seeking a balance between language and representation. In short, unless another theory is found, radically different from what we have now, I do not think that the task of unification is possible. And I refer here precisely to the needs of conceptual renewal, which can only be satisfied by the tenacious will of philosophy of science.

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