Unspeakables and the Epistemological path towards Quantum Gravity.

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Abstract

We offer a critical assessment of some generic features of various of the current approaches towards the construction of a Theory of Quantum Gravity. We will argue that there is a need for further conceptual clarifications before such an enterprise can be launched on a truly well grounded setting, and that one of the guiding principles that can be viewed as part of the reasons for successes of the past theoretical developments is the identification of Unspeakables: Concepts that should not only play no role in the formulation of the theories, but ones that the formalism of the theory itself should prevent from ever been spoken about.

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I. MOTIVATION

The search for a theory that bridges the apparent abyss that separates the General Theory of Relativity and Quantum Theory has absorbed the efforts of an important segment of the theoretical physics community for decades, and although there is no doubt, that progress in various of the lines of approach has been substantial, particularly during the last decade, we are still far from the stage in which we could argue we have a fully satisfactory theory. The main contenders (as measured by the size of the community that works in the approach) are, of course, String Theory [1] and Loop Quantum Gravity [2], with some less popular candidates like The Partial Ordered Causal Sets program [3], and the Non-commutative Geometry program [4] maintaining an important presence in the field, while the initial impetus of the so called Wheeler de Witt [5] approach is almost completely gone.

I find it to be a healthy trend that people have started looking at the limitations and problems of the different approaches because science can only progress in an environment of robust and open criticism, and of constant focus on the problematic aspects of its current understandings. In this regard, several works have been written concerning the limitations of String Theory [6], among which we can cite its reliance of the formulation of the theory on a background metric for space-time, the absence of a clear and a priori identification of the physical degrees of freedom, the absence of a unique vacuum, etc. The Loop Quantum Gravity approach suffers from the absence of a wide enough class of solutions to the Hamiltonian constraint, the existence of ambiguities that might be similar to those associated with the non-renormalizability of the perturbative approach to the quantization of gravitation [7], to name the most important. This is not to say, however, that some of the above programs have not encountered some important successes. In fact, one of the main challenges that the theory of quantum gravity is supposed to address is the calculation, from first principles, of the Beekenstein-Hawking entropy for black holes. In this regard, both String Theory and Loop Quantum Gravity can claim relative success in a limited set of circumstances [8]. Technical difficulties impair their progress into the more general setting where they can be expected to be able to deliver similar success. Enormous amounts of efforts are being invested in these enterprises. However, I should like to point out that there is a realm where they are not expected to be able to deliver satisfactory answers and that concerns precisely the type of situation where strong quantum effects are combined with strong gravitational effects: The so called Schrödinger Black Hole, a situation where a quantum process determines whether or not a Black hole is present at an earlier time [9]. The situation is essentially a setup where an initially static thin spherically symmetric shell with mass M will be conditionally allowed to collapse at the speed of light leading to the formation of a Schwarzschild Black Hole. The crucial aspect is that the condition for allowing the collapse depends on the outcome of a quantum mechanical measurement, set up in such a way that there will be regions of space-time that will be located behind the event horizon in the event that the collapse is triggered, but that will precede in time the event at which the quantum measurement takes place. The result is that the location, and, therefore, the area of the event horizon will be undetermined at some times, leading to a problem when trying to assign to it the corresponding entropy. The example is quite contrived, of course, but it serves to illustrate several fundamental aspects of the current understanding about black hole entropy and its identification with the area of the event horizon, that one would expect a fundamental theory would be able to elucidate.

The relative small amount of interest by the quantum gravity community on this, and
similar issues, is an illustration of what I feel is an overemphasis on the technical aspects of quantum gravity in detriment of a concerted effort in advancement on the conceptual problems that plague the unification of the theories [10].

My point of view is that true success will elude us unless we start focussing on the various conceptual problems that should face any attempt to construct a unified version of quantum theory and gravitation, if that enterprise is to lead to a satisfactory theoretical understanding of physical reality. By these, I mean, among other things, facing the measurement problem in quantum theory [11], in particular, in regard with the suggestions that some novel aspects of physics would be needed to address the issues in a satisfactory manner [12]. These issues can be seen to become particularly acute when dealing with the problems that arise when trying to extend the standard interpretative schemes to the realm of quantum field theory [13], and when considering questions concerning quantum theory and cosmology [14]. There are, of course, several other problems that need addressing such as the problem of time in quantum gravity [15]. In this regard I would like to echo the concerns expressed, for instance, by R. Penrose [16] but I might add, that in my view, what is at stake is more than what it seems, because if we did manage to solve the problem of quantum gravity without having to address the foundational problems of Quantum Mechanics, we would be in a situation in which all hope for a guiding path towards its solution would be gone. Therefore, the posture I am exposing here could be considered to arise out of a certain “faith” that nature would not deprive us from reaching a true understanding of the rules that it follows. Faith that can only be justified by the previous historical development of our science, and perhaps by an irrational preconception about the innate abilities of men and the un-mischievous character of nature itself.

In this article, I will argue in favor of a certain type of guiding principle, which has the advantage of allowing itself to being casted in negative terms, thus avoiding the need for a clear and a priori elucidation of the ideas. The principle is based on the recognition of unspeakables. That is, the identification of concepts that are being dragged uncritically from previous stages of the understanding of the phenomena, and that upon further analysis are understood to be of such nature that they should play no role whatsoever in the more profound theoretical construct one is seeking. The principle to be followed once the unspeakables are identified, is that the theory should be constructed to avoid even the possibility that such concepts might be considered within its formalism.

II. THE ROLE OF UNSPEAKABLES IN THE PAST CONCEPTUAL DEVELOPMENTS IN THEORETICAL PHYSICS

Looking back at the history of the development of our current physical theories it is easy to spot several occasions where the breakthroughs were associated with the identification of previously unexpected classes of unspeakables. Let us briefly review some of the most important cases.

1) The Galilean insight about the absence of meaning in the concept of absolute rest frames in mechanics: One of the first instances, if not the first one, in the history of science where a great leap forward was achieved in connection with the rejection due to lack of meaning of a previously well accepted concept involves the Aristotelian notion of absolute state of motion. It is well known that in the Aristotelian ideas about nature, the everyday intuition of rest and motion was elevated to an absolute conceptual construct thought to be central in the laws governing the behavior of objects. This was particularly explicit as
it concerned inert objects, but in truth ultimately thought to apply to all objects, whose 

motion would need to be caused by some external entity.

This notion when confronted with the observation that the celestial bodies were, in con-

trast with the terrestrial ones, in a state of permanent motion, led to the even more pernicious 

notion (for the development of science) of a separation between the “Laws of the Earth” 

and the “Laws of the Heavens”. Needless is to recount here the details of the story that 
goes from Ptolemeo, Copernicus, etc. to Galileo who faces for the first time, in a coherent 

and methodical way, the concept of absolute motion. In doing so, he is able to unearth 

the unexpected compatibility of the idea that the Earth might be moving through space 

(around the sun) and that we might not feel the motion. The story of Galileos description 

of the happenings on the surface of a ship as described by the sailors aboard it and by the 
onlookers on the ground, brought to life the centrality of the notion of relative motion in 

contrast with the concept of absolute motion of Aristotelian physics, which, as we know, 

led to the Newtonian revolution, mother of other scientific and technological revolutions 

itself. One way, and the one I am advocating here, to look at the rise of the centrality of 

the notion of relative motion is to consider it the natural outcome of taking absolute motion 

and making it an Unspeakeable. That is, in all subsequent developments, thinkers about these 

issues would have known that they were deviating from the correct path whenever, in their 

arguments, they were making use, even in indirect ways, of the notion of absolute motion. 
The emergence of such concept would be automatically taken as a sign that something was 

not being analyzed correctly\(^1\). In fact, at the time when Newtonian Physics was being 

applauded for all its successes, there were some voices pointing out some unsettling aspects 
of the conceptual construct: The existence of absolute space, with respect to which no ab-
solute notion of uniform motion could be identified, but which permitted the identification 
of absolute acceleration. The theory of Newton, and, in particular, the famous three laws 
of motion, were supposed to be valid descriptions of physics if that description was made 
using observations carried out in connection with any \textit{inertial} frame. Those frames, which 

played such a central role both in Newtonian Mechanics, and latter in Special Relativity, 

were identified as a problematic concept by E. Mach who observed that the notion of abso-
lute acceleration without reference to any particular object seem to be quite different from 
the other conceptual constructs of the theory. The idea that an object would be accelerating 
with respect to space itself was deemed epistemologically ungrounded as there seem to be 
no possible way to directly observe this space, and thus, of determining if the object was or 
not accelerated with respect to it\(^2\).

\(^1\) Nowadays, notions of absolute motion are again being considered\(^{17}\), but in those cases people regard 

space-time as endowed with some additional microscopic structure, and the absolute motion under consider-

ation is, in fact, motion relative to a preferential rest frame associated with such hypothetical structure. 

Such point of view, thus evades the above criticisms of the older conceptual incarnation of absolute mo-
tion, but interestingly enough such ideas have encountered exceedingly tight bounds for the effects\(^{18}\) 

and serious problems when analyzed in the light of modern quantum field theory\(^{19}\).

\(^2\) In fact, it is quite amusing to note that even today this issue can put in serious trouble many undergraduate 

and graduate physics students and even some otherwise very well versed and qualified professionals in our 
field: Q: What is the law of inertia? A: A free particle moves with constant velocity. Q: Is that supposed 
to hold in any possible frame? A: No!, of course not, only in inertial frames! Q: What is an “Inertial 
Frame”? A: Well...one in which the law of inertia holds. Q: So the first law is not a law at all, but a 
mere tautology, right? A: Yes.. well no.. hmm.. let me think. There was something about the frame of
2) As we all know that Galilean revolution came to be revisited as a result of the studies on the electromagnetic phenomena. Those studies culminated in the formulation of Maxwells equations, which, in turn, predicted a finite and specific value for the velocity of light. The conflict of such notion with the Galilean relativity of velocities, led naturally to the concept of a special reference frame, the only one, where Maxwell’s equations where thought to be exactly valid: The frame of the “Luminous Ether”. These notions led in turn, to the search for indications of the Earths motion relative to such frame, and eventually to the development of the Special Theory of Relativity. While it is possible to look at this development as emphasizing the absolute nature of the velocity of light, I think it is more illuminating to regard it not only as reenforcing the Galilean identification of the unspeakable nature of the concept of absolute motion, but as the unearthing of a whole new collection of unspeakables: The duration of a process, the notion of simultaneity, the length of an object, etc. Of course, these concepts would resurge in a more modest incarnation, as relative concepts to be associated with a particular frame of reference, but with no meaning whatsoever in the absence of that specification. The theory, on the other hand, leads to some new concepts that are thought to have absolute meaning: The four momentum of a particle or of a system, the interval between two events etc. We should, however, note that the special theory of relativity, made absolutely no progress in dealing with one of the major criticisms of the Newtonian conceptual edifice: The epistemologically problematic concept of absolute state of acceleration and the related notion of inertial frames.

3) The next revolutionary change in our conceptual understanding in physics emerges from the impulse to bring gravitation into the new general scheme of special relativity. As is well known, this culminated in the development of the General Theory of Relativity. Here, the geniality of Einstein is observed, among other things, in his willingness to give up further conceptual pillars of the theoretical understandings of the day, just to free the theory from notions that had little epistemological justification, and, in particular, to address at the same time the issue of making the theory compatible with new insights gained from special relativity and the epistemological problems associated with the concept of inertia, as pointed out by Mach.

I consider the following to be a convenient way to look at the development of General Relativity, whether or not it is an accurate historical account of that process (most probably not). Let us take the notion of inertia as described in the footnote 1. As noted there, the conceptual construct would work if we were able to turn gravity off. But of course we are not, so why is such construction of any utility whatsoever? Why is it that we can make the fixed stars, and those moving with uniform velocity with respect to it......but there are no fixed stars! Hmm..It must be the frame associated with CMB, right?. The answer is of course the following: We take 3 free point particles (the identification of which is another story, but which in particular implies that we must neglect gravitation as its universality would preempt the existence of free particles) whose motion is not coplanar, adjust our motion so that we see them moving inertially (i.e with constant velocity), then we define our frame to be an inertial one. The law of inertia then states, that all other free particles would move inertially when described in that frame. This is clearly not a tautology as one can imagine a universe where this would not hold. Anyway the point here is just an illustration of the type of considerations that I feel have been largely forgotten in our days. I think that the fact that this type of problem is so common, is a result of an educating system that puts to much of its emphasis in “training people to solve problems” in detriment of the work associated with clarifying conceptual structures.
so much progress using this notion to do physics, to construct buildings and bridges, fly airplanes etc? After all, the Earth is certainly not inertial, and furthermore there is gravity all around us. It is true, we always consider gravity in our treatments, but we, in practice, consider only that due to Earth and ignore, for instance, the gravitational effects associated with the Sun or the Galaxy. The answer lies, of course, on the universality of gravity, which can be seen as indicating that one may, in carrying out the “construction” of the inertial frame described in the footnote 2, ignore the fact that gravity is there, and proceed with the prescription as if gravity did not exist. The universality of free fall would ensure that when following the instructions given in footnote 2, all the bodies, including the observer would “fall at the same rate”, and thus that the law of inertia will be satisfied in the constructed frame. The only point is that construction will only have local validity: the law of inertia will be valid to the extent that you limit observations to a sufficiently small space-time region. The notion of global Inertial frame is thus turned into an Unspeakable, and in so doing, help us understand the effectiveness of the Laws of Newtonian physics as used in our everyday lives. In short, while it seemed that gravity would invalidate the whole conceptual construct leading to the clarification of the content of the Law of Inertia, one crucial characteristic of gravity, namely, its universality, saves the day, and resurrects the notion of inertia but in a fashion which ties it inextricably with the Equivalence Principle. In this regard, the view, which I think is quite common outside the gravity community, that the Equivalence Principle is just a “curious” aspect of gravitation, is quite misleading. As we saw, we could not even make sense of the laws of inertia if the gravitational interaction did not lead to a universality of free fall, but still, acted on all bodies, and thus denied us the free particles we need to define inertial frames. Thus, the Equivalence Principle should be seen as the “reason” behind inertia itself.

This stage of understanding evidently gives rise to other unspeakables such as the notion of “a global inertial frame”, and all related ones, but perhaps, even more unexpectedly it renders generally meaningless, concepts such as the total energy or four momentum of an extended system: There is, in general, no way, to give meaning to the sum of the four momenta of a collection of particles, or the integral of the energy momentum of a continuous distribution of matter fields. To see this, consider a region of space-time in which we have a distribution of matter characterized by an energy momentum tensor \( T_{ab} \), and imagine that we want to compute the total energy momentum tensor. First, of course, we would need to identify an instant of time, which in general relativity would correspond to identifying a certain 3 dimensional space-like hypersurface \( \Sigma \). The problem is then how to define \( \int_\Sigma T_{ab}(x) dV_x \), as we do not know how to add tensors that are associated with different points. The possibility of using the notion of parallel transport is precluded, in general, due to the dependence of the resulting transport with the path that is used and that is characteristic of curved space-times.

In fact this type of problems leads to other unspeakables such as the generic notion of center of mass of a distribution of matter, and to the absence of a well defined procedure for the identification of a world line characterizing an extended system in general [20]. We will see that this particular unspeakable reappears in a more dramatic way at the moment we start to consider the concepts associated with gravitation in a quantum context.

4) The quantum revolution, exemplified for simplicity in the relatively simple theory of Quantum Mechanics, brings about some well known unspeakables. We learn that there is no meaning to the notion a particular path to a particle, as a path would require the particle to have at every instant a well defined position and a well defined momentum. In fact, we learn
that there is no physical reality to the points in phase space, and no meaning for that concept exists in the formalism. Two important new unspeakables. In fact, in general, things can be even more problematic because a subsystem that is part of a larger system can not be thought as having a well defined state of its own: The situation where there is entanglement imply that the parts can have, at most, a partial description (in terms of a density matrix) where other relevant information will appear only in the complete description of the system as a whole \[21\]. There is, of course, an extended literature dealing with the surprising and counter-intuitive aspects of the quantum world, where, in fact, the notion of unspeakable seems to first find its use\[22\], so here I only mentioned some of the most important concepts of the classical theories that became, strictly speaking, unspeakables after the quantum aspects of nature are taken into account.

5) Quantum field theory in curved space-time. The marriage of quantum theory with special relativity brings about the quantum theory of fields. There one learns of complications that have to do with incorporating the negative energy solutions, the ensuing notion of anti-particles, and, in dealing with all but the simplest case on noninteracting theories the complex issues of renormalization, anomalies etc. However, it is only at the next stage when one is forced to consider the situation resulting from replacing the Minkowski space-time background with the more general case of a curved space-time background, that an important actual new unspeakable emerges: The concept of particle. For the benefit of readers not familiar with this point we present next a very brief description of the problem.

Consider a theory of a scalar quantum field in a background space-time with metric \(g_{\mu\nu}\) and described by the Lagrangian density \(\mathcal{L} = \sqrt{-g}(\nabla_\mu \phi \nabla^\mu \phi - m^2 \phi^2)\). In constructing the quantum theory we are led to write the field as an operator \(\hat{\phi}(x) = \Sigma_i(\hat{a}_i f_i(x) + \hat{a}^*_i f_i(x)^*)\), where the functions \(f_i(x), f_i(x)^*\) are a complete set of, suitable normalized, solutions of the Klein Gordon equation in the background space-time, i.e. \(\nabla^\mu \nabla_\mu f_i(x) - m^2 f_i(x) = 0\), and the \(\hat{a}_i, \hat{a}^*_i\) are annihilation and creation operators, respectively. It is at this stage that the vacuum state \(|0>\) can be defined by the requirement that \(\hat{a}_i|0'>= 0, \forall i\). The point is, that we could have used another complete set of solutions to the Klein Gordon equation, for instance, if we define \(g_i(x) = \alpha f_i(x) + \beta f_i(x)^*\), with suitable conditions on the coefficients \(\alpha\) and \(\beta\) to preserve the appropriate normalization, the set of functions \(g_i(x), g_i(x)^*\) are an equally valid complete set of solutions leading now to the decomposition of the field operator as \(\hat{\phi}(x) = \Sigma_i(\hat{b}_i g_i(x) + \hat{b}^*_i g_i(x)^*)\). The new operator coefficients \(\hat{b}_i, \hat{b}^*_i\) are again annihilation and creation operators in the sense that they satisfy the corresponding commutation relations. In fact, one can check that \(\hat{b}_i = \gamma \hat{a}_i + \delta \hat{a}^*_i\) for some coefficients \(\gamma\) and \(\delta\) (depending on \(\alpha\) and \(\beta\)). Then we can define a new vacuum state \(|0'>\) such that \(\hat{b}_i|0'>= 0, \forall i\). It is quite clear that the two vacua are very different states, because \(\hat{b}_i|0>= (\gamma \hat{a}_i + \delta \hat{a}^*_i)|0>= \delta \hat{a}^*_i|0>= 0\). This problem is not encountered in the usual quantum field theory construction in Minkowski space because in that case one can use the fact that Minowski space-time is stationary, to define the notion of positive/negative energy solutions. The ambiguity is thus resolved, by the election to associate the annihilation operators with the positive energy solutions. However, in dealing with non stationary space-times, there is, in general, no way to make any sort of canonical selection of the mode functions that are used in the expansion of the quantum field operator. For a more comprehensive discussion of these issues see for instance \[23\]. Thus the notion of a vacuum state is not well defined, i.e. it becomes a new unspeakable, and the notion of a particle, being the result of acting by a creation operator on the vacuum, becomes, in the absence of further specifications, another unspeakable.
III. NEW UNSPEAKABLES IN QUANTUM GRAVITY

One thing that needs emphasizing is that almost without exceptions the concepts that are identified as unspeakables at one stage of understanding of nature, maintain their characters of unspeakables in the later developments associated with a deeper understanding. As indicated above, one such exception is the velocity of light that becomes absolute as a result of developments that occur after the stage in which all velocities are deemed to be relative.

Therefore, in discussing the next (and perhaps, ultimate) level of understanding of nature, which we naturally associate with a theory of quantum gravity, a set of guiding lampposts should be that in its conceptual development all previously identified unspeaksables should be regarded as such. Namely, that theory should have no place, and make no use of concepts like: the energy of a particle (unless one specifies the frame with respect to which it is considered) on account of 1) & 2), the notion of a particle other that as a relatively compact distribution of energy momentum, on account of 5), and then the notion of the energy-momentum of such distribution, on account of 3).

I find it quite surprising, therefore, that some of the attempts to formulate a quantum theory of gravity, have no qualms in embarking in such an enterprise, carrying along some of the conceptual baggage that should have been discarded according to the lessons from the previous levels of understanding.

I will leave it to the people working on such approaches to address this point, and will instead focus now on further lessons that, I believe, can be of use in the search for the desired theoretical path, one that should have, by its non-reliance on unspeakables, the right a priori features giving one the confidence that it might end in a success.

Thus, I propose we ask ourselves next: What about the marriage of Quantum Theory and gravitation?. Are there any new unspeakables that can be unearthed even before we have a theory of quantum gravity? For, if some of those were to exist, their identification could be an important guiding light into the eventual formulation of the theory. If we did identify one unspeakable, and it turned out to be a concept of common and widespread use in the discussions about Quantum Gravity, the efforts that would be required to avoid its usage, would be, in themselves efforts to replace the unsuitable concepts by others having more potential for lying at the basis of an appropriate formulation of the sought theory. In the following, I will discuss, using an epistemologically inspired line of reasoning, what I believe should be regarded as some of the new unspeakables that we must learn to contend with. Needless is to say that as the theory must contain, or at least accommodate, in principle, the previously discussed and well established theoretical advances, all the unspeakables listed before should also be unspeakables of quantum gravity: energy, length, absolute velocity, precise number of particles in a state, etc. Our discussion will concentrate in what we believe to be the novel unspeakables. In this discussion, we will allow ourselves the use of some of the concepts and language of the pervious stages, because the discussion, carried out in the absence of a selected candidate theory of quantum gravity, will be carried out in the meta-language afforded by the earlier stages. It is on the actual candidate theories that the demand should be imposed that their formalism is such that it makes it impossible to

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3 One of the astonishing facts that can be observed in looking at some of the prevailing approaches, such as String Theory, is the complete naturality with which some of the well known unspeakables, thoroughly identified in the preceding stages of the theoretical advancement, come back into the lexicon of the discussion. The most glaring example of this is the concept of energy.
talk about the unspeakables.

Let us consider the notion of space-time geometry. In all preceding stages of development of this notion, and, in particular, in The General Theory of Relativity, the space-time geometry is directly linked to observations: Using free test point particles one can identify the space-time geodesics and from these, in principle, one can extract the geometry. In fact, it should be clear that one can, in principle, read off the metric of space-time, for instance, by identifying both the light cones and the conformal factor, and that in a classical realm there are no impediments to doing so. The point in which we want to focus is that, in order to give an operational meaning to the geometry, we need those free test point particles. The problems one faces in going to the quantum gravity realm will be, precisely, those associated to the notions represented by the four words: free, test, point, particles. Some considerations of similar nature have been expressed before for instance in [24].

i) The first issue one confronts is the identification of objects as free, and it involves their coupling to other objects. The point is, of course, that nature does not offer us in reality any interaction free matter field. Retaking for a moment the notion of particles, we know that all of them do interact via some of the interactions in standard model. Photons scatter of other photons and even neutrinos are not free from the electro-weak couplings. This is, of course, irrelevant at the macroscopic scales where one is usually concerned with gravity, but if we pretend to extrapolate the conceptual constructs to the sub-atomic realm, which presumably are still quite removed from the regime where quantum gravity would be relevant, we must face the fact that there, the situation is fully reversed. In those conditions all actual particles and fields must be accepted as fully interacting. In fact, if there did exist some species of particle that was actually free, it would be rather difficult if not outright impossible to use them to identify the geodesics as they would be essentially invisible, and, in the situation where they could be considered as acting only as test objects, they would be actually invisible. We could, however, take the view that this is only an issue “in practice” and not one of principle, but even then this would not be the end of our problems.

ii) Let us take, for instance, the view that in the limit, when electrically neutral particles, are infinitely far from each other, they can be regarded as free. Consider then, the task of identifying, for instance the null geodesics of a space-time, which would lead us naturally to consider photons as the ideal class of objects to be employed for the task. The problem we would need to confront is that, even if distant from all objects, the interaction of the photon with the virtual particles of other species, results in the failure of the photon to propagate along null geodesics. In fact, things become even more dire when we note that a real photon is not actually in a four momentum eigenstate, because if it were, that would imply that it is not at all spatially localized, a condition rendering it completely useless for a world line identification in any case. The point is that in these circumstances its four momentum is not null. Let us consider the flat space-time limit and the decomposition of the photon state into four momentum eigenstates reflected in a distribution of four momenta represented by $P(p^\mu) = f(p^\mu)\delta(p^2)$. Then, the mean four momenta is $<p^\mu> = \int d^3pP(p) p^\mu$ which is, in general, a time-like vector, as can be seen by noting that $<p^\mu><p^\nu> = \int d^3p d^3p' P(p) P(p') p^\mu p^\nu = EE' - \vec{p}\cdot\vec{p}' = EE'(1 - \cos(\theta)) \geq 0$, where $\theta$ is the angle.
between $\vec{p}$ and $\vec{p}'$ with the last equality holding only for $\theta = 0$. Thus, if we want to consider partially localized photon wave packets, we would not be investigating the null geodesics.

iii) Moreover, having recognized that we must deal with photons that are extended objects with a four momentum that is not well defined, we are then led to consider the “mean momenta” and “mean position” to be the quantities which in the quantum world would correspond to the classical quantities that are used in the identification of geodesics. The problem is that, in a curved space-time, it is rather unclear how to make sense of such concepts. We can see the severity of the difficulty by considering the simpler case of a classically extended object, described, say, by its energy momentum tensor $T_{ab}(x)$. We already noted the problem of extracting, on a given hypersurface the four momentum of the object, but we would have to face what seems to be an even more daunting problem: that of extracting on that hypersurface the center of mass, and, in general, the world line of the center of mass. The classical (in contrast with the quantum mechanical) version of the problem has been considered in various works in the past \[20\], but the results are not sufficiently reassuring, even in this relatively simple setting (which suggests that the problems would become even more serious in the full quantum setting). To name some of the disquieting aspects, let us start by noting that the constructions considered so far for defining the center of mass world line of an extended object in curved space-time are all based on the corresponding definition in Spacial Relativity, and, there, the only possibility which satisfies the essential requirements of frame independence and four momentum conservation, leads surprisingly to the non-vanishing of the Poisson bracket among the center of mass coordinates \[26\]. This would undoubtedly translate in non-commutativity in the quantum version of the problem. The next problem is that, in the curved space-time setting, the definitions can be made only as long as the extent of the matter distribution is small enough so that the energy momentum tensor of the object in question vanishes outside a convex normal neighborhood (a neighborhood $U$ where any two points $p, q \in U$ are connected by a unique geodesic within $U$). Other problems are that, in general, the four momentum of the system is not tangent to the center of mass world-line, and perhaps, more disastrous, that its world line is not, in general, a geodesic of the space-time geometry. In short, in the quantum realm we have, in principle, no way to access, or identify, the geodesics of space-time. This means that, even if we consider a situation where the metric is well defined, we would have no way to access it. It is an object that is in essence unobservable. So we should ask ourselves: Why should such an object play any role in physics?.

iv) The possibility of exploring space-time with test particles, and, in general, test probes, has been considered at length and we will not repeat here all the arguments, but essentially recall the fact that a test object would have to be both highly localized (to explore the small regions of space-time one would in principle be interested in), and to have a sufficiently small contribution to the energy momentum tensor, so that it could be considered to be testing of the preexisting metric with a negligible effect on it. The point is that these two aspects are mutually exclusive when considering probes from the quantum realm. These considerations seem quite valid of course, but they are a bit different from some of the other considerations we have made above, in that the former rely on the dynamics of General Relativity in reaching the conflicting stage. That is, the considerations made in regard to this last point, are based on the extrapolation to untested realms of Einstein’s equation $G_{ab} = 8\pi G_N T_{ab}$, something that, in principle, one might want to reconsider. Moreover, we see that one can take the formal limit $G_N \to 0$ and use it to bypass the problem in at least certain limits. The problems raised in i), ii) and iii) indicate that the notion itself, of a
space-time metric even in the limiting regime where $G$ is set to 0, would be inappropriate in the quantum realm.

v) One further obstacle that would seem to emerge from the previous considerations is that, as we saw, in curved space-time, quantum field theory allows, in general no satisfactory definition of a particle. It seems to me that this is not really an issue as long as one could consider a concentrated bunch of energy momentum tensor. That is, as long as there are states for which the energy momentum tensor remains localized in sufficiently small regions. The problem that remains, of course, is that of extracting from those states the underlying geometry, which as we saw, could probably not be done relying on the identification of center of mass world lines with the geodesics of the space-time.

IV. WHAT IS, OR SHOULD BE, A QUANTUM GEOMETRY?

Our experience with other theories describing fundamental aspects of the physical world, such as Maxwell’s Theory or the Standard Model of Particle Physics, is that there is a relatively well defined procedure to transform a classical theory into a quantum one. We call this the quantization of the theory. This procedure takes the fundamental objects from the classical theory $\Xi_{\text{Class}}$ and transforms them into “similar” objects $\hat{\Xi}_{\text{Quant}}$. The similarity just alluded refers to both their tensor structure (i.e., the quantum version of a vector field, is an operator valued vector field), and the type of information they convey. The scheme has been quite successful, of course, but it is nonetheless a mysterious procedure and it is fair to say we do not completely understand what does it mean, and why does it work so well [27].

When we acknowledge that, in this respect, gravity seems to be quite different from other theories, for instance in not yielding after all the heroic efforts made so far, to direct (or even rather indirect) application of the quantization recipe, it becomes, not only legitimate, but also strongly compelling to start considering the issue in a different light.

What is being advocated here, is a reconsideration of what should be the object representing geometry in a quantum world. By this I mean what type of information it should be thought to convey, and what should it not. Some of these considerations have been expressed in a work that advocates that geometry in a quantum world should be an essentially relational construct [28]. That is certainly not the first time that relational ideas have been advocated, either at the pure quantum mechanical level [29], or in connection with gravitation [30], but perhaps it is the first case in which the proposal is made in conjunction with the suggestion of doing away with a quantum version of the space-time geometry. In [28] a suggestion is made regarding a modification of the algebraic approach to quantum field theory in curved space-time to make it compatible with a novel concept of quantum space-time [31]. Here, we will limit ourselves to discussing the use of the notion of unspeakables and avoid entering into any detailed proposal realizing the guiding principle.

In considering these problematic issues, we must keep in mind that there are, in principle, two roles played by the physical geometry in a geometric theory of gravitation: A) It is an entity codifying relationships between “events” defined in terms of the “matter” content of the theory (the quotations indicate that these notions would need to be clarified and specified in the appropriate context before any formal developments could even be attempted), and B) it is a dynamical entity whose behavior is part of the subject of the theory. I should focus in aspect A), which needless is to say will not be analyzed exhaustively or to any sort of finishing stage. Aspect B) will necessarily become susceptible of a careful analysis only
after A) has been thoroughly carried out.

Let us commence by reviewing the role of geometry in classical (as opposed to quantum) physics. More precisely, one wants to consider the meaning of the assignment of a “geometry” to our physical world. We have learned from Einstein that we should be concerned with the “measurements” of “intervals” between “events”. It is quite clear that before addressing this issue one must identify these events. In the classical realm, we could do this, for instance, by singling out one point on the world line of a point-like object, something that could be done, in principle, by considering the intersection of two such world lines (we can think of the “passing of one object in front of a particular observer”, or the emission of a light pulse from a certain source). When considering the measurement of the interval, one should focus on our reliance on a physical device to actually specify the measuring procedure. Normally, we think of using a “clock”, if the interval is time-like; a “ruler”, if the interval is space-like; or define it as null if the two events can be connected by a light signal. In all these cases, we must recognize the central role played by the physical objects, clocks, rulers, or light pulses, in order to allow us to determine what the geometry is. Here the point is not to restate the obvious fact that we need such objects to measure the geometry. What we want to stress is that we need to specify these physical objects in order to define what we mean by “the geometry of our physical world”. That is, we need to deal with those issues in order to give meaning to the words. It must be noted, for instance, that it is, in principle, not a priori at all certain, that the geometry could be defined in such a way that it does not depend on the objects we choose to use in defining it. For instance, we could have chosen to measure spatial intervals (of say, an instant, or spatial section of space-time taken for simplicity to be static) with either ceramic rods, or alternatively with metallic rods, and imagine a situation in which the temperature through the region being examined is not uniform. Under such circumstances, the straightforward determination of the geometry of the region with the two types of roads would give different results. For instance, the geometry determined with the ceramic rods could be flat while the one determined with the metallic rods could have nonzero curvature. This is all obvious, and every physicist “knows” that the use of the ceramic rods is the “correct choice” in this case because of the large thermal dilation coefficient of the metal. Actually, we would be told that even if we use ceramic rods we need to correct for the residual thermal effects, and only after doing so, would we obtain a faithful determination of the “true geometry” corresponding to that which would be determined by means of ideal “length preserving” rods. We all know that there are no ideal rods, however, the more critical fact is that, in principle, there is a serious problem in establishing what is even meant by a “length preserving” object. Let us consider how would we know, even in principle, when we have identified an object that does not change its length?. The evident answer is: by measuring its length in different circumstances. However, in order to measure its length in the various circumstances and compare the results, we need to use a length preserving object! We have found ourselves immersed in a nasty circular set of definitions. Technically we could consider —and in practice we do— replacing standard physical objects by “generalized objects”: that is actual physical objects complemented by well defined prescriptions of how to correct for the changes in their assigned lengths under specific circumstances (such as taking into account the corresponding thermal expansion coefficients and accompanying every length determination with a simultaneous temperature determination). However, even after doing so we are still faced with the issue of having to define the operational procedure to determine the length preserving assignment to a physical object or a generalized object. The consideration of other methods, as for example,
the measurement of an object’s length with light signals and clocks, while taking the speed of light as 1 by definition, only converts our problem into that of choosing clocks that run at a “constant” rate. It is evident that this faces us with complete analogous conundrums: How could we measure the rate of ticking of a clock to determine whether it is “constant” without the use of another clock? In classical physics one solves these dilemmas by the use of judicious definitions which make use of the following empirical fact, F: There exist objects and clocks (usually generalized objects and clocks) that, when used to define the lengths of intervals, result in empirical laws of physics that are particularly simple (as for example, the law of inertia) \[32\]. In this way, we select the objects, in practice generalized objects, that give an empirical content to our assignment of geometry to the classical level of description of our world.

Let us turn now to the quantum realm, and consider what are the objects, actually the class of objects \(\mathcal{O}\), that give a meaning to the geometry at the quantum level? Does such class of objects exist at all? Are there different classes of objects, say \(\mathcal{O}_1\) and \(\mathcal{O}_2\), each leading to equally simple laws of nature, which are however different for the different selections of the class of objects? In this case, we would be confronted with the problem of having two different geometries for the same physical situation, one associated with the class \(\mathcal{O}_1\) and the other with the class \(\mathcal{O}_2\)! No attempt to give definite answers to these questions will even be considered at this point as we are only attempting to raise awareness of the problematic issues.

There are several issues associated with the previous considerations that need further discussion. First, we note that, while at the classical level we must consider the objects which are used to define the geometry (i.e. the objects satisfying F) as classical objects, at the quantum level, the natural objects that should be considered as defining the geometry should be themselves “quantum objects”. Thus, given that the meaning of the physical geometry arises solely from statements which must be expressible in terms of the objects selected to define it, such meaning should be taken to be a certain codification of correlations between physical “events” (this word is used here in an imprecise sense because at this point the discussion refers to both the classical and the quantum cases) associated with such objects. At the classical level, we could be talking about the number of ticks of a clock along the world line segment joining two events with which the clock eventually coincides. At the quantum level, we need to consider very different sorts of things. One must then expect such correlations and their codification to depend on the type of objects one is considering, and, therefore, the kind of objects representing this information (the kind of objects that represent geometry) should be expected to be very different in the classical and the quantum cases. In particular, we don’t expect the quantum objects to be described by the same constructs as ordinary quantum matter. These differences should be as significant, say, as the difference between a space-time vector (considered here as describing the state of a classical particle), and a wave function (considered here as describing a quantum state of a particle). Note that up to this point we have not specified what we mean by “quantum objects”. Our considerations have so far been very general. On the other hand, taking a look at the previous advances, it seems clear that the quantum objects will quite likely be connected with either quantum states of quantum fields, or some further generalization of such conceptual constructs.

Following the general approach taken in this manuscript, that it is easier to make negative statements than to make concrete proposals, and to further illuminate the ideas towards which we are driven by the epistemological considerations so far, let us end by discussing,
what should not be done and why. The (most widely used) classical description of gravitation involves a space-time (i.e., a manifold with a pseudo-Riemannian metric) \((M, g_{ab})\), which carries information about the behavior of geodesics, their points of intersection, which would define events, the length of the interval between two such events along a given geodesic, etc. It is natural that such an object (i.e. a tensor field) should be used to describe the geometry which is defined in terms of point particles whose states can be described in terms of a four vector \(u^a\) and a point \(x\) in space-time. On the other hand, when the geometry is defined in terms of quantum fields\(^5\), the physical counterpart of a geodesic (viewed as the world line of a classical test particle) or the physical counterpart of a four vector tangent to a space-time point (viewed as a perfectly localized particle with a well defined four momentum), cease to exist! They have turned into unspeakables. That is, the objects that would give meaning to \(g_{ab}\) are not part of the realm of physics we are attempting to describe. Therefore, we should not try to construct a quantum counterpart of \(g_{ab}\), i.e., a quantized gravitational field \(\hat{g}_{ab}\) or any equivalent object, because such a construct would be a quantum object carrying information about classical correlations! That is, the quantum object would carry information about unspeakables, and such a thing could not be information at all. In fact, doing this would have meant that we changed aspect B) of the geometry from classical to quantum, but did not change aspect A). Our previous arguments indicated that would make no sense.

Recognizing and keeping in mind these points seem to me essential for considerations about the nature of a Quantum Theory of Gravitation. The fact is that the standard views on these issues rely on idealizations, that are not unlike the idealizations of pre-relativistic physics about the existence of absolute space and absolute time, or those in pre-quantum mechanics about the existence of well defined particle trajectories or the existence of a fully deterministic physical world. The fact is that the starting point of most attempts to construct candidate theories of quantum gravity fail to properly guard against the use of rather well identified unspeakables. As we saw in retrospect, the failure to properly identified unspeakables and to take precautions against their use, turned out to be serious impediments for the advancements in theoretical development in the past. I believe that the notion of a physical geometry existing independently of the physical objects with which to determine it (in the sense of defining it), is an impediment towards the construction of a quantum theory of gravitation.

V. CONCLUSIONS

We have argued for an approach to the question of bringing together Gravitation and Quantum Theory that starts by identifying the concepts that should be ascribed the role of unspeakables of that theory.

Having made such identifications, the challenge would be to identify the concepts that should replace the ones deemed obsolete, and to construct the language and mathematical structure that would, at the same time, allow one to consider the relevant issues, and that would make it impossible to deal with, or even to mention the unspeakables. As an illustration of what I have in mind, we can point to Quantum Mechanics: once one decided

\(^5\) At this point the use of these words should not be taken to indicate the standard mathematical description of such objects, but the underlying physical entities they are thought to represent.
that in this theory one describes the state of a particle by a wave function one can not, even if one tries, go back and consider a particle with a well defined position and momentum. The formalism does not allow consideration of such a thing. Something similar should be our goal, and our guiding principle indicates that the formalism for the sought theory, should be such that the identified unspeakables, can not even be referred too.

Needless is to say that I have not made any real concrete proposal here that matches the desiderata that has been argued for throughout the paper, but it is my hope that the points of view expressed would be of help, at least in identifying the general character of the approaches to the problem, which based on many of the previous experiences in the historical development of our current understanding of the foundations of physics, would seem to offer an a priori enhanced likelihood of success.

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