Is the Universe the only existing Black Hole?

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Abstract

We investigate the physics of black holes in the light of the quantum theoretical framework proposed in [1]. It is argued that black holes are completely non-local objects, and that the only one which really exists is the universe itself.

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1 Introduction

Black holes are “singularities” of the space-time, that, according to the Einstein’s theory of Relativity, occur when the matter/energy density contained within a region of space exceeds a bound, given by the Schwarzschild relation:

\[
\frac{2GM}{c^2} = R
\]  

(1.1)

Black holes are expected to exist and probably lie at the center of every Galaxy. Only in this way it seems possible to justify the high gravitational attraction implied by the observed orbital speed of stars in the part of the coil near the center. However, is it really possible to localize such a huge concentration of mass/energy within a well defined sub-region of the universe? From a classical point of view there is no problem to give a positive answer. The situation may however be rather different from a quantum point of view. Indeed, although black holes are introduced as “classical” objects, predicted by the theory of Relativity, we know that, at a certain scale, the physical world shows out its quantum mechanical nature. This is expected to occur also for black holes. The quantum physics of black holes has been the matter of several investigations, in more recent times also within the context of string theory. Fundamental in this respect are the studies carried out by J. Bekenstein and S. Hawking, leading to the evaluation of the black holes entropy as a function of the area of the horizon \[2, 3\], and to the prediction of their evaporation \[4\].

In Refs. \[1, 5\] I proposed a theoretical framework based on few fundamental assumptions, that produce a physical scenario which embeds both Quantum Mechanics and Relativity, to which it reduces in appropriate limits. However, it is constructed by assuming no one of the usual properties at the ground of either one of these theories. The way it reduces to the one or the other resembles a bit the way quantum mechanics ”reduces” to classical mechanics in the limit \(\hbar \rightarrow 0\). That is, there is indeed no real smooth limit in the mathematical sense, the sense in which a term of a Lagrangian, or something alike, which parametrizes the deviation from the classical theory, goes to zero. Quantum mechanics can only be formally put in the form of a \(\hbar\)-dependent correction to classical mechanics. Indeed, it entails a completely different approach to causality, temporal evolution, etc... In a similar way, the approach introduced in \[1\] is well approximated by Quantum Mechanics, or Relativity, under certain conditions, without being (an extension of) either of them in a strict sense.

As the resulting scenario has proven to be compatible with all current experimental results for what concerns the physics of elementary particles and several basic aspects of cosmology and the evolution of the universe \[6\], it is interesting to investigate within this theoretical framework also the physics of black holes. Namely, to see what are the implications for the physics of black holes of a relativistic-quantum mechanical scenario, i.e. a quantum gravity scenario, in which quantum mechanics is not dealt with, as usual, as an “ad hoc” modification of the rules of classical mechanics, but is a necessary and fundamental theoretical implication.
2 The combinatorial scenario

In Ref. [1] I proposed that our quantum world can be viewed as the result of the superposition of any possible configuration. By configuration it is here meant any assignment/distribution of “energy” along a target space, that can be of whatever number of dimensions. Energy too is intended in the most elementary sense. One could also speak of “units of curvature”, but more fundamentally it is only an assignment of a binary code of “occupation” to a target space of “unoccupied” positions. At any fixed amount $E$ of “energy units”, the “partition function” of the universe, i.e. the generating function for the mean value of any observable, of the universe, is given by the sum over all such configurations $\psi_E$, weighted with their volume of occupation in the phase space of all the configurations, $W(\psi_E) = \exp S(\psi_E)$:

$$Z_E = \int D\psi_E e^{S(\psi_E)}. \tag{2.1}$$

Only in an average sense, and only once a limit to a continuum description is taken, after the introduction of a unit of length and of energy, one can speak of energy, space, curvature in the ordinary sense. As nothing basically distinguishes the nature of the elements of the “energy” space from those of the “positions space”, apart from being the ones working as target and the others as “base” space, in some sense the set $\{\psi_E\}$ of all the maps at given $E$ can be viewed as the space of all possible structures one can think about, all possible assignments from a space to another one. The energy $E$ turns out to play the role of a label for an ordering, given by the inclusion of phase spaces, $\{\psi_E\} \subseteq \{\psi_{E'}\}$ if $E \leq E'$. In the continuum limit, $E$ plays therefore also the role of time, or age of the universe. The fact that concepts like energy, space, time, curvature, are only “large scale” and mean quantities, leads to an indeterminacy of observables, whose mean values are smeared, unfocused, by an amount that turns out to correspond to the Heisenberg’s uncertainty of quantum mechanics. Indeed, the latter can be viewed as the implementation of this uncertainty principle, obtained through a scenario of waves and probabilities.

As discussed in Ref. [1], 2.1 implies that the appearance of the universe is dominated by the most entropic configurations; in these configurations the space is three dimensional, with the curvature of a three-sphere, whose radius is given by the total energy/age of the universe $E$. One can then show that the speed of expansion of the – average, three-dimensional – universe, that by convention and choice of units we can call “$c$”, is also the maximal speed of propagation of coherent, i.e. non-dispersive, information. In the limit in which one passes to the continuum and speaks of space, namely when one speaks of average three-dimensional world, this can be shown to correspond to the $v = c$ bound of the speed of light[1]. Moreover, the geometry of geodesics in this space corresponds to the one generated by the energy distribution. This means that this framework “embeds” in itself Special and General Relativity [5].

The theoretical framework proposed in [1] goes therefore beyond both quantum mechanics and the theory of relativity, lifting them to a description which is fundamentally\footnote{Here it is essential that we are talking of coherent information, as tachyonic configurations also exist in this scenario, which embeds also Quantum Mechanics.}
neither quantum mechanical nor relativistic, and therefore not quantum-field-theoretical either. These theories constitute good approximations of it in appropriate limits.

Relevant for our present discussion is that, in particular, this scenario allows us to deal with coordinate transformations, and therefore also with the metric, in a generalised sense, beyond the usual distinction between relativistic (classical geometrical) and quantum mechanical aspects. There is no more “classical theory” which is going to be quantised, by applying a “quantum suit” to a basically classical description. To better appreciate the fundamental difference of the two approaches, one must consider that, when quantizing a classical system, certainly one modifies the rules of the classical game, but, in some sense, he works on an already “projected out” system, which has been first reduced to classical terms, and then “theoretically expanded” through a quantization procedure. Already thinking in terms of space, and a theory of quantum fields on it, is such a kind of “two steps procedure”, which can be misleading in some cases. This is particularly true when quantum effects eventually destroy the classical sense of space and time. Black holes are an example of system in which indeed these concepts are pushed to their natural limits of definition already within the classical theory. Applying a “quantization procedure” to such a critical situation may be not appropriate. The framework introduced in [1] provides us with a direct way of dealing with observables without passing through a classical description of physics.

3 The metric around a black hole

Space, and metric, are average concepts that arise only at a relatively “large” scale. As a consequence, this is true also for coordinate transformations, and the metric of space. At a more microscopical level, i.e. at a shorter length scale (and therefore also in a deeply quantum regime), they must be substituted by expressions relating the variation of entropy, as it is perceived by different observers [5]. The metric of space-time precisely arises as large scale limit of a quantity that expresses the rate of local variation of entropy. Entropy is the quantity that substitutes, at a more fundamental level, time variation and curvature of space. The general expression relating the evolution of a system as is seen by the system itself, that we indicate with \( A' \), and by an external observer, \( A \), is given, according to [5], by:

\[
\Delta S(A) = \Delta S(\text{internal \ at rest}) + \Delta S(\text{external})
\]

(3.1)

\[
= \Delta S(A') + \Delta S_{\text{external}}(A),
\]

(3.2)

where \( \Delta S(A) \) on the left hand side is the variation of entropy of the event which is detected, as seen from the observer \( A \), whereas on the right hand side \( \Delta S(A') \) is the variation of entropy as seen from the system itself, \( A' \). \( \Delta S(\text{external}) \) is the difference between the two, namely, the amount of entropy variation that \( A \) refers to the environment of \( A' \), and not to something “built in” in \( A' \). For instance, \( \Delta S(\text{external}) \) is the effect of an external force, or the variation of entropy due to the motion itself of the frame comoving with \( A' \) (see Ref. [5] for more detail and explanations).

The classical limit of a physical system corresponds to the limit in which the scale is
sufficiently large to enable not only talking of smooth geometry, smooth coordinates like space, energy, time, instead of simple combinatorials of distributions of energy, but also to make possible considering the average, mean values of observables to be well approximated by the dominant, most entropic configurations of the universe. More remote configurations build up the “quantum fluctuation” around classical values. Deeply quantum mechanical systems are those in which the contribution of more remote configurations is no more negligible.

In the large-scale, classical limit, the variations of entropy $\Delta S(A)$ and $\Delta S(A')$ can be written in terms of time intervals:

$$\Delta S(A) \rightarrow \langle \Delta S(A) \rangle \approx (c\Delta t)^2,$$

and

$$\Delta S(A') \rightarrow \langle \Delta S(A') \rangle \approx (c\Delta t')^2,$$

where we omitted universal proportionality constants (from now on, we will also omit the speed of light $c$, that we set to 1, as we also implicitly did for the Boltzmann constant, and all other fundamental scales and constants). $t$ and $t'$ are respectively the time as measured by the observer, and the proper time of the system $A'$. In this case, expression 3.2 can be written as:

$$(\Delta t')^2 = (\Delta t)^2 - \langle \Delta S'_{\text{external}}(t) \rangle,$$

The temporal part of the metric is therefore given by:

$$g_{00} = \frac{\langle \Delta S'_{\text{external}}(t) \rangle}{(\Delta t)^2} - 1.$$

As long as we consider systems for which $g_{00}$ is far from its extremal value, expression 3.6 constitutes a good approximation of the time component of the metric. However, a black hole does not fall within the domain of this approximation. According to its very (classical) definition, the only part we can probe of a black hole is the surface at the horizon. In the classical limit the metric at this surface vanishes: $g_{00} \rightarrow 0$ (an object falling from outside toward the black hole appears to take an infinite time in order to reach the surface). This means,

$$\langle \Delta S_{\text{external}} \rangle \approx \propto (\Delta t)^2.$$

However, in our set up time is only an average, “large scale” concept, and only in the large scale, classical limit we can write variations of entropy in terms of progress of a time coordinate as in 3.3 and 3.4. The fundamental transformation is the one given in expressions 3.1, 3.2, and the term $g_{00}$ has only to be understood in the sense of:

$$\Delta S(A') \rightarrow \langle \Delta S(A') \rangle \equiv \Delta t' g_{00} \Delta t'.$$

As discussed in Ref. [5], the apparent vanishing of the metric 3.6 is due to the fact that we are subtracting contributions from the first term of the r.h.s. of expression 3.2, namely $\Delta S(A')$, and attributing them to the contribution of the environment, the world external to the system of which we consider the proper time, the second term in the r.h.s. of 3.2 $\Delta S_{\text{external}}(A)$. Any physical system is given by the superposition of an infinite number
of configurations, of which only the most entropic ones (those with the highest weight in the phase space) build up the classical physics, while the more remote ones contribute to what we globally call “quantum effects”. Therefore, taking out classical terms from the first term, \( \Delta S(A') \), the “proper frame” term, means transforming the system the more and more into a “quantum system”. In particular, this means that the mean value of whatever observable of the system will receive the more and more contribution by less localized, more exotic, configurations, thereby showing an increasing quantum uncertainty. In particular, the system moves toward configurations for which \( \Delta x \rightarrow \gg 1/\Delta p \). Indeed, one never reaches the condition of vanishing of 3.8 because, well before this limit is attained, also the notion itself of space, and time, and three dimensions, localized object, geometry, etc..., are lost. The most remote configurations in general do not describe a universe in a three-dimensional space, and the “energy” distributions are not even interpretable in terms of ordinary observables (see discussion in [1, 5]). At the limit in which we reach the surface of the horizon, the black hole will therefore look like a completely delocalized object.

According to 2.1 the universe that one observes is the superposition of all its possible configurations. In this theoretical framework, the existence of a black hole as a localized object within the universe does not simply mean that there exist configurations in which a concentration of mass with the characteristics of a black hole: this is obviously true, because 2.1 sums over all the configurations one can think about. In order to have a localized black hole it is also necessary that these configurations contribute to 2.1 with a sufficiently large weight (i.e. they must be sufficiently entropic in the phase space of all the configurations of the universe). Otherwise, if such configurations are only “remote”, the averaged effect of the superposition with configurations which don’t show such a concentration of mass results in the spoiling of the black hole, the effective removal of the Schwarzschild singularity. Saying that the horizon of a well localized black hole belongs to a class of configurations which are remote in the phase space precisely means that, in the resulting universe, such a black hole in practice does not exist (see figure 1).

4 The universe itself as a black hole

Saying that an object is completely delocalized is like saying that it is extended as the universe itself. In Refs. [6 [1] we indeed spoke of the universe as a black hole. In the theoretical framework we are considering, the universe is classically extended up to the horizon corresponding in light years to its age, \( R = cT \), and has a total energy also proportional to its age/radius, \( E \propto R(\propto T) \). The energy density of the universe is of order \( \rho \sim 1/T^2 \) for any of the three types of energy density (cosmological, matter and radiation densities). In particular, this is true also for the cosmological constant: \( \Lambda \sim 1/T^2 \). At the present, the latter corresponds to \( H^2 \), the Hubble parameter to the square. However, the relation \( \rho \sim 1/T^2 \), a pure experimental numerical observation of the present time universe, in our set up is promoted to a general functional dependence of the energy densities on the age of the universe. Since the universe is trivially “at rest”, its total energy coincides with its “rest mass”; the relation between energy and radius of the universe corresponds therefore to the Schwarzschild relation for the radius of a black hole. Indeed, a black hole doesn’t need to
Figure 1: The superposition of two configurations of the universe: \( A \), which has a region of mass density corresponding to a black hole, here coloured in black, and \( B \), where this region is absent. If we represent the amount of mass density through tones of grey, so that black is the critical black hole mass, and white is zero mass (or, more precisely, the ground energy density of the universe, \( \Lambda \)), we can represent the superposition of \( A \) and \( B \) as \( C \), where the black hole region of \( A \) is “softened” to a grey coloured region, no more a black hole. The tone of grey is the more and more lighter, the smaller is the weight of configurations like \( A \) as compared to configurations of the type \( B \) in the phase space of all the configurations. Saying that around a black hole physics is in a highly quantum, delocalized regime, means precisely that configurations like \( A \) weight much less than those like \( B \), or \( C \).

have an extremely high mass density, because the relation \( \frac{M}{R^2} \) only states a proportionality of mass and radius of a spheric region of space. As the radius increases, the mass density decreases like \( \sim 1/R^2 \), and the black hole becomes the more and more rarefied. There is nothing odd in a universe behaving like a black hole. The universe is non-observable from outside, because of the simple fact that there is no outside of it. As there is no outside of the universe, there is also trivially no information “going out” from it. Or, if one prefers, information expands comovingly with the horizon of the universe, i.e. at speed \( c \), the speed of light. Therefore, the forefront of the wave carrying information is always “stuck” on the horizon. Light rays don’t travel across the horizon, therefore don’t go out of the universe, for the simple fact that they “stir” the horizon itself. In our scenario, light rays are the more and more red-shifted, the closer and closer they are to the classical horizon of the universe, till a limit of infinite wavelength \( \delta \), as it happens in the case of a black hole, as seen both from the outside and from the inside. On the other hand, infinite wavelength does not mean that light employs an infinite time for travelling from the horizon to us: the universe is a black hole in expansion at the speed of light, and the horizon is at a distance corresponding in light years to the age of the universe. We remark that a quantum delocalization of any point at the horizon of the universe is precisely what we need in order to resolve the apparent paradox originating from the fact that, in this interpretation, the surface at the horizon corresponds to a (Planck size) point, the origin of the universe \( 3 \) (see figure 2).

\[ 2 \text{The closer and closer to the horizon, radiation emitted by matter gets on the other hand a violet-shift that partially counters the red-shift effect. For a discussion of this, and also the consequent apparent acceleration of the expansion of the Universe, see [6].} \]

\[ 3 \text{See discussion of section 2 of Ref. [6].} \]
According to our considerations, the only black hole in the whole universe is the universe itself, trivially non-local, non-observable from outside, and with all the characteristics of mass, radius, shifts of frequencies typical of a black hole. Our conclusions are therefore quite far away from the ones derived within a traditional quantum analysis of the physics of a classical black hole. The only result we have in common with the traditional quantum mechanical analysis is about the black holes entropy, given in terms of the area of the surface at the horizon. In our case, the only physical system to which this concretely applies is however the universe itself. The scaling of the entropy like the square of the radius/time/energy is derived from statistical considerations, as a consequence of the fact that in our scenario the universe turns out to possess in the average the geometry of a three-sphere (see Ref. [1], section 7).

5 Black holes at the center of galaxies?

Observations made on the orbital speed of stars relatively close to the center of some galaxies indicate the typical behaviour of a body subjected to a very strong gravitational force. This has induced to suspect the existence of a black hole possibly at the center of every galaxy [7, 8, 9, 10]. Indeed, the angular velocity $\omega$ of an orbiting object is related to the radius $R$ of the orbit and the mass $M$ of the center 4 by the well known expression:

$$\frac{1}{2} \omega^2 R^2 = \frac{M}{R}. \quad (5.1)$$

This relation is in general valid only pointwise along an elliptical orbit, but for the present discussion we can even assume to work with circular ones. Here it is important to point out what is experimentally measured, and what is derived through an interpretation of

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4 We assume here for simplicity the mass of the center of the galaxy to be much larger than the mass of the orbiting star, so that we can approximate the reduced mass with the mass of the star, and the mass of the center of mass with the mass of the center of the galaxy.
experimental data within a theoretical framework. The key experimental observation is the period of the orbit, from which one derives the angular velocity $\omega$. The mass $M$ of the supposed-to-be black hole is then derived after the measurement of the radius $R$ of the orbit.

According to the cosmological scenario resulting from our theoretical framework, distances in regions of space corresponding to the past of our universe appear the more and more expanded, as we approach the horizon of observation. This means that the orbital lengths in galaxies which are far away from us appear larger than what they indeed are (see for instance the discussion in section 9 of Ref. [6]). Measured lengths must be contracted in order to obtain the real ones. By looking at expression 5.1 one can see that, at fixed $\omega$, the mass $M$ scales with $R^3$. This means that, if the real orbital radius is a factor $K < 1$ smaller than the observed one, the mass $M$ of the center of the galaxy is indeed a factor $K^3 \ll 1$ smaller than what inferred within the usual theoretical schemes. Since the Schwarzschild radius scales linearly with the black hole mass, the rescaling between apparent and real lengths leads us a factor $1/K^2 \gg 1$ far away from the critical mass/radius threshold that would induce one to expect the presence of a black hole at the center of the galaxy. In other words, not only the observed orbital periods can be justified with much smaller central masses, but the scaling relation is such that masses decrease much faster than radii, in such a way that they remain much further below the critical black hole mass density.

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