Beyond Quantum Mechanics and General Relativity

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Abstract

In this note I present the main ideas of my proposal about the theoretical framework that could underlie, and therefore “unify”, Quantum Mechanics and Relativity, and I briefly summarize the implications and predictions.

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The entire last century of physics is marked by two main theories: Quantum Mechanics, and Relativity. Implementation of Relativity in Quantum Mechanics has produced the branch of Field Theory. It is widely accepted that, as it happens for electromagnetism, and the weak and strong forces, at a certain scale also gravity should be quantized, and that perhaps all fundamental forces should be “unified” in a quantum theory of gravity.

Various progresses have been made in the study of string theory, considered the most promising candidate to be the theory satisfying this kind of theoretical expectations. However, until now “the” solution still seems to remain elusive, because string theory is built as a “free” theory, seemingly allowed to take any form one wants to force on it (apart from the right one!). Indeed, as it is by now so common to think in terms of “quantization” of a theory, it is however not as much clear, even for the cases in which the quantum nature is out of discussion, why physical phenomena do show a quantum behaviour, and therefore also why should we expect to find quantum aspects also in gravity, apart from its loose analogy with the other forces. Similarly, also the fact that the speed of light has a universal bound, \( c \), a clear experimental observation, is assumed, rather than derived, in the theoretical formulation that implements this phenomenon; namely, the Einstein’s Theory of Relativity.

All these aspects, namely, the fact that we don’t know why nature is quantized, why the speed of light is finite, and finally why String Theory doesn’t show us the answer we want, appear as well distinguished, and apparently unrelated, problems. However, in this note I am going to shortly discuss why I do believe that not only they are deeply related to each other, but that they may find a common solution into a theoretical framework that goes beyond Quantum Mechanics and Relativity, that are there lifted to a description of physical phenomena which is basically neither of them, i.e. neither quantum mechanical, nor special/general relativistic (and therefore also not field theoretical), although in appropriate limits it reproduces the aspects these theories describe.

The set up

The question we start with can be formulated as follows: is it possible that the physical world, as we see it, doesn’t proceed from a “selection” principle, whatever this can be, but it is just the result, the “superposition”, the “mean value” of all the possible configurations, in the most general case and with the most general meaning? May the history of the Universe be viewed somehow as a path through these configurations, and what we call time ordering an ordering through the inclusion of sets, so that the configuration at a certain time is characterized by its containing as subsets all previous configurations, whereas configurations which are not contained belong to the future of the Universe? What is the meaning of “configuration”, and how are then characterized configurations, in order to say which one is contained and which not?

\[1\] There have been attempts to derive Quantum Mechanics within the framework of Classical Mechanics, but these, apart from providing an interesting mapping of the problem into the formalism of statistical theory, don’t solve the main question.
Following [1], let us call configuration a particular way of distributing the most elementary attributes we can think about, “cells” into a space of cells. We may think of it in terms of assigning which cells of a (target) space are “occupied” and which ones are “empty”. This problem can be viewed in geometric terms, via appropriate discretization of the coordinates of a vector space through the introduction of a minimal length. A configuration is then a mapping $\psi$ from a space of “cells to be assigned” to a target space of “empty cells”. A configuration $\psi(N)$ is an assignment of $N$ cells:

$$N \xrightarrow{\psi(N)} M_1 \otimes M_2 \cdots M_i \cdots \otimes M_n, \quad \forall \{M_i, n\}, \ 1 \leq i \leq n.$$  

(1)

Think at a binary string of information; a binary system is the simplest and most elementary way of writing an information code, the building block of any more complex system. We may then view the target space as a multi-dimensional collection of vector spaces of binary strings. A configuration is a particular choice of a code in this space. We may introduce a regularization and work at finite volume $V$, defined as the total number of cells of the target space: $V = \sum_i M_i$, having however in mind that we will eventually take the infinite volume limit $M_i \to \infty, \forall i$. Simply, when working at finite volume, we must have care that, if $N$ is the number of occupied cells we are going to distribute in the target space, at any $V$ we must have $V > N$.

Let’s now consider the set of all possible configurations at fixed $N$: $\{\psi(N)\}$. It is clear that for any configuration $\psi(N')$, $N' < N$, there is a configuration $\psi(N)$ that contains $\psi(N')$ as a subset (in general, there is more than one configuration $\psi(N)$ that contains $\psi(N')$ as a subset). Therefore, we can say that:

$$\{\psi(N)\} \supset \{\psi(N')\}.$$  

(2)

$N$ plays therefore the role of “time”, and the ordering (2) is a time ordering for our system. The set $\{\psi(N)\}$ is the phase space of the configurations at time $N$.

In order to understand what kind of physics comes out, it is convenient to map this scenario to an isomorphic description in terms of geometry, in which $N$ is interpreted as the total energy, $E$, of a configuration: $E \overset{\text{def}}{=} N$, $\psi(E) \overset{\text{def}}{=} \psi(N)$. A distribution of energy through space determines at any point what kind of curvature the space possesses. For the time being, by geometry we intend nothing more than the geometry of the distribution of energy, that is, of the energy density. As I will mention later, the geometry of the energy distribution corresponds also to the geometry of space in the sense of General Relativity. Since any particle, field, wave packet, and physical phenomenon in general, consists in a particular geometry of space (i.e. shape of spatial distribution of energy) that evolves in time, it is clear that, through the interpretation in terms of geometries of spaces of arbitrary extension and dimension, this set up is potentially able to describe all what we observe. Indeed, this framework contains also configurations that do not correspond to smooth geometries in our ordinary sense. This perspective reverses the way of looking at things, and raises the question on whether all what we see and measure, what we interpret as the real world, the “objects that exist”, indeed everything what exists, are, in their deepest essence, nothing else than distributions of degrees of freedom, that we interpret in terms of space, particles, and fields.
The average “geometry” at any time/energy $E$ is given by the superposition of all the configurations belonging to \{\psi(E)\}, weighted by their volume of occupation in the phase space. Of course, the phase space contains at any time an infinite number of elements. This is not true at finite volume. This is why it is convenient to work at arbitrarily large, but finite, volume. It is then possible to classify the configurations at any time $E$ and volume $V$ according to the (relative) number of ways they can be realized; this in turn allows establishing a hierarchy of weights in the phase space, or, passing to logarithm, of entropies. An important observation is that configurations are identified by their group of symmetry and, since we work at finite volume and discrete groups, there are no two inequivalent configurations with the same entropy, in the sense that, from a physical point of view, equivalent configurations are the same configuration. In other words, we can consider working with equivalence classes of configurations, labelled by their symmetry group, rather than with single configurations. We can then define a “generating function” for the average geometry and all the observables of the theory:

$$Z_v(E) = \int_v D\psi(E) e^{\frac{1}{k}S},$$

where $k$ is the Boltzmann constant, and $D\psi$ simply means the sum over all configurations, the measure of the integral being $\exp S/k$. Since any mean value (of observable) is defined through a logarithmic derivative, overall volume factors cancel and (3) remains well defined also in the infinite volume limit.

Rather evidently, the integral is dominated by the configurations of highest entropy. Indeed, it happens that, at any time (energy) $E$, the dominant configuration corresponds to three sphere of radius proportional to $E^2$. The “universe” is therefore predominantly a black hole of radius $\propto E$, and curvature/energy density $\propto 1/E^2$. This looks much like our universe, in which the matter/cosmological energy density is indeed $1/T^2$, where $T$ is the age/radius up to the horizon of observation, once units are converted through appropriate powers of the fundamental constants. In our case, $T = E$. Perhaps more astonishingly, it is possible to evaluate the contribution of all the other configurations at time $E$ to the total energy of the universe. It turns out that all the remaining configurations contribute for a total amount $\Delta E \sim 1/E$. $E$, the age of the universe, can also be written as $\Delta t$, the interval of time during which the universe of radius $E$ has been produced. That means, the universe is mostly a classical black hole, plus a “smearing” that quantitatively corresponds to the Heisenberg Uncertainty, $\Delta E \sim 1/\Delta T$. This is due to the fact that the universe is not just given by one configuration, the dominant one, but by the superposition of all possible configurations, an infinite number in which many (an infinite number) don’t even correspond to a three dimensional geometry, or even to a geometry in ordinary sense at all. This argument can be refined and applied to any observable one may define: all what we observe is in fact given by a superposition of configurations, and whatever value of

\footnote{Needless to say, the passage from combinatorics of “occupation of cells” to a physical/geometrical interpretation requires the introduction of appropriate units and conversion factors: $c, \hbar, M_{Pl}$.}

\footnote{I adopt here the usual convention of omitting for simplicity dimensional constants and normalization factors such as $c, \hbar, M_{Pl}, 1/2$ etc.}

\footnote{See previous footnote.}
observable quantity we can measure is smeared around, is given with a certain fuzziness, that corresponds to the Heisenberg’s inequality. In this framework, the uncertainty relation arises as a “global” way of accounting not simply for our ignorance about the observables, but for the ill definiteness of these quantities in themselves, that exist only “in the average”. For instance, three-dimensional space itself is such an “average” concept, because to the mean geometry contribute configurations of any dimension. As it arises in this framework, the Heisenberg Uncertainty accounts for the contribution of all of them.

It is also possible to 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. 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 [2].

The major novelty of this approach lies in the fact that (3) says that the world as we observe it is just the superposition of all possible configurations. It states somehow a principle of “intrinsic necessity” for the physical world, that does not come out from a selection principle, whatever this can be, and whatever can be the form we use to express it, but simply is the whole of what can be. For astonishing this may be, it seems to pop out precisely the physics we experience.

\[ \text{The dynamics} \]

The dynamics implied by (3) is neither deterministic nor probabilistic: it is rather a “determined” evolution, in which everything doesn’t follow classical causality rules, but the rule of the highest entropy at any time. On the large scale, this produces an approximately smooth evolution that we can, up to a certain extent, parametrize through evolution equations. Since the real world is the superposition of all configurations at a given time, classical (= central) values have a spreading out. Even if we could perform the infinite sum (3) in a finite amount of time (something clearly not possible), we would anyway not know exactly these values. The reason is that quantities corresponding to our concept of space (and therefore also position, wave packet), energy, momentum, etc... are only defined as average quantities, around the dominant configuration. The sum (3) contains however also configurations that we cannot interpret in the usual terms of geometry, particles, fields, etc. Therefore, for practical purposes, it turns out to be convenient to accept a certain amount of unpredictability, introduce probability amplitudes and work in terms of the rules of quantum mechanics. These appear as precisely tuned to embed the Heisenberg Uncertainties, as we found in our framework, into a viable framework enabling to have some control of the unknown, by endowing them with a probabilistic interpretation. Within this theoretical

\[ \text{Here it is essential that we are talking of coherent information, as tachyonic configurations also exist in this scenario, which embeds also Quantum Mechanics.} \]
framework, we can therefore give an interesting interpretation of the Heisenberg’s Uncertainty Principle, and consequently of the necessity of a quantum description of the world. From this point of view, quantization appears as a useful way of parametrizing the fact of being the observed reality a superposition of an infinite number of configurations. The spreading of values of observables implicit in the Heisenberg Uncertainty Principle does not simply express a limitation of our possibility of knowledge, but corresponds to the limit under which observable quantities in themselves are defined. Beyond the Uncertainty Principle’s threshold, space and time in themselves are not defined, as we are going to count also the contribution of configurations that don’t have an interpretation in terms of (classical) geometry, energy, space: they are just assignments of degrees of freedom (units of energy, if one wants) to a target space of “units of position”.

The resulting scenario provides us with a theoretical frame that unifies quantum mechanics and relativity in a description that, basically, is neither of them: these turn out to be only approximations, valid in a certain limit, of a more comprehensive formulation. Therefore, what had been introduced as a combinatorial game seems to be the appropriate structure for the description of the physical world. The scenario that comes out from (3) is highly predictive, in that there is basically no free parameter, except from the only running quantity, the age of the universe, in terms of which everything is computed. Out of the dominant configuration, a three-sphere, the averaged contribution given by the other configurations to (3) is responsible for the introduction of “inhomogeneities” in the universe, that give rise to the varied spectrum of energy clusters that we interpret as matter and fields, and, through the time evolution, their interactions. All of them fall within the corrections to the dominant geometry implied by the Heisenberg’s inequality. For instance, matter clusters constitute local deviations of the mean energy/curvature of order $\Delta E \sim 1/\Delta t$, where $\Delta t$ is the typical time extension (or, appropriately converted through the speed of light, the space extension) of the cluster. The details of the spectrum can be derived through a string theoretical representation of the combinatorial-geometric scenario.

String Theory

In this framework, String Theory arises as a consistent quantum theory of gravity and interactions, which constitutes a useful mapping of the combinatorial problem of “distributions of energy along a target space” into a continuum space, endowed with a minimal length, the continuum version of the unit cell. To this purpose, one must think at string theory as defined in an always compact, although arbitrarily extended, space. In this case, T-duality, as an exact symmetry in the case of toroidal compactification, or as an approximate, “softly broken” symmetry in more general compactifications, ensures the existence of an effective minimal length. Owing to quantization, and therefore the embedding of the Heisenberg’s Uncertainties, the space of all possible string configurations “covers” all the cases of the

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6By “String Theory” we mean here the unique theory which is supposed to underly all the different string constructions. In this sense, a string configuration has to be intended as a generally non-perturbative, configuration of which the possible perturbative constructions made in terms of heterotic, or type II, or type
combinatorial formulation, of which it provides a mapping into a probabilistic scenario, useful for practical computations. This mapping entails somehow a “rearrangement” of degrees of freedom, because string theory is a quantum theory in which fluctuations of the geometry are described in terms of a spectrum of excitations that we interpret as particles and fields, that can propagate. Each string configuration corresponds therefore to a full collection of “static” combinatorial-geometric configurations, of which it provides a representation in terms of interactions of propagating particles and fields.

The configuration of highest entropy in the phase space of string configurations, i.e., the dominant string configuration, corresponds to the most singular one, that is, the one with the highest degree of reduction of the initial symmetry, obtained through compactification on curved spaces. Its identification is not an easy task, as the perturbative consistency of a construction is not enough: the real spectrum and physical content can only be analyzed with strong use of non-perturbative string dualities [3]. The result is a non-perturbative configuration in which the string target space stabilizes into one time coordinate and three space coordinates which expand with time, while all the remaining coordinates are twisted, and therefore stuck, at the Planck scale. This scenario describes a non-accelerated expanding Universe of radius $R \propto T$ and energy density $\sim 1/R^2$. Therefore, a three sphere, the dominant geometric configuration. The spectrum corresponds to the degrees of freedom of all the known elementary particles, and their interactions. However, everything appears described in a non-standard way, as compared to the usual way one expects things to appear in a field-, and string-, theory analysis.

A first big change of perspective is that, since we work on a space-time which is always compact, there is no invariance under time translations, because any progress in time is a progress in the history of the universe, and therefore a flow toward a configuration with different total energy, etc. There is in general no invariance under space translations either, because, unless special boundary conditions are imposed, any displacement implies approaching, or going away, from the boundary of space. The basic absence of invariance under space-time translations implies, by construction, a different normalization of string amplitudes, and therefore a different interpretation of the computed mean values: owing to the absence of a normalization factor $1/V$, where $V$, the four-volume of space, corresponds to the volume of the group of translations, densities are now lifted to global quantities. For instance, the so found string vacuum is non-supersymmetric, with supersymmetry broken at the Planck scale. Nevertheless, it produces the correct value of the cosmological constant, in that the so computed $\langle \Lambda \rangle = 1$ vacuum energy expectation value does not correspond to an energy density, but to a quantity that, in order to be transformed into a density, must be rescaled by a Jacobian corresponding to a two-volume, the square radius of space-time. The so produced true density is therefore $\Lambda = 1/R^2 \sim H^2$, where $H$ is the Hubble constant. The cosmological constant is correctly predicted in its present day value, and it turns out to be not at all a constant, but it evolves with the inverse square of the age of the Universe.

I string, represent “slices”, dual aspects of the same object. The existence of such a unique string theory is still an hypothesis, although well supported by several evidences, that we assume to be true.
Another major discrepancy with respect to the traditional scenarios is that here masses are not generated through a Higgs mechanism, but are related to the size of space. This in turn is related to the age of the expanding universe. Therefore, masses depend on time. Roughly speaking, from a technical point of view masses of elementary particles arise as ground Kaluza-Klein modes in a shifted space-time. In an infinitely extended space-time they would therefore all vanish. Here they are related to some power of the inverse of the age of the Universe. Differently from the massive modes arising from twists and shifts acting on the internal string coordinates, they lie therefore under the Planck scale, whereas all the degrees of freedom projected out (such as for instance extra bosons) are stuck at (or above) the Planck scale. Sub-Planckian masses arise therefore as a Casimir effect, the lowest energy modes of a quantum scenario in a compact space. Like the masses of the internal modes, their existence is consistent with string theory, and does not require Higgs mechanisms to make the theory renormalizable. This on the other hand means that gauge theory must be considered only as an approximation, an effective description. Indeed, in this scenario, apart from electromagnetism there are no gauge symmetries in strict terms, as, apart from the photon, there are no massless bosons in the string spectrum. All symmetries except the electromagnetic one appear as either already broken, by mass shifts that lift the corresponding bosons to a non-zero mass (the case of the $SU(2)$ of the weak interactions), or in the strong coupling regime (the $SU(3)$ colour symmetry), and can be investigated only indirectly through non-perturbative string dualities and mappings to particular limits. There is therefore no explicit low energy $U(1) \times SU(2) \times SU(3)$ phase. On the other hand, this doesn’t exist in nature either!

Apart from the technical details of the way matter and fields degrees of freedom are generated in the string representation, the very origin of a varied spectrum of masses, and couplings, is due to the fact that particles and fields have a “width” in the phase space. We are used to see the problem in the other way around, namely, by inserting mass values and couplings into scattering amplitudes, and obtain that scattering/decay amplitudes are larger the larger is the initial-to-final mass ratio, or the stronger is the coupling of the interaction. In our perspective, the size of masses and couplings is a consequence of the size of the corresponding process in the phase space. Namely, a decay that occurs more frequently than another one, has a stronger coupling. The strength of the coupling is related to the frequency the process occurs. In a similar way, a heavier particle decays into lighter particles, and therefore its phase space “contains” also the phase space of the lighter particles. In other words, masses and couplings are somehow related to the “geometrical probability” of particles and their interactions in the phase space.

As any string configuration represents a collection of static, geometric configurations, a spectrum of matter states obtained through a process of increasing symmetry reduction, such as the one of the highest entropy string configuration, can be viewed as produced by the
superposition of configurations with progressively reduced amount of symmetry. At any step
the symmetry is reduced, a differentiation in the matter/field spectrum is introduced. As
the volumes occupied in the whole phase space by configurations are inversely proportional
to the volumes of their symmetry group, the mass ratios between former and new particles
are related to the ratios of the volumes of the symmetry group of the configurations that give
rise to them. The relations are not so simple to be quoted in this small note, so I refer the
reader to [3] for details. To give anyway the flavour of what happens, let us consider a simple
(unphysical) example. Let us suppose there is a configuration \( A \) with a spectrum containing
four particles with a symmetry \( SU(4) \). Consider now the configuration \( B \) in which the \( SU(4) \)
symmetry has been broken to \( SU(2) \). The resulting configuration, superposition of the two,
has therefore a symmetry \( SU(2) \times SU(2) \), that we can indicate as \( SU(2)_I \times SU(2)_{II} \), and
two types of particles: the two of type “I”, with mass, say, \( m_I \), and the two of type “II”,
with mass \( m_{II} \neq m_I \). The particles of type I correspond to the \( SU(2)_I \) symmetry, subgroup
of \( SU(4) \), and are present in both \( A \) and \( B \), whereas the particles of type II are those of the
broken symmetry, and are present only in \( A \). The mass difference between particles I and
II is due to the fact that, if the configuration \( A \) has weight \( W(A) \) and the configuration \( B \)
has weight \( W(B) \) in the phase space, the particles \( I \), present in both \( A \) and \( B \), will occur a
number \( W(A) + W(B) \) of times in the phase space, whereas the particles II, being present
only in \( A \), will occur only a number of times \( W(A) \). The first ones will be therefore heavier
than the second ones by a factor \( m_I = m_{II} \times [(W(A) + W(B))/W(A)] \), as it has to be
expected by the fact that the first ones “contain” as a subgroup also the physics of the
second ones.

By arguments of this kind, although more complicated than in this elementary example,
namely, by following the pattern of symmetry reduction in the highest entropy string config-
uration, we can determine the relative weight in the phase space of all types of particles, as
functions of the relative weight of symmetry groups. The couplings too are related to these
weights. The relative ratios of the weight in the phase space of the various symmetry groups
are not pure numerical coefficients: pure coefficients are obtained when working on the tan-
gent space, with algebras instead of groups. Indeed, owing to the multiplicative structure
of the phase space, weights do not sum, as we wrote in the simple example of above, but
rather multiply. As a consequence, the ratios of weights depend on the volume of the target
space of the string configuration, i.e., on the age of the universe. Proceeding in this way,
it is possible to uniquely fix all the ratios of masses, and the gauge couplings, as different
powers of the age of the universe.

We stress here that, owing to the properties of the interpretation of the Heisenberg’s
uncertainty we gave, the spectrum of particles and fields can be inferred by looking just
at the dominant string vacuum, i.e. the most singular one, being the other configurations
“covered” by imposing quantization of the string. In other words, the contribution of string
configurations with exotic particles and symmetry groups reflects in the quantum uncertainty

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The phase space of all the string configurations, that we may call the “macroscopic” entropy, one can introduce
a “microscopic entropy”, defined as the statistical entropy of the system constituted by the degrees of freedom
of the spectrum of a string configuration. It is then possible to show that, at any finite \( E \), “macroscopic” and
“microscopic” entropy are dual to each other, in the sense that, up to an additive constant, \( S_{\text{micro}} = -S_{\text{macro}} \). Expressions of Ref. [3] refer to this second quantity.
with which mean energy values, decays, and scattering amplitudes, are known.

String techniques allow then to explicitly calculate the mass exponent corresponding to the lightest mass excitation, which is produced by the minimal shift along the space-time coordinates, in the dominant string configuration. It corresponds to the lowest mass scale. This identification makes possible to compute then all masses and couplings\textsuperscript{8}. Indeed, since ratios of volumes of symmetry groups are related to the strength of couplings, which in turn determine the size of masses, and the couplings themselves, a fine evaluation of these quantities proceeds through an iterative series of steps of improving approximation, in which the values obtained at the first order are plugged again in the expressions, to obtain second order values, which are further plugged in the expressions to obtain the third order, and so on. The so approximated results can then be compared with the experimental values of masses and couplings, in order to test the theoretical predictions.

Behind the rather cumbersome procedure of calculation, the rationale is anyway that masses and couplings too are a manifestation of the physics as it comes out from (3), for which any observable/observed quantity is the result of a superposition of everything possible, weighted according to the intrinsic statistics of the ways it can occur. The theoretical scenario expressed by (3) represents therefore a radical change of perspective with respect to the way physical phenomena are traditionally looked at.

Owing to the absence of freely adjustable parameters, any departure from the experimental value, in just one prediction, can rule out the whole theoretical scenario. It is therefore rather remarkable that the spectrum of elementary particles and fields precisely contains all the known elementary particles and bosons, and that within this framework it has been possible to compute the fine structure constant with an accuracy of $\Delta \alpha/\alpha \sim \mathcal{O}(10^{-5})$, the electron and proton mass within $\Delta m/m \sim \mathcal{O}(10^{-4})$, etc. (see Ref. \textsuperscript{3}). Even though, for technical reasons, not every quantity can be computed with the same degree of accuracy, all the predictions so far derived are in agreement with the experimental observations: all the experimentally detected properties of the known world of elementary particles and high-energy physics are in this way correctly reproduced, as a necessary and uniquely determined result. On the other hand, no Higgs fields are predicted to exist, nor low-energy supersymmetry. According to this scenario, no “new physics” in the common sense (new elementary particles, gauge bosons of unification groups, etc...) is expected to show up at a certain high-energy, under-Planckian scale. The degrees of freedom of the spectrum correspond to all the already known elementary particles and fields, and no more.

Along with a remarkable agreement with the experimental observations, obtained without tuning of free parameters, this scenario shows therefore also an almost complete disagreement with common widely accepted theoretical expectations.

\textsuperscript{8}The uncertainty under which the age of the universe is known reflects in an uncertainty also for the values of couplings and masses. On the other hand, one can reverse the argument, and use one mass value in order to fix the age of the universe, and then derive all other masses, and couplings. In \textsuperscript{3} we used the experimental value of the neutron mass, because this is related in simple way to the mass of the only non-perturbative stable state, neutral for all interactions, therefore the only true mass eigenstate, at finite time.
The dependence of the masses of elementary particles and couplings on the age of the Universe is of the order of $\sim 1/T^\alpha$, for appropriate exponents $\alpha$, different for each mass and coupling. This gives a small, almost negligible rate of change at present day, but it becomes relevant on a cosmic scale, where it produces detectable effects. Indeed, (3) describes not just the physics at present time, but provides us with a cosmological scenario, predicting the evolution of the Universe. The Universe turns out to expand in a non-accelerated way; nevertheless, owing to the time dependence of masses and couplings, and the consequent shift in the observed wavelengths of distant objects, the expansion appears accelerated like in a “matter dominated universe”. Furthermore, the scaling of masses and couplings is such that cosmological “early universe” conditions like the nucleosynthesis bound, or the Oklo bound, usually considered model-killers, are easily satisfied and provide no significant constraint. On the other hand, the particular scaling of masses and couplings correctly predicts certain wavelength shifts observed in the emission spectra of Quasars.

Interestingly, within this framework it is also possible to address questions of interest for other domains of natural science, such as the evolutionary biology. The time dependence of masses and couplings results in the time dependence also of the atomic/molecular emission and absorption spectra, in particular for what concerns the bounds responsible for the genetic mutation. If one makes the hypothesis that mutagenesis is mostly caused by the absorption of natural radiation, it turns out that mutations are highly favoured during the peaks of resonance between the frequencies of the absorbing molecule and the emitting one. As a consequence, natural mutagenesis is expected to occur in temporal “phases” that in this theoretical framework can be up to a certain extent predicted. In particular, under the hypothesis of radiation produced by hydrogen-like sources, an assumption justified by the fact that the universe is constituted for 3/4 by hydrogen, it is possible to correctly predict the duration of the Eras of the evolution of the primates, or the Big Eras of life (Paleozoic, Mesozoic, Cenozoic) [4]. This approach opens therefore new perspectives also for this branch of science.

Indeed, one of the most novel aspects of this theoretical approach is that it goes beyond the usual organization of physical phenomena we have in mind, into what we consider pertaining to Quantum Mechanics, and what to Relativity, allowing us to embrace various aspects in a perspective “from above”. An example is the one just mentioned, in which a deeply “quantum-gravitational-cosmological” framework is invoked in order to give a possible explanation of problems of biology, whose physical aspects we would consider of complete pertinence of more classical domains of physics.

The scenario implied by (3) in some sense “unifies” General Relativity and Quantum Mechanics, in that it underlies both of them. Within this framework, it is possible to investigate phenomena like the behaviour of a quantum system under relativistic conditions. For instance, to study black holes in a true quantum gravity scenario, or the behaviour of electrons in a complex system such as a superconductor, i.e. physical systems which are perhaps beyond the border of the domain of a perturbative quantum mechanical approach. These topics are the matter of current investigation.
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