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Spinorial space-time and the origin of Quantum Mechanics

The dynamical role of the physical vacuum

Luis Gonzalez-Mestres[1,a]

[1] *Megatrend Cosmology Laboratory, John Naisbitt University, Belgrade and Paris*
Goce Delceva 8, 11070 Novi Beograd, Serbia

Abstract. Is Quantum Mechanics really and ultimate principle of Physics described by a set of intrinsic exact laws? Are standard particles the ultimate constituents of matter? The two questions appear to be closely related, as a preonic structure of the physical vacuum would have an influence on the properties of quantum particles. Although the first preon models were just « quark-like » and assumed preons to be direct constituents of the conventional « elementary » particles, we suggested in 1995 that they could instead be constituents of the physical vacuum (the superbradyon hypothesis). Standard particles would then be excitations of the preonic vacuum and have substantially different properties from those of preons themselves (critical speed...). The standard laws of Particle Physics would then be approximate expressions obtained from preon dynamics. In parallel, the mathematical properties of space-time structures such as the spinoral space-time (SST) we introduced in 1996-97 can have strong implications for Quantum Mechanics and even be its real origin. We complete here our recent discussion of the subject by pointing out that: i) Quantum Mechanics corresponds to a natural set of properties of vacuum excitations in the presence of a SST geometry ; ii) the recently observed entanglement at long distances would be a logical property if preons are superluminal (superbradyons), so that superluminal signals and correlations can propagate in vacuum ; iii) in a specific mechanism, the function of space-time associated to the extended internal structure of a spin-1/2 particle at very small distances can be incompatible with a continuous motion at space and time scales where the internal structure of vacuum can be felt. In the dynam:ics associated to iii), and using the SST description of space-time, a contradiction can appear between macroscopic and microscopic space-times due to the overlap in the time variable directly related to the fact that a spinor function takes nonzero values simultaneously in a whole time interval. Then, continuous motion can be precluded at very small space-time scales. If discrete motion is required at such scales, the situation will be possibly close to that generating the Feynman path integral. Quantum Mechanics can therefore directly emerge from the spinorial space-time and from other unconventional space-time structures in a fundamental preon dynamics leading the properties of vacuum. In such scenarios, the application of Gödel - Cohen mathematics to quantum-mechanical calculations can yield substantially different results from those recently considered by other authors using the standard quantum approach without any preonic underlying structure. This is also a crucial open question for Quantum Mechanics and Particle Physics.

This paper is dedicated to the memory of Bernard d'Espagnat

[a] e-mail: luis.gonzalez-mestres@cosmology.megatrend.edu.rs ; personal e-mail: lgmsci@yahoo.fr

1 Introduction

What are the actual origin and meaning of Quantum Mechanics? Is it an ultimate fundamental property of Physics, or a dynamical feature of standard matter generated by a more basic scenario related to a deeper set of laws of Nature? In the present situation, the answer to this question is far from obvious, even if Quantum Mechanics is in practice dealt with as an ultimate principle of Physics [1].

The origin and the ultimate nature of Quantum Mechanics stay by now unknown, even if a link between wave-particle duality and entropic uncertainty is strongly suggested [2, 3] and applications of entropic uncertainty relations are given particular attention [4, 5].

Following our previous work, a reflexion was developed in [6, 7] on the possible origin of Quantum Mechanics from a preonic (superbradyonic?) vacuum with a specific (spinorial) space-time geometry. New ideas submitted to this Conference [8, 9] introduce explicit patterns completing the possible grounds of such a hypothesis. The constructions considered are specific examples of a more general approach. Some of the consequences of these patterns and of the new kind of theory considered are analyzed in [10] and further in what follows. Describing and developing the suggested new approach, we present here explicit examples of attempts to explain and enforce Quantum Mechanics starting from a more fundamental scenario. The explicit models illustrating the basic idea use a spinorial space-time (SST) together with a pre-existing vacuum dynamics that can be associated to a preonic picture. Quantum Mechanics appears as natural in a general SST superbradyonic scenario.

It furthermore turns out, in such an explicit picture, that Quantum Mechanics can even be a direct consequence of the original time uncertainty induced by the SST when conventional particles are described as spinorial extended objects. From this point of view, the basic properties of the SST appear to be crucially different from those of a standard Euclidean or relativistic space-time where there is no obvious contradiction between the macroscopic space-time and the space-time felt by ultimate matter at very small scales as a natural extrapolation relies both descriptions.

In a version of the SST picture, the time spread of a spinorial extended function used to describe a standard particle can naturally generate an overlap between structures of this kind "centered" at different times. Such an overlap can in turn lead to an overall structure for particle propagation incompatible with the initial dynamics that produces an isolated single particle solution to the basic vacuum equations for a given "central" time. This incompatibility would prevent continuous motion of standard particles and lead instead to a Feynman-like discrete path. Standard Quantum Mechanics would then be a large-scale limit of such a Feynman-like path[11, 12]. Quantum Mechanics can then be the dynamical expression of a contradiction between two space-time structures if the macroscopic space-time incorporates a curved space and a time origin of the Universe, and if simultaneously an ultimate structure of matter exists beyond standard particles at very small scales with an unconventional local space-time. The SST can provide a simple example of this space-time contradiction.

Similarly, the observed quantum entanglement at large distances would be a natural property of a superbradyonic vacuum where superluminal signals and correlations can in principle propagate, contrary to the standard space-time with the speed of light as the critical speed. Globally, a preonic scenario with a superbradyonic vacuum seems to lead to more natural properties for standard particles than the conventional postulates of Particle Physics [6, 7].

Recently, the Gödel incompleteness theorem [13, 14] has been claimed [15, 16] to lead to unsolvable calculations in quantum physics for conventional particles. Standard Quantum Mechanics has been used to reach such a conclusion. However, the situation can possibly be different in our preonic approach if the Gödel - Cohen incompleteness actually applies to the vacuum structure and dynamics and to the excitations of vacuum as described in terms of vacuum dynamics.

The search for signatures of deformations of Quantum Mechanics at ultra-high energy (possible expressions of a preonic dynamics) is also a relevant basic phenomenology [17, 18].

2 The spinorial space-time (SST)

The spinorial space-time (SST) we introduced in 1996-97 [19, 20] can possibly be the natural frame to describe a world where fermions exist. Its implications turn out to be highly nontrivial for Particle Physics and Cosmology, at small and large distances [21].

From a mathematical point of view, the SST is a SU(2) space-time with two complex coordinates replacing the four standard real ones. Its properties, with possible cosmological implications coming directly from this mathematical structure, have been dealt with in several subsequent papers including in particular [17, 22], [23, 24] and [7].

SU(2) is just the universal covering group of the standard space rotations usually described by SO(3). But this simple transition from SO(3) to SU(2), allowing spinors to be actual representations of the group associated to space transformations, turns out to have important consequences for both Cosmology and Particle Physics.

In particular, the SST illustrates how nontrivial space-time can be as compared to the usual euclidean and relativistic pictures. An example is provided by Quantum Mechanics may, that turn out to be a consequence of the properties of such a nontrivial space-time.

2.1 SST and cosmic coordinates

If ξ is a SU(2) spinor describing the cosmic SST coordinates (two complex variables replacing the standard four real ones) of a point of our space-time, it is possible to associate to ξ a positive SU(2) scalar $\mid \xi \mid$ such that $\mid \xi \mid^2 = \xi^\dagger \xi$ (the dagger stands for hermitic conjugate). A new invariant with respect to space SU(2) transformations is thus obtained.

A possible definition of cosmic time (in principle equivalent to the age of the Universe) can then be $t = \mid \xi \mid$. Associated to this definition of time is a space given by the S^3 hypersphere $\mid \xi \mid = t$ with an additional spinorial structure that would not exist in a S^3 space hypersphere obtained from a relativistic approach to Cosmology. Other definitions of the cosmic time t in terms of $\mid \xi \mid$ in the SST (f.i. $t = \mid \xi \mid^2$) are possible, but they lead to similar cosmological results as long as a single-valued function of $\mid \xi \mid$ is used to define the cosmic time.

With these definitions, the origin of cosmic time naturally associated to the beginning of the Universe is given by the point $\xi = 0$ where the initial space is contracted to a single point.

One then gets an expanding universe where cosmological comoving frames are described by straight lines crossing the time origin $\xi = 0$ and are transformed into eachother by the cosmic SU(2). Thus, the SST geometry provides in a natural way a local privileged rest frame for each comoving observer, compatible with existing cosmological observations.

Such an approach clearly suggests potential limitations of general relativity and standard cosmology. Rather than an intrinsic fundamental property of space and time, conventional relativity can be expected to be a low-energy symmetry of standard matter similar to the effective Lorentz-like symmetry of the kinematics of low-momentum phonons or solitons in a condensed medium [25, 26] where the speed of sound or the maximum speed of solitons plays the role of the critical speed. The speed of light would then be the critical speed of a family of vacuum excitations (the standard particles) not directly related to an intrinsic space-time geometry [26, 27].

2.2 SST transformations and coordinates

Then, taking $t = \mid \xi \mid$, and ξ_0 to be the observer position on the $\mid \xi \mid = t_0$ hypersphere, space translations inside this hypersphere (the space at $t = \mid \xi_0 \mid$) and simultaneously on all the constant-time hyperspheres of the SST are described by SU(2) transformations acting on the cosmic spinor space, i.e. $\xi = U\,\xi_0$ with:

$$U = exp\,(i/2\ t_0^{-1}\ \vec{\sigma}.\vec{\mathbf{x}}) \equiv U(\vec{\mathbf{x}}) \tag{1}$$

$\vec{\sigma}$ being the vector formed by the usual Pauli matrices and the vector $\vec{\mathbf{x}}$ the spatial position (in time units, at the present stage) of ξ with respect to ξ_0 at constant time t_0.

As already shown in [19, 20], an attempt to associate to the cosmic spinor ξ a space-like position vector with real cosmic space coordinates defined by $\vec{\mathbf{x}_c} = \xi^\dagger \vec{\sigma} \xi$ does not actually generate such spatial coordinates. One gets instead $|\ \xi\ |^2$ times a unit vector defining a local privileged space direction (PSD) "parallel" (in the SST) to the cosmic spinor ξ. In other words, the direction of $\xi^\dagger \vec{\sigma} \xi$ corresponds to the set of points whose SST space-time position is equal to ξ times a complex phase. This definition turns out to be invariant under the cosmic SU(2) transformations [23, 24] and generates a natural local anisotropy able to produce observable signatures at the cosmological level.

To define the standard real space coordinates in the SST, a space origin ξ_0 at the cosmic time $t_0 = |\ \xi_0\ |$ is necessary, as in (1). Such coordinates correspond to a local description of the S^3 hypersphere.

Space rotations with respect to a fixed point ξ_0 are then given by SU(2) transformations acting on the spatial position vector $\vec{\mathbf{x}}$ defined by (1). A standard spatial rotation around ξ_0 is now given by a SU(2) element $U(\vec{\mathbf{y}})$ turning $U(\vec{\mathbf{x}})$ into $U(\vec{\mathbf{y}})\ U(\vec{\mathbf{x}})\ U(\vec{\mathbf{y}})^\dagger$. The vector $\vec{\mathbf{y}}$, related to $U(\vec{\mathbf{y}})$ in a similar way to (1), provides the rotation axis and angle. If a spin-1/2 particle is present at the position $\vec{\mathbf{x}}$ with an associated spinor ξ_p describing its internal structure, then ξ_p transforms into $\xi'_p = U(\vec{\mathbf{y}})\ \xi_p$.

3 Some properties of a SST Universe

Nontrivial properties of the cosmic spinorial space-time turn out to be close to cosmological observations.

In particular, three basic cosmological phenomena are automatically generated by the SST in a purely geometric way [17, 22] and without any explicit presence of standard matter:

i) The standard Lundmark-Lemaître-Hubble relation between relative velocities and distances at cosmic scale, with a ratio H (velocity/distance) equal to the inverse of the age of the Universe ($H = t^{-1}$) and quite compatible with observational data.

ii) The privileged space direction (PSD) for each comoving observer, leading to a local asymmetry between two cosmic hemispheres as observed by satellite experiments [28].

iii) Furthermore, in the direct SST formulation, space translations form a (non-abelian) compact group, contrary to standard space-time geometry.

More details, including a study of the cosmological implications of these properties, are given in [17, 22], [23, 24] and [6, 7].

3.1 SST at small distances

Similarly to the cosmic SST with the associated SU(2) structure, a local spinorial space-time with its own SU(2) group can be potentially associated to each point ξ_0 in the SST, taking ξ_0 as the local (preonic) space-time origin.

If such a local SST description makes sense, the internal properties of the standard "elementary" particles can possibly be described by structure functions taking values in this local SST. Similarly, such a local SST can be relevant to describe the local structure of the vacuum.

A spin-1/2 particle wave or structure function with position at ξ_0 would then be a spinorial wave function "centered" at ξ_0 and taking significant values around this space-time position. However, $|\ \xi_0\ |$ is far from being the only value of time concerned, as will be discussed in what follows.

Such a local SST is just an illustrative example of the nontrivial space-time structures that can manifest themselves when trying to describe the internal structure of conventional particles and the local properties of the physical vacuum.

Assuming the (extended) internal structure of a standard "elementary" particle to be an eigentstate of the local SU(2) space-time, the allowed spin (spinorial angular momentum) values would be multiples of 1/2, including 0, 1/2, 1, 3/2 and 2 but also possibly higher spins contrary to standard assumptions. Regge-like trajectories spaced by 1/2 in angular momentum cannot be excluded in this approach [6, 7].

All particles of standard physics can thus be generated starting from spinorial extended internal structures, and the existence of "elementary" spin-3/2 particles may even be natural in such a pattern. As the Poincaré group is no longer an exact symmetry, an alternative to the supersymmetry approach to space-time and internal symmetries can emerge as a new (approximate and broken) symmetry escaping standard theorems and no-go constraints [17, 22].

The search for new particles belonging to spinorial (with 1/2 spin spacing) Regge trajectories or to similar sets generated by the SST-based dynamics is therefore an important subject and should in particular be performed in current CERN experiments.

4 SST and quantum mechanics

What can then be the origin of the complex wave functions used in standard Quantum Mechanics (SQM)? The SST geometry can possibly play a significant role, if the excitations of the physical vacuum associated to standard particles correspond to (extended) functions of the internal spinorial complex coordinates inside this vacuum. Such functions of the vacuum structure, as well as the scalar products of these complex coordinates, will naturally be complex quantities and *a priori* compatible with a quantum-mechanical description.

In the SST, the four standard real space-time coordinates are replaced in by two complex one and spinors replace the usual four-vectors. Then, a function Ψ describing the internal structure of a scalar particle can naturally be complex and, for instance, proportional to the hermitic scalar product of two SST spinors ξ_1 and ξ_2 : $\Psi \sim \xi_2^\dagger \xi_1$ where ξ_1 and ξ_2 can describe preonic constituents of the scalar particle. The additivity of this kind of spinors can be at the origin of the additivity of the wave functions of standard particles.

Thus, the usual complex wave properties of quantum particles can be a direct consequence of the more fundamental SST geometry holding already inside the vacuum.

4.1 Fron SST to quantum objects

As pointed out in [6, 7], one can also hope that quantization be generated as a natural property in a SST-based preonic description of standard particles. The most basic "elementary" particles of the standard model, the fermions like quarks and leptons, can in principle, be formed as vacuum excitations if the vacuum structure incorporates a spinorial space-time.

What can then be the internal structure of "elementary" fermions? A classical SST internal wave function for a spin-1/2 particle around a space-time origin ξ_0 can be, for instance, of the form:

$$\Psi_{sp}\,(\xi) = F(|\,\xi - \xi_0\,|^2)\,(\xi - \xi_0) \tag{2}$$

together with:

$$\Psi^*_{sp}\,(\xi) = F(|\,\xi - \xi_0\,|^2)\,(\xi - \xi_0)^* \tag{3}$$

where * stands for complex conjugate (opposite spin). The real function F contains a suitable cutoff in $\mid \xi - \xi_0 \mid^2$ to ensure a finite particle size.

It then turns out that the wave functions Ψ_{sp} and Ψ^*_{sp} explicitly violate standard local causality, as they take nonzero values for past and future values of cosmic time around $\mid \xi_0 \mid$. They replace distances on the S^3 space-like hypersphere associated to ξ_0 by direct spinorial distances on the SST. Thus, F tacitly defines a space-time distance scale λ_{SST} below which causality does no longer hold in the conventional sense used for the standard space-time. The time-dependence of $F(\mid \xi - \xi_0 \mid^2)$ naturally introduces an intrinsic time uncertainty for the particles so described.

It seems reasonable to conjecture that λ_{SST} corresponds to the space-time scale below which conventional physics does no longer hold. Its definition from (2) and (3) has preceded the introduction of any characteristic speed relating space and time units. At this stage, only time units are actually present [20, 22]. As discussed in [7], we expect a relevant velocity scale to emerge from the basic dynamical process that generates such a spin-1/2 particle. Similarly, the propagation of the particle will produce a measurable critical speed. Distance scales will thus arise together with the generation and the propagation of the particle.

In such a scenario, vacuum excitations possibly described by complex wave functions spreading over larger (space-time) distance scales than the λ_{SST} scale can be associated to combinations of plane waves, leading to practical definitions of h, energy and momentum. At this stage, some uncertainty relations can be generated from the intrinsic SST time uncertainty just described.

However, a crucial question remains to be dealt with: that of the quantization of vacuum excitations. In other words, why are there particles instead of just waves? The SST appears also to be able to solve this enigma.

If the spinorial wave function of the spin-1/2 excitation describes a deformation of the vacuum structure, it seems reasonable that its normalization be determined by the requirement of preserving the validity of the same (preonic) fundamental equations that generate the ground-state configuration of the physical vacuum. Just as the vacuum structure would be a unique solution of these equations, the same can happen for a local spinorial excitation of each relevant degree of freedom. The Pauli exclusion principle for spin-1/2 particles can also be generated in this way, if the vacuum structure does not allow for several identical spin-1/2 deformations at once in the same space-time region at very small scales. Thus, Quantum Mechanics can have in any case a simple physical interpretation as a result of vacuum dynamics rather than as an unexplained, independent fundamental principle.

It must also be noticed that if vacuum excitations were not quantized, decays would in principle be possible and one could expect none of such excitations to be stable. Thus, quantization appears to be required in order to allow for stable standard particles.

4.2 How the SST geometry can possibly forbid continuous motion and generate the Feynman path integral

An explicit, alternative, way to generate Quantum Mechanics in a SST scenario can be through the contradiction between a local SST and the cosmic, macroscopic one.

A continous motion of a spin-1/2 particle described by a spinorial function of the type Ψ_{sp} (ξ) "centered" around a time-dependent ξ_0 would generate a significant time overlap in a region of the order of the size λ_{SST} covered by Ψ_{sp}. But the fact that a vacuum excitation defined by Ψ_{sp} (ξ) be a solution of the equations of vacuum dynamics does not imply that this would be the case for the superimposed structure generated by continuous motion.

Ψ_{sp} (ξ) can be an acceptable excitation of vacuum dynamics, but not necessarily its continous motion in a time interval of the order of the particle spinorial size. If the continous motion of the spin-1/2 structure is not acceptable by the vacuum dynamics, only a discrete motion will be possible with structures of the Ψ_{sp} type separated by large enough space-time intervals.

If the only solution for spin-1/2 excitations compatible with vacuum dynamics can be a discrete distribution with Ψ_{sp}'s separated by space-time distances larger than the particle size, several discrete trajectories can in principle be possible for a given particle. This would generate a situation potentially close to the grounds of the Feynman path integral. The Feynman approach to Quantum Mechanics can then be close to the limit of the presently considered dynamics when space-time distances are much larger than λ_{SST} .

Given the implications of the space-time contradiction, we expect Fermi statistics to naturally hold for such quantum particles.

Similarly, the Bose statistics for integer spin particles will in this case be naturally generated if they are made of two spin-1/2 structures and their internal size is at least larger than 2 λ_{SST} . More sophisticated compositions for particles of all spins can obviously be imagined, provided the above description applies for the "most elementary" conventional particles.

At scale-time distances much larger than λ_{SST} but much smaller than the cosmic time t, the local SST centered around a comoving observer placed at ξ_0 can still allow for a sufficiently exact SU(2) symmetry acting on a spinor $\xi - \xi_0$. Local conservation laws can be defined in this way with the local SU(2) accounting in particular for space rotations, and time invariance still leading to a suitable energy conservation law. Space translations involving low enough distances can be phenomenologically described by SU(2) rotations around a point placed on the same straight line with respect to the point $\xi = 0$ of the cosmic SST and at a distance to ξ_0 much larger than the space distance considered. But this requires the knowledge of the comic space-time origin. Strictly speaking, a cosmic rotation around $\xi = 0$ is required to really describe space translations at a finite cosmic time together with the associated privileged space direction. A purely local definition of translations would "lose the memory" of the PSD.

5 Superdradyons, vacuum, matter and space-time

In [29] and [17], we remind and analyse this statement by Abdus Salam in his December 1979 Nobel lecture [30]:

"Einstein knew that nature was not economical of structures: only of principles of fundamental applicability. The question we must ask ourselves is this: have we yet discovered such principles in our quest for elementarity, to justify having fields with such large numbers of components as elementary.

Recall that quarks carry at least three charges (colour, flavour and a family number). Should one not, by now, entertain the notions of quarks (and possibly of leptons) as being composites of some more basic entities (PRE-QUARKS or PREENS), which each carry but one basic charge."

(Salam cites here several articles)

These initial preon models were "quark-like", and attempted to better describe the variety of quantum numbers of the "elementary" particles by assuming quarks and leptons to be made of "more elementary" constituents. But the question whether the ultimate constituents of matter should really obey the same laws of Physics (standard relativity, quantum mechanics...) as quarks and leptons was only raised in [25, 27] and in our subsequent papers.

Similarly, the preons initially considered by Salam and other authors were direct constituents of the standard particles. The possibility that they actually be constituents of the physical vacuum, and the standard particles excitations of this vacuum, was an original suggestion of [25, 27] followed by [19, 20], [26] and subsequent work on the subject.

The approach presented here is therefore radically different from the initial preon models, and the deformation of Quantum Mechanics at high energy a logical consequence of the way this law of standard paricles is generated. Similarly, we expect Quantum Gravity to be deformed at high energy and no longer make sense beyond the space and time scales where Quantum Mechanics begins to exist. The effects of the preonic vacuum on renormalization at high energy should also be taken into account and can in particular solve the cosmological constant problem [17, 21].

As already emphasized in [25, 27] and in subsequent papers such as [19, 26], if the standard "elementary" particles are actually excitations of a more fundamental preonic vacuum structure, we do not expect the preon critical speed to be equal to the speed of light c . Just as the speed of light is much larger than that of sound in condensed matter, the critical speed of preons is expected to be much larger than c (the superbradyon hypothesis [25]). This can be a crucial point to understand quantum mechanics and its phenomenological implications.

5.1 Superbradyons faster than light

Assuming superbradyons can also exist as free particles in our Universe with a critical speed c_s much larger than the speed of light c, it was already pointed out in [20] that:

"A superluminal particle moving at speed $\vec{\mathbf{v}}$ with respect to the vacuum rest frame, and emitted by an astrophysical object, can reach an observer, moving with laboratory speed $\vec{\mathbf{V}}$ with respect to the same frame, at a time (as measured by the observer) previous to the emission time. Such a phenomenon will happen if $\vec{\mathbf{v}}.\vec{\mathbf{V}} > c^2$, and the emitted particle will be seen to evolve backward in time (but it evolves forward in time in the vacuum rest frame)."

(end of quote)

This conclusion was based on a simple calculation. In the rest frame of a standard particle moving with speed $\vec{\mathbf{V}}$ with respect to the vacuum rest frame (VRF), if $\vec{\mathbf{v}}$ is the speed of the superluminal particle with respect to the VRF and assuming for simplicity $\vec{\mathbf{v}}$ to be parallel to $\vec{\mathbf{V}}$, the speed $\vec{\mathbf{v'}}$ of the superluminal particle in the rest frame of the standard particle (the laboratory frame) is given by:

$$\vec{\mathbf{v'}} = (\vec{\mathbf{v}}_i - \vec{\mathbf{V}})\,(1 - \vec{\mathbf{v}}_i.\vec{\mathbf{V}}\,c^{-2})^{-1} \tag{4}$$

leading to a singularity at $\vec{\mathbf{v}}_i.\vec{\mathbf{V}} = c^2$ which corresponds to a change in the arrow of time

At $v > c^2\,V^{-1}$, a superluminal particle moving forward in time in the vacuum rest frame appears as moving backward in time to an observer made of ordinary matter and moving with speed $\vec{\mathbf{V}}$ in the same frame. It must be noticed, however, that the interaction between the physical vacuum and an important concentration of matter (f.i. inside a galaxy) can modify local properties of such vacuum. Thus, it is not excluded that the local VRF be changed and that, actually, our rest frame be close to the local rest frame of vacuum leading to a small value of $\vec{\mathbf{V}}$ and to a much larger value of $v > c^2\,V^{-1}$ than initially expected.

In any case, it clearly follows from this explicit example that the mathematical connection between macroscopic and preonic time is far from trivial and can involve significant contradictions.

In general, we do not expect to find superbradyons traveling around us at a speed larger than c because of their "Cherenkov" decay in vacuum [17, 25] spontaneously emitting standard particles since an early stage of the Universe formation. As superbradyons are constituents of vacuum, some confinement mechanism can be at work and it may happen that not all of them be allowed to exist as free particles. Free superbradyons are expected to interact weakly with standard matter. They may have kept a speed close to c or lost energy in further collisions with "ordinary" particles. They can in any case be a significant part of the cosmic and galactic dark matter.

High-energy astrophysical events can involve superbradyon emission at speeds initially larger than c and potentially able to reach the Earth with a superluminal velocity.

6 Preonic vacuum, space-time and Quantum Field Theory

A preonic description of vacuum and standard particles can also play an important role in Quantum Field Theory at large energy and momentum scales. It can in particular generate natural solutions to standard problems in Particle Physics and Cosmology, including the energy dependence of boson fields and the cosmological constant problem [17, 21].

Standard Quantum Field Theory (SQFT) develops a purely phenomenological approach to vacuum structure, where the only relevant information concerns boson condensates and the bosonic zero modes. Nothing is known in SQFT about a possible underlying preonic structure that can in particular account for such condensates and zero modes and lead to a new high-energy description of boson fields with a new energy dependence of the parameters of zero modes naturally solving the cosmological constant problem [17, 22]. Taking into account the internal vacuum structure, SQFT would undergo increasing modifications as the distance scale decreases and the effects of the underlying preonic dynamics become more and more able to influence dynamics and calculations. Renormalization may thus become an easier task for currently unsolved problems.

Similarly, fermion quantum fields would become operators acting on the preonic vacuum structure and such that the square of any fermionic operator vanishes identically.

With a spinorial space-time structure, the standard harmonic expansion of the quantum fields would be replaced by its equivalent on the S^3 space hypersphere. The SU(2) operators acting on the SST and on the matter properties would then generate the relevant observables and the equivalent of momentum conservation corresponding to the invariance under SST translations (cosmic rotations around the origin $\xi = 0$). An "almost energy conservation" would be associated to the "almost time invariance" of the laws of Physics.

6.1 Preons and Quantum Gravity

As the preonic structure generates new space, time, momentum and energy scales, the Planck scale is expected to no longer make sense in patterns incorporating preon dynamics [17, 22].

In particular, preon dynamics can produce observable effects at scales closer to us than the Planck scale. Ultra-high energy cosmic-ray (UHECR) experiments are particularly important to search for possible signatures of such new Physics [17, 21].

The theory of Quantum Gravity would be strongly modified [6, 7] by a preonic scenario invalidating the standard role of the Planck scale and dynamically generating Quantum Mechanics.

6.2 Some open questions

A particularly important question is that of the vacuum rest frame previously discussed, and already considered in [25, 27] when formulating the superbradyon hypothesis. The natural assumption is to identify the VRF with the reference frame of the cosmic microwave background radiation that can in turn be identified with the associated comoving frame of the cosmic SST.

But strictly speaking, this astrophysical determination of the VRF is based only on specific standard matter measurements and it is not certain that it would correspond exactly to the internal rest frame of a preonic vacuum.

The precise fundamental space-time structure remains also an open question, as already emphasized. The internal space-time structure of the preonic vacuum is expected to incorporate some crucial aspects of the SST, so as to be able to generate and describe spin-1/2 standard particles. But apart from this requirement, a more general view of space and time is in principle allowed and can lead to a birth of Quantum Mechanics similar to that previously considered, including the possible effect of a space-time contradiction between the fundamental preon dynamics and the macroscopic world.

7 Some experimental and cosmological considerations

A this stage, an important question arises: how to test experimentally the relevant new physics associated to the scenarios just described? This turns out to be a difficult task.

The possible tests of standard basic principles with ultra-high energy cosmic-ray (UHECR) data [17, 26] have already been discussed in previous papers [7, 18], including possible deformations of Quantum Mechanics [29]. New generations of UHECR experiments will certainly be required.

But the experimental and instrumental achievements of the recent period can also make feasible some attempts of direct searches for free superbradyons.

Thirty years ago, Goodman and Witten suggested [31] dark matter detection through nucleus recoil, the maximum recoil energy being $\epsilon = 4\ E\ m/M$ where E and m are the kinetic energy and the mass of the incoming particle, and M the mass of the target nucleus. Detectors developed for this goal include superheated superconducting granules [32, 33], crystal scintillators [34] presently used by DAMA/LIBRA [35] or the luminescent bolometer [36, 37] currently used by CRESST [38, 39].

For a dark matter superbradyon with speed c [17], the same formula used by Goodman and Witten would yield $\epsilon = 8\ E^2\ (Mc^2)^{-1}$ for an incoming momentum $p = 2\ E\ c^{-1}$. But the superbradyon-nucleus elastic cross-section can in practice be small even if we expect p to be in most cases compatible with coherent scattering. As the superbradyon rest energy will be much larger than its kinetic energy, the most interesting signature would possibly be the explosion of the target nucleus or of surrounding material due to a large energy transfer in an inelastic collision. Building large specific detectors devoted to such inelastic collisions between superbradyons and standard matter deserves a serious study. Experiments like AUGER or the Telescope Array can be sensitive to such events generated at the atmosphere or near a detector, even if possible background must be considered in detail.

Possible superbradyon production at high-energy accelerators should also carefully studied and searched for, looking for atypical events with a large missing energy without a significant missing momentum. The rest energy $m\ c_s^2$ where m is the superbradyon mass, or the superbradyon kinetic energy, would be much larger than $p\ c$ where p is the momentum of the produced particle. A spontaneous decay of the particle may complete such a signature if its speed is larger than c. The very large number of accelerator events can compensate a very weak superbradyon cross-section. In particular, proton-antiproton and electron-positron collisions at the highest possible energies should be made available for such searches.

Detecting a high-speed superbradyon (with velocity $v \gg c$) emitted by an astrophysical explosion or a similar event would be a unique scientific opportunity. But the probability of such a performance seems difficult to estimate.

Cosmology can possibly provide an additional signature for primordial superbradyons and other ultimate constituents of vacuum and matter, with a preonic era replacing the Big Bang + inflation scenario [6, 27]. The space-time scale at which the preonic vacuum generates standard "elementary" particles can be a new fundamental scale larger than the Planck scale and leading to a new phase of the history of the Universe.

8 Superluminal preons, Bell inequalities, Gödel indetermination...

In [7], the following question was explicitly raised about the origin of Quantum Mechanics:

"The subject of the origin of Quantum Mechanics is a very fundamental one and, by now, looks particularly mysterious. It therefore seems necessary to elucidate if it can be naturally understood in terms of a preonic (superbradyonic?) underlying vacuum structure and in the framework of a specific space-time geometry (the SST?)."

(end of quote)

Actually, as discussed in Section 4, Quantum Mechanics seems indeed to be a possible natural property of standard matter in a vacuum with a spinorial space-time geometry.

Furthermore, the recently observed large-distance quantum entanglement [40, 41] violating Bell inequalities [42] can then be naturally produced in a superbradyonic vacuum [10, 25].

Simultaneously, a difficulty expected from a logical point of view has been raised for standard Quantum Mechanics in [15, 16] and already in [43, 44] (see also [45, 46]) : if Quantum Mechanics is to be considered as based on a closed, consistent system of axioms, it cannot be complete and must lead to explicit incompleteness effects. The authors provide the example of an attempt to calculate the gap between the lowest energy level of electrons in a material and the next level, using an infinite lattice. Although a finite result is obtained with a finite lattice, no infinite lattice limit seems to exist.

8.1 Superbradyons and entanglement

A superbradyonic vacuum would obviously violate a basic principle leading to the Bell inequalities [42]: the requirement that any theory of Physics be "local" in the sense that no influence or information should propagate faster than light. Precisely, the authors of [40, 41] report a clear violation of the CHSH (Clauser et al.) - Bell inequality [47].

If preons are superluminal, faster-than-light propagation of signals and correlations in vacuum will necessarily be allowed. The speed of light will just not be a fundamental parameter of space, time and ultimate superbradyonic constituents inside the vacuum. As previously explained, the superbradyon critical speed c_s is expected to be much larger than c just as c is much larger than the speed of sound.

Therefore, a superbradyonic vacuum would be naturally consistent with the data announced in [40, 41]. If $c_s \simeq 10^6\ c$ (10^6 is the ratio between c and the speed of sound), the time scale associated to a distance of 1.3 Km would be $\simeq 4.10^{-12}$ seconds.

It clearly appears that a superbradyonic vacuum can not only generate Quantum Mechanics but naturally produce the observed entanglement.

8.2 Gödel indetermination and preonic vacuum

In [44], the authors explicitly claim that "for any consistent, recursive axiomatisation of mathematics, there exist specific Hamiltonians for which the presence or absence of a spectral gap is independent of the axioms". But what can be the situation if the version of Quantum Mechanics used for quantum calculations is not a consistent system of axioms but an approximation emerging from the preonic vacuum dynamics where particles are vacuum excitations and Quantum Mechanics is generated?

And if Quantum Mechanics is actually generated in a superbradyonic vacuum with a more fundamental dynamics, is it possible to obtain a deformed, approximate version of the quantum theory such that all relevant calculations of Quantum Physics escape the consequences of Gödel incompleteness?

Further work in this direction is obviously required, searching in particular for a pattern where incompleteness would possibly apply to the preonic vacuum dynamics but quantum calculations would escape its implications, at least with a reasonable approximate version of Quantum Mechanics.

8.3 Preons and deformed quantum mechanics

As previously considered, if Quantum Mechanics is generated from a preonic vacuum of from a space-time contradiction between the preonic vacuum and the macroscopic world, a deformed version of Quantum Mechanics is expected hold at very high energy. The usual quantum-mechanical equations of standard Physics will then be a low-energy limit.

Possible deformations of Quantum Mechanics have been considered, in particular, citeGonzalez-MestresCrete2014bis,Gonzalez-Mestres2009b band in [17, 18] and in [7, 29].

9 Conclusion and comments

A possible fundamental origin of Quantum Mechanics has been considered and naturally generated from the spinorial space-time with a dynamical preonic vacuum. In one of the versions dealt with, the time dispersion of the spinorial extended objects plays a crucial role to prevent a continuous motion of vacuum spinorial excitations and produce a Feynman-like path integral scenario.

A crucial question concerning the mathematical space-time structure of the preonic vacuum is that of the critical speed of preons. In connection with this basic interrogation and with recent data on entanglement, the direct experimental search for free superbradyons becomes an important subject.

Exploring other unconventional space-time geometries compatible with a similar description of the preonic vacuum and leading to similar results is obviously an urgent task.

Entanglement is by itself a potential evidence for a superbradyonic vacuum with a SST geometry. Possible deformations of quantum mechanics at ultra-high energy, as well as cosmological data on the early Universe, can also provide tests of the pattern suggested. And can some suitable version of deformed Quantum Mechanics escape incompleteness in a preonic pattern?

The question of the origin of Quantum Mechanics clearly needs further work.

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