Cosmological implications of a preonic vacuum (I)

Luis Gonzalez-Mestres*

Cosmology Laboratory, John Naisbitt University, Belgrade and Paris
Goce Delceva 8, 11070 Novi Beograd, Serbia

August 2, 2016

Abstract

The mathematical and dynamical structure of standard Physics at very short distances can be significantly modified by and underlying preonic structure. But the implications of such a new dynamics can produce important effects well beyond the directly concerned domain. Preons can, in particular, be the constituents of the physical vacuum as postulated two decades ago with the superbradyon (superluminal preon) hypothesis. Indeed, if a fundamental form of matter or pre-matter beyond standard particles exists, there is no reason to assume that its critical speed is equal to the speed of light c. The propagation of superluminal signals in vacuum can in particular be at the origin of the observed quantum entanglement. But the strongest implication of a preonic vacuum would be the possibility that it actually drives the expansion of the Universe. If an unstable (metastable) vacuum permanently expands, it can release energy in the form of conventional matter and of its associated kinetic energy. Then, the cosmological energy density of standard matter may be able by itself to accelerate the expansion of the Universe making useless dark energy and the standard cosmological constant. The spinorial space-time (SST) we introduced in 1996-97 can be the expression of such an expanding vacuum at cosmic level. In the presence of a preonic vacuum, the structure and properties of black holes can be modified in several ways by the interaction between the content of the black hole and the vacuum dynamics. The emission of superluminal preons through the black hole cannot be excluded if such objects can exist as free particles in our Universe. Besides gravitational waves, astrophysical events such as black hole mergers may also emit preonic waves. Similarly, the preonic vacuum may have nontrivial implications for gravitational waves propagating at very large distances. We briefly discuss these and related issues, as well as relevant open questions.

1 Introduction

The Planck collaboration [1] has not yet released its final results, and previously reported possible evidences for new physics and alternative cosmologies [2, 3] have not by now been excluded. In particular, the existence of a privileged space direction reported by Planck [4] can be a signature of the cosmic spinorial space-time (SST) we introduced in 1996-97 [5, 6].

A study of the implications of the cosmic SST geometry can be found in [7, 8], [9, 10], [11] and [12]. A really new cosmology can emerge from the pattern considered.

*luis.gonzalez-mestres@megatrend.edu.rs at the Cosmology Laboratory
lgmsci@yahoo.fr, personal e-mail

As discussed in [2, 3] and in [12, 13], as well as in previous papers, a crucial open interrogation is that concerning the structure of the physical vacuum. A question not really dealt with by standard quantum field theory, that is basically a phenomenological description of a family of vacuum excitations (the standard particles). The original preon hypothesis [14] assumed preons to be direct constituents of standard particles, but in 1995 we introduced the superbradyon hypothesis [15, 16] assuming that the physical vacuum is made of superluminal preons (superbradyons) and that conventional particles are excitations of the preonic vacuum.

The superluminal character of the vacuum constituents with a critical speed much larger than that of light would then be a natural property, just as the speed of light is much larger than that of phonons or solitons in condensed matter [15, 17]. Superbradyons (bradyons of a super-relativity) would be expected to obey a Lorentz-like symmetry with a new critical speed c_s instead of the speed of light c .

Combining superbradyons with the cosmic SST geometry, a new cosmology can then be built [2, 18] incorporating a pre-Big Bang scenario where Quantum Mechanics would be deformed at very high energy [19, 24] and no longer be an ultimate principle of Physics. Superbradyons and the SST can be at the origin of Quantum Mechanics [3].

New forms of matter, with new physical properties, would also be generated by a superbradyonic vacuum and a new (SST) space-time geometry [2, 13], and some of them can potentially be produced at CERN experiments as new particles.

1.1 An unstable (metastable) expanding vacuum?

In [12],we considered the possibility of a physical vacuum expanding in an unstable (metastable) state and releasing conventional matter and energy as a form of cosmic latent heat. If, as a consequence, the matter energy density ρ decreases with time more slowly than in standard cosmology, important effects can be expected. In particular, if ρ decreases like t^{-2} (t = age of the Universe) or more slowly, matter alone can accelerate the expansion of our Universe without any need for dark energy or the standard cosmological constant.

But the most important effect would come from the vacuum itself. In such a scenario, the unstable (metastable) vacuum would actually drive the expansion of the Universe. Thus, the by now unknown internal structure and dynamics of the physical vacuum would be the most important ingredient for modern Cosmology. In all cases, the possibly nontrivial structure and dynamics of the physical vacuum require further investigation.

The cosmic SST geometry can actually be the expression of the expansion of a physical vacuum at very large distance scales, even beyond our standard Universe.

1.2 New physics, gravitational and preonic waves, black holes...

New physics and new vacuum properties can also play a role in the dynamics involving black holes and gravitational waves. A black hole is expected to interact with a superbradyonic vacuum, and the same may happen with gravitational waves propagating at very large distance scales.

If superbradyons can exist as free particles in our Universe, preonic waves can also be emitted similarly to gravitational waves and in the same kind of astrophysical processes.

Assuming they can interact with standard matter, free superbradyons would in all cases spontaneously decay in vacuum releasing standard particles (Cherenkov effect in vacuum) until they reach a speed close to the speed of light c [15, 8]. Massive superbradyons traveling at the speed of light would in principle be able to reach our detectors.

Even if the direct interaction of superbradyons with standard matter is expected to be weak at low energy, their possible detection is not excluded as the same occurs with neutrinos and *a fortiori* with the graviton (but gravitational waves are detectable). The energy of massive superbradyons traveling at the speed of light would be much larger than their momentum times c due to the rest energy term.

The question can therefore be raised of the possible influence of new physics on the signals observed by LIGO, and on the parameters measured or estimated. More generally, a search for superbradyons and preonic waves should be considered.

2 The spinorial space-time (SST)

We basically follow here the content of the equivalent Section of reference [3]. The SST can possibly be the natural space-time geometry to describe a world where fermions exist with spinorial wave functions. Its implications are surprisingly nontrivial for Particle Physics and Cosmology.

The cosmic spinorial space-time automatically leads to the $H\ t = 1$ relation (H = ratio between relative velocities and distances at cosmic level, t = age of the Universe) in a purely geometric way, already before introducing conventional matter and the associated dynamics.

The spinorial space-time defined in [5, 6] is a simple SU(2) representation with two complex coordinates replacing the conventional four real ones of the standard space-time. Its properties, with possible cosmological implications coming directly from its mathematical structure, have been further studied in subsequent papers including [7, 8], [9, 10] and [2, 18].

2.1 SST and cosmic time

If ξ is a SU(2) spinor describing the cosmic SST coordinates (two complex variables instead of 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 definition of cosmic time (equivalent to the age of the Universe) can then be $t = \mid \xi \mid$ with an associated space given by the S^3 hypersphere $\mid \xi \mid = t$ incorporating an additional spinorial structure that does not exist in the standard space. Other definitions of the cosmic time t in terms of $\mid \xi \mid$ (f.i. $t = \mid \xi \mid^2$) can be considered, 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.

2.2 SST, cosmic coordinates and the expansion of the Universe

With the definition $t = \mid \xi \mid$, and taking ξ_0 to be the observer position on the $\mid \xi \mid = t_0$ hypersphere, space translations inside the associated space hypersphere (the space at $t = \mid \xi_0 \mid$) and simultaneously on all the space hyperspheres of the SST are described by SU(2) transformations acting on the 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 cosmic time t_0.

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 starting from 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.

As already pointed out in [5, 6], 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 $\mid \xi \mid^2$ times a unit vector defining a local privileged space direction (PSD) "parallel" (in the SST) to the cosmic spinor ξ. The direction of $\xi^\dagger \vec{\sigma} \xi$ corresponds to the set of points whose cosmic SST space-time position is equal to ξ times a complex phase.

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

Such a new space-time geometry clearly suggests potential limitations of general relativity and standard cosmology. Rather than an intrinsic fundamental property of space and time, conventional relativity is 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 [17, 15] where the speed of sound or the maximum speed of solitons plays the role of the critical speed. The speed of light c would then be the critical speed of a family of excitations of the physical vacuum (the standard particles) not directly related to an intrinsic geometry of the space-time.

Space rotations around a fixed point ξ_0 are given by SU(2) transformations acting on the spatial position vector $\vec{\mathbf{x}}$ defined by (1). A standard spatial rotation with respect to tha origin 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 $\xi'_p = U(\vec{\mathbf{y}})\ \xi_p$.

2.3 Some properties of a SST Universe

The cosmic SST automatically generates three basic cosmological phenomena in a purely geometric way [7, 8] and without any explicit presence of matter and energy:

i) The standard Lundmark-Lemaître-Hubble (LLH) 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 ($H = t^{-1}$). As t is the radius of the spatial hypersphere, and comoving frames correspond to straight lines starting from the time origin, distances between comoving objects will be proportional to t and the (constant) associated speeds will be given by the distances divided by t. t^{-1} is then the automatic geometric value of the LLH constant H.

ii) The existence of a privileged space direction (PSD) for each comoving observer, as already obtained in [5, 6] and further developed in [7, 8] and in subsequent papers.

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

More details, including a study of the cosmological implications of these unconventional properties of the cosmic SST, are given in [7, 8], [9, 10], [2, 18] and in related papers.

A fundamental feature of the cosmic SST geometry is that it is not dominated by standard matter or dark energy, and that its structure is defined in a totally independent way suggesting a more primordial origin. In the SST without standard matter, space units are not required, as time provides an effective distance scale.

The possible connection between the cosmic spinorial space-time structure and the ultimate dynamics of matter and vacuum is a crucial open question requiring further fundamental research. Preonic and and pre-Big Bang scenarios should be considered in this respect [2, 3].

3 SST and an expanding vacuum

It clearly emerges from the properties just discussed and obtained without any explicit presence of matter, that the question of a possible primordial origin of the SST naturally points to the structure and dynamics of the physical vacuum.

The superbradyonic vacuum appears then as a well-suited scenario, and may even be at the origin of the recently reported evidence for quantum entanglement [20, 21] if superluminal signals can propagate inside the physical vacuum [3]. Indeed, a superbradyon critical speed equal to a million times the speed of light (just as the speed of light is around a million times the speed of sound) would be compatible (around 4 picoseconds time interval) with the observed simultaneity at a distance of 1.3 km.

If the physical vacuum has a nontrivial internal structure, this structure is sensitive to the expansion of the Universe where vacuum expands like space and its internal structure must follow this cosmic process. It seems then reasonable to expect that "creating more vacuum" should in principle have a nontrivial cost in energy. This cost remains by now unknown, but in any case it does not prevent the space from expanding.

A natural assumption can be that the physical vacuum "likes expanding" (a negative cost in energy) and releases energy in this dynamical process.

3.1 An unstable (metastable) vacuum driving the expansion of the Universe?

If the expansion of the physical vacuum is energetically favored, it can actually be at the origin of the expansion of space and of our Universe. The observed expansion of the matter Universe would then actually be driven by that of the physical vacuum.

Then, the Cosmology of the matter Universe would not actually describe the deep Universe dynamics but the way matter adapts itself to the expansion of the internal vacuum structure.

As discussed later, the standard dark energy and cosmological constant will not be required in such a scenario. Instead, the expanding vacuum can emit conventional matter and associated energy, possibly leading to a matter energy density decreasing with time more slowly than in standard cosmology and able by itself to accelerate the expansion of the matter Universe [12].

4 SST, matter and the acceleration of the expansion of a matter Universe

In [23] and in other papers, we considered the following Friedmann-like relation for the standard matter universe within the cosmic SST geometry:

$$H^2 \ = \ 8\pi \ G \ \rho/3 \ - \ k \ R^{-2} \ c^2 \ + \ t^{-2} \ + \ K \ + \ \Lambda \ c^2/3 \qquad (2)$$

t is the cosmic time (age of the Universe), ρ the energy density associated to standard matter, c the speed of light, k the standard curvature parameter, R the present curvature distance scale of the Universe (the curvature radius, and possibly the radius of the Universe, for $k = 1$) and Λ a possible new version of the cosmological constant decreasing as the Universe expands.

Λ would now be free of any cosmological constant problem. The new term t^{-2}, of cosmic geometric origin as suggested by the SST structure and the $H\ t\ =\ 1$ law in the absence of matter, would be larger than the standard curvature term and has a positive sign independent of k. It would in principle dominate the large scale expansion of the Universe at large values of t.

K is a correction term that will be neglected in what follows. It accounts in particular for:

- a possible small difference between the comoving frames of standard cosmology and those (pre-existing) obtained from the underlying SST cosmic geometry;

- similarly, a correction related to remnant effects from the pre-Big Bang era;

- a reaction of the nucleated standard matter to the pre-existing expansion of the Universe led by the SST geometry and the pre-Big Bang vacuum [7, 22];

- vacuum inhomogeneities at cosmic scale and other non-standard effects.

Crucial questions to dealt with equation (2) are the dependence of ρ and Λ on the age and the size of the Universe. The curvature term $-\ k\ R^{-2}\ c^2$ will in any case be substantially smaller than t^{-2}.

Ignoring K and the standard curvature term, we can write:

$$H^2\ \simeq\ 8\pi\ G\ \rho/3\ +\ t^{-2}\ +\ \Lambda\ c^2/3\ =\ t^{-2}\ +\ \Gamma \qquad (3)$$

where $\Gamma\ =\ \pi\ G\ \rho/3\ +\ \Lambda\ c^2/3$ is the sum of the contributions of matter (including dark matter) and of the cosmological constant.

In what follows, we consider the unconventional possibility that Γ is basically dominated by matter, and that the matter energy density decreases more slowly with the Universe expansion than in standard cosmology.

5 An unconventional way to accelerate the expansion of the matter Universe

In previous papers, we considered a scenario where in the early Universe the standard matter just generated reacts gravitationally to the pre-existing expansion of space generated by the cosmic SST geometry. This may have slowed the expansion of the Universe. As the matter density becomes smaller and the gravitational force decreases, the effect becomes weaker and the expansion of the Universe accelerates to reach an asymptotic regime with the limit $H\ t = 1$ at large t. [22, 23].

In what follows, we consider an alternative, or complementary, cosmic mechanism involving the dynamics of the physical vacuum. We assume here that:

- The physical vacuum releases a positive amount of energy as it expands leading the present Universe evolution.

- This energy is converted into matter (standard and dark) and in associated energy.

- As a consequence, the cosmic matter energy density decreases more slowly than usually expected as the Universe expands.

Then, if Γ corresponds basically to the matter energy density, its new dependence on the age and size of the Universe can lead to nontrivial effects and, in particular, make unnecessary the usual role of dark energy and the cosmological constant. The basic mechanism can be illustrated in a simple way writing:

$$\Gamma\ =\ \gamma\ t^{-2} \qquad (4)$$

where γ is a constant, and for equation (3):

$$H^2\ =\ t^{-2}\ (1\ +\ \gamma) \qquad (5)$$

where it has been assumed that the matter energy density varies like t^{-2}. One then gets, using the equation $H = a^{-1}\, da/dt$ where a is the usual cosmic distance scale:

$$da/a = (1 + \gamma)^{1/2}\, dt/t \tag{6}$$

leading to:

$$a = f\, t^{\lambda} \tag{7}$$

where f is a constant and $\lambda = (1 + \gamma)^{1/2}$, and subsequently to:

$$d^2a/dt^2 = \lambda\, (\lambda - 1)\, t^{\lambda - 2} \tag{8}$$

Therefore, the expansion of the Universe is accelerated for all positive values of γ without any need for a standard cosmological constant. A positive matter energy density varying like t^{-2} is enough to produce such an effect.

Writing, as usual, for the standard deceleration parameter q_0 :

$$q_0 = -\, a\, d^2a/dt^2\, (da/dt)^{-2} \tag{9}$$

One gets the value $q_0 = -0.55$ for $\gamma \simeq 1$ corresponding to $\Gamma \simeq t^{-2}$ (matter energy term $\simeq$ SST term).

5.1 Other scenarios involving the SST

In the previous example, the limit $H\, t \rightarrow 1$ is replaced by $H\, t \rightarrow (1 + \gamma)^{1/2}$ with $(1 + \gamma)^{1/2} \simeq \sqrt{2}$ for $\Gamma \simeq t^{-2}$. The relation between H and t is then significantly modified with respect to conventional cosmology or to standard SST predictions.

There is, however, no experimental evidence against equations (4)-(5).

The limit $H\, t \rightarrow 1$ would be preserved, simultaneously to the positive sign of d^2a/dt^2 (positive acceleration of the expansion of the Universe), replacing equation (4) by a similar law:

$$\Gamma = \gamma'\, t^{-\alpha} \tag{10}$$

where γ' is a constant and $2 < \alpha < 3$. The value $\alpha = 3$ is a limiting case, where one gets:

$$H^2 = t^{-2} + \gamma'\, t^{-3} \tag{11}$$

with a vanishing acceleration at the first order for small t^{-1}. For higher values of α, the acceleration becomes negative at small t^{-1}.

Thus, a matter energy density of the form (10) with $2 < \alpha < 3$ can : i) preserve the $H\, t \rightarrow 1$ limit at large t ; ii) generate the observed acceleration of the Universe expansion using a suitable value of γ'.

A more precise observational knowledge of the matter energy density in the Universe (including dark matter) would allow to further constrain the parameters α and γ'. In all cases, the considered examples lead to an acceleration of the expansion of the Universe decreasing with cosmic time.

A brief dicussion of alternatives to the SST geometry leading to a similar situation can be found in [12].

6 New physics and black holes

The existence of a preonic vacuum structure can modify some aspects of black hole dynamics. Not only the equations of standard physics would cease to hold below some critical distance scale, but the vacuum structure may interact with the trapped matter. Superbradyons released by vacuum inside the black hole or produced otherwise would possibly be able to escape the black hole region, as: i) they can travel at a speed much larger than that of light ; ii) their coupling to gravitation is expected to be much smaller than that of standard matter. Once outside the black hole, superbradyons would undergo Cherenkov decay in vacuum and produce standard matter in this way.

The possibility that the preonic vacuum absorbs matter trapped in the black hole and releases it outside the black hole should also be considered. Thus, a superbradyonic vacuum can possibly generate new black hole radiation mechanisms in competition with the thermal radiation considered by Stephen Hawking [25], and involving much higher energies.

The recent results ([26, 27] and [28, 29] reported by the collaborations LIGO [30] and VIRGO [31] indicate the detection of gravitational waves generated by two binary black hole mergers (GW150914 and GW151226) at a luminosity distance from Earth around 410 and 440 Mpc. The initial source frame masses of the black holes are estimated to around 36, 29, 14 and 7.5 solar masses, leading to final black hole masses around 62 and 21 solar masses and releasing gravitational waves with a total energy around 3 and 1 times the solar rest energy.

ANTARES [32] and IceCube [33] have found no high energy neutrino in coincidence with the first gravitational wave event reported by LIGO and VIRGO [34].

Introductions to black holes can be found in [35, 36] and in [37, 38]. Writing the general relativistic line element for a mass M and using the Eddington-Finkelstein coordinates, one gets:

$$ds^2 \ = \ - \ c^2(1 \ - \ 2GMc^{-2}/r) \ dv^2 + \ 2c \ dv \ dr \ + r^2 d\Omega^2 \tag{12}$$

where:

$$d\Omega^2 \ = \ d\theta^2 \ + \ sin^2\theta \ d\phi^2 \tag{13}$$

G is the gravitational constant, r the usual spatial radius and $v = t$ (time) $r^* c^{-1}$ where $r^* = r + 2GMc^{-2} \ ln \ |rc^2(2GM)^{-1} \ - 1|$. The symbol ln stands for neperian logarithm.

The singularity at $r = 0$ will necessarily trigger and interaction between the black hole and the superbradyonic vacuum leading the a new black hole dynamics at very short distances. A similar situation may have ruled out primordial black holes, especially in the presence of a pre-Big Bang scenario leading to an evolution of the Universe without the standard cosmic inflation. The possible implications of a new black hole dynamics in the presence of a superbradyonic vacuum remain to be further explored.

7 New physics, gravitational waves, preonic waves...

The propagation of gravitational waves over very large cosmic distances can also be influenced by unconventional interactions with the superbradyonic vacuum. Some of their properties may be modified in this way before they reach Earth detectors.

Also, even if superbradyons are expected to be weakly coupled to gravitation, the physical vacuum may react in some situations to the surrounding gravitational waves, in particular close to a strong source of such waves.

The dynamics of black hole mergers for gravitational wave emission can in particular be modified by the interaction with the superbradyonic vacuum.

Simutaneously, vacuum, black holes and other sources including the recently observed black hole mergers, can possibly emit preonic waves and particles. For free super-relativistic preons obeying a super-relativity with c_s as the critical speed, the energy would be close to c_s times the momentum.

Such preonic waves and particles would radiate (Cherenkov in vacuum) standard particles and wavesuntil they reach a propagation speed close to the speed of light c , in the case of massive superbradyons obeying the above super-relativity. For massless superbradyons, the Cherenkov-like decay would continue until all the energy is exhausted except if the superbradyons interact again with the physical vacuum.

It must be noticed that the rest energy mc_s^2 of a superbradyon moving at a speed equal to c and obeying super-relativity laws would be equal to 2 $(c_s c{-}1)^2$ times its kinetic energy (more than 10^{12} times for $c_s c{-}1 = 10^6$). Then, even weakly coupled to gravitation, the superbradyon would be sensitive to this force and generate it.

It is therefore not impossible that a signature of preonic waves and particles can be found in detectors and observations. Many questions remain to be answered concerning the interaction of such objects with standard matter.

8 Other possible effects

As already discussed in previous papers [2, 18], free massive superbradyons with a speed close to c can form a new kind of dark matter in our Universe [8, 39]. Such a dark matter can escape conventional searches for single particles beyond the standard model and have important cosmological implications. In particular, free superbradyons would contribute to the effective gravitational matter energy density in our Universe.

An important open question is how would two free superbradyons interact, and what can emerge from such a process.

The possibility that superbradyons are produced at LHC or spontaneously emitted by vacuum inside this accelerator should also be considered. A signature being the strong Cherenkov-like emission of standard particles by an object with low momentum.

In a recent search, the CMS collaboration has displayed [40] multi-jet events that could potentially be associated to black holes. The possibility that similar events actually involve a superbradyonic component should also be studied, together with the search for possible black hole candidates.

As both the SST and the superbradyonic vacuum will generate violations of standard relativity at very short distance and very large energy scales, the study of ultra-high energy cosmic rays is an important experimental and phenomenological tool [8, 17]. Forthcoming results of the AUGER experiment [41] can play a crucial role in this domain.

9 Conclusion and prospects

The possibility that the vacuum actually leads the expansion of the Universe, and that it expands permanenty in an unstable (metastable) state must be seriously considered. Such an expansion of the physical vacuum can be closely connected to the cosmic SST geometry and lead to a new approach to Cosmology.

Experimental tests of quantum entanglement can in principle be used to set lower bounds on the superbradyon critical speed c_s assuming that c_s corresponds to the critical speed of signals exchanged in vacuum. As an example, a time resolution of a fraction of nanosecond for a distance of the order of 1 km can roughly exclude relevant values of c_s smaller than 10^4 times c . If entanglement is found to fail in a further experiment, the associated distance scale and time resolution would in principle allow the determine the value of c_s .

In view of the possible cosmological role of the physical vacuum, careful studies of the time dependence of the matter energy density in our Universe should be carried out.

The search for free preons and preonic waves also requires an adapted use of detectors and observatories with suitable data analyses considering the many unknown parameters about the properties and interactions of such objects.

References

[1] Planck Collaboration, ESA site: http://www.cosmos.esa.int/web/planck

[2] For a recent review of the subject, see for instance L. Gonzalez-Mestres, *Big Bang, inflation, standard Physics... and the potentialities of new Physics and alternative cosmologies*, talk given at the 4th International Conference on New Frontiers in Physics, ICNFP 2015, Kolymbary, Crete, August 2015, and references therein. Preprint version available at mp_arc 16-11.

[3] A recent analysis concerning the possible origin of Quantum Mechanics can be found in L. Gonzalez-Mestres, *Spinorial space-time and the origin of Quantum Mechanics*, presented at ICNFP 2015, and references therein. Preprint version available at mp_arc 16-12.

[4] Planck Collaboration, *Planck 2013 results. XXIII. Isotropy and statistics of the CMB*, *Astronomy and Astrophysics* **571**, A23 (2014), also available at http://arxiv.org/abs/1303.5083

[5] L. Gonzalez-Mestres, *Physical and Cosmological Implications of a Possible Class of Particles Able to Travel Faster than Light*, contribution to the 28th International Conference on High Energy Physics, Warsaw 1996, arXiv:hep-ph/9610474, and references therein.

[6] L. Gonzalez-Mestres, *Space, Time and Superluminal Particles*, arXiv:physics/9702026 [12] L. Gonzalez-Mestres, *Spinorial Regge trajectories and Hagedorn-like temperatures*, presented at ICNFP 2015, and references therein. Preprint version available at mp_arc 16-15.

[7] L. Gonzalez-Mestres *Pre-Big Bang, fundamental Physics and noncyclic cosmologies*, presented at the International Conference on New Frontiers in Physics, ICFP 2012, Kolymbari, Crete, June 10-16 2012, *EPJ Web of Conferences* **70**, 00035 (2014), and references therein. Preprint version at mp_arc 13-18.

[8] L. Gonzalez-Mestres, *Cosmic rays and tests of fundamental principles*, CRIS 2010 Proceedings, *Nucl. Phys. B, Proc. Suppl.* **212-213** (2011), 26, and references therein. The *arXiv.org* version arXiv:1011.4889 includes a relevant Post Scriptum.

[9] L. Gonzalez-Mestres, *Spinorial space-time and privileged space direction (I)*, mp_arc 13-75, and references therein.

[10] L. Gonzalez-Mestres, *Spinorial space-time and Friedmann-like equations (I)*, mp_arc 13-80, and references therein.

[11] L. Gonzalez-Mestres, *Tests and prospects of new physics at very high energy*, contribution the 3rd International Conference on New Frontiers in Physics, Kolymbari, Crete, Greece, August 23 - 30, 2014, *EPJ Web of Conferences* **95**, 05007 (2015), and references therein.

[12] L. Gonzalez-Mestres, *Can matter accelerate the expansion of the Universe? (I)* (April 26, 2016), Part I of a contribution to the 5th International Conference on New Frontiers in Physics, Kolymbari, Crete, Greece, July 5 - 15, 2016. Available at mp_arc 16-33.

[13] See also L. Gonzalez-Mestres, *Spinorial Regge trajectories and Hagedorn-like temperatures*, presented at ICNFP 2015, and references therein. Preprint version available at mp_arc 16-15.

[14] See, for instance, the 1979 Nobel lecture by Abdus Salam, and references therein.

[15] L. Gonzalez-Mestres, *Properties of a possible class of particles able to travel faster than light*, Proceedings of the January 1995 Moriond Workshop, Ed. Frontières, arXiv:astro-ph/9505117

[16] L. Gonzalez-Mestres, *Cosmological Implications of a Possible Class of Particles Able to Travel Faster than Light*, Proceedings of the TAUP 1995 Conference, *Nucl. Phys. Proc. Suppl.* **48** (1996), 131, arXiv:astro-ph/9601090.

[17] L. Gonzalez-Mestres, *Vacuum Structure, Lorentz Symmetry and Superluminal Particles*, arXiv:physics/9704017

[18] L. Gonzalez-Mestres, *BICEP2, Planck, spinorial space-time, pre-Big Bang*, contribution the 3rd International Conference on New Frontiers in Physics, Kolymbari, Crete, Greece, August 23 - 30, 2014, *EPJ Web of Conferences* **95**, 03014 (2015), and references therein.

[19] L. Gonzalez-Mestres, *High-energy cosmic rays and tests of basic principles of Physics*, presented at the International Conference on New Frontiers in Physics, ICFP 2012, Kolymbari, Crete, June 10-16 2012, *EPJ Web of Conferences* **70**, 00047 (2014), and references therein. Preprint version at mp_arc 13-19.

[20] B. Hensen et al., *Experimental loophole-free violation of a Bell inequality using entangled electron spins separated by 1.3 km*, *Nature***526**, 682 (2015).

[21] B. Hensen et al., *Loophole-free Bell test using electron spins in diamond: second experiment and additional analysis*, http://arxiv.org/abs/1603.05705

[22] L. Gonzalez-Mestres, *Planck data, spinorial space-time and asymptotic Universe*, mp_arc 13-33, and references therein.

[23] L. Gonzalez-Mestres, *Pre-Big Bang, space-time structure, asymptotic Universe*, 2nd International Conference on New Frontiers in Physics, Kolymbari, Crete, Greece, August 28 - September 5, 2013, *EPJ Web of Conferences* **71**, 00063 (2014), references therein and Post Scriptum to the preprint hal-00983005.

[24] L. Gonzalez-Mestres, *Preon models, relativity, quantum mechanics and cosmology (I)*, arXiv:0908.4070.

[25] S. Hawking, *Black hole explosions?*, *Nature* **248**, 30 (1974).

[26] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), *Phys. Rev. Lett.* **116**, 061102 (2016).

[27] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), *Astrophysical Implications of the Binary Black-Hole Merger GW150914*, *The Astrophysical Journal Letters* **818**, L22 (2016).

[28] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), *Observation of Gravitational Waves from a 22-Solar-Mass Binary Black Hole Coalescence*, *Phys. Rev. Lett.* **116**, 241103 (2016).

[29] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), *Binary Black Hole Mergers in the first Advanced LIGO Observing Run*, arXiv:1606.04856

[30] LIGO Scientific Collaboration, http://www.ligo.org/

[31] VIRGO Collaboration, http://www.virgo-gw.eu/

[32] ANTARES Collaboration, http://antares.in2p3.fr/

[33] IceCube South Pole Neutrino Observatory, http://icecube.wisc.edu/

[34] ANTARES Collaboration, IceCube Collaboration, LIGO Scientific Collaboration, Virgo Collaboration, *High-energy Neutrino follow-up search of Gravitational Wave Event GW150914 with ANTARES and IceCube*, arXiv:1602.05411

[35] T. Jacobson, *Introductory Lectures on Black Hole Thermodynamics*, 1996 Lectures given at the University of Utrecht.

[36] G. t Hooft, *Introduction to the Theory of Black Holes*, 2009 Lectures presented at the Utrecht University, ITP-UU-09/11, SPIN-09/11.

[37] L. Gualtieri and V. Ferrari, *Black Holes in general Relativity*, Università degli studi di Roma, 2011.

[38] Harvey Reall, Lecture notes on Black Holes (2016), University of Cambridge.

[39] L. Gonzalez-Mestres, *Lorentz symmetry violation, dark matter and dark energy*, Invisible Universe International Conference, Paris June 29 - July 3, 2009. The *arXiv.org* version arXiv:0912.0725 includes a relevant Post Scriptum.

[40] CMS Collaboration, *Search for black holes at* $\sqrt{s} = 13$ *TeV*

[41] Pierre Auger Observatory, https://www.auger.org/