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Value of H, space-time patterns, vacuum, matter, expansion of the Universe, alternative cosmologies

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Abstract. To the experimental uncertainties on the present value H_0 of the Lundmark - Lemaître - Hubble constant, fundamental theoretical uncertainties of several kinds should also be added. In standard Cosmology, consistency problems are really serious. The cosmological constant is a source of well-known difficulties while the associated dark energy is assumed to be at the origin of the observed acceleration of the expansion of the Universe. But in alternative cosmologies, possible approaches without these problems exist. An example is the pattern based on the spinorial space-time (SST) we introduced in 1996-97 where the $H\ t = 1$ relation (t = cosmic time = age of the Universe) is automatically generated by a pre-existing cosmic geometry before standard matter and conventional forces, including gravitation and relativity, are introduced. We analyse present theoretical, experimental and observational uncertainties, focusing also on the possible sources of the acceleration of the expansion of the Universe as well as on the structure of the physical vacuum and its potential cosmological role. Particular attention is given to alternative approaches to both Particle Physics and Cosmology including possible preonic constituents of the physical vacuum and associated pre-Big Bang patterns. A significant example is provided by the cosmic SST geometry together with the possibility that the expanding cosmological vacuum releases energy in the form of standard matter and dark matter, thus modifying the dependence of the matter energy density with respect to the age and size of our Universe. The SST naturally generates a new leading contribution to the value of H. If the matter energy density decreases more slowly than in standard patterns, it can naturally be at the origin of the observed acceleration of the expansion of the Universe. The mathematical and dynamical structure of standard Physics at very short distances can also be modified by an underlying preonic structure. If preons are the constituents of the physical vacuum, as postulated two decades ago with the superbradyon (superluminal preon) hypothesis, the strongest implication would be the possibility that vacuum 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. The SST can be the expression of such an expanding vacuum at cosmic level. We briefly discuss these and related issues, as well as relevant open questions including the problematics of the initial singularity and the cosmic vacuum dynamics in a pre-Big Bang era. The possibility to obtain experimental information on the preonic internal structure of vacuum is also considered.

This paper is dedicated to the memory of Henri Poincaré

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1 Introduction

What is the *"trouble with H_0"* recently considered by several authors [1]? *Nature News* wrote on April 2016 [2] *"Measurement of Universe's expansion rate creates cosmological puzzle. Discrepancy between observations could point to new physics."*, referring to the April 2016 paper by Adam G. Riess and other authors *"A 2.4 % Determination of the Local Value of the Hubble Constant"* [3].

Using the Wide Field Camera 3 (WFC3) on the Hubble Space Telescope (HST) [4], Riess et al. announce a best estimate of 73.24±1.74 km/sec/Mpc for the present value H_0 of the Lundmark - Lemaître - Hubble (LLH) constant H (usually called the Hubble constant, but actually due to the work of these three scientists). This result appears to contrast with previous estimates from other experiments, including *Planck* [5].

Riess et al. compare the new obtained value of H_0 with *"the prediction of 69.3±0.7 km/sec/Mpc with the combination of WMAP + ACT + SPT + BAO"* [6, 7] and with the value of *"66.93±0.7 km/sec/Mpc predicted by ΛCDM with 3 neutrinos with mass 0.06 eV and the Planck data"*. To explain the observed differences between the measured values, they consider the possibility of an additional source of dark radiation in the early Universe. Actually, the evolution of the number density of galaxies in our Universe remains an open subject [8].

To the present experimental and observational uncertainties, basic theoretical puzzles and unknowns should be also added. They concern in particular the mathematical structure of space-time, the origin of the Universe, its age and size, the density of matter, the nature and origin of the cosmological constant, the structure and dynamical properties of vacuum, a possible preonic structure...

In particular, if the arrow of time makes sense, what is the force driving the expansion of space in our Universe as the cosmic time increases? What are its nature and its origin? Standard cosmology deals with these questions in a purely phenomenological way starting from the Big Bang hypothesis of Georges Lemaître [9] and adding to it a the *ad hoc* inflationary scenario [10–12]. But alternative cosmologies involving pre-Big Bang scenarios and incorporating new physics can naturally avoid the conventional Big Bang and cosmic inflation [13, 14].

This contribution is devoted to alternative approaches to some basic questions in Cosmology and Particle Physics, with particular emphasis on space-time and on the possible internal structure of the physical vacuum (see also [15]). The potential implications of new physics, including superluminal preons as fundamental vacuum constituents, together with a pre-Big Bang era, are given particular attention including the question of a possible initial singularity.

2 The physical vacuum in an expanding universe

If the Universe expands, how does the physical vacuum evolve? How can vacuum adapt itself to this expansion of space? Or can it actually play a more "active" role in Cosmology?

The answer to these questions will depend crucially on the, by now totally unknown, internal vacuum structure and dynamics.

Is this problematics too complex or far from experiment and observation? In what follows and in [15], we consider some possible signatures of such a new physics and cosmology. Furthermore, standard concepts including Big Bang, inflation, strings, quantum gravity... have led to involved situations [16–18] while: i) direct particle physics tests become more and more difficult as the energy scale increases beyond those of accelerator experiments; ii) astrophysical and cosmological data are incomplete and difficult to interpret in an unambiguous way.

In such a situation, new physics can be present at energy scales far below the Planck energy. There is by now no evidence for a standard Grand Unification scale and the theoretical situation is uncertain [19–23]. Most likely, the Planck scale and standard quantum gravity do no longer make sense [13, 25] in the presence of new physics. All standard forces, including gravity, are then expected to be composite phenomena and standard symmetries become low-energy approximations for conventional matter. The dynamical role of the physical vacuum is a crucial subject in this respect, together with the space-time structure [14, 24].

In standard Quantum Field Theory (QFT), the physical vacuum is a purely passive object where fields associated to conventional "elementary" particles can condensate. But boson fields involve harmonic oscillators with nontrivial "zero modes". Such an amboguity is by itself a source of theoretical and phenomenological problems when a possible "active" role of vacuum is considered.

Attempts to describe the cosmological role of vacuum using standard quantum field theory have led to the well-known cosmological constant problem [26, 27]. But as pointed out in previous papers [13, 28], the situation can be radically different with a preonic vacuum structure naturally avoiding a permanent static presence of the (composite) QFT standard condensates and bosonic zero modes [29]. If the conventional particles are actually excitations of the physical vacuum, the underlying vacuum dynamics can generate them in specific situations and in a way compatible with the successful experimental tests of QFT.

In a preonic vacuum where signals can propagate faster than light [15], the Higgs boson and the zero modes of bosonic harmonic oscillators do not need to be permanently materialized, as the vacuum dynamics can temporarily produce them when required by the presence of surrounding matter and thus make possible the standard particle interactions. In this case, the (ground) state of vacuum in regions of the Universe without matter would be substantially different from the (excited) one observed in the laboratory. Leaving aside possible controversies on the precise origin of the Casimir effect [30–32], one can expect the structure and dynamics of the physical vacuum in the laboratory, even with a locally void setup, to be influenced by the presence of surrounding matter. The fact that quantum entanglement is being successfully checked at rather large distances [33, 34] can be an indication on the propagation of signals in vacuum [15].

An important nontrivial information emerges from cosmological data: the physical vacuum appears to be able to naturally expand in space. But the energetic balance of such an expansion and the force driving it remain unknown and can play a crucial role in the present dynamics of our Universe. Patterns incorporating dark energy the a cosmological cosmological constant tacitly postulate a crucial role of vacuum in the expansion of the Universe. But what is the nature of this physical vacuum and what is its internal dynamics?

As discussed in [15], the definition itself of the physical vacuum is far fron trivial. Assuming a preonic vacuum, a practical choice can be to define vacuum as the set of preons, including virtual ones, trapped in its internal structure. Then, "real" preons able to travel over long distances will be dealt with as free particles.

If the expansion of the physical vacuum is energetically favored and standard particles are actually vacuum excitations, the evolution of our Universe can lead vacuum to release matter and matter energy as it expands. This can fundamentally change the dependence of the matter energy density with respect to the age and size of our Universe.

Then, equations involving matter alone can in principle formally describe the observed acceleration of the expansion of the matter Universe, and no conventional dark energy would be required to produce such an important effect. We present here a simple illustration of this fundamentally new situation, using the cosmology based on the spinorial space-time (SST) we introduced in [35, 36]. We also briefly consider other cosmological scenarios leading to the same phenomenon and discuss the possibility that vacuum actually leads the expansion of the Universe. A preliminary version of the work presented here can be found in two preprints contributed to this Conference [37, 38].

In all cases, it clearly appears that the hypothesis of a preonic vacuum is not more involved than the scenarios of standard cosmology and that, combined with a pre-Big Bang description of the origin of the Universe, it can lead to a much more natural cosmic dynamics. Phenomenology, experiments and observations should focuse on this possibility and search for relevant signatures.

3 The spinorial space-time (SST)

If the physical vacuum has a nontrivial internal structure, what can be the relevant space-time geometry? And if standard particles are just vacuum excitations, can they be sensitive in the laboratory to the actual space-time structure? A first question must be raised: why are the fermion wave functions representations of the covering group SU(2) of the standard space rotation group S0(3), and not of the rotation group itself?

It is a fact that the usual description of space-time is based on everyday's life and on macroscopic objects around us. It was not conceived to describe particles or the very large scale structure of the Universe. Precisely, the SST seems to be able to improve the situation in both domains.

The spinorial space-time (SST) introduced in [35, 36] automatically generates the $H\,t = 1$ relation (t = cosmic time = age of the Universe) in a purely geometric way, already before introducing conventional matter and the associated forces. Its properties have been briefly reminded in [15, 39] and previously dealt with in several papers including [13, 28], [40, 41] and [14, 42].

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, the cosmic time to associated to ξ can be defined by the positive scalar $t = \mid \xi \mid$ with the relation $\mid \xi \mid^2 = \xi^\dagger \xi$ where the dagger stands for hermitic conjugate. Other definitions of t (a function of $\mid \xi \mid$) would lead to equivalent results provided the cosmic time is positive, increases with $\mid \xi \mid$ and is equal to zero for $\mid \xi \mid = 0$.

In such an approach where the cosmic space-time coordinates are no longer real numbers, the status of relativity necessarily changes. Rather than an intrinsic fundamental property of space and time defining a global space-time geometry, 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 [43, 44]. In the present case, the preonic vacuum can play the role of the condensed medium and the SST can be the space-time geometry of the internal vacuum structure [15, 39]..

Indeed, 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 at cosmic level.

In practice, the possible connection between the cosmic spinorial space-time structure and the ultimate dynamics of matter and vacuum remains an open question requiring further fundamental research in both Particle Physics and Cosmology. Clearly, preonic and and pre-Big Bang scenarios should be considered in this respect [14, 45] together with possible sources of signatures (particle accelerators, high-energy cosmic rays, black holes, gravitational waves...). The automatic $H\,t = 1$ relation can be an encouraging signature in spite of the "trouble with H_0".

As reminded in [15] and already found in [35, 36], the SST naturally generates a local privileged space direction (PSD) for each comoving observer. The existence of the local PSD may be consistent with Planck data [46] and does not imply any anisotropy of the Universe at cosmic level, as the PSD is different for any point of the SST except for those lying on the PSD itself. Again, a signature of the SST can result from such an effect.

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

What do the equations of standard cosmology become if the usual real space-time is replaced by the SST? The equation $H\,t = 1$ in the absence of matter must be a basic startpoint.

In [47] and in other papers, we considered the following Friedmann-like relation for the standard matter universe within the cosmic SST geometry:

$$H^2 \;=\; 8\pi\, G\, \rho/3 \;-\; k\, R^{-2}\, c^2 \;+ t^{-2} \;+\; K \;+\; \Lambda\, c^2/3 \qquad (1)$$

t is the above defined 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 is now 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, is larger than the standard curvature term $-\,k\,R^{-2}\,c^2$ and has a positive sign independent of k. It in principle clearly dominates the large scale expansion of the Universe at large values of t. *Planck* measured [5]: $\mid\; \Omega_k \;\mid = \;\mid\; k\, c^2\, R^{-2}\, H_0^{-2} \;\mid < 0.005$.

K is a correction term that will be neglected in what follows. It can account 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.

Crucial questions to deal with equation (1) are the dependence of ρ and Λ on the age and the size of the Universe. We consider here some specific unconventional approaches to this basic question.

Ignoring, to a first approximation, K and the standard curvature term, one can write:

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

where $\Gamma \;=\; 8\pi\, G\, \rho/3 \;+\; \Lambda\, c^2/3$ is the sum of the contributions of matter (including dark matter) and of the new cosmological constant.

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

5 An unconventional way to accelerate the expansion of the Universe

Two basic question are: i) how do matter and the vacuum interact, and what can the preonic vacuum radiate? ; ii) how do matter and vacuum interact with a possible leading role of the SST in the Universe expansion?

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.

Then, 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 [47, 48]. This is just an example of possible alternative approaches to the current standard acceleration of the expansion of the Universe.

Other alternative, or complementary, cosmic mechanisms involving the dynamics of the physical vacuum are presented in this and the following sections. The above mechanism can complete those considered below.

If the physical vacuum has a nontrivial internal structure, this structure is in all cases sensitive to the expansion of the Universe. In the most conservative hypothesis, vacuum expands like the available space and its internal structure must follow this nontrivial cosmic process.

It seems then reasonable to expect that "creating more vacuum" should in principle have a nontrivial cost in energy. This cost can, in the same conservative approach, be positive or negative and remains by now unknown. But in all realistic scenarios, such an energy cost does not prevent the space and the vacuum from expanding.

In this respect, a possible set of assumptions can be that:

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

- This energy is mainly converted into matter (standard and dark), and there is no leading conventional dark 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 density, its new dependence on the age and size of the Universe can lead to nontrivial effects and, in particular, make indeed unnecessary the usual role of dark energy and of the cosmological constant. A simple way to illustrate the most essential mechanism can be to write for equation (2):

$$\Gamma = \gamma \, t^{-2} \tag{3}$$

where γ is a constant, and the dependence of the matter energy density with respect to cosmic time leads to:

$$H^2 = t^{-2} \, (1 + \gamma) \tag{4}$$

thus modifying H at the leading level.

It has been assumed in this specific example that the matter energy density varies proportionally to t^{-2}, similarly to the geometric SST term and contrary to standard patterns where matter plays a much less important role and dark energy replaces the SST term.

One then gets, using simultaneously the equation $H = a^{-1} \, da/dt$ where a is the usual cosmic distance scale:

$$da/a = (1 + \gamma)^{1/2} \, dt/t \tag{5}$$

so that, as a consequence of (3) and (4), the cosmic distance scale grows faster than the cosmic time for positive values of γ.

Equation (5) trivially leads to:

$$a = f \, t^{\lambda} \tag{6}$$

where f is a positive constant, not dimensionless, and $\lambda = (1 + \gamma)^{1/2}$. One therefore has, for positive γ, $\lambda > 1$ and $da/dt = (1 + \gamma)^{1/2} \, a/t = f \, \lambda \, t^{\lambda-1} > a/t$ implying a permanent acceleration of the expansion of the Universe.

More explicitly, one can write:

$$d^2a/dt^2 = \lambda \, (\lambda - 1) \, f \, t^{\lambda-2} \tag{7}$$

The acceleration d^2a/dt^2 of the growth of a is therefore positive for $\lambda > 1$. It is constant for $\lambda = 2$ and tends to zero at large t if $\lambda < 2$.

It then follows, in particular, that the expansion of the Universe is permanently 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 :

$$q_0 \ = \ - \, a \, d^2a/dt^2 \, (da/dt)^{-2} \tag{8}$$

the above equations lead to

$$q_0 \ = \ - \, f \, t^{\lambda} \, \lambda \, (\lambda \ - \ 1) \, f \, t^{\lambda-2} \, (\, f \, \lambda \, t^{\lambda-1})^{-2} \ = \ - \, (\lambda \ - \ 1) \, \lambda^{-1} \tag{9}$$

One gets the value $q_0 \ \simeq \ - \, 0.05$ for $\gamma \ \simeq 0.1$ corresponding to $\Gamma \ \simeq 0.1 \, t^{-2}$ (matter energy term $\simeq$ 0.1 times the SST term). An alternative is thus provided to approaches trying to use q_0 to determine the properties of dark energy [49, 50]. The choice made here for the values of γ and λ may look modest, but it appears sufficient when added to the SST term in (1).

5.1 Some phenomenological considerations

In the previous example, the limit $H \, t \rightarrow 1$ is replaced by $H \, t \rightarrow \ (1 \ + \ \gamma)^{1/2}$ with $1 \ + \ \gamma)^{1/2} \simeq \ 1.05$ for $\Gamma \ \simeq \ 0.1 \, t^{-2}$.

It clearly follows, in particular, that the family of scenarios just considered can produce values of H_0 larger than usually expected.

The relation between H and t is thus modified with respect to conventional cosmology or to standard SST predictions. But there is by now no experimental or observational evidence against equations (3)-(4). On the contrary, the recent measurements of H_0 by Wide Field Camera 3 may tend to confirm the validity of this kind of pattern or, in any case, the need to study it closely.

Taking the age of the Universe t to be 13.799 billion years [5], the $H \, t = 1$ law would yield a value of H around 70.91 km/sec/Mpc . There is more than a standard deviation between this value and that of 73.24±1.74 km/sec/Mpc measured by the WFC3.

Then, between 70.91 km/sec/Mpc and 73.24 + 1.74 km/sec/Mpc = 74.94 km/sec/Mpc = 70.91 + 4.07 km/sec/Mpc, the difference of 4.07 km/sec/Mpc can be compatible with the value $\gamma \ \simeq 0.1$ $(1 \ + \ \gamma)^{1/2} \simeq \ 1.05)$ considered above.

This, however, does not invalidate the possibility that, instead, the $H \ t \, = \, 1$ law be correct at the leading level if all the components of equation (1) are taken into account. The difference between the value of H_0 measured by the WFC3 and the inverse of the age of the Universe is 2.33 km/sec/Mpc, which corresponds to 1.34 standard deviations.

It must also be reminded at this stage that the approach developed describes a matter Universe in terms of matter equations without explicitly considering the internal dynamics of the physical vacuum, even if the role of vacuum is tacitly important in equations (3) and (4).

5.2 A more conservative choice

The limit $H \, t \rightarrow 1$ would however be preserved, simultaneously to the positive sign of d^2a/dt^2 (positive acceleration of the expansion of the Universe), replacing equation (3) by a similar law with a less strong dynamical content:

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

and

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

where γ' is a constant and $2 < \alpha < 3$. The value of γ' can then be adjusted in terms of that of α and the results of the measurements of H_0 considering also other cosmological parameters.

The value $\alpha = 3$ is a limiting case, where one would get:

$$H^2 = t^{-2} + \gamma' t^{-3} \tag{12}$$

with

$$da/dt = a H = a (t^{-2} + \gamma' t^{-3})^{1/2} \tag{13}$$

and

$$d^2a/dt^2 = da/dt (t^{-2} + \gamma' t^{-3})^{1/2} - a (t^{-2} + \gamma' t^{-3})^{-1/2} (2 t^{-3} + 3 \gamma' t^{-4})/2 \tag{14}$$

leading to:

$$d^2a/dt^2 = a (t^{-2} + \gamma' t^{-3}) - a (t^{-2} + \gamma' t^{-3})^{-1/2} (2 t^{-3} + 3 \gamma' t^{-4})/2 \tag{15}$$

where

$$a (t^{-2} + \gamma' t^{-3})^{-1/2} (2 t^{-3} + 3 \gamma' t^{-4})/2 = a t^{-2} (1 + \gamma' t^{-1})^{-1/2} (1 + 3/2 \gamma' t^{-1}) \tag{16}$$

Then, expanding (16) in a power series of t^{-1}, the coefficients of t^{-2} and t^{-3} in the similar expansion of (15) turn out to vanish simultaneously. This does not happen for $\alpha < 3$, in which case the term proportional to $t^{-\alpha}$ yields a (leading) positive contribution to the value of d^2a/dt^2 .

It follows from (15) and (16) that, for $\alpha = 3$, a vanishing acceleration is obtained at the first relevant order for small t^{-1}. For higher values of α, the acceleration becomes negative at large t.

For $2 < \alpha < 3$, one has:

$$d^2a/dt^2 = a (t^{-2} + \gamma' t^{-\alpha}) - a (t^{-2} + \gamma' t^{-\alpha})^{-1/2} (2 t^{-3} + \alpha \gamma' t^{-\alpha-1})/2 \tag{17}$$

leading to:

$$d^2a/dt^2 \simeq (3 - \alpha) \gamma' t^{-\alpha}/2 \tag{18}$$

It seems then realistic to conclude that a matter energy density of the form (9) with $2 < \alpha < 3$ can: i) preserve the $H t \to 1$ limit at large t ; ii) generate the observed acceleration of the Universe expansion with a suitable value of γ' for the relevant value of α.

A more precise observational knowledge of the actual matter energy density in the Universe (including in particular dark matter and a deeper understanding of black hole dynamics) would allow to further constrain the parameters α and γ'.

5.3 Possible scenarios in other space-time geometries

The SST t^2 term can be removed from the formulae leading to (4) without altering the cosmological prediction if, for instance, (3) is replaced by:

$$\Gamma = (1 + \gamma) t^{-2} \tag{19}$$

In this specific example, the matter energy term would, alone, replace the role of the SST geometry in (1) and of any conventional dark energy.

Similarly, the cosmological implications of (10) and (11) can be preserved without using the t^2 term from SST if (9) is replaced by:

$$\Gamma = t^{-2} + \gamma' t^{-\alpha} \tag{20}$$

Thus, the above results for the acceleration of the expansion of the Universe apply to other cosmic space-time geometries provided suitable parameterizations are used for the matter energy density and other possible cosmological variables replacing in particular the contribution from the SST geometry.

Less strong parameterizations would not work similarly. A possible attempt without the SST term writing instead of (11) (σ is a constant):

$$H^2 \ = \ \sigma \, t^{-\alpha} \tag{21}$$

leads for $\alpha \ > \ 2$ to a negative acceleration of the expansion of the Universe and to a constant value of a in the large t limit.

The presence in equations like (10), together with the t^{-2} term, of a term proportional to $t^{-\alpha'}$ with $\alpha' \ \leq \ 2$ turns out to be necessary to obtain a positive acceleration of the expansion of the Universe and possibly explain cosmological data.

Values of α' smaller than 2 can be considered in this respect, but they would lead to an exponential expansion of the Universe at large t.

6 Further remarks

As shown in [47] and contrary to the curvature term standard patterns, the SST can account for both spherical and hyperbolic observed cosmic space curvatures with the same positive-definite dominant t^{-2} term in (1). The SST curvature term t^{-2} describes a primordial space-time geometry and not the cosmic space curvature directly seen in current observations.

Similarly, as discussed in previous papers and obtained from (11) and (18) in the approaches considered here, the observed acceleration of the expansion of the Universe is not necessarily a permanent leading phenomenon. Instead, the value $H \, t \ = \ 1$ predicted by the SST geometry can be the asymptotic limit at cosmic level for large values of t.

This is the case for some of the models discussed here, whereas other scenarios yield a large t limit of the form $H \, t \ = \ (1 + \gamma)^{1/2}$ with a positive value of γ and the matter energy density replacing the standard cosmological constant.

If the cosmic physical vacuum emits matter and matter energy as it expands, the matter energy density in our Universe will decrease more slowly than assumed in conventional patterns and can potentially be described by the models considered here for the Γ term. Matter would then naturally be at the origin of the observed acceleration of the expansion of the Universe. This unconventional hypothesis may turn out to be fully realistic when hopefully unveiling the ultimate structure of vacuum and matter [43, 44].

Then, as previously shown, dark energy and the cosmological constant would no longer be necessary, even if they can still exist in a more limited form as suggested in [47] and in subsequent work. Actually, if the acceleration of the expansion of the Universe can be generated by matter with a suitable vacuum dynamics, there is no obvious motivation for a cosmological constant.

The cosmology based on the spinorial space-time appears particularly well suited to describe a scenario where matter itself generates the observed acceleration of the expansion of the Universe. The t^{-2} term from the SST geometry in (1) and (2) directly contributes to this effect.

Simultaneously, potential evidences for the SST already exist. In particular, the PSD (local privileged space direction) may have been observed by Planck [46] through an asymmetry of the cosmic microwave background. To date, the Planck Collaboration has not modified this 2013 announcement, but its final results have not yet been made public.

A basic unknown remains: that of the global size and shape of the SST Universe in standard space units. As discussed in previous papers [14, 42], space units in the SST geometry are defined only at a later stage when introducing standard matter and the associated SST space coordinates. Then, the SST Universe may turn out to be much larger than the space occupied by conventional matter around us, and other regions of the global Universe may exist with different properties.

More generally, the role of the actual space-time structure in Particle Physics and Cosmology remains a crucial issue [15], including possible superluminal constituents of the physical vacuum [43, 44] and associated pre-Big Bang scenarios [14, 42]. Alternative approaches like those defined by (1), (3), (10) and (20) can be at the origin of a new generation of tests.

Further work is required in all cases, including measurements with higher precision and detailed data analyses as well as relevant theoretical developments beyond standard patterns. In what follows, we discuss some possible implications of a preonic vacuum structure.

In connection with attempts [19, 52] to explain a possible high-energy diphoton excess at CERN experiments [53, 54] in terms of supersymmetry and other fashionable extensions of the standard model, it must be reminded [14, 24] that the physical vacuum with the SST geometry is expected to naturally generate Regge-like trajectories of excitations (particles) with spins spaced by 1/2 instead of 1. In this way, a large number of new particles can appear at all energies. Those with the relevant masses would potentially be produced at CERN experiments.

The properties, role and interactions of such newa particles in our Universe are also open questions. String-like scenarios involvng them cannot be excluded. Also, as the SST symmetry is a compact group, it naturally escapes constraints of the Coleman-Mandula type. New kinds of symmetries for particles can therefore be considered.

If Regge-like and string-like scenarios with a spin spacing of 1/2 apply involving simultaneously standard and new particles, a universal critical speed in vacuum equal to c appears as the natural hypothesis. More involved scenarios can also be imagined, in which case superluminal new particles would be expected to spontaneously decay.

7 Possible cosmological implications of a preonic vacuum

The Planck collaboration [51] has not yet released its final results, and previously reported possible evidences for new physics and alternative cosmologies [14, 39] have not by now been excluded. Precisely, a really new cosmology can emerge from the patterns considered here.

As discussed in [15], as well as in previous papers like [14, 39] and [24, 37], the crucial open interrogation concerning the deep internal structure and dynamics of the physical vacuum is a crucial one to understand the properties of matter and of the Universe. Not only this question is not really dealt with by standard quantum field theory, that is basically a phenomenological description of a family of vacuum excitations (the standard particles), but the description of matter itself may turn out to be incomplete as just pointed out about the spinorial Regge trajectories.

The original preon hypothesis [55] assumed preons to be direct constituents of standard particles. Relativity and Quantum Mechanics where not challenged in such a context. But in 1995 we introduced the superbradyon hypothesis [44, 56] assuming that the physical vacuum is made of superluminal preons (superbradyons) and that that conventional particles are excitations of the preonic vacuum. A new approach to preons and to the vacuum structure was thus sugggested. More than twenty years later, the vacuum properties remain unknown and there is no experimental or observational evidence against the superbradyon hypothesis.

Superbradyons (bradyons of a super-relativity) would be expected to obey a Lorentz-like symmetry with a new critical speed c_s much larger than the speed of light c . The superluminal character of such vacuum constituents can be considered as a natural property, just as the speed of light is much larger than that of phonons or solitons in condensed matter [43, 56]. But what are the structure and the properties of such an underlying "condensed" medium? And what is the precise relation between vacuum and the Universe?

Combining superbradyons with the cosmic SST geometry, a new cosmology can be built [14, 42] incorporating a pre-Big Bang scenario where relativity and Quantum Mechanics would be deformed at very high energy [42, 57] and no longer be ultimate principles of Physics. Superbradyons and the SST can be at the origin of Quantum Mechanics and relativity as low-energy approximations for standard particles [15, 45] in the presence of a more fundamental dynamics. But what can be this dynamics, and how to obtain experimental and observational signatures from it? The above mentioned new particles can provide possible signatures at accelerator experiments, but what about cosmological signatures?

As developed in [15, 38], black holes interacting with the vacuum structure and gravitational waves can provide possible signatures of a preonic vacuum. But a stronger effect must be expected from pre-Big Bang patterns where the early preonic vacuum can play a crucial dynamical role.

Already in [58], it was emphasized that *"if superluminal sectors exist and Lorentz invariance is only a sectorial property, the Big Bang scenario may become quite different"*. The existence of a critical high temperature T_0 for standard particles was postulated, associated to a high energy scale such that *"above T_0 the Universe may have contained only superluminal particles"*. A pre-Big Bang scenario was then clearly formulated, together with its basic implications (no standard Big Bang, no cosmic inflation...) without any need for the "string-driven" scenario proposed in [59, 60]. As strings are known to have a composite fundamental structure (fishnet diagrams...) [57, 61], a string approach to Cosmology can naturally lead to a superbradyonic pre-Big Bang.

The composite nature of hadronic strings was also confirmed by work on the structure of the Pomeron-like double-twisted graph of dual amplitudes [62, 63]. The kinematical properties of the intermediate states at high energy and low momentum transfer where shown to be perfectly compatible with a multiperipheral configuration of constituents. But strings cannot describe the fundamental large-angle processes involving small distance scales and "hard" interactions. A similar situation can be expected for cosmic strings and the role of vacuum preons in the early Universe.

Theoretical problems raised by the first BICEP2 announcement of a possible observation of B-modes of the cosmic microwave background (CMB) radiation were discussed in [64, 65] and subsequently in [42]. In alternative cosmologies such as those based on the SST, primordial gravitational waves from inflation would not be the natural explanation for such a signal. Further experimental work on the subject is in progress at the South Pole [66] and Atacama [67].

8 An unstable(metastable) expanding vacuum?

In [37, 38], 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 *Gamma* decreases with time more slowly than in standard cosmology, important effects can be expected as just described. 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 our Universe. If this is the case, the leading role of vacuum in such an expansion would most likely have been permanent since the beginning of the Universe evolution. Thus, the by now unknown internal structure and dynamics of the physical vacuum would clearly be the most important ingredient for modern Cosmology.

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. It clearly emerges from the SST properties obtained without any explicit presence of matter and automatically incorporating an expansion of space with the $H\,t = 1$ law, that the question of a possible primordial origin of such a space-time geometry 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 [33, 68] if superluminal signals can propagate inside such a physical vacuum [14, 15]. Indeed, a superbradyon critical speed c_s equal to a million times the speed of light c (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 quantum simultaneity at a distance of 1.3 km.

Direct experimental tests of quantum entanglement at larger distances may even allow to determine the value of c_s if they reach distance scales at which entanglement ceases to hold. Thus, experiments on entanglement can provide a unique exploration of the internal vacuum structure and of its dynamical and cosmological implications.

A major step to explore the vacuum structure and the possible value of c_s through direct tests of quantum entanglement can be provided by the Quantum Science Satellite recently launched [69–71].

In all cases, if the physical vacuum has a nontrivial internal structure, this structure is necessarily sensitive to the expansion of the Universe where vacuum itself expands like space and its internal structure and dynamics 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, according to observation, it does not prevent the space (and consequently, the vacuum) from expanding.

A natural assumption can therefore be that the physical vacuum "likes expanding" (a negative cost in energy) and releases energy in this dynamical process. The implications of such a scenario are very strong from a cosmological point of view

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

If the expansion of the physical vacuum is energetically favored, it must actually be at the origin of the expansion of space and of our Universe. No other realistic explanation seems possible for such a phenomenon in the vacuum dynamics can drive it.

The observed expansion of the matter Universe would then actually be driven by that of the physical vacuum leading the expansion of the available space. A permanent interaction between vacuum and matter (they form actually a single dynamical and cosmological system [15]) is required in order to guarantee a common expansion.

Black holes are also an ingredient of such a cosmic dynamics, and vacuum directly interacts with them [15, 38].

Then, the formal cosmology of the matter Universe in terms of matter would not actually describe the deep Universe dynamics but the way matter adapts itself to the expansion of the internal vacuum structure. Instead of the standard dark energy, the expanding vacuum can emit conventional matter and associated energy, possibly leading to a matter energy density that decreases with time more slowly than in standard cosmology and is formally able by itself to accelerate the expansion of the matter Universe [37, 38].

Concerning the time spent by a pre-Big Bang era, it must be noticed that the current estimates of the age of the Universe involve error bars of the order of 20 million years [5]. A 10 million years pre-Big Bang period with a hyperspherical Universe expanding at a superluminal radial speed $\sim 10^6\, c$ would yield a hypersphere radius $\sim 10^{13}$ light years. This is far more than required to solve the horizon problem and to satisfy similar standard requirements usually leading to the standard inflationary pattern. Thus, pre-Big Bang with an expanding superbradyonic vacuum would have no actual influence on the estimated age of the Universe and can be expected to successfully replace the conventional description of the beginning of its evolution.

It therefore follows that there is in principle no conceptual or obvious phenomenological problem in assuming that an unstable or metastable preonic vacuum has been leading the expansion of the Universe since the earliest times of its evolution.

9 Why a pre-Big Bang?

At this stage, a basic question must be raised: why a pre-Big Bang? Can one imagine a specific reason for a pre-Big Bang phase preceding the present one in the history of the Universe?

If the expansion of our Universe has always been driven by the dynamics of a preonic vacuum, why did such an expansion have a previous phase different from the current one? Why not a single phase with the present $H\,t = 1$ law?

To potentially answer these questions, a complementary interrogation should be added: what is the highest temperature at which standard matter can exist and a matter Universe can be formed?

The conventional Big Bang model enforces from the beginning the presence and the dominant role of standard matter. But why should these constraints be compulsory, especially in the presence of a superbradyonic vacuum?

A simple hypothesis can be that the pre-Big Bang era corresponds to an initial phase of the history of the Universe, when the physical vacuum was so hot that standard matter could not be formed in a stable way and superbradyons were not trapped in rigid structures "inside" the vacuum.

In such a "fluid" early vacuum, it seems reasonable to assume that superbradyons traveled at speeds of the order of c_s or at least much larger than c, thus leading to a superluminal expansion of the pre-Big Bang preonic Universe in the absence of nucleated standard matter.

Then, as vacuum expanded, its temperature decreased and at a later stage the present phase was reached. This new phase can involve confined superbradyons and, in all cases, a significant population of standard matter. Conventional particles would be excitations of the new vacuum structure replacing the earlier unconfined motion of superbradyons in the pre-Big Bang vacuum.

In the current phase of the Universe evolution, possibly described by the cosmic SST, the internal strucure of vacuum would still expand and become colder following a law close to $H\ t = 1$ and releasing matter and energy in this process.

The pre-Big Bang phase and the transition from the pre-Big Bang to the present phase of the evolution of the Universe are contracted to the point $t = 0$ in the cosmic SST description developed above. A sepa rate description is therefore required for the pre-Big Bang.

A new cosmic SST can also be considered for pre-Big Bang with an expansion law for the pre-Big Bang Universe that can be of the type $H_{PBB}\ \Phi\ (t_{PBB}) = 1$ where t_{PBB} is time during pre-Big Bang, H_{PBB} a new LLH-like constat and *Phi* a well-suited fonction of which the $H_{PBB}\ t_{PBB} = 1$ equation would be a particular example. If the pre-Big Bang time is to be considered as completely decoupled from that of the present phase of the history of the Universe and independent of his scale, t_{PBB} can in principle be redefined.

In the hyperspherical configuration of space, this would be compatible with a pre-Big Bang Universe radius of $c_s\ t_{PBB}$ expanding at a velocity of c_s. In practice, the expansion velocity of the pre-Big Bang Universe may have been smaller than c_s and time-dependent but in any case much larger than c.

At "large" t_{PBB} , a transition to the present phase would occur and the $H_{PBB}\ \Phi\ (t_{PBB}) = 1$ equation would have to be adapted in order to operate the corresponding evolution where the superbradyonic structure will be "condensed" and standard matter will nucleate. In particular, the expansion of the Universe will become much slower but superluminal signals will still be allowed to propagate at a velocity of c_s or close to it.

If the transition from pre-Big Bang to the current phase of the Universe evolution is of type I, a nucleation center can expand very quickly in the superbradyonic vacuum where causality relations exist since the beginning between all points. The situation is clearly different from the conventional Big Bang, where only a small amount of standard matter exist at the beginning of the Universe and cosmic inflation is required for this reason.

Similarly, if the pre-Big Bang Universe undergoes a type II phase transition to reach the present evolution, a large amount of nucleation centers is expected to appear in a medium where all the points are causally related and can exchange signals at a velocity of c_s. Such a situation would be fundamentally different from the standard Big Bang.

Thus, a pre-Big Bang era appears as the natural alternative to the standard inflationary scenario built *ad hoc* to preserve the Big Bang theory and the description of the Universe referring only to conventional matter. The horizon and flatness problems are thus naturally solved.

10 The initial singularity

Has there been an initial singularity? If this is the case, what were its properties and its role in the origin of the Universe? How was it generated?

Stephen Hawking suggests [72, 73] that the Universe would have expanded from a single point borrowing energy from the gravitational field to create matter during its expansion. In [73], an initial gravitational singularity is considered and an updated version of this approach must possibly use quantum gravity at very low distances. But a preonic approach to vacuum structure would replace quantum gravity at much larger distance scales.

As early as 1993, Borde and Vilenkin argued [74, 75] thar *"a physically reasonable spacetime that is eternally inflating to the future must possess an initial singularity"*. Work on the initial singularity also concerns information and dynamics contained in imaginary time [76–79].

In particular, an initial imaginary time direction was considered in [76, 77] with an initial gravitational instanton and a pre-Big Bang scenario incorporating the generation of standard particles.

Attempts [80] to avoid the initial singularity pattern using an energy-dependent ("rainbow") space-time metric [81] are just direct applications of the high-energy deformation of relativity considered in [35, 43], [82, 83] and in subsequent papers. In principle, the notion itself of energy dependence requires a privileged local rest frame (the "vacuum rest frame", VRF [43, 82] to be usefully applied. Already discussed in [15] and in the present contribution, new physics can be present well before Planck scale with an associated pre-Big Bang scenario.

In the presence of a superbradyonic vacuum, an alternative to the role of gravitation in the expansion of the Universe may come from new physics. Assuming that energy conservation still holds, if the internal "condensed" vacuum structure has a negative energy, it will naturally expand by reproducing itself. The matter energy density and temperature will then decrease with time.

The questions of a possible initial singularity and of the source of the energy required for the expansion of the pre-Big Bang Universe can also be raised for a superbradyonic vacuum. The initially very high temperature can account for such an expansion, but the origin of the initial state remains an interrogation. The presence of a strong attractive force can play an important role in helping vacuum to create superbradyons, slowering the expansion and operating the transition to the present phase.

It must also be noticed that, since the superbradyons of the pre-Big Bang era did not obey Quantum Mechanics, their properties as waves or particles are a complementary interrogation. They may have existed with a variable mass and have been able to split into similar objects with lower masses following the evolution of the temperature of the Universe. For a speed v such that $c_s \gg v \gg c$, the leading energy term would be close to $m\, c_s^2$ and lower values of m will be favoured as the superbradyonic pre-Big Bang Universe cools and expands.

Another possibility for the pre-Big Bang era would be that t_{PBB} actually varies between - ∞ and the positive transition time, with a suitably defined law for H (t_{PBB}). Then, the meaning of time itself and of the arrow of time may need to be reconsidered.

Multiverse approaches [84–87] can also be substantially transformed by a preonic vacuum approach. In particular, two kinds of scenarios can be considered:

- A possible approach would be to assume that the pre-Big Bang phase does not actually become a global universe in the present phase, but remains instead a superbradyonic medium where several separate universes with standard matter can nucleate and develop without any direct contact between them. Then, the energy asociated to the initial singularity of each Universe and to its further development will be provided by the evolving pre-Big Bang medium.

- An alternative can be to assume the existence of a fundamental superbradyonic medium where pre-Big Bang universes can nucleate and further evolve. In this case, the energy for the initial singularity and the subsequent evolution will be provided by such a medium.

In both cases, there is no obvious evidence that the laws of Physics for standard matter and the associated fundamental constants would be different for different universes. The dynamics of the common superbradyonic medium in the scenarios just described can potentially generate a single set of physical laws for the excitations of this medium, including those corresponding to conventional matter in all the universes.

A relevant question, however, is that of the possible time variation of the fundamental constants that remains by now under investigation [88].

Also, in the models just described, one may think that if each universe expands forever as a law like $H\ t = 1$ suggests, two or several different universes could possibly collide as they expand and become a single cosmological object. But such a collision will be avoided if the medium where these universes have been born expands fast enough, as a supebradyonic internal structure can in principle guarantee. Thus, the pattern appears consistent from this point of view.

Obviously, the subject of the possible initial singularity and of the associated energy sources is full of open questions and uncertainties in a context where nothing is really known about the structure of the physical vacuum. Again, experiments on quantum entanglement may offer a unique chance to improve this situation by reaching a phenomenological determination of c_s.

11 Conclusion and comments

This paper actually corresponds to two posters presented at the Conference [89].

The subjects convered are full of unknowns, but also of possible alternatives to standard cosmological prejudices. It clearly turns out that the observed acceleration of the expansion of the Universe does not require the introduction of the standard cosmological constant with the usual dark energy, and that simpler and more natural mechanisms can be at work.

A preonic vacuum can: i) generate alternatives to the standard Quantum Field Theory avoiding the pattern that leads to the conventional cosmological constant; and, simultaneously, ii) play a leading role in the expansion of our Universe if its own expansion is energetically favoured. In this case, the expansion of the Universe can be basically that of the physical vacuum.

The space-time geometry introduced by the SST generates a t^{-2} contribution (t = age of the Universe) to the basic formula for H^2 that changes fundamentally the situation in Cosmology. Then, instead of dark energy, a contribution from the matter energy density can basically complete the SST description of H. Other space-time geometries, together with well-suited choices for the matter energy density, can also provide useful alternatives.

The choice of a pre-Big Bang scenario with new physics instead of the standard cosmic inflation appears really well motivated and naturally solves the horizon and flatness problems. The question of the initial singularity can be discussed in this context, with the fundamental interrogations of how did the Universe start and what is the actual source of its energy.

A crucial question is that of the possibility to get experimental information on the internal structure and dynamics of the physical vacuum. As stressed in [15] and in the present paper, direct tests of quantum entanglement at very long distances can potentially provide a unique way to determine the critical speed c_s of the possible superbradyonic constituents of vacuum if entanglement is due to the transmission of superluminal signals.

The internal structure and dynamics of the physical vacuum are nowadays the most important interrogation for Particle Physics and Cosmology. Further theoretical work is required, together with devoted long-term experimental and observational programs including the direct search for "free" superbradyons and specific tests of SST predictions.

This paper is dedicated to the memory of Henri Poincaré, remembering his pioneering role in several fields of theoretical physics and mathematics, including the birth of relativity. Unfortunately, Poincaré died of a serious health problem in 1912. He was 58 years old, and he had worked until the end in spite of his illness [90, 91].

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