

Big Bang, inflation, standard Physics... and the potentialities of new Physics and alternative cosmologies

Present status of observational and experimental Cosmology. Open questions and potentialities of alternative cosmologies

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Abstract. A year ago, we wrote [1] that the field of Cosmology was undergoing a positive and constructive crisis. The possible development of more direct links between the Mathematical Physics aspects of cosmological patterns and the interpretation of experimental and observational results was particularly emphasized. Controversies on inflation are not really new, but in any case inflation is not required in pre-Big Bang models and the validity of the standard Big Bang + inflation + Λ CDM pattern has not by now been demonstrated by data. *Planck* has even explicitly reported the existence of "anomalies". Remembering the far-reaching work of Yoichiro Nambu published in 1959-61, it seems legitimate to underline the need for a cross-disciplinary approach in the presence of deep, unsolved theoretical problems concerning new domains of matter properties and of the physical world. The physics of a possible preonic vacuum and the associated cosmology constitute one of these domains. If the vacuum is made of superluminal preons (superbradyons), and if standard particles are vacuum excitations, how to build a suitable theory to describe the internal structure of such a vacuum at both local and cosmic level? Experimental programs (South Pole, Atacama, AUGER, Telescope Array...) and observational ones (Planck, JEM-EUSO...) devoted to the study of cosmic microwave background radiation (CMB) and of ultra-high energy cosmic rays (UHECR) are crucial to elucidate such theoretical interrogations and guide new phenomenological developments. Together with a brief review of the observational and experimental situation, we also examine the main present theoretical and phenomenological problems and point out the role new physics and alternative cosmologies can potentially play. The need for data analyses less focused *a priori* on the standard models of Particle Physics and Cosmology is emphasized in this discussion. An example of a new approach to both fields is provided by the pre-Big Bang pattern based on a physical vacuum made of superbradyons with the spinorial space-time (SST) geometry we introduced in 1996-97. In particular, the SST automatically generates a local privileged space direction (PSD) for each comoving observer and such a signature may have been confirmed by *Planck* data. Both superluminal preons and the existence of the PSD would have strong cosmological implications. *Planck* 2016 results will be particularly relevant as a step in the study of present open questions.

This paper is dedicated to the memory of Yoichiro Nambu

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1 Introduction

In [1, 2], we remind the theoretical controversies that had preceded the March 2014 BICEP2 announcement [3, 4] on the polarization of cosmic microwave background radiation (CMB). These open discrepancies had followed the 2013 *Planck* results [5–7]. Such a debate [8, 9] on the predictions of inflationary models [10, 11] involved precisely the possible generation of primordial gravitational waves leading to *B*-modes of the CMB, as a consequence of cosmic inflation. To date, the theoretical debate continues [12, 13] but experimental announcements have become more decoupled from theoretical controversies. The joint *Planck* – BICEP2 – Keck Array (PBKA) analysis [14, 15] found no conclusive evidence for the primordial CMB *B*-modes initially claimed.

Actually, as underlined in [16, 17] and later in [1, 2] and in two contributions to this Conference [18, 19], the theoretical and phenomenological situation remains uncertain and requires a long-term effort together with suitable experimental and observational programs. In particular, as pointed out in [19], if Quantum Chromodynamics played a crucial role in the transition from hadrons to quarks and gluons as fundamental objects in the 1970s, no equivalent theory exists at present for a possible similar transition from standard particles to preons with a preonic vacuum of which quarks, leptons, gauge bosons... would be excitations (the superbradyon hypothesis, formulated in 1995 [20, 21]). In spite of this difficulty, a detailed discussion on the possible origin of Quantum Mechanics from a superbradyonic vacuum with a spinorial space-time (SST) geometry is presented in [18].

The standard cosmological model (Big Bang + inflation + Λ CDM) remains far from being well-defined and well-established. In particular, it cannot completely account for recent cosmological observations and analyses by the Planck Collaboration [22–24]. 2015 Planck studies [25] do not contradict the observed asymmetry between the power spectra of two hemispheres defined by a preferred direction. Such a phenomenon agrees with a natural prediction [26–29] of the cosmic SST geometry [26, 30] that automatically generates a privileged space direction (PSD) for each comoving observer.

Standard cosmological patterns can also be challenged from a more fundamental point of view including the properties of vacuum, the space-time structure and the formation of the Universe [2, 17, 31]. A pre-Big Bang scenario can naturally make the Planck scale useless [27, 28].

As already stressed in [1, 2] and in previous work, alternative cosmologies [32, 33] must be seriously taken into account in the present situation. They can turn out to be more efficient to explain real data than the conventional cosmology based on the standard Big Bang model with inflation. Actually, cosmic inflation has no reason to have existed in a Universe involving a physical vacuum made of superbradyons [20, 21] where signals and correlations can propagate faster than light and free superluminal particles (not tachyons) may have dominated an early phase of the Universe [19, 21]. Similarly, the size of a SST Universe is expected to be much larger than that of the conventional one [1, 31]. Thus, a Universe with a SST geometry can naturally fake [28, 34] a flat standard Universe with an observed small curvature as seen with a conventional approach to cosmological modeling [35].

The present theoretical uncertainties, already discussed in [1, 2], clearly require not only a long-term effort in the theoretical domain, but also strong long-term experimental and observational programs. If CMB studies are a priority task, high-energy cosmic rays are also an important field including the ultra-high energy (UHE) domain where possible violations of the standard principles of Particle Physics and Cosmology can be searched for (see, for instance, [27, 36] and [37, 38]).

In the alternative cosmologies and patterns of Particle Physics considered in [27, 28] and in [1, 2, 18], the standard principles of Physics are local low-energy limits of a more fundamental dynamics for a sector of matter, as already postulated in [20, 21]) and dealt with in [39–41]. Together with the search for new particles at high-energy accelerators, the study of ultra-high energy cosmic rays (UHECR) can in particular provide signatures of new physics and new sectors of matter [28, 42].

In this brief review, we update the discussion of the experimental and observational situation presented in [1, 2, 28] and further study some aspects of the present theoretical problematics (see also [18, 19]). A section is devoted to memory of Yoichiro Nambu.

2 Yoichiro Nambu (1921-2015)

One half of the 2008 Nobel Prize was attributed to Yoichiro Nambu "*for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics*" [43]. The press release states:

As early as 1960, Yoichiro Nambu formulated his mathematical description of spontaneous broken symmetry in elementary particle physics. Spontaneous broken symmetry conceals nature's order under an apparently jumbled surface. It has proved to be extremely useful, and Nambu's theories permeate the Standard Model of elementary particle physics. The Model unifies the smallest building blocks of all matter and three of nature's four forces in one single theory.

(end of quote)

The paper by Nambu *Quasi-Particles and Gauge Invariance in the Theory of Superconductivity* [44] was received by *The Physical Review* on July 23, 1959. In the abstract, Yoichiro Nambu starts emphasizing: "*Ideas and techniques known in quantum electrodynamics have been applied to the Bardeen-Cooper-Schrieffer theory of superconductivity*".

Eight months later, as early as April 1960, submitted in turn to an international conference (Midwest Conference, Purdue, April 1-2, 1960) a contribution [45, 46] explicitly entitled *A 'Superconductor' Model of Elementary Particles and Its Consequences* (presented by Giovanni Jona-Lasinio in the absence of Nambu). Simultaneously, another paper by Yoichiro Nambu, *Axial vector current conservation in weak interactions*, appeared in *Physical Review Letters* [47]. The article by Jeffrey Goldstone *Field theories with "Superconductor" solutions* explicitly refers to Nambu's idea [48].

Just after Goldstone's preprint, the paper by Nambu and Jona-Lasinio *Dynamical Model of Elementary Particles Based on an Analogy with Superconductivity. I* was received by *The Physical Review* on October 1960 [49]. The second article, *Dynamical Model of Elementary Particles Based on an Analogy with Superconductivity. II* [50], arrived to *The Physical Review* on May 1961. After having briefly presented the basic idea in [44, 45, 47], the authors published in these two papers a more precise illustration of the spontaneous symmetry breaking pattern Nambu had suggested.

After these major contributions, Yoichiro Nambu also played an important role in the study of the quark model and later of the string model [51, 52]. Besides his early work on dual models, a particularly important contribution (1970) is the Nambu-Goto action [53, 54]. Tetsuo Goto explicitly refers to the Copenhagen lecture by Nambu. The Nambu-Goto string is nowadays considered for cosmological applications [55] and in other fields of fundamental Physics.

Further work by Yoichiro Nambu on the dual resonance model [56] has also inspired the dual superconductor models of gluon confinement [57]. More generally, the analogies with superconductivity developed by several authors for the physics of hadrons, quark and gluons are basically updated developments of the original ideas exposed in the 1959-61 papers by Nambu and Jona-Lasinio.

2.1 From Nambu's work to preon models of vacuum?

Can the preonic vacuum be a superconductor? In a superconducting superbradyonic vacuum, free superbradyons can emerge as quasiparticles. But what about the standard particles and other similar objects? Are they similar to vortices? Actually, in the last decades work in the field of condensed matter physics has focused on the existence and properties of solitons and similar objects in superconductors [58, 59]. Analogous work is also carried out for superfluid systems [60]. No obvious incompatibility seems to exist between superconductivity or superfluidity and soliton-like excitations.

It is therefore not excluded that standard particles be nontrivial excitations of a superconducting or superfluid superbradyonic vacuum, adding solitons and similar objects to the basic initial picture by Nambu and Jona-Lasinio. A crucial question would then be the possible analogy with high- T_c superconductivity [61, 62]. The role of the space-time geometry must also be taken into account: a spinorial space-time can influence the properties of the superbradyonic vacuum as a possible superconductor.

Obviously, analogies with condensed matter physics and with other domains concerning matter around us can be very useful in order to develop an active reflection on the possible properties of a preonic vacuum and the way conventional particles can emerge as vacuum excitations. Work in this direction and original ideas are certainly needed, following Nambu's example.

3 Further theoretical uncertainties

The claim supported by the initial 2014 announcement of BICEP2 results [63, 64] was the possible detection, through a B -mode polarization of the cosmic microwave background radiation, of a signature of primordial gravitational waves from cosmic inflation. However, as immediately pointed out in [16, 17], the detection of primordial CMB B -modes would not have been an evidence for cosmic inflation in cosmological scenarios other than the standard Big Bang.

Inflation is not needed in pre-Big Bang patterns and, as reminded before, the cosmic SST geometry automatically generates a privileged space direction for each comoving observer in possible agreement with Planck [22] and WMAP [65] data. In the presence of this local PSD already in the early Universe, primordial CMB B -modes would have been generated through rotations around the privileged space direction and vector products by this direction. Contrary to standard calculations and conjectures involving the usual relativistic space-time, pre-Big Bang patterns incorporating a spinorial space-time geometry can naturally generate primordial vector perturbations producing CMB B -modes.

In such a pre-Big Bang scenario, the possible generation of gravitational waves from initial vector perturbations due to the local SST anisotropy must also be considered and requires a careful study. Whatever the result, the detection of primordial CMB B -modes would be a potential direct evidence for a primordial cosmic SST geometry. The question of possible preonic waves also deserves being raised. Can gravitational waves decay into preonic waves? How large is the preon critical speed?

Other pre-Big Bang models [66, 67] also lead naturally to the direct generation of primordial gravitational waves without any need for cosmic inflation.

Gravitational waves in our Universe remain nowadays a fundamental scientific interrogation. LIGO [68] reported no positive result [69] in spite of previous rumors [70]. Gravitational waves were predicted by Henri Poincaré in 1905 [71] together with his explicit formulation of special relativity. Their detection is a crucial issue for standard Physics and Cosmology.

More generally, tests of relativity and of other fundamental principles of Physics, including energy and momentum conservation, are an important research subject [27, 28]. Possible deviations from relativity at small distance scales were already considered by Albert Einstein in 1920 [72]. Even occurring at a much lower distance scale than considered by Einstein, they can play a crucial role.

At this stage, further unconventional questions must be raised. An important one is that of vacuum homogeneity for the propagation of gravitational waves, CMB, cosmic rays... The internal structure of vacuum is not really known, but usually a global homogeneity is tacitly postulated at cosmic level except for explicit effects from standard Physics and Cosmology. However, if vacuum has an internal structure more fundamental than that predicted by conventional Quantum Field Theory, its dynamics can lead to inhomogeneities at galactic, astrophysical and cosmic levels. Such inhomogeneities can in particular generate obstacles to the propagation of gravitational waves. This is just an example of possible nonstandard phenomena ignored in a conventional approach but leading potentially to important effects. Black hole physics is also expected to be significantly modified by preonic patterns.

4 BICEP, Keck Array and related experiments

With the title *The BICEP and Keck Array CMB experiments*, the public site of BICEP and Keck Array [73] presents itself as the *Official website for results from the BICEP and Keck Array series of CMB polarization experiments*. The goal of this important experimental program installed at the South Pole is thus clearly defined. We update here the description presented in [1] where more details can be found concerning the detector design and instrumentation.

The word BICEP (Background Imaging of Cosmic Extragalactic Polarization) designs a series of cryogenic experiments with adapted bolometers and sensors, deployed to the Amundsen-Scott South Pole Station. BICEP1, also called the Robinson Gravitational Wave Background Telescope [74], was the first BICEP experiment [75]. Its results [76] yielded no possible evidence for primordial CMB B -modes. An important long-term program progressively improving detectors and technologies has followed this first attempt and continues to develop.

The BICEP2 experiment [4] was installed and operated in 2010-2012 at the South Pole Station and has been the first experiment to use the antenna-coupled transition edge sensor (TES) arrays [77–80] fabricated at the Jet Propulsion Laboratory (JPL) [81].

More recent than BICEP2 and working together with it, the Keck Array [82] uses the same technology. It was completed in 2012 [83], modified in 2013-2014 [79] and further improved in 2015 [84]. Articles with Keck Array results are [15, 85, 86].

After BICEP2, BICEP3 [87] is an improved refracting telescope designed for CMB polarimetry at 95 GHz with a better rejection of background due to galactic dust. BICEP3 is presented [88] as the *"newest member of the BICEP/Keck family of inflationary probes specifically designed to measure the polarization of the cosmic microwave background (CMB) at degree-angular scales"*. Even if the detection of primordial CMB B -modes would not provide by itself an evidence for cosmic inflation [1, 2, 16, 17], the high relevance of such a program for Cosmology is obvious.

Similarly, a new (third generation) polarization sensitive receiver, SPT-3G, has been designed [89] for the South Pole Telescope with a high signal-to-noise ratio expecting to go beyond simple statistical detection. The SPT-3G focal plane is expected to start operating in 2016 [90].

POLAR [91, 92] is a long-term project to build the most sensitive cosmic microwave background polarimeter. Polar-1 will involve about 5000 bolometric detectors at 150 GHz, and will be followed by a Polar Array containing ten such telescopes.

The polarization-sensitive receiver SPTpol [97], installed on the South Pole Telescope, has measured [98] the CMB gravitational lensing potential and performed an optimal measurement of the sub-degree B -mode polarization of the CMB [99].

In parallel, POLARBEAR [93–95], based at the ATACAMA desert, has published results [96] announcing that for the first time *"anisotropic cosmic birefringence or primordial magnetic fields have been constrained from the ground at subdegree scales"*.

The cryogenic Atacama Cosmology Telescope (ACT) [100], located at an elevation of 5190 m, is equipped with a new polarization sensitive receiver, ACTpol [101], recently optimized [102]. ACT has by now detected [103] gravitational lensing of the CMB polarization by large-scale structure, operated *"multi-wavelength detections of nine candidate gravitationally-lensed dusty star-forming galaxies (DSFGs)"* [104] and estimated the galaxy velocity dispersions and dynamical masses for 44 galaxy clusters selected via the Sunyaev-Zel'dovich effect [105].

CLASS (Cosmology Large Angular Scale Surveyor) [106–108] is also located at the Atacama Desert and will cover 70% of the sky.

SPIDER [109–112] is a balloon-borne cryogenic instrument designed to probe the possible primordial gravitational wave signal by detecting CMB B -modes at degree angular scales.

Another balloon project in this domain is PILOT (Polarized Instrument for the Long-wavelength Observations of the Tenuous ISM) [113, 114], whose goal is to characterize the polarization of the dust continuum emission in the diffuse interstellar medium. A first flight by PILOT, in September 2015, has been successful.

The above programs form a very complete and promising set to study the CMB, together with Planck and other experiments and observations.

5 The detection of cosmic neutrino background

If the cosmic microwave background radiation is given strong attention, the cosmic neutrino background (CνB) also requires careful investigation. The CMB detection projects develop technologies that will be useful in a much larger domain of Physics and Cosmology. But the cosmology and detection of the CνB deserve a detailed specific study.

The standard cosmology of the CνB has been reminded in [115] having in view the use of the Karlsruhe Tritium Neutrino (KATRIN) spectrometer [116–118] devoted to the inelastic reaction between an electron neutrino and a ${}^3\text{H}$ nucleus: $\nu + {}^3\text{H} \rightarrow {}^3\text{He} + e^-$.

Another experimental project using a tritium target is PTOLEMY (Princeton Tritium Observatory for Light, Early Universe Massive Neutrino Yield) [119, 120].

Neutrino capture on beta decaying nuclei had already been considered, for instance, in [121, 122].

On more general grounds, a complementary approach to the detection of cosmic neutrinos can be based on the inelastic reaction between a cosmic antineutrino and a stable nucleus, producing an electron and an unstable isotope of the next element in the periodic table.

This reaction will occur if the antineutrino energy is at least of a few MeV. Then, the emission of an electron or a photon will be a first detectable event. Subsequently, the unstable nucleus will decay generating a new signal. The delayed coincidence between the two events can provide a strong enough signature to reject background.

The reaction of cosmic antineutrinos with electron-capture decaying nuclei such as ${}^{163}\text{Ho}$ has also been considered for the detection of cosmic background neutrinos other than electron neutrinos [123, 124]. Obviously, much work remains to be done in this important field.

6 Recent Planck results

The *Planck* satellite was launched on May 2009 and took data until October 2013. The 2015 results are based on data from the entire *Planck* mission, including temperature and polarization.

The first cosmological results (2013) of the Planck Collaboration based on measurements of the temperature of the cosmic microwave background radiation and the power spectra of gravitational lensing potential were presented in [6, 125] (both revised in 2014). Constraints on inflation were discussed in [7], and have been examined again in 2015 [126].

Data on CMB anisotropy were further analysed by *Planck* in January 2014, confirming [22] the observation of an asymmetry in power between two cosmic hemispheres defined by a preferred direction. No correction to this paper has been introduced in 2015, even if the question has been addressed [127]. *Planck* also reports on possible signatures of parity violation (oscillations between odd and even modes) in the hemisphere where power is larger.

Such a possible evidence for a PSD observed by *Planck* fits well with the cosmic SST prediction on the PSD [1, 2, 26–30], contrary to the Planck statement "*Although these analyses represent a step forward in building an understanding of the anomalies, a satisfactory explanation based on physically motivated models is still lacking*". But what exactly means the expression "*physically motivated*"?

The question of the relevance of alternative Physics and Cosmologies must clearly be raised at this stage. In any case, further measurements and analyses are required in order to elucidate the question of the possible existence of the PSD announced by *Planck*. Actually, as already discussed in [1], the *Planck* results on the possible observation of a PSD confirm the asymmetry previously found by Eriksen et al. [128], Hansen et al. [129] and Park [130] using WMAP data. A pre-Big Bang pattern with the SST geometry would naturally produce such an effect.

In March 2014, a new version of [6] equally confirmed the observation of an "anomaly" in the multipole range $20 < \ell < 40$ as compared to standard predictions of the Λ CDM pattern (Λ = cosmological constant, CDM = cold dark matter). No correction has been introduced in 2015.

6.1 Planck 2015-2016

Between January 2015 and the first days of 2016, *Planck* has posted 41 papers to *arXiv.org*, including the joint analysis with BICEP2 and the Keck Array of the results on CMB *B*-modes [15]. 28 articles are entitled "*Planck 2015 results*" [131], often repeating the 2013 subjects.

The *Planck 2015* results [131–134] are clearly more precise than those of 2013. The consistency of 2013 data is simultaneously further discussed [135]. A final release of *Planck* results is expected for 2016 [132, 136] and will be of particular relevance.

However, it must be noticed that *Planck* analyses [137] use to take as the basic reference framework the standard Big Bang + inflation pattern, together with the conventional Λ CDM model. Alternative physical and cosmological approaches become then marginal from the beginning in the interpretation of *Planck* results. This appears to involve some contradiction with the March 2013 statement, when *Planck* made public the first version of [22] and the ESA-*Planck* News site wrote in an article for large public [138]: "... because precision of *Planck's* map is so high, it also made it possible to reveal some peculiar unexplained features that may well require new physics to be understood". The *Planck* Collaboration seemed to argue that its results systematically favor the standard cosmological pattern, except for "anomalies" potentially related to "new physics".

But if new physics can be at work, why could it not generate an alternative cosmology (f.i. involving a pre-Big Bang scenario with the superbradyonic vacuum and a cosmic SST geometry) potentially able to consistently reproduce all the *Planck* results, and more performant than the Big Bang + inflation + Λ CDM scheme? As already pointed out in [1, 2] and [27, 28], alternative cosmologies can naturally provide original solutions to important unsolved problems (see also [18, 21, 139, 140]).

In this specific case, the use of the postulates of standard Physics and standard Cosmology as the basic principles for data analysis, and simultaneously as a theory to confirm, can lead to a deformed view of the Universe, of its real content and of its history since the origin of time.

7 The Euclid and DESI projects

The Euclid project [141, 142] defines itself as "*an ESA medium class astronomy and astrophysics space mission*" devoted to the "*geometry of the dark Universe*" and aiming "*at understanding why the expansion of the Universe is accelerating and what is the nature of the source responsible for this acceleration which physicists refer to as dark energy*".

Selected by ESA in 2011, the Euclid mission is expected to be launched in 2020. Independently, the Dark Energy Spectroscopic Instrument (DESI) [143–145] is expected to operate on Earth at the Mayall 4-Meter Telescope (Kitt Peak National Observatory, Arizona) in 2018-2022. Similar to *Euclid*, DESI plans in particular to "*probe the effects of dark energy on the expansion history*".

Dark matter and possible dark energy are certainly essential items. But are they really leading the geometry and the evolution of the Universe?

Again, standard theoretical prejudices can influence data analysis and play a negative role if conventional cosmology is used as the basic theoretical framework.

In a cosmology built on a cosmic spinorial space-time, a remarkable feature immediately arises [1, 26, 28, 34]: already before introducing any standard matter, the expansion of the Universe follows automatically an intrinsic geometric law $H = t^{-1}$ where t is the cosmic time (age of the Universe) and H the well-known universal velocity/distance ratio dealt with by Knut Lundmark, Georges Lemaître and Edwin Hubble. The Lundmark - Lemaître - Hubble (LLH) law, [146–148] is thus obtained from the beginning as a direct consequence of the cosmic SST geometry without any further cosmological dynamics (no standard matter, yet) and with a value of H compatible with observations. Such a result illustrates again the potentialities of alternative cosmologies and deserves closer consideration, not only in the analysis of Planck data but also in view of the Euclid mission. It leads in particular to significant modifications of Friedmann-like equations [32–34]

Similarly, the question of the cosmological constant changes radically if a preonic vacuum is considered [1, 2, 28, 31, 139, 149, 150] where bosonic zero modes and standard quantum-field theoretical condensates (Higgs...) are actually not permanently condensed in vacuum. The cosmological constant problem can be solved in this way, leading to a further improvement of Friedmann-like equations.

8 Gaia

The Gaia mission [151–153] was launched in December 2013 and provides an all-sky survey of the Milky Way with a rapid analysis performed by the Gaia Science Alerts group [154] and making possible additional observations for supernovae, cataclysmic variables [155], tidal disruption of stars by massive black holes, microlensing...

Gaia defines itself, in particular, as follows [151]:

(...) *Gaia* provides the detailed 3D distributions and space motions of all these stars, complete to 20th magnitude. The measurement precision, reaching a few millionths of a second of arc, is unprecedented. This allows our Galaxy to be mapped, for the first time, in three dimensions. Some 10 million stars will be measured with a distance accuracy of better than 1 percent; some 100 million to better than 10 percent.

(end of quote)

The impressive set up and performances of *Gaia* will certainly lead to many results useful to several fields of space research, including Cosmology and important questions in Particle Physics.

9 Theoretical issues for Planck, Euclid and DESI

The theoretical, phenomenological, experimental and observational issues discussed in [1, 2, 18, 19] are clearly relevant for the analysis of Planck data and for the development of the Euclid mission.

Cosmological patterns usually considered as the grounds for data analysis are based on the standard space-time with four real variables and on the associated conventional relativity. The space-time felt by macroscopic "ordinary" matter and used in laboratory particle physics is extrapolated: i) to astrophysical and cosmic level, including the largest cosmological scales ; ii) to the ultimate structure of matter, assumed to be accounted for by standard quantum field theory (SQFT). Standard general relativity is also a basic ingredient providing the framework of such a cosmology. The fact that standard relativity can be just a low-energy limit for conventional particles is ignored.

Similarly, the structure of the physical vacuum is described in terms of SQFT, in spite of the fact that this description leads to the cosmological constant problem and that the usual Higgs mechanism

is nothing else than condensing "elementary" vacuum excitations inside the vacuum itself without any further description of the internal structure of vacuum and of its excitations.

However, as recognized by *Planck*, the precision reached by astrophysical and cosmological measurements may allow to distinguish between the standard cosmology and alternative approaches beyond the conventional description of vacuum, particles and space-time (the Big Bang + inflation + Λ CDM pattern). In particular, a preonic cosmology with a new space-time structure like the spinorial one can lead to a new description of the beginning of the Universe [1, 2, 27, 28, 140, 150] and to related observable effects. Furthermore, the cosmic SST naturally suggests a much larger Universe than usually considered. In this SST Universe, the vacuum structure is not necessarily the same everywhere and other kinds of particles, including preons, can be the dominant free objects in some regions (see also [18]). The cosmic space curvature of the SST Universe is then naturally expected to be much smaller than the one estimated from data analyses using the Λ CDM model [31, 32].

In a general approach to the space-time geometry, the standard Lorentz metric can be just [1, 20, 28, 39, 139, 140] the naturally stable kinematics for free particles in our Universe. The speed of light can then be [20, 39] the low-energy critical speed of a family of vacuum excitations. Other kinds of particles can exist with different (larger) critical speeds and detectable signatures at accelerators, in Astrophysics and in Cosmology. Such superluminal particles would not be tachyons, and would have positive mass and energy with a speed larger than c [20]. In a SST Universe, contrary to the usual dark energy hypothesis, the observed acceleration of the expansion of the Universe can be only a remnant reflect of a fluctuation due to the early Universe dynamics and vanishing for $t \rightarrow \infty$ when the matter density tends to zero [32, 33]. Furthermore, in spite of its intrinsic positive space curvature, the SST Universe can actually describe apparent curvatures of both signs as seen by conventional matter [32, 34]. In all cases, the geometric $H t = 1$ law remains valid in the absence of matter.

The(1931) Big Bang hypothesis [156] was based on the recently formulated Quantum Mechanics, and assumed that the energy of the Universe had been originally concentrated in an initial quantum. At this initial stage, the notions of space and time were considered as meaningless, and Lemaître wrote "*the beginning of the world happened a little before the beginning of space and time*". Lemaître's idea was then an impressive step forward. But more than eighty years later, our present knowledge of Particle Physics and Cosmology, together with the growing experimental and observational resources, allow to examine otherwise the actual theoretical uncertainties and experimental potentialities.

The possibility that Quantum Mechanics be no longer an exact law of Physics in the high-energy and low-distance domain must now be seriously considered [18, 27, 36]. Not only at the Planck scale, but even at a lower energy scale E_{trans} where standard physics may start being replaced by a new dominant dynamics [37, 39], and similarly above some distance scale larger than the Planck length [32, 38]. A pre-Big Bang scenario can then replace standard cosmology in such a way that the origin of time $t = 0$ makes sense and starts a real cosmological era.

Low-energy symmetries do not necessarily become more exact at very high energy [27, 42], and there is by now no experimental proof of the validity of Grand Unification. The grand unification epoch of Cosmology can therefore disappear in its standard form, and also the monopole problem. Roughly, the age of the Universe t can then be written as:

$$t = t_{PBB} + t_E \quad (1)$$

where t_{PBB} is the time during which the pre-Big Bang dynamics dominates in our side of the Universe, and t_E corresponds to the subsequent evolution. The time interval t_{PBB} can be much larger than the time scale associated to cosmic inflation in the conventional cosmology. After t_{PBB} , remnants of the pre-Big Bang era may have survived until the present time and be detectable or observable.

Strings have also been considered to build Pre-Big Bang scenarios [157, 158]. However, strings are known [159] to have an underlying composite structure. The use of strings to describe standard "elementary" particles amounts to an implicit preonic pattern [18, 19, 27, 36]. As a superbradyonic vacuum with a spinorial space-time can naturally lead to spinorial Regge trajectories of the particles generated as vacuum excitations [1, 18, 19] a spinorial string-like pattern can be imagined in an energy domain far enough from the scales characterizing the internal vacuum structure.

Obviously, this set of considerations suggests a real need for strong phenomenological flexibility when analysing Planck data or developing the Euclid and DESI projects.

9.1 Properties of new Friedmann-like equations

In a SST-based cosmology, new Friedmann-like equations [1, 32, 33] can automatically solve the flatness problem without introducing the standard dark energy and cosmological constant.

A possible way to obtain modified Friedmann equations [1, 32–34] is to consider the Einstein field equation [160, 161]:

$$R_{\mu\nu} - 1/2 g_{\mu\nu} R + g_{\mu\nu} \Lambda = 8\pi G c^{-4} T_{\mu\nu} \quad (2)$$

($R_{\mu\nu}$ = Ricci curvature tensor, R = scalar curvature, $g_{\mu\nu}$ = metric tensor, $T_{\mu\nu}$ = stress-energy tensor).

In order to account for the pre-existing global cosmic curvature of the SST and the fact that, contrary to General Relativity, the SST curvature does not vanish in the absence of standard matter and of a cosmological constant, the above Einstein equation can be replaced by:

$$R_{\mu\nu} - 1/2 g_{\mu\nu} R + g'_{\mu\nu} S + g_{\mu\nu} \Lambda = 8\pi G c^{-4} T_{\mu\nu} \quad (3)$$

where the term $g'_{\mu\nu} S$ accounts for the SST curvature.

In [32], the following Friedmann-like relation for the standard matter universe was considered:

$$H^2 = 8\pi G \rho/3 - k a^{-2} c^2 + \dot{t}^{-2} + K + \Lambda c^2/3 \quad (4)$$

where ρ is the energy density associated to standard matter, c the speed of light, k the usual curvature parameter and $k a^{-2} c^2$ an extra curvature term generated by the presence of matter in the Universe. Λ stands now for a possible new version of the cosmological constant, decreasing like the matter density as the Universe expands and hence free of any cosmological constant problem. The term \dot{t}^{-2} has a positive sign independent of k and dominates the large scale expansion of the Universe. K is a correction term accounting in particular for various possible effects described in [1, 32].

Similar steps allow to account for the role of the PSD, using the standard Robertson-Walker equation [162] together with (2) and (3) and modifying these equations in order to account for the local space anisotropy associated to the privileged space direction. One can then expect to suitably modify (4), basically through K and Λ even if \dot{t}^{-2} remains the dominant term. The more the Universe will be large, the more the PSD will be astrophysically stable for observation.

Equation (4) will tend asymptotically to the $H t = 1$ law for $t \rightarrow \infty$ provided the terms other than \dot{t}^{-2} vanish faster in this limit [32, 33]. We expect the matter density and all its effects in (4) to decrease like t^{-3} . This is an important difference with respect to standard cosmology, including quantum gravity, as the \dot{t}^{-2} term in (4) has a deeper origin than gravity and field theory.

In the 2015 releases, the Planck Collaboration reports [134] values of $67.8 \pm 0.9 \text{ km s}^{-1} \text{ Mpc}^{-1}$ for the LLH constant and of 13.799 ± 0.038 billion years for the age of the Universe. The product of the two values turns out to be around 0.956 up to less than 1.5%. Therefore, there is less than 6% left for the sum of the contributions to (4) other than \dot{t}^{-2} , including those associated to dark matter and dark energy. Such a result is consistent with the previous one discussed in [32].

Thus, the purely geometric prediction of cosmic SST $H t = 1$ turns out to be remarkably close to the result of observational analyses. The cosmological effects of standard matter, including dark matter and dark energy, appear as a comparatively small correction that can naturally vanish in the $t \rightarrow \infty$ limit if K and Λ vary like the matter density in an expanding Universe. Actually, standard cosmology may even look rather artificial when assuming that the physical vacuum expands carrying everywhere a permanent density of harmonic-oscillator zero modes and other condensates. The cosmological constant problem is thus generated. In a preonic picture, this phenomenon can be readily avoided [1, 2, 28, 31, 139, 149, 150] assuming that the vacuum reacts generating such condensates only in the presence of standard matter and at the relevant frequencies.

For obvious reasons, the Planck analysis and the Euclid mission should not concentrate only on the standard cosmological pattern. Furthermore, possible implications of the Gödel incompleteness theorem [163, 164] for Particle Physics and Cosmology should also be studied [18, 19, 165, 166].

10 Ultra-high energy cosmic rays

Recent results from the AUGER [167] and Telescope Array [168] collaborations can be found in [169] and [170]. It clearly emerges (see, for instance, [171, 172]) that the basic dynamical mechanism at the origin of the flux suppression of ultra-high energy cosmic rays remains to be determined. As already recognized previously [173, 174], it is not yet clear if the observed fall of the UHECR spectrum corresponds to a signature of the Greisen-Zatsepin-Kuzmin (GZK) [175, 176] cutoff or to the maximum energies available at astrophysical sources. In particular, such a limitation makes difficult to interpret data [177] on UHECR traveling on moderate extragalactic distances.

Furthermore, fundamental physics at UHE including possible effects of new physics remains poorly known [2, 37, 38]. A consequent experimental and theoretical effort in this domain is clearly required. In [39, 40] and [178–180], a possible mechanism based on Lorentz symmetry violation (LSV) with a natural absolute rest frame (the vacuum rest frame, VRF) was suggested to explain a possible absence of the GZK cutoff. The basic idea was to compensate the effect of the small energy of a CMB photon with a small modification of the kinematics of the UHE particle due to LSV. Thus, the basic GZK reaction would be forbidden by the new kinematics. In the recent years, more sophisticated scenarios involving violations of fundamental principles (relativity, quantum mechanics, energy and momentum conservation...) have been considered [27, 28, 42] to describe the observed data. In such a general framework, various scenarios are possible with or without the UHECR flux suppression.

The decay of cosmic superluminal particles (not tachyons) through the Cherenkov effect in vacuum [20] was also considered since 1996 as a possible source of UHECR [30, 41, 181]. The search for more direct superbradyon signatures in cosmic-ray experiments can also be attempted. It must take into account the possible very weak interaction rate of individual superbradyons with conventional matter, as well as the violations of standard causality in experimental signatures that may result from superluminal propagation [26]. The ratio between the superbradyon critical speed c_s and the speed of light c is a basic unknown, and can be as large as the ratio between c and the speed of sound.

The question of the validity of standard low-energy symmetries at very high energy is also crucial to understand UHECR physics [27, 37, 42]. Particle propagation in vacuum at UHE must simultaneously be given special attention, considering possible vacuum inhomogeneities and unconventional interactions of UHE particles with vacuum over large distance scales.

In this respect, some orders of magnitude must be taken into account. While a present bound on the quark radius can be $\sim 10^{-16}$ cm [182], and the electron radius appears to be smaller than $\sim 10^{-18}$ cm [183], the proton radius [184] is $\sim 10^{-13}$ cm at rest and $\sim 10^{-24}$ cm at E (energy) $\sim 10^{20}$ eV. Its wavelength at $\sim 10^{20}$ eV has a similar value. Thus, the wavelength and longitudinal size of the proton at $\sim 10^{20}$ eV can even be smaller than the sizes of quarks and electrons at rest.

What can then be the interaction between the UHE proton and the internal structure of the physical vacuum including its excitations? In the case of a superbradyonic vacuum, standard relativity will not be an exact symmetry and LSV can play an important role for UHE particles. In view of the strength of standard Lorentz contraction, the shape itself of a $\sim 10^{20}$ eV proton can change tending to adapt itself to the transverse volume. The Lorentz contraction law can also change and no longer follow the relativistic formula. The proton size and structure can in any case be sensitive to the internal structure of vacuum and of its excitations. One can then imagine various unconventional effects, such as:

- An exchange of energy and momentum between the UHE proton and the vacuum internal structure. In particular, the vacuum can release a small amount of energy, allowing the proton to decay. Or conversely, take some energy and momentum from the proton and transfer them to preonic waves.

- UHECR can also be trapped in vacuum inhomogeneities at astrophysical level. For instance, if a UHE proton enters a vacuum region where the ground state energy is lower, its effective energy will be larger and a decay can occur. Subsequently, the UHE particle may not be allowed to automatically quit this vacuum region except possibly if a new interaction happens.

These are just two examples of cosmological and astrophysical unconventional mechanisms that can act on the UHECR flux in the presence of a nonstandard vacuum. Deformed quantum mechanics can produce small energy and momentum uncertainties equally leading to a UHECR flux suppression. A similar role can be played by small violations of energy and momentum conservation.

As a consequence of this kind of uncertainties, there is no real proof of the validity of models and algorithms for particle interactions at the highest energies used to analyse UHE data and study UHECR properties, even if interesting work is carried on [185]. Another open question is whether cosmic rays can be sensitive to the privileged space direction generated by the SST as it can well be the case for the CMB. Exploring possible correlations between high-energy cosmic rays data and the recent Planck observation of CMB anisotropies deserves a long-term systematic effort.

10.1 JEM-EUSO

Satellite detection of UHECR will also be an important new form of observation. The Extreme Universe Space Observatory (now JEM-EUSO [186–188]), to be hosted by the JEM module of the Japanese KIBO facility of the International Space Station (ISS) at an altitude of about 400 Km, will be the first space mission devoted to UHECR and UHE cosmic neutrinos. JEM-EUSO is planned to be launched in 2017. Using the Earth atmosphere as the target, JEM-EUSO is expected to reach unprecedented accuracy concerning the UHECR energy and direction, as well as spectrum composition.

11 On the status and potentialities of physics at accelerators

While no evidence for supersymmetry has yet been found [189], ATLAS and CMS have reported on other possible signatures of new physics. An example is provided by the (yet preliminary) diphoton signals [190–192]. Potential diboson signatures [193] also deserve close attention.

There have been a number of attempts to interpret recent LHC data using various patterns beyond the standard model. Precisely, new families of particles generated through excitations of the superbradyonic vacuum [1, 2, 18, 19, 28] appear as natural candidates for new physics at LHC. Not only with a critical speed equal to c , but also with a larger critical speed.

Possible effects of such a new fundamental dynamics on the quark-gluon plasma [194, 195], including unconventional interactions between the produced plasma and the preonic vacuum structure, must also be seriously considered. Superluminal particle production may occur in this context.

More generally, superluminal particles may be produced in LHC experiments through events usually considered as missing energy or background. The lifetime of a superluminal object initially

produced with a speed larger than c is then a crucial, unknown parameter, and similarly for the interaction of the superluminal particle with the detector and its surrounding. In any case, and besides possible appropriate changes in the experimental design, new specific algorithms are required for data analysis. The direct observation and identification of a "Cherenkov" decay in vacuum [20] would be an exciting possibility, although most likely difficult in practice [196].

12 Conclusion and comments

Understanding the mathematical structure of space-time and the actual content of the physical vacuum must be a primordial goal for current and future Cosmology and Particle Physics.

As already stressed in [1], the possible existence of primordial CMB B-modes of primordial origin, would in any case not be by itself an evidence cosmic inflation. Pre-Big Bang patterns would be able to provide alternative explanations of such a signature.

Alternative particle physics and cosmologies should not be considered as marginal in data analysis. The design and realization of future experimental and observational projects should not ignore them.

The 2016 *Planck* results will obviously be very important. But a new satellite mission devoted to the CMB, with new technology allowing by further data analyses, is in any case necessary. In particular, the question of the possible existence of a privileged space direction must be clearly elucidated.

Similarly, the South Pole and Atacama programs, as well as AUGER and the Telescope Array, are crucial and must remain operating long-term projects with permanent upgrading. JEM-EUSO will complete the UHECR programs. The detection of cosmic neutrinos also requires attention.

As just discussed, CERN experiments and other high-energy programs can also play an important role in the search for new physics and the identification of basic cosmological ingredients. Possible excitations of a preonic (superbradyonic) vacuum and even free preons (superbradyons) may be produced in particle collisions or released by the physical vacuum interacting with high-energy particles.

Theory and phenomenology need in turn a profound step forward. Just as Yoichiro Nambu brought new ideas and basic techniques into superconductivity and Particle Physics, current patterns and ideas beyond standard particle physics need a more precise realization with original unconventional contributions and performing technical approaches. A reflection involving the different existing forms of matter can help to formulate a suitable theory of the physical vacuum and of its excitations.

Prospects of new physics and alternative cosmologies are also discussed in [18, 19].

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