Can matter accelerate the expansion of the Universe? (I)

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To the present uncertainties of cosmological measurements, theoretical uncertainties should be added and their potential implications carefully explored. A significant example is provided by 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. In this case, if the matter energy density decreases more slowly than in standard cosmological patterns, it can naturally be at the origin of the observed acceleration of the expansion of the Universe without any need for dark energy and a cosmological constant. We illustrate this possible situation using the cosmology based on the spinorial space-time (SST) we introduced in 1996-97. Other scenarios leading to the same effect at the cosmic level are also briefly discussed. (Part I of a contribution to the ICNFP 2016 Conference, July 2016)

1. Introduction

Nature News wrote recently [1] "*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*" [2].

Using the Wide Field Camera 3 (WFC3) on the Hubble Space Telescope (HST), Riess et al. announce a best estimate of 73.03+/-1.79 km/sec/Mpc for the present value 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 contrasts with previous estimates from other experiments, including Planck.

Riess et al. compare the new obtained value of H with "*the prediction of 69.3+/-0.7 km/sec/Mpc with the combination of WMAP + ACT + SPT + BAO*" [3, 4] and with the value of 67.3+/-0.7 km/sec/Mpc from ΛCDM and 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, to the present experimental uncertainties theoretical uncertainties should be 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...

1.1. 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?

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

Attempts to describe the cosmological role of vacuum using standard quantum field theory (QFT) have led to the cosmological constant problem [5, 6]. But as pointed out in previous papers [7, 8], the situation can be radically different with a preonic vacuum structure naturally avoiding a permanent static presence of the

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QFT standard condensates [9]. If the standard particles are excitations of the physical vacuum, vacuum dynamics can produce them in specific situations and in a way compatible with the successful experimental tests of QFT.

In a preonic vacuum, the Higgs boson and the zero modes of bosonic harmonic oscillators do not need to be permanently materialized, as the vacuum dynamics can generate them when required by the presence of surrounding matter and thus make possible the standard 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.

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 remains unknown and can play a crucial role in the present dynamics of our Universe.

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

Then, matter can be at the origin of the observed acceleration of the expansion of the Universe and no 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 we introduced in [10, 11]. We also briefly consider other cosmological scenarios leading to the same phenomenon.

2. The spinorial space-time (SST): a brief reminder

The spinorial space-time leads to the $H\ t = 1$ relation in a purely geometric way, already before introducing conventional matter and the associated forces. We basically follow here the equivalent Section of reference [12].

The SST can possibly be the natural frame to describe a world where fermions exist with spinorial wave functions defined in a suitable space. Its implications turn out to be highly nontrivial for Particle Physics and Cosmology.

The spinorial space-time of [10, 11] is a simple SU(2) representation with two complex coordinates replacing the four real ones of the conventional space-time. Its properties, with possible cosmological implications coming directly from its mathematical structure, have been dealt with in several subsequent papers including [7, 8], [13, 14] and [15, 16].

2.1. SST and cosmic time

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

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

2.2. SST, cosmic coordinates and the expansion of the Universe

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

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

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

With these definitions, the origin of cosmic time naturally associated to the beginning of the Universe is given by the point $\xi = 0$ with the initial space contracted to a single point. One then gets an expanding universe where cosmological comoving frames are described by straight lines starting from the time origin $\xi = 0$ and are transformed into eachother by the cosmic SU(2). Thus, the SST geometry provides in a natural way a local privileged rest frame for each comoving observer, compatible with existing cosmological observations.

As already shown in [10, 11], an attempt to associate to the cosmic spinor ξ a space-like position vector with real cosmic space coordinates defined by $\vec{\mathbf{x}_c} = \xi^\dagger \vec{\sigma} \xi$ does not actually generate such spatial coordinates. One gets instead $\mid \xi \mid^2$ times a unit vector defining a local privileged space direction (PSD) "parallel" (in the SST) to the cosmic spinor ξ. In other words, the direction of $\xi^\dagger \vec{\sigma} \xi$ corresponds to the set of points whose SST space-time position is equal to ξ times a complex phase.

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

The new geometry clearly suggests potential limitations of general relativity and standard cosmology. Rather than an intrinsic fundamental property of space and time, conventional relativity can be dealt with as a low-energy symmetry of standard matter similar to the effective Lorentz-like symmetry of the kinematics of low-momentum phonons or solitons in a condensed medium [17, 18] where the speed of sound or the maximum speed of solitons plays the role of the critical speed. The speed of light c would then be the critical speed of a family of vacuum excitations (the standard particles) not directly related to an intrinsic space-time geometry.

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

2.3. Some properties of a SST Universe

Three basic cosmological phenomena are automatically generated by the SST in a purely geometric way [7, 8] and without any explicit presence of matter and energy:

i) The standard Lundmark-Lemaître-Hubble relation between relative velocities and distances at cosmic scale, with a ratio H (velocity/distance) equal to the inverse of the age of the Universe ($H = t^{-1}$). As t is the radius of the spatial hypersphere, and comoving frames correspond to straight lines starting from the time origin, distances between comoving objects will be proportional to t and the (constant) associated speeds will be given by the distances divided by t. t^{-1} is then the automatic geometric value of the LLH constant H.

ii) The existence of a privileged space direction (PSD) for each comoving observer, as already obtained in [10, 11] and further developed in [7, 8] and in subsequent papers.

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

More details, including a study of the cosmological implications of these unconventional properties of the cosmic SST, are given in [7, 8], [13, 14], [15, 16] and in related papers.

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

The possible connection between the cosmic spinorial space-time structure and the ultimate dynamics of matter and vacuum remains an open question requiring further fundamental research. Preonic and and pre-Big Bang scenarios should be considered in this respect [16, 19].

3. SST, matter and the acceleration of the expansion of the Universe

In [21] and other papers, we considered the following Friedmann-like relation for the standard matter universe within the cosmic SST geometry:

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

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

Λ 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 and has a positive sign independent of k. It in principle dominates the large scale expansion of the Universe at large values of t.

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

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

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

- a reaction of the nucleated standard matter to the pre-existing expansion of the Universe led by the SST geometry and the pre-Big Bang vacuum [8, 22];

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

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

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

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

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

In what follows, we consider the 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.

4. An unconventional way to accelerate the expansion of the Universe

A basic question is: how do matter and the vacuum interact with the SST cosmic geometry?

In previous papers, we considered a scenario where in the early Universe the standard matter just generated reacts gravitationally to the pre-existing expansion of space generated by the cosmic SST geometry. This may have slowed the expansion of the Universe. As the matter density becomes smaller and the gravitational force decreases, the effect becomes weaker and the expansion of the Universe accelerates to reach an asymptotic regime with the limit $H \ t = 1$ at large t. [21, 22].

In what follows, we consider an alternative, or complementary, cosmic mechanism involving the dynamics of the physical vacuum.

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

- The physical vacuum releases a positive amount of energy as it expands with the present Universe evolution.
- This energy is converted into matter (standard and dark).
- 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 unnecessary the usual role of dark energy and the cosmological constant. A simple way to illustrate the basic mechanism can be to write for equation (3):

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

where γ is a constant, and

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

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

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

leading to:

$$a \ = f \ t^{\lambda} \qquad (7)$$

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

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

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

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

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

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

4.1. Other scenarios involving the SST

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

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

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

$$\Gamma \ = \ \gamma' \ t^{-\alpha} \qquad (10)$$

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

$$H^2 \ = \ t^{-2} \ + \ \gamma' \ t^{-3} \qquad (11)$$

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

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

A more precise observational knowledge of the matter energy density in the Universe (including dark matter) would allow to further constrain the parameters α and γ'.

4.2. Possible scenarios in other space-time geometries

The SST t^{-2} term can be removed from the formulae leading to (5) without altering the cosmological prediction if (4) is replaced by $\Gamma \ = \ (1 \ + \ \gamma) \ t^{-2}$.

Similarly, (11) can be preserved without using the t^{-2} term from SST if (10) is replaced by $\Gamma \ = \ t^{-2} \ + \ \gamma' \ t^{-\alpha}$.

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 replacing the contribution from the SST geometry.

A possible attempt without the SST term writing instead of (11) (σ is a constant):

$$H^2 \;=\; \sigma\, t^{-\alpha} \tag{12}$$

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

Thus, the presence in equations like (11) 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 data. Values of α' smaller than 2 can be considered, but they lead to an exponential expansion of the Universe at large t.

5. Conclusion and comments

As discussed in previous papers, the observed acceleration of the expansion of the Universe is not necessarily a permanent 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 .

If the cosmic physical vacuum emits matter and 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 unveiling the ultimate structure of vacuum and matter [17, 18].

Then, 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 [21] and in subsequent work. Actually, if the acceleration of the expansion of the Universe can be generated by matter, 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 generates the observed acceleration of the expansion of the Universe. The t^{-2} term from the SST geometry in (2) and (3) directly contributes to this effect. Simultaneously, a potential evidence for the SST exists: the PSD (privileged space direction) may have been observed by Planck [20] 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 of the SST Universe in space units. As discussed in previous papers [15, 16], 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 Universe may exist with different properties.

More generally, the role of space-time structure in Particle Physics and Cosmology remains a crucial issue, including possible superluminal constituents of the physical vacuum [17, 18] and associated pre-Big Bang scenarios [15, 16].

Further work is required, including measurements with higher precision and detailed data analyses as well as relevant theoretical developments beyond standard patterns.

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