Planck data, spinorial space-time and asymptotic Universe

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The Planck collaboration reports an age of the Universe t close to 13.82 Gyr and a present ratio H between relative speeds and distances at cosmic scale around 67.8 km/s/Mpc. The product of these two measured quantities is then slightly below 1 (about 0.96), while it can be exactly 1 in the absence of matter and cosmological constant in suitable patterns. An example is the cosmology based on a spinorial space-time we have considered in previous papers, where such an expansion law is of purely geometric origin and can reflect an equilibrium between the dynamics of the ultimate constituents of matter and the geometry of space and time. Taking also into account the observed cosmic acceleration, the present situation suggests that the value of 1 can be a natural asymptotic limit for the product $H\,t$ in the long-term evolution of our Universe up to possible small corrections. No *ad hoc* combination of dark matter and dark energy would then be needed to get an acceptable value of the cosmic speed/distance ratio H. We briefly comment on possible realistic versions of cosmologies exhibiting this property.

1. Introduction

Obviously, WMAP [1] and Planck [2] data require a new close study after the 2013 Planck results have been made available (see [3,4] and other recent papers by the Planck Collaboration). In particular, even if WMAP and Planck have systematically used the ΛCDM model as the basic tool for data analysis, nothing prevents from exploring other possible cosmologies [5] potentially related to new physics at ultra-high energy [6] and beyond Planck scale.

The question of the space curvature is a major one, but measuring it at large cosmological scales may be extremely difficult if the actual Universe is much larger than the observable one. If the effective global curvature is very small for this reason, it can even be masked by other (more local) phenomena. But it may also happen that such a small space curvature generates the leading contribution to the expansion of the Universe [5].

And do we really understand the meaning of concepts such as dark matter and dark energy that, according to Planck analysis, would account for 95% of the energy in our Universe? The

recent AMS results [7,8] are not yet conclusive and, even assuming that a dark matter signature would have been detected, alternatives to fashionable theories already exist [9].

The situation seems even more unclear concerning what is usually called inflation, in spite of the remarkable effort in model building for more than thirty years. Suitable alternatives to inflation can naturally be provided by pre-Big Bang cosmologies [5,10].

Similarly, in the standard ΛCDM cosmology, the ratio between relative velocities and distances at cosmic scales given by the LundmarkLemaître-Hubble (LLH) constant (see [5,11] and references [12] to [16]) depends crucially on a set of poorly identified phenomenological parameters. However, if H is the LLH constant and t the age of the Universe, the product $H\,t$ is identically equal to 1 in some specific cosmological geometries before introducing matter, energy and gravitation.

An potential example can be built using the well-known Friedmann equations [17,18] as a guide. We start considering the Friedmann-like relation :

$$H^2 \;=\; 8\pi G\rho/3 \;-\; kR^{-2}\,c^2 \;+\; \Lambda\,c^2/3 \quad (1)$$

where $H \;=\; a_s^{-1}\,da_s/dt$ is the LLH constant, a_s the scale factor, G the gravitational constant, ρ the energy density, c the speed of light, $k\,R^{-2}$

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the 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 the cosmological constant. Taking $\rho = 0$, $\Lambda = 0$ and $a_s^{-1} \, da_s/dt = R-1 \, dR/dt$, one would get for $k = $ -1 (negative curvature, hyperbolic space) the simple relation $dR/dt = c$. But such a relation does not appear to be compatible with cosmological data, as $c \, t \, R^{-1}$ would be too small for a realistic fit. A possible modification of equation (1) will be discussed below.

A more clear situation concerning the geometric origin of the relation $H = t^{-1}$ is obtained with the spinorial space-time we introduced in 1996 [5,19], where the cosmic time t is given by the modulus of a cosmic spinor and the cosmic space at time t is described the associated hypersphere. In this case, the natural space curvature is positive and no critical speed is introduced, but the law $H = t^{-1}$ holds automatically in the absence of matter and cosmological constant.

In the spinorial space-time under consideration, the inverse square of the age of the Universe plays the role of the curvature term replacing the term $- \, kR^{-2} \, c^2$ in the equation equivalent to (1). The expression $c \, R^{-1}$ is directly replaced by an inverse time scale, and there is no $-$ sign associated to the space curvature. At this stage, no space units or critical speed(s) have been introduced. Similarly, matter and cosmological constant are not required to get a sensible value of H.

Even assuming the existence of a realistic concept similar to the cosmological constant, in alternative approaches to quantum field theory [5] one can expect it to be generated only in the presence of standard matter. In this case, its contribution to equations like (1) decreases like the matter density as the Universe expands and the relation $H = t^{-1}$ will be preserved as a limit at large t except if new (small) corrections to the effective geometry must be taken into account.

In the present note, we discuss the possibility that the geometric relation $H = t^{-1}$ remains, up to small extra terms, an asymptotic limit of cosmic evolution at large t in suitable cosmologies. We defer to later work a more precise insertion of general relativity within the spinorial space-time framework we have suggested.

2. The spinorial space-time

As explained in [5,19], for a SU(2) spinor ξ describing space-time coordinates, and taking the positive SU(2) scalar $\mid \xi \mid^2 = \xi^\dagger \xi$ where the dagger stands for hermitic conjugate, a definition of the cosmic time can be $t = \mid \xi \mid$ with an associated space given by the S^3 hypersphere $\mid \xi \mid = t$. Other definitions of t in terms of $\mid \xi \mid$ (f.i. $t = \mid \xi \mid^2$) lead to similar cosmological results as long as a single-valued function is used.

Then, using the definition $t = \mid \xi \mid$, if ξ_0 is the observer position on the $\mid \xi \mid = t_0$ hypersphere, space translations inside this hypersphere correspond to SU(2) transformations acting on the spinor space, i.e. $\xi = U \, \xi_0$ where:

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

$\vec{\sigma}$ being the vector formed by the usual Pauli matrices. The vector $\vec{\mathbf{x}}$ is the spatial position of ξ with respect to ξ_0 at constant time t_0. The antipodal point $- \, \xi_0$ corresponds to $U \, (2 \, \pi) = - \, 1$. The spinorial position $\xi - \xi_0$ violates causality but can be relevant at very small scales [5,21].

Space rotations with respect to a fixed point ξ_0 are SU(2) transformations of the spatial position vector $\vec{\mathbf{x}}$. A standard spatial rotation around ξ_0 corresponds now to $U(\vec{\mathbf{y}})$ turning any $U(\vec{\mathbf{x}})$ into $U(\vec{\mathbf{y}}) \; U(\vec{\mathbf{x}}) \; U(\vec{\mathbf{y}})^\dagger$, where the vector $\vec{\mathbf{y}}$ provides the rotation axis and angle.

The origin of our time can then be associated to the point $\xi = 0$. One thus gets a naturally expanding Universe where cosmological comoving frames would correspond to straight lines crossing the origin $\xi = 0$. In the absence of matter and of a cosmological constant, such a geometry can be applied to relative velocities and distances at cosmic scale for comoving frames and automatically yields the LLH law $H = t^{-1}$.

More precisely, for two cosmological comoving frames separated by a constant angular distance θ, the spatial distance D between the two corresponding points on the $\mid \xi \mid = t$ hypersphere will be $D = \theta \, t$, with a relative velocity $v = \theta$. The ratio between relative velocities and distances is therefore given by t^{-1} [5,21]. t is actually the only physical scale available, and no critical speed has been introduced at this stage.

The situation does not basically change if the distance on the S^3 hypersphere is taken to be equal to t times an arbitrary function of the angle θ. It is even possible, for each observer at a given ξ_0, to send to infinity the antipodal point $\theta = 2\pi$ turning the hypersphere into a hyperboloid. Contrary to standard cosmology, such a transformation would not change the sign of the spinorial curvature term t^{-2} [5] in the equation describing the Universe expansion through H^2.

Together with conventional matter, standard relativity can be introduced as a local low-energy limit of space-time as seen by such matter [5,6], just as low-momentum phonons in a solid can exhibit a Lorentz-like symmetry [20]. Friedmann-like equations emerging at this stage must take into account the pre-existing global spinorial space-time on which matter has been generated and the LLH law inherent to this space-time.

3. Geometry in our Universe

The ΛCDM-based data analyses presented by Planck and WMAP do not report any significant space curvature. But this is not a surprise if the actual Universe is much larger than the observed one, in which case the effective curvature can be very small even if the space geometry is spherical or hyperbolic. Furthermore, as just explained, it may turn out that the standard Friedmann equations ignore fundamental pre-matter information and fail for this reason to correctly describe the cosmological role of space curvature.

3.1. A modified Friedmann equation

Even within the ΛCDM model framework, if the radius of the actual Universe is more than $\sim$ 100 times larger than that of the observable one, a curved space does not appear to be excluded by the bounds Planck has recently presented. If most of this space is empty, and in the absence of dark matter and dark energy, a hyperbolic curvature term can become the dominant contribution to H in a Friedmann-like equation of the type (1) describing this global Universe.

Furthermore, as the matter density is expected to decrease with the Universe expansion faster than the curvature term, the relation $H = t^{-1}$

clearly appears as the natural asymptotic limit at large t in the absence of a cosmological constant.

It remains to fit the measured value of H without using dark matter and dark energy. A possibility would be to modify the value of the constant c^2 multiplying the term $-k\,R^{-2}$ in (1). Instead of the square of the speed of light, a larger effective constant c^2 allowing to account for superluminal relative speeds in the global Universe can in principle compensate the smallness of the curvature parameter itself. More precisely, the ratio $c\,R^{-1}$ should have a value close to the observed value of H (and therefore, to that of t^{-1}).

The possible physical and cosmological meaning of this modification of the Friedmann equations will be further discussed in a forthcoming paper. But the basic idea is to give the global cosmic curvature a weight accounting for its role at cosmic scale, including reminiscent effects from an inflationary or pre-Big Bang era. The spinorial space-time provides an illustration of such a new approach to space curvature in cosmology. In this case, the sign of the leading cosmic curvature term does not depend on that of the standard curvature parameter in equations like (1).

3.2. Cosmology and spinorial space-time

As explained in Section 2, the spinorial space-time considered in [5,19] and in [21,22] (see also [23,24]) presents a direct geometric description relating the expansion rate of the Universe to its age, and automatically reproducing the relation $H = t^{-1}$ in the absence of matter and of a conventional cosmological constant.

As no critical speed or space units have been introduced to obtain the $H = t^{-1}$ law, the spinorial space-time can naturally be much larger than our observable Universe and allow for critical speeds much larger than that of light. The speed of light would be just the critical speed of standard matter. Pre-Big Bang scenarios allowing for superluminal motion would thus provide a natural alternative to inflation [5,10].

Then, it seems normal to assume that our standard matter universe nucleated at a very early stage of the evolution described by the spinorial space-time geometry, so that its age does not differ from the cosmic time thus defined. But this

conventional universe does not necessarily fill the whole available space and other kinds of matter or pre-matter reminiscent from the pre-Big Bang era can exist elsewhere obeying different physical laws. In all cases, new forms of matter and pre-matter can exist everywhere, so that the stable structure of the physical vacuum is not necessarily made of the standard scalar fields and zero modes from quantum field theory [23,24].

As our standard matter universe is facing an expansion of the global Universe generated by the original spinorial space-time, fluctuations in its observable expansion rate may occur due to the interaction between conventional matter and the global space-time structure. The apparent cosmic acceleration [25] can thus actually be the expression of a temporary fluctuation without real influence on the long-term evolution of our conventional universe [23,24]. In this case, dark energy is not required to explain the present acceleration and the relation $H = t^{-1}$ will remain asymptotically valid inside our Universe. Small corrections to the relation $H = t^{-1}$ can be generated by the standard Friedmann-like curvature terms after the nucleation of conventional matter.

3.3. On cosmic acceleration

In the ΛCDM model, cosmic acceleration is linked to the second Friedmann equation:

$$A = -4/3\ \pi G\ (\rho + 3p_U c^{-2}) + \Lambda\ c^2/3 \quad (3)$$

where $A = dH/dt + H^2 = a_s^{-1}\ d^2a_s/dt^2$ and p_U is the pressure parameter. However, this equation may require a substantial modification following that of (1). Then, without using dark energy, new mechanisms can be imagined to explain the observed cosmic acceleration in our region of the Universe. In particular, a new term describing the reaction of standard matter to the geometric expansion of the Universe can provide a natural way out, together with a term describing the counter-reaction of the geometry itself.

A difference in density between this part of the Universe and the Universe as a whole may have already produced a local gravitational reaction of matter opposing the geometric expansion and making it locally slower. Later in such a scenario, as the matter density has become smaller,

the local expansion would have started to accelerate getting closer to the geometric value of H. Even without such a difference in density, the same kind of gravitational reaction can occur if the expansion of the Universe is led by other phenomena than those considered in the standard Friedmann equations. In particular, if the role of space curvature is stronger than predicted by (1) and obeys to a different geometric origin.

A similar mechanism would be expected for the spinorial space-time just discussed. In this case, when standard matter is introduced, new terms accounting for the gravitational reaction to the already existing geometric expansion of space and for the geometric counter-reaction should be added to the Friedmann-like equations. Dark energy is not required to generate such a process.

In both cases, and most likely also in other scenarios, the present cosmic acceleration would correspond to the evolution of our Universe towards the asymptotic relation $H t = 1$ (up to possible small corrections) in the large t limit.

A small correction to the asymptotic expansion law $H t = 1$ can be of the form:

$$H = D^{-1}\ dD/dt = t^{-1}\ (1 + \alpha) \quad (4)$$

where D is the distance at time t between two commoving frames. The (positive or negative) constant α can be the expression of an additional (small) space curvature term possibly related to the presence of conventional matter and reminiscent from the standard Friedmann approach as given in equation (1). One then readily gets the relation $D/D_0 = (t/t_0)^{1+\alpha}$ where D_0 is the value of the cosmic distance D at cosmic time t_0.

3.4. The arrow of time

In the spinorial description of space-time considered here, the arrow of time is of purely geometric origin, and directly related to the deepest geometric space-time structure.

If the cosmic time t is not a single-valued function of $|\xi|$ and the arrow of time is to be preserved, the picture will require some modifications such as replacing t by a function of $|\xi|$ in the definition of the space coordinates. Although this is not the scenario considered here, further work on this question is required.

Recent work on the arrow of time following different approaches can be found, for instance, in references [26,27] and in [28,29].

4. Conclusion and comments

Instead of trying to build *ad hoc* the observed value of the LLH constant using large amounts of dark matter and dark energy, we present here a natural geometric approach based on what can be the ultimate space-time structure (as seen by spin-1/2 particles) and automatically leading to the relation $H = t^{-1}$ in the absence of standard matter and of a cosmological constant. The definition of the age of the Universe t is directly linked to the geometric size of the cosmic space.

No dark energy is required, and no conventional cosmological constant is introduced, in this new cosmology where the $H = t^{-1}$ law can result from an equilibrium between geometry and the most fundamental form of matter or pre-matter.

A really new approach to the role of space curvature in cosmology is thus at the origin of a new structure of Friedmann-like equations. In particular, the leading contribution to the square of the LLH constant comes from a curvature term equal to t^{-2} whose sign does not depend on the space curvature felt by standard matter.

As the leading contribution to the Universe expansion comes from this (S^3) curvature term generated in the spinorial space-time previous to the introduction of standard matter and outside the standard general-relativistic framework, standard matter can react to this geometric constraint. Such an interaction between matter and geometry would lead to a new terms in the modified Friedmann-like equations. If the reaction of standard matter has initially slowered the Universe expansion when the matter density was much larger, the apparent cosmic acceleration can be just an evolution associated to the weakening of matter density and restoring asymptotically the expansion rate from fundamental geometry.

Thus, it is tempting to conjecture that, contrary to many claims, the observed acceleration of the expansion of the Universe is just the reflect of a fluctuation due to gravitation, and perhaps to other standard interactions, in the presence of the pre-existing spinorial space-time geometry. As the Universe expands, the product $H\,t$ tends to 1 (except possibly for a small correction to this value) as the natural asymptotic limit at $t \to \infty$. Data from Planck and other experiments appear compatible with such a hypothesis that does not appear naturally in the ΛCDM model.

Similarly, as the spinorial space-time has been previous to the formation of conventional matter, it seems reasonable to assume that its expansion is in equilibrium with a primordial vacuum possibly formed during a short pre-Big Bang era.

Then, the condensates and zero modes usually introduced in standard quantum field theory can be just a simplified way to describe the interaction between conventional particles and the physical vacuum. In such a situation, there is no compelling reason to consider an item like the standard cosmological constant, even if a related phenomenon can occur in the presence of conventional matter [5,23]. In this last case, the cosmological weight of such an effect is expected to decrease like the matter density, contrary to the standard cosmological constant.

Cosmologies naturally leading to an asymptotic value of $H\,t$ equal or close to 1 deserve particular attention. As they have not been really explored, further work in this direction is clearly necessary.

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