Dark energy without dark energy

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It is proposed that the current acceleration of the universe is not originated by the existence of a mysterious dark energy fluid nor by the action of extra terms in the gravity Lagrangian, but just from the sub-quantum potential associated with the CMB particles. The resulting cosmic scenario corresponds to a benigner phantom model which is free from the main problems of the current phantom approaches.

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I. INTRODUCTION

Besides some failed attempts to justify current acceleration of the universe by considering dimming mechanisms in the neighbourhood of distant supernovas (see e.g. [1]), essentially there are three main paradigms that have been invoked to lend physical support to the observed speeding-up of the universe: the cosmological constant [2], dark energy [3] and modified gravity [4]. It is well-known however that the existence of a cosmological term poses a fundamental problem with quantum field theory whose solution has been unsuccessfully looked for during the last quarter of century or so [5]. Then, whereas dark energy is usually implemented by introducing a scalar field that corresponds to a fluid with negative pressure [6], the idea of modifying gravity amounts to adding some extra terms to the Hilbert-Einstein Lagrangian [7] for general relativity, in both cases making recourse to older procedures already used in inflationary scenarios or quantum gravity. Nevertheless, all of these paradigms are not free from remarkable shortcomings and, of course, look quite alien to the so-called Occam Razor guiding principle; that is, no consistent new idea based just on Einstein general relativity and the checked contents of the universe has so far been advanced to justify universal acceleration.

I will consider here a cosmic model where we introduce what might be the germ of one of such ideas. In order to see how that model works, one could however make still use of a scalar field whose introduction would be motivated by up-grading-to field [8] a background set of relativistic particles, showing then that the up-grading method becomes superfluous, so that the actual physical ingredients of the resulting cosmic model are just the sub-quantum characteristics that can be associated with the original radiation particles. Our idea consists in identifying such radiation particles with the cosmic microwave background and what we currently call dark energy with the radiation sub-quantum potential energy. It will be finally shown that the resulting cosmic accelerating model describes a benigner phantom-like cosmology which is free from the main difficulties showed by that kind of cosmic models.

II. THE MODEL

Our most economical description starts with the quasi-classical wave function for the considered particles

$$\Psi = R(r, t)e^{iS(r, t)/\hbar}, \quad (2.1)$$

in which $R(r, t)$ is the probability amplitude to find the particle at position $r$ at time $t$, and $S(r, t)$ is the corresponding classical action. Now, from the real part of the expression resulting when applying the Klein-Gordon equation without any potential energy term to the above wave function we can derive the modified Hamilton-Jacobi equation

$$E^2 - p(v)^2 + \tilde{V}_{SQ}^2 = m_0^2, \quad (2.2)$$

where $E$ and $p$ are the classical energy and momentum, $m_0$ is the rest mass, and

$$\tilde{V}_{SQ} = \hbar \sqrt{\nabla^2 R - R/R} \quad (2.3)$$

is the sub-quantum potential that distinguishes the classical from the quantum particle dynamics [9]. Note that in the classical limit $\hbar \to 0$ Eq. (2) becomes the classical Hamilton-Jacobi equation. Now, a cosmic field theory could be obtained by using the motivating up-grading method according to which $v^2 = \dot{q}^2$ and $m_0$ are respectively promoted...
to the scalar field quantities \( \dot{\phi}^2 \) and \( \bar{V}(\phi) \). However, it will be shown later on that in the cosmological model we are going to build up we necessarily have \( \dot{\phi}^2 = 1 \) and \( \bar{V}(\phi) = 0 \) which are conditions that amount to convert the up-grading-to-field method into an identity operation and the original particles into radiation particles which thus becomes the sole physical entities, other than a cosmological constant, entering the model.

This result can be implemented by using the following Lagrangian density

\[
L = -m_0 \left( E(x, k) - \sqrt{1 - v^2} \right),
\]

where \( E(x, k) \) is the elliptic integral of the second kind resulting from integrating the expression for the momentum derived from Eq. (2) over the particle velocity \([10]\), with \( x = \arcsin \sqrt{1 - v^2} \) and \( k = \sqrt{1 - V^2_{SQ}/m_0^2} \), and \( V_{SQ} \) is the sub-quantum potential energy density. Deriving the subsequent expressions for the energy density, \( \rho \), and pressure, \( p \), in a flat Friedmann-Robertson-Walker scenario and assuming an equation of state \( p = w \rho \), with the parameter \( w \equiv w(t) \), after some rather trivial manipulations, we finally obtain the required condition \( m_0 = V(\phi) = 0 \) \([11]\), and

\[
\rho = 6\pi G \left( \dot{H}^{-1} H v V_{SQ} \right)
\]

\[
p = -\left(1 + \frac{2H}{3H^2}\right) \rho = w \rho,
\]

in which \( H = \dot{a}/a \), with \( a \) the scale factor of the flat universe. Now, from the Friedmann equation \( H^2 = 8\pi G \rho/3 \) derived from our Lagrangian density, it follows that

\[
\dot{H} = \pm 4\pi G v V_{SQ}.
\]

In addition, the equation of motion for coordinate \( q \) has the general form

\[
v \dot{v} = -(1 - v^2) F(H, v, m_0, V_{SQ}).
\]

It can be shown that the function \( F \) is always divergent provided \( v^2 \neq 1 \). Thus, in order to ensure regularity of the whole model we should require that \( v^2 = 1 \) which is just the remaining necessary condition for making the present model self-consistent; i.e. \( \phi^2 = v^2 = 1 \). In this way, we have for the Hubble function

\[
H = H_0 \pm 4\pi G V_{SQ} t,
\]

with \( H_0 \) an integration constant playing the role of a cosmological constant. We have then the solutions

\[
a_{\pm} = a_0 e^{H_0 t \pm 2\pi G V_{SQ}},
\]

in which \( a_0 \) is the initial value of the scale factor. In Fig. 1 we give the evolution of the scale factor corresponding to these solutions, as compared with that for a pure de Sitter universe. Solution \( a_- \) describes a universe which initially accelerates with \( w > -1 \), then decelerates for a while to finally contract all the way down to zero. Such a solution can be seen to violate the second law of thermodynamics and therefore will not be here considered as a realistic solution. Moreover, present estimates of the parameter \( w \) seem to place its value slightly beyond the de Sitter barrier, a case which can never be described by solution \( a_- \). Solution \( a_+ \) has not these shortcomings. It corresponds to what has been denoted as a phantom universe \([12]\) characterized by a parameter \( w < -1 \) and will be taken in this report as the physical solution representing the current evolution of the universe.

The point now is that the Lagrangian density and both the energy density and pressure become all zero, while the universe reduces to a de Sitter universe, in the classical limit where the sub-quantum potential vanishes. Thus, the main assumption of the present model is to interpret that it is the sub-quantum effect originated by the radiation particles that constitutes the cosmic microwave background that is the unique cause making the universe to accelerate. If so, we had accomplished a most economical model justifying the current acceleration of the universe without introducing any ad hoc mysterious dark energy field or modifying the Hilbert-Einstein gravity.

### III. A BENIGNER PHANTOM UNIVERSE

Solution \( a_+ \) actually describes what we can call a benign phantom universe. In fact, even though it corresponds to a tracking equation of state with \( w < -1 \), but very close to -1 for most of its evolution and the energy density is an
Time Scale Factor

De Sitter: \( a_0 e^{H_0 t} t \)

\( a_0 = a_0 e^{H_0 t} t \)

\( = a_0 e^{H_0 t} t \)

FIG. 1: Time evolution of the sub-quantum cosmic solutions as compared to that of de Sitter universe. Solution \( a_+ \) corresponds to an equation of state with \( w > \frac{1}{2} \) and violates the second law of thermodynamics; solution \( a_- \) corresponds to a phantom model with equation of state \( w < \frac{1}{2} \). Problems in such a model are benign than in known phantom models as it is stable, does not show any singularities at finite time in the future, corresponds to a positive kinetic term and violates dominant energy condition only quantum-mechanically.

increasing function of the cosmological time \([12]\), it can be associated with a stable field theory having a kinetic term \( \dot{\phi}^2 = q^2 > 0 \), shows no future singularity of the big rip kind and violates the dominant energy condition only quantum-mechanically, i.e. we always have \( p + \rho = -V_{SQ} \) which is a permissible violation of such a condition. We finally note that our model makes it compatible the current dominance of a sub-quantum energy phase with the previous matter domination in the universe. The ultimate reason for this consists in the realization that in a sub-quantum description all matter fields entering the Lagrangian considered by Amendola, Quartin, Tsujiwara and Waga \([13]\) behave like though they were pure radiation just at the coincidence time.

IV. CONCLUSION

The main conclusion from this report is that the current acceleration of the universe should be described by a benign phantom model which does not contain any extra fluid or modification of gravity but just the quantum effects associated with the existence of a sub-quantum potential for the CMB, superposed or not to a cosmological constant.

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