Cosmology in a scalar ether theory of gravitation

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Some motivation for an ether theory of gravitation is presented. The equations of one such theory, based on just one scalar field, are given. It is a preferred-frame theory with a flat background metric and a curved physical metric. Motion is governed by an extension of the special-relativistic form of Newton's second law. The current status of the observational test is favourable. In particular, the new theory reduces to Newton's when it has to, and it does explain the effects of gravitation on light rays. In the most general form of the metric, cosmic space expansion occurs with a cosmological time-dilation. Expansion is necessarily accelerated, according to that theory. An analytical cosmological solution is got for a general form of the matter tensor. Two kinds of scenarios are possible: either expansion from an infinite density at past infinity, or contraction-expansion cycles beginning and ending with infinite dilution, and with a bounce at a finite maximum density. In the most likely scenario, there is an infinite number of non-identical such cycles. The time scale for the current cycle is very large.

Keywords: gravitation, ether, relativity, cosmic acceleration, infinite dilution, cyclic universe

1. Introduction: why an ether theory of gravitation?

In this paper, the cosmological scenarios which are predicted by an alternative theory of gravitation shall be presented. Let us first summarize a few motivations outside the scope of cosmology. There are indeed general reasons to search for an alternative to the current theory of gravitation, namely general relativity (GR), and a good part of those reasons suggest precisely to search for an "ether theory".

i) One naturally wishes to have compatible theories for gravitation and the rest of physics, which is currently described in the framework of quantum theory. The difficulties involved under the very name "quantum gravity" do not reduce to that of building a quantum theory *of* the gravitational field, but begin with the more urgent problem of writing and using quantum theory *in* a gravitational field – which is undoubtedly necessary. Here one must face, in particular, the "problem of time" [1-3], *i.e.* the fact that quantum theory, because it starts from Hamilton's mechanics, uses a preferred time coordinate. Already in the flat space-time of special relativity, there is one time per inertial frame, but the standard quantization methods lead to Lorentz-invariant equations, so that the problem of time is not too serious in flat space-time. Yet in the curved space-time of GR, any observer has her own time, and no time coordinate can be preferred there. In the foregoing PIRT meeting, the author argued that, if one follows the spirit of Schrцdinger's wave mechanics, one is led to extend quantum wave equations to gravitation in the form of preferred-frame equations [4]. This is obviously not consistent with GR, but it is fully consistent with the "ether theory" considered here. Thus it seems that it is not curved space-time as such that poses a serious compatibility problem with quantum theory, but specifically the reject of any preferred space-time foliation [2-3], in simple words: the reject of any ether. Moreover, quantum theory attributes physical properties to what we call *vacuum: e.g.* two metallic surfaces *in vacuo* (thus without electromagnetic field in the classical sense) exert a "quantum force" on one another: this is the Casimir effect, which is now experimentally confirmed [5]. In summary, quantum theory suggests that a preferred-frame theory of gravitation should be used if gravity does curve space-time, and that empty space has physical properties, thus it seems to point to an "ether" in the strongest sense of that concept.

ii) One may observe certain difficulties in GR itself as a theory of gravitation: *a*) one may ask whether a massive star can in fact implose to a point singularity, as is predicted by GR. Perhaps this is merely an unphysical prediction of a particular theory? In any case, the alternative theory considered here predicts that the gravitational collapse leads instead to a bounce: the implosion is stopped at a finite density and is followed by an explosion [6]. The same is true [7] for Logunov's theory, which is a generally-covariant tensor theory with a flat background metric and a massive graviton. *b*) There is the question of the interpretation of the gauge condition. It is now widely known that the Einstein equations of GR do not determine unambiguously one Lorentzian metric $\boldsymbol{\gamma}$ on a given space-time manifold V (this was well-known to Einstein [8]). Instead, the Einstein equations determine an equivalence class of couples (V, $\boldsymbol{\gamma}$) modulo the equivalence relation " (V, $\boldsymbol{\gamma}$) ~ (V', $\boldsymbol{\gamma}'$) if there is a diffeomorphism of V onto V' that transforms $\boldsymbol{\gamma}$ to $\boldsymbol{\gamma}'$. " [2-3, 8-10] It means that "points of space-time (events) are not individuated apart from their metrical properties." [8] But this interpretation is difficult to handle in concrete problems. Thus, when calculating the predictions of GR for gravitational effects on light rays, or for celestial mechanics, one considers more or less explicitly that the space-time manifold V is given, and one uses the Einstein equations, plus a gauge condition (four scalar equations, often the De Donder-Fock "harmonic condition") to determine the Lorentzian metric $\boldsymbol{\gamma}$ on that manifold [11-14]. In other words, one augments the Einstein equations with four equations. To the author's knowledge, it has not been proved that this way of doing is fully compatible with the former interpretation of GR. In the scalar theory envisaged here, the space-time manifold is given, moreover it is endowed with a flat "background metric" $\boldsymbol{\gamma}^0$, and there is no need for a gauge condition. *c*) Finally, there is the question of "dark matter". It now seems that the well-identified candidates for galactic dark matter, such as brown dwarfs, are not found in sufficient amounts to explain the rotation velocities of stars around the Galaxy, and that the quest of dark matter is bifurcating towards the search for exotic particles yet to be discovered. It may be that actually it is the standard theory of gravitation, thus GR (which, for that matter, is replaced by its weak-field limit, *i.e.* Newton's theory), which is partly wrong at such large scales [15]. In the scalar ether theory, there are preferred-frame effects and, although these effects are very small in the solar system (as it will be precised in this paper), they might be more significant at the scale of a galaxy: one possible reason could be the very long time scales involved, of the order of 10^8 years, that might allow these effects to accumulate.

Thus, an ether theory of gravitation might possibly solve some problems. The theory envisaged here may be characterized thus: it is a scalar theory with a preferred reference frame E ("ether"), with two space-time metrics: a flat "background metric" $\boldsymbol{\gamma}^0$ and a curved "physical metric" $\boldsymbol{\gamma}$, the relation between the two being defined through the scalar field [6], and with the motion being governed by an extension of Newton’s second law rather than by Einstein’s geodesic assumption [16]. For the reader's convenience, a short *summary* of the theory will be given in *Section 2.* (Ref. 17 presents the complete construction of the theory, but the derivations and calculations are merely outlined there.) In *Section 3,* the current state of the *confrontation* of that theory with the current tests of a theory of gravitation will be exposed. In *Section 4*, we shall introduce the principles of the application of the theory to *cosmology.* Resulting *cosmological scenarios* will be presented in *Section 5.*

2. Main equations of the scalar ether theory of gravitation

This is a preferred-frame theory, thus the equations are given in the preferred frame E. We shall present here a self-consistent set of definitions and equations, without much explanation on the origin of these equations (see Ref. 17). According to this theory, gravitation is characterized by a *scalar* field p_e [the (macroscopic) "ether pressure"], which defines the spatial vector "gravity acceleration":

$$\mathbf{g} = -\frac{\mathrm{grad}\, p_e}{\rho_e}. \tag{2.1}$$

In this equation, ρ_e is the (macroscopic) "ether density", with $p_e = c^2 \rho_e$ where c is the velocity of light. Thus, p_e and ρ_e *decrease* towards the attraction: according to the heuristics that underlies the theory, gravitation is interpreted as Archimedes' thrust in the ether [6, 17]. The field equation of the theory [6] connects p_e (or ρ_e) with the mass-energy density σ in the preferred frame E :

$$\Delta p_e - \frac{1}{c^2}\frac{\partial^2 p_e}{\partial t_{\mathbf{x}}^2} = 4\pi G\sigma\, \rho_e. \tag{2.2}$$

Here $t_{\mathbf{x}}$ is a "local time" defined below [eqs. (2.8) and (2.12)]. The precise definition of σ is [16]:

$$\sigma \equiv (T^{00})_{\mathrm{E}} \qquad (x^0 = ct) \tag{2.3}$$

where **T** is the mass tensor (*i.e.,* the energy-momentum tensor of matter and nongravitational fields, expressed in mass units) and with $x^0 = ct$ as the time coordinate, where t is the absolute time, "defined" before eq. (2.8) below. [Equation (2.2) is covariant merely under spatial changes in the frame E.] In eqs. (2.1) and (2.2), the operators grad and Δ (Laplacian) refer to the "physical" space metric $\mathbf{g} = (g_{ij})$ in the preferred frame: [1]

$$(\mathrm{grad}\, p_e)^i = (\mathrm{grad}_{\mathbf{g}}\, p_e)^i = g^{ij}\frac{\partial p_e}{\partial x^j}, \quad (g^{ij}) \equiv (g_{ij})^{-1}, \tag{2.4}$$

$$\Delta p_e = \Delta_{\mathbf{g}}\, p_e = \mathrm{div}_{\mathbf{g}}\, \mathrm{grad}_{\mathbf{g}}\, p_e = \frac{1}{\sqrt{g}}\frac{\partial}{\partial x^i}\left(\sqrt{g}\, g^{ij}\frac{\partial p_e}{\partial x^j}\right), \quad g \equiv \det(g_{ij}). \tag{2.5}$$

[1] Latin indices vary from 1 to 3 (spatial indices), Greek indices from 0 to 3.

Metric $\mathbf{g}$ is a Riemannian metric defined on the three-dimensional "space" manifold M made of all points $\mathbf{x}$ that are bound to the preferred frame. Metric $\mathbf{g}$ is curved, due to an assumed gravitational contraction of physical rods, in the direction $\mathbf{g}$ only, and in the ratio

$$\beta \equiv \rho_e(t, \mathbf{x}) \,/\, \rho_e^{\infty}(t), \tag{2.6}$$

where $\rho_e^{\infty}(t)$ is the value of ρ_e in regions which are far enough from any matter and hence free from gravitation. Since ρ_e decreases in the direction g, $\rho_e^{\infty}(t)$ may be formally defined as the upper bound of ρ_e over the whole space:

$$\rho_e^{\infty}(t) \equiv \mathrm{Sup}_{\,\mathbf{x}\in \mathrm{M}}\ \rho_e(t, \mathbf{x}), \tag{2.7}$$

which must be finite. Thus $\beta \leq 1$: this is indeed a contraction. It occurs with respect to a flat (*i.e.,* Euclidean) space metric $\mathbf{g}^0$, with which M is assumed to be equipped (this needs that M is diffeomorphic to $\mathbf{R}^3$). The measuring rods being contracted, it follows that the physical distances, involving metric $\mathbf{g}$, are dilated as compared with distances evaluated with $\mathbf{g}^0$. Also, the clock periods are assumed to be dilated in the gravitational field, in the inverse ratio to the space-contraction ratio β. This is why a *"local time"* $t_\mathbf{x}$ appears at any fixed point $\mathbf{x}$ in the preferred frame: $t_\mathbf{x}$ flows more slowly, in the above ratio β, than the *"absolute time"* t, which is that measured by an observer bound to the preferred frame *and* far enough from any matter:

$$\mathrm{d}t_\mathbf{x} / \mathrm{d}t = \beta(t, \mathbf{x}), \qquad (\beta \leq 1). \tag{2.8}$$

Equation (2.8) implicitly assumes that the absolute time t is "globally synchronized". Thus, we assume that the physical space-time metric $\boldsymbol{\gamma}$ satisfies

$$\gamma_{0i} = 0 \ (i = 1, 2, 3) \tag{2.9}$$

in any coordinates (x^μ) adapted to the frame E *and* such that $x^0 = ct$ with t the absolute time. Therefore, we have also

$$\gamma_{ij} = -\,g_{ij}. \tag{2.10}$$

In any such coordinates, eq. (2.8) means that

$$\gamma_{00} = \beta^2. \tag{2.11}$$

The derivation with respect to local time, appearing in eq. (2.2), is defined from (2.8):

$$\frac{\partial}{\partial t_\mathbf{x}} \equiv \frac{1}{\beta(t, \mathbf{x})} \frac{\partial}{\partial t}\ . \tag{2.12}$$

The set of eqs. (2.2), (2.9) and (2.11) [with definitions (2.3) and (2.12)] is not covariant under time changes. Hence, from a more formal viewpoint, the absolute time t is that time coordinate in which these equations apply.

Motion is governed by an extension of Newton's second law "force = time-derivative of momentum" [16, 18]. This extension involves the assumed form for vector **g** [eq. (2.1)]. For a *dust,* it mathematically implies [19], independently of the assumed form for the space-time metric $\boldsymbol{\gamma}$ provided it satisfies $\gamma_{0i} = 0$ in the preferred frame, the following *equation of motion:*

$$T_{\mu}{}^{\nu}{}_{;\nu} = b_{\mu}, \tag{2.13}$$

where semi-colon means, as usual, covariant derivative associated with the curved physical metric $\boldsymbol{\gamma}$, and where the r.h.s. is defined by

$$b_0(\mathbf{T}) \equiv \frac{1}{2} g_{jk,0}\, T^{jk}, \quad b_i(\mathbf{T}) \equiv -\frac{1}{2} g_{ik,0}\, T^{0k} \tag{2.14}$$

(indices are raised and lowered with metric $\boldsymbol{\gamma}$; a "dust" may be defined by the form of its mass tensor, which is $T^{\mu\nu} = \rho^*\, U^{\mu}\, U^{\nu}$ with ρ^* the proper rest-mass density and $U^{\mu} = \mathrm{d}x^{\mu}/\mathrm{d}s$ the 4-velocity). Equation (2.13), with the definition (2.14), is assumed to hold true for whatever continuous medium, be it made of ordinary matter and/or of nongravitational field [17,19]. This expresses the universality of gravitation and the mass-energy equivalence. Equation (2.13) is covariant under purely spatial changes in the frame E : $x'^{\,i} = \psi^{i}(x^{j})$, and under space-independent time changes: $t' = \phi(t)$.

3. Confrontation with current tests of a theory of gravitation

Let us review briefly whether and how the scalar ether theory passes the different tests that may currently be imposed on an alternative theory of gravitation.

i) It should give very nearly the same predictions as Newton's gravity (NG), in the numerous observational situations where NG has proved to be extremely accurate. To check this point and other ones, an asymptotic post-Newtonian approximation (PNA) has been developed for that theory [20], thus a set of asymptotic expansions of the unknown fields, and of equations for the coefficients of the expansions. The expansions are in terms of a dimensionless small parameter ε, which may be defined by

$$\varepsilon \equiv (U_{\max}/c^2)^{1/2} << 1 \tag{3.1}$$

where $U_{\max}$ is the maximum value of the Newtonian potential U in the considered gravitating system [11,13]. The effective small parameter entering the equations is actually the square ε^2, thus $U_{\max}/c^2$. It is found that the equations of the *zero-order* PNA are just the equations of NG [20], and since the next order is ε^2, the difference between the predictions of NG and the ether theory is of the order ε^2. This may be checked by assuming instead a *first-order* expansion in ε, which also reduces to NG [21]. Now, for the solar system (in which the tests of NG have been performed, indeed a high number of tests), the parameter ε^2 is approximately equal to 10^{-6}, hence this is the order of magnitude of the relative difference between predictions of NG and the scalar theory in the solar system. The same is true for GR.

ii) The next crucial test is the study of gravitational effects on light rays, because those effects constitute the best-verified corrections of GR to NG [14]. *a*) The prediction, by GR, of the gravitational redshift, depends [12] on the expression

$$\gamma_{00} = 1 - 2U/c^2 + O(\varepsilon^4) \tag{3.2}$$

for the coefficient γ_{00} of the time-independent metric generated by a massive body, in a reference frame moving with that body – which is also true in the scalar ether theory [22], and on the assumption that the proper frequency is everywhere the same, independently of the gravitational field. This assumption is consistent with the present theory as well, because the laws of nongravitational physics (*e.g.* Maxwell equations [17] or Klein-Gordon equation [4]) are expressed in terms of the "physical" metric $\boldsymbol{\gamma}$, not in terms of the flat metric $\boldsymbol{\gamma}^0$. *b*) The other two effects on light rays, *i.e.* the light deflection and the time delay, are obtained from Schwarzschild's motion, again in the reference frame moving with a massive body, here assumed spherical [12]. This also holds true in the present theory, even if one accounts for the motion of the spherical body through the "ether" of that theory – up to $O(\varepsilon^3)$ terms which play no role in the first corrections to NG for light rays [22]. (The first corrections are those that have been tested [12-14].)

iii) The explanation of Mercury's residual advance in perihelion is essentially due, in GR, to the fact that Schwarzschild's motion is predicted for test particles in a static, spherically symmetric gravitational field [12]. Since this is also true for the present theory [6,16], there is good hope that it should be also explained by the latter. But here the situation is less simple, because preferred-frame effects do affect the motion of mass test particles already at the first PNA [20] – in contrast to what is found [22] for photons. Therefore, if the velocity of the solar system through the "ether" of the theory is of the order of several times 100 km/s, as one *a priori* expects, and if it were correct to take the first-approximation (*i.e.,* zero-order) predictions as given independently of the theory of gravitation – and hence to take these terms from Newtonian calculations – then the theory would *not* explain Mercury's perihelion.

However, several parameters, *e.g.* the masses of the planets, that intervene in the zero-order equations (thus the equations of NG), cannot be measured to sufficient accuracy independently of the celestial-mechanical calculations. This means that celestial mechanics proceeds to a *fitting,* in which a number of observational data (orbital parameters, etc.) are input data, and in which the unknown parameters (including the zero-order parameters, thus including the first-approximation masses) are output data [23]. As for any similar situation, the predictive capacity of a theory must then be checked in a subtle way, by trying different sets of input data (thus, *e.g.,* by not incorporating all elements of Mercury's orbit, so that Mercury's advance in perihelion is not an input data !) Now, since the equations of celestial mechanics obviously depend on the theory, it follows that the unknown parameters, including the first-approximation parameters, do also depend on the theory. One may show, more precisely, that those values of the first-approximation parameters that are optimal for the second approximation should differ from their "Newtonian" values by second-approximation corrections [24]. (The "Newtonian" values of the first-approximation parameters are obtained by a fitting using *merely* the equations of the first approximation, *i.e.* the equations of NG.) The consequence of this reasoning is that one cannot tell what is the exact orbit of, say, Mercury, according to a new theory, until one has done the global fitting based on that new theory. As regards the scalar ether theory, the current stage is this: the equations of motion for the mass centers in the second approximation have been obtained, and a tentative algorithm for doing the fitting has been proposed [24]. The equations involve only one second-approximation quantity, and this is the velocity **V** of the gravitating system through the ether. Thus, the fitting shall tell what should be the value of **V** in order to minimize the residual, in other words it will measure the velocity of the solar system through the ether assumed in the theory. That will be a very technical calculation for a crucial stake.

iv) A more recent duty for a theory of gravitation is to explain the observed timing between radio pulses received from some binary pulsars, especially from the 1913+16 pulsar. The companion of the pulsar, that makes it a binary pulsar, is usually not seen, and is detected from rather short-range fluctuations in the time intervals between pulses. What must in particular be explained is the longer term drift that leads to a decrease in the average time intervals. One natural way to explain that decrease is to assume that the binary system loses energy due to its relatively important production of gravitation waves (this, in turn, being due to the strong-field regime as compared with the solar system). A timing model based on GR and its famous "quadrupole formula", expressing the loss of energy due to gravitational radiation, has been very successful in reproducing the observed timing between pulses [25]. Here also it is a fitting procedure, and there is only one kind of observational input, namely the observed pulse timing. It turns out that, in the scalar ether theory, a formula very similar to the quadrupole formula of GR can be obtained for evaluating the gravitational energy radiated at large distance, if the mass center of the gravitating system is at rest in the ether (see the outline of the derivation in Ref. 26). In particular, this is indeed an energy loss, and there are neither monopole nor dipole terms. This makes it likely that pulsar data could be nicely fitted also in the investigated theory, although one will have to account for a possible velocity of the mass center in the preferred frame.

v) Finally, there are precision tests of the equivalence principle [14]. As it appears from the equation for continuum dynamics, eq. (2.13) with the definition (2.14), the scalar ether theory agrees fully with the principle of the universality of gravitation. Moreover, eq. (2.13) coincides with the equation based on Einstein's equivalence principle (EEP), $T^{\mu\nu}{}_{;\nu} = 0$, in the case that the gravitational field does not depend on time – which is the case investigated in the analysis of tests of EEP [14]. For these two reasons, it is likely that the new theory passes the existing tests more or less as does GR, but one day it should be possible to experimentally decide between EEP and the form of the equivalence principle that applies to the new theory, namely an equivalence between the absolute metrical effects of motion and gravitation [6].

4. Principles of the application to cosmological problems

As mentioned in Section 2, a gravitational contraction in the direction $\mathbf{g}$ is assumed to affect the size of physical length standards if that size is expressed in terms of the invariable Euclidean metric $\mathbf{g}^0$ on the space M. That contraction occurs in the ratio β [eq. (2.6)], it is due to the *spatial* heterogeneity of the field of the ether density, ρ_e. Once this is recognized, we should also allow that the absolute size of the length standard may vary with the *temporal* heterogeneity of the field ρ_e. The spatial heterogeneity has the preferred spatial direction $\mathbf{g}$ [since $\mathbf{g}$ is proportional to $\nabla\rho_e$, eq. (2.1)], hence it is natural to assume that it affects the physical space metric $\mathbf{g}$ in an anisotropic way, as we assume. But the temporal heterogeneity does obviously not single out any spatial direction, hence it must affect all directions equally. Therefore, $\mathbf{g}$ is equal to some time-dependent factor, say $R(t)^2$ (the square is for later convenience), times the metric $\mathbf{g}'$ deduced from the Euclidean metric $\mathbf{g}^0$ by the contraction in the direction $\mathbf{g}$ and in the ratio β. Metric $\mathbf{g}'$ is easy to deduce from $\mathbf{g}^0$ in a local system (x^i) of space coordinates such that metric $\mathbf{g}^0$ is diagonal: (g^0_{ij}) = diag $(a^0_1,\ a^0_2,\ a^0_3)$, and such that vector $\mathbf{e}_1$ of the natural basis $(\mathbf{e}_i)$, associated with (x^i), is parallel to $\mathbf{g}$ [6]. In a such system, we get:

$$(g_{ij}) = R(t)^2 \,\mathrm{diag}\,[(1/\beta)^2 a^0_1,\ a^0_2,\ a^0_3], \qquad \beta \equiv \rho_e/\rho_e^{\infty}. \tag{4.1}$$

The time-dependence of $R(t)$ means obviously an *expansion,* in the usual sense, when R increases, and conversely a contraction when R is diminished. Equation (4.1) implies the following relation between the volume elements $\mathrm{d}V$ and $\mathrm{d}V^0$, respectively associated with metrics $\mathbf{g}$ and $\mathbf{g}^0$:

$$\frac{\mathrm{d}V}{\mathrm{d}V^0} = \frac{\sqrt{g}}{\sqrt{g^0}} = R^3\,\frac{\rho_e^{\infty}}{\rho_e}. \tag{4.2}$$

Due to eq. (4.2), the *conservation of ether*, which is crucial in the theory, is expressed thus [26]:

$$\rho_e^0 \equiv \mathrm{d}m_e/\mathrm{d}V^0 = R(t)^3\,\rho_e^{\infty}(t) = \text{Constant}. \tag{4.3}$$

This equation implies that the scale factor $R(t)$ is not an independent quantity, hence the time-dependence of $R(t)$ is not a mere possibility, but actually *must* be considered in the theory. (From what we know about real expansion rates, it follows that, if the theory is correct, it should be found that R may yet be assumed constant for all purposes except in cosmological problems.) It remains some freedom, however, as to the time part of the physical space-time metric, *i.e.* [due to the global synchronization condition (2.9)] as to the γ_{00} component. If we would keep eqs. (2.8) and (2.11), it would mean that there is no cosmological time-dilation. This would be at odds with the fact that space-contraction and time-dilation occur simultaneously in the metrical effects of uniform motion, and in the metrical effects of gravitation as well. Therefore, we postulate a cosmological time-dilation in a rather general form, in modifying eq. (2.8) thus:

$$\mathrm{d}t_{\mathbf{x}}/\mathrm{d}t = \beta(t, \mathbf{x})/R(t)^n, \tag{4.4}$$

with n a real exponent. This gives the following form for the space-time metric [26]:

$$ds^2 = R(t)^{-2n}\, \beta^2\, (dx^0)^2 - g_{ij}\, dx^i\, dx^j, \qquad x^0 \equiv ct. \tag{4.5}$$

Now, as is usually done in cosmological problems, we shall state the (oversimplifying) assumption of a *homogeneous universe.* Thus the spatial distribution of ether as well as matter is uniform, which means that the mass tensor **T** and the ether density ρ_e are uniform, hence from (2.7):

$$\rho_e(t, \mathbf{x}) = \rho_e(t) = \rho_e^{\infty}(t) \quad \text{for all } \mathbf{x}. \tag{4.6}$$

Since ρ_e is uniform, *there is no gravitational attraction:* $\mathbf{g} = 0$ from (2.1). It seems that it indeed should be the case in any theory for a homogeneous universe, however in the cosmological literature one often reads statements according to which "expansion is braked by matter". This is true in GR, in the sense that an increase in the energy density tends to decelerate expansion in GR, but it cannot be interpreted as an effect of gravitational attraction in the Newtonian sense. [As to the "Newtonian cosmologies", they are not really Newtonian in fact, because there is no *global* inertial frame in those models [27], whereas global inertial frames are essential to Newton's gravitation [28]. One should remind that NG *stricto sensu* becomes *meaningless* for a (necessarily infinite) homogeneous universe.] Since we have now

$$\beta(t, \mathbf{x}) = 1 \tag{4.7}$$

[eq. (4.6)], the local time $t_{\mathbf{x}}$ becomes a uniform *cosmic time* τ defined by

$$d\tau/dt = R(t)^{-n}, \tag{4.8}$$

[eq. (4.4)], and the physical metric, (4.5) with (4.1), is the flat Robertson-Walker metric:

$$ds^2 = c^2\, d\tau^2 - R(\tau)^2\, g^0_{ij}\, dx^i\, dx^j. \tag{4.9}$$

The field equation (2.2) becomes

$$\ddot{\rho}_e + 4\pi G\sigma\, \rho_e = 0, \tag{4.10}$$

with $\sigma = \sigma(\tau)$. In eq. (4.10) and henceforth, *the upper dot means differentiation with respect to the cosmic time* τ*.* Substituting ρ_e = Const/R^3 [eqs. (4.3) and (4.6)] into (4.10) and rearranging, we get:

$$\frac{\ddot{R}}{R} = \frac{4\pi G}{3}\sigma + 4\frac{\dot{R}^2}{R^2}, \tag{4.11}$$

whence, insofar as $\sigma \geq 0$,

$$q \equiv -\frac{R\ddot{R}}{\dot{R}^2} = -\left(\frac{4\pi G}{3}\sigma\,\frac{R^2}{\dot{R}^2} + 4\right) \leq -4. \tag{4.12}$$

Hence, *expansion is necessarily accelerated, according to the scalar ether theory.* Furthermore, the higher is the matter mass-energy density σ, the *more* expansion is accelerated (thus the contrary of what is found in GR). This is a very interesting prediction of the present theory, because it turns out that expansion is now found to be accelerated [29-30], although during many decades a deceleration had been thought to take place [12, 27, 31].

Using the homogeneity of both the mass tensor and the ether density in the equations of motion (2.13) yields [26]:

$$T^{0i}(\tau) = C^i / R(\tau)^4 \qquad (i = 1, 2, 3) \tag{4.13}$$

with C^i a constant, and (setting $\varepsilon \equiv T_0^0$)

$$R^3\, \varepsilon = \text{Const.} \equiv \varepsilon^{(0)}. \tag{4.14}$$

Equations (4.13) and (4.14) express the *momentum conservation* and the *energy conservation,* respectively, in a homogeneous Universe. Using (4.3), (4.8) and (4.14), one may rewrite eq. (4.10) as

$$\ddot{\varepsilon} + \alpha' \varepsilon^{2-2n/3} = 0, \quad \alpha' \equiv 4\pi G\left[\varepsilon^{(0)}\right]^{2n/3}. \tag{4.15}$$

5. Cosmological scenarios according to the scalar ether theory

The cosmological equation (4.15) admits an analytical solution in inverse form [26]. *E.g.* for an expansion phase ($\dot{\varepsilon} \leq 0$), it may be written as

$$\tau = \tau_2 - F(\varepsilon), \tag{5. 1}$$

where F is the following integral:

$$F(\varepsilon) \equiv \int_0^{\varepsilon} \frac{\mathrm{d}\xi}{\sqrt{A - \alpha\, \xi^m}} \qquad (m \equiv 3 - 2n/3) \tag{5.2}$$

which is finite in an interval $[0, \varepsilon_{max}(m, \alpha, A)]$, for any real number $m \neq 0$, and where τ_2 is the *finite* value of the cosmic time for which expansion will have accelerated to the point of giving an *infinite dilution* ($\varepsilon = 0$ and $R = +\infty$). In eq. (5.2), A is an integration constant and

$$\alpha \equiv 2\alpha'/\, m = 24\pi G\left[\varepsilon^{(0)}\right]^{2n/3} / (9 - 2n). \tag{5.3}$$

The case $m = 0$, *i.e.* $n = 9/2$, is qualitatively identical and numerically similar to the case $3 \leq n < 9/2$, although the formulas are somewhat different. Depending on the exponent n and the integration constant A, there are two different kinds of predictions for the evolution of the Universe [26]:

i) The first kind ($n > 9/2$ and $A \geq 0$) is an expanding universe with unbounded density ($\varepsilon_{max} = +\infty$): as the cosmic time increases infinitely in the past, the density increases without limit.

This case provides thus *arbitrarily high density in the past, without a big-bang singularity.* However, it has two curious features: *a*) the absolute time *t*, which is considered in the theory, tends towards a finite value t_∞ while the physical, cosmic time τ tends towards $-\infty$; *b*) the infinite dilution shall be reached at the finite cosmic time τ_2, but this will take an infinite amount of the absolute time *t*, so that nothing can be predicted for $\tau > \tau_2$. This latter feature is true for any $n \geq 3$, independently of *A*, and seems rather unphysical. For this reason, the case $n \geq 3$ has not been considered at the stage of time-scales evaluation.

ii) The second kind [($n > 9/2$ and $A < 0$), or $n \leq 9/2$] is a *set of symmetric contraction-expansion cycles, each cycle having a finite maximum for the energy density* ($\varepsilon_{\max} < +\infty$). There is *one* such cycle, if ($n > 9/2$ and $A < 0$), as also if $3 \leq n \leq 9/2$. There is *an infinite sequence of non-identical cycles,* if $n < 3$. Each cycle starts from an infinite dilution: space contracts until the energy density reaches a finite maximum, after which expansion takes place until an infinite dilution is obtained. Thus each cycle contains a *"non-singular bounce".* This is also predicted by several other bimetric theories of gravitation when the background metric is flat [32-34]. In Rastall's theory [32], and in one case for Rosen's theory [33], the maximum density $\varepsilon_{\max}$ is only a few times higher than the current density ε_0. If one would assume no cosmological time-dilation ($n = 0$), this would be also the case for the present theory. This seems to be ruled out by the observation of high cosmological redshifts, $z \approx 4$ [26]. In addition, assuming a cosmological time-dilation is more consistent with the spirit of the present ether theory [see before eq. (4.4)]. If one indeed assumes this, then the ratio of the maximum density to the current density, $\varepsilon_{\max}/\varepsilon_0$, is not constrained by the cosmological model. This also happens in Petry's theory [34]. The "age of the Universe", *i.e.* the cosmic time elapsed since the maximum density, is then determined by the data of the current Hubble parameter H_0 and the ratio $\varepsilon_{\max}/\varepsilon_0$. If one admits the standard explanation of the cosmic microwave background (CMB) radiation as resulting from a previous stage with a very high density, one then gets a huge value for the "age of the Universe", of the order 10^{19} years [26]. Thus there is a lot of time to form galaxies, whereas they have to form in a hurry according to standard cosmology based on GR. But perhaps such enormous time scales might pose different problems. Even for a maximum density $\varepsilon_{\max}/\varepsilon_0 \approx 100$, which seems to be the minimum required to interpret the *observed* redshifts at $z \approx 4$ as cosmological, the age is very large, several hundreds of billions of years [26]. Both results are true independently of the value *n* with $n < 3$.

6. Conclusions

i) A scalar theory of gravitation with a preferred reference frame was summarized. This theory has the correct Newtonian limit and does explain the gravitational effects on light rays.
It is likely that it should also pass the current tests regarding binary pulsars or the equivalence principle. As to Mercury's perihelion, the situation is not yet conclusive: celestial mechanics involves a fitting, which must be reevaluated when one changes the theory. For the investigated ether theory, one output of the fitting will be the velocity *V* of the mass center of the solar system through the ether assumed by the theory. If *V* were found too small, that

would put the theory in a difficulty. But if a good observational agreement were found for a significant value of V, that would be a decisive argument for an ether.

ii) The scalar theory has been applied to cosmological problems. Energy and momentum of the Universe are conserved. The theory predicts that the cosmic expansion *must* be accelerated, as is currently observed. It says that: either the Universe follows an infinite sequence of symmetric contraction-expansion cycles with bounded density (the most likely case, since otherwise nothing can be predicted after some finite cosmic time from now). Or it follows one such cycle. Or still, there is only expansion, with unbounded density in the past.

iii) It seems to the author that one should not currently consider the global-high-density scenario as proved. From observations of redshifts at $z \approx 4$, it only follows that the mean density must have been some hundred times larger than the current mean density. (Already this result demands, of course, that these high redshifts are interpreted as "cosmological", *i.e.* as related to the expansion of the scale factor by the usual formula, but apart from this it is theory-independent.) This is very far from the minimum density ratio, of the order 10^9, which is necessary to explain the CMB radiation according to that scenario – not to speak of the production of the light elements [12, 31]. Thus, the global-high-density scenario is proved only in so far as it provides an explanation for the origin of the CMB and the light elements, and as long as there is no alternative explanation for both. But the latter point does not seem to be true, for an alternative explanation has been proposed, with already an amount of detail, by Hoyle *et al.* [35], in the framework of the "quasi-steady-state" (QSS) model of the Universe. The scalar ether theory is compatible with the QSS model, because the latter says that matter is created in bursts occuring in very massive objects – and precisely, the present theory of gravitation predicts that: *a*) massive objects must collapse and then explose [6], and *b*) compact fluid balls which undergo an explosion must indeed produce matter [19]. However, the scalar theory, with its cosmological models as summarized here, is also compatible with the existence of global states of high density in the past. Actually the two scenarios are compatible in the frame of that theory: *i.e.,* it might be the case that the Universe did pass through a global state of high density in the past, *and* there are bursts of creation at localized regions of space-time.

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