On the Possibility of Matter Creation/Destruction in a Variable Gravitational Field

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ABSTRACT

Newton's second law: "force = time-derivative of momentum", may also be defined for theories of gravitation endowing space-time with a curved metric. Thus, Einstein's assumption of a geodesic motion may be rewritten in that form, and it corresponds to a velocity-dependent gravity acceleration **g**. In contrast, the investigated theory states that, in the preferred reference frame assumed by the theory, **g** does not depend on the velocity. It recovers geodesic motion only for a constant gravitational field. This leads to a different equation for continuum dynamics, as compared with general relativity. For a perfect fluid, this alternative dynamics predicts tenuous amounts of matter production or destruction, by a reversible exchange with the gravitational field. This exchange is completely determined by the dynamical equation and the scalar equation of the gravitational field. In contrast, the usual equation for relativistic continuum dynamics allows matter production only if some additional field is assumed, and the production rate must be phenomenologically postulated. With the alternative equation, the mass conservation is very nearly recovered for a weak field. The explosion (implosion) of a spherical compact body implies some matter production (destruction).

1. Introduction

Einstein's general relativity (GR) may be envisaged as a modification of Newtonian gravity (NG) to account for special relativity. The key to this modification is Einstein's equivalence principle between gravitational effects and inertial effects, which leads to admit that gravitation affects our space and time standards, thus giving a "curved space-time metric". Among the most striking experimental confirmations of this concept, we may quote the effects on light rays, i.e. the gravitational red-shift, the bending of light, and the delay of the radar echo – although a true "theory of gravitation in a flat space-time", thus without any curved metric, has been recently found, that reproduces the experimentally confirmed predictions of GR for light rays [1]. Now NG is a scalar theory, whereas GR is a tensor theory: in GR, the gravitational field is the space-time metric tensor, that involves 10 independent components. Some early attempts to account for special relativity (SR) in a modified version of NG were indeed scalar theories, including two theories restricted to static fields, proposed by Einstein [2-3] (see ref. 4 for an analysis, in the context of Kepler's problem and Mercury's advance in perihelion, of the successive theories studied by Einstein before he came to GR). However, a theory of gravitation that accounts for SR must replace the mass density, which is the source of the gravitation field in NG, by some energy density, and this precludes that any "relativistic" scalar theory may be a covariant theory. For the energy concept of SR does not lead to any invariant scalar field (even if one restricts oneself to Lorentz transformations); instead, it leads to a 4-vector, the mass current, and to a second-order space-time tensor, the energy-momentum tensor. Only the latter takes fully into account the mass-energy equivalence, and it is indeed the source of the field in GR.

Thus, any scalar modification of NG that aims at describing "relativistic" effects such as the mass-energy equivalence, must be a preferred-frame theory. But is it true that no sensible theory can have a preferred frame? Certainly, any "worthy" theory must have the correct Newtonian limit, hence it must recover the Galilean invariance in the limit of weak and slowly varying fields. Undoubtedly, it must be "relativistic" in the sense that "in the limit as gravity is "turned off", the nongravitational laws of physics must reduce to the laws of special relativity" [5]. Certainly also, any such theory must explain the three gravitational effects on light rays, because those effects are confirmed by precise and repetable experiments. It still should predict that gravitation propagates with the velocity of light and that, for a non-stationary insular matter distribution, gravitational energy is radiated towards outside, because we are now almost sure that it is indeed the case [6]. Although other experimental facts are relevant to gravitation [5], it seems interesting to note that the foregoing set of facts turns out to be accounted for by a certain scalar, preferred-frame theory without any adjustable parameter [7-8]. The same effects of gravitation on light rays are predicted as in GR at the current level of accuracy, because the theory predicts no preferred-frame effect for photons at the first post-Newtonian (pN) approximation [9]. Furthermore, this theory predicts a "bounce" instead of a singularity for the gravitational collapse of a dust sphere [7b]. The preferred-frame effects that this theory will predict for massive bodies, already at the first pN approximation, might contribute to explain the anomalous rotation curves in galaxies, currently interpreted [10] by appealing to large amounts of unseen matter. Moreover, it is not unreasonable to hope that these preferred-frame effects could explain why the empirically determined inertial frames have a uniform motion and, in particular, no rotation with respect to the average rest frame of matter ("Mach's principle" or rather Mach's problem). Of course, such effects also represent a risk as to celestial mechanics, especially for the explanation of Mercury's advance in perihelion. However, some astrodynamical constants such as the masses of the planets are in practice adjusted to fit the observations. Since this adjustment is theory-dependent, it has been argued that the existence of preferred-frame effects in celestial mechanics does not kill the theory [11] (the latter paper contains also a review of this theory).

In this theory, motion is governed by a natural extension of Newton's second law, which implies Einstein's geodesic motion only for a static field [8, 12]. This extended Newton law implies a local conservation equation for the total energy, including the gravitational energy which has a simple, physically understandable expression: this equation is first deduced for dust and then induced for a general behavior, characterized by any energy-momentum tensor [8]. The purpose of this paper is to derive similar equations for the momentum, thus obtaining a complete formulation of motion for a continuum, and to investigate one interesting consequence of this formulation: a reversible creation/destruction of matter for a perfect fluid in a variable gravitational field. In this course, some previous attempts to introduce a production of matter in more conventional theories of gravitation will be discussed.

2. Basic assumptions and main equations of the theory

2.1 The extension of Newton's second law

This extension may actually be defined for any theory endowing the space-time with a (pseudo-) Riemannian metric γ with $(+ - - -)$ signature and in which SR holds true at the local scale [12]. Then, in any possible reference frame F (defined by a spatial network of observers equipped with measuring rods and clocks), we have a spatial metric $\mathbf{g} = \mathbf{g}_F$ (it depends on the frame) and, at any point $\mathbf{x}$ bound to F, a local time $t_\mathbf{x}$ [13-14]. The latter may be synchronized [13-14] along any line $\xi \to (x^\alpha(\xi))$ in space-time, whose spatial projection is open, according to the relation

$$\frac{dt_\mathbf{x}}{d\xi} = \frac{\sqrt{\gamma_{00}}}{c}\left(\frac{dx^0}{d\xi} + \frac{\gamma_{0i}}{\gamma_{00}}\frac{dx^i}{d\xi}\right). \tag{2.1}$$

The *right-hand side* of Newton's second law is the time-derivative of the momentum $\mathbf{P}$, with

$$\mathbf{P} \equiv m(v)\,\mathbf{v}, \quad m(v) \equiv m(v=0).\gamma_v \equiv m(0).(1-v^2/c^2)^{-1/2} \tag{2.2}$$

the velocity $\mathbf{v}$ of the test particle (relative to the frame F) being measured with the local time $t_\mathbf{x}$ and its modulus v being defined with the space metric $\mathbf{g}$:

$$v^i \equiv dx^i/dt_\mathbf{x}, \qquad v \equiv [\mathbf{g}(\mathbf{v},\mathbf{v})]^{1/2} = (g_{ij}\, v^i\, v^j)^{1/2}. \tag{2.3}$$

The space metric $\mathbf{g}$ at a given point bound to F varies with time, except for a stationary space-time metric γ. Thus in general we have to define the derivative of a vector $\mathbf{w} = \mathbf{w}(\chi)$ attached to a point $\mathbf{x}(\chi) = (x^i(\chi))$ which moves, as a function of the real parameter χ, in a manifold equipped with a metric field $\mathbf{g}_\chi$ that varies with the parameter χ. (Here the manifold is the 3-D domain N = $\mathrm{N_F}$ constituted by the spatial network which defines the considered frame F, and the parameter χ is the synchronized local time $t_\mathbf{x}$ defined by Eq. (2.1).) Rather compelling arguments lead to the following unique definition [12] :

$$D\mathbf{w}/D\chi \equiv D_0\mathbf{w}/D\chi + (1/2)\,\mathbf{t.w}, \qquad \mathbf{t} \equiv \mathbf{g}_\chi{}^{-1}.\frac{\partial\,\mathbf{g}_\chi}{\partial\,\chi} \equiv \mathbf{g}^{-1}.\frac{\partial\,\mathbf{g}}{\partial\,x^0}\frac{dx^0}{d\chi}, \tag{2.4}$$

ensuring in particular that Leibniz' rule is satisfied for the derivation of the scalar product. In Eq. $(2.4)_1$, $D_0\mathbf{w}/D\chi$ is the absolute derivative with respect to the "frozen" metric $\mathbf{g}_{\chi_0}$, with χ_0 the "time" where the derivative is to be calculated; thus in coordinates:

$$\left(\frac{D_0\mathbf{w}}{D\chi}\right)^i \equiv \frac{dw^i}{d\chi} + \Gamma^i_{jk}\, w^j\, \frac{dx^k}{d\chi},$$

with $\Gamma^i{}_{jk}$ the Christoffel symbols of metric $\mathbf{g}_{\chi_0}$ in the space coordinates (x^i). Moreover, tensor $\mathbf{t}$ is a mixed tensor: $\mathbf{t} = (t^i{}_j)$ with $t^i_j = g^{ij}\, g_{jk,0}\, (dx^0/d\chi)$, thus $\mathbf{t.w}$ is the space vector with components $(\mathbf{t.w})^i = t^i_j\, w^j$.

The *left-hand side* of Newton's second law is just the force. This may be decomposed into a "non-gravitational" force $\mathbf{F}_0$, and a "gravitational" force or rather a mass force $\mathbf{F}_g$ ($\mathbf{F}_g$ may contain "inertial" forces as well, if a general reference frame is considered). In order that SR hold true locally and that the Newtonian equality between inertial mass and passive gravitational mass be preserved (an assumption which contains the implication that gravitation is a universal force), the mass force must have the following form:

$$\mathbf{F}_g \equiv m(v)\,\mathbf{g}, \tag{2.5}$$

where the "gravity acceleration" $\mathbf{g}$ should depend only on the position and the velocity of the test particle (the dependence on the velocity is expected in a general reference frame, since $\mathbf{F}_g$ should in general contain "inertial" forces). Hence, the general expression of Newton's second law is

$$\mathbf{F}_0 + m(v)\,\mathbf{g} = D\,\mathbf{P}/Dt_{\mathbf{x}}, \tag{2.6}$$

with $t_{\mathbf{x}}$ from Eq. (2.1) and $\mathbf{P}$ from Eqs. (2.2) and (2.3), the derivative being defined by Eq. (2.4). Different theories may thus differ already in the expression of the gravity acceleration $\mathbf{g}$. *In the present theory*, the expression of vector $\mathbf{g}$ is given only in the preferred reference frame E (the "ether") and does not contain any "inertial" term, it is

$$\mathbf{g} = -\frac{c^2}{2}\frac{\mathrm{grad}_{\mathbf{g}}\,\gamma_{00}}{\gamma_{00}}. \tag{2.7}$$

The frame E is assumed to admit a global synchronization, which means that the time coordinate x^0 may be chosen such that the γ_{0i} components cancel (cf. Eq. (2.1)). The expression (2.7) of the gravity acceleration $\mathbf{g}$ is covariant under coordinate changes that both leave the frame unchanged and keep this property true, i.e.

$$x'^0 = \phi\,(x^0), \quad x'^i = \psi^i\,(x^1, x^2, x^3). \tag{2.8}$$

Equations (2.6) (with the definition (2.2)) and (2.7) contain the manifest identity of the inertial mass and the passive gravitational mass, perhaps in a stronger sense than in GR. Indeed, using Eq. (2.6), one may calculate the gravity aceleration $\mathbf{g}_{\text{geod}}$ which is characteristic for Einstein's geodesic motion, and one finds that, even in a "globally synchronized" frame, $\mathbf{g}_{\text{geod}}$ depends on the velocity of the test particle [12]. In frames that are not globally synchronized, one would find additional velocity-dependent terms, of the "Coriolis" type, and the whole of the velocity-dependent part could in no case cancel in a finite domain (except for a constant gravitational field). This result means that *the Newtonian concept of an inertial frame is incompatible with Einstein's geodesic motion* in a variable gravitational field, because geodesic motion implies that the gravitational force contains inevitably inertial forces (unless an infinitesimal domain is considered). As a matter of fact, the "inertial-force free" gravity acceleration assumed in the present theory, Eq. (2.7), is in general *incompatible with geodesic motion*. Indeed, Eqs. (2.6) and (2.7) imply the following expression [12] for the 4-acceleration A^0 of a *free* test particle ($\mathbf{F}_0 = 0$):

$$A^0 = \frac{1}{2\gamma_{00}}\, g_{jk,0}\, U^j U^k, \qquad A^i = \frac{1}{2} g^{ij} g_{jk,0}\, U^0 U^k \quad (g^{ij} \equiv (\mathbf{g}^{-1})^{ij}), \tag{2.9}$$

(which is covariant by any coordinate change (2.8)). Here, by definition,

$$A^\mu \equiv \frac{dU^\mu}{ds} + \Gamma'^{\mu}_{\nu\rho}\, U^\nu U^\rho,\ U^\mu \equiv dx^\mu/ds,\ \ ds^2 = c^2\, d\tau^2 = \gamma_{\mu\nu}\, dx^\mu dx^\nu, \tag{2.10}$$

the $\Gamma'^{\mu}_{\nu\rho}$ symbols being the Christoffel symbols of metric γ in coordinates (x^μ). Geodesic motion ($A^\mu = 0$) is obtained only for a gravitation field that is constant in the preferred frame ($g_{jk,0} = 0$). Such a field is in fact a static field, because $\gamma_{0i} = 0$.

2.2 Assumed metric and field equation

An alternative form of Einstein's equivalence principle follows naturally from heuristic considerations about the assumed "ether" (or "physical vacuum"). This alternative principle [7] postulates a *correspondence between the "absolute" metric effects of uniform motion* (the FitzGerald-Lorentz space contraction and the Larmor-Lorentz-Poincaré-Einstein time-dilation) *and the metric effects of gravitation.* It leads to postulate a gravitational contraction (dilation) of space (time) standards [7], both in the *same ratio* $\beta \leq 1$. The space contraction occurs with respect to an assumed Euclidean space metric $\mathbf{g}^0$ for which the preferred frame is rigid. Thus, the following expression is assumed for the space-time metric, in coordinates bound to the frame E :

$$ds^2 = \beta^2 (dx^0)^2 - g_{ij}\, dx^i dx^j, \tag{2.11}$$

where the physical space metric $\mathbf{g}$ in the frame E is related to the Euclidean metric $\mathbf{g}^0$ by the gravitational contraction of measuring rods (hence the dilation of the measured distances) in the direction of vector $\mathbf{g}$ (Eq. (2.7)) only. The following expression for $\mathbf{g}$ is obtained in coordinates (y^μ) such that, at a given time t, y^1 = Const (in space) is equivalent to β= Const, and such that the natural metric $\mathbf{g}^0$ is diagonal, $(g^0_{ij}) = \mathrm{diag}\,(a^0_i)$:

$$(g_{ij}) = \mathrm{diag}\,(a_i) \quad \text{with} \quad a_1 = a^0_1 / \beta^2, \qquad a_2 = a^0_2\,, \quad a_3 = a^0_3. \tag{2.12}$$

To have a well-defined field β, one must fix the time coordinate x^0 in Eq. (2.11) (a well-defined "time-dilation" implies that the reference time t is not allowed to be stretched by a change $t' = \phi(t)$): we define $x^0 = ct$ with t the "absolute time". The absolute time is the local time measured at any point $\mathbf{x}_0$ which is bound to E and far enough from matter so that no gravitation field is felt there, i.e. $\beta(\mathbf{x}_0, t) = 1$ for any t. In general space coordinates, the assumed space metric may be rewritten, at a generic point where $\mathbf{g} \neq 0$, in the form [9]:

$$g_{ij} = g^0{}_{ij} + [(1/\beta^2) - 1]\, N_i\, N_j, \tag{2.13}$$

with $N_i \equiv \beta_{,i} / (g^{0\,kl}\, \beta_{,k}\, \beta_{,l})^{1/2}$. It is easy to show and interesting to note that, independently of the field equations, the metric (2.11)-(2.13) cannot be reduced to that assumed in Rastall's theory [15]. It is also quite easy to convince oneself, looking this time at the field equations also, that the present theory produces a metric which is in general deductible neither from Rosen's theory, nor from the Belinfante-Swihart-Lightman-Lee theory, nor from any "stratified theory" (see Will [5] and references therein). As well as the foregoing theories, the present theory may be qualified a "bimetric theory with prior geometry". Yet, contrary to the just-quoted theories, the present theory is *not* a "metric theory", although it does endow the space-time with a curved metric which is interpreted as the "physical" one (that measured with clocks and rods). Indeed, free particles do not follow geodesics of the curved space-time metric, except for a constant gravitational field (see Eq. (2.9)).

The scalar field of the theory is in general the "ether pressure" p_e, related to the field β by $\beta = p_e / p_e^\infty$, with $p_e^\infty = p_e^\infty(t)$ a "reference pressure" [7]. Except for cosmological problems, one may assume that p_e^∞ is a constant. Then the scalar field may be taken to be β or the square $f = \beta^2$ ($f = (\gamma_{00})_{\mathrm{E}}$, i.e. in coordinates bound to E and with $x^0 = ct$ and t the absolute time), and the field equation [7] may be rewritten [8] as

$$\Delta_0 f - \frac{1}{f}\left(\frac{f_{,0}}{f}\right)_{,0} = \frac{8\pi G}{c^2}\rho\ , \tag{2.14}$$

with $\Delta_0 \equiv \mathrm{div}_0\ \mathrm{grad}_0$ the usual Laplace operator, defined with the Euclidean metric $\mathbf{g}^0$, and where G is Newton's gravitation constant, and $\rho \equiv (T^{\,00})_{\mathrm{E}}$ is the mass-energy density in the preferred frame; $\mathbf{T}$ is the energy-momentum tensor in mass units.

3. Equations of motion and energy conservation for a continuum

We have to translate the equations of motion from a test particle to a continuum. It is worth to recall that, even in classical mechanics, this transition is not a rigorous mathematical deduction but a physical induction. To do this, we first consider dust, for which the induction is obvious: dust is thought of as a continuum made of coherently moving, non-interacting particles, each of which conserves its rest mass. Hence, we may use the expression (2.9) of the 4-acceleration. For a material continuum, we have $A^{\mu} = U^{\nu} U^{\mu}{}_{;\nu}$ (semi-colon means covariant derivative with respect to the space-time metric γ). For dust, we have moreover $T^{\mu\nu} = \rho^* U^{\mu} U^{\nu}$ with ρ^* the proper rest-mass density**,** and

$$(\rho^* U^{\nu})_{;\nu} = 0, \tag{3.1}$$

the latter expressing the conservation of the rest mass. We thus get for dust:

$$T^{\mu\nu}{}_{;\nu} = \rho^* U^{\mu}{}_{;\nu} U^{\nu} = \rho^* A^{\mu}, \tag{3.2}$$

whence by (2.9):

$$T^{0\nu}{}_{;\nu} = \frac{1}{2\gamma_{00}} g_{jk,0} T^{jk} \equiv b^0(\mathbf{T}), \qquad T^{i\nu}{}_{;\nu} = \frac{1}{2} g^{ij} g_{jk,0} T^{0k} \equiv b^i(\mathbf{T}). \tag{3.3}$$

According to the mass-energy equivalence, any material behavior, characterized by an energy-momentum tensor depending on some state variables, must obey the same dynamical equations when these are expressed in terms of tensor **T**. Hence, we postulate that Eq. (3.3) holds true, in the present theory, with **T** the *total* energy-momentum tensor of any kind of continuum (matter and non-gravitational field). Thus, in accordance with the fact that free particles do not generally follow space-time geodesics in the present theory, the "divergence" of tensor **T** does not automatically cancel as it does in GR. Instead, its expression is given, *in the preferred frame*, as a linear function $b^{\mu}(\mathbf{T})$ (which is a 4-vector for transformations of the form (2.8)). We now check two points.

(i) If our induction makes sense, the data of tensor **T** as a function of the state variables, together with the dynamical equation (3.3), must determine the dynamical behavior of a given continuum. If there is no gravitation field, Eq. (3.3) reduces of course to the classical equation of SR and, in the presence of gravitation, Eq. (3.3) means new dynamics. However, for dust, Eq. (3.3) together with $T^{\mu\nu} = \rho^* U^{\mu} U^{\nu}$ should imply the two characteristic features of dust motion, viz. mass conservation (Eq. (3.1)), and "free" motion, i.e., in the present theory, Eq. (2.9) (which is equivalent to assuming $\mathbf{F}_0 = 0$ in Eq. (2.6)). Substituting $(T^{\mu\nu})_{\text{dust}} = \rho^* U^{\mu} U^{\nu}$ in Eq. (3.3) obtains

$$\rho^* U^{\mu}{}_{;\nu} U^{\nu} + U^{\mu} (\rho^* U^{\nu})_{;\nu} = b^{\mu}(\mathbf{T}_{\text{dust}}). \tag{3.4}$$

We recall two identities (indices will be raised and lowered with the space-time metric □):

$$U^{\mu} U_{\mu} = 1, \qquad U^{\mu}{}_{;\nu} U_{\mu} = 0. \tag{3.5}$$

Contracting Eq. (3.4) with U_{μ} and using Eq. (3.5), we get indeed Eq. (3.1):

$$(\rho^* U^{\nu})_{;\nu} = b^{\mu}(\mathbf{T}_{\text{dust}}) U_{\mu} = (\rho^*/2)(g_{jk,0} U^j U^k U_0/\gamma_{00} + g_{jk,0} U^0 U^k g^{ij} U_i) = 0, \tag{3.6}$$

because, owing to the fact that $\gamma_{0i} = 0$, we have $U_0/\gamma_{00} = U^0$ and $g^{ij}\, U_i = -\, U^j$. Now, with Eq. (3.1), Eq. (3.4) becomes equivalent to Eq. (2.9).

(ii) It is useful to express Eq. (3.3) in terms of that flat space-time metric which is naturally defined in terms of the absolute time t and the Euclidean space metric $\mathbf{g}^0$, i.e.

$$(ds^{\,0})^2 \equiv \gamma^0_{\mu\nu}\, dx^\mu\, dx^\nu = (dx^{\,0})^2 - g^{\,0}_{ij}\, dx^i\, dx^j \tag{3.7}$$

in coordinates bound to the frame E and with $x^0 = ct$. In particular, we may use Cartesian space coordinates for metric $\mathbf{g}^0$, i.e. coordinates $(x^{\,i})$ such that $g^{\,0}_{ij} = \delta_{ij}$: in that case, we should recover the energy equation derived in a different way in ref. 8. We rewrite Eq. (3.3) as

$$T_\mu^{\ \nu}{}_{;\,\nu} \equiv T^{\,\nu}{}_{\mu\,;\,\nu} = b_\mu, \quad b_0(\mathbf{T}) \equiv \frac{1}{2} g_{jk,0}\, T^{jk}, \quad b_i(\mathbf{T}) \equiv -\frac{1}{2} g_{ik,0}\, T^{0k}. \tag{3.8}$$

Using the identity

$$T^{\,\nu}{}_{\mu\,;\,\nu} = \frac{1}{\sqrt{-\gamma}}\left(\sqrt{-\gamma}\; T^{\,\nu}{}_\mu\right)_{,\nu} - \frac{1}{2}\gamma_{\lambda\nu,\mu}\, T^{\lambda\nu} \qquad (\,\gamma \equiv \det(\gamma_{\lambda\nu})\,) \tag{3.9}$$

and the relation, valid for the assumed space-time metric (Eqs. (2.11) and (2.12)),

$$-\gamma = \gamma_{00}.g = f.\,(g^{\,0}/f) = g^{\,0} \qquad (\,g \equiv \det(g_{ij}),\ \ g^0 \equiv \det(g^0_{ij})\,), \tag{3.10}$$

one obtains from (3.8), in Cartesian coordinates $(x^{\,i})$ and with $x^{\,0} = ct$:

$$T_0^{\ \nu}{}_{,\,\nu} = \frac{1}{2} f_{,\,0}\, T^{\,00} \equiv \frac{1}{2} f_{,\,0}\, \rho, \tag{3.11}$$

$$T_i^{\ \nu}{}_{,\,\nu} = \frac{1}{2} f_{,\,i}\, \rho \; - \frac{1}{2} g_{ik,0}\, T^{0k} \; - \frac{1}{2} g_{jk,i}\, T^{jk}. \tag{3.12}$$

Equation (3.11) is the energy equation derived previously, Eq. (4.30) with $\lambda = 1/2$ in ref. 8. Using the field equation (2.14), the r.h.s. of Eq. (3.11) may be written as a 4-divergence with respect to the flat metric. This gives *a true conservation equation involving the gravitational energy*, which means that the sum of the gravitational energy and the energy of matter is indeed a conserved quantity [8]. So the complete system "matter" (i.e., material particles plus non-gravitational fields) and "gravitational field" is *isolated*.

We conclude that it is consistent, in the present preferred-frame theory, to postulate Eq. (3.3) (or Eq. (3.8)) as the general equation for continuum dynamics. Similar considerations allow us to obtain "gravitationally-modified" Maxwell equations [11]. Photon dynamics as governed by Newton's second law [8-9] is consistent with these modified Maxwell equations [11]. In what follows, we investigate a consequence of Eq. (3.3) for a perfect fluid.

4. Consequence: matter creation/destruction in a perfect fluid

4.1 Some remarks on matter creation in relativistic theories of gravitation

Obviously, one does not expect that a reasonable physical theory might lead to measurable amounts of matter creation in "usual" laboratory conditions, for this is not observed (although particle creation/annihilation is indeed observed in high-energy physics). However, in cosmological models trying to provide a picture of the origin and evolution of our universe, it should be explained also how ordinary matter as well as radiation could emerge from a "vacuum" or from an "initial singularity". Ironically, it seems that the first cosmological models involving matter creation were models in which the Universe does not evolve at all: the steady-state models, initiated by Bondi & Gold [16] and by Hoyle [17]. The reason is that, if one wants to have an expanding universe with constant density, then matter must be steadily produced, of course.

One could *a priori* expect that, in a "relativistic" theory of gravitation involving the mass-energy equivalence, the rest-mass should not be conserved in general (since this is already the case in SR) and that, more specifically, matter might be produced or destroyed by exchange with the gravitational energy, in a variable gravitation field [8]. Roughly speaking, however, one may say that matter creation does not occur naturally in phenomenological models based on GR or on similar relativistic theories. Most cosmological models assume a perfect fluid or even a dust, and the dynamical equation usually stated in relativistic theories of gravitation, i.e. $T_{\mu}^{\ \nu}{}_{;\nu} = 0$ (which, in GR, is a consequence of the Einstein equations) implies the following equation for a perfect fluid (see Chandrasekhar [18]):

$$(\rho^* U^\nu)_{;\nu} \left(1+\frac{\Pi + p/\rho^*}{c^2}\right) + \rho^* \frac{U^\nu}{c^2}\left[\Pi_{,\nu} + p\left(\frac{1}{\rho^*}\right)_{,\nu}\right] = 0, \tag{4.1}$$

with p the pressure and Π the internal energy per unit rest mass (we adopt the notations of Fock [19]). The second term is an invariant scalar, like the first one. It may be written as

$$\rho^* \frac{U^\nu}{c^2}\left[\Pi_{,\nu} + p\left(\frac{1}{\rho^*}\right)_{,\nu}\right] = \frac{\rho^*}{c^3}\left[\frac{d\Pi}{d\tau} + p\frac{d}{d\tau}\left(\frac{1}{\rho^*}\right)\right] \equiv \frac{\rho^*}{c^3}\, T\frac{d\sigma}{d\tau} \tag{4.2}$$

with T the temperature and σ the entropy per unit rest mass, and with τ the proper time of the fluid element, such that $dt/d\tau = U^0$ (note that $V_1 \equiv 1/\rho^*$ is the proper volume of the unit rest mass). If one assumes that the specific entropy is constant ($d\sigma / d\tau = 0$, as it should be the case for a "truly perfect" fluid), then the rest-mass is conserved and *vice versa* [18]. Therefore, matter creation has occurred only as an additional term so far, which is not determined by the model and should be phenomenologically postulated. This is the case for the well-known theory proposed by Hoyle [17] and by Hoyle & Narlikar [20], which modifies the Einstein equations through the introduction of a new field ("creation field"). This creation field is, however, assumed to have a form which allows to rewrite Hoyle's field equations as the usual Einstein equations, yet with a new energy-momentum tensor, modified by the creation field. This is also true for the model introduced by Prigogine *et al.* [21], who propose that cosmological matter creation should be analysed in the framework of thermodynamics of open systems. In this context, the adiabaticity condition for a perfect fluid does not correspond to isentropic transformation, instead it means entropy production in precisely the amount given by matter production. Indeed, one has in that case for an adiabatic transformation (cf. Eq. (5) or Eq. (16) in ref. 19):

$$\frac{d(\delta S)}{\delta S} = \frac{d(\delta N)}{\delta N}, \tag{4.3}$$

with δS the entropy and δN the number of particles in a volume element which is followed in its motion (note that the appearance of new particles, and/or the disappearance of some particles, do not forbid to define the velocity of the element, as the average of the velocities of those particles which are present at the current time). Hence, assuming some creation- rate function, the entropy evolution is determined. Equation (4.3) follows from the adiabaticity assumption (again, $d\sigma/d\tau = 0$ in (4.2)) and from the fact that, if the rest-mass δm_0 of the element is not conserved (and if the entropy of the volume element is calculated as $\delta S = \sigma.\ \delta m_0$), then the entropy variation is

$$d(\delta S) = d(\sigma.\ \delta m_0) = \delta m_0.\ d\sigma + \sigma.\ d(\delta m_0), \tag{4.4}$$

hence involves also that of δm_0 [22]. The second law of thermodynamics (written locally as $d(\delta S) \geq 0$), thus applied to an element with non-constant rest-mass, forbids matter *destruction*. This would not remain true if the specific entropy were not assumed constant, $d\sigma \neq 0$ [22]. However, if one does not assume that $d\sigma/d\tau = 0$, then one should account for heat exchanges inside the fluid. Note that, to be consistent with the Einstein equations, this formulation also must be constrained to predict no creation as the pressure p cancels, i.e., for a dust. However, Prigogine *et al.* [21] assume that, in the presence of matter creation, the phenomenological pressure, that enters tensor **T** in the equation $T^{\mu\nu}{}_{;\nu} = 0$, is not the true thermodynamical pressure but the sum of the latter and a (negative or nil) "creation pressure". With this reinterpretation of the pressure, a dust can be consistently considered in a cosmological model with matter creation.

Thus, in the theories proposed by Hoyle & Narlikar [20] and by Prigogine *et al.* [21], matter creation is made consistent with the Einstein equations through a reinterpretation of tensor **T** to involve an additional field, essentially a negative pressure. As a result, the creation rate (the relative deviation to mass conservation) is not determined by the Einstein equations and has to be phenomenologically postulated. Another consequence of assuming such additional field is that there is no conservation law for the energy any more (besides the fact that, already in standard GR, the status of the conservation law for energy and momentum is still today a matter of debate [23]). The same lack of energy conservation is also true in the theory proposed by Rastall [24] and rediscovered by Al-Rawaf & Taha [25], although this theory is more constrained than the former theories [20-21]: in the latter theory [24-25], the modification of the Einstein equations involves the introduction of merely one additional constant, noted α in ref. 25. Hence, when reinterpreting the alternative field equations [24-25] as the usual Einstein equations with an additional field, the latter field turns out to be a function of α and the usual tensor **T** (Eq. (16) in ref. 25).

In the cosmological context to which these theories have been applied, the assumed creation rate is more or less directly related to the parameters of the cosmological model, such as Hubble's constant. However, it is considered, at least by Prigogine *et al.* [21] and by Al-Rawaf & Taha [25], that the energy of the created matter is taken from the gravitational field. This is, as we shall see soon, what happens in the present theory, but it can hardly be very apparent in a model that phenomenologically postulates a creation term. It seems plausible that matter might be produced (or destroyed) by an exchange with the gravitational field − at least, this possibility seems interesting to investigate. But if this is the case, then it seems to us that such exchange should not be considered merely in a cosmological context, but actually for any gravitational field. Therefore, in what follows, we will not particularly consider a cosmological context.

Furthermore, one may perhaps ask whether the second law of thermodynamics really has to be applied to an element with non-conserved rest-mass in the form $d(\delta S) \geq 0$ with $d(\delta S)$ from Eq. (4.4). For this means that an entropy increase follows automatically from an increase in δm_0, i.e., matter creation *in itself* increases the entropy. Hence, in the case of "usual" irreversible processes (heat conduction, viscous dissipation, etc.), this interpretation of the second law would mean that those usual processes are allowed to *decrease* the entropy, thus $d\sigma < 0$ in Eq. (4.4), provided this decrease is at least compensated by a sufficient creation rate. In the approaches based on GR, the creation rate is not fully constrained by the dynamical equations and so is partly uncoupled from the dynamics of the materials that are present (the uncoupling is more pronounced for the theory of ref. 21 as for the theory of refs. 24-25). Hence, this interpretation would not completely forbid, for example, to produce some mechanical energy by taking heat from a cold source. The second law of thermodynamics has arisen in a context where mass conservation was applicable, and it seems to the author that its extension to a situation with non-conserved rest mass is not straightforward. To take the foregoing remarks into account, we propose that, in this new context, only the *rate* of entropy is unambiguously defined (this is partly true already in the usual context), in the form

$$\frac{d(\delta S)}{dt} \equiv \frac{d\sigma}{dt}\,\delta m_0 = \frac{d\sigma}{d\tau}\,\frac{\delta m_0}{U^0}\,, \tag{4.5}$$

where the *proper entropy rate per unit rest mass*, still (abusively) noted $d\sigma/d\tau$, is defined by the usual Gibbs equation, i.e., for a perfect fluid, simply

$$T\,d\sigma \equiv d\,\Pi + p\,d(1/\rho^*) \equiv d\,\Pi + p\,d\,V_1\,. \tag{4.6}$$

The entropy rate, thus defined, is an extensive quantity, and so also is the variation of the entropy in a given time interval $[t_1, t_2]$, which is well-defined by time-integration of Eq. (4.5). Of course, σ (defined up to a constant by time integration of $d\sigma/\,dt$) is *not* the specific entropy any more, unless the rest-mass is conserved. That is, the former relation $\delta S = \sigma.\delta m_0$ does not hold any more. The second law in local form, $d(\delta S)\,/\,dt \geq 0$, remains equivalent to $d\sigma/\,d\tau \geq 0$, as it was for conserved rest-mass. Equation (4.5) means that the creation or destruction of matter does not produce any entropy or, in other words, that usual thermodynamics applies to matter, independently of the creation/destruction. This is consistent with the notion that the energy for matter creation (destruction) should be taken from (given to) the gravitational field in a reversible way. The reversibility, in turn, is consistent with that of the gravitational equations.

4.2 Reversible matter creation/destruction in a variable gravitational field

The energy-momentum tensor of a perfect fluid is [19]

$$(T^{\mu\nu})_{\mathrm{fluid}} = (\mu^* + p/c^2)\,U^\mu U^\nu - (p/c^2)\,\gamma^{\mu\nu}, \tag{4.7}$$

where μ^* is the volume density of the rest-mass plus internal energy in the proper frame, expressed in mass units,

$$\mu^* \equiv \rho^*(1 + \Pi/c^2). \tag{4.8}$$

Both ρ^* and Π are in principle known functions of the state variables, which may include the pressure p and possibly also the temperature T. For instance, for a barotropic fluid, one assumes $\mu^* = \mu^*(p)$; then, ρ^* and Π also depend on p only, Π having the form [19]

$$\Pi(p) \equiv \Pi(p_0) + \int_{p_0}^{p} \frac{dq}{\rho^*(q)} - \left[\frac{q}{\rho^*(q)}\right]_{p_0}^{p} = \Pi(p_0) + \int_{p_0}^{p} -q\,dV_1 . \tag{4.9}$$

Such a fluid is then automatically isentropic in the classical sense, i.e. $d\sigma/d\tau = 0$, where $d\sigma/d\tau$ is defined by Eq. (4.6). Let us insert the tensor (4.7) into Eq. (3.3), contract with U_μ and develop the right-hand side using Eq. (3.5). We get:

$$T^{\mu\nu}{}_{;\nu}\, U_\mu = b^\mu(\mathbf{T}_{\text{fluid}})U_\mu = \frac{pU^0}{2c^2}\,\phi , \tag{4.10}$$

where it has been used the fact that $\gamma_{0i} = 0$, and with

$$\phi \equiv -g_{ij,0}\,\gamma^{ij} = g_{ij,0}\,g^{ij} = \mathrm{tr}\left(\mathbf{g}_{,0}.\mathbf{g}^{-1}\right) = \frac{g_{,0}}{g}. \tag{4.11}$$

Again with the help of Eq. (3.5), the left-hand side of Eq. (4.10) is calculated as

$$T^{\mu\nu}{}_{;\nu}\, U_\mu = (\rho^*\, U^\nu)_{;\nu} \left(1 + \frac{\Pi + p/\rho^*}{c^2}\right) + \rho^* \frac{U^\nu}{c^2}\left[\Pi_{,\nu} + p\left(\frac{1}{\rho^*}\right)_{,\nu}\right], \tag{4.12}$$

so that we obtain finally, using Eq. (4.2),

$$(\rho^*\, U^\nu)_{;\nu} \left(1 + \frac{\Pi + p/\rho^*}{c^2}\right) + \frac{\rho^*}{c^3}\, T \frac{d\sigma}{d\tau} = \frac{pU^0}{2c^2}\,\phi , \tag{4.13}$$

instead of Eq. (4.1). Equation (4.13) means that an *isentropic* process ($d\sigma/d\tau = 0$, as is necessarily the case if Eq. (4.9) is assumed) leads to *either creation or destruction of matter*, depending on the sign of the time-derivative $g_{,0}$ (see Eq. (4.11)), thus *depending on the evolution of the gravitational field*. Note that the specific form of the metric has not been used, and the field equation has not been used either. What has been used is Eq. (3.3), thus essentially Newton's second law (2.6) with the gravity acceleration (2.7), plus the "global synchronization" $\gamma_{0i} = 0$ and the **T**-tensor (4.7) of a perfect fluid. With the specific form of the space metric in the investigated theory, one finds (cf. Eq. (3.10)):

$$\phi = -\frac{f_{,0}}{f}. \tag{4.14}$$

Thus, in the present theory, matter creation occurs in a thermodynamically *reversible* way. Moreover, the created amount may indeed be lost again (or *vice versa*), provided the fluid is isentropic and the gravitation field f is alternating so that $f_{,0}$ changes sign. Since the sum of the energy of matter and the gravitational energy is conserved [8], one may say that the energy of the created matter is taken from the gravitational field, and indeed the r.h.s. of Eq. (4.13) depends directly on the variation of the gravitational field. However, the "pure energy of matter" does not reduce to the rest-mass energy, it also includes the kinetic energy and the energy of the non-gravitational fields. If the gravitational energy is, for instance, reduced, the way in which the gained matter energy is distributed over the different possible forms depends crucially on the constitutive equation. Hence, in the case of a barotropic and isentropic fluid, it depends on the $p-\rho$ relationship: e.g. in the limit of a dust, mass remains conserved (i.e., $p = 0$ and $d\sigma/d\tau = 0$ in Eq. (4.13) give $(\rho^* U^{\nu})_{;\nu} = 0$. Thus, for uncharged dust, the gravitational energy is exchanged only with kinetic energy).

A very important point is that matter creation/destruction is *entirely determined* by the dynamical equation (3.3), the equation of state (e.g. Eq. (4.7) with the appropriate expressions of ρ^* and Π), and the scalar field equation (e.g. Eq. (2.14) when the "reference ether pressure" p_e^∞ is constant). For example, if we consider a barotropic and isentropic fluid, we have five independent unknowns, say the pressure p, the "absolute velocity" $\mathbf{u} = d\mathbf{x}/dt$, and the scalar field f. And we have five independent equations, viz. the scalar field equation and the four components of the dynamical equation (3.3). (In this example, the state equation, thus Eqs. (4.7)-(4.9), is merely the definition of the tensor $\mathbf{T}$ as a function of the unique state variable p.) In standard GR, one has, for a such fluid, fourteen independent unknowns: the pressure p, the coordinate velocity with components dx^i/dt, and the ten components $\gamma_{\mu\nu}$ $(0 \leq \mu \leq \nu \leq 3)$ of the metric tensor − and one has fourteen independent equations: the ten Einstein equations (which imply the dynamical equation $T^{\mu\nu}{}_{;\nu} = 0$) and the four components of the gauge condition which is selected. Mass is then automatically conserved. In the theory of Hoyle & Narlikar [20], as well as in the theory of Prigogine *et al.* [21], one has one unknown more, viz. the scalar creation field C in the former and the creation pressure p_c in the latter, but the additional equation must be phenomenologically provided. In the theory [24-25], the creation rate depends on the constant α [25], which is not constrained by the crucial tests of GR [24-25] and so remains a phenomenological parameter that plays a role in the context of cosmological models.

4.3 Mass conservation

Since here the amount of matter creation is entirely determined by the dynamical behavior of matter, we have to check whether this amount is consistent with what is found in usual laboratory conditions, namely mass conservation. To this end, we investigate the situation in the solar system, with a weak and slowly varying gravitation field f, so that [7b]

$$f \approx 1 - 2U/c^2, \qquad f_{,0} \approx -2U_{,0}/c^2, \tag{4.15}$$

with U the Newtonian potential, obeying the Poisson equation

$$\Delta_0 U = -4\pi\, G\, \rho_N \tag{4.16}$$

(here ρ_N is the Newtonian mass density, more exactly it is the approximation of the rest-mass density which is found at the first, "Newtonian" approximation of the theory [9]). From (4.15), the number ϕ, Eq. (4.14), is calculated to first-order (in U_{max}/c^2 [9]) as

$$\phi \approx \frac{2}{c^3}\frac{\partial U}{\partial t}. \tag{4.17}$$

To the same approximation, we have $U^0 \approx 1$ (since the velocity satisfies $u^2 = O(U)$), and we have rigorously

$$(\rho^* U^\nu)_{;\nu} = \frac{1}{c}\left(\frac{\partial \rho_{00}}{\partial t} + \mathrm{div}_0\left(\rho_{00}\mathbf{u}\right)\right) \equiv \frac{1}{c}\hat{\rho} \tag{4.18}$$

with $\rho_{00} \equiv \delta m_0 / \delta V^0$ the density of rest-mass evaluated in the preferred frame and with "uncontracted" measuring rods [8] ($\delta V^0 \equiv \sqrt{g^0}\, dx^1\, dx^2\, dx^3$ is the volume element with the Euclidean space metric bound to the preferred frame; anyway, $\rho_{00} \approx \rho^* \approx \rho$ at this approximation). It is easy to show, from the definition (4.18), that

$$\frac{d}{dt}\left(\int_\Omega \delta m_0\right) = \int_\Omega \hat{\rho}\, \delta V^0, \tag{4.19}$$

for any domain $\Omega(t)$ which follows the fluid motion. From (4.13) and (4.17), we obtain to first-order, in the case of an isentropic fluid:

$$\hat{\rho} \approx \frac{p}{c^4}\frac{\partial U}{\partial t}. \tag{4.20}$$

It is important to recall that, in this equation, the time derivative of the Newtonian potential has to be taken in the preferred frame (« ether »). We may take as a working assumption that the ether frame is bound to the mean motion of matter, which is consistent with the present theory [8]. To take this assumption into account, we may further assess the absolute velocity V of the mass center of the solar system by assuming that the ether frame is at rest with respect to the cosmic microwave background. Then V is approximately 300 km/s [5]. One may consider, however, that the exact value of V has to be determined internally to the present theory, from the non-Newtonian effects of V on celestial mechanics that this theory will predict [9] (no effect of V on light rays appears in the pN approximation [9]). In any case, it is very reasonable to assume that the velocity V is constant, i.e., does not vary significantly over e.g. a century, and is not greater than, say, $10^{-3}\,c$.

If V is indeed that large, the main contribution to $\partial U/\partial t$ is, by far, that which is due to this translation of (nearly spherical) solar bodies through the assumed ether:

$$\frac{\partial U}{\partial t} \approx -\nabla U.\mathbf{V} \approx g\, V_r \qquad (V_r \equiv \mathbf{V}.\mathbf{e}_r), \tag{4.21}$$

with M the mass of the body whose attraction g ($g = GM/r^2$ outside the body) dominates locally. Finally, assuming a uniform density for simplicity (this does not alter order-of-magnitude estimates of quantities like gp/ρ, which is relevant here):

$$C \equiv \frac{\hat{\rho}}{\rho} \approx \frac{p}{c^2\rho}\,\frac{GM}{c^2 R}\,\frac{r}{R}\,\frac{V_r}{R} \tag{4.22}$$

with R the radius of the body (note that, at the surface of the body, the validity of Eq. (4.22) does not depend on the assumption of uniform density). The first thing we observe is that V_r has zero average on each sphere r = Const, and since p is constant on such a sphere, the creation rate C has also a nil average on the sphere. Moreover, if we consider a fixed element of fluid in the spherical body, then this element is involved in the self-revolution of this body and in the revolution of the body around the mass center of the solar system. Hence, especially at low latitudes, the time average of matter creation $\langle C \rangle$ for a material element will be considerably smaller than the maximum value $C_{\max}(r)$ on the relevant sphere r = Const, which is obtained for $\mathbf{e}_r$ parallel to $\mathbf{V}$ and in the same direction. (However, at the poles, both g and V_r are nearly constant; so creation would steadily occur at one pole, and destruction at the other pole.) Therefore, it could be not enough to accumulate the time in order to detect this hypothetical matter creation in a laboratory experiment. Now let us assess the maximum value of the creation rate C. To be very concrete, consider first the air on the surface of the Earth: $GM/(c^2R) \approx 7.10^{-10}$, at the atmospherical pressure: $p \approx 0.1$ MPa, $\rho \approx 1.3$ kg/m^3, thus $p/(c^2\rho) \approx 10^{-12}$, whence $C_{\max} \approx 3.\ 10^{-23}$ s^{-1} (with $V \approx 300$ km/s), that is twenty molecules per second in a mole, which seems very difficult to detect. If we consider other fluids near the surface of the Earth, e.g. water in the ocean deeps, then the p/ρ ratio and so the C value do not take significantly higher values. The application of Eq. (4.20) to material behaviors that deviate strongly from that of a perfect isentropic fluid would have to be examined cautiously, of course, but still this would lead to similarly tenuous values of C. Thus, it does not seem *a priori* impossible that, so far, one might have failed to detect a more or less cyclic deviation to the mass conservation, due to a variable gravitational field and governed by Eq. (4.20).

Whether it could be indeed detected if it would be searched for seriously, is a different question. Clearly, a positive answer would represent some change in physics.

The highest value of the creation rate predicted by Eq. (4.22), in the solar system, is in the medium layer of the Sun: $GM/(c^2R) \approx 2.10^{-6}$, $p/(c^2\rho) \approx 5.10^{-7}$, $R \approx 7.10^5$ km and $r/R \approx 0.5$, hence $C_{\max} \approx 2.\ 10^{-16}\ \mathrm{s}^{-1}$ (with $V \approx 300$ km/s). Although very small, such a fraction would mean large amounts of energy. Recall, however, that C averages to zero on each sphere r = Const. The physics inside the Sun is, of course, difficult to check by direct experimental means.

4.4 The case of a highly compact spherical object in implosion or in explosion

In order to get a purely qualitative idea of the kind of predictions that the present theory could make in situations where some would indeed like to see matter creation occur, we begin to investigate the case of a spherical object at an extreme density. According to the concept of "constitutive ether" that heuristically underlies the theory [7-8], elementary particles should be locally organized flows in a perfectly fluid "micro-ether" (or physical vacuum, or subquantum medium; the preferred frame of the theory would be defined by the average motion of this micro-ether). Note that this concept would allow to get some intuitive understanding of the quantum inseparability, in the sense that even a locally organized flow is not fully distinct from the rest of the fluid, hence from the neighbouring "particles" (organized flows). If this is the case, then, when the density of matter reaches very high values, the elementary particles (organized flows in the ideal fluid) are so close to each other that all the fluid is involved in those flows, that is, matter is comoving with ether (in the domain occupied by the compact object).

Therefore, we assume, as an approximation for highly dense astronomical objects, that matter is comoving with the preferred frame, i.e., *matter is at rest in the preferred frame*. In particular, the radius R of the spherical compact body, as evaluated with the "abstract" Euclidean metric $\mathbf{g}^0$, is *constant*. But this does *not* mean that its physical radius R' is constant, for R' is evaluated with metric $\mathbf{g}$, that is affected by the gravitation field f, which may be highly variable. In the spherical coordinates $x^1 = r$, $x^2 = \theta$, $x^3 = \varphi$, the Euclidean metric is (g^0_{ij}) = diag (a^0_i) with $a^0_1 = 1$, $a^0_2 = r^2$, $a^0_3 = r^2 \sin^2\theta$, and we have $f = f(r, t)$, hence from (2.12):

$$R' = \int_0^R \frac{dr}{\sqrt{f(r,t)}}\ , \tag{4.23}$$

whence

$$\frac{dR'}{dt} = \int_0^R -\frac{\partial f / \partial t}{2 f^{3/2}} dr. \tag{4.24}$$

If the body undergoes an *explosion*, thus $dR'/dt > 0$, Eq. (4.24) shows that $-\partial f/\partial t > 0$ (assuming for simplicity that $\partial f/\partial t$ does not change sign inside the body). Hence, this means $\phi > 0$ in (4.14). And from (4.13) (with $d\sigma/d\tau = 0$), this in turn means matter is being *produced* ($\hat{\rho} > 0$). Similarly, if there is an *implosion*, then matter is being *destroyed*. Thus, according to this theory, an explosion of a very dense astronomical object (a mini big-bang, as envisaged by Hoyle *et al.* [26]) would indeed produce matter. This would occur automatically, i.e. without any phenomenological creation term.

5. CONCLUSION

We first recalled a previous result [12], according to which, for any theory of gravitation that endows space-time with a (+ − − −) metric, and in any possible reference frame, one may uniquely define the right-hand side of Newton's second law, i.e. the time derivative of the momentum. Different theories may predict different metrics in the same physical situation, but, more fundamentally, they may differ in the left-hand side, i.e. essentially in the gravity acceleration **g** (Eq. (2.6)). In general relativity (GR), in fact in all theories assuming geodesic motion, **g** depends on the space-time position *and* on the velocity, in the given arbitrary reference frame, of the matter subjected to gravitation. In contrast, the investigated ether theory assumes expression (2.7) for **g**, which depends only on the time and the spatial position − and precisely this can be true only in some preferred reference frame, for theories that take special relativity into account. It is this very assumption that determines the general equation for continuum dynamics in the present theory, Eq. (3.3) or (3.8), as well as the equation for reversible matter creation in a perfect fluid, Eq. (4.13).

In view of this latter equation, the investigated theory predicts that matter may really be produced or destroyed, due to the variation of the gravitational field. Although it is sometimes alleged that matter might be produced in this way, we have tried to summarize the reasons why things can hardly happen so simply in GR: due to the equation for continuum dynamics that goes with geodesic motion, i.e., $T^{\mu\nu}{}_{;\nu} = 0$, matter can only be produced if one inserts an additional term, which is not determined by the dynamical equation. Our main conclusion is thus: *although the mass-energy equivalence makes it plausible that matter might be produced by an exchange with a variable gravitational field* (in a theory with conserved energy), *this can occur in a natural and definite way only in a preferred-frame theory like the* *present one.* Now the way in which this matter production occurs may seem dangerous for a such theory, because it would mean that matter is continuously produced or wasted away under our eyes. However, the rates would be extremely small and often would be rather close to cyclic. Hence, it might be the case that this new form of energy exchange is possibly something real. Needless to emphasize, this would be interesting. In the case of a highly compact spherical body, the present theory says that some matter production should be associated with an explosion, and conversely some destruction with an implosion.

Endnotes

1 Greek indices will vary from 0 to 3, Latin ones from 1 to 3 (spatial indices). Here, (x^μ) is a coordinate system bound to the frame F, i.e., such that the observers of the network have constant space coordinates x^i, and c is the velocity of light.

2 This is not defined if $\mathbf{g} = 0$ at the point considered, because $\mathbf{g} = -c^2 (\mathrm{grad}_\mathbf{g}\, \beta)/\beta$ (see Eqs. (2.7) and (2.11)). Generically, vector **g** will vanish at isolated points. At any such point **x**, metric **g** is discontinuous, but it remains bounded in the neighborhood of **x** : no theoretical difficulty occurs, see ref. 9.

3 This is potentially a deadly test for the theory, of course. In contrast, models which predict matter creation as a phenomenological term may adjust this term to match with some cosmological scenario. These models also have to deal with the additional constraint that matter creation must be negligible in everyday life, but this constraint is not a severe one, at least as far as a simple cosmological model is envisaged, i.e., a homogeneous and isotropic universe. However, one may say that any theory, in which matter creation would occur really from an exchange with the gravitational field, would have to pass this potentially deadly test.

4 If it happens that $\rho(\mathbf{x} + \mathbf{V}T, t + T) = \rho(\mathbf{x}, t)$, then one has exactly $\langle \partial U/\partial t \rangle = -\langle \mathbf{V}.\nabla U \rangle$ for the time averages over the period T at a given material point.

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