The Scalar Ether-Theory of Gravitation and Some Implications

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The motivations for a theory of gravitation based on a new concept of ether are detailed: i) This concept of ether extends the Lorentz-Poincaré concept. It is hence compatible with special relativity (SR), actually the investigated theory reduces to SR if the gravitational field evanesces. ii) In this ether theory, quantum and gravitational concepts would match more easily. iii) Some problems of standard gravitation theory are or might be avoided. The construction of the theory is reviewed. 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 2nd law. The current status of the observational confrontation is favourable: there is a correct Newtonian limit; gravitational effects on light rays are as in standard general relativity; isolated systems radiate quadrupole gravitational radiation. In celestial mechanics, there are preferred-frame effects. This is shown *a priori* compatible with an improvement over Newton's theory. Current work aims at checking this. The theory makes new predictions as to gravitational collapse and cosmology, and predicts matter creation or destruction.

1. Motivations for an ether theory of gravitation

The aim of this contribution is to summarize the motivation, the construction and the present status of a *scalar* theory of gravitation, which is a preferred-frame theory based on a new concept of ether. We shall begin with an account of the current motivation for reintroducing an ether.

1.1. The first reason is **to extend the *Lorentz-Poincaré ether theory* to gravitation.** Still today, most physicists believe that the concept of ether is an obsolete one that has been disproved by Einstein when he presented special relativity (SR). It is yet rather well known that Einstein had "precursors", including such luminaries as Larmor, Lorentz, and Poincaré, and that *all* of these precursors *considered an ether.* The information that seems difficult to circulate is this: at the end of June 1905, when Einstein sent his famous work on SR [1], the collective work of those leading theoreticians over almost two decades had finally led to Poincaré's paper appeared on June 9, 1905 [2], that contains the major results of SR. We refer the reader to the monograph of Logunov [3] for a definitive proof that all of special-relativistic dynamics and electromagnetism, including the Lorentz group and the introduction of space-time, is in Poincaré's papers [2] and [4] (the former paper being a detailed summary of the later one, received on July 23, 1905, and which is a monumental paper). Here we wish to briefly comment on the "relativity of simultaneity". First in 1900 [5], and in a more detailed manner in 1904 [6], Poincaré introduced the synchronization of clocks in an inertial frame by exchange of light signals. In 1902, he explicitly noted the conventional character of the notion of simultaneity [7].

However, Poincaré did not explicitly comment on the relativity of the simultaneity which is thus defined (*i.e.,* on the fact that observers in different inertial frames will disagree on the temporal ordering of events that are separated by a space-like interval), and he designated the time defined by clock synchronization in the ether frame as the "true time". This has been often taken to mean that "Poincaré's theory was not really relativistic". As stated by Hertz about Maxwell's theory, however, "a [physical] theory is defined by the set of its equations". Since the equations of Poincaré's papers [2,4] *are* the equations of SR (as one may easily recognize once modern notations are substituted for Poincaré's [3]), it follows that Poincaré's theory is *physically* identical to SR. Yet it is true that Poincaré's version of SR differs from Einstein's at the meta-physical level, in that Poincaré prefers to consider that, only in one among the infinitely many inertial frames, the measured "local time" does coincide with the "true time".

Thus, the physical theory of special relativity has been first proposed by Poincaré as the final touch on a long work, all by ether theorists. Among those, the most important ones were certainly Lorentz and Poincaré, therefore we may call the ether version of SR the "Lorentz-Poincaré ether theory". This may be characterized as the theory according to which the ether is an inertial frame E in which Maxwell's equations are valid, and such that any material object that moves through E undergoes a "true" Lorentz contraction. (Here, "true" means: as evaluated in the frame E and, in particular, using the "true" simultaneity defined with the "true time".) Now, precisely because the Lorentz-Poincaré ether theory does lead to all equations of SR, it makes the ether indetectable. It may seem, then, that the concept of ether is not necessary to SR from a physical point of view, and hence that this concept may be suppressed. (This was Einstein's opinion in 1905 [1], but not any more in 1922 [8].) But, apart from the important fact that the Lorentz-Poincaré version has the advantage over Einstein's from the viewpoint of intuitive understanding and "paradox" resolution [9,10], there is a fundamental reason why it might be necessary to adopt the former version. As Lorentz and Poincaré themselves recognized, one day the relativity principle could be falsified by some experiment. In a such case, the interpretation of SR as due to the Lorentz contraction might be saved: only that some other physical phenomenon would intervene to break the Lorentz symmetry. But, clearly, Einstein's construct based on the relativity principle as a universal starting point could not survive. Some physicists consider the possibility that the Lorentz symmetry might be a low-energy limit in particle physics [11]. The present author is investigating another possibility – namely, that the ether might be detected by its gravitational effects. Thus, the relativity principle would be valid in SR only because the gravitational field is neglected there, and the correct theory of gravitation would be a preferred-frame theory. (Already in Einstein's general relativity (GR), the Lorentz symmetry, as a symmetry acting on the space-time manifold itself, is broken by gravitation *i.e.* by space-time curvature, but no *a priori* preferred frame does exist in GR.) As we shall see, the investigated theory, while still not proved entirely viable, has passed all the tests to which it has already been possible to confront it, and it has some positive points as compared with GR.

1.2. The second reason to reintroduce an ether is **to make quantum theory and gravitation theory compatible.** It seems to become more and more apparent that the search for "quantum gravity", *i.e.* for a quantized version of GR, leads to unsolvable difficulties. But the difficulties begin actually before one tries to quantize GR: there are different, incompatible ways to extend quantum mechanics of material particles and non-gravitational fields to the situation with gravitation. To the author's knowledge, there is not a unique way to write even the free Klein-Gordon equation in GR. If one tries to simply rewrite the free K-G equation in a covariant way, one is faced with the problem that covariant derivatives do not commute, which leaves different, non-equivalent possibilities, since the K-G equation is second-order. If one starts from the relation for the invariant length of the 4-momentum ($g^{\mu\nu}\, p_\mu\, p_\nu = m_0^2\, c^2$) and tries to rewrite it as an operator equation using the standard quantum correspondence, one is confronted with the fact that (i) there are no preferred coordinates (x^μ) in GR, and (ii) even in a given coordinate system (x^μ), the quantum correspondence is ambiguous when applied to the above relation, because the latter contains $g^{\mu\nu}$ that depends on the coordinates x^ρ: since the momentum and position operators do not commute, the operator on the left-hand side depends on the order in which the products are written. However, in the preferred-frame theory which will be presented in this contribution, there is only one extension of the free K-G equation to the situation with gravitation, and the way of extension has a general form that should allow to propose an extended equation also for *different* wave equations [12]. There are general arguments according to which a "preferred space-time foliation", *i.e.* an ether, *might* allow to extend quantum theory to the situation with gravitation [13-14]: here we have the beginning of a concrete realization of this program. Finally, in the context of the investigated ether theory, the indication is that there is no need for a quantization of gravitation whatsoever [12], which would be an elegant solution to the problem ...

1.3. A third reason for trying a very different theory of gravitation is **just as one possibility to solve some serious problems that exist in GR as a theory of gravitation:**
i) *The unavoidable existence of singularities in GR, e.g.* in gravitational collapse and in cosmology. In GR, one is enforced to give a physical status to such catastrophical predictions as the one according to which a very massive star must end its life in a point singularity, as also to that other one, which states that the whole Universe started from a point singularity. Such predictions can hardly be considered plausible. In the case that different theories could explain experimental facts while avoiding such "physical singularities", one certainly should prefer them over GR. And some alternative theories do avoid singularities. For instance, the "relativistic theory of gravitation" (RTG), developed by Logunov and coworkers [15-16], predicts that the collapse of a dust sphere begins with an implosion (as in GR), but then the implosion is stopped and is followed an explosion (in the case of a massive graviton) [17]. Just the same kind of "bounce" (though with different details) is predicted in the same situation by the proposed ether theory (without any graviton) [18]. It should be noted that the end in a singularity and the formation of a black hole are two different things. It is well-known that black holes, defined as objects from which no material object − even light − can escape, were predicted within Newton's theory. Moreover, some observed characteristic features in spectra might reveal the real existence of astronomical black holes [19]. In the investigated ether theory, it turns out that a kind of black hole is formed during the second (*exploding*) stage of the "collapse" in free fall, in the sense that a photon emitted inside the body would take an infinite time to get out [unpublished result]. In cosmology also, there is no singularity in the investigated theory (see Section 4 below).

ii) *The problem of the interpretation of the gauge condition in GR.* It is now widely known that the Einstein equations of GR (together with appropriate *boundary* conditions) do not determine unambiguously one Lorentzian metric γ on a given space-time manifold V (this was well-known to Einstein [20]). Instead, the Einstein equations determine an equivalence class of couples (V, γ) modulo the equivalence relation " (V, γ) ~ (V', γ') if there is a diffeomorphism of V onto V' that transforms γ to γ'. " [13-14, 20-22] In short, it means that "points of space-time (events) are not individuated apart from their metrical properties." [20] But it would be extremely difficult to implement this mathematical interpretation in the solution of concrete physical problems. Instead, 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 γ on that manifold [23-26]. In other words, one augments the Einstein equations with four equations. To the author's knowledge, it has not been attempted to establish a precise link with the former interpretation of GR. In the static case with spherical symmetry, and with the usual boundary conditions (ensuring that the behaviour is "Galilean at infinity"), it has been proved that the physical predictions do depend on the particular solution of the Einstein equation which is chosen [16]. To escape that situation, one would have to implement the former mathematical interpretation in the solution of physical problems – a formidable task – or, alternatively, one may try to justify the selection of a particular gauge condition *once and for all.* The latter solution is close to the RTG. In the RTG, a *generally-covariant* form of the harmonic condition is derived from specific assumptions, including that of a flat "background metric" [15-16]. In the scalar theory envisaged here, as in the RTG, the space-time manifold is given and it is endowed with a flat "background metric" γ^0 – but, due to the scalar character, there is no need for a gauge condition.

iii) *The necessity to postulate unseen matter in order to explain observed motions at large scales.* The curves indicating the rotation velocities v of stars (resp. of galaxies) around the centre of their galaxy (resp. of their cluster of galaxies), as a function of the distance *r* to the centre, are puzzling in regard of standard gravitation theory, *i.e.* GR, which, for that matter, is replaced by Newton's theory (as a weak-field limit): v does not fall off quickly enough with *r*, and instead remains nearly constant up to very large distances. This could be compatible with standard gravitation theory only if huge amounts of unseen matter were present. After enormous efforts, it now seems that well-identified candidates for that "dark matter" are far to be found in sufficient amounts. May be it is simply standard gravitation that fails at the scale of galaxies and beyond [27]. In the scalar ether-theory, there are preferred-frame effects and, although these effects are very small for usual tests in the solar system (as it will be precised in § **3.1** below), they are likely to play a more significant role at the scale of a galaxy: the reason is the very long time scales involved, of the order of 10^8 years, that should allow these effects to accumulate.

2. Principles of the theory

2.1 Ether as a perfect fluid and the preferred reference frame

In the investigated theory, a concept of the ether as a perfect fluid is considered. This concept is used in a semi-heuristic way: by some deductions from this concept, a self-consistent set of equations is proposed. It is this set of equations that has then to be assessed on the basis of the physical predictions that it implies, and their comparisons with observations. The author does not adhere to a purely realistic view of physics, but is closer to a constructivist one (in the sense discussed by Lipkin [28]), and, unlike Romani [29], he does not think that a simplistic idea as that of a perfect fluid of Newtonian mechanics could account for all phenomena in the physical Universe. Yet he believes that there is *some truth in the analogy discussed below,* and that this truth is deep enough to hope that a good model of gravitation may be derived from it. According to this analogy, the ether or rather the "micro-ether" would be a *space-filling* perfect fluid, *continuous at any scale,* so that neither temperature nor entropy can be defined for that fluid, thus a *barotropic* fluid for which a one-to-one relationship between pressure and density must exist, $p_e = p_e(\rho_e)$ [29]. Material particles should be *organized flows* in that fluid, such as vortices, which may be everlasting in a perfect fluid [29]. (Due to the lack of place, we shall not discuss further that very interesting idea here, although it plays a role [18,30] in arriving to equation (2.2) for the gravity acceleration.) But, at the same time, *the average motion of that fluid defines a preferred reference body* or "macro-ether", which plays the role of the Lorentz-Poincaré rigid ether. This is a new feature [30-32] as compared with Romani's concept [29]. Formally speaking, one starts from space-time as a flat (or possibly constant-curvature) Lorentzian manifold V, endowed with its natural metric $\boldsymbol{\gamma}^0$. In what follows, we shall assume that it is flat, for simplicity. Then, the Lorentz-Poincaré ether is one particular inertial frame for the flat metric $\boldsymbol{\gamma}^0$; this means that there is a global chart (coordinate system)[1] $\chi : X \mapsto (x^\mu)$ from V onto the arithmetic space $\mathbf{R}^4$, such that $(\gamma^0_{\mu\nu}) = (\eta_{\mu\nu}) \equiv \mathrm{diag}(1, -1, -1, -1)$ in the chart χ, and such that the three-dimensional body (manifold) "macro-ether", denoted by M, is the set of the world-lines " $x^i = \mathrm{Const} = a^i$ (i = 1, 2, 3), x^0 arbitrary. " Thus each point of M may be defined by a 3-vector $\mathbf{x} \equiv (x^i)$. The ratio $t \equiv x^0/c$ is called the "absolute time", where c is a constant (the velocity of light). The assumption that M is defined by the average motion of the fluid micro-ether may be expressed formally as follows: let $\mathbf{u}_e \equiv \mathrm{d}\mathbf{x}/\mathrm{d}t$ be the absolute velocity of the micro-ether; *the asymptotic volume average of* $\mathbf{u}_e$ *at point* $\mathbf{x} \in$ M,

$$\langle\, \mathbf{u}_e \,\rangle_\mathbf{x} \equiv \lim_{R\to\infty} \int_{\mathrm{B}(\mathbf{x},\, R)} \mathbf{u}_e \, \mathrm{d}V^0/(4\pi R^3/3) \qquad (2.1)$$

is well-defined and zero at any $\mathbf{x}$ [32]. Here, B($\mathbf{x}$, R) is the Euclidean ball with radius R, centered at $\mathbf{x}$, and V^0 is the Euclidean volume measure, both referring to the Euclidean metric $\mathbf{g}^0$ defined on the space M by $g^0{}_{ij} = \delta_{ij}$ in the chart χ. The global reference frame defined by all observers bound to the macro-ether is the preferred frame of the theory, and shall be denoted by E.

2.2 Basic equations for the field of ether pressure

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

In this Subsection, we provisionally assume that mechanics can be formulated directly in terms of the Euclidean metric $\mathbf{g}^0$ and the absolute time t (see § 2.3). The gravitation force is tentatively interpreted as Archimedes' thrust in the fluid ether. This leads to define a "gravity acceleration vector" **g** as follows [18,30]:

$$\mathbf{g} = -\frac{\mathrm{grad}\, p_e}{\rho_e} \,. \tag{2.2}$$

Although derived from that tentative interpretation, eq. (2.2) is taken as an exact phenomenological equation of the theory. Note that it implies that p_e and ρ_e *decrease* towards the attraction. Moreover, since the gravitational force varies only over macroscopic distances, p_e and ρ_e must be the macroscopic pressure and density in the fluid ether. Because Newtonian gravity (NG) propagates with infinite velocity, it must correspond to the special case where the fluid is incompressible, $\rho_e = \rho_{e0}$ = Const. From eq. (2.2), it follows that Poisson's equation and the whole of NG are exactly recovered in that case, if and only if the field p_e obeys the following equation:

$$\Delta\, p_e = 4\pi\, G\, \rho\, \rho_{e0}, \tag{2.3}$$

where ρ is the mass density and G is Newton's gravitational constant. But, in the proposed theory, the fluid is barotropic, hence NG must be recovered asymptotically in situations where the effect of the compressibility can be neglected. Now any motion of massive bodies causes a disturbance in the gravitational field, thus in the field of ether pressure p_e, and, with a compressible ether, this disturbance in the field p_e cannot propagate instantaneously and instead should propagate as a pressure wave, so that a non-static situation is obtained. Therefore, the limit where NG is a correct approximation must correspond to quasi-static situations. On assuming, moreover, that the ether is conserved and that the disturbed motion of the ether, *i.e*. its motion *with respect to the "macro-ether"* which defines the preferred frame, obeys Newton's second law, one is led to the following equation for the general, non-static situation [30]:

$$\Delta\, p_e - \frac{1}{c_e{}^2}\frac{\partial^2 p_e}{\partial t^2} = 4\,\pi\, G\, \rho\, \rho_e, \tag{2.4}$$

where $c_e = c_e\,(\rho_e)$ is the velocity of the pressure waves – *i.e.*, of the *gravitational waves* – in the barotropic ether. (But that new theory differs from NG, hence G cannot have exactly the same significance and value as in NG.)

2.3 Principle of equivalence between the metric effects of motion and gravitation

In the Lorentz-Poincaré version of special relativity, the Lorentz contraction is interpreted as a real contraction of all material objects in motion with respect to the ether. In the same way, the time period of a clock moving in the ether is interpreted as really dilated (furthermore, this "time-dilation" may be seen as a *consequence* of the Lorentz contraction [9]). Thus, there are real absolute effects of motion on the behavior of clocks and meters, *i.e.* absolute metric effects of motion. Similarly, in the scalar ether theory of gravitation, there are absolute metric effects of gravitation and, moreover, those latter effects are derived from the former ones. Gravitation is seen here as a variation in the ether density ρ_e [see eq. (2.2)], and a variation in the "apparent" ether density indeed occurs in a uniform motion, due to the Lorentz contraction: for an observer having a constant velocity **u** with respect to the ether, a given volume of ether has a greater volume, because his measuring rod is contracted in the direction **u**, thus the apparent ether density is lowered. This leads us to state the following assumption [18,31]:

(A) *In a gravitational field, material objects are contracted, only in the direction of the field* $\mathbf{g} = -(\mathrm{grad}\ p_e)/\rho_e$, *in the ratio* $\beta = \rho_e /\rho_e^\infty \leq 1$, *where* ρ_e^∞ *is the ether density at a point where no gravity is present, and the clock periods are dilated in the same ratio*.

(Recall that ρ_e decreases in the direction **g**. Therefore, ρ_e^∞ is formally defined as the upper bound:

$$\rho_e^\infty (t) \equiv \mathrm{Sup}_{\,\mathbf{x}\in \mathrm{M}}\ \rho_e(t, \mathbf{x}), \tag{2.5}$$

which must be finite.) This assumption is made for objects and clocks bound to the macro-ether; in general, one has to combine the metric effects due to motion and gravitation. Due to the space-contraction of measuring rods in the direction **g**, the "physical" space metric $\mathbf{g}$ (that measured with physical instruments) in the preferred frame E becomes a Riemannian one. The contraction occurs with respect to the Euclidean metric $\mathbf{g}^0$, introduced in § 2.1. The dilation of the clock periods in a gravitational field implies that the *local time* $t_\mathbf{x}$, measured by a clock at point **x** bound to the frame E, flows more slowly than the absolute time t :

$$\mathrm{d}t_\mathbf{x} /\mathrm{d}t = \beta(t, \mathbf{x}), \quad \beta \equiv \rho_e(t, \mathbf{x}) / \rho_e^\infty(t) \quad (\beta \leq 1). \tag{2.6}$$

Equation $(2.6)_1$ implicitly assumes that the absolute time t is "globally synchronized" [33]. Thus, it is assumed that the physical space-time metric $\boldsymbol{\gamma}$ satisfies

$$\gamma_{0i} = 0 \ (i = 1, 2, 3) \tag{2.7}$$

in any coordinates (x^μ) adapted to the frame E *and* such that $x^0 = ct$ with t the absolute time. ("Adapted coordinates" are such that any particle bound to the given reference frame has constant space coordinates [34].) As a consequence of (2.7), we have in such coordinates:

$$\gamma_{ij} = -\, g_{ij}. \tag{2.8}$$

Equation (2.6) is equivalent to say that, in any such coordinates,

$$\gamma_{00} = \beta^2. \tag{2.9}$$

Moreover, the notion that material particles are just organized flows in the fluid "micro-ether" leads to assume that their velocity cannot exceed the velocity of pressure waves in the compressible ether, c_e [29,31]. Since SR (which must apply "locally" in the proposed theory, though not exactly in the same sense than in GR) gives the other limit c, one must have $c_e = c$ (everywhere at any time), and this implies [31]:

$$p_e = c^2 \rho_e, \tag{2.10}$$

which was also assumed by Romani [29]. Thus, the waves of small disturbances of the ether pressure, *i.e.* the *gravitational waves*, propagate with the velocity of light.

As a consequence of assumption (A), the basic equations (2.2) and (2.4) are now assumed valid in terms of the "physical" metric $\mathbf{g}$ and the "local time" $t_\mathbf{x}$:

$$\mathbf{g} = -\frac{\mathrm{grad}_\mathbf{g}\, p_e}{\rho_e}, \qquad (\mathrm{grad}_\mathbf{g}\, \phi)^i \equiv g^{ij}\frac{\partial \phi}{\partial x^j}, \quad (g^{ij}) \equiv \mathbf{g}^{-1}, \tag{2.11}$$

$$\Delta_\mathbf{g}\, p_e - \frac{1}{c^2}\frac{\partial^2 p_e}{\partial t_\mathbf{x}^{\,2}} = 4\pi G \sigma\, \rho_e, \tag{2.12}$$

where

$$\Delta_\mathbf{g}\, \phi \equiv \mathrm{div}_\mathbf{g}\, \mathrm{grad}_\mathbf{g}\, \phi = \frac{1}{\sqrt{g}}\frac{\partial}{\partial x^i}\left(\sqrt{g}\, g^{ij}\frac{\partial \phi}{\partial x^j}\right), \quad g \equiv \det(g_{ij}), \tag{2.13}$$

$$\frac{\partial}{\partial t_\mathbf{x}} \equiv \frac{1}{\beta(t,\mathbf{x})}\frac{\partial}{\partial t}, \tag{2.14}$$

and where σ is the mass-energy density in the preferred frame, precisely defined by [32]

$$\sigma \equiv (T^{00})_\mathrm{E} \qquad (x^0 = ct) \tag{2.15}$$

where $\mathbf{T}$ 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.

2.4 Dynamical equations

Motion is governed by an extension of Newton's second law [32]: for a test particle, it is written as

$$\mathbf{F}_0 + m(v)\mathbf{g} = D\mathbf{P}/Dt_\mathbf{x}, \tag{2.16}$$

where $\mathbf{F}_0$ is the non-gravitational force and v is the modulus of the velocity $\mathbf{v}$ of the test particle (relative to the considered arbitrary frame F), the velocity $\mathbf{v}$ being measured with the local time $t_\mathbf{x}$ synchronized along the given trajectory [33,35] [$t_\mathbf{x}$ is given by eq. (2.6) if the preferred frame of the present theory is considered, thus if F = E] and its modulus v being defined with the spatial metric **h** in the frame F (thus **h** = **g** if F = E):

$$v^i \equiv \mathrm{d}x^i/\mathrm{d}t_\mathbf{x}\,, \qquad v \equiv [\mathbf{h}(\mathbf{v},\mathbf{v})]^{1/2} = (h_{ij}\, v^i\, v^j)^{1/2}. \tag{2.17}$$

Moreover, $m(v) \equiv m(0).\gamma_v \equiv m(0).(1 - v^2/c^2)^{-1/2}$ is the relativistic inertial mass, $\mathbf{P} \equiv m(v)\ \mathbf{v}$ is the momentum, and $D/Dt_\mathbf{x}$ is the derivative of a spatial vector appropriate to the case where the Riemannian spatial metric **h** varies with time. In particular, with this derivative, Leibniz' rule for the time derivative of a scalar product **v.w** = **h**(**v**,**w**) is satisfied [32,33]. With the gravity acceleration **g** assumed (in the preferred frame E) in the theory [eq. (2.11)], the extended form (2.16) of Newton's second law implies Einstein's motion along geodesics of metric $\boldsymbol{\gamma}$, but only for a static gravitational field; however, (2.16) may be defined in any reference frame, and also for metric theories like GR: for those, one adds to the **g** of eq. (2.11) a certain *velocity-dependent term*, which gives geodesic motion in the general case [33].

Equations (2.11) and (2.16) define Newton's second law in the preferred frame, for any mass particle. It is thereby defined also for a dust, since dust is a continuum made of coherently moving, non-interacting particles, each of which conserves its rest mass. It then mathematically implies, independently of the assumed form for the space-time metric $\boldsymbol{\gamma}$ provided it satisfies $\gamma_{0i} = 0$ in the preferred frame, the following dynamical equation for the dust, in terms of its mass tensor $T^{\mu\nu} = \rho^* U^\mu U^\nu$ (with ρ^* the proper rest-mass density and $U^\mu = \mathrm{d}x^\mu/\mathrm{d}s$ the 4-velocity) [36]:

$$T^{\mu\nu}{}_{;\nu} = b^\mu. \tag{2.18}$$

Here b_μ is defined by

$$b_0(\mathbf{T}) \equiv \frac{1}{2} g_{jk,0}\, T^{jk}\,, \qquad b_i(\mathbf{T}) \equiv -\frac{1}{2} g_{ik,0}\, T^{0k}\,. \tag{2.19}$$

(Indices are raised and lowered with metric $\boldsymbol{\gamma}$, unless mentioned otherwise. Semicolon means covariant differentiation using the Christoffel connection associated with metric $\boldsymbol{\gamma}$.) Equation (2.18), with the definition (2.19), is assumed to hold for any material continuum: accounting for the mass-energy equivalence, this is the expression of the universality of gravitation. Equation (2.18) is valid in any coordinates (x^μ) that are adapted to the frame E and such that $x^0 = \phi(t)$ with t the absolute time.

3. Current status of the observational confrontation

We shall review below the question whether and how the scalar ether theory passes the different tests that may currently be imposed on an alternative theory of gravitation.

3.1. The theory should give very nearly the same predictions as Newtonian 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 [37], 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

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

where $U_{\max}$ is the maximum value of the Newtonian potential U in the considered gravitating system [23,25]. 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 [37], 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 [38]. 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.

3.2. 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 [26]. *a*) The prediction, by GR, of the gravitational redshift, depends [24] on the expression

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

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 [39], 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 [40] or Klein-Gordon equation [12]) 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 [24]. 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 [39]. (Note that the first corrections of GR to NG are those that have been tested for light rays [23-25].)

3.3. 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 [24]. Since this is also true for the present theory [18,32], 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 [37] – in contrast to what is found [39] for photons. Therefore, if the velocity of the solar system through the "ether" of the theory is of the order of $10^{-3}\,c$, 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, the zero-order equations of motion for the mass centers (thus the equations of NG) contain some parameters α^0 that cannot be measured to sufficient accuracy independently of the celestial-mechanical calculations: the masses of the planets, some higher-order multipoles of the mass density, and also the initial conditions (position and velocity). This means that celestial mechanics based on some theory of gravitation, *e.g.* GR, proceeds to a *fitting*, in which a number of observational data (transit circles, radar ranging, *etc.*) are input data, and in which the unknown parameters (including the zero-order parameters α^0, thus including the first-approximation masses) are output data [41-42]. As for any similar situation, the predictive capacity of different theories must then be assessed in a subtle way, by comparing the least-squares residuals and also by trying different sets of 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 α^0, 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 [43]. (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 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 [43]. The equations involve only one second-approximation parameter, and this is the velocity **V** of the gravitating system through the ether (hence a vector parameter). 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. The numerical implementation is in progress and the author hopes to get meaningful results in a few monthes from now (October 2000).

3.4. 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 [44]. Here also it is a fitting procedure, the main observational input being just 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. 45). 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.

3.5. Finally, there are **precision tests of the equivalence principle** [26]. As it appears from the equation for continuum dynamics, eq. (2.18) with the definition (2.19), the scalar ether-theory agrees fully with the principle of the universality of gravitation. Moreover, eq. (2.18) 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 [26]. 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 metric effects of motion and gravitation [18,31].

4. Original predictions of the scalar ether-theory

4.1. In § **1.3**, point **i)**, it has been pointed out that **the theory both avoids a singularity in gravitational collapse and yet predicts a kind of black holes.**

4.2. The scalar theory has been applied to study **the evolution of a homogeneous Universe** [45]. Energy and momentum of the Universe are conserved. The theory predicts that *the cosmic expansion must be accelerated,* as is currently observed [46-47]. 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. *There is no singularity with infinite density:* The energy density remains finite for any (finite) value of the cosmic time, in all scenarios. However, an *infinite dilution* is predicted in a *finite* cosmic time from now, also in all scenarios.

4.3. This ether theory indeed predicts preferred-frame effects in celestial mechanics, as pointed out in § **3.3**. In a first stage, such effects represent a risk for the theory, because they are of the same order of magnitude as the "relativistic effects". More precisely, preliminary calculations indicate that the preferred-frame effects are likely to be somewhat *larger* than the relativistic effects, even for Mercury, if the relevant "absolute velocity" is of the order 10^{-3} *c*. (In any case the preferred-frame effects shall be very small, at most some ppm of the Newtonian contribution.) It is therefore not *a priori* obvious that the theory will be able to account for celestial mechanics in the solar system with a comparable accuracy to that which is reached with standard GR. Clearly, a negative answer would be a weak point for the theory. (Recall, however, that the predictions of the theory are indistinguishable from the standard predictions of GR for *light rays*, as deduced from Schwarzschild's metric: see § **3.2**.) However, *in the case that* a reevaluation of the parameters of celestial mechanics (including a reevaluation of the masses of the Sun and planets, though by very small corrections) should turn out to allow a small residual with observations, *then* it would become extremely interesting to investigate what the preferred-frame effects exactly are, *e.g.* in the solar system. In particular, since accurate observations are all recent, the adjustment and the accurate test of the theory shall concern a relatively very short period of time – one or two centuries at most, say. Over a long time span, however, it is likely that the secular part of the preferred-frame effects of the ether theory should give to the solar system an aspect differing significantly from what is found from NG. For the same reason (the accumulation of secular preferred-frame effects over hundreds of millions of years), the galactical dynamics predicted by the ether theory is probably quite different from Newtonian predictions. One should investigate the question whether this could be a substitute for dark matter.

4.4. The scalar ether theory predicts reversible matter creation/destruction in a variable gravitational field. In special relativity, the energy conservation for an isolated system of point particles (assumed *e.g.* to interact merely during collisions) leads to the possibility of creating new particles, and in such events the sum of the rest-masses is not conserved in general. This is routinely observed in particle accelerators. Thus, one would *a priori* expect that, in a "relativistic" theory of gravitation involving the mass-energy equivalence, the rest-mass should not be conserved in general and that, more specifically, matter might be produced *or destroyed* by exchange with the gravitational energy, in a variable gravitational field. However, in relativistic theories of gravitation based on EEP, the dynamical equation is $T_{\mu}{}^{\nu}{}_{;\nu} = 0$, [2]and this equation implies the following one for an isentropic perfect fluid [48]:

$$(\rho^* U^{\nu})_{;\nu} = 0, \tag{4.1}$$

where ρ^* is the proper rest-mass density, and U^{ν} the four-velocity. A "truly perfect" fluid should be isentropic, and (4.1) means that the rest-mass is conserved for such a fluid, thus in nearly all relativistic theories of gravitation. But, in the scalar ether-theory, we have eq. (2.18) instead of $T^{\mu\nu}{}_{;\nu} = 0$. Hence, *mass non-conservation* is expected in that theory. And indeed one finds [36] that, for an isentropic perfect fluid, eq. (4.1) is replaced by:

[2] In GR, this equation is also a consequence of the Einstein equations. In the RTG, the same equation holds true for the latter reason, although EEP does not apply.

$$\left(\rho^* U^\nu\right)_{;\nu}\left(1+\frac{\Pi+p/\rho^*}{c^2}\right)=-\frac{pU^0}{2c^2}\frac{f_{,0}}{f}, \qquad f\equiv(\gamma_{00})_{\mathrm{E}} \tag{4.2}$$

(p is the fluid pressure and Π is its internal energy per unit rest-mass). Ref. 36 includes a rather detailed discussion of the thermodynamical constraints and a critical analysis of the way in which matter creation is usually introduced in cosmological models. For a weak gravitational field, the creation rate (the amount of rest-mass that is produced in the unit volume during the unit time) deduced from eq. (4.2) is found to be:

$$\hat{\rho} \approx \frac{p}{c^4}\frac{\partial U}{\partial t}, \tag{4.3}$$

in which the time derivative of the Newtonian potential must be taken in the preferred frame. If the absolute velocity V of the solar system is of the order of 300 km.s^{-1}, the main contribution to $\partial U/\partial t$ is that which is due to this translation through the ether. This leads to extremely small creation/ destruction rates: for instance $|\hat{\rho}|/\rho \leq$ some 10^{-23} s^{-1} near the surface of the Earth. This seems hard to detect. The creation/destruction would yet reach much higher rates inside dense astronomical objects (already inside the Sun, actually), thus it might play an important role in astrophysics.

References

[1] A. Einstein, *Ann. der Phys.* (4) **17**, 891-921 (1905).

[2] H. Poincaré, *C.-R. Acad. Sci. Paris* **140**, 1504-1508 (1905).

[3] A.A. Logunov, *On the Articles by Henri Poincaré "On the Dynamics of the Electron"* (English edition), Publishing Department of the Joint Institute for Nuclear Research, Dubna (1995).

[4] H. Poincaré, *Rendic. Circ. Matemat. Palermo* **21**, 129-176 (1906).

[5] H. Poincaré, *Arch. Néerland. Sci. Ex. Nat.* (2) **5**, 252-278 (1900).

[6] H. Poincaré, *Bull. Sci. Math.* **28** (2ème série), 302-326 (1904).

[7] H. Poincaré, *La Science et l'Hypothèse*, Flammarion, Paris (1902).

[8] A. Einstein, *Sidelights on Relativity* (English edition), Dover, Dutton & Co, New York (1922).

[9] S.J. Prokhovnik, *The Logic of Special Relativity*, Cambridge University Press, Cambridge (1967).

[10] J.S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press, Cambridge (1987), pp. 67-80.

[11] L. Gonzalez-Mestres, *26th ICRC* (Utah, August 1999), as *LANL preprint* hep-ph/9905430 (1999).

[12] M. Arminjon, *6th Conf. Physical Interpretations of Relativity Theory, Proceedings,* edited by M.C. Duffy, University of Sunderland / Brit. Soc. Phil. Sci. (1998), pp. 1-17.

[13] J. Butterfield and C.J. Isham, in *Physics meets Philosophy at the Planck Scale,* edited by C. Callender and N. Huggett (Cambridge University Press, to appear); also as *LANL preprint* gr-qc/9903072 (1999).

[14] I. Schmelzer, *LANL preprint* gr-qc/0001095 (2000).
[15] A.A. Logunov and M.A. Mestvirishvili, *The Relativistic Theory of Gravitation* (English edition), Mir, Moscow (1989). [*Osnovy relyativistskoï teoriï gravitatsii,* Izd. Mosk. Univ., 1986.]
[16] A.A. Logunov, Yu.M. Loskutov and M.A. Mestvirishvili, *Sov. Phys. Usp.* **31**, 581-596 (1988). [*Usp. Fiz. Nauk* **155**, 369-396 (1988).]
[17] A.A. Vlasov and A.A. Logunov, *Theor. Math. Phys.* **78**, 229-233 (1989). [*Teor. Mat. Fiz.* **78**, 323-329 (1989).]
[18] M. Arminjon, *Rev. Roum. Sci. Tech. - Méc. Appl.* **42**, 27-57 (1997).
[19] A. Zakharov, *XXIIIrd Internat. Workshop "Fundamental Problems of High Energy Physics and Field Theory"*, Protvino, June 2000 (this Conference).
[20] J. Stachel, in *Einstein and the History of General Relativity,* edited by D. Howard & J. Stachel, Birkhaüser, Boston-Basel-Berlin (1989), pp. 63-100.
[21] S.W. Hawking and G.F.R. Ellis, *The Large-Scale Structure of Space-Time*, Cambridge University Press, Cambridge (1973).
[22] J. Christian, in *Physics meets Philosophy at the Planck Scale, cf.* Ref. 13; also as *LANL preprint* gr-qc/9810078 (1998).
[23] V. Fock, *The Theory of Space, Time and Gravitation* (2nd English edn.), Pergamon, Oxford (1964). [*Teoriya Prostranstva, Vremeni i Tyagotenie*]
[24] S. Weinberg, *Gravitation and Cosmology,* J. Wiley & Sons, New York (1972).
[25] C.W. Misner, K.S. Thorne and J.A. Wheeler, *Gravitation*, Freeman, San Francisco (1973).
[26] C.M. Will, *Theory and Experiment in Gravitational Physics* (2nd edn.), Cambridge University Press, Cambridge (1993).
[27] M. Milgrom, *Astroph. J.* **270**, 365 (1983).
[28] A. Lipkin, *XXIIIrd Internat. Workshop "Fundamental Problems of High Energy Physics and Field Theory"*, Protvino, June 2000 (this Conference).
[29] L. Romani, *Théorie Générale de l'Univers Physique (Réduction à la Cinématique),* two volumes, Blanchard, Paris (1975 and 1976).
[30] M. Arminjon, *Rev. Roum. Sci. Tech. - Méc. Appl.* **38**, 3-24 (1993).
[31] M. Arminjon, *Rev. Roum. Sci. Tech. - Méc. Appl.* **38**, 107-128 (1993).
[32] M. Arminjon, *Arch. Mech.* **48**, 25-52 (1996).
[33] M. Arminjon, *Arch. Mech.* **48**, 551-576 (1996).
[34] C. Cattaneo, *Nuovo Cimento* **10**, 318-337 (1958).
[35] L. Landau and E. Lifchitz, *Théorie des Champs* (4th French edn.), Mir, Moscow (1989). [*Teoriya Polya*, Izd. "Nauka", Moskva, 1989.]
[36] M. Arminjon, *Analele Universitatii Bucuresti - Fizica* **47** (1998), to appear; also as *LANL preprint* physics/9911025 (1999).
[37] M. Arminjon, *Roman. J. Physics* (to appear); also as *LANL preprint* gr-qc/0003066 (2000).
[38] M. Arminjon, *LANL preprint* gr-qc/9912070 (1999).
[39] M. Arminjon, *Rev. Roum. Sci. Tech. - Méc. Appl.* **43**, 135-153 (1998).
[40] M. Arminjon, *5th Conf. Physical Interpretations of Relativity Theory, Supplementary Papers,* edited by M.C. Duffy, University of Sunderland / Brit. Soc. Phil. Sci. (1998), pp. 1-27.

[41] X.X. Newhall, E.M. Standish and J.G. Williams, *Astron. & Astroph.* **125**, 150-167 (1983).
[42] E.M. Standish, *Astron. & Astroph.* **233**, 252-271 (1990).
[43] M. Arminjon, *Equations of Motion for the Mass Centers in a Scalar Theory of Gravitation*, submitted for publication; also as *LANL preprint* astro-ph/0006093 (2000).
[44] J.H. Taylor and J.M. Weisberg, *Astroph. J.* **253**, 908-920 (1982).
[45] M. Arminjon, *Accelerated Expansion as Predicted by an Ether Theory of Gravitation*, submitted for publication; also as *LANL preprint* gr-qc/9911057 (1999).
[46] A. Riess *et al.*, *Astron. J.* **116**, 1009 (1998); also as *LANL preprint* astro-ph/9805201 (1998).
[47] S. Perlmutter *et al.*, *Astroph. J.* **517**, 565 (1999); also as *LANL preprint* astro-ph/9812133 (1998).
[48] S. Chandrasekhar, *Astroph. J.* **158**, 45-54 (1969).