Gravitation as a pressure force: a scalar ether theory, by M. Arminjon

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8. Consistency with observations and the question of the preferred-frame effects

This tentative ether theory is now rather complete, and it is self-consistent. The obvious question is: does this theory agree with experiment? There is a vast amount of experimental and observational data as regards gravitational physics [40], so that a very detailed analysis should be performed, of course. For instance, there are numerous tests of the "*weak equivalence principle* ", but the latter is none other, after all, than the statement that gravitation is a universal force. Due to the basic equation of motion in the theory, i.e. "Newton's second law" (19), this is obviously true in this theory. There are also tests of the more specific statement that: "in a local freely falling frame, the laws of non-gravitational physics are the same as in SR", which is *Einstein's equivalence principle* (EEP), and which we also call the equivalence principle in the standard form, because a different equivalence principle is postulated in the present theory (Sect. 3). It should be clear that EEP is *not* true in this theory, since EEP implies Eq. (24) for continuum dynamics, as opposed to Eq. (37). Let us recall, however, that these two equations are equivalent for the case of a constant gravitational field, and note that the best-known theoretical frame for testing EEP, known as the $TH\varepsilon\mu$ formalism, is restricted to static gravitational fields [40], and so does not allow to analyse experiments that should decide between EEP and the proposed equivalence principle. Furthermore, as well as for any theory based on EEP and Eq. (24), our Equation (37) and the whole theory are in full agreement with the assumption of a *universal coupling*, since the same equation applies to any kind of matter and/or non-gravitational field. For these two reasons, it would be probably quite difficult to find laboratory experiments accurate enough to distinguish between the usual form of the equivalence principle and the alternative form which is postulated in the present theory.

Hence, we are inclined to believe that the main challenge for this preferred-frame theory is to recover the "classical tests" of GR, i.e. the effects of gravitation on light rays and the general relativistic corrections to Newtonian celestial mechanics. The latter consist essentially in the prediction, by GR, of Mercury's very small residual advance in perihelion but, in our opinion, one should pose the question in a more general way: does the theory produce a celestial mechanics which is more accurate than Newton's theory?

In order to investigate the effects of gravitation on light rays and the corrections made by this non-linear theory to Newtonian celestial mechanics, it is necessary, as well as in GR, to develop an iterative approximation scheme, i.e., to develop a *post-Newtonian (pN) approximation scheme*. The pN approximation *scheme* is the method of asymptotic expansion of the dependent variables and the equations in powers of a small parameter ε, which is defined by $U_{\max} /c^2 \equiv \varepsilon^2$, with $U_{\max}$ the maximum value of the Newtonian potential in the considered gravitating system (assumed isolated, and the gravitational field being assumed weak and slowly varying; *cf.* Fock [18], Chandrasekhar [14], Weinberg [38], Misner *et al.* [26], Will [40]). (The term *pN approximation* alone usually makes reference to the approximation immediately following the first, "Newtonian" approximation; this second approximation is largely sufficient in the solar system.) Actually, the small parameter will be taken simply as $\varepsilon' = 1/c$ as in Refs. 14 and 18. Note that, choosing the units such that $U_{\max} = 1$, we get indeed $\varepsilon = \varepsilon'$. More generally, constraining the units merely so that $U_{\max} \approx 1$, we may take $\varepsilon' = 1/c$ as the small parameter. Then all relevant quantities such as U, v, etc., are O(1). Choosing the time coordinate as $x^0 = T$ (instead of cT), the assumption of a slowly varying gravitational field is then automatically satisfied. Moreover, only one term among two successive ones appears in the relevant expansions. Whereas the usual explanation makes appeal to the behaviour under time reversal [26, 40], we note that, in the proposed ether theory, all non-Newtonian effects come from the "ether compressibility", $K \equiv 1/c^2$. So K itself (or $U_{\max} K$, if the units are not constrained so that $U_{\max} \approx 1$) could be considered as the small parameter, whence the appearance of only one among two successive terms in any expansion with respect to $1/c = \sqrt{K}$ – the leading ("Newtonian") term giving the parity. Finally, in a preferred-frame theory, the absolute velocity V of the mass-center of the system with respect to the ether frame should not exceed the order $\varepsilon\, c$, as is the case for the typical orbital velocity v in the mass-center frame. We note that, if V is approximately 300 km/s for the solar system (as one finds if one assumes that the cosmic microwave background is "at rest" with respect to the preferred frame [40]), then one has indeed $V/c \leq \varepsilon$ in the solar system [6], because there $\varepsilon^2 \equiv U_{\max}/c^2 \approx 10^{-5}$ [26].

i) *Expansion of the metric and the field equation in the preferred frame*

The leading expansion is that of the scalar field, β or $f = \beta^2$:

$$\beta = 1 - U/c^2 + S/c^4 + \dots, \qquad f = 1 - 2U/c^2 + (U^2 + 2S)/c^4 + \dots = 1 - 2U/c^2 + A/c^4 + \dots \quad (64)$$

The space metric deduced from the Euclidean metric $\mathbf{g}^0$ by assumption (A) (Sect. 3) is then obtained [6] as

$$g_{ij} = g^0_{ij} + (2U/c^2) h^{(1)}_{ij} + O(1/c^4), \qquad h^{(1)}_{ij} \equiv (U_{,i}\, U_{,j})/(g^{0\,kl}\, U_{,k}\, U_{,l}) \quad (65)$$

(with $g^0_{ij} = g^{0\,ij} = \delta_{ij}$ in Cartesian coordinates), and the space-time metric is

$$\gamma_{00} = c^2 f = c^2(1 - 2U/c^2 + A/c^4 + \dots), \gamma_{0i} = 0,\ \gamma_{ij} = -g_{ij}. \quad (66)$$

The mass-energy density $\rho = [(T^{00})_{\mathrm{E}}]/c^2$ may be written in the form

$$\rho = \rho^0 + w^1/c^2 + \dots, \quad (67)$$

where ρ^0 is the conserved mass density which is found at the first approximation (expanding, for a perfect fluid, the energy equation (34), one finds that ρ^0 obeys the usual continuity equation and that mass is conserved at the pN approximation also). The pN expansion of the field equation (13) follows easily from Eqs. (64) and (67) :

$$\Delta_0 U = -4\pi G \rho^0, \quad (68)$$

$$\Delta_0 S = 4\pi G\, w^1 - \Delta_0 U^2/2 - \partial^2 U/\partial t^2, \text{ or } \qquad \Delta_0 A = 8\pi G\, w^1 - 2\partial^2 U/\partial t^2. \quad (69)$$

ii) *Post-Newtonian equations of motion for a test particle in the preferred frame*

Using the energy equation (28), one first rewrites Newton's second law for a free test particle, Eq. (19) with $\mathbf{F}_0 = 0$, as [6]

$$\frac{du^i}{dT} = -\Gamma'^i_{00} - \Gamma'^i_{0j} u^j - \Gamma^i_{jk} u^j u^k + \left(\Gamma'^0_{00} + 2\Gamma'^0_{0j} u^j\right) u^i \quad (x^0 = T), \quad (70)$$

where the $\Gamma'^{\mu}_{\nu\rho}$ symbols are the Christoffel symbols of the space-time metric and the Γ^i_{jk} 's are those of the space metric (with $\Gamma^i_{jk} = \Gamma'^i_{jk}$ for the spatial indices, due to the fact that $\gamma_{0i} = 0$). Therefore, expanding the equation of motion amounts to expanding the Christoffel symbols, using Eqs. (64)-(66). In doing so at the pN level, one has to distinguish between the case of a photon, for which the velocity **u** is O(c), and the case of a mass particle moving under the action of the weak gravitational field, for which **u** is O(1). Hence, the expanded equation of motion involves less terms for a photon, for which it is, in Cartesian coordinates for metric $\mathbf{g}^0$:

$$\frac{du^i}{dT} = U_{,i} - 2\left(U_{,j}u^j\right)\frac{u^i}{c^2} - \left((Uh^{(1)}{}_{ij})_{,k} + (Uh^{(1)}{}_{ik})_{,j} - (Uh^{(1)}{}_{jk})_{,i}\right)\frac{u^j u^k}{c^2} + O\left(\frac{1}{c}\right). \quad (71)$$

An important point is that Eq. (71), derived from Newton's second law, is nevertheless *undistinguishable from the pN expansion of the equation for null space-time geodesics*. For a mass point, the expanded equation is

$$\frac{du^i}{dT} = U_{,i} - \frac{1}{c^2}\left[\frac{A_{,i}}{2} + 2Uh^{(1)}{}_{ij}U_{,j} + \left(Uh^{(1)}{}_{ij}\right)_{,0}u^j + u^i\left(U_{,0} + 2U_{,j}u^j\right)\right]$$
$$-\left((Uh^{(1)}{}_{ij})_{,k} + (Uh^{(1)}{}_{ik})_{,j} - (Uh^{(1)}{}_{jk})_{,i}\right)\frac{u^j u^k}{c^2} + O\left(\frac{1}{c^4}\right). \quad (72)$$

Note that, in the pN equation of motion for a photon, Eq. (71), the "Newtonian" gravity acceleration $\mathbf{g}^0 \equiv \mathrm{grad}_0\, U$ (with components $U_{,i}$ in the Cartesian coordinates utilized) intervenes at the same order in ε as the other terms (i.e. the order zero, although it is really a second-approximation formula: the first approximation gives simply $du^i/dT = 0$). In contrast, in the pN equation of motion for a mass point, Eq. (72), $U_{,i}$ represents the first approximation to the acceleration, of order zero in ε, and the other, pN terms, are of the order ε^2.

iii) *Transition to a moving frame. Application to the effects of a weak gravitational field on light rays*
In order that the pN motion may be considered as a perturbation of the problem in classical celestial mechanics, one has to work in the mass-center frame, as in classical mechanics. Let $\mathbf{V}(T)$ be the current absolute velocity of the mass-center. We define the mass-center frame $\mathrm{E}_\mathbf{V}$ as the frame that undergoes a pure translation, with velocity **V**, with respect to the ether frame E (**V** may vary with T, although very slowly in the case of the solar system). We may pass from E to $\mathrm{E}_\mathbf{V}$ by a Lorentz transformation of the flat space-time metric $\boldsymbol{\gamma}^0$ (that one whose line element is $(ds^0)^2 = c^2\, dT^2 - dx^i\, dx^i$ in Cartesian coordinates for the Euclidean space metric $\mathbf{g}^0$). In a such transformation, the components of the velocity $\mathbf{u} = d\mathbf{x}/dT$ and the acceleration $\mathbf{a} = d\mathbf{u}/dT$ transform by the classical formulas of *special* relativity (as far as we assume, as it is very reasonable, that the acceleration $d\mathbf{V}/dT$ plays no role at the pN approximation). Expanding the corresponding transformations of Eqs. (71) and (72) gives the pN equations of motion in the uniformly moving frame $\mathrm{E}_\mathbf{V}$, for a photon and for a mass point.

However, at the pN approximation, a photon follows a null geodesic of the physical space-time metric $\boldsymbol{\gamma}$, and, by the Lorentz transformation, the components of this space-time tensor transform thus like a (twice covariant) tensor, of course: this gives an alternative way to get the pN equations of motion for a photon in the frame $\mathrm{E}_\mathbf{V}$. Neglecting $O(1/c^4)$ terms, and except for a $O(1/c^3)$ term in γ'_{0i} (which does not play any role in the pN expansion of the null geodesic equation), the new components $\gamma'_{\mu\nu}$ (in the frame $\mathrm{E}_\mathbf{V}$) depend only on the "Newtonian" potential U, by just the same equations (65) and (66) as they do in the preferred frame. Now the effects of gravitation on light rays are always calculated at the pN approximation and using the additional assumption of a *spherical* and *static* gravitational field [18, 26, 38, 40]. In the case of spherical symmetry, the "Newtonian" potential is simply $U = GM^0/r$ with $M^0 \equiv \int \rho^0\, dV$: then, Eqs. (65) and (66) represent just the pN expansion of Schwarzschild's exterior metric. Whereas this spherical potential is, in general, not constant in the frame E, it is indeed constant in the frame $\mathrm{E_V}$ which moves with the spherical massive body (e.g. the Sun) that creates the relevant field, so that the geodesic equation is really that deduced from Schwarzschild's metric. We conclude that, *to just the same level of approximation as in the pN approximation of GR,* in particular neglecting the γ_{0i} components of the metric, which are $O(1/c^3)$, *the present theory predicts exactly the same gravitational effects on light rays as does standard general relativity, and this is true accounting for the preferred-frame effects (which do not appear at this approximation).* (The arguments are detailed in Ref. 6 .)

iv) *Remarks on the adjustment of astrodynamical constants and the preferred-frame effects*
In contrast to the pN acceleration (71) for a photon, which is invariant by a Lorentz transformation of the flat metric (provided the velocity V of the moving frame is compatible with the pN approximation, i.e. such that $V/c = O(\varepsilon)$), the pN acceleration for a mass point, Eq. (72), is *not* invariant. For a mass point, the pN acceleration in the moving frame is, in space vector form,

$$d\mathbf{u}/dT = (d\mathbf{u}/dT)_0 + (d\mathbf{u}/dT)_\mathrm{V}, \tag{73}$$

where $(d\mathbf{u}/dT)_0$ is given, in the Lorentz-transformed Galilean coordinates x'^μ for the flat metric, by just the same formula (72), but with the indices and derivatives referring to the x'^μ coordinates, and where $(d\mathbf{u}/dT)_\mathrm{V}$ is a sum of a few terms, each term containing explicitly the velocity $\mathbf{V}$. Thus, the theory does predict preferred-frame effects for mass particles such as the planets. It is not difficult (though rather tedious) to calculate the magnitude of the effect, on Mercury's perihelion motion, of the $(d\mathbf{u}/dT)_\mathrm{V}$ part: for an absolute velocity of the order $V \approx 10^{-3}\, c$, it is comparable to that of the "relativistic" correction based on the motion in the Schwarzschild field. On the other hand, for $V = 0$, and for a spherical body, the $(d\mathbf{u}/dT)_0$ acceleration is just that derived from Schwarzschild's metric at the pN level, and which gives the "miraculous" 43" per century. Since $V \approx 10^{-3}\, c$ is much more plausible than $V \approx 0$, the theory would appear, at first sight, unable to explain Mercury's residual advance in perihelion. A number of other alternative theories are in the same situation, and it is often concluded on this basis that such theories are to be rejected [40].

However, one may consider that things are less simple than this. The main point is that, in classical celestial mechanics, the astrodynamical constants such as the Newtonian masses M_i^N of the celestial bodies (or rather the products GM_i^N) are not *measured* (one cannot weigh a planet!), instead they are *adjusted to best fit the observations.* As an illustrative example, if a system of two celestial bodies with masses M_1^N and M_2^N is considered as isolated (the Sun and Venus, say), Kepler's third law (which is exact *in the frame of NG* for the case of a two-bodies problem) allows deduction of $G.(M_1^\mathrm{N} + M_2^\mathrm{N})$ from the observed period T and semi-major axis a of the relative motion:

$$G.\left(M_1^\mathrm{N} + M_2^\mathrm{N}\right) = \left(\frac{2\pi}{T}\right)^2 a^3. \tag{74}$$

In reality, no couple of celestial bodies is exactly isolated, and perturbation theory allows to modify the astrodynamical constants by successive corrections, always remaining in the frame of Newtonian theory (NG). With modern computers, one may calculate hundreds of Newtonian parameters by a global fitting based on a numerical approximation scheme of NG and using hundreds of input data from various observation devices (*cf.* Müller *et al.* [28]).

We know that the correct theory of gravitation is not NG. Let us assume for a moment that it is instead some non-linear theory (T), the equations of which reduce to NG in the first approximation. The pN approximation of theory (T) will introduce, in addition to the first-approximation masses $M_i^{\,0}$ (and higher-order multipole moments of the mass density ρ^0 of the first approximation, etc.), some pN parameters such as the pN corrections to the active masses, say $M_i^{\,1}$. Obviously, the fitting of observational data must now be carried out *within the pN approximation of theory (T).* There is simply no reason that the first-approximation masses $M_i^{\,0}$, which are obtained (together with the corrections $M_i^{\,1}$) by this fitting, coincide with the "effective Newtonian" masses $M_i^{\,N}$, that are obtained by fitting the observational data *within NG.* In other words, Newtonian astrodynamics *in praxi* does not coincide with the first approximation of the non-linear theory (T) – unless the pN approximation of theory (T) makes negligible corrections to NG. Specifically, if the theory predicts significant preferred-frame effects, and if turns out that these effects are really present in Nature, the masses $M_i^{\,N}$ will be affected by the preferred-frame effects (in particular, they would be found different for two otherwise identical systems moving at different absolute velocities), whereas the first-order masses $M_i^{\,0}$ will not be affected – at least under the assumption that the pN approximation of theory (T) describes the system up to a negligible error.

To investigate the consequence of this state of things, let us call $D_j^{\,0}$ and $D_j^{\,1}$ the first-order prediction and the pN correction for an observational data D_j such as Jupiter's period or Mercury's advance in perihelion: thus, $D_j^{\,0}$ is obtained by using the "true" values of the first-approximation parameters, e.g. the first-order masses $M_i^{\,0}$. (The values $M_i^{\,0}$, $M_i^{\,1}$, and so on, obtained by a least-squares fitting of some subset of the parameters D_j using the the pN approximation of theory (T), are indeed the "true" ones if this pN approximation describes the system up to a negligible error.) Since Newtonian astrodynamics *in praxi* tries to accommodate a subset of the observational data D_j, which are affected by pN effects $D_j^{\,1}$, by using merely the first-approximation formulas, one may expect that, in general, it will lead to values for the first-order parameters and predictions, $M_i^{\,N}$ and $D_j^{\,N}$, differing from the true first-order values $M_i^{\,0}$ and $D_j^{\,0}$ by quantities whose order of magnitude is that of the pN corrections $M_j^{\,1}$ and $D_j^{\,1}$. But, in turn, the pN calculation based on the wrong values of the first-order parameters, such as the wrong first-order masses, thus $M_i^{\,N}$ instead of $M_i^{\,0}$, will predict pN corrections $D'_j{}^{1}$ differing from the true ones $D_j^{\,1}$ by *third-order* quantities, which are likely to be negligible. As a consequence, this wrong pN calculation, using the effective Newtonian masses $M_i^{\,N}$ instead of the true first-order masses $M_i^{\,0}$, will give pN predictions $D'_j{}^{\mathrm{pN}}$:

$$D'_j{}^{\mathrm{pN}} \equiv D_j^{\,N} + D'_j{}^{1} \approx D_j^{\,N} + D_j^{\,1} \neq D_j^{\,0} + D_j^{\,1} \equiv D_j^{\,\mathrm{pN}}, \tag{75}$$

differing from the correct pN predictions $D_j^{\,\mathrm{pN}}$ by quantities of the same order of magnitude as the pN corrections. In summary, if the *correct* pN approximation of theory (T) turns out to describe celestial mechanics in the solar system up to a negligible error, then the *incorrect* pN procedure, that consists in assigning to the first-order parameters the values of the Newtonian effective parameters, is likely to give rather poor predictions, which might well be less accurate than Newtonian theory, i.e. less accurate than the first-approximation alone.

The foregoing argument applies *a priori* also to *general relativity* (although there is no preferred-frame effect in GR, there are of course non-Newtonian, "relativistic" effects). As a relevant example, the standard pN approximation of GR, using the harmonic gauge condition [38], introduces, besides the "Newtonian" (first-approximation) potential U (denoted $-\phi$ by Weinberg [38]), still another scalar potential obeying a Poisson equation. Namely, it introduces the pN potential denoted ψ by Weinberg [38], which plays exactly the same role as $A/2$ in the present theory (cf. Eqs. (66) and (69) hereabove). Weinberg writes explicitly that "we can take account of ψ by simply replacing ϕ everywhere by $\psi + \phi$ " [or $\psi /c^2 + \phi$, since Weinberg sets $c = 1$], consistently with our statement that Newtonian astrodynamics *in praxi* does not coincide with the first approximation of the non-linear theory, here GR.

Coming back to the proposed theory, the foregoing argument is not a proof, of course, that the theory does correctly explain all minute discrepancies between classical celestial mechanics and observations in the solar system. This argument merely suggests that the present theory should not be *a priori* rejected on the basis that it predicts preferred-frame effects in celestial mechanics – the more so as this theory correctly explains the gravitational effects on light rays, which are the most striking and the best established predictions of GR.

9. Conclusion

A rather complete theory of gravitation may be built from an extremely simple heuristics, already imagined by Euler, and that sees gravity as Archimedes' thrust in a perfectly fluid ether. The theory thus obtained is very simple also, as it is a scalar bimetric theory in which the metric effects of gravitation are essentially the same as the metric effects of uniform motion, and with the field equation being a modification of d'Alembert's equation. Perhaps the most important finding is that Newton's second law may be extended to a general space-time curved by gravitation, in a way that is both consistent and seemingly compelling. This extension is not restricted to point particles: it applies also to any kind of continuous medium, in fact it is Newton's second law for the electromagnetic *field continuum* that gives the Maxwell equations of the theory.

Although the general extension of Newton's second law is unique, its exact expression still depends on which assumption is stated for the gravity acceleration. It is at this point that the ether heuristics makes its demarcation from the logic of space-time which leads to Einstein's geodesic assumption and Einstein's equivalence principle. The ether heuristics leads indeed to postulate that the gravity acceleration depends only on the local state of the imagined fluid, whereas geodesic motion can be true in a general, time-dependent metric, only if the gravity acceleration depends also on the velocity of the particle – and this, in such a way that the velocity-dependent part of the gravitation force does work [5]. Hence, the here-assumed gravity acceleration is in general incompatible with geodesic motion and, in connection with this, it leads to an equation for continuum dynamics, Eq. (37), which differs from the equation that goes with geodesic assumption and Einstein's equivalence principle, Eq. (24). It also enforces that the theory is a preferred-frame theory, which is independently enforced by the scalar character of the theory. It is interesting to note that the non-Newtonian effects, as well as the preferred-frame character, come once a non-zero compressibility is attributed to the ether, just like in Dmitriev's theory [16].

The alternative continuum dynamics implies that, in a variable gravitational field at a high pressure, matter is produced or destroyed, by a reversible exchange with the gravitational field, Eq. (44). The tenuous amounts seem compatible with the experimental evidence on "mass conservation". An experimental confirmation or refutation of this new form of energy exchange would be extremely interesting. In the same way, the alternative continuum dynamics leads to Maxwell equations that contain the possibility of electric charge production/destruction in an electromagnetic field *subjected to* a variable gravitational field. However, the amounts cannot be estimated without having recourse to a numerical work, which is yet to be done. This is obviously a dangerous point for the theory, although it is also an interesting one.

As to the classical tests, it has been shown that no preferred-frame effect exists for light rays at the first post-Newtonian approximation, and that in fact the gravitational effects on light rays are correctly predicted. It has also been shown that preferred-frame effects do exist in celestial mechanics, and it has been argued that this does not kill the theory. Furthermore, such effects might play an interesting role at larger scales, e.g. they might contribute to explain rotation curves in galaxies. We mention also that, contrary to general relativity, the theory predicts a *bounce* instead of a *singularity* for the gravitational collapse of a dust sphere [3]; and that, like general relativity, it leads to a "quadrupole formula" that rules the energy *loss*, thus the correct sign, for a gravitating system with rapidly varying field (this is less shortly outlined in Ref. 3).

Finally, it has not been attempted to attack the impressive task of linking the present theory with quantum mechanics and quantum field theory. Only some preliminary remarks may be done: first, the abandon of the relativity principle (in the presence of a gravitational field) and its replacement by a preferred frame (presumably the average rest frame of the universe/ether) change drastically the problematic. In particular, it makes sense, in this framework, to assign a non-punctual (albeit fuzzy) extension to particles. Further, the quantum non-separability, and the unity of matter and fields, are strongly compatible with the heuristic interpretation of particles as organized flows in the fluid ether. Another remark is that quantum theory is based on the Hamiltonian/Lagrangian formalism, and that the present theory is not amenable to this formalism, except for a constant gravitational field. But Newton's second law is a more general tool than these variational principles, since it makes sense also in non-conservative situations. However, the existence, in the present theory, of a local conserved energy (made of the gravitational energy, plus the energy of matter and non-gravitational fields), should play an important role.

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