Scalar gravity with preferred reference frame: summary and observational test

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Part I: Motivation and Overview

- Motivation
- Gravity as Archimedes' thrust (semi-heuristic)
- Relativity vs physical effects on clocks & rods
- Relativistic dynamics and Newton's second law
- Basic observational tests

Motivation

- For searching a mechanism for gravity:
  - Newton's instantaneous action at a distance is efficient but puzzling (this was already Newton's opinion!)
  - Einstein's geometrized gravity propagates with finite velocity, but is even much more abstract.
- For building an "ether theory of gravity":
  - Extend *Lorentz-Poincaré ether theory* (= a version of special relativity) to gravitation.
  - With an "ether" (preferred reference frame), gravity and quantum theory would match more easily.
  - General relativity has its own problems (singularities, interpretation of the gauge condition, complexity).

Gravity as Archimedes' thrust

- Resultant of pressure p_e over object of a small volume δV (Archimedes' thrust) : $\mathbf{F}_{\mathrm{A}} = -\delta V \, \mathrm{grad} \, p_e$.

- If elementary particles all have same density $\rho_p = \delta m / \delta V$, Archimedes' thrust $\mathbf{F}_{\mathrm{A}}$ becomes proportional to the *mass*. Gravity acceleration is then: $\mathbf{g} = -\frac{\mathrm{grad} \, p_e}{\rho_p}$.

- Lucien Romani (1975) : Elementary particles themselves could be flows in an imagined "ether" (helps thinking of creation/ annihilation and instable "resonances," all observed in particle physics).
  In that case, $\rho_p = \rho_e$, the local "ether density." Then

$$\mathbf{g} = -\frac{\mathrm{grad} \, p_e}{\rho_e}, \ \text{with } \rho_e = \rho_e(p_e) \quad \text{(barotropic fluid)}.$$

Consequences for gravity description

- Eqn. $\mathbf{g} = -\frac{\mathrm{grad}\, p_e}{\rho_e}$ taken as starting point: replaces $\mathbf{g} = \mathrm{grad}\, U$ of Newtonian gravity.

- The latter propagates instantaneously $\Rightarrow$ corresponds with limiting case of incompressible fluid: $\rho_e = \mathrm{Constant}$

- Now, Newtonian gravity $\Leftrightarrow$ $\mathrm{div}\, \mathbf{g} = -4\pi G\rho$.
$\Rightarrow$ for incompressible case, we must have:

$$\Delta p_e = 4\pi G \rho \rho_e\,.$$

- In non-degenerate (compressible) case, modificat$^{\mathrm{ns}}$ of p_e (or of $\rho_e = \rho_e(p_e)$) should propagate with "sound" velocity,

$$c_e = \left(\frac{\mathrm{d}p_e}{\mathrm{d}\rho_e}\right)^{1/2}.$$

Lorentz-Poincaré relativity

Special Relativity: based on Lorentz transform!

relating space & time coordinates in 2 inertial reference frames

- Lorentz's ether: Inertial frame E with Maxwell eqs. valid and such that, $\forall$ moving object (at $\mathbf{v}$) w.r.t. E, $\exists$ "Lorentz contraction" $\| \mathbf{v}$.
- In this theory, Lorentz contract$^{\mathrm{n}}$ $\Leftrightarrow$ Michelson-Morley=0 *but* the contraction comes up naturally: not "ad hoc".
- One shows: *physics is slowed down* in moving frame/ E.

One gets Lorentz transform and the whole of SR, without changing the concepts of space and time.
"Space-time" is a (very useful) *mathematical concept.*

Effects of gravity on clocks and rods

- In Special Relativity, space & time are *homogeneous*.
- If gravity is due to *gradient* of density in a *universal* fluid, *heterogeneous* space & time are expected, in contrast.
- Gravity as Archimedes' thrust: "ether density" ρ_e decreased. Now in SR, Lorentz contract$^{\mathrm{n}}$ $\Rightarrow \rho_e$ smaller in a moving frame, by precisely the Lorentz factor.
- Leads to postulate gravitational rod contraction and clock slowing, both in the ratio $\beta \equiv \rho_e(\mathbf{x}, T)/\rho_e^\infty(T)$.
- *But* the gravitational rod contraction can take place:
  - either (**v1**), as in SR, in one direction only, hence $\mathbf{g}$,
  - or (**v2** of the theory) in a (locally) *isotropic* way.

Relativistic dynamics and Newton's second law

- In SR, Newton's second law is modified (Planck):

$$\mathbf{F} = \frac{\mathrm{d}\mathbf{P}}{\mathrm{d}t}, \quad \mathbf{P} \equiv m(v)\mathbf{v}, \quad m(v) \equiv m(0).\gamma_v, \quad \gamma_v \equiv \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$

- In *GR*, one doesn't try to use Newton's second law: instead, "Free particles follow space-time geodesics." Thus, in GR, space-time becomes "physical." (In SR, it is not necessarily so: cf. Lorentz-Poincaré version.)

- In the present attempt, we like to consider space-time as a mere mathematical tool. This needs that we extend Newton's second law of SR to the case with gravity.

Dynamical equations of the theory

- *Motion of a free test particle* defined by an extension of the special-relativistic form of Newton's second law:

$$\frac{E}{c^2}\,\mathbf{g} = \frac{D\mathbf{P}}{Dt_{\mathbf{x}}}, \qquad \left(\mathbf{P} \equiv \frac{E}{c^2}\,\mathbf{v}, \quad \mathbf{g} \equiv -c^2\,\frac{\mathrm{grad}_{\boldsymbol{g}}\beta}{\beta}\right) \tag{1}$$

  E= energy = $m(v)c^2$ or $h\nu$, $\mathbf{g}$: gravity accel $^{\mathrm{n}}$, $\mathbf{v}$: velocity, $D/Dt_{\mathbf{x}}$: correct time-derivative with variable curved metric

- *Motion of a continuous medium* (fluid, e.m. field, ...): For a *dust*, Eq. (1) may be applied pointwise and implies an equation for energy-momentum tensor $\mathbf{T}$. Universality of gravity: *Same eqn must hold true for any continuous medium*.

Basic observational tests

- *Newton´s theory recovered in first approximation*. Corrections are indeed very small e.g. in solar system. Asymptotic PN scheme to calculate them (*Part II*).

- *Same effects as in GR for electromagnetic rays*.

- Energy loss by gravitat^{al} radiation: same structure as in GR $\Rightarrow$ Binary pulsars data should be nicely fitted (as in GR).

Part II: Formal Principles and Asymptotic PN Scheme

- Formal Principles of the Scalar Theory (v1 & v2)
- Asymptotic Post-Newtonian scheme
- Eqs of motion of the mass centers
- Conclusion

Formal Principles of the Scalar Theory (v1 & v2)

- Space-time assumed to be a product R $\times \mathrm{M}$, where M is the preferred reference body (as Newton's absolute space), endowed with an Euclidean metric $\boldsymbol{g}^0$.

- The Euclidean metrics on the component spaces R and M allow to define a flat Lorentzian metric:

$$\text{for a } 4-\text{vector } \mathsf{U} = (U^0, \mathbf{u}), \quad \boldsymbol{\gamma}^0(\mathsf{U},\mathsf{U}) = (U^0)^2 - \boldsymbol{g}^0(\mathbf{u},\mathbf{u}).$$

- Gravity field: scalar β: has metrical effects *and* produces a gravity acceleration.
  Physical space-time metric $\boldsymbol{\gamma}$ is "deformed from $\boldsymbol{\gamma}^0$:"

$$\boldsymbol{\gamma}(\mathsf{U},\mathsf{U}) = \beta^2 (U^0)^2 - \boldsymbol{g}(\mathbf{u},\mathbf{u}).$$

  with $\boldsymbol{g}$ the physical space metric on the preferred body M: $\boldsymbol{g}$ is itself "deformed from $\boldsymbol{g}^0$" through the scalar field β.

Newton's second law in a "curved space-time"

- A *given* reference frame (= reference body = world-line congruence) is considered. The Riemannian *spatial* metric $\boldsymbol{g} = (g_{ij})$, also depends in general on the *time* t.

- Gravity force must be $m(v)\mathbf{g}$. **Problem**: define $D\mathbf{P}/Dt$ ($\mathbf{P} \equiv m(v)\mathbf{v}$ is the momentum: a 3-vector)

- For constant gravity field, $\boldsymbol{g} = \boldsymbol{g}_{\mathbf{x}}$ independent of t. Then the "absolute derivative" of vector $\mathbf{P}$ is appropriate.

- General case: it can be shown that Leibniz's rule (+ obvious requirements) lead to *unique* definition for $D\mathbf{P}/Dt$.

- Thus, Newton's second law is defined. For a constant field, *this motion follows space-time geodesics.*

Dynamics of a continuous medium

Obtained by considering a "dust," i.e., a continuous medium made of non-interacting particles, subjected to gravity force.

- For a dust, Newton's second law can be used pointwise.
- One thus gets an equation for the energy-momentum tensor $\mathbf{T}$:

$$T_{\mu;\nu}^{\nu} = b_\mu \, , \tag{2}$$

$$b_0(\mathbf{T}) \equiv \frac{1}{2}\, g_{jk,0}\, T^{jk}, \quad b_i(\mathbf{T}) \equiv -\frac{1}{2}\, g_{ik,0}\, T^{0k}. \tag{3}$$

with (g_{ij}) the (curved) space metric. Universality of gravity: *Same eqn must hold true for any continuous medium* (including the case of an electromagnetic field).

Specific form for the spatial metric

- The foregoing dynamics holds *independently of any specific form for the spatial metric* $\boldsymbol{g}$. Heuristically, one expects a gravitational space contraction in the ratio β. Hence:

- *Physical* $(\boldsymbol{g})$ & *Euclidean* $(\boldsymbol{g}^0)$ space metrics on M related by
  - *either* an anisotropic contraction (in direction $\mathbf{g}$) $\quad(\mathbf{v1})$
  - *or* an isotropic contraction:

$$\boldsymbol{g} = \beta^{-2}\boldsymbol{g}^0 \quad (\mathbf{v2}).$$

General energy conservation in this theory

Eqn. $T^{\nu}_{\mu;\nu} = b_\mu(\mathbf{T})$ rewritten in terms of usual derivatives, giving as the time component:

$$\left(\sqrt{-\gamma}\,T^j_0\right)_{,j} + \left(\sqrt{-\gamma}\,T^0_0\right)_{,0} = \sqrt{-\gamma}\,\beta\beta_{,0}\,T^{00}, \tag{4}$$

where

$$\gamma \equiv \det(\gamma_{\mu\nu}) = -\beta^2 \det(g_{ij}). \tag{5}$$

The scalar field is $\beta \equiv \sqrt{\gamma_{00}}$ or some function of it. This function and the equation for the scalar field are not fully constrained by the heuristic principles (gravity as Archimedes' thrust in a compressible fluid).

Another constraint: by virtue of the scalar field equation, the r.h.s. of (4) must be transformed to a 4-divergence, in order to get a *conservation equation* for a (material + gravitational) energy. Due to eq. (5), this depends on the form assumed for $\boldsymbol{g}$.

Formal Principles of the Scalar Theory (end)

- **v1**: Eqn for the field $(\gamma_{00})_{\text{preferred frame}} = \beta^2$ was a *nonlinear wave equation*.

- **v2**: Eqn for the field $\psi \equiv -\mathrm{Log}\beta$ is a *linear wave eqn*:

$$\Box\psi \equiv \psi_{,0,0} - \Delta\psi = \frac{4\pi G}{c^2}\sigma.$$

  with $\sigma \equiv T^{00}$ where $\mathbf{T}$ is the energy-momentum tensor

- In both cases, this ensures that a true, local, conservation equation is got for the energy.

Asymptotic post-Newtonian (PN) approximation for relativistic theories of gravitation

- Based on *initial-value problem*: a *family* of initial data.

- In GR, the asymptotic scheme was introduced by Futamase & Schutz (1983).
  They derived (not detailed) local equations (expansion of exact PDE's) but no "global" eqs i.e. for mass centers of extended bodies.
  Now done for GR by this speaker: PRD, to appear.

- Scalar theory: detailed local and global eqs were derived.
  A *family* of systems, (S^λ), derived from the given system S (made of fluids), in a general case.

- In Newton's gravity, there's exact similarity transformation: given one solution $(p, \rho, U, \mathbf{u})$ of Euler-Newton eqs., (p: pressure, ρ: density, U: Newt. potential, $\mathbf{u}$: velocity), one gets a family of solutions: $(p^\lambda, \rho^\lambda, U^\lambda, \mathbf{u}^\lambda)$.

- This Newtonian similarity transformation is applied to initial data for system S, giving initial data for S^λ.

- Change units: $[\mathrm{M}]_\lambda = \lambda[\mathrm{M}]$ and $[\mathrm{T}]_\lambda = [\mathrm{T}]/\sqrt{\lambda}$. Then all fields: p^λ, ρ^λ, $\mathbf{u}^\lambda$, V^λ, are $\mathrm{ord}(\lambda^0)$, and $\lambda \propto 1/c^2$ $\Rightarrow$ expansions are straightforward.

- All fields are expanded, each with 2 terms (for 1PN approximation) $\Rightarrow$ each exact equation splits into 2 eqs (it is just coefficient identification for a polynomial in λ)
$\Rightarrow$ same number of independent equations & unknowns.

- The theory admits consistent expansions in powers of λ.
First term (order λ^0): Euler-Newton equations
$\Rightarrow$ Newtonian limit OK.

- *Standard PNA (Fock-Chandrasekhar):*
matter fields $p, \rho, \mathbf{u}$ are *not* expanded.
Thus if a family (S^λ) is considered, these fields depend on λ
$\Rightarrow$ splitting of each exact eqn into 2 eqs can't be justified.
But $(\gamma_{00})_{1\mathrm{PN}}$ depends on two unknowns,
hence in fact the eqn for γ_{00} *must* be split into 2 eqs.
The standard PNA scheme does not pertain to the asymptotic expansion method.

PN eqs of motion of the mass centers

- To get these PN eqs of motion: local PN eqs of motion (expansion of $T^{\nu}_{\mu;\nu} = b_{\mu}$) are integrated in domain D_a occupied by body (a).

- Eqn for PN correction to motion of mass centers (order 1):

$$M_a^1 \, \ddot{a}_1^i = \int_{\mathrm{D}_a} f_1^i dV$$

- The "PN force" density f_1^i depends e.g. on 0-order pressure p, density ρ, velocity $\mathbf{u}$, Newtonian potential U.

  $\Rightarrow$ *internal structure of the bodies influences the motion already from the first PNA*. Was to be expected.

- The "asymptotic" PNA just confirms this expectation. *Holds true for GR when asymptotic PNA is used* (PRD, to appear).

Conclusion

- **v1**: anisotropic space metric, **v2**: isotropic.
- Effects on light rays are OK in **v1** and **v2** as well.
- There is only quadrupole grav. rad., and with energy *loss* (for **v1**; very likely also true for **v2**)
- To test that theory in celestial mechanics, an "asymptotic" PN scheme, as in applied maths, was developed.
- The resulting eqs for a self-gravitating system of extended bodies include internal-structure effects. *Also true for GR.*
- For **v1** only, the internal-structure influence subsists at the point-particle limit. (Severe violation of the WEP .)

Point-particle limit of the EMMC's and the WEP

- Framework for point-particle limit: (size of one body) = ξ
  $\xi \to 0$, thus a family (S^ξ) of 1PN systems is considered. (The eqs of the asymptotic 1PN approx. make a closed exact system.) Initial data is independent of ξ apart from the size of the small body.

- Result: *for* **v1** *only*, a structure-dependent part of the acceleration, $\mathbf{A}_S = \mathrm{ord}(\xi^0)$, remains at the point-particle limit $\xi \to 0$ (indeed $\mathbf{A}_S = \mathbf{0}$ for **v2**, *has been checked*).

- Static spherical case: limit differs from test particle just by $\mathbf{A}_S$: $\mathbf{A}_{\mathrm{lim}} = \mathbf{A}_S$ + (1PN accel$^{\mathrm{n}}$ of test particle in SS field).

- Thus: *Weak Equivalence Principle violated !* **kills v1** !
  $|\mathbf{A}_S| \approx 10^5$ times the residual acceleration for Pioneer 10 !!

Reasons for WEP violation in v1 & no violation in v2

- General reasons making WEP violation *a priori possible:*
  - *Non-linearity of the theory:* self-forces are excluded from Newton's theory by actio-reactio equality, which cannot even be *formulated* in a nonlinear theory.
  - *Structure influence* generally expected due to mass-energy equivalence. Asymptotic PNA separates the eqns of different orders, thus making the structure influence explicit.
- Specific reason for WEP violation occur in **v1** and not in **v2**:
  - Presence in **v1**'s PN metric of derivatives $U_{,i}$ of Newt. potent.
- But the $U_{,i}$'s also there in PN Schwarzschild metric ("anisotropy") (Schwarzschild metric = unique solution of **v1** for SSS case).
- So what about GR?? Should depend on the gauge condition. Note: In GR, gauges do exist, in which standard Schwarzschild is the unique solution of SSS case.

Eqs of motion in harmonic GR according to the asymptotic PN scheme

The same asymptotic PN scheme was applied to GR under the harmonic gauge condition (M.A., PRD, to appear).

$\Rightarrow$ Acceleration = Lorentz-Droste (Einstein-Infeld-Hoffmann), *plus*

- 1PN corrections that cancel for exact spherical symmetry (should be very small),
- and one new term depending on the rotation velocity of the body and on its internal structure.

  For the giant planets, this new term is not negligible.