On principles of repulsive gravity: the Elementary Process Theory

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Abstract. Although a matter-antimatter repulsive gravity has never been observed, currently its existence cannot be excluded either. The purpose here is to review ideas on elementary physical principles by which matter and antimatter can repulse each other gravitationally: this is relevant since both General Relativity (GR) and the Standard Model (SM) are certain to be incorrect in case repulsive gravity indeed exists. Modifications of GR by Santilli and Villata predicting antimatter antigravity are empirically inadequate at subatomic level, and thus not fundamental. And Kowitts extended Dirac theory, also predicting antimatter antigravity, is inconsistent with results of Eötvös-like experiments. The recently developed Elementary Process Theory (EPT) is consistent with a matter-antimatter gravitational repulsion; however, although it's not inconsistent with experiment, it does entail a radical departure from modern physics: not only is it a set of new physical principles expressed in terms of new physical concepts, in addition it is incompatible with both GR and the SM. Correspondence to Special Relativity has recently been shown, but the main issue remains that there is insufficient proof that the EPT satisfies the correspondence principle. For that matter, future work has to be aimed at proving correspondence to Classical Mechanics, GR, and the SM.

1. Introduction

Currently, there are at least four sizeable experimental projects going on to establish the coupling of rest-mass-having antimatter with the gravitational field of ordinary rest-mass-having matter: three projects at CERN using anti-hydrogen, AEgIS [1], GBAR [2], and ALPHA [3], and one project at the PSI using muonium [4]. The current state of affairs is that the said coupling has thus far not been established experimentally. Now a basic principle of science, as put into words by Feynman, is that "experiment is the *sole judge* of scientific truth" [5]. In the present context, this means thus that currently a repulsive gravity between rest-mass-having matter particles and rest-mass-having antimatter particles **cannot** be excluded—although undoubtedly the experimental physicists involved in the aforementioned projects are driven by *curiosity* rather than by a *belief in repulsive gravity*.

In the literature several theoretical arguments against repulsive gravity can be found; these, however, lean on assumptions that include the validity of contemporary physical theories. An overview of these arguments can be found in [6]; since then only one new argument has been published by 't Hooft. The reasoning is as follows: if we throw a ball up in the air, then its motion is a parabola that is symmetric under time reversal; given Feynman's interpretation of antimatter [7], the ball is in the opposite time-direction an "anti-ball", which thus also falls down—ergo, no repulsive gravity [8]. The reply, however, is that this "anti-ball" falls down on an "anti-earth": the argument by 't Hooft, thus, doesn't prove a thing for the motion of the "anti-ball" on 'our' earth—it isn't a valid argument against repulsive gravity [9]. But rather than

reiterating how improbable repulsive gravity is from the perspective of contemporary physical theories, our purpose here is to examine the case that such a repulsive gravity is a fact of nature, centralizing at the question: What are the elementary physical principles by which matter and antimatter can repulse each other gravitationally?

The remainder of this introduction presents an important implication of repulsive gravity in terms of the observable properties 'inertial mass' and 'gravitational mass'. The next section argues that this implication necessitates a departure from modern physics for the formulation of principles of repulsive gravity, pointing out inadequacies of modifications of contemporary physical theories made to incorporate an eventual detection of repulsive gravity. The section thereafter sketches in broad lines the principles of the Elementary Process Theory (EPT) relevant for understanding repulsive gravity, and reviews the open issues. The final section briefly summarizes the current outlook for theoretical research on the principles of repulsive gravity.

To start with, let's recall that *inertial mass* is the observable resistance of a body against a change in motion; *rest mass* is then the inertial mass of a body in rest, that is, a body that doesn't move relative to an observer. Now it has already been established that antimatter has *positive* rest mass: a negative rest mass would, for example, be impossible to reconcile with the stability of antihydrogen observed by Hangst *et al.* [10], because the Coulomb force would then cause the antiproton and the positron to repel each other.

Gravitational mass, on the other hand, is the observable 'charge' of a body for the gravitational force. Now in case the earth's gravitational force on a body of antimatter is the *only* force, an observation of an acceleration *away from* earth means that the gravitational force on the body of antimatter is also directed away from earth, since antimatter has *positive* rest mass. But that is only possible if the gravitational mass of the body of antimatter is *negative*: all other factors in Newton's equation for the gravitational force are namely *positive*.

Thus speaking, a matter-antimatter gravitational repulsion being a fact of nature *necessarily implies* that the following conjunction holds for the observable properties gravitational mass $\overline{m}_g$ and rest mass $\overline{m}_0$ of a body of antimatter:

$$\overline{m}_0 > 0 \wedge \overline{m}_g < 0 \tag{1}$$

Historically, this combination of positive inertial mass and negative gravitational mass has occurred in the literature since the late 1950's [11, 12, 13]; in their 1957 essay, Morrison and Gold were the first to conclude that antimatter must have this combination of properties in case of a matter-antimatter gravitational repulsion.

What is important is that when repulsive gravity exists, formula (1) is a **universal truth** for *all* rest-mass-having antimatter bodies, and thus a criterion for the evaluation of theories. Note that, in addition, it is model-free: it has been derived without any assumption on what antimatter *is*, and without taking a stance on whether inertial mass and gravitational mass are *primary* or *secondary* properties as meant by Locke, that is, whether these are observable properties that are also present in the thing in itself, or properties that are observable but not present in the thing in itself (like color). In terms of *active gravitational mass* and *passive gravitational mass* as meant by Bondi—passive gravitational mass is the one that occurs in Newton's law, active gravitational mass is the source of the gravitational field [12]—conjunction (1) is about passive gravitational mass: the point is thus that this has to be distinguished from inertial mass in case repulsive gravity exists.

2. Why repulsive gravity necessitates a departure from modern physics

2.1. The argument against General Relativity

In General Relativity (GR), the Weak Equivalence Principle (WEP) "is not a separate fact but is basic to the theory. Accordingly the ratio of inertial and passive gravitational masses is the same

for all bodies" [12]. Thus speaking, in the framework of GR we get the following conjunction for the rest mass $\overline{m}_0$ and the (passive) gravitational mass $\overline{m}_g$ of a body of antimatter:

$$\overline{m}_0 > 0 \wedge \overline{m}_g > 0 \tag{2}$$

On account of the WEP, it is thus **absolutely impossible** from the perspective of GR that rest mass and gravitational mass of a body of antimatter have opposite signs. That is, GR is inconsistent with conjunction (1), the main implication of a matter-antimatter gravitational repulsion derived in the previous section.

The point here is the following: given the criterion for theory rejection by Descartes—if we have a reason for doubting a theory, then the theory should be rejected *in its entirety* [14]—and given the above inconsistency of GR with the main implication of repulsive gravity, a detection of repulsive gravity provides a reason to reject GR in its entirety.

2.2. The argument against modifications of General Relativty

Santilli and Villata have developed modifications of GR that predict antimatter antigravity [15, 16]. Experimentally the two theories are indistinguishable, but Santilli has formulated his theory using what he calls *isodual mathematics*.[1] The principle of gravitation is that of GR: gravity is the deflection of a continuous particle trajectory due to the curvature of spacetime. But antimatter now "sees" an inverted spacetime, causing antigravity: as Santilli put it, "the trajectories we observe for antiparticles are the *projection* in our spacetime of the actual trajectories in isodual [i.e. inverted] space" [15]. And according to Villata, "all masses are and remain positive" [16]: in this framework, the passive gravitational mass $\overline{m}_g$ in conjunction (1) is thus a *secondary property* in Locke's sense.

At a macroscopic level where planets can be modeled as classical particles, these modifications of GR are consistent with a matter-antimatter repulsive gravity. But the central question is: Can such a modified GR be *fundamentally* correct? There are, then, several arguments why this cannot be the case. First of all, it is epistemologically a questionable practice—to say the least—to use GR to construct a new theory that is to be consistent with repulsive gravity: the latter being a fact of nature would, namely, imply that GR itself is developed from a falsehood—to wit: the assumption that gravity is attraction only. But even apart from this and other philosophical objections raised against Villata's theory [18], fact of the matter is that these modifications of GR are (just like GR itself) *empirically inadequate*[2]: the discreteness of the microcosmos cannot be described as a prediction of the theory. In a hydrogen atom, for example, only discrete energy levels occur. A transition from the ground state E_0 to the second excited state E_2 is thus a *discrete* transition: the intermediate energies E, for which $E_0 < E < E_2$, are **not** attained. This is not predicted by GR nor by the modifications thereof by Santilli and Villata: these predict that every change of state is *continuous*. Therefore, fundamental principles of repulsive gravity have to be formulated *outside* the framework of GR—nevertheless, Villata's equation of motion for antimatter in the gravitational field of matter is an emergent law of fundamental importance: any empirically adequate theory of repulsive gravity has to reproduce it at macroscopic level.

[1] Its basis is the isodual real number field $(\mathbb{R}, +, \cdot^d)$, for which the binary operation multiplication '$\cdot^d$' is given by $x \cdot^d y = -xy$: this yields the claim in [15] that the multiplicative unit -1 of the isodual real number field is *negative*. It is a well-known corollary of modern mathematics that the only possible ordering of the real number field is the natural ordering [17], in which the multiplicative unit is *positive*: the isodual real numbers with its *negative* multiplicative unit thus seem to yield spectacular new mathematics. That, however, is not the case: the adjective 'negative' in 'negative multiplicative unit' comes from ordering the isodual real numbers as a *set*, not as a *field*. The isodual real number field is, in fact, isomorphic to the real number field; at best, this yields a new notation 'x^d' for the isodual image of a real number x, with $x^d = -x$.

[2] A theory is *empirically adequate* if and only if all observations in its area of application—past, present and future—can be described as predictions of the theory [19].

2.3. The argument against contemporary quantum theory

The Standard Model (SM) contains CPT-invariance. In [20], Kellerbauer *et al.* stated that

> *the problem of the gravitational interaction of antimatter is completely independent from the question of matter-antimatter symmetry (CPT), as CPT-invariance merely dictates the equality of the inertial masses of particle and antiparticle pairs, but places no restriction on the gravitational masses.*

But that is not true, for if we view CPT-invariance as a *correct* feature of the SM, then we implicitly take the position that the relation between the properties of a matter particle and those of its antimatter counterpart is *correctly* described by C-inversion, which leaves gravitational mass untouched (and since quantum theory is about *observable* properties, this is about *passive* gravitational mass). So contrary to the statement of Kellerbauer *et al.*, the SM dictates that the rest masses m_0 and $\overline{m}_0$ and the gravitational masses m_g and $\overline{m}_g$ of a particle and its antimatter counterpart are related according to

$$\overline{m}_0 = C(m_0) = m_0 > 0 \wedge \overline{m}_g = C(m_g) = m_g > 0 \tag{3}$$

On account of C-inversion, it is thus **absolutely impossible** from the perspective of the SM that rest mass and gravitational mass of an antimatter particle have opposite signs. That is, just like GR, the SM is inconsistent with conjunction (1), the main implication of a matter-antimatter gravitational repulsion.

The point here is then the following: a detection of repulsive gravity inevitably means that the C-inversion laid down in the SM is wrong, so applying the aforementioned cartesian criterion for theory rejection such a detection provides thus a reason to reject the SM *in its entirety.*

2.4. The argument against modifications of quantum theory

One might believe that the inconsistency of contemporary quantum physics with repulsive gravity is easily resolved by modifying C-inversion. In fact, such a modification has been proposed by Kowitt in his modified Dirac theory [21]: a positron then has *positive* energy and *negative* gravitational mass in accordance with conjunction (1), as it is a hole in the sea of negative-energy electrons with positive gravitational mass. Repulsive gravity then emerges from the additional terms $m_g\Phi_g$ and $m_g\mathbf{A}_g$ in the generalized Dirac equation

$$[(cp_0 - q\Phi - m_g\Phi_g) - \alpha \cdot (c\mathbf{p}) - q\mathbf{A} - m_g\mathbf{A}_g) - \alpha_0 mc^2]\psi = 0 \tag{4}$$

where m_g is the gravitational mass, Φ_g the scalar gravitational potential, and $\mathbf{A}_g$ the gravitational vector potential (see [21] for an interpretation of the other symbols).

The belief that this restores consistency of quantum physics with repulsive gravity is, however, **false**. Namely, from a set Σ_{QM} of premises from quantum theory and the premise P that the rest masses and gravitational masses of antimatter particles and their matter counterparts are related according to $\overline{m}_0 = m_0 \wedge \overline{m}_g = -m_g$, it *inevitably* follows that the Eötvos parameter of Beryllium and Titanium η_{Be-Ti} should be 10^{-6} (see [22] for the detailed argument):

$$\Sigma_{QM}, P \vdash \eta_{Be-Ti} = 10^{-6} \tag{5}$$

However, experimentally it has been established that η_{Be-Ti} is much smaller:

$$\eta_{Be-Ti} \lesssim 10^{-13} \tag{6}$$

By modus tollens, it thus follows from (5) and (6) that the conjunction of Σ_{QM} and P cannot be true. From the perspective of quantum theory, that is, from the point of view that Σ_{QM} is

true, the premise P can thus not be true: this is Schiff's argument against repulsive gravity, originally published in [23]. But if repulsive gravity exists, then P is true, see Sect. 1, which leaves that Σ_{QM} is then false. In other words, quantum theory is *fundamentally incompatible* with repulsive gravity.

Kowitt's reply is that we can only infer from the experimental result (6) that the relation $\overline{m}_0 = m_0 \wedge \overline{m}_g = -m_g$ cannot hold *for virtual pairs*: this experimental result, thus, doesn't rule out that conjunction (1) holds for *real* positrons in the framework of quantum physics [21]. The reply to that reply is that the theory then would become *conceptually incoherent*: apart from lifetime, virtual and real particles are supposed to have the same properties—if not, we would need two C-inversions: one for real particles and one for virtual particles.

The inevitable conclusion is, therefore, that a detection of repulsive gravity would mean that there is no such thing as a virtual pair. Physicists, however, have commented that they cannot believe that virtual pairs don't exist because of the Lamb experiment [24]: it is apparently widely believed that the existence of virtual pairs has been confirmed by this experiment. This belief, however, is **false**. The Lamb shift, namely, is not a *physical* shift, such as the frequency shift that is observable due to the Doppler effect, but a *theoretical* shift—that is, a difference between theoretical predictions. Consequently, there is no such thing as an "observation" of the Lamb shift: there is only the fact that the experimental data confirm the predictions of QED and falsify the predictions of Dirac theory. This fact doesn't rule out that virtual pairs don't exist: *a detection of repulsive gravity thus means that there has to be a theory T with an ontology **without** virtual pairs, such that T reproduces the experimental data.* This may indicate the enormity of the consequences of a detection of repulsive gravity for physics.

3. Elementary Process Theory: principles underlying repulsive gravity

The EPT consists of seven elementary physical principles that support a matter-antimatter gravitational repulsion [25, 26]. The theory is rigorously formalized and axiomatized, so as to provide—at least in potential—a foundational theory for physics that satisfies the criteria of rigor of a solution to Hilbert's sixth problem; see [27] for a statement of the latter. The EPT has, obviously, not been developed from empirical data, but instead from what Descartes called a *clear and distinct idea*. That immediately raises the question: can that idea be a source of knowledge of the physical world? This question has been answered affirmatively in [28]; the argument will not be repeated *hic et nunc*, but the point is that it is an error to think that empirical data are *the only source* of knowledge in physics—it is true that a theory must have been tested experimentally according to the scientific method before we can conclude that it's a scientific theory, but the experiment is then not necessarily the *source* of the knowledge.

3.1. The principles of the Elementary Process Theory

The EPT entails a radical departure from modern physics: its principles are not based on any of the existing classical or quantum theories. But not only that. The EPT also uses a different ontology: the universe is not described in terms of 'particles' or 'quanta', but in terms of 'phase quanta'—these are the ultimate constituents of the universe. A crucial difference with quantum theory is then this: in the quantum framework, the electron is an indivisible quantum, which can have wavelike and particlelike properties; in the framework of the EPT, however, the electron alternates between a particlelike and a wavelike state, and exists thus alternately in the form of a particlelike and a wavelike phase quantum. Consequently, rest-mass-having entities exhibit stepwise motion: being in the form of a particlelike phase quantum they are in a *motionless state of rest*, and being in the form of a wavelike phase quantum they are in a *state of motion*.[3]

[3] It is, thus, **not** the case that a rest-mass-having entity, e.g. an electron, alternately *moves* in particlelike and wavelike form: it alternately *exists* in particlelike and wavelike form, but it *moves* in wavelike form only.

As to the principles of the EPT, the overall picture is that the observable process of evolution can be indexed by integer-valued degrees of evolution, and at every such degree of evolution n there are then a finite number $\omega(n)$ of elementary processes from that degree of evolution to the next: the principles of the EPT then describe what happens in such an elementary process—the aforementioned process of alternation between particlelike and wavelike states of nonzero rest mass entities takes place in a sequence of these individual processes. So, let's look in detail at the k^{th} process of the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution; to keep things simple we assume that this process only involves gravity and/or electromagnetism—that is, no nuclear fission, fusion, or decay takes place. With a slight abusive of language, what happens is the following:[4]

(i) the process begins with a **spatially extended particle**, in the EPT denoted by a symbol ${}^{EP}\Phi_k^n$, centered at a spatial position $\vec{x}_n$ at the n^{th} degree of evolution;

(ii) by a discrete transition ${}^{EP}\Phi_k^n \rightarrow {}^{NW}\Phi_k^n$, the spatially extended particle transforms into a **nonlocal matter wave**, in the EPT denoted by a symbol ${}^{NW}\Phi_k^n$, which is an object spread out over space that has its spatial extension instantaneously;

(iii) after a finite amount of time, the nonlocal matter wave spontaneously collapses into a **point-particle**, in the EPT denoted by a symbol ${}^{NP}\Phi_k^{n+1}$, at a spatial position $\vec{x}_{n+1}$ at the $(n+1)^{\text{th}}$ degree of evolution—the collapse is a discrete transition ${}^{NW}\Phi_k^n \rightarrow {}^{NP}\Phi_k^{n+1}$;[5]

(iv) immediately after creation, the point-particle emits a **local matter wave**, in the EPT denoted by a symbol ${}^{LW}\Phi_k^{n+1}$, which spreads out gradually over space at the $(n+1)^{\text{th}}$ degree of evolution—the emission is a discrete transition ${}^{NP}\Phi_k^{n+1} \rightarrow {}^{LW}\Phi_k^{n+1}$;

(v) the emission of the local matter wave causes the point-particle to transform into a **new spatially extended particle**, centered at the spatial position $\vec{x}_{n+1}$ at the $(n+1)^{\text{th}}$ degree of evolution: this is the starting point of a new elementary process, say the l^{th}, from the $(n+1)^{\text{th}}$ to the $(n+2)^{\text{th}}$ degree of evolution.[6]

So this is how a nonzero rest mass entity, e.g. an electron, alternates between a particlelike and a wavelike state: in the above process the nonzero rest mass entity *is* the superposition ${}^{EP}\Phi_k^n + {}^{NW}\Phi_k^n$. In the process energy is only once absorbed from the surroundings, to wit: in step (ii), and only once emitted, to wit: in step (iv). The idea is thus that this description of the process is **fundamental**: there are no separate processes for the electromagnetic and the gravitational interaction, there is only one process in which a single long-distance interaction takes place of which electromagnetism and gravity are aspects. This remains the case when nuclear reactions are taken into consideration: all processes are essentially the same. Although not a unified field theory, the EPT thus brings about *unification of processes*.

3.2. Repulsive gravity in the framework of the Elementary Process Theory

The separation of states of rest and states of motion described in the previous section corresponds in a natural way with the decoupling of rest mass and gravitational mass in conjunction (1): rest mass is then a property of a state of rest (an extended particle with a symbol ${}^{EP}\Phi_k^n$ in the EPT), and gravitational mass a property of a state of motion in which gravity takes place (a nonlocal matter wave with a symbol ${}^{NW}\Phi_k^n$ in the EPT).

As to the principle of repulsive gravity, all rest-mass-having entities are endowed with a **characteristic number of normality** χ, which has the value $+1$ for ordinary matter and -1 for antimatter: ordinary matter particles with the characteristic number of normality $\chi = +1$

[4] For a rigorous treatment in correct terminology, see the Annalen papers [25, 26] or the dissertation [28].

[5] Effectively, the nonlocal matter wave has thus brought about a transition from the extended particle to the point-particle, which in the EPT is expressed as ${}^{NW}\Phi_k^n : {}^{EP}\Phi_k^n \rightarrow {}^{NP}\Phi_k^{n+1}$.

[6] Effectively, the emitted local matter wave has thus brought about a transition from the point-particle to the extended particle, which in the formalism of the EPT can be expressed as ${}^{LW}\Phi_k^{n+1} : {}^{NP}\Phi_k^{n+1} \rightarrow {}^{EP}\Phi_l^{n+1}$.

are then "strong field seekers", while antimatter particles with the characteristic number of normality $\chi = -1$ are then "weak field seekers". Thus speaking, in the process of stepwise motion, the nonlocal matter wave of e.g. an antiproton will tend to move towards a *weaker* field: the antiproton will thus be repulsed by the gravitational field of a body of ordinary matter. So that's the principle of repulsive gravity.

In the framework of the SM, every photon is identical to its antiparticle: this is another argument against repulsive gravity, because one and the same photon cannot simultaneously be both attracted and repulsed by a body of matter. In the framework of the EPT, however, photons are contained in local matter waves (i.e., local wavelike phase quanta): there is then no such thing as an "antiphoton". The observed deflection of photons in the gravitational field of the sun, see e.g. [29], is therefore interpreted as a mere proof that the geometry of the vacuum is non-Euclidean. But of course these observations form a boundary condition for an empirically adequate model of the EPT: the observed behavior of photons has to be predicted by the model.

3.3. Open issue: the correspondence principle

The main issue is that the EPT is not proven to satisfy the correspondence principle, although correspondence to Special Relativity (SR) has recently been shown by postulating that the degrees of evolution form and additional dimension that is curled up [30]. For the purpose of discussing the relation between space and time, we can represent this curled-up dimension mathematically by the set of real numbers $\mathbb{R}$ together with the equivalence relation '$\sim$' given by

$$x \sim y \Leftrightarrow x \equiv y (\text{mod } 1) \tag{7}$$

where $x \sim y$ has to be interpreted as: x and y are **physically** the same point. We can then postulate that space-time has five dimensions: three "regular" spatial dimensions, one curled-up dimension of degrees of evolution, and one temporal dimension. And if we use Planck units (so Planck length and Planck time are scaled to 1), we can endow this 5D space-time $\mathbb{R}^5$ with a metric tensor $g = \text{diag}(-1, -1, -1, -1, +1)$. Under the presupposition that interactions are negligible (so that all motion is linear), we can then postulate that all particles move on null lines in this 5D space-time.[7] For any displacement vector $\Delta\vec{x} = (\Delta x, \Delta y, \Delta z, \Delta n, \Delta t)$ of any particle in this 5D space-time we thus have

$$g(\Delta\vec{x}, \Delta\vec{x}) = -(\Delta x)^2 - (\Delta y)^2 - (\Delta z)^2 - (\Delta n)^2 + (\Delta t)^2 = 0 \tag{8}$$

So, the duration of a particle leap becomes simply the Euclidean measure of a displacement in 4D space: $\Delta t = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2 + (\Delta n)^2}$. Also, the observer-independent displacement in degrees of evolution Δn is then numerically identical to the invariant interval Δs of the corresponding displacement vector $(\Delta x, \Delta y, \Delta z, \Delta t)$ in 4D Minkowskian space-time.[8] This fully reproduces SR: the EPT is thus consistent with the outcome of the Michelson-Morley experiment and with observations of time dilation. This result lays the groundwork for further developments towards a full proof of correspondence of the EPT.

4. Conclusion

Of course, a detection of a matter-antimatter gravitational attraction would put modern physics on an even more firm empirical basis than it is already, and would provide a reason to reject the EPT as having been developed from a falsehood. A detection of repulsive gravity, on the other hand, would have far-reaching implications—for theoretical physics research in particular.

[7] The stepwise motion yields an array of points on a null line: every step in the stepwise motion of a nonzero rest mass particle is a leap $(x_1, y_1, z_1, n_1, t_1) \rightarrow (x_2, y_2, z_2, n_2, t_2)$ in 5D space-time with $n_1 \in \mathbb{N}$ and $(n_2 - n_1) = 1$.

[8] However, the degrees of evolution should **not** be viewed as a physical interpretation of the invariant interval: see [30] for the argument.

Research programs, aimed at a quantum-theoretical foundation for physics, find themselves then in trouble because of the inconsistency of the quantum ontology with repulsive gravity: a search for new first principles is then required. That means that a detection of repulsive gravity would throw the quantum research programs back to a pre-Newtonian stage of speculative philosophy, defined by Whitehead as "the endeavor to frame a coherent, local, necessary system of ideas in terms of which every elements of our experience can be interpreted" [31].

The research program aimed at an empirically adequate model of the EPT, on the other hand, is consistent with repulsive gravity: a detection thereof would thus be a strong motivation for further work in this area. The next step would be the development of a toy model of the EPT, such that the predictions of the toy model are the same as those of classical mechanics: that would prove correspondence of the EPT with classical mechanics—such a toy model is in the works. Thereafter a less restricted model would have to be developed to prove correspondence with GR and Villata's equation, and, last but certainly not least, after that correspondence with quantum theory still has to be proven.

However, although a failure of any of the above steps would suffice for a rejection of the EPT, it should be realized that the research does not constitute a search for first principles: these are, namely, already given by the EPT. Thus speaking, the difficulties in this research program are then far less than the difficulties that the quantum research program faces in this scenario.

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