

On the very low probability of complex life forms to be just emergent phenomena and about the “continuous” versus “intermittent” free will

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Abstract

This paper discusses on:

- (1) the very low probability of complex [life forms](#) (LFs) to be just [emergent](#) phenomena based on simple but strong physic-chemical and biological arguments regarding the limits of DNA and RNA to store multidimensional hierarchical multiple-layered biological information (BI);
- (2) the continuous vs intermittent “quasi-quantum” [free will](#) (FW);
- (3) a hypothesis on the physical causes of the subjective sensation (illusion) of irreversible time arrow created by the human/animal mind;

Keywords: [life forms](#), [emergent](#) phenomena, limits of DNA and RNA, multidimensional hierarchical multiple-layered information;

1. On the very low probability of complex life forms to be just emergent phenomena

Introduction. The generic [life phenomenon](#) (LP) is currently regarded (defined and studied) by modern [biology](#) as an [emergent](#) property of [chemical](#) phenomena (CP), thus an [emergent](#) property of [physics](#) itself (as all CP is currently defined as [causal physical epiphenomena](#)): [psychological](#) phenomena (PLP) are also “[deterministically](#)” defined as [emergent](#) from the [neurobiological phenomena](#) (NBP) of [life forms](#) (LFs). This modern “vertically”-deterministic [emergentism](#) that dominates the modern biology (and modern science in general) is probably a wrong assumption (one of the greatest mistakes in human history, including the history of science and thought), as argued next in this paper.

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Let’s start with a couple of observations, definitions and a conjecture that were all proposed by the same author in his past article entitled “[Life forms, “hybrid” causality, gravity and hierarchical parallel universes](#)” [1].

Observation no. 1 (Obs1) (life forms as dissipative systems).

Being [complex dissipative systems](#), [life forms](#) (LFs) periodically (and progressively) change/refresh significant fractions of their molecules, atoms and subatomic [quantum particles](#) (QPs) [2, 3], by interchanging significant percents of the total number of these [physical particles](#) (PPs) (found inside those LFs) with their [outer environment](#) (outENV), to preserve (at least their vital) [energy](#) and (at least their vital) [structural and functional biological information](#) (BI) and to replicate. It is clear that LFs use each (internalized) PP not only for the [energetic content](#) of that PP (the “caloric value” of that PP), but also (very frequently and essentially for survival!) for the (bio-structural and bio-functional biophysical and biochemical) bio-informational (carried) content of that PP (including, for example, the photons that hit the retina and are used for creating perceptual images), including the capacity of that PP to (chemically) “donate” or “accept” any other QP or PP, so that all PPs may be considered “[energo-informational packs](#)” when analyzed in the “frame of reference” of any LF, especially in the context that energy and information are intricate (and indissolubly related) concepts in both physics and biology.

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Definition no. 1 (Def1) (the inner environment of a life form). The [inner ENV](#) (innENV) of an LF is also defined as the 3D space (plus all the PPs it contains) “trapped” within the approximate spatial borders of any LF phenotype, at any instance of its lifetime.

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Observation no. 2 (Obs2) (the physical particles defined as “vital” for any life form in part). Given the total dependence of an LF on some demonstrated “vital” PPs (vPPs) from its outENV and its innENV (which vPPs are defined as sine-qua-non for the existence of that LF phenotype and genotype), it is very clear that all LFs are indissolubly related to their outENV.

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Conjecture no. 1 (Conj1) (the ternary structure of any life form). Based on Obs.1, Def1 and Obs2, LFs are conjectured to be essentially composed from **three main parts**:

(1) a biological “LF code” (LFcode), defined as a set of laws and rules which allow the existence, survival and replication of LFs:

- (i) the known laws of physics which allow the existence of LFs (no matter the complexity of LFs) are all considered the main/primary parts/modules of the LFcode;
- (ii) Every structural and functional information of every (transitory) PP contained by innENV is also considered a secondary part/module of the LFcode (for example, the [DNA/RNA code](#), the [epigenetic code](#) ^[URL2] and generally the set of all physical [including energetic, geometrical etc.] and chemical properties of all substances from any innENV useful for the survival and replication of any LF)

(iii) any other rule used by any LF (at any of its structural and functional innENV levels) for survival and replication is considered a tertiary part of the LFcode;

(2) an “LF body” (**LFbody**), which is defined as the innENV, no matter the rate of “refresh” of each PP from that innENV;

(3) an “extended LFbody” (**extLFbody**), which is defined as the sum of all 3D space plus vPPs from the outENV (of any LF) which may be potentially used by any LF for its survival and replication at any instance of its own lifetime (as an individual) or its whole lifetime (as an LF species);

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On the very low probability of complex LFs to be just emergent phenomena. Hypothesis 1 (Hyp1). If we start with the deterministic emergentism hypothesis (named here as “**Hyp1**”) that all the superior organization levels of cells (tissues, systems, organs and their specific functions, including the brain and its functions, including consciousness and self-aware) of all complex LFs are JUST an emergent phenomenon generated by the fact that all these cells “simply” follow a very complex “emergent” code (**EC**) unitarily, then we must accept that this very complex structural and functional EC (with at least 6 levels of organization: (1) locally tissular [the coordination between adjacent/neighbor cells of the same tissue], (2) globally tissular (the coordination between cells of the same type of tissue but localized in distinct anatomic regions of that same whole body), (3) organs [defined as being composed from many types of tissues], (4) systems [defined as being composed from organs composed from the same types of tissues], (5) apparatuses [defined as being composed from organs composed from the at least partially distinct types of tissues] and (6) whole body), this EC WOULD BE ENCODED in BOTH the **genetic (nuclear and mitochondrial DNA and RNA) plus epigenetic codes of the primary cell** (the stem cell or the fecundated ovule) AND in the **cellular organelles of that primary cell**. This paper estimates that there is a very small probability for our DNA/RNA (which is known to only encode [in its various codons] various amino acids for building various proteins) to additionally contain/encode on possibly larger scales/patterns (even partially and even in a small part) this **highly complex hypothetical EC, which EC has so many level of hierarchical code organization (with so many multi-nested “subroutines”)**. In other words, when pushed to its extremes, Hyp1 would imply that DNA and RNA not only store of a relatively simple codon-based genetic code, but a much more complex EC, with very many levels of (down-to-up) hierarchical organization: this paper considers Hyp1 (and its consequent) to be possible but highly improbable, given the strong (anti-Hyp1) argument (**Arg1**) that: **in such a complex EC (hypothetically partially encoded in DNA/RNA), even a very small variation of the DNA/RNA structure is expected to exponentially (and totally unpredictable!) disturb all the 6 (multi-nested) levels of superior organization of the EC of very complex LFs.**

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Prediction 1 (Pred1) (based on Arg1). Based on this anti-Hyp1 strong Arg1, this paper proposes/predicts that complex LFs are NOT actually true (totally) emergent phenomena, BUT ONLY PARTIALLY EMERGENT PHENOMENA, with a large part of their LFcode being actually stored NOT only in their primary totipotent stem cell (like the fecundated ovule is) but probably in all the physical fields (**PFs**) of our physical universe (**OPU**) and (“engraved” in) all physical laws (**PLs**) of our OPU (a prediction also launched in the 1st reference of this paper and other older papers of the same authors, with other arguments), BUT probably also encoded/engraved in other still unknown PFs of our OPU, like some PSI phenomena suggest [4].

When analyzed “down-to-up” (from the basic PLs of our OPU to their highest possible biological and social rules/“laws”), complex social LFs have 12 BI (biological [including biophysical] information) levels of integration (**BILIs**) that can be indexed from 0: **see the next table.**

Table 1. The 12 biological (including biophysical) information levels (BI) of integration (BILIs) that can be indexed from 0.

BILIs	Definition of each BILI in part
BILI(0)	The <u>bosons-fermions</u> dichotomy (BFD) with its associated <u>Pauli exclusion principle</u> (PEP) association: BFD-PEP was intentionally indexed with 0, as it represents the quantum 3D “volumic” “basement”/ “skeleton” of all atoms and molecules and thus of all known LFs from our OPU.
BILI(1)	The <u>gravitational field</u> (GF) which has so many implications for atoms/molecules stability, thus vital implications for LFs existence, development and survival.
BILI(2)	The <u>electromagnetic field</u> (EMF) which has so many vital implications for LFs existence, development and survival.
BILI(3)	The <u>weak nuclear field</u> (WNF) which has so many implications for atoms/molecules stability, thus vital implications for LFs existence, development and survival.
BILI(4)	The <u>strong nuclear field</u> (SNF) which has so many implications for atoms/molecules stability, thus vital implications for LFs existence, development and survival.
BILI(5)	The cellular <u>organelles</u> of all the biological cells: <u>viruses</u> have only these first six BILIs(0 to 5) as their DNA, RNA and protective chemical envelopes may all be considered subcellular/acellular organelles.
BILI(6)	The (biological) cells: all the unicellular and multicellular organism possess this BILI(6)
BILI(7)	The biological tissues: only the multicellular organisms possess this BILI(7)

BILI(8)	The biological organs: only some multicellular organisms possess this BILI (8)
BILI(9)	The biological systems/apparatuses: only the advanced multicellular organisms possess this BILI(9).
BILI(10)	The systems/apparatuses-based organisms: only the advanced multicellular organisms possess this BILI(10), including multicellular plants and animals from worms to humans.
BILI(11)	The systems/apparatuses-based social organisms: only the relatively advanced multicellular organisms possess the BILI(11).

II. On the continuous vs intermittent free will (FW) and the quantum limits of measurement and extended perception.

The analysis of the free will concept. The [free will](#) (FW) concept can be analyzed based on two possible hypotheses regarding the maximum allowed speed of physical information (PI) travel in our OPU:

- (1) **Hypothesis 2a (Hyp2a)** proposed in this paper states that “the maximum PI speed $\mathbf{v}_{\max(PI)}$ allowed in our OPU is finite, not infinitesimal and the same for all observers, regardless of the (accelerated or inertial) motion of the PI source”;
- (2) **Hypothesis 2b (Hyp2b)** proposed in this paper states that “the maximum PI speed $\mathbf{v}_{\max(PI)}$ allowed in our OPU is infinite”;

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Both Einstein’s Special Relativity (ESR) and General Relativity (EGR) are essentially based on the special sub-case of Hyp2a defined as $\mathbf{v}_{\max(PI)} = c$ (with c being the [speed of light in vacuum](#)).

On the other hand, the demonstrated existence of [quantum entanglement](#) suggests that Hyp2b could be also valid (at least in some specific conditions).

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This paper also uses an additional **Hypothesis 3 (Hyp3)** which states that: “Any quantum particle (QP) can be conceived to interact (interchange PI) with any physical field (PF) (a PF permeating all space of our OPU) at a very close local distance so <<intimately>> (definable by a minimal finite zero/non-zero conceivable distance $d_{\min(PI)}$) so that it is not practical for anyone to conceive a finite or infinitesimal distance of physical interaction (PI interchange) smaller than $d_{\min(PI)}$ (for the subcase $d_{\min(PI)} > 0m$), simply because distances smaller than

$d_{\min(PI)}$ would NOT have any practical physical meaning, except the importance of defining a space/spacetime continuum (the subcases $d_{\min(PI)} = 0m$ or $d_{\min(PI)} = (1/\infty)m$, on which ESR and EGR are both based by definition) on which continuous mathematical functions can be applied.”

Based on the hypothetical time quanta $(t_{\min(PI)})$ defined as the ratio $t_{\min(PI)} = d_{\min(PI)} / \mathbf{v}_{\max(PI)}$ which can be finite (when combining Hyp2a and Hyp3) or infinitesimal (when combining Hyp2b and Hyp3), 4 major categories of physical theories (PTs) are definable, such as:

- (1) PTs based on a quantum(/quantized/discrete) spacetime (like [Loop Quantum Gravity \[LQG\]](#) is);
- (2) PTs based on a quantum space and a continuous time (defined as a 4th space-like dimension) (LQG variants);
- (3) PTs based on a continuous space and a quantum time (LQG variants);
- (4) PTs based on a continuous spacetime (like ESR and EGR);

Important remark. Note that, when combining the special subcase of Hyp3 in which $d_{\min(PI)} = 0m$ WITH both Hyp2a and Hyp2b, $t_{\min(PI)} = 0$ (local instantaneous PI transfer between any QP and any PF for $d_{\min(PI)} = 0m$), which also implies an infinite frequency of PI interchange/interaction between any QP and any PF interacting with that “target”-QP no matter if $\mathbf{v}_{\max(PI)}$ is finite or infinite. In this special case, the maximum speed of interaction between a “generator”-QP (which QP produces a PF) and any other target-QP (on which that generated PF acts on) only depends on the maximum speed of PI transfer between adjacent but distinct points of that PF $\mathbf{v}_{\max(PF)}$ (a speed that could be finite or infinite, depending on the nature of both the generator-QP and the nature of its associated PF, but also depending on the minimum distance between any two adjacent points of that PF $d_{\min(PF)}$, which $d_{\min(PF)}$ can be either zero, infinitesimal or finite non-zero non-infinitesimal). However, there is an intrinsic paradox in the mathematical definition of the geometrical point (GP) (which GP is a [primitive](#) ^[URL2]), a paradox which is inherent to any GP of any continuous PF: we’ve also tried to analytically solve this paradox in another (older) paper [5].

The indubitable existence of [quantum entanglement \(QE\)](#) seems to support type-4 PTs (continuous spacetime models) in which $d_{\min(PI)} = 0m$ or $d_{\min(PI)} = (1/\infty)m$, $t_{\min(PI)} = 0$ (instantaneous interaction from zero-distance in a possible 4th dimension named “time”, no matter if $\mathbf{v}_{\max(PI)}$ is finite or infinite). QE may be thus

regarded as a possible “clue” of a hidden spacetime continuum that “hides” behind our observational quantum world, indicating that, if it exists, the hypothetical subquantum world could be continuous (not quantum!): **ironically, although Einstein didn’t believe in QE, it’s actually QE that may represent the only solid indirect proof of a 4D spacetime (ST) continuum, which is the theoretical “scene” of both ESR and EGR.**

In a checkpoint conclusion, it is very plausible that ST is actually a 4D continuum (“populated” with generator/target-QPs and PFs) in which PFs may locally interact instantaneously with QPs, BUT with finite non-zero non-infinitesimal speed of PI transfer between the GPs of that PF (which makes interactions at distance [mediated by that PF] between any two or more QPs to be generally non-instantaneous, except QE).

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The direct connection between free will (FW) and the finite/infinite maximum PI-transfer speed $v_{\max(PI)}$ allowed in our OPU.

For example, in the case of any chosen LF voluntary or involuntary controlling (by any means) the trajectory (in spacetime) of any PP using a PF (that can act on that chosen PP), we have three main types of FW manifestation on that chosen PP:

(1) **“Continuous” FW locally-only (cFWloc)**, in which that LF controls that PP (by using that PF) on all the infinitesimal GPs of the trajectory of that PP, but only from very small distances (locally-only): this situation implies $v_{\max(PI)} = \infty$ (as stated by Hyp2b), no matter if

$v_{\max(PF)}$ is finite or infinite;

(2) **“Continuous” FW globally (cFWglob)**, in which that LF controls that PP (by using that PF) on all the infinitesimal GPs of the trajectory of that PP, from both very small and very large distances: this situation implies $v_{\max(PI)} = \infty$

and $v_{\max(PF)} = \infty$;

(3) **“Intermittent” FW (iFW)**, in which that LF controls that PP (by using that PF) only on some GPs of the trajectory of that PP, either from both very small or very large distances:

this situation implies $v_{\max(PI)} = \textit{finite}$ OR

$v_{\max(PF)} = \textit{finite}$ (as stated in Hyp2a); our iFW

(implied by finite $v_{\max(PI)}$ or $v_{\max(PF)}$) may “distort” both our manipulation of any PP and our measurements on any PP, in the sense that we can only “digitally sample” our OPU and we can produce only “digital copies” of various objects or phenomena of our OPU: that is why, although ST maybe an ideal 4D continuum manifold, our ST may be “doomed” (by our iFW) to appear to us only as a quantized entity AND that is how [quantum mechanics](#) can actually cohabitate with EGR (under the iFW “umbrella”), without contradicting each other; the vice versa is also true, in the

sense that, in a quantum/quantized ST (composed from spacetime “atoms” or spacetime 4D [hyper]voxels), FW cannot manifest itself other than intermittently (as an iFW).

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Important note (1). As already expressed in the first part of this paper, complex LFs aren’t probably just emergent phenomena (generated exclusively by unitary behavior of their subcomponent biological cells [BCs], a behavior so complex [on so many levels of integration] that cannot be encoded in DNA/RNA only), BUT very probably complex LFs have a part of their properties encoded in some unknown PF or some informational/mind field (IF): that is why, this paper predicts that **FW is also partially encoded “out-of-body”, in this unknown PF or IF.**

Important note (2). In the case of complex LFs’ minds (which minds [MND] have both a voluntary/conscious [vMND] and involuntary/unconscious component [ivMND]), FW may not only be a “function” of vMND, but also a function of ivMND: it is also clear that not all vMND is controlled by FW AND it’s also probable that ivMND is controlled by FW in a lesser degree than vMND is.

Important note (3). Each healthy/damaged biological cell (BC) of any complex LF can have its own FW (cancer is the most eloquent proof of this fact, as cancerous BCs eludes many “orders” and biological “messages”/signals received from the rest of that LF body): it is clear that, contrary to cancerous BCs, each healthy BC also has FW but it exerts their FW intermittently (alternatively to the whole LF body’s FW), NOT almost-permanently like cancerous BCs do.

Important note (4). The classification cFW-iFW holds, no matter if [FW theorem](#) will ever be definitively proved to be true or false in the future: in a universe with a finite maximum speed of PF-QP interaction (PI transfer speed), even if they’ll ever be proved to have FW, QPs will surely manifest this FW as an iFW.

III. On the illusion of “time” and what generates this illusion

A 4D model of our OPU, with an optional 5th “time” dimension. Our OPU can be modeled as a 4D matrix with 4 axes:

(1,2,3) one axis for each of the three independent coordinates (x,y,z) of each point from our OPU 3D space (with a standard Oxyz system of axes): each of these points could be a GP in a 3D ST continuum OR it can be identified with the geometrical center of a minimal spherical volume “allowed” in our OPU (like the [Planck volume](#) for example) which is named “[voxel](#)” (defined as a units of a theoretical 3D spatial grid, analogously to the “[pixel](#)” which is defined as a unit of a 2D grid) in this paper; **Important note.** Regardless our 3D space is continuous or quantized, it may be very useful in physics to organize this space in a 3D grid composed of 3D spherical voxels, with each “voxel” defined as the minimal spatial volume with a theoretical/practical physical sense/meaning

(like the [Planck volume](#), for example, which is proposed in LQG as a “space-atom”).

- (4) a 4th axis containing the energetic (excitation) level (**EL**) in each GP (with x,y,z coordinates) of our 3D space (with EL being measured in [Joules](#) [**J**] and allowing positive but also negative [energy](#) quantities [measured in $\pm J$ units]) OR the energy (volumic) density (**ED**) in each 3D voxel (with ED being measured in $\pm J/m^3$ units); the spectrum of EL and ED quantities can be continuous or discrete; this 4th matricial dimension may be independent from the first three (x,y,z) dimensions of this 4D matrix OR it may subtly dependent on them.

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The optional “time” dimension. We can also add an optional 5th “time” dimension to this 4D matrix (of our OPU) to “record” the sequences of ED variations in each voxel of our OPU: this 5th dimension can be regarded as an abstract mathematical dimension which can be very useful in observing various patterns and correlations between the GPs/voxels of our OPU (together with their variable ELs/EDs); this optional 5th matricial dimension may be independent from the first four (x,y,z, EL/ED) dimensions of this 4D matrix OR it may dependent on them (as already demonstrated by [quantum mechanics](#) and theorized by using the [wave function](#) concept); this 5th “temporal” dimension describes/records (in a classical linear way!) the succession of energetical micro-states and macro-states of our OPU in this abstract/artificial/subjective (linear) “time”: in other words, it’s actually the EDs/ELs quantitative variations/fluctuations that generate the illusion of “time”; practically, if a GP/voxel of our OPU would keep its EL/ED constant on all the “energetical” evolution of our OPU, one can say that “time stood still” for that GP/voxel. In a checkpoint conclusion, it’s clear that energy and time are indissolubly related so that a “1D time film for each GP/voxel” can be defined qualitatively as the succession of all EL/ED values associated with that GP/voxel: the same “1D time film for each GP/voxel” can be defined quantitatively as the sum of all differences between successive ELs

$$\Delta EL [= EL(t) - EL(t-1)] \text{ or}$$

EDs

$$\Delta ED [= ED(t) - ED(t-1)]$$

variations. A **remark**. If this 5th

optional “time” dimension will be proved to have its own laws (at least partially independent on the other 4 distinct dimensions previously listed), then our OPU should be treated as a 5D spacetime entity, with “time” being actually defined as a 2D entity with both an energetic and a temporal dimension indissolubly related to (inseparable from) one another. **Important note.** Even if our OPU was almost completely “empty” (containing only “empty” 3D space) except containing just one photon (moving from a GP/voxel “A” to a distinct GP/voxel “B”), that photon would produce ELs/EDs variations at least on the GPs/voxels contained/encountered by/in its A-to-B trajectory and its surroundings: these ELs/EDs variations would be sufficient to legitimate an abstract clock named “time-dimension” that would

start recording the succession of micro- and macro-states of our OPU; in other words, one needs just one photon as a pretext to start a universal “Clock” measuring a universal “Time”, as if that photon would be the “Clock” and “Time” itself. If the succession of these ELs/EDs variations (produced by that theoretically unique photon) has a periodical pattern then our OPU would be perceived by an outside observer as having a cyclic evolution, and the time arrow would be perceived as reversible and cyclic by that external/outside observer: in contrast, if the succession of these ELs/EDs variations (produced by that theoretically unique photon) has an aperiodical pattern then our OPU would be perceived as having an irreversible time arrow and an aperiodical evolution (governed by a law similar to the 2nd law of thermodynamics [**2LT**]) by an external observer. The combination between these two extreme possibilities (reversible and irreversible time) is also possible, because an aperiodical macro-cycle of ELs/EDs variations can be composed from a succession of periodic micro-cycles of ELs/EDs variations.

“Inductive” analogy. Similarly to the [chess game](#) (in which the subjective sensation of time is given by “[pawns](#)” which can only and irreversibly move forward on the chess table), the subjective sensation of time (that probably all LFs or at least complex LFs have) is plausibly generated by specific irreversible chemical reactions in the brain cells and/or other organs and/or tissues involved in mimicking various internal [biological clocks](#).

Important note. From all the four known [fundamental PFs](#) (**FPFs**), gravity is the most “asymmetric”, in the sense that gravity doesn’t seem to have a repulsive component (at least not at the large scales verified until present): because it appears to be only attractive, gravity is the FPF with the highest probability to generate irreversible phenomena (irreversible ELs/EDs variations of GPs/voxels) that is why gravity may be considered the main contributor to the subjective sensation of a universal time arrow oriented from “past” to “future”. Interestingly, there are strong similitudes between gravitational laws (laws by which a PP positioned in a gravitational field [**GF**] would always fall from a higher gravitational potential to a lower gravitational potential) and 2LT: these similitudes have also inspired [entropic gravity theories](#) (**EGTs**).

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A possible explanation on why inertial and gravitational mass (iM and gM) of the same physical particle (PP) appear to be equal quantitatively (which is a postulate/assumption in EGR, with no explanation inside EGR). The simplest possible explanation of the (experimentally proven) iM-gM quantitative equivalence (which is a postulate/assumption with NO given explanation inside/by EGR, but with possible explanations outside EGR, including this explanation given by string theory) is THAT, NO MATTER IF an arbitrarily chosen PP is accelerated by gravity or by any other fundamental/non-fundamental PF, our 4D spacetime is more or less curved on all its (microcosmic/macrocsmic) length scales (a curvature describable by a set of continuum or possibly quantized geodesics) SO THAT any accelerated PP will always move on a specific geodesic of a curved spacetime (**ST**) SO THAT any possible PP movement

ONLY depends on that geodesic (thus on ST geometry ONLY and NOT on the identity/nature/substructure of that PP) so THAT

$$iM(= F/a) \text{ and } gM \left(= \frac{F_g \cdot r^2}{G \cdot iM_{known}} \right) \text{ remain reciprocally}$$

equal in all possible experiments. In fact, the iM-gM equivalence (which still stands in all experiments until present) is the EGR's strongest argument, an argument which clearly indicates gravity being NOT a true force, but only the consequence of ST curvature.

Prediction. This paper predicts that ST geodesics are generated by variable ELs/EDs of various GPs/voxels of our 3D space (which variability actually creates the illusion of a 2D time (with both an energetic and a temporal dimension): the illusion of ST macro and micro-curvature may thus be created by these variable ELs/EDs at both large (macrocosmic) and small (microcosmic) scales.

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