Multi-fold Non-Commutative Spacetime, Higgs and The Standard Model with Gravity

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Abstract:

In a multi-fold universe, gravity emerges from entanglement through the multi-fold mechanisms. As a result, gravity-like effects appear in between entangled particles, whether they be real or virtual. Long range, massless gravity results from entanglement of massless virtual particles. Entanglement of massive virtual particles leads to massive gravity contributions at very smalls scales. Multi-folds mechanisms also result in a spacetime that is discrete, with a random walk fractal structure and non-commutative geometry that is Lorentz invariant, and where spacetime nodes and particles can be modeled with microscopic black holes. All these recover General Relativity (GR) at large scales, and semi-classical models remain valid till smaller scale than usually expected. Gravity can therefore be added to the Standard Model resulting in what we defined as SM_G. This can contribute to resolving several open issues with the Standard Model without New Physics other than gravity, i.e., no new particles or forces. These considerations hints at a even stronger relationship between gravity and the Standard Model.

Among the multi-fold SM_G discoveries, the apparition of an-always in-flight, and hence non-interacting, right-handed neutrinos, coupled to the Higgs boson is quite notable. It is supposedly always around right-handed neutrinos, due to spacetime orientation or chirality flips by gravity of the massless Weyl fermions, induced by 7D space time matter and scattering models, and hidden behind the Higgs boson, or field at the entry points, and exit points of the multi-folds. Massless Higgs bosons modeled as minimal microscopic black holes mark concretized spacetime locations. They can condensate into Dirac Kerr-Newman soliton Qballs to produce massive and charged particles, thereby providing a microscopic explanation for a Higgs driven inflation, the gravity electroweak symmetry breaking, the Higgs mechanism, the mass acquisition and the chirality of fermions and orientation of spacetime; all resulting from the multi-fold gravity electroweak symmetry breaking.

At small scale and during the spacetime reconstruction phase, spacetime is discrete and anticommutative; something motivated by the multi-fold mechanisms, and by spacetime reconstruction using random walks of massless Higgs bosons; something corroborated with Group Field Theory (GFT). Non-commutativity ensures preservation of Lorentz invariance, and absence of supra luminosity (in vacuum) over the discrete spacetime. Even more interesting, we see that matter dynamics appear from the geometry of such a non-commutative spacetime, defined by the Higgs field, and that the number of SM particles and interactions, as well as behaviors like neutrino mixing, directly result from the non-commutativity. A consistent picture gets reinforced: in multi-fold universes, spacetime is implemented by the Higgs field, and the SM results from its geometrical properties, and Higgs dynamics. (Effective) QFTs and GR are models, at larger scale and statistical models, which approximate the microscopic behavior, that we encounter in multi-fold universes. Spacetime evolves from 2D massless regime, nonlocal thanks to the multi-fold effects, to massive 3D then 4D random walk the continuous spacetime, local except for entanglement, or implications of the W-type multi-fold hypothesis, and emerges suitable for quantum, semi-classical and classical physics.

We also conjecture a relationship between non-commutativity and 7D space time matter induction and scattering.

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1. Introduction

The multi-fold paper [1] proposes contributions to several open problems in physics, like the reconciliation of General Relativity (GR) with Quantum Physics, explaining the origin of gravity proposed as emerging from quantum (EPR- Einstein Podolsky Rosen) entanglement between particles, detailing contributions to dark matter and dark energy [1,63,72,83,84,85,86,*105-108*], and explaining other Standard Model (SM) mysteries without requiring New Physics beyond the Standard Model other than the addition of gravity to the Standard Model Lagrangian [1,11,37,38,41,42,44-46,48,73-79,80-82,*95-104*]. All this is achieved in a multi-fold universe, which may well model our real universe, which remains to be validated. *Note added on December 3, 2022: See [91-94] for strong hints that this may be the case. In the paper, references in italic have been added on December 3, 2022.*

With the proposed model of [1], spacetime and Physics are modeled from Planck scales to quantum and macroscopic scales and semi-classical approaches appear valid till very small scales. In [1], it is argued that spacetime is discrete, with a random walk-based fractal structure, fractional and noncommutative at, and above, Planck scales (with a 2-D behavior and Lorentz invariance preserved by random walks till the early moments of the universe) [1,20,25,43,63,*109*]. Spacetime results from past random walks of particles. Spacetime locations and particles can be modeled as microscopic black holes (Schwarzschild for photons and concretized spacetime coordinates, and metrics between Reissner Nordström [2], and Kerr Newman [3] for massive and possibly charged particles – the latter being possibly extremal). Although possibly surprising, [1] recovers results consistent with others (see [4] and its references), while also being able to justify the initial assumptions of black holes from the gravity or entanglement model in a multi-fold universe. The resulting gravity model recovers General Relativity at larger scale, as a 4D process, with massless gravity, but also with massive gravity components at very small scale that make gravity non-negligible at these scales [1,*91*]. Semi-classical models also turn out to work well till way smaller scales than usually expected.

The paper starts with reviews of results already encountered in multi-fold universe, in terms of non-commutativity of spacetime, and some of its already established implications [1]. From there, we explore new interpretations and combinations of several research results published a while ago in the literature, but seemingly no more that actively pursued, at least by a wide community: global methods for spacetime reconstruction based on Group Field Theory (GFT) [5-8], and derivation of the SM from the non-commutativity of spacetime (e.g., Non-commutative Spectral geometry (NCSG) and others)[9,10]. These models are consistent with several results of the multi-fold theory, that we published so far [1,11,12,*95-97*], and that provide microscopic explanations and confirmations to them.

Putting all these approaches together, and explaining them microscopically reinforces the multi-fold theory. Interestingly, it also confirms the unique role of the Higgs field and boson, massless and massive, in multi-fold universes, and how spacetime quanta indeed relate to massless Higgs bosons that concretize them.

2. Non-commutative spacetime

In [1], we derived, from the relationship between the multi-folds and the linear momentum of the entangled particles, that the positions along different axes, in the multi-folds, do not commute, and, as a result, that the same applies to the multi-fold spacetime.

- This spacetime non-commutativity in multi-fold universes can also be derived for the random walk regime as follows: in the 2D (massless) regime, any uncertainty in position implies an uncertainty in time (remember we are in 2D)[2], and therefore non-commutativity.
- In addition, in the subsequent transitions via 3D to 4D, any uncertainty in spacetime position in one direction implies that the position in another direction depends on the uncertainty on the momentum; hence an uncertainty relations and non-commutativity.

It is a new derivation, which was not provided in [1], and does not depend on the assumption that multi-fold mechanisms must extend to random walk regimes[3].

We also note that, in the literature, such non-commutativity had already been presented as a generic property that can be derived from combining the uncertainty principle with GR e.g., [13,14].

In [1], we used the non-commutativity property[4] of spacetime to formalize our answer to one of the typically most challenging objection to a discrete spacetime: the need to maintain (or approximate) Lorentz invariance. Indeed, the randomness of the random walk ensures a fractal / random concretized[5] discrete spacetime that, therefore, can be Lorentz invariant[6] [15,30]. As spatial scales increase, still in the random walk regime, spacetime, or whatever its fuzzy non-commutative state amounts to, is well formalized as a non-commutative spacetime [16-19], transitioning from 2D to 3D then 4D spacetime, can then appear continuous, while also, losing its random walk/non-commutative, and non-local (as multi-folds / wormholes are just additional traversable segments in the lattice [*91*,47], and because fractals spacetime can have very close location associated to quite different particle paths: with uncertainty, interactions on a path can affect paths passing at far away places and finality as discussed in section 4), behavior. The latter is something that we extraordinarily demonstrated by the recovery, at high enough scales, of GR, and, therefore, of its 4D continuous pseudo-Riemannian spacetime [1,*91*]. The multi-fold derivation of gravity, as a result of the multi-fold mechanisms, ensures that semi-classical approaches remain valid till below the spatial scales of the SM.

The 2D random walk regime is essential to guarantee asymptotic safety of quantum gravity [1,24,25,*110*]. This 2D regime is encountered in multi-fold universes as well as in most other consistent gravity theories [20-23]. Asymptotic safety of gravity implies incompatibility of SM with theories like superstrings or supersymmetry that introduce more particles (e.g. super partners) than SM, or live in universes of more than 4 dimensions (compactified or not). This result affects many popular grand unification theories (GUTs) and TOEs [24,87-90].

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[2] Dimensions of the random walk processes will be discussed in an upcoming section. Till then, we assume the reader familiar with [1], and / or other related derived papers like [11,12].
[3] Of course, they do as we will reconfirm in an upcoming section.
[4] In [1], we also suggested possible non-associativity properties. The present paper will not discuss this as an important property of spacetime. Spacetime may or may not be non-associative. We leave related more detailed analyses for future work.
[5] By concretized location, we mean a spacetime location that has been visited by a particle (e.g., out of a regular lattice that has also locations not yet concretized).
[6] The argument used in [1] relied on [15]. As discussed in [30], such arguments require reliance on a Poisson sprinkling [31] of the spacetime concretized locations, i.e. where the probability for sprinkling elements into a region depends only on the volume; hence the Lorentz invariance of the resulting discrete spacetime. (Quantum) random walks result into such sprinkling, except maybe at the edges of a growing universe, or very near the source of a quasi-singular big bang, something that may or may not have happened. Today, when considering Planck scales of the current universe, the sprinkling is certainly Poisson-like. As a side note, and tutorial, we would like to point the reader to [32], for an illustration of how using random distributions that are not Poisson distributions for the sprinkling would not be Lorentz invariant, typically under boosts. We should have mentioned it in [1], when making that argument, by adding the explanation provided in this footnote.

3. Discrete spacetime and non-commutativity

As part of the spacetime reconstruction model, inspired from the quantization of gravity [1], and the modeling of spacetime as a graph of microscopic black holes, a multi-fold spacetime appears as a fractal discrete spacetime generated by random walks [1,*109*]. It recovers the result, already well known in Physics, that discreteness of spacetime is a direct result of the quantization of gravity [1,15].

In the context of multi-fold universes, where no supra luminosity can take place (in vacuum), discreteness implies minimum length [1,26-29]. Interestingly, non-commutativity also implies minimum length: simple ways to see that spacetime non-commutativity implies minimal length can be found in [33-35]. As mentioned in [1], [35] also illustrates how non-commutativity implies absence of singularities (we will take it as gravitational and cosmological), and good UV behaviors, which we will take as asymptotic safety, at the minimum; recently a recurrent theme [24,25,*110*]. It also shows that such behavior can be expected as the UV evolution of correctly approximating QFT / field theories of gravity (including those based on GR).

4. Causality and discrete multi-folds

The reconstruction of spacetime based on random walks, and discreteness, [1] ensure that the concretized spacetime locations form a casual set (as they were causally concretized from past walks) [31], and, therefore, alignment of multi-fold theory with causal set theory. Interestingly, causal sets entails non-locality of field theories built on it [30,36]; especially in 2D (See [36]), our massless random walk regime.

The need to account for non-locality at small scales, where spacetime is discrete and Poisson sprinkled concretized fractals implies that, at such scales, spacetime seems connected with short cuts linking each concretized location to other locations non-locally impacting it. We read this observation as another argument, besides our commonsense reasoning in [1], that multi-fold mechanisms must still exist in the 2D (discrete) spacetime associated to 2D massless random walk regime[7]. The persistence of the non-locality effects, at mesoscales (i.e. 3D and 4D massive random walk regime), as in [36] matches our multi-fold model where we have

- i) a 2D dominated massless random walk model [1,20,21]. It is the domain of the Ultimate Unification (UU)[1,38].
- ii) a 3D to 4D massive random walk transition post gravity electroweak symmetry breaking [37], where spacetime starts to appear continuous but is still non-commutative and with related non-locality effects
- iii) a 4D quantum (semi-classical) and classical domain which are the domains of SM_G / Quantum physics and then GR / classical physics. At such scales most of physics is local, except for entanglement (and implications of the W-type multi-fold hypothesis [66]); the foundation for our proposal for multi-fold mechanisms.

Note added on December 3, 3033: These observation corroborate our encounter of multi-folds in GR at Planck scales as in [91], where we encountered the same short cuts, also invoked in [47] for 2D wormhole traversability.

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[7] This is our best derivation so far of relevance of multi-fold mechanisms at very small scale. It supports local entanglement and hence the possible negative cosmological constant at very small scale already encountered in [25,39], but also the proof that entanglement therefore probably also exists during the 2D regime. With respect the random walks of massless particles. At this regime and very small spatial scales, they still follow quantum physics as we do within the context of the W-type multi-fold hypothesis.

5. Discrete Spacetime Consistent with SM and SM_G

The discreteness of spacetime has led to additional concerns, related to the incompatibility of the standard model (SM) on a 4D lattice, due to the apparition quantum anomalies. In [40], we discuss how in 4D spacetime, an equal number of types of left and right-handed chiral fermions cancel such anomalies. Our proposal for handling the neutrino mass with a non-interacting, always in-flight right-handed neutrino [1,41], and absence of sterile (or Majorana) neutrinos [42], provides exactly that [40].

The right-handed neutrino itself appears coupled to the Higgs boson as part of the gravity electroweak symmetry breaking [37], or the SM_G derivation by space time matter induction from 7D embedding flat universe [45,46]. In addition, its apparition as proposed allows the ER=EPR conjecture to be compatible with the multi-fold theory: it is a particular case where wormholes can be traversable, due to the presence of entangled massive right-handed neutrinos and therefore play the role of GR governed multi-folds that can be traversed by path integrals and therefore generate the effective attractive potentials responsible for the apparition of gravity [1,47].

A by-product is that, on such a lattice, we know that the mass gap has been proven for Yang Mills fields, therefore ensure consistency and stability of the SM mathematical model [1,48,*99*]: in multi-fold universes, the mass gap problem is proven and the SM, or rather SM_G, the standard model with gravity effects non-negligible at its scales, is stable, consistent, and, as already known, well behaved/renormalizable in spacetime of dimensions 4D or smaller, with massless and/or massive bosons, and not renormalizable above 4D [49,50]. That property applies to all the regime: 4D continuous spacetime, 4D and 3D random walk regimes and 2D UU regime[8] [1,38,*99*].

6. Random walk, dimension reduction and non-commutativity

Random walk can be seen as a 2D process when the particle are massless, and, therefore, all moving at c [1,20,21]. One essentially achieves scale invariance and asymptotic safety, for gravity but also any other interaction, consistent with Yang Mills asymptotic safety, and our proposal for UU [1,38,*99,112*]. We will publish on paper in the future on how all this relate and implies CFTs and asymptotic safety.

As particles become massive, the process will grow to a 3D process (speed in two direction matters now that the velocity is no more locked at *c*) [51] before reaching 4D, and as scale increase becomes continuous, local and still Lorentz invariant [36].

As discussed in a previous section, and independently of the multi-fold derivation provided in [1], if we accept that random walks are essentially happening as sequences of position in a plane, when the particle are massless and moving at *c*, the position in one dimension depends on its linear momentum in the other: the process is essentially 2D and positions are non-commutative. When the particles are massive, such dependency is alleviated and the process becomes 3D then 4D at a larger scale. It completes the explanation of the 3D, aka (2+1)D dimensions reduction of 't Hooft versus the 2D regime encountered by most consistent theories of quantum gravities [1,20-25,51].

Non-commutativity is still present for a while in 3D and 4D, as energy still mostly defines linear momentum, and time and energy do not commute. As the particles energy can decrease and its distribution broadens, such

[8] Of course, the 4D limit has also consequences for many theories.

relationships disappear ,and the spacetime non-commutativity relations disappear into a continuous, local, except for entanglement (and implications of the W-type multi-fold hypothesis [66]), and causal spacetime.

7. Particles as Kerr-Newman black hole like solitons of Higgs condensate

In [1], we derive that particles and concretized spacetime locations can be represented as microscopic black holes, usually (beyond) extremal when the particles are charged. At very small scales, the ultimate unification (UU) dominates with a regime where all particles appear as similarly behaving with interactions equivalent to gravity [1,4,20,21,25,38].

Later in our work, as captured in [40,43], we determined that the Higgs boson is an ideal candidate both for concretized spacetime location, and as the massless particle responsible for the random walks and UU, at very smalls scales, in the 2D massless regime, and at the beginning of the universe, as well as to provide a random walk microscopic model for inflation [63].

The special role for the Higgs field was first determined by 7D space time matter induction [37,43,45-47], where the Higgs is seen at the edge of spacetime, along with the right-handed neutrino coupled behind it [37, 46,47].

The role of the Higgs boson and coupled right-handed neutrinos is further clarified by two analyses:

- The multi-fold gravity electroweak symmetry breaking shows how, and why, the Higgs and the right-handed neutrinos appear and are coupled as a isospin doublet [37].
- The role of the right-handed neutrino, (and neutrino in 7D, prior to gravity electroweak symmetry breaking) in ensuring traversability of wormholes, allowing multi-folds to possibly be implemented as wormholes governed by GR in embedding universes. It also opens the door to the possibility to see the ER = EPR conjecture [1,52] as a particular case of multi-folds [47].

The multi-fold gravity electroweak theory provides microscopic explanations to the 2D / UU regime, the multi-fold gravity electroweak symmetry breaking, and the mass generation of the Higgs mechanism [37]. In particular, particles appear as Higgs condensations into QBalls solitons that regularize Kerr Newman solutions with symmetries, and charges dictated by the geometry of the 7D objects that induce these solutions.

8. GFT, Global approach to reconstruction-based quantum gravity

As discussed in [1], many of the challenges with the behavior of quantum gravity when relying on QFTs or superstrings seem to stem from the fact that GR, and hence quantum gravity, is background independent while QFTs, strings and many other models aren't [53][9]. Since then, we know more, and in particular also understand that the statistical aspects of QFT and its inability to explicitly track particles, in between their creation and annihilation, and therefore their entanglement is probably also fundamental [1,54].

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[9] In [1] we argued why the multi-fold theory is background independent. This can also be seen in the rest of the section as a result of the fact that GFT models multi-fold spacetime reconstruction and the multi-fold mechanisms and its relationship to path integrals are covariant and as such background independent.

In [1], we lumped together multi-fold spacetime reconstruction with other reconstruction-based gravity theories like Loop Quantum Gravity (LQG), Spin networks, Spin Foams, etc. (e.g., see an overview of a whole lot of these theories in [55]).

A global approach has been proposed as a non-perturbative model suited for all these theories. It is called the Group Field theory (GFT). It is a field theory on a group as base manifold [57], thereby ensuring background independence. GFT can model the spacetime reconstruction methods, mentioned earlier, as background independent models that, when perturbatively computed, create pseudo-manifolds using simplices (i.e. triangles and higher dimensional versions of triangles [56]) [5-8]. The GFT approach was introduced to formalize, and provide rigor to the computation of path integrals over the different possible spacetime configurations or topologies, in order to extremize the action: i.e. treating spacetime as composed of spacetime quanta, with dynamics described by an action derived from Hilbert Einstein action (e.g., based on Regge action as computed in [71]).

Multi-fold universes, although non-perturbative and background independent by their definition or reconstruction [1], can also be considered as well approximated with GFTs, except again for the challenges in tracking particles (matter, aka fermions and bosons, for QFT) and entanglement. See [58] for an analogous analysis in the case of LQG. So, we speak of approximations because GFTs suffers from these same model limitations as do QFTs, or superstrings, when it comes to track individual particles (e.g. or individual spacetime quanta in the case of GFT) or model individual entanglements.

In general, the physical interpretations of the field(s) appearing in GFT, to encode the dynamics of the theory used to compute the path integrals, are still considered as not entirely clear [59]. Based on [60], and our multi-fold results so far [11,12], we argue that, as a background independent scalar field, such a GFT field should be understood as the Higgs field. Indeed, based on the multi-fold spacetime reconstruction, and follow-up work [1,37,43,47,63,*109*], the dynamics of spacetime result from the random walks of a massless Higgs boson, besides entanglement, and it is encountered in the Higgs fields (and the cosmological or gravity couplings as in [25]).

To confirm, and reinforce, this view, let us examine section 3 in [60], that shows that GFT can be seen as matching a real Bose Einstein condensate, recovering the idea that the early universe can be seen as a Bose Einstein condensate (BEC), and can support i) inflation ii) absence of cosmological singularity (e.g. big bounce if the universe were to encounter a big crunch phase). It is something that we already knew [63,64]. Such an analysis indicates that typical inflatons, or Bose Einstein condensates, approaches to inflations are different facets of the high energy 2D random walks encountered at early stage of the universe [1,37,38,43,63]. The multi-fold theory view, that, in the 2D random walk and UU regime, the dominant player are massless Higgs bosons, also fits perfectly a BEC model; thereby reconciling these different proposals. It also aligns with the fact that CFTs, encountered with renormalization at high energy or very small spatial scales, correspond to the propagation of free bosons, i.e., Higgs boson random walks [20]. Therefore, it appears that, in a multi-fold universe, the field that appears in GFT, is indeed the Higgs field[10] and along with its potential, it models the effects of random walks[11]. The role in characterizing dynamics, and the physical nature of the field in GFT, as well the success of GFT and derived reconstruction methods, besides the multi-fold theory, to model aspects of quantum gravity, is now physically and microscopically explained, and its rigor and formalism now extends also to multi-fold models.

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[10] Something that in our view is usually not explicitly acknowledged even in a paper like [60], despite the fact that it seems to have all the ingredients to make such conclusion in the context of the study. Instead, it just rather interprets the field in GFT as a test field for Feynman integral computations, with unclear physical interpretation.
[11] As do also aspects of running of the cosmological constant or the gravity constant [25].

Such an interpretation is fundamental, especially because it brings together why we discovered such an intimate role between Higgs and gravity / space time in multi-fold theories[12].

Interestingly, GFTs also predict a matter / mass generation process in a non-commutative manifold/spacetime [59]. The mathematical reasoning is rather complicated, and based on spin foam models. We will not attempt to summarize, reproduce or paraphrase it here, letting interested readers go study the original papers. Accordingly, a 2D effective field theory (EFT) on a non-commutative manifold can be built with a 2D GFT embedded in a 3D GFT, as can a 3D GFT be expressed as non-commutative 2D EFTs [68]. The absence, for now, of a 4D analogous statement may mean that this non-commutative property of spacetime stops being relevant before the transition to 4D behaviors, when increasing the spatial scales. Let's see how.

2D perturbations around classical solutions of a 3D GFT display the dynamics characteristics of massive matter (i.e. aligned with our definition of matter as in [65]: fermions and bosons). That dynamics are associated to matter comes from [68], where it is recovered, after integration of the gravitational degrees of freedom which provides the instanton (i.e. the classical solutions) for the spacetime. The results are also expected to be renormalizable. The introduction of a scalar GFT field, versus say just spin foams, allows for curved non-commutative spacetime [59]. The apparition of matter implies that matter dynamics are defined by excited geometrical states of spacetime as GFT solutions. It is quite an important result! With our multi-fold understanding: matter are excitation of massless Higgs bosons, into massless soliton patterns that appear as larger microscopic black holes or massive Higgs condensate into solitons that also appear as larger microscopic black holes. The solitons confer the charges and other quantum number by inductions and scattering from the 7D embedding space created by the multi-folds [45,46,*111*].

These results directly recover our multi-fold results: in the 2D random walk / UU regime, only massless particles participate. Except for fluctuations, no massive matter dynamics appears, just as in [59]. In a multi-fold 3D spacetime, i.e. when random walk can become massive, post gravity electroweak symmetry breaking, while transitioning from a 2D to a 4D regime, we encounter a non-commutative spacetime and phase transitions where Qballs of the field (Higgs) become (massive) particles (with Higgs condensation within the Qballs), or massless soliton patterns. It matches the effective quantum fields, and matter dynamics resulting from excitations of the scalar field behind the GFT, as in [59]. These solitons correspond to classical instantons solution of the Dirac Kerr Newman metric, which can also be seen as induced and scattered 7D geometrical objects in an 7D embedding (flat) universe governed by GR in 7D [4,45,46,*111*]. In both cases, matter results from purely geometric considerations, and Higgs dynamics.

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[12] The role of Higgs in the electroweak symmetry breaking, and in mass generation, has also been encountered in universes other than multi-fold universes, e.g., [64]. In multi-fold spacetime reconstruction, the Higgs field role as inflaton, or as an inflaton alternative depending on the point of view, and its potential, are also directly related to random walks, when modeling the early universe, the big bang, and the inflationary phase, as well as the subsequent slow roll and re-heating [43,63].

Some conventional models identified issues with associating the inflaton and Higgs, while some have shown plausible compatibility. We decided to go with the plausible models and claim that the Higgs field governs inflation and the inflaton is the Higgs boson [73].

In [1], we also encountered in [1] the plausible suitability of BECs to model the early universe. BECs are often presented as alternatives to inflation. We see this option as another hint of the suitability of the Higgs boson as inflaton [73]. Abiding to the Occam razor principle, it is easy to ask what else would be omnipresent in the initial universe as inflaton (in inflationary models) or BEC (otherwise); especially as, in a multi-fold universe, these two options are not incompatible, but rather different facets of an exponentially accelerating expansion phase of the universe in the very early ages.

When scales increase sufficiently, gravity and spacetime become essentially 4D processes. The non-commutative properties fade away and spacetime appears Lorentzian, local (except for entanglement and implications of the W-type multi-fold hypothesis [66]) and continuous. At such scales, GFT does not apply any more. It may explain in our view why, to the best of our knowledge, no consistent EFT embedded in 4D GFT seems to have been encountered yet by the GFT community[13].

9. Extracting the Standard Model from spacetime non-commutativity

Alain Connes, and its collaborators and supporters, proposed a model that seems to derive/predict many aspects of the SM from a theory, called non-commutative spectral geometry (NCSG) [9,60], that involves a non-commutative spacetime, and the introduction of algebra doubling in order to support gauge symmetry [9,60,68]. On that basis, the model is able to predict the three gauge interactions of the SM [9,60], the Higgs boson, the different SM fermions, including the neutrinos and neutrino (mass) mixing [9,60,68,69]. To that effect, the neutrino mixing, although illustrated for Majorana neutrinos, also applies to Dirac neutrinos, as we prefer in multi-fold universes because of [1,40-43,45-47].

Therefore, it appears that the non-commutativity of spacetime may be key to construct the SM[14] (in the multi-fold universe), and its dynamics (per the previous section) and explain its particle including the mass matrices and in particular neutrino mixing.

Note added on December 3, 2022: in [98], we explained why the SM has the symmetry that it has, and that it results from how the 7D embedding is constructed and perceived in spacetime by the multi-folds. It is 7D, even if dominating 5D, [45,46] ruled by GR [45,46,111], but also discrete and non-commutative [1]. As a result, we expect that the algebra doubling comes from 3D spacetime + 3D extra (sharing the time dimension). It is consistent with [68] that clearly identifies the algebra in use as "the algebra of coordinates; all information about space". Therefore we conjecture that the algebra doubling recovery of the SM, is in fact related and equivalent to the algebra of the 7D embedding space with SM symmetry. Discussing or proving it is for future work.

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[13] For example, we suspect that it is why the paper, promised as reference 28 in [59], seems to have never panned out: one dimensional extended solutions, à la string, are really not needed, when massless random walks dominate in a 2D and 2D-to-3D massive transition. Because the particles are created with the 2D perturbations in 3D, it really correspond to our multi-fold gravity electroweak symmetry breaking [37], which occurs while transitioning from 2D random walk to 3D massive random walk then 4D spacetime. As this happens, spacetime appears now continuous, and no more subject to the GFT models of fluctuating simplices: 4D modeling of instanton perturbation is moot. It has been our experience that things that conventionally work in some dimensions, have often a purpose in multi-fold theory, and things that do not conventionally work seem to be so because they are not needed. Good behavior (e.g. renormalizability or proven asymptotic behavior) of gravity is one aspect, mass gap on lattice is another [99], and other examples exist; maybe it is once again what happens here. In any case, if future work were to complete the 4D GFT models with 3D perturbations, we would be interesting to see what would pan out…

[14] It is not the only line of research that derived the SM from non-commutative geometry. Consider for example [10], describing the situation post gravity electroweak symmetry breaking. [10] rather predicted additional dimensions to model the actual symmetry breaking. In this present paper we conclude the opposite: the symmetry breaking occurs during or after a phase transition from essentially 2D to 4D spacetime, not a higher dimensional spacetime.

This occur is probably occurring before (or during) the gravity electroweak symmetry breaking. "Before"ensures that massless particles like the Weyl fermions will also be described by the relevant symmetries, charges and quantum numbers as patterns of Higgs induced or scattered from the 7D solitons.

Remembering [45-47,*98*,*99*], the particles then get their quantum numbers from the symmetries of the solitons resulting from 7D geometrical objects, in a space initially non-commutative. Handling fermion chirality is then further addressed in [4,37,74,*98*,*99*].

In our view, the persistent confusion about the Higgs and Majorana, or Sterile neutrinos, across all these models, including for example [64], at the difference of our multi-fold model [37], could come from the coupling of these two particles (Higgs and right-handed neutrino), and the role of the Higgs in gravity/spacetime representation (massless), in addition to being a massive boson post gravity electroweak symmetry breaking. Alternatively, the helicity / chirality flips or spacetime orientation flips in massless mode discussed in [1,40,41,44,74,*98,99*] are key to understand that, as argued in [1,44], we consider that the conservation of the lepton number is to be taken more seriously than what may be conventionally thought Today. It further excludes massive Majorana neutrino [70]: these effects and the lepton number symmetry should suppress any apparition of sterile or Majorana neutrinos[15].

Of course, the models of [9,60] is also approximative: the mass estimates are not exactly correct. Frankly, that is to be expected with all the approximations involved: only a microscopic model of random walk is actually physically correct. The NCSG model is only making estimations based on non-commutativity models and symmetry considerations. Yet, it is amazing how it hones on key properties of the SM, i.e. the number of gauge interactions, bosons and fermions and some of their rough behavior, including neutrino mixing. All these seem to result from the non-commutativity of spacetime, with the right symmetries. Such non-commutativity is something derived from the multi-fold mechanisms in [1], and confirmed above through multiple reasoning.

The notion of almost-commutativity, behind the approach touted in [60], may also directly relate to our discussion, in the previous section, that the gravity electroweak symmetry breaking occurs at the transition from 2D to 4D spacetime (i.e. ~ in 3D process), when spacetime is about to become continuous (and semi-classical) as encountered in QFT then GR.

10. Conclusions

Based on the multi-fold theory, we have shown that spacetime seems non-commutative in its random walk regime. This non-commutativity at small scales is encountered in many other quantum gravity theories.

By relying on the work of many the preceded this paper, it becomes clear that non-commutativity seems key to imply:

- The existence of a minimum length in the 2D discrete spacetime.
- The absence of any supra luminosity, valid at all scales.
- A bottom-up derivation that matter and matter dynamics come from spacetime geometry; an independent corroboration of the space time matter induction and scattering model proposed in [45,46,74,*99*], the particles as microscopic black holes as Higgs condensate solitons, or patterns as solution while still massless [37,47], and the associated mass generation at gravity electroweak symmetry breaking.

[15] However, it might also possible that the extra neutrino may rather be representing the 7D particles that ensures traversability of wormholes even in the 2D massless regime as discussed in [37], in which case the sterile neutrino is the right-handed neutrino, and the discussion is moot.

- A rigorous formalism, à la GFT, shows that the Higgs boson is responsible for the spacetime dynamics, the characterization of matter dynamics, which emerges from it geometry (as excitations of spacetime, i.e., massless Higgs bosons), inflation (or other accelerated expansion models) and for defining spacetime quanta (concretized spacetime locations). This relationship between Higgs and what would otherwise have been considered to be graviton properties may come as a surprise for many.
- An account for the presence of gauge symmetry, three symmetry gauge bosons and Yang Mills interactions, the fermions and gauge bosons of the Standard model, the Higgs boson and neutrinos (mass) mixing. In other words a bottom-up derivation of SM, or rather SM_G.
    - It comes along a conjecture consistency between the algebra doubling on non-commutative spacetime and the 7D space time matter induction and scattering.
- A detailed accounting for the emergence of spacetime from 2D causal, non-local, massless random via a transition through a non-commutative spacetime during a massive 3D, at or before the gravity electroweak symmetry breaking, to a 4D random walk that ensures Lorentz invariance, and becomes progressively local and continuous; thereby also explaining quantum semi-classical physics and classical physics and spacetime emergence.

As has been the case for other models, like, for example, the modeling of particles and spacetime locations as microscopic black holes or the gravity electroweak symmetry breaking, we reused past results of others, and put them into a consistent framework, where they mutually confirm and reinforce each other, and the multi-fold theory. The latter, with its random walk spacetime reconstruction model, provides physical microscopic explanations, instead of pure mathematical, often symmetry-based considerations, to many phenomena. The resulting consistency of our proposal for multi-fold universes, grow stronger with every new analysis.

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