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A tutorial on the Multi-fold theory principles and the SM_G

Stephane H. Maes¹ 

March 11, 2022

Abstract:

The paper explains sometimes in simplified terms, sometimes in more details the principles that motivate and are behind the Multi-fold theory. It provides an overview of some of the key results in particular the SM_G , i.e., the Standard Model with gravity effects non-negligible at its scales.

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 small scales. Multi-folds mechanisms also result into a spacetime that is discrete, with a random walk fractal structure, and non-commutative geometry, which 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 model remain valid till smaller scale than usually expected. Gravity can therefore be added to the Standard Model (SM) resulting into what we define as SM_G . This can contribute to resolving several open issues with the Standard Model without new Physics other than gravity. These considerations hint at an even stronger relationship between gravity and the Standard Model.

Recent work shows that the multi-fold theory can be encountered in GR at Planck scales, in spacetime quantization starting from the Hilbert Einstein action, and in the equivalence principle of suitable quantum reference frames in relational quantum physics. Conversely, GR and Quantum physics, including path integrals, the Born rule, and wave functions, can be recovered through different paths from multi-fold spacetime reconstruction and the W-type multi-fold hypothesis. In a multi-fold universe, GR and Quantum Physics are not incompatible, they are just different facets of multi-fold mechanisms, something that neither theory can well model.

The main principles of the multi-fold theory are that while in GR spacetime tells matter how to move; matter tells spacetime how to curve, when adding Quantum Physics with entanglement, we also impose a non-local wave function behavior, and Lorentz invariance imposes no supra-luminosity. As a result, gravity is the result of spacetime going out of its way, and contorting, to support such requirements, as demanded by the content of the universe. The multi-fold theory is about explaining and reconciling this, and all the consequences of it. These include the SM_G , i.e., the Standard Model where gravity is non-negligible at its scales, multi-fold dark matter and energy, the E/G factual conjecture, and a discrete spacetime that is 2D at small scale, Lorentz invariant, fractal and non-commutative. The SM_G potentially explains many problems with the SM.

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 [1], detailing contributions to dark matter and dark energy [1,40-43,45,59,61,62,84,93,94,97,103,108], and explaining other Standard Model (SM) mysteries without requiring New Physics beyond the Standard Model other than the addition of non-negligible gravity effects to the Standard Model Lagrangian [1,4-36,39-49, 51-62,66,68-70,73-111]. All this is achieved in a multi-fold universe that may well model our real universe, which of course remains to be validated.

¹ shmaes.physics@gmail.com

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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 [1,13,31,34,36,85,86], 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). 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 Reisner Nordstrom [2] and Kerr Newman [3] for massive and possibly charged particles – the latter being possibly extremal). Particles result from patterns of massless Higgs random walk (massless particles above gravity electroweak symmetry breaking [1,23,85-87]) or condensates of massless Higgs (massive, below gravity electroweak symmetry breaking [1,23,85-87]), implementing solitons obtained by space time matter induction and scattering from a 7D spacetime [1,30,31,47]. 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 [1,69,110], with massless gravity, but also with massive gravity [1,10,46] components at very small scale that contributes making gravity non-negligible at these scales. Semi-classical models also turn out to work well till way smaller scales than usually expected.

This paper focuses on intuitively explaining, and justifying, some of the core principles, a bit like a “multi-fold theory for dummies” book, and some of the motivations of the theory, and its key derived results, especially in terms of SM_G . Because it takes time to write papers or books, a lot of progress took place between the beginning and the end of this paper. A major part of the paper was written before some of the latest breakthrough [51-53,69,70] that i) derive multi-fold theory from GR, spacetime quantization from the Hilbert Einstein action, or equivalence of suitable reference frames ii) recover GR and Quantum Physics via multi-fold spacetime reconstruction iii) and establish that quantum physics and GR are different facets of multi-fold mechanisms that neither can well model. As such, the paper also contains a few considerations that may be new.

The most important source for references to topics discussed here, and work related to, or derived from the multi-fold theory can be found at [1,7,46,90]. They are the best starting point to further study the research, and track the latest results, including after this paper. *Note added on March 5, 2023: to that effect, some more recent results are mentioned when possible. References in italic were added on March 5, 2023.*

2. Multi-fold mechanisms and spacetime

The basic idea and principle behind the introduction of multi-folds is that entanglement, and associated 4D non-local realism, must be supported by the spacetime, in whatever dimensions needed, without violating the no supra luminosity principle that nothing can propagate faster than light(in vacuum). In other words, the theory and mechanisms comes from postulating that entangled particles must have a growing pathway that allows a path, as understood in path integrals, from one particles to always be in contact with a path from the other entangled particle. It fundamentally results from believing that a principle of least action / path integral among all possible spacetime topologies must apply to support entanglement: the multi-folds, and their mechanisms result from most probable resulting spacetime topology to support entanglement and associated implications [1,104]. It turns out that [70,104] that having the exchanges, like interaction or the shared / combined state of entanglement, among entangled systems, then builds a Lorentzian spacetime, (as long that non-zero spins are involved) which means than massless (then massive) particles other than the Higgs boson can appear [70]. With the multi-fold gravity electroweak symmetry breaking, massless particles appear when the random walks of massless boson form patters matching the solitons obtained by spacetime matter induction and scattering from the 7D space embedding our 4D spacetime, and spacetime gets oriented by their spin [1,23,47,83,85-87,91].

Entanglement, and the considerations above, imply the need of having ways to connect entangled particles at different 4D spacetime locations through additional spacetime pathways. The multi-folds and their mechanisms achieve that. These multi-folds could be, but do not have to be, implemented with traversable wormholes following GR [1,5,6,48,69,91,101]. However wormholes may lead to challenges in explaining how they would be in 4D spacetimes or outside (e.g., in embedding spacetime or tangent dual spacetime), yet not observed so far, and, how to address their traversability, and how to ensure that their required multi-fold like kinematics and dynamics are compatible with GR [1].

Multi-folds, mechanisms and mappings are illustrated in figure 1. Accordingly, one can understand why, at any time, a path of the path integral formalism, associated to an entangled particle can remain in contact with a path of the other entangled particle. This way distant particles can interact and exchange, without any communication violating the no supra luminosity principle. The idea is just that simple, and the plausibility of the approach directly justified by path integral and the least action principle [104].

Multi-folds and associated mapping mechanisms [1], were introduced, in a multi-fold universe as we do not know if it models well our real universe, as an alternative that does not have any GR kinematics and dynamics or traversability restrictions, as we know that both Quantum Physics and general Relativity can only reflect facet of them, not the full details [1,69,70]. Multi-folds can be seen as adding handles attached to entangled particles in 4D spacetime (background spacetime). Figure 2 illustrates this with an intuitive simple 2D analogy to 3D. The reader needs to consult [1] for the actual mechanisms and mappings.

In a multi-fold universe, spacetime locations in between which there is entanglement are now linked by these handles and the handles are constructed so that some aspects between the two end points can always be in instant contact. Of course, the actual multi-folds mechanisms and mappings in 4D are more complex; Figure 2 is just for illustration and explanation purpose.

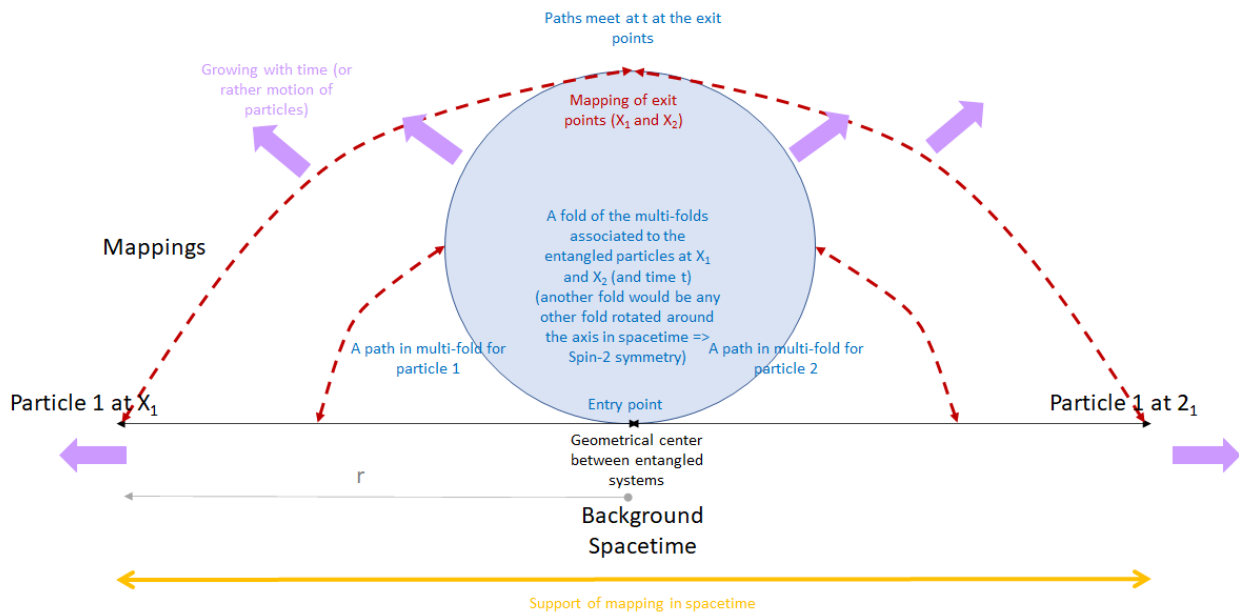


Figure 1 illustrates, in a simplified manner, the multi-folds, multi-fold mechanisms, their kinematics/dynamics and mappings for two entangled particles moving in opposite directions.

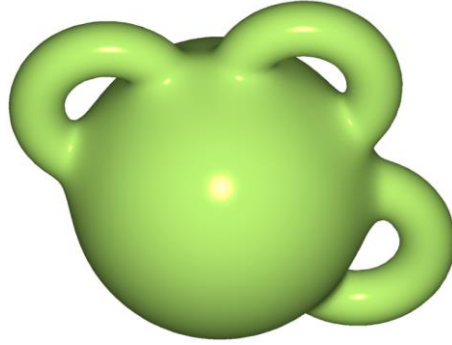


Figure 2: It illustrates a 4D multi-fold spacetime as the 2D surface (background spacetime) of the 3D spheres. The effects of multi-folds, their mechanisms and mappings amount to connect the spacetime locations where entangled systems are with the handles. It is a simplified picture. The true mechanisms are rather represented by figure 1, and discussed in [1].

Doing so it is possible by ensuring that at least a path of the path integral associated to the wave function of each particle can propagate in the handles and so always be in contact with a path of the particle in the handle. The handle itself grows and follows the movement of the particles. This is a unique connection versus all the other models, in the literature so far, which may have considered entanglement and gravity like those discussed in [50], and ER=EPR/GR=QM as discussed in [48,49]: multi-folds must be traversable for at least one path integral path. In fact, no energy (or other conserved quantity) is lost as this can be as small ϵ as desired (compensated by a coupling constant, which measures the probability of such a path, and explain why the Newton gravitational constant is so small) and multi-fold deactivation recovers any energy in flight. All the other models linked to such ideas, typically based on wormholes, do not consider opening paths to the path integrals; most probably because of the traversability challenges. Also, traversable wormholes lead to concerns of losses of global symmetries. See [69] and references therein. The small ϵ and associated coupling explains why gravity is so much weaker than the other fundamental interactions.

Multi-fold mappings may be a strange idea from [1] that some may consider as ad hoc. In reality they reflect the W-type multi-fold hypothesis [8,6], further discussed in section 16. According to it, another particle crossing the region in spacetime between the entangled particles (in simple scenarios), gets a path in the corresponding multi-folds of the entangled particles, and so feels a gravity like effect when they are entangled real particles and gravity when they are virtual. Note that if the entangled particles followed a non-trivial path, moving the centroid/center of mass, then one needs to capture the kinematics of each $1/r^2$ contributions of each past position of the particles. Such dynamic effects are for example what creates gravity rotation and linear frame dragging or the Lens-Thirring effect [1,111]. Because each folds in multi-folds (see [1] for details) have spherical symmetry, the W-type multi-fold hypothesis can bring the support crossing particle anywhere on the multi-fold path, without changing the effective potential mentioned below, and in [1]. Also, the spherical symmetry ensures that no particles are created by the time evolution of the curved spacetime formed by the multi-folds [1]. It justifies the growing, to follow the entangled particles to which it is attached, spherical shape of the folds forming the multi-folds in [1]. It is that, and not another one: other shapes would not address these considerations of consistency with conventional physics.

Disentanglement results into collapse of the multi-folds, starting from the exit points, in ways analogous to a progressive wavefunction collapse [1]. It is expected to probably be irreversible. *Note added on March 5, 2023: This prediction recently seems to have been confirmed as discussed in [104] and reference therein.*

In general, multi-folds are single tenant, i.e. no other physics take place in the multi-folds with the exceptions of Higgs bosons and entrance and exit points (to ensure mass in the multi-folds, and per 7D space time matter induction and scattering) [1,29,47,91,101], massless Higgs bosons building the multi-fold spacetimes (by construction as topology variations of spacetime), right-handed neutrinos and its anti-particles [1,6,23,28-

31,47,48,57,85-87,91,101,104]. As discussed in [91,101], vacuum fluctuations are preferably also not present. This is because we do not observe any additional ghost interactions. [1] also relies on additional principles like hierarchical considerations.

[1,99] also discusses an interesting way to understand spin as a representation of rotation (wavefunction or multi-folds) due to the distribution of paths picked on the multi-folds.

Note that the multi-fold mechanisms of figure 1 are the first ones that we picked based on the reasoning presented above. Yes, one could imagine other mechanisms that result into the same effective potential or effective curvature or simply postulated that such curvature or potential appear. Doing so however may not lead to the same ability to predict what happens in the surroundings spaces, (e.g., in spaces embedding or tangent dual to the 4D spacetime). The beauty of the approach provided above is that a single postulate (the multi-folds as proposed in figure 1 and in [1]) allows us to consistently deduct everything that is described in the theory and recover many touch point of explanations for the real universe and, or results, and mysteries from conventional physics or New Physics theories like strings, M-theory, Group Field Theory, non-commutative geometry or LQG [1,4-36,39-49, 51-62,66,68-70,73-111].

3. Gravity-like effects from Multi-folds

[1] models the effects of such additional paths.

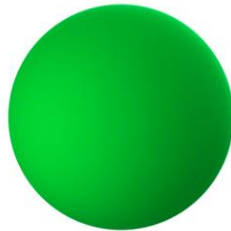


Figure 3: 2D surface of 3D sphere as analogy to 4D spacetime, with effects of multi-folds in spacetime

Interestingly, when looking at the impact on the background 4D spacetime of a multi-fold universe, if one considered only a simplified spacetime as in Figure 3, the contributions of the extra paths amount to effective potentials in r^{-2} along the mapping path between the two entangled locations and attractive towards the center of mass between the entangled particles. r is the distance to that center. It results into a gravity-like effects.

The potential can be modeled as a curvature contribution from the multi-fold that would add an additional effective curvature / deformation to the 4D spacetime: r^{-2} is also the Ricci curvature scalar from the multi-fold involved at the spacetime location in between the entangled particles.

This is the basis for the E/G conjecture [11,49]:

- In a multi-fold universe, entanglement factually results into gravity-like effects in 4D spacetime of a multi-fold universe.
- In the real universe, we conjecture that the same occurs.

Therefore, the multi-fold theory predicts gravity-like fluctuations in quantum material like superconductor. Detecting such fluctuations, expected to be very weak is a way to validate if the real universe is multi-fold or not. Past experiments, mentioned in [1], have claimed such observations but the studies have been considered

controversial as rather picked up by the crowds of anti-gravity aficionados. Thus, more rigorous and less controversial research is needed.

Theoretically, results like [1,52,69,70] indicate that a GR-based universe like ours may be multi-fold. The success encountered in qualitatively and possibly partially explaining open issues with the SM, especially with the introduction of SM_G , and with the Standard Cosmological Model (Λ CDM) [1,4-36,39-49, 51-62,66,68-70,73-111].

4. Gravity from entangled virtual particles

As any particle or energy content generates myriads of entangled pairs of virtual particles, proportional to the involved energy content, or mass, the same mechanism recovers gravity effective potential, and effective curvature contributions, proportional to the mass (energy) of a particle around any particle. It allows recovery of GR field equations and Newton approximations [1,69]. In static cases, integrating all the multi-fold encountered by a test particle, leads to an effective attractive potential in $1/r$, as is gravity. When the center of mass, or the source, moves, kinematics of the folds result in effects like gravity rotation and linear frame dragging or the Lens-Thirring effect [1,111]. The proportionality to masses or energy of source and test particles recovers the equivalence principle [1,60].

This completes the E/G conjecture [1,11,47,49]:

- In a multi-fold universe gravity results from entanglement (or the virtual particles surrounding any energy source)
- In the real universe, it is conjectured that the same occurs.

The conjecture meets other results in non-multi-fold universes as discussed in like references in [1], and in [50]. In addition, in recent works, we have shown that Loop Quantum Gravity (LQG) provides a rigorous approach to quantizing GR and spacetime, however with some problematic steps [51-53]. Fixing these steps require adding constraints or considerations that one may consider as equivalent to adding enhancement constraints, between spacetime locations, that tame the quantum foam fluctuations, vs. what LQG has so far incorrectly, or excessively, deducted [52].

The proposed multi-fold mechanisms ensure recovery of Einstein equivalence principles [1]. It also a priori hints as a non-time-varying gravity constant, unless if the effects, were affected by discreteness of spacetime as very small scale.

Because of the uncertainty principle, and the non-point particle aspects, each pair of entangled particle and anti-particle attract via multi-fold towards a region around the particle center of mass instead of a singularity [54]. It is sketched in figure 4.

Note that [1] also identifies discrete space time (see later), and the possibility of torsion within matter (fermions or bosons)[1] as an additional reasons why no gravity or cosmological singularities exist in a multi-fold universe. This is why multi-fold gravity avoid gravity singularities. The jury is out in terms of the initial big bang situation.

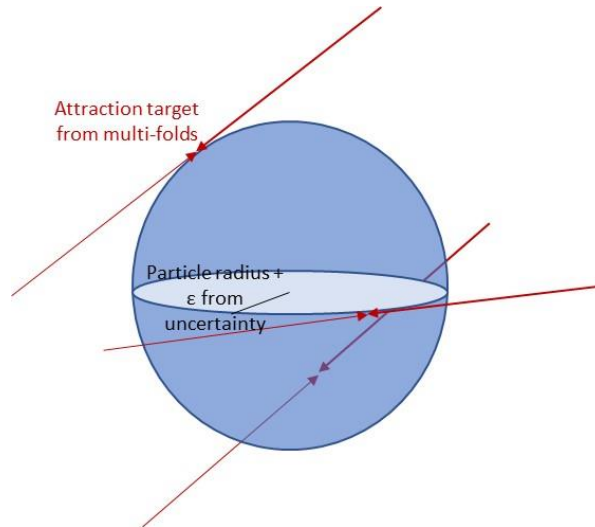


Figure 4: Why there is no gravity (or cosmological) singularity in a multi-fold universe: attractive potential miss the singularity due to finite size of particles (See later with microscopic black hole model, which allows black hole behavior even without actual singularity. Such black holes are typically external or rather over-extremal and with curves of singularities curve), are also explained microscopically in this figure. Particles as microscopic black holes [1,4] are in any case regularized by the notion of Qball skin mentioned later [4], discreteness and quantum uncertainties.

The multi-fold model also implies that antimatter falls down as matter [29], as multi-fold only results into attractive potentials², something confirmed by recent results [112].

5. Massless and massive gravity

Entangled virtual massless particles lead to massless gravity à la GR [1,69]. However, entangled virtual massive particles imply also massive gravity with finite ranges, and without the problems typically encountered with massive gravity models. See [1,10] and references therein. Of course, massive gravity coupling could also be null. This is for further study.

Therefore, at very small range (at the scales of the weak and strong interactions) the gravity effects increase significantly, and not only because of the dependency in r^{-1} .

For an astute reader, this multi-fold massive gravity is different from the non-multi-fold attempts discussed in [1,10] and references therein that have typically encountered many complications.

6. Dual Tangent AdS(5) and Microscopic black holes

² If anti particles were repulsed, the mechanisms would become problematic, and no more universal. Fortunately, as discussed, they aren't.

The multi-folds surrounding particles create black hole effects, and AdS(5) appears tangent dual to every point in the multi-fold 4D spacetime. This is also reminiscent of the AdS/CFT correspondence of superstrings/M-theory [1,5,49].

The notion of particles as microscopic blackholes has been proposed in non-multi-fold context [1,4]. The blackholes are often beyond extremal, but it is not an issue that can be seen as the result of a Qball of Higgs superconductor condensates that avoid singularity problems: the superconducting skin of the Qball matches the region of attraction of the effective potential mentioned in section 3. The Qball's skin coincides with, and hides, the singularity and the beyond the extremalities associated to such model. When massless particles, e.g., above the gravity electroweak symmetry breaking energy scales, massless Higgs boson rather walk in a similar pattern, copying the corresponding soliton.

Other papers, discussed in [1], showed that a spacetime built as a graph of microscopic black holes recovers GR. It inspired the next steps.

7. Multi-fold Spacetime reconstruction

Using the last results of section 5, and additional considerations encountered through various reasonings, with or without multi-fold assumptions [1,31], including the fact that multi-folds imply non-commutative spacetime in the multi-folds, and therefore in the 4D spacetime, we model spacetime as a graph of microscopic blackholes. It is microscopically justified as the result of spacetime location concretization, if the location was previously occupied by a particle, i.e., other microscopic blackholes with quantum and geometric characteristics of the corresponding particles [1,4], at very small scales, typically a massless Higgs boson,.

Spacetime is therefore discrete, fractal, non-commutative and the result of random walks of the particles that live in it [1,36,43,47,69,85,86]. Random walks implies a Poisson sprinkling that also ensure that spacetime is a casual set (as the result of random walks and particle creations), and Lorentz invariance, thereby answering the main arguments against discrete spacetime that have plagued discrete spacetime approaches, especially LQG [1,52].

At every time click, particles could also create pairs of entangled particles and antiparticles; more often when energies are high like at the beginning of the universe, at the time of inflation. See figure 7 for more details. Time itself results from the random walks [1,10].

Random walks at very small scales is essentially a 2D process. It matches the quantum gravity results obtained by most consistent theories of quantum gravity that all encounter a reduction of dimensionality of gravity and spacetime at very small scales (to 3D then 2D spacetime) [1,32,33,69,85,86].

Discreteness ensures the absence of gravity and cosmological singularities.

As, in [1], random walks are associated to time clicks, one can invert the analysis and infer that time is only detected within the spacetime, or universe, as the result of the random walk steps (and creation or annihilation of particle pairs) [55].

We will later see in Section 22.3, which relies on the results of [1,69], that one can show that multi-folds recover GR, that spacetime reconstruction recovers GR, that GR contains multi-fold behaviors modeled at Planck scales, and that GR spacetime has all the same properties as a multi-fold spacetime at very small scales.

8. SM_G: The Standard Model with gravity non-negligible at the SM scales

SM_G stands for the Standard Model with gravity non-negligible at the SM scales [1].

In a multi-fold universe, down the smallest scales where spacetime is discrete, multi-folds apply and gravity therefore grows significantly very close to a particle, and shouldn't be considered as negligible anymore. With massive and massless gravity at very small scales, in a multi-fold universe, gravity also receives additional contributions [1,10,11,56]. It is therefore not entirely negligible at the SM scales, contrary to common practices and assumptions in High Energy physics.

A proposal like SM_G does not have to be limited to a multi-fold universe. In fact recent results confirm that gravity can be felt by atoms with changing interference patterns, due to the curvature of spacetime, resulting from other atoms [56].

9. SM_G: potentially solving many SM open issues

Multi-fold and SM_G can (at least partially) address many open problems in physics. Several of these proposals can also apply to just the SM_G, even without multi-fold properties.

SM open issues that can be addressed³:

- The strong CP problem [SM_G is sufficient] [1,25]
- Stability of the Electroweak vacuum [SM_G is sufficient] [1,27]
- The neutrino mass and existence of right-handed neutrinos. SM_G is sufficient, to justify the existence of the right-handed neutrinos, but something like the gravity electroweak symmetry breaking and multi-folds are key to explain how it hides behind the Higgs boson and at the entrance and exit of the multi-folds [1,6,28,29,31,57,85-87].
- Why three and only three generations per fermion families? [SM_G is sufficient] [1,26]
- The absence of observed magnetic monopoles [SM_G is sufficient] [1,58]
- The absence of observed proton decay [SM_G is sufficient] [1,22]
- Following the last 2 bullets above, the subsequent challenges to supersymmetry, superstrings and most GUTs and TOEs [SM_G is sufficient but multi-fold universe reinforces the challenges to these theories with gravity asymptotic safety] [1,5,12,17,24,58,,69,86,89].
- Matter antimatter asymmetry and origin of the existence of matter as well as the now confirmed way that antimatter falls down like matter [1,29,112].
- The mass gap for Yang-Mills theories [Discrete spacetime and right-handed neutrinos existence are also needed], and QCD [1,35,87].
- Space time matter induction and scattering as source of the types of SM particles [SM_G may, or may not, be sufficient as multi-folds are how the 7D ϵ neighborhood are created and felt in 4D spacetime through the multi-fold mechanisms and entry/exit points (and mappings). Anything else requires another way to achieve the same, without leading to problems with explaining how chiral fermions would exist or how we do not perceive 7D macroscopic dimensions. Also massless particle behaviors above the gravity

³ When marked as [SM_G is sufficient], it means the universe may not have to be multi-fold. Otherwise the results assume that the universe is multi-fold.

electroweak symmetry breaking may need a different model if not involving random walks.]
[1,23,47,83,85-87,91]

- Particles as microscopic black holes, and solitons of massless Higgs random walk patterns, or condensates and the gravity electroweak symmetry breaking instead of point particles [SM_G may be sufficient]
[1,4,86,87].

Text added on March 5, 2023:

- *Asymptotic safety of gravity [We argue that a GR based spacetime is sufficient]
[1,12,13,17,24,69,86,89,113].*
- *Why the SM, or SM_G , $Sl(2, \mathbb{C}) \times U(1) \times SU(2) \times SU(3)$ symmetries [91]. There, we show that the symmetries of the 7D embedding space appearing in space time matter induction and scattering are coming directly from the multi-fold SM_G , and include the Lorentz symmetries of spacetime and gravity, and the symmetries of the SM. To our knowledge no other theory out there has ever been able to provide such an unambiguous explanation, in general simply because they do not have the multi-folds as generators of the symmetries or do not have the embedding 7D spacetime. In the 7D embedding spacetime, symmetries can now be $Spin(7,7)$, because of the doubling for left and right chirality (spacetime orientation). The same considerations explain how and why the algebra doubling on non-commutative geometry in 4D also predicts the SM particles including neutrino mixing [1,31,86,99].*
- *A quasi TOE explaining most of Today's physics, based on the least action principle and the action path integral [104].*
- *The double copy duality between Yang Mills and (Einstein) gravity, explained by multi-fold gravity, and, as a result, multi-folds are also indirectly encountered in Yang Mills theory: Yang mills interactions also define GR gravity via the duality that models particle doubling, i.e. two entangle particles, real or virtual. That is the E/G conjecture [1,11,47,49,75,96,114].*
- *The problems facing superstrings, supergravity, M-Theory and most popular GUTs and TOEs [1,5,7,12,13,16,17,22,24,39,46,51,58,66,69,86,88,89].*
- *Trans-Planckian Censorship Conjecture [113].*
- *A desert of new fundamental particle above the energy scales of the gravity electroweak symmetry breaking [1,24,77-78,83,85-87,95,97,101,104].*

In general these results come from gravity smearing symmetries (and anomalies) that otherwise would have allowed, for example, proton decay, or magnetic monopoles, or from modifying the Lagrangian (i.e. the dynamics) of the system just enough to ensure the observed behaviors.

10. Multi-fold: potentially solving many open issues in Standard Cosmology

Multi-folds explain (some) dark matter effects as entanglement between entangled particles emitted from sources in the galaxy: attraction appears as gravity towards the center of mass [1,59], in a halo around. Validating such contributions is, at this stage, the best way to validate that our real universe may be multi-fold [1,59].

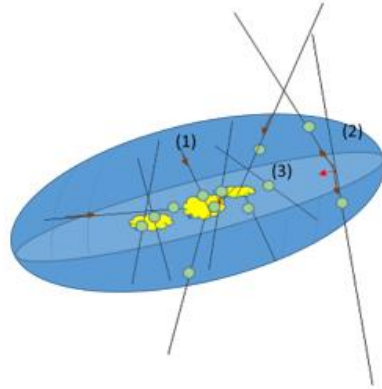


Figure 5: It illustrates how entanglement between entangled systems (particles and radiation) can produce attractive effects analogous to dark matter in a multi-fold universe. (From [1]).

This model [1,59] is compatible with many observations including the existence of galaxies with no or little dark matter [40-42]. The principle is very simple: if entangled particles are captured by another system or destroyed by interactions, the effect disappears or at least reduces.

It also supports recent studies that show dark matter density is essentially within a certain radius that seems to be expanding with time [61]: as time passes, radiation reaches further, and so does entanglement or explains why, in a multi-fold universe, dark matter effects occurs between entangled systems, not beyond. So one can therefore also conclude that it does not really attract as many other galaxies and the observations mentioned in [63] are also compatible with multi-fold dark matter effects: the Standard Cosmological Model (Λ -CMD) [109] can't account for the amount/distribution of disk galaxies out there, because, if formed by mergers, many should lose angular momentum and not rotate fast enough to be disk shaped. Alternate gravity theory like MOND, variations on the GR and Newton theory at large distances, would be compatible with these results, because, without as many mergers as in Λ -CMD where they are due to the dark matter, which increases attraction between galaxies. In a multi-fold universe, dark matter effects occur between entangled systems, not beyond. So one can therefore also conclude that it does not really attract as many other galaxies as in , and the observations reported in [63] are therefore also compatible with multi-fold dark matter effects [62].

Multi-fold dark matter effects is possibly the most promising way to validate that entanglement creates gravity like effects, and therefore to validate if our real universe is a multi-fold universe. We do not imply that there are no other mechanisms involved in dark matter, but we argue that such alternatives, e.g., axions, may not be needed, especially after [1,25,29,84]. It presents the advantage that it would explain why no dark matter has ever been observed and remain such a theoretical mystery, and, at the difference of MOND, we do not have to modify GR in ways that have been so far invalidated by observations.

Note added on March 5, 2023: Many issues encountered with dark matter due to recent observations can also be qualitatively compatible with the multi-fold dark matter effects [93,94,115]. Again these offer better alternatives than MOND, which has fundamental issues with gravitational lensing, as mentioned in [115].

Multi-fold mechanisms can also explain the observed expansion of the universe, and its acceleration as the result of quantum walks, and fluctuations of the positions of the particles and the resulting impact on the multi-fold effects: a contribution appears that "expands" and "accelerates the expansion" of spacetime as in figure 6 [1,43,84]. These results also can explain why the cosmological constant is small compared to the value expected from the SM quantum field vacuum energy: it is due to the multi-fold effects of fluctuations rather than the energy of the fluctuations [43,84,103].

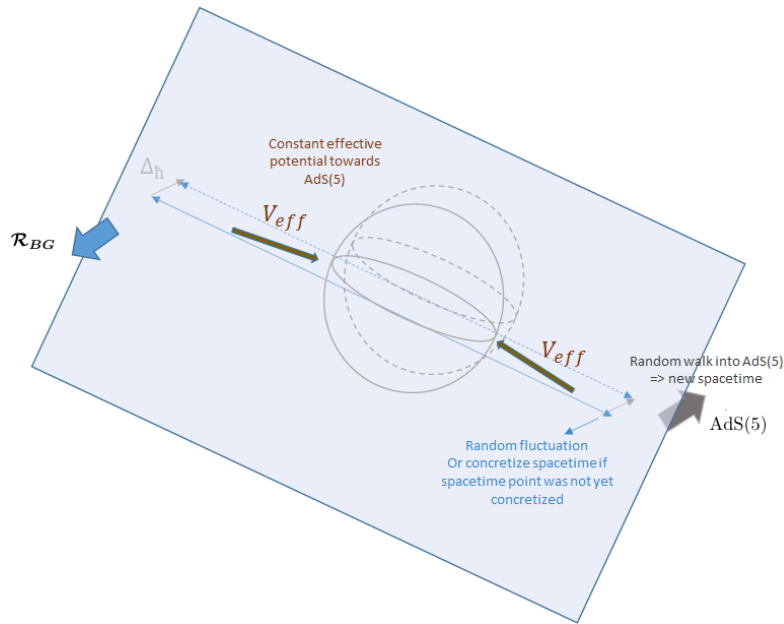


Figure 6: It shows how position fluctuations introduce a multi-fold effect potential contribution external to spacetime that can explain the acceleration of the universe expansion, in a multifold universe. (From [1])

Finally quantum random walk can explain the early universe inflation (exponential expansion), and the current steady contribution of expansion to the cosmological constant. With such models, the cosmological constant may vary in time, and within dense matter versus sparse vacuum [1,13,36,93]. At the beginning of the universe, with a localized or distributed region, every step is accompanied by additional spacetime (inflation) particle creations, in particular massless Higgs bosons. This reduces after inflation, but continues to this day as part of the expansion, as shown in figure 7. Particle / anti-particle pairs creations involve expanding interstitial steps that can take place, e.g. when there would be particle overlap, which matches the vision of expansion everywhere (not just pushes at the edges). This is also true for the mechanism described in figure 6. The particle and interstitial steps reduce multipoint correlations rendering ability to detect, without implying that inflation did not exist; a different conclusions from more conventional models [45].

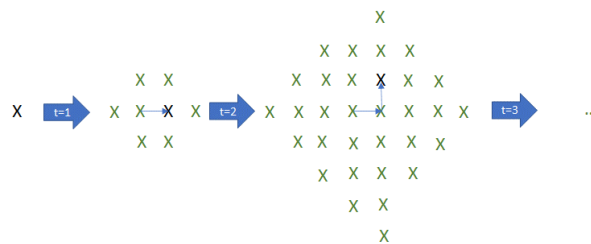


Figure 7: Inflation effects due to the random walk (of massless Higgs particles) and interstitial growth with each particle creating many pairs of particles and anti-particles. After inflation, such generation is greatly reduced and random: many of the spacetime locations become “not yet concretized” and “awaiting to be occupied” by future particles in random walks, and random walks create new spacetime locations at a much lower rate, and, instead of concretizing spacetime, locations are waiting to be concretized).

The multi-fold mechanisms imply only positive curvature [1], unless if we start from a significantly negative background. It matters for cosmology, and to validate compatibility with many theories, like supersymmetry, that only exist in negative cosmological constant universes [1,5,12,13,16].

Note added on March 5, 2023: The multi-fold dark energy effects are also a better alternative to proposals like voids, black holes as source of dark energy. See [108] and references therein.

11. Higgs, Ultimate Unification and more

[1,101,102] shows how the weak gravity conjecture (WGC) is no more strictly respected as typically expected in multi-fold universes, due to the multi-fold effects, the Ultimate Unification (UU) [24] and massive gravity [10]. As a result, instead of the typical models of GUTs, already in trouble with the lack of observed proton decay [22] or magnetic monopoles [104], and asymptotic safety of gravity [1,12,13,17,24,69,86,89,113], it is projected that at high energies, or very small spatial scales, all particles behave the same way with interactions at a same magnitude, instead of a grand unification where all forces become ones. *Note added on March 5, 2023: [86], provides a clear explanation: below a certain spatial scale, solitons and charges / quantum numbers are way larger than the scale effects and interactions are only random walks, entanglement/gravity, collisions/scatterings.*

The new fundamental particle landscape is expected to be desert between the electroweak scale and UU and above [1,24,73,74,77-78,83,85-87,95,97,101,102,104].

It leads to the proposal that the UU associate particle is the Higgs field, just as for inflation: it populates concretized spacetime locations, and it is responsible for the random walk during inflation [1,43]. It is the condensation of the Higgs field that results into massive SM particles as Qballs of superconductor Higgs condensate that also regularize singularity or over extremality of the microscopic black holes⁴ [4]. Above the multi-fold gravity electroweak, massless SM particles are the result of patterns of random walks of massless Higgs bosons [1,23,47,83,85-87,91]. Condensates and patterns match solitons solution of GR in 7D, through 7D space time matter induction and scattering.

Such a model recovers and explains models for particles as microscopic blackholes, as well as a Higgs-based inflation theory [1,31,36,42,86,87,89]. It also explains results of GFT (Group Field Theory) and non-commutative geometry [1,31,36,42,86,87,89]. With regularized black holes, behaviors match but singularities do not exist and there is no crossing of horizons, the Qball's skin, or Hawking evaporation, therefore avoiding all the issues of other typical of models suggesting that particles are black holes but unable to account for example with the fact that microscopic black holes should immediately evaporate, because the temperature of a black hole horizon increases as its size decreases [1,4].

12. Multi-fold gravity electroweak theory

⁴ As a more questionable idea, the particle Qball, existing within its skin or the black hole skin, may feel the outside world appearing to move fast, i.e. as tachyons. An interesting hypothesis [1,64,65] showed that this could explain the true randomness and path integral aspects behind quantum physics. It is farfetched and not something we claim to be happening, but this situation could be met if one accept the model of particles as regularized microscopic black holes: particles behave as if blackhole from the Qballs skins and outward [1,4], so the particle physics may appear as if seen from a tachyon reference frame for it. We leave at it for now, happy to just have mentioned it, just as in [1], but we are not taking a firm point of view on this. It requires more thoughts, and answers to the many questions and contradictions associated with such a view.

The Higgs condensation recovers and explains non-multi-fold gravity electroweak symmetry breaking as well as the orientation of spacetime [23,34,83,87]. Even better, it recovers a Higgs/right-handed neutrino doublet that confirms our Higgs and neutrino earlier results [1,4,23,29,31,36,57]:

- Higgs is at the entrance and exit of multi-folds (e.g. to ensure paths on the multi-folds continue to correspond to massive particles when they are massive) [1,29,60].
- Right-handed neutrinos and their corresponding antineutrinos are hidden in the multi-folds behind the Higgs. This conveys mass to the neutrinos and prevents observation of other right-handed neutrino interactions. [1,6,23,28,29,31,60].

As a result, SM, or SM_G , on a discrete spacetime remains consistent by eliminating the gravity anomaly problems implied by otherwise imbalanced numbers of chiral fermion types [34]. This also completes, in a multi-fold universe, the resolution of the SM Yang Mills mass gap problem, that had already be proven over lattices [1,35,87]: it is valid on a discrete spacetime and probably not on a continuous spacetime. The existence of the right-handed neutrino [1,28,29,57] also ensures that anomalies and inconsistencies are eliminated and the theory is compatible with SM [34].

13. Multi-fold space time matter induction and scattering in embedding space

Multi-folds generate at each location a 7D embedding space that can follow GR in 7D, and be flat or Einsteinian [1,21,47]. The effects of multi-folds are essentially with a spin-2 symmetry, which also explains the holographic principle of gravity or the area laws of black holes. The spin-2 symmetry implies the embedding space effects are mostly 5D. In the 4D multi-fold spacetime, the embedding space is only felt through the multi-folds as infinitesimal and essentially 5D.

Particles in 4D spacetime feel a 5D, or rather 7D, through the ϵ region at entry, exit, or mapping points. It is an additional reason for the tenancy principle: as each location only sees multi-fold due to their involvement with a multi-fold, they do not see other particles, e.g. like the entangled ones, or other particles crossing the support between them, unless if already overlapping in spacetime. The (massive) Higgs boson everywhere in spacetime and at the entrance and exit being the only exception and due to the interaction with it to enter or exit.

5D space time matter induction (effects of 7D, mainly 5D, geometrical objects impacting the 4D spacetime), and scattering with 7D, mainly 5D, objects when feeling the embedding space in an ϵ region, and encountering a 5D/7D soliton, recovers particles and interactions in the 4D multi-fold space time that match the SM particles, fields and interactions [21,30,47]. It can also be seen as a new approach: unconstrained Kaluza Klein theory. The 7D space supports the symmetries of the SM [30,47].

In other words, we can recover the SM in multi-fold 4D spacetime via space time matter induction. The remaining challenges of chiral fermions, not available in 5D or 7D, is resolved in the 4D spacetime by the Multi-fold gravity electroweak symmetry breaking described in section 11: it (globally) orients spacetime, and makes some microscopic black hole particles rotate. Above that energy level, it only locally exist around massless particles as patterns of Higgs random walks.

The particles exist in 4D spacetime, and only feel the multi-folds in such a 4D spacetime, therefore resolving the challenges of the absence of chirality at higher odd dimensions, of dimensions to compactify (embedding space is just no visible), or of incompatibilities between say 7D and the SM, as discussed in the next section. Higgs and

neutrinos are recovered together by scattering from within the multi-fold, as already encountered in previous sections.

Non-commutative theories also encountered in a multifold universe also recovers the SM [31,1,31,86,99].

Note that we do not say that the 7D embedding space is physical, beyond the portion built by the multi-folds, and the 4D spacetime particles ϵ neighborhood feeling at the points of entry, exit and mappings. This way, 4D Physics is not 7D or 5D physics, and so chiral fermions are possible (as in 4D), and we do not have a challenge of explaining why 3 large dimensions would not be visible to us, which is the reason why superstrings have had to compactify their extra dimensions because they form a real embedding space and no concept of it being locally generated as a ϵ neighborhood exists in their case.

14. 2D and asymptotic safety of gravity

At very small scales or large energies, 2D processes dominate in the multi-fold theory and in many other sensible or apparently consistent theories [33]. As a result, we can prove that gravity is asymptotically safe, for sure in multi-fold, but also most probably in the real universe [12,13]. Indeed most of the reasonings of [13] can be repeated with other theories that also indicate a 2D process at very small scales.

As we encountered multi-fold in GR, we de facto not only provided that multi-fold and multi-fold spacetime reconstruction recovers GR, but also that GR is asymptotically safe [69].

Note added on March 5, 2023: Establishing the Trans-Planckian Censorship Conjecture (TCC) also implies asymptotic safety of gravity [113]. And, Since writing of the preprint for this paper, we have produced a new non-perturbative proof of asymptotic safety of gravity [69], based on the Yang Mills / gravity double copy duality [89]. This duality also show that Yang Mills Gauge QFTs also contain multi-folds [75,96,114].

Other results have shown that asymptotic gravity is not compatible with the standard model if we have supersymmetry (above 6D), superstrings/supergravity/M-theory (10 or 11D) or most GUTs and TOEs [12,86]. It seems like a death knell to these theories. Especially after we proved that, as even conjectured by the string community, superstrings can only live in a negative curvature universe⁵ [7,12,13,16], something at best only plausible in 2D regime, where all consistent theories of gravity converge anyway. Our universe has a small but positive curvature... *Note added on March 5, 2023: [86], and references therein, further confirm that such incompatibilities remain in the presence of matter (fermions, bosons and scalars) along with gravity.*

Interestingly, one can show that the main reason why strings were considered as the ideal TOE, i.e. the recovery of a spin-2 graviton, and supersymmetric Yang Mills in 10D, is naturally the result of how strings are modeled, not a divine indication of it being the right TOE [1,5,7]. It is because the Hilbert Einstein action is trivially⁶ contained in the string actions, as is their association to negative (or at best flat) curvature [13,42].

⁵ In fact our proof [5,12,13,16,85,86] would rather argue that tentative answers from the superstring community, with constructed / uplifted vacua, still make no sense because still not compatible with the Hilbert-Einstein action for a negative cosmological constant.

⁶ Albeit nobody seems to have explicitly reported that till [1], and the details in [5].

15. AdS/CFT correspondence

Superstrings and M-theory have defined an AdS/CFT correspondence conjecture between CFT (i.e., \sim SM as renormalizable QFTs, albeit (maximally) supersymmetric in the case of the conventional AdS/CFT correspondence conjecture) without gravity, i.e. a flat spacetime, and an AdS(5), plus additional compact dimensions, universe with only gravity, i.e. with bulk gravity. It is a nice mathematical formalism, that implements a holographic principle [1,101], and allows simplifying models of strongly coupled fields, or strong gravity [19,67]. Unfortunately, with the considerations of incompatibility between superstrings and M-theory on one hand, and SM and positive curvature on the other, as discussed in section 14, the correspondence does not seem to be applicable to an (\sim asymptotic) dS (\sim asymptotic) de Sitter) universe as is our real universe.

A multi-fold universe has a factual correspondence between the 4D spacetime, and AdS(5) as tangent dual space, where multi-fold live [1,14]: multi-folds are the hints of gravitons in superstrings: they live in AdS(5), they are attached to entangled particles, and they evolve looking as closed strings. But superstrings do not live in our spacetime, and, at best, only relate to it, tangentially, at 2D regime scales [1,5,13,16,17,32,33,39]. In the case of a multi-fold universe, we have the renormalizable QFT of SM and a renormalizable (asymptotically safe gravity) on one hand and AdS(5) with superstrings outside the physical space [1,5,26,39,85,86]. Gravitons are just a reflection of multi-folds. They do not physically exist in our real universe, or rather should be viewed as quasi particles of effective theories [14,68].

In fact, as discussed in [47], coming from the M-theory AdS/CFT correspondence conjecture, one can see that adding a renormalized gravity to the picture recovers the standard cosmology results (Λ -CMB) and an effective positive cosmological constant, without considering the SM, as we have done so far. However, we already know, per the previous section, that superstrings in AdS(5), i.e. renormalizable and hence asymptotically safe, are not compatible with SM: a fundamental inconsistency. Anyway, there are also other theorems showing that supersymmetry at 4D is incompatible with positive cosmological constant [5,66].

Several conjectures have been built on the AdS/CFT correspondence conjecture, besides developing non-perturbative views of M-theory: ER = EPR and GR = QM. See [1,5,49] and references therein. They have equivalences in a multi-fold universe [1,47,69]. The key concepts behind these conjectures, like wormhole traversability with coupled extremities, or entangled massive fermions at their throat [6], entanglement of two black holes [37], the notion entangled particles / fermions with entangled black holes attached to their world sheet [38], the multi-fold hierarchical principle⁷ in [1] vs. the ER bridge cases in [5], and the match of entropy of ER bridges following the entropy (or information) laws and inequalities, all emerge in a multi-fold universe, with factual explanations, several encountered in this paper (See [1,5,39] for more details).

In a multi-fold universe, one may also make similarly sense of the AdS/QCD correspondence used in QCD as an application of the mathematical formalism of the AdS/CFT correspondence conjecture [5,17,39,87,116]. One expect the same for holographic material in material physics (See references in [1]).

16. Quantum fundamentals: the W-type multi-fold hypothesis

⁷ It is the absence of multi-fold mechanisms in hierarchical entanglements without local entanglement initiation proposed in [1].

Multi-folds can open the door to a new interpretation of Quantum physics: the W-type of multi-fold universe, where not only entangled systems but also spacetime locations covered by a same wave function identified with a same particle (in as much that it is possible) also activate multi-fold mechanisms with any other similarly covered locations (i.e. between spacetime points in the support of the same wave function), except maybe between a point and an uncertainty reason around it where jumps would not violate the no supra luminosity principle. It presents the advantage to justify the Born rule, and other quantum physics challenges in understanding it [8].

With the W-type multi-fold hypothesis, Figure 1 allows the two entangled particles to physically encounter at same point hence always being indistinguishable from each other and able to be in state that reflect at any time the impact on one particle of interactions with the other. This is why; indeed, entangled particles are in a state where they cannot be distinguished.

This may also give a real concept associated to the notion of wave function, and its QFT equivalent.

Recent results, in [70] and references therein, and discussed in section 22, confirm such an hypothesis if quantum physics is relative and equivalent in suitable quantum reference frameworks of entangled, coherent or correlated systems.

We also saw earlier in this paper that the W-type multi-fold hypothesis motivates the multi-fold mappings that result into gravity and gravity-like effects.

17. Fields or particles

The multi-fold theory puts back emphasis on particles and virtual particles instead of just fields that it now sees rather as another model approximation [1,15]. It should be considered by theories like superstrings, QFT, CFT and LQG for formulations that model explicitly entanglement and multi-fold like mechanisms.

Alternatively, one should search for a multi-fold QFT variation.[HERE]

[1,5,14,17,39,68] also discuss that gravitons are not physical, in 4D spacetime and are at best quasi particles emulating the attractive effective potential effects of the multi-folds in 4D spacetime. Strings on the other hand seem to provide hints of the multi-folds in AdS(5) (+ additional dimensions).

18. Black holes, area laws and wormholes

Because multi-fold mechanisms have spin-2 symmetry, they follow an holographic principle and entropy of spacetime in suitable regions is proportional to the area of its surface [20]. In particular it applies to black holes that follow the Hawking-Bekenstein area formula [71]. This is demonstrated by counting states at the horizon considering quantum fluctuations, as illustrated in figure 8 [1].

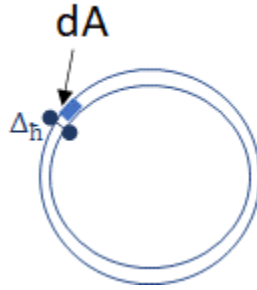


Figure 8: how the entropy of a black hole is a function of the area of its horizon. (From [1])

Note on March 5, 2023: Discussion of the holographic principle and proof of the covariant entropy bound can be found at [1,101].

In [1,44,101,102], we also discussed resolution of the black hole information paradox with the introduction of the notion of quantum extremal surface. The physics of the quantum extremal surface differs, in our view in a better and more convincing way, from the conventional approaches derived with the replica trick and island formula. The latter leads to baby universes as Wheeler's bag of gold.

Multi-fold Black holes have no actual singularity [1,44], and it is possible to recover the results of Page curve and Quantum extremal functions that seems critical to quantum gravity, the evolution of black holes and the resolution of the information paradox. This is demonstrated by modeling a microscopic evolution of particles and multi-folds within the horizon of a black hole.

The evolution at very small scale, especially for extremal black holes, varies from conventional Physics, leading to the concepts of Ultimate Unification (UU) [1,4,24]. Note added on March 5, 2023: [101,102] encounters confirmation of our proposed evolution.

The multi-fold theory also explores the possibility to rely on traversable wormholes to implement multi-folds [,,,,]. Entangled massive (or massless) fermions in a wormhole render the wormhole traversable [6,7,48,69,91,101]. It opens the door for a particular case of the multi-fold theory, where multi-folds are implemented by traversable wormholes, and follow GR [5,7,17,39,47,69]. Additional mechanisms can further contribute to traversability as discussed in [91,101].

[69] then encounters microscopic and traversable wormholes at Planck scales, as a sign of multi-folds in GR.

Finally, modeling particles as microscopic black hole is at the core of the multi-fold spacetime reconstruction and the multi-fold gravity electroweak symmetry breaking [1,4,23,31,34,83,85-87].

19. Quantitative results

The theory is mainly qualitative. Mostly because it awaits a confirmation of the E/G conjecture [1,9,11,49,52,70]. Theoretical progress could be made for example by rebuilding a LQG theory addressing the challenges mentioned in section 3, by adding entanglement constraints expressed as multi-folds [52], or by starting from the derivation of multi-folds from GR at Planck scales [69], as discussed in section 22. One could also try to build GR or Newton estimates from the attractive effective potential in [1].

Note added on March 5, 2023: Some quantitative results have been sketched for dark energy and dark matter that show compatibility of the estimates [84,103].

20. Applications

Interesting applications can be derived from the multi-fold theory. However until validated for our real universe they are mostly science fictions. Some are discussed in [1,46].

21. Other theories of Quantum Gravity

This paper intends to provide a view on the multi-fold theory, and therefore it intentionally did not try to analyze in details other approaches, or compare too much with them other than to seek corroborations. Interested readers can peruse the papers and comments at [7] and [1,46] for more details of the relationships, and differences, with other theories, as well as our points of view on some of their aspects at the light of the lessons learned from multi-fold theory, or of the hints about these theories encountered during our work.

For pedagogical considerations, one should mention that:

- We encounter superstrings, supersymmetry and AdS/CFT M-theory through the tangent dual of spacetime that surrounds any particle or concretized spacetime location, as microscopic blackholes created by the multi-folds [1]. It encompasses also ER = EPR and GR = QM and branes [1,5,17,39,49,68].
- We encounter 2D strings as part of the analysis of asymptotic safety of gravity [1,13,32,33]
- We encounter 2D (then 2D+1) gravity (QFT, Strings, CFT, etc.) as part of the random walks constructing spacetime [1,13,32,48,85-86].
- We encounter causal sets, and fit the model as part of random walk [1,31,68,85-86,114].
- We encounter (multi-)fractal and/or discrete spacetime as part of the random walk and spacetime reconstruction [1,31,69,85]
- We encounter non-commutative (quantum) geometry as part of the multi-fold, 2D random walks and spacetime reconstruction between 2D and 4D [1,13,31,32,43,85-86].
- We encounter LQG and other spacetime reconstructive theories as discrete spacetime following Hilbert Einstein action [1,18,31,52]
- We encounter GFT as part of spacetime reconstruction, random walk and the multi-fold gravity electroweak symmetry breaking [31].
- We encounter gravity as QFTs as part of the 2D random walks and analysis asymptotic safety of gravity [31-48].
- We encounter QM and emergent gravity with entanglement and particle models [1,7-9,15].
- We encounter massive gravity with the contributions from the virtual massive particles [1,10].
- We encounter the holographic principle with the spin 2 symmetry of the multi-fold mechanisms [1,91,101].
- We recover GR and Newton gravity at suitable scales [1,68,69].
- We encounter semiclassical models till way smaller scales that usually expected with SM_G [1,69,85,86].
- Gravitons do not exist as non-perturbative particles, as predicted by the multi-fold theory [1,5,17,39,14,47,70]. We believe that it may be the reason why we can draw so many pertinent considerations on these other models.
- We encounter multi-folds in Quantum Physics [70] and Yang Mills [96].

Much more, latest and future development can be tracked at [7].

The next section then also clarifies the relationship between GR, Quantum Physics and the multi-fold theory.

22. The universe of GR and Quantum Physics is Multi-fold

22.1 Hints of Multi-folds in the universe described by non-multi-fold Physics

Among the latest results of the Multi-fold theory, we have shown that one can encounter hints of multi-folds in GR and Quantum Physics:

- Repeating the Dirac's approach to quantized constrained Hamiltonians, derived from the Hilbert Einstein action, when avoiding the issues with the LQG approach [51,53], implies entanglement and multi-fold effects at Planck scales [52].
- Ensuring equivalence of quantum reference frames (QRF) to model Physics, and correcting other papers errors that would otherwise imply that quantum entanglement, coherence and correlation would not be invariant, implies recovering multi-fold mechanisms for QRFs associated to entangled systems [70], and building Lorentz spacetime with exchanges. For entanglement, this means activating multi-fold and their kinematics/dynamics.
- Analyzing Planck scale fluctuation effects in GR, we are able to encounter traversable wormholes, they should be traversable even if the authors of [118] did not see it that way, and on that basis to recover the whole multi-fold spacetime reconstruction of [1,69], including recovering GR. This is what we call the top-down-up-and-upper derivation of the multi-fold theory.
- *Note added on March 5, 2023: [96] also encounters multi-fold in Yang Mills interactions. That was expected following [69], as we already had shown that the Hilbert Einstein action, and the superstrings actions, imply Yang Mills and GR [5].*

22.2 General Relativity and Quantum Physics not incompatible, just incomplete facets of Multi-fold Physics

Such results, in addition to the considerations, in section 21, of the challenges encountered by other theories, may indicate that the real universe, assumed so far relatively well modeled by conventional Physics, would be multi-fold.

According to [69], wormholes encountered at Planck scales in GR, that are conventionally considered as not traversable according to GR are actually traversable, and QM, along with entanglement in Quantum Physics, as in the ER=EPR and GR=QM conjectures, are in fact different facets of multi-fold mechanisms, however unable to fully describe the mechanisms of [1]:

- GR can describe some local wormholes at Planck scales, and allow modeling them at larger scales, but it can't model stable traversability, per [1,5,17,39], and in multi-fold theory, per [6], this is because entangled fermions are involved, and these are concepts foreign to GR. Exotic matter, the other option, that we do not need in multi-fold theory, is unpalatable in conventional Physics. *Note added on March 5, 2023: We also discussed rotation and Casimir effects in [6,91,101].*

- Quantum Physics models only entanglement, not spacetime, and therefore how entanglement, or wavefunctions [117,119-121], affects it or the Hilbert spaces, and relies on this. As a result it is also not able to correctly model gravity, just hints of it.

22.3 Top-down-up-and-upper derivation of the multi-fold theory

The top-down-up-and-upper derivation of the multi-fold theory is provided in [69,118]. Accordingly, one can see that at Planck scales we encounter multi-folds, as wormholes, and that spacetime appears as discrete clumps at spacetime locations, connected by mostly one wormhole between neighboring clumps, and additional ones between entangled clumps. The picture is essentially 1-D spatial, generated à la random walk, and spacetime is non-commutative yet Lorentz invariant and with minimum length. This is illustrated in figure 9 and 10, copied from [69].

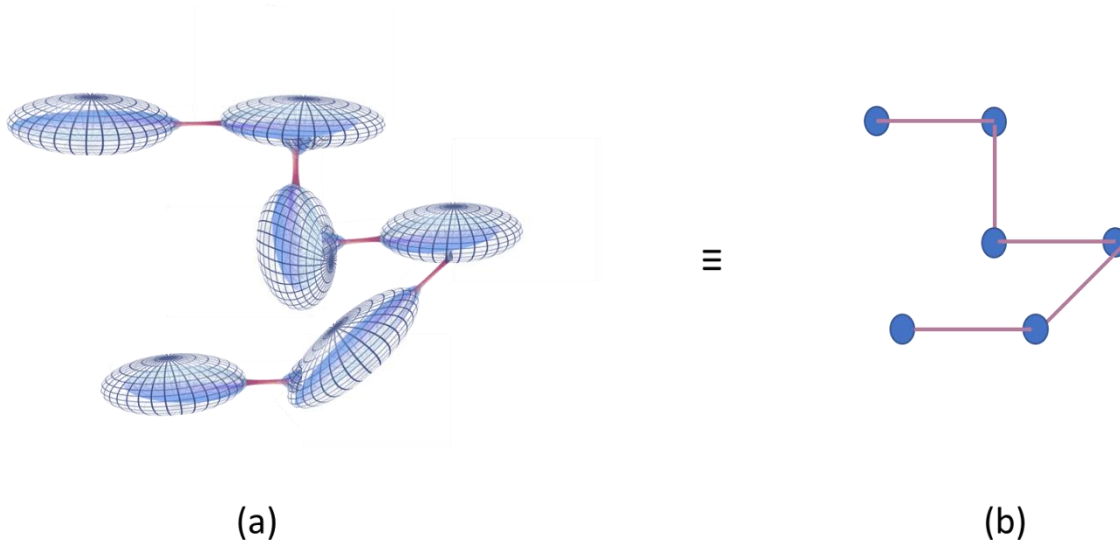


Figure 9: It illustrates the Planck scale spacetime contained in GR, from [69], that recovers spacetime reconstruction, GR and multi-folds, as in figure 10. (From [69])



Figure 10: Multi-folds between non-neighboring nodes as in [69]. (from [69]).

In fact, this way, spacetime is both continuous and discrete depending on how one wants to look at the clumps: the impossible has been achieved: the concepts of spacetime both continuous and discrete, while non-commutative yet Lorentz invariant, are not contradictory and are contained in GR, again as facets of the best that GR can describe.

Starting from these results, [69,72] shows that GR is recovered⁸, that it is a 2D random walk process, and that spacetime at such scales is inherently non-commutative.

22.4. What about Quantum Physics?

With the W-type multi-fold hypothesis [8], strongly reinforced by [69], we explain the Born rule across regions that support a physical quantum wave function, i.e. entangled, coherent and correlated regions. Coupled with random walks across the 1D spatial spacetime of section 22.3, particles, and fields, jump between random walk trajectories, essentially recovering Feynman's path integral approach to Quantum Physics [1,104].

[1] provides also a justification for Dirac's and Klein Gordon (and therefore Schrödinger equation), as a result of spacetime fluctuations, compatible with [69].

Note that [1] also mentioned another curiosity where quantum physics like multi-path and decays could appear as classical physics viewed from tachyonic reference frames [64,65]. If particles are behaving as microscopic black holes [1,4], then one could potentially argue that with respect to the Qball skin and within.

23. Conclusions

As an overview of the multi-fold theory, the paper gives simple motivations and explanations for multi-folds mechanisms, its implications and the SM_G, the Standard Model with gravity not negligible at its scales. We focus also on providing a big picture, putting many different contributions together.

We hope that it provides suitable ways for non-expert Physicists to also understand the current state of the theory, and for all readers to be motivated to explore further. All aspects of the theory are currently available at [1,7,46], and new developments and results are explicitly tracked at [7].

At the same time, some nuggets of new considerations have been provided.

The main things to remember are that while in GR spacetime tells matter how to move; matter tells spacetime how to curve, when adding Quantum Physics with entanglement, we also impose a non-local wave function behavior, yet Lorentz invariance impose no supra-luminosity. As a result, gravity (metrics or spacetime curvature - how to curve) is the result of spacetime going out of its way, and contorting, to support such requirements, as demanded by the content of the universe [90]. The multi-fold theory is about explaining and reconciling that and all the consequences of it. It can also be viewed as topologies that extremize an action.

⁸ This is really another derivation of "upper" GR, besides the recovery of GR from multi-folds as in [1], and its recovery from graphs of microscopic black holes [1] as part of the multi-fold reconstruction [1].

These consequences include the SM_G , i.e., the Standard Model where gravity has non-negligible effects at its scales, multi-fold dark matter and energy, and a discrete spacetime that is 2D at small scale, Lorentz invariant, fractal and non-commutative. The SM_G potentially explains many open problems with the SM. And we also address many issues with the Standard Cosmological model (Λ CDM).

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