


Right-handed Neutrinos and Traversable Wormholes: the key to entanglement, gravity and multi-folds extensions to ER=EPR?

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April 3, 2021

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 small scales. Also, multi-folds mechanisms result in 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. Therefore, gravity can be added to the Standard Model resulting in what we defined as SM_G , the SM with gravity effects non-negligible at its scales. It can contribute to resolving several open issues with the Standard Model without new Physics other than adding gravity. These considerations hint at an 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 is notable. They are always behind Higgs boson, emerging by 7D space time matter induction and scattering models, and by spacetime orientation flips, or chirality flips by gravity. They are hidden behind the Higgs boson or field, at the exit points of the multi-folds. Massless Higgs bosons, modeled as minimal microscopic black holes mark concretized spacetime location, move by random walk, and can condensate into Dirac Kerr-Newman soliton Qballs, to produce massive particles, thereby providing a microscopic explanation for a Higgs driven inflation, the gravity electroweak symmetry breaking, the Higgs mechanism with the mass acquisition, the chirality of fermions, and the orientation spacetime; all resulting from the multi-fold gravity electroweak symmetry breaking. They also explain spacetime reconstruction, first as a 2D process which ensures asymptotic safety of gravity.

Yet, so far, the multi-fold theory has left unexplained, other than by principles, several key aspects including why and how multi-folds are associated to EPR entanglement as proposed in the multi-fold theory, how multi-folds are activated or deactivated; why no multi-folds between hierarchical entanglements; how the multi-fold mappings works; could GR govern the dynamics and kinematics (in $AdS(5)$) of the multi-folds.

Recent analyses of traversable wormhole in 4D spacetime show that they can exist, without involving exotic theories and matter, if they contain two massive EPR entangled fermions in their throat: something immediately reminiscent of the right-handed neutrino stuck behind the Higgs boson in the multi-folds; if multi-folds were traversable wormholes. We also discuss traversability above the multi-fold gravity electroweak symmetry breaking energy, when all particles are massless and the case where the fermions are neutral, and in the 2D regime. It would make it plausible for GR to govern the dynamics and kinematics of multi-folds (in $AdS(5)$) and mappings, and provide a microscopic explanation to convergence of the ER-EPR conjecture with the multi-fold theory. Doing so shines a new light on entanglement, as resulting from attaching entangled right-handed neutrinos, and anti-particles, to entangled particles and the multi-folds, now as traversable wormholes, can be understood as gravitons. Also it can justify the dynamics and kinematics of the multi-fold mechanisms.

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Doing so, we derive microscopic interpretations, and justifications, for several of the multi-fold principles and heuristics mentioned in previous papers. The resulting self-consistency of the theory is compelling. Also it provides a different point of view on how more conventional approaches like ER=EPR should evolve, and could be used to move to a more quantitative formulation of the multi-fold theory.

In a discrete 2D spacetime, massive, entangled (charged) fermions are not needed to ensure traversability: the multi-folds are traversable, and could still be considered as wormholes. It is at higher scales that the (continuous) models require it to be consistent with approximations of wormholes.

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, and explaining other Standard Model mysteries without requiring, New Physics beyond the Standard Model other than the addition of gravity to the Standard Model Lagrangian. All this is achieved in a multi-fold universe that may well model our real universe, which remains to be validated. *Note added on November 25, 2022: See [67] for recent hints that our real universe is probably multi-fold.*

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, fractal 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 massless neutral particles and concretized spacetime locations, and metrics à la Reissner Nordström [2], and Kerr Newman [3], for massive and possibly charged particles – the latter being possibly extremal). Although surprising, [1] recovers results consistent with others (see [11] 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 significant at these scales. Semi-classical models also turn out to work well till way smaller scales than usually expected. *Note added on November 25, 2022: See also [12,71,72,91] for details and references on the above.*

Among the multi-fold SMG discoveries [1,12,13], the apparition of an always-in-flight, and hence non-interacting, right-handed neutrinos [5-7], coupled to the Higgs boson [7-10] is notable. They are always behind Higgs boson, emerging by 7D space time matter induction and scattering models [9-10], and by spacetime orientation flips, or chirality flips by gravity. They are hidden behind the Higgs boson or field, at the entry points (at entanglement) and exit points of the multi-folds. Massless Higgs bosons, modeled as minimal microscopic black holes mark concretized spacetime location [1-7], move by random walk [1,36,37], and can condensate into Dirac Kerr-Newman soliton Qballs, to produce massive possibly charged particles [11] (before condensation, they are massless, possibly charged, particles as solitons implemented as patterns of the massless Higgs), thereby providing a microscopic explanation for a Higgs driven inflation [1,7,8,36], the gravity electroweak symmetry breaking [8], the Higgs mechanism with the mass acquisition, the chirality of fermion, and the orientation spacetime [8,10,41]; all resulting from the multi-fold gravity electroweak symmetry breaking [8]. They also explain spacetime reconstruction [1], first as a 2D process which ensures asymptotic safety of gravity [37].

The present paper starts a discussion of the relationship between multi-folds and ER=EPR, already discussed in [14], and, in particular, it discusses the issues related to the lack of traversability of wormholes in ER=EPR models, so far. As a result of the lack of traversability, ER=EPR could not deduce emergence of gravity from entanglement.

Then, we discuss how [15] may be a game changer in this area. The approach proposed in [16] directly relates to our proposal for right-handed neutrinos in multi-folds, thereby offering a way to reconcile all the different approach and provide microscopic interpretation to several multi-fold mechanisms and effects.

We also discuss traversability of wormholes at scales where all particles are massless, or when spacetime and gravity are essentially 2D and ensure that traversability also supports neutral fermions.

2. The ER = EPR Conjecture and Traversable Wormholes vs Multi-folds

ER=EPR was proposed by Maldacena and Susskind (fathers of the holographic principle and its AdS/CFT version), as their way to use entangled black hole analogies to handle the hints of a link between entanglement and gravity [16]; which [1] explains for multi-fold universes, where we discover that entanglement generates gravity (like) effects and gravity is due to entanglement of virtual particles. It is also captured by the E/G conjecture [29], and as a result entanglement between real particles, is also expected to produce gravity effects [1,19], e.g. in quantum material like super conductors, or as source of eth multi-fold dark matter effects [1,56].

A simplified derivation of ER=EPR is provided in [14].

Multi-folds mechanisms were proposed in [1], initially without knowledge of ER=EPR, and therefore without using its model.

The original reasoning behind ER=EPR goes as follows:

- Consider two black holes (in AdS) with entangled horizons. We are using black holes analogies, and the AdS/CFT correspondence conjecture, to model CFTs, or Gravity [14,24-28].
 - We start from one black hole that radiates per Hawking's theory
 - The second black holes is composed of all the particles produced outside the black hole horizon, by Hawking radiation: if all these particles are brought together they will collapse into another blackhole entangled with the first one acting as source.
- Link their regions behind the horizon to form a ER (Einstein Rosen) bridge [42], i.e., a wormhole, which at this stage of the model is non-traversable.
 - Doing so, one can resolve the Black Hole information paradoxes (AMPS / firewall, complementarity) relying on the entanglement between the inside and the outside radiations. See also [4]. *Note added on November 25, 2022: See also: [68,69].* Also, this is not to be confused with the absence of gravity shields in multi-fold universes as discussed in [45].
 - It correctly "emulates" the EPR paradox with Alice and Bob's experiments².
- So it would make sense to deduce that two entangled blackholes be linked by ER bridges as manifestation of entanglement.
- The result is conjectured to be generalizable to any entanglement. It is quite a jump but it seems a good model:
 - [17] proposes an example between pairs of particles, using the AdS/CFT correspondence conjecture, and [18] shows that the entropy of ER bridges follows the entropy (or information) laws and inequalities.

² This emulation is probably the inspiration for the GR=QM conjecture [21].

- As discussed next, [1] proposes a stronger model for this, with many more consequences, including ultimately the demise of superstrings as TOE, or even as a correct model of gravity in our universe, beyond being able to provide approximations of gravitons. Yet, the multi-fold theory preserves the idea of AdS/CFT correspondence, which it makes factual, and also it allows superstrings as possible models of gravity and spacetime, but only in the 2D limit at very small spatial scales, or at very high energies [30,37,43,44].

Multi-folds mechanisms were proposed in [1], initially without knowledge of the ER=EPR conjecture, while building the theory, and therefore without using its model. In hindsight:

- Multi-folds are equivalent to many aspects of ER=EPR, but without resorting to strings or holographic postulates to derive the model. Instead the goal of the work in [1] was only to address the ER paradox and locality vs. non-locality of real realities.
 - Many would now argue on the string side that the AdS/CFT correspondence is often used without any reference to strings anymore.
- Multi-fold mechanisms resulted into showing that:
 - Entanglement is gravity: entangled systems are attracted by gravity like effects [19,29]
 - Gravity is entanglement: by relying on virtual pair productions, and therefore entangled, around sources, gravity appears and GR can be recovered at the right scales [1,29].
 - Massive virtual particles add massive gravity effects [20] at very small scales that renders possible a standard model with non-negligible gravity at the SM scales, aka SM_G [1,12-13]. It does not impact the ability to recover GR as [1]. *Note on November 25, 2022: See also the top-down-up-and-upper derivation in [70].*
 - Multi-fold universes, and / or SM_G , explain many open issues with the standard model and standard cosmological model [1,5-10,12,35,36,41,41-62] (*Note added on November 25, 2022: See also [71-83]*). It also demonstrates that supersymmetry, higher dimensions and superstrings are not compatible with SM and unphysical (as are most conventional GUTs and TOEs) [1,14,37].
 - The AdS/CFT correspondence conjecture is factual in a multi-fold universe [1,14].
 - An holographic principle and a covariant entropy bound also exists [1] (*Note added on November 5, 2022: Also see [68]*).

In the context of the current discussion, the most important aspect is that the multi-fold mechanisms add to ER=EPR (besides a completely different derivation and model), the ability to traverse them (so that path integrals include paths in the multi-folds). This is what is responsible for the appearance in spacetime of gravity like attractive effective potentials (or positive effective curvatures).

- Wormhole in ER=EPR proposal were so far considered as not traversable, and so traversability was not modeled in ER=EPR
- Wormholes / blackholes in AdS may be traversable, but only when involving unphysical considerations like exotic matter with negative mass/energy, and/or, with unreasonably large duration

Recent work [22] suggests that in the presence of ER=EPR, reasonable traversability may be possible without exotic matter³. [23,24] provide a viable way to ensure that traversability of wormholes in GR governed AdS(5) can be achieved with couplings of their Left and Right boundaries; which is exactly what happens when they are entangled... If any of these were the case, so that worm holes in ER=EPR would be traversable:

- It would validate the multi-fold mechanisms (when wormholes are in AdS for [23]).

³ Ironically, [22] relies on asymptotic safety of quantum gravity to “help”, which is hinted in [92] and derived in [37,93]. Of course, [23,24] do not require asymptotic safety of gravity. *Text in italics were added on November 25, 2022.*

- It should help ER=EPR researchers to now derive gravity, as we did in [1,20], and to associate gravity fluctuations to entanglement as in [1,19].

Interestingly, the absence of multi-fold mechanisms in hierarchical entanglements without local entanglement initiation [1] is related, or somehow equivalent to the entanglement cases where classical ER bridges appear in [18]. If they did not coincide in the past they can't be linked by wormholes or attached to multi-folds.

[15] shows other examples of traversable wormholes associated to entangled massive fermions which could also be a way to realize multi-folds. Our initial view (*) was that the proposal of [15] is limited to encountering traversable wormholes associated to entangled massive fermions. To support multi-folds, there should also be solutions associated to entangled massless fermions with entangled bosons (massless and massive). Otherwise, the wormholes cannot match, and support the multi-folds as they wouldn't always be traversable.

ER=EPR is a priori limited to CFTs as boundary to AdS spacetimes. It results from the AdS/CFT correspondence conjecture behind the ER=EPR conjecture [14,24-28]; which, more recently, is often no more attached when many speak of the ER = EPR conjecture: supporters of the ER=EPR conjecture assume that CFT spacetime without gravity is the 4D spacetime of our real universe, without necessarily the theoretical justification for it. In the multi-fold model, nothing is limited to CFTs (without gravity) in spacetime, and superstrings are not involved. So the associated limitations (i.e., CFT, AdS/CFT correspondence, supersymmetry) can indeed be lifted when ER=EPR is derived the multi-fold way instead.

Our statements, e.g., in the E/G conjecture, that entanglement is gravity, and gravity is entanglement [29], are stronger than ER=EPR, factual in multi-fold universe, and a proposal for experimental validations in our real universe [1,19]. In its quantum computing variation, with Qubit variation, it encompasses, and is stronger than, the GR = QM conjecture [21], that we also discovered post our initial work that led to [1]. GR = QM is about Qubits wormhole-based teleportation in lab experiments, resulting from the connection of entangled Qubits via wormholes, and, this way, it derives properties of bulk gravity (in AdS(5) (+...)). As mentioned so far, traversability is not resolved (e.g. see (*) for wormholes associated to bosons or massless fermions), nor is there a hint of the resulting gravity effects in spacetime. Also, the need to invoke CFTs, requires a lab able to work beyond the gravity critical fixed point (UV Point); something that may not be achievable within the promised timeframe either... But yes, everything proposed in [21], and more, is also plausible with multi-folds [1] where traversability problems, and critical fixed (UV) point/CFT concerns do not apply.

The non-traversability in ER=EPR has probably been the main hurdle that has so far prevent the String community to uncover that entanglement is gravity and gravity is entanglement, à la E/G conjecture (Factual in a multi-fold universe). Some recent works have explored aspects related to gravity, and concluded that ER=EPR could apply beyond AdS spacetime (as we do), and that gravity could emerge from entanglement (as we do) with the exchange of gravitons between entangled systems – hence the analogy with gravity), yet without justifying what the entanglement is about when it comes to gravity, vs. gravity-like effects of entanglement [40]. Also, they missed that entangled virtual particles generate this entanglement. As they exploit lessons from ER=EPR, they did not add paths in the wormholes either. *Note added on November 25, 2022: The lack of traversability also prevented [40] to realize that there are hints of multi-folds at Planck scales in GR [67].*

In hindsight, we can see that the string community has grasped for a non-perturbative theory, but it managed to model it essentially only through its dualities. Doing so, it only got blurry picture of Physics, using mathematical and unphysical concepts, which have some relation to Physics. The circumvolved way to work with CFTs, and AdS, and the role of black holes in AdS vs. entanglement in CFT, led them only to hints of the multi-fold mechanisms.

3. SM_G , right-handed neutrinos in a Multi-fold universe to the rescue

3.1 Massive and charged fermions

Maybe (*) was a too quick interpretation of [15]. What if [15] was actually providing a different prescription?

Interesting the approach of [15] relies heavily on adding a modeling in terms of wavefunctions, instead of QFTs, something we have argued in [1,76] to be essential to recover multi-folds, and to correctly model EPR entanglement [1].

The only requirement to ensure traversability of the wormholes modeled in [15] is not that the black holes be entangled at both end (à la [23,24]), and, therefore associated with entangled particles. Instead, it says that the black holes connected as wormholes must each contain an entangled massive (charged) fermion in their throat, although a neutral one would probably still work as discussed later. Massless case are handled later also.

In a multi-fold universe, we reviewed that right-handed neutrinos appear at the exit points of multi-folds, behind the Higgs black holes, i.e. in the throat of these black holes. According to [15], in the QFT approximation, that would be enough to ensure transferability of wormholes behaving like multi-folds. And it works for black holes / wormholes associated to entangled (EPR) massive, or massless, charged, or neutral, fermions or bosons.

Note added on November 25, 2022:

3.2 neutral or massless fermions

As discussed in [68,84], the limit of the charge to zero, i.e. massless fermions, does not nullify the condition: traversability remains valid provided that there is matter in the throat, something achieved by having the Higgs boson also shoving the right-handed neutrinos and anti-particles into the multi-folds [1,5,6], and providing the extra matter at the throat (independently of the path of the entangled particles to which the multi-folds are attached). The relationship between the right-handed neutrino and anti-particle was also encountered in [64].

It can be reinforced with [85] that offers another option to ensure wormhole traversability by massless or neutral particle relying on Casimir effect at the throat that ensure slow collapse. It is possible, but not required (following Occam's razor principle), and its slow decay may in fact slow down the multi-fold kinematics and dynamics proposed in [1], like multi-fold deactivation. Note that while the effects may appear to indicate quantum physics in 7D, it is not the case as the Casimir effects would come from within the multi-folds, where we have 4D spacetimes "short cuts". Therefore, we actually do not require quantum physics in the 7D embedding spacetime, consistent with [9,10]. Also, the Casimir effects assume no contradiction with the tenancy model for multi-folds [1,8,52,63,71].

Note also that the rotation of the wormhole could similarly help [86]. Also as discussed in [84], above gravity electroweak symmetry breaking energy levels [8], all particles are massless [84], and traversability by massless particles is not an issue [15,84]. Interestingly, rotations would even work for spin 0 cases, if we were to consider that, as in [1], the spin 0 case is the result of rotations in opposite directions. The rotation contribution has the advantage of not requiring questioning the tenancy model of the multi-folds [1,8,52,63,71]. Revisiting and expanding the spin model and its implications, not just for traversability, is for future work.

3.3 Discrete 2D scales

When spacetime appears to be 2D and discrete, at very small spatial scales, or at very large energy, there are no real difference between 2D spacetime and a worm hole: all are 2D links, as are also multi-folds as in [1], and they are traversable. This is also related to how we derived discreteness of spacetime in [1] from the multi-folds. It is just a different random walk that initially creates spacetime in another direction. To some extent it could remind us of [66], albeit a different theory and proposal. As a result, in 2D, wormholes are traversable without problem.

3.4. Why does it matter beyond section 3.1?

Section 3.2 matters to ensure that the mechanisms to ensure wormhole traversability, that we proposed in section 3.1, also works with right-handed neutrinos and their anti-particle, massive neutral fermion as the entangled fermions at the exit, of a wormhole. It also matters above the energy scales of the multi-fold gravity electroweak symmetry breaking, when all particles are massless, including the neutrinos.

Section 3.3 matters because we know that ultimately all physics is driven by 2D random walk of particles [1,7,30,36,37,64,87] and the ultimate unification (UU) [1,35,83].

4. Multi-fold mechanisms, mappings, activation and deactivation

Each particle brings its own microscopic black hole that surrounds it [1,11]. When they are entangled, the hierarchical principle [1] implies that the black holes separate from the same location, and so, associated right-handed neutrinos, and anti-particles, can also be entangled and ensure traversability. This provides a good microscopic explanation of how entanglement initiates the multi-fold mechanisms as well as the associated principle that they are only associated to non-hierarchical entanglement [1] (*Note added on November 25, 2022: and also [68,87]*).

As wormholes, following [1,14], multi-folds can be governed by a GR/Hilbert Einstein action in $AdS(5)^4$. GR reign in $AdS(5)$, where multi-folds can live as gravitons [1,14,31] (*Note on November 25, 2022: , albeit gravitons are probably not physical [88]*). Therefore, as wormholes, multi-fold activation and deactivation can follow the mechanisms described in [1], as we had intentionally proposed them that way.

Note that it does not lead to a contradiction, or violation of relativity [1]. Indeed, one could infer that the mechanisms as described in [1] and combined with the proposal involving wormholes, right-handed neutrinos and Higgs (massive below the multi-fold gravity electroweak energy scale, massless above), would imply that neutrinos and massive Higgs, when massive, would have to travel at the speed of light. But that is not the case. It is in fact why we say that neutrinos are at the edge and in the multi-folds: they are in the wormhole, in the embedding space. So the right-handed neutrinos and their anti-neutrinos, do not travel at c , even if the multi-fold attach to entangled massless particles like photons. On the other hand the massive Higgs boson occupy concretized spacetime locations (many when massive) and multi-fold exit points move from one location to another: the Higgs bosons do not travel with the multi-folds or wormholes. Again no issues.

⁴ It is probably why, from early on, wormhole traversability was known as possible in $AdS(5)$. It seems that all these particular cases suddenly have a reason for being, when considered from a multi-fold angle, just like $2D(+\epsilon)$ gravity is asymptotically safe, which means that models with a 2D regime will have quantum gravity that is asymptotically safe [30,37,65]. *Note on November 25, 2022: This is further confirmed in [93].*

Now, multi-fold mappings, as described in [1], can be seen as the result of the W-type multi-fold hypothesis [32]: anything crossing the spacetime region between the entangled particles, i.e. the support of the multi-fold mapping, will overlap the support of the wavefunction shared by these particles. With the W-type multi-fold hypothesis, it means that it will therefore be able to visit any other locations occupied by that wavefunction, including the exit points of the multi-folds. With traversability of the wormholes, it can therefore have path in the wormholes. i.e. multi-fold, and feel the resulting effective potential that implements gravity attraction [1]. Even when the wavefunction goes to zero between the entangled particles, which it probably never really is, the mapping remain active until the multi-folds are deactivated, roughly along the geodesic between the entangled particles at a given moment. That could be seen as the source of effects like rotational- and linear-frame dragging [1,94]. We may detail it further in the future.

With this, all these proposed multi-fold mechanisms now have microscopic physical explanations. It really reinforces our multi-fold universe proposal for our real universe. It also indicates consistency of modeling particles, and microscopic black holes. *Note added on November 25, 2022: especially when also considering [67].*

It also proves that the ER=EPR conjecture (brought beyond its original formulation as part of AdS/CFT correspondence conjecture) can be a particular case of the multi-fold theory, but incomplete as it is missing the multi-fold mechanisms, and gravity emergence [1,19,29] due to the absence in ER=EPR of paths traversing the fold/wormhole. In the multi-fold theory, the wormhole is now implemented by the multi-folds, and the multi-fold mappings at the exit points. As a result, this paper also recovers, without the supersymmetry and superstring hooplas, consistent results analogous to [33] à la Randall–Sundrum, but, again, without the restriction to D-branes [34]. It suddenly gives more weights to our far reaching and science fiction types of applications that we discussed towards the end of [1].

In this proposal, the fact the pairs of right-handed neutrinos and anti-particles at the exit points of the multi-folds must be entangled, when the particles are entangled directly explains the hierarchy principle of [1,b,s]. This does not happen between particles that historically have not been in direct contact (at entry point). Also, we already saw the relationship of the (non-)hierarchical principle to the models in [18] as mentioned in section 2.

5. Challenge with the Ultimate Unification regime or 2D random walks?

In the 2D regime prior to gravity electroweak symmetry breaking [1,8], all real particles are massless, up to quantum fluctuations, and spacetime is perceived as discrete. It is the domain of the Ultimate Unification [1,35] and inflation [1,7,36]. In this 2D regime, at very small scales the cosmological constant may appear negative [37].

Yet, with the analysis proposed above, would there be a challenge with the absence of a massive right-handed neutrino behind the Higgs? The answer is no per section 3.3. Let's revisit anyway.

Let us first review some options to address this:

The first option is as follows. As discussed in [9,10] the Higgs is an object in the 7D universe embedding the 4D multi-fold spacetime. In this 7D universe, the Higgs is a soliton that correspond to massive particle, as is the neutrino massive [10]. The neutrino cannot be chiral [9] in 7D. In the absence of chirality symmetry breaking which occurs at the gravity electroweak symmetry breaking, the neutrino is a massless soliton, implemented as a pattern of massless Higgs bosons. If it stays behind the Higgs boson, it appears massive in 7D. That is what happened with the multi-fold gravity electroweak symmetry breaking [8], and confirmed in [64]. When [10] sees it as encountered by scattering, we can understand this as being entirely in the 7D spacetime, not at the edge, i.e. entry or exit entry points. It is a pre-chirality symmetry breaking 7D non-chiral (neutrino) fermion, something detected in and aligned

with apparition of chiral fermions in [8,9,41] and felt via scattering [10]. This also works above multi-fold gravity electroweak symmetry breaking. Then as discussed in section 3.3. the massless particles in 2D above multi-fold gravity electroweak symmetry breaking can traverse wormholes. It is what we have assumed as main model for spacetime reconstruction as in [1].

Another options, that we list here but do not constitute the main multi-fold theory, could include: zero gravity at very small scales, or a different, yet to be defined model for multi-folds and their mechanism at discrete scales (e.g. minimum distance segments between locations of entangled particles or among a hub, the particles and their path or wave function (to support the W-type multi-fold hypothesis)). Some consequences of such alternatives might be that:

- Superstrings could end up not even being physical even at scales or energy of the 2D random walk regime, i.e. above the strings Hagedorn temperature [37]. It would be disappointing to say the least. That would be the case if gravity also disappears or weakens so that no negative cosmological constant, or at least strong enough attraction regime is encountered.
- It could also mean that in the UU / 2D regime, interactions are essentially only those of mechanics and collisions of billiard balls plus creation, annihilation and fluctuations, not even gravity.
- The model of particles as microscopic black holes, and its motivation may also become more complex.

A third option could be that 2D (spacetime gravity) is stranger than expected. In particular, it does not exist in the sense that it does not lead to any field equation at the level of GR in 2D, and it does not propagate nor depend on the matter content (because the GR field equations are trivially satisfied) [38]. So that would seem to indicate no gravity, no negative cosmological constant, unless if set negative for other a priori initial conditions, and no attractive potential associated to entanglement: there would be no multi-fold activated due to entanglement in such a regime.

These options are for further study. The mainstream model assumes that the first option, unless specified otherwise in this or future papers.

Yet, there is another aspect to consider, as envisaged in [38]: the 2D gravity that we consider is more about degrees of freedom than actual limitations to 2D; and the effects (multi-folds for entanglement or gravity) are rather tied to multi-folds in AdS(5). The situation is therefore rather a 2D gravity à la KK (Kaluza-Klein): 2D gravity correspond to plane wave gravitational propagation, at each step, along a principal direction (between the moving particles).

No matter what, we will assume that multi-folds are activated in the 2D regime and attractive effective potentials appear. Their intensity may differ from the 4D regime.

More importantly we should consider that because the 2D spacetime is essentially a 2D process over a discrete spacetime, multi-folds appear as proposed so far in 2D, are discrete multi-folds. Again, nothing prevents their traversability: entangled massive fermions are not needed for massless jumps across two linked nodes. So no issues occurs: in 2D discrete spacetime (2D dominating process), discrete multi-folds as wormholes are by definition traversable (and may still qualify as wormholes linking entangled spacetime locations per [39]).

Higher scale (continuous models) requires the entangled massive fermions. So in the early universe when its spatial scale was way below the gravity electroweak symmetry breaking, there were no issues with traversability of the wormholes, and resulting attraction may have the same or different coupling constants. Then massless particles may appear as solitons patterns from 7D space time matter induction and scattering [9,10]. There is no condensation yet so it's just preferred patterns of the massless Higgs bosons. Post multi-fold gravity electroweak symmetry breaking, massive particles appear, spacetime is oriented and therefore chiral [8], and multi-fold can, or could, be understood as wormholes as they include the entangled coupled massive neutrinos. In the later universe, at very small scales, there are only Higgs concretizing spacetime locations and condensed into particles and gravity

is due to the entanglement among these different massless Higgs bosons, that they be at concretized spacetime locations, or in particles (virtual or real) / Qballs as BECs. It is at higher scales that entangled massive fermions are needed to allow wormholes to approximate multi-folds and their mechanisms.

Note that we maintain that GR and conventional physics is in general only able to describe objects that fit its models, and so just facets of reality. *Note added on November 25, 2022: See in particular the challenges with GR to models multi-folds that it must then describe just as some of their facets: wormholes [67]. Other examples include [81,89,90]. Interesting, by encountering wormholes, [67] therefore will have traversable wormholes as deduced here.*

6. Conclusions

We have shown that it is possible to provide a complete microscopic interpretation of the principles and mechanisms of multi-folds if we accept that pairs of entangled right-handed neutrinos and anti-particles, massive through the Higgs mechanisms post gravity electroweak symmetry breaking, follow the exit points of the activated multi-folds. It accounts for multi-folds as traversable wormholes living in AdS(5), and described by GR in AdS(5). It proves full compatibility to ER=EPR, and its extensions to multi-fold spacetime, i.e. not AdS(5) + whatever was needed rigorously for the superstrings, as well as its extension to support gravity as a result of paths of the path integrals going through the traversable wormhole that consists of the mapping at exit points and multi-folds. It demonstrates full self-consistency of the multi-fold theory. The W-type multi-fold hypothesis is then needed to complete the explanation of the multi-fold mappings. It also explains the hierarchical principle. No requirement of massive neutrinos having to move at c , is encountered; it is all consistent.

Massless and neutral traversability cases are also elucidated

In 2D regimes, support of the same mechanism and principles exists, and it does not require entangled massive fermions in the folds, as spacetime is 2D discrete: multi-folds are traversable. It maintains consistency of the theory. However we recognized that other options could apply, something to keep in mind in future investigations, but, unless mentioned otherwise, they are not part of the multi-fold theory. It is at higher spatial scales that a (continuous) spacetime requires to model correctly enough the traversability of wormholes.

Wormholes may also be seen as a facet that GR can use to describe multi-folds that go beyond its model capabilities (that do not include the notions of entanglement)

Extension of ER=EPR to multi-folds and entanglement as source of gravity and gravity like attraction due to entanglement, as in the E/G conjecture, is now appearing as a possible valuable path to progress on a quantitative model of multi-fold universe. This is for upcoming work.

We must admit that we are impressed at the self-consistency so far of the multi-fold theory, and how it comes surprisingly together as more aspects are being studied and covered by it. We would like to borrow from the superstring theory that this can't be a coincidence, but we do not want to jinx the process by using it as a too strong argument.

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