Renormalization and Asymptotic Safety of Gravity in a Multi-Fold Universe: More Tracking of the Standard Model at the Cost of Supersymmetries, GUTs and Superstrings

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September 18, 2020

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 that they be real or virtual. Long range, massless gravity results from entanglement of massless virtual particles. Entanglement of massive virtual particles leads to massive gravity contributions at very smalls scales. Multi-folds mechanisms also result into a spacetime that is discrete, with a random walk fractal structure and non-commutative geometry that is Lorentz invariant and where spacetime nodes and particles can be modeled with microscopic black holes. All these recover General Relativity (GR) at large scales and semi-classical model remain valid till smaller scale than usually expected. Gravity can therefore be added to the Standard Model (SM). This can contribute to resolving several open issues with the Standard Model without new Physics other than gravity. These considerations hints at a even stronger relationship between gravity and the Standard Model.

Conventional quantum gravity is typically known, or assumed, to be non-renormalizable; something that has so far prevented reconciliation of GR and Quantum Gravity. In this paper, we discuss what should be said about renormalization in a multi-fold universe, where discreteness (while fractal, random, non-commutative and Lorentz invariant), multi-fold dark energy (repulsive), as well as the support for in matter, and among particles, torsion, guarantee the absence of divergences, and of any gravity or cosmological singularities.

We argue that quantum gravity in a multi-fold universe is asymptotically safe: an alternate renormalizability criteria, that was originally proposed by S. Weinberg in the 70s to guarantee that no unphysical singularities or misbehaviors should appear in quantum gravity.

Re-using results obtained by others, we argue that asymptotic safety implies constraints on the allowed number of particle types that can be present in a 4D universe (roughly the same as in the SM), as well as estimates of the top quark and Higgs boson masses. It adds to our previous thesis, that gravity is key to the properties of SM, with the standard model with gravity not negligible at its scales (SM_G), as it enables us to explain, at least partially, open issues with SM and the standard cosmology model. These constraints on the number of particle types, now in effect in a multi-fold universe, further render unphysical theories like supersymmetry, supergravity, superstrings (and as a result M-Theory) as well as many GUTs and TOEs: the additional super partners needed by these theories, and universes with more than 4 dimensional spacetime are not compatible asymptotic safety.

These conclusions extend to many universe models beyond multi-fold universes; in fact, possibly, to any consistent model of the real universe where gravity is well behaved and follows Quantum Physics and General relativity at suitable scales. There are many indications that conventional quantum gravity derived from QFT would be asymptotically safe, without needing to bring in any multi-fold assumption. The reasoning in this paper adds arguments to the compelling conjecture of asymptotic safety of quantum gravity, with the same implications for all the incompatible theories, and to the need for SM_G, where non negligible gravity at small scales is considered.

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1. Introduction

The new preprint [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.

With the proposed model of [1], spacetime and Physics are modeled from Planck scales to quantum and macroscopic scales and semi classical approaches appear valid till very small scales. In [1], it is argued that spacetime is discrete, with a random walk-based fractal structure, fractional and noncommutative at, and above Planck scales (with a 2-D behavior and Lorentz invariance preserved by random walks till the early moments of the universe). Spacetime results from past random walks of particles. Spacetime locations and particles can be modeled as microscopic black holes (Schwarzschild for photons and spacetime coordinates, and metrics between Reisner Nordstrom [2] and Kerr Newman [3] for massive and possibly charged particles – the latter being possibly extremal). Although surprising, [1] recovers results consistent with other like [4], 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 4-D 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 that usually expected.

The present paper reviews renormalization and asymptotic safety of gravity and present the consequences of asymptotic safety for the standard model. We then discuss applicability to Multi-fold universes and derive consequences for Physics in general, in terms of supersymmetry, superstrings and related GUTs and TOEs.

In this paper, we remain at a high level of discussion of the analysis and references are generic for the subjects. It makes the points accessible to a wider audience and keeps the door open to further papers or discussions devoted to details of interest. Yet, it requires the reader to review [1], as we do not revisit here all the details of the multi-fold mechanisms or reconstruction of spacetime. More targeted references for all the material discussed here are compiled in [1] and derived papers.

2. Gravity and Renormalization

It is conventionally accepted that quantum gravity is not renormalizable and that perturbative expansions are not well behaved and probably diverge [5]. For a good introduction to renormalization, see [7]. It has been argued that this challenge would more or less result from the background dependence of QFT [6,15] and the related divergences of self-interactions (e.g. one-loop and higher loop divergences [14]). This explanations makes a lot of sense when thinking about renormalization as originally pursued in QED to cleverly cancel infinities.

Superstrings are believed to avoid divergences as would Loop Quantum Gravity (LQG). Besides the “discovery” of the graviton, to be taken with a grain of salt as discussed in [1,8,9], it is one of the main reason for “believing in superstrings”. Indeed, in perturbative string theory, because of extended objects, superstrings are expected to behave well, and be renormalizable in the UV. LQG (and other reconstructive models) skirts the problem by being on a discrete spacetime albeit unfortunately never actually able to recover a macroscopic spacetime as governed by GR [10].

This discreteness argument and reconstructive model is also part of multi-fold approaches [1].

3. Asymptotic Safety of Gravity

Confronted with the indications that (perturbative) renormalization is not looking like a property for conventional QFT-inspired quantum gravity approaches, Steven Weinberg proposed a new generalized criteria for a well-behaved (in the UV region) quantum gravity theory: Asymptotic safety [11,13]. The criteria is not limited to gravity: it has been shown to apply to Yang Mills theories, e.g., [46,47], and therefore to the SM.

Intuitively, a theory is asymptotically safe if, above very high energies (i.e. below very small scales, it is associated to a non-trivial, and non-gaussian, fixed point), it starts to behave (in terms of its main couplings – i.e. the strength of the interactions involved) as if independent of the scale, and with no significant increase of degrees if freedom [15]. This way, its behavior can be extrapolated to infinity without divergences or unphysical singularities: above a certain scale, the theory masks the microscopic specificities with universal behaviors and as such it can be considered as a consistent effective theory above such scale that does not mischaracterize, at higher scales, the (combined) effects from lower scales.. Typically it would be expected that, below that scale, there may be opportunities for New Physics.

Asymptotic safety of quantum gravity has not yet been (conventionally) proven, and it is in fact criticized, as misguided, by many.

It can be seen as a possible criteria aspired upon for a theory or a conjecture for the actual real-world quantum gravity theory still to be discovered. As the latter, it arguments in its favor include:

i) It is the case at lower dimensions (2+ε)D (but not up to 4) [13]
ii) Approximations (the Hilbert Einstein action Truncation) seem to show a fixed point [13]
iii) The model works for non-gravity models [15].
iv) Remembering that we know that gravity appears as 2D processes at very small scales, as discussed in [16] and recovered in multi-fold universes [1], where it results from the random walk fractal reconstruction; we know that 2D gravity is renormalizable [11,13,43].

More details are in [13.15], yet none of these references provide a firm final confirmation in 4-D.

It is to be noted that supersymmetry is considered to guarantee asymptotic safety for 4D gauge theories [48].

Note on 2/20/2021: More details and references can be found in [63]. In that work, we use a new approach to derive what we consider to be a proof of asymptotic safety of gravity.

4. Asymptotic Safety and the Standard model.

Follow-up works have shown that the constraints of asymptotic safety have significant impacts on acceptable actions of coexisting fields. It has been proven that Yang Mills theories are asymptotically safe, even when asymptotic freedom fails, when the SM is present [46,47].

In particular [17,18] showed that:

- The number of particles and fields, especially fermions allowed with asymptotically safe quantum gravity is limited by a strong upper limit on fermions, (vectors) and scalar fields. In 4-D the Standard Model is compatible with a asymptotically safe quantum gravity.
- Super partners are not compatible with an asymptotically safe quantum gravity in 4-D, even if supersymmetry guarantees asymptotic safety in 4D [48]. (SUGRA would compatible, but it is known to have other problems [49]).

- Most popular Conventional GUTs (e.g., SU(5) and SO(10)) require super partners that are not compatible with an asymptotically safe quantum gravity in 4D
- 5D is compatible with asymptotically safe quantum gravity but, in general the Standard Model, is not (under some approaches it may be) [17]. Any higher dimension is not compatible with the Standard Model.
- Compact or large dimensions are similarly treated as at very high energy, scales will appear be so small that the differences aren't noticeable [17]: the difference between continuous spectrum and discrete ones of compact dimensions have no effect on the results.

In addition, [19,50] showed that the Higgs boson and top quark mass can be predicted (from the bottom quark mass for the top quark). It is work in progress and subject also to the approximation of the truncation approach.

As an aside, recent work also used similar considerations to go beyond the standard model to narrow down on the mass Higgs prediction [51]. We know that there are many prediction of the Higgs mass that were made (see [52] for a compilation up to the Higgs discovery) and that the (low) value found by many is believed to be linked to the Higgs potential (vacuum) potential stability (also related to, and addressed by [53]). *Note added on 2/21/2021: yet this convergence across approaches [54] reinforces the outcome of the analysis reported in [62] and the importance of 2D gravity in the (multi-fold) random walk regime (or beyond Hagedorn temperature for superstrings).*

Considering the implications of the above, it would be great to prove asymptotic safety of quantum gravity not only in multi-fold universes but also in our real universe, as it would have huge impact on many New Physics theories.

Note added on 2/21/2021: See [63] for such a proof independent of multi-fold mechanisms.

5. Gravity is Asymptotically Safe in a Multi-fold Universe

In a multi-fold universe, asymptotic safety results from different paths of reasonings:

- A) The multi-fold spacetime is discrete, fractal and random [1]. [20] proposes an approach to renormalize the spacetime geometry modeled by a random fractal graph (which is how a multi-fold spacetime can be modeled), which is another way to see how a reconstructed multi-fold universe behaves as a macroscopic spacetime that follows GR ([1] instead simply achieved that same analysis with the microscopic black holes surrounding every concretized spacetime location and every particles.). That approach leads to UV fixed points.
- B) The spacetime of a non-commutative and (multi)fractal which also leads to UV fixed points [21]. This path is a bit more elaborate to use as a proof and we will not explain it in this paper other than by pointing at some hints that can be found in [54-60], where black hole singularities are cured by non-commutativity, fields are renormalizable with asymptotic safety (UV Fixed points), torsion, known to prevent misbehaviors, results into non-commutativity, and non-commutativity regularize the theory and results into/from minimal length concepts [61].
- C) Starting from the Ultimate Unification (UU) reasoning around falsifying (e.g. at least no strict inequality) the Weak Gravity Conjecture, with a phase (at very small scales), where all particle equally contribute with interactions of same intensity, as presented in [1,22]:
    - at very small scales, all entangled virtual pairs are massless and of same ranges. At smaller scale, it becomes apparent that they propagate via random walk leading to a fractal (and Lorentz invariant and non-commutative) spacetime. When reaching the scale where the random walks are visible, the process becomes scale independent and essentially 2D (i.e., asymptotically safe / renormalizable [11,13,43]). *(Note on 2/21/2021 – See [63] for a much more detailed discussion.)*

    - Unoccupied (but concretized – see [1]) spacetime points are simply following a scale independent random fractal structure
    - Spacetime points occupied by particles are within a microscopic blackhole where no singularity is involved because of discreteness, torsion and dark energy (repulsive) effects and have there effects externally only visible via the horizon(s) at a fixed scale defined by the nature of the particle. Effects are therefore also scale independent.
- D) Spacetime is randomly fractal at the discrete scale and so pure gravity corresponds to a critical fixed point (RG) [13], where universality takes over for the effective theories at higher scales. The formulation above the scale of the critical point are asymptotically safe, and these scales are the scales that matter for SM.
- E) [1] showed that spacetime and gravity in a multi-fold universe becomes a 2D process at small scales (where random fractal walks dominate). 2-D gravity is renormalizable [11,13,43]
- F) Combining of all of some of the arguments A)- through E)

These different reasonings demonstrate a UV fixed point and asymptotic safety of gravity in a multi-fold universe. C) and D) are in our view the most rigorous and complete arguments but each of the argument above are probably sufficient on their own.

6. Standard Model support and very limited options for New Physics in a Multi-fold universe

The reasonings of section 5 lead to a step that, so far, could not be made by all the works and initiatives around conventional asymptotically safe quantum gravity that have been summarized in section 4: in a multi-fold universe[2], gravity is asymptotically safe. It is not an aspire, a criteria or a conjecture. It is a fact.

6.1 SM_G

As a consequence, we recover support for SM_G (i.e. Standard Model with non-negligible gravity at the standard model scales) in multi-fold universe, in a way complementary to the hints recovered in [23], or the ability of SM_G, in a multi-fold universe, to explain many open issues in the standard model and the standard cosmology model [1,23,24]. The order of magnitude of the numbers of particles (fermion, bosons, scalars) and some mass estimates, as well as the 4D dimensions of spacetime are the main new deductions that result from asymptotic safety and match observations. The latter is a different and complementary argument for 4D (and not more) from the ones that we presented in [1].

Note on February 21, 2021: More arguments are getting assembled in [64,65] and a related paper will be published in the future.

Note that the derivation of SM_G, by induction from a 7D unconstrained Kaluza-Klein (KK) model, as in [23], is not impacted by the higher dimension constraints discussed in section 4. Indeed, in such a model, the 7D spacetime is flat / vacuum (no sources) and with a multi-fold universe, no particles actually live in it.

[2] Please note that towards the end we will actually lift that restriction. But bear with us: the approach, that we follow, is driven by our multi-fold model, and more can be said on the topics addressed here when we indeed have a Multi-fold universe, or at least SM_G. SM_G itself is not limited to multi-fold universes, but the argument for asymptotic stability can be more generic.

Note on February 21, 2021. Even the proposals of [66], do only assume access by particles, including Higgs boson and right-handed neutrinos, to the multi-folds; not existence in 7D. The embedding 7D space is only felt due to uncertainty fluctuations.

In [23], we mentioned the possibility to also consider non-flat embedding spaces. It may still work with multi-fold universes (as no particle really enters the extra dimensions), but trying to build such models would require paying attention to the dimension considerations. Finally, in [23], the extra dimensions are a new 3 space + 1 (shared time) dimension spacetime "added" to the multi-fold spacetime (and with no source/particles); so that there is no need to have a SM_G in that spacetime. In other words, the 7D embedding does not care to support SM_G in its 7D, and there are no issues with the 7D embedding space being incompatible with SM_G, just as for the incompatibilities of 7D spaces and chiral fermions.

6.2 Not too much room for New Physics

With our convention, used since [1], that SM_G is not New Physics, as SM lives in a universe where gravity is present anyway, "no New Physics" is strongly motivated at this stage in a asymptotically safe universe.

However, very early on, multi-fold universes also hinted at a relationship with superstrings [8,9] and negative implications for superstrings (and related theories), including supersymmetry, popular conventional GUTs and TOEs [8,22]. We already knew that multi-fold gravity impacts on proton decay [40] and on magnetic monopoles [39] were bad augurs for all these theories, from which ultimately only gravitons in AdS(5) [8,9,25], the AdS / CFT correspondence conjecture [8,9,25] and the ER=EPR conjecture [1,8,9,25] seem to manage survive as plausible approximations of (multi-fold) Physics, with a potential pass when it comes to their relevance in 2D regimes, if they have one. After all, these theories have already seen the writing on the wall on their own with the absence of any observation of proton decay, magnetic monopoles or any new super partner as new particles; or with the potentially devastating conjectures that superstrings are no compatible with positive cosmological constant (and positive curvature) spacetime and can only live in negative spacetime where we know GR is unstable in the presence of matter!

Note on February 21, 2021: More details on the de Sitter vacua as swampland can be found in [67].

At this stage of the multi-fold program, the conclusions are rather striking: in a multi-fold universe [1,24],

- Superstrings seem unphysical and model at best gravitons in AdS(5) tangent to spacetime. All the related and derived theories (e.g. M-Theory) are similarly threatened. The main reasons being:
    - 10 or 11 dimensions (or more) are no compatible with SM_G. Compactification does not change the outcome
    - No observed proton decay, magnetic monopoles or super partners
    - Conjectured (*Note on February 21, 2021: It has become an established fact through work published meanwhile*) incompatibility with a positive cosmological constant as apparently encountered in the real universe [41]
    - Triviality of the highlights of superstrings (e.g. graviton discovery resulting simply from the inclusion of the Hilbert Einstein action in the string actions [1,62]) that justified its raison d'être.
- Supergravity, although plausible without supersymmetry, under certain conditions at low dimensions, e.g. 4D or 6D, as SUGRA, suffers the same fate for its 11 dimensions theory (i.e. with supersymmetry). We know that simple SUGRA has its own problems and that is why it was happy to hijack a ride with supersymmetry, superstrings and M-theory. See [38] for an historical overview.

- Supersymmetry seems not viable because of the required number of particles with super partners would be incompatible with a 4D spacetime and SM_G
    - We already had established many challenges for these theories related to proton decay, magnetic monopoles, etc. [1,8,9,22,24]
- Similarly, popular GUTs like SU(5) and SO(10) seem not viable:
    - Because of the required number of particles with super partners would be incompatible with a 4D spacetime and SM_G.
    - It is also worth noting that, as suggested in [7], the scalar fields (how many appear, especially how many fields) in these theories is a key reason for their demise. That is good: physical reasoning can still see through the fog of mathematics and their beauty.
    - Also, just as for supersymmetry, we already had established many challenges for these theories related to proton decay, magnetic monopoles, multiple / recurrent Higgs mechanisms etc. [1,8,9,22,24]
- All of the above, and any other GUT or TOE requiring more dimensions than 4D, or significantly more new particles, or predicting proton decay or magnetic monopole seem not viable.
- Symmetry breaking mechanisms are not expected to reduce the number of particles or the required spacetime dimensions, to the contrary. It does not seem to be a escape mechanism, as when that argument is used to argue that super partners masses would have been shifted to way higher energy level, thereby hoping to account for their non-observation so far.

Essentially, all these major New Physics candidates are eliminated in a multi-fold universe, and those, that may have survived the hit of asymptotic safety of section 4, are eliminated by their prediction of proton decay or magnetic monopoles that we have already invalidated [1,24]. It has been a significant decimation; at least in a multi-fold universe.

There is of course a possible loophole: with UU, that could reduce the viable types of particles during its regime, as they behave similarly, these models that support a 2D regime, may be suitable during the 2D regime at very small scales, or very high energies. That would be the equivalent to, i.e. the approximation by these models of, the random walk period of spacetime reconstruction in our multi-fold model [1]. But no matter what, they can't model higher scale processes and have persistent problems with the super partners.

Besides this 2D regime options, with are mainly left only with gravity approaches still standing like LQG and reconstructive theories [1,10], our multi-fold universe model (which has a strong reconstructive aspect and a Ultimate Unification proposal [22]), and some esoteric models like say causal fermion systems [26], which we do consider to possibly be compatible with multi-folds, in as much as when it comes to the outcome of induction of space-time-matter from 7D unconstrained Kaluza-Klein vacuum [23], or universes as Quantum computers, something that we also embraced in [1,27].

6.3 Beyond Multi-fold Universes

Of course, one could argue that multi-fold mechanisms are just a model and nothing proves that it is relevant to our real universe. Besides the ability of Multi-fold models to explain many open issues and to offer falsifiable predictions, the hints of aspects of multi-fold mechanism in conventional physics, and their ability to explain aspects of the New Physics models (e.g. Area laws and Gravitons in AdS(5) [1,28], ER=EPR [1,8,9,25], AdS/CFT correspondence conjecture [1,8,9,25], etc.), we should note that many features used to reach our devastating conclusions for the affected models could be repeated without invoking multi-fold universes:

- SM_G fundamentally amounts to adding a gravity contribution to SM, that is non-negligible at the SM scales. There are many ways to justify this, including, simply pushing semi-classical approaches down to as small scales as possible (by the way, something that multi-fold mechanisms justify) and remembering that r^{-2} can become non-negligible at very small r. Only dark energy, inflation and dark matter would not be explained just by doing so [1,29,30,31]. Most of the other open issues of SM addressed by SM_G, remain addressable in a non multi-fold SM_G.
- Recovery of the SM_G by induction from 7D flat spacetime governed by (7D) GR (unconstrained Kaluza-Klein models) [23] can be achieved.
- The issues proper to the negatively affected theories (positive cosmological constant in the swampland, super partners, proton decay and magnetic monopole observations), and our invalidations of proton decay and magnetic monopoles in the presence of gravity are, by no means, requiring a multi-fold universe, but rather just non-negligible gravity effects at small scales.
- The asymptotic safety is not far-fetched as discussed in section 3. Also the reasonings presented in section 5 can be repeated beyond multi-fold theories. *(Note on February 21, 2021: See [63] for a more complete analysis).*
    - Referring to [1], we saw that discrete, random fractal non-commutative and Lorentz invariant spacetimes are predicted by many other approaches[3], with all or a subset of these properties. While these approaches may not derive SM_G, or explain its open problems, as can be done with multi-fold mechanisms, all would have the same negative implications on much of the affected conventional or popular New Physics out there.
    - In fact, argument iv) in section 4, combined with [14,42,44] (i.e. option E (or F of course) in section 5, but derived for generic gravity using [14,42,44]) seals the deal, even without a multi-fold universe. We assert that it extends our conclusions to any consistent model of the real universe with gravity that follows Quantum Physics and GR at suitable scales. Therefore, we conclude that Gravity is asymptotically safe, in the real universe. And so, much of New Physics in in trouble. Restrictions of our reasoning to a multi-fold universe do not restrict the conclusions to such universe because of iv). *(Note on February 21, 2021: Again see [63] for a more complete analysis and a definitive proof).*

So while our reasoning is primarily a proof only in multi-fold universes, we should not disregard its applicability to our real universe, even without complete validation yet (not yet but soon to come hopefully) of it being multi-fold.

Note on February 21, 2021: [63] completes the proof of asymptotic safety in a conventional universes and then firms up our conclusions.

7. Conclusions

Our ability to prove asymptotic safety for gravity in a multi-fold universe recovers more predictions for SM_G, that are complementary to our previous results. Also, it allows us to reject, as unphysical, most New Physics theories in multi-fold universes, and possibly in a whole class of other universes where we can justify SM_G, or a discrete,

[3] Remember that the introduction of the microscopic black holes from [1] is only one reasoning (option C). Also, the microscopic black hole model is not unique to multi-fold universe. [1] provide references to works, unrelated to multi-fold universes, that model spacetime with networks of black holes, study microscopic and Planck scale black holes or model particles as black holes: remember Wheeler's original proposals (See for example [32]) or the ER=EPR conjecture, albeit never explicitly stated as such in most of related publications (with a notable exception of [33], mentioned in [8]).

random fractal non-commutative and Lorentz invariant spacetime (visible when in a 2D regime at very small scales).

Fundamentally, we borrowed the results from others. Our main contribution being to add our complementary, and already derived impacts of SM_G to the consequences of asymptotic safety and to provide reasonings to prove its applicability to gravity, as well as a concrete model (i.e. multi-fold universes), where it is the case. We conjecture that the reasonings apply to any consistent model of the real universe that include gravity, that follows Quantum Physics and GR, at suitable scales, where we can conclude that quantum gravity is also asymptotically safe.

Needless to say that the consequences for New Physics are daunting. Certainly, this analysis, already out there for pondering since publication of [17], may not be popular with aficionados of specific New Physics theories. But it behooves to everybody to internalize it, properly decide if it is relevant or not, and determine what's next for each of these New Physics programs. Interestingly, besides the status of non-observation of predictions by the affected theories, the analysis above could be a first experimental invalidation of these theories, especially supersymmetry, superstrings and M-theory: observations of SM, done over the last few decades, are compatible with asymptotic safety of gravity, and seem to invalidate New Physics. It is the case in multi-fold universes. Experimental validation of SM_G, in the real universe, would close the deal. For example, validations of multi-fold mechanisms could be explored as discussed in [34].

It is somehow ironic[4] (everybody was wrong: the naysayers and the afficionados) that superstrings, and supersymmetries and all their associated models, but really the irony is on superstrings, so often accused of not providing falsifiable predictions [35-37], would have delivered on falsifiability after all (i.e. provide falsifiable predictions in terms of super partners beyond SM, in order to explain SM and higher dimensions). These theories would be invalidated by the same SM model that they tried to explain and supersede, and by the addition of gravity (non-negligible at the SM scale) to it (SM_G). Especially, as quantum gravity is something that superstrings claimed to be their birth rights, since the "discovery" of a graviton created the craze; never mind that it was a direct consequence of how the string actions (and world sheet actions) had been expressed.

At this stage, the conclusions of the paper and the executive summary of the multi-fold program are:

In a Multi-fold universe,

1) Gravity is non-negligible at the Standard Model scales. The resulting SM_G explains much of the Standard model behaviors, quantum properties (including amounts and masses of particles and fields) as well the standard cosmological model.
2) Spacetime is 4D *(Note on February 21, 2021: See also [64,65]).*
3) New Physics, GUTs and TOEs that require:
    a. Significantly more particles or fields with respect to SM
    b. More than 4D where gravity and particles exist

    are unphysical and conflict with the SM (and SM_G) and therefore are invalidated by asymptotic safety of gravity and observations of SM.

4) (3) affect all GUTs, TOE, Supersymmetry, Superstrings, Modern supergravity and M-theory (and 12D evolutions), already called in question earlier [24], as well as most GUTs that escaped the analysis from [8,22].

[4] Because this topic seems filled with passions, we want to emphasize that reaching such conclusions was not at all our objective. While the conclusions did not come as a surprise, as our work evolved, we initially thought that, instead, the complementarity would help explore new options for these approaches now put in doubts. Of course, if we are proven wrong, then these latter approaches would emerge more consistent.

5) Induction with unconstrained KK models may escape the issues as the embedded spacetime is empty (vacuum solutions) and particles do not live in it.
6) AdS(5) aspects (e.g. ER=EPR, Holography, AdS/CFT correspondence, gravitons in AdS(5)) may survive, as only gravitons live in AdS(5). It is fortunate, as these results were also derived from multi-fold mechanisms. They are valid because they are recovered in multi-fold universe, or possible with other holographic motivations. Consistency expectations had to keep these aspects valid. Yet, their formulations now depend on the underlying theory. We have covered, in [1,24], the variations of these frameworks with respect to multi-fold universes.
7) On the other hand, across [1,24], we used to say AdS(5) (+ additional dimensions) when trying to reconcile with say superstrings. At this stage, we have determined that what happens in these additional dimensions are probably only mathematical curiosities.
8) A 2D regime remain the only domain where these New Physics theories, if they also include a 2D regime, may still be physical as an approximation of random walk during spacetime reconstruction à la [1].
9) Many more Physics implications especially in terms of entanglement and quantum gravity (reconciliation of GR and Quantum Physics) exist [1], and the latest set of discoveries can be found at [24].

In our real universe, (assuming here that it may differ from multi-fold universes. If it is correctly modeled by multi-fold universe then obviously 1) thru 9) hold):

- 1) may or may not hold, although we believe we can make a case for it independently of multi-fold universes.
- 2) thru 8) hold even in the absence of multi-fold behavior. (3) is obviously the highlight!
- So let us state it explicitly: In the real universe, New Physics like supersymmetry and superstrings, GUTs and TOEs that require:
    a. Significantly more particles or fields with respect to SM
    b. More than 4-D where gravity and particles exist

  seem unphysical and conflict with the SM (and SM_G), and therefore are invalidated by asymptotic safety of gravity, along with observations of the SM.

The bottom line is that, over the last two decades, many expected New Physics have failed to materialize to appear in the latest colliders. It just didn't happen. We can't help but think that this paper provides a first glimpse at why not.

We want to conclude with a strong caveat. These conclusions do not invalidate the mathematical framework of strings and superstrings, and the dualities that were established nor, of course, the suitability of strings as dual resonant model for the strong interaction [45].

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References: (most references come from popular science to make the discussion more approachable)
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