Circular Arguments in String and Superstring Theory from a Multi-fold Universe Perspective

Stephane H. Maes[1]

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Abstract:

Following our derivation of multi-fold models, we revisited the main aspects and claims of self-consistencies of strings and superstrings. Rather than focusing on their relationship to multi-fold universes, we used our lessons learned to show how many claims or results rely on circular arguments coming from the resonance dual model: many consistent results are derived from this model rather than proofs of self-consistency.

The previously shown incompatibility between the standard model and superstrings if quantum gravity is asymptotically stable remains standing post analysis of superstrings self-consistency claims. Its applicability to the real universe repositions the role of superstrings and its derived conjectures and models.

No matter what, it demonstrates that claims of self-consistency are not validation of the theory as model of the real universe: experimental validations or invalidations are required, as many have argued before.

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1. Introduction

The 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 (à la 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 locations, and black hole 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 than usually expected.

[1] shmaes.physics@gmail.com

The present paper reviews a set of circular arguments encountered in Strings and Superstring Theories and its derivative like M-theory. We do not aim this as a critic of strings and superstring theories. Unfortunately, from that point of view, the multi-fold approach of [1] has already led us to conclude that superstrings are not physical for multi-fold universes or the real universe [5]. For sure, quite a shocking statement for strings aficionados and it results from different considerations [5-9,13,14]. We also do not pretend or aim at arguing the scientific processes followed by the string community or the often-associated (alleged; depending on the point of view,) problems with falsifiability [10-12]. No, instead we observed many times that beliefs and arguments are either obvious or not proofs because based on assumptions that render the result obvious but maybe less interesting (e.g. not credibly contributing to reinforcing the arguments in favor of strings). Yet, these points seem to not have often been pointed out within, or outside, the string community.

Our arguments are often based on what we believe to be simple or straightforward considerations developed as we modeled the multi-fold mechanisms [1] and subsequent analyses [15], but much is generic and not limited to multi-fold universes. In fact, the conclusions of [5] are not at all limited to multi-fold universes.

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.

In general, it would be a good idea, for the reader, to understand the history of String Theory. An overview is available in [16]. Details are provided in [17].

2. The Graviton Contained in Strings / Superstrings

A priori, we are only interested in discussing Superstrings. However, historically, String Theory was introduced to study hadrons, especially mesons. It is in that context that some of the core initial aspects of superstrings were introduced.

Historically, the origin of strings is often associated to the discovery by Veneziano of a mathematical formula (based on the Euler beta function) [18] to model the scattering amplitude of strongly interacting mesons, while also presenting the right behavior and symmetries prescribed by the dual resonance model [19]. This formula reminds of an infinite set of harmonic oscillators; something that reminds of elastic rubber bands [20] or strings and leading to the string equations and Nambu-Goto action, or the Polyakov version [17,21,22]. With these models, it is possible to account for the Veneziano amplitude [38] as well as the Virasoro-Shapiro version; hence the birth of the strings [36,37]. Thereafter, these models have be shown to contain, at lower order, the Yang-Mills [25,26] and GR field equations [24].

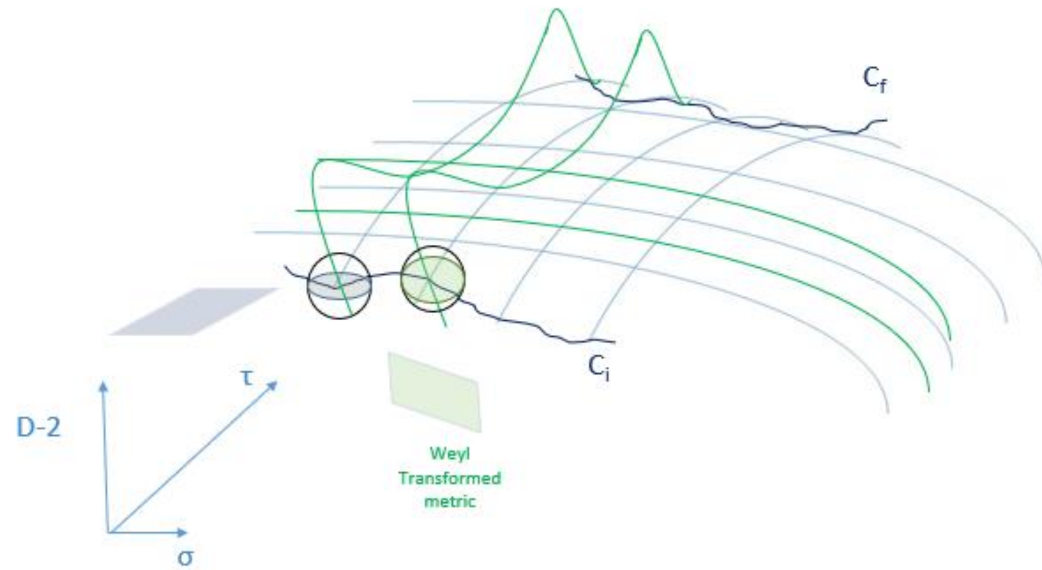

Figure 1 – The Ricci Curvature scalar is computed as a limit of ratio of deficit surface of small spheres [34]. The Nambu-Goto or Polyakov actions extremization operations extremize an area which is, to the first order, equivalent to extremizing grand circle surfaces for a D dimensional Hilbert Einstein action (with a sign difference and up to a monotonic transformation). String action invariance under Weyl metric transformations, ensures covering other "inclinations of the grand circles" in one shot. A Einstein Hilbert action would instead also consider smaller circles and multiple effects and it would also consider non-conformal cases (where different inclinations are not equivalent). However, as explained in the text, in the presence of strings, we would expect that the background or derived fields will be "essentially" conformant also (as an effective model of the impact of the strings). Therefore, the extremization of string actions, computed over the whole manifold of spacetime, contains and is essentially equivalent to, at least to the first order, the extremization of the Hilbert-Einstein action, computed over the whole manifold of spacetime. However we need to "play" with the sign: the string action is always positive (area), but equivalently (through a monotonic transformation) decreasing as curvature increases while the Ricci curvature scalar can be positive or negative. Yet extremizing one amounts to extremizing the other, by changing the sign (and adequately shifting to ensure all encountered Ricci curvature scalars are of the same sign when extremizing if we wanted to match the same action appearance): the string action (in a covariant volume) increases (as the manifold is uncompressed and so the area contribution of (σ,τ) can increase), as the Ricci curvature over an covariant volume decreases (negatively), i.e. the manifold is uncompressed) and conversely. This analysis was hinted in [1], but not detailed.

The Nambu-Goto (or Polyakov version) action is used to extremize the area for the metric of the world sheet [17,23]. As such it is expressing the same action as the Einstein-Hilbert action on the world sheet (when using Riemann curvature in D dimensions (as we are talking about strings and superstrings), by geometrical interpretation of the Ricci scalar curvature [33,34]. Indeed, an infinitesimal sphere/ball in D dimension has a corresponding infinitesimal grand circle, which is what is tracked in the string action. The Hilbert-Einstein extremization in D-dimension (from τ to $\tau+\varepsilon$) for a given D-spacetime position is in first order well approximated by the Polyakov action extremization because of the Weyl-invariance of the metric on the world sheet [23] as sketched on Figure 1: deformations of the world sheet metric are all equivalent and therefore taken into account in one shot by Polyakov action extremization. Higher order effects, e.g. non-equivalent grand circles (if we are in a non-conformal also considered in the extremization of the Hilbert-Einstein action), other smaller circle, multiple effects, not grouped within bands of support of the string (world sheet) along each axis, are missed by the string action extremization with respect to what is modeled by the Hilbert Einstein action extremization. As conformality is assumed when comparing the operations, as strings are expected to generate spacetime bring in that property, these higher order effects will be even smaller. The difference between treating negative curvature extremization (directly matching the string action sign) vs. positive curvature (requiring mathematical handling with sign change and/or shift) hints that, while GR and gravitons are recoverable and contained in the string actions, strings may not be able to similarly handle or generate negative and positive curved spacetimes, and that may impact QFT vacua (spacetime without matter, i.e. at minima excitation).

Note added on 3/30/2021: See [89] for an important confirmation of this prediction.

As a side note, the finite length of the strings ensure finite increases or decreases (the function flattens asymptotically) of the action, which explains the good behavior of superstrings (action) even at very high curvatures, and hence renormalizability of quantum gravity etc.: after a while, at very high energy (curvatures) or small scales, while reaching similar extrema solutions, the action of the string theory does not diverge. This concrete derivation of the good behavior (no divergences at large curvature (i.e. high energy or very small scales)) of superstrings is original to this paper. As far as we know, this results has been in general only conjectured based on series expansions and arguments about non-point like properties of the (super)strings.

Therefore, the Nambu-Goto action, or the Polyakov version, and conformal symmetry (Weyl invariance with respect to the world sheet metric) of strings ensures that the extremization are to the first order equivalent to a Hilbert Einstein action extremization. Therefore, to first order, we should recover GR if we model strings in a manifold.

Such reasonings indeed directly recovers GR, when string action is extremized on a manifold with background fields [33,36,39,40]. It is suggesting that, in a string or superstring model, the metric background fields are the result of string effect aggregations (string condensation) into the definition of the manifold. This amounts to our statement that if strings models physics the manifold will be built on strings and hence a priori conformant. Whenever that happen results coincide very closely to the lower orders. Interestingly, it is also directly related to the acceptable dimensions of string spacetime (D=26 for boson strings and D=10 for superstrings). The same approach also similarly uncovers Yang-Mills fields. We will discuss that combined effect in the next section.

A consequence is also that "solutions" are associated to conformal symmetries. So we expect the high energy contributions of the associated GR fields[2] (e.g. at higher order) to be more scale independent (may be with

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[2] By this, we mean the field (classic or quantum) extracted from the string models as their effect in D dimension (or, especially D=4) spacetime. This statement is fundamentally different from quantum gravity non-renormalizability [50]: we do not suggest (in fact, following [51], we know that it is not the case) that this field theory is correctly modeling quantum gravity; just that when extracted from strings or superstrings, we expect such behaviors. It is in our view as for CFT vs. Yang-Mills QFT and in particular QCD: QCD is not exactly CFT (think about confinement for example); but it can look like a CFT at high enough energies, as it has been proven that nonabelian gauge theories are renormalizable (e.g. see [52]). Also, note that we do not state asymptotic safety of strings as that may not be a well-defined concept as already mentioned above.

This handling of asymptotic safe QFT above superstring scales is proposed in [51] as a bridge between superstrings and SM. We can also predict the right part of the graph from [51]-FIG. 1. However, because of [5] and arguments of [5-9,13,14], we argue that superstrings are unphysical and not compatible with SM/SM_G (Standard model with Gravity). So the QFT on the left side of [51]-FIG. 1 are "mathematical" fields, not connected to the real universe spacetime and QFTs: this way, citing analogy to [51] is not contradictory.

analogies to scale relativity approaches[48]) and well behaved (e.g. like asymptotic safe [49] (although this property is typically considered as distinct from, and incompatible/undefined with, what is expected from 1D objects), or renormalizable (e.g. if on discrete spacetime). *Note added on 3/30/21: See [89,90] for how this concern about strings vs. asymptotic safety can actually be addressed.*), at the difference of direct GR quantization [50]. Similarly, Yang Mills fields should appear (though not be rigorously) like a CFT, in such high energy regimes, something that has been proven by now (e.g. [52]).

With respect to Figure 1, we also can see what happens when we apply the Scherk limit (or zero-slope dual of the resonance model), i.e. when α' goes to zero (see [45]), which amounts to strings of zero length (and infinity energy density). In such case figure 1 reduces its "band effects" and we get less higher order variations from GR. It is as expected.

The above explains how graviton appears in strings and superstrings as a spin 2 (tensor) massless boson. An example of a more rigorous derivation with superstrings (instead of dual resonances) can be found in [27].

Based on the previous paragraph, this was a straightforward result of the fact that conformance + world sheet area extremization (in D dimension) amount, to the first order, to GR in D dimensions. Because strings are quantizable, it should have been obvious that we would recover a graviton. It is a great result; but in no way a sign from above. Instead, it is a consequence of selecting from day 1 a model where the Hilbert Einstein is baked in (to the first order). It makes it a candidate to model quantum gravity but it does not prove that it would be the (only) correct theory of quantum gravity. In fact, most quantum gravity theories do start from a baked in or variations of the Hilbert Einstein action. Strings and superstrings just do the same and so they are bound to model aspects of gravity. Which aspects and under what conditions is of course what really matters. In fact, at the light of [1,5-9], we could explain this result differently: it results from the insight that gravity exists in AdS(5); not because it models it correctly (e.g. if AdS(5) is not governed by GR) nor are the other particles that it models physical. Note that the multi-fold theory [1], does not bake in at all the Hilbert Einstein action. It recovers it from the multi-fold mechanism proposed to address and model quantum entanglement (EPR). It may be an important distinction if we want to be impressed for being able to extract GR or graviton from a theory…

Encountering GR and gravitons in strings and superstrings was predictable but it was and is a good result. It shows relevance of strings and superstrings to study quantum gravity. It does not proves validity or superiority of the approach. It also does not tell us in what context it is relevant.

Note added on 3/30/2021: We refer to [89] for a discussion of the quantum gravity regime possibly suitable, but by no means certain to be relevant, for superstrings.

3. Yang Mills and Strings or Superstrings as TOE

As already indicated, Yang Mills fields appear also in Veneziano / Virasoro-Shapiro dual models [25,26] and in string/superstring [33,36,40]. In the latter case, the same conclusions also appear in terms of "condensation" of

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Somehow our statements here will amount to state in the domain of potential physical validity, fields extracts from superstrings (especially gravity ones or Yang Mills ones) will be like CFT at these scales, but possibly not at lower scales. *Note added on 3/30/21: Again [89,90] should help concretize what we mean.*

It should also not be contradictory with UU (Ultimate Unification) proposed of [7], where we do not validate a Weak Gravity Conjecture: as all interactions converge, gravity matches the other interactions but they all behave well asymptotically (if nothing else because they end up on a discrete spacetime in a multi-fold universe) [1].

background field and dependency on conformal invariance that fixes the dimensions (and supersymmetry to encompass fermions).

The discovery that strings (and superstrings) model can reduce to Yang Mills combined with GR, at low energy, and models the graviton [24,25], is considered as the greatest sign that strings would be the right theory and the only game in town when it comes to Theories of Everything (TOEs), e.g. [28-31]. In fact, this argument is a big part of the disagreement, that non string supporters seem to have with the string community: instead of falsifiable predictions, the apparition of the graviton/GR (and their consistency as later discussed later) and of Yang Mills fields, combined with GR, are argued as sufficient proof of superstrings being the only game in town, or the best guess so far [10-12].

Again, the Yang Mills apparition is not transcendent. Considering that strings model the dual resonance model which models the strong interactions, involving a kind of Yang Mills field, this result was again to be expected.

More physically, we can see that Yang Mills fields result directly from the string conformance within a D dimensions manifold. Indeed, consider [41] (we invert the reasoning from that paper), a string world sheet (2D) in a larger spacetime (D dimensional). The world sheets fluctuates (e.g. due to uncertainties) and let us consider that the fluctuations tend towards zero. As a result, it leads a field in a surrounding manifold that can be seen as a small deformation of the worlds sheet. The field on the world sheet and in the deformed surroundings must satisfy consistency requirements on its energy momentum stress tensor which implies that its components along the world sheet must vanish (on word sheet and in the deformation). Such field follows Yang Mills equations on the world sheet and in the deformed region. Said differently, as shown in [41], the limit of the deformation of Yang Mills is a string on the world sheet and the consistency condition amounts to conformality of the strings and Yang Mills in the surroundings. And this why [25,26] works and why they are renormalizable (Yang Mills and (super)strings). We then need to remember that Yang-Mills fields are renormalizable/CFT-like at high energy.

Mathematically, it is also related to the relationship between covariance and gauge invariance already identified in Ashtekar's work [42]: compatibility/generation of GR can also generate Yang Mills with similar models: tools and approaches can be reused; something also observed, in a different context, by Feynman in his talks on quantum gravity [44].

In summary: conformance of strings and Polyakov action imply first order match of Hilbert Einstein action and therefore containing GR to the first order (and gravitons) and leaking or condensing Yang Mills fields (because of quantum uncertainty). Strings => GR (+ field as matter) and strings => Yang Mills Field (= matter fields) => fits also within GR (first order) and models Yang Mills bosons. The latter step is encountered when modeling gravity with fermions, which from a string point of view requires D=10 and supersymmetry, as the only way to consistently bring fermions into (super)strings) [33,40].

In fact, if we start from superstrings, then the leaked Yang Mills are supersymmetric [43], and, because of the reasoning of section 2, we again expect asymptotically safe or renormalizable / with a CFT-like behaviors at high energy, for whatever fields are modeled in 4D (or D, as long that it is a field, i.e. localized; not an extended object) spacetime.

So encountering Yang Mills in strings and superstrings was predictable but it was and is a good result. It shows relevance of strings and superstrings to study QFT or rather TOE and SM. It does not proves validity or superiority of the approach. In fact as hinted, the link to QFT is predominantly for CFTs on supersymmetric spaces.

4. String Anomalies Avoidance, Renormalizability of Superstrings and Asymptotic Safety

The onset of the second superstrings explosion (post the loss to QCD as model of the strong interaction [17]) resulted in great part from the proof that superstring (in 10D) are well behaved, without quantum anomalies with respect to gauge invariance and/or general coordinate invariance, possibly renormalizable (and hopefully non-divergent) [32]. Following this, in addition to the previous discovery of the graviton, many in the Physics community got convinced that superstrings are consistent and therefore have good potentials as a theory of quantum gravity as well as a TOE (see for example the first sections of [53]).

Since then, the string community has claimed that superstring is the only quantum gravity theory proven consistent [17], and used this statement as another proof for being the only game in town.

Let us revisit this. Yes, anomalies disappear and renormalization seems possible: several superstring models are (believed) anomaly free and believed finite (D=10 or 26 depending on the cases like the mixings of heterotic strings): e.g. Type I open and closed with N=1 and SO(32), type II N=2 supersymmetric closed strings and heterotic on E_8xE_8 or SO(32). We believe that such finiteness is not accepted by all. However, so far, guarantees of finiteness and renormalizability can also be obtained for models where strings are associated to non-associative and / or non-commutative geometry, i.e. implicitly, or explicitly discrete, e.g. [47].

If we remember that strings and superstrings are conformant, then we suspect that there should be renormalizable schemes for (some of) them [46]. These have not been demonstrated yet, with many instead searching for a non-perturbative approach (including M-theory) and using dualities to also argue renormalizability.

So much for consistency! While it should be (per our conformant reasoning or discrete spacetime emergence), nothing is definitely proven and agreed upon… Yet, argument in favor of superstrings usually mention this desired, and possibly achieved, but not unambiguously confirmed, "consistency".

What about asymptotic safety [49]? As already mentioned, the concept does not really make sense for strings and strings and superstrings that are not local, bit extended, at the difference of QFT. However, asymptotic safety of quantum gravity would, and in fact does [5], forbid superstrings as models compatible with the Standard Model SM / SM_G [5]. As the SM is well established and experimentally confirmed (never ever disproved so far), it does not bode well for superstrings. *Note added on March 31, 2021: [90] provides a possible way out for the 2D regime.*

There have been a wide range of reactions and criticism of the asymptotic safety of quantum gravity, but mostly only in blogs, something also surprising (e.g. [57-60]). If one didn't know better one could think it might be possibly motivated by concerns of the impact of conclusions as in [5,54,55] piling up on all the other criticism of superstrings [10-12]. It also implies that much of the Physics community may not be aware of these concerns, especially outside the string community. However, we note that the concerns essentially result from criticism of proofs of asymptotic stability based on analysis of the evolution (e.g. expansion beyond the Ricci scalar) of the Hilbert Einstein action, or assumptions on high energy behavior of QFT formulations vs. CFT; thereby concluding, of course, that QFT models for gravity, as they exist today, would not be CFT-like, and that quantum gravity would not be asymptotically safe[3]. It is again a circular argument.

In fact we know a counter argument based on the fact that quantum gravity becomes 2-D, with a random, discrete (and other properties depending on the model) spacetime and entropy evolves from proportionality to area to logarithm proportionality to areas (See [1] for references. *Note added on March 31, 2021: [90-92] show the universality of the result, including for non-multi-fold universes*). In other words, yes, QFT formulation of quantum gravity will have to look like a CFT at high energy. In fact, and ironically, we have explained in section 2 why even

[3] By the way, these are not the arguments that we used in [5] for multi-fold universes or even for the real universe. The conclusions from [5] remain valid for quantum gravity and are not refuted by the criticism provided so far. In fact, it is also interesting to see how [56] is criticized as non-conclusive (By the way, we agree with that view: it's just at best corroborating [54,55], not a proof). *Note added on March 31, 2021: [90] in our view directly addresses and resolves the matter.*

superstrings (if they were physical) would also imply such a conclusion. Current shortcomings of a model do not imply that the underlying Physics would have the same issues.

5. The AdS/CFT Correspondence Conjecture

5.1 Dualities between string theories and M-theory

Superstrings love dualities [17,61,62], in part because of its dual resonance model origin and philosophy but also because it is seen as a way to address the challenges with not being directly experimentally verifiable and because dualities provide a way to model non-perturbative considerations. To a large extent, superstrings are in a similar position as QFT for gravity: they are missing part of the picture. As discussed in section 4, for QFT, we need a UV completion story, hence the renormalization challenge, asymptotic safety discussions. For superstrings, the issue is similar to QFT: the theory is perturbative, not accepted by all as proven consistent (finite/renormalizable etc.), and believed to present similar issues as the Gribov ambiguity discussed in another context in [60] for Yang Mills and envisaged for gravity: there are parts of the model that are (topologically) disconnected from others and inaccessible by only-perturbative methods. The observation that dualities exists across the different superstring theories (and supergravity), allows perturbations to reach into some of these other disconnected regions (because, through dualities, strong couplings in one theory can be transposed into weak couplings in another, etc.). As part of this work, D-branes (higher dimensional objects, besides strings, aka 1-brane) were encountered. It led to the assumption that an 11-D non perturbative theory exists, M-theory [17,62], which is still quite mysterious to this day. The dualities are conjectures and mathematical tools to guess the unknown non-perturbative M-theory.

As such, one can hardly say that superstrings are really better positioned that any other approach to quantum gravity, including hopes of a QFT approach the quantum gravity that would be more CFT-like, renormalizable or asymptotically safe at high energies (i.e. very small scales).

5.2 AdS/CFT correspondence Conjecture

Often labelled as the biggest discovery in the field of the last 25 years, the AdS/CFT conjecture establishes a concrete duality between supersymmetric gauge CFT in D-1 dimensions and gravity in D dimensions [63,65]. It implements the holographic principle assumed from the Bekenstein-Hawking area formula for black hole entropy [17,64].

Reasoning-based derivation can be found in [28,66]. [66] explains both Maldacena's derivation and a hindsight reasoning analogous to what we have done so far in the previous sections. Let us repeat the latter, but this time at the light of our work on multi-fold universes, which also recovers a factual (multi-fold spacetime)/AdS(5) correspondence [1,5,6,8,15,67] and holographic principles with area laws (e.g. [1,15,28]).

We refer to [66], section 3.2, for the steps of the proof; just adding relevant comments:

- D+1=5 per the holographic principle. The duality or holographic principle is between a bulk AdS(5) universe (+ compactified dimensions in S^5 per supersymmetry and section 2/3: 10D is needed for conformance of superstrings), where we know that superstrings can exist (per [68], they can't be in a positively curved (or rather, with a positive cosmological constant) universe nor really even in a flat spacetime (no conformant solution) per an older result [69], although there could be ways around), where quantum gravity exists and a particular 4D supersymmetric ($\mathcal{N}$ =4, for maximally supersymmetric)

CFT (The choice of CFT is justified in next bullet) without gravity. So the graviton lives in AdS(5)(+…), something recovered in multi-fold universes [1,67], where the graviton appears as multi-folds.

- D=4 is a spacetime boundary to AdS(5)(+…). It is consistent, as there are different ways that we know for sure that spacetime is 4D [1,5] (*Note added on March 31, 2021: see also [93-96]*). The justification for AdS(5) (+…) comes from proposing a 5th large dimension that can only be added to provide a negative curvature (cosmological constant), as mentioned above (de Sitter dS(5)(+…) would therefore not work as no superstring could live in it). The criteria of having a stable energy behavior over large-scale ranges implies that scale can be used as 5th dimension. Such stability implies that CFT reigns on the D=4 spacetime. Based on the previous sections we would rather state that, if (Yang-Mills like) fields are to appear around superstrings they will be CFT-like (remember sections 2 and 3): super Yang Mills in this case. Note that in multi-fold universe, the 5th dimension rather results from the scale of the distance between entangled systems that generate gravity or gravity like effects [1].
- In addition, because the fields model matter and interactions with and among matter, and because they are expected to be related to superstrings, the fields will be also supersymmetric. Therefore, in 4D spacetime, we have supersymmetric CFTs. Also, in order to bring comparable degrees of freedoms between CFTs (few) and superstrings, we need take the largest possible symmetry (in supersymmetry: we pick $\lim_{N\to+\infty}$ SU(N). Of course, it does not really matter the physical significance, as we already know that supersymmetry is unphysical [5,6,7].
- Per section 3, superstrings on world sheets in AdS(5) (+…) in contact to the boundary D=4 spacetime, generate super Yang Mills CFT on D=4 spacetime, or following more properly [43], super Yang Mills CFTs ($\mathcal{N}$=4) on D=4 result into superstrings in AdS(5) (+…). The superstrings further away from the boundary have little or no effect in terms of Yang Mills CFT generation in the D=4 spacetime. N ~ different layers of spacetime or 3D-branes.
- The rest can be derived following the reasoning of [66] – section 3.1.
  - When coupling is weak ($g_sN<<1$), D=5 spacetime is not curved. Curved string (gravitons) are in the bulk, away from surface (as no gravity is present). We have just 4D Yang Mills (supersymmetric) on 4D spacetime (flat). Gravity is present in the bulk, and decoupled from Yang Mills.
  - When $g_sN>>1$, many 3D-branes are added in the limit of N and it becomes like a black hole, i.e. a 3D black brane in superstring theory. Gravity is responsible for the behavior near the surface. Further away, it is beyond a black hole horizon: only gravity really matters, described by closed strings (gravitons) in AdS(5) (+…).
  - Because Yang Mills is renormalizable, the solution on the 3D-brane for $g_sN<<1$ is also known for $g_sN>>1$. We have encountered the same solution for $g_sN>>1$: Yang Mills CFT (i.e. supersymmetric $\mathcal{N}$=4) on 3D (+1) spacetime and gravity (i.e. modeled by superstrings) in AdS(5)(+..) describe the same Physics (for $g_sN>>1$). That is the correspondence.
  - The conjecture is that this works for all g_sN.

It can be seen first and foremost as a mathematical conjecture between two frameworks. It has been proved to work in other context of physics like material science [68], and in mathematics. But it is an unproven conjecture. And it results mainly from a) the superstring model elaborated in sections 2 and 3 (i.e. the string action, conformant invariance and gauge invariances) b) Black hole behaviors with respect to its horizon. Nothing more.

The conjecture models a universe (D=4, supersymmetric $\mathcal{N}$=4, with CFT and no gravity) that is not exactly our real universe, although, it may be a closer match when energies are high. Remember that we said that all QFT including gravity should look like CFTs[4].

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[4] Do not hold your breath. [5] killed the supersymmetry option for our universe as incompatible with SM/SM_G, because quantum gravity seems asymptotically safe. *Note on March 31, 2021: [90] confirms that view.*

This AdS/CFT correspondence conjecture is the closest link to multi-fold universes, where we have a factual holography due to the mappings and the multi-fold mechanisms, between entangled particles (i.e. fields) in 4D spacetime and AdS(5). Entanglement seems the biggest difference between statements (besides fact vs. conjecture), but it is recovered in the ER=EPR conjecture discussed in the next section.

The relationship to entanglement is also present in the AdS/CFT correspondence conjecture: the entanglement entropy of the CFT fields can be expressed as proportional to an minimal surface area in AdS(5). It is known as the Ryu–Takayanagi equation [71] and it relates to the Hawking-Bekenstein formula. Again, it may appear surprising, but it is in fact a circular result because black holes were also the source of the derivation of the AdS/CFT correspondence conjecture: of course the area law is therefore baked in it. In fact, Ted Jacobson [72], ignoring the AdS/CFT correspondence conjecture, recovered variations of the formula in the 4D spacetime both for QFTs and CFTs and showed that the framework implies recovering, linearized, but [73] can then be adapted to make it full, GR in 4-D spacetime. Entanglement, entropy of entanglement and entropy of Black holes, GR and AdS/CFT are directly related [71,72]. All this shows a duality between GR and its linearization in 4D spacetime vs. gravitons in AdS(5) and the ability to use one (gravitons in spacetime) or the other (gravitons, or multi-folds, in AdS(5)) to model gravity. It was also our contention in [1,67] for multi-fold universes and the reason why, despite the outcome of [5], we still consider that gravitons in AdS(5) and the holographic correspondence, as well as the principle that gravity = entanglement and entanglement = gravity, survive even if superstrings are not physical: the AdS(5) graviton effects seem physical, at least for a multi-fold universe.

Going further, [73] showed that the AdS/CFT correspondence conjecture, its dictionary and entanglement (entropy) implies that GR governs AdS(5) (+…). In other words:

GR in AdS(5) => superstrings in 10D => AdS/CFT correspondence conjecture => CFT (supersymmetric etc.) + entanglement => Ryu–Takayanagi equation => (full) GR in AdS(5) (1)

(1) allows to invert the arrows as a mathematical proof. It can be considered as a strong example of a consistent approach.

About [73], we may ask if it means that GR reigns in AdS(5) implies superstrings in AdS(5) +(…). [43] only studied AdS(D) via the AdS/CFT correspondence conjecture. To that effect, let us consider two other papers [74,75] that infer that the outcome seems to be that indeed AdS(5) (+…) is populated with extended objects (i.e. strings or D-branes), detected by their energy spectrum that provides a characteristic Hagedorn phase, at very high energy (i.e. exponential growth with energy due to each element of the string / D-brane contributing significantly), that differs from the behavior of CFT or QFT (or conventional black holes): AdS(5) appear stringy. The derivation chain from above therefore becomes:

GR in AdS(5) => Super strings in 10D => AdS/CFT correspondence conjecture => CFT (supersymmetric etc.) + entanglement => Ryu–Takayanagi equation => (full) GR in AdS(5) & superstrings in AdS(5) +(…) (2)

In a multi-fold universe, we also recover a version of Ryu–Takayanagi equations, that explains the minimum surface area as being as far as the multi-fold reach in AdS(5)[28], but GR may or may not reign in AdS(5), and so superstrings may or may not be physical… Also, multi-fold dynamics may or may not governed by GR/Hilbert Einstein action or variations [1,6,8,9,15].

Is there a problem for multi-fold universes because of [5] vs. [74,75]? The answer is no: the result of [74,75] assumes the full dictionary and properties of AdS/CFT correspondence conjecture. (1) was satisfied and (1) implies superstrings in AdS(5) and therefore also in (+…) = (+ S^5). The outcome was circularly baked in.

Multi-fold changes AdS/CFT correspondence into spacetime of Multi-fold Universe with matter gravity & QFT / AdS(5) mapping, and, as a result, (1) and (2) evolve as:

4D spacetime with gravity ⇔ Entanglement => AdS(5)/spacetime mapping and multi-fold mechanisms (=> Ryu–Takayanagi equation) ⇔ multi-folds in AdS(5) => maybe or maybe no GR in AdS(5) to govern multi-folds. (3)

GR in AdS(5) => Maybe or Maybe no superstrings in AdS(5) (+…) (4)

(3) and (4) are now fully decoupled and (4) can be a valid mathematical result. [5] only says that no matter what, it has no impact on the 4D spacetime with gravity in (3). *Note added on March 31, 2021: The 2D regime and model of [90] may allow the relationship to work between AdS(3) & 2D spacetime. Amazingly, AdS(3)/CFT2 correspondence is a mathematically proven theorem, not just a conjecture [97]. In our view this is another hint that this maybe the only case that is physical.*

To conclude this discussion, we will also point out, as mentioned in [6], that GR is unstable with matter in AdS(5) [86]. In our view, it implies that superstrings other than closed strings, aka massless gravitons, probably cannot physically live in AdS(5) (even with (+…)); therefore destroying the conventional derivations of AdS/CFT correspondence conjectures as above; while the multi-fold approach still works. However, (3) and (4) may remain valid with GR reigning in AdS(5) (it is of course valid without GR) if, as expected, paths in multi-folds are not resulting to any energy momentum stress tensor leaks into AdS(5).

5.3 ER = EPR Conjecture (and more)

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 [76]; 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.

The original reasoning behind ER=EPR goes as follows:

- Consider two black holes (in AdS) with entangled horizon. We are continuing to use black holes analogies and to AdS/CFT correspondence conjecture to model CFTs or Gravity.
    - They start from one black hole that radiates per Hawking's theory
    - The second black holes is composed of all the particles produced 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, i.e. a wormhole which 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.
    - It correctly "emulates" the EPR paradox with Alice and Bob's experiments[5].
- So it would make sense 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:
        - [77] proposes an example between pairs of particles, using the AdS/CFT correspondence conjecture and [78] shows that entropy of ER bridges follows the entropy (or information) laws and inequality.

[5] This emulation is probably the inspiration for the GR=QM conjecture mentioned later in this section [84].

        - As discussed next, [1] proposed a stronger model for it with many more consequences, including ultimately the demise of superstrings as TOE, or even as correct gravity model, beyond approximations of gravitons (but preserving the idea of AdS/CFT correspondence).

Multi-folds mechanisms were proposed in [1], without knowledge of ER=EPR 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 was only to address the ER paradox and locality vs. non-locality.
    - 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 [79]
    - 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].
    - Massive virtual particles add massive gravity effects [80] at very small scales that renders possible a standard model with non-negligible gravity at the SM scales, aka SM_G [1,15].
    - Multi-fold universes and / or SM_G explain many open issues with the standard model and standard cosmological model. It also demonstrates that supersymmetry, higher dimensions and superstrings are not compatible with SM and unphysical (as are most conventional GUTs and TOEs) [1,5,6,8,9].
- 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 are not traversable
    - 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 [81] suggests that in the presence of ER=EPR, reasonable traversability may be possible without exotic matter[6]. [82,83] provide a possible 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:
        - It would validate the multi-fold mechanisms (when wormholes are in AdS for [82]).
        - It should derive gravity as we did in [1].
    - *Note added on March 31, 2021: [98] shows examples of traversable wormholes associated to entangled massive fermions which could also be a way to realize multi-folds (although it should also work with massless fermions and with entangled bosons to match multi-folds).*
- 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 [78].
- In the multi-fold model, nothing is limited to CFTs (without gravity) in spacetime and superstrings are not involved.

Our statement that entanglement is gravity and gravity is entanglement [15] is stronger than ER=EPR, factual in multi-fold universe and a proposal for experimental verifications in our real universe [1,79]. In its quantum

[6] Ironically, [81] relies on asymptotic stability of quantum gravity to "help". Of course [82,83] do not require it.

computing with Qubit variations, it encompasses, and is stronger than, the GR = QM conjecture [84], that we also discovered post our proposal. GR = QM is about Qubits proposed wormhole-based teleportation in lab experiments resulting from the connection of entangled Qubits via wormholes and this way derive properties of bulk gravity (in AdS(5) (+…)). Of course traversability is not resolved nor the resulting gravity effects in spacetime. The need to invoke CFTs, requires a lab beyond critical fixed point may not be achievable within the promised timeframe either… But yes, everything proposed in [84] and more is also plausible with multi-folds [1] where traversability problems and critical fixed point/CFT concerns do not apply.

The non-traversability in ER=EPR has probably been the hurdle that has so far prevent the String community to uncover that entanglement is gravity and gravity is entanglement…

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

We do not know how much of AdS(5) is governed by an GR/Hilbert Einstein action and if multi-fold are therefore wormholes or can have unrelated dynamics. Sure, AdS(5) is a solution of GR, so we can mathematically model it via GR and end up with superstrings and the circular reasonings of (2). Yet, the reasoning in (2) does not model the real universe per [5]. Having wormholes, as multi-folds, has no impact if they can't support our proposed mechanisms. In such case, physically, we would still follow (3) and (4) and not imply that superstrings are physical (other than the fact that they can model gravitons in AdS(5)).

6. The String Landscape

Upon discovering that many superstring universes can exist, the notion of swampland and landscape (of acceptable) superstring universes was introduced [85].

Unfortunately, it turned out that superstrings can not live in a universe with positive cosmological constant / curvature (and it is borderline on flat spacetime) [68, 69]; which does not match our real universe observations. The instability of AdS with GR when matter is present further reduces the possibilities of supersymmetric particles modeling anything other than gravitons.

The superstring community claims that it finds standard model compatible universes in the string landscape like for example in [87]. It is a supersymmetric version of SM (known as Minimal Supersymmetric Standard Model – MSSM [88]). No MSSM extension to the SM has ever been observed (no New Physics particle and No New Physics yet despite the open issues [15]) and the incompatibility with SM/SM_G derived in [5], implies also incompatibility of superstrings with MSSM if quantum gravity is asymptotically safe; which we argued to be the case for multi-fold universes and for the real universe. With MSSM, we have the typical problem that without questioning supersymmetry, models assume that finding MSSM amounts to modeling the real universe[7]. Results like [87] do not at all invalidate [5].

Note added on March 31, 2021: See also the considerations in [89] that further explore the landscape and swampland issues.

[7] After all, for example, assuming supersymmetric CFTs in the real universe also seems to turn out to be a bridge too far for applicability of the AdS/CFT correspondence conjecture.

7. Conclusions

With the benefit of our multi-fold models [1,15], we showed how we can (better) understand the main aspects of superstrings theory. We also showed how the claimed consistency of superstrings is at time incomplete or leading to circular, and, in hindsight, obvious models where consistency often results from the circular arguments instead of deriving an unexpected consistency with the physical reality. As claimed by others (e.g. [10-12]), it implies that experimental confirmation can not be acceptably replaced by superstrings claims of consistency; nor even by its modeling of gravitons, alleged renormalizability or cancellation of some anomalies.

[1,5-9] arguments that superstrings are incompatible with SM/SM_G remains standing in the face of superstring self-consistency claims.

The discovery of hints of superstrings in [1,5-9] also help us position superstrings: they are a mathematical model for dual resonance models and to study properties of supersymmetry, supersymmetric Yang Mills CFTs and GR in the context of supersymmetry. They do not correspond to physical effects but can approximate aspects of them, and be useful to discover physical effects (just as strings are undisputed as a mathematical model of the dual resonance model of aspects of the strong interaction) and as a mathematical framework. As such they can have a bright future and be part of the Physics and Mathematics arsenals of tools. Hints about GR / quantum gravity UV completion, AdS/CFT correspondence conjecture and ER=EPR conjecture are invaluable, have led and will lead to key insights and provide approaches to solve or, guess properties of still, unsolvable physical and mathematical problems.

It also cautions against moving from models of the universe (e.g. as we have also with multi-fold universes) to claims about the real universe. Strings and superstrings model stringy and supersymmetric worlds; having them self-consistent does not ensure that they are good model or compatible with the real universe. The same holds for our multi-fold approach. Only experimental results can provide confirmation. For us [1,68,15] provide plausible ways forward towards validation, or invalidation. Any progress, theoretical or, better yet, experimental, towards determining if gravity is asymptotically safe in our real universe, and not somewhere else, is obviously critical considering [5][8].

We believe that, throughout [1,15], we have been careful in restricting our claims to multi-fold universes. But we also believe that aspects of SM_G already go beyond multi-fold universes and that the conclusions of [5] about incompatibilities between supersymmetry, superstrings and higher dimensions, and SM/SM_G are valid in our real universe. It is why in this paper we allowed ourselves to present [5] as slated to read on superstrings always without restrictions to multi-fold universes.

We realize that aspects of this paper run the risk to generate negative reactions. It is provocative to get a reaction, not to present a negative perspective. The intent has always been to do a fair analysis, albeit with a purely outside perspective, and with full admiration for the derivation of superstring model, its mathematics and the potential of its framework. We hope this will help progress string theory, quantum gravity and Multi-fold models and foster discussions, self-evaluations and collaborations.

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[8] If superstring were to infer asymptotic stability on 4D spacetime, it would settle the matter once and for all. *Note added on March 31, 2021: We believe that [89,90] show that superstrings indeed provide such an inference.*

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