The String Swampland and de Sitter Vacua: A Consistent Perspective for Superstrings and Multi-fold Universes

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Abstract:

In a multi-fold universe, gravity emerges from Entanglement through the multi-fold mechanisms. As a result, gravity-like effects appear in between entangled particles 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 at large scales and semi-classical model remain valid till smaller scales than usually expected. Gravity can therefore be added to the Standard Model resulting into what we define as SM_G, the Standard Model with non-negligible gravity effects at its scales. 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.

Superstrings are encountered in the context of Multi-fold universes; but not as physical entities, or as entities encountered in the multi-fold universe spacetime. Their discovery in AdS(5) (+ extra dimensions) tangent to every multi-fold universe spacetime points are physically consistent with superstrings that would only exist in universes with negative cosmological constants.

Yet, in previous papers, we did not analyze the details of the related string theory theorems and conjectures, about curvature and viable curvatures, and, in particular, we did not discuss criticisms made by some to the main incompatibility results. These are conjectures not accepted by all, or alternatives that seem to be able to avoid them. This paper provides an analysis that supports the proposal of the incompatibility of superstrings with positive curvature (asymptotic De Sitter), dark energy or cosmological constant. This result applies to superstring theories. But it is good to note that the reasoning is consistent with the multi-fold universe spacetime reconstruction model (random walks), inflation (including the approach based on Higgs field (minimally) coupled to gravity), and multi-fold dark energy mechanisms. It piles on the already asserted incompatibility of superstrings, and supersymmetry, with SM_G based on asymptotic safety of gravity in multi-fold universes.

In the context of multi-fold universes, it appears that the multi-fold universe spacetime emerges from the multi-fold random walk, while its dual tangent AdS(5), where the multi-folds, or gravitons, live, could be seen as emerging from superstrings. Superstrings are buffered by AdS(5) from (asymptotic) dS, and relieved from having to support its emergence or existence. The jury remains out on the exact physical relevance of superstrings beyond gravitons in AdS(5).

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1. Introduction

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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 (EPR - Einstein Podolsky Rosen) entanglement between particles, detailing contributions to dark matter, and dark energy, as well as 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 our points of view on superstrings, and supersymmetry, derived in the context of multi-fold universes, including how our results were consistent with the relationship so far with Vafa's and others' swampland analyses, which propose or conjecture that superstrings are no compatible with positive cosmological constant, asymptotic de Sitter spacetime, or de Sitter vacua [5,6]. We review related key papers that seem to criticize, violate (e.g. by proposing counter examples), or support [5,6]. Our conclusions support the corner of the proponents of incompatibility: de Sitter vacua are in the superstring swampland.

2. Multi-fold Perspective on Superstrings and Super Symmetry

The multi-fold mechanisms described in [1] result into a dual AdS(5) universe created by the multi-folds, and where the multi-folds live. In [1], we encountered multi-folds as resembling gravitons (which does not necessarily make gravitons physical), quantized per the spacetime reconstruction model, which could be considered as approximated by the graviton superstrings in AdS(5) (+ additional dimensions).

[7-10] further discusses how other, by opposition to gravitons, superstrings (and as a result, M-theory/supergravity entities like (D-)branes) seem unphysical. This does not dispute the mathematical framework behind superstrings, or the existence of the AdS/CFT correspondence conjecture.

Per [1], a multi-fold universe spacetime always has a positive effective curvature. In the associated duality, between spacetime and AdS(5), GR may or may not reign in AdS(5) with respect to multi-fold kinematics and dynamics.

In [11], we argued incompatibility of superstrings and supersymmetry with the standard model (SM) and SM_G. [12,13] further discusses the challenges with the physicality of supersymmetry, and associated (grand) unification theories (GUTs). It is something that was also hinted by [14], which showed that it is impossible to define a supersymmetry algebra in a (an asymptotic) de Sitter spacetime. Indeed it is widely believed that our real universe is asymptotic de Sitter (dS). The addition of asymptotic is to capture the locally non-perfect de Sitter behavior, for example due to the presence of matter.

3. Swampland Criteria and de Sitter Vacua

Superstrings are supposed to define an absurdly large number of possible universes, and physics defined, as the string landscape. Yet some universe models are expected to not emerge from, i.e. be UV completed by, superstrings. These models are deemed to be part of the string swampland [5].

Strings afficionados are not agreeing on the feasibility, or not, for a (an asymptotic) de Sitter spacetime to emerge from superstrings (and supergravity or M-theory). There are two schools of thoughts: the ones who constructed de Sitter vacua by defining spacetime effective potentials that are positive (stable), metastable (e.g. KKLT [15], where a metastable positive potential is created by uplifting a stable AdS vacuum potential by adding other string or brane objects like anti-D3-brane), or unstable but slow evolving (e.g. quintessence with an unstable positive potential slow rolling down to zero) [15-20], and those who put de Sitter vacua theories as part of the swampland [6,21,22]. Many of the papers mentioned here also dispute results of each other, and provide good analyses of the challenges of their own or others' proposals. Let us note in particular [6,17,21,23] to understand the problems with both uplifting, or quintessence, approaches, and variations like [18-20]. Metastable uplifted models have instabilities, or fine-tuning issues, leading to slow roll away from dS vacua, and / or decompactification (also encountered with quintessence), as well as non-linearity mutual interaction effects that induce these issues, or invalidate the uplifting model, when all the events that are interactions across the sources of the fields are considered. Quintessence [17,21,25] have problems including violation of the Weak Gravity Conjecture (WGC) [26], with a fifth force at scales where it is expected to hold conventionally, and are difficult to consistently obtain from superstrings models. Racetrack models in uplifting [15,17] also seem to violate WGC. Note that a violation of the strict inequality in WGC is also proposed in multi-fold universes [1,12], but probably at lower scales than envisaged here, and with a different reasoning that does not involve quintessence or fifth force, but rather democratization of all the interactions with the same strength (and particles).

With disagreements (e.g. [17]), it looks like fields generating de Sitter vacua are in the swampland. It is arguably still a conjecture. [21] elegantly argues that all strings model seem to conspire against being able to obtain a (and asymptotic) de Sitter spacetime; which of course has far reaching consequences for cosmology, e.g. [24], and physics [21].

It is probably worth noting that, while the swampland criteria proposals [6], seem to introduce tensions with inflation [24] (something disputed in part in [17], who argue that the swampland criteria just don't apply to inflation as unrelated to, and not taking place near, a de Sitter vacuum) multi-field proposals for inflation fields and dark energy fields have been made without violating the mathematical de Sitter criterion of the swampland, e.g. [27,28], implying that swampland criteria do not necessarily prevent modeling these inflation and dark energy, effects, but without actually modeling their emergence from superstrings, so that we do not know if they are plagued by problems like say the quintessence (e.g. decompactification), or being too time varying effects to justify an asymptotic de Sitter spacetime over the lifetime of the universe. In general new (vs. initial models of Guth) inflation models are not yet well fully understood, or explained, in string theories [29], nor compatible with all the envisaged approaches [30,31]. So, for this paper, we will consider that multi-field approaches do not yet provide counter examples addressing the question of de Sitter vacua emerging from superstrings. If it changes we can revisit, but it does not mean that we would ultimately reach a different conclusion.

4. An Outsider Perspective

4.1 Discussion of the approaches so far

Let us offer a slightly different perspective, not tied to multi-fold universes. Not being practitioners of string theory, we admit that we don't know what we don't know; but the approach of de Sitter vacua construction seems, in itself, problematic.

Let us assume that inflation, or whatever alternative, resulted into an essentially flat spacetime. In later time, e.g. reheating and beyond, matter is present, and by this, in the philosophy of [1], we mean covering both fermions and bosons / radiation. It is in these epochs that the curvature of spacetime is determined, and, logically, that large scale positive curvature appears as cumulative results of matter, and of any other energy (let us not drop dark components) contributions. We know that these conditions, i.e. the presence of matter, systematically threaten decompactification in a superstring universe, if positive accelerations of the universe expansion are to be maintained [17,21]. In fact, it could be intuitively understood by seeing that matter and dark energy act in opposite direction: when matter is present new lower energy vacua exists, leading to AdS solutions, or requiring stronger positive dark energy effect to counter the impact, otherwise, the compactified dimensions tend to get a negative curvature: they become unstable and want to decompactify.

On the other hand, superstrings have no problem generating negative potentials and AdS spacetime. Adding matter to AdS lower also the energy level, but does not threaten the nature of the vacua and decompactification; even if AdS itself is unstable to matter (at least for GR, which we claim results from the same observations [32]).

The constructions (uplifting or quintessence) result from certain combinations of certain types of strings and branes. What about the other "entities" (like other branes types, or strings), that they be gravity, matter or supersymmetry/superstrings related? Why select some or the other? Wouldn't contributions or fluctuations from any other entity also bring back the potentials to AdS vacua or spacetime? It has already been seen that non-linear effect of combination have so far put in question the uplifting models [6,17,21,23].

We are inclined to endorse a priori the fact that dS vacua, positive cosmological constant, dark energy or possibly even well-behaved inflation are in the swampland. To be convinced otherwise, we would prefer to see conditions where all the string and brane contributions that could be considered would be positive (e.g. as in multi-fold universes, all scenarios of gravity and expansion are associated with a positive curvatures [1]), or remain positive when interacting. Such scenario does not (yet) exist, and to our knowledge, there is no corresponding string model.

4.2. Superstring Spacetime Emerges With A Negative Cosmology Constant

In this section we will argue that the fundamental approach of string implies a model that favor negative cosmological constant. To do so we go back to the reasoning that we made showing that GR and gravitons are of course contained in strings because the string actions contain to the first order the Hilbert Einstein action for the embedding spacetime [10].

Indeed, the preference for negative cosmological constant can also be derived from [10]. The Nambu-Goto or Polyakov actions extremize areas of grand circles in the world sheet instead of sphere areas in space time. They grow as curvature decreases (and goes negative). As a result, the action estimates are always a bit smaller than the expected action (smaller Ricci scalar curvature) (and with a different sign) For a give extremum in the embedding spacetime. [10] shows that we can extremize one, or the other of the Hilbert Einstein action, or one of the string actions. The string actions extremize an action in $(- \alpha R + 1)$ which correspond to extremizing a Hilbert Einstein action in $(R' + \alpha^{-1})$, i.e. a manifold of Ricci curvature scalar R' with a negative cosmological constant). α is positive. R is the Ricci curvature scalar before "change of variable".

The outcome is that while both can produce similar extrema (when embedded in an imposed spacetime with a certain curvature as referenced in [10] (especially reference [36] in [10])), only the negative curvature is emerging (without tricks) from the string action. Therefore, strings can only generate negatively curved spacetime. This is the result obtained without extra fields. Additional fields, as in the references in [10], will further create negative curvature as discussed in section 4.1. Therefore, nothing built on the string actions can contribute a positive curvature.

Therefore, it is a normal consequence of the Nambu-Goto or Polyakov actions extremization, that characterize strings (and superstrings), that the strings spacetime that they would generate (i.e., we are no more looking at them as embedded in an existing spacetime, but seeing what they model as a spacetime that emerge from them) be AdS, with AdS vacua, or with negative cosmological constant. The problems discussed in section 3, and concerns of section 4.1, further justify the futility of trying to generate a dS vacua, at least without a clear physical explanations for the additional terms (fields) that would create the positive curvature, something that does not exist within the context of superstrings as sources for such fields.

The reasoning extends to cases where the cosmological constant would not be constant.

So we believe that we can say that (asymptotic) dS spacetime, de Sitter Vacua, and positive cosmological constant or positive dark energy emerging from strings, are in the string swampland, and that the reasoning above is the proof of that statement. To our knowledge, such a proof had never been concretely provided so far in the literature.

With the above, we can complete the analysis of [22] and affirm statements of its section 2.10:

- (Asymptotic) dS spacetime does not exist as a consistent quantum theory of gravity emerging from superstrings, and it belongs to the swampland. (1)
- Non-supersymmetric AdS/CFT holography (i.e. the correspondence conjecture) lies in the swampland:
    - Non-SUSY is not allowed <= $\Lambda < 0$ = > SUSY is allowed ([22]-(2.17))
- dS/CFT (holography) lies in the swampland:
    - SUSY is not allowed <= $\Lambda > 0$ => Non-SUSY are not allowed (2)

Therefore, we propose that (2) can now be more strongly considered as a fact instead of the question ([22]-(2.18)).

It is important to note that we also rephrased the first statement (1). Indeed our multi-fold work, so far, and as tracked in [1,33], and other non-stringy approaches to quantum gravity, like LQG [34], do not equate consistency with meaning the ability to emerge from superstrings.

Finally let us note that differences between ([22]-(2.17)) and (2) for spacetime generated by superstrings was anticipated, and predicted in [10], simply based on analysis of the respective actions. This result comes from the relationships between the actions, not from other deeper stringy or quantum (correction) considerations! [10] offered already all the bases for proofs needed.

5. Multi-fold Universes, dS and AdS spacetimes

5.1 Multi-fold spacetime / AdS(5) factual correspondence

The multi-fold QFT in Multi-fold spacetime (DS) / AdS(5) correspondence [1], is different from (5). [1] derives a factual dS + QFT/AdS(5) correspondence for Multi-fold universes: multi-folds live in an AdS(5) spacetime tangent to, and dual of, the 4D multi-fold spacetime.

A multi-fold spacetime is flat or (asymptotic) de Sitter, unless if starting with different initial curvatures, to be separately justified. Entanglement and gravity always contribute positive effective curvature that result form the multi-fold mechanisms [1].

5.2. Multi-fold dark energy effects

By spacetime reconstruction [1], the multi-fold spacetime is generated by random walk as a discrete, fractal random, anti-commutative, and Lorentz invariant spacetime, with null or positive curvature. Per [1], spacetime locations are associated to minimum microscopic black holes, further explored and related to Higgs fields in [35].

The Random walk concretization could be modeled by an (effective) QFT with a field potential of the type presented in Figure 1.

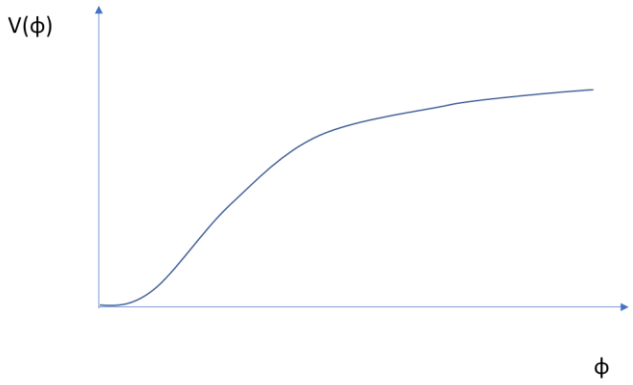

Figure 1: The random walk and concretization mechanism modeled by an effective field: growth increase with energy or particles up to a certain point after which it can only concretized points not yet visited or concretize what dark energy mechanisms have gained, so the potentials reaches a titled plateau.

[1,37] presented an additional explanation for dark energy. Again, could be modeled by an (effective) QFT with a field potential of the type presented in Figure 2.

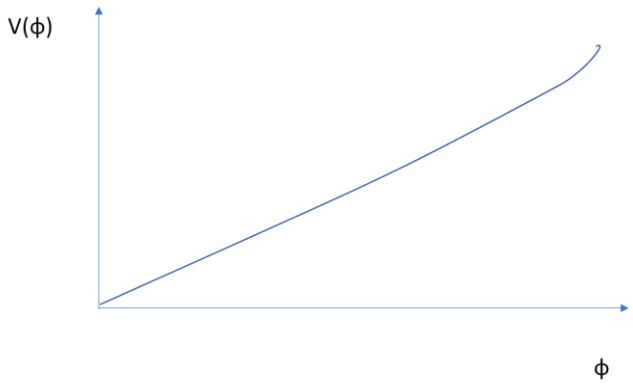

Figure 2: The dark energy mechanisms of [1,37] start from vacuum fluctuation effect contribution to fluctuation effects between entangled virtual pairs emitted by real particles / energy sources and finally fluctuations effects between entangled systems.

We note that this gives us a multi-field model and each field satisfy the de Sitter swampland criterion [6]. We did not check other swampland criteria [38], as they fundamentally do not mean much.

In previous papers, we proposed how inflation can be seen as a model for the initial random walk growth at high energy [1,37], and Higgs Field (Minimally) Coupled to Gravity as possible concrete examples [35].

6. Multi-fold vs Superstring Universes

Based on our analysis of the inability of superstrings to generate asymptotic de Sitter spacetimes, while being able to generate asymptotic AdS spacetime. Based on the positioning between AdS and Multi-fold space time. We would like to propose the following:

- Supersymmetry and superstrings generate the tangent/dual spacetime of a multi-fold universe spacetime and where multi-folds evolve.
- Random walk and multi-fold mechanisms generate the multi-fold spacetime. It cannot be emerge per superstrings (per the above).
- Multi-folds attach to entangled particles in multi-fold spacetime and provide extra path that explain entanglement, gravity-like effects [1,39] and gravity [1,40]. This can be seen as the multi-fold factual versions of the AdS/CFT correspondence [41] and ER=EPR conjectures [42,8], albeit GR may not governs aspects of the kinematics and dynamics of the multi-fold when attached to entangled entities [10].
- So far, anything from supersymmetry and superstrings that is beyond characterization of the physics of gravitons in AdS(5) may not be physical. Even the latter may be unphysical.
- The standard model SM or SM_G, in a multi-fold universe, can be recovered from induced space time matter models from a 7D (vacuum) universe, where the multifold universe is embedded [36].

For multi-fold universes, AdS(5) seems to buffer superstrings from the asymptotic dS spacetime, relieving superstrings from having to explain or generate asymptotic dS spacetime.

There are still major open issues to this picture with respect to superstrings: while we know that superstrings are not compatible with SM or SM_G [11], we do not yet know all what to make of the Yang Mills field also emerging from superstrings [10], as well as all the supersymmetric and higher spin particles that we have suggested so far to be non-physical [7,12]. Do they play a role, or are they just there as a consequence of needing an AdS(5) as part or as a result of the multi-fold mechanisms? If we look at the AdS/CFT correspondence conjecture, by analogy, one might suspect that Yang Mills in AdS(5) (from superstrings) may relate to Yang mills in the multi-fold spacetime, building on the reasoning in [10,41]. But we do not have a way so far to explain or even guess what it would consist of, other than possibly something like proximity effects as in [10,43].

Considering the above, it is important to remember that, if the standard model SM, or SM_G, lives in an asymptotic de Sitter universe, as we believe that the real universe is, then [11] adds to the conclusion that a (and asymptotic) de Sitter Universe, or a Multi-fold Universe, with SM / SM_G, cannot emerge from superstrings: the asymptotic safety of quantum gravity in a multi-fold universe and suspected within the real universe is not compatible with SM/SM_G.

9. Conclusions

We have provided a perspective on why superstrings cannot generate a (an asymptotic) de Sitter spacetime, or dS vacua. Based on past work, it leads to the conclusion that spacetime geometry, and acceleration, as well as its content (SM/SM_G) seem to be incompatible with the emergence from superstrings.

When it comes to multi-fold universes, the AdS(5) dual to multi-fold spacetime buffers superstrings from dS spaces. Multi-fold spacetime emerges from random walks. One can take two consistent point of views: AdS(5) can be seen as emerging from superstrings to support multi-folds, or as emerging from multi-fold dynamics and create a spacetime compatible with supporting superstrings. We believe it is the latter as it is consistent also with the

model of a locally embedding 7D space felt from the 4D spacetime and responsible for space time matter induction that creates the SM, as proposed in [36,44].

The new result from this paper reinforces the view that asymptotic de Sitter (multi-fold universe, or the real universe) spacetime geometry and acceleration as well as its content (SM/SM_G) seem to be incompatible with its emergence from superstrings, or coexistence with superstrings reigning in that spacetime.

The physical role, or impact, of superstrings other than possibly graviton, or graviton-like effects of multi-folds, in the dual manifolds emerging and hosting superstrings is still an open issue for future work. A priori, they have no physical effect, other than maybe to the extent that, at very small scales so that curvature is not really seen, space time matter induction from 7D spacetime (viewed from inside the 4D spacetime) is essentially equivalent to coming from the AdS(5) viewed from the outside. So, maybe there is a mathematical relationship or duality between the two that allows multi-fold 7D space time matter induction to appear as if an effect from superstrings in AdS(5) (+…).

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