Gravitational Bootstrap, S-matrix, Superstrings, and The Plausible Unphysicality of Gravitons

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Abstract

Historically, string theory was the result of modeling amplitude scattering for hadronic physics, then discovering that it contains a spin-2 massless boson reminiscent of the graviton. Adding conformal conditions, General relativity and Yang Mills field equations can be recovered in a 10D universe, as a supersymmetric theory. This evolution implies that superstrings are derived from the bootstrap and string theory, and that, therefore, recent claims of range compatibilities between superstring results and gravitational bootstrap are actually expected and not the surprise, or divine sign of nature, that some have claimed.

In fact pursuing the reasoning, also inspired from our multi-fold theory work, we conclude also that indeed superstrings is the only theory that satisfies sufficiently well-defined, essentially non perturbative, gravitational bootstrap. While this may sound like a resounding confirmation of string theory, we then discussed why it might not be so, but instead emphasize that conventional gravitons, susceptible to scattering modeled with S-matrices, simply do not exist in any other consistent theory of quantum gravity like QFT-based gravity, LQG, Causal set sand other reconstructive theories. In particular, this is confirmed in the Multi-fold theory.

We take it as a hint that much of the challenges encountered in quantum gravity may come from gravitons not existing. As a result, we continue to argue string challenges to the physicality of superstrings, now also including the physicality of gravity.

The paper introduces a few theorems on gravitational bootstraps and gravitons and a new notion of quasiparticles, when the theory is not non-perturbatively renormalizable.

1. Introduction

Quanta Magazine recently published a paper arguing that coincidence of results between gravitational bootstraps, and superstring perturbative expansion up to two-to-two graviton scattering would imply a new sign in favor of superstrings as theory of everything (ToE), or at least gravity [2]. [2] goes as far as quoting, early on, a strong assertion that when it comes to determining if "string theory is the unique

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theory of quantum gravity or not, […]. This [*Our phrasing: i.e., results of [3]*] goes along the lines that string theory is unique". They were encouraged by the tone of the authors in [3].

We do not agree with such a contention, arguing that the credibility of validity of superstrings has not been changed by a iota with such results, because the results were obvious, considering the history and steps behind the development of strings then superstrings! To us, it is another circular argument to add to the long list started in [4] and follow-up comments also published on the web page. It results in a first theorem that should have been obvious and known to any string partitioner. Apparently it might not be as widely known, or even actually formulated as we do. It may be because our reasoning tangentially relies on another result provided in [4], that showed that the Hilbert Einstein action is trivially included in string actions. Something that again implies no miracle or divine sign of God or nature in favor of the strings.

Expanding on such a theorem, we concur that string theory satisfies the gravitational bootstrap [6], and is indeed the only theory to do so, in 10D, by adding suitable additional gravitational bootstrap conditions. Our simple reasoning proves the assertion made in [5]. We do not know if other proofs exist other than a collection of work as compiled in [5] and repeating a reasoning like ours.

Such a result may make string supporters quite happy, while possibly also dismaying other parties. However, the paper then provides a follow-up result actually consistent with all other quantum gravity theories, including our multi-fold theory [1,6,7]. The analysis should inspire all non-string-based quantum gravity alternatives, and we show that indeed it also applies to LQG [8], QFT/EFT (Effective Field Theories) [9], other gravity with spacetime reconstruction theories [10], or causal sets [11,12].

In conclusion, no, superstrings are not necessarily the winner of the ups and downs of our study; to the contrary. The concept the most significantly affected is probably the notion of graviton. As massless, or massive, gravity carrier boson: it is unphysical in all the theories other than superstrings. We already suspected that in multi-fold universes [1,13]. Our previous work has shown the challenges already encountered in terms of physicality of superstrings, as well as supersymmetry, and most GUTs and TOEs for that matter [4,37-42].

Note added on January 30, 3023: [84,85] further indicates challenges for superstrings and super symmetry.

2. Bootstrap as another circular argument

The arguments of [2,3] is that the coincidence or range consistency of the parameters obtained by bootstrap, and by suitable expansion to the two-to-two graviton scatterings associated to the superstring action would be an unexpected result that would reflect a sort of divine confirmation and sign of nature that superstrings are the right and only self-consistent theory of gravity and TOE.

However, we contend that this result was actually trivially expected, and that the numerical confirmation only provides validation that no mathematical mistake has been introduced in the last 50 years of strings and superstrings work. Note that this is not at all denigrating this work and results. We only dispute the subsequent divine interpretation.

The reasoning or proof that we provide is actually rather straightforward, and does not require writing any new mathematical equations. We just need to refer to the sequence of historical events and associated papers. For this, we refer to [14,15,16], and encourage the reader to then read the sequence of key papers that [14] tracks.

2.1 Strings derived from Bootstrap

Following [14], and our analysis as in [4], the bootstrap and S-matrix programs were originally applied to hadronic physics. The scattering amplitudes under considerations were first modeled mathematically by Veneziano, then Virasoro and Shapiro[2]. These models amounted to oscillators with infinite degrees of freedom. Strings are such oscillators.

Also, as discussed in [4], the actions for strings, initially Nambu Goto then Polyakov variations, and all the subsequent string and superstring variations, were shown to contain gravitons, as a Spin-2 massless particles. That was also encountered directly within the Veneziano scattering amplitudes. Again, see references in [4,14].

In [4], we also argued that all this was expected because the string action contains the Hilbert Einstein action, and so perturbative expansions would of course provide gravitons[3]. And yes, analyses of the Veneziano, and Virasoro and Shapiro amplitudes also directly showed the graviton showing the consistency of the relationship. Again it is covered in [4,14].

Strings, bosonic strings (in 26D), then supersymmetric strings (in 10D), when also extracting Yang Mills, and imposing the conformance condition [4,14,17,19,24], contain the graviton (and (supersymmetric) Yang Mills in the latter case).

[4] emphasized how expected that was if one didn't know history. No miracle here, it was bound to happen.

2.2. Bootstrap and (superstrings) are equivalent for a same system

All this leads us to claim, what we believed to be well know:

> **Theorem:** Bootstrap & S-Matrices of a system described by Veneziano, and / or Virasoro and Shapiro amplitudes can be equivalently modeled by string actions: one can consistently model scattering at the same order via bootstrap, or perturbative expansion of the string action.

[2] See [4] for references.

[3] In retrospect, we also argue that such a result, initially modeling hadronic physics, illustrates how QCD can in fact be modeled in part by gravity and therefore announces mathematical results like the AdS/QCD correspondence [51]. *Note added on January 30, 3023: See also [86] for more considerations on the conjecture and QCD.*

Therefore, the results implies that the same parameters must fit range compatibility bounds. In our view, which is exactly what was found in [3]. It confirms our analysis.

Ranges for parameters and different results from the different superstrings models come from: i) the limitation of what can be extracted from bootstrap ii) additional considerations put into the different superstring / supergravity models and actions.

2.3. An expected result

As a consequence, [2,3] were indeed expected tautology, and more gently confirmation of our expectations. This is not denying the impressive work done, but rather stating that the result was expected and it is rather a confirmation that all the mathematical computations and modeling put in string theory over the last 50 years did not introduce a mistake, rather than anything else.

Nobody should be more convinced one way or another of the validity of the superstrings approach. They only confirmed that no mathematical mistake has been introduced since the original derivation of the strings to model the bootstrap.

3. The gravitational bootstrap conjecture

[5], for example, provides a stronger statement about the gravitational bootstrap: that is that string theory is the unique theory that satisfies the gravitational bootstrap.

Per the above, we proved, by following the historical steps, that superstrings is derived from the bootstrap, not that it is the only model that does so, or that would satisfy the bootstrap. It is the case, as indeed strings model oscillators with infinite degrees of freedom. Any such a system can be mapped to some sort of strings (or membranes (think of branes) if dimensionalities are increased) [18,19].

Furthermore, the conformance condition, to escape the 26D bosonic only challenges, and recover Yang Mills, and the additional considerations imposed on the definition of the gravitational bootstrap discussed in [5], lead us to accept the following theorem.

> **Theorem:** String theory is the unique solution to the condition of gravitational bootstrap (partially still to be defined in terms of constraints on the physics of black holes or recovery of classical or semiclassical results).

The undefined aspects create fuzziness leading from a true theorem to a conjecture.

Because the conclusions and usage of the Veneziano, and Virasoro and Shapiro, amplitudes are essentially experimental, and not perturbative, this last result is non-perturbative and should apply to M-theory, whatever that might be. This argument is somehow anticipated in the conclusions of [3].

4. At this stage, do strings win?

It may surprise and rejoice, or dismay, the reader. Have we essentially proven that the Superstrings theory is indeed the only valid theory of quantum gravity, or even theory of everything?

It seems that the only way to argue against such a conclusion would be to reject the derivation of quantum gravity from (gravitational) bootstrap… In our view, that could only mean rejecting that the bootstrap with S-matrix applies to gravity. Said otherwise, it requires rejecting that gravitons exist or behave as any other (spin-2) particles in at least non-perturbative scatterings, even if they might in perturbative approximations fit Feynman diagrams and perturbative expansions to certain orders. That is really more a mathematical expansion result.

Therefore we have the following theorem and corollary:

> **Theorem:** Any theory of quantum gravity other than the family of superstrings[4] that would hope to be relevant and consistent must reject the bootstrap with the S-matrix as suitable to non-perturbatively model gravity.

and therefore,

> **Corollary:** Any theory of quantum gravity other than the family of superstrings[5] that would hope to be relevant, and consistent, cannot model gravitons as a conventional particles subject to conventional quantum scattering, and used to carry the gravity force.

It is quite a conclusion. But is it surprising, unexpected or inconsistent with quantum gravity?

We argue that every relevant contender as a theory competing with superstrings, supergravity and M-theory indeed fulfills these conditions and do not have gravitons as conventional particles. Even QFT/EFT based gravity. So our answer is that, again, the jury is out: all this work still does not mean that superstrings are the theory of quantum gravity or TOE.

Indeed, let us consider a few key contenders to a theory of quantum gravity.

4.1. LQG gravitons

Loop Quantum Gravity (LQG) never introduces a background, and excitations living on this background, so LQG does not use gravitons as building blocks. Instead one expects that one may recover a kind of semiclassical limit or weak field limit where something like “gravitons” will show up. In low-energy approximations of the theory, the loops tracked in LQG may appear as gravitons and propagators have been computed with geometrical interpretation. No matter what, it requires some leap of faith to see the outcome as “conventional” gravitons, and in any case, they are no more just “conventional

[4] This would include supergravity and M-theory.
[5] This would also include supergravity and M-theory.

particles", as we predicted. Even if LQG still aims at computing scattering: they are different concepts. For some entry points, consider [8,20-22]. [1,58] discusses a multi-fold perspective on LQG.

Furthermore, we showed in [54-57] that LQG does not seem to recover smooth manifolds a larger macroscopic scales, where the perturbative notion of graviton was first introduced [24,53,54].

4.2. Causal set gravitons

Causal sets are even further from any such notions [11], especially, as even the notion of particle is different from Quantum mechanics [23], and gravity is rather directly related to a notion of curvature with limited room for its interpretation as graviton [12]. Anyway, in causal sets spacetime [25] is a causal set and particles [26,27] are also causal sets. Scattering and S-matrix exist [23], but the notion of graviton never appears.

4.3. EFT/QFT gravitons

What about QFT, QM, EFT (Effective Field theory) and its graviton? Weinberg [28], and Feynman [29] famously used the S-matrix bootstrap and bootstrap like reasoning derived gravitons properties and spin from covariance, Lorentz invariance for General Relativity (GR), and conversely, GR from Lorentz symmetry and massless spin-2 gravitons (see [1] and reference therein). All this is in perturbative approaches [24,30-32] with expansions into Feynman diagrams that account for virtual exchanges of gravitons in the Feynman diagrams associated to S-matrices. However, perturbative is exactly the point. As formulated by QFT, the effective theory is perturbatively non-renormalizable [33], it actually implies that the graviton characterized by these models should not be understood as conveying gravity as a cloud of virtual gravitons with contribution at infinite order, as can be assumed in QED for the photons as QED is renormalizable [34]. Said differently, gravitons in QFTs are not a well-defined particle, non-perturbatively. While maybe an unconventional result, or point of view, it agrees with our earlier results above, and it is something that may not have really been that clearly realized so far: there is no conventional graviton in (effective) QFT models of GR; only approximations up to a given order. Gravitons do not exist as particles and by this we mean non-perturbatively.

Said differently:

> **Theorem:** the notion of graviton in EFT/QFT is not physical because it is an approximation that does not converge to a renormalizable model of a particle.

Our result in section 3, and here, implies that a renormalized non-perturbative version of QFT gravity, i.e. asymptotically safe gravity [35], if it exists, see section 5, does not involve exchanging virtual gravitons: something is missing or something is incorrect.

A consequence also is that we propose that the notion of quasi-particle [60] be understood as extending also to models where the emergent particle can be valid only up to certain order (e.g. energy level, order of correction, scale) as if higher energy were filtered out. As such, graviton are a type of lower

order space time phenomena, but not full spectrum (quasi)particle. This means lower order Taylor expansions and associated Feynman diagrams are low order approximation valid at low energy, nothing new here. One can perform low energy/low order S-matrix or boot strap but one cannot perform an non-perturbative bootstrap / S-matrix analysis.

4.4 Winner?

All this unfortunately means that the analysis above is not enough to conclude a winner in the competition between these theories.

Nor does it disqualify multi-folds, as discussed in the next section, quite to the contrary. As part of the work on muti-fold universe we encountered several other arguments challenging superstrings and M-theory [1,4,37-43].

5. Gravitons in multi-fold theory

The notion of graviton as a quasi-particle is consistent with the multi-fold theory [1,13,59].

The analysis of EFT/QFT gravitons is most probably confusing, and frustrating for many, as we only could argue that the conventional image of (virtual) graviton interactions in Feynman diagrams and scattering do not suffice or apply correctly; something additional or different occurs across orders that is not correctly modeled in GR as QFT. Considering how multi-fold universes have so far given us interesting insights on the conventional physics, including in particular Quantum mechanics, QFT, LQG, superstrings, supergravity, M-theory and many GUTs, TOEs, or supersymmetry [1,6,7], it is worth understanding what the multi-fold theory view is.

In a multi-fold universe, we already know that gravitons are, at best, quasi particle effects (hence work perturbatively at low orders), living out of the multi-fold universe spacetime and modeled as multi-folds attached to entangled particles [1,4,6,7,13,37-43]. It is fundamentally a non-perturbative model and it does not match a typical graviton (particle or virtual particle model). Conventional scattering of graviton does not exists conventionally. Of course as GR can be recovered [1], one can mathematically model low order effects with Feynman diagrams involving gravitons, and recover the results of Feynman and Weinberg [29,28]

It is rather the result of the sum of all the effective potential effects and their impact on the dynamics of the impacted particles, including the effects felt by the virtual particles [1].

Multi-fold gravity is asymptotically safe, i.e. non-perturbatively renormalizable, as argued in [1,40-42]. But it does not have an actual conventional graviton. Our assertions that this asymptotic safety also extends to the real universe gravity [42]. *Note added on January 30, 2023: and of course especially if we consider [84].* In such a case, it would be why the EFT/QFT graviton is not physical. Note that this is at

the difference of strings, and superstrings, who claim (perturbative) renormalizability, and, therefore, do not have this problem with the definition of the graviton.

In a multi-fold universe, as proposed in [1], multi-folds can be seen as gravitons attached to entangled real or virtual particles. They do not live in the multi-fold universe spacetime [1,4,6,7,13,37-43], in fact hinting at unphysical (closed) superstrings also living in AdS(5) ++[6]. The attachment is kinematic. Dynamics outside of spacetime are irrelevant when it comes to multi-folds. It is the same when it comes to the flow of virtual particles surrounding a source: as long that the kinematics, from [1], are possible, it takes place. Examples, where it can't take place, are: within the horizon of a black hole [1,44], or with, say, a Faraday cage as described in [45], there, the absence of shielding for gravity results from the changes of the potential energy of the "shield". Therefore, there just are no scattering effect of multi-folds with other multi-folds. They are single-tenants, except for Higgs and right-handed neutrinos (see [1,46-50]), and non-interacting (as well as not supporting interactions within the multi-folds). There is simply no notion of S-matrix: the bootstrap[7] does not apply to multi-folds as gravitons analogies.

In recovering GR and the Hilbert Einstein action in [1] *(Note added January 30, 2023, See also [52])*, the order of the invariants were restricted to Ricci scalar and tensor. If higher order corrections have to be introduced they rather really result from the discrete fractal like non-commutative Lorentz invariant as a 2D, then 3D, and eventually 4D spacetime rather than scattering interpretations.

6. Unphysical gravitons

If multi-folds universes model well our real universe then its should hint why so many problems are encountered with QFT gravity in 4D: it's nonlinear model as scatterings is not supposed to model scatterings but rather corrections to be understood as discrete spacetimes corrections. We conjecture that this may be why it is not renormalizable. Furthermore, we already know based on our work on multi-fold theory that there are many challenges to the physicality of superstrings in multi-fold universe, and also, as a result, in our conventional real universe. It may not be that surprising to conclude that gravitons are unphysical and at best quasi particles.

Note added on January 30 2023: [85] adds to the pressure that our real universe may be well ,modeled as a multi-fold universe. [43] adds color to why gravity is differently handled. The way that multi-fold seem to encounter and address open issues with the Standard Model (SM), with the SM_G, the SM with non-negligible gravity effects at its scales, and with Standard Cosmological Model (ΛCDM), [1,6,7,38,44,48,49,50,52,61-67,69,70,71,72-83,86-98] also strongly encourage thinking that our real universe may be multi-fold.

[6] ++ denotes possible additional dimensions required by the model (e.g. S^5 compactified for superstrings).
[7] Note that this does not mean that in a semiclassical QFT built on multi-fold one cannot apply S-matrix or bootstrap on graviton approximations to derive the equivalence principle or GR. These are first order results with gravitons, not higher order scattering between gravitons.

7. Conclusions

This paper presents a few key results and theorems. Some that in our view should not be new, yet may not been that well known by many.

First we argued, and claimed, that it is a theorem that strings and superstrings derive form the bootstrap and S-matrix and that therefore result an analysis from one must coincide or be compatible with results from the other. As a result compatible alpha ranges between bootstrap on two-to-two graviton scatterings versus same order expansion of the perturbative theory was an expected result, that validated mathematics, not another sign anointing the strings as the only TOE and theory of gravity.

Yet doing so we immediately encountered another theorem that seems to indicate that if we use reasonable bootstrap to model gravity, and graviton scattering we automatically imply that superstrings theory is the unique solution to the gravitational bootstrap. This could be a bad story for competing theories of quantum gravity, and a resounding validation of string theory. Note that such a result is different from the claims in [2,3], that were based on a circular argument.

We concluded that therefore any other theory of gravity that would hope to be relevant and consistent must reject the bootstrap with the S-matrix as suitable to model gravity, and therefore not model the graviton as a conventional particle! We confirmed that other contending quantum gravity theories fit our result. It is also the case for the multi-fold theory.

With the other objections to the physicality of superstrings and supersymmetry, we conclude that gravitons are not only unphysical in multi-fold universes, but they seems unphysical in the real universe.

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