The Yang Mills Double Copy leads to New AdS/CFT + Gravity Correspondences, or How the M-theory encounters Multi-fold Universes

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Abstract:

Following up on our recent analysis of the double copy behavior of Yang Mills scatterings, and its duality with gravity, we review the conventional AdS/CFT correspondence and ER=EPR conjectures, and, in particular, the link between entangled CFTs on one hand, and gravity on the other. Combining the dualities, we derive new types of AdS/CFT correspondences respectively for renormalized / asymptotically safe gravity derived from dual copy (AdS/CFT$_{2CG}$ Correspondence), and then for CFTs in the presence of such gravity (AdS/CFT$_{YM2CG}$ Correspondence), a priori a much better match for our real universe. We submit that such reasonings have not been encountered before, probably due to the aversion of QFTs and Superstrings to rely on particles; something that we see more as a limitations of QFTs and Superstrings approaches rather than a superiority of these approaches, as is typically argued. CFT$_{2CG}$ and CFT$_{YM2CG}$ are not necessary CFTs, i.e. they are not necessarily conformant. It is also important to note that the new correspondences do not require supersymmetry, which is consistent with such possible loss of conformance.

Sources, i.e., particles, can be seen as colored/charged microscopic black holes linked by (potentially traversable) wormholes when entangled. These new dualities, and results, do not require multi-fold mechanisms for their derivation. However, the latter duality, Ads/(CFT plus double copy gravity), recovers explicitly the multi-fold mechanisms, implemented the best way that conventional physics can model them, i.e., as wormholes between entangled fields, generating gravity effects. In other words, a suitable 4D CFT spacetime with gravity is a multi-fold universe (possibly without CFTs but with asymptotic safety), where the AdS/CFT correspondence, ER=EPR and E/G conjectures are factual and one could expect to see emerge the SM$_G$: The Standard model with gravity non-negligible at its scales.

As we reviewed the conventional AdS/CFT correspondence, we revisit our suggested variations in its derivation that allows CFTs, or Yang Mills, to be generated and entangled by local brane to brane leakage. It allows for the emergence of the CFTs, and their entanglement, without depending on superstrings, and as a result without implying supersymmetry. This way, among the new AdS/CFT duality encountered, we can also discuss, and distinguish, flat 4D spacetime versus (asymptotic) de Sitter spacetime, i.e. with positive cosmological constant, and the implication on CFTs modeling super Yang Mills vs. Yang Mills; distinctions that are not really conventionally envisaged.

So, we now encountered multi-folds in M-theory, as embodied in the conventional AdS/CFT correspondence conjecture, its only known approximation. Also, we clarify how the AdS/CFT correspondence conjecture relates to our real universe, beyond duality statements, including the real possibility of our universe being the boundary of an AdS(5)(+…) space, and gives hints that multi-folds may also be the source of gravity / General Relativity in AdS(5)(+…). The AdS/CFT$_{YM2CG}$ correspondence is what applies to our real universe as a dS/(C)QFT correspondence better suited to our real universe.

All, these results are derived without multi-fold assumptions, only using the multi-fold theory as guidance.

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The paper also provides interesting considerations on the derivation of the AdS/CFT correspondence conjecture, leakage of Yang Mills fields, and the associated asymptotic safety of such fields, and the glimpse a new proof of asymptotic safety of (GR-based) gravity in 4D, that is detailed in an upcoming paper.

We also argue that the Ultimate Unification (UU) symmetry breaking, although maybe just a progressive evolution, could involve a continuous switch from AdS/CFT$_{2CG}$ Correspondence to the AdS/CFT$_{YM2CG}$ Correspondence.

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1. Introduction

The multi-fold paper [1] proposes contributions to several open problems in physics, like the reconciliation of General Relativity (GR) with Quantum Physics, explaining the origin of gravity proposed as emerging from quantum (EPR- Einstein Podolsky Rosen) entanglement between particles, detailing contributions to dark matter and dark energy, and explaining other Standard Model mysteries without requiring New Physics beyond the Standard Model other than the addition of gravity to the Standard Model Lagrangian. All this is achieved in a multi-fold universe that may well model our real universe, which remains to be validated.

Note added on April 8, 2023: references in italic refers to references added on April 8, 2023.

As a summary, see [1,8-10,*122*] for more, the whole multi-fold theory derivation, including the introduction of SM$_G$, can then be repeated. And so, accordingly, in a multi-fold universe, gravity emerges from entanglement through the multi-fold mechanisms. As a result, gravity-like effects appear in between entangled particles, whether they be real or virtual. Long range, massless gravity results from entanglement of massless virtual particles. Entanglement of massive virtual particles leads to massive gravity contributions at very 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. So, 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. Concretized spacetime results from past random walks of particles. Spacetime locations and particles can be modeled as (Higgs boson condensate) microscopic black holes (Schwarzschild for photons and concretized spacetime coordinates, and metrics between Reisner Nordstrom [2] and Kerr Newman [3] for massive, and possibly charged, particles – the latter being possibly extremal), or patterns of massless Higgs boson random walk (massless above electroweak symmetry breaking) [1,4,34,92,96,101,*120*]. Although possibly surprising, [1] recovers results consistent with others (see [4], and its references), while also being able to justify the initial assumptions of black holes from the gravity or entanglement model in a multi-fold universe. The solitons black hole condensates or random walk patterns result from spacetime matter induction and scattering that recovers all the particles, interactions and symmetries of SM [32,37,38,126,*123,135,146*]. All these recover 4D General Relativity (GR) at large scales, and semi-classical models remain valid till smaller scales than usually expected. Gravity can therefore be added to the Standard Model resulting into what we define as the SM$_G$. This can contribute to resolving several open issues with the Standard Model without New Physics other than gravity, i.e. no new particles or forces, or with the standard cosmological model (ΛCDM) in terms of dark matter and dark energy [1,4-13,29-32,34-42,48,49,52,53,75,79-*147*]. Multi-folds can be encountered in GR at Plank scales, in spacetime quantization starting from the Hilbert Einstein action, and in the equivalence principle of suitable quantum reference frames in relational quantum physics. Conversely, GR and Quantum physics, including path integrals, the Born rule, and wave functions, can be recovered through different paths from multi-fold spacetime reconstruction, and the W-type multi-fold hypothesis. In a multi-fold universe, GR and Quantum Physics are not incompatible, they are just different facets of multi-fold mechanisms, something that neither theory can well model.

With the double copy behavior of Yang Mills scattering Feynman diagram [22-28], we also show that multi-folds and the E/G conjecture [11] are contained in Yang Mills theory, and that Yang Mills models gravity, as far as a duality [12,13]. This paper uses such dualities to complement the AdS/CFT conjecture, and make it more suitable to universe like our real universe, in particular dS (de Sitter) – like, with positive cosmological constant and Yang Mills fields that are renormalizable but not conformant.

The present paper starts by reviewing the conventional derivation of the AdS/CFT correspondence conjecture [14,15]. In particular, relying on [15], we refer to [16] that provides our preferred way to derive the conjecture, and in particular relies on Yang Mills leakage rather than entirely on superstrings [16,17].

Then, the paper discusses some follow-up results in the form of conjectures on the mapping of wormholes to two entangled CFTs [18,20,21], and the ER=EPR conjecture [19]. The two entangled CFTs, mapped to a wormholes, are reminiscent to the double copy behavior of Yang Mills scattering [12,13,22-28].

We also discuss past results of the multifold theory where AdS/CFT correspondence, ER=EPR and E/G conjectures are factual [1,16,29-32].

Then, we review the double copy behavior of Yang Mills scattering Feynman diagram [12,13,22-28], and the associated microscopic interpretation and its relationship to the multi-fold mechanisms and multi-fold gravity that seem to therefore emerge from Yang Mills Theory [13], something that we had already encountered with the Hilbert Einstein action and superstrings, when a conformant condition is added/present [1,16].

Building on these considerations, while not yet introducing dependencies on multi-folds, we use the double copy behavior of Yang Mills scattering to derive a variation of the conventional AdS/CFT correspondence conjecture between AdS, and the gravity defined by the double copy, that we renormalize or rather treat as asymptotically safe, following the approach of [32,33]. It is a new duality. Combining the two dualities (the conventional one and the new one), we obtain another new duality between gravity in AdS(5) and a 4D spacetime of CFTs with gravity, a priori a closer match to our real universe than the conventional AdS/CFT correspondence conjecture; if it wasn't for pesky remaining supersymmetry challenges and some renormalizability aspects, still to settle. Therefore, the cases of Yang Mills versus super Yang Mills are reviewed and discussed. It leads to considerations for flat and (asymptotic) de Sitter universes as CFT spacetime or AdS(5) boundary.

Doing so, the new correspondences lead us to the sources of gravity, which we will take as particles, as microscopic black holes[2], that become connected through a wormhole when the particles are entangled [18]. With this, and the consequences of the double copy behavior of Yang Mills scattering, we recover key results of the multi-fold theory, leading us to conclude that the AdS/CFT correspondence conjecture, a non-perturbative window into M-theory, recovers the multi-fold theory, including multi-fold mechanisms, their links to entanglement and the emergence of gravity [1,35], or gravity fluctuations [1,36], and the E/G conjecture [11], and particles as microscopic black holes [1,4,34], as well as the SM_G [1,8-10].

The steps discussed in the two previous paragraphs, especially the former one, may seem obvious, or at least expected. Yet we have not encountered any discussion relating the double copy behavior of Yang Mills, and the AdS/CFT correspondence. So, our results should be of wide interest beyond our claims of encountering multi-folds, M-theory and the AdS/CFT correspondence conjecture. We suspect that it may be because, in QFTs and Superstrings, one is reluctant to consider particles as physical, instead of fields, especially when it comes to virtual

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[2] Concerns about (over)extremality and singularities are appeased with [1,4,34], and references therein: some conventional models have reached similar conclusions and, more importantly, once we accept such a model, the rest of the multi-fold theory [1,8-10], built on the results recovered in the present paper, provides resolution of the concerns as we can recover [4,34]. Also, once understood as Higgs boson superconductor condensates as in [4], extremality, or black hole evaporation are no more concerns.

particles, and explicitly expose their entanglement. We already discussed these in [1,13,29,39], and consider it as a limitation of these approaches. Traversability of the wormholes, ensured by multi-folds or the presence of massive fermions in the wormholes (See [40] and references therein), probably also played a secondary role as already discussed in [1,6,16,29-31,*123,132*]: so far, none of the conventional AdS/CFT correspondence conjecture models have managed to extract the multi-fold effective potential, aka gravity, as they did not assume traversability of wormholes, implementing multi-folds, by some paths of the path integral [1]. The presence of these fermions, in the form of right-handed neutrinos and their antiparticle is also key to ensure stability of the multi-fold space time matter induction and scattering that recovers the SM, or shall we rather say the SM_G [32,37,38,*123,135,146*]. *Note added on April 8, 2023: The multi-fold mechanisms and symmetries in turns ensure the correct set of particles, interactions, constant and symmetries for SM_G [123,132,147]. This is also why we can assert that superstrings and supersymmetry does not define SM or SM_G, it comes from spacetime matter induction instead. Yes in AdS(5), because space time matter induction comes from embedding feelings in a ε 7D region, with a 5D dominant effect, AdS(5), so small that they all appear flat, AdS(5) space time matter induction and scattering could also induce SM and SMG, if influence can be similarly narrowed to a ε domain of influence. But that is not superstrings as particles, it's GR/unconstrained Kaluza Klein effects on 4D spacetime.*

Encountering multi-folds, and their mechanisms, in the (conventional) AdS/CFT conjecture correspondence Is an interesting result, considering that the conventional AdS/CFT correspondence conjecture is usually considered as one of the most established window into the M-theory: the non-perturbative theory of superstrings and supergravity. After encountering hints of superstrings, but also exposing real challenge to their physicality [1,13,16,30,29,41,48,52,53,79,80,97], beyond mathematical results, we now have superstrings and the M-theory encountering multi-folds[3]. With [6,13,16], it was bound to happen but we needed to figure out a way to derive it conveniently. Doing so, we believe that we also illuminate how the AdS/CFT conjecture really relates to the real universe, beyond dualities, and seeing it as really the boundary of an AdS(5)+… space as we encountered in [1] with multi-fold universes. With that, we recover the ability to encounter SM particles via space time matter induction and scattering as in [32,37,38,*123,135,147*].

As we go through the paper, we also derive a proof that 4D GR-based gravity is asymptotically safe. It may not be that ostensible, but it is of course a very important result. It has huge implications on the viability of superstring, supergravity, M-theory, supersymmetry and most GUTs and TOEs [1,13,16,30,29,41,48,52,53,79,80,97]

Note added on April 8, 2023.: This result is so important that we did devote a separate paper[117], entirely to that that result, clarifying also explicitly some of the considerations passed a bit rapidly in the present paper. Then, we reconfirmed in [120] that, in the presence of SM particles, our results on asymptotic safety of gravity, obtained in different ways [1,52,53,120,137,139], the challenge to the viability of superstrings, supergravity, M-theory, supersymmetry and most GUTs and TOEs, holds.

2. The AdS/CFT correspondence conjecture and our perspective

2.1. The basics

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[3] Of course, the surprise is for effect. Results like [5-7,13] implied such an encounter, considering that we already knew that the different (super)string actions contain the Hilbert Einstein Action, GR and Yang Mills fields [1,16], and that the multi-fold theory recovers GR [1,6].

The AdS/CFT correspondence conjecture was introduced by Maldacena in [14]. Since, it has dominated the field of superstrings, and as the most concrete window on M-theory, as non-perturbative theory of strings and gravity [14,15].

[15,16] provides a summary of the derivation of the conjecture based on our view and work on the relationship between CFTs, Yang Mills and superstrings, and on [17][4]. That derivation reduces significantly the dependency of the derivation of the AdS/CFT conjecture correspondence on superstrings, and relies rather on Yang Mills fields leaked outside the 4D spacetime. We will get back to this in section 7. Of course, the branes used in the derivation come directly from superstrings and M-theory. *Note added on April 8, 2023: these branes are regular D-branes [148], they are not the ones we encounter as other Worlds à la MWI (Many Worlds Interpretation) in [147].*

[15,16] do not detail the extension of [17] to 4D manifold in surrounded by 5D tangent AdS(5). Per sections 2 and 3 in [17], if a Yang Mills field is defined in a 2D manifold, it leaks around that manifold[5]. So, we can have a 4D manifold (the branes) with Yang Mills fields on it, as we can pick any 2D manifold and apply [17]. In 5D, i.e. 2D + 3D, the Yang Mills field also leaks as a 5D Yang Mills field, extending the 4D one. Therefore the result holds for 4D Yang Mills leaking in a 5D space[6] like the dual / tangent AdS(5).

With this, in section 5.2 of [16], each brane is a layer of non-interacting 4D spacetime with a different CFT. N branes means N fields. In [14,15], superstrings that concretize the branes, source the CFT of the brane. In [16], and especially with our extra explanation presented here, one sees that these fields can also be seen as excited from AdS(5) bulk, or from sources, i.e. particles, on a brane as background field, into the other branes. So N slices of 4D spacetimes of thickness ε in the fifth of the 5D direction, can be excited and even be entangled despite being in different 4D spacetimes (D-branes), and without obtaining these properties from superstrings[7]. N -> ∞ and ε -> 0 ensures that it can always be the case. *Note added on April 8, 2023: that is not the case for the multi-fold types of branes in [147], as discussed in that paper.*

Accordingly, maximally supersymmetric CFT on 4D flat spacetime without gravity is dual of strongly coupled AdS(5) (+…)[8] gravity, i.e., an AdS(5) black hole geometry. The result is often presented also as holding for a (asymptotic) dS spacetime, which is often presented to be the actual boundary of the AdS(5)(+…), but it isn't really, because of inconsistency between curvature and zero gravity. It is illustrated in Figure 1. The figure should familiarize the reader without sketches a we propose new dualities based on the AdS/CFT correspondence conjecture.

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[4] See the steps in section 5.2 of [16], also relying on section 3 of [15], and [17] for the justification of boundary conditions, and leakage between Yang Mills and strings.

[5] One may think as if it was due to the uncertainty principle, just as in [1] we used it to explain hairs around black holes, or the black hole area law and evaporation [1,102]. *Note added on April 8, 2023: See also [149].*

[6] We will address in section 2.2, the question of the existence and renormalizability or asymptotic safety of (super)Yang Mills in 5D. In 4D, and below, it is renormalizable (see for example [57]).

[7] Note that [17], beyond section 2 and 3, involves and derives relationships to superstrings. We use only sections 2 and 3 that depends only on Yang Mills. The relationship between Yang Mills and Superstring further discussed in [16,17] ensures that, in the conventional case, our derivation and [14,15] are equivalent.

[8] Per [16], AdS(5) (+…) denotes the possibility of extra dimensions like S^5 as needed by superstrings. It does not really matter in the regime close to the boundary where gravity / coupling goes to zero, as discussed in [14,15,20,21]. In these papers, we see why the focus on AdS(5) is sufficient for the rest of the discussions and for AdS/CFT correspondence conjecture in general. It should always be kept in mind that sometimes, one may have to add (+…). (Note that in the presence of multi-folds, one can always drop (+…), but we may need to add this term, if/when we want to discuss superstrings living in it [1,16,29-31], that may provide hints of the multi-folds, as is the graviton living also in AdS(5)(+…), not in 4D spacetime [1,13,48,49]).
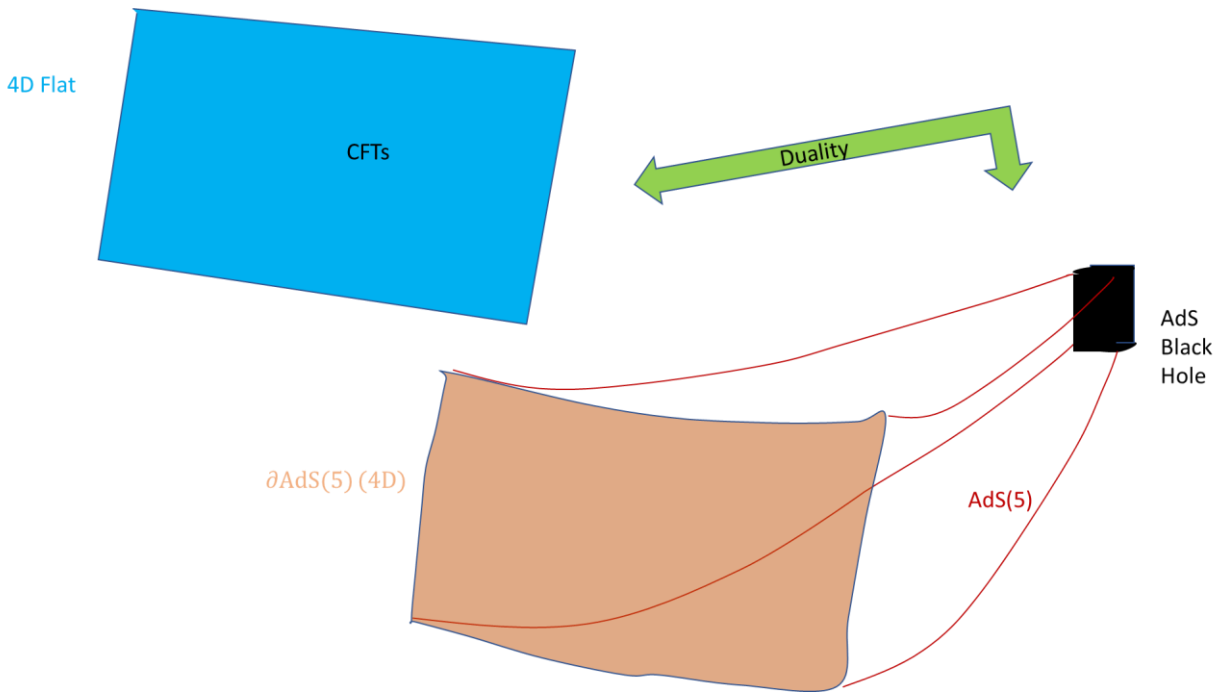
Figure 1: AdS/CFT correspondence conjecture from [14] between correspondence between a flat 4D spacetime (no gravity) with CFTs gauge fields and AdS(5) space with bulk gravity. It is not a physical and geometrical correspondence but rather a mathematical duality between the blue CFT domain, and the brown bulk gravity and its objects.

Note that equation (2) in [41], forbids SUSY on dS spacetime (i.e., with positive cosmological constant or asymptotically de Sitter), so dS is not really a suitable boundary unless maybe if seen as a deformation with very small curvature. In any case, without gravity it is hard to justify a curvature of any type. Note that we gave additional considerations of this in [32], where we discuss a case, based on [33], where the 4D spacetime can be curved dS and everything asymptotically safe.

One need to keep in mind a few points, when it comes to the derivation of the AdS/CFT correspondence conjecture:

- At the time of the derivation of [14], SUSY was not really as developed as QFT/CFT on curved spacetime. So, such considerations did not matter, and in fact the swampland, discussed in [1,41] and references therein, and theorems behind equation (2) in [41] were not yet that established. Curvature was not a central consideration.
- The conventional AdS/CFT correspondence conjecture is a mathematical duality, obtained by a physical reasoning and string approximations, and it has then been re-interpreted as a physical duality. The duality does not imply that the CFT spacetime is dS, nor the boundary of AdS(5)(+…). That is the subsequent interpretation, or rather visual and pedagogical representation. It is just not what the conjecture states/stated.
- So the issue of dS, or no dS, vs. AdS is in general ignored in discussions of the AdS/CFT correspondence conjecture, at least as far as we know. It's just sometimes assumed that the CFT is a good picture of our spacetime; never mind that it really isn't.
- Continuing on the handwaving to apply AdS/CFT correspondence conjecture o our real universe, the absence of gravity in the CFT spacetime, is assumed ok as gravity is typically weak. Of course that is also

questionable i) as string coupling is involved in the derivation and so if no strong coupling ever exists, one may argue the derivation à [14,15] may not hold in our context ii) Yet the interest in superstrings and M-theory should be first and foremost for very small spatial scales, or very large energy, when one typically argues that gravity coupling can become strong (think very large curvature at very small scales and with quantum fluctuations, or (quasi) black hole singularity like behaviors at Planck scales, or simply the arguments of GUTs and above where gravity would be of same order of magnitude as the other unified forces (even within or around the Weak Gravity Conjecture (WGC) to remain strictly or not satisfied [1]).

- CFTs are also a good matches with the SM, as renormalized QFTs can be considered as modeled by CFTs, which have the right UV behavior (2D and 4D scale invariance implies conformance symmetry) to characterized renormalized QFTs [53,75,*120,150*].

For completeness, note that the AdS/CFT correspondence conjecture has also applicability for QCD (it had too as strings come from initial attempts at modeling the strong interaction, especially confinement, before QCD was formulated [121,151]), and Condensed matter, fluid physics, Black hole physics and GR [17,42,43]. Versions of the duality exist for different values of the dimensions D of CFT spacetime boundary to D+1 AdS(D+1). We focus on 4D CFTs and AdS(5) but many results of the paper extend or can be adapted to other cases where CFTs exist well defined, and a conventional AdS/CFT correspondence conjecture exists.

We believe that the extra considerations from [16], and their expansion in this section, warrant some detailed investigation by the Physics community. Section 7 relies in part on this section, and our details on our derivation of the conventional AdS/CFT correspondence conjecture, to reach new variations of the duality.

2.2. 5D Yang Mills

In [16], and in section 2.1, we assumed no issues with the Yang Mills field. It turns out that we got cavalierly lucky, because there were potential issues: 5D Yang Mills [58] is non-renormalizable [57]. But at least, it is defined in 5D [58].

However, it has been shown numerically, that 5D Yang Mills, for the SM symmetries, seem asymptotically safe for dimensions smaller that D_c = 5.26 [59-61]. In truth, we knew that it would be the case because of [16,17], and 4D Yang Mills being renormalizable [62]; the leaks are to remain locally defined and well behaved in a neighboring embedding region: 5D most probably had to be asymptotically safe, but we were not sure how large ε would be beyond. It turns out to be ~ 1.26. Alternatively, it had to be able to support massive Yang Mills in 4D by Kaluza Klein compactification [58], and so Yang Mills had to be at least asymptotic safe in 5D, which it is.

We do not have such issues with say 5D super Yang Mills [63,64], but other super Yang Mills (4D, with $\mathcal{N} \neq 4$) aren't necessarily renormalizable either, and, as maximally super Yang Mills, the only renormalizable one corresponds to D=4 $\mathcal{N}$ =4 super Yang Mills [65], which is the maximally supersymmetric Yang Mills in 4D. It is that one which is involved in the AdS/CFT correspondence conjecture.

This consistency and more detailed analysis ensures that our proposed variation in the derivation is fully consistent.

3. Two entangled copies of CFTs and AdS back holes

While building a dictionary of the AdS/CFT correspondence conjecture, Maldacena's genius stroke again, proposing that the dual of the eternal black hole, which can be seen as a wormhole formed from two copies of the blackholes, would correspond to two CFT copies [18], as shown in Figure 2.
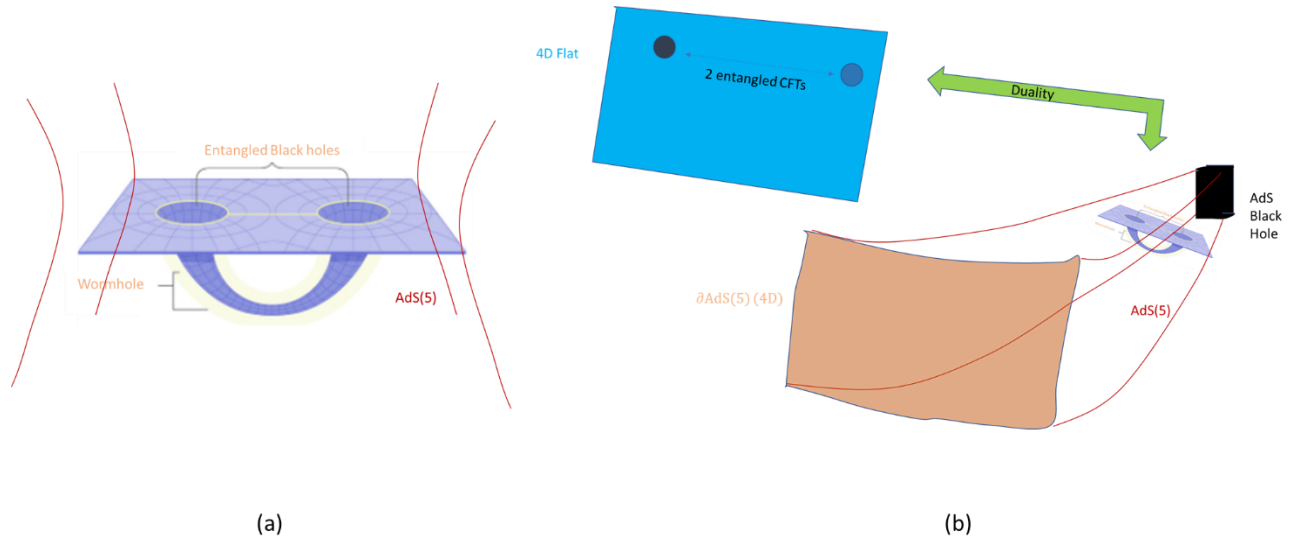

<div align="center">(a)   (b)</div>

Figure 2: (a) shows the result of [18]: entangled black holes in AdS(5) are connected via a wormhole bridge (considered as not traversable, at least in [18]). (b) position this in the context of the AdS/CFT correspondence conjecture, which is not a physical and geometric duality as discussed in figure 1.

More precisely, two copies of the CFTs in a particular pure (entangled) state is approximately matched by a Schwarzschild AdS black hole [16,18,20,21]. The resulting solution has two asymptotic regions, connected by an Einstein-Rosen bridge that can be seen as implemented by two black holes connected by a(n) (ER) bridge. Hence the proposal that it matches, and describes, two CFTs, that do not interact with each other, but are in some (pure) entangled state. The understanding in [14-16] that each brane contains a different field can explain their lack of interaction: they are in different spacetime (i.e., different branes) even if ε -> 0. The source of entanglement is a bit harder to justify, and in fact never addressed in [18,20,21], but most probably assumed supported through superstrings between branes. The reader will note that our variant of derivation as here and in [16], discussed in section 2, allows for entanglement across branes, while keeping the absence of Yang Mills interactions across branes due to the different spacetimes of the branes.

Considering [12,13], this result is reminiscent to our microscopic explanation for the double copy behavior of Yang Mills scattering Feynman diagrams [13,22-28]: entangled Yang Mills systems create gravity structures (wormhole). It is that insight that led to present paper, and especially section 7. As discussed in [13], such explanations can also be seen as Yang Mills hinting at / predicting the multi-fold mechanisms and multi-fold gravity [1]. We will revisit in section 6.

4. ER=EPR Conjecture

Building on [18], [19] introduced the ER = EPR conjecture, which has many commonalities with the multi-fold mechanisms [1], as well as with our derivation of multi-fold mechanism from GR at Planck scales [6]. We actually

discovered [18,19], post our initial formulation of the multi-fold mechanisms, while drafting [1]. Regarding ER=EPR, an overview is available at [1,16,44]. 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 that gravity is due to the entanglement of virtual particles [1,13], and that entanglement creates gravity fluctuations [36], all resulting into the E/G conjecture [11].

[16] summarized the derivation from [19], in our own way. Note also that [19] focuses on entangled black holes, linked by non-traversable[9] blackholes, and explains why, or how, such scenarios could naturally occur.

The assumed absence of traversable wormholes without exotic matter has slowed down deriving gravity from Er = EPR, despite many hints as in [20,45,46]. Since Maldacena and others have introduced traversable scenarios but they are not as cleans as our multi-folds or their implementations with traversable wormholes, where traversability is ensured by massive right-handed entangled neutrinos and its anti-particles in the multi-folds/wormholes, and possible rotation, dark energy and Casimir effects. See [1,10,16,29-31,*123,132*] and references therein. Without traversability, no path of the path integrals cross the wormholes, and all these papers miss the emergence of gravity as encountered in [1]. *Note added on April 8, 2023: Even with traversable wormholes, the Physics community has still not, as of now, and to our knowledge, made the last step, of letting path integral paths traverse the wormholes.*

5. Factual AdS/CFT correspondence and ER=EPR in Multi-fold universes

So far, all of the above is not dependent on multi-fold assumptions. So we tried to minimize mention of the multi-fold theory, to remain appealing to the broadest possible audience. Before expanding on the conjectures above, we believe that it is worth positioning them in multi-fold universes.

Accordingly:

- The AdS/CFT correspondence is factual in multi-fold universes with the spacetime populated by SM particles (i.e., the CFT fields), non-supersymmetric, while gravitons quasi particles, and superstrings, are living in AdS(5) dual tangent to every spacetime location. AdS(5) is built by / contains multi-folds [1,16,29-31].
- Multi-folds are traversable [1]. They can be implemented by traversable wormholes [40], or not [1,10,16,29-31,*123,132*]. They are encountered as plausibly traversable wormholes in GR at Planck scales [6].
- ER = EPR is factual in multi-fold universes, where traversability of multi-folds, or of wormholes, is available for quantum paths of the path integrals, and in fact better represented by the E/G conjecture, also factual in multi-fold universe, which adds gravity emergence from entanglement [1,11,16,29-31,40].
  - o The result extends to the GR=QM conjecture as factual in multi-fold universes, as discussed in [1,16,29-31,47].

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[9] [1,16,29-31,40] discuss the implications of non-traversable wormholes. References therein also discussed traversable options. Maldacena has continued to research wormhole traversability, especially with AdS. If of interest, we recommend following his recent publications. A good starting point are references in [40]. For us, [40] and [56], provided the solution for traversable wormholes compatible with multi-folds: they could implement the multi-folds. In any case, multi-folds do not have to be implemented via GR and wormholes. Also, [6] hints at multi-folds as Planck scale traversable wormholes in the context of GR at Planck scale.

- The graviton is a quasi-particle that is not physical and does not exist non-perturbatively [1,13,48,49]. This result does not seem limited to multi-fold universes[10].
- Area laws also applies as discussed in [1,73], as in the conventional conjecture. See for example our discussion of the equivalent of the Ryu–Takayanagi conjecture [74].

In the next few sections, except when mentioned explicitly, the discussion will still continue to not assume multi-folds, but they clearly become increasingly inspired by multi-fold results that guide our analyses.

6. Double copy behavior of Yang Mills scattering

6.1 Scattering

The double copy behavior of Yang Mills scattering Feynman diagram has been know for a little bit more than 10 years, and starts to be well understood [21-26,28]. Accordingly, when rewriting the scattering amplitude for a Yang Mill scattering Feynman diagram, to suitably expose a colored interaction part, and a kinematic part, and when we replace the colored interaction by a copy of the kinematic part, the resulting Feynman diagram define a theory of gravity. It covers many scenarios, important to us is the validity of the double copy duality for Yang Mills and Super Yang Mills (SUSY) as well as for super gravity.

Degrees of freedom differences may result into additional scalars when scatterings involve massive particles, but in massless case it is pure GR. Interpreting some of these was handled in [12,13].

6.2 Black holes and EM/YM potentials linked Coulomb and its YM generalization potential

Besides the analogy between particles and black holes, as discussed for example in [1,4] and references therein, the double copy can also be used to model back holes collisions [27,51]. It is relevant considering our comments at the end of section 3, and our propensity at modeling of particles as microscopic black holes [1,4].

With the double copy, one understands that Coulomb potentials and Yang Mills generalized potentials can be derived from gravity potential gravity, e.g., think à la Newton, for point (colored/charged) charges (particles) [22], or black hole metrics [27].

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[10] By the way, a Weinberg-Witten no-go theorem also predicts this for QFT/EFT approaches to quantum gravity [50]. Indeed, accordingly, all theories with a Lorentz-covariant energy-momentum tensor, such as all known renormalizable quantum field theories, composite as well as elementary massless particles with j > 1 are forbidden. Also, in all theories with a Lorentz-covariant conserved current, such as renormalizable theories with a symmetry that commutes with all local symmetries, there cannot exist composite or elementary particles with nonvanishing values of the corresponding charge and j > ½. Therefore a graviton can't exist as a massless spin 2 particle in spacetime, or be composed of spin-1 particles. This is not covering superstrings or LQG (Loop Quantum Gravity) , and other non-QFT/EFT approaches, but these are addressed in [48].

6.3 Gravity and Yang Mills

Throughout the AdS/CFT literature, authors always wonder at the fact that gauge theory contain and model gravity. [1,16] convinced us very early on that it was the case: no need of the whole AdS/CFT correspondence conjecture to reach such a conclusion. In other words, had somebody shown earlier that the Hilbert Einstein action contains the Yang Mills actions, and the strings actions, all this would have been expected. But instead such properties were rather considered as divine signs anointing superstrings, and so, this relationship between Yang Mills and Gravity came, and still comes, as a total surprise to many in the Physics community.

The same is true for the double copy behavior of Yang Mils scattering Feynman diagram vs. gravity scattering Feynman diagrams. Again our results from [1,16] in terms of the actions make such results quite plausible. No surprise at the existence of a correspondence.

The difference between the two types of dualities is really that one is in spacetime of different dimensions (D and D+1), while the other stays in spacetimes of same dimension[11].

As the double copy was discovered after the AdS/CFT correspondence conjecture, and its correspondence dictionary, including for entangled CFTs, one would have expected that the double copy would not have been a surprise on that basis alone. Yet, as far as we know, we have not found any dedicated publication or work.

6.4 Multi-folds and Yang Mills

[12,13] discussed how Feynman diagrams scattering for electromagnetism (QED), and Yang Mills (YM), compare to a analogous multi-fold (scattering) diagrams. Inspired by the multi-fold case, it becomes clear that the double copy can be simply explained microscopically as the result of scatterings with the two entangled particles, real or virtual, that generate gravity effects. It is illustrated in Figure 3.

It provided the first microscopic justification for the double copy behavior of Yang Mills scattering Feynman diagrams, and, interestingly enough, as a result, it also indicates that multi-folds mechanisms, and multi-fold gravity are encountered, and contained within the Yang Mills theory.

If all of these considerations are true, it is also not surprising that quantum gravity and GR must also encounter multi-folds. This was obtained in [5,6], while GR was recovered from multi-folds in [1,6].

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[11] We still speak of different spacetimes, in that latter case, because gravity (conventionally) modifies the spacetime manifold, at least at large enough scale. So speaking of same spacetime would be confusing.
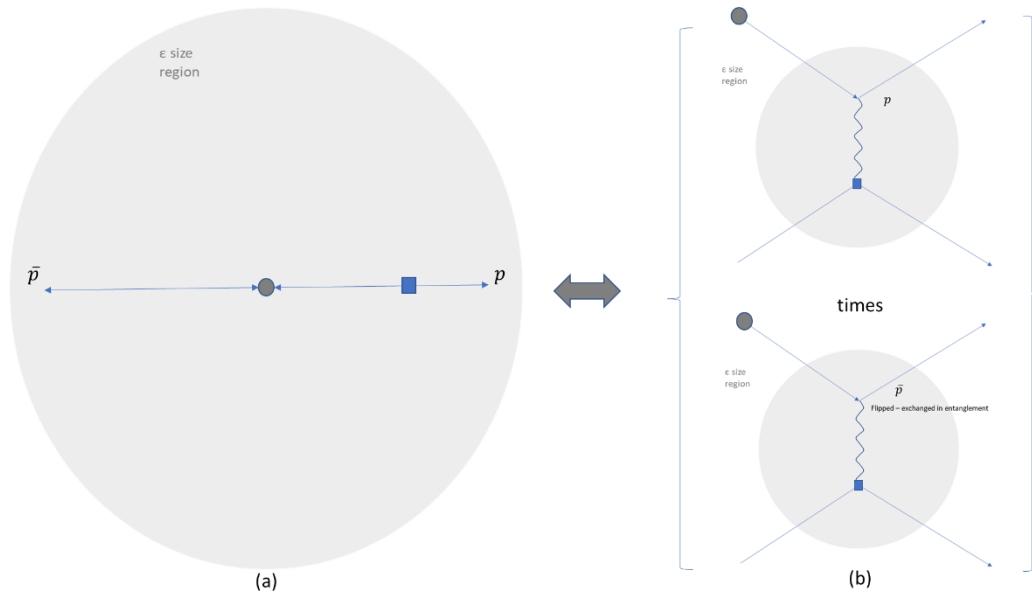
Figure 3: This figure comes from [13]. (a) sketches a pair of entangled particle and anti-particle that are emitted by the source (grey) as encountered on the mapping support (blue square) [1]. (b) shows that within the scattering ε region, the interaction can be with the virtual particle, or its entangled anti-particle moving in the opposite direction from (a). It results that multi-fold gravity scattering amplitude is indeed the square of the kinematic scattering amplitude of the corresponding SM particle. It is a product because uncertainty and "switch" are therefore rendering kinematics independent of each other's, within the uncertainty region.

6.5 Any universe with double copy can use this

The double copy behavior of (super) Yang Mills[12] scattering Feynman diagrams, and its microscopic interpretation, applies also in non-multi-fold universes[13]. It is our inspiration starting point for what comes next.

On the flip side of it, as it also hints at multi-fold mechanisms, it motivates our discussion of potentially explaining GR in AdS(5)(+…) as in [circ, embed]. So far we had just assumed that it was needed explain GR reigning in AdS(5), after ensuring that GR was recovered this way in 4D spacetime. It is important to consistency check for such reasonings.

7. Revisiting the AdS/CFT Correspondence Conjecture

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[12] Or more generally, Gauge theory.

[13] Indeed the double copy is well established in conventional Physics, i.e., as in non-multi-fold Physics. Our reasoning is that in all these cases, we have actually multi-fold mechanism behind, and these theories will also encounter multi-fold as did GR and Yang Mills respectively in [1,6] and [12,13]. It matters. As mentioned later, this is the true reason why we can also consider muti-fold to explain GR in AdS(5)(+…) [16,32].

Armed with the results discussed above, let us go back to the AdS/CFT correspondence conjecture. In this section, as already mentioned, we do not assume that any multi-fold physics is involved.

If we revisit the derivation of the AdS/CFT correspondence conjecture, as discussed in section 2, one can see that it fundamentally relies on the introduction of a dark brane, as the result of the accumulation of N -> ∞ branes with a CFT in each. N -> ∞ really only ensures that the CFT degrees of freedom match the ones of superstrings.

At this stage, we would recommend considering that N rather corresponds to N Yang Mills particles rather than N colors, saving the honor of strings physicist from the joke that claims that, for them, 3, as in 3 colors in QCD, amounts to infinite. After all, in the derivation and application of the correspondence, not much use is made of the colors or Yang Mills interactions, other than acknowledging the gauge behavior, and maximal supersymmetry (to match the symmetries of the superstring and supergravity in AdS(5)(+…)).

We suspect that the original derivation approaches did not rely on particles because of the view that particles would not be relevant to quantum fields: fields would only what matters. We disagree with such a view, as discussed in [1,13,29,20,39]. A reader not willing to take that point of view should still be able to repeat most of the analysis below with fields and colors.

7.1 The AdS/CFT$_{2CG}$ Correspondence Conjecture

Because none of the colors or interactions behaviors of Yang Mills are really needed to obtain any of the results in sections 2 to 4, we argue that the key behavior relevant to the conjectures or dualities discussed in section 2 to 4 comes from the double copy behavior of Yang Mills scattering: yes CFTs, as modeling renormalized Yang Mills, contain a model of gravity: the double copy behavior. So one can repeated the derivations of sections 2 and 3, and even 4, with respect to the double copy gravity.
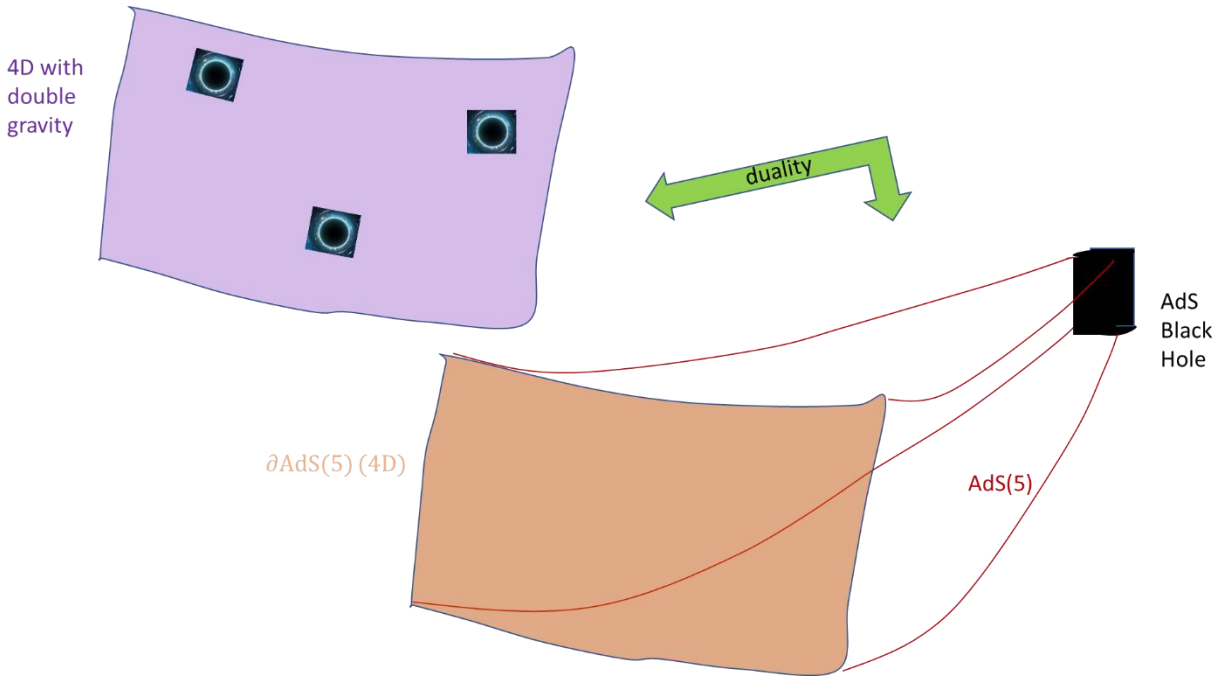
Figure 4: It illustrates the AdS/CFT$_{2CG}$ correspondence conjecture where CFTs are replaced by gravity sources, which can be seen as microscopic black holes, where particles are located. It is represented as a non-physical duality but could also be a geometrical and physical duality.

An astute reader could take exception to one step: the assumption that the duality exists at all couplings, on the basis that Yang Mills are renormalizable (as CFTs), and therefore the stability and validity is used in [14-16]. With gravity as QFT/EFT, we do not have renormalizability, and asymptotic safety is disputed. See [52-53], and references therein.

To that point, we want to rely on the reasoning of holographic renormalization [33], that we discussed in [32]. Accordingly, we can assume, without relying on [1,52,53], that gravity is asymptotically safe in AdS(5) and its boundary, and it can be renormalized as proposed in [33]. The argument of validity across all coupling level can now be repeated. Alternatively one can rely on [1,52,53], that we argue to also apply to a non-multi-fold universe, especially on the basis that any consistent theory of quantum gravity seems to predict a 2D regime at very small scales [75]. For now this (asymptotic safety of gravity) is our assumption in this paper and it is the assumption behind the new proposed conjecture within the scope of this paper. It is also reinforced by the fact that that there is a known formulation for the non-perturbative double copy duality that ensure that the duality also exists non-perturbatively and therefore can map the Yang Mills CFTs to something well defined for gravity [13,77].

This way, we now have an equivalent AdS/CFT$_{2CG}$ correspondence conjecture, where 2CG stands for double copy gravity as interaction, or field, in the CFT$_{2CG}$ 4D spacetime 4D spacetime: CFTs are the (UV) fixed point of Yang Mills obtained by regularization and renormalization, which amount to running the coupling constants [76]. To build CFT$_{2CG,}$ one starts from the Yang Mills theory and replace ever order with the dual copy dual. Running the correspondent coupling constants on these, which does not affect the dual scattering diagrams per se as there is a non-perturbative version of the double copy duality [77], as already mentioned, we obtain the CFT$_{2CG}$. It is a fixed point because it is the convergence of the different functions considered to run the constants with Yang Mills, and hence also for the double copy gravity, which therefore also has a UV fixed point[14]. This point is the projection

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[14] This is a new way to prove asymptotic safety of gravity / GR in 4D from the conventional approaches, e.g. truncated flows [66,67-69,71], and our proof [52,53]. It is also why 3D gravity is asymptotically safe. An even more

from the non-renormalized UV divergence (limit) onto the set of manifold of theories built on the IR double gravity, by say different runs of the coupling constants: the critical surface of GR (when only involving massless sources) [66]. *(Note added on April 8, 2023: See also the scalar discussion in [13]).* Alternatively, it is the transformation of CFT$_{YM}$ via the duality changes of section 5 in [77], which leads to the same CFT$_{2CG}$. Both definitions are equivalent. We do not know what it is exactly, unless if we accept the multifold theory [1], or [6], or we would have resolved the quantum gravity problem, but this way we know that the UV fixed point exists along with a critical surface for GR. A more detailed proof will be provided in an upcoming paper. (*Edit on May 5, 2022: See [117] for this proof*). Note that we could also argue taking the non-perturbative double copy gravity version [77], mentioned above, in case there are still doubts with the different ways to look at the limit, as presented so far in this paragraph.

Note that our derivation as in [16], and section 2, using Yang Mills in a neighborhood of the 4D spacetime now directly matches the reasoning done in say 2D+ε, as in [54], and therefore its usage for 4D+ε should not draw particular concerns. After all, the string community has been argued that AdS(5)(+…) has (perturbatively) renormalizable superstrings, which happens to also be an window on the M-theory, allegedly a non-perturbative theory; it's its whole reason for being. See [55] for some of the original thoughts on this. So, if you approach it from a superstrings point of view, it is not even an issue. However, as mentioned in [32], the reliance on superstrings as sources, and [33] to renormalize CFT gravity, à la asymptotic safety, may then lead to inconsistencies, as being incompatible with SM related CFTs on the 4D spacetime per [52,53], and references therein. Hence our desire to not depend on superstrings for the derivation of the new conjecture, and us pointing out the UV fixed point arguments instead. Note also that our use of [33] in the previous section was to repeat the AdS/CFT reasoning of section 2, and tolerate gravity on the branes in such a reasoning, not so much to argue renormalizability and asymptotic safety, even if that is also a consequence as discussed in [32,33]

In this AdS/CFT$_{2CG}$ correspondence conjecture, entanglement in the 4D CFT$_{2CG}$ spacetime must now come from the derived double copy gravity. The 4D CFT$_{2CG}$ are to be understood as the asymptotic safe version of the theory obtained by applying the double copy duality on every Yang Mills scattering Feynman diagram at every order, and so it can also be modeled as CFTs, and can be perturbatively modeled, especially at lower energy, per the dual copy, just as we see Yang Mills CFT perturbatively modeled, especially at lower energy, with Yang Mills scattering Feynman diagrams. Alternatively it results from the non-perturbative formulation of the duality [77]. Because it is an asymptotic result, CFT$_{2CG}$ may not be conformant fields across energy scales. This explains why the section 7.3 does not require supersymmetry anymore without contradictions: it is consistent. CFT$_{2CG}$ is therefore a notation, not implying that the fields are actually conformant CFTs. The reader may also be interested in the discussion of section 8 in [78] on gravity and conformal symmetry, if conformance is of interest.

If we assume that the CFT$_{2CG}$ spacetime is populated by related particles, they are the sources of the double copy gravity potential. Considering particles as point particles, then the reasonings of section 7.5, 9/9.2 in [1], [4], and references therein, the sources behave as a microscopic black hole, which will give sizes which are typically the largest of its horizon, Compton length, and the uncertainties region due to the uncertainty principle. External curvatures of these black holes in the 4D spacetime define the tangent dual AdS(5) space [1]. Readers who do not like the reference to particles can simply revert to Dirac function (typically blunt and spread out depending on the field density) as field sources. But we are intent on referring to particles because that is what they are and our point of view on the topic [1,13,29,39].

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interesting aspect is that this proof derives from M-theory, and therefore superstrings; considering that the main objections so far to the asymptotic safety of gravity came from the string community, as well as how such a result impact compatibility of the M-theory, superstrings, supergravity, supersymmetry and most GUTS or TOEs, with the SM [52,53,*120*]. This result renders these objections moot. *Note added in April 8, 2023: [117,120] expand in more details on this result.*

Entanglement in CFT_{2CG} comes from (past) double copy gravity interactions. And, per [13], (copy double) gravity comes from entangled particles (virtual or real). Of course that result is also encountered in multi-fold theory [1,11,35,36].

All results and dictionaries of the conventional AdS/CFT correspondence conjecture can be translated to correspondences between AdS(5)(+…) bulk gravity and double copy gravity in 4D, somehow another version of holography.

Per section 3, adapted to the AdS/CFT_{2CG} correspondence conjecture, entangled sources, associated to different entangled CFTs, in different branes in Maldacena's derivation, are actually black holes in AdS(5) connected via wormholes. With particles, or field sources, as microscopic black holes, when entangled they are linked by wormholes. When entangling massive fermions, [56] can be used to ensure that such wormholes can be stable and traversable at least to path integral paths. Reusing the references used in [16,40,*123,132*], other effects can also play like rotation, dark energy/Casimir effects etc.

The AdS/CFT_{2CG} correspondence conjecture is illustrated in Figure 4.

It is a conjecture where the AdS/CFT correspondence is a conjecture, and it is factual where the AdS/CFT correspondence is factual. Of courses, there may be some cases where gravity could make it factual on its own.

7.2. The AdS/CFT_{YM2CG} Correspondence Conjecture

It is possible to consider a case where the scatterings now include all the Feynman diagrams of CFT_{YM} and CFT_{2CG} to create the AdS/CFT_{YM2CG} Correspondence Conjecture, as the combination of the conjectures of sections 2 and 7.1. They can be intuitively understood as adding together, per order of number of particle involves and loops, the respective scattering amplitudes from the Feynman diagrams (or working off the non-perturbative duality [77]). Again, asymptotic safety is addressed and assured as in section 7.1.

With respect to section 7.1, entanglement can now come from (past) particle interactions. The potentials derived from the C2G correspondence, add to the (generalized) Yang Mills potentials (e.g. see [17]).

Particles, or field sources, are now leading to charged or colored black holes.

For the rest, we obtain the same results as in sections 2 and 7.1.

It is a conjecture where the AdS/CFT correspondence is a conjecture and factual where the AdS/CFT correspondence is factual. There may be some cases where gravity could make it factual on its own, e.g. by enabling the duality to become physical (and geometrical) as discussed in the next section.
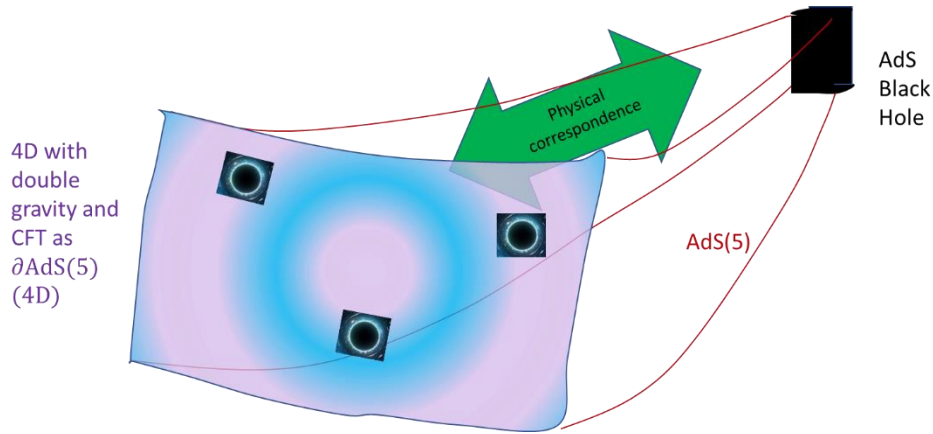
It is illustrated in figure 5.

Figure 5: It illustrates the AdS/CFT$_{YM2CG}$ correspondence conjecture where CFTs are also associated with additional gravity sources, which can be seen as microscopic colored black holes where particles are located. It is represented as a geometrical and physical duality where the CFT + gravity 4D spacetime is the boundary of AdS(5), i.e., ∂AdS(5)

The change from double copy gravity only scattering to Yang Mills and gravity may actually be a duality symmetry breaking that occurs from the Ultimate Unification (UU) regime [72,120,121] to lower energy regimes [13]. We may study this further in future papers.

To a large extent, ignoring the microscopic black holes on the 4D spacetime, this is the most realistic and complete version of the holographic principle typically associated to the AdS/CFT correspondence conjecture so far.

As for section 7.1, CFT$_{YM2CG}$ is also a notation, not implying that all the fields are conformant CFT fields.

7.3. Supersymmetry or not?

The conventional AdS/CFT Correspondence Conjecture is supersymmetric because it is fundamentally a (non-perturbative) supersymmetric result, and a window into the M-theory, which is supersymmetric. However it is a duality, and not a geometrical or physical picture: the CFT spacetime is not the boundary of AdS(5)(+…), and it is not dS. It is instead a flat spacetime without gravity related via the duality to AdS(5)(+…). [33] can make it a geometrical solution as dS boundary to AdS(5), where gravity can exist, asymptotically safe, but it is null. Even that leads to the inconsistencies of incompatibility with the SM discussed in [32,52,53,67-69,79,117,*120*]. In addition, we encounter another related inconsistency: SUSY can't exists in a dS spacetime (asymptotic dS or with positive cosmological constant). See equation (2) in [40]. It is a generic theorem, and it means that in such a case to be physical, supersymmetry must be broken. See [40,70] and reference therein.

However our Yang Mills leakage derivation, of section 2, can repeat the derivation of an AdS/CFT correspondence with Yang Mills fields instead of super Yang Mills. Doing so, we solve the incompatibilities with SM and dS. It is allowed, as we saw in section 7.1 and 7.2 that, in the presence of gravity, CFT$_{2CG}$ or CFT$_{YM2CG}$ are not necessarily conformant anymore.

Therefore, we believe that in the presence of double copy, the AdS/CFT$_{2CG}$ Correspondence Conjecture and AdS/CFT$_{YM2CG}$ Correspondence Conjecture should be considered with Yang Mills fields and CFT instead of supersymmetric fields.

The supersymmetric versions remain mathematically correct, albeit in our view potentially unphysical, with supersymmetric Yang Mills: the dualities without geometrical and physical interpretation are valid or can map to flat spacetime as for the AdS/CFT correspondence conjecture.

The reader will note that, in conventional Physics, CFT$_{YM2CG}$ looks like a AdS/CFT correspondence that can factually applies to our universe. More on this in the upcoming sections.

8. Key aspects of the Multi-fold theory from AdS/CFT$_{YM2CG}$ Correspondence Conjecture
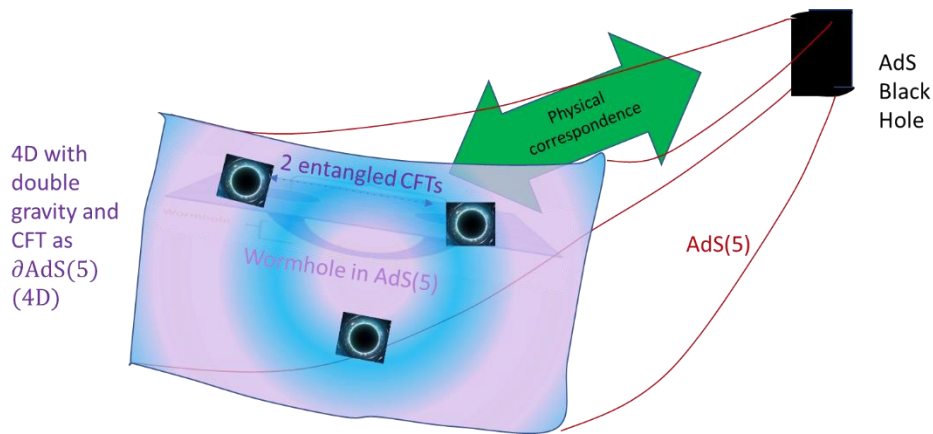
Figure 6: The AdS/CFT$_{YM2CG}$ Correspondence Conjecture implements multi-folds with wormholes.

Section 7, recovers some key multi-fold results. However before enumerating these, we need to remember that, as we discussed in [13], encountering wormholes playing / implementing aspects of multi-folds, does not mean that multi-folds are wormholes. They might be or not. Theories can only give hints to the limits of what they can model and therefore describe them using only concepts that they contain. We already encountered that in [1,16,29-32].

We have obtained, relying on the double copy of Yang Mills and the original AdS/CFT correspondence conjecture that:

- i) Particles are charged or colored (any relevant quantum charge) microscopic black holes in the CFT$_{YM2CG}$ spacetime. They may be neutral for some interactions (e.g. electromagnetism, vs. weak, vs. strong interactions).
- ii) Entangled particles have these microscopic black holes connected via wormholes, as illustrated in Figure 6.
- iii) Gravity from Yang Mills double copy can now be present, asymptotically safe, in the CFT$_{YM2CG}$ spacetime, and it is implemented by entangled particles as in [1,12,13]. Therefore, gravity, as modeled by the double copy, comes from entanglement. We already knew that from [1,11,35,36].

These are results of the multi-fold theory:

- i) matches spacetime reconstructions results in [1,6]
- ii) matches the multi-fold core mechanisms that may be implemented by wormholes or other equivalent multi-fold mechanisms [1,6,16].

- iii) implies that entanglement produces gravity [1,11,36]. In particular, entanglement between real particles creates gravity fluctuations, and gravity results from the entanglement of virtual pairs of particles and anti-particles emitted by a source of energy. We recover the E/G conjecture [11,31,32]. Entanglement produces gravity effects and gravity results from entanglement [1,11,36]. Effects are massless are large scales with massive gravity effects at the scales of the SM [1,35].

In addition, while outside of what is modeled here, with entangled massive fermions at both sides, the wormholes can be traversable [40], completing the ability to implement multi-fold mechanisms. Additional effects like rotation, dark energy, Casimir effects etc. can help [16,40,*123,132*]. When involving wormholes, it is possible to show that GR reigns in AdS(5) [21], as expected, and consistent with [1,16,29-32].

The double copy behavior of Yang Mills scattering allows us to reintroduce renormalized, or rather asymptotically safe, gravity in the 4D flat, or (asymptotic) dS spacetime that is boundary to the AdS(5). Doing so reveals a multi-fold universe where the AdS/CFT correspondence, ER=EPR and the E/G conjectures are factual and the SM is actually SM_G, as all the results that led to it can be repeated [1,8-10].

In multi-fold universes, all these new (and older) conjectures are factual.

With CFT_{YM2CG} not necessarily a conformant field in the presence of gravity, we explain also why AdS/CFT can popup as it does in the multi-fold theory, without conformant fields, nor supersymmetry ,and therefore live in a universe with positive curvature, or positive cosmological constant, which can be seen as asymptotic dS. This explains what otherwise might have remains a mystery when linking the conventional AdS/CFT correspondence conjecture and the factual version of a multi-fold universe. It is in our view the correct way to conventionally (i.e., even without multi-folds) extend the AdS/CFT correspondence conjecture to a dS/(C)QFT correspondence.

9. SM_G

In particular, with AdS(5) tangent dual to spacetime, and traversable wormhole as multi-folds, we can repeat the derivation of the SM from space time matter induction and scattering and entry points of the multi-folds [32,37,38]. Indeed the 5D (or actually 7D, but it's essentially 5D) extensions are visible only in an infinitesimal ε region.

There, it does not matter than the embedding space is (asymptotic) dS or AdS [32]. In fact [33], showed that when renormalizing, the induction equations of the space after holographic renormalization match the 5D Ricci flat equations, used in [37] and references therein. Chirality conundrum is similarly managed as in [37].

10. Conclusions

The paper introduces two new families of AdS/CFT correspondences derived from the conventional AdS/CFT correspondence conjecture, built by relying on the double copy behavior of Yang Mills or gauge theories: the AdS/CFT$_{2CG}$ correspondence, and the AdS/CFT$_{YM2CG}$ correspondence. Depending on the context they can be conjectures or factual. In particular, the latter is a good candidate for a geometrical and physically factual correspondence in the real universe, with non-supersymmetric fields and dS CFT spacetime (with gravity). We also note that CFT$_{2CG}$ and CFT$_{YM2CG}$ are fields that may not be conformant: they involve asymptotically safe UV fixed

points with possibly non-conformant behaviors across energy scales. This is key to allow non-supersymmetric cases, including the factual AdS/CFT correspondence encountered in multi-fold universes.

We can apply other conjectures derived from the conventional AdS/CFT correspondence conjecture to the AdS/CFT$_{YM2CG}$ correspondence, like ER =EPR and the correspondence between entangled CFT and AdS blackholes connected as wormholes. From the blackhole / double copy duality applied to the new conjectures we also obtain that CFT field sources, i.e. particles, are surrounded by blackholes and connected by wormholes when entangled. Traversability of wormholes is also addressed when entangled particles are massive fermions (or massless for exchange of massless particles and possible infinitesimal paths of path integrals), or if we can assume that entangled fermions are in the wormholes as with right-handed neutrinos and their anti-particles in multi-fold universes.

All these conjectures do not require any multi-fold assumption. In particular they apply to the M-theory and superstrings, and can be used whenever the AdS/CFT correspondence conjecture is used. The composition of the double copy duality with the conventional AdS/CFT correspondence conjecture, seems to be a first, which frankly surprises us. It may come from the reluctance of many physicists to work with particles, consider gravity as asymptotically free, deriving AdS/CFT correspondence conjecture with minimum/no supersymmetric or superstring dependencies, or believing that wormholes can be traversable.

With this, we recover multi-fold mechanisms, multi-fold gravity due to entanglement and the E/G conjecture. All this allow us to rebuild the multi-fold theory and the SM$_G$.

In other words, the multi-fold theory is encountered in the AdS/CFT correspondence conjecture, a window on the M-theory, the non-perturbative version of superstrings and supergravity. This result is both expected as we had already encountered multi-fold in quantum gravity [5], in GR at Planck scales [6], in QM [7] and in Yang Mills theory [13], and multi-folds also encountered hints of AdS(5) tangent dual to the multi-fold spacetime where superstrings can live, especially ~gravitons as closed strings. But its also surprising as we have argued the non-physicality of supersymmetry and superstrings (and gravitons [1,16,48,49]), and at time the obviousness of some of their results [1,16]. In any case, discovering that the multi-fold theory is non-perturbatively contained in the M-theory is quite a result, and a bit ironic []. We take as a reinforcing hint that it is worth investing in further analyzing what the multi-fold theory entails.

In the paper, we have also derived interesting results like new derivation of AdS/CFT correspondence conjecture, renormalizability or asymptotic safety of leaked gauge / Yang Mills fields as well as a different proof that gravity derived from GR is asymptotically safe.

We argue that the AdS/CFT$_{YM2CG}$ correspondence and its derived dualities are factual in our real universe, not just in multi-fold universes. It provides a dS/(C)QFT correspondence better suited to our real universe.

Eventually, explaining the possible relationship of Ultimate Unification (UU) symmetry breaking as a (extended) switch from AdS/CFT$_{2CG}$ Correspondence to the AdS/CFT$_{YM2CG}$ correspondence is also a very important hypothesis.

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