A Non-perturbative Proof of the Asymptotic Safety of 4D Einstein Gravity, With or Without Matter

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Abstract:

Today, two distinct camps exist in the Physics community: those who believe in the asymptotic safe gravity program for gravity, and those who don't. Not many physicists are undecided, even if those who claim not to care. It is a polarizing topic, and nobody seems to ever be really convinced by the arguments of the others. Add to this, the existential threat potentially posed by asymptotic safety to the physicality of supersymmetry, supergravity, superstrings, M-Theory, and many of the popular GUTs and TOEs out there, and one can understand why the question of asymptotic safety of gravity is often either viewed as critical, or dismissed as irrelevant. Yet, the asymptotic safety program has claimed indications that gravity may be asymptotically safe. So far, none are definitive, and most are derided by the other camp.

In the context of the multi-fold theory, we have shown that multi-fold gravity is asymptotically safe. Using arguments, that gravity is 2D at small scales, something agreed upon by most consistent theories of quantum gravity, we inferred that gravity is most probably asymptotically safe, even in non-muti-fold universes, and yet, we could manage to save superstrings as relevant around that 2D regime, while (mathematically) living in a tangent dual space.

More recent results reinterpret the double copy duality and behavior of Yang Mills scattering to i) defined new AdS/CFT dualities, ii) encounter gravity as part of Yang Mills theory, iii) and encounter the multi-fold theory in both Yang Mills Actions, and in M-theory, through the AdS/CFT correspondence conjecture.

Part of these previous works led us to announce that the AdS/CFT correspondence conjecture implies that General Relativity (GR) – based gravity is indeed asymptotically safe in a 4D spacetime. In the present paper, we detail such a non-perturbative derivation for GR-based gravity, and for GR-based gravity with. It does not require faith into evolution of time series, 2D processes, nor a priori multi-fold assumptions. In other words, the proof applies to Einstein gravity, in general, for conventional Physics, as well as for multi-fold universes.

The paper also discusses considerations on why arguments, presented so far, against the asymptotic safety of gravity program would have been flawed, and, in particular, it shows how our proof is not affected by the Gribov ambiguity concerns, which does not apply to gravity + SM or SM_G matter. Also supersymmetric matter are not asymptotically safe in 4D. Higher dimensions are also confirmed incompatible.

2. 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 and standard cosmological model mysteries without requiring New Physics beyond the Standard Model other than the addition of non-negligible gravity to the Standard Model

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Lagrangian and / or multi-fold mechanisms. All this is achieved in a multi-fold universe that may well model our real universe, which remains to be validated. See [1,75-78,*150*] for more.

Note added on April 28, 2023: references in italic have been added on April 28, 2023.

And so, accordingly, in a multi-fold universe, gravity emerges from entanglement through the multi-fold mechanisms [1]. As a result, gravity-like effects appear in between entangled particles, whether they be real or virtual [1,15,32]. Long range, massless gravity results from entanglement of massless virtual particles [1,15,105]. Entanglement of massive virtual particles leads to massive gravity contributions at very smalls scales [1,15,105]. Multi-fold 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 [1,4,6,20,59,86,95,106,*157,170,180*]. By resulting from past random walks of particles, spacetime appears 2D at very small scales. Spacetime locations and particles can be modeled as microscopic black holes (Schwarzschild for photons, and concretized spacetime coordinates, and metrics between Reissner Nordström [2] and Kerr Newman [3] for massive, and possibly charged, or colored, particles – the latter being possibly extremal). 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 models in a multi-fold universe. The massive particles are in fact condensates of massless Higgs bosons into the black hole solitons regularized by this process [1,4], while the massless particles and above the gravity electroweak symmetry breaking energies are the results of random walk patterns of the massless Higgs bosons, according to the solitons that are the outcome of multi-fold space time matter induction and scattering, analogous to some extent to (unconstrained) Kaluza Klein mechanisms [1,4,94,95,122,124,125,131,*151,155,157,164,167,180*]. The SM, or rather SM_G, symmetries, particles and interactions are dictated by these mechanisms [*151,164,167*].

All these recover General Relativity (GR) at large scales and semi-classical models remain valid till smaller scale than usually expected [1,6]. Gravity can therefore be added to the Standard Model resulting into what we define as SM_G , the SM with gravity non-negligible at its scales [1,75-78,*150*]. 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 [1,4-7,15-20,25,28-30,32,59,75-79,86,87,94,95,99-*170,176-180*]. 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 [1,75-78,*150,164,170*]. 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.

Multi-folds are encountered in GR, at Planck scales [5,6], and in Quantum Mechanics[2] (QM) if different suitable quantum reference frames (QRFs) are to be equivalent relatively to entangled, coherent or correlated systems [7]. This shows that GR and QM are different facets of something that they cannot well model: multi-folds. With the double copy behavior of Yang Mills scattering Feynman diagram [8-14], we also showed that multi-folds and the E/G conjecture [15] are contained in Yang Mills theory, and that Yang Mills models gravity, as far as, a duality [16,17,81]. New AdS/CFT conjectures can also be derived [18].

The present paper starts from a quick review of different relevant dualities: the double copy duality, the AdS/CFT correspondence conjecture, and our new versions of it introduced as AdS/CFT_{2CG} and AdS/CFT_{YM2CG}, the latter being, in our view, well suited to characterize our real universe [18]. We rely on them to create a mapping between Yang Mills in a 4D spacetime without gravity, and a 4D spacetime with the dual copy gravity. It provides the basis for a proof that the Yang Mills trivial UV fixed point defines a UV fixed point for double copy gravity, which is Einstein gravity at very high energy, or very small scale, when everything is massless.

[2] Standing in for Quantum Physics in general.

Note added on April 28, 2023: While it does not really matter, as UV regime is always at such very energies, in [170], we explain the massless scalar appearing in the double copy in the massive regime as the Higgs in the multi-folds, which acts as dilaton for the multi-fold mechanisms dynamics and kinematics. With this, the statement that we are working with Einstein GR-based gravity extends to the massive regime. But all this confirms that our results refer to the same theory as the one investigated with the truncation flow method [21,52] and underlying FRGE [97,98].

Then, we revisit the implications of such a proof of asymptotic safety of gravity, without many additional assumptions, in terms of the implications and challenges to supersymmetry, supergravity, superstrings, M-Theory, and many of the popular GUTs and TOEs based on [19,20,*157*], and references therein.

Also, we briefly investigate what went wrong in the main counter arguments presented so far against asymptotic safety of gravity, including in particular the Gribov ambiguity concerns. At this stage, we consider that these arguments are moot: it is no more about the unknowns of the truncation flow method [21,52] and underlying FRGE [97,98]: our proof does not depend on any of those, but only on the double copy duality that we know to work across a large set of Yang Mills and super Yang Mills theories and gravity theories.

*Note added on April 28, 2023: With 2D random walks, we confirm that matters like the SM does not change our conclusions in terms of asymptotic safety, or similar results already obtained in [19,20,87] and references therein. In [170], we provide additional justification for the massless scalars encountered in the duality even in the presence of massive particles: it reflects the role of the Higgs appearing in the multi-folds [1,*75-78,107,146,*150,157], as dilaton associated to the multi-fold kinematics and dynamics, and the multi-fold space time matter induction and scattering [1,4,94,95,122,124,125,131,151,155,157,164,167,180].*

2. The AdS/CFT correspondence conjecture and our perspective

The AdS/CFT correspondence conjecture was introduced by Maldacena in [14]. Since, it has dominated the field of superstrings, and it is considered as the most concrete window on M-theory, and as non-perturbative theory of strings and gravity [23,24].

[16,18,25,28,29,131] provide a summary of the derivation of the conjecture, with some twists, and variations, coming from our multi-fold work, which allow us to avoid having to assume supersymmetry, absence of gravity and superstrings at every step of the derivation. [1,20,25,28,29] encountered a factual relationship between the multi-folds and AdS (5), which leads us to state that the conjecture is factual in multi-fold universes.

According to the AdS/CFT correspondence conjecture, maximally supersymmetric CFT on 4D flat spacetime without gravity is dual of strongly coupled AdS(5) (+…)[3] 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)(+…), except that it isn't because of the inconsistencies that exist between curvature and zero gravity. It is illustrated in Figure 1.

[3] Per [25], 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 [23,24,26,27]. In these papers, we see why the focus on AdS(5) is sufficient for the rest of the discussions, and for the AdS/CFT correspondence conjecture in general. However, 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 want to add this term, if/when we want to discuss superstrings living in AdS(5) (+…), and approximating some of the multi-fold properties [1,25,28-30,78,*170*]).

Multiple other correspondences and conjectures have been derived from the AdS/CFT correspondence conjecture [14], including:

- The correspondence of two entangled copies of CFTs and AdS back holes [33].
- The ER=EPR conjecture [34].
- The GR=QM conjecture [35].
- The AdS/QCD conjecture [24].
- The AdS/CMT conjecture [24].
- Gravity / fluid correspondences [24].
- AdS black hole properties [24].

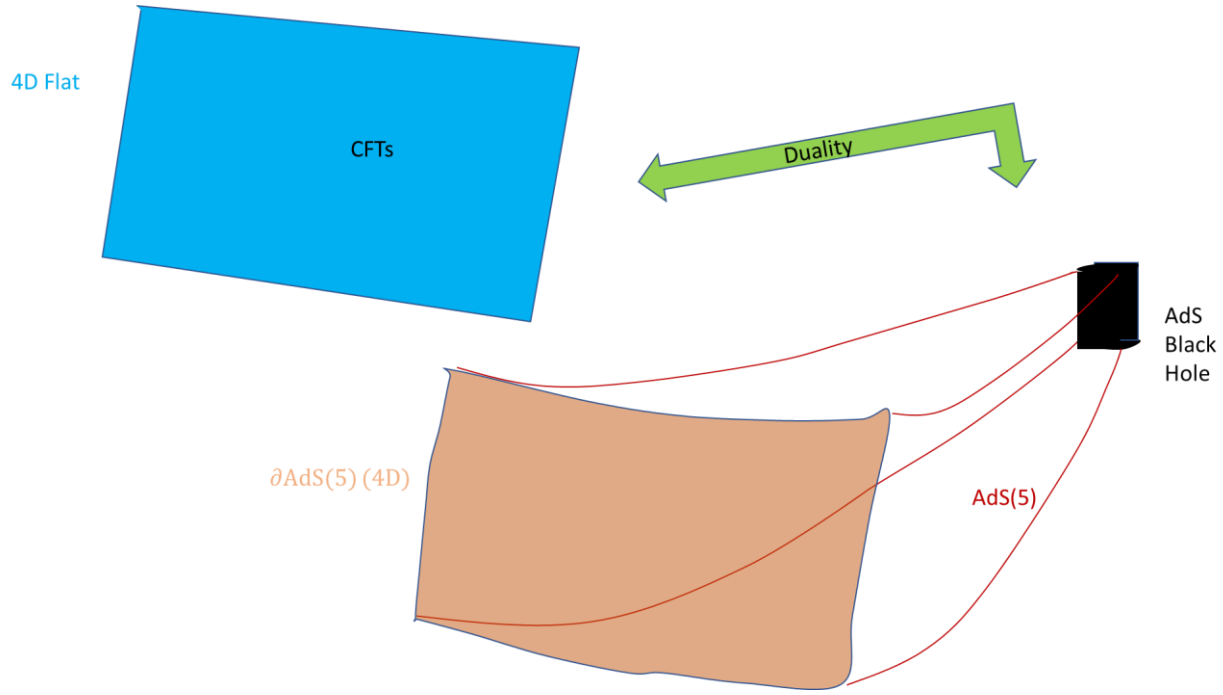

Figure 1: AdS/CFT correspondence conjecture from [23] between correspondence between a flat 4D spacetime (no gravity) with CFTs gauge fields, and AdS(5) space with bulk gravity. It is not a physical and geometrical correspondence, but rather a mathematical duality between the blue CFT domain, and the brown bulk gravity and its objects.

We have provided some derivations, analyses, and multi-fold considerations for some of these conjectures in [1,6,20, 25,28,29,131].

3. Double copy behavior of Yang Mills scattering

3.1 Scattering

The double copy behavior of Yang Mills scattering Feynman diagram has been known for a little more than 10 years, and starts to be well understood [8-12,14,81]. 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 diagrams define a theory of gravity. It covers many scenarios, important to us is the validity for Yang Mills, and Super Yang Mills (SUSY), as well as for super gravity (SUGRA). Degrees of freedom differences may result into additional massless scalars when scatterings involve massive particles, but in massless case it is pure GR.

Note added on April 28. 2023:

In [170], we link the massless scalar as a dilaton which explains why the Higgs Boson appears in the multi-fold to match the effects of the multi-fold mechanism dynamics and kinematics, in the context of the multi-fold space time matter induction and scattering. Witt this, we can now really argue that the double copy gravity is indeed pure Einstein GR, including in the massive regime, as we can explain the only potential source of discrepancy, the massless scalar, as the massless Higgs boson which is also always present in the multi-folds.

The dual copy of the classical action, and Lagrangian, are discussed in [81]. It provides clear duality rules.

3.2 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 [13,31].

With the double copy, one understands that Coulomb potentials (for electromagnetism (EM), and Yang Mills (YM) generalized potential scan be derived from gravity potential gravity, e.g., think à la Newton, for point colored/charged particles [8], or black hole metrics [13].

3.3 Gravity and Yang Mills

Throughout the AdS/CFT literature, many authors always wonder at the fact that gauge theories contain and model gravity. [1,25,131] 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 (superstrings leading to GR and YM, and AdS/CFT correspondence) should have been expected. But instead such properties were rather considered as divine signs anointing superstrings, and so such relationships between Yang Mills and Gravity came as a total surprise to many in the Physics community. One can also look at how Kaluza Klein, besides it conventional instability problems, uses gravity to be able to induce and recover all the SM interactions, ignoring for example stability issues when quantization takes place *as discussed in [167,170,178]*. See [131] and references therein.

The same is true for the double copy behavior of Yang Mils scattering Feynman diagram vs. gravity scattering Feynman diagrams. Again our results from [1,25,131] in terms of the actions make such results [16-18] quite plausible. No surprise at the existence of a double copy 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[4].

[4] We speak of different spacetimes, in that latter case, because gravity modifies the spacetime manifold, at least at large enough scales. So speaking of the same spacetime could arguably be confusing.

As the double copy was discovered after the AdS/CFT correspondence conjecture, and its correspondence dictionary, including for entangled CFTs, one would have expected again that the double copy should not have been a surprise on that basis alone. Yet, as far as we know, we have not find any dedicated publication or work considering such an angle or really combining the dualities, until [18], and the present paper.

3.4. Microscopic justifications

[16,17] provides a microscopic justification for the double copy behavior of the Yang Mills scattering Feynman diagrams: gravity results from scattering of a pair of, real or virtual, entangled particles[5].

It is illustrated in figure 2.

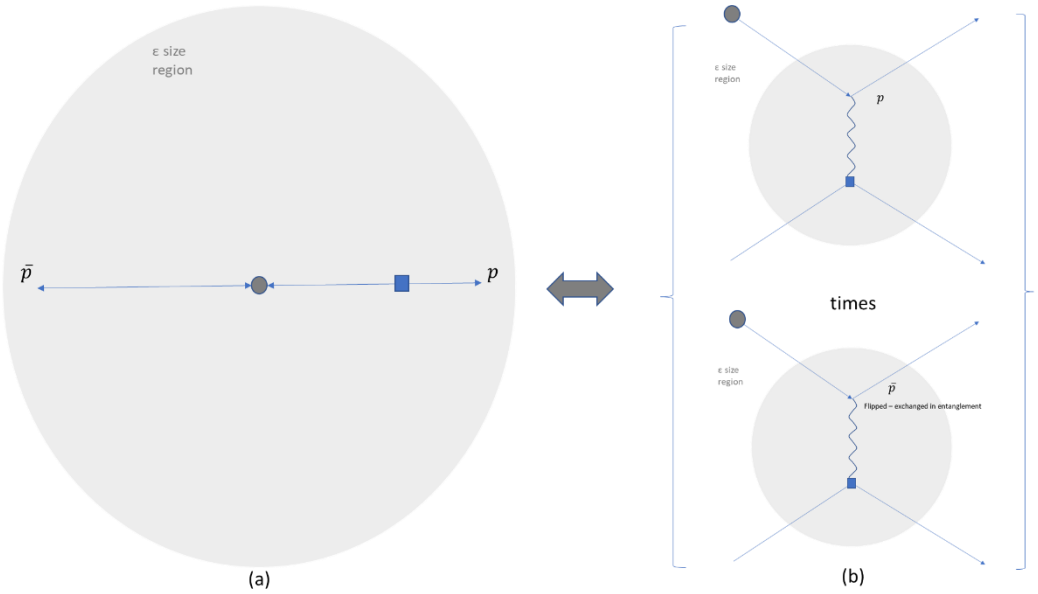

Figure 2: This figure comes from [17]. (a) sketches a pair of entangled particle and anti-particle that are emitted by the source (grey) as encountered on the mapping support (blue square) [1]. (b) shows that within the scattering ε region, the interaction can be with the virtual particle, or its entangled anti-particle moving in the opposite direction form (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 "switches" are therefore rending kinematics independent of each other's, within the uncertainty region.

This microscopic interpretation, shows the multi-fold mechanisms behind gravity [17]. Without invoking multi-folds, one can consider that the figure implements the E/G conjecture (factual in multi-fold universes), that gravity results from entanglement, and entanglement produces gravity effects [1,15].With [5-7], and all the success to qualitatively explain many open challenges of the SM and ΛCDM

[5] This result is also immediately consistent with the multi-fold theory [1,32], and the E/G conjecture [15].

[1,4-7,15-20,25,28-30,32,59,75-79,86,87,94,95,99-*170,176-180*], with multi-folds and the SMG, we see hints that our real universe may be multi-fold. However, we will not depend on this to derive what comes next.

3.5 Any universe with double copy can use this

The double copy behavior of (super) Yang Mills[6] scattering Feynman diagrams, and its microscopic interpretation, apply also in non-multi-fold universes[7]. In fact, it is the inspiration for our starting point for what comes next.

4. New AdS/CFT Correspondence Conjectures

4.1 The AdS/CFT_{2CG} Correspondence Conjecture

Because none of the charges/colors, or interactions behaviors of Yang Mills are really needed to obtain any of the results in sections 2, we argue that the key behavior relevant to the conjectures or dualities discussed in section 2 comes from the double copy behavior of Yang Mills scattering: CFTs, as modeling Yang Mills, contain a model of gravity: the double copy behavior. So, one can repeat the derivations of section 2 with respect to the double copy gravity [18].

This way, we now have an equivalent AdS/CFT_{2CG} correspondence conjecture, where 2CG stands for double copy gravity modeled as interactions, or field in the CFT_{2CG} 4D spacetime.

At the difference of [18], we do not need to include, in the discussion here, sources as microscopic black holes[8]. Also, we will only focus on massless cases. After all, behaviors at high enough energy where everything is massless are all what matters ultimately for analysis of the UV behaviors, besides checking the implication of the presence of matter on such behaviors.

Note added on April 28, 2023: As Physics is dominantly described by random walks at 2D [1,157,170], it's good enough, per [156]. However, we know that we can also consider the massive regime now that we have accounted for the massless scalar as the massless Higgs boson playing the role of dilaton associated to the multi-fold mechanisms [170]. We still are with pure GR (and matter).

The presence of matter is also discussed in later sections.

[6] Or more generally, Gauge theory.
[7] Indeed the double copy is well established in non-multi-fold Physics.
[8] See [18] for any of these aspects.

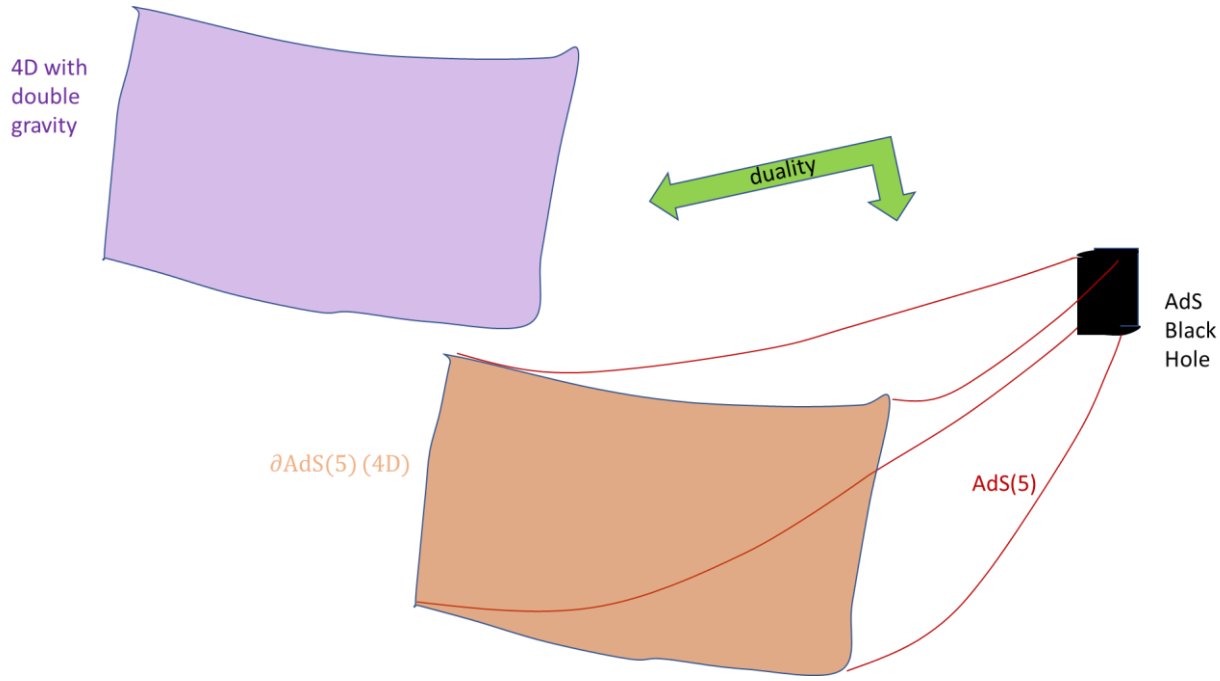

Figure 3: It illustrates the AdS/CFT$_{2CG}$ correspondence conjecture where CFTs are replaced by gravity. It is represented as a non-physical duality, but could also be a geometrical and physical duality. (From [18]).

The AdS/CFT$_{2CG}$ correspondence conjecture introduced in [18], is illustrated in Figure 3, ignoring sources.

Note added on April 28, 2023: [157] also provides a way to understand why, even in the presence of sources, ultimately, the model of figure 3 without sources is all what matters. Consider figure 1 in [18].

This new correspondence is a conjecture where the AdS/CFT correspondence is a conjecture, and it is factual where it is factual, in particular in multi-fold universes. Note that there could be some cases where gravity could make the correspondence factual on its own, even if say the AdS/CFT correspondence still was just a conjecture.

4.2. The AdS/CFT$_{YM2CG}$ Correspondence Conjecture

It is possible to consider a case where counting all the scatterings now include all the 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 4.1. They can be intuitively understood as adding together, per order of number of particle involves and loops, the respective scattering amplitude form the Feynman diagrams. Asymptotic renormalizability is addressed and assured as in section 7.1 of [18].

We obtain the same results as in sections 2 and 4.1. Massless cases and sources as addressed as in the previous section. *Note added on April 28, 2023: This is including the additional comments added on April 28, 2023 in section 4.1: I can also apply to energy scales where we have massive particles, and not worry about any massive particle fluctuation or due to chiral symmetry breaking: we still obtain pure Einstein GR by the double copy duality. But, again, only energies where everything is massless is what really matters to discuss asymptotic safety.*

This new conjecture is a conjecture where the AdS/CFT correspondence is a conjecture and factual where the AdS/CFT correspondence is factual. Again, 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.

The AdS/CFT$_{YM2CG}$ correspondence is detailed in [18], and illustrated in Figure 4.

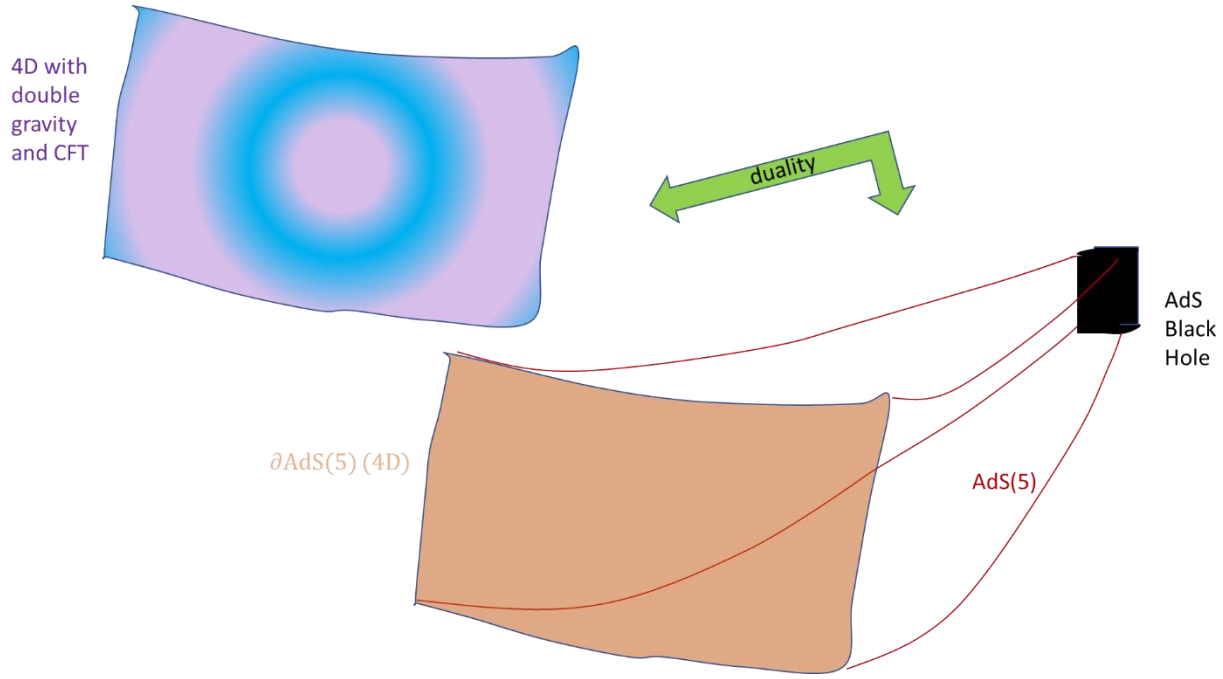

Figure 4: It illustrates the AdS/CFT$_{YM2CG}$ correspondence conjecture where CFTs and gravity are present. Sources are not discussed. It is represented as a mathematical duality as in Figure 4, i.e., CFT and gravity are in a different spacetime from ∂AdS(5). It could also be represented as a geometrical and physical duality where the CFT + gravity 4D spacetime is the boundary of AdS(5), i.e., ∂AdS(5), as in Figure 5 in [18]. (From [18]).

The change from double copy gravity only scattering to Yang Mills and gravity may actually be the duality symmetry breaking that occurs from the Ultimate Unification regime [72] to lower energy regimes [13]. We will revisit in the future.

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 that can best apply to our real universe. We sometimes refer to it as the AdS/(C)QFT conjecture in [18], and other papers.

4.3. Non-supersymmetric Yang Mills in AdS/CFT correspondence

[18] discusses how the correspondence can involve Yang Mills fields, or super Yang Mills fields. It is less important to our next steps here. Let us just make a note that, in our case, the new AdS/CFT$_{2CG}$ and AdS/CFT$_{YM2CG}$ correspondence conjectures can be used for regular Yang Mills, not just supersymmetric.

5 Yang Mills renormalizability and asymptotic safety

Since the work of 't Hooft and Veltman, we know that Yang Mills is renormalizable in 4D spacetime. See [36,37] and reference therein. It has since also been shown that 5D Yang Mills seems asymptotically safe too [18,*170*] and references there, including YM with the SM symmetry groups [38-41]. [18,*170*] provide our view on why it had to be the case. It typically covers the asymptotic freedom aspects of Yang Mills and QCD. These can be approached in massless and massive cases. Because we are only care about asymptotic safety, we are not interested too much in the massive cases: we consider scales and energy above the electroweak symmetry breaking and Higgs mechanisms, and higher if needed, so that everything is massless[9]. *Note added on April 28, 2023: It is at the difference of the gravity case where we still wanted to also make sure that gravity was pure Einstein GR and not another version, something that we addressed in [170], with the Higgs as multi-fold dilaton discussions.*

There are additional Yang Mills challenges related to confinement and mass gap [46], where quark pairs hide their colors by creating new pairs when stretched beyond the required energy. In the case of quark-less/fermion-less Yang Mills, the same occur with gluons who analogously create gluon-balls [45] *(note added on April 28, 2023: This is at least in a discrete spacetime [141,155,170])*. These considerations matter to ensure the existence of Yang Mills [*155,157,170*], but as they encounter a natural energy cut off, they do not matter above these energies, or below the corresponding spatial scales (for confinement). The considered energies are way higher than the mass gap energies. So we do not have to consider these aspects here as part of the regularization, renormalization and asymptotic safety model. The reader may also want to remember that we proved the Yang Mills mass gap in multi-fold universes [1,99,141,*155*].

Also, supersymmetric ($\mathcal{N}$=4 maximally super Yang Mills in 4D and 5D super Yang Mills) are renormalizable [42-44].

Typically, supersymmetry ensures better behaviors, including asymptotic safety [73].

6. Renormalization and Asymptotic safety of gravity, so far

Good introductions to renormalization in the context of QFTs can be find in [47-50].

[9] There is also no need to cover the Ultimate Unification (UU) aspects here either. We refer the reader to [1,18,94,*155,157,160*] for that. Indeed, UU ensures that all physical behaviors will be tamed and well behaved. But here we are interested in in the behavior of the Yang Mills equations, not in UU. If all is well, and consistently modeled, then Yang Mills only considerations should also encounter and foretell the UU behaviors. The paper here aims to rely only the knowledge that the Yang Mills QFT formulation is aligned and asymptotically safe. *Note added on April 28, 2023: This is actually what we have encountered in [155,170], where we analyze the 3D, then 2D, behaviors of Yang Mills interactions, and explain how and why they are well modeled by UU and 2D random walks. UU reflects the 2D random walks also, therefore everything is consistent. The analysis is also consistent and analogous to [20] with Yang Mills converging with gravity behaviors. Both approaches confirm that, physically, we have asymptotic safety. These random walk reasonings, allow us to conclude that Yang Mills, for the SM, remains well behaved with matter (fermions, in particular masses ones).* As the behavior with fermion at 2D and 3D is not really controversial, see [*155,157,170*] and references therein, we will not elaborate much more in the present paper.

It is known that, conventionally, gravity is non-renormalizable [53], hence the focus instead on asymptotic safety of gravity is discussed in [51,52].

Following Wilson's work, Weinberg proposed asymptotic safety, i.e., non-perturbative renormalizability, for gravity, based on a nontrivial fixed point of the underlying renormalization group (RG) flow for gravity [50,51,54-57,61,66]. There are many conventional indications that gravity may be asymptotically safe. Our work on the multi-fold universe already indicates asymptotic safety in multi-fold universe as well as in the real universe [19,20,58].

There are strongly dissenting, and at time vitriolic, views on the value, and validity of the asymptotic safety program for gravity. Discussions can be found in [19,20,58] and references therein. We will note in particular, [59,62-66].

From our viewpoint, we identify two main types of pushback. Some based on solid mathematical arguments around potential mistakes included in the methodology followed to confirm or deny asymptotic safety, and some potentially more motivated by the belief that asymptotic safety of gravity for QFT/EFT, and superstrings are fundamentally incompatible. The latter appears sometimes as an existential fight; which it could really be [19,20]: asymptotic safety of gravity renders many New Physics theories incompatible with the SM: supersymmetry in 6D and above, and superstrings, supergravity, M-theory, with their additional dimensions, and most GUTs and TOEs [19,20,25,*170*].

Note that [20,58] shows that total incompatibility between gravity as QFT/EFT and superstrings may not be entirely correct: a 2D regime of gravity at very small scales seems to be agreed by these and more theories of gravity and [20,58] argues that this is where a (non-trivial) UV fixed point for gravity is encountered. But it still relegates these theory mathematical models, only valid at very small scales, and denoting, in the case of supersymmetry, superstrings, super gravity and M-theory, that what is modeled is unphysical, at best existing in a space dual tangent to our 4D universe, and at best modeling multi-fold effects [19,20,25,28,29,30,78,79,100,101,*167,170*].

The conventional FRGE and approach of truncating the Hilbert Einstein action is not convincing opponents who dispute the adequacy of the methodology. Methods and application based on perturbative approaches and /or estimates built on the results of the SM, including prediction of the mass of the top quark and Higgs boson[10] are also pushed back against as too sensitive to the observed estimates and their evolution [22,67-72].

Note added April 28, 2023: Recent papers [157,171] also discuss the validity of the asymptotic model in the presence of the different matter components (e.g. SM fermions and scalars), multiple dimensions, cosmological constant etc. In general conventionally, i.e., with multi-fold considerations, or in multi-fold universes, the conclusions of [19,167] and references therein hold.

7. Gravity is asymptotically safe

The different conjectures discussed above, when phrased and organized appropriately, allow us to prove that gravity is asymptotically safe, in ways that escape the arguments about the mathematical methodology, perturbative approach, or SM estimates. Of course, the conjectures may still be argued against, if [18] is argued against. We expect that the challenges would then be in interpretating CFT_{2CG}. We will further address aspects of such interpretation. Also, yes, the (conventional) AdS/CFT correspondence conjecture is just a conjecture in

[10] For example, it is argued that many other approaches reached correct estimations of the Higgs mass, and that this may rather reflect a special reason for such mass than correctness of some of the assumptions of several of such predictive methods.

conventional Physics; but it is at the core of superstrings, holography and M-theory, and it is encountered explicitly as factual in the multi-fold theory [1,19,25,28,29,78,131].

7.1 The steps of the proof

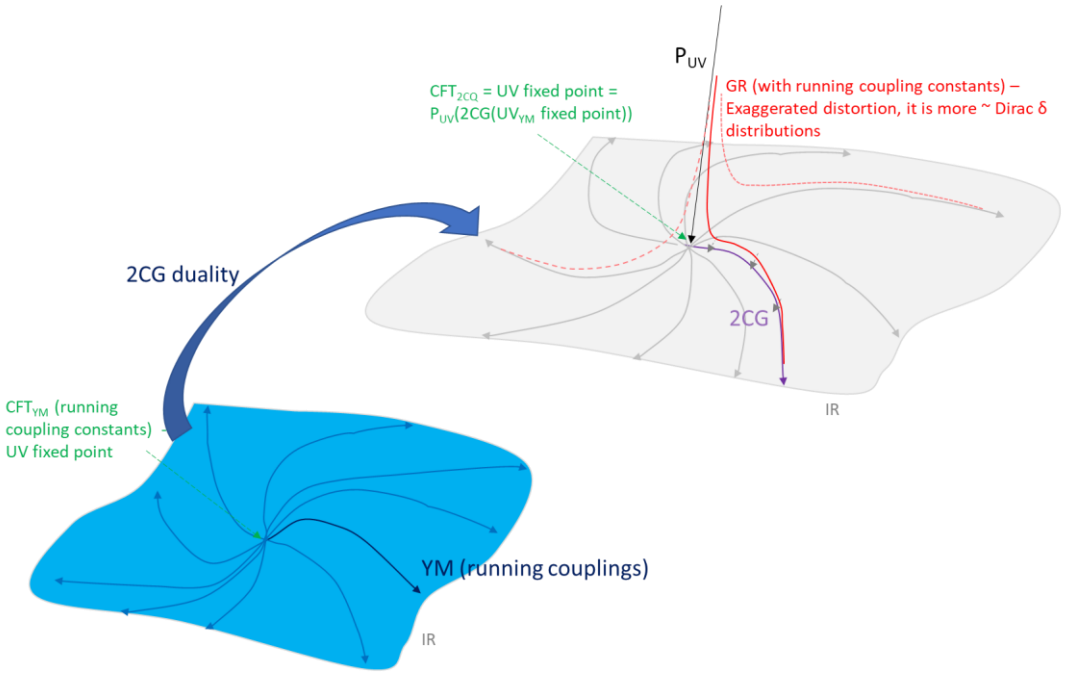

Figure 5: illustration of the proof of a UV fixed point for gravity from the trivial UV fixed point of Yang Mills through the dual copy transformation, which ensures the existence of a critical surface and UV fixed point, albeit not, necessarily trivial.

Our approach is based on expanding on [17,18]. The main argument stems from a different approach to the RG group. Instead of focusing on all the possible actions with the right degrees of freedom and symmetries to find a fix point, we rely on [17,18,81] and references therein to transform the Yang Mills trivial fixed point, and, as a result, confirm that a critical surface a (non-trivial) UV fixed point exists for gravity.

In this subsection, we do not discuss if we have supersymmetry or not, nor do we argue conjecture versus facts. We assume that the AdS/CFT and the AdS/CFT_{2CG} correspondences are factual. We will then revisit and discuss aspects of these considerations in the following subsections.

We start from the AdS/CFT correspondence, and we only care about high enough energies. The analysis is also sketched in Figure 5.

- We know that CFTs, which can be seen at very high energies, or very small spatial scales, Yang Mills fields, are renormalizable in 4D spacetime, as discussed in section 5. When renormalized, they are the fields at / near the trivial UV fixed point of Yang Mills.
- Using the double copy behavior of Yang Mills scattering, valid at any order, including in the classical action [81], discussed in section 3, through the steps of regularization, and establishment of a trivial UV fixed point, all consisting into manipulation and rearrangements / approximation of the scattering amplitudes

of these diagrams. The sums of dual double copy scattering diagrams may diverge, with any run of the coupling constants, and we know that GR-based gravity is non-renormalizable [53].

- Because we consider / argue only about the UV point, we do not have to worry about massive interactions. We know that in the double copy gravity of Yang Mills is pure Einstein gravity [8].
    - *Note added on April 28, 2023: Also, [170] gave us additional arguments even for the massive regime, with the massless Higgs (which can condensate in massive Higgs) at the entry/exit/mapping points of the multi-fold that can be understood as the dilaton coming from the kinematics and dynamics in the multi-fold space time matter induction and scattering [122,124,131,151].*
    - If we do not accept that our universe may be multi-fold despite [1,5-7,*164*,*170*] and the explanations of SM and ΛCDM challenges mentioned earlier and tracked at [1,75-77,*150*], then we stick to the first argument: do not consider the massive regime, it does not matter for asymptotic safety and rely on [16,17] to explain away the massless scalars in Einstein GR-based gravity.
- A critical surface for GR, obtained typically by conventional RG approaches, will include the 2CG(CFT_{YM}), defined by the changes of section 5 in [81], applied to CFT_{YM}. The different curves obtained by running the coupling constants between IR and this point define a critical surface.
- 2CG(x) is a well behaved transformation as it reflects just the square of the YM → CFT_{YM} kinematics scattering amplitudes. We do not expect discontinuities of the transformation to the purple curve capturing the running of the coupling constants, even if the GR-based perturbative series diverge near the transformed UV point.
- That divergence can take many forms, and for example could look like a ~ Dirac distribution near the UV point. also allows to define a projection onto that surface P_{UV}. Figure 5 is just a symbolic representation.
- The double copy UV fixed point can be defined as divergence $\lim_{n\to\infty} 2CG(YM_n)$, or 2CG($CFT_{YM}$), or P_{UV}(RG(GR)), and it exists per the reasoning we provided, and shown in figure 5. It is well defined even if unknown, and can handle any of the divergence forms.
- The asymptotically safely renormalized non-perturbative theory is the violet curve on Figure 5.
- We also know that for our purpose it is sufficient to manage quark-less (Yang Mills) or Fermion-less (gravity) when it comes to studying asymptotic safety.
    - As already mentioned, gluon balls are not relevant at high energies, where the bound states are torn apart, or said differently, the mass gap is on the IR side of the diagrams.
- Everything discussed so far can also apply to CFT_{YM2CG}, which adds CFT_{YM} in 4D spacetime.

It demonstrates that Einstein GR-based quantum gravity in 4D has a well-defined UV fixed point, albeit unknow to us to date, and it is asymptotically safe, including in the presence of Yang Mills fields, and therefore bosons; no matter how many YM fields are involved. From this we can see that YM and bosons facilitate asymptotic safety of GR-based quantum gravity as argued in [19,20,66-69,92,*167*]: indeed it handles well the negative effect of any YM source. *Note added on April 28, 2023: These conclusions are corroborated and explained differently in [157].*

This reasoning is not inconsistent with what we have said so far across papers like [1,19,20,144,*157,170*], and reference therein. Indeed:

- Per [18,*170*], there are no well behaved or defined Yang Mills in spacetimes of dimensions larger than 5D, 5.26 to be exact, so dimensions larger than 6D are incompatible with asymptotic safety of Einstein GR-based quantum gravity. Yes supersymmetric solution can behave well, but the reasoning here does not lead to Einstein GR-based quantum gravity.
- While we just saw that Yang Mills vector bosons help achieving asymptotic safety of GR, the same is not true for scalars and fermions. There is no contradiction, so far, in the reasoning above, we have not shown that asymptotic safety is of gravity is not negatively affected by scalars or fermions. *Note added on April*

28, 2023: [157] provides stronger arguments, more developed by the time of that paper argument, in our view. However, in this paper, we did not yet have the details of [157], and in any case as already mentioned, to be self-contained the reasoning should not be based on random walks, discreteness of spacetime, multi-fold space time matter induction and scattering, UU, and Figure 1 in [157], UU.

- Scalars can accumulate and condensate without contributing to the asymptotic freedom that can be associated to YM (color whitening), or neutralization (electromagnetism). So scalars create obstacles to a smooth behavior, enabling energy fluctuation that in turn create non smooth gravity fluctuations. It is consistent with [84,*151*] and references therein.
- Fermions, are subject to the Pauli exclusion principle also imply orbits or fluctuations (at least 2 x per species). The obstacles to a smooth behaviors of gravity are expected to be stronger than scalar, per fermion species. Again, this is consistent with [84,*155*] and references therein.
- These results match [19,20,144,*157,170*]: adding scalars and fermion species, will at some point prevent asymptotic safety of GR-based quantum gravity, as we see the YM bosons as having a rather small positive effect. Unfortunately, the multi-fold theory is qualitative. But we have shown here, and in [16-18,*167,170*], that GR-based gravity is what we study here, and therefore a correct target for the GR asymptotic program [19,20,56-58,*157*] and references therein. There it has been shown that the limit for compatible dimensions (for asymptotic safety) is indeed 5D to 6D, and that supersymmetry is incompatible with it [19,66-68,*170*].

The above demonstrates that Einstein / GR based gravity has a well-defined UV fixed point, albeit unknow to us to date, and it is asymptotically safe, including in the presence of the SM, or rather SM_G, but not in the presence of larger set of particles like the MSSM [85]. The MSSM case is further discussed in sections 7.2 and 8.

Note added on April 28 2023: [157,170] also discuss asymptotic safety and positive cosmological constant. At a high level we will say: expansion of the universe and dark energy should be understood as smoothening out any fluctuation: they facilitate asymptotic safety. Interestingly, positive cosmological constant is also incompatible with supersymmetry and superstrings [1,19,20,79,100].

We know the UV fixed point in multi-fold universes [1,75-77], and we could argue to know it in a GR-based universe [6]. This is the main result of this paper. CFT_{2CG} is a notation. It is not necessarily purely conformant as discussed in [18] and section 8 or [66], but roughly behave as such.

AdS(5) objects associated to CFT via AdS/CFT correspondence are similarly associated to CFT_{2CG} per AdS/CFT_{2CG} via [18,81], which is another way to assess well defined existence of the UV fixed point. It perturbatively works also pre and post renormalization.

The case of supersymmetry, superstrings and M-theory is a bit more complicated. We will discuss it in the next section, the case has been essentially settled for what concerns us in the bullets above. Especially as we know that our spacetime is 4D [144,*170*].

In multi-fold universes, we could also argue that the difference between the red and the purple curve explains the differences between the multi-fold scattering and Yang Mills scattering discussed in [17], or why gravitons do not exist as non-perturbative[11] particles [78]. Regarding CFT, we also want to remind the reader about our observation from [20,*157,180*] that 2D CFTs are actually good models of free massless boson random paths [96], quite consistent with the multi-fold reconstruction model above Ultimate Unification [1,4,6,18,94,95,*155,160*].

So, in particular for universes that may not be multi-fold, the difference between the violet curve(s) (in figure 5_, and the actual GR expansion in n^{th} order Feynman diagrams, reflects the non-perturbative terms or corrections.

[11] Another angle is to see that gravity is ultimately a 2D process, and with Physics governed by random walks, per [1,20,59,*157,180*]. In 2D, gravitons do not exist [82]. *Note added on April 28, 2023: [170] then reconciles this with a macroscopically 4D spacetime.*

They may have physical meanings, like instantons in tunneling, or not, i.e., contributions with unknown physical meaning. Based on figure 1 and 2 in [17], vs. figure 3 in [7] and the reasonings in [1,6,78,139], we suspect that, in the gravity case, these terms reflect the missing dynamic contributions of the multi-folds [1,17,*163*] coming from multi-folds further away (as we can't do just an integration in r^{-1} as in the static cases, something that is missing in the nth order Feynman diagrams of QFT models [17]. In QFT, these contributions can't be matched by up to n^{th} order contributions and so perturbative QFT just cannot capture such dynamic effects: they are missing from the Feynman diagram at every order, but they are physically present and non-negligible for good behavior (always) and sometimes in macroscopic effects like in the Lens-Thirring gravity effects [1,17,*163*].

Note added on April 28, 2023: Since web publication of the present paper, we have looked at formalism to study such effects. Recently, as popularly discussed in [172] and references therein, it was pointed out that, under certain circumstances, Alien calculus can be used to model in divergent series the contributions from terms smaller than any order, which can be used to tame these misbehaviors. A few key references can be used as entry point in [172,173] and references therein. The interesting part is that similar considerations may have been encountered in QCD, with the renormalons, or in some generalized string theory [172]. In an upcoming paper, we may revisit and detail more properties of the resurgent terms from such an Alien calculus approach applied against analysis à la [17].

7.2 The supersymmetry question

The result obtained in section 7.1 is not tied to supersymmetry or conformance symmetry, except for the Yang Mills UV trivial fixed point. As a result, supersymmetry is not mandated, and in fact nor desired if we seek physicality of the model [101], considering that our universe is macroscopically 4D, and with a positive cosmological constant [1,25,79,*170*]. That's where the Yang Mills or Gravity leakage arguments is useful, as presented in [17,*170*].

It is good because we know that supersymmetry is not compatible with positive cosmological constant or (asymptotic) dS spacetime with positive global curvature. See [1,25,79,101] and references therein. *Note added on April 28, 2023: In [170], we encountered some supersymmetric cases on a asymptotic dS, aka with positive cosmological constant spacetime, but showed that the quantized versions misbehave, confirming what we stated here, instead of having provided a counterexamples.*

That being said, the derivation presented here remains valid for supersymmetric cases, if not tied to a AdS/CFT correspondence conjecture beyond a mathematical duality. For matter it is however tied to the fact that the SM is not supersymmetric, and MSSM is not compatible with the derivation of asymptotic safety of 4D (non-supersymmetric) GR-based gravity. This means that, if other dimensional AdS/CFT correspondence conjectures exist, with well-behaved CFTs/Yang Mills, we have a well behaved dual copy gravity. At larger dimensions, above 5D, this can only be done by using supersymmetry [18,*170*], and the double copy gravity won't be Einstein GR [14]. So, no contradiction with our earlier results of incompatibility between asymptotically safe GR, supersymmetry, and higher dimensions. Also, the 6D case is not working, although there is an AdS(7)/CFT(6) duality, as no non-supersymmetric Yang Mills exists with the right UV behavior.

Note added on April 28, 2023: From [170] we know that our spacetime cannot be 5D. That option is also excluded.

The discussion is therefore moot: supersymmetric dualities are not expected to be physical.

8. Gravity plus matter is asymptotically safe, up to a limit

As already mentioned, in section 7.1 we can repeat the analysis for CFT_{YM2CFT}, and obtain the same result for Yang Mills plus Matter. In general the presence of (abstract) Yang Mills sources do not impede asymptotic safety, and, in fact, it slightly helps. On the other hand, the presence of scalars and fermions as sources, including in the vacuum, acts against asymptotic safety. The asymptotic safety of gravity program shows that in 4D, the SM is still on the asymptotic safety side [19,20,56-58,*157*], while the MSSM, and larger models, aren't. We realize that a superficial reading may confuse the reader about the MSSM [85]: if every boson is complemented by a fermion (negative effect) and conversely (positive effect), there may still be room for asymptotic safety as there are more fermion types than bosons types to convert. However for the MSSM, conversions of fermions, quarks and leptons, are towards scalars, which also have a significant negative effect. Hence the consistent result.

A few other and larger supersymmetric models have been considered like the NMSSM [89,90,*174*], as far as we know they all limit the introduction of additional vectorial bosons, and the same conclusions hold. We would characterize these proposals as constraining the existence of additional forces. Maybe other supersymmetric schemes could be considered that would remain compatible with asymptotic safety. To our knowledge no proof prevents it absolutely. We conjecture that it is not likely simply because the positive effect of new super partners vector bosons does not match the destructive effect of fermions and scalars and so: adding more vector bosons would mean more super partner fermions or converting some fermions to vector bosons instead of scalars would probably at best only slightly push a bit more towards compatibility towards asymptotic safety. No such model exist yet to our knowledge anyway. Also such model introduce fifth or more forces and therefore require (e.g. symmetry breaking) mechanisms to hide their effects at lower energy scales, or to believe into dark (matter) sectors (*Note added on April 28, 2023: see for example the related programs like [175]*), where such matter and interactions would be invisible to the SM, except for gravity. Based on [1,108-113,*154*], we have argued against such models and provide alternate proposals to dark matter.

It has significant implications discussed in [1,20,67-69] in terms of compatibility of supersymmetry or superstrings with the standard model, in fact SM_G, modeled with minimum coupling of matter to gravity. This is discussed in the next section.

Note that if we were using super Yang Mills instead, the approach works only when we have good behavior (e.g., $\mathcal{N}$=4), but that gives us supergravity, not Einstein gravity. No such good behavior exists on a (asymptotic) dS spacetime with positive cosmological constant. *Note added on April 28, 2023: See also [170] and reference therein, for some examples.*

9. Implications

Let us first refer the reader to the applications of the asymptotic safety of gravity compiled in [80].

In [19,20] and reference therein, especially [67-69], it is argued that asymptotic safety implies incompatibility of asymptotic safety with SM and supersymmetry at dimensions larger than 6D, or for theories with more dimensions like superstrings, supergravity, M-theory, as well, as a result, most GUTs and TOEs. Note that CFT_{YM+2CG} matches the case of gravity + matter, as from the SM or SM_G, as UV fixed point.

Note added on April 23, 2023: [157,167] and references therein, confirm that such a analysis remains valid in the presence of the SM or SM_G and at low enough dimensions. However, more matter types, like the MSSM [85], does not work in all quantitative estimates.

[92] identified also that asymptotic safety would imply minimum length which, combined with [6], seems to indicate that the real universe could be discrete and even multi-fold per [6].

10. What went wrong with the opposing arguments?

We will not attempt to address all the counter arguments presented against asymptotic safety. Instead we focus on those that we have encountered so far as part of our analysis of the space. Some were already explicitly addressed in [19,20], others like the Gribov anomaly were not really addressed other than handwaving that it might not well model the 2D dimension reduction. In the present paper, we aim to provide an arguments that are based on widely accepted QFT, and not depend on the 2D, and discrete, or even multi-fold, arguments, which is the correct microscopic explanation but not a way to easily convince entrenched parties waring with conventional QFT and superstring tools and arguments.

Note added on April 28, 2023: On the other hand, the adequacy of random walks, and quantum cellular automata to model QFTs, as reported in [170] and references therein, can be seen as rendering equivalent all our derivations of asymptotic safety of gravity methods, QFTS/EFTs and 2D random walks. It is good news, and all our result so far as well as the conventional asymptotic safety program for gravity all pint out to the same conclusions.

10.1 Asymptotic safety of gravity

[19,20], and references therein, discuss some views opposed to the program for asymptotic safety of gravity.

These papers also present our arguments so far based on gravity being a dominantly 2D process at very small scale [1,19,20], something agreed by all consistent gravity theories [59], and therefore, not tied to multi-fold principles. We could also rely on the notion that spacetime is discrete with a minimum length, while non-commutative and still Lorentz invariant [1,6,86], and generated by random walks, to reach a similar conclusion. Unfortunately, such an assumption is also controversial for conventional Physics, even if we have now shown that it can be encountered from GR at Planck scales, without having to initially rely on multi-fold principles [6]. Let us see if we can have some less controversial answers, also relying on the results obtained so far in this paper. *Note added on April 28, 2023: Per our previous note, the concerns, and difference between the models, do not exists: QFT and random walk model the same Physics!*

The arguments about black holes collisions at very small scales [53,88,66], ironically align with the approaches of sources as microscopic black holes [1,4,18], and the use of the double copy duality between black holes [13,31]. [6] shows that one can also see the black hole argument as an argument in favor of a discrete spacetime. Our explanation of the trans Planckian conjecture [87], in multi-folds or in GR-based conventional universes, can then answer that part of the [88] argument. Discussions can also be found in [66].

Regarding arguments, as mentioned in [22], that the correctness of predictions (e.g. Higgs mass, e.g., [72], or Top Mass, e.g., [69]) built using the asymptotic safety, might have shifted, by now, when using the latest (updated) values of the SM, and therefore no more hint at the validity of the asymptotic safety, we answer that our derivation presented here is not affected by such considerations, which we see just as due to the limitations of observations and numerical approximations. Tongue in cheek, one could also state that the arguments that such masses prediction can be obtained through many reasoning because of special properties of such state, not

because of asymptotic safety, should lead to the same prediction with any new update more precise values, shouldn't it?

The strongest QFT centric counter argument is, in our view, based on the Gribov ambiguity[12] [64,65], that fundamentally questions the main approach taken by the conventional asymptotic safety of gravity program. It is quite a challenge to this program considering the (apparent) consistency of the argument, and the importance of truncation flows and FRGE. See the amount of work compiled in [66]. Essentially, this counter argument argues that the truncation program, in place so far, and as sketched in [56], would be incorrect because the functional path integrals to consider miss a whole (set of) region(s) or patches, and therefore paths for the path integrals, due to the alleged non-triviality of the space (group representations) on which to integrate – another example of extension of the notion of integral. *Note added on April 28, 2023: we like to justify this with [164]*. This is by analogy with what happens with Yang Mills theory with the Gribov ambiguity. Because patches are not connected, perturbative methods can never see the other patches to cover. There are ways to cover them as discussed in [64], but these are not what is being done in truncation flows studies. On that basis, it is therefore argued that we waste our time with the method of [56]; the results are meaningless. If one wanted to provide a suitable analysis, we must work with an approach covering all patches. It is a pretty solid argument, which can't just be waived away easily[13]. Yet the argument is mostly an analogy, motivated by Gauge gravity, and possibly even, at first sight, bolstered with the double copy duality. Yet, the assumption, that this applies to gravity, and impacts the validity of [56], has actually not been proven to be the case. For example, as far as we know, it has not been shown that there is even a Gribov Ambiguity for gravity. In section 10.2 we show why there probably isn't.

Along the same lines, there could also be issues with the definition of a suitable measure mentioned in [64], and answered in [19,20]. We will not deal with that one here, because the IR cutoff and 2D argument are just better ways to deal with it.

Our result presented in this paper is not affected by the Gribov ambiguity. Indeed the existence of the Yang Mills Gribov Ambiguity existence does not question the existence of a trivial UV fixed point in Yang Mills in 4D, as discussed earlier. The double copy duality is not affected either. So our proof does not care of the existence or effects of Gribov ambiguity that it be on the side of Yang Mills or of the double copy gravity: whatever integration is implicitly correctly done. But we agree that, if it exists, it might affect the numerical results, and conclusions of much of the truncation flow work as compiled in [66]. However per our derivation, it does not change the conclusion that gravity is asymptotically safe. Dealing with matter and the SM or SM_G, is further discussed above [*a60*] and we show also consistency of the conclusions on matter. But yes the Gribov ambiguity, if it were to exist, could affect when incompatibility with asymptotic safety of gravity occurs. Let's keep the hopes up for supersymmetry, superstrings and most GUTs till section 10.2.

Finally, note that the derivation, from GR at Planck scales, of a discrete spacetime as in [6], is in our view the way to address another remaining argument: the GR equation applies till very small scales and contain all the ingredients to characterize the 2D discrete behavior behind the microscopic explanation to GR-based asymptotic safe gravity [20,59]. In fact, following the top-down-up-and-upper analysis of [6], we can recover GR, and / or the multi-fold spacetime reconstruction, from the Planck scales. This allows us to argue that we did not get lost into GR as an EFT with a UV fixed point only valid for scales that would not yet correctly characterize the Planck scales, i.e., with another better EFT theory sandwiched between that apparent UC point and Planck scales. GR and semi

[12] See [47,91] for more background on this Gribov ambiguity.

[13] So far, in our multi-fold approach, we managed to waive it away with the 2D process regime and discreteness of spacetime (and no Gauge fixing), so that we were not affected [19,20,59]. In section 10.2 we offer other possible answer. So from a multi-fold point of view, we do not believe that the argument holds: the other patch do not exist and section 10.2 mentions why.

classical models remain valid till very small scales, as low as Planck scales, as argued as early as in our first Multi-fold paper [1].

So, we can fairly say that we now have two completely different arguments to conventionally prove asymptotic safety of (GR-based / Einstein) gravity. The fact that the Hilbert Einstein action contains gravity (GR) and Yang Mills, see [19], is the key reason why these two different paths lead to such proofs, and that once one derivation was obtained, the other was to be expected. This paper completed the reasoning using the underlying double copy duality that also results from Yang Mills and GR being dual copies contained in the Hilbert Einstein action. *Note added on April 28, 2023: the equivalence between QFT models and random walks / quantum cellular automata, also implies equivalence of the derivations and the models that are shown to be asymptotically safe.*

10.2 Asymptotic safety of gravity + matter

On the other hand, we admit that the presence of a Gribov ambiguity in the approach of [67,68] could a priori affect the estimates in their truncation approach, on which we relied in [19] and in sections 7.1 and 8. Could it be possible that the Gribov ambiguity could impact the inferred incompatibility of (minimally coupled) SM and gravity and save supersymmetry, and superstrings, supergravity, M-theory, as well as most GUTs or TOEs, at least for the criteria of compatibility with the SM? That latter qualification matters, as we have discussed in [1], and in the publications compiled in [75-77], there are many more challenges to the physicality of these theories. So we do not expect that superstrings, supersymmetry or most GUTs and TOEs are saved. But yes, with the Gribov Ambiguity, one may be tempted to pretend to believe that asymptotic safety (with the SM) is not a clear cut proof of their non-physicality.

Unfortunately, we will now argue that there is no Gribov anomaly in the presence of matter, even if there was one without matter:

- The question affects only the double copy gravity, not Yang Mills, which has a trivial UV fixed point, unaffected by the Gribov ambiguity. The truncations and counting of particles in [67,68], has already integrated whatever is to be integrated from the SM symmetry groups.
- For Gravity, the only potential source of the Gribov Ambiguity would be involving the GR (global) diffeomorphism symmetry, best known for being behind and motivated by the background independence of gravity.
- However, in the presence of matter, i.e., particles, the global diffeomorphism is a broken symmetry. It only exist locally [93,147-149,*177*]. The missed patches, if any, do not matter, or, said differently, they have zero integrands, or, said differently, they are not physically allowed paths.
    - Diffeomorphism is the most obviously broken symmetry due to quantum gravity, black holes or simply non-flatness.
    - Even if we consider only very high energy scales, for asymptotic safety, curvature is typically assumed very large, or microscopic wormhole to appear [6]: the non-conservation applies as translation / Lorentz transformation are not invariant within strong curvature and wormhole do not conserve charges. So extremely local considerations also break the symmetry.
- Therefore integration can limit to a local diffeomorphism, and we do not care if the group included in the path integral is non-trivial with other patches.
- The results of the conventional asymptotic safety gravity program with the truncation flow method estimates are correct with matter (SM, SM_G, MSSM, NMSSM etc.).

If we consider that any energy source or particle breaks the global symmetries, the explanation extends to the discussion in section 10.1: there would never be any physical relevant situation where the Gribov anomaly would be allowed, if it were even existing without any matter or energy source.

Note added on April 28, 2023: the reasoning is not invalidated at the smallest scales with say the figure 1 of [157]: the massless Higgs boson suffice to break the symmetry. Such consideration alone allows us to argue that in any case the Gribov ambiguity will not exist, even as in section 10.1: any gravity effects results from entanglement between "matter" and so we will always avoid the problem. [6] is then one way to argue that it extends to non-multi-fold universe, for those who do not like the random walk of massless Higgs bosons, even if, by now, we have established that it is an equivalent perspective to QFTs [170]. Conventionally on can still just see this as the result of spacetime curvature and its fluctuations: they destroy any global symmetry, and for sure diffeomorphisms.

As a result the truncated flow method used by [67,68] is not negated (at least with matter, in our view also without matter because of the multi-fold reconstruction model which involves matter [1,6]) by the Gribov anomaly concerns, that are in any case unproven. The implications mentioned in section 10 are alive and kicking.

11. Conclusions

The paper provides a proof that GR-based gravity is asymptotically safe as is gravity + matter (SM or SM_G).

The proof is non-perturbative, and it is not based on the conventional truncation approaches, even if consequences for supersymmetry or higher dimensions may rely on such approaches. This way, it escapes some of the criticisms, in particular the concerns raised about the consequences of the Gribov ambiguity, which have been raised against the asymptotic safety program: it relies on the double copy duality between Yang Mills and gravity. We also explained why the Gribov ambiguity does not apply anyway.

Other counter arguments have been handled elsewhere. The results also do not depend on multi-fold principles, nor do they invoke gravity as 2D process at small scale or discrete spacetime; although these are compatible or possibly even consequences, as microscopic explanations, of gravity being asymptotically safe. *Note added on April 28, 2023: we noted that in a future paper, we argue that (2D) random walks and QFT are equivalent models of the same Physics, and so such statement have been therefore confirmed.*

The paper also confirms the suitability of the truncation method estimates for gravity + matter, therefore reinforcing the challenge presented by asymptotic safety of gravity for supersymmetry, superstrings, supergravity, M-theory and most GUTS and TOEs.

While we expect reticence to wide acceptance of the result, we believe that our analysis is closing the argument. It is very important, because of its far reaching consequences, which are exactly why our unconventional approach has so many hurdles to pass.

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