Multi-fold gravity and double copy of gauge theory

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Abstract:

In a multi-fold universe, gravity emerges from Entanglement through the multi-fold mechanisms. As a result, gravity-like effects appear in between entangled particles, 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. All these recover General Relativity (GR) at large scales and semi-classical model remain valid till smaller scale than usually expected. Gravity can therefore be added to the Standard Model resulting into what we define as the SM_G., the Standard Model (SM) with gravity non-negligible at its scales. This can contribute to resolving several open issues with the SM, and the Standard Cosmological Model, without new Physics other than gravity.

Among the multi-fold SM_G discoveries, the apparition of an-always in-flight, and hence non-interacting, right-handed neutrinos, coupled to the Higgs boson is quite notable. It is supposedly always around right-handed neutrinos, due to chirality flips by gravity of the massless Weyl fermions, induced by 7D space time matter models, and hidden behind the Higgs boson, or field, at the entry points and exit points of the multi-folds. Massless Higgs bosons modeled as minimal microscopic black holes mark concretized spacetime location. They can condensate into Dirac Kerr-Newman soliton Qballs to produce massive and charged particles, thereby providing a microscopic explanation for a Higgs driven inflation, the electroweak symmetry breaking, the Higgs mechanism, the mass acquisition, and the chirality of fermions and spacetime; all resulting from the multi-fold gravity electroweak symmetry breaking.

Over the last 20 years, a set of papers have introduced studies that indicate that gravity appears to be the dual of a suitable squared gauge theory: the double copy duality. This property appears through multiple order of perturbations, and multiple loop, and it is conjectured to extend through any order.

In this short note, we explain how such a results is actually directly, and globally, i.e. not only perturbatively, or, in other words, to any order, explained by the multi-fold mechanisms behind gravity and entanglement along with the underlying spin-2 symmetry. It physically, and microscopically explains both the double copy duality, and its validity to any order. The results holds for massless gravity and for massive multi-fold gravity.

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1. Introduction

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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 [1,30]. Entanglement of massive virtual particles leads to massive gravity contributions at very smalls scales without the usual problems of massive gravity (See references in [1,30]). Multi-folds mechanisms also result in a spacetime that is discrete, with a random walk fractal structure, and non-commutative geometry, which is Lorentz invariant, and where spacetime nodes and particles can be modeled with microscopic black holes. All these recover General Relativity (GR) at large scales and semi-classical models remain valid till smaller scale than usually expected [1,*64*]. Gravity can therefore be added to the Standard Model resulting into what we define as SM$_G$, i.e., SM with gravity effects non-negligible at its scales. 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, and Standard cosmological model [1,4,5,12-*98*]. These considerations hints at a even stronger relationship between gravity and the Standard Model. *Note added on March 15, 2003: In this paper, references in italic were added on March 15, 2003.*

Among the multi-fold SM$_G$ discoveries, the apparition of an-always in-flight, and hence non-interacting, right-handed neutrinos, coupled to the Higgs boson is quite notable [1,38,44]. It is supposedly always around right-handed neutrinos, due to chirality flips by gravity of the massless Weyl fermions [1,*70*], induced by 7D space time matter and scattering models [1,5,31,32,43,45,*71,75,87*] and hidden behind the Higgs boson or field at the entry points and exit points of the multi-folds. Massless Higgs bosons modeled as minimal microscopic black holes mark concretized spacetime location. They can condensate into Dirac Kerr-Newman soliton Qballs to produce massive and charged particles, thereby providing a microscopic explanation for a Higgs driven inflation, the electroweak symmetry breaking, the Higgs mechanism, the mass acquisition and the chirality of fermions and spacetime; all resulting from the multi-fold gravity electroweak symmetry breaking [31]. At energies above the electroweak symmetry breaking, massless particles are similar solitons induced by massless Higgs random walks [*75-77*].

In [1], it is argued that spacetime is discrete, with a random walk-based fractal structure, fractional and noncommutative at, and above Planck scales (with a 2-D behavior and Lorentz invariance preserved by random walks till the early moments of the universe). Spacetime results from past random walks of particles. Spacetime locations and particles can be modeled as microscopic black holes (Schwarzschild for photons and concretized spacetime coordinates, and metrics between Reisner Nordstrom [2] and Kerr Newman [3] for massive and possibly charged 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 model in a multi-fold universe. The resulting gravity model recovers General Relativity at larger scale, as a 4D process, with massless gravity [1,*64*], but also with massive gravity components at very small scale that make gravity non-negligible at these scales[1,30,32,70]. Semi-classical models also turn out to work well till way smaller scales that usually expected. [5] may also justify different coupling values at very small scales, in the 2D massless random walk regime [1,14,26,*75,76*].

The multi-fold theory is best described with follow-up work tracked at [1,20,*66,67,79*].

[6] introduced the concepts that gravity is a double copy of other forces and its impact. *(Note added on March 15, 2023: [78] provides the non-perturbative version of it [99].)* The present paper compiles some of the most relevant papers, as entry points to the subjects, and results, then it shows how these results are to be expected in a multi-fold universe.

2. Copy double theory of gauge theory and gravity

An overview of the potential of this approach is discussed in [6,7].

The actual detailed papers are:

- The original paper where it is shown that (classical) tree-level gauge theory amplitudes can be rearranged to display a duality between color and kinematics: [8].
- The paper that understands this as a duality with gravity: Gravity diagrammatic numerators are the product of two corresponding gauge theory numerators (Feynman diagrams): [9].
- The Conjecture that such duality, and the notion of double copy, are perturbatively valid to all order (loops): [10].
- A general class of gauge theory solutions that double copy to gravity, namely those involving stationary Kerr-child metrics: [11]. These include the Schwarzschild and the Kerr-Newman black hole solutions. This paper explicitly details the double copy $k_\mu k_\nu$ contributions.
- A non-perturbative formulation of the duality [*99*], that ensure that the relationship also exists non-perturbatively, as long that the non-perturbative theory can be understood as the / a well-defined limit of the perturbative approach, i.e., the limit of one of the series exist (then, the duality and [99] then ensuring existence of a well defined version of the other). This is indeed achieved because Yang Mills is renormalizable, in 2 to 4D spacetime. *Note added March 15, 2023: See references in [76,78,84], for a discussion that Yang Mills is well behaved from 2D till (5+ε)D.*

3. The copy double duality in Multi-fold theory

The multi-fold theory can explain this! Indeed, in multi-fold theory, a graviton, and we know that graviton is non-perturbatively unphysical in multi-fold theory, but it can be associated a perturbative quasi particle on one hand [1,12,24,27,29,*100*], and to multi-folds (creating a 7D embedding space and living in AdS(5), or to closed superstrings living in AdS(5) ++ (where ++ denotes additional dimensions where superstrings live)[1,24,27,29,*71*], is attached to an entangled pair [1].

Now, if we want to model all possible interactions of these gravitons with other particles, including other gravitons, in a multi-fold, it amounts to including interactions with one, or the other entangled particles involved in providing the effective potential [1]. This is justifiable for a infinitesimally small ε neighborhood, as envisaged by perturbative QFT and Feynman diagrams.

To match such a behavior, à la Feynman diagram, one needs therefore two (gauge) particles corresponding to the degrees of freedom to interact with each entangled particles in the pair. Therefore, indeed, we predict that diagrams (perturbatively) associated to graviton (even if quasi particle only valid to a (low) perturbative order) result from the product of all the diagrams, associated to two, not one, gauge particles. As a result indeed, we also see that gravity / entanglement multi-fold interactions are the square of gauge interactions [9]. *Note added on March 15, 2023: more details are provided in [84].*

A key consequence is also that, in general, entanglement is, a double copy dual (or square) of the suitable gauge theory. This is not just true for gravity. *Note added on March 15, 2023: New dualities result from it as discussed in [97], while [64] exploits the reasoning of the last bullet of section 2, and models of [97], to confirm that GR based gravity is asymptotically safe. This result has long lasting impact on the physicality of superstrings, M-theory, and most popular GUTs and TOEs [1,23-27,29,60,76].*

Interestingly, the particular solutions for suitable gauge theories are Schwarzschild and Kerr-Newman solutions [11]. This is in direct alignment with our results in [1,4]: we recovered microscopic black holes as implementation of massless and massive bosons and fermions in the multi-fold theory, they themselves are implemented as

patterns (massless at energies above the multi-fold gravity electroweak symmetry breaking, and condensates of massless Higgs bosons at energies below the multi-fold gravity electroweak symmetry breaking) [31,*75-77*].

As, in multi-fold universes, gravitons do not exactly exist in spacetime [1,12,24,27,29,*100*], one could argue if multi-folds are one (like a closed string), or a pair of entangled gravitons (one at each extremity/entangled particle and exit points of the multi-folds). It makes no difference: the diagrams involves two particles instead of one in both points of views. Indeed, when evaluating gravity at one spacetime location, i.e., the effective potential effects as in [1], at a distance r from the source (mass or energy), we are perturbatively involving just one (perturbative) graviton, determined by the sets of two entangled (virtual) (e.g. Gauge) particles beyond r. The fact that many (pairs of entangled particles beyond r) are to be considered is another reason why the graviton is not physical in the 4D (multi-fold) spacetime [1]. *Note added on March 15, 2023: [101] then discusses how to deal with dynamic cases, where the history of entangled virtual pairs is dynamic, and leads to effects like frame-dragging and Lens-Thirring effects.*

It seems that the multi-fold theory provides a global approach to (massless) gravity that explains this double copy result at all orders. There also are symmetries and physical interpretations behind: the multi-fold mechanisms and mappings, that are also behind AdS/CFT correspondence, and the spin-2 (a set of 180° symmetries from one entangled particle to the other) properties of the multi-folds [1]. *Note added on March 15, 2023: It is among the key symmetry involved in justifying the symmetry of the SM , or rather SM$_G$, as shown in [80,102].*

Of course, one could also argue that, from a degrees of freedom point of view, the spin-2 of the graviton could be seem as a sum of two spin-1 bosons, and that this would be the reason for the double copy duality, e.g. as 2 sets of independently polarized massless bosons, instead of what we just explained. In a multi-fold universe, we can invalidate such an argument. Indeed, this explanation does not hold for multi-fold massive gravity [1,30]. Massive gravity, as encountered in multi-fold universes, would require massive spin-1 gauge bosons. These can't match all the massive gravity ranges due to the different massive SM particles, and multi-folds then would have to be matched: the explanation just does not work, while the reasoning above based on multi-fold mechanisms holds.

Therefore, through our reasoning, we predict that a double copy also holds for the massive gravity components, that only matters at the very small scales of the SM.

Based on [1,63-65] and the already mentioned ability to offer qualitative answers to many open issues of the SM and the Standard Cosmological Model (ΛCDM) [96], it is quite plausible that our real universe be multi-folds [1,4,5,12-*98*].

4. Conclusions

The copy double duality of gravity and suitable gauge theory is explained by the multi-fold mechanisms. In multi-fold universes, the duality is also extended to entanglement, not just gravity; as expected considering the E/G conjecture [13], a factual duality in multi-fold universe.

The analysis presented in this paper offers a good physical and microscopic explanation to the double copy duality between massless gravity and gauge theory. It seems an additional argument that the multi-fold theory is relevant to the real universe. We also argue that it holds for massive multi-fold gravity.

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