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 models remain valid till smaller scales than usually expected. Gravity can therefore be added to the Standard Model resulting into what we define as SM\(_G\). 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. These considerations hint at an even stronger relationship between gravity and the Standard Model. Multi-folds can be encountered in GR at Planck 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.

This paper discusses the implications of the multi-fold spacetime reconstruction, or its encounter in GR, in terms of the Trans-Planckian Censorship Conjecture. We provide a microscopic explanation to the conjecture that becomes factual in a multi-fold universe and relate it to the issues of inflation, black hole physics and Planck scale Physics. The results extend to any universe described by GR, and probably to any universe with minimum length. In fact we see acceptance of TCC as another way to deduce that spacetime must be discrete or with minimum length.

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.

With the proposed model of [1], spacetime and Physics are modeled from Planck scales to quantum and macroscopic scales and semi-classical approaches appear valid till very small scales. In [1], it is argued that spacetime is discrete, with a random walk-based fractal structure, fractional and noncommutative at, and above Planck scales (with a 2-D behavior and Lorentz invariance preserved by random walks till the early moments of the universe). Spacetime results from concretization by past random walks of particles. Spacetime locations and particles can be modeled as microscopic black holes (Schwarzschild for photons and massless Higgs and...

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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, but also with massive gravity components at very small scale that make gravity non-negligible at these scales. Semi-classical models also turn out to work well till way smaller scales that usually expected.

Multi-folds\(^2\) are encountered in GR at Planck scales [5,6] and in Quantum Mechanics\(^3\) (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.

In general, the multi-fold theory seems to be able to provide ways to qualitatively address (fully or partially) many open issues with the SM, or rather SM\(_0\) the SM with gravity effect not negligible at its scales, and with the standard cosmological model \(\Lambda\)CDM [1,4-7,9-11,16,19,20,22,27,29,33,36-102].

In this paper, we start with a brief discussion of the usual motivation for the Trans-Planckian Censorship Conjecture (TCC) [8,14,18]. Then, it illustrates how a discrete, fractal, non-commutative Lorentz invariant spacetime, generated by random walks [1,9], and particle pairs creations, indeed hides effects from scales smaller than the minimum length of the spacetime, i.e. the Planck length, when it comes to inflation [1,10,11], spacetime expansion [1,6,10], Black hole physics as well as Planck scale physics.

Because Planck scale GR encounters the multi-fold theory [6], the analysis and model extends to non-multi-fold universes.

Note added on Mach 4, 2023: In this paper, numbers for references that are in italic indicate references added on March 4, 2023.

2. Challenges of Trans-Planckian Physics

If one expects that Physics is significantly different at Planck scales, one can expect that challenges will be encountered, when effects of Planck scales Physics would have large effects in larger scale Physics: a priori, these effects put in doubt models that do not account for such effects. Said differently, there are cases when it seems hard to model Physics correctly without taking account what happens at scales below the Planck scales.

Let us a consider two examples.

2.1. Inflation and Cosmological Considerations

While Trans-Planckian scales are many orders of magnitude below conventional Quantum Physics or (semi-) classical Physics, in a post inflation universe, pre-inflation or early-inflation effects at sub-Planckian scales are expected to have grown to cosmological scales where, therefore, they would now be observable [12,13].

\(^2\) Tracked at [37-39,85].
\(^3\) Standing in for Quantum Physics in general.
2.2. Black Holes Considerations

The Hawking radiation derivation [15], involves contributions from wavelength well below Planck scales: particles with finite frequency far away from the black hole would need an infinite frequency/energy if their source is the black hole horizon, i.e., following [15], to reach the horizon before going back to infinity. See also [16,102] for references on variations on where the radiated particles would originate.

This issue may also be related to motivating, or explaining the black hole firewall proposals [32].

Solutions exist, like [31], that amounts to a different variation on [15,16,87,102] where Hawking’s radiation occurs at an radius (“effective horizon”) larger than the black hole horizon. It leads to the suggestion that Black hole trans-Planckian effects would be artefact of the way that the Hawking radiation is computed.

We also encountered related concerns when we encountered hints of strings on a blackhole horizon in [1,17].

3. Planck Scales Physics

As part of our research, we devoted significant efforts addressing the issues of gravity asymptotic safety, i.e. being non-perturbatively renormalizable [19,20,79,80,84]. This was driven by the fact that:

- GR-based (perturbative) quantum gravity is non-renormalizable [21].
- Gravity becomes 2D at Planck scales [1,20,27,79,80] and references therein.
- Superstrings and LQG claim renormalizability without universally accepted arguments, i.e. without convincing proofs so far.
  - Handwaving about no singularities in LQG [23,24,26], and related theory with an intrinsic UV cutoff at Planck scales.
  - Handwaving about (lower orders) counter terms cancellations for strings. [25,26,30]
  - Inconsistencies of the model: a real universe dS(4) with asymptotic safe gravity is consistent with the SM [19,20,80], but AdS(5) (+...) isn’t which means that superstrings can’t characterize the SM even with AdS/CFT models [19,20,22,80].
- Asymptotic safety of quantum gravity seems to imply incompatibility of superstrings, supergravity, M-theory, supersymmetry in dimensions above 6D and most popular GUTs and TOEs, with the SM particles [19,20,40-42,80].
- The Multi-fold theory is asymptotically safe [1,19,20,80], and seems to apply to our real universe [1,4-7,9-11,16,19,20,22,27,29,33,36-102].

In that context, it is interesting to note the non-multi-fold view of asymptotic darkness presented in [28], which limits trans-Planckian Physics to blackhole scattering and life cycle, something that [28] claims that it would

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4 We are not fond of the black hole firewall proposals, especially as it is not needed, as discussed in [1,33,96,97,103], to address the black hole information paradox [34].
5 The black hole would rather be a gray body, therefore with less radiations than expected, which implies a larger horizon.
6 Note that in [1], we explained why these hints were illusions due to quantum fluctuations of the horizon. In the present context, they a priori still encompass only fluctuations at energy above Planck scales, because the minimum length cuts off any smaller fluctuations in spacetime.
preclude gravity asymptotic safety. The multi-fold model [1,4] is aligned with the Ultimate Unification (UU) [1,4,19,20,29,50,67,68,79-81], explains the black hole scattering and lifecycle aspects, and justifies other black hole considerations [1,4,96]. It prefers to see Trans-Planckian Physics as a 2D process, and as a result a renormalizable and asymptotically safe model [19,20,79,80,84].

Of course, our work in [1,5,6,9-11,19,20, 37-39,79,80,84,85], also provides additional insights in Planck scale Physics.

4. The Trans-Planckian Censorship Conjecture

The Trans-Planckian Censorship conjecture [8,14,18], is introduced to ensure that when, in quantum gravity, expansions in the background (e.g. due to inflation) become larger than Planck scales, or radiation of Trans-Planckian modes impact larger scale Physics, the Trans-Planckian quantum fluctuations remain quantum, in a way not to be contradictory with a classical picture of spacetime at larger scales [35].

The rigorous formulation [35] is:

\[
\text{We conjecture that a field theory consistent with a quantum theory of gravity does not lead to a cosmological expansion where any perturbation with length scale greater than the Hubble radius traces back to trans-Planckian scales at an earlier time.}
\]

Better yet, 35]:

\[
\text{Sub-Planckian quantum fluctuations should remain quantum.}
\]

Note that [31], discussed in section 2.2, amounts to similar considerations: models with an effective horizon larger than the actual horizon freeze out Planckian effects: radiated particles that would have been trans-Planckian can’t be traced back in time to states on the actual black hole horizon.

With this conjecture all goes well, no issue. Unless of course if one wanted to provide an actual (microscopic) explanation for the validity of the conjecture. And no, arguments à la [28] do not explain it.

5. Multi-fold universes and the Trans-Planckian censorship Conjecture

Do we fare better in multi-fold universes?

The answer is yes, and immediate. Let us consider the two use cases.

5.1 Black holes

Following the black hole radiation and entropy models, described in [1,16,33,96,97,102], we know that the minimum length of the multi-fold spacetime [1,6] acts as a cut-off: no smaller scale fluctuations occur. The problem is solved: the TCC applies.
In the other case of hints of stringy entities on the black hole horizon, mentioned in [1], and in section 2.2 along with one of its footnote, the same applies: as fluctuations of the horizon are cut off with no fluctuations at scales below the minimum length, no hints of stringy behavior occurs with trans-Planckian scales. Any problem is solved, the TCC applies.

The multi-fold point of view from [1 16,33,102] resolves this infinite energy dilemma of section 2.2, with a model that links radiations to fluctuations of the horizon: horizon fluctuations have a minimum fluctuation, imposed by the discreteness of spacetime and particles emitted as a result do not have infinity problems.

5.2 Inflation

With the inflation and expansions of spacetime based on random walk and creation of particle and antiparticle pairs, especially massless Higgs during inflation [1,11,20,79,80], figure 2 shows that expansion is adding concretized locations, not stretching events initially smaller than the minimum length. Therefore, no effect smaller than the minimum length ever appears. Again the cutoff provided the explanation. The problem is solved, the TCC applies.

5.3 Other use cases

The approach is generic: the minimum length ensures resolution of the problem in multi-fold universes. The TCC relates also to the absence of gravitational or cosmological singularities in multi-fold universes.
6. TCC, beyond Multi-fold universes

[5,6] extends applicability of the result to any universe described by GR. We conjecture that it could extend to any universe with minimum length.\(^7\)

7. Conclusions

This short paper provides a microscopic explanation and validation of the TCC in multi-fold universes, and in any universe described by GR, or possibly with just minimum length. Examples are detailed for black holes and for the inflation / expansion of the universe.

We would argue that our microscopic interpretation approach demonstrates the need for a discrete or minimum length spacetime. Anything else cannot explain the TCC, other than accepting it as an axiom.

\(^7\) Any GR universe has a minimum length per [6], at least if it also supports Quantum Mechanics.

References:


References added on March 4, 2023


