The Possibility of a Multi-fold Time-Varying Hubble Constant

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Abstract:

The multi-fold theory provides microscopic interpretations to the universe accelerated expansion, inflation mechanisms and dark energy. From the beginning, the multi-fold dark matter main mechanisms have been identified as being stronger in the presence of matter, or energy increasing spacetime curvature. One could therefore naively expect that these mechanisms will also be globally time-dependent, when it comes to the early epochs of the universe. Indeed, during the early cosmological eras, including pre-CMB, different matter densities and curvatures reigned. Each would lead to a different global average cosmological constant. Such a reasoning would predict a Hubble constant that is larger for early time than late time observations.

As discussed in multiple papers and articles, proposing a time-varying dark energy density can obviously be a simple way to address the Hubble constant tension: early time estimates would correspond to such a different value, and no Hubble constant tension would exist.

However, in our naïve initial analysis above, obtaining larger pre-CMB values could a priori go in the wrong direction when it comes to observations: one would expect a larger Hubble constant at early times, unless if it is rather an additional contribution to the CMB derived Hubble constant.

Considering the multi-fold dark energy mechanisms, in all the early stages of the universe, i.e., pre-CMB, aka pre-recombination, which led to the CMB, plasma, dominated by electromagnetic and possibly other interactions, occupied the whole concretized spacetime. This way, multi-fold dark energy effects were partially countered by more dominant interactions, and the resulting accelerations of expansion were reduced. It can explain why current early time estimates for the Hubble constant would differ from late time results, and lead to a smaller Hubble constant value at early time. However, it may not fit that well the overall standard cosmological model à la ΛCMD.

However, note that recent papers show that a short term increase of the dark energy (5% for redshift $z > 5000$), can resolve the tension, by pushing up the CMB inferred Hubble constant, i.e. early time estimates, and better match overall the ΛCDM. So maybe our naïve reasoning was not that bad.

Combining the two considerations above, our paper shows that multi-fold dark energy mechanisms intrinsically, and microscopically, justify such a behavior that can resolve the Hubble tension. It is another hint in favor of the multi-fold mechanisms, to add to several others. There is also a range where a multi-fold universe appear fractal, which may result into scaling of the cosmological constant, and reducing its value, during this period; again a move in the right direction.

The result extends to the real universe, if it is multi-fold, as hinted by past results.

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1. Introduction

In a multi-fold universe [1,8-10,22,*114-116*,*148*], gravity emerges from entanglement through the multi-fold mechanisms. As a result, gravity-like effects appear in between entangled particles [1,24,25], whether they be real or virtual. Long range, massless gravity results from entanglement of massless virtual particles [1,26]. Entanglement of massive virtual particles leads to massive gravity contributions at very smalls scales [1,27]. It is at the base of the E/G Conjecture [24], and one of the main characteristics of the multi-fold theory [55]. Multi-folds mechanisms also result in a spacetime that is discrete, with a random walk fractal structure and a non-commutative geometry that is Lorentz invariant and where spacetime nodes and particles can be modeled with microscopic black holes [1,27-32]. All these recover General Relativity (GR) at large scales [1,6], and semi-classical model remain valid till smaller scale than usually expected. Gravity can therefore be added to the Standard Model (SM) resulting into what we define as SM_G: the SM with gravity effects non-negligible at its scales. This can contribute to resolving several open issues with the Standard Model and the Standard Cosmological model without new Physics other than adding gravity [1,4-32,42-48,50,54-109,*112-151*]. These considerations hint at an even stronger relationship between gravity and the Standard Model, as finally shown in [23].

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 induction and scattering 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 locations. Massless Higgs bosons can condensate into Dirac Kerr-Newman soliton Qballs to produce massive and charged particles [1,4], or randomly walk according to induced patterns, 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 orientation; all resulting from the multi-fold gravity electroweak symmetry breaking [1,23,27,28,31,32,75,*119,127*]. The multi-fold theory has also concrete implications on New Physics like supersymmetry, superstrings, M-theory and Loop Quantum Gravity (LQG) [1,8-21,*112,123*].

Note added on December 13, 2023: References in italic denote references added on December 13, 2023.

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.

The paper starts by reviewing the Hubble tension, that results from differences in the Hubble constant measured at early time, i.e. derived from the Cosmological Microwave Background (CMB), and. at late time, based on the evolution of observed redshifts vs. estimated distances [33-37].

Then, we discuss how quantum fluctuations impact the multi-fold mechanisms to create an additional force (effective potential) towards the outside of spacetime, resulting in an acceleration of its expansion, and explaining the problem of the small cosmological constant [1,4,27-30]. These multi-fold dark energy effects add to random walk effects, responsible for inflation, and then expansion, which accelerates.

[2] Standing in for Quantum Physics in general.

Analyzing the effects near matter, and with plasmas, we can predict that the dark energy effects could qualitatively have a larger, a smaller or a slightly larger evolving impact, pre-CMB, at early time, before slowly rolling to its current effect. It can result in the different observed Hubble constant values, or in converging the value. Either way makes the Hubble tension disappear. *Note added on December 13, 2023: We also discuss indications that while the universe was fractal, the cosmological constant could have been reduced [151,152].*

Yet the analysis is not quantitative, and therefore, the effects may be too small, in which case the tension would remain, and other resolutions would be needed. We provide some related pointers to such analyses [36,38]. We would be ok with that: it would be because the effects we described would be quantitatively too small: they would still exist anyway. Our goal with this paper is illustrate these mechanisms and their compatibility with, and interpretation of, select models that address the Hubble tension; not to argue resolution of the Hubble tension.

2. The Hubble Tension

The Hubble tension denotes statistically significant differences between estimates of the Hubble constant obtained via different approaches: the early time estimates, mainly based on the CMB and the Baryonic Acoustic Oscillations (BAO) estimated in the CMB observations [33-37], and the late time estimates, usually relying heavily on distance estimates vs. redshift [33-38].

Several papers claim to reduce, or even possibly eliminate the differences. See for example [39,40,53], and references therein. There is no consensus at this stage, and the feeling of crisis remain: a recipe for April fools publications [41].

Alternatively, in [36,38], and references therein, authors propose that the differences, assuming they exist, would rather be hints of varying dark energy effects. In their case, it would be early dark energy contributions while the universe was very young.

If it is the case, then, of course, it is possible to simply argue that late time, and early time Hubble constant estimates do not have to match any more: they would be different, and no Hubble tension results. And the change in early times is a value that could maintains compatibility with the CMB and BOA, and with the rest of ΛCDM, while justifying a different value for the early time Hubble constant, or raising the early time estimates to remove the differences.

The purpose of the rest of this paper is not to defend proposals as in [38,40], but to show that it would be compatible with the multi-fold theory, which provides an intrinsic microscopic interpretation to this. However, we admit that [40] is attractive, and we will see that we can motivate the proposed behavior.

Note added on December 13, 2023: See also [146] for additional context, and considerations on the Hubble tension, in the context of the dominating open questions with the standard cosmological model, aka ΛCDM [85].

Along the lines of time-varying dark matter effects, [151,152] analyze the effects of fractal spacetime and show that it can result into a time-varying cosmological constant.

3. Multi-fold dark energy effects

Besides a dark matter explanation as the result of large scale entanglement [1,43,45,46-48], multi-fold mechanisms can explain the observed accelerated expansion of the universe, as the result of quantum walks (and inflation by adding systematic creation of new particle pairs), and its acceleration because of fluctuations of the positions of the particles, and their resulting impact on the multi-fold effects: a contribution appears that "expands" and "accelerates the expansion" of spacetime as in figure 1 [1,42,43]. These results also can explain why the cosmological constant is small, compared to the value expected from the SM quantum field vacuum energy: it is due to the multi-fold effects of fluctuation rather than the energy of the fluctuations [1,42,*121*].

As noted in [1], the effect is larger near matter because of the curvature resulting from the matter. However, this is not necessarily true for a strongly positively curved spacetime where the effect might be reduced by curvature.

Also, quantum random walk can explain the early universe inflation (exponential expansion), and the current steady contribution of expansion to the cosmological constant. With such models, the cosmological constant may vary in time, and within dense matter versus sparse vacuum [1,16,28]. At the beginning of the universe, within a localized or distributed region, every step is accompanied by additional spacetime (inflation) particle creations, i.e., mostly massless Higgs bosons [1,15,27,28,31,*127*]. Particle pair creation reduces after inflation, but continues to this day as part of the expansion, as shown in figure 2. Particle / anti-particle pairs creations involve expanding interstitial steps that can take place, e.g., when otherwise there would be particle overlap, which matches the vision of expansion everywhere (not just pushes at the edges). This is also true for the mechanism described in figure 1. The particles and interstitial steps reduce multipoint correlations reducing our ability to detect them, without implying that inflation did not exist; a different conclusions from more conventional models [45].

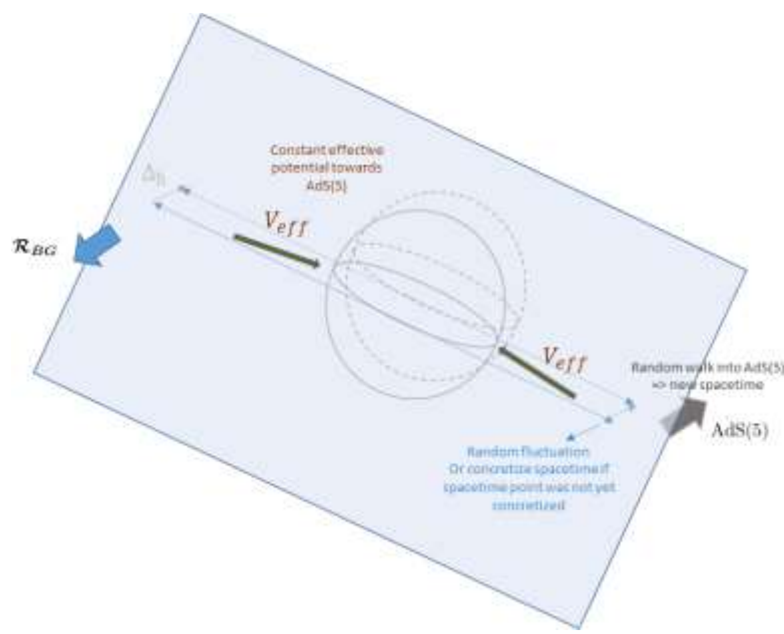

Figure 1: It shows how position fluctuations introduce a multi-fold effect potential contribution external to spacetime that can explain the acceleration of the universe expansion, in a multifold universe. (From [1,27]).

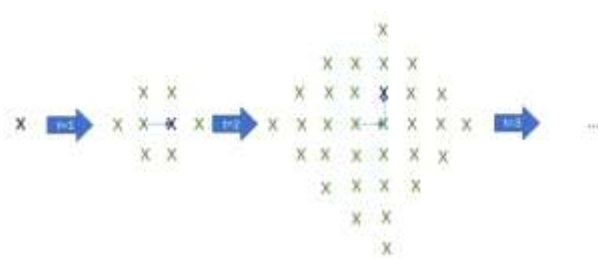

Figure 2: Inflation effects due to the random walk (of massless Higgs boson particles), and interstitial growth with each particle creating many pairs of particles and anti-particles. After inflation, such generation is greatly reduced and random: many of the spacetime locations become not yet concretized and awaiting to be occupied by future particles in random walks and random walk creates new spacetime locations at a much lower rate, and instead of concretizing spacetime, locations are waiting to be concretized). The wait can be long for a 4D spacetime as a result of Polya's random walk theorem [110,111].

The multi-fold mechanisms imply only positive curvatures unless we were starting from a significantly negative background [1]. It matters for cosmology, and to validate compatibility with many theories, like supersymmetry, that only exist in negative, or zero, cosmological constant universes [12,13,15-17,*123*]. *Note added on December 13, 2023: in particular, see [123].*

Also we note that, based on the proposed mechanisms, [50] predicts the current ratios of multi-fold dark matter and energy, and it matches current estimates in our real universe.

4. Suitably time-varying multi-fold dark energy effects

The multi-fold dark matter effects [1,43] intrinsically imply different values for the cosmological constant, in different regions of an inhomogeneous space, and therefore also across different epochs of the universe.

Let us evolve the reasoning. The model that we propose in section 4.3. The first two subsections below, should be seen as ways to discuss the different contributing mechanisms, and their separate effects.

4.1 A naïve analysis: more density matter and larger curvatures

Per [1,43], we know that dark energy effects will be amplified within or near matter. It is a departure from conventional model that assume that it is homogeneously distributed in spacetime.

This reasoning suggests that at early times, pre-CMB, the dark energy effects would be larger, than at later times. The effects would be a larger Hubble constant estimate at early times, when concretized spacetime contains high density plasmas as matter was more densely presented in the concretized spacetime.

Inflation is important: in an asymptotic de Sitter universes, as ours seems to be, large positive curvature would reduce dark matter effects. Which means no effect pre-inflation, but rather further inhibitors to the kick-off of inflation. Post inflation, the curvature effect is way smaller, and the multi-fold dark energy effects can kick off as envisaged here. These considerations also apply to the other options.

4.2. A wiser analysis: tamed effects in plasmas?

The naïve reasoning of section 4.1 may seem incorrect. At early times, until recombination, spacetime was dominated by radiations and plasma. The plasma implies global bound systems where the electromagnetic interactions, and other interactions at high enough energies, dominate the dark energy effects that were therefore at best negligible.

It is conceptually consistent with the view in conventional cosmology that dark energy effects were far from dominant in early ages, pre-CMB, where radiation dominated (then normal matter then, soon after, dark[3]). See for example [50].

Therefore, instead of an increase of the dark energy effects, and as a result of the Hubble constant obtained from early times, we could argue that that we rather see a reduction of their values vs. late time estimates. This would be pre-CMB, before recombination which is what the CMB reflects. After, the plasma densities drop, and matter is already more widely interspersed with vacuum. The contribution of multi-fold dark energy effects moves closer to the current values: the early time value would therefore be smaller than the late time value, hopefully as obtained by CMB with BAO estimates. No Hubble constant tension would result.

It may be the case, but it is not certain with just a qualitative model. Extrapolating from [51,52] for smaller early time dark energy effects, the Hubble constant would indeed appear reduced. Therefore, instead of reducing the differences between early and late time, this is rather arguing that the difference is expected, and not a tension: the Hubble constant may not be a constant.

However, some papers looking at matching ΛCDM, point rather at increasing the pre-CMB dark energy effects, instead of reducing them [40,51]. That is explainable with the increased early density off matter*, and with the fractal effects [151,152] ((Added on December 13, 2023)*.

4.3 Learning our lessons: combining the wise and naïve analyses.

Section 4.2 seems to indicate that pre-CMB effects do not so much seed the value of the Hubble constant derived for early time, but rather relatively add to that estimate. In other words, temporarily larger pre-CMB dark energy effects increase the early time CMB-derived Hubble constant [40,51].

[40] shows quantitatively that such an evolution, with even just a 5% contribution of dark energy versus the radiation energy densities (at $z > 5000$), then a slow roll decay, suffices to eliminate the Hubble tension, without adversely impacting BAO, and provides a good, or even better, subsequent match with the ΛCDM.

Combining the reasonings of sections 4.1 and 4.2 may therefore actually be the answer. Accordingly, a larger contribution would be associated to the multi-fold dark energy effects, à la section 4.1, especially early on, pre-CMB, but post inflation, but it is tempered by the plasma effects that increase till going back to the conventional effects towards recombination. It makes sense as the former effects would grow as density, i.e., when going back to earlier ages, albeit also constrained by curvature before inflation, assuming that it took place, while the second effect (plasma reduction of the effects) stalls. Per [40], only a small percentage of dark energy contributions, versus radiation energy is needed.

As spacetime expands, the increased dark energy effects reduce, and plasma effects continue à la section 4.2, eliminating the effect due to high density of matter and radiation everywhere. Later, as matter and radiation dilute, the dark energy effects progressively (and exponentially) increase, consistent with the evolution of the

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[3] By the way, this is also expected: entanglement from matter requires matter first: a very consistent result of multi-fold dark matter effects, also consistent with the ratios as in [50].

ratios of energy densities, as shown, for example, in the figure on the relative importance of different energy components in [49].

The scenario above provides a microscopic interpretation for [40,51], with probably a preference for the slow roll over the oscillating scalar field model [40]. The slow roll is justified as above with the plasma effects. Oscillations would probably be harder to motivate.

We did not introduce any new mechanisms, fields particles or effects. Therefore, in a multi-fold universe, the multi-fold dark energy mechanisms intrinsically contains such a scenario, and provide a microscopic interpretation to [40,51], at least qualitatively, without requiring new fields. It is intrinsic to the multi-fold mechanisms, the multi-fold dark energy mechanisms [1,44] and spacetime reconstruction [1,31,32]. And it seems that it leads to better match to the ΛCDM.

We see this results as an significant additional arguments in favor of the multi-fold theory.

Note added on December 15, 2023:

4.4. Fractal Universe

As already mentioned, [151,152] analyze the effects of fractal spacetime and show that it could result into a time-varying cosmological constant

As discussed in [1,32], the universe spacetime (multi-fold) was fractal or rather multi-fractal during a time range, during the early times, where 2D random walk took place with a fractional spacetime [32]. It should be considered as an additional qualitative contribution to reducing the Hubble tension, in the second phase of section 4.3 (between the increased effects and the evolution towards today's value.

5. And the real universe?

Based on the multi-fold theory, the multi-fold theory can provide contributions to open issues encountered with the Standard Model or standard cosmological model [1,4-32,42-48,50,54-109,*112-151*]. In particular, [6] showed that our real universe, well modeled macroscopically by General Relativity, may very well be multi-fold.

Therefore, our results can also be relevant to our real universe. The paper complements well proposals like [40,51,*b39,b40*] with a detailed microscopic interpretation of what can physically produce the proposed dark energy effects and it is entirely intrinsic to the original multi-fold dark matter effects, proposed in [1]. It is not the result of late tuning. Yes, in [1] we did not entirely understand and discuss these effects, but they were implicit to the model from the beginning.

If the models à la [40] turns out to be disproven, or if late estimates of the Hubble constant must be modified instead, the resolution will have to come from elsewhere, as in some of the papers discussed in section 2. But that would not invalidate our analysis, that, unfortunately, so far, is purely qualitative.

6. Conclusions

This paper shows the compatibility of the multi-fold theory with a time-varying cosmological constant, and provides a microscopic explanation for it. With our approach we can motivate such effects that seem to reduce the Hubble tension and match ΛCDM.

Furthermore, the other options described in sections 4.1, 4.2 *and 4.4*, remain alternate candidates, if [40,51] do not pan out as expected, in terms of how pre-CMB dark energy impacts the Hubble constant derived from the CMB. Of course we stand for the combine model of section 4.3 *plus 4.4*. *(Text in italic added on December 13, 2023)*.

If the real universe is multi-fold then the explanation could help explain the Hubble constant tension.

If it turns out that the tension results from errors in late time measurements, then it would mean that the qualitative analysis presented in this paper, does not quantitatively impact significantly the early time estimates.

It was not the purpose of our paper to argue resolving the Hubble tension, albeit [40] seems to indicate that the effects could be good enough, and with our microscopic interpretation, it is becoming very attractive if not very convincing.

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