Yeah or Nay on Black Holes as Explanation for Dark Energy?

Stephane H. Maes[1]

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Abstract

Two recent papers argue having observationally confirmed that black holes could explain the universe accelerated expansion as sources of such expansion. These papers have generated a large interest in the wider public.

The present paper presents arguments against, and a few in favor of such a proposal, as well as some variations on what could happen if the answer to the title was positive. Even if it isn't.

Then, we analyze the proposal in a multi-fold universe, where we can take advantage of more microscopic interpretations. Some could support the new proposal, but overall, most seem to go against it.

Our conclusions are that while it might be possible that black holes could explain the acceleration of the universe expansion, because based on solutions to General Relativity (GR), we have more arguments against that view than in favor. It is therefore our conclusion on the matter: it's a nay.

1. Introduction

Dark energy is one of the most frustrating open problem of Physics and cosmology [2]. When related to the small cosmological constant value, it has been labeled by many as the biggest failure of physics, especially for QFT [1]. And it is, to the extent that we have still have no conventional[2] idea to suitably explain its existence, although many different candidate explanations have been proposed.

[9,10] are two recent papers who started a recent popular interest on the idea that black holes may be behind dark energy and the accelerated expansion of the universe [11-13]. Some physicists have provided their views on the matter [23,124], but most resulting analyses seen so far do not seem to have reviewed in details the theoretical bases for the proposal [14], championing GEODEs (GEneric Object of Dark Energy), and the actual origins of it, almost 60 years ago, by Erast Gliner and his team, associated with Landau and Ginzburg [15-19,31]. Gliner, while still widely unknown, is now considered as having paved the way to dark energy modeling, and influenced the ideas of cosmological inflation introduced by Guth and Linde [20-23]. It is quite a pedigree. But across all these models, these theories are still controversial, and far from unambiguously validated by observations. The same continues for [9,10]. Some physicists have stepped in with objections [23], asserting for example that the data used in [9,10] is too small, questionable, or that anything can increase mass, not necessarily implying dark energy.

In this paper, we review the results and claims of [9,10]. Then, we discuss the underlying theories as in [15-18]m and [14]. The paper also discusses different ways to understand the resulting proposal ,and follows up with a pros

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[1] shmaes.physics@gmail.com

[2] Conventional as in non-multi-fold-based. In the multi-fold we have a possible qualitative explanation that may contribute to explaining dark energy, in part, or fully, is also open-ended [3-8].

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and cons analysis based on conventional arguments. It includes reviewing both the reported observations, but more importantly the theoretical derivations.

Then, the paper reviews the multi-fold theory, and points out aspects relevant to dark energy [3,48-50,62]. The multi-fold theory presents the advantage to often being able to provide microscopic models, and interpretations, that so far have turned out to align well qualitatively with the real universe, and contribute to addressing many still open issues in Physics, with the Standard Model (SM) or rather the Standard Model with gravity non-negligible at its scales (SM_G), and the Standard Cosmological Model (ΛCDM) [3-8,27,30,34,44-109,121].

The paper continues by providing a pros and cons qualitative analysis of the proposals from [9,10,14] and [15-18], in the context of a multi-fold universe. Overall, we show that while some aspects of these proposals can relate in a multi-fold universe, many other considerations seem too much at odds to make the ideas plausible.

Overall, the two pros and cons sections lead us to the conclusions that, while relying on GR compatible solutions, [10,14] and [15-18] may not be physical, i.e. encountered in our universe, at least as black holes sources of dark energy.

2. Black holes as dark energy source: the proposals

Let us go back to the origin of it all. In 1966, [15] proposed a μ-vacuum, which can be seen as a macroscopic form of matter, with property of vacuum, filling spacetime, and resulting in a de Sitter spacetime with

$$p = - \mu \tag{1}$$

, and μ, the vacuum energy. [16,17] shows that a cosmology built around $p = - \mu$, is an expanding Friedmann Le Maître Robertson Walker (FLRW) universe [25], i.e., describes a homogeneous, isotropic, expanding universe that is path-connected, but now, without singularity.

While collapse is only hinted in [15,16][3], as the result of a phase transition when compression on matter is very large so that repulsive forces disappear, attraction dominates, and pressure becomes negative, [18] proposes an black hole composed of vacuum and without singularity: a spherically symmetric vacuum stress-energy tensor with one assumption concerning its specific form generates the exact analytic solution of the Einstein equations which at large distances coincides with the Schwarzschild solution, for small distance it behaves like a de Sitter solution, and describes a spherically symmetric black hole singularity free everywhere.

The key statements are

- A) exact solutions, and therefore subject to simplifications of the model, as are roughly all general relativity (GR) exact solutions, by the way, also tractable, and categorized with Petrov Approach [28,29]
- B) without singularity.

The latter bullet is justified in [15] as follow:

- i) GR is unable to account for a transition of normal matter to a new state within the black hole. So GR will not tell us about it.
- ii) QFT can work with μ-vacuum as vacuum
- iii) On that basis, μ-vacuum is assumed to be the lowest energy level of matter.

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[3] Interestingly, the reasoning in [15] also reminds of QCD asymptotic freedom, not yet understood at the time, and to be discovered only in 1973. See [27] for some references.

- iv) When compressed, to a state beyond asymptotic freedom that eliminates mostly the repulsion forces, matter would be a continuum of material attracting each other, and therefore with negative pressure per [15].
- v) Such a state could appear inside a black hole as otherwise pressure goes to infinity on the way to its singularity.

(iv) assumes that compression of matter can be so strong that repulsion disappears resulting in a negative pressure and external movement of the "transformed new phase of matter". The black hole would fill μ-vacuum up to a point where:

$$p + \mu = 0 \qquad (2)$$

Note that (iv) would potentially carry quantum numbers (like B, the baryonic number), and bit like the sea of Higgs and vacuum can in interactions with the Higgs, or these numbers may not be conserved in the phase transition to μ-vacuum. Both options can be considered.

[14] does essentially the same thing, imposing instead perturbation to a black hole metric that follow FLRW symmetries. It amounts to pushing the accelerated expanding homogeneous and isotopic behavior, that [15-18] attached to the μ-vacuum.

[14] attempts to provide quantitative estimates for the effects, and doing so to argue for contributions to the expansion of the universe. Computations are done via perturbation of the Hilbert Einstein action, and imposing a FLRW symmetry on (the result of) the perturbations; which amounts to bringing an assumption as in equation (1). It leads to estimates of the energy shifts for different cosmic objects (stars, galaxy clusters and GEODEs) as a result of the universe accelerated expansion. And yes, they all result in an increase of energy, i.e., increases of mass. Of course one could argue that μ-vacuum is the justification for this, and that therefore all these objects other than GEODEs, if they were to exist, and black holes, if indeed there were to be a phase transition to μ-vacuum in (some) black holes, would not a priori be subject to such a transition. Therefore, the results for stars and galaxy clusters in [14] are immediately suspect.

Of course, that is for a case where FLRW is selected to expand, which is motivated by the reasonings of [15-18], and with the assumption that the FLRW symmetries of the perturbation is what ensure that the universe would asymptotically be FLRW. As [14] is very detailed, anybody interested can follow the derivation, and lack of mention of black holes vs. GEODEs or μ-vacuum or equivalent for the other cosmic bodies. We see more value to motivate why [9,10,14] really argue for a source of dark energy, because that is what others have criticized as not justified in the papers [24]. Now you know that there is a justification, and that it comes from [15-18]. [14] shows that the ideas are corroborated by the zeroth order perturbative pressure expression which can provide a negative pressure, and recovers a Friedmann equation with an expression for the scale factor that corresponds to an accelerated expanding universe. The view that the black hole is the source of it, and therefore provides the dark energy or μ-vacuum energy, results from such reasoning.

Then [9], compiles a list of black holes for stellar and super massive black holes (SMBH), as function of the redshift, with the idea that these go back in time, and finds that the mass growth rate of SMBH cannot be explained by conventional models, i.e., essentially cosmic object collapses, accretion/feeding and mergers, and, therefore, that there must be (an)other processes feeding the growth of SMBHs. Such challenges with explaining black holes is well known.

[10] suggests that such an extra growth feeding process is in fact the mass gain of the GEODEs estimated in [14]. Looking at the data they have compiled, they see that they can find a subset of SMBH in their list that would fit the data, and that the μ-vacuum estimates would then fit in lieu of dark energy in ΛCDM, the standard cosmological model [30]. And so, the problem of the dark energy and its small cosmological constant would both be resolved.

3. Conventional Pros and Cons Analysis

In this section, we discuss some of aspects of the proposals in [9.10,14] from a conventional, i.e., non multi-fold, point of view.

3.1. GEODEs

Nobody has ever found evidence that the GEODE model is physical, i.e., encountered in our universe. Of course, one could counter that it is why [9,10] is relevant as a first hint that GEODEs may exist.

There are however some challenges with the reasoning that become apparent in the following sections, if we were to replace “black holes” by “GEODEs".

3.2 Matter to μ-vacuum phase transition

It is not at all obvious that, at very high pressure, matter interactions, other than gravity, would turn attractive and that therefore the pressure would turns negative. It could remain positive (with or without phase transition, when particles overlap, and continue to be compressed), null, or rather result into further decompositions like a block of colored/charged bosons and/or neutral bosons, where we use color/charge generically for all the conserved quantum numbers. The choice of negative pressure is just a choice, unproven so far. Sure analogies with the earlier times of the big bang and inflation could be invoked, but it is still unproven that later (re-)compression would result in such a phase transition.

3.3. Kerr vs. FLWR incompatibilities

In [10,14], and references therein, the authors argue the incompatibility of black hole metrics, especially Kerr-like metrics for rotating and charged black holes [123], with the FLWR metric and symmetries. The key steps in [14] (and [18]) rely, in [14], on trying to reconcile the black hole metrics (Schwarzschild or Kerr) with the FLRW symmetries, with the expectation to asymptotically reconcile these two metrics. It begs to mimic [18]. In [18], a solution is found that matches the Schwarzschild metric away from the “origin”, and a de Sitter metric towards the origin, and doing so, without any singularity. But it is also to be noted that the differences between [14] and [18] come also from the fact that [18] is focused on proving that the proposed approach with μ-vacuum leads to black hole looking objects without singularities, and with μ-vacuum. So it is really [14] that leads to the main results of black holes as sources of the universe accelerated expansion, or, said different, as sources of dark energy.

However, we question two aspects, of the mentioned incompatibility, different from just the challenges in obtaining exact or numerical estimates of GR solutions for black holes in an expanding universe; something that we do not question or dispute (See also [41]), as discussed in section 3.6:

- Firstly, the asymptotic incompatibility between the Kerr metric and the FLRW metric and symmetries is not an issue. The FLWR describes a homogeneous, isotropic, expanding universe, and it is asymptotically characterizing the state that has evolved from early on after the big bang. The Schwarzschild and Kerr metrics characterize the spacetime around an existing, already formed black hole of a certain mass (and angular momentum or charge). It does not characterize the past history of formation of the back hole till its current state, nor do they characterize the dynamics of the propagation of the metric changes during the formation as gravitational waves reflecting the history of the formation of the black hole. These waves are way behind the asymptotic FLRW state (e.g., boundaries or horizon of the universe), and will never catch up with it to modify it from a FLRW to a metric that now reflects one or multiple black holes, i.e., inhomogeneous with matter sources. There is just no issue: the reality is that a(n) (expanding) universe with (a) black hole(s) is no more FLWR, period.
- Secondly, there is therefore no need to impose the FLRW symmetries onto any allowed variation and outcome of the metric resulting from the introduction of the black hole. Even if imposing such constraints leads to solutions of GR as shown in [14]. Yet, these constraints are what leads to the results of increasing energy and mass of cosmic objects in an expanding FLWR universe, and encountering GEODEs.

This is why we question if the reasoning of [14], while mathematically correct in the sense that the solution obtained is indeed a solution of GR, is ever physically encountered in our universe. Even for primordial black holes, that would exist from the (quasi) beginning of spacetime, which they most certainly don't: fluctuations have had to take some time to lead to black holes, or dark energy sources, humor us for now, especially if coupled to the exponential inflation that would have first smoothed out the amplitudes of any pre-existing fluctuation. In any cases, even if a black hole, small, had already formed, it would still run behind the ~ FLRW symmetry, no matter what.

Therefore, as a GR solution, it may be adequate, but that does mean that it does physically exist in our universe.

3.4 SMBH

It is well known that the formation of SBMH is problematic: we have challenge to explain it. This, along with the very old galaxies recently encountered with JWST are challenging Cosmology today. Especially very early on after the big bang as for example reported in [32,33], and references in [34]. Yet it does not challenge the existence of the big bang contrary to what others have claimed [125,126].

As discussed in the previous subsection, in general, we do not expect that black holes would form early on to be fed by inflation into SBMH with the process proposed in [14]. However, let us assume that fluctuations created a primordial black hole before the onset of inflation. If that were the case, we believe that effects of inflation on the black hole would lead to a way too large SMBH compared to anything observed so far. The reasoning is in part that the exponential expansion is simply too strong, if inflation has to satisfy all the motivations for proposing inflation as discussed in [3,6,23], and references therein. Observed SMBHs should be too small for such a scenario, and that includes the SMBHs considered as sources of dark energy in [10].

Alternatively, if one wants to address this issue by proposing that only a portion of the inflation phase would have contributed, i.e., that the black holes would have formed during the inflation phase, we reach another challenge: during inflation, spacetime is stretched exponentially which flattens fluctuations and curvature. It seems hard to envisage how that could coincide with black hole formation by fluctuations.

Any other primordial black hole, born after the inflation phase would not be able to capitalize on inflation to grow to SMBH, with the mechanisms of [10,14], which invalidates one of the motivation behind their proposal. And we conjecture that any primordial black hole, born before the inflation phase would be too big for what we observe.

Also, we conjecture that no black hole can appear during the inflation. And yes, if the inflation took place in several phases, separated by non-inflationary periods, one could imagine a way around this. It is not so far how the inflation is typically envisaged, but it is true that it may happen, for example if the inflation was explicitly fueled by a series of major symmetry breakings like GUT, electroweak, chirality etc. It may be possible.

Conventional views agree with our analysis: inflation (from 10^{-36} seconds to between 10−33 and 10^{-32} seconds after the Big Bang) takes place before the radiation dominated area (After Inflation, and until about 47,000 years after the Big Bang), when the primordial black holes are expected to have appeared [23,33-37], if they exist at all.

3.5 Spacetime expansion and bound objects

A key aspect of the universe expansion is that it does not affect bound objects because the binding interactions are way stronger than the impact of the expansion. It is well known, and for example popularized in [38-40]. This is true for electromagnetic, as well as gravitation bindings.

Yes, it is true that, when it comes to objects gravitationally bound considerations, the statement really refers to the Newton approximation. In general relativity, one should compute the solution. This is what [14] does, but with a model that presupposes a behavior that is questionable, i.e., possibly unphysical assumptions of a phase transition to a μ-vacuum, or constraints of perturbations with the FLRW symmetries. In general, the reasoning that the gravitational binding overwhelms any expansion effect should remain true.

Also, as far as we can see, the assumption of no expansion of bound systems holds for all the cosmic system we observe. Things may have been different during inflation, or earlier, but we already saw that this is probably not when (first) black holes (or GEODEs) would have formed.

3.6 Black holes in an expanding universe

As already mentioned, [10,14] argue that black holes are not well modeled by typical / static equations in an expanding / FLRW universe. They provide an extensive set of references documenting these discrepancies. And yes there are problems with exact solutions, see the references in [41][4], for more independent examples of challenges.

However, as explained in section 3.3., new solutions for an expanding solutions is a different problem than finding solutions asymptotically compatible with a FLRW metric. The former must physically exist, while the latter may simply not be physical.

In our view, GR solutions as black hole models in expanding universe should also exist without involving μ-vacuum assumptions. In fact, there must be GR solutions that reflect the bound system behavior, and remain essentially static, possibly swollen as a function of the acceleration rate of expansion. This is exactly what [41] obtains with R_ for a charged (not rotating black hole)[5]. We expect that rotating black holes will behave similarly, respectively in analogy to [43] and [42,123] in a non-expanding universe / asymptotically flat.

A way to understand what happens is that as the spacetime expansion accelerates, an additional force appears, repulsive, on the content of the black hole. As a result the horizon changes a bit (expand to have more gravity pull

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[4] [41] is not mentioned in [9,10,14] and related papers.

[5] 2 horizons form depending on the mass and charge. It is well known. With rotation, similar behaviors, especially swollen horizon are encountered.

to counter these effects), just as a charged and / or rotating black hole have (a) different horizon)s) than neutral non-rotating black hole (contracting) [42,43]. It may also similarly split into two horizons (with frame dragging in the ergosphere in-between to prevent tangential velocity larger than c [130]), and change the details of its singularity region. You will note that no mass increase, à la mass to Schwarzschild radius relationship, is implied[6]. No extra mass need to be created in the black hole to match the radius horizon increase, with $E=Mc^2$ applying of course: the mass to horizon size relationship is just changed from the equation for a similar black hole in a static universe. That is all.

What we describe here seems a more appropriate model than the proposal of [10,14], as it is intuitive, corresponds also to a solution of GR, matches analogies with effects of charges or rotations on black hole horizons, and does not require an hypothetical, and unproven phase transition to an unknown μ-vacuum state of matter.

A consequence of this analysis is that black holes, i.e., as conventionally understood and potentially with a singularities, and as the result of gravitational collapse and with singularities, can still exist, including SMBH.

Then, the question becomes: could some black holes evolve into μ-vacuum GEODEs instead of conventional black holes, and if yes, how, when and why would some evolve into μ-vacuum GEODEs instead of conventional black holes? That is unclear and unanswered by the [10,14,15-18]. Could it be because the pressure reaches a level not met in non SMBH? It is questionable as conventional black holes, even if the actual physicality of singularity is also still open-ended, would have regions trending toward infinite pressure near their singularity, in as much that black holes are modeled. It seems that it should be a whole or nothing; something not confirmed by the observations of [9,10]. Also, we note also that [14] only speaks of GEODEs, not black holes; in our view possibly to avoid such a discussion that has so far no answer in [9m10,14,15-18].

We could accept that GEODEs may still exist, as the result of other processes than collapse into conventional black holes, black hole feeding, accretion or mergers. Such processes have not been detailed, or encountered so far, and no GEODEs has been observed, besides of course the claims of [10] and some references therein.

3.7 Page curve, black hole information paradox and the Hawking's radiation saga

The black hole information paradox can be resolved if its entropy evolution follow a Page Curve [115,116]. Using path integrals, the island formula and the replica trick, it has been proposed that the black hole information paradox can be resolved, with radiation through a quantum extremal surface, which reduces the entanglement with the outside of the black hole, resulting into a Page curve. See references in [102,103]. Usually, the quantum extremal surface is conventionally understood as defining a Wheeler's bag of gold, where the particles radiated into it would no longer contribute to the entanglement with the outside, and to its mass[7]. The latter only if the geometry of the Wheeler's bag of gold would ensure that gravity from matter in the bag can never reaches back the "entrance" to Wheeler's bag of gold, e.g. with a FLRW baby universe; otherwise the mass of the black hole remains constant for evaporation through the quantum extremal surface; a bit of a problem.

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[6] Besides of course the idea that an energy increase implies mass increase.

[7] Mass hiding is a more controversial aspect if we consider that there exists no gravity shield [102]. That is why we recommend instead to follow the multi-fold version of the interpretation, that also can apply to the conventional world as long that a particle picture is accepted [3,69,101-103,110,129].

Could it be that, instead of radiating into a Wheeler's bag of gold, the quantum extremal surface would denote, and delimit, a region of phase transition to μ-vacuum [8]? It would handle the singularity as [15-18] eliminate the singularity from their black hole model.

If only what is inside the quantum extremal surface becomes μ-vacuum, then that information (and entanglement) is lost, and the model can continue to address the resolution of the black hole information paradox. Unfortunately, radiation into the quantum extremal surface occurs after a while, and slowly over time. It does not match exactly the view of an existing pool of μ-vacuum in the black hole, even if the content of the quantum extremal surface grows with time. Plus the mass behavior mentioned in the previous footnote leads to a challenge towards the end of the cycle.

Following section 3.6, add spacetime accelerated expansion, and the black hole horizon, as well as the quantum extremal surface would be larger, than if the black hole was in a static universe, again by analogy with [42,43]. None of this provides ways to further grow the mass or continuously radiate gravitational waves as a result. Negative pressure would not leave the black hole.

So it does not seem that we have an agreement between these approaches. If only what is inside the quantum extremal surface becomes μ-vacuum, then that information (and entanglement) is lost and the model can continue to address the resolution of the black hole information paradox. But that still does not expel any accelerating effects from the black hole, and the total mass of the black hole is not growing.

3.8 Non-GEODEs

Note that [14] is also applied to other cosmic objects like stars and clusters of galaxies. Yet, we already saw that these do not encounter the proposed compression required for phase transition to μ-vacuum, and at best mass increases are really based on $E = Mc^2$. But for these objects, the lack of expansion of bound systems applies.

Therefore, the extension of [14] beyond black hole is suspicious and indicate to us the lack of a well-motivated microscopic interpretation to support imposing only FLWR symmetric perturbation to the Hilbert Einstein action. It may point to another inconsistence of the proposal. Again, there may be better ways, à la section 3.6, to model cosmic objects and gravity in an expanding universe à la FLRW.

Note that other proposals, without μ-vacuum exist out there to explain the accelerated expansion of the universe. Among exotic ideas, consider for example [120,122], of the multi-fold dark energy mechanisms discussed in upcoming sections [3-8].

3.9 Reported experimental results

[24] does a great job at critically questioning the reported results, obtained with a just subset of selected black holes that happens to match their model with very small errors, something that [24] finds to possibly be a red sign.

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[8] Now the mass would remain the same. A problem for [10,14] and a problem for the resolution of the black hole information paradox relying on the conventional quantum extremal surface: that mass would remain at the end of the cycle. Also, the total mass of the black hole does not grow.

The bottom line is that a much more extensive study would be needed to validate and reproduce the results. And even then, it still does not mean too much till the issues above are clarified, and a more convincing case put forward. As is well known, correlation does not mean causality.

As indicated in the previous section, the fact that only a subset of the data seems to follow the prediction, raises the question of why some black holes would be black holes and others GEODEs, as discussed in section 3.6. Until a plausible explanation is proposed, these results rather suggest that the theory and results are inconclusive.

4. A different interpretation?

Note that we like to also look at the proposal of [14] a bit differently.

If a black hole is dropped in an expanding universe, the metric change would also propagate as a gravitational wave, say perturbing FLRW into a Schwarzschild or Kerr metric with a swollen (possibly splitting) horizon.

Consider a black hole suddenly stretched by an acceleration of the spacetime accelerated expansion, which exercises an extra force. The energy is increased with an associated mass increase. The gravity effects outside change, and the change propagates at c as a gravitational wave (as a step function).

If the acceleration continuously increases, the gravitational wave becomes a ramp that propagates at c. But the gravitational wave could never be seen as contributing to the acceleration increase of the universe: the effect is an increased attraction towards the expanding (as acceleration continuously grows) black hole.

5. Multi-fold theory

In a multi-fold universe [3,48-50,62], gravity emerges from entanglement through the multi-fold mechanisms. As a result, gravity-like effects appear in between entangled particles [3,64,65], whether they be real or virtual. Long range, massless gravity results from entanglement of massless virtual particles [3,65]. Entanglement of massive virtual particles leads to massive gravity contributions at very smalls scales [3,66]. It is at the base of the E/G Conjecture [64], and the main characteristics of the multi-fold theory [62]. 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 [3,4,5,7,56,67,68]. 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 (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 without new Physics other than gravity added to SM. These considerations hint at an even stronger relationship between gravity and the Standard Model, as finally shown in [63].

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 the Higgs boson, due to chirality flips by gravity of the massless Weyl fermions [3,89], induced by 7D space time matter induction and scattering models, and hidden behind the Higgs bosons 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. They can condensate into Dirac Kerr-Newman soliton Qballs to produce massive and charged particles [3,101], 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. Above it, massless Higgs boson create massless particles through patterns of random walk matching the 7D induced solitons. The multi-fold theory has also concrete implications on New Physics like supersymmetry, superstrings, M-theory and Loop Quantum Gravity (LQG) [3,48-61].

The multi-fold paper [3] 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 (SM_G). 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 [3], spacetime and Physics are modeled from Planck scales to quantum and macroscopic scales, and semi-classical approaches appear valid till very small scales. In [3], it is argued that spacetime is discrete, with a random walk-based fractal structure, fractal/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 Reissner Nordström [42], and Kerr Newman [43] for massive, and possibly charged, particles – the latter being possibly extremal). Although possibly surprising, [3] recovers results consistent with others (see [101], and its references), while also being able to justify the initial assumptions of black holes from the models of gravity or entanglement 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 scales, which make gravity non-negligible at these scales. Semi-classical models also turn out to work well till way smaller scales than usually expected.

Multi-folds are encountered in GR at Planck scales [45,46] and in Quantum Mechanics (QM) if different suitable quantum reference frames (QRFs) are to be equivalent relatively to entangled, coherent or correlated systems [47]. This shows that GR and QM are different facets of something that they cannot well model: multi-folds.

Considering results as in [46], and our answers to so many open issues with the SM_G as discussed for example in [3-8,27,34,44-109,121], we can then argue that these conclusions could apply to our real universe, especially considering how the multi-fold mechanisms recover GR [3,46], and can be encountered in GR at Planck scales[9], with the spacetime reconstruction [3,7,46], and with the top-down-up-and-upper derivation of the multi-fold theory [46].

6. Multi-fold pros and cons analysis

In this section we list some pros and cons arguments for proposals similar to [10,14,15-18], but now in a multi-fold universe. It turns out that, among all the work done so far on the, multi-fold theory, we have systematically seen that multi-folds may apply to the real universe, and the resulting properties often can give insights relevant to the real universe [3,48-50,62]. Therefore, it is valuable to see if anything in the multi-fold theory so far gives hints to answer the question asked in the title of our paper.

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[9] Aligned with the views of for example [117], even if the coupling and details differ from [3].

6.1 Multi-fold dark energy effects

[3-8] provides a proposal for inflation and dark energy effects due to fluctuations of the quantum fluctuations, which as such can also account for a cosmological constant way smaller than QFT estimates. It is only a qualitative proposal, but some related results about fluctuations of fluctuations obtain the correct quantitative order of magnitude [112,113]. So we argue that our approach could quantitatively fit[10] [111].

We acknowledge that what we propose may also be just a partial contribution to dark energy. Other sources may exist, and therefore a priori confirming that black holes would also contribute would be incompatible. That is only if the overall model makes sense. Does it?

6.2 GEODEs

So far, we have not encountered objects like GEODEs, that would be composed of μ-vacuum, in a multi-fold universe.

6.3 Matter to μ-vacuum phase transition

We have shown that at very small scales, or very early after the big bang, entanglement between neighboring nodes of the discrete multi-fold spacetime [3,56]. These entanglements create attraction between the nodes, as well as between massless Higgs bosons that would occupy them to mark concretization of spacetime. If one follows the reasoning of [15], it could result in a negative pressure. It could also make sense as a Bose Einstein Condensate (BEC), which we know can also well model inflation and early stages after the big bang [3,68,118,119]. However, such a model would be different from the multi-fold inflation that results from exponential combination of random walk and pair of particles, anti-particle creations or our proposal for (a contribution to) multi-fold dark energy [3,4,5].In other word, another mechanism at play.

Yes, our model of particles as resulting from patterns or condensation of Higgs bosons, allows for μ-vacuum to be such a soup of BEC of massless Higgs.

And we know that random walks of entangled bosons, as in a multi-fold universe, could be a BEC. So it's possible that early multi-fold random walks are the microscopic interpretation of μ-vacuum, at least at the scale of the universe. But what about within a black hole?

It is plausible that high pressures, and high temperatures, as in a small black hole, and therefore high energy, we revert back to the random walk of massless Higgs bosons, when then may be able to "expand" if with enough energy to walk away and may be create new pairs of particles and anti-particles, although only as a baby inflation effect. This way all effects would again be based on random walks, and we may recover a notion of μ-vacuum across all these cases. but creation of new pairs is critical to gain the exponential growth of the inflation , and in this scenario, we do not see where the extra energy required to expand and leave the black hole would come from.

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[10] A future paper with discuss these aspects in more details.

Handwaving something like the ideas of total collisions, as in [114] to help avoid singularities, would not work to escape the quantum extremal surface ahead of its time [101], and the black hole horizon.

In a black holes, none of those can escape, other than by radiation (Hawking and unentangled) as in [3,101-103], and mass would not increase, unless some magic was to be involved.

6.4 Kerr and FLRW incompatibilities

Just as discussed in section 3.3, the black hole formation and the propagation of its multi-folds to the outside, i.e., its gravity effects and gravitational waves, is always running way behind the expansion of the universe. Black holes, as any other matter, render spacetime non-homogeneous and non-isotropic. It's normal and expected. There are no issues with this contrary to what [14] claims.

Our construction of the black hole area law [3,101-103,108], can be repeated in an accelerated expanding universe, with just an enlarged and possibly doubled / split horizon, by seeing the acceleration as an additional repulsive force contribution to add to the electromagnetic repulsion for charged black hole and centrifugal effect of rotation for spinning black holes. Nothing more.

6.5 SMBH

The same considerations as in section 3.4 apply.

However, we have already argued in [3,4], that multi-fold dark matter effects, proposed to result from entanglement [3,6,34,71-75,96], something abundant in the early universe, could (partially and qualitatively) explain SMBH in ways that can't be conventionally explained. It could reduce the motivation for alternate mechanisms as pushed by [9,10,14].

6.6 Spacetime expansion and bound objects, including black holes

Same considerations as in section 3.5.

6.7 Page curve and the Hawking's radiation saga

In [3,101-103], we discuss how in a multi-fold universe we can resolve the black hole information paradox and recover the Page curve predicted as required to do so. Our approach also encounters the equivalent to the quantum extremal surface of section 3.6, but it interprets the physics related to it differently from the approaches based on the island formula and replica trick. See [3,101-103] and references therein. In particular, we do not encounter a Wheeler's bag of gold. Escapes from the horizon, or, in time from the quantum extremal surface, only occur through evaporation, and/or with a decrease in mass. This reduces the size of the quantum extremal surface offering new candidate particles for evaporation.

Turning the inside of the black hole, or of its quantum extremal surface, into μ-vacuum, would be compatible with resolving the black hole information paradox only if it only occurs within the quantum extremal surface (or within another surface within it). Otherwise, the black hole information paradox would remain in force. And we must again emphasize that mass issues may result (remnants and no increase).

In multi-fold black holes, gravitational singularities are avoided with the discrete spacetime, torsion and multi-fold dark energy effects as well as possibly with the total collision scenario mentioned in [114]. The same would be true for any future cosmological singularities (big Crunch or cyclic universe), but it is open ended for the actual big bang [3]. So, from that point of view, we can match this result from [10,14,15-18], but essentially without involving the μ-vacuum[11].

Also, at the difference of conventional cases, multi-fold dark energy is larger near matter, and, in our case, outside the black hole, due to the curvature of spacetime. But these do not globally accelerate the expansion of the universe much more than the contribution from everywhere else. And it has nothing to do with the expansion of spacetime. It's a local effect.

6.6 Non GEODEs

The multi-fold dark energy effects are stronger near matter, independently of the expansion of spacetime. We stick to the view that, in a multi-fold universe, bound matter is not affected by expansion.

7. Conclusions

With this paper, we conclude that, while some aspects of μ-vacuum, and its apparition in black holes, could be justified or even have a microscopic explanation, in general, both conventional and multi-fold analyses suggest that the proposal of black hole as source of dark energy is not fully consistent, possibly not fully motivated, and not un-controversially confirmed by the accompanying reported observations.

Therefore, we conclude that Black holes are not likely sources of dark energy, and that it most probably means that GEODEs do not exist, unless if justified by completely different and so far unknown processes than gravitation collapses, accretion, feeding and mergers.

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[11] Let us not be confused, we mention dark energy for completeness, and only as a contributing factor. The main contribution comes from the discreteness of a multi-fold spacetime.

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