Oops For The Loops: Mounting LQG Woes And A Challenge To The LQG Community

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December 29, 2021

Abstract:

This paper results from work done on the multi-fold theory which resulted in a proposal for quantum gravity. 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 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. All these recover General Relativity (GR) at large scales, and semi-classical models remain valid till smaller scale than usually expected. Gravity, with non-negligible effects can therefore be added to the Standard Model resulting in what we defined 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.

The multi-fold theory obviously overlaps and relates to other TOEs like superstrings and quantum gravity e.g.., Loop Quantum Gravity (LQG). Considerations about some of these other theories have been published, including lessons learned, and recommendations to fill gaps, or address issues. However, our initial analysis of LQG focused more on similarities, and our perceived gap in terms of particles, and entanglement modeling by LQG. We had not yet encountered an analysis, unrelated to the multi-fold theory, which argues that there would be a technical error in LQG quantization scheme that may also explain why LQG can't recover GR, and a classical smooth spacetime so far. This argument may not have been explicitly published to, or discussed by, the LQG community.

This paper points out and amplifies the arguments encountered around this possible error, and it challenges the LQG community to provide an answer, or a mitigating reformulated model.

1. Introduction

LQG [5-7] is a quantum theory of gravity built on a reformulation of GR using new variables [8]. It is a background-independent quantum theory of gravity in terms of loop solutions expressed in the new variables.

2. Multi-fold Analysis of LQG

Note added on December 22, 2022: The multi-fold theory, can be tracked at [34], and it is further explained at [1,21,36,37]. In addition, we also have several hints that a GR defined universe, as the real universe seems to be, may be multi-fold [38-43].

The multi-fold paper [1], and the following-up analysis [3], discussed the alignments and differences between LQG and the multi-fold theory, mainly in terms of:

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Cite as: Stephane H Maes, (2021), "Oops For The Loops: Mounting LQG Woes And A Challenge To The LGQ Community", viXra:2212.0168, https://vixra.org/abs/2212.0168, https://shmaesphysics.wordpress.com/2021/12/30/oops-for-loops-mounting-lqg-woes-and-a-challenge-to-the-lgq-community/, December 29, 2021.

- Alignment between multi-fold theory and LQG:
    - Discrete spacetime
    - The apparition of Non-commutative geometry
    - The idea of spacetime reconstruction.
- Gaps of LQG, from a multi-fold point of view:
    - Lack of particle modeling and tracking: how to introduce the fields, and, just as for QFT, how to track particles.
    - Explicit entanglement modeling, related to the lack of a good particle model.

Of course, the LQG spacetime reconstruction and recovery is based on a quite different approach from the muti-fold spacetime reconstruction. Yet the analyses of [17] and [21], show that consistency of the approaches, even if the steps seem quite different: GFT and multi-fold reconstruction rely on random walk of Higgs bosons, seen also as a graph of microscopic black holes that can be aligned with concepts of spin foams and spin networks.

3. A Problem with the Quantization Scheme

While checking for any recent progress in LQG, we encountered [9], where Urs Schreiber answered a question asking why LQG + SM was not usually not listed as a TOE.

He made the following troubling observations [9], that we rephrase here in our own way as follows:

- Barrett's theorem shows a requirement for continuous and smooth mapping of loops on smooth manifolds to smooth curves to use these curves as representation of the original holonomies. Smoothness seems critical to the proof of the Barrett's theorem [10] (or generalizations like [13]), and ensure the ability to revert/recover the original information.
- LQG uses holonomies of not-continuous or smoothly stitched together, curves called generalized connections ,as one of the (new) configuration space variables (Hilbert pre-quantization), and fluxes of tetrads as the other variables. Then, it quantizes using the constraints.
- The constraints that generate spatial diffeomorphisms are not suitable operators (equation (122) in [11] and step (123) also in [11]). So, in order to generate the Hamiltonian, the quantization relies on these holonomies and unitary transforms of the diffeomorphisms [11,12]. The latter mapping is a priori not weakly continuous, therefore violating the premises of the Stone-Neumann Theorem [19].
- [9] also criticizes the differences between the quantization results for simple QM problems, and QFT/QM [12,14] as well as the non-separability of the Hilbert Space used at that stage (pre-quantization) by LQG.

This is on top of the LQG challenges typically encountered in the industry about a) the inability to recover GR, smooth macroscopic spacetime, or black hole physics without fixing a free parameter, the Immirzi parameter [5-7,15], b) and questions about the big bounce prediction before the big bang [5-7,15], c) as well as how matter/fermions are modeled by LQG [6,7,15]. The dependency on the Immirzi parameter, and associated quantization schemes, is an often raised concern [34].

Note that arguments have also often been raised about the apparent contradiction between discrete spacetime and Lorentz invariance. [1,21] showed that both are not incompatible. Therefore, this one does not require more discussion. Even if the LQG community also provided different attempts at addressing that latter criticism, we rather believe in the [1,21] point of view.

Notes added on January 3, 2022: Finally, arguments have been raised that the cosmological constant would not result from gravity only but requires to also include the Standard Model fields [15], which relates also to Witten argument that GR can't be quantized, in de Sitter-like universes, without a proper cosmological constant model

[28,29]. A key push back against quantizing gravity "stand alone", as done by LQG (and resulting from not being able to well model matter fields, or particles).

Note added on December 22, 2022: An upcoming paper, to be published towards the end of 2022 and tracked on [34], will discuss aspects of these latter considerations in terms of asymptotic safety of gravity [1,30-33,35,47-50].

4. Details of the Mapping Issue

The cusp of the issues, identified in [9]. seems to be section 4.1.2 in [11], and the discussion between equation (122) and step (123), also in [11].

The interpretation of Urs [9] matches what is mentioned in section 4.1.2. in [11]: no smooth mapping any more for generalized connections. The use of Gelfand's triplet space to define the Kinematic Hilbert space, the algebra of kinematic observables, physically relaxes the smoothness requirement on the affine connections by allowing any number of segments to be stitched together on a path without any condition of smoothness or continuity. As such the algebra, and the space of "generalized affine", is not any more representative of the physical spacetime where the GR and Ashtekar's classical models live (prior to quantization).

The proposed formalism of section 4.1.2 has wide ranging implications. It is also the cause of the lack of weak continuity encountered for (122), that prevents the definition of self-adjoint operator and implies, per [18], that a different representation from what is usually encountered for quantization [12]: a very concerning result, considering the subsequent implication of this, even for modeling a particle or a scalar field [12] that can't be, so far, convincingly beaten back into shape [14].

It is now really unclear what the mapping is; not only is it not smooth but it's also being mucked with, by the Polymer quantization steps, in a even more nontrivial way. Doing so may have helped progressing the quantization program, but it certainly does not address the non-continuity/smoothness, that it obfuscates, and that seems also linked to the non-self-adjoint behavior of diffeomorphism operators.

A priori, it seems that the spin network representations may have lost the ability, or at least the justification, to encode smooth manifold connections and in such case, it is unclear, at least, what it still represents. Mappings may not be used in semiclassical / macroscopic / IR Regime, recovery. But it is in the setup of LQG spin networks. So this issue is certainly involved and fundamental. Even if one can justify or clean up the polymer quantization challenges (see the next section), the selection of such quantization does not address, and in fact worsen, the loss of smoothness issues with the mappings.

5. LQG Answers so far

Most of these criticisms in section 3, were known by the LQG community, and addressed, at least in ways that satisfy, to some extent, the LQG community, albeit not always outside the LQG community:

- [3] addresses the non-separability of Hilbert space showing that is essentially (quasi) separable, and arguing, correctly, in our opinion, that, in any case, this is not an issue, and non-separability should not invalidate the theory.

- The quantization scheme, known as the Polymer quantization [12,14], is different from QFT and Quantum Physics quantization à la Schrödinger. Something that is a challenge on its own. But, at least, [14] provides a discussion, and there is a LQG point of view on the issue.
- It is also argued that LQG recovers the black hole entropy without involving the Immirzi parameter *[25,26],* and that therefore there would be no issues [5-7]. *[References added on January 3, 2022]. Note added on December 22, 2022: the multi-fold recovery of black hole entropy and Page curve is discussed in [1,44-46].*
- The LQC (Loop Quantum Cosmology) big bounce discussions [5-7] are still problematic (and dependent on the Immirzi parameter) *[27]* but maybe less critical to the viability of LQG. *[References added on January 3, 2022]*
- Fermion coupling and handling is supported by LQG [6,7,15], but it says nothing about it something seen as an issue by many [5,15] about how does the SM impact spacetime reconstruction, quantization and behaviors, and conversely. The view outside the LQG community is that both influence each other.

For the rest, the LQG community argues that the theory is work in progress and that, indeed, progress is taking place, albeit slowly, but that the direction is promising [15].

Note that there also are discussions, which could be seen as endorsement of the LQG quantization algorithm in [18]. Also, [18] refers to the Bohr quantization, invoked as analogous to the Polymer Quantization. However, one may be able to argue that the Bohr quantization does not have to worry about smoothness recovery, while LQG has to connect to GR, in IR. The author also studied, in other papers, regular connections among generalized connections and uniqueness of invariant states in holonomy/fluxes, but none of those address the issue at hand, they address different questions! For example, and not denying the mathematical rigor of [18], arguing "*The continuity is lost, when the cylindrical functions have been used to form basic variables. Of course, since the continuity is lost already at the level of the algebra, and not only at that of representations, this does not weaken the results reviewed in the present articles*", as in [18], does not render the discontinuity behaviors physical. It is these discontinuities that seem unphysical.

Also, this Twitter discussion [20] discusses the motivations of generalized connections, not their physical suitability. All, these are purely statements of suitable mathematical definition of the proposals, not of their physicality, and as such, they do not address the concerns: we did not say that the variations introduces are not mathematically rigorously defined. We are saying that they have physical implications that are not explained, justified, or validated.

Note added on January 3, 2022: See[15] for an answer to the cosmological constant arguments by Rovelli. Unfortunately, it does not put that controversy to rest. Our point of view was presented in [29] for Multi-fold universes.

6. Oops for the Loops?

Unfortunately, with the above (section 5), we do not believe that any of the answers, or other developments of LQG that we have encountered, have addressed what is the main issue that interpellated us in [9] and section 4: the loss of the smoothness and continuity of the generalized connections and therefore the physical meaning in terms of spacetime or applicability of Barrett's theorem, and its impact on spin networks (and, as result, spin foam [6,7]: the consistency and relationships between the two imply continued concerns for spin foam also).

We would have expected answers or arguments as the ones provided to the other issues discussed in section 5, so that the LQG community would:

- (1) Argue why the addition of unphysical (non-smooth and / or not continuous) paths can still contain in the generalized connections the original information about spacetime in the case of LQG, despite violating Barrett's condition for it to be guaranteed. In our view it is not obvious, but let's see.
- (2) Argue that Barrett's theorem is not if-and-only-if, and that the LQG scheme (123) in [11] would still provide the required equivalence for the proposed mappings, smooth or not. It would still require to also explain why the noisy, not continuous and not smooth additions to the space of possible paths is acceptable.
- (3) Explain why the quantization scheme would remain valid without further fixes or concern about the introduction of the generalized connections.. That is probably, consciously or not, the approach of justifying, and fixing after the fact, the polymer quantization as in [14]. So maybe [14] is indeed the LQG answer to [9].
- (4) Or reformulate the model, e.g., without generalized connections, or a variation to them bringing back physicality, and quantization schemes, to fit the Barrett's theorem, while not introducing unphysical noise, and, maybe, if needed or possible, address the challenges to the Polymer quantization. This is what is probably needed if the previous bullet fails, or does not apply. At this stage, it is unclear to us how that would be achieved.

Otherwise, it seems that if the noisy mapping issue is real, as it seems to be, and not addressed in LQG, spin networks, and spin foams. These models may have lost connection, no pun intended, with spacetime. Therefore, it would not be surprising that LQG cannot recover GR, or a macroscopic smooth spacetime, as it is unclear what its model characterizes. It puts LQG at risk of being unphysical, i.e., a nice mathematical exercise disconnected from the real universe, not just for the IR regime but for the whole theory including UV, its main focus.

References added on January 3, 2022: We would also argue that the significant dependency of the quantization schemes (for a given Immirzi parameter type or value) further exacerbates the concern that the noise of the quantization scheme dominates. Indeed [24], shows disparate results with different scheme all ultimately relying on generalized connections but different on the holonomy functions selected. This also seems directly related in our view to challenges coming from not satisfying Barrett's theorem and its generalizations.

7. A way forward?

We call the LQG community to consider this issue, and clarify if there are issues, as we suspect, or if all is ultimately fine based on additional considerations, that we missed, or simply do not understand, or based on other results of which we are not aware.

We suspect that there must be a not too disruptive resolution as we know that other related discrete reconstruction schemes [17,21] provide results aligned with aspects of LGQ and the multi-fold theory [1,22].

8. Conclusions

This short paper brings attention to an issue reported in [9]. In our view, it could have fundamental impact on the foundations of LQG, in particular spin networks, and it could explain why LQG has so far been unable to recover a semi classical regime with a smooth or macroscopic spacetime governed by Einstein's GR field equations. This goes to the core of the criticism addressed to LQG as in [15].

A multi-fold-inspired proposal is for future work. *Note added on January 3, 2022: See [23] for a proposal for E/G-LQG, which proposes additional constraints that also hint at entanglement and multi-folds.*

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Appendix A: Any concerns for spacetime discreteness?

Note also that the discreteness of spacetime in LQG somehow results from the choice of generalized connections as modeled on Cyl / Cyl*. Although it is a possible dependency; it can be shielded from issues we raised in this paper. [1,17,21] provide other arguments for discreteness, so we are not questioning these results. But it is always good to understand when results depends on questionable steps.

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Acknowledgments

We want to thank the reddit /r/AskPhysics community members who have helped in discussing the root of this issue [16].