“A CAUTIOUS ONTOLOGY OF SPACETIME IN QUANTUM GRAVITY”

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I. INTRODUCTION

In 1988, Robert Weingard presented a paper on string theory at the Biennial Meeting of the Philosophy of Science Association much to the dismay of several colleagues. They told him that it's too early for philosophers of physics to be making any sort of foundational remarks about quantum gravity. Why would these sort of worried comments be made to Weingard? The primary concern stems from the still-changing mathematical structure of string theory/M-theory as well as the lack of empirical evidence to date. So are Weingard's colleagues justified in their focus on solidified formalisms? Or is there a place for philosophical inquiry (or scientific inquiry for that matter) concerning quantum gravity? If one does give the go-ahead for making deeper insights relevant to quantum gravity, a host of philosophical and scientific issues immediately come to the foreground: the reconciliation of gravity and quantum theory, the need or disregard of quantization, the problem of time, the ontology of spacetime, as well as the challenge of "doing science" without empirical proof. In this paper I will be discussing the core ontological issue of quantum spacetime where the properties of spacetime become indefinite, infused into the field itself.

II. WHAT IS QUANTUM GRAVITY?

II.A. OVERVIEW

Before delving into interpretations and questions in quantum gravity, I will discuss the basics of quantum gravity. As a perfunctory definition, quantum gravity is the attempt by physicists to reconcile theories of the very big and the very small, i.e. general theory of relativity (GR) and quantum mechanics, respectively. Steven Weinstein sums it up as "a physical theory describing the gravitational interactions of matter and energy in which matter and energy are also described by quantum theory."[1] Many theories of quantum gravity quantize gravity but, as Callender and Huggett point out, this is an empirical choice rather than a logical one. Finally, a quantization of gravity via GR suggests to most, especially those in the canonical quantum gravity (CQG) camp that some method of quantization is necessary for spacetime.

Unlike other modern theories in physics where consensus in the theory has been reached, quantum gravity has a number of alternative research programs searching for a core hypothesis by frequently jostling about auxiliary hypotheses. Three of the more popular of quantum gravity's research programs throughout its short history include the semi-classical theory, string theory, and canonical quantum gravity.

II.B. SEMI-CLASSICAL THEORY

One of the earlier attempts at reconciliation of the quantum with gravity came about in the 1960s and is known as the semi-classical theory: $G_{\mu\nu} = 8\pi \left\langle T_{\mu\nu} \right\rangle_{\Psi}$. This equation takes Einstein's field equations, $G_{\mu\nu} = 8\pi\ T_{\mu\nu}$, and makes the stress-energy tensor into an expectation value given by the quantum state of the energy density, momentum density, and stress in both matter *and* fields as denoted by Ψ.

There is a problem with this, however, since $G_{\mu\nu}$ is a complicated form of the metric tensor (namely a combination of the Ricci tensor and the curvature scalar), representing how spacetime curves in a four-dimensional manifold and cannot be represented as an expectation value in this way. Inherit in the Einstein tensor is a notion of conservation as noted by the non-diverging nature of its covariant differentiation equaling zero. The same is also true of the stress-

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[1] Weinstein, Steven. "Quantum Gravity," article posted to The Stanford Encyclopedia of Philosophy (Spring 2006 Edition), Edward N. Zalta (ed.) [accessed March 18, 2006]; available at http://plato.stanford.edu/entries/quantum-gravity/.

energy tensor ($\nabla \bullet T = 0$) thus unitary evolution is impossible since there is a discontinuity in the stress-energy expectation value.[2]

Although the semi-classical theory was quickly understood to be faulty, it was viewed as an excellent heuristic device for fueling the question of quantum gravity. This theory, along with other dilemmas such as the quantization debate, elicited the need for more robust theories of quantum gravity. I will now discuss the two major competing research programs, string theory (ST) and canonical quantum gravity (CQG), then discuss how each of these programs present new difficulties for the way physicists and philosophers should think about spacetime.

II.C. STRING THEORY

Unlike the weak, strong, and electromagnetic forces, gravity is the only one of the four fundamental forces that leads to a nonrenormalizable theory when quantization[3] is attempted. ST was birthed in hopes of unifying quantum field theory (QFT) with GR by giving up the quantum field theory notion of point particles in favor of one-dimensional extended objects known as strings. All particles are represented, then, by their unique vibration modes. One of the benefits of this theory is that gravity is included among the other fundamental forces, however, in order to achieve this unifying goal there are some strange side effects – namely the addition of seven (currently) other spatial dimensions needed to make the theory mathematically sound. Another vital component of string theory is supersymmetry which suggests the unification of top and

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[2] Callender, Craig and Nick Huggett, "Introduction" in *Physics Meets Philosophy at the Planck Scale* (Cambridge: Cambridge University Press, 2001: 1-32), 13.

[3] In Callender and Huggett's introductory remarks from *Physics Meets Philosophy at the Planck Scale* to quantize something means to "make them operators subject to non-vanishing commutation relations."

bottom quarks and the breaking of electroweak symmetry.[4] According to Witten, the next goal for particle accelerators is to find this elusive supersymmetry.

For string theory to be a relativistic quantum theory it requires a few ingredients: fundamental constants such as the speed of light, $\hbar / 2$, and Newton's gravitational constant. From this one can derive Planck's length and mass which, at this size becomes beneficial for string tension control as well as smoothing out Feynman diagrams. The result is a prediction and inclusion of gravity that implements a massless spin-2 particle, thus eliminating the problematic singularities of the Feynman diagrams in QFT.

For our purposes concerning spacetime it is interesting to note that these strings follow a lightlike geodesic, the orbit of this string (in this example, a closed string) is a two-dimensional tube or "world-sheet" in spacetime.[5] This perturbative, propagating string maps as $X : W \rightarrow M$ with W being the two-dimensional world-sheet and M being the target spacetime. In this scenario, X is quantized yet the metric γ on M remains classical, thus distinguishing ST from CQG which *directly* quantizes GR. Instead, GR emerges from ST as a low-energy limit; this is a key conceptual point which bears numerous philosophical ramifications as elaborated in depth by Butterfield and Isham. Should ST, or its more recent incarnation, M-theory, become more theoretically sound in the upcoming decades, the transition from point particle carving out a one-dimensional world-line as opposed to the two-dimensional tube of string theory would give philosophers of physics plenty to discuss.

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[4] Schwarz, John H. "Introduction to String Theory," article posted to arXiv.org e-Print archive CALT-68-2293 CITUSC/00-045, Mar. 21, 1996 [accessed April 18, 2006]; available at http://arxiv.org/pdf/hep-ex/0008017, 5.

[5] Witten, Edward, "Reflections on the fate of spacetime" in *Physics Meets Philosophy at the Planck Scale* (Cambridge: Cambridge University Press, 2001: 125-137), 127.

II.D. CANONICAL AND LOOP QUANTUM GRAVITY

Although string theory has captured the imagination of the popular science crowd (primarily thanks to Brian Greene's best-selling book *The Elegant Universe*), CQG has garnered more attention from both physicists and philosophers despite its extensive conceptual problems. Theoretical physicists in this camp treat g_{ij} as a field and attempt to quantize the metric itself. Unlike ST, CQG does *not* try to unify the various fields, instead choosing to find a consistent method of quantum mechanic and gravitational interaction via quantization of GR. Dirac attempted this by first placing GR into "canonical Hamiltonian form," then quantizing it. "Quantization proceeds by treating the configuration and momentum variables as operators on a quantum state space (a Hilbert space) obeying certain commutation relations analogous to the classical Poisson-bracket relations, which effectively encode the quantum fuzziness associated with Hesienberg's uncertainty principle."[6]

In CQG the Hamiltonian for the system evolves, splintering into a three-dimensional spatial manifold (Σ) and time. This splintering becomes important when dealing with diffeomporphic representation in CQG. The phase space of the system, then, is the entirety of complex conjugate 3-space momenta thus fixing the momentum/position at each instant of Σ. A Hamiltonian trajectory of this phase space form a model of Einstein's field equations resulting in an agreement of covariance along arclengths. We can then replace the canonical variables with a quantum Hamiltonian operator, represented as such:

$$\mathrm{H}(x,p) \rightarrow \hat{H}(\hat{x},\hat{p})$$

At this point the quantum system emerges and is represented by the wave function, its GR conjunction being $\Psi(h)$ over the four-dimensional Riemann curvature. Unfortunately, variations

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[6] Weinstein, "Quantum Gravity," Section 4.2.

of position and momentum within the canonical variables only yield six of Einstein's ten equations of motion resulting in a sort of "constrained Hamiltonian system": $C = C_i = 0$.[7] These constraints are also written as $H_a(x) = 0$ and $H_\perp(x) = 0$, where the non-zero side of the equations are complicated functions and their derivates of g and p in the canonical conjugate: $p^{ab}(x)$ which is related to the Σ curvature of four-dimensional spacetime.

This constraint, or gauge theory, shows that only some points in the phase space correspond to GR; a quantization of spacetime becomes more of an approximation than a crisp evolution of the system! To solve this issue gauge invariance is a must. There must be diffeomorphic invariance with the manifold mapping smoothly from point to point, which is by definition the job of the fundamental form seen in covariant differentiation.

We are left with another problem at this point – the diffeomorphisms give us a "superspace" so that the remnants of the Hamiltonian merely yields another Hamiltonian constraint. Just as the stress-energy and Einstein tensors show no divergence, many physicists focus on finding a solution to the Wheeler-DeWitt represented formally as $\hat{C}\Psi = 0$.[8] As of yet there are no working solutions to this problem although Ashtekar has presented a set of canonical "loop" variables to simplify the structure of the $H_a(x)$ and $H_\perp(x)$ constraints, potentially drawing ST and loop quantum gravity towards one another in the future.[9]

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[7] Callender and Huggett, "Introduction," 17.

[8] Ibid., 19.

[9] Butterfield, Jeremy and Christopher Isham, "Spacetime and the philosophical challenge of quantum gravity" in *Physics Meets Philosophy at the Planck Scale* (Cambridge: Cambridge University Press, 2001: 33-89), 75.

II.E. THE PHILOSOPHICAL ISSUES OF QUANTUM GRAVITY

One doesn't need to dig very deep in quantum gravity to find a host of philosophical issues that would drastically alter how we answer ontological questions should an M-theory (at least in its current incarnation) or loop quantum gravity obtain experimentally positive results. Before prototypical questions can be approached, however, there are others that can be addressed until that day comes. Many of the "proper" questions asked of a philosophy of quantum mechanics or special theory of relativity are unanswerable with quantum gravity, but this should not deter us from asking other equally valid questions.

First of all, I answer in the "affirmative" to the question of whether quantum gravity should even be discussed among philosophers yet. If one accepts this task, an obvious follow-up question would be: How, then, should physicists proceed in a theory that has no empirical proof or even a consistent mathematical model? This is not a new problem. When Einstein first envisioned a way of keeping Maxwell's equations invariant by choosing the Lorentz transformations, he had little empirical encouragement that his theory would be correct. It didn't come until several years later, with Einstein nervously awaiting experimental proof for his mind-bending idea of light and the status of inertial observers.

Today the gap between theory and experimentation has grown exponentially due to the unfathomably small Planck length needed in quantum gravity as well as the high energy requirements needed to test such a theory. Butterfield notes that in addition to a lack of data, constructing a theory is difficult because physicists disagree on what sorts of data quantum gravity should yield to begin with. He continues by saying:

> The most obvious consequence of such uncertainty is that it makes for a sort of circularity. On the one hand, it is ferociously difficult to find the theory without the help of data, or even an agreed conception of the sort of data that would be relevant. On the other hand, we can only apply our present theories to (and get

> evidence from) regimes well way from those determined by the Planck scale; so we cannot judge what phenomena might be relevant to a theory of quantum gravity, until we know what the theory is.[10]

One result of this phenomenon is that quantum gravity theories are often grounded in the philosophical prejudices of the researcher. The same is also true of mathematical models chosen for aesthetic simplicity or cohesiveness that may be formally intriguing yet ontologically vacant. This can be seen as an applicable case to ST which has five competing research programs, each continuing down one path of mathematical progress. M-theory could be conceived as an attempt to form bridges between the various string theories in order to check and balance one another.

Aside from methodological issues in quantum gravity research programs, Weinstein, Rovelli, and Butterfield, among others draw out four recurring philosophical issues in quantum gravity. I will briefly summarize Callender and Huggett's four major categories, the first of which is what Witten calls the supposed *"demise of classical spacetime."* In ST, the debate is this: spacetime is no longer distinct from matter, but derives from the physicality of the strings themselves! This goes back to the age-old Leibniz versus Clarke debate over absolute/relative space relations which ST and CQG are bringing back into philosophical debate. Witten places spacetime wherever the field is not, so is this implying a refurbished relational aspect of space? Also, in CQG spacetime no longer acts as a fundamental feature, becoming instead part of the underlying spin network, which ends in a form of relationalism similar to that of ST.

One convincing note of caution comes from Steven Weinstein who discusses the problem of fluctuation in a gravitational field in both ST and CQG. The basic argument is that any fluctuation of the field disturbs the localized results of the Riemann curvature tensor, thus fluctuating the spacetime structure itself which is an issue when translating to QFT. Weinstein

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[10] Ibid., 36.

suggests that a “theory that truly unifies quantum theory and gravity will be one in which the idea of local fluctuations in a field plays no role….”[11]

The second problem concerns *the nature of time*. With regards to CQG, it is based on the Hamiltonian, thus time parameterization for the evolving system is necessary. This becomes difficult seeing as GR resists time parameterization (except at the fiducial observers clock which is seen only in regards to two fiducial perspectives with relation to the separation vector in spacetime geodesic deviation). It becomes obvious then that GR is a dynamical construct as noted by the $\eta_{\mu\nu}$ Minkowski metric; the quantum mechanic spacetime metric, on the other hand, is not dynamical. I will address this more thoroughly in the next section.

The next two issues that Callender and Huggett address are not central to the theme of this paper, so I will only mention them briefly. Thirdly, there is the *varied interpretations of our existing theories* – GR and QM. Butterfield calls these “the ingredient theories.” In GR the hot topic is that of general covariance which has been known to raise Einstein’s “hole argument” debate concerning manifold substantivalism. In QM there are numerous interpretation problems which continue to plague philosophers of physics, namely the measurement problem. One intriguing interpretation comes from Roger Penrose’s idea of wave function collapse which sets the gravitational field as the Hermitian operator and induces quantum superposition to collapse. Thus, magnitude of a gravitational wave itself becomes the measuring device which reduces the state vector. Penrose calls this “orchestrated objective reduction” and has used this same argument as driving force for his controversial quantum consciousness theory.[12,13]

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[11] Weinstein, Steven, “Naïve quantum gravity” in *Physics Meets Philosophy at the Planck Scale* (Cambridge: Cambridge University Press, 2001: 90-100), 98.

[12] Penrose, Roger, “On gravity’s role in quantum state reduction” in *Physics Meets Philosophy at the Planck Scale* (Cambridge: Cambridge University Press, 2001: 290-304), 290.

[13] Penrose, Roger, *The Emperor’s New Mind* (Oxford: Oxford University Press, 1989).

Closely related to the third philosophical problem of quantum gravity is the *status of the wave function* as approached by quantum cosmologists. Physicists such as Steven Hawking are seeking to discover the initial wave function of the universe in attempts to construct laws for big bang cosmology's initial conditions. Quantum gravity becomes a mandatory element for quantum cosmologists since Einstein's field equations are the cornerstone of contemporary cosmological investigation.

III. SPACETIME ISSUES IN QUANTUM GRAVITY

In this section I will pursue the treatment of spacetime from the perspectives of two leading research programs in quantum gravity: string theory and canonical quantum gravity. Butterfield and Isham present details on both of these programs nicely by addressing their use of standard quantum theory, use of standard spacetime concepts, the spacetime diffeomorphism group, and the problem of time. My goal is to summarize Butterfield and Isham's critiques while added details from Carvo Rovelli's research.

III.A. STRING THEORY SPACETIME

The following four statements[14] are restricted to *perturbative* string theory:

1. *Use of standard quantum theory*. In perturbative superstring theories, the Copenhagen interpretation is applied with the low-energy field equations for γ on a background structure. Several physicists, however, take issue with quantum theory being restricted only to low energies. ST has responded to this criticism by offering different quantization methods.

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[14] Butterfield and Isham, 72-3.

2. *Use of standard spacetime concepts.* This is where the 11-dimensional spacetime picture, *M*, comes into play, with our four-dimensional notion of reality looking the same, yet another seven spatial dimensions are curled up somewhere as shown in the Kaluza-Klein equations.
3. *The spacetime diffeomorphism group.* ST makes GR only one element of many, distorting our current understanding of spacetime. Why does spacetime take a backseat in this scenario? The graviton just becomes one of numerous particles in ST. From this we can see that spacetime diffeomorphism in GR becomes only a small portion of the larger picture.
4. *The problem of time*. A background (which is in this case the gravitational field) is the location where perturbative ST takes place as noted by the low-energy equations needed to make ST work properly. This means the background has a *causal* structure which, at first glance, means there is no problem of time. How this causal background structure relates to physical reality, however, is a largely unanswered question in ST.

With these conclusions, we can now feel the true weight behind Witten's declaring the "demise of spacetime." If spacetime becomes only an approximate, derived concept, then what if anything becomes precise in ST? How, if it is possible, do we erase this sort of fuzziness that arises from an approximation which rids us of invariance in observer interaction which Einstein worked so hard to construct? What ontological claims can be constructed from this spacetime metric prediction of a two-dimensional field theory that creates a "duality symmetry"[15]? Witten states that "one does not really have a classical spacetime, but only the corresponding two-dimensional field theory; two apparently different spacetimes *X* and *Y* might correspond to equivalent two-dimensional field theories."[16] There exists here a sort of variance between two completely different spatial manifolds, rendering the classical notion of spacetime incomplete

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[15] Witten, "Reflections on the fate of spacetime," 135.
[16] Ibid., 136-7.

and meaningless. All of the questions mentioned above are now being addressed in the non-perturbative theories of ST first put forth in the early 1990s, and, more recently, by way of unifying the five string theories into the TOE M-theory which is still in formal infancy.

III.B. CANONICAL QUANTUM GRAVITY

1. *Use of standard quantum theory.* Quantum theory is able to accommodate the non-linear canonical variable constraints listed in section II.D, yet it breaks down under the Copenhagen interpretation that requires a background spatial metric. Most CQG physicists, unlike those in the ST camp, reject this set-up. Some have suggested a Bohmian pilot-wave approach involving a "preferred foliation of spacetime" yet this interpretation does not work well with the Ashtekar's loop variables showing much promise for the future of CQG. The case for a universal Bohmian theory with regards to the problem of diffeomorphism-invariant observers is addressed by Goldstein and Teufel who respond back to this challenge by saying that Ashtekar's formulation of GR doesn't address the key conceptual problems of CQG.[17]
2. *Use of standard spacetime concepts.* Although CQG uses a background dimensional *manifold* it varies from ST by not relying on a background *metric*. The spacetime manifold, then, is diffeomorphic to $\Sigma \times \mathbb{R}$ where Σ is some 3-manifold being part of the QM fixed background.[18]
3. *The spacetime diffeomorphism group*. Simply put, in CQG the Dirac algebra of the constraint functions mentioned earlier project along the spatial hypersurface as Diff (Σ) - being

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[17] Goldstein, Sheldon and Stefan Teufel, "Quantum spacetime without observers: Ontological clarity and the conceptual foundations of quantum gravity" in *Physics Meets Philosophy at the Planck Scale* (Cambridge: Cambridge University Press, 2001: 275-289), 278-87.

[18] Butterfield and Isham, 76.

somewhat similar to spacetime diffeomorphisms found in GR. Loop theories have been helpful in keeping these spatial diffeomorphisms invariant.

4. *The problem of time*. The CQG research program prides itself in avoiding a background spatial metric, yet it does so at a great cost: time. First, the problem can be seen in the Wheeler-DeWitt equation hinted at briefly in section II.D., formally represented as $\hat{H}_{\perp}(x)\Psi = 0$. This equation is the dynamic centerpiece of the CQG program yet it completely disregards time, and it is for this reason that Ashtekar's new formalism tries to dismiss the Wheeler-DeWitt equation as being a heuristic tool. Second, the canonical commutation relations that quantize the full set of fields $(g_{ab}(x), p^{cd}(x))$ does not fully show first derivative evolution from x to x' since there is no background causal structure to denote spatial separation.[19] Time, then, is reintroduced "as the values of special *physical* entities" in CQG which includes particle and gravitational values. In English this means time is defined as a clock, not the measurement deriving from the clock, meaning that the entire system is quantized. This (via approximation) makes time a *physical* thing; time for CQG becomes an emergent or phenomenological concept such as a temperature function.[20]

IV. SOME COMMENTS ON QUANTUM GRAVITY SPACETIME

Much of this paper relies heavily on several essays found in Callender and Huggett's groundbreaking *Physics Meets Philosophy at the Planck Scale*, yet I have integrated my opinion on quantum gravity by way of selectively choosing which authors were included in this paper. With that said, I find Butterfield and Isham's careful and steadied synopsis to be the most compelling in C&H's compilation. By presenting pros and cons of both ST and CQG, I believe

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[19] Ibid., 77.

[20] Ibid.

the best conclusion in quantum gravity to be this: we simply do not know yet. To date there is no empirical evidence (current ST brane/black hole research aside) or solidified quantum gravity formalism from either of the two main camps, thus we can only go so far in answering certain philosophical questions that quickly arise.

As the field currently stands, I disagree with quantizing general theory and advocate string theory's emergence of GR from a unique quantum theory. One problem with this stems from the notion of spacetime as it currently stands in ST with ten spatial dimensions that are intertwined within our own three spatial dimensions, defying ontological simplicity in favor of mathematical consistency. It must be said, however, that a physicist in the 17th century would find the idea of returning to Earth younger after a near-light speed trip to Alpha Centauri completely ridiculous so I do not rule out the hard to grasp yet not impossible existence of eleven dimensional reality.

No matter what, it seems as if the nature of time "is due for a grand shake up" as Penrose would put it.[21] Physicists such as Abner Shimony and Joy Christian[22] concur. Although the nature of time in both ST and CGR looks quite bizarre, I believe Christian is correct in his assertion that the quantum *must* yield to gravity due to the fundamental incompatibility of the two theories primarily for the reason that quantum dynamics presupposes a fixed causal structure where general relativity is non-dynamical on a background causal structure.

Moving on to CQG, the advent of Ashtekar's canonical loop variables now supports a non-perturbative method of constructing quantum gravity which may explain why ST and CQG are finding more and more similarities despite their vastly different "traditional" approaches.

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[21] Penrose, *The Emperor's New Mind*, 371.

[22] Christian, Joy, "Why the quantum must yield to gravity" in *Physics Meets Philosophy at the Planck Scale* (Cambridge: Cambridge University Press, 2001: 305-338), 336.

These two programs differ, however, in that the latter does not require a unification of the four fundamental forces whereas the former integrates gravity as a key element in the "theory of everything" holy grail search. Another key difference between the two programs is that ST requires a background spatial metric whereas CQG most definitely does not. The two are coming somewhat closer (depending on who you ask) by way of gauge-invariant loop variables introduced into the ST-friendly interpretations of supersymmetry in Yang-Mills theory. There is also the opinion that Ashtekar's loop-variable approach to CQG may just be a different "mode" or phase of a more basic string-like, non-local structure.

With these considerations in mind, I want to bring the topic back to spacetime and physicality within that space and time. What constitutes an observable in CQG spacetime diffeomorphism? This is paralleled by the issue of time in CQG which I find most problematic in its current manifestation. An emergent form of time makes it difficult to understand when translating the all-important geodesic deviation in four-dimensions, $\frac{D^2\xi^\alpha}{d\tau^2} + R^\alpha_{\beta\gamma\delta}\frac{dx^\beta}{d\tau}\xi^\gamma\frac{dx^\delta}{d\tau} = 0$, if the fiducial observer's own clock at nonrelativistic speeds becomes part of the "*x*" half of the velocity vector itself. If this renders true, then one must look at spacetime as a phenomenological entity.

Rovelli sees time as a sort of defunct property in quantum gravity, but "the *nostalgia for time* is hard to resist for technical as well as emotional reasons."[23] Before simply abandoning time to fit a mathematical construct in quantum gravity, it might be best to step back from the formalism and ponder what a statement of this magnitude means for physical theories. Rovelli is

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[23] Rovelli, Carlo, "Quantum spacetime: What do we know?" in *Physics Meets Philosophy at the Planck Scale* (Cambridge: Cambridge University Press, 2001: 101-123), 114.

aware of this precaution and comments that a map is still valid even if a better map comes along that looks quite different from the earlier, less precise map.[24]

V. CONCLUSION

So what's a better choice? Abandoning four-dimensional reality in lieu of ST's eleven-dimensional mind-bending reality? Making time an emergent physical property due to the lack of a background spacetime metric in CQG? Or perhaps we should heed the instrumentalist's suggestion – just calculate and be quiet. Although this approach works wonderfully for producing extremely accurate results in quantum mechanical experiments or quasar distribution in Einstein's field equations, it denies the possibility for any unified theory in the future. Also, the instrumentalist must admit that theoretical approaches to physics in fields such as quantum gravity may indeed render accurate empirical results in the future. This possibility, in my opinion, makes the endeavor worth the risk…although such a journey must be taken with cautious steps.

Erik Curiel likened the quantum gravity craze at the turn of the new millennium to the 17th century hypothetico-deductive model of scientific inquiry which failed to present the weak points of the theory, opting only to express excitement for future possibilities.[25] Curiel thinks such an attitude damages science thus a "plea for modesty" is in order; I wholeheartedly agree. Rovelli and Witten's assessment of spacetime's demise may turn out to be correct, yet in the meantime it is vital that a cautious optimism parallel any quantum gravity declarations on the nature of spacetime.

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[24] Ibid., 121.

[25] Curiel, Erik. "Against the excess of quantum gravity: a plea for modesty." *Philosophy of Science*, Vol. 68, No. 3, Supplement: Proceedings of the 2000 Biennial Meeting of the Philosophy of Science Association. Part I: Contributing Papers (Sep., 2001): S424-S441, 425.

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