Opinion

Challenges of Quantum Gravity and Higher-Dimensional Field Theories

Ervin Goldfain*

Photonics CoE, Welch Allyn Inc., Skaneateles Falls, NY 13153, USA

Abstract

We give a concise but incomplete list of reasons why Quantum Gravity and Higher-Dimensional field theories are likely to point in the wrong direction. For the sake of clarity and due to the vast volume of research on these topics, no references are included. The interested reader can search for key words relevant to the context using Google Scholar or similar internet engines.

Key words: Quantum Gravity, Higher Dimensional field theories, TeV scale, Planck scale

In our view, it is likely that many modeling efforts of recent years concerning Quantum Gravity and Higher-Dimensional Field Theories are built on a faulty foundation. Specifically,

1. Extra dimensions are presumed to lead to space-time instability (via the Hawking-Penrose theorem and the Ehrenfest argument).

2. As coherent synthesis of Quantum Mechanics and Special Relativity, Quantum Field Theory (QFT) provides a successful description of phenomena up to the energy scales probed by present accelerators. Nevertheless, there are plausible reasons to suspect that QFT breaks down at some high-energy threshold (Λ_{UV}), above which it needs to be replaced by a more fundamental theory. Although there is no consensus among theorists on this issue, the underlying reasons may be summarized as follows:

> **a)** New interactions, symmetries or any other exotic extensions of QFT could likely unfold near Λ_{UV}.
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> **b)** Integration of classical gravity within the standard framework of QFT appears to be an insurmountable challenge. A major obstacle is that perturbative quantization of classical gravity cannot be extrapolated at energies close to the Planck scale, $\Lambda_{UV} = O(M_{Pl})$. As a result, the theory is said to be "*non-renormalizable*", meaning that it lacks any predictive power at scales comparable with Λ_{UV}. There are non-perturbative models of Quantum Gravity near M_{Pl} that have been proposed as alternative solutions, but it is presently unclear if they yield a consistent integration scheme of General Relativity and QFT. In fact, there is

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* Correspondence: Ervin Goldfain, Ph.D., Photonics CoE, Welch Allyn Inc., Skaneateles Falls, NY 13153, USA
E-mail: ervingoldfain@gmail.com

currently no direct experimental evidence that gravitation survives as a relevant interaction field below a distance scale of about 50 microns. Despite these observations, programs such as Asymptotic Safety, Superstring/M theories, SUGRA, Loop Quantum Gravity, the underlying physics of Black Holes typically assume that gravitation maintains its status as relevant interaction all the way up to the Planck scale *or* in ultra-strong coupling regimes where large erratic fluctuations of space-time geometry are bound to develop.

c) The current accelerator technology probes energies moderately above the range defining the Standard Model (SM) of particle physics ($\mu_{SM} = O$ (TeV)). The prevalent view is that M_{Pl} is the only genuine scale in QFT and stems from the assumption that no dramatic change in physics develops between μ_{SM} and M_{Pl}. But if this assumption is true, there is at present no compelling explanation for the *mass hierarchy*, brought about by the observation that fermion masses are scattered over thirteen orders of magnitude and are confined around $\mu_{SM} << M_{Pl}$. In addition, quantum corrections applied to the Higgs vacuum can shift the Higgs mass close to M_{Pl}, leading to the so-called "*fine-tuning problem*".

d) The dynamics of QFT may undergo the transition to classical behavior as a result of *decoherence* or become *unstable* near or below Λ_{UV}. The instability can arise from unbalanced quantum corrections or from the transition to chaos in nonlinear evolution of interacting fields.

3. Typical higher-dimensional theories (for example ADD, Randall-Sundrum, Superstring/M, AdS/CFT) assume that extra-dimensions are smooth and differentiable in the ordinary sense, thus allowing for straightforward extrapolation of concepts such as the light speed in vacuum, Poincare invariance and relativistic kinematics on Minkowski space-time. But there is no evidence that this remains true at energies far above the low TeV scale, where large space-time fluctuations are bound to develop. As the Poincare symmetry becomes ill-defined in extra dimensions, discrete or fractional space-time, direct application of relativistic QFT to higher-dimensional theories becomes problematic.

4. There is no evidence that quantum theory stays valid in the deep TeV region due to transition to quantum chaos, non-perturbative and out-of-equilibrium effects, as well as classicalization via decoherence. Same pitfalls exist in quantum cosmology.