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Editorial

Symmetry in Quantum Theory of Gravity

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Nicolas Gisin [1,2] has emphasized that, prior to Einstein's imposition of a finite speed of light, and hence of information, in the Special Theory of Relativity, physics was nonlocal. While Newton was, as Gisin points out, rather unhappy with this situation, pre-relativistic classical physics was a physics of "instantaneous" (prior to Cantor, this must be considered an informal notion) interactions across arbitrary distances. Spacetime in this classical setting was merely a container; indeed, it was merely a set of labels. The gravitational and, later, electromagnetic interactions operating in this classical container were, moreover, in principle completely deterministic. Indeed, Tipler [3] has shown that this Laplacian, globally deterministic classical theory is equivalent to quantum theory in its Bohmian representation. Classical physics is not, of course, globally deterministic in the classroom or in practice; classical interactions are typically represented as occurring on isolated billiard tables or in isolated solar systems. It is the sigularities created by assumptions of isolation—effectively, screening of all exterior forces—that are removed by adding a Bohmian "quantum" potential to classical physics.

What, then, is the relationship between classical and quantum physics? How does this relationship depend on assumptions of locality or isolation? The difficulty of obtaining a satisfactory quantum theory of gravity is often attributed to a fundamental conflict between the demands of covariance and those of unitarity, as illustrated, for example, by discussions of the black hole information paradox [4–10]. These, as well as [3], suggest, however, that what is fundamentally at stake is the relation between classical and quantum information, or in more operational (or indeed philosophical) language, the relation between observational outcomes and the physics that they describe. Observational outcomes always characterize particular physical systems; hence this question can be rephrased as the question of whether "systems" can be considered to be both local and observer-independent.

The papers in this Special Issue all address some aspect of this latter question. The first, by Y.-Q. Gu, continues the author's previous efforts [11] to develop a fully "realist" representation—with observer-independent space and time coordinates—of spacetime that is consistent with GR by deriving a representation for the spinor connection within such a spacetime [12]. The treatment is fully geometric, employing the formalism of Clifford algebra to represent both the spinor and the spacetime. Gu suggests that, in these coordinates, the (global) cosmological constant is reproduced by the self-interaction of the (global) spinor field.

The second paper, by Illuminati, Lambiasi, and Petruzziello, extends previous work [13] on the breaking of Lorentz symmetry that results when the Heisenberg uncertainty principle is generalized to account for the effects of long-range spacetime curvature on locally-observable momenta [14]. This symmetry breaking is shown to be equivalent to one generated by a string-theoretic extension of the standard model. They provide an improved theoretical bound on the strength of this symmetry breaking, but note that this bound is still much larger than values that near-Earth observations might be expected to yield.

The paper of Moradpour, Aghababaei, and Ziaie examines the effects of generalizing the uncertainty principle from a different perspective, computing the behavior of both the Maxwell–Boltzmann distribution and its relativistic extension, the Jüttner distribution, as

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the long-range curvature effects are increased [15]. As expected, long-range corrections have a smaller effect on the Jüttner distribution; however, and consistent with the above, they remain far outside the bounds of current observational capabilities.

The paper of Kaparulin, Lyakhovich, and Nosyrev extends previous work [16] that seeks to achieve both stability and gauge invariance in higher-order (extended Cherns-Simons) theories with n-particle interactions [17]. Its key result is that achieving both stability and gauge invariance requires introducing a further "gauging field" that deforms the equations of motion. This additional field is interpreted as a "Higgs-like" mechanism that maintains on-shell masses.

Jack Ng's paper applies a previously developed heuristic model of spacetime foam that is compliant with the holographic principle [18] to characterize the accelerating regimes of the early (i.e., inflationary) and late (i.e., dark energy-dominated) universe [19]. Ng equates the "quanta" of spacetime foam with holographically encoded bits of information, and shows that these quanta must be distinguishable—i.e., must collectively encode macroscopic, multibit information—to generate a macroscopic spacetime. He suggests that "ordinary" bosons and fermions can be considered collective modes of these foam quanta.

The final paper, by Fields, Glazebrook, and Marcianò, develops some consequences of a previous [20] generalization of the holographic principle to arbitrary pairs of finite quantum systems in the weak interaction limit [21]. We provide formal criteria under which arbitrary interactions can be regarded as "measurements" that deploy defined quantum reference frames (QRFs) [22], and show that such interactions induce decoherent sectors on the holographic screen separating the interacting systems. We also show that joint-state separability breaks down as the QRFs deployed by the interacting systems approach functional equivalence.

While the papers collected here do not, and could not be expected to, reach a consensus on the path forward toward a satisfactory quantum theory of gravity, they do share a common theme: that nonlocality must be built somehow into coordinate systems (Gu), measurement uncertainties (Illuminati et al., Moradpour et al.), ancillary fields (Kaparulin et al.), underlying fundamental quanta (Ng) or the notion of "system" itself (Fields et al.). They thus contribute to the growing body of evidence that a local theory of observation, i.e., of classical information exchange, does not require, and may indeed be inconsistent with, a local theory of physics.

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Abbreviations

The following abbreviations are used in this manuscript:

GR	General relativity
QRF	Quantum reference frame

References

1. Gisin, N. Can relativity be considered complete? From Newtonian nonlocality to quantum nonlocality and beyond. In *The Message of Quantum Science*; Blanchard, P., Fröhlich, J., Eds.; Springer: Heidelberg, Germany, 2015; pp. 195–217.
2. Gisin, N. Quantum correlations in Newtonian space and time: Faster than light communication or nonlocality. In *Quantum Theory: A Two-Time Success Story*; Struppa, D., Tollaksen, J., Eds.; Springer: Milan, Italy, 2014; pp. 185–203.
3. Tipler, F.J. Quantum nonlocality does not exist. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 11281–11286. [CrossRef] [PubMed]
4. Hawking, S.W. Breakdown of predictability in gravitational collapse. *Phys. Rev. D* **1976**, *14*, 2460–2473. [CrossRef]
5. Susskind, L.; Thorlacius, L. Gedanken experiments involving black holes. *Phys. Rev. D* **1994**, *49*, 966–974. [CrossRef] [PubMed]
6. Almheiri, A.; Marolf, D.; Polchinski, J.; Sully, J. Black Holes: Complementarity or firewalls? *J. High Energy Phys.* **2013**, *2013*, 062. [CrossRef]
7. Harlow, D.; Hayden, P. Quantum computation vs. firewalls. *J. High Energy Phys.* **2013**, *2013*, 085. [CrossRef]
8. Susskind, L. Entanglement is not enough. *arXiv* **2014**, arXiv:1411.0690.
9. Rovelli, C. The subtle unphysical hypothesis of the firewall theorem. *Entropy* **2019** *21*, 839. [CrossRef]

10. Almheiri, A.; Hartman, T.; Maldacena, J.; Shaghoulian, E.; Tajdini, A. The entropy of Hawking radiation. *arXiv* **2020**, arXiv:2006.06872.
11. Gu, Y.-Q. Natural coordinate system in curved space-time. *J. Geom. Symmetry Phys.* **2018**, *47*, 51–62. [CrossRef]
12. Gu, Y.-Q. Theory of spinors in curved space-time. *Symmetry* **2021**, *13*, 1931. [CrossRef]
13. Lambiasi G.; Scardigli F. Lorentz violation and generalized uncertainty principle. *Phys. Rev. D* **2018**, *97*, 075003. [CrossRef]
14. Illuminati F.; Lambiasi G, Petruzziello L. Spontaneous Lorentz violation from infrared gravity. *Symmetry* **2021**, *13*, 1854. [CrossRef]
15. Moradpour, H.; Aghababaei, S.; and Ziaie, A.H. A note on effects of generalized and extended uncertainty principles on Jüttner gas. *Symmetry* **2021**, *13*, 213. [CrossRef]
16. Abakumova, V.A.; Kaparulin, D.S.; Lyakhovich, S.L. Stable interactions in higher derivative field theories of derived type. *Phys. Rev. D* **2019**, *99*, 045020. [CrossRef]
17. Kaparulin, D.S.; Lyakhovich, S.L.; Nosyrev O.D. Extended Chern–Simons model for a vector multiplet. *Symmetry* **2021**, *13*, 1004. [CrossRef]
18. Arzano, M.; Kephart, T.W.; Ng, Y.J. From spacetime foam to holographic foam cosmology. *Phys. Lett. B* **2007**, *649*, 243–246. [CrossRef]
19. Ng, Y.J. Holographic foam cosmology: From the late to the early universe. *Symmetry* **2021**, *13*, 435. [CrossRef]
20. Addazi, A.; Chen, P.; Fabrocini, F.; Fields, C.; Greco, E.; Lutti, M.; Marcianò, A.; Pasechnik, R. Generalized holographic principle, gauge invariance and the emergence of gravity à la Wilczek. *Front. Astron. Space Sci.* **2021**, *8*, 563450. [CrossRef]
21. Fields, C.; Glazebrook, J.F.; Marcianò, A. Reference frame induced symmetry breaking on holographic screens. *Symmetry* **2021**, *13*, 408. [CrossRef]
22. Bartlett, S.D.; Rudolph, T.; Spekkens, R.W. Reference frames, superselection rules, and quantum information. *Rev. Mod. Phys.* **2007**, *79*, 555–609. [CrossRef]