Epistemology of Quantum Gravity

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Recent decades indicate "a blurring of distinction between physical science and mathematical abstraction ... [reflecting] a growing tendency to accept, and in some cases ignore, serious testability problems." [1] Oldershaw lists dozens of major non-testing issues in the pre-instrumentalist era.

From a methodological point of view, both Newton and Einstein, and later Dirac, unreservedly supported the principle of mathematical simplicity in discovering the new physical laws of nature. They were joined by Poincaré and Weyl. "For Dirac the principle of mathematical beauty was partly a method-ological moral and partly a postulate about nature's qualities. It was clearly inspired by the theory of relativity, the general theory in particular, and also by the development of quantum mechanics... mathematical-aesthetic considerations should (sometimes) have priority over experimental facts and in this way act as criteria of truth." [2]

Eduard Prugovecki states that quantum gravity has required the consideration of fundamental epistemological questions, which can be identified in philosophy with the mind-body problem and the problem of free will. [3] These questions influenced the epistemology of quantum mechanics in the form of von Neumann's "psycho-physical parallelism"[4] and the subsequent analysis of the thesis by Wigner[5] that "the collapse of the wave packet" occurs in the mind of the "observer". Quantum gravity in cosmology involves the problem of the experimenter's freedom to change local physical conditions, a passive "observer". In any theory that describes a single universe, questions arise about the nature of causality in the traditional philosophical sense. [6]

A quantum theory of gravity may be useful in unifying general relativity with the principles of quantum mechanics, but difficulties arise in this attempt. [7] The resulting theory is not renormalizable,[8] and cannot make significant physical predictions. Later developments led to string

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[1] Robert L. Oldershaw, "The New Physics—Physical or Mathematical Science?," *American Journal of Physics* 56, no. 12 (December 1, 1988): 1076, https://doi.org/10.1119/1.15749.

[2] Helge Kragh, *Dirac: A Scientific Biography*, 1 edition (Cambridge England ; New York: Cambridge University Press, 1990), 277, 284.

[3] Hermann Weyl and Frank Wilczek, *Philosophy of Mathematics and Natural Science*, Revised ed. edition (Princeton, N.J: Princeton University Press, 2009).

[4] John Von Neumann, *Mathematische grundlagen der quantenmechanik,* (Berlin: J. Springer, 1932).

[5] E. P. Wigner et al., "The Scientist Speculates: An Anthology of Partly-Baked Ideas," *American Journal of Physics* 32, no. 4 (April 1, 1964): 168–81, https://doi.org/10.1119/1.1970298.

[6] Mario Bunge, "The Revival of Causality," in *La Philosophie Contemporaine / Contemporary Philosophy: Chroniques Nouvelles / A New Survey*, ed. Guttorm Fløistad, International Institute of Philosophy / Institut International de Philosophie (Dordrecht: Springer Netherlands, 1982), 133–55, https://doi.org/10.1007/978-94-010-9940-0_6.

[7] A. Zee, *Quantum Field Theory in a Nutshell, 2nd Edition*, 2 edition (Princeton, N.J: Princeton University Press, 2010), 172, 434–435.

[8] Renormalization is an "absorption" of infinities by redefining a finite number of physical parameters. The physical parameters (mass, charge, etc.) have perfectly finite values when observed in real experiments. In the case of

theory and loop quantum gravity.[9] The structure of general relativity would result from the quantum mechanics of the interaction of theoretical particles without mass of spin-2, called gravitons,[10] although there is no concrete evidence of them.

The dilaton appeared in Kaluza-Klein theory, a five-dimensional theory that combines gravity and electromagnetism, and later in string theory. The equation of the field that governs the dilaton, derived from the differential geometry, could be subject to quantization.[11] Because this theory can combine gravitational, electromagnetic and quantum effects, their coupling could lead to a means of justifying the theory through cosmology and experiments.

However, gravity is perturbatively nonrenormalizable.[12] The theory must be characterized by a choice of *finitely many* parameters which, in principle, can be established by experiment. But, in quantifying gravity, in the theory of perturbation, there are *infinitely many independent parameters* needed to define the theory.

It is possible that, in a correct quantum gravity theory, the infinite unknown parameters are reduced to a finite number which can then be measured. One of the possibilities is to have new, undiscovered principles of symmetry that constrain the parameters and reduce them to a finite set, a path followed by string theory.

There are several theories that address quantum gravity, but none are complete and consistent. The models must overcome major formal and conceptual problems, including the formulation of predictions that can be verified by experimental tests.[13]

String theory involves objects similar to strings propagating in a fixed spacetime background, and interactions between closed strings give rise to spacetime in a dynamic way. This promises to be a

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gravity, the perturbative theory is not renormalizable. In order to renormalize the theory, we should introduce infinitely many "absorption parameters", each having to be determined by experiment.

[9] Roger Penrose, *The Road to Reality: A Complete Guide to the Laws of the Universe*, Reprint edition (New York: Vintage, 2007), 1017.

[10] S. Deser, “Self-Interaction and Gauge Invariance,” *General Relativity and Gravitation* 1, no. 1 (March 1, 1970): 1: 9–18, https://doi.org/10.1007/BF00759198.

[11] T. Ohta and R. B. Mann, “Canonical Reduction of Two-Dimensional Gravity for Particle Dynamics,” *Classical and Quantum Gravity* 13, no. 9 (September 1, 1996): 13 (9): 2585–2602, https://doi.org/10.1088/0264-9381/13/9/022.

[12] Richard P Feynman et al., *Feynman Lectures on Gravitation* (Reading, Mass.: Addison-Wesley, 1995), xxxvi–xxxviii; 211–12.

[13] Abhay Ashtekar, “Loop Quantum Gravity: Four Recent Advances and a Dozen Frequently Asked Questions,” in *The Eleventh Marcel Grossmann Meeting* (World Scientific Publishing Company, 2008), 126, https://doi.org/10.1142/9789812834300_0008.

unified description of all particles and interactions. [14] One way in string theory will always correspond to a graviton, but to this theory unusual features appear, such as six additional dimensions of space. In an evolution of this program, the superstring theory, it is trying to unify the string theory, general relativity and supersymmetry, known as supergravity in an eleven-dimensional hypothetical model known as M-theory. [15]

Quantum gravitational effects are extremely weak, and therefore difficult to test. In recent years physicists have concentrated on studying the possibilities of experimental tests, [16] the most targeted being the violations of Lorentz invariance, the quantum gravitational effects in the cosmic microwave background, and the decoherence induced by the spacetime fluctuations.

Quantum gravity theories are affected by a lot of technical and conceptual problems. Tian Cao argues that quantum gravity offers a unique opportunity for philosophers, allowing them "a good chance to make some positive contributions, rather than just analysing philosophically what physicists have already established." [17] Carlo Rovelli (the architect of loop quantum gravity) urges philosophers not to limit themselves to "commenting and polishing the present fragmentary physical theories, but would take the risk of trying to look ahead." [18]

Conceptual difficulties arise mainly from the nature of gravitational interaction, in particular the equivalence of gravitational and inertial masses, which allows the representation of gravity as a property of space itself, rather than as a field propagated in spacetime. When quantizing gravity some of the properties of spacetime are subjected to quantum fluctuations. But quantum theory implies a well-defined classical background for these fluctuations. [19]

Yoichiro Nambu[20] has researched the "postmodern physics" of quantum gravity, of its spacing from experiments. There are certain methods of evaluating the theory, and constraints. Their

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[14] L. E. Ibanez, "The Second String (Phenomenology) Revolution," *Classical and Quantum Gravity* 17, no. 5 (March 7, 2000): 17 (5): 1117–1128, https://doi.org/10.1088/0264-9381/17/5/321.

[15] P. K. Townsend, "Four Lectures on M-Theory," *ArXiv:Hep-Th/9612121*, December 11, 1996, 13: 385, http://arxiv.org/abs/hep-th/9612121.

[16] Sabine Hossenfelder, "Experimental Search for Quantum Gravity," *ArXiv:1010.3420 [Gr-Qc, Physics:Hep-Ph, Physics:Hep-Th]*, October 17, 2010, chap. 5, http://arxiv.org/abs/1010.3420.

[17] Tian Yu Cao, "Prerequisites for a Consistent Framework of Quantum Gravity," *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 32, no. 2 (2001): 138.

[18] Carlo Rovelli, "Halfway Through the Woods: Contemporary Research on Space and Time," in *The Cosmos of Science*, ed. John Earman and John Norton (University of Pittsburgh Press, 1997), 182.

[19] Steven Weinstein, "Absolute Quantum Mechanics," Preprint, 2000, 52: 67–73, http://philsci-archive.pitt.edu/836/.

[20] Y. Nambu, "Directions of Particle Physics," *Progress of Theoretical Physics Supplement* 85 (1985): 104–110, https://doi.org/10.1143/PTPS.85.104.

investigation is a current research problem.[21] Audretsch[22] argues that quantum gravity research runs counter to Kuhn's paradigms, in quantum gravity co-existing several paradigms, both well-confirmed and universal. Given that both general relativity and quantum theory claim to be universal theories, any conceptual or formal tension between them would indicate that the universality of one or both theories is wrong. Peter Galison[23] argues that mathematical constraints take the place, in quantum gravity, of empirical constraints.

Most physicists focus their attention on string theory, but loop quantum gravity (LQG) is an active program, as are other programs. It is extremely difficult to make concrete predictions in these theories. String theory is affected by the lack of testable experimental predictions due to the extremely large number of distinct states, and the absence of guiding principles for highlighting the physically significant ones.[24] The LQG seems to be less affected by the lack of predictions, the discreteness of the area and volume operators represent concrete forecasts of the theory, with potentially verifiable consequences, making the theory more susceptible to falsification and therefore more scientific than string theory.[25] But it is not clear how these quantities can actually be observed.

Steven Weinstein and Dean Rickles state that it is difficult to develop an observational test of a theory if we do not know where to look or what to look at,[26] due to the fact that most quantum gravity theories seem to consider only very large energy scales, of the order 10^{19} GeV, needing a particle accelerator of galactic size to approach the necessary energies.

The most notable "test" of theories of quantum gravity imposed by the community to date involves a phenomenon that has never been observed, the so-called Hawking radiation from black holes. The string theory and the loop quantum gravity both passed the test, using different degrees of

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[21] Dean Rickles, "A Philosopher Looks at String Dualities," *Studies in the History and Philosophy of Modern Physics* 42 (2011): 42: 54–67, https://doi.org/10.1016/j.shpsb.2010.12.005.

[22] Jürgen Audretsch, "Quantum Gravity and the Structure of Scientific Revolutions," *Zeitschrift Für Allgemeine Wissenschaftstheorie* 12, no. 2 (September 1, 1981): 12(2): 322–339, https://doi.org/10.1007/BF01801202.

[23] Peter Galison, *Laws of Nature: Essays on the Philosophic, Scientific, and Historical Dimensions* (Berlin and New York: Walter de Gruyter, 1995), 369–408.

[24] Steven Weinstein and Dean Rickles, "Quantum Gravity," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Winter 2018 (Metaphysics Research Lab, Stanford University, 2018), https://plato.stanford.edu/archives/win2018/entries/quantum-gravity/.

[25] Lee Smolin, *The Trouble With Physics: The Rise of String Theory, The Fall of a Science, and What Comes Next*, Reprint edition (Boston u.a: Mariner Books, 2007).

[26] Katherine Brading, Elena Castellani, and Nicholas Teh, "Symmetry and Symmetry Breaking," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Winter 2017 (Metaphysics Research Lab, Stanford University, 2017), https://plato.stanford.edu/archives/win2017/entries/symmetry-breaking/.

microscopic freedom. Erik Curiel[27] argued how this test is used as evidence in the same way that empirical evidence is used to justify a common theory. Although the result of Bekenstein-Hawking does not have the empirical factual status, it is a powerful deduction from a framework that is quite mature, namely the quantum field theory on a curved spacetime background, which may function as a constraint on possible theories.

In quantum gravity, it is particularly important to have some constraints agreed to guide the construction, and a complete theory of quantum gravity should reproduce the predictions of the semi-classical theory of gravity as one of its possible limits. [28] Curiel questions the classification of quantum gravity approaches according to scientific merit, such as elegance and coherence, which he does not consider to be scientific. He states that the explanatory potential of theories must be taken into account. So far, none of the main research programs has shown that it properly reproduces the world at low energies. There are indications that both theories will overcome this challenge. [29] [30]

Bryce DeWitt stated that the gravitational field should be quantized to be consistent with quantum mechanics, [31] based on two premises: logical arguments, and the analogy between the electromagnetic and gravitational fields. But Planck's length is so small that aspects of reality that define a theory of quantum gravity, such as "emergence", "phenomenon" or "empirical", cannot be considered under this dimension.

The first approach to interpreting quantum theory was "instrumentalist". Jeremy Butterfield and Christopher Isham state that the Copenhagen interpretation of quantum theory is not only as a minimal statistical interpretation of quantum formalism in terms of frequency of measurement results, but as insisting on a classical domain which, if it includes space and classical time, involves the fact that, speaking of "quantum gravity", we are wrong in trying to apply quantum theory to something that belongs to the classical background of this theory. A quantum theory of gravity should be avoided, but we can try the development of a "quantum theory of space and time." [32]

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[27] Erik Curiel, "Against the Excesses of Quantum Gravity: A Plea for Modesty," *Proceedings of the Philosophy of Science Association* 2001, no. 3 (2001): 68(3): S424–S441.

[28] Weinstein and Rickles, "Quantum Gravity."

[29] Thomas Thiemann, "The Phoenix Project: Master Constraint Programme for Loop Quantum Gravity," *Classical and Quantum Gravity* 23, no. 7 (April 7, 2006): 23(7): 2211, https://doi.org/10.1088/0264-9381/23/7/002.

[30] Mariana Graña, "The Low Energy Limit of String Theory and Its Compactifications with Background Fluxes," *Letters in Mathematical Physics* 78, no. 3 (December 1, 2006): 78(3): 279–305, https://doi.org/10.1007/s11005-006-0125-z.

[31] Bryce S. DeWitt, "Definition of Commutators via the Uncertainty Principle," *Journal of Mathematical Physics* 3 (July 1, 1962): 619–24, https://doi.org/10.1063/1.1724265.

[32] Jeremy Butterfield and Chris Isham, "Spacetime and the Philosophical Challenge of Quantum Gravity," in *Physics Meets Philosophy at the Panck Scale* (Cambridge University Press, 2001).

The "literalist" vision implies the interpretation of quantum theory "as close as possible" to quantum formalism. This involves two versions, one by Everett and one based on quantum logic. Everett's literalism has been discussed in relation to quantum gravity (especially quantum cosmology). Its purpose is to solve the "measurement problem": when the wave function collapse occurs in relation to macroscopic objects (such as instruments).

The theories of the extra values aim to interpret the quantum theory, especially in the measurement problem, without resorting to the collapse of the state vector, by postulating extra values for a certain "preferred quantity", together with a rule for the evolution of these values. But, contrary to Everett's theory, "extra values" do not imply other real physical worlds; they are just trying to be more accurate about the preferred quantity and dynamics of its values. Such theories are deBroglie-Bohm's interpretation of the "pilot wave" of quantum theory, and the various types of modal interpretation. [33] Basically, "extra values" preserve the ordinary unit dynamics (Schrodinger equation) of quantum theory but add equations that describe the temporal evolution of its extra values. The pilot wave interpretation was applied only to the quantum gravity research program based on quantum geometrodynamics. [34]

According to Jeremy Butterfield and Christopher Isham, the new dynamic is more radical than "extra values". It replaces the usual dynamics for solving the measurement problem by dynamically suppressing overlays. In recent years, the new dynamics, especially as a result of Ghirardi, Rimini and Weber[35] and Pearle's "spontaneous localization" theories, [36] have developed considerably. Penrose was particularly active in supporting this idea.

Motivations for a theory of quantum gravity, from the perspective of elementary particle physics and quantum field theory:

1. Matter is made of elementary particles described in terms of quantum and interacting gravitationally.
2. The relativistic quantum field theory could only make sense by including gravity.
3. Quantum gravity will help unify the three fundamental non-gravitational forces.

Motivations for a theory of quantum gravity, from the perspective of general relativity:

1. The hope of eliminating singularities by introducing quantum effects.
2. The quantum explanation of the final nature of the black holes that lose mass through Hawking radiation.

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[33] Jeffrey Bub, *Interpreting the Quantum World*, 1st edition (Cambridge: Cambridge University Press, 1999).

[34] Butterfield and Isham, “Spacetime and the Philosophical Challenge of Quantum Gravity.”

[35] G. C. Ghirardi, A. Rimini, and T. Weber, “Unified Dynamics for Microscopic and Macroscopic Systems,” *Physical Review D* 34, no. 2 (July 15, 1986): D34:470–491, https://doi.org/10.1103/PhysRevD.34.470.

[36] null Pearle, “Combining Stochastic Dynamical State-Vector Reduction with Spontaneous Localization,” *Physical Review. A, General Physics* 39, no. 5 (March 1, 1989): A39:2277–2289.

3. Quantum gravity can help explain the very early universe, deducing from here the 4-dimensionality of spacetime, and the origin of the inflationary evolution.
4. It is hoped that a theory of quantum gravity will provide a quantum cosmology.

J. Butterfield lists four types of approaches in search of a theory of gravity:[37]

1. *Quantized general relativity*: it starts with the general relativity to which a certain type of quantification algorithm is applied. Two types of techniques are used for this purpose: a 4-dimensional spacetime approach to quantum field theory, and a canonical 3-dimensional approach to physical space. It was the first type of approach.
2. *General relativity as a limit to the low energy of a quantification of a different classical theory*: quantification algorithm is applied to a certain classical theory, recovered as a classical limit of the new quantum theory. This type of approach is exemplified by the main current research program: the superstring theory. There have been also several attempts to construct quantum theories of topology, and of causal structures.
3. *General relativity as a limit to the low energy of a quantum theory which is not a quantification of a classical theory*: it is considered to construct a quantum theory from scratch without a reference to a classical theory, without a certain classical limit.
4. *Starting from scratch with a radical new theory*. it is developed a theory that differs from both general relativity and quantum theory.

The fundamental principles of general relativity and quantum theory are so incompatible that any reconciliation will require a rethinking of the categories of space, time and matter. Currently, the dominant program is that of the superstrings, of the second type. The canonical quantum gravity in the Ashtekar approach is of the first type.

The construction of a quantum gravity theory is associated with two assumptions: classical notions of space and time are only approximately valid concepts, resulting from the "real" quantum nature of space and time,[38] and quantum gravity will provide classical physics on a deeper level.[39] [40]

The measurement problem implies that quantum theory cannot, in itself, explain any classical phenomenon - such as measurement results defined with well-defined spacetime and energy properties.[41] The need for general relativity for quantum gravity is somewhat analogous to the need for classical mechanics for quantum mechanics, the role of general relativity in the first case being

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[37] Butterfield and Isham, "Spacetime and the Philosophical Challenge of Quantum Gravity."

[38] J. Butterfield and C. J. Isham, "On the Emergence of Time in Quantum Gravity," *ArXiv:Gr-Qc/9901024*, January 8, 1999, 111–68, http://arxiv.org/abs/gr-qc/9901024.

[39] Steven Weinberg, *Dreams Of A Final Theory: The Search for The Fundamental Laws of Nature* (Random House, 2010).

[40] Max Tegmark and John Archibald Wheeler, "100 Years of the Quantum," *ArXiv:Quant-Ph/0101077*, January 17, 2001, 68–75, http://arxiv.org/abs/quant-ph/0101077.

[41] Henrik Zinkernagel, "The Philosophy Behind Quantum Gravity," *Theoria : An International Journal for Theory, History and Fundations of Science* 21, no. 3 (2010): 295–312.

to specify the scope of quantum theory. But quantum gravity can circumvent the need for a classical theory by choosing a different interpretation of quantum mechanics.

A first attempt to develop a theory of quantum gravity was the coupling of GR and quantum field theory (QFT), forming the so-called semi-classical theories.[42] In these theories matter fields are fundamental quantum theoretical structures, and gravity, that is, spacetime, is fundamentally classical (non-quantum). Basically, such a theory rewrites Einstein's equation.

Currently, "quantum gravity" is a more substantial reconciliation of gravity quantization,[43] building a quantum theory whose classical limit is in agreement with classical theory. Quantization does not necessarily imply the discretion of all observables, as in the case of position and momentum operators. Therefore, quantification of GR does not imply the discreteness of space.

According to Kiefer,[44] quantum gravity (QG) theories can be grouped into primary and secondary theories. The former use standard quantization procedures (canonical or covariant) as in the case of quantum electrodynamics. The second includes QG as a limit of a fundamental quantum theoretical framework, e.g. string theory. It should be noted that this classification is based on how the approaches are conducted. From a systemic point of view, however, these approaches can be correlated.[45]

It is hoped that the quantum gravity will resolve the incompleteness of the current physics related to the QG problem, having as motivated cosmological considerations, the evolution of black holes, theoretical problems in QFT and unification.[46] [47] But there is no empirical need to build the theory. Both theories (quantum theory and general relativity) are in perfect agreement with all available data. The typical energy scale (or length) in which quantum gravitational effects become relevant is about 16 orders of magnitude larger than the current one.[48] So, pragmatically we cannot really hope for direct experimental data.[49]

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[42] S. Carlip, "Is Quantum Gravity Necessary?," *Classical and Quantum Gravity* 25, no. 15 (August 7, 2008): 154010, https://doi.org/10.1088/0264-9381/25/15/154010.

[43] Christian Wuthrich, "To Quantize or Not to Quantize: Fact and Folklore in Quantum Gravity," Published Article or Volume, Philosophy of Science, 2005, 777–788, http://www.jstor.org/stable/10.1086/508946.

[44] C. Kiefer, "Quantum Gravity: General Introduction and Recent Developments," *Annalen Der Physik* 518 (January 1, 2006): 15(12), 129148, https://doi.org/10.1002/andp.200510175.

[45] Steven Weinberg, "What Is Quantum Field Theory, and What Did We Think It Is?," *ArXiv:Hep-Th/9702027*, February 3, 1997, 241–251, http://arxiv.org/abs/hep-th/9702027.

[46] Wuthrich, "To Quantize or Not to Quantize," 777–788.

[47] Kiefer, "Quantum Gravity," 15(12), 129148.

[48] Nima Arkani-Hamed, "The Future of Fundamental Physics," 2012, 141(3), 53–66.

[49] Kian Salimkhani, "Quantum Gravity: A Dogma of Unification?," in *Philosophy of Science. European Studies in Philosophy of Science, Vol 9.*, ed. Alexander Christian et al. (Cham: Springer, 2018), 23–41.

In quantum gravity, the Planck length dimension is so small that it suggests that those aspects of reality that require a quantum gravity theory to describe them should not be referred to as, for example, "aspect", "phenomenon" or "empirical". Kantians assert that "emergence" is not only what is practically accessible, but whatever is located in space is part of the empirical reality. But J. Butterfield considers it unacceptable that these scales of length, energy, etc., being so small, really exist "in principle." [50] He states that these elements or their localized aspects are not empirical, although we might still call them "physical" and "real". If this is accepted, the various Kantian claims that space and time may have certain characteristics - for example, continuity - as a matter of *a priori* to the claims of those quantum gravity programs that deny space and time have to be reconciled. "The apparent contradiction would be an artefact of an ambiguity in 'space and time': the quantum gravity programmes would not be about space and time in the Kantian sense." [51]

The Copenhagen interpretation can be understood not only as a minimal statistical interpretation of the quantum formalism for the frequency of the measurement results, but also as emphasizing a classical domain in the quantum system, with a firm separation from it and a quantum description of the first interpretation. If the classical domain includes the classical space and time, with regard to "quantum gravity" we would be wrong in applying quantum theory to something that is related to the classical background of that theory. To build a "quantum theory of space and time", a radical change of interpretation, possibly also of mathematical formalism and of quantum theory itself, is needed. [52]

An instrumentalist view specific to quantum theory should either deny that the quantum state describes individual systems, at least between measurements (similarly, be cautious in quantum description of these systems), or postulate a "non-quantum" domain whose description can be taken literally (not instrumentalist as in the first condition), with the respective domain being postulated as "classical domain" understood as macroscopic and / or the field of "measurements" and / or described by classical physics. [53] But recent applications of quantum theory make these conditions difficult to meet. It follows that we should seek an interpretation in which no fundamental role is assigned to "measurement", understood as an operation outside the domain of formalism.

If the instrumentalist interpretation of quantum theory is "as close as possible" to quantum formalism ("literalism"), one may reject the use of ideas such as measurement, "classical domain" or "external observer" to which a quantum-theoretical description is denied, rather a search for an interpretation of formalism is sought.

The question now arises whether theoretical statements can address any topic beyond observational data. Scientific anti-realists deny this possibility, as opposed to scientific realists. The scientific

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[50] Butterfield and Isham, "Spacetime and the Philosophical Challenge of Quantum Gravity."

[51] Butterfield and Isham.

[52] Butterfield and Isham.

[53] Butterfield and Isham.

realist gives the electron and quark the same ontological status as the chairs and tables. The antirealist considers the concepts of invisible objects as mere technical tools to describe and predict visible phenomena, useful but without a value of truth. The instrumentalist also denies the possibility of true statements about invisible theoretical objects. Bas van Fraassen considers a less radical way to reject scientific realism. His constructive empiricism believes that statements about theoretical objects may in principle have a truth value, but it is impossible to gather sufficient evidence for the truth of any particular statement. Richard Dawid states that by avoiding the ontological quality of the instrumentalist claim, constructive empiricism remains at an epistemological level. [54]

Due to the multitude of empirical data, scientists must build theoretical structures to help manipulate and analyze such data. There may be several sets of such theoretical structures that compete with each other and replace one another over time. Even the essential elements of scientific theories are not uniquely determined by empirical data (the principle of underdetermining scientific theories by experimental data). So there are no scientific statements that need to be considered indisputable (pessimistic meta-induction). Scientific theories seem too underdetermined to fit into a realistic scheme, but they are not sufficiently underdetermined to allow empiricism, this dilemma being difficult to avoid. [55]

A generalization of the underdetermination hypothesis espoused in particular by Quine, argues that no hypothetical ideal theoretical description, consistently covering all possible experimental data, would be unique. He admits the existence of theories that have identical phenomenological consequences but are still "logically incompatible" because of their incompatible sets of ontological objects. Quine is thus forced to distinguish between different theories by purely conceptual means, and on an ontological basis.

Richard Dawid believes that instrumentalism is most plausible in the context of underdeveloped theory, because the ascension of the theory can open "new frontiers of the visible whose identification with frontiers of existence appears less plausible than in the classical cases", and because "once the balance between theoretical effort and observational consequence has become too tilted, it gets quite problematic to hold that the theoretical physicist's sound motivations for his activity exclusively lie in the visible regime." [56] His conclusion is that physicists working in string theory are not interested in experiments for predicting visible phenomena. Their theory is not yet capable of such a thing. But observation is a prerequisite for attributing the meaning of concepts and string theory. A motivation for possible future visible consequences does not seem convincing.

Steven Weinstein considers QG as a "a physical theory describing the gravitational interactions of matter and energy in which matter and energy are also described by quantum theory." [57] Many

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[54] Richard Dawid, "Scientific Realism in the Age of String Theory," *Physics and Philosophy*, 2007.

[55] Dawid.

[56] Dawid.

[57] Weinstein and Rickles, "Quantum Gravity."

theories of quantum gravity are quantizations of gravity but, as Callender and Huggett point out, this is an empirical choice, rather than a logical one. [58] Finally, a quantification of gravity by GR suggests more, especially those in the canonical quantum gravity field (CQG), that a certain quantization method is required for space.

One of the earlier attempts to reconcile quantum with gravity appeared in the 1960s and is known as semi-classical theory. Although semi-classical theory was quickly understood to be flawed, it was seen as an excellent heuristic device for feeding the problem of quantum gravity. This theory, along with other dilemmas, such as the quantification debate, has led to the need for more robust theories about quantum gravity.

Unlike other modern theories in physics, where consensus has been reached in theory, quantum gravity has a number of alternative research programs that develop a basic hypothesis through the auxiliary hypotheses. Three of the most popular quantum gravity research programs in its short history include semi-classical theory, string theory, and canonical quantum gravity. But so far, none have experimental support. Some experiments were performed, but all were negative. The experiments were developed in such a way that the theory predicts only what might happen according to a certain specific scenario, which is not the only one possible, so they are not potentially refutable.

Given the lack of empirical progress, a pluralistic strategy for theoretical development is recommended in all quantum gravity approaches. In string theory there are different theoretical formulations, or physically equivalent dualities, which is relevant to the problem of sub-determining theories by data. It is argued that a more empirical perspective on the semantics of theories should be adopted, in order to understand what the theories of space and time tell us.

In string theory, unlike other approaches, there is a true unification of different forces, not just a quantum description of gravity, but some scientists criticize this theory as using too many resources at the expense of other approaches to quantum gravity.

Thinking experiments may be important for heuristic purposes, but in the case of quantum gravity, conclusions based on thought experiments are not very reliable. The lack of empirical results has led some scientists and philosophers to assert that these theories are not truly scientific.

Simonluca Pinna and Simone Pinna propose a "conceptual test" to evaluate whether the mathematical content of quantum gravity theory refers to a possible verifiable empirical model. [59] The best empirical observations are the astrophysical ones for the strong gravity, so there are two

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[58] Craig Callender and Nick Huggett, *Physics Meets Philosophy at the Planck Scale: Contemporary Theories in Quantum Gravity* (Cambridge University Press, 2001).

[59] S. Pinna and Simone Pinna, “A Conceptual Test for Cognitively Coherent Quantum Gravity Models,” 2017, https://doi.org/10.3390/technologies5030051.

options: (1) the development of new appropriate experimental frameworks,[60] and (2) the possibility of replacing the standard scientific verification criteria with the least empirically regulated ones.[61] There are two opinions of scientists: those who consider that spacetime is not a fundamental physical structure,[62] and those who consider it fundamental in any physical field[63] that presuppose the epistemological conservative approach expressed by (1). Those who support the disappearance of spacetime seem to follow the perspective, (2).

Some methodologists claim that the thesis of the disappearance of spacetime at high energies requires a change of the criteria of scientific verification, in order to adapt the empirical coherence to these theses in quantum gravity. This would involve changes in the concepts of "observer" and its connection with observations and measurements.

Geometrodynamics[64] was the first attempt to quantify gravity starting from the canonical (Hamiltonian) formulation of the general theory of relativity interpreted as a background-independent theory.[65] Subsequently, the followers of loop quantum gravity, a canonical approach, assert that relativistic spacetime disappears to the limit of high energy. This could imply the absence of a spacetime framework.[66] There are suspicions about the disappearance of spacetime and other approaches,[67] including string theory that is generally interpreted as background dependent.

Hagar and Hemmo declare the need for a certain type of spacetime even at QG level; physics consists not only of dynamic theories, but also of experiments and measurements by which models must be tested. So, there must be something observable with geometric features or that can be translated into geometric terms.[68] They assert that the interpretation of QG theories as spaceless

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[60] Sabine Hossenfelder and Lee Smolin, “Phenomenological Quantum Gravity,” *ArXiv:0911.2761 [Gr-Qc, Physics:Physics]*, November 14, 2009, 66, 99–102, http://arxiv.org/abs/0911.2761.

[61] Richard Dawid, *String Theory and the Scientific Method*, 1 edition (Cambridge: Cambridge University Press, 2013).

[62] Carlo Rovelli, “Quantum Gravity,” Cambridge Core, November 2004, https://doi.org/10.1017/CBO9780511755804.

[63] Amit Hagar and Meir Hemmo, “The Primacy of Geometry,” ResearchGate, 2013, 44, 357–364, https://www.researchgate.net/publication/259158226_The_primacy_of_geometry.

[64] Karel Kuchar, “Canonical Quantum Gravity,” *ArXiv:Gr-Qc/9304012*, April 8, 1993, 119–150, http://arxiv.org/abs/gr-qc/9304012.

[65] C. Kiefer, “Time in Quantum Gravity,” in *The Oxford Handbook of Philosophy of Time*, ed. Craig Callender (Oxford University Press, 2011), 663–678.

[66] Carlo Rovelli, “The Disappearance of Space and Time,” in *The Disappearance of Space and Time*, ed. Dennis Dieks (Elsevier, 2007), 25–36.

[67] Nick Huggett, Tiziana Vistarini, and Christian Wuthrich, “Time in Quantum Gravity,” *ArXiv:1207.1635 [Gr-Qc, Physics:Physics]*, July 3, 2012, 242–261, http://arxiv.org/abs/1207.1635.

[68] Hagar and Hemmo, “The Primacy of Geometry,” 44, 357–364.

theories would be in contradiction with the epistemic basis of experimental physics, respectively with the primacy of geometric observations and measurements.

Supporters of the disappearance of spacetime follow a leibnizian approach, according to Earman, even Pythagorean, of reality, according to which the sense of physical reality can be derived directly from mathematical theory using *a priori* more "reasonable" criteria.[69] The operationalist perspective defines the physical reality with respect to its measurability, respectively any concept is "nothing more than a set of operations; the concept is synonymous with the corresponding set of operations."[70] Detection of measurable quantities in quantum gravity is the main goal of the experimenters, as measurability is an essential feature for identifying physically relevant quantities.

It has not yet been possible to include gravity in the theoretical framework of the quantum field of the standard model, because gravitational interactions do not meet the principles of renormalizability.

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[69] John Earman, "Thoroughly Modern Mctaggart: Or, What Mctaggart Would Have Said If He Had Read the General Theory of Relativity," *Philosophers' Imprint* 2 (2002): 2, 1–28.

[70] Richard Feldman, "Naturalized Epistemology," July 5, 2001, 5, https://plato.stanford.edu/archives/sum2012/entries/epistemology-naturalized/.

Bibliography

Arkani-Hamed, Nima. “The Future of Fundamental Physics,” 2012, 14.

Ashtekar, Abhay. “Loop Quantum Gravity: Four Recent Advances and a Dozen Frequently Asked Questions.” In *The Eleventh Marcel Grossmann Meeting*, 126–47. World Scientific Publishing Company, 2008. https://doi.org/10.1142/9789812834300_0008.

Audretsch, Jürgen. “Quantum Gravity and the Structure of Scientific Revolutions.” *Zeitschrift Für Allgemeine Wissenschaftstheorie* 12, no. 2 (September 1, 1981): 322–39. https://doi.org/10.1007/BF01801202.

Brading, Katherine, Elena Castellani, and Nicholas Teh. “Symmetry and Symmetry Breaking.” In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta, Winter 2017. Metaphysics Research Lab, Stanford University, 2017. https://plato.stanford.edu/archives/win2017/entries/symmetry-breaking/.

Bub, Jeffrey. *Interpreting the Quantum World.* 1st edition. Cambridge: Cambridge University Press, 1999.

Bunge, Mario. “The Revival of Causality.” In *La Philosophie Contemporaine / Contemporary Philosophy: Chroniques Nouvelles / A New Survey*, edited by Guttorm Fløistad, 133–55. International Institute of Philosophy / Institut International de Philosophie. Dordrecht: Springer Netherlands, 1982. https://doi.org/10.1007/978-94-010-9940-0_6.

Butterfield, J., and C. J. Isham. “On the Emergence of Time in Quantum Gravity.” *ArXiv:Gr-Qc/9901024*, January 8, 1999. http://arxiv.org/abs/gr-qc/9901024.

Butterfield, Jeremy, and Chris Isham. “Spacetime and the Philosophical Challenge of Quantum Gravity.” In *Physics Meets Philosophy at the Panck Scale.* Cambridge University Press, 2001.

Callender, Craig, and Nick Huggett. *Physics Meets Philosophy at the Planck Scale: Contemporary Theories in Quantum Gravity.* Cambridge University Press, 2001.

Cao, Tian Yu. “Prerequisites for a Consistent Framework of Quantum Gravity.” *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 32, no. 2 (2001): 181–204.

Carlip, S. “Is Quantum Gravity Necessary?” *Classical and Quantum Gravity* 25, no. 15 (August 7, 2008): 154010. https://doi.org/10.1088/0264-9381/25/15/154010.

Curiel, Erik. “Against the Excesses of Quantum Gravity: A Plea for Modesty.” *Proceedings of the Philosophy of Science Association* 2001, no. 3 (2001): S424-.

Dawid, Richard. “Scientific Realism in the Age of String Theory.” *Physics and Philosophy*, 2007.

———. *String Theory and the Scientific Method.* 1 edition. Cambridge: Cambridge University Press, 2013.

Deser, S. “Self-Interaction and Gauge Invariance.” *General Relativity and Gravitation* 1, no. 1 (March 1, 1970): 9–18. https://doi.org/10.1007/BF00759198.

DeWitt, Bryce S. “Definition of Commutators via the Uncertainty Principle.” *Journal of Mathematical Physics* 3 (July 1, 1962): 619–24. https://doi.org/10.1063/1.1724265.

Earman, John. “Thoroughly Modern Mctaggart: Or, What Mctaggart Would Have Said If He Had Read the General Theory of Relativity.” *Philosophers' Imprint* 2 (2002): 1–28.

Feldman, Richard. “Naturalized Epistemology,” July 5, 2001. https://plato.stanford.edu/archives/sum2012/entries/epistemology-naturalized/.

Feynman, Richard P, Fernando B Morinigo, William G Wagner, and Brian Hatfield. *Feynman Lectures on Gravitation.* Reading, Mass.: Addison-Wesley, 1995.

Galison, Peter. *Laws of Nature: Essays on the Philosophic, Scientific, and Historical Dimensions.* Berlin and New York: Walter de Gruyter, 1995.

Ghirardi, G. C., A. Rimini, and T. Weber. “Unified Dynamics for Microscopic and Macroscopic Systems.” *Physical Review D* 34, no. 2 (July 15, 1986): 470–91. https://doi.org/10.1103/PhysRevD.34.470.

Graña, Mariana. "The Low Energy Limit of String Theory and Its Compactifications with Background Fluxes." *Letters in Mathematical Physics* 78, no. 3 (December 1, 2006): 279–305. https://doi.org/10.1007/s11005-006-0125-z.

Hagar, Amit, and Meir Hemmo. "The Primacy of Geometry." ResearchGate, 2013. https://www.researchgate.net/publication/259158226_The_primacy_of_geometry.

Hossenfelder, Sabine. "Experimental Search for Quantum Gravity." *ArXiv:1010.3420 [Gr-Qc, Physics:Hep-Ph, Physics:Hep-Th]*, October 17, 2010. http://arxiv.org/abs/1010.3420.

Hossenfelder, Sabine, and Lee Smolin. "Phenomenological Quantum Gravity." *ArXiv:0911.2761 [Gr-Qc, Physics:Physics]*, November 14, 2009. http://arxiv.org/abs/0911.2761.

Huggett, Nick, Tiziana Vistarini, and Christian Wuthrich. "Time in Quantum Gravity." *ArXiv:1207.1635 [Gr-Qc, Physics:Physics]*, July 3, 2012. http://arxiv.org/abs/1207.1635.

Ibanez, L. E. "The Second String (Phenomenology) Revolution." *Classical and Quantum Gravity* 17, no. 5 (March 7, 2000): 1117–28. https://doi.org/10.1088/0264-9381/17/5/321.

Kiefer, C. "Quantum Gravity: General Introduction and Recent Developments." *Annalen Der Physik* 518 (January 1, 2006): 129–48. https://doi.org/10.1002/andp.200510175.

———. "Time in Quantum Gravity." In *The Oxford Handbook of Philosophy of Time*, edited by Craig Callender, 667. Oxford University Press, 2011.

Kragh, Helge. *Dirac: A Scientific Biography*. 1 edition. Cambridge England ; New York: Cambridge University Press, 1990.

Kuchar, Karel. "Canonical Quantum Gravity." *ArXiv:Gr-Qc/9304012*, April 8, 1993. http://arxiv.org/abs/gr-qc/9304012.

Nambu, Y. "Directions of Particle Physics." *Progress of Theoretical Physics Supplement* 85 (1985): 104–10. https://doi.org/10.1143/PTPS.85.104.

Ohta, T., and R. B. Mann. "Canonical Reduction of Two-Dimensional Gravity for Particle Dynamics." *Classical and Quantum Gravity* 13, no. 9 (September 1, 1996): 2585–2602. https://doi.org/10.1088/0264-9381/13/9/022.

Oldershaw, Robert L. "The New Physics—Physical or Mathematical Science?" *American Journal of Physics* 56, no. 12 (December 1, 1988): 1075–81. https://doi.org/10.1119/1.15749.

Pearle, null. "Combining Stochastic Dynamical State-Vector Reduction with Spontaneous Localization." *Physical Review. A, General Physics* 39, no. 5 (March 1, 1989): 2277–89.

Penrose, Roger. *The Road to Reality: A Complete Guide to the Laws of the Universe*. Reprint edition. New York: Vintage, 2007.

Pinna, S., and Simone Pinna. "A Conceptual Test for Cognitively Coherent Quantum Gravity Models," 2017. https://doi.org/10.3390/technologies5030051.

Rickles, Dean. "A Philosopher Looks at String Dualities." *Studies in the History and Philosophy of Modern Physics* 42 (2011): 54–67. https://doi.org/10.1016/j.shpsb.2010.12.005.

Rovelli, Carlo. "Halfway Through the Woods: Contemporary Research on Space and Time." In *The Cosmos of Science*, edited by John Earman and John Norton, 180–223. University of Pittsburgh Press, 1997.

———. "Quantum Gravity." Cambridge Core, November 2004. https://doi.org/10.1017/CBO9780511755804.

———. "The Disappearance of Space and Time." In *The Disappearance of Space and Time*, edited by Dennis Dieks. Elsevier, 2007.

Salimkhani, Kian. "Quantum Gravity: A Dogma of Unification?" In *Philosophy of Science. European Studies in Philosophy of Science, Vol 9.*, edited by Alexander Christian, David Hommen, Nina Retzlaff, and Gerhard Schurz, 23–41. Cham: Springer, 2018.

Smolin, Lee. *The Trouble With Physics: The Rise of String Theory, The Fall of a Science, and What Comes Next*. Reprint edition. Boston u.a: Mariner Books, 2007.

Tegmark, Max, and John Archibald Wheeler. "100 Years of the Quantum." *ArXiv:Quant-Ph/0101077*, January 17, 2001. http://arxiv.org/abs/quant-ph/0101077.

Thiemann, Thomas. "The Phoenix Project: Master Constraint Programme for Loop Quantum Gravity." *Classical and Quantum Gravity* 23, no. 7 (April 7, 2006): 2211–47. https://doi.org/10.1088/0264-9381/23/7/002.

Townsend, P. K. "Four Lectures on M-Theory." *ArXiv:Hep-Th/9612121*, December 11, 1996. http://arxiv.org/abs/hep-th/9612121.

Von Neumann, John. *Mathematische grundlagen der quantenmechanik,*. Berlin: J. Springer, 1932.

Weinberg, Steven. *Dreams Of A Final Theory: The Search for The Fundamental Laws of Nature*. Random House, 2010.

———. "What Is Quantum Field Theory, and What Did We Think It Is?" *ArXiv:Hep-Th/9702027*, February 3, 1997. http://arxiv.org/abs/hep-th/9702027.

Weinstein, Steven. "Absolute Quantum Mechanics." Preprint, 2000. http://philsci-archive.pitt.edu/836/.

Weinstein, Steven, and Dean Rickles. "Quantum Gravity." In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta, Winter 2018. Metaphysics Research Lab, Stanford University, 2018. https://plato.stanford.edu/archives/win2018/entries/quantum-gravity/.

Weyl, Hermann, and Frank Wilczek. *Philosophy of Mathematics and Natural Science*. Revised ed. edition. Princeton, N.J: Princeton University Press, 2009.

Wigner, E. P., I. J. Good, A. J. Mayne, J. M. Smith, and Thornton Page. "The Scientist Speculates: An Anthology of Partly-Baked Ideas." *American Journal of Physics* 32, no. 4 (April 1, 1964): 322–322. https://doi.org/10.1119/1.1970298.

Wuthrich, Christian. "To Quantize or Not to Quantize: Fact and Folklore in Quantum Gravity." Published Article or Volume. Philosophy of Science, 2005. http://www.jstor.org/stable/10.1086/508946.

Zee, A. *Quantum Field Theory in a Nutshell, 2nd Edition*. 2 edition. Princeton, N.J: Princeton University Press, 2010.

Zinkernagel, Henrik. "The Philosophy Behind Quantum Gravity." *Theoria : An International Journal for Theory, History and Fundations of Science* 21, no. 3 (2010): 295–312.