Extensions of quantum gravity theories - Final theory and cosmology

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Other theories of quantum gravity

Bimetric gravity is a class of modified theories of gravity in which two metric tensors are used instead of one, [1] the second metric being used at high energies. If the two metrics interact, two types of gravitons appear, one massive and one massless. The set of theories tries to explain the massive gravity. [2] Such theories are those of Nathan Rosen (1909-1995) [3] or Mordehai Milgrom's Modified Newtonian Dynamics (MOND). The evolutions of massive gravity have encouraged the emergence of new consistent theories of bimetric gravity, [4] but none have reflected physical observations better than general relativity theory. [5] Some of these theories (MOND, for example) are alternatives to dark energy. Other biometric theories do not take into account massive gravitons and do not change Newton's law, describing the universe as a variety of two coupled Riemannian metrics, where matter interacts by gravity. Some of them stipulate the variable speed of light at high energy density. [6]

Rosen's bigravity (1940) [7] proposes that at every point of spacetime there is a Euclidean metric tensor in addition to the Riemannian metric tensor. Thus, at each point of spacetime there are two values. The first metric tensor describes the geometry of spacetime, and therefore the gravitational field. The second metric tensor refers to spacetime flat and describes the inertial forces. Rosen's bigravity satisfies the principle of covariance and equivalence. Rosen's bigravity and GR differ in the case of the propagation of electromagnetic waves, of the external field of a high-density star, and in the behavior of intense gravitational waves that propagate through a strong static gravitational field. The predictions of gravitational radiation from Rosen's theory were refuted by the observations of the Hulse-Taylor binary pulsar. [8]

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[1] N. Rosen, "General Relativity and Flat Space. I," *Physical Review* 57, no. 2 (January 15, 1940): 57 (2): 147–150, https://doi.org/10.1103/PhysRev.57.147.

[2] S. F. Hassan and Rachel A. Rosen, "Bimetric Gravity from Ghost-Free Massive Gravity," *Journal of High Energy Physics* 2012, no. 2 (February 24, 2012): 1202 (2): 126, https://doi.org/10.1007/JHEP02(2012)126.

[3] Rosen, "General Relativity and Flat Space. I," 57 (2): 147–150.

[4] Lisa Zyga, "Gravitational Waves May Oscillate, Just like Neutrinos," 2017, https://phys.org/news/2017-09-gravitational-oscillate-neutrinos.html.

[5] Clifford Will, *The Renaissance of General Relativity, in The New Physics* (Cambridge: Cambridge University Press, 1992), 18.

[6] J. P. Petit and G. D'Agostini, "Cosmological Bimetric Model with Interacting Positive and Negative Masses and Two Different Speeds of Light, in Agreement with the Observed Acceleration of the Universe," *Modern Physics Letters A* 29, no. 34 (October 27, 2014): 29 (34): 1450182, https://doi.org/10.1142/S021773231450182X.

[7] Rosen, "General Relativity and Flat Space. I," 57 (2): 147–150.

[8] Will, *The Renaissance of General Relativity, in The New Physics*, 18.

Massive bigravity appeared in 2010, developed by Claudia de Rham, Gregory Gabadadze and Andrew Tolley (dRGT). [9] A non-dynamic "reference metric" appears in dRGT theory. The reference metric value must be specified manually. A further extension was introduced by Fawad Hassan and Rachel Rosen. [10]

Bohmian quantum gravity incorporates the real configuration in theory as the basic variable and stipulates that it evolves in a natural way suggested by symmetry and Schrodinger's equation. [11] The theory solves the problem of time (the same role as in GR), and partly the problem of diffeomorphism. It has no problems with the role of observers and observables because they play no role in this theory. The time-dependent wave function, which satisfies the Schrodinger equation, is not necessary here.

Bohmian quantum gravity implies a simple transition from quantum mechanics, incorporating the actual configuration into theory as the basic variable and stipulating that it evolves in a natural manner suggested by Schrodinger's symmetry and equation.

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[9] Claudia de Rham, Gregory Gabadadze, and Andrew J. Tolley, "Resummation of Massive Gravity," *Physical Review Letters* 106, no. 23 (June 10, 2011): 106 (23): 231101, https://doi.org/10.1103/PhysRevLett.106.231101.

[10] Hassan and Rosen, "Bimetric Gravity from Ghost-Free Massive Gravity," 1202 (2): 126.

[11] Sheldon Goldstein and Stefan Teufel, "Quantum Spacetime without Observers: Ontological Clarity and the Conceptual Foundations of Quantum Gravity," *ArXiv:Quant-Ph/9902018*, February 5, 1999, http://arxiv.org/abs/quant-ph/9902018.

Unification (The Final Theory)

The fields of application of general relativity (GR) and quantum field theory (QFT) are different, so most situations require the use of only one of the two theories. [12] The overlaps occur in regions of extremely small size and high mass, such as the black hole or the early universe (immediately after the Big Bang). This conflict is supposed to be solved only by unifying gravity with the other three interactions, to integrate GR and QFT into one theory. The string theory states that at the beginning of the universe (up to 10^{-43} seconds after the Big Bang), the four fundamental forces were a single fundamental force. According to physicism in philosophy, a physical final theory will coincide with a final philosophical theory.

Several unifying theories have been proposed. Great unification implies the existence of an electronuclear force. The last step in unification would require a theory that includes both quantum mechanics and gravity through general relativity ("the final theory"). After 1990, some physicists consider that the 11-dimensional M-theory, often identified with one of the five perturbative superstring theories, or sometimes with the 11-dimensional maximal-supersymmetric supergravity, is the final theory. The idea of M theory[13] took over from the ideas of the Kaluza-Klein theory, in which it was found that the use of a 5-dimensional spacetime for general relativity (with a small one) is seen, from the 4-dimensional perspective, like the usual general relativity along with Maxwell's electrodynamics. An important property of string theory is its supersymmetry (version of superstring theory) which, along with the additional dimensions, are the two main proposals for solving the problem. The additional dimensions would allow gravity to spread to the other dimensions, the other forces remaining limited in a 4-dimensional spacetime.

Attempts to use loop quantum gravity (LQG) in a final theory (FT) have failed, but supporters of this program are continuing their research. [14]

There are attempts to develop a final theory through other theories, such as the causal fermions systems theory, which contains the two current physical theories (general relativity and quantum field theory) as limiting cases. Another theory is that of causal sets. Another proposal is Garrett Lisi's E8, [15] which proposes unification within the Lie group. Christoph Schiller's Strand model attempts to reflect the gauge symmetry of the standard particle physics model,

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[12] S. Carlip, "Quantum Gravity: A Progress Report," *Reports on Progress in Physics* 64, no. 8 (August 1, 2001): 64 (8): 885–942, https://doi.org/10.1088/0034-4885/64/8/301.

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

[14] Sundance Bilson-Thompson et al., "Particle Identifications from Symmetries of Braided Ribbon Network Invariants," *ArXiv:0804.0037 [Hep-Th]*, April 1, 2008, http://arxiv.org/abs/0804.0037.

[15] A. Garrett Lisi, "An Exceptionally Simple Theory of Everything," *ArXiv:0711.0770 [Gr-Qc, Physics:Hep-Th]*, November 6, 2007, http://arxiv.org/abs/0711.0770.

and another version involves ER = EPR, a conjecture in physics stating that entangled particles are connected by a wormhole (or Einstein–Rosen bridge). [16]

Jürgen Schmidhuber is for FT, stating that Gödel's incompleteness theorems[17] are irrelevant to computational physics. [18] Most physicists claim that Gödel's theorem does not imply the impossibility of a FT. [19] Some physicists, including Einstein, believe that theoretical models should not be confused with the true nature of reality, and argue that approximations will never reach a complete description of reality. [20] A philosophical debate is about whether a final theory can be called the *fundamental law of the universe*. [21] The reductionist FT supporters claim that theory is the fundamental law. Another view is that emerging laws (such as the second law of thermodynamics and the theory of natural selection) should be considered as fundamental, and therefore independent.

The name "final theory" is contradicted by the probabilistic nature of quantum mechanics predictions, sensitivity to initial conditions, limitations due to event horizons, and other deterministic difficulties. Frank Close contradicts the idea of FT claiming that the layers of nature are like layers of onion, and the number of these layers could be infinite, [22] implying an infinite series of physical theories. Weinberg[23] states that since it is impossible to accurately calculate even a real projectile in the Earth's atmosphere, we cannot speak of a FT.

Unification does not necessarily mean reduction. Quantum field theory and general relativity are unified theories themselves. General relativity is a gravitational generalization of the special theory of relativity that unified electromagnetism with classical non-gravitational mechanics, and quantum field theory is a combination of special relativity and quantum mechanics. The

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[16] Ron Cowen, "The Quantum Source of Space-Time," *Nature News* 527, no. 7578 (November 19, 2015): 527 (7578): 290–293, https://doi.org/10.1038/527290a.

[17] Gödel's incompleteness theorems are two theorems of mathematical logic that establish limitations inherent in all axiomatic systems, except for the most trivial ones, capable of arithmetic. The first theorem states that any effectively generated theory, capable of expressing elementary arithmetic, cannot be both consistent and complete.

[18] Jürgen Schmidhuber, "A Computer Scientist's View of Life, the Universe, and Everything. Lecture Notes in Computer Science," 1997, 201–208, http://people.idsia.ch/~juergen/everything/.

[19] Jürgen Schmidhuber, "Hierarchies of Generalized Kolmogorov Complexities and Nonenumerable Universal Measures Computable in the Limit," *International Journal of Foundations of Computer Science* 13, no. 04 (August 1, 2002): 13 (4): 587–612, https://doi.org/10.1142/S0129054102001291.

[20] Abraham Pais, *Subtle Is the Lord: The Science and the Life of Albert Einstein* (Oxford ; New York: Oxford University Press, 2005), chap. 17.

[21] Weinberg, *Dreams Of A Final Theory.*

[22] Frank Close, *The New Cosmic Onion: Quarks and the Nature of the Universe*, Revised edition (New York: CRC Press, 2006).

[23] Weinberg, *Dreams Of A Final Theory.*

standard model is often presented as an example of successful unification. In trying to unify gravity with other forces, loop quantum gravity is a "minimalist" version (it is just an attempt to quantify general relativity). String theory tries to be the "theory of everything", in which a single type of interaction determines any other aspects of reality.

Between quantum theory and general relativity there are problems of conceptual compatibility in the development of quantum gravity: the background independence of general relativity due to the lack of a preferred frame of reference, is opposed to the geometry of quantum theory which implies a background dependence related to the existence of a preferred frame of reference. [24] The metric in general relativity determines the geometry of spacetime and acts as a potential. Because it is a dynamic variable, it turns out that geometry itself is dynamic. Quantum theory requires a fixed geometry, resulting in a very different treatment of spacetime compared to GR. A theory of quantum gravity can give up substance dependence, or quantum theory can be modified.

According to Reiner Hedrich, string theory is a mathematical construct without any empirical control, which seems to transcend more and more the context of physics, by increasing self-immunization, eventually becoming a metaphysical form of a mathematical inspiration nature. [25] The return to a metaphysical nature must be seen as a retrograde step. String theory can be understood as a return to the ancient ideal of a deepening of nature exclusively through our (mathematical) intellect, without observations or experimental devices. Jeremy Butterfield and Christopher Isham point out that the immense self-reference that is found in all theories of quantum gravity is a consequence of the absence of empirical data, of the metaphysical significance of hypotheses and bias, and of the mathematical apparatus and theoretical model on which those theories are conceived. [26]

The mathematical basis of string theory (an extended version of the quantum field theory apparatus) has not changed significantly during its evolution. There have also been attempts to unify gravity with other forces on mathematical bases, such as Einstein, Schrodinger, Misner and Wheeler's theories of geometrically unifying gravity and electromagnetism, but they have also failed. [27] All researchers, regardless of whether they are followers or critics of the Final Theory, are trying to find an answer to the question why this unification has not succeeded so far. After all, there is no consensus even on defining what unification actually is, and to what

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

[25] Reiner Hedrich, "The Internal and External Problems of String Theory: A Philosophical View," *Journal for General Philosophy of Science / Zeitschrift Für Allgemeine Wissenschaftstheorie* 38, no. 2 (2006): 261–278.

[26] 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), 33–89.

[27] Robert Weingard, "A Philosopher Looks at String Theory," *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association* 1988 (1988): 95–106.

extent it can epistemically reflect this eventual ontic unity. Our epistemic boundaries could make such an exploration impossible.

Basically, the philosophers of science are skeptical of the philosophical motivations of this unification, and of its scientific success. [28]

[28] Nancy Cartwright, *The Dappled World: A Study of the Boundaries of Science* (Cambridge University Press, 1999).

Cosmology

At the cosmological level, the standard cosmological model contains Einstein's theory of gravity as part of the "hard core". Dark matter, dark energy, and inflation were added to the theory in response to observations. None of these ancillary hypotheses have yet been confirmed. The standard cosmological model does not have predictions of success, it is constantly adjusted following observations. The reproduction of the spectrum of temperature fluctuations in the cosmic microwave environment is considered a success of the model, but it was obtained by the forced modification of the model parameters, with inconsistencies with the values determined in other, more direct ways.

David Merritt[29] draws attention to an alternative research program, which was initiated in the early 1980s and made new predictions; the program of Mordehai Milgrom (MOND), initiated in 1983, whose specific principle states that the laws of gravity and motion differ from those of Newton or Einstein in the very low acceleration regime (at the level of galaxies). The program has a long list of other predictions, avoiding the assumptions of dark matter and dark energy.

In cosmology, metaphysics involves a wide range of questions beyond empirical evidence, sometimes using speculative inference. Epistemological analysis in cosmology helps model evaluation. The philosophical study provides a general framework for interpreting inferences that go beyond science. [30]

In cosmology there are some ontological principles that help to classify the models according to characteristics, to conceive the cosmic reality in a more transparent description and allow us to solve mathematical equations as central constructions of any model. These principles are: [31]

1. Homogeneity of space (uniform distribution of matter)
2. Homogeneity of time (structure independent of global cosmic time)
3. Isotropy of space (independence of structure from the direction of observation)
4. Homothety of space (independence of structure from scalar transformations)

Thus, the standard model (Hot Big Bang) includes the models (a, c), the stationary model includes (a, b, c), the hierarchical model includes (c, d).

In order to epistemically evaluate cosmological models, we assume that the physical laws are valid and the same everywhere in the cosmos, in space and time. Isotropy of space is the only property of the cosmos that is easy to verify. Because the inference on physical properties and

[29] David Merritt, "Gravity: The Popper Problem," IAI TV - Changing how the world thinks, October 2, 2017, https://iai.tv/articles/gravity-the-popper-problem-auid-899.

[30] Petar V. Grujic, "Some Epistemic Questions of Cosmology," *ArXiv:0709.3191 [Physics]*, September 20, 2007, http://arxiv.org/abs/0709.3191.

[31] Grujic.

phenomena is always indirect and related to theoretical models, empirical evidence is based on the validity of these theoretical constructs. [32] In estimating the cosmic distances we take into account the color change of the spectral lines from these objects and we rely on the interpretation of this change, attributed to the Doppler effect (kinematic), gravitational phenomena (dynamic), space expansion (geometric), etc., depending on the ours model of the universe. Within the "epistemic space", the ontologically defined principles (a, b, c) are postulated, but the fourth (d) is no longer valid at sufficiently small scales, including probably the gravitational one. Part of the observable cosmos, cosmography, can be viewed as a structure built on particular elemental components.

Cosmographic models begin with the galaxy as an elemental unit. Cosmology treats galaxies as physical points, endowed with collective (coherent) and own (chaotic) movements.

In cosmology, the theoretical predictions or descriptions must be in accordance with the empirical evidence, it turns out that the models will be adapted to the new empirical situations, or new external elements may be introduced into the model, provided they do not contradict the initial structure. [33]

The test stone for a cosmological model is how it treats the problem of the Beginning, including the initial conditions and the eschatological problem. The Abderian approach is immune to these problems. In general, a good theory includes a formal mathematical model and the procedure of coupling with physical reality. Hawking proposed a solution that aims to formulate a model that is self-sufficient.

Thus, the research program for the standard cosmological model is a unifying program in the sense of the methodology of Lakatos' research programs, including several unified programs (such as the one for the Big Bang, stellar and galaxy evolution, gravitational singularities, etc.). These unified programs are at the same time research sub-programs of the unifying program because, even if they are created and developed without being required by the unifying program, they must take into account its requirements in order to be validated and included in it.

General relativity has emerged as an extremely successful model for gravity and cosmology, which has so far passed many unequivocal observational and experimental tests. However, there are strong indications that the theory is incomplete. [34] The question of quantum gravity and the question of the reality of spacetime singularities remain open. Observational data taken as evidence of dark energy and dark matter could indicate the need for new physics. Even as it is,

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[32] Grujic.

[33] P. Duhem, "La Théorie Physique, Son Objet Et Sa Structure," *Revue Philosophique de La France Et de l'Etranger* 61 (1906): 324–327.

[34] John Maddox, *What Remains to Be Discovered: Mapping the Secrets of the Universe, the Origins of Life, and the Future of the Human Race*, 1st Touchstone Ed edition (New York: Free Press, 1999), 52–59, 98–122.

general relativity is rich in possibilities for further exploration. Mathematical relativists seek to understand the nature of the singularities and fundamental properties of Einstein's equations,[35] while numerical relativists run increasingly powerful computer simulations (such as those describing black holes merging). A century after its introduction, general relativity remains a very active research area.

[35] H. Friedrich, "Is General Relativity 'Essentially Understood'?," *Annalen Der Physik* 15, no. 1–2 (2006): 15 (1–2): 84–108, https://doi.org/10.1002/andp.200510173.

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