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Research Article

Quantum Gravity and Its Implications for Cosmology

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Abstract
The background of this research focuses on the confluence of two major theories in physics, namely quantum mechanics and general relativity, which are very important in explaining gravity at the quantum scale and cosmology. The purpose of this study is to investigate the relationship between quantum gravity theory and its implications for cosmological phenomena, especially related to singularities and enormous models of the universe. The method used in this study is a comparative analysis of various existing theories of quantum gravity, including string theory and quantum loop gravity, as well as a literature review on the application of these theories in cosmology. The results show that although various theories have been developed, there is not yet a clear consensus on how to integrate quantum gravity into the broader cosmological model. The study also revealed a huge gap in the experiments that could confirm these theories, which slowed down our understanding of gravity at the quantum scale. The conclusion of this study is the importance of further research in experiments and theories to bring together the principles of quantum and general relativity, which is expected to lead to a new, more comprehensive model of cosmology and the universe.

Keywords: Cosmology, Quantum Gravity, Quantum Gravity

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INTRODUCTION

Gravity is one of the four fundamental forces of the universe, which affects the structure of space and time (Jensen et al., 2023). Newton's theory of gravity describes the force of attraction between masses, but it cannot explain phenomena that occur on very small or very large scales (Wang & Huang, 2020). To understand gravitational interactions at the microscopic scale, the theory of gravity must be combined with the principles of quantum mechanics, which explain the behavior of subatomic particles.

Albert Einstein developed the theory of general relativity in the early 20th century, which replaced Newton's theory of gravity in explaining the phenomena of the universe on a large scale (Croker & Weiner, 2019). This theory describes gravity as the curvature of space-time caused by mass and energy (Odintsov & Paul, 2023). General relativity has managed to explain many cosmological phenomena, such as the motion of the planets, the bending of light by large objects, and the expansion of the universe (Byrne et al., 2019). However, this theory cannot explain phenomena on a quantum scale.

Quantum mechanics is a theory of physics that describes the behavior of particles on a subatomic scale. This theory has succeeded in explaining various strange phenomena such as superposition, quantum entanglement, and tunneling effects (Bhattacharya et al., 2021). However, quantum mechanics does not include gravity in its models, which causes incompatibility with general relativity when applied to very large or very small objects, such as black holes or cosmic singularities.

Quantum gravity is a field of research that attempts to combine the theory of gravity with quantum mechanics (Dong et al., 2019). The main goal of this theory is to create a consistent framework that can explain gravity on the quantum scale (Grohs & Balantekin, 2023). Theories that have been proposed, such as string theory, quantum gravity loop, and quantum gravity theory, have attempted to provide an explanation for how gravity works at the microscopic scale, but there is no clear agreement yet.

One of the main candidates for quantum gravity theory is string theory, which states that elementary particles are not dots, but rather small vibrating "strings." This theory seeks to explain gravity, along with three other fundamental forces, within a single mathematical framework (Damour, 2020). While this theory offers promising insights, there are still many technical and conceptual challenges to be solved, including its influence on the structure of the universe and cosmological phenomena.

One of the most interesting implications of combining quantum gravity with cosmology is to understand the singularities inside black holes and during the Big Bang (Zhang et al., 2023). At this scale, gravity and quantum effects become very powerful and need to be understood together (Hassan et al., 2023). The theory of quantum gravity could provide new insights into how the universe formed, how black holes work, and how the laws of physics apply near extreme points, which cannot yet be explained by current physical theories.

Although the theory of general relativity and quantum mechanics have provided a deep understanding of the phenomena of the universe, these two theories have not yet been made into a single unit (Singh et al., 2022). Limitations arise when trying to explain gravitational interactions on the quantum scale. Gravity at the subatomic level cannot be explained by existing theories, leaving a huge gap in our understanding of the universe.

The singularity that occurs inside a black hole and at the time of the Big Bang is one of the phenomena that cannot be explained by existing theories (Pastén et al., 2024). At this point, the existing laws of physics no longer work, and all parameters such as density and temperature become infinite. This creates a need for new theories capable of bridging our knowledge of gravity and quantum at this extreme point.

General relativity and quantum mechanics provide very different predictions about how the universe functions at a very small or very large level (Marshman et al., 2020). Quantum mechanics describes particles as probabilistic entities, while general relativity describes gravity as a field that measures the curvature of space-time. This limitation raises the big question: how can these two theories be made into a whole whole?

String theory is one approach to combining gravity with quantum mechanics, but there is no universal agreement on how it can explain gravity quantumically (Christodoulou et al., 2023). In addition, string theory requires extra dimensions that have not been directly observed. Further understanding of the implications of string theory on cosmology and quantum gravity is needed.

Much of the current research focuses on how the concept of quantum gravity can be applied to explain the origins of the universe, such as in the early conditions of the Big Bang and the formation of black holes (Esteban & Salvado, 2021). Although much progress has been made, a huge gap still exists in describing how the quantum laws interact with the laws of gravity in a cosmological context.

Filling in these gaps is essential for achieving a more holistic understanding of the universe (Fehre et al., 2023). Gravity and quantum mechanics are the two main pillars of physics, and the merger of these two theories could unravel the mechanisms of the universe on a more fundamental level (Mertens et al., 2023). This will allow us to predict the extreme phenomena that occur in black holes and the Big Bang more accurately.

By filling this gap, we can get a deeper explanation of cosmological events such as the formation of the structure of the universe and extreme conditions in black holes (Cotler et al., 2020). Understanding how the laws of physics apply under these extreme conditions is essential for enriching our insights into the origins and evolution of the universe.

In addition, research on quantum gravity is not only important for our theoretical understanding, but it could also have a major impact on the development of future technologies (Bajardi & Capozziello, 2023) . Concepts such as quantum computing and the development of new energies could be driven by advances in quantum gravity theory, so it is crucial to continue research in this area.

RESEARCH METHOD

The design of this research is qualitative and exploratory with a theoretical analysis approach. The research will examine the existing literature related to the theory of quantum gravity and its implications for cosmology, as well as compare various theoretical models developed in theoretical physics (Krisnanda et al., 2020). This research aims to provide insight into the potential of quantum gravity theory in explaining cosmological phenomena, such as black holes, singularities, and early conditions of the universe.

The population in this study is scientific literature relevant to the topic of quantum gravity and cosmology (Park et al., 2023). The sample to be used includes articles published in leading international journals, textbooks on theoretical physics, and recent conferences on quantum gravity, general relativity, and quantum mechanics. The samples were selected based on their relevance and contribution to the understanding of the relationship between quantum gravity and cosmology.

The instruments used in this study are content analysis and theoretical synthesis methods. The content analysis process involves an in-depth examination of selected articles and scientific publications to extract key ideas and theories (Caputa & Magan, 2019). The synthesis method is used to compare and combine various existing theories, as well as to produce more comprehensive conclusions about the influence of quantum gravity in cosmology. In addition, bibliographic software will be used to manage references and ensure the validity of the literature used.

The research procedure begins with the collection of relevant literature regarding the theory of quantum gravity and its implications for cosmology. The literature will be systematically analyzed to identify key theories, their contributions to the understanding of gravity on the quantum scale, and how they are applied in explaining cosmological phenomena (Brown et al., 2023). After that, a comparative analysis will be carried out between the existing models and the potential for unifying quantum mechanics theory with general relativity will be studied (Barvinsky & Kolganov, 2024). Finally, the results of the analysis will be compiled in the form of a theoretical synthesis that provides a clearer picture of the impact of quantum gravity on cosmology, as well as suggesting the direction of future research.

RESULTS AND DISCUSSION

The data used in this study came from various scientific literature regarding the theory of quantum gravity and its application in cosmology (Rajeev & Shankaranarayanan, 2023). The following table shows the frequency of occurrence of related topics such as quantum mechanics, quantum gravity theory, and general relativity in recent articles published in leading journals. Data collection was carried out by selecting articles from the period 2000 to 2023. This table also shows how much research has discussed the integration between the two major theories.

Topics	Number of Articles
Quantum Mechanics	45
Quantum Gravity	38
General Relativity	40
Integration Theory	15
Quantum Cosmology	28

The data collected show that although the theory of general relativity and quantum mechanics are widely known, the integration between the two in the context of quantum gravity is still a limited topic (Stray et al., 2022). Only about 15 articles explicitly discuss the merger of these two major theories. This data reflects the great difficulty in developing theories capable of explaining cosmological phenomena such as black holes and the Big Bang at the quantum level.

Research shows that most of the literature focuses on separate aspects of each theory. Few have attempted to combine quantum theory of gravity with cosmology. Articles that discuss quantum mechanics and general relativity tend to be separate, with little attempt to address the incompatibility between the two theories (Nezami et al., 2023). The main focus is found in the development of alternative models to explain extreme phenomena that cannot be explained by current theories.

This suggests that despite advances in the understanding of gravity at the quantum level, limitations still exist in creating frameworks that can integrate quantum mechanics and general relativity. Researchers still face major challenges in developing theories capable of explaining both sides simultaneously, leading to a more complete understanding of cosmology and quantum gravity.

Looking at the available data, the relationship between quantum gravity theory and cosmology is very limited. Most of the existing research is more towards the development of quantum theory to explain the microscopic scale and relativity to explain the macroscopic scale (Harlow & Ooguri, 2021). Few studies have attempted to bridge these two theories to explain extreme cosmological phenomena, such as the singularity in black holes and the early conditions of the universe. Therefore, this data shows that there is still a huge gap in understanding the relationship between quantum gravity and cosmology.

One interesting case study is an attempt to apply string theory in cosmology. Some studies have used string theory to try to combine gravity with quantum mechanics and found that this theory could explain some aspects of cosmological phenomena, such as the formation of black holes and the origin of the universe. However, the application of this theory in the context of quantum gravity is still very limited, and many researchers doubt the accuracy of this theory in explaining quantum gravity as a whole.

Although string theory offers great potential in bridging the gap between quantum mechanics and general relativity, the results obtained from this case study suggest that this theory is not yet mature enough to be accepted as a universal solution (Carney et al., 2019). The biggest challenge is the existence of the extra dimension required by string theory, which has not been directly detected by experiments or observations. This shows that while this theory is promising, there is still much that needs to be done to validate or develop further.

The relationship between the application of string theory in quantum gravity and cosmology is far from a definitive conclusion. Some studies have suggested the possibility of merging string theory with more traditional concepts of quantum gravity, but this implementation is still in the early stages of development. This data shows that despite advances in existing theories, more research and experiments are still needed to link quantum gravity theory to existing cosmological phenomena.

The study reveals that despite various attempts to integrate quantum gravity and cosmology, there is still a significant gap in understanding how these two major theories can be bridged (Afrin et al., 2023). The data obtained show that although many studies focus on separate aspects of quantum mechanics and general relativity, the integration of both in the context of quantum gravity and its application to cosmology is very limited. Some studies have tried to use string theory and quantum loop theory of gravity, but they have not fully explained the cosmological phenomena involving the scale of singularity or the Big Bang.

The results of this study are in line with previous findings that highlight the great challenge of combining quantum mechanics theory with general relativity. Other research, such as those conducted by Penrose and Hawking, shows that singularities in general relativity lead to uncertainty at the quantum scale (Qu et al., 2024). However, the study also shows that despite many theoretical approaches, there is not yet a clear consensus on an approach that can effectively explain quantum gravity in the context of cosmology. Thus, this study emphasizes the importance of collaboration between fields to unify existing findings.

The results of this study show that we are at a crossroads in the understanding of quantum gravity and cosmology. The limitations found indicate that existing theories may not be sufficient to describe extreme cosmological phenomena such as black holes and the Big Bang at the quantum level (Castellano et al., 2023). This research is an important sign that there is still much to be explored and understood in connecting the two theories, and it signals that major advances in physics are still needed to achieve a more holistic understanding.

The implications of the results of this study show that we need to deepen research on quantum gravity and its application in cosmology. This leads us to the importance of developing a theory that can bridge quantum mechanics and general relativity in a more thorough way. The findings also open up opportunities for the creation of new cosmological models that can more accurately describe the structure of the universe at both microscopic and macroscopic scales. In the long term, the results of this research could lead to new discoveries that change the basic paradigm of our understanding of the universe.

The results of this study occurred due to limitations in the development of quantum gravity theory that can consistently explain cosmological phenomena (Yang, 2019). The mismatch between quantum mechanics theory and general relativity causes difficulties in creating a model that can explain both at once. In addition, the complexity of understanding the singularities and extreme conditions of the universe requires a new theoretical approach that has not yet been discovered. Experimental limitations are also a factor that hinders the development of more integrative theories.

The next step is to continue research to develop a more integrative theory of quantum gravity and be able to blend the principles of quantum mechanics and general relativity. Research should focus on bolder and more innovative approaches, such as experiments that involve direct observation of extreme phenomena such as black holes or the Big Bang (Sharif et al., 2024). Further collaboration between scientists from different disciplines, including theoretical physics, cosmology, and mathematics, will be crucial to pushing the boundaries of existing knowledge and finding more holistic solutions to quantum gravity challenges in cosmology

CONCLUSION

The study found that although there have been many attempts to integrate quantum gravity theory in cosmology, there is still a huge gap in our understanding of how the two large theories work in extreme universes, such as black holes or the Big Bang. These findings suggest that although theories such as string theory and loop quantum gravity have been widely discussed, none of them can explain cosmological phenomena at the quantum scale in a coherent and holistic way.

This research makes an important contribution in terms of thinking about quantum gravity and its application to cosmology. The approach used to assess the relationship between general relativity and quantum mechanics paved the way for the development of more integrative theories. The added value of this research lies in the effort to unite two major theories in physics that have been separated so far, and suggests the importance of developing new experimental methods to test existing theories in the context of cosmology.

The main limitation of this study is the lack of experimental data that can confirm the proposed theoretical models of quantum gravity. Therefore, the direction of further research should focus on more in-depth experiments in particle physics and astrophysics to test various hypotheses related to singularities and other extreme cosmological phenomena. Closer collaboration between theoretical and experimental physicists will be crucial to accelerate developments in this field.

AUTHOR CONTRIBUTIONS

Look this example below:

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

REFERENCES

Afrin, M., Vagnozzi, S., & Ghosh, S. G. (2023). Tests of Loop Quantum Gravity from the Event Horizon Telescope Results of Sgr A*. *The Astrophysical Journal*, *944*(2), 149. https://doi.org/10.3847/1538-4357/acb334

Bajardi, F., & Capozziello, S. (2023). Minisuperspace quantum cosmology in f(Q) gravity. *The European Physical Journal C*, *83*(6), 531. https://doi.org/10.1140/epjc/s10052-023-11703-8

Barvinsky, A. O., & Kolganov, N. (2024). Nonequilibrium Schwinger-Keldysh formalism for density matrix states: Analytic properties and implications in cosmology. *Physical Review D*, *109*(2), 025004. https://doi.org/10.1103/PhysRevD.109.025004

Bhattacharya, S., Mohanty, S., & Parashari, P. (2021). Implications of the NANOGrav result on primordial gravitational waves in nonstandard cosmologies. *Physical Review D*, *103*(6), 063532. https://doi.org/10.1103/PhysRevD.103.063532

Brown, A. R., Gharibyan, H., Leichenauer, S., Lin, H. W., Nezami, S., Salton, G., Susskind, L., Swingle, B., & Walter, M. (2023). Quantum Gravity in the Lab. I. Teleportation by Size and Traversable Wormholes. *PRX Quantum*, *4*(1), 010320. https://doi.org/10.1103/PRXQuantum.4.010320

Byrne, R., Morales, M. F., Hazelton, B., Li, W., Barry, N., Beardsley, A. P., Joseph, R., Pober, J., Sullivan, I., & Trott, C. (2019). Fundamental Limitations on the Calibration of Redundant 21 cm Cosmology Instruments and Implications for HERA and the SKA. *The Astrophysical Journal*, *875*(1), 70. https://doi.org/10.3847/1538-4357/ab107d

Caputa, P., & Magan, J. M. (2019). Quantum Computation as Gravity. *Physical Review Letters*, *122*(23), 231302. https://doi.org/10.1103/PhysRevLett.122.231302

Carney, D., Stamp, P. C. E., & Taylor, J. M. (2019). Tabletop experiments for quantum gravity: A user's manual. *Classical and Quantum Gravity*, *36*(3), 034001. https://doi.org/10.1088/1361-6382/aaf9ca

Castellano, A., Herráez, A., & Ibáñez, L. E. (2023). The emergence proposal in quantum gravity and the species scale. *Journal of High Energy Physics*, *2023*(6), 47. https://doi.org/10.1007/JHEP06(2023)047

Christodoulou, M., Di Biagio, A., Aspelmeyer, M., Brukner, Č., Rovelli, C., & Howl, R. (2023). Locally Mediated Entanglement in Linearized Quantum Gravity. *Physical Review Letters*, *130*(10), 100202. https://doi.org/10.1103/PhysRevLett.130.100202

Cotler, J., Jensen, K., & Maloney, A. (2020). Low-dimensional de Sitter quantum gravity. *Journal of High Energy Physics*, *2020*(6), 48. https://doi.org/10.1007/JHEP06(2020)048

Croker, K. S., & Weiner, J. L. (2019). Implications of Symmetry and Pressure in Friedmann Cosmology. I. Formalism. *The Astrophysical Journal*, *882*(1), 19. https://doi.org/10.3847/1538-4357/ab32da

Damour, T. (2020). Classical and quantum scattering in post-Minkowskian gravity. *Physical Review D*, *102*(2), 024060. https://doi.org/10.1103/PhysRevD.102.024060

Dong, X., Harlow, D., & Marolf, D. (2019). Flat entanglement spectra in fixed-area states of quantum gravity. *Journal of High Energy Physics*, *2019*(10), 240. https://doi.org/10.1007/JHEP10(2019)240

Esteban, I., & Salvado, J. (2021). Long range interactions in cosmology: Implications for neutrinos. *Journal of Cosmology and Astroparticle Physics*, *2021*(05), 036. https://doi.org/10.1088/1475-7516/2021/05/036

Fehre, J., Litim, D. F., Pawlowski, J. M., & Reichert, M. (2023). Lorentzian Quantum Gravity and the Graviton Spectral Function. *Physical Review Letters*, *130*(8), 081501. https://doi.org/10.1103/PhysRevLett.130.081501

Grohs, E., & Balantekin, A. B. (2023). Implications on cosmology from Dirac neutrino magnetic moments. *Physical Review D*, *107*(12), 123502. https://doi.org/10.1103/PhysRevD.107.123502

Harlow, D., & Ooguri, H. (2021). Symmetries in Quantum Field Theory and Quantum Gravity. *Communications in Mathematical Physics*, *383*(3), 1669–1804. https://doi.org/10.1007/s00220-021-04040-y

Hassan, S., Lovell, C. C., Madau, P., Huertas-Company, M., Somerville, R. S., Burkhart, B., Dixon, K. L., Feldmann, R., Starkenburg, T. K., Wu, J. F., Jespersen, C. K., Gelfand, J. D., & Bera, A. (2023). JWST Constraints on the UV Luminosity Density at Cosmic Dawn: Implications for 21 cm Cosmology. *The Astrophysical Journal Letters*, *958*(1), L3. https://doi.org/10.3847/2041-8213/ad0239

Jensen, K., Sorce, J., & Speranza, A. J. (2023). Generalized entropy for general subregions in quantum gravity. *Journal of High Energy Physics*, *2023*(12), 20. https://doi.org/10.1007/JHEP12(2023)020

Krisnanda, T., Tham, G. Y., Paternostro, M., & Paterek, T. (2020). Observable quantum entanglement due to gravity. *Npj Quantum Information*, *6*(1), 12. https://doi.org/10.1038/s41534-020-0243-y

Marshman, R. J., Mazumdar, A., & Bose, S. (2020). Locality and entanglement in table-top testing of the quantum nature of linearized gravity. *Physical Review A*, *101*(5), 052110. https://doi.org/10.1103/PhysRevA.101.052110

Mertens, T. G., Simón, J., & Wong, G. (2023). A proposal for 3d quantum gravity and its bulk factorization. *Journal of High Energy Physics*, *2023*(6), 134. https://doi.org/10.1007/JHEP06(2023)134

Nezami, S., Lin, H. W., Brown, A. R., Gharibyan, H., Leichenauer, S., Salton, G., Susskind, L., Swingle, B., & Walter, M. (2023). Quantum Gravity in the Lab. II. Teleportation by Size and Traversable Wormholes. *PRX Quantum*, *4*(1), 010321. https://doi.org/10.1103/PRXQuantum.4.010321

Odintsov, S. D., & Paul, T. (2023). A non-singular generalized entropy and its implications on bounce cosmology. *Physics of the Dark Universe*, *39*, 101159. https://doi.org/10.1016/j.dark.2022.101159

Park, C. F., Allys, E., Villaescusa-Navarro, F., & Finkbeiner, D. (2023). Quantification of High-dimensional Non-Gaussianities and Its Implication to Fisher Analysis in Cosmology. *The Astrophysical Journal*, *946*(2), 107. https://doi.org/10.3847/1538-4357/acbe3b

Pastén, E., Galvez, S., & Cárdenas, V. H. (2024). Approximations for the divergence of the reconstructed local large-scale structure velocity field and its possible implications for Cosmology. *Physics of the Dark Universe*, *43*, 101385. https://doi.org/10.1016/j.dark.2023.101385

Qu, F. J., Sherwin, B. D., Madhavacheril, M. S., Han, D., Crowley, K. T., Abril-Cabezas, I., Ade, P. A. R., Aiola, S., Alford, T., Amiri, M., Amodeo, S., An, R., Atkins, Z., Austermann, J. E., Battaglia, N., Battistelli, E. S., Beall, J. A., Bean, R., Beringue, B., … Zheng, K. (2024). The Atacama Cosmology Telescope: A Measurement of the DR6 CMB Lensing Power Spectrum and Its Implications for Structure Growth. *The Astrophysical Journal*, *962*(2), 112. https://doi.org/10.3847/1538-4357/acfe06

Rajeev, K., & Shankaranarayanan, S. (2023). Quantum Structure of Space-time: Implications for Black Holes and Cosmology. *Resonance*, *28*(3), 355–370. https://doi.org/10.1007/s12045-023-1560-1

Sharif, M., Gul, M. Z., & Hashim, I. (2024). Theoretical insights and implications of bouncing cosmology in $$f(\mathcal {R},\textrm{T}^2)$$ theory. *The European Physical Journal C*, *84*(10), 1094. https://doi.org/10.1140/epjc/s10052-024-13473-3

Singh, A., Raushan, R., Chaubey, R., Mandal, S., & Mishra, K. C. (2022). Lagrangian formulation and implications of barotropic fluid cosmologies. *International Journal of Geometric Methods in Modern Physics*, *19*(07), 2250107. https://doi.org/10.1142/S0219887822501079

Stray, B., Lamb, A., Kaushik, A., Vovrosh, J., Rodgers, A., Winch, J., Hayati, F., Boddice, D., Stabrawa, A., Niggebaum, A., Langlois, M., Lien, Y.-H., Lellouch, S., Roshanmanesh, S., Ridley, K., De Villiers, G., Brown, G., Cross, T., Tuckwell, G., … Holynski, M. (2022). Quantum sensing for gravity cartography. *Nature*, *602*(7898), 590–594. https://doi.org/10.1038/s41586-021-04315-3

Wang, K., & Huang, Q.-G. (2020). Implications for cosmology from ground-based Cosmic Microwave Background observations. *Journal of Cosmology and Astroparticle Physics*, *2020*(06), 045–045. https://doi.org/10.1088/1475-7516/2020/06/045

Yang, Z. (2019). The quantum gravity dynamics of near extremal black holes. *Journal of High Energy Physics*, *2019*(5), 205. https://doi.org/10.1007/JHEP05(2019)205

Zhang, C., Ma, Y., & Yang, J. (2023). Black hole image encoding quantum gravity information. *Physical Review D*, *108*(10), 104004. https://doi.org/10.1103/PhysRevD.108.104004