An Investigation on Quantum Decoherence as a Cause of Emergent Gravitational Effects

- CERN Beamline For Schools Proposal by the **Bohrderline Deco-heros**

Yuvraj Arora, Daksh Arora, Soham Arun Kashyap, Keyur Kumar, and Aditya Singla

1 Motivation

Galactic Rotation Curves have long evaded all explanations and predictions based on Newtonian and relativistic gravitational models. Commonly, this evasion has been attributed to dark matter, one of our vast universe's most enigmatic elements, making up about eighty-five per cent of the mass in our universe. Dark Matter interacts gravitationally but has not been able to be found using direct detection techniques.[1]
However, a relatively new line of research suggests that modifications to gravitational laws caused by quantum effects may account for these anomalies without the requirement of any additional matter.[2]
Members of our team have plenty of previously conducted research on Verlinde's Emergent Gravity model, Quantum Coherence and Decoherence, and the role of Quantum Fluctuations in macroscopic phenomena in the form of independent research papers. These investigations have allowed us to hypothesize that quantum decoherence effects could be a crucial player in the emergence of gravitational behavior.
Precisely, we suggest that quantum information loss due to decoherence may, in fact, contribute to digressions from classical gravitational models, acting as a potential alternative to dark matter. The experiment proposed by *Bohrderline Deco-heros* aims to study the impact of decoherence on energy distributions in a well-controlled high-energy beamline environment.
We will now be extensively discussing the theoretical validity of our hypothesis.

2 Theoretical Background

Quantum Decoherence occurs when a quantum system interacts with its surroundings and loses its quantum behavior. The process leads to a more classical behavior and causes the loss of the system's quantum superposition and entanglement qualities (*Figure 1*).[3]

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[1] White, Martin. "Rotation Curves." *W.astro.berkeley.edu*, w.astro.berkeley.edu/~mwhite/darkmatter/rotcurve.html. Accessed 3 Apr. 2025.

[2] Verlinde, Erik. "On the Origin of Gravity and the Laws of Newton." *Journal of High Energy Physics*, vol. 2011, no. 4, Apr. 2011, https://doi.org/10.1007/jhep04(2011)029.

[3] "Quantum Decoherence - Quantum Computing Explained." *Quandela*, 16 Oct. 2024, www.quandela.com/resources/quantum-computing-glossary/quantum-decoherence/. Accessed 3 Apr. 2025.

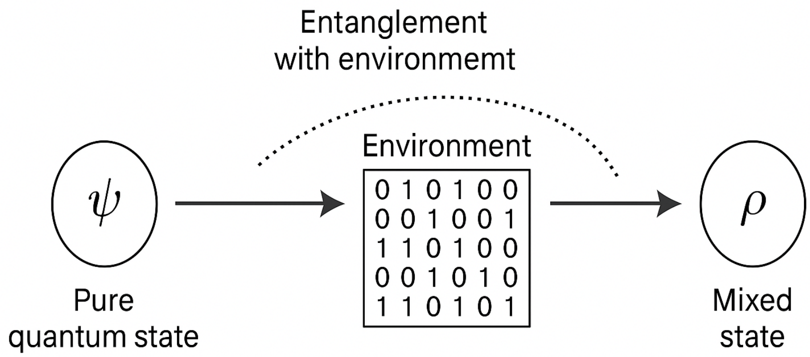

Figure 1 A conceptual illustration of how quantum decoherence—through interaction with the environment—leads to the emergence of classicality and may underlie gravitational phenomena previously attributed to dark matter.

Verlinde's Emergent Gravity theory views gravity as a large-scale expression of underlying microscopic degrees of freedom, similar to how temperature arises from the collective motion of molecules in thermodynamics. Instead of considering spacetime as a rigid background where particles move, emergent gravity suggests that spacetime originates from more fundamental components, where gravitational fields and curvature are products of a deeper quantum structure that is only apparent at macroscopic scales.[4]

From a quantum information theoretic perspective, gravity emerges as a way to explain how matter changes entanglement. The best way to comprehend these new concepts is in Anti-de Sitter space, where the microscopic entanglement can be calculated in a precise environment thanks to the description in terms of a dual conformal field theory.[5]

If quantum decoherence affects the fabric of space-time, then quantum decoherence could bring changes to gravitational equations accounting for galactic rotation anomalies without invoking dark matter.

In our experiment, we aim to determine whether quantum decoherence may produce observable changes in energy distributions. This will allow us to determine whether the same phenomenon can be observed on cosmic scales, providing a different explanation for gravitational effects akin to those of dark matter.

3 Proposed Experiment

3.1 Objective

Simply put, our proposed experiment's goal is to investigate whether the loss of coherence in a quantum system brings about measurable changes in energy distribution, possibly mimicking dark matter-like effects. If successful, this could provide experimental evidence to support alternate gravity theories, such as Verlinde's Emergent Gravity Model.

[4] Vonk, Marcel. "Emergent Gravity and the Dark Universe | the Quantum Universe." *The Quantum Universe*, 17 Nov. 2016, www.quantumuniverse.nl/emergent-gravity-and-the-dark-universe. Accessed 3 Apr. 2025.

[5] Verlinde, Erik. "Emergent Gravity and the Dark Universe." *SciPost Physics*, vol. 2, no. 3, May 2017, https://doi.org/10.21468/scipostphys.2.3.016. Accessed 3 Apr. 2025.

3.2 Experimental Design

Our proposed experiment will follow a multi-phased procedure using a high energy particle beamline (CERN PS East Area T9/T10 / DESY II Test Beam Facility) which will help us analyze the effects of quantum decoherence on scattering behaviour of particles in different materials.

Stage 1: Material Selection and Coherence Characterization

We aim to characterize each material into two main categories: high coherence and low coherence, precisely done with the use of Raman Spectroscopy (photon interactions, coherence length)[6], LTSTM (quantum stats)[7], and SQID (coherence properties)[8].

Stage 2: Beamline Experimentation and Decoherence Manipulation

We propose the direction of a high energy particle beam at each material under different quantum coherence conditions. To ensure a seamless experiment, we will use electrons or muons since there is pre-existing information on their interactions with quantum materials and vary the beam energy between 50 MeV and 5 GeV. We will maintain appropriate temperatures for each material depending on their varying properties and ensure that they are kept in a vacuum to avoid the influence of erroneous factors on our research. The effects of the perturbations will be analyzed in real-time and the decoherence will be manipulated by introducing electromagnetic noise, thermal fluctuations, and more (*Figure 2*).

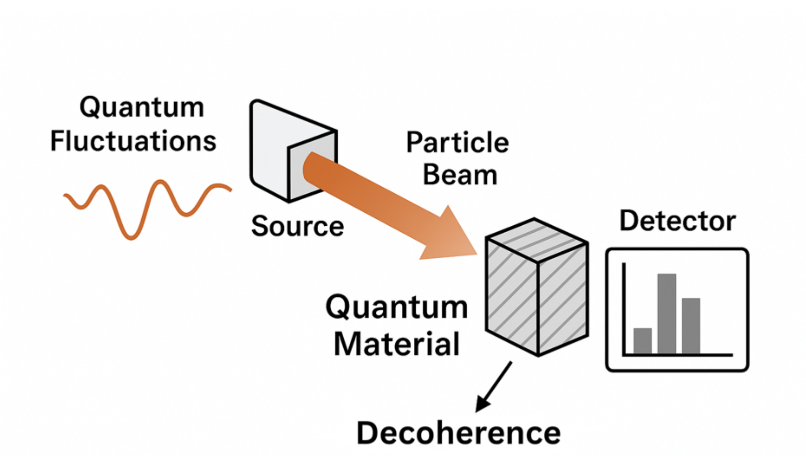

Figure 2 Schematic overview of the proposed experiment showing the particle beam interacting with decoherence-inducing materials and detection via calorimetry and photodetectors.

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[6] "18.1: Theory of Raman Spectroscopy." *Chemistry LibreTexts*, 11 Jan. 2017, chem.libretexts.org/Under_Construction/Purgatory/Principles_of_Instrumental_Analysis_(Skoog_et_al.)_-_Under_Construction/18%3A_Raman_Spectroscopy/18.01%3A_Theory_of_Raman_Spectroscopy. Accessed 3 Apr. 2025.

[7] "Home - Scienta Omicron." *Scientaomicron.com*, 2025, scientaomicron.com/en/technology/LT%20STM/101. Accessed 3 Apr. 2025.

[8] Kraft, Aaron, et al. "Superconducting Quantum Interference Device (SQUID)." *UBC PHYSICS*, vol. 502, 2017, p. 1, phas.ubc.ca/~berciu/TEACHING/PHYS502/PROJECTS/17SQUID.pdf.

Stage 3: Data Collection and Analysis

We will make the use of colorimeters and time-of-flight detectors to detect any unexpected energy losses or redistribution patterns and to measure the momentum transfer of scattered particles respectively, while Mach-Zehnder Interferometry would be used to verify whether decoherence causes a shift in interference patterns. In case quantum decoherence causes changes in energy-momentum conservation, we'll compare our experiment's results to those predicted by Verlinde's Emergent Gravity model. To validate our experiment, we'll conduct identical tests as control experiments to have an established baseline with the use of classical materials. We aim to conduct each test more than one hundred times to ensure that our results are statistically robust. Lastly, we'll employ MCMC simulations[9] for validation of our experimental results.

4 Expected Impact

This experiment would bring about changes across multiple disciplines; it may enhance our understanding of quantum coherence and decoherence – two crucial factors which affect quantum computing, while also helping advance material sciences by identifying materials that can withstand extreme conditions, thereby leading to better quantum technologies. Moreover, insights into decoherence may also improve neuromorphic computing which would have a direct impact on brain-machine interfaces. Additionally, it could redefine our approach towards cosmic structure formation and galaxy dynamics by challenging the dark matter paradigm.

5 Conclusion

This experiment aims to bridge the gap between quantum mechanics and gravitational physics by exploring the effects of quantum decoherence and whether they can mimic those of dark matter. Given that there is yet to be any substantive experimental evidence of dark matter, we must explore alternative options. With the use of the CERN beamline, we aim to provide data which could very well redefine our understanding of the fundamental forces that shape our universe, positively affect multiple disciplines, and much more. Due to the word limit, all citations are present as footnotes.

6 Educational Outreach Activity

As an extension to Universe to Us – Yuvraj Arora and Daksh Arora's educational organization with the goal of teaching fundamental Physics concepts to underprivileged Indian students – we will, with the use of this project's insights and simplify it into fun activities, stories, and more. These creative pieces will be used to instill a sense of inspiration and curiosity amongst the target audience, helping the organization truly realize it's goal. Moreover, if possible, if selected, we will make sure to stream our experiment live to our students, with an on-field coordinator explaining the ins and outs it.

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[9] "Markov Chain Monte Carlo | Columbia Public Health." *Www.publichealth.columbia.edu*, www.publichealth.columbia.edu/research/population-health-methods/markov-chain-monte-carlo. Accessed 3 Apr. 2025.