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Quantum Uncertainty and Superposition under the Influence of Gravity

Investigating quantum mechanical principles within the context of gravity reveals significant insights into how spacetime curvature fundamentally influences quantum phenomena, particularly regarding the uncertainty principle and quantum coherence. This study presents a covariant Generalized Uncertainty Principle (GUP) that incorporates curvature-induced modifications to canonical commutation relations, resulting in non-commutative position operators. Adopting a geometric formalism, we establish a connection between the uncertainty principle and momentum space geometry, which is modeled as a four-dimensional extension of Lobachevsky space, where the Riemann curvature is dictated by modified dispersion relations. Additionally, we analyze gravitational decoherence as driven by the Riemann curvature tensor, demonstrating its consistent role in diminishing quantum coherence within gravitational fields. In contrast to kinematic effects, curvature-induced decoherence persistently disrupts quantum superpositions, thereby providing a direct relationship between the structure of spacetime and the behavior of quantum systems.

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