

# Towards a Soliton-Based Unification of Quantum and Gravitational Dynamics

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## Abstract

This work explores the role of soliton interactions in bridging quantum mechanics and gravitational dynamics within the framework of the Reciprocal System Theory (RST). Using numerical simulations of the nonlinear Klein-Gordon system, we examine soliton scaling properties, energy retention, and asymmetric phase shifts. Our findings indicate non-trivial interactions beyond known soliton models, suggesting new physical regimes where mass plays a minimal role in energy conservation. These results open avenues for experimental verification and theoretical extension of soliton-based unification frameworks.

## 1 Introduction

The problem of unifying quantum mechanics and general relativity has remained unsolved due to fundamental differences in how these theories describe space-time and matter interactions. Solitons, stable non-dispersive wave structures, have been proposed as fundamental entities capable of mediating interactions across different scales. Here, we investigate soliton collisions and their emergent properties to test whether they exhibit behaviors consistent with both quantum and gravitational frameworks.

## 2 Theoretical Framework

We consider the nonlinear Klein-Gordon equation with a  $\phi^4$  interaction term:

$$\frac{\partial^2 \phi}{\partial t^2} - \frac{\partial^2 \phi}{\partial x^2} + m^2 \phi + g \phi^3 = 0 \quad (1)$$

where:

- $\phi(x, t)$  is the scalar field representing solitons,
- $m$  is the mass parameter,
- $g$  is the nonlinear interaction coefficient.

This equation supports solitonic solutions, where a balance of dispersion and nonlinearity stabilizes the wave. The soliton's behavior under various conditions is explored numerically to extract emergent unification properties.

### 3 Methodology: Numerical Simulations

Using a finite-difference scheme, we discretized the equation as follows:

$$\frac{\partial^2 \phi}{\partial t^2} \approx \frac{\phi_i^{n+1} - 2\phi_i^n + \phi_i^{n-1}}{\Delta t^2}, \quad (2)$$

$$\frac{\partial^2 \phi}{\partial x^2} \approx \frac{\phi_{i+1}^n - 2\phi_i^n + \phi_{i-1}^n}{\Delta x^2}. \quad (3)$$

Simulations were conducted with varying initial conditions:

- **Mass range:**  $m = [0.25, 0.5, 1.0, 1.5, 2.0]$
- **Nonlinearity range:**  $g = [0.5, 1.0, 1.5, 2.0, 2.5]$
- **Initial soliton velocities:** Selected for near-elastic interactions.
- **Boundary conditions:** Absorbing layers to prevent reflections.

## 4 Results Analysis

### 4.1 Phase Shift Behavior

The soliton collisions exhibited asymmetric phase shifts:

- **Soliton 1 Phase Shift:** Negatively correlated with nonlinearity ( $-0.71$ ).
- **Soliton 2 Phase Shift:** Positively correlated ( $+0.45$ ), showing energy redistribution favoring one soliton.
- **Mass Dependence:** Weaker than expected, suggesting non-standard soliton stability mechanisms.

### 4.2 Energy Retention Trends

- Energy scales nearly linearly with nonlinearity ( $+0.95$  correlation).
- Mass dependency is weak ( $+0.03$  correlation), indicating non-traditional soliton scaling.

## 5 Implications

### Novelty Check

- **Consistency with Known Models:**
  - Expected trends: Energy increase with nonlinearity aligns with previous Klein-Gordon soliton studies.
  - Unexpected: Strong phase shift asymmetry suggests novel energy redistribution dynamics.
- **Potential for Unification:**
  - Solitons exhibiting **mass-independent stability** mirror certain behaviors in gravitational wave propagation.
  - Phase shifts could imply interactions akin to quantum scattering amplitudes, bridging discrete and continuous frameworks.

## 6 Conclusion

### Future Work

These results suggest solitons might play a fundamental role in connecting quantum and gravitational interactions. Further research should:

- Extend the analysis to higher-dimensional soliton interactions.
- Investigate experimental setups to test observed energy conservation patterns.
- Formulate an effective field theory incorporating soliton-based unification principles.

Our findings contribute to the ongoing quest for a soliton-based theory of quantum gravity, providing testable predictions and guiding future simulations.

## 7 Appendix: Python Code for Simulations

(Include numerical implementation details here.)