Predictive Phenomenology of Toroidal Solitons

Dynamical, Geometric, and Spectral Signatures of the Motion-Based Field Theory

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December 2025

Abstract

This ninth document establishes the predictive content of the unified motion-based theory developed in Documents 1–8. While earlier works formulated the ontology, field-theoretic dynamics, numerical construction, physical anchoring, and coupling to GR and QFT, this document identifies a set of *unique, falsifiable, and quantitatively specific predictions* that distinguish the toroidal solitons of this theory from standard Q-balls, vortons, or generic nonlinear scalar-field configurations. We detail predictions in geometry, dynamics, scattering, radiation, and spectral structure, providing a phenomenological roadmap for numerical, experimental, or cosmological tests.

1 Introduction

The unified theory of motion produces stable toroidal solitons with fixed geometry and variable internal motion. This structure is in itself predictive and distinguishes the model from generic scalar-field theories.

This document identifies the most robust predictions:

1. geometric invariants independent of Q;
2. universal scaling with winding number n;
3. unique scattering phenomenology between two tori;
4. characteristic vibrational spectra;

5. quantized decay channels and selection rules;
6. distinct gravitational signatures;
7. stability and interaction rules in curved spacetime.

These form the core phenomenological fingerprint of the theory.

2 Prediction 1: Geometry Independent of Q

The toroidal soliton maintains fixed radii

$$(R_{\text{in}}, R_{\text{out}}, R_c, a)$$

independent of the conserved charge Q.

This is unlike:

- standard Q-balls (radius grows with Q);
- vortons (geometry depends on angular momentum);
- oscillons (geometry unstable and time-dependent).

Thus the measurement of a *fixed geometric scale* under increasing internal energy is a discriminating signature.

3 Prediction 2: Scaling with Winding Number n

The phase gradient is

$$\nabla\theta = \frac{n}{R_c}\,\hat{\varphi},$$

implying:

$$R_c(n) \propto n, \qquad a(n) \approx \text{constant}.$$

Thus:

- the major radius scales linearly with n;
- the minor radius is nearly n-independent;
- energy scales as $E(n) \approx n^2 E(1)$ for fixed Q/n.

This combination of scalings is unique to the motion-based model.

4 Prediction 3: Soliton–Soliton Scattering

Two toroidal solitons interact via their phase flow fields.

There exist three regimes:

(i) Elastic deflection. For large impact parameters:

$$b \gg R_c,$$

the solitons behave as repulsive gyroscopic particles, with scattering angle

$$\Theta_{\rm scatt} \propto \frac{n_1 n_2}{b^2}.$$

(ii) Bound states. For intermediate b, the solitons can form a stable "binary torus" configuration with locked phases:

$$\theta_1 - \theta_2 = \text{constant}.$$

(iii) Fusion. For head-on collisions:

$$b \lesssim a,$$

the two rings merge into a single torus with charge

$$Q_{\rm final} = Q_1 + Q_2,$$

preserving the geometric invariants.

This behaviour is fundamentally different from Q-ball scattering, where fusion typically leads to growth of the radius.

5 Prediction 4: Spectral Structure of Vibrational Modes

Linear stability implies a discrete set of oscillation modes:

$$\Omega_k^2 > 0.$$

The key prediction is the presence of:

- a *breathing mode* at frequency $\Omega_{\rm br} \sim \mathcal{O}(m)$;
- an n-dependent *torsional mode* with $\Omega_{\rm tors} \propto n/R_c$;
- azimuthal harmonic modes with quantized wavenumber k around the ring.

The spectral structure is determined by the geometry and therefore provides a direct test of the predicted invariants.

6 Prediction 5: Selection Rules and Decay Channels

Because the soliton is a closed loop of organized motion, decay channels obey conservation of:

- global charge Q,
- winding number n,
- topological flow orientation.

Thus a torus can decay only as:

$$(Q, n) \to (Q_1, n) \ + \ (Q_2, 0),$$

i.e. a torus plus a spherical Q-ball, or into two smaller tori:

$$(Q, n) \to (Q_1, n_1) \ + \ (Q_2, n_2)$$

with

$$n = n_1 + n_2.$$

These decay rules are *absent* in ordinary Q-ball physics.

7 Prediction 6: Gravitational Signatures

For sufficiently large Q, the torus produces:

- a ring-shaped mass distribution;
- gravitational lensing with characteristic central brightening;
- anisotropic gravitational waves during collisions or mergers;
- redshifted internal frequency ω in strong fields.

These signatures differ from those of boson stars (spherical) and vortons (centrally hollow but R_c grows with Q).

8 Prediction 7: Curved-Space Stability Rules

In GR, the torus remains stable provided

$$a \ll R_{\mathrm{curv}}, \qquad \omega_{\mathrm{local}} = \frac{\omega}{\sqrt{-g_{tt}}}.$$

This predicts frequency shifts and possible instability bands near black-hole horizons or regions of rapidly varying curvature.

Such behaviour is not present in standard Q-ball or oscillon models.

9 Conclusion

This document identifies a set of precise, falsifiable predictions of the unified motion-based theory. The geometric invariants, scaling relations with n, scattering patterns, vibrational spectra, decay selection rules, and gravitational signatures form a complete phenomenological fingerprint. They provide the basis for future numerical tests, potential condensed- matter analogues, or cosmological applications.