Electromagnetic Phenomenology of Toroidal Solitons

Scattering, Waveguiding, Plasma Interaction, and Observable EM Signatures

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Abstract

This twelfth document establishes the electromagnetic (EM) and radiative phenomenology of the toroidal solitons introduced in the unified motion- based theory (Documents 1–11). While the solitons were originally formulated without gauge fields, their ring-shaped energy density, internal flow, and geometric cavity induce strong and unique EM effects when photons, charged particles, or external fields interact with them. We analyze scattering, waveguiding, resonances, plasma coupling, polarization rotation, and observable signatures across laboratory, astrophysical, and cosmological regimes. The resulting EM phenomenology provides another layer of testability for the theory.

1 Introduction

The toroidal soliton is electrically neutral but interacts with electromagnetic fields through:

- its spatially varying energy density T_{00},

- its annular geometry,

- its internal phase flow $\nabla\theta$,

- its topologically protected cavity.

These features produce EM responses analogous to:

- dielectric ring waveguides,

- hollow plasma toroids,

- photonic traps,

- anisotropic refractive media.

But here these effects arise *without conventional matter*, purely from organized motion.

2   Prediction 1: Photon Scattering and Resonant Modes

Maxwell's equations in curved or effective media read:

$$\nabla_\mu F^{\mu\nu} = J^\nu_{\text{eff}},$$

where the effective current arises from spacetime curvature or polarization induced by the soliton's stress tensor.

The ring geometry produces:

- azimuthal resonant scattering at frequencies

$$\omega_k \approx \frac{k}{R_c}, \quad k \in \mathbb{Z},$$

- a photonic band gap inside the core,

- strong forward scattering for $\lambda \sim a$.

Photons circulating around the ring satisfy a quantization condition:

$$2\pi R_c \omega = 2\pi m, \qquad m \in \mathbb{Z},$$

yielding discrete allowed frequencies.

This creates a natural *toroidal waveguide.*

3   Prediction 2: Electromagnetic Trapping in the Cavity

Inside the hollow core (radius $R < R_c - a$), the effective refractive geometry allows long-lived confined modes.

The trapping condition follows from the effective potential

$$V_{\text{eff}}(R) = \frac{L^2}{2R^2} + \Phi_{\text{grav}}(R),$$

with a minimum at the cavity center.

Consequences:

- photons can orbit for many cycles,

- narrow spectral lines from trapped modes,

- partial transparency at specific incident angles.

This is a unique signature, as boson stars or Q-balls lack a stable inner cavity.

4 Prediction 3: Plasma Coupling and Toroidal Confinement

When embedded in ionized environments (accretion disks, cosmic plasma), the soliton acts as a magnetic bottle without magnetic fields.

A charged particle with energy E and impact parameter b experiences:

$$\ddot{\mathbf{x}} = -\nabla \Phi_{\text{eff}},$$

with Φ_{eff} derived from T_{00}.

This produces:

- charged-particle trapping along the ring,

- plasma torus formation around the soliton,

- enhanced synchrotron-like emission.

5 Prediction 4: Polarization Rotation and Birefringence

Because the stress-energy tensor is anisotropic:

$$T_{ij}(R, z, \varphi)$$

photons experience polarization-dependent propagation:

$$\Delta \phi \propto \int (T_{RR} - T_{\varphi\varphi}) \, dl.$$

This yields:

- rotation of linear polarization,

- birefringence for off-plane propagation,

- helicity-dependent phase shift.

This is not predicted in spherical scalar configurations.

6   Prediction 5: Electromagnetic Emission During Soliton Mergers

Soliton–soliton mergers (Document 9) produce:

- gravitational-wave bursts (Document 11),

- rapid deformation of the geometry,

- oscillatory internal flow reconfiguration.

Coupling to EM fields produces:

- broadband EM bursts,

- spectral peaks at the breathing and torsional frequencies,

- polarization chirps synchronized with the ringdown.

Such mixed GW/EM signals are an exceptional observational signature.

7   Prediction 6: EM Transparency Windows and Ring Shadow Patterns

The toroidal structure creates:

- alternating transparent and opaque angular sectors,

- a characteristic "toroidal shadow" in EM imaging,

- frequency-dependent shadow boundaries.

At high frequencies, light penetrates the cavity; at low frequencies, the core appears opaque and produces a double-lobed shadow.

This differs from black-hole shadows and from boson-star halos.

8 Prediction 7: Electromagnetic Signatures in Cosmology

If toroidal solitons formed in the early universe, they could imprint:

- ring-like anisotropies in the CMB,

- frequency-dependent distortions in background radiation,

- circular polarization correlations,

- lensing-induced ring multipoles in large-scale structure.

These effects are absent in spherical dark-matter models.

9 Conclusion

The toroidal solitons introduced in the unified motion-based theory possess a rich electromagnetic phenomenology, including resonant scattering, internal trapping, plasma confinement, birefringence, EM-GW correlated bursts, and characteristic shadow signatures. Together with their gravitational properties, these EM signatures offer multiple observational pathways for detecting such structures in laboratory settings, astrophysical environments, or cosmological data.