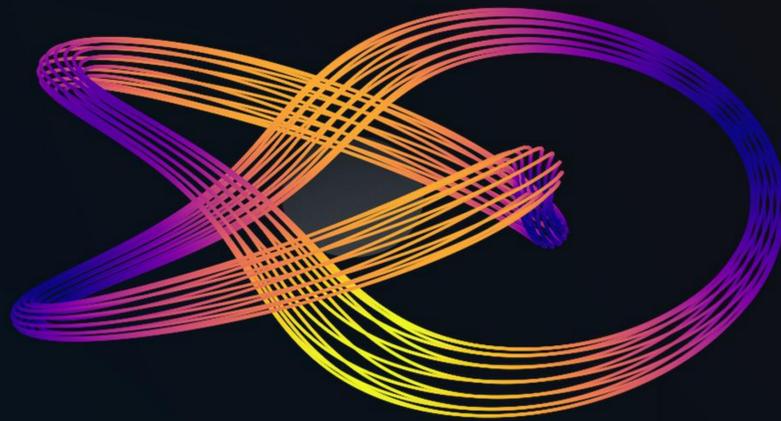


Electromagnetic Bound Field Configurations and the Emergence of Effective Rest Mass



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Field-first, conservative, Maxwell/GR-consistent

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space0.4cm eginabstract The origin of rest mass from fundamentally massless fields remains one of the most subtle conceptual gaps in modern theoretical physics. While electromagnetic radiation is traditionally treated as freely propagating and intrinsically massless, this description implicitly assumes unconstrained wave modes and neglects the possibility of persistent, dynamically confined field configurations. In this work, we introduce the concept of *Electromagnetic Bound Field Configurations (EBFCs)*—localized, non-radiative arrangements of electromagnetic fields characterized by sustained energy–momentum confinement and an associated effective invariant rest-mass component.

Crucially, the EBFC framework does not modify Maxwell’s equations, General Relativity, or the invariant speed of light. Instead, rest mass emerges as a consequence of energy–momentum redistribution under confinement, independent of photon number or discrete particle assumptions. We show that ordinary electromagnetic superposition fails to generate such configurations, identify the physical conditions required for confinement, and clarify the role of internal field structure—including helical features—as stabilizing rather than binding elements. The EBFC framework provides a conservative, falsifiable pathway for understanding how matter-like behavior may arise from classical electromagnetic fields without introducing new forces or speculative dynamics.

1 Introduction: Conceptual Gap and Motivation

Electromagnetic fields occupy a unique position in fundamental physics. They are fully described by Maxwell’s equations, propagate at an invariant speed, and carry energy and momentum without rest mass. Yet, the material world is dominated by objects whose defining property is precisely the possession of invariant rest mass.

Standard quantum field theory addresses this gap by postulating elementary massive fields or invoking symmetry-breaking mechanisms. While successful operationally, these approaches do not directly address a deeper structural question:

Can rest mass emerge from electromagnetic fields themselves without modifying their governing equations?

This paper explores that question within a strictly conservative framework. We do not alter known laws, introduce new interactions, or rely on speculative particle ontologies. Instead, we re-examine an often-overlooked assumption: that electromagnetic fields must always be describable as freely propagating wave modes.

We argue that this assumption is not logically required—and that its relaxation opens a physically consistent path toward emergent rest mass.

Internal context and related work. Several foundational aspects underlying the present framework have been developed independently in earlier works. In particular, relativistic energy–momentum accounting in photon interactions and the emergence of effective rest mass from momentum redistribution have been analyzed at the interaction level in Ref. [3]. The physical origin and invariance of the electromagnetic propagation speed, which remains unmodified in the present model, were clarified directly from Maxwellian dynamics in Ref. [1]. In addition, the geometric structure of electromagnetic fields, including the interpretation of rotational and helical field configurations without invoking curved photon trajectories or non-Maxwellian behavior, has been discussed in Ref. [2]. The present work builds on these results by elevating the analysis from interaction-level processes to fully localized electromagnetic field configurations, introducing Electromagnetic Bound Field Configurations (EBFCs) as a conservative and self-contained framework for the emergence of effective rest mass.

2 Limitations of photon-count-based descriptions

Descriptions of electromagnetic processes frequently rely on photon number as a book-keeping tool. While effective in scattering and emission contexts, photon counting becomes conceptually fragile when applied to strongly interacting or confined field systems.

Several limitations are immediately apparent:

- Photon number is not Lorentz invariant.

- Photon identity becomes ill-defined in overlapping or non-asymptotic field configurations.
- Energy–momentum conservation does not require discretization into countable quanta.

More importantly, rest mass is not defined by particle count, but by the invariant norm of the total energy–momentum four-vector [4, 5]. Any framework that treats photon number as fundamental risks obscuring this central fact.

The EBFC approach explicitly abandons photon counting as a foundational variable and replaces it with a field-level, energy–momentum-based description.

3 Definition of EBFC (conceptual + operational)

We define an *Electromagnetic Bound Field Configuration (EBFC)* as:

A localized electromagnetic field arrangement in which a portion of the total energy–momentum is dynamically confined, such that the configuration possesses a non-zero invariant rest-mass component, despite being governed entirely by Maxwellian dynamics.

3.1 Operational characteristics

An EBFC is characterized by:

- **Localization:** The field energy remains spatially confined over timescales far exceeding the natural propagation time.
- **Non-radiative dominance:** The configuration is not describable as a superposition of outgoing free-wave modes.
- **Invariant mass:** The total four-momentum satisfies

$$m_{\text{eff}}^2 c^4 = E^2 - (pc)^2 > 0, \quad (1)$$

where E and p are the total energy and the magnitude of total momentum of the configuration.

- **No modification of c :** All local propagation occurs at the invariant speed of light.

Importantly, photon number is neither specified nor required. The EBFC is defined entirely at the field level.

4 Energy–momentum redistribution and confinement mechanism

In free electromagnetic radiation, energy and momentum are rigidly linked: $E = pc$. As a result, the invariant mass vanishes.

Confinement changes this balance.

When electromagnetic fields interact strongly with themselves or with boundary-like conditions generated by their own configuration, momentum components can partially cancel while energy remains stored. The result is a net reduction in total momentum without a corresponding loss of energy.

This redistribution alone is sufficient to generate a non-zero invariant mass—without any alteration to field equations or propagation speed. EBFCs thus arise not from new physics, but from *non-trivial momentum geometry* within classical electromagnetism [4–6].

5 Internal structure: core + surrounding field

An EBFC naturally separates into two coupled regions:

5.1 Localized core

- Contains the dominant contribution to invariant rest mass.
- Characterized by high energy density and strong field curvature.
- Exhibits reduced net momentum flow relative to stored energy.

5.2 Surrounding electromagnetic field

- Extends outward but is no longer a freely propagating wave.
- Participates in stabilization and energy exchange with the core.
- Acts as a structured field environment rather than radiation.

This core–field duality is essential: neither region alone constitutes an EBFC.

6 Limiting regimes (why ordinary EM superposition does not form matter)

6.1 Why ordinary electromagnetic superposition does not form matter

Most electromagnetic systems fail to produce EBFCs because:

- Field modes are weakly interacting.
- Momentum vectors add coherently rather than canceling.
- Radiation rapidly escapes.

A flashlight beam, regardless of intensity, remains momentum-dominated and thus massless in the invariant sense.

6.2 Two-photon knots as a limiting case

Highly constrained, idealized configurations—sometimes described as “two-photon knots”—may be interpreted as extreme, minimal EBFCs. However:

- They are not universal.
- They are not required.
- They are not foundational.

EBFCs generalize beyond such constructions and should not be reduced to them.

7 Helical structure as a stabilizing (not binding) feature

Helical or twisted field structures may naturally arise in EBFCs due to angular momentum conservation and phase coherence.

Crucially:

- Helicity does *not* bind the configuration.
- Helicity increases stability by raising the energetic cost of reconfiguration.
- Binding arises from momentum redistribution, not topology alone.

This distinction preserves physical clarity and avoids over-attribution of structural features. Related discussions of structured electromagnetic fields and topological field configurations can be found in [2, 9–11].

8 Physical consistency and falsifiability

The EBFC framework is physically conservative and testable:

- No new constants or forces
- Compatible with GR coupling via stress–energy [7]

- Predicts mass emergence only under extreme confinement

Potential falsification routes include:

- High-intensity field experiments probing momentum cancellation in confined geometries
- Astrophysical environments with extreme electromagnetic confinement
- Numerical solutions of Maxwell fields exhibiting persistent localization under physically admissible boundary/self-organization conditions

9 Discussion and outlook

EBFCs offer a bridge between classical field theory and mass emergence without speculative extensions. They reframe matter not as a collection of particles, but as a family of dynamically stabilized field configurations.

This perspective aligns naturally with relativistic invariance, avoids quantum over-commitment, and invites deeper exploration of electromagnetic self-organization.

10 Conclusion

We have introduced the concept of *Electromagnetic Bound Field Configurations* as a conservative, physically grounded framework for understanding the emergence of effective rest mass from electromagnetic fields. Without modifying established laws, EBFCs demonstrate how confinement and energy–momentum geometry alone can generate matter-like behavior.

This work opens a pathway toward reinterpreting mass as a dynamical property of fields—not an intrinsic ingredient added by fiat.

Figures (placeholders and captions)

Keywords

Electromagnetic fields; rest mass emergence; energy–momentum confinement; field configurations; classical electrodynamics

Zenodo-ready description

This paper introduces Electromagnetic Bound Field Configurations (EBFCs), a conservative theoretical framework explaining how effective rest mass can emerge from electromagnetic fields through energy–momentum confinement. Without modifying

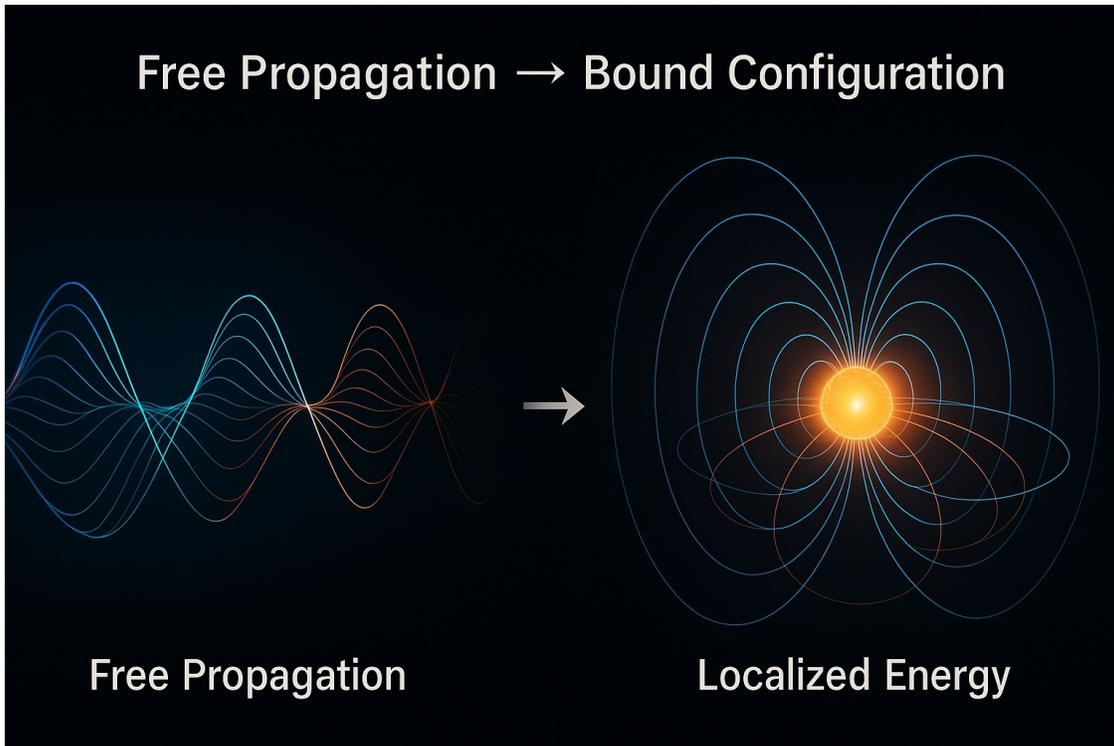


Figure 1: **Figure 1 — Transition from free electromagnetic propagation to a bound configuration.** Schematic illustration of the conceptual transition from freely propagating electromagnetic wave modes, dominated by net momentum flow, to a localized electromagnetic bound field configuration. As momentum pathways become geometrically constrained, energy density concentrates spatially, allowing for the emergence of a nonzero invariant mass component without modifying Maxwell’s equations or the invariant speed of light.

Maxwell’s equations or the speed of light, the work shows that localized, non-radiative field configurations can possess invariant mass, offering a field-based perspective on the emergence of matter-like behavior.

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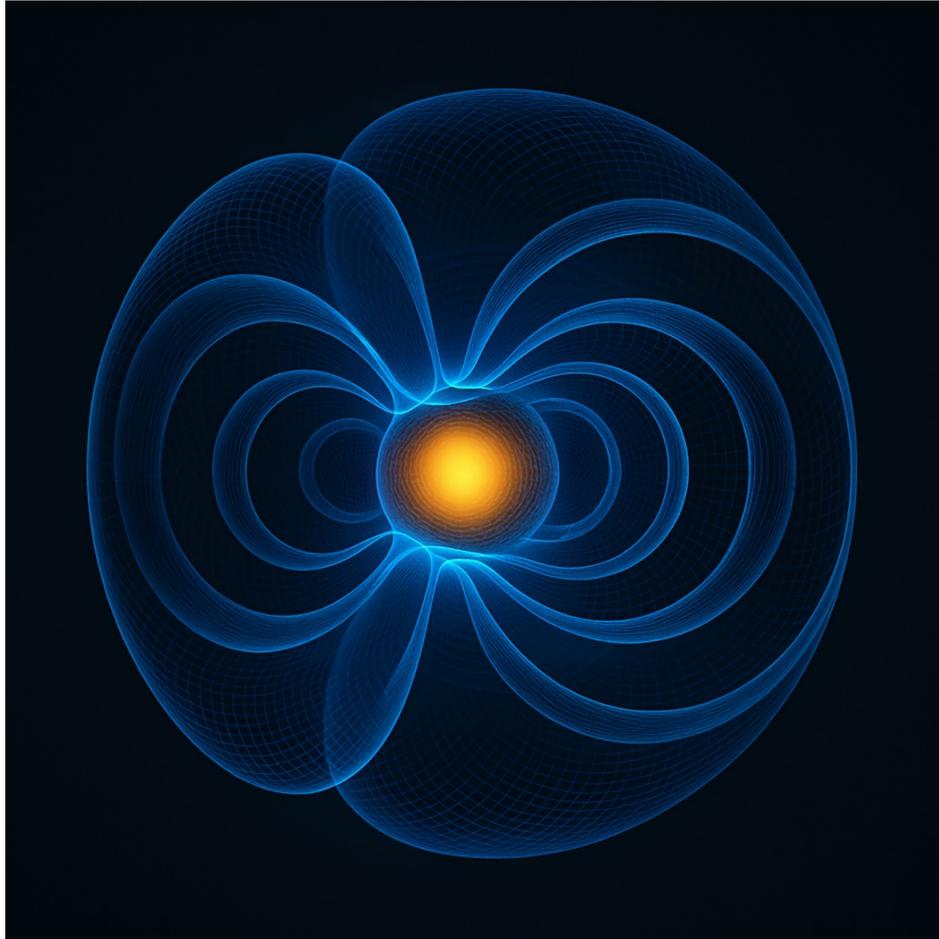


Figure 2: **Figure 2 — Internal structure of an Electromagnetic Bound Field Configuration (EBFC).** Conceptual depiction of an EBFC consisting of a localized, energy-dense core associated with an effective rest-mass component, surrounded by a structured electromagnetic field that is no longer freely radiative. The surrounding field contributes to stabilization and energy redistribution while remaining fully described by classical electrodynamics.

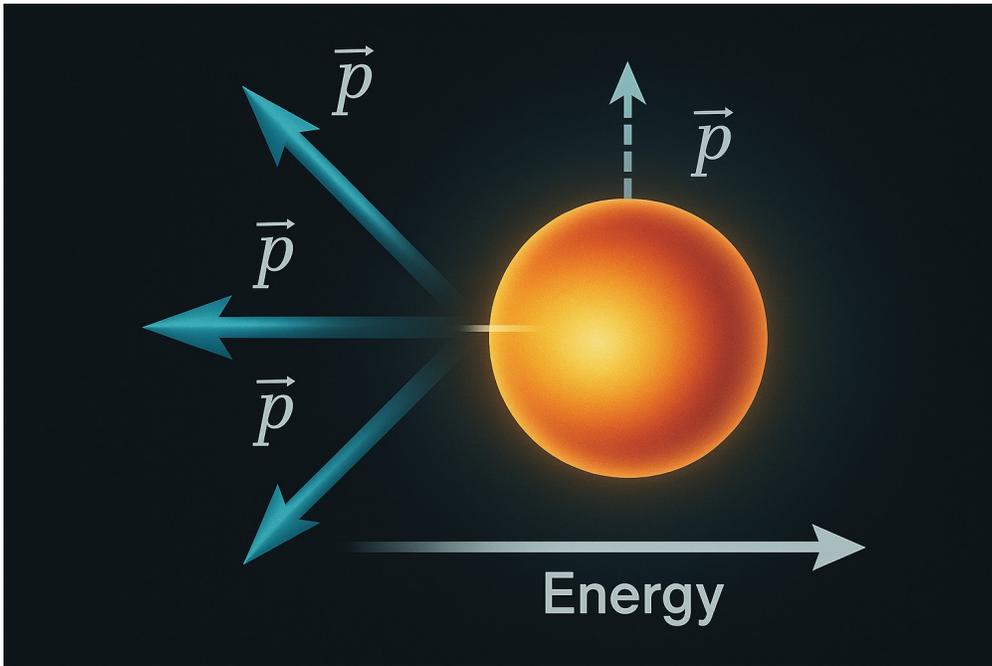


Figure 3: **Figure 3 — Momentum redistribution and the emergence of effective rest mass.** Illustration of energy–momentum redistribution within a bound electromagnetic configuration. Multiple momentum components partially cancel through geometric arrangement, reducing the net momentum while total energy remains stored. This imbalance permits a nonzero invariant mass term, expressed by $E^2 - (pc)^2 > 0$, without invoking photon counting, additional forces, or modified field dynamics.

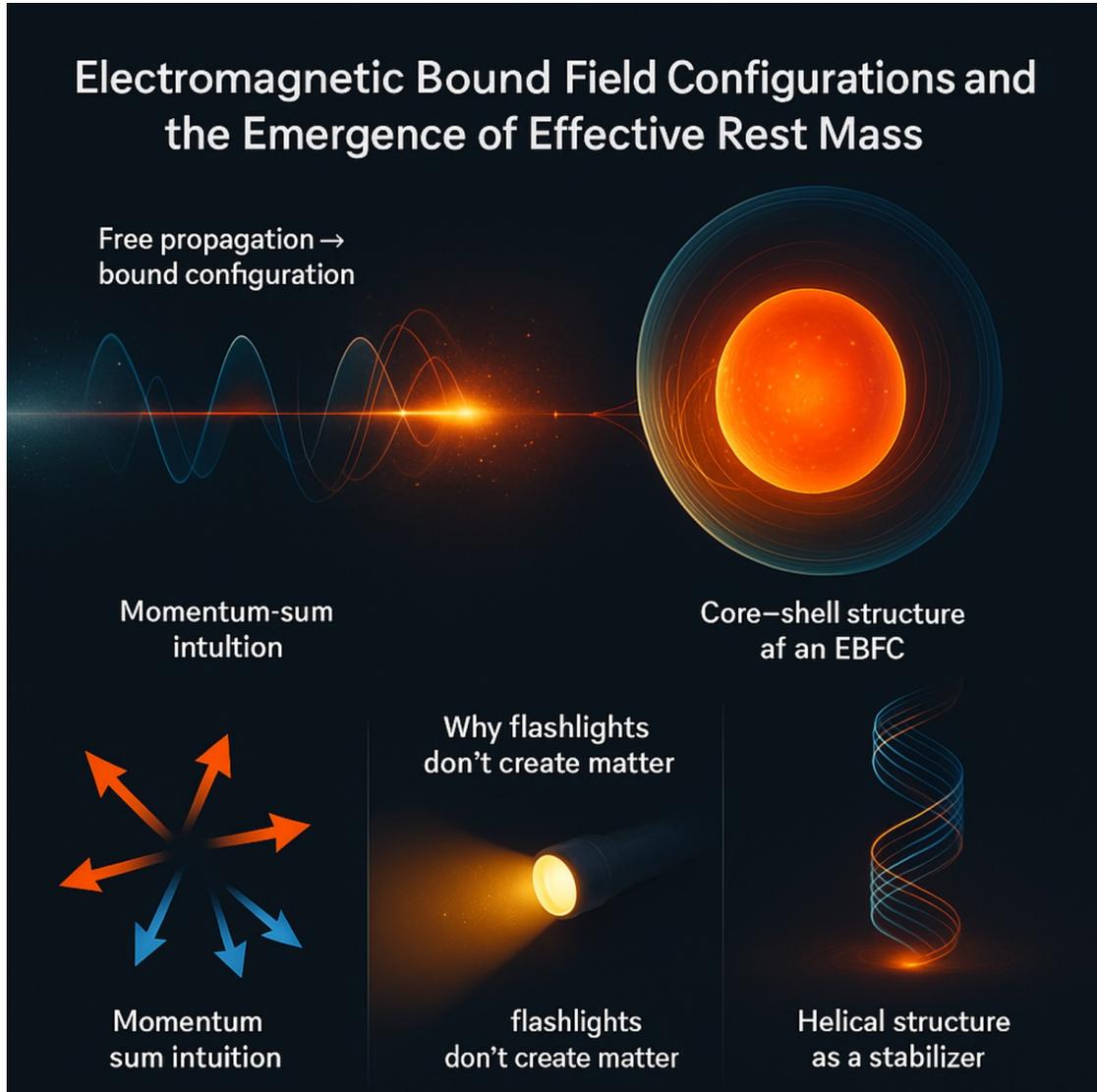


Figure 4: **Figure 4 — Why freely propagating electromagnetic radiation does not form matter.** Comparison illustrating why intense but freely propagating electromagnetic radiation, such as collimated light beams, does not generate rest mass. Despite high energy density, momentum remains strongly aligned, preserving the relation $E \approx pc$ and preventing the formation of a bound configuration with a nonzero invariant mass component.



Figure 5: **Figure 5 — Helical field structure as a stabilizing, not binding, feature.** Conceptual representation of a helical electromagnetic field geometry within a bound configuration. The helical structure reflects angular-momentum-supported rigidity, increasing the energetic cost of rapid reconfiguration and enhancing stability. This geometry does not constitute a binding force and does not alter the underlying mass-generation mechanism or Maxwellian dynamics.