

# Emergent Phase-Field Bubble Cosmology

A phenomenological and exploratory framework

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## Abstract

We present an early-stage conceptual framework in which cosmological-scale structures are interpreted as emergent phase-separated bubbles within a continuous medium. Instead of postulating fundamental long-range forces, the model explores whether local interaction rules, phase-field dynamics, and effective surface tension can give rise to expanding, contracting, and merging bubble-like domains. This work is intended as a toy model and exploratory investigation rather than as a complete or experimentally validated theory.

## 1 Introduction

Modern cosmology usually describes the large-scale evolution of the universe by combining general relativity with specified matter and energy components. This approach is extremely successful, but it treats spacetime geometry and long-range interactions as fundamental ingredients of the description.

Here we explore a different, phenomenological perspective: that cosmological behaviour might be viewed as emerging from local interactions in a continuous medium, in a way that is conceptually closer to hydrodynamics and phase separation than to explicit force mediation. In this picture, large-scale structures resemble bubbles or domains of a phase field, surrounded by other phases of the same underlying medium.

## 2 Conceptual framework: Emergent Stability Framework (ESF)

In this work, we introduce what we refer to as the *Emergent Stability Framework (ESF)*. Within ESF, physical entities such as particles and extended structures are not treated as fundamental objects, but as locally stable or metastable configurations of an underlying continuous medium. The medium itself is assumed to be continuous at the scales of interest, while its microscopic nature is left unspecified.

In this interpretation, what we usually call a “particle” corresponds to a pattern that the medium can sustain in a robust way. A configuration is considered stable if small perturbations relax back to it, and metastable if it persists for long but can eventually decay into other configurations. Apparent motion of objects is then understood as the relocation of the regions in which a given stable pattern is supported, mediated by local reconfigurations of the medium rather than by the transport of a fixed material entity.

Observable quantum phenomena—such as localisation, interference, and entanglement—are interpreted as consequences of stability redistribution under localised interactions, rather than as manifestations of fundamental indeterminism or wavefunction collapse. A measurement corresponds, in this language, to a process in which most metastable alternatives are destroyed by a strong local interaction, leaving only one energetically favored pattern that the medium can sustain in the presence of the measuring apparatus.

On cosmological scales, the same logic is applied to bubble-like domains of a phase field: a “universe” is modeled as a large-scale stable or metastable configuration (a bubble) within the medium, whose expansion, contraction, and merger with other domains follow from the same stability-based principles.

### 3 Local excitations in ESF: electrons and photons

Within the Emergent Stability Framework, microscopic excitations such as electrons and photons are described in terms of different types of stability patterns supported by the medium.

#### 3.1 Electrons as locally stable configurations

An electron is modeled as a locally stable configuration of the medium with fixed integral properties (such as effective charge and mass), rather than as a point-like object moving through space. Its persistence is understood as the reproducibility of a particular pattern: when local conditions allow, the medium relaxes into that configuration in some region, and what we call the “same” electron is the continued existence of this pattern, possibly at different locations over time.

Apparent motion of an electron corresponds to a relocation of the region in which this stable configuration exists, driven by local energy minimisation. Under sufficiently strong interactions, the configuration may lose stability in one region and reappear in another, with the underlying medium redistributing energy and charge accordingly. From this perspective, an experiment that “measures the position” of an electron does not reveal a preexisting trajectory, but selects one of the few regions where the medium can still support the electron pattern after the interaction with the measuring device.

#### 3.2 Photons as propagating reconfiguration modes

Photons, in contrast, are not associated with locally stable configurations. Instead, they are modeled as propagating modes of stability redistribution in the medium. A photon corresponds to a coherent, directed sequence of local reconfigurations, in which loss of stability in one region is compensated by the onset of a compatible configuration in a neighboring region, forming a travelling pattern.

Because photons do not admit a rest state—there is no locally stable “photon configuration” that can remain static—their propagation speed is set by the characteristic relaxation properties of the medium. In vacuum, this leads to a universal propagation speed, while the wavelength of the photon reflects the spatial scale over which the medium can coherently support a given momentum transfer. Interaction with structured media does not change the photon energy but modifies the allowed propagation modes through boundary conditions, leading to refraction, reflection, or absorption.

When a photon interacts with an electron or with matter in general, the propagating reconfiguration mode can terminate: the medium instead relaxes into a locally stable configuration (such as an excited electronic state), and the photon ceases to exist as a separate propagating pattern. In this view, emission and absorption are transitions between different stability regimes of the same underlying medium, rather than events involving the creation or annihilation of a distinct material particle.

### 4 Phase-field interpretation

To describe cosmological-scale structures, we introduce a scalar phase field  $\phi(x, t)$  that encodes local states of the medium. Different stable phases correspond to minima of an effective potential for  $\phi$ , while interface regions arise from gradient-energy terms that penalise sharp transitions.

Qualitatively, the dynamics of  $\phi$  are governed by local diffusion-like processes, free-energy minimisation, and effective surface tension at phase boundaries. Bubbles of one phase inside another arise as domains in which  $\phi$  is close to a particular minimum of the potential, separated by interfaces where  $\phi$  interpolates between distinct minima.

## 5 Bubble dynamics and merging

Within this framework, isolated bubbles tend toward approximately spherical shapes due to surface-tension minimisation: interfaces evolve in a way that reduces total surface area at fixed volume. When distinct bubbles approach and interact, their interfaces can merge, leading to transient non-spherical configurations and eventual relaxation toward new equilibrium shapes.

Such behaviour is familiar from classical fluid systems and motivates the interpretation of large-scale cosmological events—such as expansion, collision, and merging of domains—as manifestations of phase-field dynamics rather than purely as motion in a fixed background spacetime.

## 6 Relation to existing cosmology

The present model is not intended to replace standard cosmological theory. Instead, it offers a complementary phenomenological perspective through which familiar concepts—expansion, contraction, and large-scale structure—may be reinterpreted in terms of phase dynamics and emergent stability. Connections to inflationary or cyclic cosmological scenarios are speculative at this stage and are left for future exploration.

## 7 Numerical exploration (preview)

Preliminary numerical experiments based on phase-field simulations are under active development. These simulations aim to visualise bubble formation and merging, explore regimes of stability and instability, and identify generic dynamical patterns that might serve as qualitative analogues of cosmological behaviour. Details of numerical methods and code implementation are planned to be documented separately in the accompanying simulation code.

## 8 Limitations and open questions

This framework is intentionally exploratory. Important open issues include the lack of quantitative predictions, the absence of direct links to observational data, and an unclear correspondence with relativistic spacetime dynamics. Future work may clarify whether this phenomenological approach can serve as a useful conceptual or computational tool, and whether ESF can be embedded into a more complete theory that reproduces established results of quantum field theory and general relativity.

## 9 Draft interpretation: black holes in ESF

Within the Emergent Stability Framework, black holes are interpreted not as fundamental geometric singularities, but as regimes of the underlying medium in which stable outward-propagating patterns can no longer be sustained. This section presents a qualitative mapping intended to preserve consistency with known phenomenology of general relativity, while remaining explicitly exploratory.

In this interpretation, the event horizon corresponds to a phase boundary of the medium. Outside the horizon, local excitations such as photons may exist as stable propagating reconfiguration modes. As the boundary is approached, the characteristic relaxation dynamics of the

medium increasingly dominate over outward redistribution of stability, leading to strong redshift and effective time dilation for external observers.

Inside the horizon, any attempt to form outward-directed propagating modes fails dynamically: perturbations are absorbed by the medium faster than they can reorganize into stable patterns capable of escape. Information trapping thus arises as a consequence of stability loss, rather than as a fundamental causal prohibition.

Mergers of black holes are interpreted as boundary reconfiguration events between adjacent high-density stability regimes. During such events, non-spherical interface configurations relax toward new equilibrium shapes, releasing excess interfacial stress as macroscopic propagating modes, in qualitative correspondence with observed gravitational-wave signals.

Hawking radiation is treated as a boundary effect. Near the phase boundary, microscopic fluctuations of the medium may occasionally organize into outward-propagating stable modes. This endows the horizon with an effective temperature determined by the curvature and scale of the boundary, without invoking particle creation from the vacuum.

This interpretation is qualitative and phenomenological in nature. Quantitative derivations, explicit connections to relativistic field equations, and potential observational tests are left as subjects for future work.