Title

Emergent Phase-Field Bubble Cosmology
A phenomenological and exploratory framework

Author: Oleksandr Khymych
Version: v0 (conceptual draft)
Date: 2025-12-06

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 a complete or experimentally validated theory.

---

1. Introduction

Modern cosmology models the large-scale dynamics of the universe primarily through general relativity combined with matter and energy components.
While highly successful, such approaches rely on explicitly postulated long-range interactions and a predefined spacetime structure.

This work explores an alternative phenomenological perspective:
that cosmological behaviour may emerge from local interactions within a continuous medium,
in a manner conceptually closer to hydrodynamics and phase separation
than to fundamental force mediation.

---

2. Conceptual Framework

We consider a continuous medium capable of supporting multiple locally stable phases. Domains of differing phase values form bubble-like regions separated by interfaces with effective surface tension.

In this interpretation:

- “Universes” correspond to coherent phase domains,
- expansion and contraction arise from interface dynamics,
- merging events resemble coalescence of bubbles in fluids.

The framework does not assume gravity as a fundamental interaction,
but rather treats it as an emergent effective description,

analogous to how temperature emerges from microscopic motion.

---

3. Phase-Field Interpretation

A scalar phase field $\phi(x, t)$ is introduced to describe local states of the medium.
Stable phases correspond to minima of an effective potential,
while interface regions arise naturally from gradient energy terms.

The qualitative dynamics are governed by:

- local diffusion-like processes,
- free-energy minimisation,
- effective surface tension at phase boundaries.

No assumption of quantised mediator particles is required in this description.

---

4. Bubble Dynamics and Merging

Within this framework, isolated bubbles tend toward approximately spherical shapes
due to surface tension minimisation.

When bubbles approach and interact:

- interfaces may merge,
- transient non-spherical configurations can form,
- relaxation toward new equilibrium shapes occurs over time.

This behaviour is consistent with classical fluid systems
and motivates the interpretation of large-scale cosmological events
as phase-dynamic processes.

---

5. Relation to Existing Cosmology

The present model does not aim to replace standard cosmology.
Instead, it provides a complementary phenomenological lens
through which familiar concepts—such as expansion, contraction,
and large-scale structure—may be reinterpreted.

Connections to inflationary or cyclic cosmological scenarios
are speculative at this stage and remain topics for future exploration.

---

6. 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 stability regimes,
- identify qualitative dynamical patterns.

Details of numerical methods and code implementation
are provided separately in the accompanying simulation repository.

---

7. Limitations and Open Questions

This framework is intentionally exploratory.
Key open issues include:

- lack of quantitative predictions,
- absence of direct links to observational data,
- unclear correspondence with relativistic spacetime dynamics.

Future work may clarify whether this phenomenological approach
can serve as a useful conceptual or computational tool.

References (optional)

References are intentionally omitted in this conceptual draft.
Future versions may include comparisons to phase-field models,
hydrodynamics, and cosmological literature.