Hypothesis of Emergent Gravity from Substrate Phase

Arkadiusz Okupski

August 25, 2025

Abstract

We present a hypothesis in which spacetime and matter constitute different phase states of a fundamental entity called the Substrate. Gravity emerges as a macroscopic manifestation of the dynamic relaxation of the excited state of the Substrate (matter) towards its ground state. We propose a dimensionally consistent mathematical model where matter is described as a metastable solitonic configuration, and spacetime geometry emerges from the configuration and dynamics of the Substrate.

1 Basic Postulates

1.1 The Substrate and Its Phases

The hypothesis assumes the existence of a fundamental Substrate described by a dimensionless order parameter field $\psi(x^\mu)$:

- $\psi \approx 0$: **Ground state** - perceived as spacetime vacuum.
- $\psi \approx 1$: **Excited state** - metastable, perceived as matter.

The energy density difference between the phases is $\Delta V = V(1) - V(0) = \varepsilon$.

1.2 Elasticity and Geometry of the Substrate

The Substrate is characterized by:

- **Elasticity**: described by constant K ($[K] = [L^{-2}]$), which quantifies resistance to changes in phase state.
- **Geometric response**: Curvature of the Substrate, measured by scalar $\mathcal{R}$, generates energy described by potential $U(\mathcal{R})$.

2 Mathematical Structure

2.1 Action

The dynamics of the Substrate is described by the action:

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2}K\, g^{\mu\nu}\partial_\mu\psi\partial_\nu\psi - V(\psi) - U(\mathcal{R})\right] \tag{1}$$

The action structure is dimensionally consistent: $[S] = [L^0]$, $[K(\partial\psi)^2] = [L^{-4}]$, $[V(\psi)] = [L^{-4}]$, $[U(\mathcal{R})] = [L^{-4}]$.

2.2 Field Equations

Variation of the action leads to the following equations:

$$K \Box\psi + \frac{dV}{d\psi} = 0 \tag{2}$$

This equation describes the dynamics of phase transitions in the Substrate.

$$\frac{\delta U}{\delta g^{\mu\nu}} = K \left(\partial_\mu \psi \partial_\nu \psi - \frac{1}{2} g_{\mu\nu} (\partial\psi)^2 \right) - g_{\mu\nu} V(\psi) \tag{3}$$

This equation defines the process of emergence of spacetime geometry from the Substrate configuration.

3 Physical Interpretation

3.1 Matter as a Soliton

The configuration $\psi \approx 1$ in a limited spatial region, surrounded by $\psi \approx 0$, is interpreted as a soliton - a stable, localized excitation. The energy associated with this configuration is identified with rest mass.

3.2 Mechanism of Gravity

The relaxation process of the excited state ($\psi \to 0$) leads to dissipation of energy stored in the soliton. This process manifests macroscopically as the phenomenon of gravitational attraction. Quantum fluctuations around the ground state are described by an effective mass $m_{\text{eff}}^2 = (2\varepsilon + 8\lambda)/K$.

3.3 Energy Conservation

The local energy-momentum conservation principle is a consequence of the action structure and is expressed as:

$$\nabla^\mu T_{\mu\nu}^{(\text{total})} = 0 \tag{4}$$

4 Summary

The Active Substrate Hypothesis offers a consistent framework for describing the unifying nature of spacetime and matter. Key elements of the model include:

- Description of matter as a metastable solitonic configuration.
- Emergence of geometry from Substrate dynamics.
- Dimensionally correct mathematical structure.
- Strict energy conservation.

The model provides a starting point for further research on solitonic solutions and their gravitational properties.

5 Theoretical Context and Bibliography

The proposed hypothesis fits into the broad research program seeking the emergent origin of gravity and spacetime. The following works provide the theoretical context and source of inspiration for the presented ideas.

References

[1] Bailin, D., & Love, A. (1987). *Kaluza-Klein Theories*. Reports on Progress in Physics, 50(9), 1087.
Connection: Work on Kaluza-Klein theory and higher-dimensional compactification forms the cornerstone of emergent physics, showing how geometry can determine physics.

[2] Volovik, G. E. (2003). *The Universe in a helium droplet*. Oxford University Press.
Connection: Key inspiration. Volovik details how concepts of field theory and emergent gravity (e.g., effective metric, black holes) appear in condensed matter physics, such as in superfluid helium-3.

[3] Padmanabhan, T. (2010). *Gravitational entropy of static space-times and microscopic density of states*. Classical and Quantum Gravity, 27(12), 125001.
Connection: Padmanabhan's work focuses on the thermodynamic and entropic origin of gravity, which is close in spirit to the proposed hypothesis where gravity is a relaxation process.

[4] Verlinde, E. P. (2011). *On the origin of gravity and the laws of Newton*. Journal of High Energy Physics, 2011(4), 29.
Connection: Groundbreaking work on entropic gravity. Verlinde's concept that gravity is an entropic force rather than a fundamental one strongly converges with the idea of gravity as a thermodynamic relaxation process of the Substrate.

[5] A. Okupski *Big Bang as a Detonation: Hypothesis of Matter-Antimatter Annihilation in Analogy to Explosive Material*. GitHub Repository.
https://github.com/ArkOkupski-WAT/Big-Bang-as-a-Detonation-Explosive-Material
Connection: Author's work presenting a complementary cosmological hypothesis where the Big Bang is viewed as a "detonation" process and dark energy as its product. Provides broader context for considerations about the emergent nature of spacetime.

[6] Hossenfelder, S. (2015). *What if gravity is not quantized?*. Journal of Physics: Conference Series, 626(1), 012020.
Connection: Review article discussing the possibility that gravity may be an emergent effect rather than a fundamental quantum field. Supports the philosophical foundations of the hypothesis.

[7] Raju, S. (2022). *Lessons from the information paradox*. Physics Reports, 943, 1-80.
Connection: Recent reviews on the information paradox in black holes emphasize the deep tension between gravity and quantum mechanics, strengthening arguments for the emergent status of spacetime.