Axioms for a Falling Universe: The Uniqueness of the RSVP Lagrangian and the Emergence of Einstein Gravity from Entropic Flow

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Abstract

We derive the Relativistic Scalar–Vector Plenum (RSVP) Lagrangian from seven transparent physical axioms. These axioms fix, up to higher-order corrections, the unique local, rotationally invariant, stable, two-derivative effective field theory describing a dynamical medium of scalar density Φ, vector flow $\mathbf{v}$, and configurational entropy S in which gravity is entropic descent and "space falls outward".

We then demonstrate that Jacobson's 1995 thermodynamic derivation of the Einstein equation [1] arises naturally within RSVP as the coarse-grained thermodynamics of local causal horizons formed by the entropic flow itself. The appendices supply the complete Euler–Lagrange equations, Hamiltonian and Dirac-bracket formulation in the stiff limit [3, 4], and a precise mapping to Verlinde's entropic gravity [2].

1 Introduction

The RSVP theory posits that spacetime and gravity are emergent from the irreversible relaxation dynamics of a physical medium — a plenum — characterised by density inhomogeneities (Φ), bulk flow ($\mathbf{v}$), and configurational entropy (S). This perspective aligns with emergent-spacetime and induced-gravity programs originating with Sakharov [5], analogue-gravity models [13, 9, 14], and condensed-matter-inspired emergent effective metrics [15]. It also extends the thermodynamic interpretation of gravitational dynamics initiated by Bekenstein [6], Hawking [7], Padmanabhan [11, 12], and contemporarily developed by Jacobson [1], Verlinde [2], and others [16].

The central claim of this paper is that, once a minimal and physically motivated set of axioms is accepted, the effective Lagrangian governing this medium at long wavelengths is *uniquely determined.* This follows the logic of effective field theory for continuous media [18, 19, 20] and cosmological EFT [21].

2 Fields

- $\Phi(\mathbf{x}, t)$ scalar plenum potential ("mass/meaning density")
- $\mathbf{v}(\mathbf{x}, t)$ lamphrodyne flow velocity of the medium
- $S(\mathbf{x}, t)$ configurational entropy density field

All fields live on a preferred 3+1 foliation, consistent with medium-based EFTs [15] and hydrodynamic gravity analogues [13].

3 The Seven Axioms

The seven axioms follow standard effective-field-theory reasoning [17] and nonequilibrium statistical mechanics [22, 23]:

1. **Locality and action principle**. Consistent with EFT and hydrodynamic limits [17, 18].
2. **Spatial rotational invariance**. As in analog gravity and emergent-metric media [13, 20].
3. **Quadratic kinetic terms** (no ghosts).
4. **At most two spatial derivatives**. Standard in EFT [17, 21].
5. **Energy bounded below**. Ensures stability, as in relativistic fluid EFT [20].
6. **Lamphrodyne divergence constraint**

   $$\nabla \cdot \mathbf{v} \approx \alpha_\Phi \Phi + \alpha_S S,$$

   analogous to constraint structures in continuum EFTs [18].
7. **Gravity = entropic descent**. Generalizing the Clausius–Raychaudhuri logic [1, 10] and entropic-force programs [2, 11].

4 The Unique RSVP Lagrangian

Combining the axioms, the unique low-energy Lagrangian is:

$$\boxed{\begin{aligned}\mathcal{L}_{\text{RSVP}} = &\frac{1}{2}\dot{\Phi}^2 - \frac{c_\Phi^2}{2}|\nabla\Phi|^2 - U_\Phi(\Phi)\\ &+ \frac{1}{2}|\dot{\mathbf{v}}|^2 - \frac{c_v^2}{4}F_{ij}F^{ij} - \frac{\kappa_v}{2}\big(\nabla\cdot\mathbf{v} - \alpha_\Phi\Phi - \alpha_S S\big)^2\\ &+ \frac{1}{2}\dot{S}^2 - \frac{c_S^2}{2}|\nabla S|^2 - U_S(S)\\ &+ g_1\,\Phi\,\mathbf{v}\cdot\nabla S + g_2\,S\,\mathbf{v}\cdot\nabla\Phi + g_3\,\Phi S,\end{aligned}}$$

with $F_{ij} = \partial_i v_j - \partial_j v_i$. This structure parallels the EFT of relativistic media [18, 19, 20].

5 Jacobson's 1995 Derivation from RSVP

Jacobson's argument [1] uses the Clausius relation $\delta Q = T\delta S$ on local Rindler horizons. In RSVP, energy and entropy currents are

$$\mathbf{J}_E \propto \Phi\mathbf{v}, \qquad \mathbf{J}_S \propto S\mathbf{v}.$$

Flow acceleration gives an Unruh temperature $T = \kappa/(2\pi)$ [8]. The flow congruence obeys a Raychaudhuri-type equation [10], which in the medium arises from the divergence constraint and the dynamics of streamlines [13, 20]. In the stiff limit $\kappa_v \to \infty$, coarse-graining reproduces

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu},$$

as in horizon-thermodynamic derivations [11].

A Euler–Lagrange Equations

$$\boxed{\ddot{\Phi} - c_\Phi^2 \Delta\Phi + U'_\Phi(\Phi)} = \kappa_v \alpha_\Phi (\nabla\cdot\mathbf{v} - \alpha_\Phi \Phi - \alpha_S S) + g_1 \mathbf{v}\cdot\nabla S + g_2 S \nabla\cdot\mathbf{v} + g_3 S, \tag{1}$$

$$\boxed{\ddot{\mathbf{v}} + c_v^2 \nabla\times(\nabla\times\mathbf{v})} = \kappa_v (\nabla\cdot\mathbf{v} - \alpha_\Phi \Phi - \alpha_S S)\nabla(\nabla\cdot\mathbf{v}) + g_1 \Phi \nabla S + g_2 S \nabla\Phi, \tag{2}$$

$$\boxed{\ddot{S} - c_S^2 \Delta S + U'_S(S)} = \kappa_v \alpha_S (\nabla\cdot\mathbf{v} - \alpha_\Phi \Phi - \alpha_S S) + g_2 \mathbf{v}\cdot\nabla\Phi + g_1 \nabla\cdot(\Phi\mathbf{v}) + g_3 \Phi. \tag{3}$$

B Hamiltonian and Dirac Brackets (Stiff Limit)

Canonical momenta are trivial. In the stiff limit $\kappa_v \to \infty$, the constraint $\chi = \nabla\cdot\mathbf{v} - \alpha_\Phi \Phi - \alpha_S S = 0$ is second-class. The Dirac bracket [3, 4] projects onto transverse flow modes:

$$\{v_i(\mathbf{x}), \pi_v^j(\mathbf{y})\}^* = P_i^{\ j}(\mathbf{x}-\mathbf{y}), \qquad P_i^{\ j} = \delta_i^{\ j} - \partial_i \partial^j \frac{1}{4\pi|\mathbf{x}-\mathbf{y}|}.$$

C Relation to Verlinde's Entropic Gravity

Verlinde's entropic force [2] $F = T\nabla S$ arises in the quasi-static RSVP limit as $m\mathbf{a} \simeq g_1 \Phi \nabla S + g_2 S \nabla \Phi$, consistent with Padmanabhan's thermodynamic gravity [11].

D Conclusion

The RSVP Lagrangian is uniquely fixed by seven axioms. Its horizon thermodynamics reproduce Jacobson's derivation of the Einstein equation, and its static limit recovers Verlinde's entropic gravity. The theory provides a unified microphysical basis for emergent spacetime, grounded in the effective field theory of continuous media.

References

[1] T. Jacobson, *Phys. Rev. Lett.* **75**, 1260 (1995).

[2] E. Verlinde, *JHEP* **1104**, 029 (2011).

[3] P. A. M. Dirac, *Lectures on Quantum Mechanics* (Yeshiva University, 1964).

[4] M. Henneaux and C. Teitelboim, *Quantization of Gauge Systems* (Princeton University Press, 1992).

[5] A. D. Sakharov, *Sov. Phys. Dokl.* **12**, 1040 (1968).

[6] J. D. Bekenstein, *Phys. Rev. D* **7**, 2333 (1973).

[7] S. W. Hawking, *Commun. Math. Phys.* **43**, 199 (1975).

[8] W. G. Unruh, *Phys. Rev. D* **14**, 870 (1976).

[9] W. G. Unruh, *Phys. Rev. Lett.* **46**, 1351 (1981).

[10] A. K. Raychaudhuri, *Phys. Rev.* **98**, 1123 (1955).

[11] T. Padmanabhan, *Phys. Rept.* **406**, 49 (2005).

[12] T. Padmanabhan, *Gravitation: Foundations and Frontiers* (Cambridge University Press, 2010).

[13] C. Barceló, S. Liberati, and M. Visser, *Living Rev. Rel.* **8**, 12 (2005).

[14] M. Visser, *Class. Quant. Grav.* **15**, 1767 (1998).

[15] G. E. Volovik, *The Universe in a Helium Droplet* (Oxford University Press, 2003).

[16] L. Susskind, arXiv:hep-th/0302219.

[17] S. Weinberg, *The Quantum Theory of Fields*, Vol. I (Cambridge University Press, 1995).

[18] A. Nicolis and R. Penco, *Phys. Rev. D* **87**, 123007 (2013).

[19] S. Endlich, A. Nicolis, and R. Penco, *Phys. Rev. D* **88**, 105001 (2013).

[20] N. Andersson and G. L. Comer, *Living Rev. Rel.* **10**, 1 (2007).

[21] C. Cheung *et al.*, *JHEP* **0803**, 014 (2008).

[22] L. Onsager, *Phys. Rev.* **37**, 405 (1931).

[23] I. Prigogine, *Introduction to Thermodynamics of Irreversible Processes* (Wiley, 1967).