The Condensate and Its Shadows

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Gravity, Information, the Arrow of Time, and Complexity as Regimes of a Single Ginzburg-Landau Order Parameter

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Abstract

A single complex scalar order parameter W0, governed by the GL action S[W0] = int(|dW0|^2 + a0|W0|^2 + (b0/2)|W0|^4) dmu, generates as limiting regimes: (i) gravity as the mean-field geometry of the condensed phase; (ii) black-hole information preservation through unitarity of the GL partition function and replica wormhole saddles; (iii) the arrow of time as monotonically increasing condensate complexity, supported by the Komargodski-Schwimmer a-theorem; (iv) P!=NP as a structural consequence of the topological irreducibility of the pre-geometric phase. W0 is identified with the Will Field of the RTSG framework.

1. Setup

The companion paper (RTSG-2026-001) established that gravity is a GL condensation phenomenon – spacetime is the condensed phase of W0, horizons are phase boundaries, and surface gravity kappa is the logarithmic rate of the condensate at the boundary:

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kappa = -(d/du) ln|W0|  at the horizon
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2. The Kinematic Clock

The GL condensate at the phase boundary has a natural relaxation timescale:

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t_kin = S_Wald / kappa
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For Schwarzschild: t_kin recovers the scrambling time ~ $8 pi M^2$*G. For de Sitter: t_kin recovers the Poincare recurrence time ~ pi/(G*H3). Both follow from the condensate clock without additional assumptions.

3. Information Preservation

The information paradox dissolves when information loss is recognized as a phase transition, not a destruction event.

Correct mechanism: Unitarity of the full GL partition function Z = int DW0 exp(-S[W0]). Replica wormhole saddles [Penington et al. 2019] restore the Page curve at t > t_Page. The U(1) symmetry of the GL action provides structural conservation of winding numbers (topological vortices), but information preservation requires the full unitary path integral.

Correction note: U(1) conservation preserves one Noether charge, not the full quantum state. Earlier versions of this claim were a category error; this is the corrected formulation.

4. Arrow of Time

The KS a-theorem [Komargodski-Schwimmer 2011] guarantees monotone RG flow from UV (c=1, T=T_c) to IR (c=0, T->0). Active degrees of freedom decrease monotonically – the condensate becomes more ordered.

Status: dS_ent/dt >= 0 during Big Bang condensation is a well-motivated conjecture supported by exact results in 1+1D analogues [Calabrese-Cardy 2005] and RG monotonicity. Full proof requires the 3+1D quantum quench calculation – currently open.

Correction note: An earlier version used strong subadditivity (SSA) to prove this. SSA gives S(AuB) <= S(A)+S(B) – an upper bound, not a lower bound. The SSA argument was direction-reversed and has been replaced.

Physical meaning: The Second Law is not a fundamental postulate. It is the statement that the universe is still in the middle of its Big Bang phase transition. Entropy increases because condensate complexity increases.

5. Black Hole as Local Phase Inversion

Black hole evaporation is a localized phase inversion, not a time-reversal or exact symmetry. The tidal Weyl curvature drives the effective a0^eff(r) toward positive values inside the horizon, causing W0 -> 0 locally. This traverses the same Mexican-hat potential in the opposite direction from the Big Bang condensation – not related by a symmetry.

Correction note: Earlier versions called this an "exact symmetry under a0 -> -a0." This is wrong. a0 -> -a0 is a parameter change that drives a phase transition, not a symmetry of the GL action.

6. P!=NP from Phase Topology

NP-complete problems require traversing the pre-geometric (uncondensed) phase – the full configuration space of W0. P problems are solvable within the condensed phase. The kinematic clock t_kin = S/kappa gives the time to process one bit of the phase boundary. Traversing the full pre-geometric space requires exponentially many such bits.

Status: Structural argument, not a formal complexity-theoretic proof. Requires mapping logical gates to GL topological invariants.

7. The Complexity Gradient

One field, four regimes:

- Gravity: condensate at minimum complexity (min |dW0|)
- Electromagnetism, Yang-Mills: intermediate complexity
- Matter, chemistry, biology: high complexity
- Consciousness, computation: maximum local complexity

8. RTSG Identification

W0 = W_RTSG (the RTSG Will Field).

Three Spaces = three phases of the condensate: - Potentiality Space = uncondensed phase (W0 = 0) - Context Space = phase boundary (critical surface) - Actuality Space = condensed phase (|W0| = v0)

The complexification functor C = GL gradient flow. The ContextualObstruction = topological barrier of the phase transition.

References

[1] J.-P. Niko, “Gravity as Geometric Condensation,” RTSG-2026-001 (2026). [2] G. Penington et al., “Replica Wormholes,” arXiv:1911.11977 (2019). [3] Z. Komargodski and A. Schwimmer, JHEP 12, 099 (2011). [4] P. Calabrese and J. Cardy, J. Stat. Mech. P04010 (2005). [5] A. Almheiri et al., Rev. Mod. Phys. 93, 035002 (2021).