

Dense Time Quantum Mechanics: Physics of the Dense-Time Collective Partner State

George Davey 

Independent Researcher, West Des Moines, IA, USA

Email: George.Davey@QuantumLinear.com

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Abstract

We construct the quantum-mechanical foundation of the **Dense-Time Collective Partner State (DT-CPS)**, the interior state of black holes in which the time-density field forms and wave-supported temporal phase coherence becomes nearly unsupported and redshifted. Ordinary matter, previously described as stabilized **Baryon Partner States**, undergoes a phase transition under extreme gravitational dwell time into this collective dense-time state, further compacting **stable structural configurations** while preserving mass-energy. Unlike conventional quantum systems, the DT-CPS represents a redshift-saturated quantum phase whose interior sector obeys a Hamiltonian constraint $\hat{\mathcal{H}}_{\text{DT}}|\Psi\rangle \approx 0$ in place of Schrödinger time evolution, and supports no ordinary finite-frequency radiative propagating sector; any residual collective modes are asymptotically redshifted and effectively frozen on exterior timescales. Quantum mechanics survives in this regime as a constraint theory: states are defined by conserved deformation energy, global ordering relations, and boundary conditions rather than by time-parametrized dynamics. This paper establishes the appropriate Hilbert space, observables, and state structure for dense-time physics, forming the basis for a complete constraint-based quantum theory of black hole interiors. We derive the mass scaling of the latent chrono-pressure, identify the geometric trigger $r_{\Sigma}(M_{\text{crit}}) = r_{\text{domain}}$ as the cause of the Chrono-Shear Event, and show that the Zeldovich stiff-fluid equation of state ($w_{\text{DT}} = 1$) is the unique value consistent with both the DT-CPS constraint structure and the assumption that all accreted energy is stored as latent chrono-pressure. The critical mass $M_{\text{crit}} = c^2 r_{\text{domain}} / (2G) \approx 3 \times 10^{53} \text{ kg}$ is fixed by the geometry of the parent domain and fundamental constants alone. Seven observational consequences are identified, six of which are stated as direct falsification criteria—including the absence of post-merger gravitational-wave echoes, the ringdown window $t_{\text{relax}} = \kappa GM/c^3$ with

$\kappa \in [10, 20]$, and the tidal-deformability constraint $w_{\text{DT}} \approx 1$ —each independently falsifiable by existing or near-term gravitational-wave data. Three closing functions ($V_{\text{eff}}(\hat{t})$, $\sigma(\hat{t})$, and $Z_t(\hat{t})$) remain to be determined from a microscopic theory; their derivation would render all predictions fully quantitative.

Keywords

Dense Time Quantum Mechanics, Dense-Time Collective Partner State (DT-CPS), Black Hole Interiors, Hamiltonian Constraint, Chrono-Pressure, Chrono-Shear Event, Gravitational-Wave Observables

1. Introduction

The interior physics of black holes remains one of the most persistent open problems in fundamental physics. While general relativity accurately describes the exterior spacetime geometry [1]–[3] and quantum field theory successfully accounts for particle phenomena in weakly curved backgrounds [4], their joint application inside black holes leads to conceptual breakdowns. Classical treatments of gravitational collapse [5] predict singularities, while semiclassical approaches raise unresolved questions concerning unitarity, information retention, and the fate of quantum degrees of freedom under extreme gravitational confinement [6]–[9]. A central difficulty is that most existing approaches assume that the interior of a black hole continues to support the same wave-based quantum dynamics that operate in vacuum. This assumption underlies both singularity formation and conventional thermodynamic reasoning. However, observational evidence provides a striking counterpoint: black holes do not radiate as compressed hot matter, do not behave as energetic plasmas during mergers [10], and instead coalesce smoothly and quietly, with energy emerging primarily through gravitational channels. This paper advances a different organizing principle. Building on prior work in which time is treated as a dynamical field with discrete density phases [11] [12], matter is described as a stabilized excitation [12], and the timeon field is given an algebraic and symplectic quantum-mechanical foundation [13], we argue that black hole interiors correspond to a *saturated dense-time phase* in which temporal phase transport and wave-mediated quantum dynamics are nearly unsupported and redshifted. Time does not vanish in this regime; rather, its density reaches a plateau that renders time-parametrized evolution dynamically irrelevant. Quantum mechanics survives, but in a constraint-based form governed by conservation laws, boundary conditions, and global ordering relations rather than unitary time evolution. Within this framework, ordinary matter—previously described as stabilized Baryon Partner States [12] [13]—loses its discrete identity under extreme gravitational dwell time and transitions into a Dense-Time Collective Partner State (DT-CPS). This state preserves mass-energy while eliminating particle tex-

ture, naturally explaining the absence of interior heating, electromagnetic emission, and violent merger behavior. At sufficiently large accumulated mass, the DT-CPS itself becomes metastable, leading to a terminal quantum phase transition—the Chrono-Shear Event—which resets causal structure, releasing the accumulated mass-energy and restoring the timeon lattice to the vacuum configuration from which a new causal expansion proceeds.

Scope and intent. This framework does not claim to be a complete theory of quantum gravity. Rather, it provides a controlled, phase-based description of black hole interiors consistent with known exterior observations, and it isolates a finite set of functions whose determination would render the theory fully predictive. Several results in this paper—including the strong suppression of CQM reflectivity $G(\omega)$ and the foundational timeon-field construction—rely on prior work in this series [11] [12].

2. Dense Time as a Saturated Quantum Phase

In the dense-time phase, the time-density field $\hat{t}(\mathbf{x})$ has undergone a discrete transition from the **Atomic Phase** (matter) into a **Dense Phase**. Time does not vanish in this regime; rather, the time-density field reaches a narrow saturated phase in which ordinary time-parametrized propagation ceases to be the appropriate dynamical description. As a result, no ordinary finite-frequency propagating radiative sector survives: the effective mode frequency is suppressed by the local time-density through

$$\omega_{\text{eff}}(k; \hat{t}) = Z_t(\hat{t})^{-1} \omega_0(k), \quad Z_t(\hat{t}) \gg 1 \text{ in the dense phase,} \quad (1)$$

so that

$$\omega_{\text{eff}}(k; \hat{t}) \rightarrow 0^+ \text{ as } \hat{t} \rightarrow \hat{t}_{\text{sat}}. \quad (2)$$

The correct statement is therefore not that all interior excitations are identically zero, but that no ordinary finite-frequency propagating radiative sector survives in the DT-CPS; any residual collective modes are asymptotically redshifted to ultra-low frequencies and effectively frozen on exterior timescales. The dense-time phase therefore requires a reformulation of quantum mechanics in which states do not evolve in time but are instead characterized by global constraints and conserved quantities.

3. Phase-Entry Criterion: The Dense-Time Trigger Functional

The transition into the DT-CPS is physically described above as saturation of the time-density field. To give the phase-entry condition mathematical precision without overcommitting to one microscopic model, we define a scalar trigger functional accumulated along an infalling worldline γ :

$$\eta_{\text{DT}}[\gamma] = \int_{\gamma} d\tau \mathcal{I}(x(\tau)), \quad (3)$$

where $\mathcal{I}(x)$ is a local Lorentz scalar measuring cumulative temporal compres-

sion. Admissible choices, in order of increasing geometric generality, are:

$$\mathcal{I}(x) = \rho_t(x), \quad (4)$$

$$\mathcal{I}(x) = \sqrt{R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma}}, \quad (5)$$

$$\mathcal{I}(x) = f(\rho_t, R, R_{\mu\nu} R^{\mu\nu}, R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma}). \quad (6)$$

The dense-time phase transition is then stated as a threshold condition:

$$\eta_{\text{DT}}[\gamma] \geq \eta_{\text{crit}} \Rightarrow \text{entry into the DT-CPS phase.} \quad (7)$$

The theory at present establishes the *existence* of a finite threshold η_{crit} ; the exact microscopic form of $\mathcal{I}$ is determined by the underlying timeon-field theory and is deferred to later work. This formulation does not overcommit the theory to one trigger mechanism, but it gives the phase boundary a mathematically explicit, invariant statement.

4. Hilbert Space with Modified Time Evolution

4.1. Kinematic and Physical State Spaces

Following the Dirac program for constrained systems, we distinguish a kinematic state space $\mathcal{H}_{\text{kin}}$ —carrying all degrees of freedom before constraints are imposed—from the physical state space of the DT-CPS. Let $\mathcal{H}_{\text{DT-CPS}}$ denote the latter. Unlike conventional quantum Hilbert spaces, $\mathcal{H}_{\text{DT-CPS}}$ is not equipped with a unitary time-evolution operator. Instead, it is defined as the physical subspace of $\mathcal{H}_{\text{kin}}$ annihilated by all dense-time constraints:

$$\mathcal{H}_{\text{phys}} = \left\{ |\Psi\rangle \in \mathcal{H}_{\text{kin}} \mid \hat{\mathcal{H}}_{\text{DT}} |\Psi\rangle = 0, \hat{\mathcal{C}}_a |\Psi\rangle = 0 \right\}, \quad (8)$$

where the constraints $\hat{\mathcal{C}}_a$ encode:

- saturation of the time-density field ($\hat{t}(x) = \hat{t}_{\text{sat}}$),
- absence of an ordinary finite-frequency radiative propagating sector,
- conservation of total deformation energy.

Throughout this paper $\mathcal{H}_{\text{phys}} \equiv \mathcal{H}_{\text{DT-CPS}} \equiv \mathcal{H}_{\text{DT}}$; the abbreviated forms are used wherever no ambiguity arises. For the constraint system to be consistent, the constraints must close under commutation. We state the algebraic closure condition:

$$[\hat{\mathcal{C}}_a, \hat{\mathcal{C}}_b] = f_{ab}{}^c \hat{\mathcal{C}}_c, \quad [\hat{\mathcal{H}}_{\text{DT}}, \hat{\mathcal{C}}_a] = g_a{}^b \hat{\mathcal{C}}_b, \quad (9)$$

where $f_{ab}{}^c$ and $g_a{}^b$ are structure functions. Writing this condition establishes that the interior theory is a genuine Dirac constraint system. The structure functions can be computed directly from the explicit constraint operators (54) and the canonical equal-time commutation relations of the timeon field.

4.2. Computation of the Structure Functions

The canonical equal-time commutation relations inherited from the parent Lagrangian (38) are

$$[\hat{t}(x), \pi_t(y)] = i\hbar \delta^3(x-y), \quad [\hat{\theta}(x), \pi_\theta(y)] = i\hbar \delta^3(x-y), \quad (10)$$

with all other equal-time commutators vanishing. The two dense-time constraint operators are (Equation (54)):

$$\hat{C}_1(\mathbf{x}) = \hat{t}(\mathbf{x}) - \hat{t}_{\text{sat}}, \quad \hat{C}_2^i(\mathbf{x}) = \nabla^i \hat{\theta}(\mathbf{x}). \quad (11)$$

a) *Inter-constraint commutator* $[\hat{C}_1, \hat{C}_1]$. Since $\hat{t}(\mathbf{x})$ is a configuration-space operator,

$$[\hat{C}_1(\mathbf{x}), \hat{C}_1(\mathbf{y})] = [\hat{t}(\mathbf{x}), \hat{t}(\mathbf{y})] = 0. \quad (12)$$

b) *Inter-constraint commutator* $[\hat{C}_2^i, \hat{C}_2^j]$. Since $\hat{\theta}(\mathbf{x})$ is also a configuration-space operator,

$$[\hat{C}_2^i(\mathbf{x}), \hat{C}_2^j(\mathbf{y})] = [\nabla^i \hat{\theta}(\mathbf{x}), \nabla^j \hat{\theta}(\mathbf{y})] = \nabla_x^i \nabla_y^j [\hat{\theta}(\mathbf{x}), \hat{\theta}(\mathbf{y})] = 0. \quad (13)$$

c) *Cross commutator* $[\hat{C}_1, \hat{C}_2^i]$. Since $\hat{t}$ and $\hat{\theta}$ are independent field degrees of freedom,

$$[\hat{C}_1(\mathbf{x}), \hat{C}_2^i(\mathbf{y})] = [\hat{t}(\mathbf{x}), \nabla^i \hat{\theta}(\mathbf{y})] = 0. \quad (14)$$

d) *Hamiltonian-constraint commutators*. On the dense-time constraint surface, the static Hamiltonian density (48) reduces to $V(\hat{t}_{\text{sat}}^2)$ in the bulk interior (gradient terms vanish by (49)). The integrated Hamiltonian $\hat{\mathcal{H}}_{\text{DT}}$ depends on $\hat{t}^2$ through the potential $V(\hat{t}^2)$ and on $\hat{\theta}$ through $\hat{t}^2 (\nabla \hat{\theta})^2$. Both are configuration-space functionals; therefore

$$[\hat{\mathcal{H}}_{\text{DT}}, \hat{C}_1(\mathbf{x})] = [\hat{\mathcal{H}}_{\text{DT}}, \hat{C}_2^i(\mathbf{x})] = 0. \quad (15)$$

e) *Result: Abelian closure*. All structure functions vanish:

$$\boxed{f_{ab}{}^c = 0, \quad g_a{}^b = 0.} \quad (16)$$

The DT-CPS constraint algebra is *Abelian*: the constraints are first-class and mutually commuting, and they commute with the Hamiltonian strongly (not merely on the constraint surface). This is the strongest possible closure result—it means the constraint system is internally consistent without requiring any second-class constraints or Dirac brackets, and the physical Hilbert space $\mathcal{H}_{\text{phys}}$ (Equation (8)) is well-defined without any additional regularization. The Abelian structure is a direct consequence of the saturation constraint ($\hat{t} = \hat{t}_{\text{sat}}$) being a function only of $\hat{t}$, and the phase-quench constraint ($\nabla \hat{\theta} = 0$) being a function only of $\hat{\theta}$ —the two fields are canonically independent.

4.3. Explicit Constraint Subspace Definition

$$\mathcal{H}_{\text{DT-CPS}} = \{ |\Psi\rangle \mid \mathcal{C}_i |\Psi\rangle = 0, E[\Psi] = \text{finite}, \nabla \hat{t} = 0 \}, \quad (17)$$

Inner products are defined as usual,

$$\langle \Phi | \Psi \rangle = \int \mathcal{D}\chi \Phi^*[\chi] \Psi[\chi], \quad (18)$$

but expectation values correspond to static observables rather than time-dependent operators.

5. Observables in the Dense-Time Phase

Because wave dynamics are absent, admissible observables in $\mathcal{H}_{\text{DT-CPS}}$ are restricted to quantities that do not rely on temporal phase transport. These include:

- total mass–energy,
- integrated deformation pressure,
- boundary fluxes,
- geometric invariants.

Operators depending explicitly on time derivatives or oscillatory modes are undefined in $\mathcal{H}_{\text{DT-CPS}}$. This restriction is not a mathematical choice but a physical consequence of dense-time saturation.

6. Why Compression Does Not Produce Heat

In ordinary matter, compression raises temperature by exciting internal degrees of freedom that equilibrate via wave-mediated interactions. In the dense-time phase, such equilibration channels are unavailable. As a result, no ordinary interior thermalized radiative sector is generated. Energy added to the system is stored as latent chrono-pressure rather than as temperature.

To make this precise, we write a first-law bookkeeping relation for accreted mass:

$$dM = dE_{\text{lat}} + dE_{\text{bdy}} + dE_{\text{rad}}, \quad (19)$$

where E_{lat} is latent chrono-pressure energy, E_{bdy} is boundary (CQM shell) energy, and E_{rad} is any radiative emission. The dense-time assumption is:

$$dE_{\text{rad}} \approx 0, \quad dE_{\text{lat}} \gg dE_{\text{th}}, \quad (20)$$

so infalling energy is stored predominantly as latent chrono-pressure. An effective interior temperature is defined only as a response parameter via

$$T_{\text{eff}}^{-1} = \left(\frac{\partial S_{\text{DT}}}{\partial E_{\text{lat}}} \right)_{\mathcal{Q}}, \quad (21)$$

where $\mathcal{Q}$ denotes the constrained extensive variables held fixed. This effective temperature is a boundary-thermodynamic bookkeeping quantity, not evidence for an ordinary gas of propagating interior modes.

This provides a natural explanation for the observational fact that black hole interiors do not behave as hot plasmas despite extreme pressure.

7. Variational Principle in the Dense-Time Phase

Dense-time quantum mechanics is not organized around time-evolution. Instead, the DT-CPS is defined by a constrained extremum principle: the physically realized interior configuration is the stationary point of a *timeless* functional subject to saturation constraints and boundary data.

7.1. Field Content and Dense-Time Constraints

We take the interior to be described by a complex timeon field,

$$\Phi(\mathbf{x}) = \hat{t}(\mathbf{x}) e^{i\theta(\mathbf{x})}, \quad (22)$$

but in the dense phase the following physical constraints apply:

1) **Saturation:** the amplitude is driven to a plateau value,

$$\hat{t}(\mathbf{x}) \rightarrow \hat{t}_{\text{sat}} \quad \text{for } \mathbf{x} \in \mathcal{V}_{\text{int}}. \quad (23)$$

2) **No phase-transport:** extended phase gradients cannot be supported, so the interior cannot sustain coherent spatial phase structure:

$$\nabla \theta(\mathbf{x}) \rightarrow \mathbf{0} \quad \text{for } \mathbf{x} \in \mathcal{V}_{\text{int}}. \quad (24)$$

3) **No time-parametrized dynamics:** time derivatives are not physically meaningful inside the DT-CPS. Hence, the interior action contains *no* ∂_t terms.

7.2. Timeless (Euclidean) Interior Action

Because the dense-time phase cannot support time-parametrized propagation, the appropriate interior functional is a three-dimensional Euclidean action defined on spatial slices of the interior volume $\mathcal{V}_{\text{int}}$:

$$S_{\text{int}}[\hat{t}, \theta] = \int_{\mathcal{V}_{\text{int}}} d^3x \sqrt{h} \mathcal{L}_{\text{DT}}(\hat{t}, \theta; \nabla \hat{t}, \nabla \theta), \quad (25)$$

where $\sqrt{h}$ is the determinant of the induced spatial metric (in the spherical ansatz of Sec. 12 this factor is absorbed into the radial measure $r^2 dr$).

The minimal dense-time Lagrangian density consistent with: 1) finite energy, 2) saturation, 3) absence of propagating modes, is

$$\mathcal{L}_{\text{DT}} = \frac{Z_t}{2} (\nabla \hat{t})^2 + \frac{Z_\theta}{2} \hat{t}^2 (\nabla \theta)^2 + V_{\text{DT}}(\hat{t}) \quad (26)$$

where Z_t and Z_θ are the stiffness moduli (units of Force) inherited from the BPS theory, and $V_{\text{DT}}(\hat{t})$ is a dense-phase potential that enforces saturation at $\hat{t}_{\text{sat}}$. Its exact algebraic form from first principles remains an open function of the theory (see Section 15.12); a model-agnostic expansion about the saturation point is:

$$V_{\text{DT}}(\hat{t}) = \lambda_2 (\hat{t} - \hat{t}_{\text{sat}})^2 + \lambda_4 (\hat{t} - \hat{t}_{\text{sat}})^4 + \dots, \quad \lambda_2 > 0, \quad (27)$$

so that deviations from saturation carry an energetic penalty. The coefficients λ_2, λ_4 are not free parameters to be fit but stand-ins for a derivation from the microscopic BPS sector; until that derivation is completed, the precise energetic penalty for deviations from saturation and the dynamical timescale τ_{CS} of the Chrono-Shear transition (Equation (114)) cannot be computed from first principles.

7.3. Constraint-Augmented Action

To impose dense-time physics as *hard constraints* rather than soft penalties, we introduce Lagrange multiplier fields $\mu(\mathbf{x})$ and $\nu(\mathbf{x})$:

$$S_{\text{tot}} = S_{\text{int}} + \int_{\mathcal{V}_{\text{int}}} d^3x [\mu(\mathbf{x}) (\hat{t}(\mathbf{x}) - \hat{t}_{\text{sat}}) + \nu(\mathbf{x}) \cdot \nabla \theta(\mathbf{x})] + S_\Sigma. \quad (28)$$

Here:

- μ enforces saturation pointwise,
- ν enforces phase-quench (no phase texture),
- S_Σ is the boundary action at the Chrono-Quantum Mirror Σ .

8. Euler-Lagrange Equations as Constraint Equations

Varying S_{tot} with respect to $\hat{t}$, θ , μ , and ν yields the dense-time field equations.

8.1. Variation with Respect to the Multipliers

a) *Saturation constraint:*

$$\frac{\delta S_{\text{tot}}}{\delta \mu} = 0 \Rightarrow \hat{t}(\mathbf{x}) = \hat{t}_{\text{sat}}. \quad (29)$$

b) *Phase-quench constraint:*

$$\frac{\delta S_{\text{tot}}}{\delta \nu} = 0 \Rightarrow \nabla \theta(\mathbf{x}) = \mathbf{0}. \quad (30)$$

8.2. Variation with Respect to $\hat{t}$

$$\frac{\delta S_{\text{tot}}}{\delta \hat{t}} = 0 \Rightarrow -Z_t \nabla^2 \hat{t} + Z_\theta \hat{t} (\nabla \theta)^2 + \frac{dV_{\text{DT}}}{d\hat{t}} + \mu(\mathbf{x}) = 0. \quad (31)$$

Under the dense-time constraints (29) and (30), this reduces to a *static balance* condition determining μ :

$$\mu(\mathbf{x}) = - \left. \frac{dV_{\text{DT}}}{d\hat{t}} \right|_{\hat{t}=\hat{t}_{\text{sat}}}. \quad (32)$$

8.3. Variation with Respect to θ

$$\frac{\delta S_{\text{tot}}}{\delta \theta} = 0 \Rightarrow -Z_\theta \nabla \cdot (\hat{t}^2 \nabla \theta) - \nabla \cdot \nu = 0. \quad (33)$$

Under $\nabla \theta = \mathbf{0}$, (33) becomes a compatibility condition for ν .

9. Boundary Action and the Chrono-Quantum Mirror

The interior plateau alone does not define a black hole. The physics is completed by a boundary condition at the Chrono-Quantum Mirror Σ , the finite phase boundary separating the exterior wave-capable vacuum phase from the interior dense-time phase. We therefore include a boundary term:

$$S_\Sigma = \int_\Sigma d^2 \Omega \mathcal{B}(\hat{t}, \theta; \nabla_n \hat{t}, \nabla_n \theta), \quad (34)$$

where ∇_n denotes the normal derivative at the boundary. A minimal physically motivated choice is a penalty enforcing continuity of the amplitude while allowing a sharp gradient layer:

$$\mathcal{B} = \frac{\kappa_\Sigma}{2} (\hat{t}|_{\Sigma^-} - \hat{t}|_{\Sigma^+})^2 + \frac{\kappa_\theta}{2} (\theta|_{\Sigma^-} - \theta|_{\Sigma^+})^2 + \dots, \quad (35)$$

where Σ^- denotes the exterior side and Σ^+ the interior side.

Metric Junction Conditions at the CQM

To establish the CQM as a proper matching surface rather than only a narrative interface, we impose Israel junction conditions at Σ [14] [15]. Let h_{ab} denote the induced metric on Σ and K_{ab} its extrinsic curvature. The two junction conditions are:

$$[h_{ab}]_{\Sigma} = 0, \quad (36)$$

$$[K_{ab} - h_{ab}K]_{\Sigma} = 8\pi GS_{ab}^{(\Sigma)}, \quad (37)$$

where $[\cdot]_{\Sigma}$ denotes the jump across Σ and $S_{ab}^{(\Sigma)}$ is the effective surface stress-energy of the CQM shell. The first condition requires the induced metric to be continuous across the boundary. The second relates the jump in extrinsic curvature to the shell stress-energy, which encodes the interface tension $\sigma(\hat{t})$ (one of the three closing functions of Section 15.12). Even with $S_{ab}^{(\Sigma)}$ left model-dependent, writing these conditions establishes that the boundary is a proper matching surface in the sense of general relativity, and that its energetics are fully determined once $\sigma(\hat{t})$ is specified.

10. Interpretation: Why This Is Quantum Mechanics

This variational formulation is “quantum” in the following precise sense:

- The interior state is not a classical fluid of particles; it is a constrained ground configuration of a fundamental field Φ .
- The absence of wave-supported dynamics does not imply loss of quantization; it implies a change in which degrees of freedom exist. The admissible state space is reduced to constraint-satisfying sectors.
- What replaces unitary evolution is a static sector decomposition: the DT-CPS is the saturated sector, and transitions (e.g. Chrono-Shear) correspond to non-perturbative sector jumps.

11. Hamiltonian Structure in the Dense-Time Phase

In ordinary quantum theory, the Hamiltonian generates unitary evolution in time. In the dense-time phase, time-parametrized evolution is a nearly unsupported operation. Accordingly, the role of the Hamiltonian is *not* to generate wave dynamics, but to 1) define the conserved interior energy functional, 2) enforce the dense-phase constraints, and 3) provide the correct boundary bookkeeping at the Chrono-Quantum Mirror.

11.1. Canonical Momenta (Formal Completeness)

Start from a standard Lorentz-invariant parent Lagrangian for the timeon field,

$$\mathcal{L}_{\Phi}^{(4)} = \partial_{\mu}\Phi^{*}\partial^{\mu}\Phi - V(|\Phi|^2), \quad \Phi = \hat{t}e^{i\theta}, \quad (38)$$

so that (in $\hat{t}, \theta$ variables)

$$\mathcal{L}_{\Phi}^{(4)} = (\partial_{\mu} \hat{t}) (\partial^{\mu} \hat{t}) + \hat{t}^2 (\partial_{\mu} \theta) (\partial^{\mu} \theta) - V(\hat{t}^2). \quad (39)$$

The canonical momenta are then

$$\pi_{\hat{t}} \equiv \frac{\partial \mathcal{L}_{\Phi}^{(4)}}{\partial (\partial_t \hat{t})} = 2 \partial_t \hat{t}, \quad (40)$$

$$\pi_{\theta} \equiv \frac{\partial \mathcal{L}_{\Phi}^{(4)}}{\partial (\partial_t \theta)} = 2 \hat{t}^2 \partial_t \theta. \quad (41)$$

In the dense-time phase, the timeon field has reached the dense phase discrete state critical limit: $\hat{t} = \hat{t}_{\text{sat}}$. At saturation the field carries little remaining phase-gradient budget to support propagating excitations—the available degrees of freedom are bounded deformations of the lattice, redshifted waves. The physical statement is therefore that *time-parametrized transport and time-parametrized wave dynamics in conventional radiative bands have little physical support*. Operationally, the allowed interior configurations approach the static limits

$$\partial_t \hat{t} = 0, \quad \partial_t \theta = 0, \quad (42)$$

so the canonical momenta vanish on the dense-time constraint surface:

$$\pi_{\hat{t}} = 0, \quad \pi_{\theta} = 0. \quad (43)$$

11.2. Ultra-Low-Frequency Modes and Dense-Time Phase Stability

The vanishing of the canonical momenta does not imply the complete disappearance of wave dynamics. Rather, the extreme temporal dilation of the dense-time phase shifts all propagating modes to ultra-low frequencies—far below conventional electromagnetic or radiative bands, but not to zero.

The timeon phase field θ carries propagating excitations with bare dispersion relation $\omega_0(k)$ in the exterior vacuum phase. In the dense-time interior these modes are dressed by the local time-density field through a temporal dilation factor Z_t :

$$\omega_{\text{eff}}(k) = Z_t^{-1} \omega_0(k), \quad (44)$$

where Z_t is the stiffness modulus of the dense-phase Lagrangian (Section 15.12). As gravitational compression deepens into the dense-time regime, $Z_t \gg 1$, so that

$$\omega_{\text{eff}}(k) \ll \omega_0(k). \quad (45)$$

Modes are not eliminated; they are stretched to extremely long periods.

The dense-time state is further organized into discrete stable phase levels $\hat{t}_n$, analogous to quantized orbital states, which correspond to local minima of the effective dense-phase potential $V_{\text{eff}}(\hat{t})$. Under continued gravitational compression the system does not collapse continuously but settles into successive stable configurations:

$$\hat{t} = \hat{t}_n + \delta \hat{t}, \quad (46)$$

where $\delta \hat{t}$ is a small oscillatory perturbation about the stable minimum. These

perturbations are slow temporal oscillations of the dense-time field itself. Because the underlying temporal scale is strongly dilated at each level $\hat{t}_n$, such oscillations manifest as ultra-low-frequency modes—potentially in the kilohertz, hertz, or sub-hertz regime—rather than as conventional high-frequency radiation.

The dense-time interior may therefore be understood as a *redshift-saturated slow-wave resonant cavity*: oscillatory dynamics persist, but at periods so long that the interior produces no signal in any conventional radiative band. Whether these ultra-low-frequency modes couple to observable channels outside the CQM depends on the low-frequency behavior of the reflectivity $G(\omega)$ at $\omega \ll \omega_0$ —a quantity that is not yet computed and constitutes an open prediction of the framework. A complete calculation of $G(\omega)$ requires specifying the CQM constitutive law $\sigma(\hat{t})$ and solving the wave equation across the finite-thickness shell; the result would determine whether ULF interior modes produce any imprint on exterior gravitational-wave strain at frequencies accessible to current or planned detectors such as LISA or the Einstein Telescope. What the framework does establish is that the absence of high-frequency radiative signatures from black hole interiors is not evidence for the absence of all dynamics, but for the extreme redshifting of those dynamics below detectable thresholds.

11.3. Hamiltonian Density and Static Reduction

The Hamiltonian density obtained from (39) is

$$\mathcal{H}_{\Phi}^{(4)} = \frac{1}{4} \pi_{\hat{t}}^2 + \frac{1}{4\hat{t}^2} \pi_{\hat{\theta}}^2 + (\nabla \hat{t})^2 + \hat{t}^2 (\nabla \theta)^2 + V(\hat{t}^2). \quad (47)$$

Restricting to the dense-time constraint surface (43) gives the *static* Hamiltonian density:

$$\boxed{\mathcal{H}_{\text{DT}} = \frac{Z_t}{2} \left[(\nabla \hat{t})^2 + \hat{t}^2 (\nabla \theta)^2 \right] + V(\hat{t}^2)}. \quad (48)$$

11.4. Dense-Phase Constrained Hamiltonian (DT-CPS Sector)

Inside the DT-CPS, the dense-phase constraints are:

$$\hat{t}(\mathbf{x}) = \hat{t}_{\text{sat}}, \quad \nabla \theta(\mathbf{x}) = \mathbf{0}. \quad (49)$$

To enforce these as hard constraints, define the constrained Hamiltonian functional

$$\boxed{H_{\text{DT}}[\hat{t}, \theta; \mu, \mathbf{v}] = \int_{\mathcal{V}_{\text{int}}} d^3x \left[\frac{Z_t}{2} \left((\nabla \hat{t})^2 + \hat{t}^2 (\nabla \theta)^2 \right) + V_{\text{DT}}(\hat{t}) + \mu(\hat{t} - \hat{t}_{\text{sat}}) + \mathbf{v} \cdot \nabla \theta \right] + H_{\Sigma}}. \quad (50)$$

Here H_{Σ} is the boundary energy associated with the Chrono-Quantum Mirror Σ . A minimal penalty form (kept general) is:

$$H_{\Sigma} = \int_{\Sigma} d^2\Omega \left[\frac{\kappa_{\Sigma}}{2} \left(\hat{t}|_{\Sigma^-} - \hat{t}|_{\Sigma^+} \right)^2 + \frac{\kappa_{\theta}}{2} \left(\theta|_{\Sigma^-} - \theta|_{\Sigma^+} \right)^2 + \dots \right]. \quad (51)$$

11.5. Energy Accounting: Why Black Holes Do Not “Heat” Like Baryonic Cores

In a star or planet, pressure does work on *wave-supporting* microscopic degrees of freedom: collisional and radiative channels exist, enabling thermalization and temperature rise. In the DT-CPS, those channels do not exist.

On the dense-time constraint surface, (49) implies

$$\nabla \hat{t} \approx 0, \quad \nabla \theta \approx 0, \quad (52)$$

so the gradient contributions in (48) vanish, leaving

$$H_{\text{DT}} \approx \int_{\mathcal{V}_{\text{int}}} d^3x V_{\text{DT}}(\hat{t}_{\text{sat}}) + H_{\Sigma}. \quad (53)$$

Thus, the interior energy is stored primarily as *latent chrono-pressure* (potential-sector energy), not as thermal occupation of propagating modes.

11.6. Dense-Time “Quantization” and Sector Projection

Because unitary time evolution is not the organizing principle in the $\hat{t}_2$ phase, the quantum description is naturally phrased as a sector projection. Let $\mathcal{H}_{\Phi}$ be the timeon Hilbert space from the BPS theory. Define the dense-time constraint operator(s) schematically as

$$\hat{\mathcal{C}}_1(\mathbf{x}) \equiv \hat{t}(\mathbf{x}) - \hat{t}_{\text{sat}}, \quad \hat{\mathcal{C}}_2(\mathbf{x}) \equiv \nabla \hat{\theta}(\mathbf{x}), \quad (54)$$

and define the dense-time physical subspace as

$$\mathcal{H}_{\text{DT}} = \left\{ |\Psi\rangle \in \mathcal{H}_{\Phi} \mid \hat{\mathcal{C}}_1(\mathbf{x})|\Psi\rangle = 0, \hat{\mathcal{C}}_2(\mathbf{x})|\Psi\rangle = 0 \quad \forall \mathbf{x} \in \mathcal{V}_{\text{int}} \right\}. \quad (55)$$

Throughout this paper $\mathcal{H}_{\text{DT}} \equiv \mathcal{H}_{\text{DT-CPS}}$; the abbreviated form is used wherever no ambiguity arises.

12. Spherical Ansatz and Boundary Conditions for the DT-CPS

This section constructs the simplest consistent interior-boundary-exterior structure for a black hole in the timeon framework: 1) a saturated dense-time interior (DT-CPS), 2) a finite-thickness Chrono-Quantum Mirror (CQM) transition layer, and 3) an exterior wave-supporting vacuum/atomic environment.

12.1. Geometry and Regions

Assume an effective spherical symmetry about the compact object. Let r denote the areal radius and define three regions:

- 1) **Interior (DT-CPS):** $0 \leq r < r_{\Sigma}^{-}$, where the dense-time constraints hold:

$$\hat{t}(r) = \hat{t}_{\text{sat}}, \quad \theta(r) = \theta_0, \quad \nabla \theta = 0. \quad (56)$$

- 2) **CQM shell:** $r_{\Sigma}^{-} \leq r \leq r_{\Sigma}^{+}$, a finite-thickness layer of width $\Delta_{\Sigma} \equiv r_{\Sigma}^{+} - r_{\Sigma}^{-}$ in which the timeon field transitions between dense and exterior phases.

- 3) **Exterior:** $r > r_{\Sigma}^{+}$, where the timeon field relaxes to the low-density phase:

$$\hat{t}(r) \rightarrow \hat{t}_\infty \approx \hat{t}_{\text{vac}}, \quad \nabla \theta \rightarrow \mathbf{0}. \quad (57)$$

12.2. Spherical Ansatz

Write the timeon in polar form,

$$\Phi(\mathbf{x}) = \hat{t}(\mathbf{x}) e^{i\theta(\mathbf{x})}, \quad (58)$$

and adopt a purely radial ansatz in the shell:

$$\hat{t}(\mathbf{x}) = \hat{t}(r), \quad \theta(\mathbf{x}) = \theta(r). \quad (59)$$

12.3. Mass Function and Metric Coupling

To tie the dense-time matter sector directly to the spherical geometry, define the interior mass function $m(r)$ by

$$m'(r) = 4\pi r^2 \rho_{\text{DT}}(r), \quad (60)$$

so that the standard Schwarzschild-like redshift factor

$$1 - \frac{2Gm(r)}{c^2 r} \quad (61)$$

plays its usual role in the interior line element. Even though the full metric is not solved in closed form here, this relation establishes exactly how the dense-time matter sector couples into the spherical geometry and recovers $r_\Sigma = 2GM/c^2$ at the CQM boundary when $m(r_\Sigma) = M$.

The relevant functional to minimize in the shell is the static energy functional:

$$E_\Sigma[\hat{t}, \theta] = 4\pi \int_{r_\Sigma^-}^{r_\Sigma^+} dr r^2 \left[\left(\frac{d\hat{t}}{dr} \right)^2 + \hat{t}^2 \left(\frac{d\theta}{dr} \right)^2 + V_\Sigma(\hat{t}) \right], \quad (62)$$

where V_Σ is the effective shell potential.

12.4. Radial Euler-Lagrange Equations (Shell Only)

Varying (62) yields the shell equations:

a) *Amplitude equation*

$$\frac{d^2 \hat{t}}{dr^2} + \frac{2}{r} \frac{d\hat{t}}{dr} - \hat{t} \left(\frac{d\theta}{dr} \right)^2 - \frac{1}{2} \frac{dV_\Sigma}{d\hat{t}} = 0, \quad r_\Sigma^- \leq r \leq r_\Sigma^+. \quad (63)$$

b) *Phase equation*

$$\frac{d}{dr} \left(r^2 \hat{t}^2 \frac{d\theta}{dr} \right) = 0 \Rightarrow r^2 \hat{t}^2 \frac{d\theta}{dr} = J, \quad (64)$$

where J is a conserved radial phase-current constant across the shell.

12.5. Dense-Time Condition: Nearly Unsupported Phase Transport

The DT-CPS interior approaches zero phase current. Therefore,

$$J = 0 \Rightarrow \frac{d\theta}{dr} = 0 \quad \text{throughout the shell and exterior in equilibrium.} \quad (65)$$

With $d\theta/dr = 0$, (63) simplifies to

$$\frac{d^2\hat{t}}{dr^2} + \frac{2}{r} \frac{d\hat{t}}{dr} - \frac{1}{2} \frac{dV_\Sigma}{d\hat{t}} = 0, \quad r_\Sigma^- \leq r \leq r_\Sigma^+. \quad (66)$$

12.6. Boundary Conditions

a) (A) *Center regularity (interior)*

$$\hat{t}(0) = \hat{t}_{\text{sat}}, \quad \hat{t}'(0) = 0, \quad \theta(r) \equiv \theta_0. \quad (67)$$

b) (B) *Inner shell matching at $r = r_\Sigma^-$*

$$\hat{t}(r_\Sigma^-) = \hat{t}_{\text{sat}}, \quad \hat{t}'(r_\Sigma^-) = 0, \quad \theta'(r_\Sigma^-) = 0. \quad (68)$$

c) (C) *Outer shell matching at $r = r_\Sigma^+$*

$$\hat{t}(r_\Sigma^+) = \hat{t}_{\text{ext}}, \quad \hat{t}'(r_\Sigma^+) = \hat{t}'_{\text{ext}}, \quad \theta'(r_\Sigma^+) = 0. \quad (69)$$

d) (D) *Far-field asymptotics*

$$\lim_{r \rightarrow \infty} \hat{t}(r) = \hat{t}_\infty, \quad \lim_{r \rightarrow \infty} \hat{t}'(r) = 0, \quad \lim_{r \rightarrow \infty} \theta'(r) = 0. \quad (70)$$

12.7. CQM Anchoring via the Critical Time-Density Threshold

We impose the operational anchoring:

$$\boxed{\hat{t}(r_\Sigma^+) \equiv \hat{t}_{\text{ext}} \approx \hat{t}_{\text{crit}}, \quad \hat{t}(r_\Sigma^-) \equiv \hat{t}_{\text{sat}} \gg \hat{t}_{\text{crit}}.} \quad (71)$$

13. DT-CPS Hydrodynamics: Perfect-Fluid Limit, Viscosity, and Merger Timescales

In the dense-time phase, discrete BPS texture is lost and the interior approaches a saturated plateau. This motivates an effective hydrodynamic description of the DT-CPS as a relativistic fluid.

13.1. Effective Stress-Energy Tensor

We treat the DT-CPS interior as a coarse-grained continuum with four-velocity u^μ ($u_\mu u^\mu = -1$) and rest-frame energy density ρ_{DT} . To leading order it is a perfect fluid:

$$T_{\text{DT}}^{\mu\nu} = (\rho_{\text{DT}} + p_{\text{DT}}) u^\mu u^\nu + p_{\text{DT}} g^{\mu\nu}. \quad (72)$$

To capture departures from equilibrium during rapid merger/relaxation, we add standard first-order dissipative terms following the formalism of Landau and Lifshitz [16]:

$$T_{\text{DT}}^{\mu\nu} = (\rho_{\text{DT}} + p_{\text{DT}}) u^\mu u^\nu + p_{\text{DT}} g^{\mu\nu} - 2\eta \sigma^{\mu\nu} - \zeta_B \Theta \Delta^{\mu\nu}, \quad (73)$$

where $\Delta^{\mu\nu} = g^{\mu\nu} + u^\mu u^\nu$, $\Theta \equiv \nabla_\alpha u^\alpha$, and

$$\sigma^{\mu\nu} \equiv \frac{1}{2} \Delta^{\mu\alpha} \Delta^{\nu\beta} (\nabla_\alpha u_\beta + \nabla_\beta u_\alpha) - \frac{1}{3} \Theta \Delta^{\mu\nu} \quad (74)$$

is the shear tensor.

13.2. Why the DT-CPS Tends toward an Inviscid (Low- η) Fluid

When the interior saturates,

$$\nabla \hat{t} \rightarrow 0, \nabla \theta \rightarrow 0, \quad (75)$$

so the free-energy cost of transverse displacement vanishes to leading order. We therefore model an effective shear modulus G_{eff} collapsing,

$$G_{\text{eff}} \rightarrow 0 \Rightarrow \eta \approx 0 \quad (\text{near-inviscid DT-CPS}). \quad (76)$$

13.3. Equation of State and Sound Speed

We introduce an EOS parameterization:

$$p_{\text{DT}} = w_{\text{DT}} \rho_{\text{DT}}, \quad 0 \leq w_{\text{DT}} \leq 1, \quad (77)$$

with corresponding adiabatic sound speed

$$c_s^2 \equiv \left. \frac{\partial p_{\text{DT}}}{\partial \rho_{\text{DT}}} \right|_s = w_{\text{DT}} c^2. \quad (78)$$

The value of w_{DT} is uniquely determined by the DT-CPS constraint structure; the derivation is given in Section 14.4.

13.4. CQM as an Effective Surface: Tension and Capillary Relaxation

Define an effective surface tension for the CQM shell:

$$\sigma_\Sigma \equiv \int_{\hat{r}_\Sigma^-}^{\hat{r}_\Sigma^+} dr \left[\left(\frac{d\hat{t}}{dr} \right)^2 + V_\Sigma(\hat{t}) - V_{\text{DT}}(\hat{t}_{\text{sat}}) \right]. \quad (79)$$

13.5. Merger/Coalescence Timescale

A robust timescale in relativistic compact-object dynamics is $t_g \equiv GM/c^3$. In the dense-time framework, the interior does not dynamically “flow” to a new equilibrium because internal time evolution is suppressed ($\partial_t \hat{t} \approx 0$). Instead, the relaxation is driven by the **exterior** boundary dynamics and the shedding of angular momentum via gravitational radiation.

The interior updates quasi-statically, instantly satisfying the new boundary constraints imposed by the relaxing Chrono-Quantum Mirror. The observable ring-down timescale is therefore determined by the CQM response stiffness, not internal viscosity:

$$t_{\text{relax}} \sim \kappa \frac{GM}{c^3}, \quad \kappa \sim 10 - 20, \quad (80)$$

where κ characterizes the geometric response of the shell.

13.6. Why Dense Interiors Do Not “Heat Up” Like Planets or Stars

We distinguish radiative temperature from effective bookkeeping temperature:

$$\begin{aligned} T_{\text{rad}} & \text{ (radiative/Planck temperature) versus} \\ T_{\text{eff}} & \text{ (thermodynamic bookkeeping parameter).} \end{aligned} \quad (81)$$

14. Thermodynamics in the Dense-Time Phase: Effective Temperature without Radiation

14.1. Two Notions of Temperature: T_{rad} versus T_{eff}

If photon modes are nearly unsupported and redshifted near zero, a Planck bath cannot form [17]:

$$\hat{t} > \hat{t}_{\text{crit}} \Rightarrow \text{no stable Planck bath} \Rightarrow T_{\text{rad}} \text{ undefined (or operationally meaningless)}. \quad (82)$$

In this sense, the onset of the dense-time phase does not correspond to heating or cooling in the conventional thermodynamic meaning. Rather, when a collapsing object crosses into the dense-time phase, its interior loses access to *heat as a physical concept*: wave-mediated equilibration channels nearly cease to exist, radiative temperature becomes undefined, and gravitational work is stored as latent chrono-pressure instead of thermal excitation. Nevertheless, we introduce an effective temperature by a local Gibbs relation:

$$d\rho_{\text{DT}} = T_{\text{eff}} ds_{\text{DT}} + \mu_{\text{eff}} dn_{\text{eff}}. \quad (83)$$

In the simplest closure, $dn_{\text{eff}} = 0$ in the bulk:

$$d\rho_{\text{DT}} = T_{\text{eff}} ds_{\text{DT}}. \quad (84)$$

14.2. Entropy Current and the Second Law

Let $s^\mu = s_{\text{DT}} u^\mu$. The local second law is

$$\nabla_\mu s^\mu \geq 0. \quad (85)$$

A standard viscous form gives

$$\nabla_\mu s^\mu = \frac{2\eta}{T_{\text{eff}}} \sigma_{\mu\nu} \sigma^{\mu\nu} + \frac{\zeta_B}{T_{\text{eff}}} \Theta^2 + \frac{\kappa_T}{T_{\text{eff}}^2} (\nabla_\mu T_{\text{eff}}) (\nabla^\mu T_{\text{eff}}) \geq 0. \quad (86)$$

14.3. Why “No Heating” Occurs: Work Is Stored as Latent Chrono-Pressure

Local energy conservation is

$$\nabla_\mu T_{\text{DT}}^{\mu\nu} = 0. \quad (87)$$

We split the bulk energy density into thermalizable and latent parts:

$$\rho_{\text{DT}} = \rho_{\text{th}} + \rho_\chi. \quad (88)$$

Define the latent chrono-pressure:

$$P_\chi \equiv - \left. \frac{\partial E_\chi}{\partial V} \right|_{\text{bulk}} \Leftrightarrow p_\chi \equiv - \left. \frac{\partial \rho_\chi}{\partial \ln V} \right|_{\text{bulk}}. \quad (89)$$

Here P_χ (capital) denotes the total pressure (force per area) and p_χ (lower case) the energy-density form; the two are related by $P_\chi = p_\chi$ in the bulk uniform limit.

The “no heating” condition is:

$$\frac{d\rho_\chi}{d\tau} \gg \frac{d\rho_{\text{th}}}{d\tau} \quad (\hat{t} \gtrsim \hat{t}_{\text{crit}}). \quad (90)$$

14.4. Mass Scaling of Latent Chrono-Pressure

The DT-CPS interior obeys $p_{\text{DT}} = w_{\text{DT}} \rho_{\text{DT}}$ (Equation (77)), and all accreted energy is stored as latent chrono-pressure (Equation (90)):

$$\rho_{\text{DT}} \approx \frac{Mc^2}{\mathcal{V}_{\text{int}}}. \quad (91)$$

With $r_{\Sigma} = 2GM/c^2$ (Equation (104)):

$$\mathcal{V}_{\text{int}} = \frac{32\pi G^3 M^3}{3c^6}, \quad (92)$$

$$\rho_{\text{DT}} \approx \frac{3c^8}{32\pi G^3 M^2}, \quad (93)$$

giving the chrono-pressure

$$P_{\chi}(M) = w_{\text{DT}} \rho_{\text{DT}} \approx \frac{3w_{\text{DT}} c^8}{32\pi G^3 M^2}. \quad (94)$$

$P_{\chi} \propto M^{-2}$: the chrono-pressure *falls* as mass grows because interior volume grows as M^3 while stored energy grows as M . The product $P_{\chi} \cdot \mathcal{V}_{\text{int}}$ is, however,

$$P_{\chi}(M) \cdot \mathcal{V}_{\text{int}} = w_{\text{DT}} Mc^2 \stackrel{!}{=} Mc^2, \quad (95)$$

which requires

$$w_{\text{DT}} = 1, \quad (96)$$

the Zeldovich stiff-fluid limit [18] [19]. The equation-of-state parameter $w_{\text{DT}} \equiv p_{\text{DT}}/\rho_{\text{DT}}$ is dimensionless in every unit system; here ρ_{DT} denotes the dense-time energy density (so that p_{DT} and ρ_{DT} carry the same units), and the identification above is unit-independent.

To see this as a compact derivation rather than a persuasive argument: in the dense phase, all energy is stored as latent compression energy with little or no thermalizable remainder, so

$$\rho_{\text{DT}} = \rho_{\text{lat}}, \quad p_{\text{DT}} = p_{\text{lat}}, \quad (97)$$

hence

$$w_{\text{DT}} \equiv \frac{p_{\text{DT}}}{\rho_{\text{DT}}} = 1. \quad (98)$$

The causal consistency remark follows immediately:

$$c_s^2 = \frac{dp}{d\rho} = 1 \quad (\text{in units } c = 1), \quad (99)$$

identifying $w_{\text{DT}} = 1$ as the limiting causal equation of state—not an arbitrary phenomenological choice. This value is selected not merely because it is convenient, but because it is the unique barotropic value consistent with: 1) maximally stored latent compression energy, 2) absence of an ordinary radiative heat bath, and 3) causal saturation.

This EOS is not assumed; it is the unique value consistent with both the DT-

CPS structure and the deconfinement condition, and it corresponds to the maximally compact saturated condensate expected on independent grounds. Equation (95) then holds *identically for all* M : the DT-CPS is always at the energy threshold of its own deconfinement. The CQM prevents the CSE from firing until the geometric condition (105) is met.

14.5. Thermodynamic Closure: Effective Free Energy

Introduce an effective free-energy density $\mathcal{F}_{\text{DT}}(\hat{t})$:

$$\left. \frac{\partial \mathcal{F}_{\text{DT}}}{\partial \hat{t}} \right|_{\hat{t}_{\text{sat}}} = 0, \quad \left. \frac{\partial^2 \mathcal{F}_{\text{DT}}}{\partial \hat{t}^2} \right|_{\hat{t}_{\text{sat}}} \geq 0. \quad (100)$$

Identify

$$\rho_\chi \simeq \mathcal{F}_{\text{DT}}(\hat{t}_{\text{sat}}), \quad p_\chi \simeq -\mathcal{F}_{\text{DT}}(\hat{t}_{\text{sat}}). \quad (101)$$

14.6. Interface Bookkeeping Temperature

Allow an interface first-law form:

$$\delta E_\Sigma = T_\Sigma \delta S_\Sigma - p_\Sigma \delta A + \dots, \quad (102)$$

where T_Σ is not a radiative Hawking temperature but the conjugate to boundary entropy in the CQM effective theory.

14.7. Consequences

- 1) **Radiative darkness is intrinsic:** T_{rad} is not a meaningful bulk state variable.
- 2) **Merger energy partitions gravitationally:** free energy prefers GW/ring-down over EM.
- 3) **Compression stores latent energy:** accretion increases the integrated latent energy E_χ and the global lattice strain load, even though the local chrono-pressure density scales as $P_\chi \propto M^{-2}$ under the spherical volume law of Equation (94).

15. Quantum Mechanics of the Chrono-Shear Event

The Chrono-Shear Event (CSE) is the terminal phase transition of the Dense-Time Collective Partner State (DT-CPS)—and the mechanism by which an entire causal domain converts its accumulated mass–energy into the initial condition for the next. In this framework the CSE is neither an ordinary hydrodynamic blow-up nor a classical singularity; it is a *collective quantum phase transition* of the timeon lattice in which the saturated state $\hat{t}_2$ passes irreversibly into the shear phase $\hat{t}_3$.

The cause is geometric, not thermodynamic. Every Baryon Partner State [12] stores its rest-mass energy as deformation energy in the atomic well of the timeon lattice potential. The DT-CPS is the aggregate of all such wells compressed into one saturated object; its total stored energy is therefore exactly

$$E_{\text{stored}} = Mc^2, \quad (103)$$

where M is the accumulated mass. This energy is confined by the Chrono-

Quantum Mirror Σ , whose radius

$$r_{\Sigma}(M) = \frac{2GM}{c^2} \quad (104)$$

grows linearly with M . The domain embedding the DT-CPS has a fixed causal horizon r_{domain} —the Hubble radius of the parent universe, set at its causal onset. A valid CQM requires a finite exterior: $r_{\Sigma} < r_{\text{domain}}$. The phase boundary between interior dense phase and exterior wave phase requires an outside to be defined.

The CSE is triggered by the *final merger*—the single coalescence that pushes total mass across

$$M_1 + M_2 \geq M_{\text{crit}} \equiv \frac{c^2 r_{\text{domain}}}{2G}. \quad (105)$$

At this threshold the combined CQM radius equals the domain horizon. No valid exterior exists. The phase boundary has no solution. The terminal event is therefore *geometrically triggered*, not pressure-triggered in the ordinary hydrodynamic sense: it is the loss of a valid confining exterior, not a pressure blow-up, that drives the instability. This is captured compactly as

$$r_{\Sigma}(M) = \frac{2GM}{c^2} \text{ and } r_{\Sigma}(M_{\text{crit}}) = r_{\text{domain}}, \quad (106)$$

so that

$$M \uparrow M_{\text{crit}} \Rightarrow \text{loss of metastability of the DT-CPS and global causal reset.} \quad (107)$$

The approach to this threshold has a natural geometric measure. Define the *residual causal gap*

$$\Delta_c(M) \equiv r_{\text{domain}} - r_{\Sigma}(M) = r_{\text{domain}} \left(1 - \frac{M}{M_{\text{crit}}} \right), \quad (108)$$

which tracks the undeformed causal buffer remaining between the growing CQM and the domain horizon. Metastability of the DT-CPS requires

$$\Delta_c(M) > 0, \quad (109)$$

and the Chrono-Shear trigger is precisely the moment this buffer collapses:

$$\Delta_c(M_{\text{crit}}) = 0. \quad (110)$$

Every black hole merger throughout the cosmological epoch reduces Δ_c by a fixed increment $\delta\Delta = 2G\delta M/c^2$, making the approach to the terminal event a monotonic, cumulative geometric process rather than a sudden dynamical instability. The Chrono-Shear Event fires not when internal pressure exceeds a threshold, but when the universe runs out of room to contain its own black holes.

The value $M_{\text{crit}} = c^2 r_{\text{domain}} / (2G) \approx 3 \times 10^{53}$ kg is not the mass of any individual astrophysical black hole. It is the cumulative mass reached by the terminal object after complete hierarchical coalescence—successive mergers throughout the late cosmological epoch that reduce the domain to a single, final configuration. At this threshold, gravitational compression exceeds the stability range of all bound matter configurations: the system can no longer remain in any conventional matter

phase and undergoes a geometric phase conversion of the interior spacetime region. The merged object ceases to support ordinary matter degrees of freedom and enters the dense-time collective partner state—the redshift-saturated phase described in Section 14.4—where the entire accumulated mass–energy is stored as latent chrono-pressure until the CQM ceases to have a valid exterior. Every prior merger is inconsequential: each one accumulates mass and the CQM scales accordingly, with the DT-CPS remaining stable. The final merger is decisive: the confining geometry ceases to have a valid solution and the system deconfines instantaneously.

For a domain whose causal horizon matches the present observable universe ($r_{\text{domain}} \approx 4.4 \times 10^{26}$ m):

$$M_{\text{crit}} = \frac{c^2 r_{\text{domain}}}{2G} \approx 3 \times 10^{53} \text{ kg}, \quad (111)$$

consistent with the total energy content of the observable universe and providing an independent order-of-magnitude check with no free parameters. This sharpens the earlier order-of-magnitude estimate of a terminal hypermassive black-hole scale from Ref. [12] into a parameter-free geometric identity.

Because the DT-CPS rest mass arises entirely from timeon-field well depth, and that well depth approximately equals Mc^2 by construction, the deconfinement releases exactly

$$E_{\text{CSE}} = M_{\text{crit}} c^2. \quad (112)$$

Formally, the dense-time constraint subspace $\mathcal{H}_{\text{DT}}$ (Equation (55)) loses its support at $M = M_{\text{crit}}$: the constraint operators $\hat{\mathcal{C}}_1$ and $\hat{\mathcal{C}}_2$ cannot be simultaneously satisfied, and the DT-CPS state $|\Psi\rangle \in \mathcal{H}_{\text{DT}}$ becomes undefined. The CSE is the moment the universe becomes its own black hole: the inside/outside distinction dissolves, and $E_{\text{CSE}} = M_{\text{crit}} c^2$ instantaneously enters propagating vacuum-wave modes [12].

15.1. Physical Picture: TLP Landscape and the CSE Threshold

The Chrono-Shear Event is the dynamical failure of a metastable dense-time configuration once gravitational compression exceeds the stability scale of the Timeon Lattice Potential (TLP) landscape. Within this landscape the DT-CPS—including the full Baryon Partner State sector—occupies a metastable basin whose depth sets the binding energy of the configuration. As mass accumulates through hierarchical coalescence, the stored energy grows until the compression energy becomes comparable to the basin depth:

$$E_{\text{grav}} \gtrsim \Delta E_{\text{TLP}}, \quad (113)$$

at which point the metastable configuration can no longer remain confined. The geometric expression of this condition is Equation (105): the CQM radius reaches the domain horizon, the confining exterior ceases to exist, and ΔE_{TLP} is released as $E_{\text{CSE}} = M_{\text{crit}} c^2$.

Once the threshold is crossed the time-density field evolves rapidly away from

the metastable minimum $\hat{t}_2$ toward the shear phase $\hat{t}_3$. The transition proceeds on a dynamical timescale set by the curvature of the potential at the saddle:

$$\tau_{\text{CS}} \sim \left(\frac{\partial^2 V_{\text{TLP}}}{\partial \hat{t}^2} \bigg|_{\text{saddle}} \right)^{-1/2}, \quad (114)$$

which is rapid relative to the cosmological epoch but whose precise value depends on the open function $V_{\text{eff}}(\hat{t})$ (Section 15.12).

The released energy $E_{\text{CSE}} = M_{\text{crit}} c^2$ drives rapid expansion of the previously confined configuration. To observers embedded within the expanding daughter domain, this transition appears as the sudden onset of expansion of an extremely dense state—a global Chrono-Shear instability that restores propagating vacuum conditions and initiates a new causal expansion phase. It is not energy created from nothing; it is energy released from the metastable TLP basin and reorganized into propagating vacuum-wave modes. The CSE therefore provides a physical mechanism for a new causal onset that requires no initial singularity, no inflation, and no fine-tuning of initial conditions beyond the geometry of the preceding domain.

The following subsections develop the formal quantum mechanics underlying this picture.

15.2. Order Parameter and Phase Structure

We take the timeon field Φ to remain the fundamental order parameter,

$$\Phi(x) = \hat{t}(x) e^{i\theta(x)}, \quad (115)$$

with $\hat{t}$ the local time-density amplitude. The phases relevant here are:

- **Atomic phase** $\hat{t}_a$: localized BPS texture exists.
- **Dense phase** $\hat{t}_2$: DT-CPS saturation, $\nabla \hat{t} \approx 0$, wave-mediated transport suppressed.
- **Shear phase** $\hat{t}_3$: a transient reconfiguration regime in which global causal foliation fails, but local ordering remains meaningful in patches. During this phase the standard global Hilbert space $\mathcal{H}_{\text{DT}}$ loses its support (the constraint operators $\hat{\mathcal{C}}_1$ and $\hat{\mathcal{C}}_2$ cannot be simultaneously satisfied), yet local conservation laws are preserved in causally connected subregions. A rigorous mathematical treatment of this regime likely requires the machinery of algebraic quantum field theory or non-commutative geometry to formalize how patch-wise Hilbert sectors are defined and how unitarity is maintained locally while global time-ordering fails; this formal framework constitutes a major open direction for the theory and is left for future work.

The CSE is the transition $\hat{t}_2 \rightarrow \hat{t}_3$.

15.3. Effective Action and the Metastable Dense-Time Vacuum

To describe the CSE as a decay of a metastable state, we introduce an effective field theory for the $\hat{t}$ amplitude in the dense regime. The minimal Lorentz-invariant

(or near-invariant) bulk action is

$$S_{\text{bulk}}[\hat{t}, \theta] = \int d^4x \left[\frac{Z_t}{2} (\partial_\mu \hat{t}) (\partial^\mu \hat{t}) + \frac{Z_\theta}{2} \hat{t}^2 (\partial_\mu \theta) (\partial^\mu \theta) - V_{\text{eff}}(\hat{t}) \right], \quad (116)$$

where Z_t, Z_θ are effective stiffness parameters in the dense regime and $V_{\text{eff}}(\hat{t})$ is an effective potential with (at least) a metastable minimum at $\hat{t} = \hat{t}_2$ and a deeper or runaway channel associated with the shear phase. We emphasize that in the dense phase the phase degree θ is nearly unsupportive of long-range coherent transport; nevertheless, its local gradients still contribute to energy.

A minimal metastable potential structure is:

$$V_{\text{eff}}(\hat{t}) = V_2 + \frac{m_2^2}{2} (\hat{t} - \hat{t}_2)^2 - \frac{\kappa_3}{3} (\hat{t} - \hat{t}_2)^3 + \frac{\lambda_4}{4} (\hat{t} - \hat{t}_2)^4 + \dots, \quad (117)$$

with parameters chosen so that $\hat{t} = \hat{t}_2$ is a local minimum separated by a barrier from a decay channel toward a shear configuration.

15.4. Interface (CQM) Contribution and the Global Failure Channel

The CSE is not purely a bulk instability; it is precipitated by failure of the confining interface Σ . We encode the interface energetics with an effective surface action

$$S_\Sigma = - \int_\Sigma d^3y \sqrt{-\gamma} \left[\sigma(\hat{t}) + \frac{\kappa_\Sigma}{2} (\nabla_a \hat{t}) (\nabla^a \hat{t}) \right], \quad (118)$$

where γ_{ab} is the induced metric on Σ , $\sigma(\hat{t})$ is an effective surface tension, and κ_Σ is a surface stiffness. The net effect is that the DT-CPS interior behaves as a high-pressure medium confined by a finite-strength membrane. The CSE occurs when the effective membrane fails:

$$P_\chi(M) > P_{\text{yield}}(M) \Rightarrow \text{no static solution exists for } \Sigma. \quad (119)$$

Here P_{yield} is the maximum confining stress supportable by the CQM given the ambient lattice strain environment.

15.5. Euclidean Continuation and the CSE as Vacuum Decay

To compute the rate of a metastable decay, we utilize the Euclidean bounce formalism developed by Coleman and Callan [20] [21]. We pass to Euclidean time $\tau = it$ and define the Euclidean action S_E :

$$S_E[\hat{t}, \theta] = \int d^4x_E \left[\frac{Z_t}{2} (\partial_\mu \hat{t}) (\partial_\mu \hat{t}) + \frac{Z_\theta}{2} \hat{t}^2 (\partial_\mu \theta) (\partial_\mu \theta) + V_{\text{eff}}(\hat{t}) \right] + S_{\Sigma, E}. \quad (120)$$

The semiclassical decay rate per four-volume takes the standard bounce form

$$\frac{\Gamma}{\mathcal{V}_4} \sim A e^{-B/\hbar}, \quad B = S_E[\hat{t}_{\text{bounce}}] - S_E[\hat{t}_2], \quad (121)$$

where $\hat{t}_{\text{bounce}}$ is the Euclidean saddle (bounce) that connects the metastable dense minimum to the shear channel.

15.6. $O(4)$ Bounce and a “Global” Saturation Decay

A standard vacuum decay in scalar field theory is mediated by an $O(4)$ -symmetric bounce, $\hat{t} = \hat{t}(\rho)$, $\rho^2 = \tau^2 + r^2$, satisfying

$$\frac{d^2 \hat{t}}{d\rho^2} + \frac{3}{\rho} \frac{d\hat{t}}{d\rho} = \frac{dV_{\text{eff}}}{d\hat{t}}, \quad (122)$$

with boundary conditions

$$\left. \frac{d\hat{t}}{d\rho} \right|_{\rho=0} = 0, \quad \lim_{\rho \rightarrow \infty} \hat{t}(\rho) = \hat{t}_2. \quad (123)$$

However, the Chrono-Shear Event differs from ordinary bubble nucleation in one crucial way: the dense phase does not support stable intermediate gradients over macroscopic scales. As argued earlier, the dense regime suppresses wave-mediated propagation and long-lived phase interfaces. Consequently, the dominant saddle is not generically a slowly expanding bubble wall but a *near-simultaneous* global failure mode. We capture this by allowing the effective stiffness Z_t to diminish as $\hat{t} \rightarrow \hat{t}_2$, so that gradient energy is strongly penalized or becomes ill-defined:

$$Z_t(\hat{t}) \rightarrow 0 \text{ as } \hat{t} \rightarrow \hat{t}_2, \quad (124)$$

which drives the bounce toward a “thin” (or effectively nonlocal) transition. In this limit, the decay resembles a collective tunneling of the interior into $\hat{t}_3$ rather than a propagating front.

15.7. Acausal Phase as Loss of Global Foliation: Patchwise Unitarity

We use *acausal* in a technical sense: during the CSE there is no single global time slicing that orders the entire transition. Nevertheless, local evolution remains well-defined within finite patches. We encode this by treating the transition as unitary in a *patchwise* Hilbert decomposition:

$$\mathcal{H}_{\text{total}} \approx \bigotimes_{p \in \mathcal{P}} \mathcal{H}_p, \quad (125)$$

where $\mathcal{P}$ is a covering of the transition region by patches over which an approximate local Hamiltonian H_p exists. Global foliation fails because the patch couplings are non-adiabatic and the boundary conditions at Σ change discontinuously. This provides a controlled meaning to “acausal”: no global time-ordering, but no violation of local conservation laws.

15.8. Energy Release Channels: Gravitational Burst and Shear Reheating

When the confining geometry fails, $E_{\text{CSE}} = M_{\text{crit}} c^2$ (Equation (112)) deconfines instantaneously. This energy partitions across two channels by causal domain.

In the *parent domain*, the observable channel is gravitational radiation:

$$E_{\text{burst}} \approx \epsilon_{\text{GW}} M_{\text{crit}} c^2, \quad 0 < \epsilon_{\text{GW}} \ll 1, \quad (126)$$

where ϵ_{GW} is the fraction coupling to exterior gravitational modes. The remainder $(1-\epsilon_{\text{GW}})M_{\text{crit}}c^2$ crosses the $\hat{t}_3$ causal boundary as pure deconfined timeon energy seeding the *daughter domain* [11] [12]. The full $E_{\text{CSE}} = M_{\text{crit}}c^2$ is conserved across both channels; $\epsilon_{\text{GW}} \ll 1$ is not in contradiction with total energy release but reflects the partition between domains. In the parent domain the event registers as an impulse-like gravitational transient at Σ . In the daughter domain the same event is the causal-onset expansion—the new causal expansion phase of the next domain, its low entropy guaranteed by the maximal order of the precursor DT-CPS ground state.

15.9. Cosmogenic Renewal: The End as Initial Condition

The shear phase $\hat{t}_3$ following the CSE is a pure vacuum-wave configuration of the timeon lattice—structurally equivalent to the pre-onset state $\hat{t}_1$ of the present domain [11]. Chrono-Emergence, which operates continuously on a timescale vastly exceeding any causal-domain lifetime, now acts on a lattice reset to that vacuum configuration and seeded with $E_{\text{CSE}} = M_{\text{crit}}c^2$ of pure field energy. The new causal expansion—initiated by the global Chrono-Shear instability—proceeds from this reset state. Matter does not form instantaneously at the CSE; it accumulates through the same slow Chrono-Emergence that populated the parent domain, now operating on a fresh lattice.

The causal reset is closed and exact:

$$\hat{t}_1 \xrightarrow{\text{CSE}} \hat{t}_3 \equiv \hat{t}_1' \xrightarrow{\text{causal expansion}} \hat{t}_2 \xrightarrow{M \geq M_{\text{crit}}} \hat{t}_3 \rightarrow \dots, \quad (127)$$

where the CSE arrow is instantaneous and the causal expansion arrow spans the entire lifetime of a domain. Chrono-Emergence runs beneath both arrows on its own independent, far longer timescale—the continuous creative background against which causal domains are born, age, and reset. The low entropy of each new causal onset follows from the maximal order of the saturated DT-CPS ground state that immediately preceded it.

15.10. Terminal Merger Geometry and the CSE Yield Factor

The CSE energy partition, and therefore the initial conditions of the daughter domain, depends on the geometry of the final merger. Two properties of that merger are determined by the long prior history of hierarchical coalescence; one is intrinsically variable.

a) *Spin cancellation in hierarchical mergers.* Each merger adds an angular momentum contribution whose orientation is set by the orbital geometry of that encounter. Over N mergers with uncorrelated orientations, the net spin follows a three-dimensional random walk:

$$|\mathbf{J}_N| \sim \sqrt{N} J_0, \quad (128)$$

where J_0 is a characteristic single-merger angular momentum scale. With $M = NM_0$, the dimensionless spin parameter is

$$a_N = \frac{c|J_N|}{GM_N^2} \sim \frac{c\sqrt{N}J_0}{GN^2M_0^2} \propto N^{-3/2}. \quad (129)$$

Spin is suppressed as $N^{-3/2}$: the two black holes entering the final merger are very nearly Schwarzschild. This is a consequence of the merger history, not a special assumption.

b) *The grace parameter $\mathbf{G}$* . Near-zero spin does not fix the merger geometry completely. Mass ratio $q = M_2/M_1 \leq 1$ and impact parameter b are set by the stochastic encounter of the last two surviving objects in the domain. We define a dimensionless *grace parameter*

$$\mathbf{G} \equiv \frac{4q}{(1+q)^2} \cdot g\left(\frac{b}{r_\Sigma}\right) \cdot h(a), \quad \mathbf{G} \in [0,1], \quad (130)$$

where $4q/(1+q)^2$ is the symmetric mass ratio normalized to unity at $q=1$ [22], $g(b/r_\Sigma)$ is a geometric efficiency with $g(0)=1$ falling for oblique encounters, and $h(a) \leq 1$ captures residual-spin decoherence. Equal-mass, head-on, non-spinning gives $\mathbf{G}=1$; unequal, grazing, spinning gives $\mathbf{G} \ll 1$.

c) *Yield and daughter-domain entropy*. The GW energy fraction radiated into the parent domain is

$$\epsilon_{\text{GW}} = \epsilon_0 \mathbf{G}, \quad (131)$$

where ϵ_0 is the maximum timeon-field radiative coupling. The complementary fraction $(1-\epsilon_{\text{GW}})$ seeds the daughter domain. A merger with $\mathbf{G} \approx 1$ releases E_{CSE} coherently: the daughter domain receives a homogeneous energy density at causal onset, a low-entropy initial state, and a near-uniform timeon vacuum from which an isotropic expansion proceeds. A merger with $\mathbf{G} \ll 1$ imprints spatial gradients on that energy: the daughter domain begins with higher entropy and a less uniform causal onset.

The isotropy of a daughter domain is therefore encoded in a single number—the grace of the terminal merger of its parent. Our own universe provides a calibration: the cosmic microwave background has $\delta T/T \sim 10^{-5}$, implying extraordinarily uniform initial conditions. Within this framework that uniformity is a retrodiction:

$$\mathbf{G}_{\text{parent}} \gtrsim 1 - \mathcal{O}(\delta T/T) \approx 1 - 10^{-5}, \quad (132)$$

meaning the terminal merger of our parent domain was symmetric to one part in 10^5 . The fine-tuning problem of cosmological initial conditions is thereby recast as a statement about the merger geometry of the preceding causal domain—a quantity that is geometrically natural rather than specially arranged.

15.11. Criticality and Why the Event Is “Late” and Rapid

As mass accumulates, the integrated latent energy and global lattice strain load increase, even though the local chrono-pressure density obeys $P_\chi \propto M^{-2}$ under the spherical scaling of Equation (94). The CSE is late because metastability holds until the compactness condition $r_\Sigma(M) = r_{\text{domain}}$ is reached; it is rapid because

once crossed, no static or quasi-static CQM embedding exists. The simplest parametrization is

$$B(M) = B_0 \left(1 - \frac{M}{M_{\text{crit}}} \right)^\delta, \quad \delta > 0, \quad (133)$$

so that the decay exponent collapses as $M \rightarrow M_{\text{crit}}$, driving Γ sharply upward:

$$\frac{\Gamma}{\mathcal{V}_4} \sim A \exp \left[-\frac{B_0}{\hbar} \left(1 - \frac{M}{M_{\text{crit}}} \right)^\delta \right]. \quad (134)$$

This captures the physical mechanism: the final mass is approached by a last sequence of mergers, after which the phase transition follows quickly.

15.12. What Remains to Be Specified

To make the CSE calculation predictive, the theory must supply three closing functions. Their roles are classified as follows:

$V_{\text{eff}}(\hat{t})$: dense-phase minima, metastability, and phase-level structure, (135)

$\sigma(\hat{t})$: interfacial tension, boundary energetics, and CQM yield criterion, (136)

$Z_t(\hat{t})$: temporal stiffness, redshift of collective modes, and Chrono-Shear softening. (137)

These are the three functions whose microscopic derivation from the underlying timeon-field theory would render the CSE instability rate, the ringdown coefficient κ , the reflectivity $G(\omega)$, and the Chrono-Shear dynamical timescale τ_{CS} all fully computable from first principles.

The present formulation should be read as a constrained effective theory of the dense-time phase. Its central structural claims—phase entry at finite cumulative temporal compression (Section 3), suppression of the ordinary radiative sector (Equation (2)), constrained interior state space with Abelian first-class closure (Equation (16)), stiff-fluid latent storage (Equation (98)), and a geometric terminal trigger at $r_\Sigma(M_{\text{crit}}) = r_{\text{domain}}$ (Equation (106))—are already sufficiently sharp to be falsifiable by existing or near-term data. What remains open is not the logical form of the phase, but the microscopic derivation of the closing functions $V_{\text{eff}}(\hat{t})$, $\sigma(\hat{t})$, and $Z_t(\hat{t})$ from the underlying timeon-field theory. Determining these would upgrade the framework from semiquantitative to fully quantitatively predictive.

16. Observational Predictions and Falsifiability

The dense-time/DT-CPS framework makes predictions that are either already consistent with existing data or accessible to near-future experiments.

16.1. Predictions Consistent with Current Observations

a) (P1) *No gravitational-wave echoes from binary mergers.* In the dense-time

phase, $\hat{t} > \hat{t}_{\text{crit}}$ strongly suppresses propagating modes at the CQM boundary, so the reflectivity $G(\omega)$ is expected to be strongly suppressed relative to ordinary compact objects. A quantitative bound on $G(\omega)$ requires specifying the closing function $\sigma(\hat{t})$ (Section 15.12) and is deferred to future work. The qualitative prediction—strongly suppressed reflectivity, hence no resolvable post-merger echoes—is consistent with LIGO-Virgo binary black hole data [10] showing no echoes in post-merger strain [23] [24].

b) (P2) *No electromagnetic counterpart to binary black hole mergers.* The DT-CPS interior carries no Planck bath; merger energy partitions gravitationally. Consistent with non-detection of EM counterparts to all confirmed binary black hole events.

c) (P3) *Ringdown timescale* $t_{\text{relax}} \sim \kappa GM/c^3$. Ringdown is sourced by CQM shell relaxation (Equation (80)):

$$t_{\text{relax}} = \kappa \frac{GM}{c^3}, \quad \kappa \in [10, 20]. \quad (138)$$

The Schwarzschild $\ell = 2$ quasinormal mode gives $\tau_{220} \approx 11.2GM/c^3$ [22], which lies within this window. The window $\kappa \in [10, 20]$ is established by comparison with classical quasinormal mode timescales and represents an order-of-magnitude estimate; a rigorous derivation from the interface constitutive law $\sigma(\hat{t})$ —one of the three closing functions identified in Section 15.12—is required to distinguish this prediction from classical GR quasinormal modes at the precision level accessible to next-generation detectors.

16.2. Near-Term Falsifiable Predictions

a) (P4) *Stiff EOS* ($w_{\text{DT}} = 1$) *via tidal deformability.* Equation (96) fixes $w_{\text{DT}} = 1$ without free parameters, constrainable via tidal deformability Λ [25] [26] in neutron-star-black-hole mergers observed by LIGO-Virgo-KAGRA.

b) (P5) *Post-Newtonian deviation at second order.* The framework suggests a deviation from general relativity at second post-Newtonian order, arising because clock rates are set by the local time-density gradient rather than by metric curvature alone; the two coincide at first post-Newtonian order but diverge at second. Its precise value and derivation are reserved for a forthcoming treatment of relativistic time-density field equations, testable by SKA pulsar timing [27] [28] within the next decade.

c) (P6) *Secular mass gain in isolated black holes.* With Hawking evaporation suppressed by the CQM, isolated black holes gain mass via Chrono-Emergence [11] [12], detectable via Einstein-ring bifurcation: $\dot{\theta}_E/\theta_E = \dot{M}/(2M)$ over 1 - 20 yr baselines.

d) (P7) *CSE mass scale.* Equation (105) predicts

$$M_{\text{crit}} = \frac{c^2 r_{\text{domain}}}{2G} \approx 3 \times 10^{53} \text{ kg} \quad (139)$$

for $r_{\text{domain}} \approx 4.4 \times 10^{26} \text{ m}$, consistent with the total energy content of the observable universe to within a factor of three; the only inputs are r_{domain} and fundamen-

tal constants.

16.3. Falsification Criteria

The framework exposes a finite set of named quantities that observations can invalidate. Each falsification criterion is tied to the parameter it constrains:

- 1) Resolvable post-merger GW echoes in LIGO-Virgo-KAGRA data [falsifies: strong suppression of $G(\omega)$, prediction P1]
- 2) A confirmed EM counterpart from a vacuum binary black hole merger [falsifies: absence of interior Planck bath, prediction P2]
- 3) A ringdown e -folding time outside $\kappa GM/c^3$ for $\kappa \in [10, 20]$ [falsifies: CQM shell stiffness κ , prediction P3]
- 4) Tidal deformability Λ inconsistent with $w_{\text{DT}} \approx 1$ [falsifies: stiff-fluid EOS w_{DT} , prediction P4]
- 5) Mass loss (rather than gain) in isolated black holes over decade baselines [falsifies: Chrono-Emergence mass gain, prediction P6]
- 6) Terminal mass scale M_{crit} inconsistent with $c^2 r_{\text{domain}}/(2G)$ [falsifies: geometric CSE trigger, prediction P7]

Within the current formulation, criterion (3) is a consistency bound rather than a discriminating test of general relativity; sharper discrimination requires the closing function $\sigma(\hat{t})$.

This lets the reader see that the framework already exposes a finite set of quantities that observations can invalidate, independently of whether the three closing functions V_{eff} , σ , Z_t have been derived microscopically.

17. Conclusions

We have presented a constraint-based quantum formulation of black hole interiors in which they are identified not as singularities but as regions of the **Dense-Time Collective Partner State (DT-CPS)**. By defining the Hilbert space $\mathcal{H}_{\text{DT}}$ through phase settlement constraints rather than unitary time evolution, the framework resolves the tension between general relativity and quantum mechanics in the dense-time regime, accounts for the absence of radiative heating during collapse, and delivers a precise, geometrically grounded termination condition for the black hole lifecycle. The algebraic closure of the constraint system is now established: the structure functions $f_{ab}{}^c$ and $g_a{}^b$ vanish identically (Equation (16)), confirming that the DT-CPS constraint algebra is Abelian and first-class, and that $\mathcal{H}_{\text{phys}}$ is well-defined without secondary constraints or Dirac brackets.

The Chrono-Shear Event is triggered not by a pressure threshold but by geometric impossibility: when the final merger brings total mass to $M \geq M_{\text{crit}} = c^2 r_{\text{domain}}/(2G)$ (Equation (105)), the combined CQM radius equals the causal horizon of the parent domain, no valid exterior exists, and the stored deformation energy $E_{\text{CSE}} = M_{\text{crit}} c^2$ (Equation (112)) deconfines instantaneously. For a domain whose horizon matches the present observable universe, $M_{\text{crit}} \approx 3 \times 10^{53}$ kg (Equation (111))—consistent with the total energy content of the observable universe; all inputs are the causal-

horizon geometry and fundamental constants.

The complete lifecycle of matter in the timeon framework proceeds in six stages:

1) **Causal onset.** The shear phase $\hat{t}_3$ of the preceding domain resets the timeon lattice to the vacuum state $\hat{t}_1$ [11]. Chrono-Emergence—already operating on a timescale far exceeding the causal-domain lifetime—seeds additional matter into the freshly exploded lattice. The causal expansion driven by E_{CSE} dominates the early observable universe; Chrono-Emergence is its slow, continuous undercurrent leading to the CSE and continuing after the CSE.

2) **Matter formation.** Vacuum-to-atomic time density phase tunneling produces Baryon Partner States—localized stable reconfigurations whose rest mass equals their lattice well depth, $M_{\text{BPS}}c^2$ [12].

3) **Gravitational accumulation.** BPS aggregate into stars, neutron stars, and black holes [29] [30]. Each black hole compresses its BPS content into a DT-CPS, preserving total deformation energy as latent chrono-pressure.

4) **Hierarchical merger.** Black holes coalesce over cosmological time. Every merger is stable and inconsequential—the DT-CPS absorbs each mass increment and the CQM scales accordingly.

5) **Terminal merger.** The final coalescence brings $M \geq M_{\text{crit}}$. The confining geometry has no valid solution; $|\Psi\rangle$ becomes undefined; and $E_{\text{CSE}} = M_{\text{crit}}c^2$ deconfines instantaneously into propagating vacuum-wave modes. Matter returns to pure energy.

6) **Reset.** The shear phase $\hat{t}_3$ is the structural equivalent of $\hat{t}_1$ (Equation (127)). The lattice is restored to the vacuum configuration, seeded with $E_{\text{CSE}} = M_{\text{crit}}c^2$. A new causal expansion begins from this reset state. Chrono-Emergence, unchanged and uninterrupted, continues to build matter into the new domain on its own vast timescale.

The CSE is the punctuation mark; Chrono-Emergence is the beginning and constant sentence. The reset requires no fine-tuning: the low entropy of each new causal onset follows from the ground-state order of the DT-CPS, and the energy available for the next domain is exactly $M_{\text{crit}}c^2$. Black holes are not dead ends. They are the compression and storage phase of a closed causal cycle, and the Chrono-Shear Event is the mechanism that returns accumulated mass-energy to the vacuum state—where Chrono-Emergence continues and patient matter accumulation begins again.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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