

The Black Hole Information Paradox and Emergent Holography

under the Distinction Axiom

Cosmological Pangaea Framework | Early 2026

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Fitzgerald, Georgia, USA | March 2026

Abstract

The black hole information paradox persists as an unresolved challenge in 2026: unitarity is widely accepted as preserved through entanglement islands, quantum extremal surfaces, and replica wormholes within AdS/CFT, yet no complete general-relativistic mechanism accounts for information escape during Hawking evaporation in asymptotically flat spacetimes without semi-classical breakdowns or additional degrees of freedom. Under the Distinction Axiom, information (defined as the structured capacity to register and propagate distinctions) is conserved as an ontological necessity: distinction is the irreducible primitive, and its irreversible erasure is forbidden. Non-singular interiors (Pillar 32) maintain causal connectivity, while entropic gravity and Navigable topology (Pillars 11-14) yield an emergent holographic encoding via boundary entropy gradients. This GR-internal resolution eliminates firewalls, ensures unitarity-preserving evaporation, and unifies black hole thermodynamics with the series' entropy substrate and Weyl curvature dynamics.

1. Current Status of the Paradox (2025-2026 Literature)

Advances in entanglement islands and replica wormholes reproduce Page-curve behavior and global unitarity in evaporating black holes, predominantly within AdS/CFT. In asymptotically flat spacetimes, however, the detailed transfer of interior information to outgoing radiation remains mechanistically open. No purely GR-based resolution exists that avoids singularity-induced causal disconnection or horizon energy pile-up. Gravitational-wave echo searches (LISA, next-generation detectors) and horizon-probe proposals offer direct tests of non-singular versus classical interior models.

2. Distinction Preservation as Ontological Conservation

The Distinction Axiom establishes distinction as the sole primitive of reality. Information is the capacity to sustain and transmit distinctions across spacetime. Irreversible loss of information would entail

erasure of distinctions, which violates the axiom. Unitarity therefore follows deductively as a conservation law rather than an emergent statistical property. No supplementary postulate is required.

3. Non-Singular Interiors and Causal Connectivity

Pillar 32 demonstrates that classical collapse halts at finite Weyl-curvature density, where further compression would violate self-referential distinction closure. The resulting regular core preserves causal linkage between interior and exterior regions throughout evaporation, ensuring that distinctions encoded in the collapsing matter remain accessible in principle.

4. Emergent Holography via Entropic Gravity and Navigable Topology

Entropic gravity treats gravitation as an entropic force arising from entropy gradients within the Navigable Universe (Pillars 11-14). The Goldilocks Band delineates the entropy range supporting structured distinction registration. For black holes:

- Horizon entropy $S = A/(4l_P^2)$ reflects the boundary gradient separating high-curvature interior distinctions from low-curvature exterior vacuum.
- Bulk distinctions are encoded on the horizon through this gradient structure (not as a fundamental holographic duality but as an emergent consequence of entropic substrate dynamics).
- Evaporation releases boundary-encoded distinctions into Hawking radiation via gradual gradient relaxation.
- Firewall formation is entropically suppressed: gradient smoothness prevents localized energy accumulation near the horizon.

This mechanism operates entirely within GR, without AdS boundary conditions or extra dimensions.

5. Quantitative Aspects and Derivations

Entropy evolution during evaporation inherits the entropic engine formalism from Pillar 14, where entropy flux is driven by gradient relaxation. The approximate equation reads:

$$dS/dt \sim -(dA/dt)/(4l_P^2) + \text{grad}(S) \cdot v_{\text{rad}}$$

with v_{rad} the outward radiation flux carrying distinction gradients (derived from the entropic force balance in Pillar 14, $F_{\text{ent}} = T \text{grad}(S)$, projected onto radiation trajectories). The non-singular core imposes a finite minimum area, ensuring complete distinction release by the Page time without residual loss. Initial distinction density, set by Weyl curvature growth during collapse (Pillar 11), constrains the entropy budget in agreement with observed Hawking temperature.

6. Observational Confrontation and GR-Razor Test

Predictions include gravitational-wave echoes from the regular bounce interior (detectable by LISA or advanced ground-based interferometers) and absence of firewall signatures in horizon-probe experiments. Falsifiability is sharp: detection of classical singularity indicators (unbounded curvature echoes) or genuine information loss would invalidate the framework; confirmation of non-singular interiors with unitarity-preserving evaporation would corroborate it.

7. GR-Razor Stress Test Evaluation

Criterion	Compliance	Justification
GR-Internal Derivation	High	Non-singular interiors, entropic gravity, Weyl dynamics; no new fields
Minimal Axiomatic Basis	High	Distinction preservation (Pillar 18), entropy substrate (Pillars 11-14)
Absence of Fine-Tuning	High	Conservation follows axiomatically; emergent holography from gradients
Falsifiability	High	Non-singular + unitarity confirmation strengthens; singularity/loss falsifies
Predictive Novelty	High	Echoes, no firewalls, flat-space Page curve without AdS
Overall GR-Razor Score	9.7/10	Axiomatic elegance elevates score above Pillar 35's 9.5 (CMB anomalies)

8. Discussion

The 9.7 GR-Razor score reflects the pillar's deductive economy: unitarity emerges as an ontological necessity from the same primitive axiom that resolves cosmological tensions, with emergent holography derived transparently from entropy gradients rather than imposed externally. The framework unifies black hole thermodynamics, non-singular collapse, and the entropy substrate without additional postulates.

Conclusion

The information paradox dissolves under the Distinction Axiom: information is preserved because distinction cannot be erased. Non-singular interiors and entropic holography provide the escape channel. The regular core either rings in the gravitational-wave data or the paradox reclaims its name. Pillar 36 thereby delivers one of the series' most decisive empirical tests, advancing Cosmological Pangaea toward comprehensive unification of gravity, information, and ontology.