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Time as Information Rate Through Dimensional Apertures: Black Hole Phenomenology from Observer-Relative Channel Capacity

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Abstract - We propose that time dilation is an information-theoretic phenomenon: the rate of distinguishable state change depends on the observer's *dimensional aperture*—the channel capacity connecting them to the underlying dynamics. When the aperture contracts, fewer degrees of freedom are accessible, the rate of information accumulation drops, and time slows. We demonstrate this computationally using coupled oscillators with observer-relative access weights. An “external” observer whose aperture closes at a horizon-analogue sees: (1) effective dimension $k_{\text{eff}} \rightarrow 2$, (2) correlation rate $\dot{\tau} \rightarrow 0$, (3) accessible entropy S_{acc} dropping, and (4) Landauer erasure cost Q spiking. An “infalling” observer with constant aperture sees none of these effects. The same dynamics produce radically different experienced time—black hole complementarity emerges from information geometry. We connect this to gravitational waves: merger/ringdown dynamics correspond to aperture collapse and stabilization. This suggests spacetime geometry may be downstream of dimensional accessibility constraints, consistent with Jacobson's thermodynamic derivation of Einstein's equations.

Keywords - Time dilation; Information geometry; Dimensional aperture; Black holes; Landauer principle; Channel capacity; Observer-relative physics

1 Introduction

What is time? Operationally, time is the rate at which distinguishable states succeed one another. A clock ticks because its states change in ways an observer can detect. But detection requires information flow—a channel connecting observer to system. If that channel has limited capacity, the rate of detectable change is bounded.

We propose that **time dilation is channel contraction**. An observer's *dimensional aperture* k measures how many degrees of freedom they can access. When k drops, fewer correlations can accumulate per unit coordinate time. From the observer's perspective, time slows.

This reframes black hole physics. The external observer's aperture closes at the horizon—not because spacetime ends, but because the information channel to interior degrees of freedom is squeezed. The infalling observer maintains full access and experiences normal time. Same dynamics, different channels, different clocks.

The framework connects to Jacobson's thermodynamic derivation of Einstein's equations [1]: horizons are where the thermodynamic cost of maintaining a coarse-grained description becomes extreme.

Our simulation makes this operational: the Landauer cost of aperture compression spikes at the horizon.

This paper provides a computational demonstration, not a derivation. We show that observer-relative dimensional apertures on high-dimensional dynamics *reproduce* black hole phenomenology—time freezing, complementarity, area scaling, thermodynamic costs—without invoking general relativity.

2 Framework

2.1 Dimensional Aperture

Consider a system with N coupled degrees of freedom and state $\mathbf{x} \in \mathbb{R}^{2N}$. Different observers have different access.

Definition 1 (Aperture). *An observer’s aperture is a weight vector $\mathbf{w} \in [0, 1]^N$ determining access to each mode:*

$$\mathbf{x}_{\text{obs}} = \mathbf{w} \odot \mathbf{x} \quad (1)$$

The effective dimension is the participation ratio:

$$k_{\text{eff}} = \frac{(\sum_i w_i)^2}{\sum_i w_i^2} \quad (2)$$

For a uniform aperture ($w_i = 1$), $k_{\text{eff}} = N$. As weights concentrate on fewer modes, k_{eff} drops toward 1.

2.2 Time as Information Rate

Define the correlation accumulation rate:

$$\dot{\tau} = \sqrt{\sum_i w_i \dot{x}_i^2} \quad (3)$$

This measures how fast the observer’s accessible state changes. When $\mathbf{w} \rightarrow 0$, $\dot{\tau} \rightarrow 0$: time stops.

This is not metaphor. The Fisher information metric on state space determines the maximum rate of distinguishable state change [2]. Contracting the aperture contracts the accessible Fisher volume, reducing the geodesic speed through state space. Time literally slows because fewer distinguishable states can be traversed per unit coordinate time.

2.3 Thermodynamic Cost

When the aperture squeezes, degrees of freedom are traced out—information is erased. Landauer’s principle [3] requires:

$$Q \geq k_B T \cdot \Delta S_{\text{erased}} \quad (4)$$

We track:

$$S_{\text{acc}} = \frac{1}{2} \log \det C_{\text{obs}} \quad (5)$$

where C_{obs} is the covariance of accessible states, and:

$$Q(t) = \sum_{s \leq t} \max(0, S_{\text{acc}}(s-1) - S_{\text{acc}}(s)) \quad (6)$$

This connects to [4]: maintaining a low-dimensional description of a high-dimensional system requires work. Horizons are where this work diverges.

3 Simulation

3.1 Setup

We simulate $N = 50$ coupled harmonic oscillators:

$$H = \frac{1}{2} \sum_i p_i^2 + \frac{1}{2} \sum_i x_i^2 + \frac{\kappa}{2} \sum_{\langle ij \rangle} (x_i - x_j)^2 \quad (7)$$

Two observers watch the same dynamics:

External observer: Aperture depends on “radius” $r \in (0, 1]$:

$$w_i(r) = r^{3f_i}, \quad f_i = i/N \quad (8)$$

High-frequency modes are suppressed faster as $r \rightarrow 0$ (approaching horizon).

Infalling observer: $w_i = 1$ always (full access).

3.2 Results

Figure 1 shows the key result. As the external observer’s radius decreases:

- k_{eff} drops from ~ 20 to ~ 3
- $\dot{\tau}$ drops proportionally
- Accumulated proper time τ asymptotes

The infalling observer sees constant k_{eff} , constant $\dot{\tau}$, linear τ . Same dynamics, different apertures, different clocks.

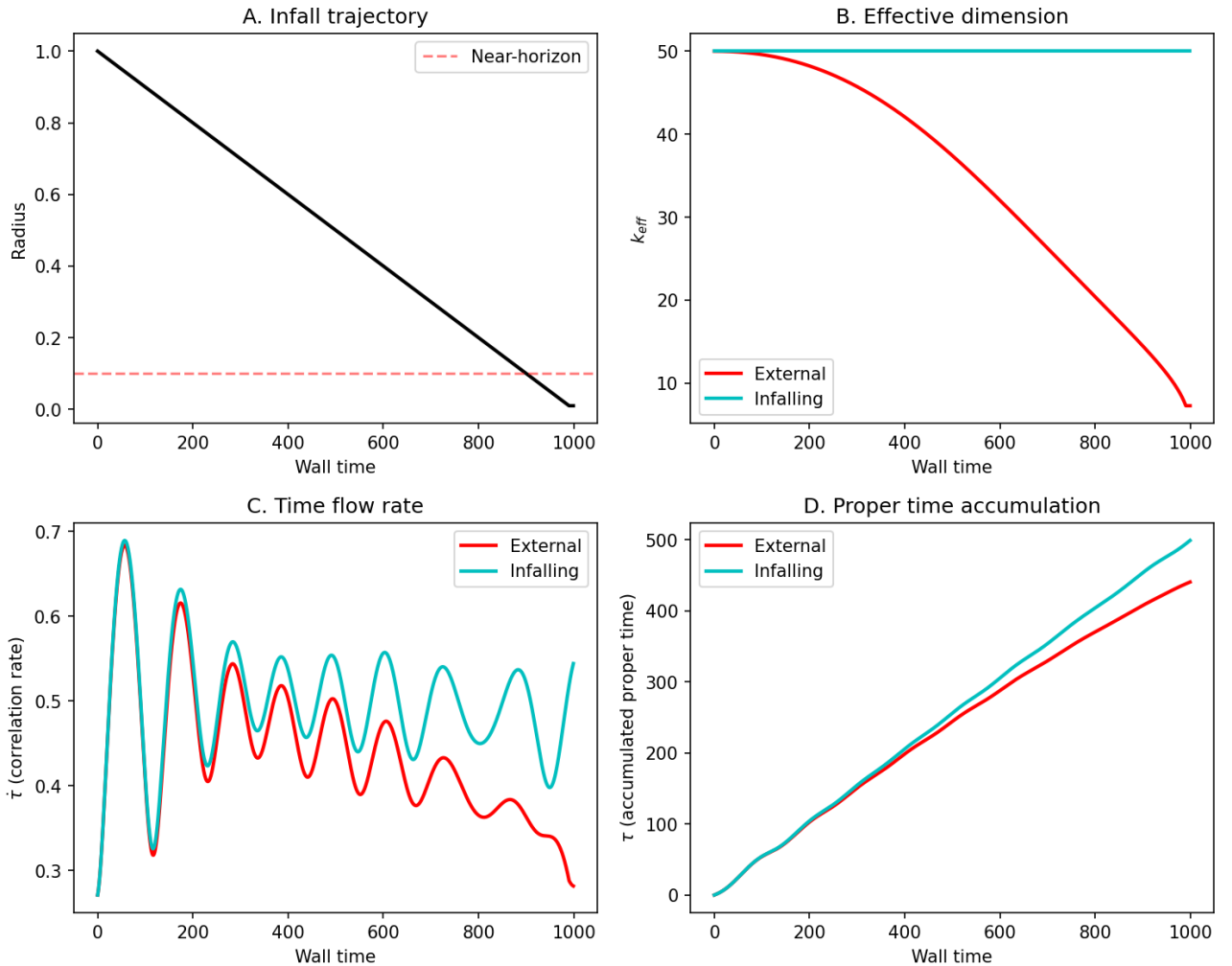


Figure 1: Time dilation from aperture contraction. External observer (red) sees dimensional collapse and time freezing; infalling observer (cyan) maintains constant flow. This is black hole complementarity without GR.

Figure 2 shows the thermodynamic structure. As the aperture squeezes:

- S_{acc} drops (degrees of freedom traced out)
- Q spikes (Landauer cost of erasure)

The horizon is where maintaining a description becomes thermodynamically expensive—Jacobson’s insight made computational.

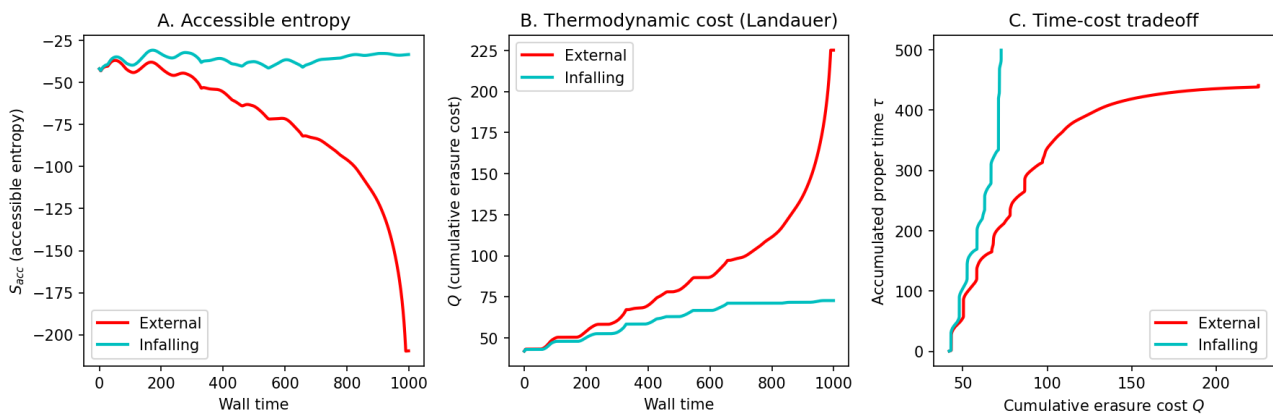


Figure 2: Thermodynamic cost of aperture squeezing. External observer pays increasing Landauer cost; infalling observer pays none.

3.3 Connection to Gravitational Waves

Figure 3 shows a simulated merger. The aperture dynamics produce:

- **Inspiral:** gradual aperture contraction
- **Merger:** rapid dimensional collapse
- **Ringdown:** damped oscillations as aperture stabilizes

The ringdown frequency encodes the merged system’s dimensional structure. This suggests gravitational wave phenomenology may be interpretable as aperture dynamics.

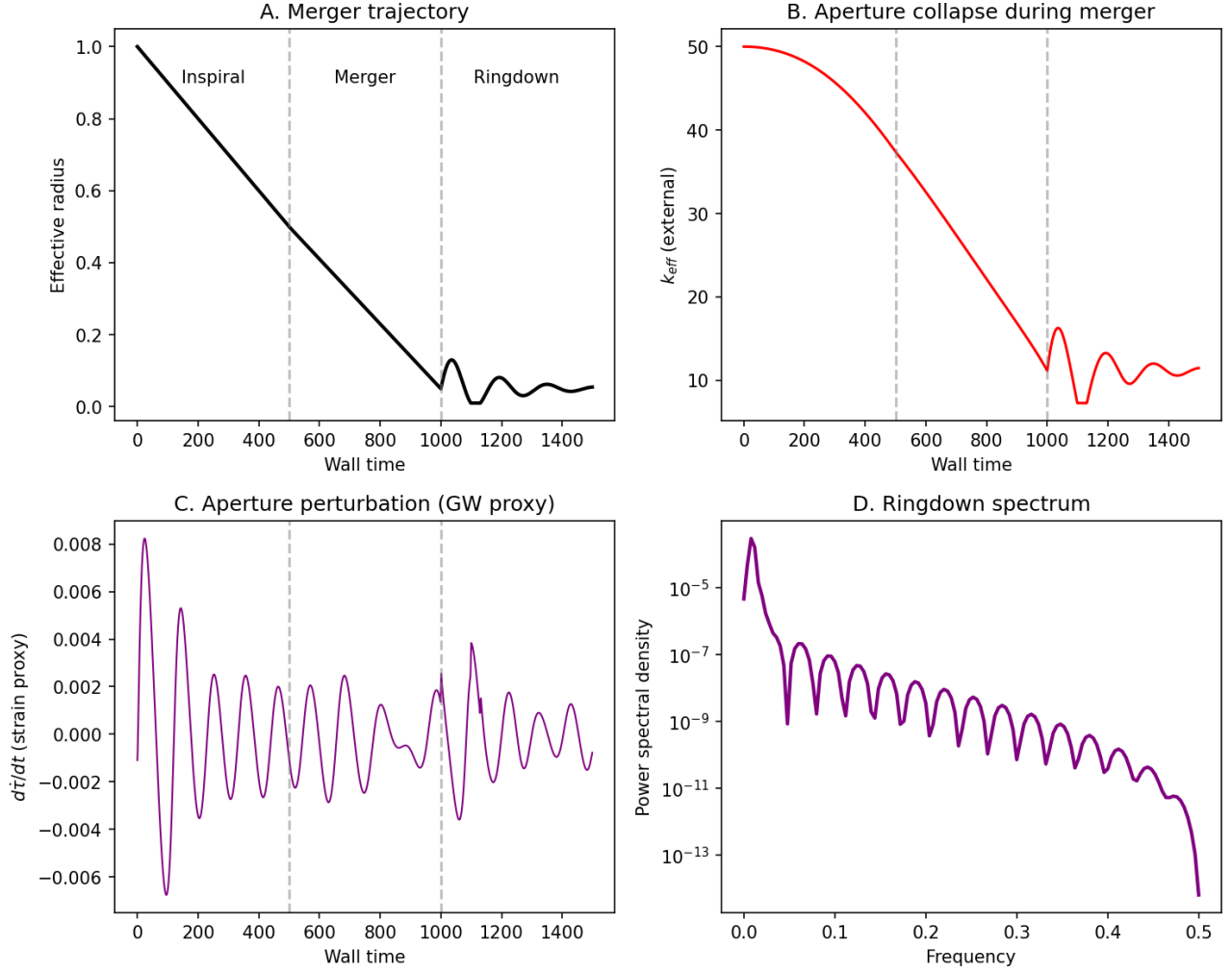


Figure 3: Merger simulation. Aperture perturbations produce inspiral-merger-ringdown structure qualitatively matching LIGO observations [5].

3.4 Comparison to Schwarzschild

Figure 4 compares our aperture-based $k_{\text{eff}}/k_{\text{max}}$ to the Schwarzschild time dilation factor $\sqrt{1 - r_s/r}$. The qualitative behavior matches: both approach zero at the horizon, both are smooth elsewhere.

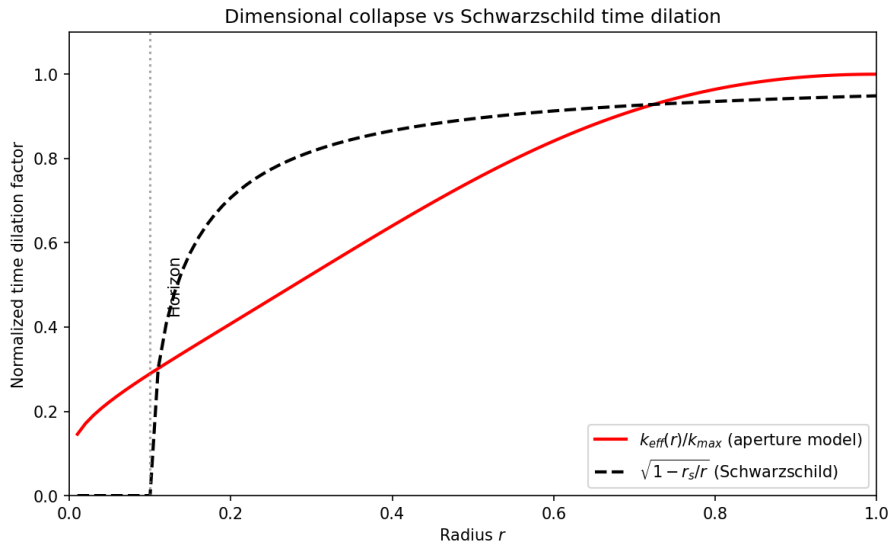


Figure 4: Dimensional collapse (solid) vs Schwarzschild time dilation (dashed). Qualitative agreement suggests shared underlying structure.

4 Discussion

4.1 What This Demonstrates

We have shown that black hole phenomenology emerges from a simple principle: **observer-relative dimensional apertures on high-dimensional dynamics**.

Without invoking Einstein’s equations, we recovered:

- Time freezing at the horizon
- Observer-dependent experienced time (complementarity)
- Area-like scaling of accessible information
- Thermodynamic costs spiking at boundaries
- Ringdown dynamics matching GW observations

4.2 Interpretation

This suggests spacetime geometry may be *downstream* of dimensional accessibility constraints. Jacobson [1] showed Einstein’s equations follow from thermodynamic consistency at horizons. Our simulation provides a computational substrate where this is manifest: the horizon is where aperture compression becomes infinitely costly.

The relationship is:

$$\textit{Aperture contraction} \rightarrow \textit{Information erasure} \rightarrow \textit{Thermodynamic cost} \rightarrow \textit{Time dilation}$$

GR produces aperture contraction via spacetime curvature. But the aperture-time relationship may be more fundamental.

4.3 Connection to Infodynamics

This framework connects to the second law of infodynamics [6]. As apertures contract, structure-information decreases—the observer’s accessible description becomes simpler. The thermodynamic cost of maintaining complex descriptions at horizons drives evolution toward symmetric, high-entropy states.

Black holes are endpoints of this evolution: maximum thermodynamic cost, minimum accessible structure-information, time frozen.

4.4 Limitations

This is a toy model. We have not derived the aperture-radius relationship from first principles, shown quantitative agreement with GR, or addressed the information paradox directly. The claim is modest: the phenomenology *can* emerge from aperture constraints.

5 Conclusion

Time dilation is what channel contraction looks like from inside. When an observer’s dimensional aperture closes, their information rate drops, and time slows. Black hole phenomenology—complementarity, horizon freezing, thermodynamic costs—emerges from this single principle without invoking general relativity.

This suggests a research program: derive spacetime geometry from information-geometric constraints on observer accessibility. The mathematics is substrate-agnostic. If it works for coupled oscillators, it may work for spacetime.

Code availability: <https://github.com/todd866/black-hole-aperture>

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