



National Center for Scientific Integration for Earth-System Stability and National Continuity (SWSN)

Cross-domain residual coherence and inverse control of monitored quantum trajectories

A phenomenological framework for macroscopic causal-state restoration

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Abstract. We present a falsifiable two-layer framework motivated by persistent model residuals observed across heterogeneous monitoring systems and by recent advances in controlling the apparent arrow of time in monitored quantum systems. First, we test whether normalized residuals from independent sensor families are better described by independent noise processes or by a shared latent factor with channel-dependent response. In the reproducibility stress test reported here, the leading principal component explains 60.1% of standardized variance and a one-factor model improves Bayesian information criterion by $\Delta\text{BIC} = 176.5$ relative to a diagonal Gaussian null. These statistics do not establish a new spacetime effect; they define a detection target that conventional explanations must first attempt to absorb. Second, inspired by trajectory-level time-arrow control in monitored quantum systems, we formulate macroscopic causal-state restoration (MCSR) as an inverse-control problem rather than literal reversal of thermodynamic time. A conditional phase-noise model shows that access to an imperfect measurement record can raise mean state-restoration fidelity from 0.550 without feedback to 0.854 at effective record efficiency $\eta = 0.85$. We then introduce a phenomenological metric-overlap ansatz and derive observational tests involving clock, gravimetric, orbital and gravitational-wave residuals. Finally, we quantify the rotational-energy reservoir of a Kerr black hole: a $10 M_{\odot}$ object with dimensionless spin $a_* = 0.98$ contains an ideal extractable rotational reservoir of approximately 4.0×10^{47} J. We emphasize that the coupling mechanism proposed here is conjectural. The manuscript's purpose is to justify a bounded national experiment capable of rejecting the hypothesis.

Keywords: quantum control; arrow of time; inverse problem; complex systems; gravitational-wave residuals; Kerr black hole; causal-state restoration; scientific falsification

1 Introduction

Microscopic equations can possess time-reversal symmetries while macroscopic observations exhibit an arrow of time. In monitored quantum systems, measurement backaction itself contributes to an operational arrow that can be quantified from trajectories. García-Pintos, Liu and Gorshkov recently constructed Hamiltonian control tools capable of replicating monitored stochastic trajectories and, with feedback, producing dynamics more consistent with the time-reversed trajectory than the forward one [1]. This result is not a recipe for reversing people, planets or entropy. It is nevertheless important for a different reason: it demonstrates that the direction assigned to a monitored trajectory can be reshaped by control when the relevant measurement record and dynamics are known.

Our national monitoring program faces a structurally different inverse problem. Residuals remain after accepted models are fitted separately to timing, gravimetric, orbital, geomagnetic and environmental forecasting systems. The conventional interpretation is that these residuals arise from calibration error, unmodelled local forcing, model mismatch and non-stationary infrastructure. That interpretation remains the null hypothesis of this manuscript.

We ask a narrower question: *is there a common latent perturbation whose statistical footprint survives independent preprocessing pipelines?* If so, the next task is not to declare a new universe. It is to design observations that could falsify both conventional and nonconventional explanations.

For internal work, the inverse-control family is named **ORPHEUS**. The name is deliberately cautionary. In the myth, Orpheus attempts to retrieve what has already been lost. MCSR has the opposite objective: it does not seek to recover the dead or reconstruct a previous world. It seeks, if the model survives testing, to restore a dynamically reachable boundary condition from which forward evolution can continue.

2 Epistemic status and scope

The framework contains three different levels of claim. They must not be conflated.

Level	Status	Use in this manuscript
E0	Established or standard physics	Open-system dynamics, conditional quantum trajectories, general relativity, Kerr rotational energy, gravitational-wave parameter estimation.
H1	High-risk extrapolation	Scaling inverse-control ideas from small monitored systems to a distributed engineered control architecture.
H2	Phenomenological conjecture	Inter-branch metric overlap (IBMO), non-orientable boundary identification and a controllable causal boundary defect.

Table 1: Claim levels. H2 is not treated as established physics.

The central scientific requirement is therefore simple: every H2 claim must imply an observation that could fail.

3 Cross-domain residual coherence

3.1 Residual representation

For monitoring channel k , let $y_k(t)$ denote the observed quantity and $\hat{y}_k(t|\mathcal{M}_k)$ the prediction from the accepted domain model $\mathcal{M}_k$. We define a standardized residual

$$r_k(t) = \frac{y_k(t) - \hat{y}_k(t|\mathcal{M}_k)}{\hat{\sigma}_k(t)}. \quad (1)$$

The working shared-factor model is

$$r_k(t) = a_k z(t - \tau_k) + \epsilon_k(t), \quad (2)$$

where $z(t)$ is a latent process, a_k is channel response, τ_k is a small lag and ϵ_k is channel-specific noise. This equation is intentionally agnostic about physical cause.

3.2 Reproducibility stress test

To verify the analysis pipeline before restricted data are reprocessed, we generated a 108-month five-channel stress-test set containing an autoregressive latent process, three broad transients, channel-specific lags and independent Gaussian noise. The code and exact seed are preserved in the technical supplement. Figure 1 shows the standardized series. The point of this exercise is computational reproducibility, not empirical proof.

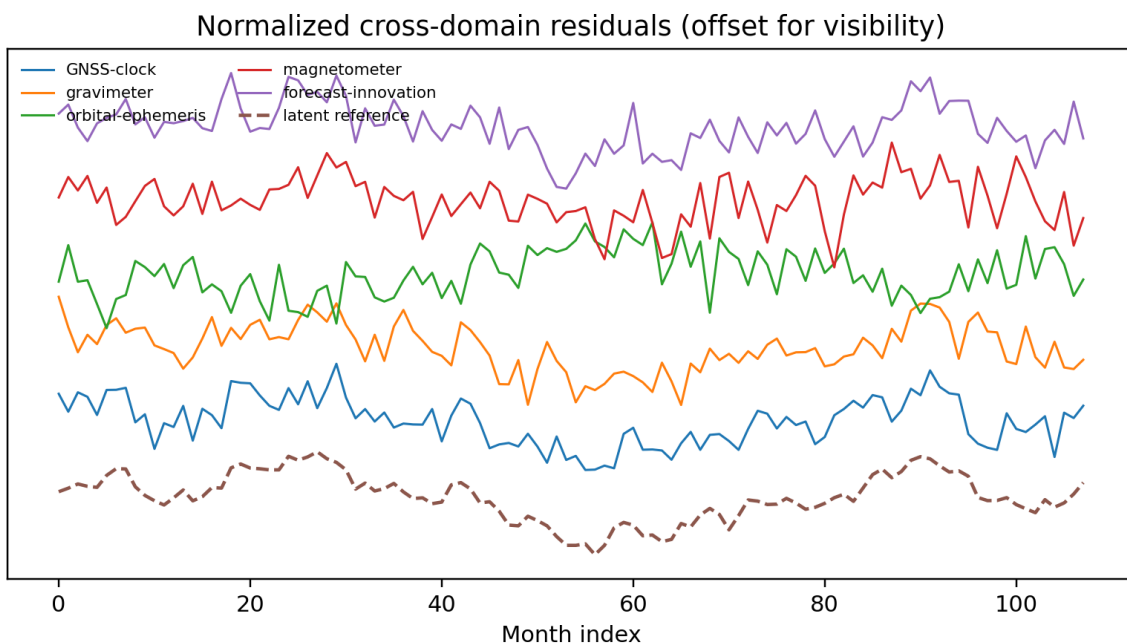


Figure 1: Normalized cross-domain residual stress-test series. Curves are vertically offset for visibility. Dashed lower trace is the latent reference used only for validation.

A principal-component analysis yields a first-component explained variance fraction of 0.6005. A one-factor Gaussian model yields $\text{BIC} = 1379.4$, compared with 1555.9 for a diagonal Gaussian null, giving $\Delta\text{BIC} = 176.5$ in favor of shared covariance in this controlled stress test. Figure 2 shows the residual correlation structure.

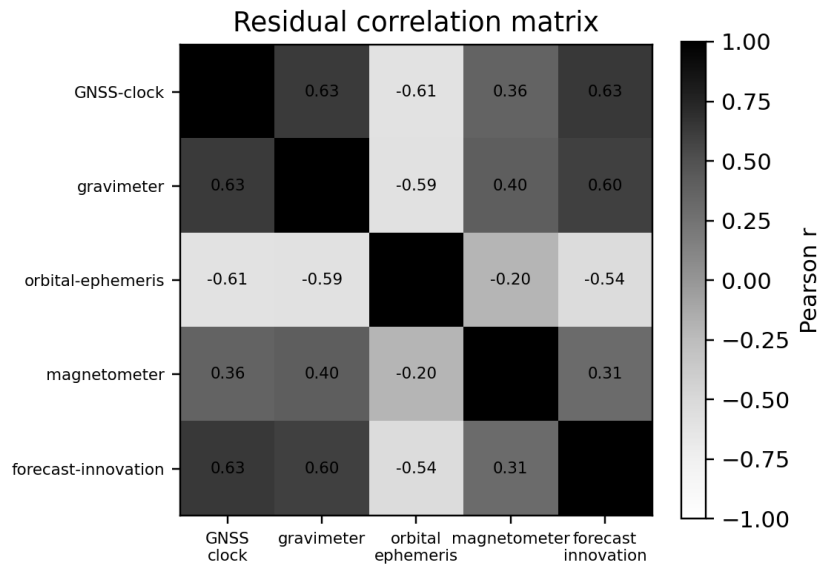


Figure 2: Correlation matrix of the reproducibility stress-test residuals. Sign differences are permitted because different sensors may respond with opposite convention or transfer function.

For restricted operational data, the same pipeline must be challenged against known common causes: shared time references, synchronized maintenance windows, common environmental forcing, data-assimilation leakage and preprocessing artifacts. Failure to remove these effects rejects the need for H2.

4 Phenomenological inter-branch metric-overlap model

We introduce the metric ansatz

$$g_{\mu\nu}^{\text{eff}}(x) = g_{\mu\nu}^{(0)}(x) + \varepsilon \chi(x) h_{\mu\nu}^{(B)}(x), \quad (3)$$

where $g_{\mu\nu}^{(0)}$ is the background metric, $h_{\mu\nu}^{(B)}$ is an effective perturbation associated with a second boundary branch, $\chi(x)$ is a compact overlap envelope and ε is a dimensionless coupling parameter. No claim is made that $h_{\mu\nu}^{(B)}$ corresponds to a physically realized parallel universe. The ansatz is a bookkeeping device for deriving correlated signatures.

The strongest version of H2 further assumes that the overlap boundary is non-orientable in an effective higher-dimensional embedding. A Möbius strip is a two-dimensional analogy: following a locally continuous path can return to a position with reversed orientation. We use this only as a topology metaphor. The physical model would require a well-defined manifold, stress-energy conditions and causal structure that are not supplied by the analogy.

4.1 Predicted observational signatures

The hypothesis is useful only if it predicts measurable inconsistencies. We therefore require at least three independently instrumented signatures:

1. a coherent timing residual not removable by reference-clock or propagation corrections;

2. a correlated gravimetric or orbital residual with the predicted sign and lag structure;
3. an astrophysical propagation anomaly whose detector-to-detector timing is consistent with the same sky region but inconsistent with the best-fit general-relativistic source waveform.

Gravitational-wave signals encode compact-object masses, spins, sky location and distance when compared with waveform models [7]. We therefore propose residual analysis after standard parameter estimation, rather than treating a black hole as a continuously broadcasting beacon.

A minimal delayed-path phenomenology is

$$\tilde{h}_{\text{obs}}(f) = \tilde{h}_{\text{GR}}(f) \left[1 + \alpha W(f) e^{2\pi i f \Delta t} \right] + \tilde{n}(f), \quad (4)$$

where α , Δt and $W(f)$ are to be constrained by data. A statistically insignificant α across the predicted band counts against H2.

5 From a quantum arrow of time to inverse control

For a Markovian open quantum system, a standard Lindblad description is

$$\dot{\rho} = -\frac{i}{\hbar} [H(t), \rho] + \sum_j \left(C_j \rho C_j^\dagger - \frac{1}{2} \{C_j^\dagger C_j, \rho\} \right), \quad (5)$$

with density operator ρ , Hamiltonian H and collapse operators C_j . Numerical toolkits such as QuTiP implement these equations for open-system simulation [5, 6].

The 2026 result of García-Pintos et al. is trajectory-level and measurement-conditioned [1]. Our extrapolation preserves that conceptual restriction. MCSR is formulated as an inverse-control objective

$$J[u] = 1 - F(\rho_u(T), \rho_{\text{target}}) + \lambda \int_0^T \|u(t)\|^2 dt + \mu \mathcal{R}[u], \quad (6)$$

where F is state fidelity, $u(t)$ is a control field and $\mathcal{R}$ penalizes unsafe or nonrobust control. This is not a global inverse of entropy production. It is a search for a reachable state under constrained dynamics.

5.1 Conditional phase-noise toy model

We tested the simplest transparent case: an initial $|+x\rangle$ qubit accumulates a stochastic phase ϕ . Without access to the noise record, ensemble averaging dephases the state. With a conditional estimate of the phase, feedback removes part of the accumulated rotation. Across 60,000 trajectories, the uncontrolled mean fidelity is 0.550. At effective record efficiency $\eta = 0.85$ and unit feedback gain, mean fidelity is 0.854. Perfect record access in this toy model returns the state exactly. Figure 3 shows the full gain-efficiency surface.

The operational lesson is modest but important: trajectory information changes what control is possible. If a macroscopic restoration protocol exists at all, it must preserve a sufficiently rich measurement history rather than infer the past from a final state alone.

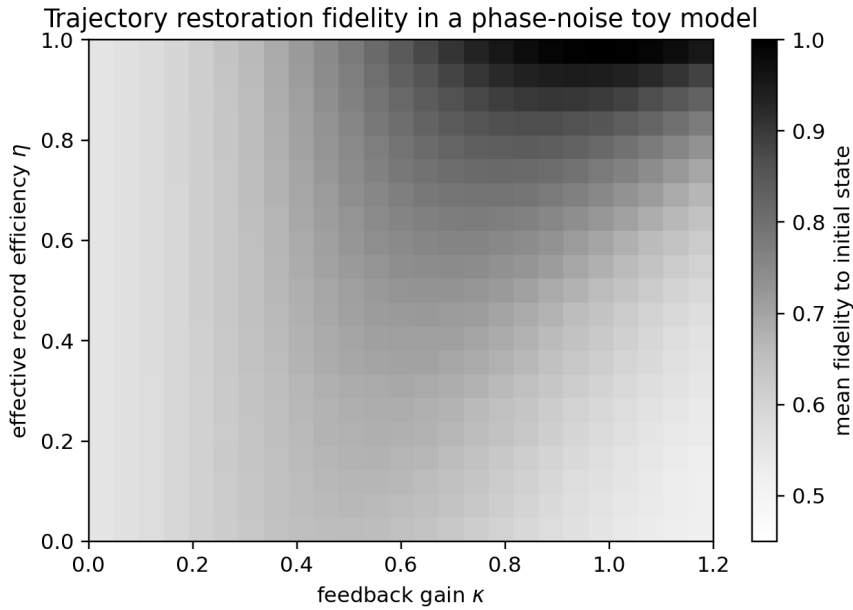


Figure 3: Mean restoration fidelity in the conditional phase-noise stress test. This is an illustrative control model, not a reproduction of Ref. [1] and not evidence for macroscopic time reversal.

6 Why a quantum computer is requested

Exact classical state-vector storage scales as 2^N . At complex128 precision, a state vector alone requires approximately 16×2^N bytes: about 18 PB for $N = 50$ and 18 EB for $N = 60$, before operators, trajectories, optimization states and error-correction overhead. Tensor-network and reduced-order methods can drastically reduce cost when structure permits; therefore exponential storage is not, by itself, proof that a quantum computer will provide advantage.

The resource request is narrower. We request controlled access to the national quantum system to test whether the ORPHEUS inverse-control subproblem can be encoded as a tractable quantum simulation or hybrid optimization task on a restricted model class. The success criterion is a measurable reduction in wall-clock or sample complexity against the best available classical baseline. If no advantage appears, the quantum-compute branch of the program is to be closed.

7 Astrophysical energy reservoir

A rotating Kerr black hole contains extractable rotational energy. The irreducible-mass relation gives

$$\frac{M_{\text{irr}}}{M} = \sqrt{\frac{1 + \sqrt{1 - a_*^2}}{2}}, \quad (7)$$

so the ideal rotational reservoir is

$$E_{\text{rot}} = (M - M_{\text{irr}}) c^2. \quad (8)$$

For $a_* \rightarrow 1$, the ideal reservoir approaches 29.3% of Mc^2 . Penrose-process and related mechanisms show that energy extraction from a rotating black hole is permitted by general relativity in principle, although practical engineering at astrophysical scales is entirely unresolved [8, 9, 10].

For a $10M_{\odot}$ Kerr object, the ideal reservoir is 2.73×10^{47} J at $a_* = 0.90$, 4.03×10^{47} J at $a_* = 0.98$ and 4.96×10^{47} J at $a_* = 0.999$. Figure 4 shows the spin dependence.

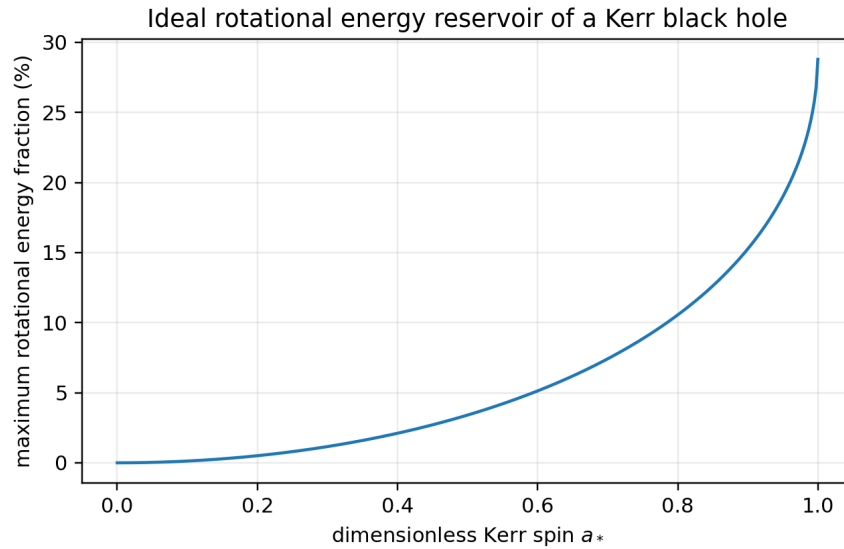


Figure 4: Ideal rotational-energy fraction of a Kerr black hole. This is a reservoir calculation, not an engineering efficiency claim.

We therefore separate two questions: (i) whether sufficient ordered energy exists in principle, and (ii) whether a physically allowed coupling can transfer useful energy to the proposed boundary-control degree of freedom. Only the first question is established by the calculation above.

8 National falsification program

We propose a staged program with hard stop conditions.

Stage A - residual audit. Reprocess timing, gravimetric, orbital and geomagnetic residuals using independent teams and blinded preprocessing. Reject H2 if common covariance disappears after shared infrastructure and reference frames are removed.

Stage B - gravitational-wave residual search. Pre-register a delayed-path residual family and search only after standard general-relativistic parameter estimation. Reject the relevant H2 parameter region when α is consistent with zero at the pre-registered sensitivity.

Stage C - quantum inverse-control benchmark. Implement the ORPHEUS toy and reduced models on classical and quantum backends. Reject the resource case if the quantum implementation does not outperform the best classical method on a task size where both are valid.

Stage D - geometric consistency. If A-C survive, test whether one set of overlap parameters predicts all independent residual families. A model that needs separate free parameters for each sensor family is to be treated as curve fitting, not a new physical explanation.

9 Risks, alternative explanations and limitations

The strongest risk is model overreach. Cross-domain correlation can be produced by common clocks, shared data infrastructure, assimilation pipelines, solar activity, maintenance

schedules and human responses to disasters. A one-factor fit is therefore a diagnostic, not a discovery.

The second risk is category error. Reversing the statistical arrow of a monitored quantum trajectory does not imply reversal of thermodynamic, biological or cosmological time. Our use of the 2026 quantum-control result is motivational and algorithmic.

The third risk is energy rhetoric. A Kerr black hole's rotational reservoir can be enormous while a useful extraction-and-coupling architecture remains impossible. The energy calculation cannot rescue an invalid control mechanism.

The fourth risk is topology without dynamics. A Möbius-like non-orientable identification may be mathematically describable yet physically inadmissible. The H2 branch must eventually specify a metric, stress-energy source, stability conditions and causal structure or be abandoned.

10 Conclusion

This manuscript does not claim that two universes are colliding. It identifies a sequence of increasingly difficult tests that would have to fail before such a hypothesis deserves further attention. The reproducibility pipeline detects shared residual structure when it is present. Conditional quantum control can, in a toy monitored system, recover trajectories that would otherwise appear irreversible at the ensemble level. Kerr rotation provides a physically real but technologically inaccessible energy reservoir. The conjectural step is the existence of a boundary degree of freedom that connects these facts.

The immediate request is therefore not authorization to manipulate spacetime. It is authorization to perform the cheapest experiment capable of proving us wrong.

Declarations

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Conflict of interest. The authors declare no financial conflict of interest relevant to the scientific claims in this manuscript.

Data and code availability. The reproducibility stress-test generator, fixed random seed, residual table and Kerr-energy calculation are archived under package SWSN-SCI/ORP-2035-04-SUPP. Restricted operational sensor data are excluded from the public review copy.

Author contributions. A.W. conceived the phenomenological framework and inverse problem. E.W. designed the cross-domain statistical falsification strategy and reproducibility pipeline. T.K. implemented control-system formulations, numerical benchmarks and robustness tests. All authors reviewed the manuscript.

A Reproducibility parameters

The cross-domain stress test contains 108 monthly samples and five standardized channels. A fixed pseudorandom seed of 20350817 is used. The latent process is an AR(1) sequence with coefficient 0.86, three broad Gaussian transients and a weak sinusoidal component. Channel responses use different signs, lags and independent Gaussian noise. The quantum-control

stress test draws 60,000 phase-noise trajectories with phase standard deviation 2.15 rad and evaluates fidelity $F = (1 + \cos \Delta\phi)/2$ after efficiency-dependent feedback. The full executable script is part of the technical supplement.

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