

CHRONON-1

Experimental Pre-Registration of the Chronon Field Residual

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Résumé

We pre-register a falsifiable test of a dimensionless signed slope ε_Φ after full GR subtraction. **Design sensitivity (v1.0)** : $|\varepsilon_\Phi| \sim 5 \times 10^{-5} - 6 \times 10^{-4}$ (lab-dependent) for $\Delta h_{\text{rms}} \in [10, 30]$ m with $N \in [20, 40]$ and hourly fractional-frequency scatter $\sigma_Y \sim 10^{-18}$. **Decision rule** : detection declared at 5σ under the pre-registered invariances (Secs. 4–5). **Method** : vertical optical-clock comparisons and qubit coherence-time tracking (T_2). **Principle** : all signals are GR-corrected ; any remaining signed slope vs $X = g\Delta h/c^2$ is attributed to the Chronon Field $\Phi(x)$ (local tempo). **Output** : a bound or signed slope ε_Φ , and phenomenological coefficients ξ, b in the loss law $\Gamma(x) = \Gamma_{\text{env}} + \xi \Phi + b |\nabla \ln \Phi|$. Geometry and null cones remain unchanged ; detection is strictly differential.

Keywords : Chronon Field, temporal coherence, differential metrology, synchronization, decoherence, falsifiability, pre-registration

I — REGISTERED SCOPE, AXIOMS & IDENTIFIABILITY

Registered scope (frozen). This pre-registration fixes design, preprocessing, blinding, primary/secondary endpoints, acceptance gates, and the decision rule. Geometry (GR) and light cones remain unchanged ; only differential observables are admissible.

Axioms (master laws, single source).

$$d\tau = \Phi^{-1}(x) dt, \quad J^\mu = \Phi u^\mu, \quad \partial_\mu J^\mu = \Gamma(x).$$

Non-energetic, covariant reading ; GR intact ; detection is strictly differential (post-GR subtraction).

Identifiability & endpoints. Use X and Y as *defined once* in Sec. 2 (Definitions & measurables).

Primary (M1). Two-sided *signed* slope ε_Φ in Y vs X , *invariant* under link swaps (fiber/GNSS/free-space) and site/operator permutation $A \leftrightarrow B$; null witnesses must pass. *Decision rule* : see Sec. 5.

Secondaries (M2). (i) Qubits : signed β in $T_2^{-1} = T_\phi^{-1} + \frac{1}{2}T_1^{-1} + \beta \Delta \ln \Phi$ with $\Delta \ln \Phi \simeq g\Delta h/c^2$. (ii) Networks : common-mode spectral excess (pre-registered band) reported as $\delta\Phi/\Phi$ after independent-link veto ; multiplicity handled per Sec. 8.

Decision rule. See Sec. 5 (single pre-registered endpoint).

II — INTRODUCTION & HYPOTHESIS

Conventions (single source). Coordinates $x^\mu = (ct, \mathbf{x})$; 4-divergence $\partial_\mu = (\frac{1}{c}\partial_t, \nabla)$; four-velocity $u^\mu = (\gamma c, \gamma \mathbf{v})$. Covariant laws keep c explicit ; weak-field estimates restore units via the dictionary g/c^2 .

Working hypothesis. After full subtraction of the GR redshift $y_{\text{GR}} = g\Delta h/c^2$, a residual proportional to $g\Delta h/c^2$ may remain and trace a non-metric coherence field $\Phi(x)$.

Definitions & measurables (single source). Let $y \equiv \delta\nu/\nu$ be the fractional frequency difference between two vertically separated clocks (height offset $\Delta h > 0$, upward), and let y_{meas} denote the measured fractional offset *after all instrumental/transfer corrections, GR excluded*. We define the GR-subtracted residual

$$\delta y_{\text{res}} \equiv y_{\text{meas}} - \frac{g \Delta h}{c^2}, \quad X \equiv \frac{g \Delta h}{c^2}, \quad Y \equiv \delta y_{\text{res}}.$$

Units & Signs (operational)

Sign. Upward step $\Delta h > 0$. $X \equiv g\Delta h/c^2$, $Y \equiv y_{\text{meas}} - X$. A positive ε_Φ means Y increases with Δh (measured offset $>$ GR prediction).

Units. $[\Phi] = \text{s}^{-1}$, $[\varepsilon_\Phi] = 1$, $[\beta] = \text{s}^{-1}$, $g/c^2 \simeq 1.09 \times 10^{-16} \text{ m}^{-1}$ (for $g = 9.81 \text{ m s}^{-2}$).

GR intact. Light cones and $T_{\mu\nu}$ unchanged; detection is *strictly differential* (post-GR subtraction).

Weak-field dictionary. $\partial_z \ln \Phi \simeq g/c^2$, $\Delta \ln \Phi \simeq (g/c^2) \Delta h$.

Loss channel (coherence platforms, Option A — recommended).

$$\Gamma(x) = \Gamma_{\text{env}} + \xi \Phi(x) + \beta \Delta \ln \Phi, \quad \Delta \ln \Phi \simeq \frac{g}{c^2} \Delta h \quad (\text{vertical weak-field increment}).$$

Domain. This ansatz is used only for (i) co-located vertical stacks and (ii) controlled exposure profiles; it is *not* invoked in clock-network or cosmology analyses.

Scope and invariance. $\Phi(x)$ does not modify light cones nor introduce any additional $T_{\mu\nu}$; GR geometry and energy accounting remain intact. All claims are strictly *differential*: only GR-subtracted slopes, spatial increments $\Delta \ln \Phi$ and inter-epoch ratios $\dot{\Phi}/\Phi$ are observable; a constant Φ is operationally indiscernible (pure re-timing; see Sec. 12).

Abbreviations : WLS = Weighted Least Squares; HAC = Heteroskedasticity- and Autocorrelation-Consistent; EIV = Errors-In-Variables; DD = Dynamical Decoupling.

III — EXPERIMENTAL OBJECTIVES

Use X and Y as defined once in Sec. 2. Multiplicity handled in Sec. 8.

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Test type	Observable	Domain	Target	Detection criterion
Vertical optical clocks	GR-subtracted residual δy_{res}	0–30 m	ε_{Φ}	Signed slope of δy_{res} vs Δh , invariant under link swaps (fiber/GNSS/free-space) and site/operator permutations $A \leftrightarrow B$; witnesses ($\Delta h = 0$) must pass.
Qubits (cQED / trapped ions)	T_2, T_1, T_{ϕ}	Stacked/elevator/hoist ($\Delta \ln \Phi \simeq g \Delta h / c^2$)	β	Monotone signed variation consistent with $T_2^{-1} = T_{\phi}^{-1} + \frac{1}{2T_1} + \beta \Delta \ln \Phi$; DD-robust with environmental controls; bounds adjusted via Holm–Bonferroni (Sec. 8).
Cross-link clock network	Spectral coherence $\mathcal{C}(f)$	$10^2 - 10^5$ m	$\delta \Phi / \Phi$	Common-mode excess in pre-registered band surviving independent-link vetoes; Bayesian evidence threshold $\ln B_{10} \geq \ln B^* (= 5)$; stable under site/operator permutations (Sec. 8).

Table 1 Pre-registered detection channels (landscape).

Realistic sensitivity targets. With $\Delta h_{\text{rms}} \in [10, 30]$ m, $N \in [20, 60]$, and per-hour fractional noise σ_Y [h⁻¹],

$$\sigma_{\hat{\varepsilon}_\Phi} \approx \frac{\sigma_Y}{\sqrt{N}} \frac{c^2}{g \Delta h_{\text{rms}}}, \quad \frac{g}{c^2} \simeq 1.09 \times 10^{-16} \text{ m}^{-1}.$$

Scenario	Δh_{rms}	N	σ_Y [h ⁻¹]	$ \varepsilon_\Phi _{95\%}(\text{computed})$
S1 (baseline)	10 m	20	3×10^{-18}	1.2×10^{-3}
S2 (good lab)	30 m	40	1×10^{-18}	9.5×10^{-5}
S3 (ambitious)*	30 m	60	2×10^{-19}	1.6×10^{-5}

* Effective via 4–8 h co-integration (documented Allan stability).

95% limits use $1.96 \sigma_{\hat{\varepsilon}_\Phi}$. Values reflect the stated σ_Y , N , and Δh_{rms} .

IV — METHODOLOGY & RUNBOOK

Use X and Y as defined in Sec. 2. HAC/Andrews and Deming/WTLS details centralized in Sec. 5. Controls/gates in Sec. 6.

Design (frozen). Vertical staircase with randomized ascents/descents; $N \in [20, 60]$ runs; identical cabling per level; fixed duty cycle; co-located neutral witnesses; link permutations (fiber/GNSS/free-space) scheduled; environment setpoints logged.

Preprocessing (frozen). UTC/PTP disciplining; RTK/laser geodesy with solid/ocean tides and pressure-loading; compute $X = g\Delta h/c^2$; form $Y = \delta y_{\text{res}} = y_{\text{meas}} - X$; window averages (60–300 s); HAC-ready series. Switch to *Deming/WTLS* if $\sigma_X/X_{\text{rms}} \gtrsim 0.1$ (ratio λ from instrumented uncertainties). *Exception (co-located stacks)* : when $\sigma_{\Delta h} \ll \Delta h_{\text{rms}}$, we keep WLS; small tide/loading jitter entering $X(t)$ does not trigger Deming as long as $\sigma_X/X_{\text{rms}} < 0.1$.

Blinding. Freeze code/configs (hashes); blind Δh labels & link types; run Sec. 6 checks on *blinded* data; unblind only for the final fit.

Let $y(t) = \delta\nu/\nu$; $\Delta h > 0$ is upward; $y_{\text{GR}} = g\Delta h/c^2$; $\delta y_{\text{res}} = y_{\text{meas}} - y_{\text{GR}}$.

1. **Calibrate to UTC/PTP.** Phase-lock all clocks/links to a common timebase (UTC traceable, PTP discipline). Record drift of local references.
2. **Measure Δh with tides correction.** Laser/RTK geodesy with solid Earth/ocean tides & pressure-loading corrections. Estimate $\sigma_{\Delta h}$ per window.
3. **Synchronous acquisition (≥ 1 h).** Record $y(t)$ with common timestamps, duty cycle, link type, environment (temperature, vibration proxies).
4. **Subtract GR prediction.** Compute $y_{\text{GR}} = g\Delta h/c^2$ from contemporaneous $\Delta h(t)$. Form $\delta y_{\text{res}}(t) = y_{\text{meas}}(t) - y_{\text{GR}}(t)$.
5. **Aggregate residuals.** Average δy_{res} over windows (60–300 s) to whiten HF noise; propagate uncertainties; pre-whiten if needed for HAC (Sec. 5).
6. **Permuted ascents/descents.** $N = 20$ –60 staircase runs (A/B swaps : top \leftrightarrow bottom), randomized order; identical cabling per level (*see Fig. 1*).
7. **Neutral witnesses ($\Delta h = 0$).** Co-located oscillators and dummy links; require null within errors before proceeding.
8. **Qubit coherence tracking.** Measure $T_2(\Delta \ln \Phi)$ (and T_1, T_ϕ); log pulse sequences; enforce environmental setpoints; DD toggles planned.
9. **Blinding \rightarrow unblinding.** Keep labels/link types blinded until Sec. 6 checks pass; then *unblind* only for the final fit.
10. **Signed-slope analysis.** Primary analysis is **free-intercept WLS** with **HAC (Newey–West; Andrews bandwidth)**; wild bootstrap as non-gating check; switch to **Deming/WTLS** when

$\sigma_X/X_{\text{rms}} \gtrsim 0.1$ (λ from instrumented uncertainties). Robust overlay (Huber) reported as sensitivity — *all rules in Sec. 5*.

11. **Inference and report.** Combine runs with meta-aggregation (Sec. 8); emit ledger row with hashes, tests, and verdict (Sec. 6).

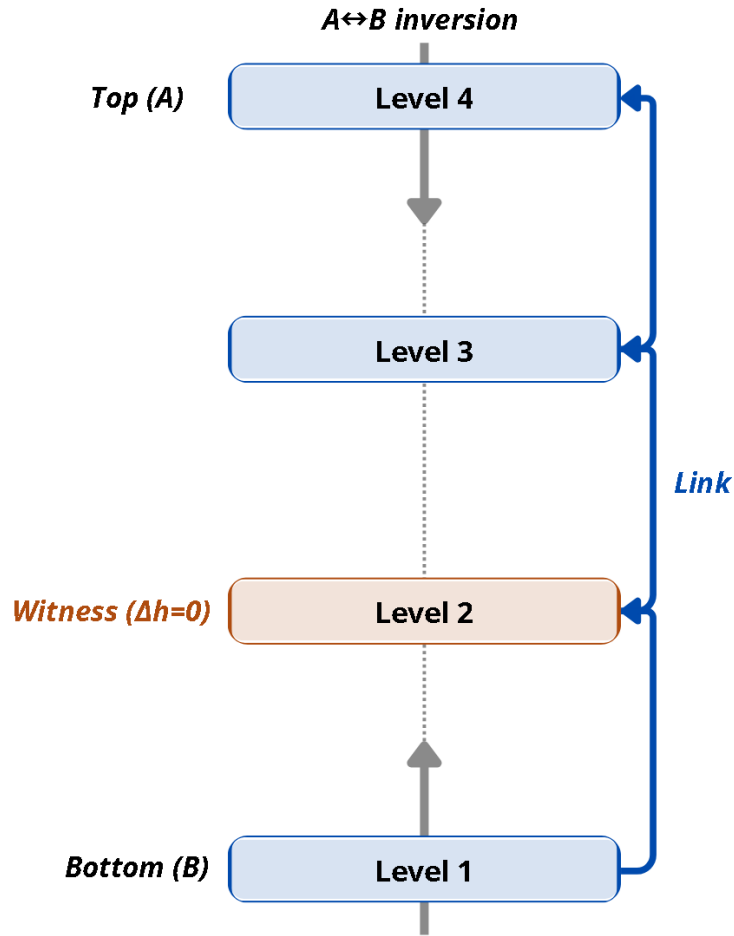


Figure 1 Four-level staircase with witness ($\Delta h = 0$); $A \leftrightarrow B$ inversion and link routing (fiber/GNSS/free-space) shown.

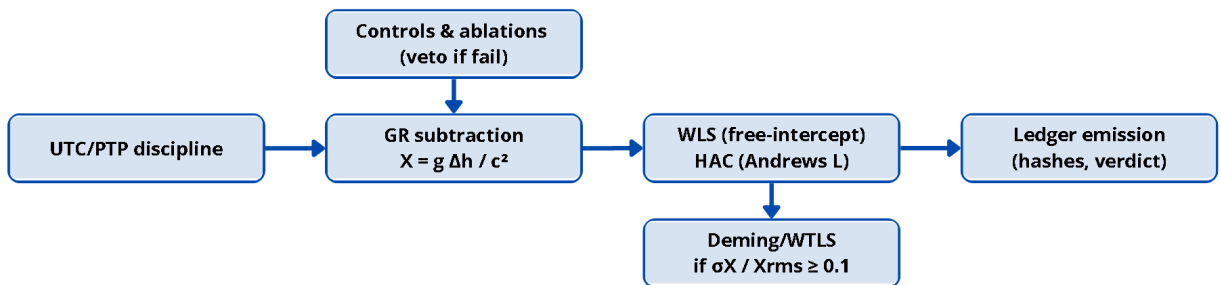


Figure 2 Analysis pipeline : discipline \rightarrow controls/ablations \rightarrow GR subtraction \rightarrow WLS (free-intercept, HAC) \rightarrow Deming/WTLS if $\sigma_X/X_{\text{rms}} \geq 0.1 \rightarrow$ ledger.

V — EXPECTED SENSITIVITY & DECISION BOUNDARIES

Model (free-intercept WLS).

$$Y_i \equiv \delta y_{\text{res},i}, \quad X_i \equiv \frac{g \Delta h_i}{c^2}, \quad Y_i = \alpha + \varepsilon_\Phi X_i + \epsilon_i,$$

with HAC (Newey–West) errors; Andrews plug-in bandwidth L . Report the empirical autocorrelation time τ_c (first zero of the ACF).

HAC bandwidth (Andrews)

Default : $L = \lfloor 4(T/100)^{2/9} \rfloor$, T = number of effective windows.

Sensitivity & policy : re-fit with $L/2$ and $2L$. If resulting 1σ bands differ by $>15\%$, *inflate* the primary SE to cover the wider envelope and use that CI for inference (non-gating diagnostic otherwise).

Errors-in-variables (Deming/WTLS). Use Deming/WTLS when $\sigma_X/X_{\text{rms}} \gtrsim 0.1$; TLS is $\lambda = 1$.

$\lambda = \frac{\sigma_Y^2}{\sigma_X^2}$ fixed from instrumented/propagated uncertainties (geodesy, tides, loading), *never* from residuals (anti-cir

Exception. Strictly co-located vertical stacks with $\sigma_{\Delta h} \ll \Delta h_{\text{rms}}$ remain in WLS; Deming/WTLS is only used when $\sigma_X/X_{\text{rms}} \geq 0.1$.

Intercept policy (stability-first). α must be (i) constant across permutations/site/operator and (ii) null on witnesses $\Delta h = 0$; weak nonzero α off-witness is tolerated if (i) holds.

Robust overlay (policy). Report Huber-robust ($k = 1.345$) as *non-gating* sensitivity. *Switch rule :* if $|\hat{\varepsilon}_\Phi|$ shifts $>15\%$ or $\text{SE}_{\text{robust}} > 1.25 \text{SE}_{\text{WLS}}$, adopt the wider CI.

Decision rule (pre-registered, single endpoint)

Detection if : two-sided 5σ on $\hat{\varepsilon}_\Phi$ plus all invariances and witness/intercept stability (Sec. 6).

Diagnostic only : hourly $|\overline{\delta y_{\text{res}}}| \sim 10^{-18}$ is *diagnostic*, not a gate.

If not detected, publish 95% bounds.

Scaling.

$$\sigma_{\hat{\varepsilon}_\Phi} \approx \frac{\sigma_Y}{\sqrt{N}} \frac{c^2}{g \Delta h_{\text{rms}}} \Rightarrow \text{gain via larger } \Delta h, \text{ longer co-integration, and more permutations.}$$

Required integration time (rule-of-thumb).

$$\tau_{\text{req}} \simeq \left(\frac{5 \sigma_y(\tau_0)}{|\varepsilon_\Phi| g \Delta h_{\text{rms}} / c^2} \right)^2 \tau_0,$$

for a target $|\varepsilon_\Phi|$ at given Δh_{rms} and per-window noise $\sigma_y(\tau_0)$.

Power budget. Use Table 1 (Sec. 3) given $\sigma_Y, N, \Delta h_{\text{rms}}$.

VI — NULL-TESTS & CONTROLS

Witness & invariance gates (hard thresholds)

Witness ($\Delta h = 0$). Hourly $|\overline{Y}| < 1.5 \times 10^{-18}$ and slope $0 \pm \sigma$.

Invariances. $\hat{\epsilon}_\Phi$ unchanged (within errors) under link swap and site/operator permutations $A \leftrightarrow B$.

Covariate veto. A covariate that explains $\geq 70\%$ of Y (partial R^2) and drives $\hat{\epsilon}_\Phi$ to $0 \pm \sigma$ triggers a veto in the Ledger.

1. **Link swap (fiber/GNSS/free-space).** $\hat{\epsilon}_\Phi$ invariant within 1σ ; path-specific artifacts veto a detection.
2. **A/B inversion (top \leftrightarrow bottom).** Swap definitions so that both Y and X flip sign; the estimated slope $\hat{\epsilon}_\Phi$ is invariant.
3. **Site/operator permutations.** Slopes agree within uncertainties; heterogeneity triggers hierarchical/meta aggregation (Sec. 8) and can only *weaken* claims.
4. **Thermal, vibrational, RF controls (auto-veto).** Partial correlations of Y with environment $\leq 1\sigma$. *Auto-veto* : if a covariate explains $\geq 70\%$ of Y and cancels the slope within errors, detection is vetoed.
5. **Neutral witnesses ($\Delta h = 0$) — hard gate.** Hourly mean $|\overline{Y}| < 1.5 \times 10^{-18}$ and slope $0 \pm \sigma$. Any witness failure \Rightarrow pipeline freeze and *neutral/falsify* verdict (see Sec. 8).
6. **Temporal correlation check (network band).** After GR subtraction, $r_{XY}(0) \rightarrow 0$; off-zero peaks must be absent or vetoed by independent-link repeats. Pre-registered band : $[f_1, f_2] = [0.1, 10]$ mHz, excluding diurnal/weekly lines and mains harmonics; stability under $\pm 30\%$ band variation required (details Sec. 12).
7. **Intercept stability (diagnostic, not a gate).** α constant across permutations/site/operator and null on $\Delta h = 0$ witnesses. Nonzero α off-witness tolerated if witness is null and stability holds.
8. **Ablations.** Height-label permutations, time desynchronization, window mixing, sign inversions, synthetic $1/f^\alpha$: all must yield slopes $0 \pm \sigma$ with uniform permutation p -histograms (Sec. 12).

VII — DATA SCHEMA & LEDGER

Primary CSV (one row = one measurement window).

```
# Geometry / identification
timestamp.UTC,site_id,site_pair,site_pair_label,pair_orientation
operator_id,run_id,height_m,Delta_h_m

# Measurement (clock/qubit)
y_frac,allan_tau_s,allan_sy_per_h
T2_s,T1_s,Tphi_s

# Environment
temp_C,pressure_hPa,humidity_pct,a_rms_ms2,rf_intrusion_flag

# Transfer link
link_type,link_SNR_dB,firmware_tag

# Physical models / corrections
g_local_mps2,geoid_model,geoid_version,tide_model
sagnac_applied,sagnac_value,pressure_load_corr

# Uncertainties
sigma_dh_m
```

Software / reproducibility
duty_cycle,software_env,random_seed

Notes (schema)

$\text{pair_orientation} \in \{\text{top-minus-bottom, A-minus-B}\}$; site_pair_label is a human-readable alias.
 g_local_mps2 = local gravity used; $\text{geoid_model/geoid_version}$, tide_model logged for reproducibility; $\text{sagnac_applied} \in \{0,1\}$ with numeric sagnac_value . For strictly co-located vertical tests, SR/Sagnac terms are negligible but *still logged*; long baselines use full corrections (Sec. 12).
QC gate : require $\text{link_SNR_dB} \geq 20$ or flag the window for exclusion/sensitivity runs.

EIV switch (pre-registered). Use **Deming/WTLS** if $\sigma_X/X_{\text{rms}} \gtrsim 0.1$ with $\lambda = \sigma_Y^2/\sigma_X^2$ fixed from instrumented/propagated uncertainties (geodesy, tides, loading) — never from residuals (anti-circularity). Details in Sec. 5.

Derived analysis table.

timestamp.UTC,site_pair,swap_flag,operator_id,run_id
X_GR,Delta_lnPhi
Y_res
sigma_X,sigma_Y
band_id

with $X_{\text{GR}} = g \Delta h / c^2$ and $\Delta \ln \Phi \simeq (g/c^2) \Delta h$.

Units (schema). Δh [m]; $y = \delta\nu/\nu$ [1]; $X = g\Delta h/c^2$ [1]; T_1, T_2, T_ϕ [s]; temp_C [°C]; $g/c^2 \simeq 1.09 \times 10^{-16} \text{ m}^{-1}$.

Ledger of proof (immutable append-only).

raw_hash,code_hash,config_hash,blind_labels
fit_model,lambda_ratio,huber_k
alpha_stability_pass,controls_pass,ablations_pass
eps_hat,eps_se,eps_pval,decision_primary
beta_hat,beta_se
common_mode_lnB10,band_f1_mHz,band_f2_mHz,lnB_star
n_perm,n_boot
verdict,{confirm|neutral|falsify},ORCID_signoff

Pre-registered thresholds : $\ln B^* = 5$; $n_{\text{perm}} \geq 4999$; $n_{\text{boot}} \geq 1999$.

Deviation plan & governance (frozen)

Roles. Blinding owner / Analysis runner / Stats reviewer.

Deviation log. Timestamp; scope; rationale; impact; pre/post hashes; reviewer sign-off.

Resampling sizes. Permutation ≥ 4999 , bootstrap ≥ 1999 (report seeds/hashes).

Licenses & deposits. Code MIT; data CC-BY 4.0; Zenodo deposits with SHA-256 of raw/clean bundles.

Licensing & public deposits

Code : MIT. **Data** : CC-BY 4.0.

Archive full snapshots (code, data, figures, ledger) with a Zenodo DOI for `chrononlabmeta`.

Outputs include : `lnB_band_table.csv` (network band evidence) and `ledger_row.json` (human-readable ledger extract).

Conflicts & role split. No conflicts of interest declared. Roles split where possible (biostatistics vs analysis execution) to reduce analytic bias.

Any control failure freezes the analysis; the ledger records a *neutral/falsify* verdict and its cause. All hashes are SHA-256.

VIII — STATISTICAL FRAMEWORK

Primary estimation is free-intercept WLS on Y vs X with HAC (Newey–West ; Andrews plug-in bandwidth). Errors-in-variables handled by Deming/WTLS when $\sigma_X/X_{\text{rms}} \gtrsim 0.1$. All fit policies are centralized in Sec. 5.

Wild bootstrap (finite-sample check). Validate HAC errors via studentized wild bootstrap (Andrews–Mammen) with $N_{\text{boot}} \geq 1999$. *Non-gating*; disagreement $> 15\%$ between HAC and bootstrap widens the reported SE (policy in Sec. 5).

Errors-in-variables (Deming/WTLS)

When : Use Deming/WTLS when $\sigma_X/X_{\text{rms}} \gtrsim 0.1$, with $\lambda = \sigma_Y^2/\sigma_X^2$.

Provenance of λ : λ is *fixed from instrumented and propagated uncertainties* (geodesy, tides, loading) — never from residual fits (anti-circularity).

Vertical co-located : $\sigma_X = \frac{g}{c^2} \sigma_{\Delta h}$, where $\sigma_{\Delta h} = \sqrt{\sigma_{\text{geod}}^2 + \sigma_{\text{tides}}^2 + \sigma_{\text{load}}^2}$.

Robust regression (sensitivity only). Report *Huber* robust fit with $k = 1.345$ as sensitivity (non-gating). *Switch rule* : adopt the wider CI if either (i) $|\hat{\varepsilon}_\Phi|$ shifts by $> 15\%$ between WLS and Huber, or (ii) $\text{SE}_{\text{robust}} > 1.25 \text{SE}_{\text{WLS}}$ (Sec. 5).

Resampling sizes (pre-registered). Permutation tests use $N_{\text{perm}} \geq 4999$ and wild bootstrap $N_{\text{boot}} \geq 1999$; both counts are logged in the Ledger (Sec. 7).

Hierarchical meta-aggregation. Random-effects (lab, link as random factors) combine per-site estimates to obtain a global $\hat{\varepsilon}_\Phi$ robust to heterogeneity. Forest plots and inverse-variance aggregates are produced once per lab/link family.

Decision reference. Apply the **single pre-registered endpoint** defined in Sec. 5. Report 95% bounds when the endpoint is not met.

Bounds under null.

$$|\varepsilon_\Phi| < 1.96 \sigma_{\hat{\varepsilon}_\Phi} \quad (95\% \text{ CL}).$$

Qubit branch (for β). Regress $Y = T_2^{-1} - (T_\phi^{-1} + \frac{1}{2T_1})$ on $X = \Delta \ln \Phi$ with *free intercept*; HAC errors if colored, wild-bootstrap check. Report $\hat{\beta} \pm 1\sigma$; publish 95% bound if null.

Blinding statement. Configs/code frozen and hashed prior to analysis; Δh labels blinded until freeze; unblinding only for the final fit; ledger records the freeze/unfreeze timestamps.

Multiplicity & stopping (frozen)

Primary. Single endpoint (Sec. 5).

Secondaries. Qubits/networks controlled by Holm–Bonferroni.

Stopping. Calendar-based; no interim looks; no data-dependent peeking.

IX — FALSIFICATION CRITERIA

Fail-fast box (pre-registered)

What kills a claim (all must pass).

1. **Primary slope null.** Free-intercept WLS and (if applicable) Deming/WTLS give $\hat{\epsilon}_\Phi = 0 \pm \sigma \Rightarrow$ publish 95% bounds (rule in Sec. 5).
2. **Witness/intercept sanity.** $\Delta h = 0$ witnesses : hourly $|\bar{Y}| < 1.5 \times 10^{-18}$ and slope $0 \pm \sigma$. Intercept α stable across permutations/site/operator and null on witnesses (Sec. 6).
3. **Controls & ablations.** Link swap, A/B inversion, temporal checks, and the full ablation suite $\Rightarrow 0 \pm \sigma$ with uniform permutation p -histograms (Sec. 12). Any single failure \Rightarrow veto.
4. **Covariate veto.** Any covariate explaining $\geq 70\%$ of Y and cancelling the slope \Rightarrow veto in the Ledger (Sec. 7).
5. **Cross-axis coherence.** If used, network common-mode must survive independent-link veto and band stability (Sec. 12); qubit branch must be DD-robust (Sec. 12). Cross-axis inconsistency \Rightarrow downgrade to systematics.

Freeze-and-publish. Any gate/control failure \Rightarrow pipeline freeze, Ledger entry, and *neutral/falsify* verdict with public bounds and hashes. Decision endpoint : *see Sec. 5*.

X — FIGURES & ANNEXES

TABLE DES FIGURES

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XI — FINAL SUMMARY

Single primary endpoint. Detect a *signed* slope ε_Φ in the GR-subtracted vertical-clock residual, fitting the **free-intercept** model

$$Y = \alpha + \varepsilon_\Phi X + \epsilon, \quad X \equiv \frac{g \Delta h}{c^2},$$

using **WLS** with **HAC** (Newey–West; Andrews bandwidth); **switch to Deming/WTLS** when $\sigma_X/X_{\text{rms}} \gtrsim 0.1$ with $\lambda = \sigma_Y^2/\sigma_X^2$ fixed from instrumented/propagated uncertainties. The claim must be **stable under** link/site/operator permutations (Secs. 4–6) and show **intercept** $\alpha = 0 \pm \sigma$ on $\Delta h = 0$ witnesses (Sec. 6). Hourly amplitudes (e.g. $|\overline{\delta y_{\text{res}}}| \sim 10^{-18}$) are *diagnostics*, **not** decision gates (Sec. 5).

Orthogonal confirmers.

- **Qubits.** $T_2^{-1} = T_\phi^{-1} + \frac{1}{2T_1} + \beta \Delta \ln \Phi$ with $\Delta \ln \Phi \simeq (g/c^2)\Delta h$; DD robustness and environmental vetoes; intercept/slope separation (ξ vs β). See Sec. 8.
- **Common-mode networks.** Band-limited search for spatially coherent $|\delta\Phi/\Phi|$ with $\ln B_{10} \geq \ln B^*$ (= 5) and independent-link vetoes. If $\ln B_{10} < \ln B^*$, convert the upper bound on the common PSD $S_c(f)$ into a bound on $\langle |\delta\Phi/\Phi|^2 \rangle_{[f_1, f_2]}$ and quote the band-limited amplitude $|\delta\Phi/\Phi|_{[f_1, f_2]} < \sigma_c$ (95% CL), as in Sec. 12.

Decision rule (reference). Two-sided 5σ on $\hat{\varepsilon}_\Phi$ + invariances + witness/intercept stability (Sec. 5). Secondaries controlled by Holm–Bonferroni (Sec. 8).

Outcomes.

- *Null primary endpoint.* Publish 95% bounds $|\varepsilon_\Phi| < 1.96 \sigma_{\hat{\varepsilon}_\Phi}$ (typ. $10^{-5} - 10^{-3}$, scenarios S1–S3); report $|\beta|$ and band-limited $|\delta\Phi/\Phi|$; freeze-and-publish with full reproducibility (immutable ledger of hashes/configs/data; Sec. 7).
- *Surviving detection.* If 5σ & controls hold, release the complete replication package and prioritize that configuration for a decisive public CHRONON-1 run.

XII — WHAT CAN BE PROVEN NOW (WITHOUT NEW LAB)

A — Vertical clocks — meta-analysis

Scope. Re-analyze published vertical optical-clock comparisons (height offsets 0.1–30 m) with reported $\Delta\nu/\nu$, site geometry, link type (fiber/GNSS/free-space), and uncertainty budgets.

Predictor and subtraction. For each datapoint i ,

$$X_i \equiv \frac{g_i \Delta h_i}{c^2}, \quad Y_i \equiv \delta y_{\text{res},i} = y_{\text{meas},i} - X_i,$$

with g_i from local geoid/gravimetry and Δh_i corrected for solid Earth/ocean tides and pressure loading. *Sign conventions.* See Sec. 2 (*Units & Signs*).

Estimators (pre-registered). *Primary (free-intercept WLS + HAC).* Fit $Y_i = \alpha + \varepsilon_\Phi X_i + \epsilon_i$ with inverse-variance weights; HAC (Newey–West) errors, Andrews plug-in bandwidth $L = \lfloor 4(T/100)^{2/9} \rfloor$; sensitivity at $L/2, 2L$; wild-bootstrap check (Andrews–Mammen) *non-gating*. *Secondary (origin-constrained overlay).*

$$\hat{\varepsilon}_\Phi^{(0)} = \frac{\sum_i w_i X_i Y_i}{\sum_i w_i X_i^2}, \quad \text{Var}(\hat{\varepsilon}_\Phi^{(0)}) = \frac{1}{\sum_i w_i X_i^2}.$$

EIV condition (Deming/WTLS). If $\sigma_{\Delta h}$ is non-negligible ($\sigma_X/X_{\text{rms}} \gtrsim 0.1$), use Deming/WTLS with ratio

$$\lambda = \frac{\sigma_Y^2}{\sigma_X^2} \quad \text{fixed from } \textit{instrumented/propagated} \text{ uncertainties (geodesy, tides, loading)} \text{ — never from residual fits.}$$

For co-located vertical stacks $\sigma_X = (g/c^2) \sigma_{\Delta h}$ with $\sigma_{\Delta h}$ from quadrature of geodesy + solid/ocean tides + pressure-loading models. The *primary verdict follows Deming/WTLS* when this condition holds.

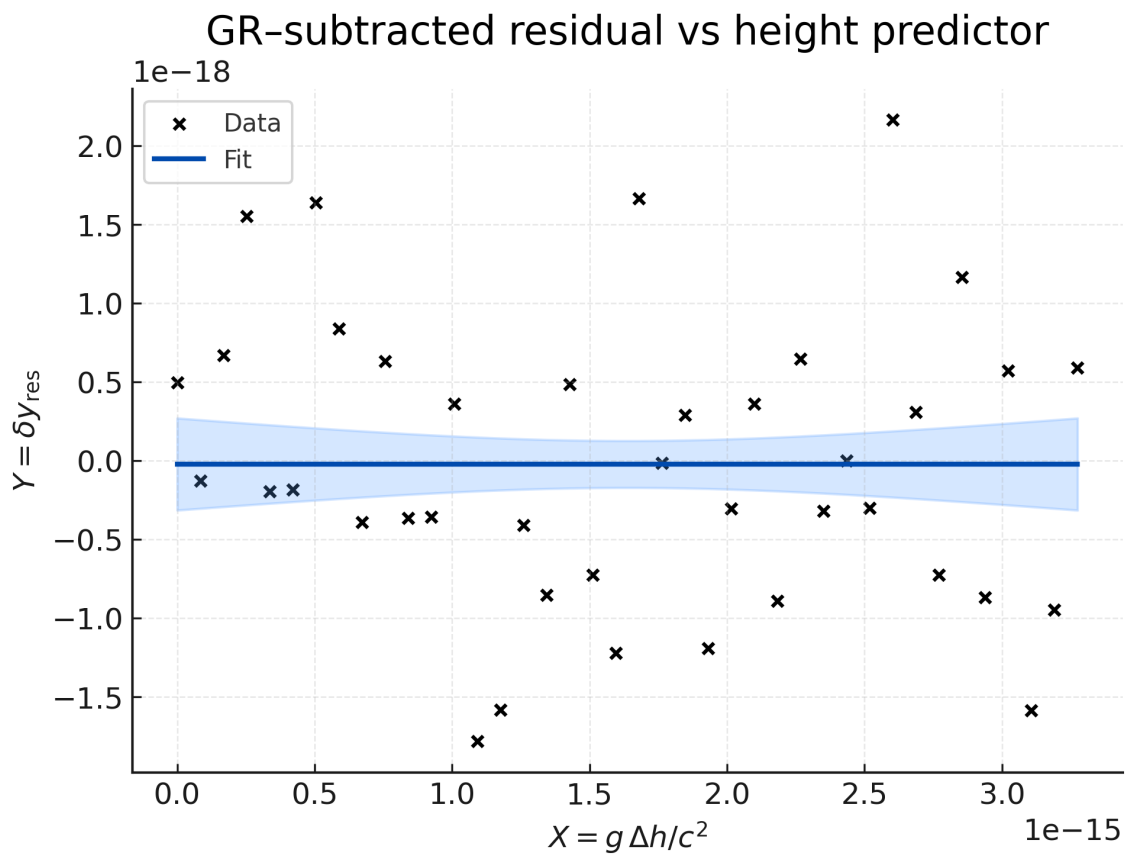


Figure 3 GR-subtracted residual $Y = \delta y_{\text{res}}$ versus $X = g\Delta h/c^2$ fitted by free-intercept WLS with HAC (Andrews bandwidth) and a 95% CI band.

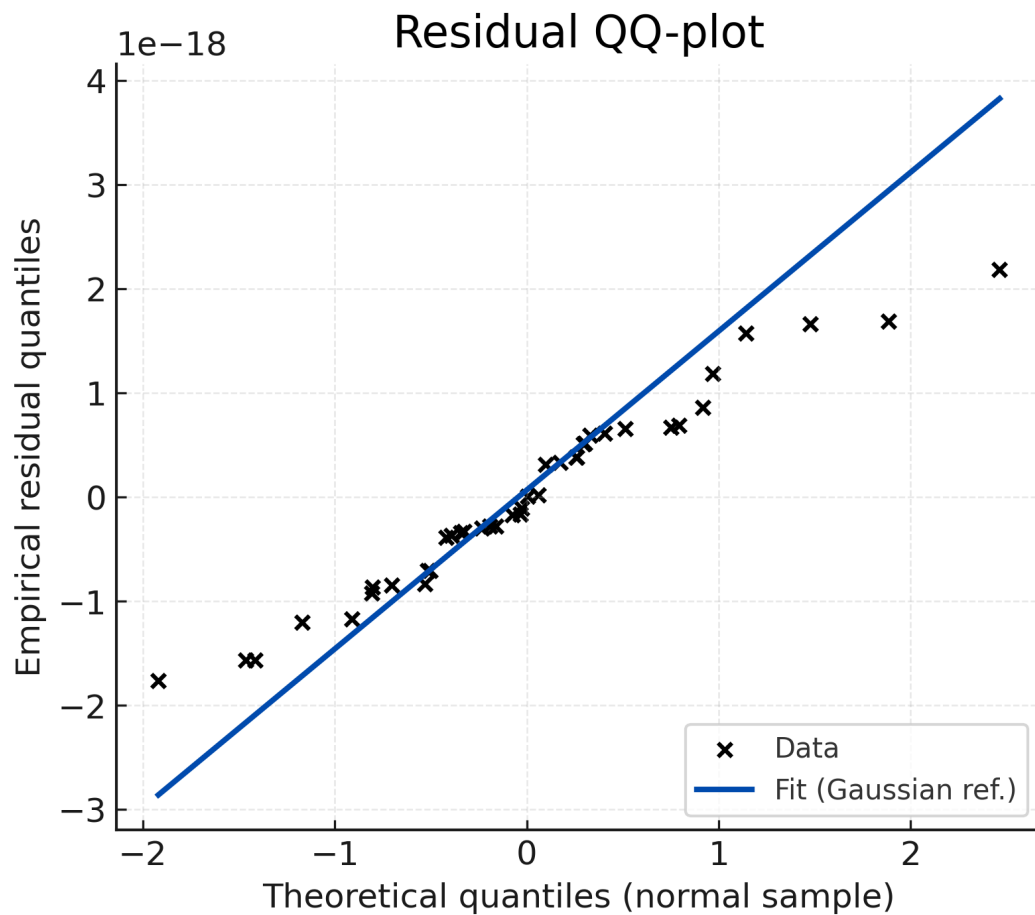


Figure 4 Quantile–quantile plot of WLS residuals (windowed averages) against a Gaussian reference with a dashed identity line.

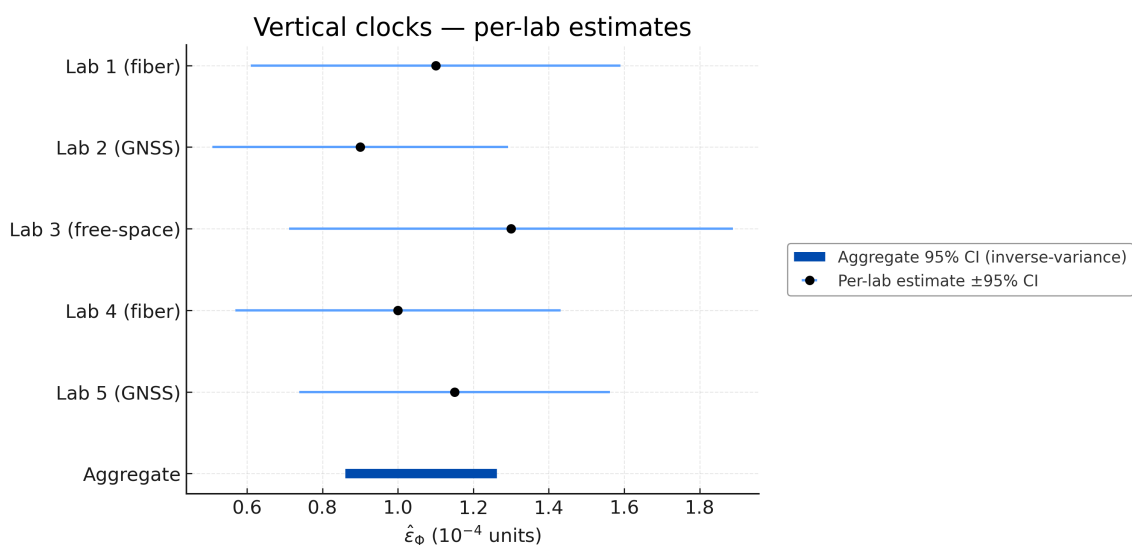


Figure 5 Vertical clocks : per-lab $\hat{\varepsilon}_\phi$ with 95% CI and inverse-variance aggregate band at the bottom.

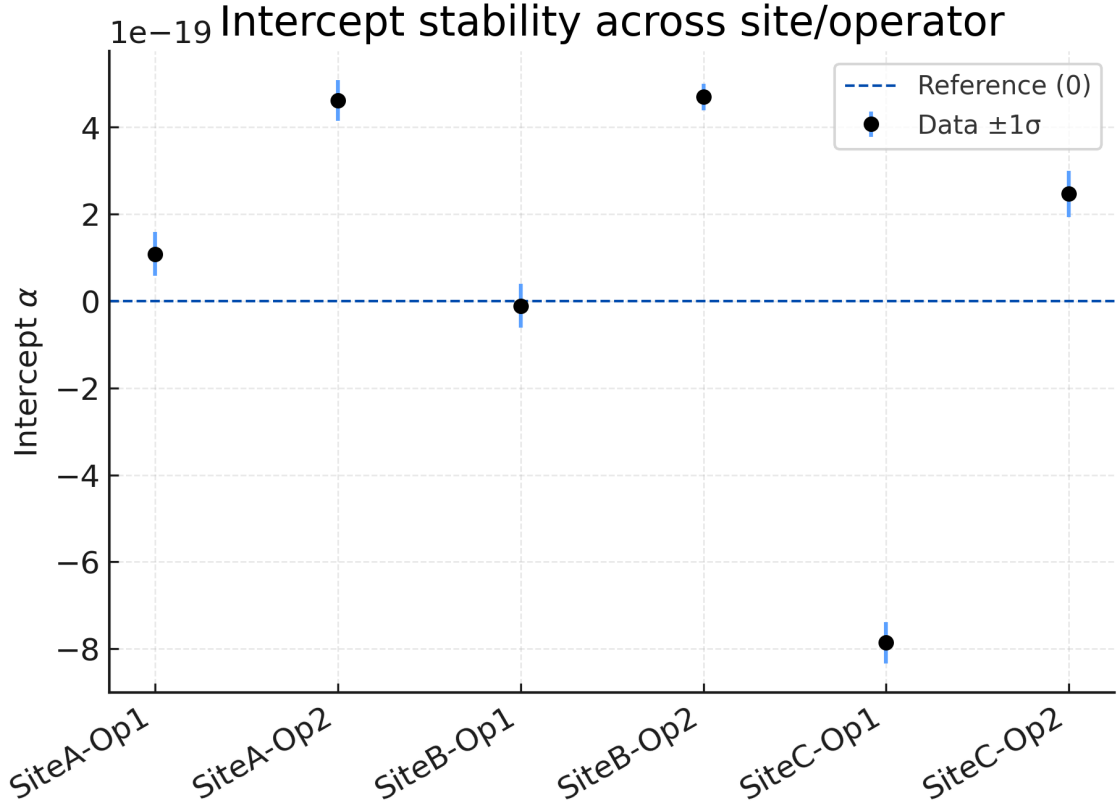


Figure 6 Intercept α across permutations, sites, and operators with a 1σ band and witness panels ($\Delta h = 0$) showing $\alpha \approx 0$.

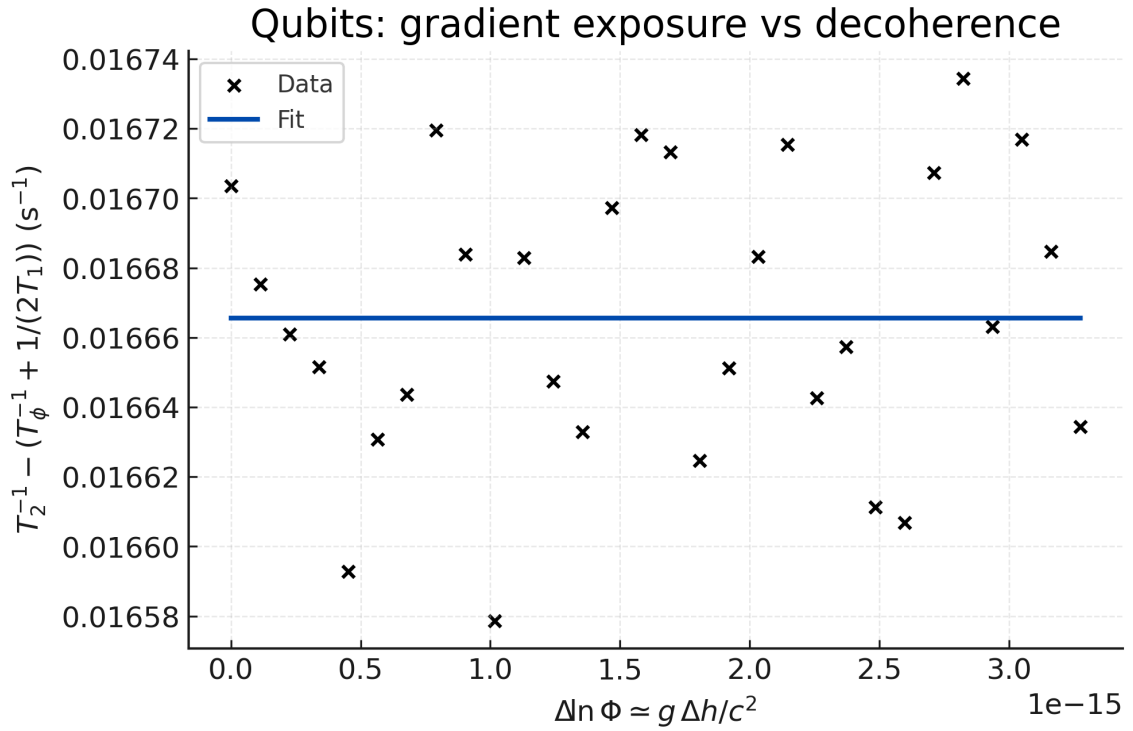


Figure 7 Qubits : T_2^{-1} versus exposure $X = \Delta \ln \Phi$ with a free-intercept fit and HAC band, including DD on/off markers.

Invariance and null-tests. Report $\hat{\varepsilon}_\Phi$ per link type and site pair; require consistency within 1σ . Permutation tests : (i) height-label shuffles, (ii) non-simultaneous mixes \Rightarrow zero slope within errors. **Witness panels** ($\Delta h = 0$) **gate** : hourly $|\overline{Y}| < 1.5 \times 10^{-18}$ and slope $0 \pm \sigma$. If any covariate (thermal/vibrational/RF) explains $\geq 70\%$ of the variance of Y and kills the slope, *veto*.

Decision and output. Apply the *single endpoint* of Sec. 5. If no detection, quote

$$|\varepsilon_\Phi| < 1.96 \sigma_{\hat{\varepsilon}_\Phi} \quad (95\% \text{ CL})$$

per lab and combined (fixed- or random-effects meta-estimate). Deliverables : Y vs X plot (free-intercept primary + origin-constrained overlay), forest plot by lab/link, bounds table (68/95%), HAC vs bootstrap errors, invariance checks.

B — Relativistic geodesy / chronometric leveling

Scope. Reprocess long-baseline clock comparisons used for chronometric leveling (inter-city to continental baselines; mixed relief), using public $\Delta\nu/\nu$, geoid models, and transfer-link metadata.

Predictor (full relativistic correction). For each pair $i-j$,

$$X_{ij}^{\text{GR}} \equiv \frac{\Delta U_{ij}}{c^2} + \frac{\Delta(v^2/2)_{ij}}{c^2} + X_{ij}^{\text{Sagnac}} + X_{ij}^{\text{tides/loads}},$$

where ΔU_{ij} is the geopotential difference with topography, v are local velocities (SR term), and the last terms account for transfer-path and Earth-tide corrections.

Residual and bound.

$$Y_{ij} \equiv \left(\frac{\delta\nu}{\nu} \right)_{ij}^{\text{meas}} - X_{ij}^{\text{GR}} = \left(\frac{\delta\Phi}{\Phi} \right)_{ij} + \epsilon_{ij}.$$

Estimate per-baseline bounds via inverse-variance weighting (or HAC if colored) :

$$\left| \frac{\widehat{\delta\Phi}}{\Phi} \right|_{ij} = |\overline{Y_{ij}}|, \quad \text{report 68\%/95\% CL using measured Allan deviation at integration time.}$$

Mapping and binning. Bin baselines by length L and relief Δh :

$$\mathcal{B}_{mn} = \{(i, j) : L \in L_m, \Delta h \in \Delta h_n\}, \quad \text{aggregate } |\widehat{\delta\Phi/\Phi}| \text{ via fixed-effects meta-estimates.}$$

World map (grid 1°) of local upper bounds : assign each site the tightest bound from incident baselines and interpolate conservatively.

Controls & null-tests. (1) *Link invariance* : identical bounds across fiber/GNSS/free-space within 1σ . (2) *Path veto* : remove epochs with anomalous tropospheric/ionospheric indices; bounds must tighten or stay unchanged. (3) *Permutations* : shuffle time tags or pairings \Rightarrow residuals vanish within errors.

Deliverables. Figure : global map of 95% CL bounds on $|\delta\Phi/\Phi|$ with length/relief insets. Tables : per-baseline $|\delta\Phi/\Phi|$ (68/95%), per-bin aggregates, link-type ANOVA p -values.

C — Long-distance common-mode (public time archives)

Scope. Exploit UTC/TAI ensemble series and logs of ultra-stable oscillators (when available) to search for a common-mode fractional-frequency process across distant, *independently linked* sites not sharing the same transfer path.

Data and preprocessing. Construct site-wise $y_k(t) = \delta\nu_k/\nu_k$ on a common grid (1–60 s) : detrend steps, remove steering terms, gap-fill conservatively (flagged), pre-whiten (first difference or HP filter) before spectral analysis. **Apply anti-aliasing FIR before any decimation; document the decimation factor and cutoff to avoid diurnal/weekly leakage into [0.1, 10] mHz.**

Spectral/coherence tests. For independent-link sites k, ℓ , estimate one-sided PSDs $S_{y_k}(f)$, $S_{y_\ell}(f)$ and cross-PSD $S_{k\ell}(f)$. Coherence :

$$\mathcal{C}_{k\ell}(f) = \frac{|S_{k\ell}(f)|^2}{S_{y_k}(f) S_{y_\ell}(f)}.$$

Under the null, $\mathcal{C}_{k\ell}(f)$ sits within finite-sample baselines; a bandwidth-stable excess indicates a common mode. Pre-registered band : $[f_1, f_2] = [0.1, 10]$ mHz, excluding diurnal/weekly lines; $\pm 30\%$ band stability required.

Bayesian common-mode model.

$$y_k(t) = a_k s_c(t) + n_k(t),$$

with s_c zero-mean common process (PSD $S_c(f)$), $a_k \approx 1$, n_k independent link/site noises. Compare $H_1 : S_c > 0$ vs $H_0 : S_c = 0$ in frequency space; report aggregated evidence over $[f_1, f_2]$ with the **pre-registered threshold**

$$\boxed{\ln B^* = 5} \quad (\text{“strong” level}).$$

Chronon translation and bound. Spatially coherent fractional-frequency implies a coherent $\delta\Phi/\Phi$. If $\ln B_{10} < \ln B^*$,

$$\left\langle \left| \frac{\delta\Phi}{\Phi} \right|^2 \right\rangle_{[f_1, f_2]} = \int_{f_1}^{f_2} S_c(f) df < \sigma_c^2 \text{ (95\% CL),}$$

quote $|\delta\Phi/\Phi|_{[f_1, f_2]} < \sigma_c$ at regional/continental scales.

Controls and nulls. (1) *Surrogates* : circular time-shifts and phase randomization return coherence to baseline.

(2) *Link independence* : repeat on alternative links; any persistent peak must survive path changes.

(3) *Band stability* : peaks persist under moderate $[f_1, f_2]$ and windowing variations.

Deliverables. Figure : $\mathcal{C}_{k\ell}(f)$ with null bands and vetted region; inset $|S_{k\ell}(f)|$.

Table : $\ln B_{10}$ per pair and combined; 95% CL bounds on $|\delta\Phi/\Phi|$ (band-limited).

D — Qubits — documentary reanalysis

Scope. Re-examine published coherence datasets T_2 (with T_1 , T_ϕ controls) from circuit QED and trapped-ion platforms that include : (i) stacked levels with known Δh ; (ii) elevator/hoist/tower moves; (iii) parabolic-flight or centrifuge runs with controlled $g_{\text{eff}}(t)$ profiles.

Chronon model (Option A — dimensionless exposure).

$$\Gamma = \Gamma_{\text{env}} + \xi \Phi + \beta \Delta \ln \Phi, \quad \Delta \ln \Phi \equiv \int_{\mathcal{C}} (\partial_n \ln \Phi) dl.$$

Static vertical stacks : $\Delta \ln \Phi \simeq (g/c^2) \Delta h$. Profiled accelerations : $\Delta \ln \Phi_{\text{eff}} \simeq \int (g_{\text{eff}}(t)/c^2) v_n(t) dt$.

Predictors and regressions. For each controlled segment k ,

$$X_k \equiv \Delta \ln \Phi_k, \quad Y_k \equiv T_{2,k}^{-1} - \left(T_{\phi,k}^{-1} + \frac{1}{2T_{1,k}} \right).$$

Primary fit (sensitivity) : free-intercept WLS with HAC (Newey–West ; Andrews bandwidth, policy Sec. 5) ; studentized wild bootstrap (Andrews–Mammen) as non-gating check.

Origin-constrained overlay (diagnostic) :

$$\hat{\beta}^{(0)} = \frac{\sum_k w_k X_k Y_k}{\sum_k w_k X_k^2}, \quad \text{Var}(\hat{\beta}^{(0)}) = \frac{1}{\sum_k w_k X_k^2}, \quad w_k = 1/\sigma_{Y,k}^2.$$

Separating ξ from β . Across epochs/platforms with identical X_k but offset shifts, absorb platform-wise shifts into $\xi \Phi$ (intercepts) while keeping cross-condition slope for β . Validate with DD toggles : ξ -like offsets respond to DD ; a true $\beta \Delta \ln \Phi$ term is DD-robust.

Controls and nulls. Hold cryostat T , magnetic map, flux-bias, phonon environment fixed ; veto segments with T_1 or T_ϕ excursions $> 1\sigma$. Negative controls : exposure shuffles ; non-simultaneous mixes ; synthetic $1/f^\alpha$ injections \Rightarrow zero slope within errors.

Inference and output. Report $\hat{\beta} \pm 1\sigma$; apply the multiplicity policy (Holm–Bonferroni ; Sec. 8). If null, publish $|\beta| < 1.96 \sigma_{\hat{\beta}}$ (95%). Deliverables : T_2^{-1} vs X figure (free-intercept + origin-constrained overlay) ; DD on/off comparison ; table of $\hat{\beta}$, controls, and platform meta-estimate.

E — Cosmology — model selection (dimensionless)

Priors (recall). Flat : $\Omega_m \in [0.1, 0.5]$, $H_0 \in [50, 90] \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\varepsilon_\Phi^{\cos} \in [-0.1, 0.1]$.

Scope. Implement the rhythmic mapping

$$H(z) \equiv -\frac{\dot{\Phi}}{\Phi}, \quad a(t) \propto \Phi^{-1}(t),$$

and test minimal deformations of the expansion history against public $H(z)$, anisotropic BAO, strong-lens time delays, and SN *shape-only* (no absolute magnitude).

Datasets and predictors. Use $\{E(z) = H(z)/H_0\}$ (cosmic chronometers), anisotropic BAO $\{D_A/r_s, c/(Hr_s)\}$, Alcock–Paczynski

$$F_{\text{AP}}(z) = (1+z) \frac{D_A(z)H(z)}{c},$$

strong-lens $D_{\Delta t}H_0/c$, and SN Hubble diagram with free M_B (shape-only).

Model families (pre-registered).

- \mathcal{M}_0 : flat Λ CDM cast into the same dimensionless observables.
- \mathcal{M}_Φ : minimal rhythmic deformation

$$E_\Phi(z) = E_{\Lambda\text{CDM}}(z) [1 + \varepsilon_\Phi^{\cos} f(z)], \quad f(z) \in \{\ln(1+z), z/(1+z)\}, \quad f(0) = 0.$$

Fit. Joint likelihood with published covariances (block-diagonal across probe families) ; SN block marginalized over (M_B, α, β) . HAC/Andrews and wild-bootstrap policies as in Sec. 5 for any time-series components.

Decision and reconstruction. Preference via $\Delta\chi^2 \equiv \chi^2(\mathcal{M}_0) - \chi^2(\mathcal{M}_\Phi)$.

$$\Delta\chi^2 > 6 \quad \text{and} \quad \text{sign}(\hat{\varepsilon}_\Phi^{\text{cos}}) \text{ stable under probe-split cross-validation.}$$

From the posterior,

$$\frac{\dot{\Phi}}{\Phi}(z) = -H_0 E_\Phi(z), \quad \ln \frac{\Phi(z)}{\Phi_0} = - \int_0^z \frac{E_\Phi(z')}{1+z'} dz'.$$

Degeneracies (checks). (1) H_0 - M_B neutralized by SN shape-only; cross-check with BAO/AP and $D_{\Delta t} H_0 / c$.

(2) $\Omega_m - \varepsilon_\Phi^{\text{cos}}$ broken by combining D_A/r_s with $c/(Hr_s)$ and adding F_{AP} .

Deliverables. Figure : posterior $E_\Phi(z)$ vs $E_{\Lambda\text{CDM}}(z)$ with 1σ bands; inset $\ln[\Phi(z)/\Phi_0]$. Table : $\varepsilon_\Phi^{\text{cos}} \pm 1\sigma$, $\Delta\chi^2$, probe-split stability, and 95% bounds.

F — Precision spectroscopy — retrodiction

Claim (minimal universality). If $\Phi(t)$ is spatially uniform over an epoch $t_0 \pm \Delta t$ and acts universally, then laboratory spectra co-scale with Φ and *dimensionless* ratios are invariant :

$$\nu_a(t) = \Phi(t) \nu_a^{(0)}, \quad R_{ab}(t) \equiv \frac{\nu_a(t)}{\nu_b(t)} = \frac{\nu_a^{(0)}}{\nu_b^{(0)}} = \text{const.}$$

Hence, intra-epoch spectroscopy cannot detect a constant Φ (pure re-timing; see also Sec. 12 for gradients-only observables).

Inter-epoch test (anchored to a standard). With a stable reference S (e.g., TAI/Cs ensemble),

$$y_a(t) \equiv \frac{\nu_a(t)}{\nu_S(t)} - 1 \simeq -\frac{\dot{\Phi}}{\Phi} t + n_a(t) - n_S(t),$$

so a secular drift in y_a bounds $|\dot{\Phi}/\Phi|$ over multi-year baselines.

Estimators and bounds. Fit $y_a(t) = \alpha_a + \beta_a t + \epsilon(t)$ by free-intercept WLS with HAC errors (Andrews bandwidth; policy Sec. 5) and wild bootstrap (Andrews–Mammen; non-gating). Quote

$$|\dot{\Phi}/\Phi| < 1.96 \sigma_{\hat{\beta}_a} \quad (95\% \text{ CL})$$

per species; combine by inverse-variance meta-estimate. Universality check : optical–optical ratios $R_{ab}(t)$ must satisfy $\frac{d}{dt} \ln R_{ab} = 0$ within errors.

Dataset requirements & deliverables. Long baselines (\gtrsim year), documented steering of S , environmental logs; include Al⁺, Sr, Yb, Hg. Deliverables : $y_a(t)$ with linear/piecewise fits; residual histogram and HAC window; table of per-species $\hat{\beta}_a \pm 1\sigma$ and the combined bound on $|\dot{\Phi}/\Phi|$; optical–optical \dot{R}_{ab} checks.

G — Equivalence theorem (partial no-go)

Statement.

- (i) **Re-timing equivalence.** If $\Phi(x) = \Phi_0$ is constant on a spacetime domain \mathcal{D} , all admissible observables in \mathcal{D} are invariant under $t' = \Phi_0 t$; thus Φ_0 is operationally indiscernible (pure re-timing).
- (ii) **Gradient-only observables.** Detectable signatures require spatial increments $\Delta \ln \Phi \neq 0$ (co-located differential tests) or inter-epoch variation $\dot{\Phi}/\Phi \neq 0$ (multi-epoch drifts). Otherwise, null by (i).

Proof sketch. The master laws

$$d\tau = \Phi^{-1} dt, \quad J^\mu = \Phi u^\mu, \quad \partial_\mu J^\mu = \Gamma$$

are covariant under $t \mapsto t' = \Phi_0 t$ when $\Phi = \Phi_0$. Any phase integral $\varphi = \int \omega dt$ becomes $\varphi = \int (\omega/\Phi_0) dt'$: uniform rescaling of all rates. Dimensionless ratios are unchanged ; GR observables are unmodified since Φ neither alters the metric nor adds stress–energy.

Weak-field dictionary (operational).

$$\partial_z \ln \Phi \simeq \frac{g}{c^2} \quad (\text{m}^{-1}), \quad \Delta \ln \Phi \simeq \frac{g}{c^2} \Delta h \quad (\text{dimensionless}), \quad \frac{g}{c^2} \simeq 1.09 \times 10^{-16} \text{ m}^{-1}.$$

Consequence. All CHRONON-1 claims must be **differential** (signed slopes vs $X = g\Delta h/c^2$; $\Delta \ln \Phi$ exposures ; inter-epoch drifts) and survive invariances/controls ; otherwise re-timing artifacts. Sign conventions : see Sec. 2 (*Units & Signs*).

H — Pre-registered simulations (false-positive calibration)

Purpose. Quantify the false-positive rate and statistical power *before* any new data, using open simulations with re-injected real noise.

Signal+noise model. Generate paired series on a grid $\Delta t \in [1, 60]$ s :

$$X(t) = \frac{g \Delta h(t)}{c^2}, \quad y_{\text{meas}}(t) = X(t) + \varepsilon_\Phi X(t) + n(t) + s(t),$$

where $n(t)$ mixes white/flicker/random-walk FM (weights tuned to target $\sigma_y(\tau)$) ; $s(t)$ are optional small systematics for stress tests.

Qubit branch : $X(t) = \Delta \ln \Phi(t)$, $Y(t) = T_2^{-1} - (T_\phi^{-1} + \frac{1}{2T_1})$ with parameter β .

Parameter sweeps (pre-registered).

$$\varepsilon_\Phi \in [10^{-4}, 10^{-3}], \quad \beta \in [10^{-4}, 10^{-2}] \text{ s}^{-1}, \quad N_{\text{runs}} \in \{10, 20, 40\}, \quad \Delta h_{\text{rms}} \in \{5, 10, 20, 30\} \text{ m}.$$

Analysis pipeline

Compute $Y_{\text{res}} = y_{\text{meas}} - X$.

Primary : free-intercept WLS with HAC (Newey–West ; Andrews plug-in bandwidth $L = \lfloor 4(T/100)^{2/9} \rfloor$).

Sensitivity : re-fit with $L/2$ and $2L$; widen CI if $> 15\%$ spread.

EIV switch : Deming/WTLS if $\sigma_X/X_{\text{rms}} \gtrsim 0.1$ with $\lambda = \sigma_Y^2/\sigma_X^2$ from instrumented uncertainties (never residuals).

Wild bootstrap (Andrews–Mammen) $N_{\text{boot}} \geq 1999$ (non-gating ; widen CI if disagreement $> 15\%$).

Vertical co-located uncertainty.

$$\sigma_X = \frac{g}{c^2} \sigma_{\Delta h}, \quad \sigma_{\Delta h} = \sqrt{\sigma_{\text{geod}}^2 + \sigma_{\text{tides}}^2 + \sigma_{\text{load}}^2}.$$

Controls embedded in sims. Include link swaps, A/B inversions, witness panels ($\Delta h = 0$), and covariate injections (thermal, vibrational, RF) with known coupling.

Outputs & pass criteria. ROC curves (TPR vs FPR) for the 5σ rule ; null p -histograms (uniform) ; QQ-plots ; operating points vs $\Delta h_{\text{rms}}, N$.

Pass if (all)

1. Empirical FPR at $5\sigma \leq 3 \times 10^{-7}$.
2. Power ≥ 0.8 for $\varepsilon_\Phi \geq 10^{-3} \times \frac{30\text{m}}{\Delta h_{\text{rms}}}$ with $N \geq 20$.
3. Witness gate ($\Delta h = 0$) : hourly $|\overline{Y}| < 1.5 \times 10^{-18}$ and slope $0 \pm \sigma$.
4. Covariate veto : any covariate explaining $\geq 70\%$ of Y and killing the slope triggers a *veto* flag in the Ledger.

I — Ablations & negative controls

Purpose. Demonstrate that the pipeline does not manufacture spurious slopes/coherences ; any genuine signal must vanish under label destruction or non-simultaneity.

Ablation suite (pre-registered).

1. **Height-label permutation.** Randomly permute Δh within runs $\Rightarrow \hat{\varepsilon}_\Phi^{\text{perm}} = 0 \pm \sigma$; permutation p -values uniform.
2. **Time desynchronization.** Pair $y(t)$ with $X(t + \Delta T)$ for random ΔT beyond correlation time \Rightarrow slope $0 \pm \sigma$.
3. **Window mixing.** Mix non-overlapping segments across days/runs (same Δh histogram) \Rightarrow slope vanishes ; HAC errors match null sims.
4. **Sign inversion.** Flip $\Delta h \rightarrow -\Delta h$ without moving hardware \Rightarrow fitted slope flips sign (diagnoses static systematics).
5. **Covariate regression-out.** Regress y on environmental logs (temp., vibration, RF). **Automatic veto** : a covariate explaining $\geq 70\%$ of Y and killing the slope triggers a veto.
6. **Synthetic $1/f^\alpha$ injections.** Ensure colored noise is not converted into signed slope ; $|\hat{\varepsilon}_\Phi| < 1\sigma$.
7. **Negative-height control.** Two co-located heads ($\Delta h = 0$) with cabling/link variations : hourly $|\overline{\delta y_{\text{res}}}| < 1.5 \times 10^{-18}$; slope $0 \pm \sigma$.

Reporting. Histogram of t -statistics (KS vs $\mathcal{N}(0,1)$) ; permutation p -histogram ; HAC bandwidth sensitivity (Andrews $L, L/2, 2L$) ; robust overlay (Huber $k = 1.345$). Any failure is recorded in the Ledger (Sec. 7) ; discrepancies $> 15\%$ widen the reported CI (policy Sec. 5).

J — Canonical Bounds 2025 (short, publishable)

Format (one page per axis). Each page reports : *Equation/Model* (testable law), *Dataset* (public sources), *Method* (analysis sketch), *Numerical bound* (68/95%), *Controls* (key nulls), *Reproducibility* (hashes/links).

J.1 — Vertical clocks (co-located, GR-subtracted).

$$\text{Model : } Y = \alpha + \varepsilon_\Phi X + \epsilon, \quad X = \frac{g \Delta h}{c^2}, \quad Y = \delta y_{\text{res}}. \quad \Rightarrow \quad |\varepsilon_\Phi| < \{\varepsilon_{\Phi,68}, \varepsilon_{\Phi,95}\}.$$

J.2 — Clock networks (long baselines / chronometric leveling).

$$Y_{ij} = (\delta\nu/\nu)_{ij}^{\text{meas}} - X_{ij}^{\text{GR}} \quad \Rightarrow \quad \left| \frac{\delta\Phi}{\Phi} \right|_{ij} \lesssim |\overline{Y_{ij}}| \quad (68/95\%).$$

J.3 — Qubits (documentary reanalysis).

$$T_2^{-1} = T_\phi^{-1} + \frac{1}{2T_1} + \beta \Delta \ln \Phi; \quad |\beta| < \{\beta_{68}, \beta_{95}\}.$$

J.4 — Cosmology (dimensionless selection).

$$E_\Phi(z) = E_{\Lambda\text{CDM}}(z) [1 + \varepsilon_\Phi^{\text{cos}} f(z)], \quad f(0) = 0; \quad |\varepsilon_\Phi^{\text{cos}}| < \{\varepsilon_{\Phi,\text{cos},68}, \varepsilon_{\Phi,\text{cos},95}\}.$$

Canonical table (publication-ready).

Axis	Parameter	68%	95%	Notes / Controls
Vertical clocks	$ \varepsilon_\Phi $	$\varepsilon_{\Phi,68}$	$\varepsilon_{\Phi,95}$	link/A \leftrightarrow B/dummy pass
Clock networks	$ \delta\Phi/\Phi $	$\Delta_{\Phi,68}$	$\Delta_{\Phi,95}$	path veto, permutations
Qubits	$ \beta $	β_{68}	β_{95}	DD-robust, env. veto
Cosmology	$ \varepsilon_\Phi^{\text{cos}} $	$\varepsilon_{\Phi,\text{cos},68}$	$\varepsilon_{\Phi,\text{cos},95}$	probe-split stable

K — Execution order (fast path)**Milestones (calendar from day $J = 0$).**

1. **J+2 — Repo bootstrap.** Create `chronon-lab-meta` (public) : simulators, CSV schemas (Sec. 7), notebook for GR subtraction $\Rightarrow \varepsilon_\Phi$; CI to rebuild Sec. 12 figures from processed CSV.
2. **J+5 — First vertical-clock bounds.** Reprocess 2–3 published stair runs; produce Y vs X plots and WLS+HAC slope table; run link/A \leftrightarrow B/dummy invariances (Secs. 4–6). Output : preliminary $|\varepsilon_\Phi|$ 68/95% per lab.
3. **J+10 — Theory notes.** (i) *No-go (constant Φ)* two-page memo (Sec. 12); (ii) cosmology pre-fit (Sec. 12) with SN shape-only + BAO/AP + $D_{\Delta t}H_0/c$. Output : $|\varepsilon_\Phi^{\text{cos}}|$ bound and $\Delta\chi^2$.
4. **J+14 — Short preprint.** “*Bounds without new experiments*” (5–8 pages) : methods (Secs. 2, 7, 8), results (A–F), controls (Secs. 6, 12), canonical table (Sec. 12), code/data hashes (Sec. 7).

Pass/fail gates (each milestone). Proceed only if : (a) reproducibility hashes match; (b) invariance checks pass; (c) ablations are null (Secs. 6, 12). Otherwise, stop and issue a falsification or revise pipeline.

L — Interpretation grid (outcomes)

If all tests are null (within errors). No signed slope or coherence co-variation survives controls :

$$\hat{\varepsilon}_\Phi = 0 \pm \sigma, \quad |\beta| < \beta_{95}, \quad \left| \frac{\delta\Phi}{\Phi} \right| < \Delta_{\Phi,95}.$$

Outcome : the Chronon framework *survives by tightening* — you chart where it cannot act (tested domain), upgrade canonical bounds (Sec. 12), and calibrate CHRONON-1 power (Sec. 12).

If there is a weak, consistent preference. Any axis (vertical clocks, networks, qubits, cosmology) shows stable evidence :

$$\text{either } \Delta\chi^2 > 6 \text{ (model selection) or } \ln B_{10} > \ln B^* \text{ (common mode).}$$

Outcome : *prioritize* a concrete hypothesis (signed ε_Φ or β) and a configuration (height range, link type, platform) for the next decisive run (Sec. 12).

If signals disagree across axes. Cross-axis inconsistency (e.g., clock slope but no network mode, or T_2 effect without vertical slope) is treated as *systematics* until a common signed parameter survives Secs. 4–6–12. Outcome : *falsified for the claimed domain* or sent back to ablations.

If a detection survives all controls. A 5σ signed slope/invariance-persistent result or a DD-robust T_2 co-variation is *potential evidence* for a non-metric coherence field $\Phi(x)$ under the minimal dictionary. Outcome : release the replication package (ledger, code, raw CSV) \rightarrow public CHRONON-1; summarize in Sec. 11.

M — Ready-to-generate deliverables (templates & scripts)**Bundle structure (reproducible layout).**

```

chronon-lab-meta/
  data/
    raw/                                # published CSVs / digitized points
    processed/                          # Sec. VII schema-conformant tables
      lnB_band_table.csv                # network band evidence (pre-registered band)
      expected_residual_curves.csv
    templates/
      primary_schema.csv                # header from Sec. VII (Sec.~\ref{sec:schema})
  img/
    staircase_schematic.pdf
    staircase_schematic.png
    metrology_pipeline.pdf
    metrology_pipeline.png
    expected_residual_vs_height.pdf
    expected_residual_vs_height.png
    expected_T2_vs_height.pdf
    expected_T2_vs_height.png
    residual_qqplot.pdf
    residual_qqplot.png
    forest_vertical_clocks.pdf
    forest_vertical_clocks.png
    intercept_stability.pdf
    intercept_stability.png
    map_dPhi_over_Phi_bounds.pdf
    map_dPhi_over_Phi_bounds.png
  notebooks/
    01_gr_subtraction_slope_fit.ipynb
    02_clock_residual_simulator.ipynb
    03_common_mode_bayes.ipynb
    04_qubit_T2_gradient_fit.ipynb
    05_cosmo_Ephi_fit.ipynb
    06_spectroscopy_drift_bounds.ipynb
  scripts/
    00_ledger_packager.py               # hashes, ledger rows, CI hooks
    make_fig_staircase.py               # staircase schematic (h)
    make_pipeline_diagram.py            # metrology pipeline 1e-16-1e-18
  configs/
    analysis.yaml                      # prereg params (Secs.~\ref{sec:decisions}-\ref{sec:stats})
    noise_palette.yaml                 # synth weights for sims (Sec.~\ref{sec:sims})
  memos/
    no_go_constant_phi.tex              # 2p formal note (Sec.~\ref{sec:equivalence})
  legal/
    LICENSE_CODE.txt                   # MIT
    LICENSE_DATA.txt                   # CC-BY 4.0
  ledger/
    runs_ledger.csv                    # append-only (Sec.~\ref{sec:schema})
    ledger_row.json                     # human-readable extract (per run)

```

Figures & diagrams (auto-built). Staircase schematic (Δh , A/B permutations, link paths) → staircase_schematic.{pdf,png}.

Metrology pipeline (UTC/PTP → GR subtraction → WLS; Deming branch; vetoes) → metrology_pipeline.{pdf,png}.

Expected residual vs height and T_2^{-1} vs exposure $\Delta \ln \Phi \rightarrow$ `expected_residual_vs_height.{pdf,png}`,
`expected_T2_vs_height.{pdf,png}`.

Residual diagnostics \rightarrow `residual_qqplot.{pdf,png}`; per-lab forest \rightarrow `forest_vertical_clocks.{pdf,png}`;

intercept stability \rightarrow `intercept_stability.{pdf,png}`; network map \rightarrow `map_dPhi_over_Phi_bounds.{pdf,png}`.

Notebook	Inputs	Outputs
01_gr_subtraction_slope_fit.ipynb	<code>primary_schema.csv</code> $\rightarrow X = g\Delta h/c^2$, $Y = \delta y_{\text{res}}$	<code>expected_residual_vs_height.png</code> , WLS/HAC slope table, forest plot
02_clock_residual_simulator.ipynb	<code>noise_palette.yaml</code> , ε_Φ , N , Δh_{rms}	<code>sim_runs.csv</code> , ROC/power curves (Sec. 12)
03_common_mode_bayes.ipynb	UTC/TAI series, site logs	Coherence plots, $\ln B_{10}$ table, regional $ \delta\Phi/\Phi $ bounds (Sec. 12)
04_qubit_T2_gradient_fit.ipynb	T_2, T_1, T_ϕ datasets, exposure $X = \Delta \ln \Phi$	T_2^{-1} vs X figure, $\hat{\beta} \pm 1\sigma$ table (Sec. 12)
05_cosmo_Ephi_fit.ipynb	$H(z)$, BAO/AP, $D_{\Delta t}H_0/c$, SN (shape-only)	Posterior $E_\Phi(z)$, $\Delta\chi^2$, 95% $ \varepsilon_\Phi^{\text{cos}} $ bounds (Sec. 12)
06_spectroscopy_drift_bounds.ipynb	Multi-year ν_a/ν_S , optical ratios R_{ab}	$ \dot{\Phi}/\Phi $ bound, \dot{R}_{ab} null checks (Sec. 12)

Table 2 Notebook deliverables (inputs \rightarrow outputs).

CI hooks & ledger packaging (helpers).

- `00_ledger_packager.py` : compute SHA-256 for raw/clean bundles ; emit `ledger_row.json` ; update `runs_ledger.csv`.
- `analysis.yaml` : freeze prereg parameters (Andrews bandwidth L , bootstrap sizes, veto thresholds, band $[f_1, f_2]$; policies from Secs. 5, 8).
- Continuous integration : rebuild figs/tables from `data/processed/` on commit ; verify invariance/ablations checks (Secs. 6, 12) ; fail CI if any gate flips to “veto”.