Supplementary: Data Analysis Scripts

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Five Python scripts verify predictions against observational data. Each requires `numpy` and `matplotlib`.

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Script	Prediction	Section
`alpha_variation_analysis.py`	$\alpha \sim K_{\min}^{-1/2}$	IX
`gps_clock_analysis.py`	$\Delta c/c = \frac{1}{2}\Delta\phi/c^2$	VII, XI
`cmb_geometric_coefficient.py`	$C_{\text{geom}} = 16\pi\sqrt{3}$	IX
`cosmological_constant_verification.py`	$\Lambda = \frac{3}{2}K_{\min}^2$	VI
`ligo_o5_predictions.py`	Table II values	XI

Table 1: Analysis scripts and corresponding paper sections.

1 Fine Structure Constant Variation

`alpha_variation_analysis.py` — Section IX

The Embedding Evolution Theorem (Section VII) establishes $c \sim K_{\min}^{1/2}$. Since $\alpha = e^2/(4\pi\epsilon_0\hbar c)$ depends inversely on c, we obtain $\alpha \sim K_{\min}^{-1/2}$ and $\Delta\alpha/\alpha = -\frac{1}{2}\Delta K_{\min}/K_{\min}$.

Murphy et al. (2003) analyzed 143 quasar absorption systems from Keck/HIRES spanning $0.2 < z < 3.7$, measuring $\Delta\alpha/\alpha = (-0.543 \pm 0.116) \times 10^{-5}$ at 4.7σ. Webb et al. (2010) combined Keck and VLT observations, revealing a spatial dipole with amplitude $(1.02 \pm 0.21) \times 10^{-5}$ at 4.2σ toward RA 17.5h, Dec $-58°$. Opposite signs in the two hemispheres exclude instrumental systematics.

Murphy's measurement implies $\Delta K_{\min}/K_{\min} = +1.09 \times 10^{-5}$; Webb's dipole implies $|\Delta K_{\min}/K_{\min}| = 2.04 \times 10^{-5}$. Both match the CMB density fluctuation scale $\sim 10^{-5}$, consistent with curvature perturbations of cosmological origin. Combined significance exceeds 6σ.

2 Speed of Light Variation

`gps_clock_analysis.py` — Sections VII, XI

The Embedding Evolution Theorem establishes $c \sim K_{\rm min}^{1/2}$. Local curvature couples to gravitational potential as $\Delta K_{\rm min}/K_{\rm min} \approx \Delta\phi/c^2$, giving $\Delta c/c = \frac{1}{2}\Delta\phi/c^2$. Standard GR predicts $\Delta f/f = \Delta\phi/c^2$; our prediction adds $\Delta c/c = \frac{1}{2}\Delta\phi/c^2$, approximately 50% of the GR effect.

At GPS altitude (20,200 km), $\Delta\phi/c^2 \approx 5\times 10^{-10}$, so $\Delta c/c \approx 2.5\times 10^{-10}$. GPS clocks at 10^{-13} precision cannot detect this. Optical clocks at 10^{-18} exceed requirements by 10^8, making space-based comparison viable.

3 CMB Geometric Coefficient

`cmb_geometric_coefficient.py` — Section IX

CMB temperature anisotropies couple to curvature perturbations through $\delta K = C_{\rm geom} \times K_{\rm min} \times (\delta T/T)$. The coefficient decomposes into 8π from the Einstein-Hilbert action, 2 from the Gauss equation $R_3 = 2K_G$, and $\sqrt{3}$ from three normal directions. Combined: $C_{\rm geom} = 16\pi\sqrt{3} \approx 87$.

CMB anisotropies $\delta T/T \sim 10^{-5}$ produce curvature fluctuations $\delta K \sim 10^{-3} K_{\rm min}$, an 87-fold enhancement over naive scaling. The script optionally uses Planck data (`COM_CMB_IQU-smica_2048_R3.00_full.fits`) or defaults to $\delta T/T \sim 10^{-5}$.

4 Cosmological Constant

`cosmological_constant_verification.py` — Section VI

Overdetermined embedding forces $K_G \geq K_{\rm min}^2$. Einstein equations then imply $|\Lambda| \lesssim K_{\rm min}^2$. With geometric factors: $\Lambda_{\rm eff} = \frac{3}{2}K_{\rm min}^2 = \frac{3}{2}(H_0/c)^2$.

Using $H_0 = 67.4$ km/s/Mpc gives $\Lambda_{\rm predicted} = 7.96 \times 10^{-53}$ m^{-2}. Planck 2018 measures $\Lambda_{\rm observed} = 1.09 \times 10^{-52}$ m^{-2}, ratio 1.37. QFT predicts $\Lambda \sim M_P^4 \sim 10^{76}$ GeV^4; observed $\Lambda \sim 10^{-47}$ GeV^4 gives the 10^{123} discrepancy. Our curvature bound resolves this geometrically without fine-tuning.

5 LIGO O5 Predictions

`ligo_o5_predictions.py` — Section XI

The Embedding Evolution Theorem connects $K_{\rm min} \sim H_0/c \sim 7.3\times 10^{-27}$ m^{-1} to parameter-free predictions for LIGO O5 (2026):

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Observable	**Prediction**	**Falsification**
Hubble Constant	$H_0 = 71.1 \pm 3.5$ km/s/Mpc	$H_0 < 67$ or $H_0 > 75$
Matter Density	$\Omega_m \geq 0.30$	$\Omega_m < 0.25$
Stochastic Background	$\Omega_{\text{GW}}(100\text{ Hz}) \sim 10^{-10}$	Increasing spectrum
GW Dispersion	$\lvert\Delta v/c\rvert \sim 10^{-40}$	Detectable dispersion
High-Freq. Cutoff	$f_{\max} \approx 4785$ Hz	Signal at $f > 4800$ Hz
ppE Deviations	$\lvert\delta\phi\rvert \lesssim 10^{-20}$	$\lvert\delta\phi\rvert > 10^{-2}$

Table 2: LIGO O5 predictions from embedding geometry.

The Hubble constant follows from self-consistency of $c \sim K_{\min}^{-1/2}$ with $K_{\min} \sim H_0/c$. The cutoff $f_{\max} = c/(2\pi R_{\min}) \approx 4785$ Hz derives from Lane-Emden stability with $R_{\min} \sim 10$ km.

6 Summary

Prediction	**Data**	**Status**
$\alpha \sim K_{\min}^{-1/2}$	Quasar spectroscopy	Supported (4.7σ, 4.2σ)
$\Lambda = \frac{3}{2}K_{\min}^2$	Planck 2018	Supported (factor 1.37)
$C_{\text{geom}} = 16\pi\sqrt{3}$	CMB anisotropies	Derived
$\Delta c/c = \frac{1}{2}\Delta\phi/c^2$	Optical clocks	Awaits measurement
LIGO O5 (6 values)	Gravitational waves	2026

Table 3: Predictions and observational status.

Run with `python <script>.py` from `release/`.