

# Supplementary: Data Analysis Scripts

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

XI		
Script Prediction Section		
<code>alpha_variation_analysis.py</code>	$\alpha \sim K_{\min}^{-1/2}$	IX
<code>gps_clock_analysis.py</code>	$\Delta c/c = \frac{1}{2}\Delta\phi/c^2$	VII, XI
<code>cmb_geometric_coefficient.py</code>	$C_{\text{geom}} = 16\pi\sqrt{3}$	IX
<code>cosmological_constant_verification.py</code>	$\Lambda = \frac{3}{2}K_{\min}^2$	VI
<code>ligo_o5_predictions.py</code>	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  $4.7\sigma$ . Webb et al. (2010) combined Keck and VLT observations, revealing a spatial dipole with amplitude  $(1.02 \pm 0.21) \times 10^{-5}$  at  $4.2\sigma$  toward RA 17.5h, Dec  $-58^\circ$ . 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  $6\sigma$ .

## 2 Speed of Light Variation

`gps_clock_analysis.py` — Sections VII, XI

The Embedding Evolution Theorem establishes  $c \sim K_{\min}^{1/2}$ . Local curvature couples to gravitational potential as  $\Delta K_{\min}/K_{\min} \approx \Delta\phi/c^2$ , 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  $\delta K = C_{\text{geom}} \times K_{\min} \times (\delta T/T)$ . The coefficient decomposes into  $8\pi$  from the Einstein-Hilbert action, 2 from the Gauss equation  $R_3 = 2K_G$ , and  $\sqrt{3}$  from three normal directions. Combined:  $C_{\text{geom}} = 16\pi\sqrt{3} \approx 87$ .

CMB anisotropies  $\delta T/T \sim 10^{-5}$  produce curvature fluctuations  $\delta K \sim 10^{-3}K_{\min}$ , 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  $K_G \geq K_{\min}^2$ . Einstein equations then imply  $|\Lambda| \lesssim K_{\min}^2$ . With geometric factors:  $\Lambda_{\text{eff}} = \frac{3}{2}K_{\min}^2 = \frac{3}{2}(H_0/c)^2$ .

Using  $H_0 = 67.4$  km/s/Mpc gives  $\Lambda_{\text{predicted}} = 7.96 \times 10^{-53} \text{ m}^{-2}$ . Planck 2018 measures  $\Lambda_{\text{observed}} = 1.09 \times 10^{-52} \text{ m}^{-2}$ , ratio 1.37. QFT predicts  $\Lambda \sim M_P^4 \sim 10^{76} \text{ GeV}^4$ ; observed  $\Lambda \sim 10^{-47} \text{ GeV}^4$  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  $K_{\min} \sim H_0/c \sim 7.3 \times 10^{-27} \text{ m}^{-1}$  to parameter-free predictions for LIGO O5 (2026):

Observable Prediction Falsification		
Hubble Constant	$H_0 = 71.1 \pm 3.5 \text{ km/s/Mpc}$	$H_0 < 67$ 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	$ \Delta v/c  \sim 10^{-40}$	Detectable dispersion
High-Freq. Cutoff	$f_{\text{max}} \approx 4785 \text{ Hz}$	Signal at $f > 4800 \text{ Hz}$
ppE Deviations	$ \delta\phi  \lesssim 10^{-20}$	$ \delta\phi  > 10^{-2}$

Table 2: LIGO O5 predictions from embedding geometry.

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

## 6 Summary

Prediction	Data	Status
$\alpha \sim K_{\text{min}}^{-1/2}$	Quasar spectroscopy	Supported ( $4.7\sigma$ , $4.2\sigma$ )
$\Lambda = \frac{3}{2}K_{\text{min}}^2$	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/`.