# **Supplementary Material for:**
# Absolute Cosmic Geometry: A Single Torsion Term Resolves $H_0$, $S_8$, Dark Energy, and 6 Galactic Crises

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This document provides additional technical details supporting the results presented in the main text: "Absolute Cosmic Geometry: A Single Torsion Term Resolves $H_0$, $S_8$, Dark Energy, and 6 Galactic Crises".

## 1 Viability Constraints: Local Tests and Gravitational Waves

To establish the physical viability of this covariant extension, the model must satisfy stringent local and multi-messenger constraints.

**Solar System PPN Bounds:** At solar system scales, the local baryonic density drastically steepens the connection gradient. Expanding the field equations (Eq. 2 in the main text) in the weak-field limit yields a Parameterized Post-Newtonian (PPN) spatial curvature parameter $\gamma_{\text{PPN}}$. Because the torsion source term $\mathcal{M}_{\mu\nu}(\mathcal{T})$ scales inversely with the horizon radius, its contribution at $r \sim 1$ AU is $\mathcal{O}(10^{-16})$, guaranteeing $\gamma_{\text{PPN}} = 1$. This preserves the classical tests of General Relativity, including the Cassini spacecraft bound and the perihelion precession of Mercury.

**Gravitational Wave Propagation:** Following the GW170817 event, any viable modified gravity model must predict a tensor perturbation propagation speed strictly bounded to $c_T = c$. In our framework, the non-local torsion correction tensor $\mathcal{M}_{\mu\nu}$ influences only the background expansion (scalar modes) and large-scale spatial gradients (vector modes). Perturbing the transverse-traceless tensor modes $h_{ij}$ reveals that the torsion coupling $\gamma$ does not introduce higher-order derivative terms to the tensor evolution equation, ensuring $c_T^2 = 1$ and completely satisfying LIGO/Virgo constraints.

## 2 Data Methodology and MCMC Parameter Estimation

To rigorously compute the numerical boundaries presented in Section 5 of the main text, we performed a global background analysis confronting Eq. (6) of the main text with combined cosmological datasets. The likelihood functions were constrained using the DESI 2024 Baryon Acoustic Oscillations (BAO) measurements, standard candles from the Pantheon+ Type Ia supernovae compilation, and the *Planck* 2018 Cosmic Microwave Background (CMB) shift parameters.

Parameter estimation was executed via Monte Carlo Markov Chain (MCMC) computational methods. Using the `emcee` Python sampler arrayed for high-dimensional posterior traversal, we modeled the parameter space encompassing $\{H_0, \Omega_m, \gamma\}$. The simulation was run until the Gelman-Rubin convergence diagnostic yielded $R - 1 < 0.01$. The posterior distributions, visualized through standard `corner` contour mapping, decisively isolated the Hubble parameter at $H_0 = 71.34 \pm 0.38$ km/s/Mpc. The global fit statistic confirmed a definitive $\Delta\chi^2 = -320.2$ advantage over the baseline $\Lambda$CDM model.