Phenomenological Bounds on the Photon Soul Framework

1 Introduction

While the core calculus of the Photon Soul Continuity framework is fully verified via a zero-axiom Lean 4 mechanization (`PROOFPS.pdf`, Sections 1–4), the physical viability of the higher-dimensional bulk relies on phenomenological constraints.

By integrating out the $(4 + k)$-dimensional bulk, the effective field theory predicts a stochastic scalar coupling that degrades quantum phase coherence, leading to an interferometric fringe visibility loss:

$$1 - V = \mathcal{O}(1) \times \left(\frac{E}{\Lambda}\right)^{2k}$$

where E is the photon energy, Λ is the effective Kaluza-Klein mass scale of the bulk ($M_{KK} \sim \Lambda$), and k represents the number of extra dimensions.

This addendum applies published observational data from both table-top interferometry and ultra-high-energy astrophysics to establish hard empirical lower bounds on the bulk scale Λ.

2 Table-Top Optical Interferometry (QUEST / Holometer)

Twin-interferometer experiments (such as the Fermilab Holometer and Cardiff's QUEST) are designed to detect stochastic, cross-correlated phase noise at high frequencies.

- **Experimental Limit:** These experiments achieve a high-frequency correlated phase variance limit of $\langle \delta\phi^2 \rangle_{\text{exp}} \approx 10^{-40}$ rad^2.
- **Photon Energy:** Standard table-top setups utilize near-infrared lasers (1064 nm), equating to a photon energy of $E \approx 1$ eV $= 10^{-9}$ GeV.

By equating the theoretical phase variance $\langle \delta\phi^2 \rangle \propto (E/\Lambda)^{4k}$ to the experimental limit, we can isolate Λ:

$$\left(\frac{10^{-9}\ \text{GeV}}{\Lambda}\right)^{4k} \approx 10^{-40}$$

- **For $k = 1$ (5D spacetime):** $\Lambda 10$ GeV
- **For $k = 2$ (6D spacetime):** $\Lambda 100$ keV

Conclusion: Due to the steep $(E/\Lambda)^{2k}$ energy suppression, optical photons are highly shielded from high-energy bulk fluctuations. Table-top interferometers can only rule out highly macroscopic or extremely low-energy extra dimensions.

3 Ultra-High-Energy Astrophysics (LHAASO)

To probe higher values of Λ relevant to quantum gravity or string-theoretic compactifications, we must use the highest energy photons ever recorded. The Large High Altitude Air Shower Observatory (LHAASO) has definitively detected individual gamma rays arriving from the Cygnus star-forming region.

- **Experimental Observation:** Detection of a 1.42 PeV gamma ray.
- **Photon Energy:** $E = 1.42 \times 10^6$ GeV.

For this gamma ray to be detected as a directional point-source after traversing thousands of light-years, its quantum phase coherence cannot be completely destroyed by bulk stochastic fluctuations. Therefore, the visibility loss must be strictly less than total decoherence ($1 - V < 1$).

$$\left(\frac{E}{\Lambda}\right)^{2k} 1 \implies \Lambda E$$

Conclusion: The LHAASO dataset places a rigorous lower bound on the topological bulk scale:

$$\Lambda 1.42 \times 10^6 \text{ GeV} \quad (\text{or } 1.42 \text{ PeV})$$

4 Summary Implications

The available physical data successfully constrains but does not rule out the Photon Soul framework. The survival of PeV-scale cosmic gamma rays proves that if a higher-dimensional topological leakage exists, the extra dimensions must be tightly compactified with an effective energy scale strictly greater than 1.42 PeV.