Program for Testing Polarization Phase-Locking (P1)

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Goal

Test whether the phases of primordial CMB polarization modes (TE/EE) are coupled to the observational context. Define the phase alignment statistic

$$S_\gamma \equiv \frac{\sum_{\ell,m} w_{\ell m} \cos(\phi_{\ell m}^{\mathrm{CMB}} - \phi_{\ell m}^{\mathrm{ctx}})}{\sum_{\ell,m} w_{\ell m}}, \tag{1}$$

where ϕ denotes the phase of the spherical harmonic coefficient $a_{\ell m}$ and weights $w_{\ell m}$ are determined by the power of the context template. S_γ should vanish under ΛCDM (random phases) but deviates proportionally to the coupling strength λ_γ in the Causal Evolution (CE) framework.

0. Pre-registration

- Masks: Planck PR4 "Common" mask for Temperature/Polarization analysis.
- Multipoles: Low-ℓ focus, $2 \leq \ell \leq 20$, where the scan strategy geometry is most coherent.
- Frequency: SMICA (PR4/NPIPE) as primary; SEVEM as cross-check.
- Estimator: Direct harmonic phase extraction from $a_{\ell m}^E$.
- Context template: Ecliptic-aligned low-ℓ basis (T_{ctx}), pre-registered and fixed.
- Output: Single S_γ statistic per mode (TE, EE) and combined.

1. Data Products

- CMB maps: Planck PR4/NPIPE component-separated I/Q/U (SMICA, SEVEM).
- Ancillary: HFI 143/217 GHz hit-count maps (proxy for integration depth).
- Foregrounds: Planck 2018 Zodiacal emission model.
- Simulations: NPIPE End-to-End (E2E) simulation suite.

2. Context Template Construction

The context template T_{ctx} defines the "cost" of the observation.

1. Input: Load Exposure $E(\hat{n})$ and Zodiacal $Z(\hat{n})$ maps.
2. Rotation: Rotate all maps from Galactic to Ecliptic coordinates to align with the satellite scan topology.
3. Feature Extraction: Project onto spherical harmonics $Y_{\ell m}$ for $\ell \leq 20$.
4. Orthogonalization: Regress out beam asymmetries and standard Galactic cut residuals.
5. Basis Selection: Perform SVD on the design matrix. The leading left-singular vector defines the canonical context vector c.

3. The Metric (S_γ)

We quantify the "pinning" of history by the observer's context using the phase-locking metric:

$$\Delta\phi_{\ell m} = \arg(a_{\ell m}^{\text{CMB}}) - \arg(a_{\ell m}^{\text{ctx}}) \tag{2}$$

$$w_{\ell m} = |a_{\ell m}^{\text{ctx}}| \tag{3}$$

Standard ΛCDM assumes $\phi^{\text{CMB}} \sim U(-\pi, \pi)$ independent of ϕ^{ctx}. The Causal Evolution hypothesis predicts a concentration of $\Delta\phi$ around 0 (or π) weighted by the intensity of the observation context.

4. Splits & Replication

- Planck Half-Mission A vs. Half-Mission B (temporal split).
- Detector splits (DetSet 1 vs DetSet 2).
- Frequency cross-checks (100, 143, 217 GHz).
- Hold out Half-Mission B as validation.

5. Simulation Calibration

- Null suite: 1000 ΛCDM skies with NPIPE noise properties. Determine $1\sigma, 2\sigma, 3\sigma$ confidence intervals for S_γ.
- Injection suite: Inject signal $a^{\text{obs}} = a^{\text{CMB}} + \lambda_{\text{true}} a^{\text{ctx}}$.
- Recovery: Verify S_γ scales linearly with λ_{true} and establish minimum detectable coupling λ_{min}.

6. Systematics Triage

- Coordinate Rotation: Analyze in Galactic coordinates without Ecliptic rotation (should reduce significance).
- Beam Asymmetry: Toggle beam orthogonalization step in context builder.
- Zodiacal Residuals: Include/exclude Zodi template from basis construction.

7. Statistical Reporting

- Primary outcomes: Z-score of observed S_γ relative to Null Suite.
- Bounds: If $|Z| < 2$, place upper limit $\lambda_\gamma < \lambda_{95\%}$.
- Detection: Requires $|Z| > 3$ combined and $|Z| > 2$ in both Half-Mission splits.

8. Expected Sensitivity

- Planck (Current): Sensitivity to coupling strengths of order $\lambda \sim 10^{-2}$.
- LiteBIRD (Future): Sensitivity $\lambda \sim 10^{-3}$ due to improved large-angle polarization stability.

9. Minimal Stack

- Python 3.10+, NumPy, Healpy.
- `ledger` repository: `pbc.context` (templates), `pbc.stats` (metrics).

10. Stop-loss Rules

- If null variance > 30% worse than forecast, publish null.
- If split signs inconsistent, declare null.
- If held-out fails, stop and publish bounds.

11. Paper Skeleton

1. Introduction: TE vs. CE distinction.
2. Data & Context: Planck scan strategy and Ecliptic geometry.
3. Methodology: Derivation of S_γ from Woodbury update.
4. Results: Audit of Planck archive.
5. Sensitivity Analysis: Injection recovery curves.
6. Conclusion: Constraints on mutability of the past.

References

References

[1] Hewitt, A. Parochial by Construction: Dual Constructions for Cosmological Inference. *Draft* (2025).

[2] Planck Collaboration. Planck intermediate results. LVII. Joint Planck LFI and HFI data processing. *Astronomy & Astrophysics* **643** (2020) A42. doi:10.1051/0004-6361/202038073.