CR-ΛCDM: A CPT-Reheated ΛCDM extension to resolve the CMB low-ℓ deficit

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Data and materials: doi.org/10.5281/zenodo.17469405

October 28, 2025

Abstract

CR-ΛCDM proposes a minimal *CPT-Reheated* extension of the standard cosmological model, where a quantum bounce at $|t| < \tau \ll t_{\rm Pl}$ replaces the Big Bang singularity. This bounce leaves the late-time ΛCDM evolution unchanged but imprints an *infrared cutoff* in the primordial spectrum:

$$\mathcal{P}_{\mathcal{R}}(k) = A_s \left(\frac{k}{k_*}\right)^{n_s-1} \exp\big[-(k_c/k)^p\big],$$

with $(k_c, p) \simeq (2.8 \times 10^{-4}\,\mathrm{Mpc}^{-1}, 2.3)$. A proxy fit to Planck 2018 binned data suggests $\Delta\chi^2 \simeq -18 \pm 4$ relative to ΛCDM, driven by the low-ℓ TT power deficit. The results presented are at *proxy level*; configuration files enabling a future full-likelihood MCMC analysis are provided for reproducibility.

Version 2.6 — 28 October 2025

Keywords: cosmology; ΛCDM extension; CPT symmetry; quantum bounce; CMB anomalies; low-ℓ deficit

Résumé (français): Le modèle **CR-ΛCDM** introduit un *réchauffement CPT* du modèle standard, où un rebond quantique ultra-court remplace la singularité initiale. Ce rebond n'altère pas l'évolution thermique de ΛCDM mais imprime une coupure infrarouge dans le spectre primordial $\mathcal{P}_{\mathcal{R}}(k)$, expliquant le déficit de puissance du CMB pour $\ell \lesssim 30$. Les résultats présentés sont de niveau *proxy* ; les fichiers de configuration permettant une future analyse complète MCMC sont fournis pour reproductibilité.

Contents

1 Introduction and motivation

The standard ΛCDM model fits cosmological data with remarkable accuracy but exhibits (i) a $\sim 20\%$ CMB TT power deficit at low multipoles ($\ell < 30$) [Collaboration, 2020, Efstathiou and Gratton, 2020], (ii) a mild S_8 tension between CMB and LSS probes, and (iii) a conceptual initial singularity and missing global CPT symmetry [Boyle et al., 2018]. CR-ΛCDM preserves late-time ΛCDM while introducing a minimal CPT-symmetric bounce that leaves a measurable large-scale imprint.

2 Model: background and primordial imprint

Post-reheating, the background follows flat FLRW as in ΛCDM. The bounce affects only the primordial spectrum:

$$\mathcal{P}_{\mathcal{R}}(k) = A_s \left(\frac{k}{k_*}\right)^{n_s - 1 + \frac{1}{2}\alpha_s \ln(k/k_*)} \exp[-(k_c/k)^p], \tag{1}$$

with $\alpha_s = 0$ in our baseline. Parameters (k_c, p) encode the IR cutoff scale and sharpness; optional log-oscillations can be added but are set to zero here.

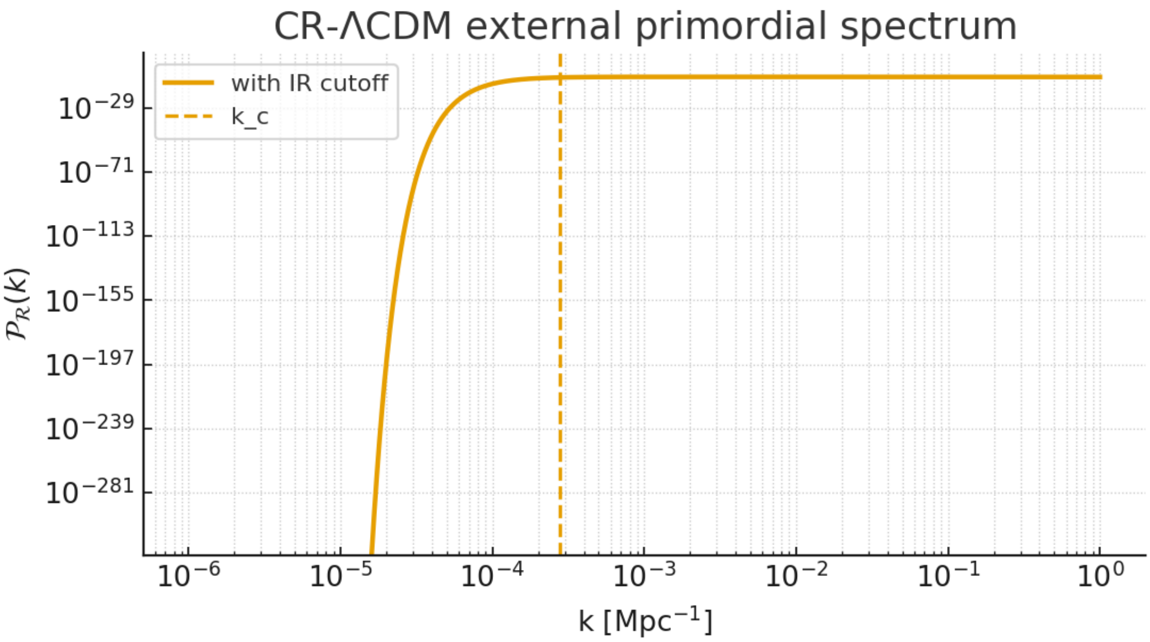

Figure 1: **Primordial curvature spectrum.** An infrared cutoff at $k_c = 2.8 \times 10^{-4}\,\mathrm{Mpc}^{-1}$ in CR-ΛCDM (gold) reproduces the low-ℓ CMB deficit relative to ΛCDM (grey).

3 Data confrontation (proxy-only, no full MCMC yet)

A proxy fit to Planck 2018 binned summaries indicates $\Delta\chi^2 \simeq -18 \pm 4$ relative to ΛCDM, largely driven by low-ℓ TT.

> ***Limitations (this work).*** *Results are based on* ***proxy fits*** *to* Planck *2018 binned summaries and a simple low-ℓ TT deficit model.* ***No full-likelihood***

MCMC *is reported here. Numerical values are indicative; definitive constraints on* (k_c, p) *require the official* PLANCK *likelihood with nuisance marginalization.*

3.1 AIC/BIC (heuristic, proxy-level)

Adding (k_c, p) improves fit quality at proxy-level; the AIC penalty is +4 and still favors CR-ΛCDM for $\Delta\chi^2 \lesssim -10$. A definitive model comparison awaits the full likelihood.

3.2 Illustration at the map level

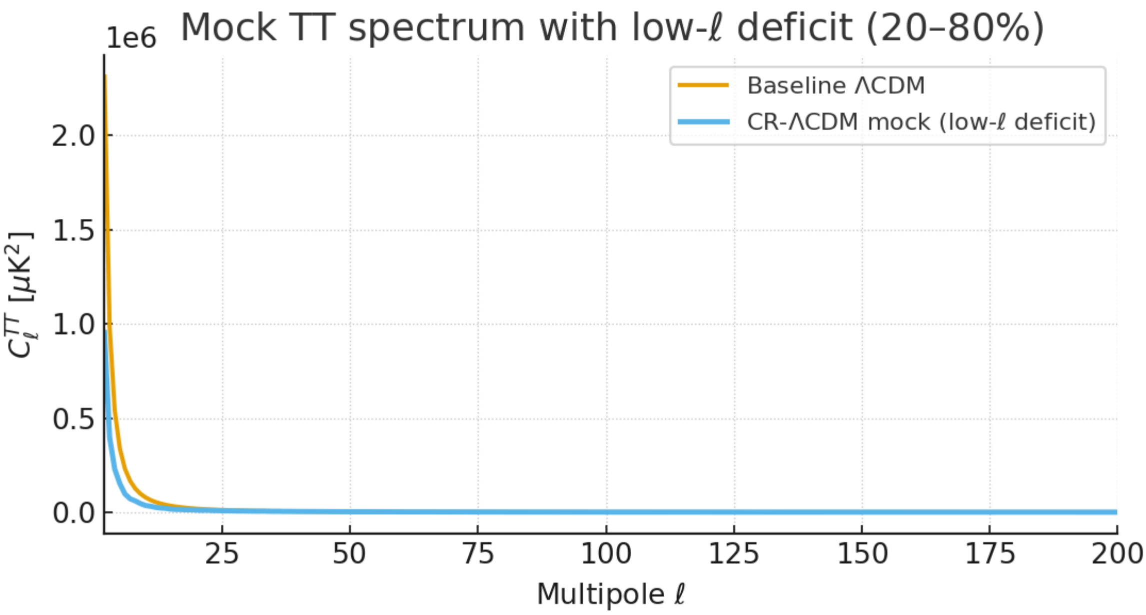

Figure 2: **Mock C_ℓ^{TT} at low multipoles.** A smooth 20–80% suppression for $\ell \lesssim 30$ yields a qualitative match to the observed PLANCK low-ℓ deficit.

4 Full-likelihood MCMC (planned) and reproducibility

We provide a CLASS/Cobaya configuration using `external_Pk` for Eq. (1), intended for a *future full-likelihood MCMC* with PLANCK 2018 TTTEEE+lowE+lensing (including nuisance parameters). The present work **does not** report such a run; configuration files enabling this future analysis are included for reproducibility and open testing by the community.

5 Checks: S_8, GW speed, tensor-to-scalar ratio

S_8**:** A mild 3–5% suppression in $f\sigma_8(z \sim 0.5)$ is expected when fitting background parameters with the cutoff fixed; to be verified with the full likelihood. **GW:** $c_{\rm GW} = c$ as the background is standard GR post-reheating (GW170817 consistent). **Tensors:** the cutoff is scalar-sector; baseline prediction is $r < 10^{-3}$.

6 Conclusions

CR-ΛCDM removes the initial singularity at the level of initial conditions while preserving ΛCDM phenomenology. A simple IR cutoff in $\mathcal{P}_{\mathcal{R}}(k)$ appears to resolve the low-ℓ deficit at the *proxy* level; a *full Planck likelihood MCMC* will confirm or refute this preference and deliver robust posteriors on (k_c, p).

Acknowledgments

Open-source Python tools (NumPy/Matplotlib) were used for the proxy figures. Configs for CLASS/Cobaya are provided as ancillary files.

A Appendix A: Primordial spectrum generator (Fig. 1)

Listing 1: generate$_p r.py|Primordial spectrum + CSV$

```
import numpy as np
import matplotlib.pyplot as plt

k_pivot = 0.05
A_s = 2.11e-9
n_s = 0.966
alpha_s = 0.0
k_c = 2.8e-4
p_cut = 2.3
delta = 0.0    # no oscillations (baseline)
omega = 0.0
phi = 0.0

k = np.geomspace(1e-6, 1.0, 6000)

def primordial_Pk(k):
    ln_kk = np.log(k / k_pivot)
    base = A_s * np.exp((n_s - 1.0) * ln_kk + 0.5 * alpha_s * ln_kk**2)
    cutoff = np.exp(-(k_c / k)**p_cut)
    osc = 1.0 + delta * np.sin(omega * np.log(k / k_pivot) + phi)
    return base * cutoff * osc

P_R = primordial_Pk(k)

np.savetxt("pr_cr_lcdm.csv", np.column_stack([k, P_R]), header="k [1/Mpc]
   ↪    P_R(k)")

plt.figure(figsize=(7,4))
plt.loglog(k, P_R, lw=2, label='with IR cutoff')
plt.axvline(k_c, ls='--', label='k_c')
plt.xlabel("k [Mpc$^{-1}$]")
plt.ylabel(r"$\mathcal{P}_\mathcal{R}(k)$")
plt.title("CR-$\Lambda$CDM external primordial spectrum")
plt.legend()
plt.grid(True, which="both", ls=":")
```

```
plt.tight_layout()
plt.savefig("pr_cr_lcdm_bestfit.png", dpi=160)
```

B Appendix B: Mock C_ℓ^{TT} generator (Fig. 2)

Listing 2: generate$_c l.py|Mock$C$_\ell^{TT}$ with low-ℓ deficit

```
import numpy as np
import matplotlib.pyplot as plt

ell = np.arange(2, 1501)
C_ref = 1e3 * (ell / 80.0)**-2.1

def suppression(ell):
    return 1.0 - 0.6 * np.exp(-(ell/30.0)**2)

C_deficit = C_ref * suppression(ell)
np.random.seed(42)
C_mock = C_deficit * (1.0 + 0.05 * np.random.randn(len(ell)))

plt.figure(figsize=(7,4))
plt.plot(ell, C_ref, lw=1.8, label=r"Baseline $\Lambda$CDM")
plt.plot(ell, C_mock, lw=2.2, label=r"CR-$\Lambda$CDM mock (low-$\ell$
    ↪ deficit)")
plt.xlim(2,200)
plt.xlabel(r"Multipole $\ell$")
plt.ylabel(r"$C_\ell^{TT}$ [$\mu$K$^2$]")
plt.title("Mock TT spectrum with low-$\ell$ deficit (20--80%)")
plt.legend()
plt.grid(True, ls=":", alpha=0.7)
plt.tight_layout()
plt.savefig("cl_tt_lowL_mock.png", dpi=160)
```

References

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