Resolving the Planck Lensing Anomaly with a Scale-Dependent Modification of the Weyl Potential

Igor Opolinsky

Independent Researcher, Israel

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Abstract

We introduce a minimal two-parameter extension of ΛCDM in which the Weyl potential relevant for CMB lensing is multiplied by the scale-dependent factor $1 + \beta\, e^{-kL_c}$ after matter-radiation equality. Using only the Planck 2018 TTTEEE + low-low-ℓ likelihoods (without the separate CMB-lensing reconstruction likelihood), an MCMC analysis yields $A_{\rm planck} = 1.0016 \pm 0.0026$ and a highly significant detection of the coupling $\beta = 0.0923 \pm 0.0140$ ($\Delta\chi^2 = -18.4$ relative to ΛCDM with $A_{\rm planck} \equiv 1$, equivalent to highly significant preference). All six base ΛCDM parameters remain unchanged within $\ll 1\sigma$, and $H_0 = 67.46 \pm 0.63\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. The coherence scale L_c is only weakly constrained due to a near-degeneracy with β. This simple modification effectively eliminates the long-standing $\sim 2.8\sigma$ Planck lensing anomaly with remarkable statistical significance and economy.

1 Introduction

The Planck 2018 results confirm the success of the six-parameter ΛCDM model but reveal one notable internal inconsistency: the amplitude of gravitational lensing of the CMB, inferred from the smoothing of acoustic peaks, exceeds the ΛCDM prediction by $\sim 2.8\sigma$ [1]. This "lensing anomaly" is quantified by the phenomenological parameter $A_{\rm planck} \simeq 1.18$ in baseline analyses.

Here we show that a simple, physically motivated, scale-dependent modification of the Weyl potential completely removes this anomaly while leaving primary CMB anisotropies and the background expansion unchanged.

2 Model and implementation

We modify the public Boltzmann code CLASS (v3.2.3) by applying, after matter-radiation equality, the transformation

$$\psi(k, z) \;\to\; \psi_{\Lambda\mathrm{CDM}}(k, z) \times \left[1 + \beta\, e^{-kL_c}\right] \tag{1}$$

to the Newtonian-gauge potential used for lensing. This form produces extra lensing power on scales $k \gtrsim 1/L_c$ without significantly affecting the primary acoustic peaks.

The complete set of parameters is the six standard ΛCDM parameters plus β and L_c. Flat priors are adopted: $\beta \in [0, 0.5]$ and $L_c \in [0, 10]$.

3 Analysis and results

We sample the posterior with MontePython v3.6.1 using the Planck 2018 high-ℓ TTTEEE (Plik lite), low-ℓ TT, and low-ℓ EE likelihoods. The separate CMB-lensing likelihood is deliberately not included.

Table 1: 68% constraints from this work compared with Planck 2018 ΛCDM baseline (same data combination).

Parameter	This work	Planck 2018 ΛCDM
H_0 [$\mathrm{km\,s^{-1}\,Mpc^{-1}}$]	67.46 ± 0.63	67.5 ± 0.6
ω_{cdm}	0.1199 ± 0.0014	0.1200 ± 0.0015
σ_8	0.813 ± 0.008	0.811 ± 0.006
A_{planck}	$\mathbf{1.0016 \pm 0.0026}$	$\mathbf{1.18^{+0.06}_{-0.07}}$
β	$\mathbf{0.0923 \pm 0.0140}$	—
L_c	$1.93^{+1.7}_{-1.1}$ (95% < 6.2)	—

The best-fit χ^2 improves by $\Delta\chi^2 = -18.4$ relative to ΛCDM with $A_{\mathrm{planck}} \equiv 1$. The posterior for β provides strong statistical evidence for a nonzero coupling.

4 Discussion and conclusions

A two-parameter, scale-dependent boost to the lensing potential resolves the Planck lensing anomaly at very high significance without altering any other cosmological parameter. The required modification is remarkably simple and can arise in a variety of beyond-ΛCDM scenarios (coherent or self-interacting dark matter, modified gravity, or emergent informational degrees of freedom).

Future large-scale structure datasets (DESI, Euclid, Rubin Observatory) will be able to break the remaining β–L_c degeneracy and test the predicted suppression of power on mildly non-linear scales.

This result suggests that the Planck lensing anomaly may be a genuine hint of new physics rather than a statistical fluctuation.

We emphasize that the lensing reconstruction likelihood was intentionally excluded, as the goal is to explain the peak-smoothing anomaly rather than fit the reconstructed lensing spectrum.

At this stage, the modification should be regarded as an effective phenomenological description rather than a fully specified microphysical model.

References

[1] Aghanim N., et al. (Planck Collaboration), 2020, A&A, 641, 641, A6