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Pre-inflationary relics in the CMB?

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ABSTRACT

String Theory and Supergravity allow, in principle, to follow the transition of the inflaton from pre-inflationary fast roll to slow roll. This introduces an infrared depression in the primordial power spectrum that might have left an imprint in the CMB anisotropy, if it occurred at accessible wavelengths. We model the effect extending ΛCDM with a scale Δ related to the infrared depression and explore the constraints allowed by Planck 2015 data, employing also more conservative, wider Galactic masks in the low resolution CMB likelihood. In an extended mask with $f_{sky} = 39\%$, we thus find $\Delta = (0.351 \pm 0.114) \times 10^{-3}$ Mpc^{-1}, at 99.4% confidence level, to be compared with a nearby value at 88.5% with the standard $f_{sky} = 94\%$ mask. With about 64 e-folds of inflation, these values for Δ would translate into primordial energy scales $\mathcal{O}(10^{14})$ GeV.

1. Introduction

As a unified framework for all interactions, String Theory [1] ought to provide some insights into the Early Universe, but attempts to extract concrete information have foundered on our incomplete grasp of its key principles. On the other hand, the low-energy Supergravity [2] leaves aside higher-derivative stringy corrections, which cast a shadow of doubt on the resulting dynamics. Probably also as a result of these facts, the analysis of inflation [3] has been largely confined to its steady state.

Slow-roll models with a single scalar field yield the power spectra of scalar perturbations [4]

$$\mathcal{P}(k) = A\ (k/k_0)^{n_s - 1}\,, \tag{1}$$

where the amplitude A reflects typical energy scales during inflation and k_0 is a pivot scale.[1] Planck recently obtained the result $n_s = 0.968 \pm 0.006$ for the spectral index [5], so that this peculiar behavior finds indeed a place in the CMB. There are, however, some intriguing discrepancies with the resulting ΛCDM picture, including an apparent lack of power at large angular scales, with a sizable quadrupole depression.

The discrepancies appear in the first few angular power spectrum coefficients C_ℓ, which then converge to the ΛCDM expectations within a decade or so. Theory associates these low-ℓ values with the earliest accessible epochs of inflation, so any departure from ΛCDM would be of utmost interest. There is, of course, the issue of "cosmic variance", since we can detect only a single realization of the CMB anisotropy pattern. Still, the discrepancies have surfaced in independent experiments, so that explaining them in terms of systematics or unresolved foregrounds would be contrived. Hence, in this paper, we propose to take low-ℓ anomalies seriously, combining the relevant Planck data with clues from String Theory and Supergravity. This approach parallels the analysis in [6], but is based on a different philosophy.

It is tempting, if not fully justified within Supergravity alone, to explore how slow-roll was originally attained. We shall insist on models with a single scalar field ϕ, starting from a Bunch–Davies vacuum in a background

$$ds^2 = e^{2\mathcal{A}(\eta)}\left(-d\eta^2 + d\mathbf{x}\cdot d\mathbf{x}\right)\,, \tag{2}$$

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[1] We set $k_0 = 0.05$ Mpc^{-1}, checking however that this standard choice has no impact on the ensuing analysis.

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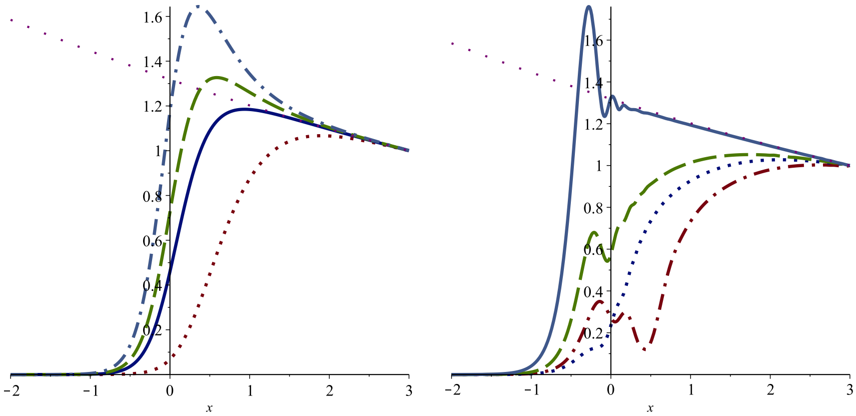

Fig. 1. Some power spectra in arbitrary units *vs.* $x = \log_{10}(k/k_0)$, compared with the light dotted curves obtained from Eq. (1). *Left:* analytic power spectra from Eq. (10) for $\gamma = -1$ (dotted), 0 (continuous), 0.2 (dashed), 0.4 (dashed–dotted). *Right:* four types of spectra from BSB, where the scalar bounces against a steep exponential potential before attaining slow-roll. An initial condition, φ_0, gauges the bounce, and mild bounces (continuous) recover the spectra of [10].

where the conformal time η is conventionally set to zero at the end of inflation, while putting some emphasis on the approach to slow-roll. $\mathcal{A}(\eta)$ and $\phi(\eta)$ determine [7]

$$W_s(\eta) = \frac{1}{z}\,\frac{d^2 z}{d\eta^2}, \quad \text{where} \quad z(\eta) = e^{\mathcal{A}}\,\frac{d\phi}{d\mathcal{A}}, \tag{3}$$

and thus the Mukhanov–Sasaki equation

$$\frac{d^2 v_k(\eta)}{d\eta^2} + \left[k^2 - W_s(\eta)\right] v_k(\eta) = 0. \tag{4}$$

The power spectrum of scalar perturbations that builds up after many *e*-folds of inflation is then

$$\mathcal{P}(k) = \frac{k^3}{2\pi^2}\, \lim_{\eta\to 0^-} \left|\frac{v_k(\eta)}{z(\eta)}\right|^2 . \tag{5}$$

Close to an initial singularity, set here at $\eta = -\eta_0$, one can show that

$$W_s(\eta) \simeq -\frac{1}{4\,(\eta+\eta_0)^2}, \tag{6}$$

while after several *e*-folds

$$W_s(\eta) \simeq \frac{\nu^2 - \frac{1}{4}}{\eta^2}, \qquad \nu = 2 - \frac{n_s}{2}. \tag{7}$$

When exploring the onset of inflation one is thus confronted with *Mukhanov–Sasaki potentials that cross the* η *axis*. They bring along *an infra-red depression sized by the measure factor* in (5), so that $\mathcal{P}(k) \sim k^3$, but the approach to the profile (1) is not universal [8,9]. For instance, subtracting from the Mukhanov–Sasaki potential (7) a positive quantity Δ^2 makes it cross the negative η-axis but turns k^2 into $k^2 + \Delta^2$, and thus Eq. (1) into the exact result

$$\mathcal{P}(k) = \frac{A\,(k/k_0)^3}{\left[(k/k_0)^2 + (\Delta/k_0)^2\right]^{\nu}}, \tag{8}$$

which brings in the new scale Δ.

More generally, for the Coulomb-like potentials

$$W_s = \frac{\nu^2 - \frac{1}{4}}{\eta^2}\left[c\left(1+\frac{\eta}{\eta_0}\right) + (1-c)\left(1+\frac{\eta}{\eta_0}\right)^2\right] \tag{9}$$

the Mukhanov–Sasaki problem admits the family of exact solutions [8]

$$\mathcal{P}(k) = \frac{A\,(k/k_0)^3\,\mathcal{C}(k)}{\left[(k/k_0)^2 + (\Delta/k_0)^2\right]^{\nu}}, \tag{10}$$

$$\mathcal{C}(k) = \frac{\Gamma\left(\nu+\frac{1}{2}\right)^2 e^{\pi B(k)}}{\left|\Gamma\left(\nu+\frac{1}{2}+iB(k)\right)\right|^2}, \qquad \Delta^2 = \frac{(c-1)\left(\nu^2-\frac{1}{4}\right)}{\eta_0^2}$$

$$B(k) = \frac{\gamma}{\sqrt{\left(\frac{k}{k_0}\right)^2 + \left(\frac{\Delta}{k_0}\right)^2}}, \qquad \gamma = \frac{\left(\frac{c}{2}-1\right)\left(\nu^2-\frac{1}{4}\right)}{k_0\,\eta_0}.$$

For $1 < c < 2$, these power spectra are along the lines of the $c = 2$ case of Eq. (8), but for $c > 2$ a caricature pre-inflationary peak builds up. It lies next to the almost scale invariant profile, as in [10], since Δ enters both factors in Eqs. (10). On the other hand (see Fig. 1), in the orientifold vacua [11] of String Theory with "Brane Supersymmetry Breaking" (BSB) [12,13] pre-inflationary peaks can lie well apart from the limiting profile, an option that appears favored by low CMB multipoles [9].

The models of Eqs. (8) and (10) provide a convenient point of departure from ΛCDM. We shall first analyze the new scale Δ, and then we shall also include γ to take a first look at pre-inflationary features. Our approach differs from the previous work in [10] that also addressed the full spectrum in three respects. The first is the emphasis on Eq. (8), which is motivated by the Mukhanov–Sasaki equation and, as we have seen, by the sign change of W_s that accompanies the approach to slow-roll. The others are the use of recent Planck 2015 data and, as we about to explain, the use of different Galactic masks.

2. Data set

We used the recently released Planck likelihood module [14], considering the CMB temperature (TT), low-ℓ polarization (lowP) and lensing likelihoods. We sampled over the six standard ΛCDM cosmological parameters (θ_{MC}, $\Omega_b h^2$, $\Omega_c h^2$, n_s, τ and $\ln(10^{10} A_s)$) [5] and over Δ, which models the low-ℓ depression via Eq. (8). We also sampled over the instrumental and foreground parameters that appear in the Planck likelihood: we do not report on them here for the sake of brevity, but we did verify that their posteriors did not depart from the ΛCDM case. We also implemented a conservative modification of the low ℓ part of the Planck likelihood code, allowing for low-ℓ larger temperature masks. The masks are *blindly* built, extending the edges of the standard temperature mask by fringes of widths 6°, 12°, 18°, 24°, 30° and 36°, as shown in Fig. 2. They reduce the allowed sky fraction, f_{sky}, for $\ell \leq 29$ from 94% to 84%, 71%, 59%, 49%, 39% and 31%, and are applied to a foreground reduced CMB map based on the `Commander` algorithm [15], as in the original Planck release. Cosmological parameters should not depend on the specific part of the sky that is analyzed if the CMB pattern