Signature from early Universe solves major anomalies and tensions in cosmology

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Overview

Introduction

- The standard model of cosmology is largely supported by the Cosmic Microwave Background (CMB) data from the Planck observation.
- However, underneath this largely consistent picture, certain anomalies and tensions emerge as crucial problems of modern cosmology.
- There are various anomalies such Alens tension, Curvature problem, discordances with low redshift measurements.
- As a solution to these anomalies, we propose a signature from the early Universe, specifically in the spectrum of primordial quantum fluctuation.

Anomalies and Tensions I

- Lensing amplitude (A_{lens}) Anomaly: It is an amplitude parameter that scales the theoretical prediction for lensing power spectrum. When A_{lens} is allowed to vary in an analysis with Planck temperature angular power spectrum data, it is found to be higher than 1 ($A_{lens} = 1.243 \pm 0.096$ from P18TT and $A_{lens} = 1.180 \pm 0.065$ from P18TP).

Anomalies and Tensions II

- Curvature anomaly: There is a positive correlation between the curvature and lensing amplitude and a closed Universe can solve the lensing anomaly problem. Since curvature changes the distance measure, it shifts the position of the acoustic peaks. Lowering the value of Hubble constant ($H_0 = 52.2 \pm 4.3$ from P18TT) helps in shifting back the peaks to the observed positions. This further increases the disagreement with local measurements of H_0 measurements ($H_0 = 73.04 \pm 1.04$).

Anomalies and Tensions III

- The Hubble tension: Hubble constant obtained from the `Standard Model` fit to the Planck CMB data is estimated to be $H_0 = 66.88 \pm 0.92$ (from P18TT) and 67.27 ± 0.60 (from P18TP). Local measurement of Hubble constant from Cepheids and supernovae indicates a value significantly larger than these with $H_0 = 73.04 \pm 1.43$. Other measurements of the Hubble constant from time-delay cosmography of the lensed quasars and calibration of the Tip of Red Giant Branch (TRGB) also indicate Hubble constant to be at higher values.

Anomalies and Tensions IV

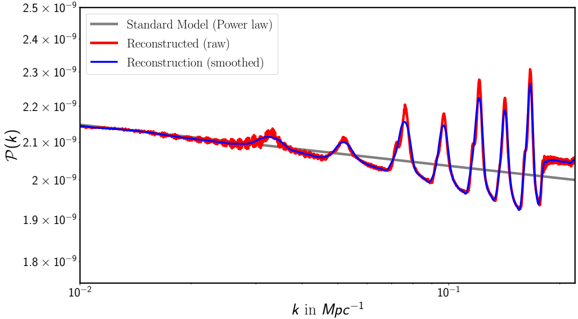
- Tension in S_8 measurement: Clustering and shear analyses provides $S_8 = 0.772^{+0.018}_{-0.017}$(DES) and $S_8 = 0.759^{+0.024}_{-0.021}$(KiDS1000). Planck CMB estimates $S_8 = 0.840 \pm 0.024$ (P18TT) and $S_8 = 0.834 \pm 0.016$ (P18TP).

Data used

Acronym	Data	Comments
P18TT	TT+lowl+lowE (CMB)	Planck CMB temperature anisotropy and large scale polarization anisotropy
P18TP	TTTEEE+lowl+lowE (CMB)	Planck CMB temperature and polarization anisotropy
DES	Clustering + Weak lensing	Dark Energy Survey year 1 likelihoods on galaxy clustering and weak lensing
ACT	ACT-TTTEEE (CMB)	Atacama Cosmology Telescope DR4 CMB likelihood on temperature and polarization
BAO	Baryon Acoustic Oscillation	Distance ratio measurements from 6df galaxy survey, Sloan Digital Sky Survey
SN	Pantheon18 Supernovae	Distance modulus from 1048 Supernovae samples
HST	H_0 local measurement (SH0ES)	Local measurement of Hubble constant from SH0ES 2019

Reconstructed spectrum

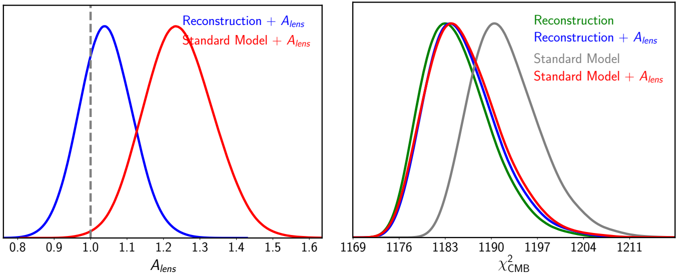
- The reconstructed primordial power spectrum mimics the best fit temperature power spectrum to the Planck temperature data in the `Standard Model` with A_{lens} extensions.



Figure

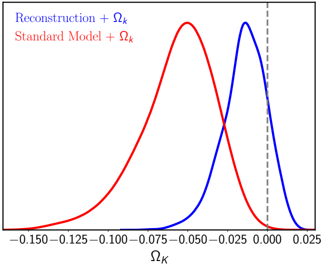
Reconstructed spectrum- A_{lens}

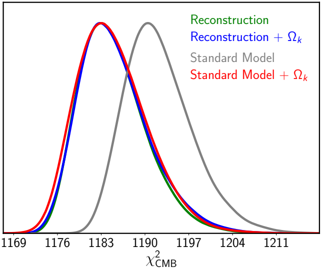
- The `Standard Model` prefers a larger value of $A_{lens} = 1.243 \pm 0.096$ while with the reconstructed power spectrum we find $A_{lens} = 1.042 \pm 0.074$.



Reconstructed spectrum- Ω_K

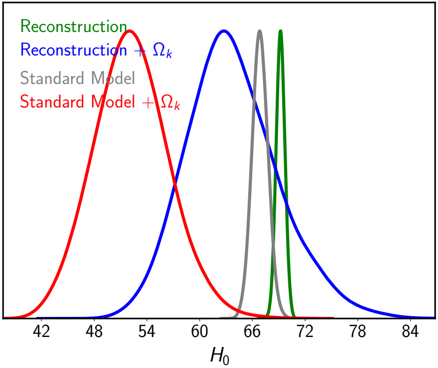
- In `Standard Model` + Ω_K, $\Omega_K = -0.056^{+0.028+0.044+0.050}_{-0.018-0.050-0.079}$ that indicates little over 3σ preference for a closed Universe from Planck temperature anisotropy data. `Reconstruction` + Ω_K analysis finds $\Omega_K = -0.014^{+0.016}_{-0.011}$.





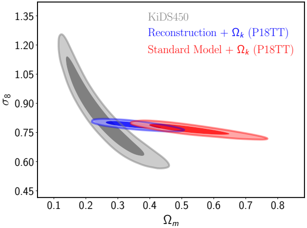
Reconstructed spectrum- H_0

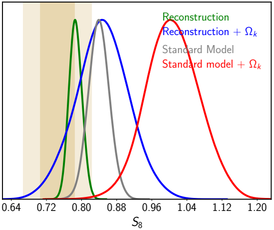
- $H_0 = 52.2 \pm 4.3$ found in `Standard Model` + Ω_K analysis while `Reconstruction` + Ω_K prefers higher value with $H_0 = 63.8^{+4.5}_{-5.8}$



Reconstructed spectrum- S_8

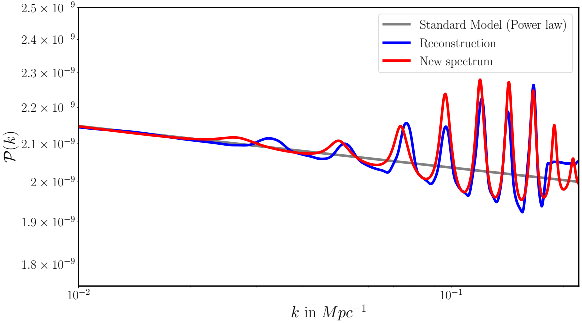
- The `Reconstruction` + Ω_K model laterally shifts the $\Omega_m - \sigma_8$ contour in the direction of lower matter density that brings back the concordance, providing substantial overlap. While S_8 posteriors from `Standard Model` is at more than 2σ, when curvature is allowed to vary, the tension becomes more than 6σ. The reconstructed spectrum removes the tension.





Power spectrum template

$$\mathcal{P}_{New}(k) = \mathcal{P}_0(k)\left[1 + \frac{\alpha_1 \sin\left(\omega(k-k_0)\right)}{\left(1-\alpha_2 \sin\left(\omega(k-k_0)\right)\right)\left(1+\beta(k-k_0)^4\right)}\right]$$

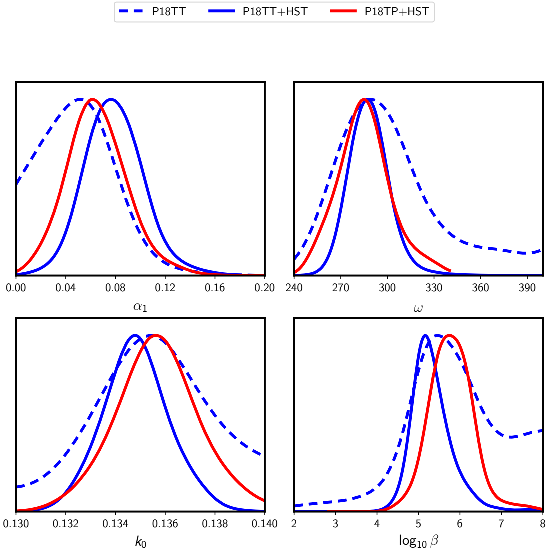


Restricted spectrum

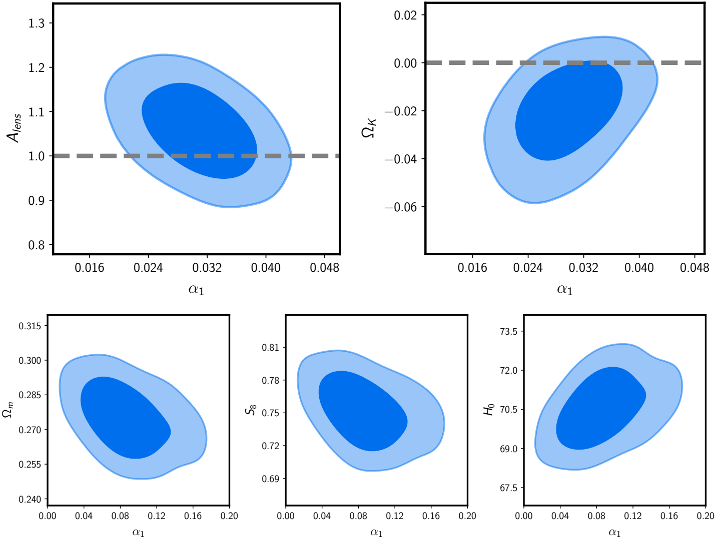
$$\mathcal{P}_{Restricted}(k) = \mathcal{P}_0(k)\left[1 + \frac{\alpha_1 \sin\left(\omega(k-k_0)\right)}{1+\beta(k-k_0)^4}\right]$$

Models/Data	P18TT	P18TT + HST
New spectrum	-1.14 $\pm$ 0.53	2.67 $\pm$ 0.53
Restricted spectrum	-0.58 $\pm$ 0.52	3.4 $\pm$ 0.53

Posterior distribution



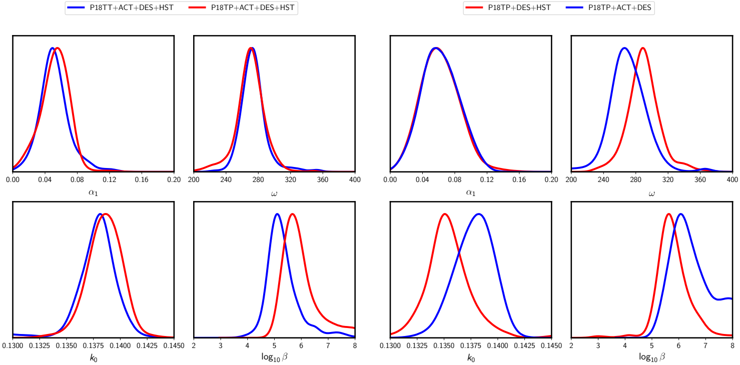
Correlations



Extended Analysis

Data	ln[Bayes factor]	C.L.
P18TP+HST	1.46 ± 0.55	99.5%
P18TT+ACT+DES+HST	2.28 ± 0.65	99.6%
P18TP+ACT+DES+HST	1.94 ± 0.66	98.7%
P18TP+DES+HST	2.32 ± 0.64	99.5%
P18TP+ACT+DES+BAO+SN+HST	-0.34 ± 0.66	98.5%
P18TP+ACT+DES	-0.85 ± 0.66	99.5%

Extended Analysis



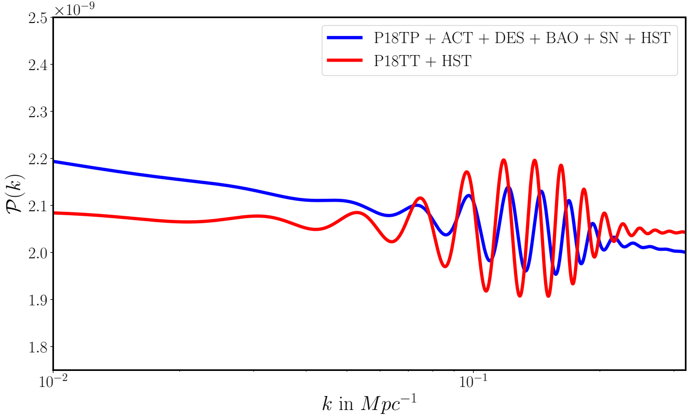
Extended Analysis I

- When small scale CMB temperature and polarization data from ACTPol are included in the analysis, the peak position of the oscillation shifts to a smaller scale compared to analyses with Planck CMB and HST.
- DES data prefers lower matter density and σ_8 and therefore smaller S_8 compared to `Standard Model` results with Planck. Since our model naturally prefers smaller S_8, inclusion of DES data increases the significance compared to the results obtained in P18TP+HST analysis.

Extended Analysis II

- BAO + SN prefers higher matter density. Therefore adding these two datasets drags the parameter space towards `Standard Model` to accommodate higher matter density.
- When DES and ACT data are used for joint analysis with P18TP without the prior on Hubble constant, we still find 99.5% significance for the proposed model (The marginal likelihood decreases as the decay parameter, β is not well constrained).

Best fit power spectrum



Conclusion I

- A simple shape of primordial power spectrum, obtained through deconvolution *solves the lensing amplitude anomaly*.
- The `Reconstruction` also *solves the closed Universe anomaly and brings back cosmic concordance*.
- Importantly, we find that a solution to the anomalies within the Planck CMB data automatically resolves or greatly reduces the tension between different datasets.

Conclusion II

- Our analytical power spectrum model, `New Spectrum`, that is designed to match the `Reconstruction`, prefers lower matter density and lower σ_8 and higher H_0. When the `New Spectrum` and `Restricted Spectrum` (a simpler version of the former) are compared with Planck temperature data with priors on Hubble constant, we get moderate to very strong evidence for the models compared to the `Standard Model`.

Conclusion III

- The proposed form of the spectrum stays consistent with small scale CMB measurements from Atacama Cosmology Telescope observation, large scale structure measurements from Dark Energy Survey and recently estimated age of the Universe from globular clusters.