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Cosmic Inflation: Theoretical Exploration and Observational Constraints

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Abstract

Cosmological observations are explained well by the concordance model of cosmology with six parameters. Two of these six parameters parameterize the "Primordial Density Perturbation" (PDPs). Inflation provides the most promising explanation for the origin of PDP. The standard slow-roll inflation model predicts the form of PDP assumed in the concordance model. However, future observations with higher precision may reveal deviation from the form of PDP assumed in the concordance model. Theoretically, the slow-roll inflation model has fine-tuning issue regarding the flatness of the inflaton potential. The major target for constructing the slow-roll inflation model is to solve this fine-tuning problem from a more "microscopic" or fundamental theory. The mechanism that makes the inflaton potential flat can introduce additional structure to the inflation model, which in turn leads to a deviation from the concordance model.

This thesis is based on three works [1–3]: in the first work, we propose an inflation model based on "Higher Dimensional Gauge Theory" (HDGT). The inflaton in this model is the "zero-mode" of a component of the gauge field in the "Deconstructed Extra Dimension" (DEDs). At low energy, below the compactification scale of DED, we find that the inflaton field range is enhanced compared with the original field range of the microscopic theory, achieving a large-field inflation model, and the model also explains the flatness of the inflaton potential. It is natural to have bursts of particle productions during inflation in this model that may lead to bump-like primordial features in the scalar PS. We find that the upper limits on the amplitude of such features puts constraints on the microscopic parameters, such as gauge coupling and the number of lattice points in the DED. To investigate the signatures of bump-like features in the cosmological observations, we next carry out a detailed analysis using two of the major probes of PDP: anisotropy in "Cosmic Microwave Background" (CMB) radiation, and matter density fluctuation probed

by redshifted 21cm signals from neutral hydrogen, as follows.

In the second work, we analyze the bump-like features in PDP from particle productions during inflation predicted by a class of inflation models including our above model with the latest CMB data from *Planck*. We perform Bayesian analysis considering two scenarios of particle productions: the first one is a simple scenario consisting of a single burst of particle productions during observable inflation - *single bump model*. The second one consists of multiple bursts of particle productions that lead to a series of bump-like features in the primordial PS - *multi-bump model*. We find that the multi-bump model fits the CMB data better compared to the concordance model. We also carry out model comparisons using Bayesian evidence. Though the Bayes factors for the single bump and multi-bump models show inconclusive preference (as per Jeffreys' scale), the signatures of bump-like features with certain amplitudes are consistent with the CMB data from *Planck* 2018. From the posterior probability, we find the upper bound on the amplitudes of the bump-like features in the co-moving wavenumber range $10^{-4} < k\,(\mathrm{Mpc}^{-1}) < 2 \times 10^{-1}$. From the observational constraints on the amplitude of bump-like features, we in turn find upper limits on the microscopic parameter of the theory, i.e., gauge coupling responsible for the particle productions.

In the third work, we study the potential of upcoming observations of redshifted 21cm line by SKA-Low at multiple redshifts in the range $6 \lesssim z \lesssim 20$ and co-moving wavenumber range $10^{-1} \lesssim k\,(\mathrm{Mpc}^{-1}) \lesssim 1.0$, to constrain the parameters of the bump-like features. We estimate the sensitivity of SKA-Low by considering different foreground removal models. We carry out Bayesian analysis for two scenarios: in the first scenario, considering that the astrophysical parameters relevant to the "Epoch of Reionization" (EoR) are known, we fix them in the analysis and sample the parameters of bump-like features only. From the analyses of bump-like features with amplitudes ranging from $O(10^{-11})$ - $O(10^{-9})$ at different scales, we find that the 21 cm Power Spectra (PS), with SKA-Low sensitivity, do have the potential to probe the primordial bump-like features. In the second scenario, we analyze the achievable constraints on primordial features when two of the EoR parameters, namely, minimum halo mass and ionizing efficiency, are uncertain. We find that the effect of the bump on the profile and the amplitude of the 21 cm PS is distinct from the impact of changing the EoR parameters, and hence they may potentially be distinguished. With SKA-Low sensitivity, we also recover the parameters of EoR and primordial bump-like features.