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Nuclear Physics B 906 (2016) 367–380

NUCLEAR PHYSICS B

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# CMB cold spot from inflationary feature scattering

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Received 4 July 2015; received in revised form 8 March 2016; accepted 15 March 2016

Available online 21 March 2016

Editor: Hong-Jian He

**Abstract**

We propose a "feature-scattering" mechanism to explain the cosmic microwave background cold spot seen from *WMAP* and *Planck* maps. If there are hidden features in the potential of multi-field inflation, the inflationary trajectory can be scattered by such features. The scattering is controlled by the amount of isocurvature fluctuations, and thus can be considered as a mechanism to convert isocurvature fluctuations into curvature fluctuations. This mechanism predicts localized cold spots (instead of hot ones) on the CMB. In addition, it may also bridge a connection between the cold spot and a dip on the CMB power spectrum at $\ell \sim 20$.



## 1. Introduction

In the recent years, observations of the cosmic microwave background (CMB) radiation fluctuations by the *Wilkinson Microwave Anisotropy Probe* (*WMAP*) and *Planck* satellite have led to a precise measurement of temperature fluctuations on the sky from the largest scales down to

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http://dx.doi.org/10.1016/j.nuclphysb.2016.03.020

arcmin scales [1,2]. The temperature anisotropy is found to be highly Gaussian and "statistically isotropic" in the sense that nearly all statistical proprieties of the temperature anisotropy can be described by the angular power spectrum $C_\ell^{TT}$ [3]. However, it was found since *WMAP* 1-year data that there is a deep cold spot ($\Delta T \simeq -120$ K) in the southern Galactic hemisphere along the direction ($l = 209°$, $b = -57°$) with angular radius $\theta \simeq 10°$ [4,5], which is further confirmed by *Planck* nominal mission data [3]. The cold spot is highly non-Gaussian in the sense that the probability of the cold spot existing in the statistical isotropic Gaussian universe is less than 0.1 percent [6].

Since then, the cold spot feature in the CMB map has invoked many observational and theoretical investigations. Initially, it was suggested that the unsubtracted foreground contamination might be responsible for the apparent non-Gaussian features [7,8], but later studies [3, 9] showed that the significance of cold spot is not affected by Galactic residues in the region of the spot. It was also proposed that a spherically symmetric void with radius $\sim 300$ Mpc at redshift $z = 1$ can produce a large and deep CMB cold spot through the late-time integrated Sachs–Wolfe effect (ISW) [10] (also known as the Rees–Sciama effect [11]). Later studies [12, 13] with the galaxy survey data [14] did find such a supervoid of size $r \simeq 195$ Mpc with density contrast $\delta_0 \simeq -0.1$ at redshift $z = 0.16$ align with the cold spot direction. However, more detailed following-up studies [15,16] showed that the Rees–Sciama effect produced by such a void is several orders of magnitude lower than the linear ISW effect therefore is not able to account for the observed feature.

The interesting non-Gaussian feature of cold-spot also invokes theorists to investigate the plausible explanation from the early universe. By considering various cosmological defects in the early universe, Refs. [17,18] proposed that a cosmic "texture" (i.e. a concentration of stress-energy and a time-varying gravitational potential due to the symmetry-breaking phase transition) can generate hot and cold spots on the last-scattering surface, with the fundamental symmetry-breaking scale found to be $\phi_0 \sim 10^{15}$ GeV. However, by applying the Bayesian method to *WMAP* full-sky data, Ref. [19] did not find strong evidence of the texture model, neither completely rule out the possibility (at 95% confidence level). It was also proposed that cosmic bubble collision, predicted by eternal inflation theories, can induce the density perturbation between our bubble and others, which can give arise to the localized features in the CMB [20,21]. But more detail data analysis [22] showed that the expected number of bubble collision is too few to account for the features in the CMB. Alternatively, a cold spot may follow from a different trajectory during multi-stream inflation [23,24] or modulated reheating after multi-field inflation [25].

The above physical or astronomical interpretations of cold spot either fail at some level, or require fine tuning or exotic scenarios of the early universe. Economically, some cosmologists would prefer to interpret the cold spot merely as a "$3\sigma$" statistical fluke. In this paper, we will provide a natural and physically plausible explanation of the cold spot, through multiple-field inflation. If the inflationary trajectory is scattered by a feature hidden in the isocurvature direction, the inflaton loses some energy and thus inflation tends to be longer. Therefore, it is possible that only a small portion of the sky hits the feature due to stochastic fluctuations, then that local patch of the universe experiences longer period of inflation and thus produces a cold spot. The mechanism is illustrated in Fig. 1.

This paper is organized as follows. In Section 2, we provide an explicit example of feature scattering, from massless isocurvature directions. Our predictions are compared with the measurement of the cold-spot in *Planck*'s `SMICA` map. In Section 3, we consider isocurvature directions with mass $m \sim H$. We conclude in Section 4 and discuss possible future directions. Throughout the paper, the unit $\mathrm{M_{pl}} = 1/\sqrt{8\pi G} = 1$ is used unless otherwise stated.