The Current Status of Late Time Phase Transition Models

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Abstract

The current status of late time phase transitions (LTPT) for cosmic structure formation is presented. It is shown that LTPT have been seriously constrained by the recent data but that viable models do remain which provide more power on the 100 - 200 Mpc scales than do more traditional primordial Gaussian density fluctuation models. Thus LTPT are one option that can be added to cure the well known problems of the standard structure formation models. The combination that works best is LTPT plus hot dark matter (HDM). In fact, LTPT provides a mechanism to make HDM viable. (Pure LTPT without primordial large scale fluctuations is no longer viable.) Tests for such models are presented, including possible anisotropies on angular scales $< 8$ arcminutes and characteristic non-gaussian behavior.

1 Introduction

The purpose of this paper is to review the status of late-time phase transitions (LTPT), as a mechanism for structure formation. Models for structure formation have been constrained tremendously by the recent measurements and limits placed on the anisotropy of the cosmic background radiation (CBR) by the COBE satellite [1], [2], [3] and by balloon experiments [4] and studies at the South Pole [5]. These measurements from the recombination epoch are confronted by the traditional observations of the distributions of galaxies and clusters of galaxies on scales of 10’s to 100’s of Mpc. Models for structure formation generally consist of assumptions about composition (percentages of baryons and hot (HDM) and/or cold (CDM) non-baryonic dark matter) coupled with some assumptions about the seeds to initiate the clumping of the matter. Seeds can be divided into different categories, for example, Gaussian density fluctuations versus topological defects, or primordially generated versus possible generation after recombination. This latter category of late-time generation of seeds (which could produce Gaussian and/or topological seeds) is the class of seeds we will
focus on in this paper. Possible physical mechanisms for such late-time seed generation include low temperature fundamental phase transitions [6], [7], [8] or maybe even some instability at the end of recombination itself [9]. We will refer to all such seed generation mechanisms as late-time phase transitions (LTPT), although the recombination proposal is an instability rather than a true phase transition.

Before addressing these points, let us review a motivation behind LTPT which will guide our discussion. One of the key concepts of standard cosmology is the particle horizon. It sets the scale within which causal physics processes are important. The horizon size $R$ is evolving as the universe expands. In the matter dominated epoch, $R = H_0^{-1}/\sqrt{1+z}$ where $H_0$ is the present Hubble constant and $z$ is the redshift. It is interesting to note that the comoving horizon size at redshift $z \sim 100$ is approximately $300h^{-1}$ Mpc, which is about the same size as the largest structure observed today [10], [11]. This interesting relation is a prime motivation for us to pursue the possibility that the perturbation of large scale structures in the universe today is created at redshift $z \sim 100$. Since this epoch is after the recombination epoch, it falls in the generic domain of LTPT. This paper will discuss some relatively model independent results of LTPT. This is an update to the paper by [12].

2 Power Spectra from LTPT

For discussion, let us set the phase transition epoch to be at $z \sim 100$, which corresponds to a comoving scale of $\lambda_e \sim 300h^{-1}$ Mpc. The density perturbations inside the horizon are very model dependent. However, it is straightforward to calculate the power spectrum on the superhorizon scale. It is just a white noise spectrum

$$P_0(k) \sim k^0,$$

since the density fluctuations are simply the incoherent sum over different horizon volumes. However, the equal time power spectrum should take into account the different growth factors that different wavelengths have. All the density waves whose wavelength is larger than this value are superhorizon and the amplitude of the perturbation will not grow until it is inside the horizon at some later epoch. Thus, the processed superhorizon power spectrum is:

$$P(k) = \left(\frac{g(\lambda)}{g(\lambda_e)}\right)^2 P_0(k),$$

where $g(\lambda)$ is the growth factor for the density perturbation with wavelength equal to the comoving horizon size. We can parameterize the density evolution as: $\delta(R) = a(R)\delta_0$, where $\delta_0$ is the perturbation generated at the phase transition epoch. Then, as the growth factor $g(\lambda)$ is related to $a(R)$ through $g(\lambda) = a(R_0)/a(R(\lambda))$, where $R_0$ is the scale factor today and $R(\lambda)$ is the scale factor when the density wave just enters the horizon.