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Thermal duality and non-singular cosmology in d-dimensional superstrings

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Abstract

We are presenting the basic ingredients of a stringy mechanism able to resolve both the Hagedorn instabilities of finite temperature superstrings as well as the initial singularity of the induced cosmology in arbitrary dimensions. These are shown to be generic in a large class of $(4,0)$ type II superstring vacua, where non-trivial "gravito-magnetic" fluxes lift the Hagedorn instabilities of the thermal ensemble and the temperature duality symmetry is restored. This symmetry implies a universal maximal critical temperature. In all such models there are three characteristic regimes, each with a distinct effective field theory description: Two dual asymptotically cold regimes associated with the light thermal momentum and light thermal winding states, and the intermediate regime where additional massless thermal states appear. The partition function exhibits a conical structure as a function of the thermal modulus, irrespectively of the space–time dimension. Thanks to asymptotic right-moving supersymmetry, the genus-1 partition function is well-approximated by that of massless thermal radiation in all of the three effective field theory regimes. The resulting time-evolution describes a bouncing cosmology connecting, via spacelike branes, a contracting thermal "winding" Universe to an expanding thermal "momentum" Universe, free of any essential curvature singularities. The string coupling remains perturbative throughout the cosmological evolution. Bouncing cosmologies are presented for both zero and negative spatial curvature.
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1. Introduction

Observational evidence strongly supports that during an early cosmological era, the matter content of the Universe was in (near) thermal equilibrium, with very high temperature. If the degrees of freedom are to be described by a set of local quantum fields, such a state results in a singular cosmology. Indeed, if we follow the cosmological evolution backward in time, using Einstein's gravity field equations, we are driven to the initial curvature singularity [1]. Even if a period of inflation preceded the high temperature phase, it is found in typical field theory models that the cosmological evolution begins at a singularity.

In string theory we expect a drastically different picture to emerge since new purely stringy degrees of freedom can dominate the high curvature and high temperature regimes, leading to phenomena that do not admit a conventional field theory description [2], with Riemannian concepts breaking down. String oscillators and winding states become relevant around the Hagedorn temperature T_H (which is of order the string scale M_s), before the onset of curvature singularities, and drive a phase transition towards a new stringy thermal vacuum [3–12]. The simplest way to isolate the relevant critical phenomena is via the Euclidean description of the thermal system, where Euclidean time is compactified on a circle with period given by the inverse temperature [5–7]. At temperatures just above Hagedorn, certain string states winding the Euclidean time circle become tachyonic. These instabilities can be lifted either by condensing the tachyons [5,7], or by turning on special gravito-magnetic fluxes, which inject into the thermal vacuum non-trivial winding and momentum charges, as in [13–16]. If a stable stringy phase gets realized, it could be that the back-reacted cosmological evolution is non-singular and the initial singularity is absent.

A mechanism within which the Hagedorn instabilities of the string gas are resolved and the initial curvature singularity is bypassed was realized recently in a class of two-dimensional superstring cosmologies, the so-called Hybrid cosmologies [16]. The scope of the present work is to show that the key ingredients of this mechanism are generic in a diverse class of higher-dimensional superstring models as well. In all of these models, finite temperature is introduced along with non-trivial gravito-magnetic fluxes [13–16], which lead to a restoration of the thermal duality symmetry of the partition function: $Z(\beta/\beta_c) = Z(\beta_c/\beta)$. Here β denotes the period of the Euclidean time cycle, attaining a critical value β_c at the self-dual point. At this critical point additional massless thermal states appear, enhancing the local Euclidean gauge symmetry. Typical examples include the tachyon-free type II $\mathcal{N}_4 = (4, 0)$ models at finite temperature and in the presence of non-trivial gravito-magnetic fluxes, which are described in great detail in the literature [13–16]. The fundamental properties of these models, which can lead to the resolution of the Hagedorn and the initial singularity, are well understood from the recent study of the two-dimensional Hybrid models [16], and are exhibited below:

- The canonical thermal ensemble is modified by turning on non-trivial gravito-magnetic fluxes, which lift the usual Hagedorn instabilities. The fluxes inject non-trivial winding and momentum charges into the thermal vacuum and render the mass of the would-be tachyonic states semi-positive definite. The tachyon-free models are equivalent to freely acting asymmetric orbifolds obtained by modding out with $(-1)^{F_L}\delta_0$, F_L being the left-moving space–time fermion number and δ_0 an order-2 shift along the Euclidean time cycle. Essentially, the fluxes regulate the contribution to the free energy of the massive string states.

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