論文内容の要旨

Aspects of D-Brane Inflation in String Cosmology

ストリング宇宙論における Dブレーン・インフレーションの諸問題

小林　洸

Connections between physics at microscopic and macroscopic scales are the keys to understanding the origin of our universe. In this thesis, we discuss inflationary cosmology in the framework of string theory, with special emphasis on D-brane inflation models. We focus on ten-dimensional type IIB string theory compactified on an internal manifold containing warped throat regions, and investigate the possibility that a D-brane moving along such warped throat geometries drives cosmic inflation, with its position in the internal space playing the role of the inflaton in the four-dimensional effective theory. After introducing the basics of inflationary cosmology and string compactification, we study three domains of D-brane inflation: slow-rolling, rapid-rolling, and relativistically moving D-branes.

First we review that effects related to moduli stabilization of the compactified space give a mass of order the Hubble parameter to the inflaton corresponding to the D-brane position. Such large mass speeds up the D-brane in the throat, therefore prevents the well-studied slow-roll inflation occurring from this system.

Then we move on to studying D-branes moving with relativistic velocity inside the warped throat, and show that such relativistic D-branes can drive inflation, due to the warping of the geometry. Such scenario for driving inflation from a relativistic D-brane, which is often called DBI inflation, is shown to leave special features in cosmological observables. However, we also find that in order for DBI inflation to produce primordial density perturbations that are compatible with current observational data, the D-brane needs to travel a distance which exceeds the size of the internal space. In other words, the range required by a relativistically moving D-brane to drive sufficient inflation cannot be supported by the compactified space. We show that this is a rather general result which holds not only for D3-branes, but also for higher dimensional D-branes wrapping internal cycles of the throat, and that the constraints come from either the limited size of the internal space or from the known maximal value of the background charge.

After discussing the difficulties of DBI inflation, we explore new possibilities for D-brane inflation, that is, inflation driven by rapid-rolling D-branes. This is an intermediate domain between

slow-roll and DBI inflation, in the sense that the D-brane is moving at a nonrelativistic velocity but with large acceleration/deceleration. Rapid-roll solutions are shown to be stable inflationary attractors, and we lay out conditions under which rapid-roll inflation occurs. D-branes in a warped throat geometry turns out to provide a suitable system for realizing rapid-roll inflation, circumventing problems with which slow-roll and DBI inflation models confronted. Furthermore, rapid-roll inflation is shown to source distinguishing observational consequences such as running spectral index of the primordial perturbation spectrum. We also impose cosmological constraints on rapid-roll inflation models.

Despite the ability of rapid-roll inflation to support a sufficiently long inflationary era, we note that the rapid-rolling inflaton itself cannot produce a (nearly) scale-invariant primordial perturbation spectrum which is suggested by current observations. Hence we put forward two ideas for generating primordial perturbations without relying on the inflaton. The first mechanism invokes additional fields which are coupled to the rapid-rolling inflaton, such as the moving degrees of freedom of the D-brane along directions of the throat other than that corresponding to the inflaton. Such an additional field, given that it is light, is able to convert its isocurvature field fluctuations into nearly scale-invariant density perturbations of the universe during the inflationary era.

As another scenario for generating perturbations, we present a curvaton model (which is pretty much independent of the details of the inflationary mechanism, hence is not restricted to rapid-roll inflation) from a D-brane sitting at the tip of a warped throat possessing approximate isometries. The D-brane's position in the isometry directions play the role of a curvaton, and produces primordial perturbations after inflation, and then decays as the D-brane's oscillation excites other open string modes on the D-brane.