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Instanton transition in thermal and moduli deformed de Sitter cosmology ☆

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Abstract

We consider the de Sitter cosmology deformed by the presence of a thermal bath of radiation and/or time-dependent moduli fields. Depending on the parameters, either a first or second-order phase transition can occur. In the first case, an instanton allows a double analytic continuation. It induces a probability to enter the inflationary evolution by tunnel effect from another cosmological solution. The latter starts with a big bang and, in the case the transition does not occur, ends with a big crunch. A temperature duality exchanges the two cosmological branches. In the limit where the pure de Sitter universe is recovered, the tunnel effect reduces to a "creation from nothing", due to the vanishing of the big bang branch. However, the latter may be viable in some range of the deformation parameter. In the second case, there is a smooth evolution from a big bang to the inflationary phase.

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1. Introduction

The recent astrophysical observations indicate that our universe is in a phase of classical expansion, with a small positive cosmological term, Λ, representing 60–70% of the total energy density. However, at early time, quantum corrections to this trajectory are expected to be of first significance. For instance, drastic non-perturbative effects could occur as topology changes, as can be seen in the context of field theory in semi classical approximation. As an example, a topology change is provided by the instability of the five-dimensional Kaluza–Klein (KK) space–time [1]. In that case, one observes the nucleation of a finite size "bubble of nothing" that is then growing up at the speed of light. The transition is described by tunnel effect in terms of an instanton configuration allowing a "double analytic continuation". This means that at two different Euclidean times τ_i and τ_f, analytic continuations to real times $\tau = \tau_i + it$ and $\tau = \tau_f + it$ are allowed. To be specific, the configuration admits a time independent asymptotic behavior allowing a continuation at $\tau_i = +\infty$ to the KK universe, while another continuation at $\tau_f = 0$ describes the evolution of a bubble.

Actually, the KK universe is suffering from a first-order phase transition where bubbles appear instantaneously, grow and coalesce, so that the space "evaporates" into nothing (after an infinite time, since the volume is itself infinite). In some sense, some reversed ideas can be invoked in another example of topology change, namely in Vilenkin's scenario of the de Sitter space "creation from nothing" [2,3]. In that case, a finite radius S^3 space appears instantaneously by tunnel effect from a space–time state that amounts to the empty set. This S^3 "bubble" is then following a de Sitter growing up evolution. The transition involves an instanton, whose shape is an S^4 hemisphere. An analytic continuation on its boundary amounts to "gluing" a de Sitter universe, while the fact that the instanton is compact with no other boundary to analytically continue allows an interpretation in terms of a transition from an empty set.

Concerning the birth of the de Sitter space, the instanton method provides an estimate of the transition probability equivalent to the one derived from the Hartle–Hawking wave function [4] approach. The transition amplitude and wave function Ψ being proportional to e^{-S_E}, where S_E is the Euclidean action, the probability of the event is

$$p \propto e^{-2S_E}. \tag{1.1}$$

A selection principle of the cosmological constant Λ based on the extremum of p leads to a favored value $\Lambda \to 0_+$ [5]. However, a present too small cosmological term cannot account for the 60% to 70% of the total energy density, which is necessary to explain the recent dark energy data. To remedy to this problem, it as been stressed [6,7] that since the de Sitter space has an horizon, it can be associated a Hawking temperature. Thus, quantum fluctuations of the metric (or any massless mode introduced in the model) induce a space filling thermal bath. The latter implies an additional radiation term in the action[3] and thus a back reaction on the metric background that deforms the de Sitter solution (see also [9]). In that case, the modified probability transition derived from the Euclidean action is maximal for a non-vanishing finite value of Λ. This computation has also been addressed by the authors of [10] and refined in [11], who considered the Wheeler–de Witt equation in the WKB approximation. They found that the tunnel effect is not connecting the deformed de Sitter expansion to "nothing", but to what they called a thermally excited era. However, the latter is Λ-dependent. This point makes the difference with the pure

[3] See [8] for a cosmological scenario based on a cascade of transitions between vacuum and radiation energy.