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Cyclic universes from general collisionless braneworld models

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Abstract

We investigate the full 5D dynamics of general braneworld models. Without making any further assumptions we show that cyclic behavior can arise naturally in a fraction of physically accepted solutions. The model does not require brane collisions, which in the stationary case remain fixed, and cyclicity takes place on the branes. We indicate that the cosmological constants play the central role for the realization of cyclic solutions and we show that its extremely small value on the observable universe makes the period of the cycles and the maximum scale factor astronomically large.

1. Introduction

The last decade proves to be really exciting for cosmology. Observational data indicated, among other very interesting results, that the expansion of the universe is accelerated [1]. At the same time the braneworld scenario appeared in the literature [2,3]. Though the exciting idea that we live in a fundamentally higher-dimensional spacetime which is greatly curved by vacuum energy was older [4], the new class of "warped" geometries offered a simple way of localizing the low energy gravitons on the brane.

In this novel background the old idea of a cyclic Universe was reheated. Started as ekpyrotic [5,6], enriched to ekpyrotic/cyclic [6–12] and recently to new ekpyrotic [13–16], the new paradigm tries to be established as an alternative to standard cosmology. According to its basic contents, our universe experiences an infinite or extremely large number of cycles, each one consisting of a hot bang phase, a phase of accelerated expansion, a phase of slow-ekpyrotic

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contraction and a bounce-bang that triggers the next cycle. Starting with a simplified notional framework (infinite and not "created" time) cyclic cosmology have many advantages. It successfully faces the homogeneity, isotropy, topological and flatness problems, it handles the issue of initial conditions, it incorporates the dark energy and transforms it to an important factor, and it provides the mechanism of the generation of cosmic perturbations and of structure formation. However, there are some key issues that do not have a consistent and efficient approach so far, despite the great progress. These are the settlement of the singularity, although temperature and density remain finite, the entropy evolution, and the fate of the perturbations through the bounce. Through this research, cyclic scenarios have become more complicated, by the insertion of more complex potentials, of more branes [5], of the mechanism of ghost condensation [13,17], of more scalar fields [14] and of procedures which cancel the tachyonic instabilities [15].

Most of the works on cyclic cosmology involve, initially or at some stage, the transition to effective 4D equations. However, as it was mentioned in [18,19], such a procedure does not lead to reliable results since one cannot return to the 5D description self-consistently. Furthermore, the old 4D-singularity problem (of both Big Bang and traditional cyclic universes), has been replaced by a new one (equally annoying) concerning the singularity of extra dimension(s). This later case is accompanied by the brane collision phenomenon, which seems to be a basic constituent of the ekpyrotic scenario.

In this work we desire to investigate the full 5D dynamics of general braneworld models and examine if a cyclic behavior is possible. This is an essential procedure in order to consistently confront the arguments of the authors of [18], which claim that cyclic behavior cannot arise from a complete 5D description, and our study must not include any additional assumptions or fine tunings in order to remain general and therefore convincing. Secondly, we are interested to explore if a cyclic behavior of 5D dynamics is necessarily related to brane collisions. This work is organized as follows: In Section 2 we present the 5D braneworld model and we derive the equations of motion. In Section 3 we provide analytical solutions for two simplified stationary solution subclasses, while in Section 4 we investigate numerically the full stationary dynamics. Finally, in Section 5 we discuss the physical implications of our analysis and we summarize the obtained results.

2. The model

We consider quite general braneworld models, characterized by the action [20,21]:

$$\kappa_5^2 S = \frac{1}{2}\int d^4x\,dy\,\sqrt{-g}R + \int d^4x\,dy\,\sqrt{-g}\left[-\frac{1}{2}(\partial\phi)^2 - V(\phi)\right] - \sum_{i=1,2}\int_{b_i} d^4x\,\sqrt{-\gamma}\big\{[K] + U_i(\phi)\big\}, \tag{1}$$

where $\kappa_5^2 = \frac{1}{M_5^3}$ is a 5D gravitational constant, and all quantities are measured in units of M_5. The first term describes gravity in the five-dimensional bulk space. The second term corresponds to a minimally coupled bulk scalar field with the potential $V(\phi)$. The last term corresponds to two $(3+1)$-dimensional branes, which constitutes the boundary of the 5D space. We allow for a potential term $U(\phi)$ for the scalar field at each of the two branes, and we denote by γ the induced metric on them and by K their extrinsic curvature. Here and in the following the square brackets denote the jump of any quantity across a brane ($[Q] \equiv Q(y_+) - Q(y_-)$). The reason we