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Phantom-like behaviour in dilatonic brane-world scenario with induced gravity

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Abstract

The Dvali, Gabadadze and Porrati (DGP) model has a self-accelerating solution, the positive branch, where the brane is asymptotically de Sitter. A de Sitter space–time can be seen as a boundary between quintessence-like behaviour and phantom-like behaviour. We show that in a 5D dilatonic bulk, where the dilaton has an exponential potential, with an induced gravity term on the brane, whose matter content corresponds only to vacuum energy, the positive branch solution undergoes a phantom-like stage where it faces a curvature singularity in its infinite future. The singularity can be interpreted as the "big rip" singularity pushed towards an infinite future cosmic time. The phantom-like behaviour on the brane occurs without violating the null energy condition. There is another solution, the negative branch, where the brane can undergo an early-epoch (transient) inflationary phase induced by the dilaton field.

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1. Introduction

The supernova Ia (SNIa) observations [1] and the cosmic microwave background (CMB) anisotropy data [2] suggest that the expansion of our universe seems to be accelerating. A possible explanation for this evolution is the usual vacuum energy represented by a cosmological constant providing a negative pressure [3]. However, the observational value of Λ is about 120 orders of magnitude smaller than that established from field theory methods [3]. So far, alterna-

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tive phenomenological models have been proposed to describe the late-time acceleration of the universe [4].

One approach is to consider an effective dark energy component in the energy momentum tensor. For example, this component can be described by a scalar field as in quintessence models [5] or tachyonic models [6]. Dark energy can also be described effectively by a perfect fluid with a linear equation of state or a more general barotropic equation of state like in Chaplygin gas models [7]. Motivated initially by SNIa observations, phantom energy models [8–11] have also been proposed to account for the late-time acceleration of the universe. A recent analysis [12] of the current equation of state for dark energy based on CMB anisotropies, SNIa and X-ray galaxy cluster data concluded that the current equation of state is compatible with a phantom-like behaviour of dark energy; i.e., w, the ratio of the pressure and the energy density of dark energy, could be less than -1. A similar conclusion is reached in [13]; i.e., observational data do not seem incompatible with phantom-like behaviour of dark energy. In phantom energy models the null energy condition is not satisfied. Hence, the energy density is an increasing function of the scale factor in an expanding Friedmann–Lemaître–Robertson–Walker (FLRW) universe. This may lead to the occurrence of a big rip singularity in the future evolution of a phantom energy dominated universe [9–11].

An alternative approach to account for the late-time acceleration of the universe is to consider a generalised Einstein theory of gravity like brane-world models (for reviews, see Ref. [14]) where the observable four-dimensional (4D) universe is a brane (hyper-surface) embedded in a higher dimensional space (bulk). For example, the Dvali, Gabadadze and Porrati (DGP) model [15] has a self-accelerating solution at late-time which is asymptotically de Sitter [16,17]. In this model the bulk is a 5D Minkowski space–time and the brane action contains an induced gravity term [15–24] which is proportional to the 4D Ricci scalar curvature of the brane. Dilatonic brane-world models [25–28] can also account for late-time acceleration of the brane through a quintessence-like behaviour driven by a bulk dilaton [29]. One aim of this paper is to show that a dilatonic brane-world model with an induced gravity term in the brane can mimic a phantom-like behaviour without including matter on the brane that violates the null energy condition.

In an induced gravity brane-world model the Friedmann equation has two solutions (depending on the embedding of the brane in the bulk [16]). One of these solutions (the self-accelerating solution or the positive branch) can account for the late-time evolution of the universe [16,17]. The other solution (the negative branch) can describe the early-time evolution of the universe[1] [20–24] and in particular corresponds to a correction to Randall–Sundrum (RS) model [30]. In the dilatonic brane-world model with induced gravity that we will analyse, the negative branch may undergo a transient inflationary epoch.

The layout of this paper is as follows. In Section 2, we present our dilatonic brane-world model with induced gravity. The bulk scalar field potential is a Liouville potential. The matter content of the brane is coupled to the dilaton field. We deduce the modified Friedmann equation for both branches, the junction condition of the dilaton across the brane, which constrains the brane tension, and the energy balance on the brane. In Section 3, we analytically derive the solutions of a vacuum brane for both branches; i.e., whose matter content is described through the brane tension. We show that the brane tension has a phantom-like energy density behaviour on the positive branch in the sense that the brane tension grows as the brane expands. The brane hits a singularity in its future evolution which may be interpreted as a "big rip" singularity pushed

[1] For an alternative use of the negative branch of the DGP scenario see Ref. [18].