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Configurational entropy as a tool to select a physical thick brane model

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ABSTRACT

We analize braneworld scenarios via a configurational entropy (CE) formalism. Braneworld scenarios have drawn attention mainly due to the fact that they can explain the hierarchy problem and unify the fundamental forces through a symmetry breaking procedure. Those scenarios localize matter in a $(3+1)$ hypersurface, the brane, which is inserted in a higher dimensional space, the bulk. Novel analytical braneworld models, in which the warp factor depends on a free parameter n, were recently released in the literature. In this article we will provide a way to constrain this parameter through the relation between information and dynamics of a system described by the CE. We demonstrate that in some cases the CE is an important tool in order to provide the most probable physical system among all the possibilities. In addition, we show that the highest CE is correlated to a tachyonic sector of the configuration, where the solutions for the corresponding model are dynamically unstable.

1. Introduction

Due to the inability revealed by General Relativity (GR) in accurately describe some cosmological and astrophysical issues [1–5], new theories of gravity have been proposed. Braneworld models are a possibility have been in vogue in the last decades because when extra dimensions are considered, they lead to modified field equations that can handle some of those issues in a healthy way. For example, brane scenarios allow for neutron star masses around 2 solar masses, in agreement with observations. Those limits cannot be attained by GR, unless an exotic equation of state is introduced. Besides, this scenarios could be a properly way to solve the hierarchy problem [6,7].

Novel analytical models derived in [8] describe the universe through the brane paradigm and have the prerogative of depending on a free parameter n. Although varying n leads to different characteristics in comparison to the literature until then, this parameter has never been constrained by any physical approach.

However, a few years ago, Gleiser and Stamatopoulos, motivated by the Shannon's information theory [10], have introduced in the literature the so-called configurational entropy (CE) concept [9]. This new physical quantity, which is a measure in the functional space, is able to relate the dynamical and informational content of physical models with localized energy configurations, allowing the establishment of optimized analytical solutions in nonlinear field theories. CE also can be used to resolve situations where the configurations present degeneracy [11], providing us a complementary perspective to understand situations where arguments based in the energy analysis are inconclusive.

Interesting applications of the CE approach can be found in several areas, such as the spontaneous symmetry breaking context [12], Q-balls structures [13], the study of self-gravitating astrophysical objects [14], the critical behavior of continuous phase transitions in the context of $(2+1)$-dimensional Ginzburg–Landau model [15], the framework of the Color-Glass Condensate (b-CGC) dipole model [16], anti-de Sitter black holes [17], dynamical AdS/QCD holographic models [18–21] and charged AdS black holes [22].

Another important scenario, where CE plays a fundamental role, is in Lorentz and CPT breaking systems [23]. In this context, it is possible to determine the bounds for the Lorentz violation parameters, which opens a new window to experimental investigations in theories with Lorentz symmetry breaking.

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CE has also been shown to be very useful in restricting braneworld parameters. We can think of our universe as a $(3+1)$ dimensional space–time, regarded as a brane, embedded in a higher-dimensional bulk, where the extra dimension can be large or compact. Within this scope, it was shown by Correa and Rocha [24] that information entropic measure is an accurate way for providing the most suitable values for the bulk AdS curvature. Following that work, we can find different lines of investigations in braneworld models, in which the CE allows one to obtain important results. Such studies arise in $f(R)$ [25] and $f(R,T)$ [26] theories, in Weyl [27] and Gauss–Bonnet brane models [28], in string scenarios [29] and in thick branes [30].

Thus, in the present work we propose to use the CE concept presented by Gleiser and Stamatopoulos in order to investigate some of the novel analytical braneworld models presented in [8]. Our goal is to provide a physical constrain on the parameter n, which is responsible for generating different classes of configurations. This analysis will allow us to find the most-likely physical scenario among all possible values that n can assume. Therefore, we will use the informational-entropic measure in order to find which is the most favorable configuration of a given family with same genealogy. It is important to remark that a similar analysis was made in [26] in favor of finding a bound in $f(R,T)$ theories.

The paper is organized as follows: in Section 2 we describe the braneworld model in question, in Section 3 we review the mathematical approach for the CE calculation, in Section 4 we present the CE calculation for the brane scenarios, in Section 5 we discuss the results and, finally, in Section 6 we present the conclusions.

2. Brane models

In this section we will look at a braneworld scenario in $(4+1)$ dimensions. We will work with a theory which consists of a scalar field and a manifold with a 4D subspace controlled by a warp factor, where the equations of motion are derived for both. In this case, we show that it is possible to use an ansatz for the solution to the warp factor by invoking cyclic deformation chains. As a consequence, using these analytical solutions, we can write the energy density of these models in the bulk.

We would like to highlight that braneworld scenarios were studied through several analytical procedure strategies [31,32]. Concerning this paradigm, the observable universe is a manifold with $(3+1)$ dimensions supported by a warp factor responsible for matter localization inside the brane.

The braneworld models studied in this paper were derived in [8] where they were associated with generic solutions of an effective action driven by a real scalar field, ϕ, coupled to gravity as in the model of Reference [31]. In the case of Ref. [8], the corresponding action is written as

$$S=\int d^4x dy\sqrt{|g|}\left[-\frac{1}{4}R+\frac{1}{2}\partial_a\phi\partial^a\phi-V(\phi)\right], \tag{1}$$

where $|g|=det(g_{ab})$, R is the scalar curvature in 5D, a varies from 0 to 4 and $V(\phi)$ is the scalar field potential.

In [8], it was chosen a 5-dimensional braneworld scenario, whose interval is expressed by

$$ds^2=e^{2A}\eta_{\mu\nu}dx^\mu dx^\nu-dy^2, \tag{2}$$

with e^{2A} being the warp factor, $\eta_{\mu\nu}$ is the Minkowski metric, μ,ν run from 0 to 3 and y is the extra coordinate.

Assuming a dependency of ϕ exclusively on the extra dimensional coordinate y, i.e., $\phi=\phi(y)$, the equation of motion for the scalar field arising from the action (1) is given by

$$\frac{d^2\phi}{dy^2}+4\frac{dA}{dy}\frac{d\phi}{dy}-\frac{d}{d\phi}V(\phi)=0. \tag{3}$$

On the other hand, by varying action (1) with respect to the metric, one obtains

$$\frac{3}{2}\frac{d^2A}{dy^2}=-\left(\frac{d\phi}{dy}\right)^2. \tag{4}$$

We would like to remark that the warp factor, e^{2A}, was constrained from the ansatz used in [8]. Considering that energy density localized structures demand for a lump-like warp factor behavior, so that matter integrability and localization are assured on the brane, there can be assumed a straightforward identification such as $e^{2A}=\psi$, where ψ is the bell-shaped analytical expression known *a priori*. This assumption leads to [8]

$$A=\frac{1}{2}\ln\psi. \tag{5}$$

A plethora of analytical lump solutions was obtained in [34], generated via cyclic deformation chains (CDC). They were triggered by the solution of the $\lambda\chi^4$ potential (in addition of other three deformed models). Chinaglia, Bernardini and Rocha inserted some of the deformed lump solutions as the ansatz for ψ in Eq. (5) in order to build up novel analytical braneworld scenarios. A complete review of generic deformations can be found, for example, in [33], while the CDC procedure was proposed in [34]. In [33] the deformation generates a new system in a way such that one increases or decreases the amplitude and width of the defect, without changing the corresponding topological behavior. In [34] the authors derived deformed defects that, in spite of having different amplitudes and widths, can interchange from topological (kink) to non-topological (lump) profiles. Such a behavior can also be seen in [35]. The deformation procedure as well as the lump solutions are quite extensive and do not concerns the scope of this work, however we dedicate a consistent review of it in Appendix A.

Since the lump solutions derived in [34] have a dependency on the parameter n, the brane warp factor also presents such a dependency. Our interest is to make use of the CE [9] as a tool to set the free parameter n. Here, we will use the CE approach with the purpose of