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Unifying inflation with late-time acceleration by a BIonic system

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ABSTRACT

We propose a cosmological model that unifies inflation, deceleration and acceleration phases of expansion history by a BIonic system. At the beginning, there are k black fundamental strings that transited to the BIon configuration at a given corresponding point. Here, two coupled universes, brane and antibrane, are created interacting each other through a wormhole and inflate. With decreasing temperature, the energy of this wormhole flows into the universe branes and leads to inflation. After a short time, the wormhole evaporates, the inflation ends and a deceleration epoch starts. By approaching the brane and antibrane universes together, a tachyon is born, grows and causes the creation of a new wormhole. At this time, the brane and antibrane universes result connected again and the late-time acceleration era of the universe begins. We compare our model with previous unified phantom models and observational data obtaining some cosmological parameters like temperature in terms of time. We also find that deceleration parameter is negative during inflation and late-time acceleration epochs, while it is positive during the deceleration era. This means that the model is consistent, in principle, with cosmological observations.

1. Introduction

Recent observations coming from supernovae surveys, large scale structure and cosmic microwave background radiation show that the Universe is presently undergoing a phase of accelerated phantom expansion [1,2]. Before this era, expansion was decelerated, at least up to the nucleosynthesis time. This stage of universe history is well explained by the non-phantom type cosmic fluids. However, another period of accelerated expansion, named inflation, acts at very early epochs describing expansion in agreement with observational data [3–7]. Up to now, several models have been presented to unify the early time inflation with the today observed accelerated phantom phase. For example, some authors have found that the Universe dynamics begins by an inflationary phase and converges towards a ΛCDM model if the fluid coupled to dark energy has a negative energy density at early time [8]. Other authors have considered the recent cosmological deceleration-acceleration transition redshift in $f(R)$ gravity. They proposed a model where the deceleration parameter changes sign at a redshift consistent with observations [9]. In other scenarios, the future evolution of quintessence/phantom dominated epoch in modified $f(R)$ gravity has been considered [10,11]. This type of gravity unifies the early-time inflation with late-time acceleration and is consistent, in principle, with observational data [12]. Furthermore the universe expansion history, unifying early-time inflation and late-time acceleration, can be realized in scalar-tensor gravity minimally or non-minimally coupled to curvature [13].

However, one of the best models unifying the early-time inflation with late-time acceleration is the phantom cosmology. This model allows to study the inflationary epoch, the transition to the non-phantom standard cosmology (radiation/matter dominated eras) and today observed dark energy epoch. In the unified phantom cosmology, the same scalar field plays the role of early time (phantom) inflaton and late-time Dark Energy. The recent transi-

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tion from decelerating to accelerating phase can be also described by the same scalar field [14]. Despite these reliable features, the main question that arises is about the origin of the phantom field. The answer to this question can come, at a fundamental level, by taking into account a brane–antibrane system undergoing three different stages along its evolution. At first stage, k black fundamental strings transit to the so-called *BIon configuration* at matching point. The BIon is a configuration in flat space of a brane universe and a parallel antibrane universe connected by a wormhole [15,16]. At transition point, the thermodynamics of this configuration can be matched to that of k non-extremal black fundamental strings. At lower temperature, the wormhole throat becomes smaller, its energy is transferred to the universe branes and leads to its accelerated expansion. After a short time, this wormhole evaporates, inflation ends and non-phantom era begins. This is the second stage of Universe expansion history. Eventually, two brane and antibrane universes become close to each other, the tachyonic potential between them increases and a new wormhole is formed. At this stage, the Universe evolves from the non-phantom phase to the phantom one and consequently, the late phantom-dominated era starts and ends up in the Big-Rip singularity.

We can compare this dynamics with the results in Ref. [14] and obtain the wormhole throat features and temperature in terms of time.

The outline of the paper is the following. In Section 2, we discuss the inflationary stage in BIon system and show that all cosmological parameters depend on the wormhole parameters between the two branes. In Section 3, we study the second stage where the wormhole evaporates and the pair brane and antibrane universes result disconnected. In Section 4, we consider the third stage where a new tachyonic wormhole is formed between branes and accelerates the destruction of the universes towards a big rip. In Section 5, we test our model against observational data. The last section is devoted to summary and conclusions.

2. Stage 1: the early time inflation

In this section, we assume that there is only a fluid of k black fundamental strings at the beginning. In our model, the Universe is born at a point corresponding where the thermodynamics of k non-extremal black fundamental strings is matched to that of the BIon configuration. We will construct the inflation in BIon and discuss that the wormholes between branes have direct effect on the inflation. We can also show that all parameters of inflation depend on the number of branes and on the distance between branes.

Let us start with the supergravity solution for k coincident non-extremal black F-strings lying along the z direction as discussed in [16,17]:

$$ds^2 = H^{-1}(-f dt^2 + dz^2) + f^{-1}dr^2 + r^2 d\Omega_7^2,$$
$$H = 1 + \frac{r_0^6 \sinh^2\bar{\alpha}}{r^6}, \qquad f = 1 - \frac{r_0^6}{r^6},$$
$$k^2 = \frac{3^{12} T_{D3}^4(\cosh^2\bar{\alpha} - 1)}{2^{12}\pi^6 T_{F1}^2 T^{12}\cosh^{10}\bar{\alpha}}. \tag{1}$$

In above equation, T is the finite temperature of BIon, k is the number of black F-strings and T_{D3} and T_{F1} are tensions of brane and fundamental strings respectively. The mass density along the z direction can be found from the metric [17]:

$$\frac{dM_{F1}}{dz} = T_{F1}k + \frac{16(T_{F1}k\pi)^{3/2}T^3}{81T_{D3}} + \frac{40T_{F1}^2 k^2\pi^3 T^6}{729T_{D3}^2}. \tag{2}$$

At the corresponding point, the k black F-strings transit to the BIon configuration where the string coupling constant ($g_s \ll 1$) becomes very small. On the other hand, brane tension depends on the inverse of string coupling ($T_{D3} = \frac{1}{(2\pi)^3 g_s l_s^4}$) and tends to larger values at transition point. However, the string tension ($T_{F1} = \frac{1}{2\pi l_s^2}$) remains constant and thus $\frac{40T_{F1}^2k^2\pi^3T^6}{729T_{D3}^2} = \frac{840g_s^2l_s^4k^2\pi^7T^6}{729}$ is smaller than $\frac{16(T_{F1}k\pi)^{3/2}T^3}{81T_{D3}} = \frac{16g_sl_s\pi^3(2k)^{3/2}T^3}{81}$ and both are smaller than 1. Finally, we can write:

$$\frac{dM_{F1}}{dz} = T_{F1}k + AT^3 + BT^6$$
$$A = \frac{16(T_{F1}k\pi)^{3/2}}{81T_{D3}} = \frac{16g_sl_s\pi^3(2k)^{3/2}}{81} \ll 1$$
$$B = \frac{40T_{F1}^2k^2\pi^3}{729T_{D3}^2} = \frac{840g_s^2l_s^4k^2\pi^7}{729} \ll 1$$
$$\frac{B}{A} \simeq g_s l_s^4 \ll 1 \tag{3}$$

Thus, we can ignore higher orders of $(\frac{1}{T_{D3}})$ in our calculations but the above approximation is valid. For finite temperature BIon configurations, the metric takes the form [16]:

$$ds^2 = -dt^2 + dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2) + \sum_{i=1}^{6} dx_i^2. \tag{4}$$

If one chooses the world volume coordinates of the $D3$-brane as $\{\sigma^a, a = 0,\ldots,3\}$ and defining $\tau = \sigma^0$, $\sigma = \sigma^1$, then, the coordinates of BIon assume the form [15,16]:

$$t(\sigma^a) = \tau,\ r(\sigma^a) = \sigma,\ x_1(\sigma^a) = z(\sigma),\ \theta(\sigma^a) = \sigma^2,\ \phi(\sigma^a) = \sigma^3 \tag{5}$$

and the remaining coordinates $x_{i=2,\ldots,6}$ are constant. The embedding function $z(\sigma)$ describes the bending of the brane. Let z be a transverse coordinate to the branes and σ be the radius on the world-volume. The induced metric on the brane is:

$$\gamma_{ab}d\sigma^a d\sigma^b = -d\tau^2 + (1 + z'(\sigma)^2)d\sigma^2 + \sigma^2(d\theta^2 + \sin^2\theta d\phi^2) \tag{6}$$

so that the spatial volume element is $dV_3 = \sqrt{1 + z'(\sigma)^2}\sigma^2 d\Omega_2$. We impose the two boundary conditions $z(\sigma) \to 0$ for $\sigma \to \infty$ and $z'(\sigma) \to -\infty$ for $\sigma \to \sigma_0$, where σ_0 is the minimal two-sphere radius of the configuration. For this BIon, the mass density along the z direction can be obtained [16]:

$$\frac{dM_{BIon}}{dz} = T_{F1}k + \frac{3\pi T_{F1}^2 k^2 T^4}{32T_{D3}^2\sigma_0^2} + \frac{7\pi^2 T_{F1}^3 k^3 T^8}{512T_{D3}^4\sigma_0^4}. \tag{7}$$

As it can be seen from the above equation, the mass density along the z direction depends on the brane tension (T_{D3}). At transition point, a brane and an antibrane are produced and expand very fast. Consequently, T_{D3} grows and achieve large values. On the hand, the string tension ($T_{F1} = \frac{1}{2\pi l_s^2}$) remains constant and thus $\frac{7\pi^2T_{F1}^3k^3T^8}{512T_{D3}^4\sigma_0^4}$ is smaller than $\frac{3\pi T_{F1}^2k^2T^4}{32T_{D3}^2\sigma_0^2}$ and both are smaller than 1. It is

$$\frac{dM_{BIon}}{dz} = T_{F1}k + A'T^4 + B'T^8$$
$$A' = \frac{3\pi T_{F1}^2 k^2}{32T_{D3}^2\sigma_0^2} = \frac{48\pi^5 g_s^2 l_s^2 k^2}{32\sigma_0^2} \ll 1$$