The Effect of Bulk Tachyon Field on the Dynamics of Geometrical Tachyon

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Abstract. We study the dynamics of the geometrical tachyon field on an unstable D3-brane in the background of a bulk tachyon field of a D3-brane solution of Type-0 string theory. We find that the geometrical tachyon potential is modified by a function of the bulk tachyon and inflation occurs at weak string coupling, where the bulk tachyon condenses, near the top of the geometrical tachyon potential. We also find a late accelerating phase when the bulk tachyon asymptotes to zero and the geometrical tachyon field reaches the minimum of the potential.

1. Introduction

In open string theory the presence of a tachyon field indicates an instability in its world-volume. There is strong evidence of a relation between the full dynamical evolution in string theory and renormalization group flows on the world-sheet, having both many features in common. The most profound one is that a world-sheet RG flow, away from an unstable string background, ends at an infrared conformal field theory that may generically be expected to be stable. Similarly, the dynamical process of tachyon condensation is generically expected to decay into a stable solution of string theory \cite{1}.

The time evolution of a decaying D-brane in an open string theory can be described by an exact solution called rolling tachyon \cite{2} or S-brane \cite{3}. The homogeneous decay can be described by perturbing the D-brane boundary conformal field theory. During this decay described by an instability of the RG flow on the world-sheet of the string, the spacetime energy decreases along the RG flow. The end point of this evolution is to dump the energy released by the tachyon condensation into the surrounding space, presumably in the form of closed string radiation, and then relax to its ground state.

Closed string theories are theories of gravity where spacetime is dynamical. An instability in the spacetime theory implies also an instability of RG flow, on the world-sheet of the string.

\cite{1} For reviews on open tachyon condensation see \cite{1}.

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Therefore we expect similar behaviour as in the open string case. There are however some important differences. The condensation of a closed tachyon field modifies the asymptotics of spacetime (for a review on closed tachyon condensation see [4]). Nevertheless it was found that the spacetime energy decreases along bulk world-sheet RG flows, at least for the flows for which this statement may be sensibly formulated. Also, for the case of the closed tachyons, conservation of energy severely complicates the issue of whether condensation leads to the true vacuum of the theory, if it has one.

The Dirac-Born-Infeld action as an effective theory successfully describes the physics in the world-volume of string theory. In the case of open string theory, the DBI action was employed to describe the dynamics of an open tachyon field and in particular the time evolution of an unstable D-brane by the rolling of a tachyon field down its potential. When a closed tachyon field is present in the bulk, the world-volume dynamics is described by a modified DBI action. In the case of Type-0 string theory, the world-volume couplings of the tachyon with itself and with massless fields on a D-brane were calculated [5, 6]. It was found that the bulk tachyon appears as an overall coupling function in the DBI action [5, 7].

The Type-0 string theory is an example of a closed string theory, where the tachyon condensation stabilizes the theory. We are far from understanding its full dynamics but nevertheless it gives us some information about the gravitational dynamics of the bulk. It would be interesting to see what is the effect of the closed tachyon condensation on the boundary theory.

In this talk we will consider a probe D3-brane moving in the background of a Type-0 string. We will study a particular D3-brane bulk solution of this string theory, for which we know an exact solution at least in the weak string limit. At that limit on the other hand, open strings do not feel the strong gravity effects and therefore open string tachyon condensation can take place on this fixed D3-brane background geometry. However, the probe D3-brane will be affected by the bulk geometry through a modified DBI action describing its dynamics, and through the Wess-Zumino term which encodes the structure of the bulk. Further we will study the influence if a bulk tachyon field to the cosmological evolution of the geometrical tachyon.

2. A Probe D3-Brane Moving in the Background of D3-Branes with a Bulk Tachyon Field

We consider a general non-conformal string background, with the presence of a dilaton field, of a stack of D3-branes which are RR-charged. In particular, we are interested in the movement of a probe D3-brane in a specific type of the above background, namely the Type-0 string background [8, 9, 7] in which, except from the RR fluxes there is also a bulk tachyon field, coupled to them.

The action of the Type-0 string is given by [9]

\[
S_{10} = \int d^{10}x \sqrt{-g} \left[ e^{-2\Phi} \left( R + 4(\partial_\mu \Phi)^2 - \frac{1}{4} (\partial_\mu T_{bulk})^2 - \frac{1}{4} m^2 T_{bulk}^2 - \frac{1}{12} H_{\mu \nu \rho} H^{\mu \nu \rho} \right) - \frac{1}{4} f(T_{bulk}) |F_5|^2 \right],
\]

where \( F_5 = dC_4 \) is the 5-form field strength of the RR field. The tachyon is coupled to the RR field via the function \( f(T_{bulk}) = 1 + T_{bulk} + \frac{1}{2} T_{bulk}^2 \). The bulk tachyon field appearing in (1) is a closed tachyon field which is the result of GSO projection and there is no spacetime supersymmetry in the theory. The tachyon field appears in (1) via its kinetic term, its potential and via the tachyon function \( f(T_{bulk}) \). The potential term is giving a negative mass squared term which is signaling an instability in the bulk. However, it was shown in [7, 9, 10] that
because of the coupling of the tachyon field to the RR flux, the negative mass squared term can be shifted to positive values if the function \( f(T_{\text{bulk}}) \) has an extremum, i.e. \( f'(T_{\text{bulk}}) = 0 \). This happens in the background where the tachyon field acquires vacuum expectation value \( T_{\text{bulk, vac}} = -1 \) \([7, 9]\). In this background the dilaton equation is \( \nabla^2 \Phi = -\frac{1}{e^{2\Phi}} T^2_{\text{bulk, vac}} \). This equation is giving a running of the dilaton field which means that the conformal invariance is lost, and \( AdS_5 \times S^5 \) is not a solution. Therefore, the closed tachyon condensation is responsible for breaking the 4-D conformal invariance of the theory. However, the conformal invariance is restored in two conformal points, corresponding to IR and UV fixed points, when the tachyon field gets a constant value. The flow from IR to UV as exact solutions of the equations of motion derived from action (1) is not known, only approximate solutions exist \([7, 11, 12]\). In these solutions, the closed tachyon field starts in the UV from \( T_{\text{bulk}} = -1 \), grows to larger values and passing from an oscillating phase it reaches \( T_{\text{bulk}} = 0 \) at the IR. However, if the dilaton and tachyon fields are constant, an exact solution of a D3-brane can be found \([9, 7]\)

\[
ds_{10}^2 = \frac{1}{\sqrt{H}} \left( -dt^2 + (d\vec{x})^2 \right) + \sqrt{H} \, dr^2 + \sqrt{H} \, r^2 \, d\Omega_5^2, \tag{2}
\]

where \( H = 1 + \left( \frac{e^{\Phi_0} Q}{\tau} \right)^2 \), Q is the electric RR charge and \( \Phi_0 \) denotes a constant value of the dilaton field. If we define \( L = \left( e^{\Phi_0} Q/2 \right)^{1/4} \), \( H \) can be rewritten as \( H = 1 + \left( \frac{\tau}{T} \right)^4 \). The RR field takes the form \( C_{0123} = \sqrt{1 + \left( \frac{\tau}{T} \right)^4 \frac{1-H}{H}} \).

The dynamics on the probe D3-brane will be described by the Dirac-Born-Infeld plus the Wess-Zumino action,

\[
S_{\text{probe}} = S_{\text{DBI}} + S_{\text{WZ}} = \tau \int d^4 \xi \, e^{-\Phi} \sqrt{-\det(G_{\alpha\beta} + (2\pi \alpha') F_{\alpha\beta} - B_{\alpha\beta})} + \tau \int d^4 \xi \, \hat{C}_4. \tag{3}
\]

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The induced metric on the brane is \( \hat{G}_{\alpha\beta} = G_{\mu\nu} \frac{\partial x^\mu}{\partial \xi^\alpha} \frac{\partial x^\nu}{\partial \xi^\beta} \), with similar expressions for \( F_{\alpha\beta} \) and \( B_{\alpha\beta} \). For an observer on the brane the Dirac-Born-Infeld action is the volume of the brane trajectory modified by the presence of the anti-symmetric two-form \( B_{\alpha\beta} \), and world-volume anti-symmetric gauge fields \( F_{\alpha\beta} \).

In this background, assuming that there are no anti-symmetric two-form \( B_{\alpha\beta} \) fields and world-volume anti-symmetric gauge fields \( F_{\alpha\beta} \), in the static gauge, \( x^i = \xi^\alpha, \alpha = 0, 1, 2, 3 \) using the induced metric we can calculate the bosonic part of the brane Lagrangian which reads

\[
\mathcal{L} = \sqrt{A(r) - B(r) \dot{r}^2 - D(r) h_{ij} \dot{\varphi}^i \dot{\varphi}^j - C(r)}, \tag{4}
\]

where \( h_{ij} d\varphi^i d\varphi^j \) is the line element of the unit five-sphere, and

\[
A(r) = e^{-\Phi_0} k(T_{\text{bulk}})^2 H^{-2}(r), \quad B(r) = e^{-\Phi_0} k(T_{\text{bulk}})^2 H^{-1}(r), \quad D(r) = e^{-\Phi_0} k(T_{\text{bulk}})^2 H^{-1}(r) \dot{r}^2, \tag{5}
\]

where \( C(r) \) is the RR background. The problem is effectively one-dimensional and can be solved easily. Since (4) is not explicitly time dependent and the \( \phi \)-dependence is confined to the kinetic term for \( \phi \), for an observer in the bulk, the brane moves in a geodesic parameterized by a conserved energy \( E \) and a conserved angular momentum \( l^2 \) which can easily be calculated and together with the expressions of the momenta give the following form of the DBI action

\[
S_{\text{probe}} = \tau \int d^4 x \, k(T_{\text{bulk}}) H^{-1} \left[ \sqrt{1 - \left( 1 - \frac{\alpha^2}{(C(r) + E)^2} \right) H^{-2}} - f^{-1}(T_{\text{bulk}}) k^{-1}(T_{\text{bulk}}) \right]. \tag{6}
\]
where $\alpha = e^{-\Phi_0} k(T_{bulk})$ and $C(r) = \tau f^{-1}(T_{bulk}) H^{-1} + Q_1$ with $Q_1$ an integration constant [13] which will be absorbed in the energy $E$ while the factor $e^{-\Phi_0}$ has been absorbed in the coupling $\tau$. The function $k(T_{bulk})$ appears because of the presence of the tachyon field in the bulk. Its form is found to be $k(T_{bulk}) = 1 + \frac{T_{bulk}}{4} + \frac{3 T_{bulk}^2}{32} + \ldots$ [7, 5, 6]. Note that there is no world-volume coupling of the bulk tachyon field to the RR fields [6].

The motion of the probe brane in a geodesic with a conserved energy $E$ and without angular momentum $l^2$ ([?] for the case including a conserved angular momentum), can be parameterized by a single scalar field $T_{geo}$ if we define

$$ T_{geo} = \int dH \left( -\frac{L}{4} H^{1/2} (H-1)^{-5/4} \right). \quad (7) $$

This relation gives an explicit relation between the radial coordinate $r$ and the field $T_{geo}$. Therefore, the scalar field $T_{geo}$ has a clear geometrical interpretation in term of the coordinate $r$, the distance of the probe brane from the D3-branes in the bulk [15]. If we use the field redefinition (7) the action (6) becomes

$$ S_{probe} = \int d^4 x \left[ \sqrt{1 + g_{\alpha\beta} \partial^\alpha T_{geo} \partial^\beta T_{geo}} - f^{-1}(T_{bulk}) k^{-1}(T_{bulk}) \right], \quad (8) $$

where the only nontrivial component of the metric $g_{\alpha\beta}$ is the time component and the open tachyon potential is given by

$$ V(T_{geo}) = \frac{\tau k(T_{bulk})}{H(T_{geo})}. \quad (9) $$

The term $\int d^4 x V(T_{geo}) f^{-1}(T_{bulk}) k^{-1}(T_{bulk})$ in (8), is the familiar Wess-Zumino term which is a function of the geometrical tachyon field and the projection of the RR field of the bulk on the brane [16].

The form of the tachyonic action (8) implies the well discussed physical picture, that the movement of the probe D3-brane in the field of other D3-branes, corresponds to an open tachyon field rolling down its potential [2, 17]. The novel feature here is the presence of the bulk tachyon field $T_{bulk}$. The bulk tachyon field appears in the potential (9) and if $l \neq 0$ it also appears in the definition of $T_{geo}$ in (7). Further we will study what is its effect on the dynamics of the open tachyon field as it rolls down its potential. For simplicity we will consider the probe D3-brane moving radially in this non-conformal string background. From (7) we can easily derive the following equation

$$ \frac{dT_{geo}}{dr} = \sqrt{H(r)} = \sqrt{1 + \frac{L^2}{r^4}}, \quad (10) $$

which relates the tachyon field $T_{geo}$ to the distance $r$ of the probe brane from the bulk D3-branes and its potential (for $l = 0$) is given by (9). Because of (10), the relation between the radial mode and $T_{geo}$ is polynomial, which means that the explicit form of $T_{geo}(r)$ can not be found. Indeed, $T_{geo}(r)$ is a combination of elliptic integrals of the first and the second kind. Nevertheless asymptotically the differential equation (10) can be evaluated.

$$ \begin{align*}
IR \text{ limit } & \quad \begin{cases} T_{geo}(r) \sim -\frac{L^2}{r} \rightarrow -\infty, \\ \frac{1}{2} V(T_{geo}) \sim k(T_{bulk}) \frac{L^4}{T_{geo}^2} \rightarrow 0, \end{cases} \\
UV \text{ limit } & \quad \begin{cases} T_{geo}(r) \sim r \rightarrow \infty, \\ \frac{1}{2} V(T_{geo}) \sim k(T_{bulk}) \simeq \text{const}. \end{cases}
\end{align*} \quad (11) $$
The presence of the bulk tachyon field through the function $k(T_{\text{bulk}})$ in (9) influences the shape of the geometrical tachyon potential. According to Sen’s conjecture, the height of the geometrical tachyon potential in its maximum value, is equal to the tension of the D3-brane. In the UV fixed point where the bulk tachyon field condenses, $k(T_{\text{bulk}}) = 3/4$, indicating that the presence of the bulk tachyon is lowering the D3-brane tension. The bulk tachyon field changes from -1 in the UV to 0 in the IR, therefore the geometrical tachyon potential (9) alters its shape as the geometrical tachyon rolls down to its minimum. As we will see in the next section this has important consequences in the cosmological evolution of the brane-universe.

Observe that in the D3-brane bulk solution because $k(T_{\text{bulk}}) = 1$ in the infrared, the condensation of the open tachyon field exactly cancels the probe D3-brane tension and then we do not have any perturbative open string states in the spectrum. We note also here that if we do not restrict ourselves to the D3-brane exact solution (2) and we consider the full system of equations resulting from the action (1), there are approximate solutions with non-constant tachyon and dilaton fields [7, 11]. In these solutions, the dilaton field in the infrared gets large values and as a consequence, the string effective coupling becomes large, making the whole behaviour of the tachyon condensation in the infrared questionable.

3. Coupling to Gravity-Tachyon Cosmology

The study of the dynamics of the rolling tachyon describing the time evolution of a decaying D-brane in open string theory, initiated the development of the tachyon cosmology [18]. In this section we will study the influence of a bulk tachyon field to the cosmological evolution of the geometrical tachyon. Phrasing it in an other way, we will consider the cosmological evolution of a probe D3-brane as it moves in the gravitational field of other D3-branes of Type-0. On the probe D3-brane we will introduce a four-dimensional scalar curvature term. The motivation for introducing a local gravitational field on the brane is twofold: strong effects are arising on the brane because of tachyon condensation, so it is natural to expect the presence of a gravitational field, and any matter source on the brane, because of the gravitational field of the bulk, will generate kinetic gravitational terms on the brane [19].

To capture the dynamics of the induced gravitational field on the brane, assuming that it is minimally coupled, we consider the DBI action of the geometrical tachyon field coupled to gravity

$$S_{\text{cosmo}} = \int d^4x \sqrt{-g} \left( \frac{R}{16\pi G} - V(T_{\text{geo}}) \sqrt{1 + g^{\mu\nu} \partial_\mu T_{\text{geo}} \partial_\nu T_{\text{geo}}} \right).$$  \hspace{1cm} (12)

In the above action the geometrical tachyon field acts as a local matter source on the brane. Assuming that the tachyon field is described by a homogeneous fluid with $T_{\mu\nu} = pg_{\mu\nu} + (p + \rho)u_\mu u_\nu$, and the fact that $T_{\mu\nu} = \frac{-2}{\sqrt{-g}} \frac{\partial S_{\text{cosmo}}}{\partial g^{\mu\nu}}$, we can extract the expressions of the energy density and pressure. Moreover, for the string background we are considering, from equations (6) and (8) we have that

$$\sqrt{1 - T_{\text{geo}}^2} = \frac{\alpha(T_{\text{bulk}})}{H} \left( E + \frac{\beta(T_{\text{bulk}})}{H} \right)^{-1},$$  \hspace{1cm} (13)

thus obtaining the following expressions for the energy density and the pressure

$$\frac{\rho_{\text{tch}}(H)}{\tau} = E + \frac{\beta(T_{\text{bulk}})}{H},$$  \hspace{1cm} (14)

$$\frac{p_{\text{tch}}(H)}{\tau} = -\alpha^2(T_{\text{bulk}}) \left( E + \frac{\beta(T_{\text{bulk}})}{H} \right)^{-1}.$$  \hspace{1cm} (15)
One should keep in mind here, that in our approach the geometrical tachyon field we are considering, because of the identification we did in (7) is a mirage tachyon field on the probe brane, in the sense that it is an expression of bulk quantities. For this reason, we use relation (13) which is not derived from the action (12). Also observe that as the brane moves towards the bulk D3-branes, $\rho_{\text{tch}}$ and $p_{\text{tch}}$ of (14) and (15) are changing, being functions of $r$. The presence of the scalar curvature term in the action (12), assuming a flat Robertson-Walker metric on the brane, leads to the Friedmann equation \( \mathcal{H}_{\text{tch}}^2 = \frac{8\pi G T}{3} \rho_{\text{tch}} \), which gives a cosmological evolution because of the presence of the gravitational field on the brane.

As the probe brane is moving in the background string theory, it will also experience the effect of the bulk gravitational field. This effect can be calculated with the techniques of mirage cosmology [20, 13, 21]. The presence of the Type-0 string background induces on the probe brane [13], a four-dimensional metric

\[
d\tilde{s}^2 = -d\eta^2 + g(r(\eta))(dx^2),
\]

which is the standard form of a flat expanding universe where $\eta$ is the cosmic time defined by $d\eta = \frac{H^{−5/4} \alpha(T_{\text{bulk}})}{\beta(T_{\text{bulk}}) H^{−1} + 1} dt$. Moreover setting $g = a$ we get [13]

\[
(\frac{\dot{a}}{a})^2 = \frac{\tau}{L^2}(\frac{H - 1}{H})^{5/2} \left( \alpha(T_{\text{bulk}})^{-2}(\beta(T_{\text{bulk}}) + EH)^2 - 1 \right),
\]

where the dot stands for derivative with respect to cosmic time. The right hand side of (17) can be interpreted in terms of an effective or “mirage” matter density on the probe brane

\[
\rho_{\text{mir}} = \frac{3\tau}{8\pi G L^2} \left( \frac{H - 1}{H} \right)^{5/2} \left( \alpha(T_{\text{bulk}})^{-2} H^2 \left( E + \frac{\beta(T_{\text{bulk}})}{H} \right)^2 - 1 \right).
\]

We can also calculate the “mirage” pressure using $\frac{\dot{a}}{a} = \left[ 1 + \frac{1}{2} \alpha \frac{\beta}{\alpha} \right] \frac{8\pi G}{3} \rho_{\text{mir}}$ and setting the above equal to $-\frac{4\pi G T}{3} (\rho_{\text{mir}} + 3p_{\text{mir}})$, we can calculate the “mirage” pressure $p_{\text{mir}}$. Then, as the brane is moving in the gravitational field of the bulk, because of this motion [20], there will be a cosmological evolution on the brane described by the Friedmann equation \( \mathcal{H}_{\text{mir}}^2 = \frac{8\pi G}{3} \rho_{\text{mir}} \).

Therefore, as the geometrical tachyon rolls down its potential it feels two effects: the gravitational field of its own and the gravitational field of the bulk D3-branes. Our basic assumption of the probe approximation allows us to assume, because the D3-brane as it moves does not backreact with the background, that the above two contributions give an additive effect on the cosmological evolution of the probe brane, and hence it is described by the Friedmann equation

\[
\mathcal{H}_{\text{probe}}^2 = \frac{8\pi G}{3} (\rho_{\text{tch}} + \rho_{\text{mir}}).
\]

Also the Raychaudhury equation \( \mathcal{H}_{\text{probe}} \) can be calculated. The inflationary parameter $I(H)$ can be defined as $I(H) = \mathcal{H}_{\text{probe}}^2 + \mathcal{H}_{\text{probe}}^2$ and is found to be

\[
I(H) = -\frac{4\pi G T_j}{3} (H - 1)^{5/4} \left( \frac{4\sqrt{3}}{\alpha(T_{\text{bulk}})^2} \frac{\beta(T_{\text{bulk}}) H^{5/4}}{\sqrt{8\pi G L^2}} \left( E + \frac{\beta(T_{\text{bulk}})}{H} \right)^{1/2} \times \left[ \frac{1}{H^2} - \frac{1}{2} \frac{(\beta(T_{\text{bulk}}))^{-2}}{H^2} \right]^{1/2} \right).
\]
The inflationary parameter \( I(H) \) depends on the value of \( T_{\text{bulk}} \). As we discussed before, we do not know the exact variation of the bulk tachyon field from UV to IR. The existing approximate solutions are valid only in the vicinity of the fixed points and they can not give us a cosmological evolution from large to small distances. However, we know that the bulk tachyon field varies from the UV value \( T_{\text{bulk}} = -1 \) to the IR value \( T_{\text{bulk}} = 0 \). We will simulate then this variation with a smooth function

\[
T_{\text{bulk}}(H) = \frac{1}{2} \left( \tanh(\zeta(H - \sigma)) - 1 \right),
\]

(21)

where the parameter \( \zeta \) controls how steep is the variation, while \( \sigma \) indicates when the transition from -1 to 0 occurs. Using this function, in Fig. 1 we have plotted the inflationary parameter as a function of \( H \) and for various values of the energy \( E \) (in units of \( \tau \)). The cosmological evolution of the brane-universe starts with an early inflationary phase near the value \( T_{\text{bulk}} = -1 \), where the bulk tachyon field condenses and the string coupling is weak, and as the bulk tachyon field gets larger values, there is an exit from inflation and a late acceleration phase as the bulk tachyon field approaches \( T_{\text{bulk}} \to 0 \).

We can see the cosmological evolution on the brane-universe using the geometrical tachyon picture. As we discussed in the Sect. 2, the geometrical tachyon rolling down its potential has two different asymptotic behaviours. At the UV it starts with \( T_{\text{geo}} = \infty \) at the top of the potential, and rolls down to \( V(T_{\text{geo}}) = 0 \) in the IR where \( T_{\text{geo}} = -\infty \). The transition to the two regimes occurs where \( r = L \) or \( H = 2 \). On the other hand, the background string solution (2), is reliable near the UV and IR fixed points in which \( H = 1 \) and \( H \to \infty \) respectively. As we can see in Fig. 1, there is a choice of parameters for which the early inflationary phase and the exit from it occurs around \( H = 1 \) which corresponds to the top of the geometrical tachyon potential. The late inflationary phase occurs for large \( H \) values, where the bulk tachyon field has decoupled, and this happens in the bottom of the geometrical tachyon potential.

We can also define the equation of state parameter \( w(H) = p_{\text{probe}}/\rho_{\text{probe}} \). Then, using (14), (15), (18) and the expression of \( p_{\text{mix}} \) we can plot \( w \) as a function of \( H \) and for various values of the energy. We see in Fig. 1 that it starts with the value \( w = -1 \) in the early inflationary phase, then it gets positive values and finally relaxes again to \( w = -1 \) in the late accelerating phase. This picture is appealing, because the whole cosmological evolution is driven by the dynamics of the theory, without any dark matter or dark energy. If we switch off the gravitational field on the moving brane then, the mirage effect [13] gives only the late accelerating phase as the probe brane is approaching the bulk. If we switch off the mirage contribution then the brane-universe has the early inflationary phase, where the tachyon field condenses, near the top of the geometrical tachyon potential. If we decouple the bulk tachyon field from the start, having a probe brane moving in the background of other D3-branes then, we have a very short inflationary period in the top of the geometrical tachyon potential. This can be attributed to the presence of the gravitational field on the brane.

A remark concerning the consistency of our approach. Let us recall what happens in the DGP model [19]. We have a static brane in a time dependent five-dimensional pure gravitational bulk. As it was showed in [22], the introduction of a four-dimensional scalar curvature term on the brane, simply redefines the energy momentum tensor on the brane. If we go to the picture in which the brane is moving and the bulk is static, it can be shown [23], that the \( R \)
term has the same effect, it redefines the energy momentum tensor in the junctions conditions which play the rôle of the equations of motion of the moving brane. In both pictures, there is an effective four-dimensional Einstein equation which describes consistently the cosmological evolution on the brane.

In the case of a Dp-brane moving in the background of other Dp-branes the situation is much more difficult [24]. The Dp-branes of the bulk are solutions of a complicated usually string theory and the only information we can get on the brane is only through the DBI action. For this reason we use the rolling tachyon picture which is described by a simple DBI action and the basic assumption of the probe brane approximation. There is no backreaction between the brane and the bulk. As the brane moves in the gravitational field of the background branes it does not disturb this background. This approach led us to the Friedmann equation (19).

4. Conclusions and Discussion
We provided some evidence that closed tachyon condensation may have some important consequences on the cosmological evolution of the boundary theory. Of course we do not fully understand the dynamics of the closed tachyon condensation and its connection to the gravitational dynamics, but nevertheless we provided an example in which the condensation of the bulk tachyon, except that it stabilizes the bulk theory, it is responsible for the inflation on the boundary theory.

More work is needed to understand the phenomenological aspects of the inflation on the brane, like how long it lasts, what are the scalar perturbations produced during inflation, what is the mechanism for reheating. Can the condensation of the bulk tachyon provide the energy needed for the reheating? However, there is a drawback in these considerations, because the relation (13) indicates that the kinetic energy of the geometrical tachyon field is not small and it can not be ignored compared to unity and hence slow-roll inflation can not be applied. This can be understood because of the strong bulk effects of the bulk tachyon condensation.

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