Assisted inflation from geometric tachyon

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ABSTRACT: We study the effect of rolling of N D3-branes in the vicinity of NS5-branes. We find out that this system coupled with the four dimensional gravity gives the slow roll assisted inflation of the scalar field theory. Once again this expectation is exactly similar to that of N-tachyon assisted inflation on unstable D-branes.

Contents

1. Introduction

During inflation [1] the spacetime must expand with an accelerated expansion. Allowing this phenomenon in the early universe solves many cosmological puzzles; e.g. the isotropy and homogeneity of the large scale structures and the flatness of the universe. Inflation is also considered to be the most plausible source of the primordial density perturbations in the universe. The conventional inflationary models deal with a scalar field rolling down a slowly varying potential in FRW spacetime [2]. But, it is now well accepted that string theory also has many cosmological vacua which have inflationary properties, *a la* [3, 4]. In fact there are plentiful of them. The early models, called brane-inflation models [5], have an attractive brane-antibrane force which drives the modulus (inflaton) separating the branes. But, generally, the inflation is not the slow-roll one there. The brane-antibrane models in a warped compactification scenario [4], partly solve the slow-roll problem, but lack the precise knowledge of the inflaton potential in presence of fluxes. There are other models based on open-string tachyon condensation which are capable of providing inflation, see [6 – 14]. In general, the tachyon models are also plagued with the same large η-problem as the conventional models and are not favoured for slow-roll inflation, see [15]. Although, this difficulty can be overcome by allowing a large number of tachyons to simultaneously roll down and assist the inflation [14]. There are number of various other attempts to provide stringy inflation models. These are for instance inflationary models based on branes intersecting at special angles [16], and also the D3/D7 models where the distance modulus plays the role of inflaton field [17, 18]. The race-track inflation models driven by closed string modulus could be found in [19].

Time dependent solutions in string theory are very interesting and challenging in view of solving puzzles in early universe cosmology. However there are quite a few number of known examples of such solutions in string theory/supergravity. In particular the rolling

tachyon solution [20] represents the decay of the unstable branes by the rolling of the open string tachyon in the potential valley. The end product of such a rolling process has been shown to comprise of a closed string excitation–the tachyon matter. Various cosmological applications has also been studied using this open string tachyon solution of string theory. Not long back Kutasov [21] proposed an example of such a time dependent solution in string theory, whose properties are strikingly similar to that of rolling tachyon solution of open string models. This is the D-NS5 brane system, where the dynamics of the BPS D-brane has been studied in the vicinity of a stack of BPS NS5-branes. As such this system is nonsupersymmetric as D-brane and NS5-branes break different halves of supersymmetry. The time-dependent dynamics has been studied both from the point of view of effective field theory and from the full string theory by constructing the relevant boundary states in NS5-brane near horizon geometry. It has been shown that when the Dp-branes are very far away from the NS5-branes there is the usual gravitational interaction between the two, and the D-branes will start to move towards the NS5-brane. When the D-brane is close enough to the NS5-brane (at a distance below l_s) it behaves exactly like that of the rolling tachyon. It has also been shown that there are no open string degrees of freedom at this point and all the other qualitative behaviour of the open string tachyons are also present. Hence the rolling tachyon of the open string models get a geometrical meaning- it is the 'radial' distance between the D-brane and the NS5-branes. This tachyon-radion correspondence has been analyzed more from the full string theory view point [22] and considerable amount of work has been done in connection with this (see for example [23] and more recently [24]). The cosmological applications of this solution has been analyzed in detail in the literature [25]. The inflationary scenario has also been worked out when the NS5-branes are distributed over a particular ring in the transverse space. It has been shown that the slow roll conditions and number of e-foldings are consistent with that of a 4-dimensional model with a perturbative string coupling. The traditional reheating mechanism has also been reproduced in this set up.

In [13, 14] N-tachyon assisted inflation was studied, where all the N tachyon fields on the non-BPS branes have been allowed to roll simultaneously in the valley of the potential. Coupling this system of N unstable D3-branes to gravity the inflationary scenario has been observed and the slow roll parameters are shown to be consistent with the assisted inflation of the N scalar fields.

Knowing the results of the tachyon assisted inflation on a system of N non-BPS branes and the by now well known correspondence between the tachyon-radion, it is tempting to analyze the assisted inflation in the (D-NS5)-brane system. The geometric tachyon can be viewed as the field responsible for inflation, and one could study the slow roll parameters, e-foldings and critical number density. We have addressed this problem in the present paper. We assume that all the N number of D3-branes roll simultaneously into the NS5-brane throat. All the D3-branes are coincident, hence the stack of parallel and coincident branes is BPS. We further assume that all the perturbative open string tachyons between the D3-branes are switched off. Hence the dynamics of this system is governed by the so called geometric tachyon.

Rest of the paper is organized as follows. In section 2, we review the basic ideas of

assisted inflation. Section 3 is devoted to the study of assisted inflation from geometric tachyon, by studying the system of D-branes into the NS5-brane throat. In section 4, we make some numerical studies. We conclude in section 5 with some comments.

2. Brief review: assisted inflation

The assisted inflation idea was proposed in [26] to overcome the large η problem in scalar field driven inflaton models. We review the main aspects of that work here. We consider a scalar field with potential $V(\phi)$ minimally coupled to Einstein gravity [2]

$$\int d^4x \sqrt{-g} \left[\frac{M_p^2}{2} R - \frac{1}{2} (\partial \phi)^2 - V(\phi) \right] \tag{2.1}$$

where four-dimensional Planck mass M_p is related to the Newton's constant G as $M_p^{-2} = 8\pi G$. Considering purely time-dependent field in a spatially flat FRW spacetime

$$ds^2 = -dt^2 + a(t)^2 \left(dr^2 + r^2(d\theta^2 + sin^2\theta d\phi^2) \right) \tag{2.2}$$

the classical field equations can be written as

$$\ddot{\phi} = -V_{,\phi} - 3H\dot{\phi}$$
$$H^2 = \frac{8\pi G}{3} \left(\frac{\dot{\phi}^2}{2} + V \right) \tag{2.3}$$

where $H(t) \equiv \dot{a}/a$ is the Hubble parameter. This simple model has proved to be a prototype for explaining the mechanism of inflation in early universe. For example, if we take a quadratic potential $V = m^2 \phi^2/2$ and let the field roll down from some large initial value, the field will roll down to its minimum value $\phi = 0$ and so spacetime will inflate [2]. But the inflation has to be a slowly rolling one in order to fit with cosmological observations. That is the field ϕ must vary slowly such that there is a vanishing acceleration, $\ddot{\phi} \sim 0$. Under the slow-roll conditions, the time variation of ϕ gets related to the slop of the potential as

$$\dot{\phi} \simeq -\frac{V_{,\phi}}{3H}.$$

So the potentials with gentle slop are preferred for a good inflation.

The standard slow-roll parameters are [27]

$$\epsilon \equiv \frac{M_p^2}{2} \frac{V'^2}{V^2}, \quad \eta \equiv M_p^2 \frac{V''}{V} \tag{2.4}$$

where primes are the derivatives with respect to ϕ. For the slow-roll inflation both ϵ and η will have to be small. Also these parameters are in turn related to the spectral index, n_s, of the scalar density fluctuations in the early universe as

$$n_s - 1 \simeq -6\epsilon + 2\eta. \tag{2.5}$$

A nearly uniform power spectrum observed over a wide range of frequencies in the density perturbations in CMBR measurements [29], however, requires $n_s \simeq .95$. It can be achieved only if

$$\epsilon \ll 1, \quad \eta \ll 1.$$

These are some of the stringent bounds from cosmology which inflationary models have to comply with.

For single scalar field the power spectrum of the scalar curvature perturbations can be written as [27]

$$P_R = \frac{1}{12\pi^2 M_p^6} \frac{V^3}{V'^2} \tag{2.6}$$

The amplitude (or size) of the density fluctuations are governed by

$$\delta_s = \frac{2}{5}\sqrt{P_R} = \frac{1}{5\sqrt{3}\pi M_p^3} \frac{V^{3/2}}{V'} \leq 2 \times 10^{-5} \tag{2.7}$$

The inequality on the right side of equation (2.7) indicates the COBE bounds on the size of the density perturbations at the beginning of the last 50 e-folds of inflation.[1]

It can be easily seen that the models with quadratic potentials are not useful for inflation as they are plagued with so called large η-problem. From the above we find that $\eta \sim 2M_p^2/\langle\phi\rangle^2$. Therefore η can be small only if ϕ has trans-Planckian vacuum expectation value during inflation. But allowing the quantum fields to have trans-Planckian vev will spoil the classical analysis and will involve quantum corrections to the potential.

An effective resolution of the large η problem can come from assisted inflation idea [26]. The model involves large number of scalar fields ϕ_i $(i = 1, 2, \ldots, N)$. Let us demonstrate it here for a quadratic potential $V = m^2\phi^2/2$ where all scalars have the same mass m. The scalar fields are taken to be noninteracting but are minimally coupled to gravity. The equations of motion are

$$\ddot{\phi}_i = -m^2\phi_i - 3H\dot{\phi}_i \quad \text{for each } i,$$
$$H^2 = \frac{8\pi G}{3} \sum_{i=1}^{N} \left(V(\phi) + \frac{\dot{\phi}_i^2}{2} \right). \tag{2.8}$$

Now, if all the fields are taken to be identical $\phi_1 = \phi_2 = \cdots = \phi_N = \Phi(t)$, the simplified equations become

$$\ddot{\Phi} = -m^2\Phi - 3H\dot{\Phi}$$
$$H^2 = \frac{8\pi G}{3} N \left(V(\Phi) + \frac{\dot{\Phi}^2}{2} \right) \tag{2.9}$$

One finds that due to N scalar fields, the eqs. (2.9) are having an effective Newton's constant $G.N$ when compared with the eqs. (2.3). So we easily determine that

$$\epsilon = \eta = \frac{2M_p^2}{N\Phi^2}.$$

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[1]The number of e-folds, N_e, during inflationary time interval $(t_f - t_i)$ are estimated as $N_e = \int_{t_i}^{t_f} Hdt$. The universe requires 50-60 e-folds of expansion in order to explain the present size of the observed large scale structure.

Thus for sufficiently large N, $<\Phi>$ need not be trans-Planckian. It can also be seen that since $H \sim \mathcal{O}(\sqrt{N})$ the spectral index

$$n_s - 1 = 2\eta - 6\epsilon \simeq 2\frac{\dot{H}}{H^2} \sim \mathcal{O}\left(\frac{1}{N}\right) \,.\tag{2.10}$$

If larger is the value of N, the index $n_s \sim 1$ which refers to the flatness (or no-tilt) of the spectrum of the density fluctuations in the observed universe. However recently in [28] an alternative way of warped compactification has been used to control the large η problem.

3. Inflation from N-geometric tachyon

In this section, we will study the inflation from the motion of N D3-branes falling into the NS5-brane throat geometry. The metric ($g_{\mu\nu}$), dilaton (ϕ) and Neveu Schwarz field H_{mnp} of a system of k coincident $NS5$-branes is given by:

$$ds^2 = \eta_{\mu\nu}dx^\mu dx^\nu + H(x^n)\delta_{mn}dx^m dx^n$$

$$e^{2(\phi-\phi_0)} = H(x^n), \quad H_{mnp} = \epsilon^q_{mnp}\partial_q\phi, \quad H(r) = 1 + \frac{k\alpha'}{r^2},\tag{3.1}$$

where $r = |\vec{x}|$ is the radial coordinate away from the NS5-branes in the transverse space R^4. The effective action on the world volume of Dp-brane is governed by the DBI action:

$$S_p = -T_p \int d^{p+1}\xi e^{-(\phi-\phi_0)}\sqrt{-\det(G_{ab} + B_{ab})}.\tag{3.2}$$

Where G_{ab} and B_{ab} are the induced metric and the B-field, respectively, onto the world volume of the Dp-brane:

$$G_{ab} = \frac{\partial X^\mu}{\partial \xi^a}\frac{\partial X^\nu}{\partial \xi^b}g_{\mu\nu},$$
$$B_{ab} = \frac{\partial X^\mu}{\partial \xi^a}\frac{\partial X^\nu}{\partial \xi^b}B_{\mu\nu},\tag{3.3}$$

where μ and ν runs over whole ten dimensional space time. The worldvolume coordinates of Dp-brane are leveled by ξ^a ($a = 0, \ldots, p$), and we set (by reparameterization invariance on the world-volume of the Dp-brane) $\xi^a = x^a$. The DBI action is given by

$$S_p = -\tau_p \int d^{p+1}x \frac{1}{\sqrt{H}}\sqrt{1 + H\partial_a R\partial^a R}\tag{3.4}$$

Compare with the tachyon effective action of the open string models

$$\mathcal{S}_{\text{tach}} = -\int d^{p+1}x V(T)\sqrt{1 + \partial_a T\partial^a T}\tag{3.5}$$

Comparing the above two actions, one gets

$$\pm\frac{dT}{dR} = \sqrt{1 + \frac{k\alpha'}{R^2}}$$
$$V(T) = \frac{\tau_p}{\sqrt{H(R(T))}}\tag{3.6}$$

The differential equation above, has the solution

$$\pm T = \sqrt{R^2 + a^2} - a \log\left(\frac{a + \sqrt{R^2 + a^2}}{R}\right)$$

where $a^2 = k\alpha'$. For the minus sign the potential V has a universal minimum at $T = \infty$ or $R = 0$ while it has a maximum at $T = -\infty$ or $R = \infty$. At $t = 0$, the tachyon will roll down from $T = -\infty$ to its minimum at $T = \infty$ at some later time. For the upper sign it will be opposite of this. We must employ the complete potential for the cosmological study although for the inflation purpose it will happen only near the top of the potential at $T = -\infty$. At the top the potential has a behaviour ($T^2 \gg a^2$) roughly as

$$V(T) \sim \tau_p\left(1 - \frac{a^2}{2T^2}\right) + O\left(\frac{a^4}{T^4}\right)$$

Our aim is to study the four dimensional cosmology of this system. For that purpose, we would like to solve the equations of motion derived from the effective action of the 'geometric tachyon' with the above potential for the D3-brane falling into the NS5-brane throat. In what follows we only consider the homogeneous mode, where the transverse coordinates of the NS5-branes depend on time coordinate only. To make it look familiar with that of the open string tachyon effective action on unstable D-branes to the quadratic order, we make a simple rescaling of the tachyon field $T \to \sqrt{\alpha'}T$. After the rescaling the effective action and the potential for the tachyon can be written as [2]

$$S = -\sum_{i=1}^{N} \int d^4 x V_i(T_i)\sqrt{-\det(g_{\mu\nu} + \alpha'\partial_\mu T_i(R)\partial_\nu T_i(R))} \tag{3.7}$$

where in the action above, all the potentials have same functional form, that is

$$V_i(T_i) = V(T_i) = \tau_3\left(1 - \frac{k}{2T_i^2}\right). \tag{3.8}$$

One can see that the equations of motion for the purely time dependent tachyon fields are decoupled from each other, and therefore one can take the factorization ansatz. In other words, we would like to assume that all the D3-brane roll into the NS5-brane throat at the same time. We will have the following

$$T_1(R(t)) = T_2(R(t)) = T_3(R(t)) = \cdots = T_N(R(t)) = \Phi(t)$$
$$V_1(T_1(R)) = V_2(T_2(R)) = V_3(T_3(R)) = \cdots = V_N(T_N(R)) = V(\Phi(t)) \tag{3.9}$$

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[2]Though we are taking large number of D3-branes, the NS5-branes are much heavier (of the order $\frac{k}{g_s^2}$) than the Dp-branes (of the order $\frac{N}{g_s}$) in the weak string coupling regime. For sufficiently weak coupling, the back reaction of these probe branes can be ignored. Further we restrict ourselves to the non-interacting geometric tachyon modes only in the DBI action, which are the radial distances from the core of the NS5-branes. We are ignoring other excitations on the world volume of D3-branes including gauge fields. Hence in the lowest order analysis only geometric tachyons will contribute.

With this ansatz in mind the effective action for a stack of D3-brane rolling into the NS5-brane can be given as

$$S = -N \int d^4x V(\Phi) \sqrt{-g} \sqrt{1 + \alpha'(\partial_\mu \Phi)^2} \tag{3.10}$$

Now we will couple this system with that of the four dimensional gravity given by

$$S_{\text{grav}} = \frac{M_p^2}{2} \int d^4x \sqrt{-g} R \tag{3.11}$$

The field equations we would like to solve combining gravity and the geometrical tachyon effective action are

$$\ddot{\Phi} = -(1 - \alpha' \dot{\Phi}^2) \left(M_s^2 \frac{V_{,\Phi}}{V} + 3H\dot{\Phi} \right)$$

$$H^2 = \frac{8\pi G}{3} \left(1 - \frac{k}{2\Phi^2} \right) \frac{\tau_3 N}{\sqrt{1 - \alpha' \dot{\Phi}^2}} \tag{3.12}$$

where we have taken FRW ansatz. Assuming $k \ll \Phi^2$ and $\alpha' \dot{\Phi}^2 \ll 1$, keeping the leading order terms, we get

$$\ddot{\Phi} = \left(\frac{M_s^6 k}{\Phi^3} - 3H\dot{\Phi} \right) + \mathcal{O}(\Phi^3)$$

$$H^2 = \frac{8\pi G \tau_3 N}{3} \left(1 - \frac{k}{2\Phi^2} + \alpha' \frac{\dot{\Phi}^2}{2} \right) + \mathcal{O}(\Phi^4)$$

$$= \frac{8\pi G}{3} \frac{\tilde{N}}{g_s} \left(V_{\text{eff}} + \frac{\dot{\Phi}^2}{2} \right), \tag{3.13}$$

where in the last equality

$$V_{\text{eff}} = M_s^4 \left(1 - \frac{kM_s^2}{2\Phi^2} \right), \quad \tilde{N} = \frac{N}{(2\pi)^3}, \quad \Phi \to \sqrt{\alpha'} \Phi \tag{3.14}$$

Let us redefine new fields $\psi = \sqrt{\frac{\tilde{N}}{g_s}} \Phi$. In which case

$$H^2 = \frac{8\pi G}{3} \left(V_{\text{eff}} + \frac{\dot{\psi}^2}{2} \right), \tag{3.15}$$

with

$$V_{\text{eff}}(\psi) = \frac{\tilde{N}}{g_s} M_s^4 \left(1 - \frac{\tilde{N}}{g_s} \frac{kM_s^2}{2\psi^2} \right), \tag{3.16}$$

3.1 Slow-roll and the spectrum

The standard slow-roll parameters can be evaluated by treating ψ as the inflaton field. We get

$$\epsilon = \frac{M_p^2}{2} \left(\frac{V'}{V} \right)^2 \simeq \frac{g_s}{2\tilde{N}k} \frac{M_p^2}{M_s^2} \left(\frac{kM_s^2}{\Phi^2} \right)^3$$

$$\eta = M_p^2 \frac{V''}{V} \simeq -6 \frac{g_s}{2\tilde{N}k} \frac{M_p^2}{M_s^2} \left(\frac{kM_s^2}{\Phi^2} \right)^2 . \tag{3.17}$$

The right most equalities in the above are expressed in terms of the geometric tachyon fields Φ. These expressions are valid when $\frac{kM_s^2}{\Phi^2} \ll 1$. If we simply take $k = 2$ (say), we need to have vev for fields Φ to be greater than the string mass scale! That is the inflaton fields must have trans-stringy vev's. For this reason it will be useful to keep k, the number of NS5-branes, as small as possible. These trans-stringy vev's can be realised in this geometric tachyon model at the place where the D3-branes are far away from the NS5 branes and start slowly rolling towards NS-branes. It is obvious that for $\epsilon, \eta \ll 1$, i.e. for a slow-roll, the quantity $\frac{3g_s}{\tilde{N}k}\frac{M_p^2}{M_s^2} \leq 1$. Hence we get a bound

$$\tilde{N} \geq \frac{3g_s}{k}\frac{M_p^2}{M_s^2} \ . \tag{3.18}$$

For a large $\frac{M_p^2}{M_s^2}$ ratio and weak string coupling the bound can be realised by taking sufficiently large enough N. But N cannot be too large as we will see below.

The next step we will calculate the amplitudes of the primordial density perturbations. These amplitudes can be expressed as

$$\delta_s = \frac{1}{\pi\sqrt{75}}\frac{1}{M_p^3}\frac{V^{3/2}}{V'}$$

$$\simeq \frac{1}{\pi\sqrt{75k}}\frac{\tilde{N}k}{g_s}\frac{M_s^3}{M_p^3}\left(\frac{\Phi^2}{kM_s^2}\right)^{3/2} \tag{3.19}$$

The cosmological bounds on the size of these perturbations are

$$\delta_s \overset{<}{\sim} 2 \times 10^{-5} \tag{3.20}$$

which is at the beginning of last 50 e-folds of inflation. If this bound has to be respected N cannot be very large in (3.19).

Let us take some reasonable data

$$k = 2, \ \frac{3g_s}{\tilde{N}k}\frac{M_p^2}{M_s^2} \sim 1, \ \frac{\Phi^2}{kM_s^2} \sim 10 \tag{3.21}$$

which gives from (3.17)

$$\epsilon \sim .002, \qquad \eta \sim -.01 \tag{3.22}$$

and from the bound (3.20) on the size of amplitudes we find that the ratio

$$\frac{M_s}{M_p} \leq 10^{-5}.$$

That is the string scale has to be around 10^{14} GeV. However, if we increase k and keeping rest the same, the string scale can get a higher value. In this later case, geometric tachyons must acquire even higher vev's before they roll down. So higher k value is not that favourable.

The bounds (3.18) and (3.20) immediately tell us

$$N \sim (2\pi)^3\frac{3g_s}{2} \times 10^{10}$$

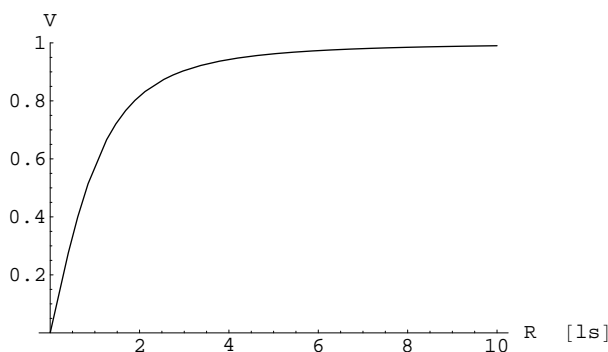which indeed constitutes a large number D3-branes for a given string coupling.

Figure 1: Plot of $V(R)$ as a function of R for $k = 2$. It has a large flat region and is suitable for eternal inflation.

4. Numerical analysis

It is imperative to study the model described earlier numerically. For this we shall like to study the model directly in terms of the field R since we know the equations exactly there while in terms of T we need to make approximations. The field equations governing the time evolution can be straight forwardly obtained

$$\ddot{R} = -\frac{h'}{2h}\dot{R}^2 - (1 - h\dot{R}^2)\left(\frac{V'}{hV} + 3H\dot{R}\right)$$

$$H^2 \equiv \frac{\dot{a}^2}{a^2} = \frac{8\pi G}{3}\frac{\tau_3 N V}{\sqrt{1 - h\dot{R}^2}} \tag{4.1}$$

where $h(R) = 1 + kl_s^2/R^2$. We shall be studying the situation where initially $R^2 \gg kl_s^2$ and R rolls down from the flat region of the potential $V(R) = 1/\sqrt{h}$, also shown in the figure 1. Note that we can also rewrite the second equation as

$$H^2 \equiv \frac{\dot{a}^2}{a^2} = \frac{M_s^2}{3k}\frac{\tilde{N}k}{g_s}\frac{M_s^2}{M_p^2}\frac{V}{\sqrt{1 - h\dot{R}^2}} \tag{4.2}$$

It is a constraint equation.

The two equations can be numerically solved given some initial conditions. We shall of course take our standard values from eq. (3.21), $k = 2$, $\frac{3g_s}{2\tilde{N}k}\frac{M_p^2}{M_s^2} \simeq 1$ as determined earlier. We take the initial values at time $t = 0$ as

$$R(0) = 4.5\,l_s, \ \dot{R}(0) = .01 \tag{4.3}$$

and the Hubble parameter as $H(0)^2 = (1/2)M_s^2$. Note that the time t is measured in the units of $1/M_s$. Now solving the equations (4.1) gives us pretty expected results. The Hubble parameter H is plotted in the figure 2. Initially it remains almost constant in time describing the slow-roll inflationary epoch. The area under the H-curve is roughly 100 which gives us an estimate of the number of e-folds of inflation. The second graph figure 3 provides the time evolution of the geometric tachyon R. Thus the initial conditions eq. (4.3)
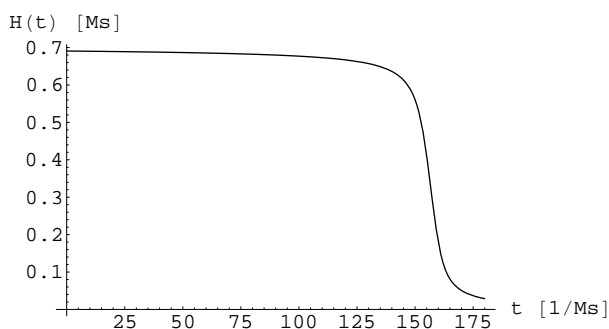
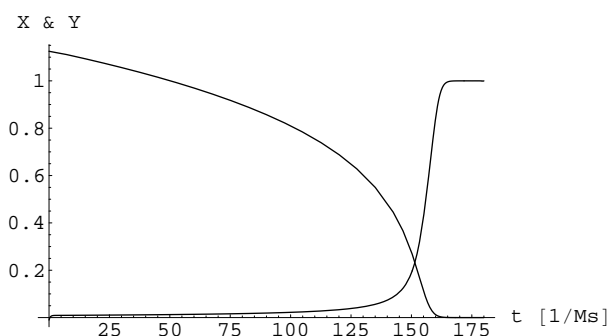**Figure 2:** Plot of $H(t)$ as a function of time. Area under the curve is roughly 100.

Figure 3: The quantities $X \equiv R/4$ and $Y \equiv |\sqrt{h}\dot{R}|$.

we have chosen do provide us sufficient e-foldings before the inflation ends. From figures 2 and 3 we find that the inflation ends where Y becomes of order 1, at the same time R becomes of the order of l_s. This describes the transition point where inflation ends and the radion matter phase takes over. This comes out exactly in the similar manner as in open-string tachyon assisted inflation [14].

5. Conclusions

We have studied in this paper assisted inflation from the motion of stable D3-branes into the NS5-branes in flat FRW cosmology. This provides us a further example of assisted inflation in string theory which involves nonperturbative objects. The slow roll parameters, when the number of D3-branes are large, has been shown to be consistent with the expectations from the scalar field theory observations. The assumption which is self imposed in our analysis is that the number of probe D3-branes is large. However, as we have demonstrated that the number of D3-branes also has to obey certain bound, which comes from the cosmological bound on the size of small perturbations. Before concluding the present analysis, we would also like mention what happens in the limit when the number of NS5-branes are too large

and when N is too small. One can express the size of the cosmological perturbation as a function of the slow roll parameter, the string scale and the Planck scale in the following manner. Using eq. (3.17) during the slow-roll, one can easily express (3.19) as

$$\delta_s = \frac{3}{\pi\sqrt{75k}}\frac{1}{|\eta|}\frac{M_s}{M_p}\sqrt{\frac{kM_s^2}{\Phi^2}}.$$

Now for a small value of $N = 1$ and for $k = 10^3 M_p^2/M_s^2$, one can show that: $\delta_s = (.11)(1/|\eta|)\sqrt{1/1000}(M_s/M_p)^2\sqrt{kM_s^2/\Phi^2}$. From the observations, we must keep $\eta \sim .01$ during the process of inflation, so $\delta_s \sim .35(M_s/M_p)^2\sqrt{kM_s^2/\Phi^2}$. Thus the amplitudes are very large unless the ratio $(M_s/M_p)^2 \sim 10^{-5}$. Which implies $k \sim 10^8$. But the problem with this large k value is that we have inherently taken $kM_s^2 > M_p^2$, the inflaton field Φ's will then be taking trans-Planckian vev's. The lesson is that we must maintain $kM_s^2 < M_p^2$. So along with eq. (3.18) we have a double bound

$$M_p^2 > kM_s^2 \geq \frac{3g_s}{\tilde{N}}M_p^2.$$

Also the ratio of two scales M_p/M_s must follow this bound. It follows that for large k one has to keep N sufficiently large, so that the amplitude of cosmological perturbations is small and the slow roll parameters could be achieved.

As it is well known that when the D-branes come very close to the NS5-brane one observes the exponential decaying behaviour of the potential. It would be interesting to show the assisted inflation with this exponential potential as well. It would further be interesting to analyze the assisted inflation with the geometric tachyon, when the NS5-branes are distributed over a ring. We would like to return to some of these issues in future.

Acknowledgments

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