Cosmic $D-$Strings as Axionic $D-$term Strings

Michele Redi (NYU)

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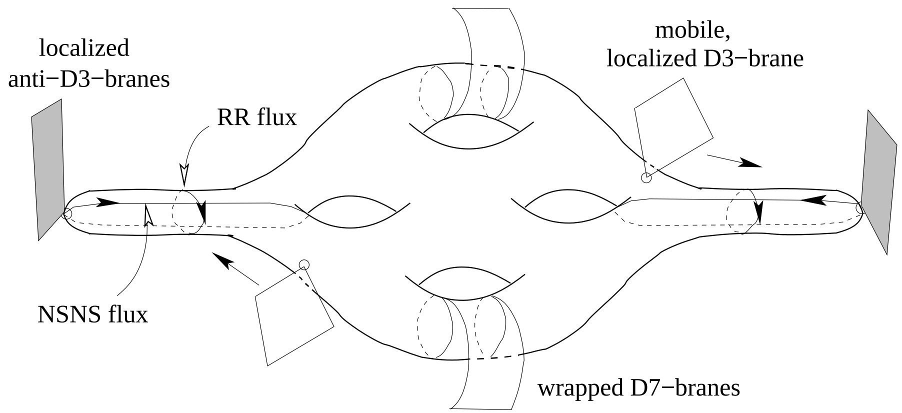
In collaboration with: J.J. Blanco-Pillado, G. Dvali

BRANE INFLATION

The most attractive model of inflation in string theory (ST) is the brane inflation scenario



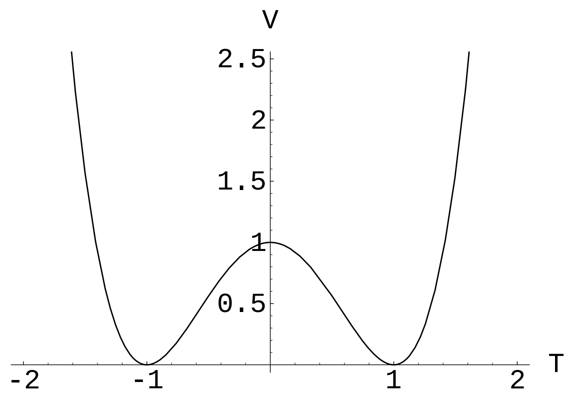
Inflation is driven by the energy density of the $D_3 - \bar{D}_3$.

A generic prediction of these models is the production of cosmic strings at the end of inflation.

When $D_3 - \bar{D}_3$ become closer than $\sqrt{\alpha'}$ the system is unstable,

$$M_T^2 = \frac{d^2}{4\pi^2\alpha'^2} - \frac{1}{2\alpha'}$$

The process of brane annihilation is described by Sen's tachyon condensation,



At the bottom of the potential the supersymmetric closed string vacuum is restored. The height of the potential is $2T_3$.

COSMIC STRINGS

The $D-\bar{D}$ pair has gauge symmetry,

$$U(1)\otimes U(1)$$

The tachyon T is a complex field charged under $U(1)_{diag}$,

$$D_\mu T=(\partial_\mu - iA^1_\mu + iA^2_\mu)T$$

The vacuum manifold is a circle $\pi_1(M)=Z$. As in the Abelian Higgs model, there exist magnetic flux vortexes. These strings will be produced by the rolling tachyon.

These strings are in fact $D-$strings.

$D-$strings are charged under a $2-$form Ramond-Ramond (RR) field C_2. In the $D_3 - \bar{D}_3$ effective action

$$S_{WZ} = \sum_{i=1,2} \int_{3+1} C \wedge e^{F_i} = \int_{3+1} C_2 \wedge (F^1 - F^2)$$

A magnetic flux vortex living on the $D_3 - \bar{D}_3$ is a source for the RR field C_2. The quantization of the magnetic flux reproduces the correct $D-$string charge.

$D-$strings are magnetic flux vortexes of the broken $U(1)$ on a $D_3 - \bar{D}_3$ pair.

We want to find a *practical* field theory model that mimics the features of the $D-$strings. Basic features:

- The strings are solitonic magnetic flux tubes of a broken $U(1)$ gauge symmetry.

- The strings should be coupled to a 2-form C_2. In $4D$ C_2 is dual to an axion so the strings will be axionic,

$$(dC_2)^2 + F \wedge C_2 \longrightarrow (da - A)^2$$

- $D-$strings in $10D$ are BPS objects. We look for BPS strings in $4D$ $N = 1$ SUSY (and SUGRA).

MODEL

We are led to,

$$L = \int d^4\theta \left[\Phi^\dagger e^{-qV}\Phi + K(S+\bar{S}+4\delta V) + 2\xi V\right] + \int d^2\theta\, \frac{1}{4} f(S) W^\alpha W_\alpha + h.c.$$

Φ is the chiral field whose lowest component is the tachyon. S is the axion-dilaton multiplet, $S = s_R + ia$.

We have included a constant Fayet-Iliopolous (FI) term. This represents the $D - \bar{D}$ energy.

We do not include superpotentials because all the $F-$terms have to be zero for the string to be BPS.

We will consider,

$$K = -M_P^2 \log[S + \bar{S}] \qquad\qquad f(S) = \frac{1}{g^2}$$

The bosonic action becomes,

$$\begin{aligned} L &= -|D_\mu \phi|^2 - K_{S\bar{S}}|D_\mu S|^2 - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{g^2}{2}D^2 \\ D &= \left(\frac{\delta\, M_P^2}{s_R} + q\,|\phi|^2 - \xi\right) \end{aligned}$$

with covariant derivatives,

$$\begin{aligned} D_\mu \phi &= (\partial_\mu - iqA_\mu)\phi \\ D_\mu S &= \partial_\mu S + 2i\delta A_\mu . \end{aligned}$$

STRING SOLUTIONS

The energy can be organized in the Bogomol'nyi form,

$$\begin{aligned} E &= \int d^3x|(D_x \pm iD_y)\phi|^2 + K_{S\bar{S}}|(D_x \pm iD_y)S|^2 + \frac{1}{2}(F_{xy} \pm D)^2 \\ &\pm \xi \int d^3x F_{xy}. \end{aligned}$$

The energy is minimum when the Bogomol'nyi equation are satisfied,

$$(D_x \pm iD_y)\phi = 0 \qquad (D_x \pm iD_y)S = 0 \qquad F_{xy} \pm D = 0$$

The tension is

$$T_1 = \pm\xi \int d^2x\, F_{xy}$$

Since the tension is proportional to ξ the Bogomol'nyi equations can only be solved for $\xi \neq 0$.

The SUSY transformations on the fermions are,

$$\begin{aligned} \delta_\epsilon \psi_i &= i\sqrt{2}\sigma^\mu \bar{\epsilon} D_\mu \phi_i \\ \delta_\epsilon \chi &= i\sqrt{2}\sigma^\mu \bar{\epsilon} D_\mu S \\ \delta_\epsilon \lambda &= \sigma^{\mu\nu} \epsilon F_{\mu\nu} + i\epsilon D \end{aligned}$$

The strings are BPS states preserving half of the supersymmetries.

$F-$term strings break all the supersymmetries. For example only $D-$terms can compensate the magnetic flux in the gaugino variation.

Let's now solve the BPS equations. At ∞ the fields approach the vacuum,

$$\frac{\delta\, M_P^2}{s_R} + q\,|\phi|^2 = \xi$$

Two basic types of solutions:

- $\phi-$strings (tachyon vortices):

$$\phi \to \sqrt{\xi}e^{in\theta}, \qquad s_R \to \infty$$

- $s-$strings (axion vortices):

$$\phi \to 0, \qquad S \to \frac{\delta M_P^2}{\xi} - 2i\delta m\theta$$

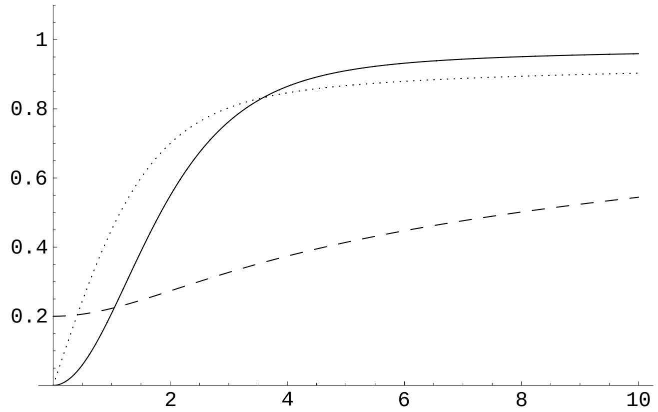
- ϕ-strings

Ansatz:

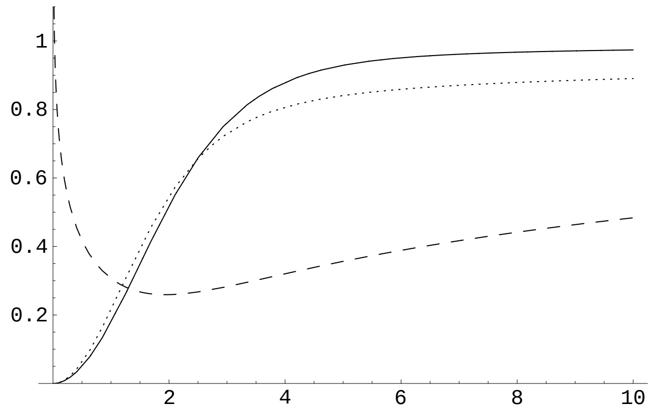
$$\begin{aligned} \phi &= f(r)e^{in\theta} \\ S &= s_R(r) - 2i\delta m\theta \\ A_\theta &= n\frac{v(r)}{r} \end{aligned}$$

BPS equations become,

$$\begin{aligned} f' &= |n|\frac{1-qv}{r}f \\ s_R' &= -2\,\delta\,\frac{|m|-|n|v}{r} \\ |n|\frac{v'}{r} &= g^2\left(\xi - \frac{\delta}{s_R} - qf^2\right) \end{aligned}$$



$$n = 1, \;\; m = 0$$



$$n = 2, \;\; m = 1$$

The tension of the $\phi-$strings is,

$$T_1 = \pm\xi \int d^2x F_{xy} = \oint A_\mu \, dx^\mu = \frac{2\pi|n|\xi}{q}$$

Solutions exist only for,

$$|n| > q|m|$$

Asymptotically,

$$\begin{aligned} f &= \sqrt{\frac{\xi}{q}} - \frac{\sqrt{q}}{4\sqrt{\xi}(|n| - q|m|)} \frac{1}{\log r} + \ldots \\ v &= \frac{1}{q} - \frac{1}{4|n|\xi} \frac{1}{(|n| - q|m|)} \frac{1}{(\log r)^2} + \ldots \end{aligned}$$

very different from AH strings...

- $s-$strings

The FI energy is compensated by the dilaton. The gauge field cancels the axion phase,

$$\begin{aligned} f' &= \frac{|n| - q|m|v}{r} f \\ s'_R &= -2\,\delta\,|m|\frac{1-v}{r} \\ |m|\frac{v'}{r} &= g^2\left(\xi - \frac{\delta}{s_R} - q f^2\right) \end{aligned}$$

The tension is,

$$T_1 = \int F_{xy} = 2\pi|m|\xi \qquad\qquad |n| < q|m|$$

We have found *finite energy* BPS strings coupled to an axion. How is this possible?

$$\int r dr d\theta \frac{1}{r^2}\left[|\phi|^2(\partial_\theta\Theta - qA_\theta)^2 + \frac{1}{s_R^2}(\partial_\theta a + 2\delta A_\theta)^2\right]$$

The variation of the dilaton screens the axion charge for the $\phi-$strings while for the $s-$strings $\phi \to 0$ cancels the tachyon winding. The strings are effectively semilocal strings.

The RR charge,

$$Q_{RR} = \oint \star dC_2 = \oint \frac{da - 2\delta A}{s_R}$$

always goes to zero at large distances. It is not zero at finite distances.

In the ST picture the FI term represents the energy of $D_3 - \bar{D}_3$,

$$2T_3 = \frac{g^2}{2}\xi^2$$

The ϕ-strings are magnetic flux tubes created by the winding of the tachyon. We interpret them as $D-$strings of ST. The tension implies the correct scaling,

$$q^2 g^2 = 8\pi g_S \qquad (1)$$

The RR charge as measured from the zero mode of the two form is zero. This is because $s \to \infty$ corresponds to decompactification of space (or zero coupling).

The $s-$strings are the strings obtained by breaking the $U(1)$ by compactification.

SUMMARY

- We considered an effective action that mimics the basic features of tachyon condensation in strings theory. The model is a supersymmetric AH model coupled to an axion multiplet.

- We found new BPS smooth string solutions coupled to an axion field. These can only exist in the presence of a constant FI term.

- For the $\phi-$strings the tachyon winds and the energy is compensated by the tachyon field. This fits the picture of $D-$strings as magnetic flux tubes. We also found $s-$strings supported by the axion winding.

- Our strings differ in interesting way from the AH model strings and it would be interesting to understand their phenomenology.