

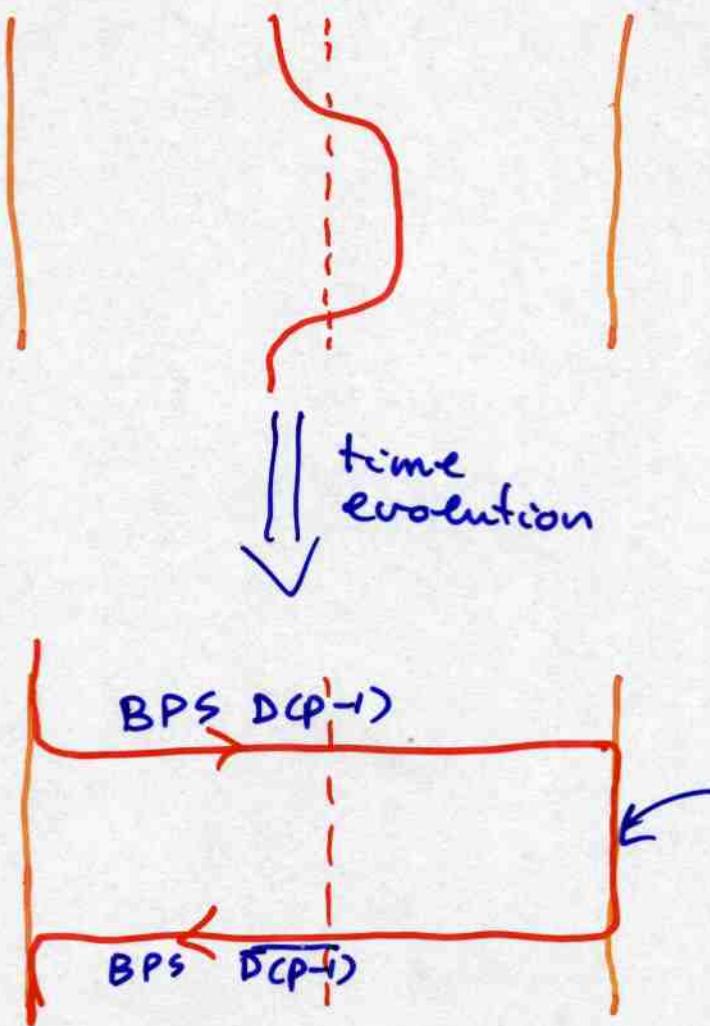
Fun with tachyons

D.K. hep-th/0405058, hep-th/0408073

Rough plan

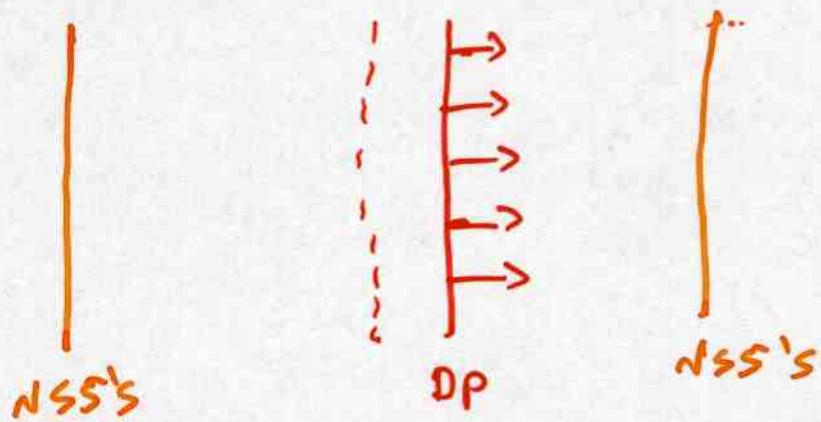
- Some properties of non-BPS D-branes.
- Open questions / puzzles.
- D-branes near Neveu-Schwarz fivebranes, and their striking analogy to (non) BPS D-branes in 10d string theory.
- Resolution of puzzles in the D/NS system.

In homogeneous tachyon condensation to lower dimensional D-branes:



segments where the D-brane is bound to the fivebranes are like no D-brane at all

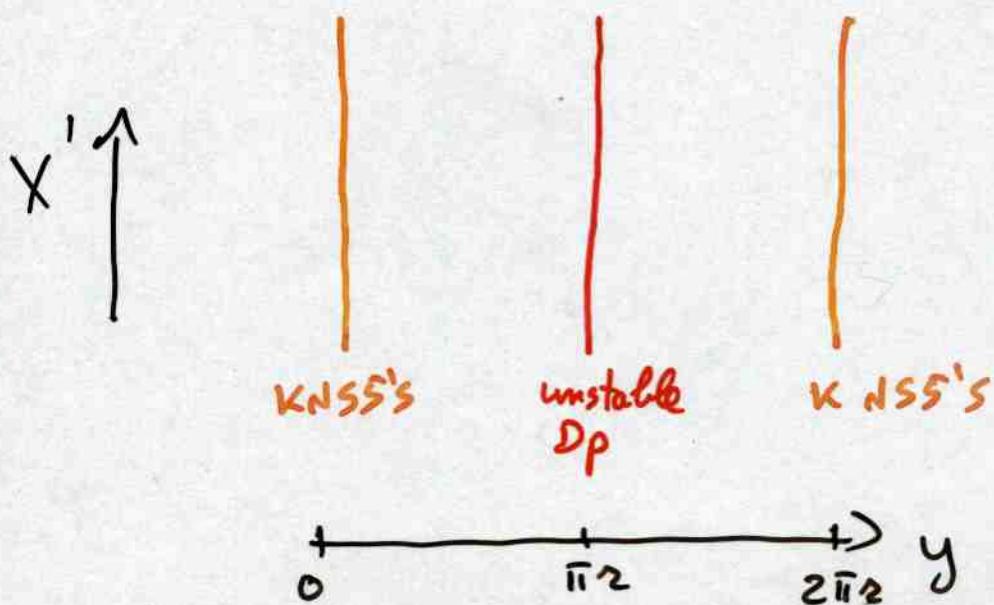
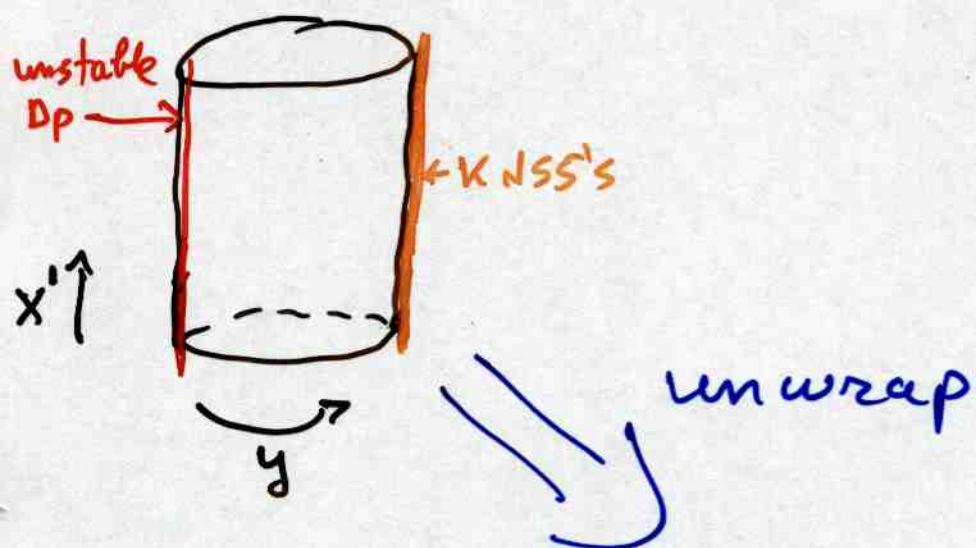
Homogeneous tachyon condensation



Classically, D_p-brane will oscillate about fivebranes. Taking into account energy loss to radiation, will form a bound state with fivebranes.

Binding energy known to be $\approx 100\%$, so D_p-brane loses all its energy to radiation (confirmed by exact CFT analysis).

Geometric interpretation of tachyon condensation:



$$y \sim y + 2\pi/2$$

What about the Wess-Zumino term
in tachyon DBI action?

Since in ten dimensions our D-brane
is BPS, it couples to a RR $(p+1)$ -form
 $A^{(p+1)}$:

$$S_{WZ} = \int A^{(p+1)}$$

W = worldvolume of brane.

Take: $A^{(p+1)} = C^{(p)} \wedge dy$

\uparrow

p-form in six dimensions
that couples to Dp-brane
wrapped around y-circle
(which looks like a $(p-1)$ -brane in 6d)

This gives:

$$S_{WZ} \stackrel{?}{=} \int C^{(p)} \wedge dy \stackrel{?}{=} \int C^{(p)} \wedge dT \frac{\tilde{\tau}_p^{(\text{non-BPS})}}{\cosh \frac{T}{\sqrt{\kappa}}}$$

Again, for $\kappa=2$ get exactly tachyon WZ
result. Overall coeff. determined by relation

Action for y can be rewritten in a way analogous to tachyon DBI:

Redefine $y \rightarrow T$, such that

$$\frac{dT}{dy} = \sqrt{h} = \frac{\sqrt{\kappa}}{2r \sin \frac{y}{2r}}$$

or: $\sinh \frac{T}{\sqrt{\kappa}} = -\cot \frac{y}{2r}$

Then, Lagrangian for y takes form:

$$L = -\tau_p^{(\text{non-BPS})} \frac{1}{\cosh \frac{T}{\sqrt{\kappa}}} \sqrt{-\det G_{\mu\nu}}$$

$$G_{\mu\nu} = \eta_{\mu\nu} + \partial_\mu T \partial_\nu T + \partial_\mu X^I \partial_\nu X^I$$

For $\kappa=2$, it is precisely the tachyon DBI
Of course, T , or y , is manifestly a
geometric coordinate - location on S' .

Thus, we find a descent relation between the tensions of BPS and non-BPS branes:

$$\tau_{p-1}^{(BPS)} = \pi \sqrt{\kappa} \tau_p^{(\text{non-BPS})}$$

For $\kappa=2$ (two fivebranes), this is precisely the brane-descent relation found for BPS & non-BPS D-branes in ten dimensions.

Here, its origin is clear: Both BPS and non-BPS branes are the same type of object in higher dimnl theory. They differ only in way they wrap extra dimns.

Dynamics of D-brane is described by DBI action in fivebrane background.
 The dependence on y is:

$$S_p = -T_p \int d^{P+1}x \frac{1}{\sqrt{h(y)}} \sqrt{1 + h(y) g_{\mu\nu} y^\mu y^\nu}$$

$y=0$: location of NS5's.

$y=\pi/2$: unstable D-brane.

$$(h(y) = \frac{\kappa}{4r^2 \sin^2 \frac{y}{2r}})$$

Tension of unstable D-brane:

$$\tau_p = T_p \frac{1}{\sqrt{h(y=\pi/2)}} = \frac{2 T_p r}{\sqrt{\kappa}}$$

Compare to tension of D-brane wrapped on S (which is BPS): $\tau_{p-1} = \frac{2\pi R \cdot T_p}{g_s} = 2\pi r T_p$

Focus on dynamics of γ :

D-brane lives in the gravitational background of the fivebranes:

$$ds^2 = \overbrace{dx_\mu dx^\mu}^{B^{S,1}} + H(\vec{z}, \gamma)(d\vec{z}^2 + dy^2)$$

$$H(\vec{z}, \gamma) = 1 + \kappa \sum_{n \in \mathbb{Z}} \frac{1}{(\gamma - 2\pi R n)^2 + \vec{z}^2}$$

Near-horizon limit:

$$(\gamma, \vec{z}, R) = g_s(y, z, r)$$

and $g_s \rightarrow 0$

Also, set $\vec{z} = 0$, since only interested in y

$$ds^2 = dx_\mu dx^\mu + h(y) dy^2$$

$$h(y) = \frac{\kappa}{4r^2 \sin^2 \frac{y}{2r}}$$

* Ten dimensional IIB , and on IIA
fivebranes: chiral SUSY, odd dim n
BPS D-branes; even dim n non-BPS.

Advantage of fivebranes is that
the six dimensions along fivebranes
are not all there is. As we will
see, ten-dimensional viewpoint is
very useful for unravelling physics.

In IIB string theory:

- * fivebranes preserve non-chiral, $(1,1)$ susy
- * BPS D-branes in $6d$ are Dp 's with p odd, wrapped on $S^1 \Rightarrow$ even dimensional.
- * non-BPS D-branes in $6d$ are Dp 's with p odd at a point on $S^1 \Rightarrow$ odd dims.

The situation is very similar to that in $10d$ critical string:

- * In ten dimensional IIA theory, as well as on a IIB fivebrane: non-chiral susy, even dimensional BPS D-branes; odd dimensional non-BPS ones.

Resulting pattern of (non-) BPS branes
in IIA string theory:

NSS-branes preserve chiral $(2,0)$
susy (= two complex supercharges
in 4 of $\text{spin}(5,1)$)

* BPS D-branes:

D_p 's with p even, wrapped on S^1 .

In six dimensions they look like

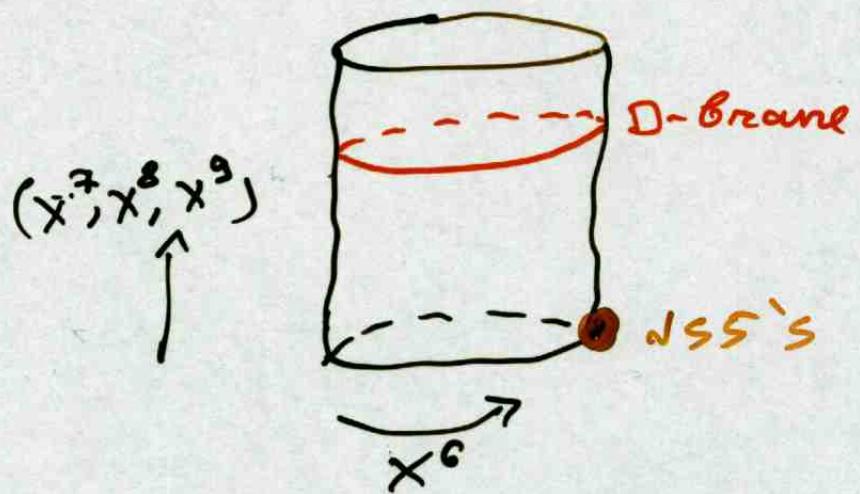
$D_{(p-1)}$ -branes, i.e. have odd dimensions

* Non-BPS D-branes:

D_p 's with p even, localized on $R^3 \times S^1$.

Give even dimensional non-BPS branes.

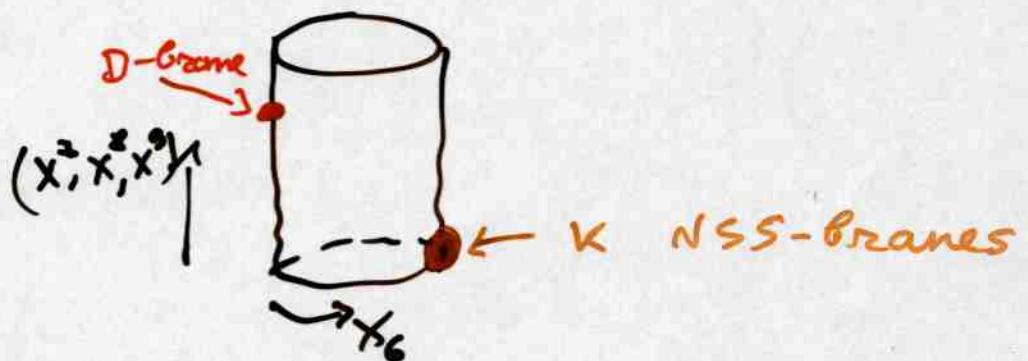
(2) Branes wrapped around circle
and localized on R^3 .



These D-Branes preserve $\frac{1}{2}$ of the 16 supercharges preserved by the fivebranes. They are $\frac{1}{2}$ -BPS.

Focus on D-branes that without fivebranes are BPS. They give two types of finite tension branes in six dim:

(1) Branes localized on $S^1 \times R^3$:



These branes are non-BPS in the presence of fivebranes:

D-branes and fivebranes break incompatible halves of susy.

Nice feature of this system is that although we are interested in six dim. physics seen by an observer living on fivebranes, can take a higher (9+1) dim. perspective.

In particular, what are finite tension D-branes in six dimensions from ten dimensional point of view?

Neveu-Schwarz (NS) fivebranes are magnetic duals of fundamental strings, i.e. they are magnetically charged under the NS $B_{\mu\nu}$ field.

It is known that the worldvolume theory on NS5-branes bears many resemblances to ordinary string theory. In fact, it is usually referred to as "Little String Theory"

We will construct the analog of non-BPS D-branes in fivebrane theory, and study their properties.

In the rest of this talk, I will describe a system that bears remarkable similarity to that described above, but allows one to answer all the questions we raised.

This system provides an excellent laboratory for studying time-dependent processes and tachyon condensation, and is of interest in its own right.

(2) Why does tachyon DBI take form it does?

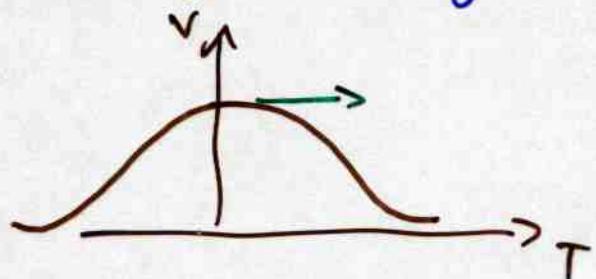
In particular, induced metric $G_{\mu\nu}$ looks as if T is an extra dimension of space. Is it?

(3) General questions:

- what is the relation between BPS and non-BPS branes?
- what fixes tension of non-BPS D-brane?
- Is there a geometric interpretation of tachyon condensation?

Some questions about non-BPS branes

(1) Rolling tachyon solution



$$\left(\sinh \frac{I}{\sqrt{2}} = \rightarrow e^{\frac{I}{2}x^0} \right)$$

Thus, it seems that $T=\infty$ (the minimum of the potential) is achieved only at $t=\infty$. But, an observer on the non-BPS D-brane sees induced (or "open string") metric, $G_{\mu\nu}$, in particular $G_{00} = -1 + \dot{T}^2$

In this metric, D-brane gets to $T=\infty$ at a finite time. What happens next?

Examples of successes of tachyon DBI action

- (1) S_p gives the correct stress-tensor $T_{\mu\nu}(t)$ for half S-brane.
- (2) correct mass of tachyon, tension of lower dimensional D-branes viewed as solitons.
- (3) S_p summarizes information about an infinite number of Veneziano amplitudes for tachyons in a particular kinematic regime.
⋮

The origin of the utility of the action S_p is understood: it is due to the existence of half S-brane solution.

* Dynamics of tachyon is well described (on-shell) by Dirac-Born-Infeld-like Lagrangian:

$$(d=1) \quad S_p = -\tau_p \int d^{p+1}x \frac{1}{\cosh \frac{T}{\sqrt{2}}} \sqrt{-\det G} + \tau_p \int \frac{dT \wedge C_p}{\sqrt{2} i \cosh \frac{T}{\sqrt{2}}}$$

where: τ_p = tension of non-BPS D_p-brane.

C_p = RR p-form gauge field which couples to BPS D(p-1)-branes.

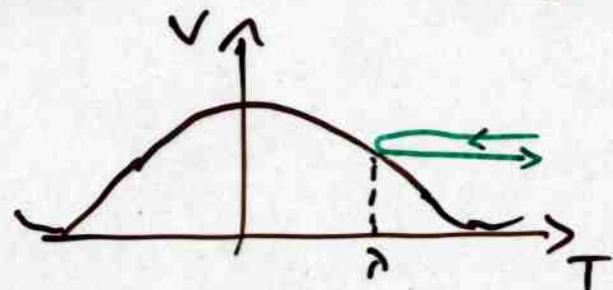
$$G_{\mu\nu} = \eta_{\mu\nu} + \partial_\mu T \partial_\nu T + \partial_\mu X^I \partial_\nu X^I$$

↑ ↓
transverse
directions
to D_p-brane.

The second ($dT \wedge C_p$) term in S is a Wess-Zumino term that ensures that the ~~wink~~ on D_p-brane couples correctly to C_p .

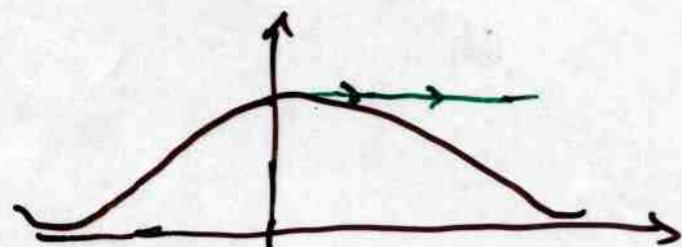
* Rolling tachyon solution:

The worldsheet CFT corresponding to
 $T(x^0) = \lambda \cosh \frac{x_0}{\sqrt{2}}$ or $T(x^0) = \lambda e^{\frac{x^0}{\sqrt{2}}}$ is
 exactly solvable. These solutions correspond to tachyon rolling as :



(full S-brane)

or:



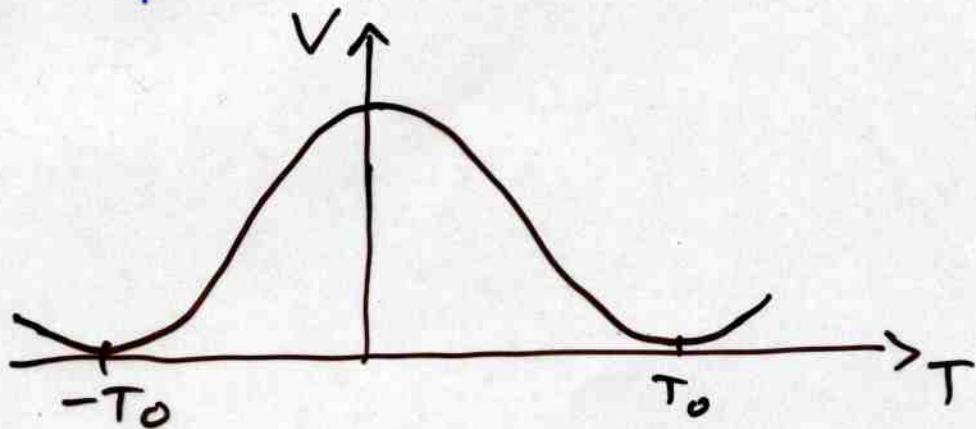
(half S-brane)

Using these solutions, one can study late time behavior of decaying D-brane ("tachyon matter"), closed string emission during D-brane decay, etc.

Some properties of non-BPS D-branes

* Real tachyon T , with mass $\omega^2 = -\frac{1}{2}$.

Tachyon potential :



- $V(T) = V(-T)$
- $T=0 \Leftrightarrow$ original brane.
- $T=\pm T_0 \Leftrightarrow$ vacuum with no brane.

Thus, tachyon condensation \Leftrightarrow ^{Disappearance} of D-brane

- kink solution, $T=T(x)$ with $T(x \rightarrow \pm \infty) = \pm T_0$, corresponds to a BPS $D(p-1)$ -brane, viewed as a soliton on non-BPS D-brane.

Non-BPS D-branes in type II string theory

* Pattern of branes:

IIA: BPS D p -branes with $p \in 2\mathbb{Z}$

non-BPS D p -branes with $p \in 2\mathbb{Z} + 1$

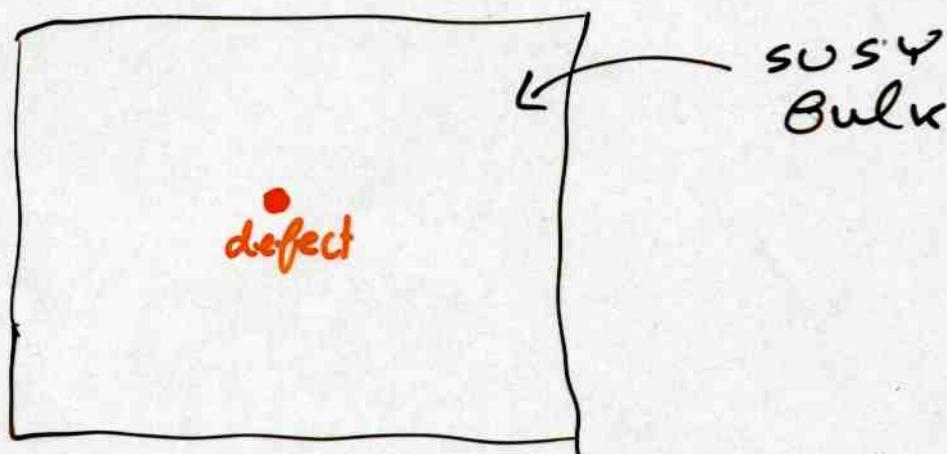
IIB: BPS D p -branes with $p \in 2\mathbb{Z} + 1$

non-BPS D p -branes with $p \in 2\mathbb{Z}$

BPS D-branes preserve 16 of 32 supercharges of type II theory.

non-BPS branes break all of them.

Situation is better, when SUSY is broken on a defect:



Two types of defects have been analyzed:

- (1) orbifold hyperplanes.
- (2) non-BPS D-branes.

In these cases, it's possible to understand in some detail the process of tachyon condensation on the defect. Today, we will focus on (2) - non-BPS D-branes.

It is believed that string propagation on a background that breaks SUSY is a hard problem, because it is not a useful starting point for a weak coupling expansion.

For example, the bosonic string in 26 dimensions has a tachyon with mass $\alpha' M^2 = -4$. Condensation of this tachyon takes theory from $25+1$ to $1+1$ dimensions, and in the process, the string coupling develops a space time dependence. This is a very violent process, whose details are not well understood.

One of the most important frontiers
of research in string theory is
broken SUSY and time-dependence.

Much was learnt in last ten years
about SUSY backgrounds. There were
many surprises: extra dimension of
M-theory, D-branes as point-like probes,
strong-weak coupling dualities, etc.

There are reasons to believe that
many additional surprises await us
in non-SUSY, time-dependent situations.

Comments

- * The late stages of homogeneous decay are described by exact boundary state (analytic continuation of "hairpin brane", $e^{-\frac{\phi}{\sqrt{\kappa}}} = \frac{\epsilon_0}{E} \cosh \frac{t}{\sqrt{\kappa}}$)
- * We have seen that the exact tachyon DBI action (including WZ term) is reproduced by D-brane dynamics near two fivebranes. Does this imply that the tachyon on non-BPS D-branes in 10d probes extra dimensions of string theory? Is the tachyon direction periodic?