Black branes and bubbles as intersecting non-SUSY branes

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Some Related Works (Static solutions):

1. B. Zhou and C. J. Zhu, ``The complete black brane solutions in D-dimensional coupled gravity system'', hep-th/9905146.

2. P. Brax, G. Mandal and Y. Oz, ``Supergravity description of non-BPS branes'', PRD 63 (2001) 064008, hep-th/0005242.

3. J. X. Lu and SR, ``Static, non-susy p-branes in diverse dimensions'', JHEP 02 (2005) 001, hep-th/0408242.

4. J. X. Lu and SR, ``Supergravity approach to tachyon condensation on the brane-antibrane system'', PLB 599 (2004) 313, hep-th/0403147.

5. J.X. Lu and SR, ``Delocalized non-susy p-branes, tachyon condensation and tachyon matter'', JHEP 11 (2004) 008, hep-th/0409019.

6. J. X. Lu and SR, ``Non-susy p-branes delocalized in two directions, tachyon condensation and T-duality'', JHEP 06 (2005) 026, hep-th/0503007.

7. J. X. Lu and SR, ``Fundamental strings and NS5-branes from unstable D-branes in supergravity'', PLB 637 (2006) 326, hep-th/0508045.

8. H. Bai, J. X. Lu and SR, ``Tachyon condensation on the intersecting brane-antibrane system'', JHEP 08 (2005) 068, hep-th/0506115.

9. J. X. Lu and SR, ``Non-susy p-branes, bubbles and tubular branes'', hep-th/0604048 (to appear in NPB).

10. H. Bai, J. X. Lu and SR, ``Intersecting non-susy p-brane with chargeless 0-brane as black p-brane'', hep-th/0610264.

Non-susy branes in the form of time-dependent solutions are given in:

1. S. Bhattacharya and SR, ``Time dependent supergravity solutions in arbitrary dimensions'', JHEP 12 (2003) 015, hep-th/0309202.

2. H. Singh, and SR, ``Space-like branes, accelerating cosmologies and the near horizon limit'', JHEP 08 (2006) 024, hep-th/0606041.

Organization:

1. Introduction and Motivation
2. Non-supersymmetric branes
3. Comparison with BPS branes
4. Intersecting non-supersymmetric branes
5. Intersecting non-susy branes as black branes and bubbles
6. Conclusion

1. Introduction and Motivation:

The success of string theory lies on its relation to the real world.

- How `standard model' of particle interactions can be obtained from string theory?

- How the various issues of quantum gravity (like unitarity and information loss in black holes, microscopic entropy calculation, singularities etc.) can be understood from string theory?

- How the cosmological observations (like inflation, de Sitter space, small +ve cosmological constant etc.) can be obtained from string theory?

There are various ways one can address these questions. We think non-supersymmetric *p*-branes of string theory may also help us to address these issues.

How?

- Remember how AdS/CFT correspondence was obtained.

Here one looks at the N-coincident BPS D3-brane solution of type IIB string theory and takes a low energy limit $\alpha' \to 0$ alongwith $N \to \infty$. This also means that one is going to the near horizon $(r \to 0)$ region of D3-branes. The geometry in this limit looks like $\mathrm{AdS}_5 \times \mathrm{S}^5$.

This is the closed string description.

The correspondence says that this theory is equivalent to the theory consisting of the open string modes living on the boundary of AdS_5 which is D = 4, $\mathcal{N} = 4$ supersymmetric SU(N) gauge theory.

This is the open string description

Note that the gauge theory we got is supersymmetric and conformal. The reason is we started with BPS branes

In order to get QCD-like gauge theory which is both non-supersymmetric and non-conformal from string theory, we must break susy and start from non-susy branes of string theory.

- Also regarding the issues mentioned for black holes, partial success has been achieved for supersymmetric as well as for some non-supersymmetric, extremal black holes. Here also one starts from BPS brane configuration of string theory. However, to understand the issues for Schwarzschild-like black holes non-susy branes could be useful.

- Finally, there is another class of non-susy branes in string theory and those are the time-dependent branes called the S-branes. Since time-translation invariance is lost, there is no energy or mass conservation. Supersymmetry is broken. These solutions can be used to understand various cosmological scenarios. Space-time singularities (like black hole or cosmolgical) may be understood from these solutions.

2. Non-supersymmetric branes

In order to construct the non-supersymmetric branes we start with the bosonic sector of the standard string effective action given below:

$$\mathrm{S} = (2\kappa_0^2)^{-1} \int d^{10}x \sqrt{-g} \left[R - \frac{1}{2}\partial_\mu \phi \partial^\mu \phi - \frac{1}{2\cdot(8-p)!} e^{a\phi} F_{[8-p]}^2 \right]$$

We use the magnetically charged *p*- brane metric ansatz with isometry $\mathrm{ISO}(1,p) \times \mathrm{SO}(9-p)$ with an explicit supersymmetry breaking and solve the following equations of motion

$$\mathrm{R}_{\mu\nu} - \frac{1}{2}\partial_\mu \phi \partial_\nu \phi - \frac{e^{a\phi}}{2(7-p)!} \left[F_{\mu\alpha_2\ldots\alpha_{8-p}} F_\nu{}^{\alpha_2\ldots\alpha_{8-p}} - \frac{7-p}{8(8-p)} F_{[8-p]}^2 g_{\mu\nu} \right] = 0$$

$$\partial_\mu \left(\sqrt{-g} e^{a\phi} F^{\mu\alpha_2\ldots\alpha_{8-p}} \right) = 0$$

$$(\sqrt{-g})^{-1} \partial_\mu \left(\sqrt{-g} \partial^\mu \phi \right) - \frac{a}{2\cdot(8-p)!} e^{a\phi} F_{[8-p]}^2 = 0$$

and the solution we get has the following form:

$$
\begin{aligned}
ds^2 &= F^{-\frac{7-p}{8}}\left(-dt^2+\sum_{i=1}^{p}(dx^i)^2\right)+F^{\frac{p+1}{8}}\left(H\tilde{H}\right)^{\frac{2}{7-p}}\left(dr^2+r^2d\Omega_{8-p}^2\right)\\
e^{2\phi} &= F^{-a}\left(\frac{H}{\tilde{H}}\right)^{2\delta}\\
F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

where the various functions in the above are defined as

$$
\begin{aligned}
F &= \left(\frac{H}{\tilde{H}}\right)^{\alpha}\cosh^2\theta-\left(\frac{\tilde{H}}{H}\right)^{\beta}\sinh^2\theta\\
H &= 1+\frac{\omega^{7-p}}{r^{7-p}}\\
\tilde{H} &= 1-\frac{\omega^{7-p}}{r^{7-p}}
\end{aligned}
$$

Here $\alpha, \beta, \theta, \delta, \omega$ are integration constants and b is the charge parameter. Note that the metric has isometry $\mathrm{ISO}(1,p)\times\mathrm{SO}(9-p)$. Also the dilaton coupling $a = (p - 3)/2$ for RR branes and $(3 - p)/2$ for NSNS branes.

Note that among the parameters $\alpha, \beta, \theta, \delta, \omega$ and b not all are independent.

From the consistency of the EOM we find three relations among them given by,

$$\alpha - \beta = a\delta$$
$$\frac{1}{2}\delta^2 + \frac{1}{2}\alpha(\alpha - a\delta) = \frac{8-p}{7-p}$$
$$b = (7-p)(\alpha + \beta)\omega^{7-p}\sinh 2\theta$$

Using these we can eliminate three constants and so, the non-susy *p*-branes contain three independent parameters δ, θ, ω (say). Since these solutions involve harmonic function $\tilde{H} = 1 - \omega^{7-p}/r^{7-p}$ they have a potential singularity at $r = \omega$. The solution is well defined only for $r > \omega$.

Note here that the uniqueness theorem does not apply for these kind of singular solutions and so, they can be characterized by more than two (corresponding to mass and charge) parameters.

Note that since all the functions defined below,

$$
\begin{aligned}
F &= \left(\frac{H}{\tilde{H}}\right)^{\alpha} \cosh^2\theta - \left(\frac{\tilde{H}}{H}\right)^{\beta} \sinh^2\theta \\
H &= 1 + \frac{\omega^{7-p}}{r^{7-p}} \\
\tilde{H} &= 1 - \frac{\omega^{7-p}}{r^{7-p}}
\end{aligned}
$$

approaches unity asymptotically as $r \rightarrow \infty$ so, the solution

$$
\begin{aligned}
ds^2 &= F^{-\frac{7-p}{8}} \left(-dt^2 + \sum_{i=1}^{p}(dx^i)^2\right) + F^{\frac{p+1}{8}} \left(H\tilde{H}\right)^{\frac{2}{7-p}} \left(dr^2 + r^2 d\Omega_{8-p}^2\right) \\
e^{2\phi} &= F^{-a} \left(\frac{H}{\tilde{H}}\right)^{2\delta} \\
F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

is asymptotically flat.

Also if we look at the metric

$$ds^2 = F^{-\frac{7-p}{8}}\left(-dt^2 + \sum_{i=1}^{p}(dx^i)^2\right) + F^{\frac{p+1}{8}}\left(H\tilde{H}\right)^{\frac{2}{7-p}}\left(dr^2 + r^2 d\Omega_{8-p}^2\right)$$

we note that the metric functions associated with ISO*(1, p)* and the SO*(9 – p)* parts satisfy

$$(p+1)\ln F^{-\frac{7-p}{8}} + (7-p)\ln\left(F^{\frac{p+1}{8}}\left(H\tilde{H}\right)^{\frac{2}{7-p}}\right) = \ln(H\tilde{H}) \neq 0$$

Since the right hand side is non-vanishing, it implies that the solution is indeed non-supersymmetric. We will later compare this solution with the BPS *p*-brane solution.

We would like to point out that the non-susy *p*-brane solutions we have written is given in isotropic coordinate and is expresed in terms of two harmonic functions H and $\tilde{H}$. However, we can express the solution also in terms of a single harmonic function if we write the solution in Schwarzschild-like coordinate as follows, Let us make a coordinate transformation,

$$r = \rho \left(\frac{1+\sqrt{f}}{2} \right)^{\frac{2}{7-p}}$$

Where we have defined, $f = 1 - \frac{4\omega^{7-p}}{\rho^{7-p}} \equiv 1 - \frac{\rho_0^{7-p}}{\rho^{7-p}}$

The above implies,

$$H = \frac{2}{1+\sqrt{f}}$$

$$\tilde{H} = \frac{2\sqrt{f}}{1+\sqrt{f}}$$

So, from here we get,

$$\frac{H}{\tilde{H}} = f^{-\frac{1}{2}}$$

$$H\tilde{H} = \left(\frac{2}{1+\sqrt{f}} \right)^2 \sqrt{f}$$

$$dr = \frac{1}{\sqrt{f}} \left(\frac{1+\sqrt{f}}{2} \right)^{\frac{2}{7-p}} d\rho$$

Using the three relations we can express the non-susy p-brane solution

$$
\begin{aligned}
ds^2 &= F^{-\frac{7-p}{8}} \left(-dt^2 + \sum_{i=1}^{p} (dx^i)^2\right) + F^{\frac{p+1}{8}} \left(H\tilde{H}\right)^{\frac{2}{7-p}} \left(dr^2 + r^2 d\Omega_{8-p}^2\right) \\
e^{2\phi} &= F^{-a} \left(\frac{H}{\tilde{H}}\right)^{2\delta} \\
F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

In terms of the single harmonic function $f = 1 - \frac{4\omega^{7-p}}{\rho^{7-p}} \equiv 1 - \frac{\rho_0^{7-p}}{\rho^{7-p}}$ as follows,

$$
\begin{aligned}
ds^2 &= F^{-\frac{7-p}{8}} \left(-dt^2 + \sum_{i=1}^{p} (dx^i)^2\right) + F^{\frac{p+1}{8}} f^{\frac{1}{7-p}} \left(\frac{d\rho^2}{f} + \rho^2 d\Omega_{8-p}^2\right) \\
e^{2\phi} &= F^{-a} f^{-\delta} \\
F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

where now

$$
F(r) = \left(\frac{H}{\tilde{H}}\right)^{\alpha} \cosh^2\theta - \left(\frac{\tilde{H}}{H}\right)^{\beta} \sinh^2\theta = f^{-\frac{\alpha}{2}} \cosh^2\theta - f^{\frac{\beta}{2}} \sinh^2\theta = F(\rho)
$$

The parameter relations remain the same as before

$$\alpha - \beta = a\delta$$
$$\frac{1}{2}\delta^2 + \frac{1}{2}\alpha(\alpha - a\delta) = \frac{8-p}{7-p}$$
$$b = (7-p)(\alpha+\beta)\omega^{7-p}\sinh 2\theta$$

Note that the singularity is now at $\rho = \rho_0 \equiv 4^{1/(7-p)}\omega$

We can also shift the singularity by making another coordinate transformation $\hat{\rho}^{7-p} = \rho^{7-p} - 4\omega^{7-p}$

The solution in this case can be written in terms of the harmonic function

$g = 1 + \dfrac{4\omega^{7-p}}{\hat{\rho}^{7-p}}$ as,

$$\begin{aligned} ds^2 &= F^{-\frac{7-p}{8}}\left(-dt^2 + \sum_{i=1}^{p}(dx^i)^2\right) + F^{\frac{p+1}{8}} g^{\frac{1}{7-p}}\left(\frac{d\hat{\rho}^2}{g} + \hat{\rho}^2 d\Omega^2_{8-p}\right) \\ e^{2\phi} &= F^{-a} g^{\delta} \\ F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p}) \end{aligned}$$

Now the singularity of the non-susy p-branes appears at $\hat{\rho} = 0$ like the BPS p-brane.

Again the parameter relations remain the same as before,

$$\begin{aligned}
&\alpha - \beta = a\delta \\
&\frac{1}{2}\delta^2 + \frac{1}{2}\alpha(\alpha - a\delta) = \frac{8-p}{7-p} \\
&b = (7-p)(\alpha+\beta)\omega^{7-p}\sinh 2\theta
\end{aligned}$$

Note that the solution

$$\begin{aligned}
ds^2 &= F^{-\frac{7-p}{8}}\left(-dt^2 + \sum_{i=1}^{p}(dx^i)^2\right) + F^{\frac{p+1}{8}}\left(H\tilde{H}\right)^{\frac{2}{7-p}}\left(dr^2 + r^2 d\Omega_{8-p}^2\right) \\
e^{2\phi} &= F^{-a}\left(\frac{H}{\tilde{H}}\right)^{2\delta} \\
F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}$$

represents the magnetically charged non-susy p-brane, the corresponding electrically charged solution can be obtained by $F_{[p+2]} = e^{a\phi} * F_{[8-p]}$.

3. Comparison with BPS branes

Let us for comparison write the magnetically charged BPS *p*-brane solution of Horowitz and Strominger,

$$
\begin{aligned}
ds^2 &= \hat{H}^{-\frac{7-p}{8}}\left(-dt^2+\sum_{i=1}^{p}(dx^i)^2\right)+\hat{H}^{\frac{p+1}{8}}\left(dr^2+r^2d\Omega_{8-p}^2\right)\\
e^{2\phi} &= \hat{H}^{-a}\\
F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

where $\hat{H}=1+\frac{\hat{\omega}^{7-p}}{r^{7-p}}$ and the charge parameter b is given as

$b=\pm(7-p)\hat{\omega}^{7-p}$. Where the +, - sign refers to brane or anti-brane.

So, unlike the non-susy *p*-branes which is characterized by three parameters BPS *p*-brane is characterized by a single parameter b (or) $\hat{\omega}$.

We also note that the metric functions associated with ISO*(1, p)* and the SO*(9 – p)* parts satisfy $(p+1)\ln\left(\hat{H}^{-\frac{7-p}{8}}\right)+(7-p)\ln\left(\hat{H}^{\frac{p+1}{8}}\right)=0.$ (BPS property) unlike in the non-susy case.

Let us now write both the BPS p-brane and non-susy p-brane solutions here for better comparison,

BPS p-brane

$$\begin{aligned} ds^2 &= \hat{H}^{-\frac{7-p}{8}}\left(-dt^2+\sum_{i=1}^{p}(dx^i)^2\right)+\hat{H}^{\frac{p+1}{8}}\left(dr^2+r^2d\Omega_{8-p}^2\right) \\ e^{2\phi} &= \hat{H}^{-a} \\ F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p}) \end{aligned}$$

Non-susy p-brane

$$\begin{aligned} ds^2 &= F^{-\frac{7-p}{8}}\left(-dt^2+\sum_{i=1}^{p}(dx^i)^2\right)+F^{\frac{p+1}{8}}\left(H\tilde{H}\right)^{\frac{2}{7-p}}\left(dr^2+r^2d\Omega_{8-p}^2\right) \\ e^{2\phi} &= F^{-a}\left(\frac{H}{\tilde{H}}\right)^{2\delta} \\ F_{[8-p]} &= b\mathrm{Vol}(\Omega_{8-p}) \end{aligned}$$

So, if somehow we could send $H,\ \tilde{H}\to 1,$ and $F\to\hat{H}$ then these two will precisely match. We will see how this can be achieved.

Note that $H,\ \tilde{H} \to 1,$ if we send $\omega \to 0$ and in that case the function $F = \left(\frac{H}{\tilde{H}}\right)^{\alpha} \cosh^2\theta - \left(\frac{\tilde{H}}{H}\right)^{\beta} \sinh^2\theta$ simplifies to

$$F \to 1 + \frac{\omega^{7-p}}{r^{7-p}}\left[(\alpha+\beta)\cosh 2\theta + (\alpha-\beta)\right]$$

There are two ways one can have $\hat{H} = 1 + \frac{\hat{\omega}^{7-p}}{r^{7-p}}$ from F

1. $$\begin{aligned} \omega^{7-p} &= \epsilon\hat{\omega}^{7-p} \\ \sinh 2\theta &= \frac{1}{\epsilon(\alpha+\beta)} \end{aligned}$$

2. $$\begin{aligned} \omega^{7-p} &= \epsilon^{1/2}\hat{\omega}^{7-p} \\ \alpha+\beta &= \epsilon^{1/2} \\ \sinh 2\theta &\simeq \cosh 2\theta = \epsilon^{-1} \end{aligned}$$

Note here that ϵ is a dimensionless parameter $\epsilon \to 0$ and $\hat{\omega}$ = finite.

Note also that in case 1, $\alpha+\beta$ remains finite. It can be checked from the parameter relation that $\alpha,\ \beta$ can never be infinity.

So, in order to recover supersymmetry we always have $\omega \to 0$ and $\theta \to \infty$
We will keep this in mind.

Now let us compare here the BPS and non-susy brane solutions:

- Both solutions are asymptotically flat.

- In isotropic coordinates BPS brane are given in terms of a single harmonic function $\hat{H}$, but the non-susy branes are given in terms of two harmonic function H and $\tilde{H}$. In Schwarzschild-like coordinate non-susy branes can also be given in terms of a single harmonic function.

- BPS branes are well defined for $r > 0$, and has a singularity at $r = 0$, whereas non-susy branes is well defined for $r > \omega$, and has singularity at $r = \omega$. But we have noted that the singularity can be shifted to $\hat{\rho} = 0$ in Schwarzschild-like coordinate , as in the BPS case.

- Due to supersymmetry BPS branes satisfy no-force condition. When two BPS brane are placed parallel to each other, there is no force acting between them. No-force condition is violated for non-susy branes.

• BPS brane will always contain a non-zero charge due to the relation $b = (7-p)\hat{\omega}^{7-p}$, whereas from the relation $b = (7-p)(\alpha+\beta)\omega^{7-p}\sinh 2\theta$, we notice that the non-susy branes could be either charged or chargeless. We note that b could be zero either for $\theta = 0$ or for $\alpha + \beta = 0$. Note that in both cases the function

$$F = \left(\frac{H}{\tilde{H}}\right)^{\alpha} \cosh^2\theta - \left(\frac{\tilde{H}}{H}\right)^{\beta} \sinh^2\theta$$

simplifies to $F = \left(\frac{H}{\tilde{H}}\right)^{\alpha}$. For the first case the solution depends on two parameters δ, ω whereas for the second case the solution depends on single parameter ω (eventhough here θ = finite, but it gets eliminated from the solution). In order to understand the one parameter dependence we note that from the parameter relation

$$\frac{1}{2}\delta^2 + \frac{1}{2}\alpha(\alpha - a\delta) = \frac{8-p}{7-p}$$

that we can obtain

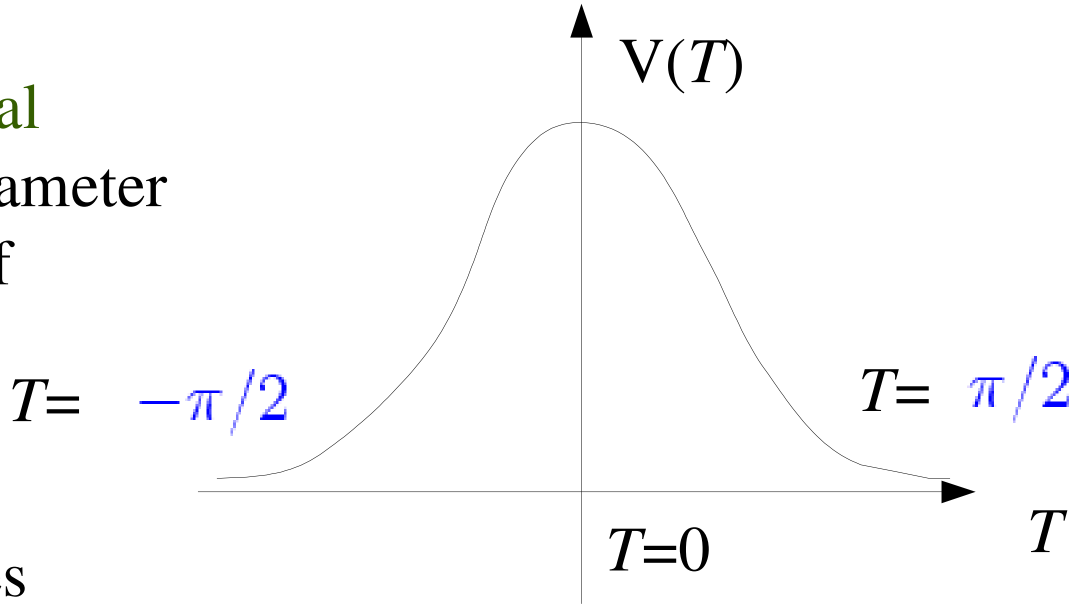
$$\alpha = \sqrt{\frac{2(8-p)}{7-p} - \delta^2\left(1 - \frac{a^2}{4}\right)} + \frac{a\delta}{2}$$

$$\beta = \sqrt{\frac{2(8-p)}{7-p} - \delta^2\left(1 - \frac{a^2}{4}\right)} - \frac{a\delta}{2}$$

so $\alpha + \beta = 0$ implies $\delta = \pm\frac{4}{7-p}\sqrt{\frac{2(8-p)}{p+1}}$.

Unlike the BPS branes the non-susy branes are usually unstable. It was argued by Brax, Mandal and Oz (PRD63 (2001) 064008, hep-th/0005242) that the non-susy branes can be regarded as brane-antibrane system and then the three parameters of the solution can be naturally interpreted as the number of branes (N), number of anti-branes ($\bar{N}$) and the tachyon parameter (T). This is not unreasonable since from open string viewpoint we know that non-susy branes contain tachyon on their world-volume.

Let us look at the tachyon potential V(T) as a function of tachyon parameter T given on the right. At the top of the potential the brane system is unstable and given by the non-susy brane configuration. Whereas as the tachyon condenses at the bottom of the potential $T = \pm\pi/2$ we get BPS configuration. Using this open string theory argument of Sen, we can relate the three supergravity parameters ω, θ, δ to the microscopic parameters $N, \bar{N}, T$ as follows,



$$
\begin{aligned}
(7-p)\omega^{7-p} &= \sqrt{\frac{7-p}{2(8-p)}}(N\bar{N})^{\frac{1}{2}}\frac{2\kappa_0^2}{\Omega_{8-p}}T_p\cos T \\
\sinh 2\theta &= \frac{|N-\bar{N}|}{(\alpha+\beta)(N\bar{N})^{1/2}\cos T}\sqrt{\frac{2(8-p)}{7-p}}
\end{aligned}
$$

and

$$\delta = \frac{1}{2c_p}\frac{a}{|a|}\left[|a|\sqrt{\cos^2 T + \frac{(N-\bar{N})^2}{4N\bar{N}\cos^2 T}}\right.$$
$$\left. - \sqrt{a^2\left(\cos^2 T + \frac{(N-\bar{N})^2}{4N\bar{N}\cos^2 T}\right) + 4\left(\frac{2(8-p)}{7-p}c_p^2 - \cos^2 T\right)}\right]$$

Here $a = (p-3)/2$ and c_p is an unknown constant depending on p but is bounded as

$$c_p \geq \frac{7-p}{4}\sqrt{\frac{p+1}{2(8-p)}}$$ for δ to remain real.

It can be easily checked that using these relations the ADM mass of the non-susy p-branes takes the form:

$$\begin{aligned} M &= \frac{\Omega_{8-p}}{2\kappa_0^2}(7-p)\omega^{7-p}\left[(\alpha+\beta)\cosh 2\theta + (\alpha-\beta)\right] \\ &= T_p\sqrt{(N+\bar{N})^2 - 4N\bar{N}(1-\cos^4 T)} \\ &\leq T_p(N+\bar{N}) \end{aligned}$$

We mention that the three parameters

$$
\begin{aligned}
(7-p)\omega^{7-p} &= \sqrt{\frac{7-p}{2(8-p)}}(N\bar{N})^{\frac{1}{2}}\frac{2\kappa_0^2}{\Omega_{8-p}}T_p\cos T \\
\sinh 2\theta &= \frac{|N-\bar{N}|}{(\alpha+\beta)(N\bar{N})^{1/2}\cos T}\sqrt{\frac{2(8-p)}{7-p}}
\end{aligned}
$$

$$
\delta = \frac{1}{2c_p}\frac{a}{|a|}\left[|a|\sqrt{\cos^2 T + \frac{(N-\bar{N})^2}{4N\bar{N}\cos^2 T}} - \sqrt{a^2\left(\cos^2 T + \frac{(N-\bar{N})^2}{4N\bar{N}\cos^2 T}\right) + 4\left(\frac{2(8-p)}{7-p}c_p^2 - \cos^2 T\right)}\right]
$$

Note that as $N \rightarrow 0$, $\bar{N} \rightarrow 0$, $T \rightarrow \pm\pi/2$, $\omega \rightarrow 0$ and $\theta \rightarrow \infty$ as we remarked earlier for the susy limit.

gives the correct supersymmetry limit when i) $N \rightarrow 0$, ii) $\bar{N} \rightarrow 0$ and iii) $T \rightarrow \pm\pi/2$. The corresponding mass formula also correctly gives the ADM mass of the system both at the top and at the bottom of the potential and also in the $N \rightarrow 0$, $\bar{N} \rightarrow 0$ limit as can be seen from

$$
M = T_p\sqrt{(N+\bar{N})^2 - 4N\bar{N}(1-\cos^4 T)} .
$$

We would like to make a couple of remarks here:

The relation between the sugra parameters ω, θ, δ with the microscopic physical parameters $N, \bar{N}, T$ we got match exactly with the relations obtained by Asakawa, Kobayashi and Matsuura (hep-th/0409044) in the boundary state approach in the limit $|N - \bar{N}| \to \infty$.

Also we would like to mention that

$$\delta = \frac{1}{2c_p}\frac{a}{|a|}\left[|a|\sqrt{\cos^2 T + \frac{(N-\bar{N})^2}{4N\bar{N}\cos^2 T}} - \sqrt{a^2\left(\cos^2 T + \frac{(N-\bar{N})^2}{4N\bar{N}\cos^2 T}\right) + 4\left(\frac{2(8-p)}{7-p}c_p^2 - \cos^2 T\right)}\right]$$

is obtained from the quadratic relation $\frac{1}{2}\delta^2 + \frac{1}{2}\alpha(\alpha - a\delta) = \frac{8-p}{7-p}$

and we have kept only one root keeping in mind that the parameters α, β appearing in the metric must be real and this gives a bound for δ , which follows from

$$\alpha = \sqrt{\frac{2(8-p)}{7-p} - \delta^2 \left(1 - \frac{a^2}{4}\right)} + \frac{a\delta}{2}$$

$$\beta = \sqrt{\frac{2(8-p)}{7-p} - \delta^2 \left(1 - \frac{a^2}{4}\right)} - \frac{a\delta}{2}$$

as

$$|\delta| \leq \frac{4}{7-p}\sqrt{\frac{2(8-p)}{p+1}}$$

However, for the other root of δ , there is no such bound and the solution in that case can become complex (except for some special case) signalling a possible phase transition in the system.

4. Intersecting non-supersymmetric branes

By intersecting branes here we mean that there are two kinds of branes, namely, a p-brane and a q-brane (where $q \leq p$) intersecting on an r-brane (where $r \leq q$). Here we will consider the simple case where $r = q$. So, q-brane will be inside the p-brane.

In order to obtain these solutions both for the BPS case and in the non-susy case one has to solve the equations of motion with two kinds of form fields $F_{[8-p]}$ and $F_{[8-q]}$ and also one might need to include the Chern-Simons term in the action (of type IIA or IIB).

However, we will not obtain them that way. We will use a solution generating technique to obtain them.

Note that we can obtain a D$(p+1)$-brane from a Dp-brane by applying T-duality in the transverse direction of the Dp-brane. Here we do not generate two kinds of branes, but for the non-susy branes we will generate two kinds of branes, one charged and the other chargeless.

The reason for this difference is that the T-duality will always give isotropic BPS-branes (due to single parameter), which is not true for non-susy branes (due to more parameters). Also since BPS branes can not be chargeless, we always need two form-fields to get intersecting solutions of two kinds of branes, which is again not true for non-susy branes.

We will in fact use T-duality to obtain non-susy p-brane intersecting with non-susy q-brane ($q \quad p$), where the non-susy p-brane is charged and the q-brane is chargeless.

But taking T-duality is a bit subtle here. For BPS case, starting from a Dp-brane, an isometry in the transverse direction is produced by placing an infinite array of Dp-branes periodically along the transverse direction (possible due to no-force condition) and then taking the continuum limit. This produces a Dp-brane delocalized along the transverse direction which is also the isometry direction. Then T-duality is taken along the isometry direction to produce a D($p+1$)-brane.

For, non-susy branes this procedure will not work since there is interaction. So, before taking T-duality we have to obtain a delocalized (in one of the transverse directions to produce the isometry direction) non-susy p-brane by some other method.

We explicitly solve the equations of motion to obtain this delocalized non-susy brane solution with an appropriate metric ansatz. The solution for a non-susy q-brane delocalized in $(p-q)$-directions has the form:

$$\begin{aligned} ds^2 &= F^{\frac{q+1}{8}}(H\tilde{H})^{\frac{2}{7-p}}\left(\frac{H}{\tilde{H}}\right)^{(-2\sum_{i=2}^{p-q+1}\delta_i)/(7-p)}\left(dr^2+r^2d\Omega_{8-p}^2\right) \\ &\quad + F^{-\frac{7-q}{8}}\left(-dt^2+\sum_{i=1}^{q}(dx^i)^2\right)+F^{\frac{q+1}{8}}\sum_{i=2}^{p-q+1}\left(\frac{H}{\tilde{H}}\right)^{2\delta_i}(dx^{q+i-1})^2 \\ e^{2\phi} &= F^{-a}\left(\frac{H}{\tilde{H}}\right)^{2\delta_1}, \qquad F_{[8-q]} = b\,\mathrm{Vol}(\Omega_{8-p})\wedge dx^{q+1}\ldots\wedge dx^p \end{aligned}$$

Here the functions have exactly the same form as before,

$$
\begin{aligned}
F &= \left(\frac{H}{\tilde{H}}\right)^{\alpha}\cosh^2\theta - \left(\frac{\tilde{H}}{H}\right)^{\beta}\sinh^2\theta \\
H &= 1 + \frac{\omega^{7-p}}{r^{7-p}} \\
\tilde{H} &= 1 - \frac{\omega^{7-p}}{r^{7-p}}
\end{aligned}
$$

and the parameters satisfy

$$\alpha - \beta = a\delta_1$$

$$\frac{1}{2}\delta_1^2 + \frac{1}{2}\alpha(\alpha - a\delta_1) + \frac{2\sum_{i>j=2}^{p-q+1}\delta_i\delta_j}{7-p} = \left(1 - \sum_{i=2}^{p-q+1}\delta_i^2\right)\frac{8-p}{7-p}$$

$$b = (7-p)\omega^{7-p}(\alpha+\beta)\sinh 2\theta$$

Note that the equation here has $(p-q+6)$ parameters (they are $\alpha, \beta, \theta, \delta_1, \delta_2, \ldots, \delta_{p-q+1}, \omega, b$), but because of the above three relations only $(p-q+3)$ are independent.

We now take T-duality transformation on all the $(p-q)$ delocalized directions and demand that the resulting solution has the isometry $\mathrm{ISO}(1,q)\times\mathrm{SO}(p-q)\times\mathrm{SO}(9-p)$ corresponding to a p-brane intersecting with a q-brane. For this we need to set $\delta_2=\delta_3=\cdots=\delta_{p-q+1}$

So, out of $(p - q + 3)$ parameters $(p-q-1)$ will be eliminated and we will be left with 4 parameters. The solution is given as,

$$
\begin{aligned}
ds^2 &= F^{\frac{p+1}{8}}(H\tilde{H})^{\frac{2}{7-p}}\left(\frac{H}{\tilde{H}}\right)^{\frac{(p-q)\delta_1}{8}+\frac{(p-q)(3-p)\delta_2}{2(7-p)}}\left(dr^2+r^2d\Omega_{8-p}^2\right)\\
&\quad +F^{-\frac{7-p}{8}}\left(\frac{H}{\tilde{H}}\right)^{\frac{(p-q)\delta_1}{8}+\frac{(p-q)\delta_2}{2}}\left(-dt^2+\sum_{i=1}^{q}(dx^i)^2\right)\\
&\quad +F^{-\frac{7-p}{8}}\sum_{j=q+1}^{p}\left(\frac{H}{\tilde{H}}\right)^{\frac{\delta_1}{8}(p-q-8)+\frac{(p-q-4)\delta_2}{2}}(dx^j)^2\\
e^{2\phi} &= F^{\frac{3-p}{2}}\left(\frac{H}{\tilde{H}}\right)^{\frac{\delta_1}{2}(4-p+q)-2(p-q)\delta_2}, \qquad F_{[8-p]}=b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

The various functions are given exactly as before:

$$
\begin{aligned}
H &= 1+\frac{\omega^{7-p}}{r^{7-p}} \\
\tilde{H} &= 1-\frac{\omega^{7-p}}{r^{7-p}} \\
F &= \left(\frac{H}{\tilde{H}}\right)^{\alpha}\cosh^2\theta-\left(\frac{\tilde{H}}{H}\right)^{\beta}\sinh^2\theta
\end{aligned}
$$

Note that we have seven parameters ($\delta_1,\delta_2,\theta,\omega,\alpha,\beta,b$) in the solution. There are three relations among them which are given as,

$$
\begin{aligned}
&\alpha-\beta=a\delta_1 \\
&\frac{1}{2}\delta_1^2+\frac{1}{2}\alpha(\alpha-a\delta_1)+\frac{(p-q)(p-q-1)}{7-p}\delta_2^2=\left(1-(p-q)\delta_2^2\right)\frac{8-p}{7-p} \\
&b=(7-p)\omega^{7-p}(\alpha+\beta)\sinh 2\theta
\end{aligned}
$$

We therefore have four independent parameters in the solution. In order to understand that the solution indeed represents intersecting non-susy p-brane with chargeless non-susy q-brane we proceed as follows:

We redefine $F = \left(\frac{H}{\tilde{H}}\right)^{\alpha} \cosh^2\theta - \left(\frac{\tilde{H}}{H}\right)^{\beta} \sinh^2\theta = F_1 \left(\frac{H}{\tilde{H}}\right)^{\tilde{\alpha}}$

where $F_1 = \left(\frac{H}{\tilde{H}}\right)^{\alpha_1} \cosh^2\theta - \left(\frac{\tilde{H}}{H}\right)^{\beta_1} \sinh^2\theta$ with

$\alpha_1 + \tilde{\alpha} = \alpha,$ and $\beta_1 - \tilde{\alpha} = \beta$.

Now defining new parameters

$$\begin{aligned}
\tilde{\alpha} &= \frac{7-p}{7-q}\alpha_2 - \frac{p-q}{7-q}\delta \\
\delta_2 &= -\frac{7-p}{2(7-q)}(\alpha_2 + \delta) \\
\delta_1 &= -\frac{p-q}{7-q}\alpha_2 + \frac{7-p}{7-q}\delta
\end{aligned}$$

We can rewrite the solution in terms of these new parameters as follows:

$$ds^2 = F_1^{\frac{p+1}{8}} F_2^{\frac{q+1}{8}} \left(H\tilde{H}\right)^{\frac{2}{7-p}} \left(dr^2 + r^2 d\Omega_{8-p}^2\right)$$

$$+F_1^{-\frac{7-p}{8}} F_2^{-\frac{7-q}{8}} \left(-dt^2 + \sum_{i=1}^{q} (dx^i)^2\right) + F_1^{-\frac{7-p}{8}} F_2^{\frac{q+1}{8}} \sum_{j=q+1}^{p} (dx^j)^2$$

$$e^{2\phi} = F_1^{\frac{3-p}{2}} F_2^{\frac{3-q}{2}} \left(\frac{H}{\tilde{H}}\right)^{2\delta}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p})$$

where $F_{1,2} = \left(\frac{H}{\tilde{H}}\right)^{\alpha_{1,2}} \cosh^2\theta_{1,2} - \left(\frac{\tilde{H}}{H}\right)^{\beta_{1,2}} \sinh^2\theta_{1,2}$

Note that in the above we actually have $\theta_1 = \theta$ and $\theta_2 = 0$ and because $\theta_2 = 0, F_2 = \left(\frac{H}{\tilde{H}}\right)^{\alpha_2}$. This is precisely the form we get from the solution given on s33. $\theta_2 = 0$ also implies that the charge associated with the q-brane is zero which is also manifested by the absence of $F_{[8-q]}$ above. But because of non-zero θ_1 and $F_{[8-p]}$, the p-brane is charged. The above solution therefore represents intersecting non-susy p-brane with chargeless non-susy q-brane where $q \leq p$. The parameter relations are:

$$\alpha_1 - \beta_1 = \left(\frac{p-q}{2} - 2\right)\alpha_2 + \frac{p-3}{2}\delta$$

$$b = (7-p)\omega^{7-p}(\alpha_1 + \beta_1)\sinh 2\theta$$

$$\frac{1}{2}\left(\delta - \frac{p-3}{4}\alpha_1 - \frac{q-3}{4}\alpha_2\right)^2$$

$$= \frac{8-p}{7-p} - \frac{(p+1)(7-p)}{32}\alpha_1^2 - \frac{(q+1)(7-q)}{32}\alpha_2^2 - \frac{(q+1)(7-p)}{16}\alpha_1\alpha_2$$

Also to verify that the our solution indeed represents intersecting solution, we have compared it with the known intersecting solutions when $p - q = 4$ and 2 and both the branes are charged, by putting the charge of the q-brane to zero.

These intersecting solutions we have obtained just by applying T-duality transformation on the non-susy q-brane delocalized in $(p - q)$ directions.

5. Intersecting non-susy branes as black branes and bubbles

Here we will show how for particular values of the parameters we recover the black-branes and bubbles from our intersecting non-susy solutions.

(a) Black-branes

Let us look at the solution:

$$ds^2 = F_1^{\frac{p+1}{8}} F_2^{\frac{q+1}{8}} \left(H\tilde{H}\right)^{\frac{2}{7-p}} \left(dr^2 + r^2 d\Omega_{8-p}^2\right)$$

$$+F_1^{-\frac{7-p}{8}} F_2^{-\frac{7-q}{8}} \left(-dt^2 + \sum_{i=1}^{q} (dx^i)^2\right) + F_1^{-\frac{7-p}{8}} F_2^{\frac{q+1}{8}} \sum_{j=q+1}^{p} (dx^j)^2$$

$$e^{2\phi} = F_1^{\frac{3-p}{2}} F_2^{\frac{3-q}{2}} \left(\frac{H}{\tilde{H}}\right)^{2\delta}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p})$$

and put $q = 0$. The above solution simplifies to,

$$
\begin{aligned}
ds^2 &= F_1^{\frac{p+1}{8}}\left(H\tilde{H}\right)^{\frac{2}{7-p}}\left(\frac{H}{\tilde{H}}\right)^{\frac{1}{8}\alpha_2}\left(dr^2+r^2d\Omega_{8-p}^2\right) \\
&- F_1^{-\frac{7-p}{8}}\left(\frac{H}{\tilde{H}}\right)^{-\frac{7}{8}\alpha_2}dt^2+F_1^{-\frac{7-p}{8}}\left(\frac{H}{\tilde{H}}\right)^{\frac{1}{8}\alpha_2}\sum_{j=1}^{p}(dx^j)^2 \\
e^{2\phi} &= F_1^{\frac{3-p}{2}}\left(\frac{H}{\tilde{H}}\right)^{\frac{3}{2}\alpha_2+2\delta}, \qquad F_{[8-p]}=b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

where the parameters satisfy,

$$
\begin{aligned}
&\alpha_1-\beta_1=\left(\frac{p}{2}-2\right)\alpha_2+\frac{p-3}{2}\delta \\
&b=(7-p)\omega^{7-p}(\alpha_1+\beta_1)\sinh 2\theta \\
&\frac{1}{2}\left(\delta-\frac{p-3}{4}\alpha_1+\frac{3}{4}\alpha_2\right)^2 \\
&=\frac{8-p}{7-p}-\frac{(p+1)(7-p)}{32}\alpha_1^2-\frac{7}{32}\alpha_2^2-\frac{7-p}{16}\alpha_1\alpha_2
\end{aligned}
$$

Now we will use the coordinate transformation to go to Schwarzschild-like coordinate we had before,

$$r = \rho \left(\frac{1+\sqrt{f}}{2} \right)^{\frac{2}{7-p}}$$

where $f = 1 - \frac{4\omega^{7-p}}{\rho^{7-p}} \equiv 1 - \frac{\rho_0^{7-p}}{\rho^{7-p}}$ and $\frac{H}{\tilde{H}} = f^{-\frac{1}{2}}$

In ρ coordinate the solution reduces to,

$$\begin{aligned} ds^2 &= G^{\frac{p+1}{8}} f^{-\frac{p+1}{16}\alpha_1 - \frac{1}{16}\alpha_2 + \frac{1}{7-p}} \left(\frac{d\rho^2}{f} + \rho^2 d\Omega_{8-p}^2 \right) \\ &+ G^{-\frac{7-p}{8}} f^{\frac{7-p}{16}\alpha_1 - \frac{1}{16}\alpha_2} \left(-f^{\frac{\alpha_2}{2}} dt^2 + \sum_{i=1}^{p} (dx^i)^2 \right) \\ e^{2\phi} &= G^{\frac{3-p}{2}} f^{-\frac{3-p}{4}\alpha_1 - \frac{3}{4}\alpha_2 - \delta}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p}) \end{aligned}$$

where $G = \cosh^2\theta - f^{\frac{\alpha_1+\beta_1}{2}} \sinh^2\theta$ and the parameter relations remain the same.

It is clear that for $\alpha_1 + \beta_1 = 2$, $G = \cosh^2\theta - f^{\frac{\alpha_1+\beta_1}{2}} \sinh^2\theta$ reduces to $G = \bar{H} = 1 + \frac{\rho_0^{7-p}\sinh^2\theta}{\rho^{7-p}}$. Also for $\alpha_1 = 2/(7-p)$, $\alpha_2 = 2$ and $\delta = -2(6-p)/(7-p)$, the solution

$$
\begin{aligned}
ds^2 &= G^{\frac{p+1}{8}} f^{-\frac{p+1}{16}\alpha_1 - \frac{1}{16}\alpha_2 + \frac{1}{7-p}} \left(\frac{d\rho^2}{f} + \rho^2 d\Omega_{8-p}^2 \right) \\
&+ G^{-\frac{7-p}{8}} f^{\frac{7-p}{16}\alpha_1 - \frac{1}{16}\alpha_2} \left(-f^{\frac{\alpha_2}{2}} dt^2 + \sum_{i=1}^{p} (dx^i)^2 \right) \\
e^{2\phi} &= G^{\frac{3-p}{2}} f^{-\frac{3-p}{4}\alpha_1 - \frac{3}{4}\alpha_2 - \delta}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

reduces to,

$$
\begin{aligned}
ds^2 &= \bar{H}^{\frac{p+1}{8}} \left(\frac{1}{f} d\rho^2 + \rho^2 d\Omega_{8-p}^2 \right) + \bar{H}^{-\frac{7-p}{8}} \left(-f dt^2 + \sum_{j=1}^{p} (dx^j)^2 \right) \\
e^{\phi} &= \bar{H}^{\frac{3-p}{2}}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

This is precisely the Horowitz-Strominger black p-brane.

Note that the black-brane has two parameters ρ_0 and θ corresponding to the mass and the charge of the black-brane. However, the original intersecting non-susy solution had four parameters $\alpha_2, \delta, \rho_0,$ and θ so, two of the parameters $\alpha_2,$ and δ got fixed while obtaining the black-brane solution.

Note that after we made the T-duality we obtained the intersecting solution in the form:

$$
\begin{aligned}
ds^2 &= F^{\frac{p+1}{8}}(H\tilde{H})^{\frac{2}{7-p}}\left(\frac{H}{\tilde{H}}\right)^{\frac{(p-q)\delta_1}{8}+\frac{(p-q)(3-p)\delta_2}{2(7-p)}}\left(dr^2+r^2d\Omega^2_{8-p}\right)\\
&\quad +F^{-\frac{7-p}{8}}\left(\frac{H}{\tilde{H}}\right)^{\frac{(p-q)\delta_1}{8}+\frac{(p-q)\delta_2}{2}}\left(-dt^2+\sum_{i=1}^{q}(dx^i)^2\right)\\
&\quad +F^{-\frac{7-p}{8}}\sum_{j=q+1}^{p}\left(\frac{H}{\tilde{H}}\right)^{\frac{\delta_1}{8}(p-q-8)+\frac{(p-q-4)\delta_2}{2}}(dx^j)^2\\
e^{2\phi} &= F^{\frac{3-p}{2}}\left(\frac{H}{\tilde{H}}\right)^{\frac{\delta_1}{2}(4-p+q)-2(p-q)\delta_2}, \qquad F_{[8-p]}=b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

Here the independent parameters are $\delta_1, \delta_2, \omega = \rho_0/4 \text{ and } \theta$. They are related to $\alpha_2, \delta, \rho_0,$ and θ as,

$$\begin{aligned}
\tilde{\alpha} &= \frac{7-p}{7-q}\alpha_2 - \frac{p-q}{7-q}\delta \\
\delta_2 &= -\frac{7-p}{2(7-q)}(\alpha_2+\delta) \\
\delta_1 &= -\frac{p-q}{7-q}\alpha_2 + \frac{7-p}{7-q}\delta
\end{aligned}$$

So, for $\delta = -2(6-p)/(7-p)$ and $\alpha_2 = 2$, we have $\delta_1 = -12/7 \text{ and } \delta_2 = -1/7$ and so they are universal in the sense that they are independent of *p*. We will use this fact to make some comments on the phase structure of the parameter space.

Also note that the original intersecting non-susy brane solution has a singularity, but for these special values of the parameters a regular horizon is formed.

(b) Bubbles

Let us again look at the four-parameter intersecting brane solution

$$ds^2 = F_1^{\frac{p+1}{8}} F_2^{\frac{q+1}{8}} \left(H\tilde{H}\right)^{\frac{2}{7-p}} \left(dr^2 + r^2 d\Omega_{8-p}^2\right)$$

$$+F_1^{-\frac{7-p}{8}} F_2^{-\frac{7-q}{8}} \left(-dt^2 + \sum_{i=1}^{q} (dx^i)^2\right) + F_1^{-\frac{7-p}{8}} F_2^{\frac{q+1}{8}} \sum_{j=q+1}^{p} (dx^j)^2$$

$$e^{2\phi} = F_1^{\frac{3-p}{2}} F_2^{\frac{3-q}{2}} \left(\frac{H}{\tilde{H}}\right)^{2\delta}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p})$$

and let us put $q = p - 1$, then the solution reduces to (put $F_2 = \left(\frac{H}{\tilde{H}}\right)^{\alpha_2}$)

$$ds^2 = F^{\frac{p+1}{8}} (H\tilde{H})^{\frac{2}{7-p}} \left(\frac{H}{\tilde{H}}\right)^{\frac{p}{8}\alpha_2} \left(dr^2 + r^2 d\Omega_{8-p}^2\right)$$

$$+F^{-\frac{7-p}{8}} \left(\frac{H}{\tilde{H}}\right)^{\frac{p-8}{8}\alpha_2} \left(-dt^2 + \sum_{i=1}^{p-1} (dx^i)^2\right) + F^{-\frac{7-p}{8}} \left(\frac{H}{\tilde{H}}\right)^{\frac{p}{8}\alpha_2} (dx^p)^2$$

$$e^{2\phi} = F^{\frac{3-p}{2}} \left(\frac{H}{\tilde{H}}\right)^{\frac{4-p}{2}\alpha_2 + 2\delta}, \qquad F_{[8-p]} = b\,\mathrm{Vol}(\Omega_{8-p})$$

The parameter relation takes the form:

$$
\begin{aligned}
&\alpha_1 - \beta_1 = -\frac{3}{2}\alpha_2 + \frac{p-3}{2}\delta \\
&b = \frac{1}{4}(7-p)\rho_0^{7-p}(\alpha_1 + \beta_1)\sinh 2\theta \\
&\frac{1}{2}\left(\delta - \frac{p-3}{4}\alpha_1 - \frac{p-4}{4}\alpha_2\right)^2 \\
&= \frac{8-p}{7-p} - \frac{(p+1)(7-p)}{32}\alpha_1^2 - \frac{p(8-p)}{32}\alpha_2^2 - \frac{p(7-p)}{16}\alpha_1\alpha_2
\end{aligned}
$$

The above solution represents intersecting non-susy Dp-brane with chargeless non-susy D$(p-1)$-brane having the four independent parameters $\alpha_2, \delta, \rho_0,$ and θ .

Now again we make the coordinate transformation to go to Schwarzschild like coordinate by,

$$
r = \rho\left(\frac{1+\sqrt{f}}{2}\right)^{\frac{2}{7-p}}
$$

Under this transformation the solution

$$\begin{aligned}
ds^2 &= F^{\frac{p+1}{8}}(H\tilde{H})^{\frac{2}{7-p}}\left(\frac{H}{\tilde{H}}\right)^{\frac{p}{8}\alpha_2}\left(dr^2+r^2d\Omega_{8-p}^2\right)\\
&\quad +F^{-\frac{7-p}{8}}\left(\frac{H}{\tilde{H}}\right)^{\frac{p-8}{8}\alpha_2}\left(-dt^2+\sum_{i=1}^{p-1}(dx^i)^2\right)+F^{-\frac{7-p}{8}}\left(\frac{H}{\tilde{H}}\right)^{\frac{p}{8}\alpha_2}(dx^p)^2\\
e^{2\phi} &= F^{\frac{3-p}{2}}\left(\frac{H}{\tilde{H}}\right)^{\frac{4-p}{2}\alpha_2+2\delta}, \qquad F_{[8-p]} = b\,\mathrm{Vol}(\Omega_{8-p})
\end{aligned}$$

takes the form

$$\begin{aligned}
ds^2 &= G^{\frac{p+1}{8}}f^{-\frac{p+1}{16}\alpha_1-\frac{p}{16}\alpha_2+\frac{1}{7-p}}\left(\frac{d\rho^2}{f}+\rho^2d\Omega_{8-p}^2\right)\\
&+ G^{-\frac{7-p}{8}}f^{\frac{7-p}{16}\alpha_1+\frac{8-p}{16}\alpha_2}\left(-dt^2+\sum_{i=1}^{p-1}(dx^i)^2+f^{-\frac{\alpha_2}{2}}(dx^p)^2\right)\\
e^{2\phi} &= G^{\frac{3-p}{2}}f^{-\frac{3-p}{4}\alpha_1-\frac{4-p}{4}\alpha_2-\delta}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}$$

Where again $G = \cosh^2\theta - f^{\frac{\alpha_1+\beta_1}{2}} \sinh^2\theta$ and the parameter relation remains the same. Again for $\alpha_1 + \beta_1 = 2$, we have $G = \bar{H} = 1 + \dfrac{\rho_0^{7-p}\sinh^2\theta}{\rho^{7-p}}$. If we now put,

$$\alpha_1 = 2(8-p)/(7-p),\ \alpha_2 = -2,\ \beta_1 = -2/(7-p),\ \delta = 2/(7-p)$$

the solution

$$\begin{aligned} ds^2 &= G^{\frac{p+1}{8}} f^{-\frac{p+1}{16}\alpha_1 - \frac{p}{16}\alpha_2 + \frac{1}{7-p}} \left(\frac{d\rho^2}{f} + \rho^2 d\Omega_{8-p}^2\right) \\ &+ G^{-\frac{7-p}{8}} f^{\frac{7-p}{16}\alpha_1 + \frac{8-p}{16}\alpha_2} \left(-dt^2 + \sum_{i=1}^{p-1}(dx^i)^2 + f^{-\frac{\alpha_2}{2}}(dx^p)^2\right) \\ e^{2\phi} &= G^{\frac{3-p}{2}} f^{-\frac{3-p}{4}\alpha_1 - \frac{4-p}{4}\alpha_2 - \delta}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p}) \end{aligned}$$

reduces to,

$$\begin{aligned} ds^2 &= \bar{H}^{\frac{p+1}{8}} \left(\frac{d\rho^2}{f} + \rho^2 d\Omega_{8-p}^2\right) + \bar{H}^{-\frac{7-p}{8}} \left(-dt^2 + \sum_{i=1}^{p-1}(dx^i)^2 + f(dx^p)^2\right) \\ e^{2\phi} &= \bar{H}^{\frac{3-p}{2}}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p}) \end{aligned}$$

We recognize the solution

$$
\begin{aligned}
ds^2 &= \bar{H}^{\frac{p+1}{8}}\left(\frac{d\rho^2}{f} + \rho^2 d\Omega_{8-p}^2\right) + \bar{H}^{-\frac{7-p}{8}}\left(-dt^2 + \sum_{i=1}^{p-1}(dx^i)^2 + f(dx^p)^2\right) \\
e^{2\phi} &= \bar{H}^{\frac{3-p}{2}}, \qquad F_{[8-p]} = b\mathrm{Vol}(\Omega_{8-p})
\end{aligned}
$$

to be the bubble solution. Note that the bubble solution can be obtained from the black p-brane solution by a Wick rotation $t \to ix^p,\ x^p \to it$.

Also in the above $f = 1 - \frac{4\omega^{7-p}}{\rho^{7-p}} \equiv 1 - \frac{\rho_0^{7-p}}{\rho^{7-p}}$. So, although the original

intersecting non-susy Dp-brane with chargeless non-susy D$(p-1)$-brane had a singularity at $\rho = \rho_0$, the singularity is completely gone for the particular choice of the parameters.

We would like to mention that the black-brane to bubble transition is actually a special case of intersecting non-susy Dp/D0 to non-susy Dp/D$(p$ - 1) transition by the above Wick rotation.

We had remarked before in the context of simple non-susy Dp-brane how it can be regarded as a system of brane-antibrane where the three supergravity parameters can be related to the nuber of branes, number of anti-branes and the tachyon parameter. These relations

$$
\begin{aligned}
(7-p)\omega^{7-p} &= \sqrt{\frac{7-p}{2(8-p)}}(N\bar{N})^{\frac{1}{2}}\frac{2\kappa_0^2}{\Omega_{8-p}}T_p\cos T \\
\sinh 2\theta &= \frac{|N-\bar{N}|}{(\alpha+\beta)(N\bar{N})^{1/2}\cos T}\sqrt{\frac{2(8-p)}{7-p}}
\end{aligned}
$$

$$
\delta = \frac{1}{2c_p}\frac{a}{|a|}\left[|a|\sqrt{\cos^2 T + \frac{(N-\bar{N})^2}{4N\bar{N}\cos^2 T}}\right.
\left. - \sqrt{a^2\left(\cos^2 T + \frac{(N-\bar{N})^2}{4N\bar{N}\cos^2 T}\right) + 4\left(\frac{2(8-p)}{7-p}c_p^2 - \cos^2 T\right)}\right]
$$

gave us the correct picture of open string tachyon condensation as observed by Sen.

Similarly the supergravity parameters of the intersecting non-susy brane solutions can also be related with the physical parameters. Although the parameters ω and θ , can be fixed uniquely the parameter δ has various branches.

As we mentioned before the open string tachyon condensation occurs in the branch of δ where it is bounded from above and the solution always remains real. However, we found that for the formation of the horizon δ must be -12/7, but this value of δ always occurs in the branch where it is not bounded.

In the branch where δ is not bounded, the solution can become imaginary indicating a possible phase transition. Whether this phase transition has anything to do with black-brane to bubble transition or closed string tachyon condensation remains to be seen.

6. Conclusion

- We have shown how black p-branes and bubble solutions appear as special cases of four parameter non-susy intersecting brane solutions when two of the four parameters are fixed. In the fomer case the parameters correspond to the mass and the charge of the black-brane while in the latter case they represent the radius and the flux associated with the bubble.

- We have seen that the parameter space of the intersecting non-susy branes has a very rich phase structure than what is hitherto known. It not only has an open string tachyon condensation phase, but also possibly contain a closed string tachyon condensation phase. It would be interesting to understand the full phase structure of the parameter space.

- We have seen that black-brane to bubble transition (which is supposed to occur through closed string tachyon condensation as argued by Horowitz (JHEP 08 (2005) 091, hep-th/0506166)) is a special case of transition from intersecting Dp/D0 system to Dp/D(p - 1) system. It would be interesting to see whether there is any closed string tachyon condensation associated with this transition.

- We have seen that black-branes are special cases of intersecting non-susy Dp-branes with chargeless non-susy D0-branes. This gives a microscopic description of black branes in terms of these constituent non-susy branes. It would be interesting to see whether this new understanding can help us in calculating the entropy of non-susy black-branes or holes.

Thank You