# Intersecting Branes and Anti-de Sitter Spacetimes in $SU(2) \times SU(2)$ Gauged Supergravity

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#### ABSTRACT

In this note we extend our work in a previous paper hep-th/9801038. We show here that various intersecting brane-like configurations can be found in the vacuum of D = 4, N = 4 supergravity with gauged R-symmetry group  $SU(2) \times SU(2)$ . These include intersections of domain-walls, strings and pointlike objects. Some of these intersecting configurations preserve 1/2 and 1/4 of supersymmetry. We observe that the previously obtained  $AdS_3 \times R^1$  pure axionic vacuum or 'axio-vac' is an intersection of domain-wall with extended string with 1/2 supersymmetries. Also the solutions known as 'electro-vac' with geometry  $AdS_2 \times R^2$  can be simply interpreted as the intersection of domain-wall with point-like object.

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### 1 Introduction

In this work we will study N = 4 gauged  $SU(2) \times SU(2)$  supergravity in four dimensions [1]. It has been recently established that this gauged supergravity can be embedded into N = 1 supergravity in ten dimensions as an  $S^3 \times S^3$  compactification [2]. A previous Kaluza-Klein (KK) interpretation for  $SU(2) \times SU(2)$  gauged supergravity was given in [3] where this model was identified as part of the effective D = 4 theory for the heterotic string in an  $S^3 \times S^3$  vacuum. These two Kaluza-Klein interpretations are similar up to consistent truncations. For a review on gauged supergravities and their KK-interpretations one can see the reports [4, 5]. Our present work is motivated in part by the recent studies on AdS-supergravities [6] in string theory. It is an observation, at least in string inspired low energy supergravities, that the Freund-Rubin type vacua  $AdS_{p+2} \times S^m$  [7] do arise in the near horizon limit of the spacetimes around fundamental p-branes, like M2, M5 and D3-branes. In addition various intersections of M-p-branes and D-p-branes do also give rise to spacetimes which have near horizon geometries as  $AdS_{p+2} \times S^m \times \mathcal{M}^n$  [8]. Our aim is here to realise this observation in the context of above gauged supergravity in four dimensions. There are known anti-de Sitter vacua like  $AdS_2 \times R^2$ , the 'electro-vac' solution [9], and the pure axionic background or 'axio-vac' <sup>2</sup> with the geometry  $AdS_3 \times R^1$ [10] in four dimensional gauged supergravity. The idea is that the connection between AdS vacua and brane geometries must also exist in the case of gauged supergravity backgrounds. This connection might help us to extend the AdS/CFT-conjecture [6] to the gauged supergravity sector. We will show explicitly that the axio-vac and electro-vac are nothing but the intersections of domain-walls with strings and point-like objects in four dimensions.

We start with the D = 4, N = 4 gauged  $SU(2)_A \times SU(2)_B$  supergravity which in the gravity multiplet contains the graviton  $E^m_{\mu}$ , four Majorana spin-3/2 gravitinos  $\Psi^I_{\mu}$ , three non-abelian vector fields  $A^a_{\mu}$  belonging to  $SU(2)_A$ , three non-abelian axial-vector fields  $B^a_{\mu}$  belonging to  $SU(2)_B$ , four Majorana spin-1/2 fields  $\chi^I$ , the dilaton field  $\phi$ , and an axion  $\eta$  [1]. Here we consider the truncated version where half of the gauge fields  $B^a_{\mu}$  are vanishing. We will also set all the spinor background fields to zero. Under these specifications the bosonic action [1] becomes

$$S = \int d^4x \sqrt{-g} \left[ -R + \frac{1}{2} \partial_\mu \phi \partial^\mu \phi + \frac{1}{2} e^{2\phi} \partial_\mu \eta \partial^\mu \eta - \frac{1}{2 \cdot 2!} e^{-\phi} F^a_{\mu\nu} F^{a\mu\nu} - \frac{1}{2 \cdot 2!} \eta F^a_{\mu\nu} \tilde{F}^{a\mu\nu} + \frac{\Lambda^2}{2} e^{\phi} \right]$$
(1)

<sup>&</sup>lt;sup>2</sup>This terminology was adopted in [12] and we shall be using it throughout this work.

where  $\Lambda^2 = e_A^2 + e_B^2$ ,  $e_A$  and  $e_B$  being the gauge couplings of respective SU(2) groups and the field strength  $F^a_{\mu\nu}$  is defined as

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + e_A \epsilon_{abc} A^b_\mu A^c_\nu, \quad \tilde{F}^a_{\mu\nu} = \frac{1}{2} \epsilon^{\ \sigma\rho}_{\mu\nu} F^a_{\sigma\rho}.$$
 (2)

The corresponding supersymmetry transformations for the vanishing fermionic background are [1],

$$\delta \bar{\chi}^{I} = \frac{i}{2\sqrt{2}} \bar{\epsilon}^{I} \left( \partial_{\mu} \phi + i\gamma_{5} e^{\phi} \partial_{\mu} \eta \right) \gamma^{\mu} - \frac{1}{4} e^{-\frac{\phi}{2}} \bar{\epsilon}^{I} \alpha^{a} F^{a}_{\mu\nu} \Gamma^{\mu\nu} + \frac{1}{4} e^{\frac{\phi}{2}} \bar{\epsilon}^{I} \left( e_{A} + i\gamma_{5} e_{B} \right),$$
  

$$\delta \bar{\Psi}^{I}_{\mu} = \bar{\epsilon}^{I} \left( \overleftarrow{\partial}_{\mu} - \frac{1}{2} \omega_{\mu,mn} \Gamma^{mn} + \frac{1}{2} e_{A} \alpha^{a} A^{a}_{\mu} \right) - \frac{i}{4} e^{\phi} \bar{\epsilon} \gamma_{5} \partial_{\mu} \eta - \frac{i}{4\sqrt{2}} e^{-\frac{\phi}{2}} \bar{\epsilon}^{I} \alpha^{a} F^{a}_{\nu\rho} \gamma_{\mu} \Gamma^{\nu\rho} + \frac{i}{4\sqrt{2}} e^{\frac{\phi}{2}} \bar{\epsilon}^{I} \left( e_{A} + i\gamma_{5} e_{B} \right) \gamma_{\mu}, \qquad (3)$$

where  $\epsilon^{I}$  are four spacetime dependent Majorana spinors. Since fermionic backgrounds are absent therefore the bosonic fields do not vary under supersymmetry. Our convention for the metric is with mostly minus signs (+ - - -).  $\{\gamma_{\mu}, \gamma_{\nu}\} = 2 g_{\mu\nu}, \mu = 0, 1, 2, 3, \text{ and}$  $\gamma_{5}^{2} = 1. \ \omega_{\mu},^{mn}$  are the spin connections, and  $\Gamma_{mn} = \frac{1}{4}[\Gamma_{m}, \Gamma_{n}]$ , where m, n are tangent space indices.  $\alpha^{a}$  are three  $4 \times 4$  matrices belonging to  $SU(2)_{A}$  which along with rest three generators of  $SU(2)_{B}$  generate the  $(\frac{1}{2}, \frac{1}{2})$  representation of the gauged model [1].

As can be seen from (1) that dilaton potential has nonvanishing contribution from the cosmological constant term. It suggests that one can obtain a domain-wall (membrane) configuration in the vacuum of this theory. This background, independently reported in [11] and [10], is given by

$$ds^{2} = U(y) \left( dt^{2} - dx_{1}^{2} - dx_{2}^{2} \right) - U(y)^{-1} dy^{2},$$
  

$$\phi = -\ln U, \qquad U = m|y - y_{0}|,$$
  

$$A_{\mu}^{a} = 0, \qquad \eta = 0,$$
(4)

 $m^2 = \Lambda^2/2$ . For this background,  $e^{\phi}$ , analog of string coupling, vanishes at asymptotic infinity  $(y \to \pm \infty)$  and so also the curvature scalar. But both are divergent at  $y = y_0$ . Singularity at  $y = y_0$  is the position of the domain wall. The isometry group of this background is  $P_3(1,2) \times \mathbb{Z}_2$ , where  $P_3$  is three dimensional Pöncare group and  $\mathbb{Z}_2$  is the reflection symmetry of the dilaton potential around  $y = y_0$ . Domain-wall solution in (4) preserves half supersymmetries with the supersymmetry parameter for  $e_B = 0$ ,  $\Lambda = e_A$ given by

$$\bar{\epsilon}^I \Gamma_3 = i \ \bar{\epsilon}^I, \qquad \bar{\epsilon}^I = U^{\frac{1}{4}} \ \bar{\epsilon}_0^I$$
(5)

 $\epsilon_0^I$  is a constant spinor.

Apart from domain-walls we also obtained in [10] axio-vac solution with geometry  $AdS_3 \times R^1$  and a 'dilaton-axion' background both of them preserve 1/4 supersymmetries. Below we will see that these two backgrounds are two different intersections of domain-walls with string.

# 2 Orthogonally intersecting double domain-walls

As we saw in the previous section that domain-wall is the most natural (fundamental) object in gauged supergravity which preserves 1/2 supersymmetries, one can also extend the programme and obtain various intersections of domain walls which will preserve less than half supersymmetries. Correspondingly we obtain a background configuration representing an orthogonal intersection of two domain walls given by

$$ds^{2} = U_{1}U_{2}(dt^{2} - dx^{2}) - U_{2}U_{1}^{-1}dy_{1}^{2} - U_{1}U_{2}^{-1}dy_{2}^{2}$$
  

$$\phi = -\log U_{1}U_{2},$$
(6)

while other bosonic fields are set to zero. Here  $U_1 = m_1|y_1|$  and  $U_2 = m_2|y_2|$  are the two harmonic functions along the transverse directions  $y_1$  and  $y_2$  respectively,  $m_1^2 + m_2^2 = \Lambda^2/2$ . Note that t - x plain represents the common intersection plain of two walls while  $y_1$  and  $y_2$  serve as their mutual transverse coordinates. The background configuration in (6) preserves 1/4 of the supersymmetries.

Having obtained orthogonally intersecting domain-walls it is quite straightforward to embed an extended string at the common intersection line of the two domain walls. In doing this we do not break any more supersymmetries and get a new background

$$ds^{2} = U_{1}U_{2}(dt^{2} - dx^{2}) - FU_{2}U_{1}^{-1}dy_{1}^{2} - FU_{1}U_{2}^{-1}dy_{2}^{2}$$
  

$$\phi = -\log FU_{1}U_{2}, \quad d\eta =^{*} e^{-2\phi}H_{(3)}$$
  

$$H_{(3)} = dt \wedge dx \wedge dF^{-1}$$
(7)

such that the new function F depends only on  $y_1$  and  $y_2$  and satisfies the constraint

$$(\partial_1 U_1^2 \partial_1 + \partial_2 U_2^2 \partial_2) F(y_1, y_2) = 0.$$
(8)

The harmonic functions  $U_1$  and  $U_2$  are same as in (6). The Killing spinors for the background (7) are, for  $m_1 = e_A/\sqrt{2}$ ,  $m_2 = e_B/\sqrt{2}$ ,

$$\bar{\epsilon}^I = U_1^{1/4} \ U_2^{1/4} \ \bar{\epsilon}_0^I, \quad \bar{\epsilon}^I (i \ \Gamma_2 + 1) = 0, \quad \bar{\epsilon}^I (\Gamma_3 + \gamma_5) = 0.$$

Before dwelling further let us discuss some specific cases below which follow from the solutions of eq.(8). It is clear that there are two nontrivial solutions of the equation (8). For the trivial one F = constant the background (7) reduces to intersecting wall configuration in (6) with 'no' string.

• The first nontrivial configuration is obtained when we solve (8) by setting  $F^{-1} = U_1 U_2$ . Then we get

$$ds^{2} = U_{1}U_{2}(dt^{2} - dx^{2}) - U_{1}^{-2}dy_{1}^{2} - U_{2}^{-2}dy_{2}^{2}$$
  

$$\phi = 0, \quad d\eta =^{*} e^{-2\phi}H_{(3)}$$
  

$$H_{(3)} = dt \wedge dx \wedge dF^{-1}.$$
(9)

We note that (9) could be the background obtained in near horizon limit of intersecting string-five-brane description in ten dimensions [12]. In that case analog of parameters  $m_1$  and  $m_2$  would be the charges  $Q_5$  and  $Q'_5$  of two orthogonally intersecting NS5-branes. In background (9) when  $m_1 = m_2 = \Lambda/2$  one can define new coordinates in the upper right (+ve) quardrant of the  $y_1 - y_2$  plain,

$$|y_1||y_2| = e^{-\Lambda/\sqrt{2}\rho}, \quad |y_1|/|y_2| = e^{\Lambda/\sqrt{2}\sigma}$$

then it becomes after the rescaling  $t \to \Lambda/2 t$ ,  $x \to \Lambda/2 x$ 

$$ds^{2} = e^{-\Lambda/\sqrt{2}\rho} (dt^{2} - dx^{2}) - d\rho^{2} - d\sigma^{2}, \quad \phi = 0, \quad d\eta = -\Lambda/\sqrt{2} \, d\sigma \tag{10}$$

This has a geometry of  $AdS_3 \times R^1$  and is similar to the axio-vac in [10] as recently discussed in [12] in the frame work of ten dimensional theory.

• Instead if we consider  $F^{-1} = U_2$  then we obtain from (8)

$$ds^{2} = U_{1} \left( U_{2} (dt^{2} - dx^{2}) - \frac{dy_{2}^{2}}{U_{2}^{2}} \right) - U_{1}^{-1} dy_{1}^{2}$$
  

$$\phi = \log U_{1}, \quad d\eta =^{*} e^{-2\phi} H_{(3)}$$
  

$$H_{(3)} = dt \wedge dx \wedge dF^{-1}.$$
(11)

Note the three spacetime line element within bracketts in (11) is an  $AdS_3$  space. Thus what we have got is nothing but the 'dilaton-axion' background of [10]. Further, if we set  $U_1 = 1$ ,  $e_A = 0$  in (11) then it reduces to the 'axio-vac' where only axion field  $\eta$  is nontrivial in addition to gravity. The geometry also becomes  $AdS_3 \times R^1$ . It was shown explicitly in [10] that dilaton-axion and axio-vac backgrounds preserve at least one quarter of the supersymmetry. Since for the axio-vacs the space-time geometry is anti-de Sitter space there will be more Killing spinors in addition to those reported in [10]. We write down complete set of Killing spinors for the axio-vac which follows from (11) along the lines discussed above

$$\bar{\epsilon}^{I} = U_{2}^{1/4} \bar{\epsilon}_{+}^{I}, \quad \text{for } \bar{\epsilon}_{+}^{I} (i\Gamma_{3} + 1)(\Gamma_{2}\gamma_{5} + 1) = 0$$
  
=  $\bar{\epsilon}_{-}^{I} \left( U_{2}^{-1/4} + \frac{m_{2}}{2} U^{1/4} \gamma_{5}(\Gamma_{0}t + \Gamma_{1}x) \right), \quad \text{for } \bar{\epsilon}_{-}^{I} (i\Gamma_{3} + 1)(\Gamma_{2}\gamma_{5} - 1) = 0, (12)$ 

where  $\bar{\epsilon}^{I}_{\pm}$  are constant spinors. The fact that we are in an anti-de Sitter spacetime there is always an enhancement (doubling) of the supersymmetries [4]<sup>3</sup>. This doubles the amount of supersymmetry for axio-vacs to N = 2. This fact will also be at work when we discuss electro-vacs in the next section <sup>4</sup>.

## 3 Intersections of three domain-walls

We are also able to obtain a spacetime configuration as the vacuum of the supergravity theory in (1) where all spatial directions are occupied by domain walls. This is given by

$$ds^{2} = U_{1}U_{2}U_{3}dt^{2} - U_{1}^{-1}U_{2}U_{3}dy_{1}^{2} - U_{1}U_{2}^{-1}U_{3}dy_{2}^{2} - U_{1}U_{2}U_{3}^{-1}dy_{3}^{2}$$
  

$$\phi = -\log U_{1}U_{2}U_{3}, \quad U_{i} = m_{i}|y_{i}|, \qquad (13)$$

such that  $\sum_{i=1}^{3} m_i^2 = \Lambda^2/2$  while other bosonic fields are trivial. This background however breaks all supersymmetries in the theory. It can be supersymmetric only if one of the functions  $U_i$  is switched off in that case it reduces to the double-wall configuration. Let us now dress this background with U(1) charges. To keep it simple we consider the case when single U(1) gauge field is nontrivial and is such that it gives rise to electric fields only. This background is

$$ds^{2} = F^{-1}U_{1}U_{2}U_{3}dt^{2} - F\left(U_{1}^{-1}U_{2}U_{3}dy_{1}^{2} + U_{1}U_{2}^{-1}U_{3}dy_{2}^{2} + U_{1}U_{2}U_{3}^{-1}dy_{3}^{2}\right)$$
  

$$\phi = -\log FU_{1}U_{2}U_{3}, \quad U_{i} = m_{i}|y_{i}|,$$
  

$$F_{(2)}^{a} = \sqrt{2} \,\delta^{a3}dt \wedge dF^{-1}$$
(14)

where  $m_i$ 's satisfy the constraint as in (13) and the new function  $F(y_1, y_2, y_3)$  satisfies

$$(\partial_1 U_1^2 \partial_1 + \partial_2 U_2^2 \partial_2 + \partial_3 U_3^2 \partial_3)F = 0.$$
(15)

 $<sup>^{3}\</sup>mathrm{I}$  am grateful to M. Tonin for the discussions on this subject.

<sup>&</sup>lt;sup>4</sup> We note that Killing spinors for various  $AdS \times Sphere$  spaces have been recently constructed in [13].

Given this general situation there can be many solutions of (15) and hence many new backgrounds. However, not all of them will be supersymmetric. Consider first the special case when  $e_A = 0$ ,  $m_1 = e_B/\sqrt{2}$  and the harmonic functions  $U_2 = 1$ ,  $U_3 = 1$ . In that case (14) reduces to a single domain-wall with electric U(1) flux

$$ds^{2} = F^{-1}U_{1}dt^{2} - F\left(U_{1}^{-1}dy_{1}^{2} + U_{1}dy_{2}^{2} + U_{1}dy_{3}^{2}\right)$$
  

$$\phi = -\log FU_{1}, \quad U_{1} = (e_{B}/\sqrt{2}) |y_{1}|,$$
  

$$F_{(2)}^{a} = \sqrt{2}\delta^{a3}dt \wedge dF^{-1}$$
(16)

where F satisfies

$$\partial_1 U_1^2 \partial_1 F = 0. \tag{17}$$

The Killing spinors in this background are

$$\bar{\epsilon}^{I} = F^{-\frac{1}{4}} U_{1}^{\frac{1}{4}} \bar{\epsilon}_{0}^{I}$$
(18)

where the arbitrary constant spinors satisfy the constraints  $\bar{\epsilon}_0^I(\Gamma_1 + \gamma_5) = 0$ ,  $\bar{\epsilon}_0^I(i\alpha^3\Gamma_0 + 1) = 0$ . These two conditions on Killing spinors break supersymmetry to 1/4 leaving behind only four independent components hence N = 1 supersymmetry. However if we consider the solution of (17) to be  $F^{-1} = U_1$  we get

$$ds^{2} = U_{1}^{2}dt^{2} - \frac{dy_{1}^{2}}{U_{1}^{2}} - dy_{2}^{2} - dy_{3}^{2}$$
  

$$\phi = 0, \quad F_{(2)}^{a} = \sqrt{2} \ m_{1}\delta^{a3}dt \wedge d|y_{1}|$$
(19)

which is the well known *electro-vac* solution with geometry  $AdS_2 \times R^2$  obtained by Freedmann and Gibbons[9] and preserving N = 2 supersymmetry. It was shown in [9] that supersymmetric electro-vacs exist only for purely electric configuration while in the presence of magnetic field the spacetime geometry becomes  $AdS_2 \times S^2$  and it does not preserve any supersymmetry. This is the reason why we started with a purely electric configuration in (14). For the electro-vac (19) we write down the (static) Killing spinors which straightforwardly follow from (18) after the substitution  $F^{-1} = U_1$ 

$$\bar{\epsilon}^{I} = U_{1}^{1/2} \ \bar{\epsilon}_{+}^{I}$$
$$\bar{\epsilon}_{+}^{I} (\Gamma_{1} + \gamma_{5}) = 0, \quad \bar{\epsilon}_{+}^{I} (1 - \alpha^{3} \Gamma_{2} \Gamma_{3}) = 0.$$
(20)

These twin conditions, however, leave only 1/4 supersymmetries intact. But the electrovac (19) must preserve 1/2 supersymmetries [9]. So there must be more Killing spinors. One can find there does exist another set of (nonstatic) Killing spinors for the background (19)

$$\bar{\epsilon}^{I} = \bar{\epsilon}^{I}_{-} \left( U_{1}^{-1/2} + m_{1} U_{1}^{1/2} \gamma_{5} \Gamma_{0} t \right)$$
  
$$\bar{\epsilon}^{I}_{-} (\Gamma_{1} - \gamma_{5}) = 0, \quad \bar{\epsilon}^{I}_{-} (1 - \alpha^{3} \Gamma_{2} \Gamma_{3}) = 0.$$
(21)

which gives four more independent components. Hence Killing spinors (20) and (21) together make N = 2 supersymmetry.

Thus the electro-vac configuration (19) describes a domain-wall with U(1) electricflux along the transverse  $y_1$  direction. The domain-wall occupies the directions t,  $y_1$ ,  $y_2$ . Other solutions of eq.(15) such as  $F^{-1} = U_1U_2$  and  $F^{-1} = U_1U_2U_3$  will generate further new backgrounds.

# 4 Conclusion

In this work we have found the existence of various intersecting domain-wall configurations in the vacuum of the  $SU(2) \times SU(2)$  gauged supergravity in four dimensions. We have explicitly shown that some of the previously known AdS backgrounds of this gauged supergravity are essentially the intersecting domain-wall configurations. These include the identification of anti-de Sitter vacua like 'axio-vac' [10] with the intersection of the domain-wall with an extended string and that of 'electro-vac' [9] with the intersection of a domain-wall with point-like objects. An issue relating to the supersymmetries preserved by axio-vac backgrounds is also clarified. We speculate that these identifications of antide Sitter gauged supergravity vacua with the intersecting branes might help in extending AdS/CFT-conjecture [6] down to gauged supergravity, at least in four dimensions.

This work also suggests that similar intersecting domain-wall configurations can also be obtained in other gauged supergravities in dimensions greater than four.

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