The conformal brane-scan: an update

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Abstract

Generalizing the The Membrane at the End of the Universe, a 1987 paper Supersingletons by Blencowe and the author conjectured the existence of BPS $p$-brane configurations ($p = 2, 3, 4, 5$) and corresponding CFTs on the boundary of anti-de Sitter space with symmetries appearing in Nahm’s classification of superconformal algebras: $\text{OSp}(N|4)$ $N = 8, 4, 2, 1$; $\text{SU}(2, 2|N)$ $N = 4, 2, 1$; $F^2(4)$; $\text{OSp}(8^*|N)$, $N = 4, 2$. This correctly predicted the $D3$-brane with $\text{SU}(2, 2|4)$ on $AdS_5 \times S^5$ and the $M5$-brane with $\text{OSp}(8^*|2)$ on $AdS_7 \times S^4$, in addition to the known $M2$-brane with $\text{OSp}(8|4)$ on $AdS_3 \times S^7$. However, finding non-singular AdS solutions matching the other symmetries was less straightforward. Here we perform a literature search and confirm that all of the empty slots have now been filled, thanks to a number of extra ingredients including warped products and massive Type IIA. Orbifolds, orientifolds and S-folds also play a part providing examples not predicted: $\text{SU}(2, 2|3)$, $\text{OSp}(3, 4)$ and $\text{OSp}(5, 4)$ (but not $\text{OSp}(7, 4)$). We also examine the status of $p = (0, 1)$ configurations.

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Our mistake is not that we take our theories too seriously, but that we do not take them seriously enough.

Steven Weinberg

1 Supersingletons

The Membrane at the End of the Universe [1, 2, 3, 4, 5, 6, 7, 8, 9, 10] was the name given to a supermembrane [11] (later called the M2-brane) on the $S^1 \times S^2$ boundary of $AdS_4 \times S^7$ described by a SCFT with symmetry

$$OSp(8|4) \supset SO(3, 2) \times SO(8) \quad (1.1)$$

namely the $N = 8$ singleton supermultiplet with 8 scalar and 8 spinors and $SO(8)$ R symmetry. We recall that representations of $SO(3, 2)$ are denoted $D(E_0, s)$ where $E_0$ is the lowest energy eigenvalue which occurs and $s$ is the total angular momentum quantum number of the lowest energy state, analogous to the mass and spin of the Poincare group. However, Dirac’s singletons $D(1/2, 0)$ and $D(1, 1/2)$ have no four-dimensional Poincare analogue [12] and are best interpreted a residing on the three-dimensional boundary [13] [14] [2].

| $d$ | $G$ | $H$ | $N$ even | Susy |
|-----|-----|-----|--------|------|
| 6   | $OSp(8^*|N)$ | $SO^*(8) \times USp(N)$ | $N$ even | $8N$ |
| 5   | $F^2(4)$ | $SO(5, 2) \times SU(2)$ |  | 16   |
| 4   | $SU(2, 2|N)$ | $SU(2, 2) \times U(N)$ | $N \neq 4$ | $8N$ |
|     | $SU(2, 2|4)$ | $SU(2, 2)$ |  | 32   |
| 3   | $OSp(N|4)$ | $SO(N) \times Sp(4, R)$ |  | $4N$ |
| 2   | $G_+ \times G_-$ |  |  |  |
| 1   | $G_+ = OSp(N|2)$ | $O(N)$ |  | $2N$ |
|     | $SU(N/1, 1)$ | $U(N) \times SU(1, 1)$ | $N \neq 2$ | $4N$ |
|     | $SU(2/1, 1)$ | $SU(2) \times SU(1, 1)$ |  | 8    |
|     | $OSp(4^*/2N)$ | $SU(2) \times USp(2N) \times SU(1, 1)$ |  | $8N$ |
|     | $G(3)$ | $G_2 \times SU(1, 1)$ |  | 14   |
|     | $F(4)$ | $Spin(7) \times SU(1, 1)$ |  | 16   |
|     | $D^1(2, 1, \alpha)$ | $SU(2) \times SU(2) \times SU(1, 1)$ |  | 8    |

Table 1: Following [15] [16] we list the AdS supergroups in $d \leq 6$ and their bosonic subgroups in the notation of [17].

Accordingly, in 1987 Blencowe and the author [3] conjectured the existence of other BPS $p$-brane configurations with $p = (2, 3, 4, 5)$ on the $S^1 \times S^p$ boundary of $AdS_{(p+2)}$ and corresponding
| Supergroup | Supermultiplet | $B^-$ | $V$ | $\chi$ | $\phi$ | $D$ |
|------------|----------------|-----|-----|-----|-----|-----|
| $AdS_3$    | $OSp(n|2) \times OSp(8-n|2)$ | $(n_+, n_-) = (n, 8-n), d = 2$ | singleton | 0 | 0 | 8 | 8 | 10 |
|            | $OSp(n|2) \times OSp(4-n|2)$ | $(n_+, n_-) = (n, 4-n), d = 2$ | singleton | 0 | 0 | 4 | 4 | 6 |
|            | $OSp(n|2) \times OSp(2-n|2)$ | $(n_+, n_-) = (n, 2-n), d = 2$ | singleton | 0 | 0 | 2 | 2 | 4 |
|            | $OSp(n|2) \times OSp(1-n|2)$ | $(n_+, n_-) = (n, 1-n), d = 2$ | singleton | 0 | 0 | 1 | 1 | 3 |
| $AdS_4$    | $OSp(8|4)$     | $n = 8, d = 3$ | singleton | 0 | 0 | 8 | 8 | 11 |
|            | $OSp(4|4)$     | $n = 4, d = 3$ | singleton | 0 | 0 | 4 | 4 | 7 |
|            | $OSp(2|4)$     | $n = 2, d = 3$ | singleton | 0 | 0 | 2 | 2 | 5 |
|            | $OSp(1|4)$     | $n = 1, d = 3$ | singleton | 0 | 0 | 1 | 1 | 4 |
| $AdS_5$    | $SU(2,2|2)$    | $n = 2, d = 4$ | doubleton | 0 | 0 | 2 | 4 | 8 |
|            | $SU(2,2|1)$    | $n = 1, d = 4$ | doubleton | 0 | 0 | 1 | 2 | 6 |
|            | $SU(2,2|4)$    | $n = 4, d = 4$ | doubleton | 0 | 1 | 4 | 6 | 10 |
|            | $SU(2,2|2)$    | $n = 2, d = 4$ | doubleton | 0 | 1 | 2 | 2 | 6 |
|            | $SU(2,2|1)$    | $n = 1, d = 4$ | doubleton | 0 | 1 | 1 | 0 | 4 |
| $AdS_6$    | $F^2(4)$       | $n = 2, d = 5$ | doubleton | 0 | 0 | 2 | 4 | 9 |
| $AdS_7$    | $OSp(8^*|2)$   | $(n_+, n_-) = (1, 0), d = 6$ | triplet | 0 | 0 | 1 | 4 | 10 |
|            | $OSp(8^*|4)$   | $(n_+, n_-) = (2, 0), d = 6$ | triplet | 0 | 1 | 2 | 5 | 11 |
|            | $OSp(8^*|2)$   | $(n_+, n_-) = (1, 0), d = 6$ | triplet | 1 | 0 | 1 | 1 | 7 |

Table 2: Superconformal groups and their singleton, doubleton and tripleton representations. $B^-$, $V$, $\chi$, $\phi$ denote the number of chiral 2-forms, vector, spinors and scalars in each multiplet. The spacetime dimension $D$ equals the worldvolume dimension $d$ plus the number of scalars.

CFTs with other symmetries appearing in Nahm’s classification of superconformal algebras [15], listed in Table 1.

In each case the boundary CFT is described by the corresponding singleton (scalar), doubleton (scalar or vector) or tripleton (scalar or tensor) supermultiplet as shown in Table 2. The number of dimensions transverse to the brane, $D - d$, equals the number of scalars in the supermultiplets. None of these BPS brane CFTs is self-interacting. (For non-BPS see [18, 19]).

A plot of spacetime dimension $D$ vs worldvolume dimension $d = p + 1$, known as the brane-scan, is shown in Table 3. This correctly predicted the $D3$-brane [20, 21, 22, 23, 24, 25] with $SU(2,2|4)$ on $AdS_5 \times S^5$ and the $M5$-brane [26, 22, 23] with $OSp(8^*|2)$ on $AdS_7 \times S^4$, in addition to the known $M2$-brane [23] with $OSp(8^*|4)$ on $AdS_4 \times S^7$. The purpose of the present paper is

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1Our nomenclature, based on the rank of $AdS_{p+2}$, is singleton $p = 2$, doubleton $p = (2, 3)$, tripleton $p = (4, 5)$ and differs from that of Günaydin and Minic [17].
|   | SCALAR |   |
|---|--------|---|
| 11 | $\text{OSp}(n|2) \times \text{OSp}(8-n|2)$ | $\text{OSp}(8^*|2)$ |
| 10 | $\text{OSp}(n|2) \times \text{OSp}(8-n|2)$ | $F^2(4)$ |
|  9 | $\text{SU}(2,2|2)$ | |
|  8 | $\text{OSp}(4|4)$ | |
|  7 | $\text{SU}(2,2|2)$ | |
|  6 | $\text{OSp}(2|4)$ | |
|  5 | $\text{SU}(2,2|1)$ | |
|  4 | $\text{OSp}(1|4)$ | |
|  3 | $\text{OSp}(n|2) \times \text{OSp}(1-n|2)$ | |
|  2 | $\text{OSp}(n|2) \times \text{OSp}(1-n|2)$ | |
|  1 | $\text{OSp}(n|2) \times \text{OSp}(1-n|2)$ | |
|  0 | $\text{OSp}(n|2) \times \text{OSp}(1-n|2)$ | |

|   | VECTOR |   |
|---|--------|---|
| 11 | $\text{SU}(2,2|4)$ | |
| 10 | $\text{SU}(2,2|4)$ | |
|  9 | $\text{SU}(2,2|2)$ | |
|  8 | $\text{SU}(2,2|2)$ | |
|  7 | $\text{SU}(2,2|1)$ | |
|  6 | $\text{SU}(2,2|1)$ | |
|  5 | $\text{SU}(2,2|1)$ | |
|  4 | $\text{SU}(2,2|1)$ | |
|  3 | $\text{SU}(2,2|1)$ | |
|  2 | $\text{SU}(2,2|1)$ | |
|  1 | $\text{SU}(2,2|1)$ | |
|  0 | $\text{SU}(2,2|1)$ | |

|   | TENSOR |   |
|---|--------|---|
| 11 | $\text{OSp}(8^*|4)$ | |
| 10 | $\text{OSp}(8^*|4)$ | |
|  9 | $\text{OSp}(8^*|2)$ | |
|  8 | $\text{OSp}(8^*|2)$ | |
|  7 | $\text{OSp}(8^*|2)$ | |
|  6 | $\text{OSp}(8^*|2)$ | |
|  5 | $\text{OSp}(8^*|2)$ | |
|  4 | $\text{OSp}(8^*|2)$ | |
|  3 | $\text{OSp}(8^*|2)$ | |
|  2 | $\text{OSp}(8^*|2)$ | |
|  1 | $\text{OSp}(8^*|2)$ | |
|  0 | $\text{OSp}(8^*|2)$ | |

Table 3: The brane-scans of superconformal groups: scalar supermultiplets: singletons ($p = 1, 2$), doubletons ($p = 3, 4$) and tripletons ($p = 5$); vector supermultiplets: doubletons ($p = 3$); tensor supermultiplets: tripletons ($p = 5$). The M2-, D3- and M5-branes are in boldface.
to report that all of the other slots have now been filled, thanks to a number of extra ingredients: warped products, massive Type IIA and Chern-Simons theories. Orbifolds, orientifolds and S-folds also play a part providing examples not predicted: $SU(2,2|3)$ and $\text{OSp}(3,4) \text{OSp}(5,4)$ (but not $\text{OSp}(7,4)$). We also examine the status of $p = (0,1)$ configurations.

## 2 The conformal brane-scan

Comments:

- The list in Table 1 is complete if one assumes that the Killing superalgebras of $AdS$ backgrounds are simple. However a more detailed investigation reveals that there may be some additional central generators in the Killing superalgebra for $AdS_3$ and $AdS_5$ backgrounds [27, 28].

- The supersingleton lagrangian and transformation rules were also spelled out explicitly in [3]. This conformal or (in later terminology) near-horizon brane-scan differs from the scan of Green-Schwarz type kappa-symmetric branes [29] which are not in general conformal and which, in any case, include only scalar supermultiplets. Further developments and elaborations on the brane-scan are summarized in Schreiber’s n-lab https://ncatlab.org/nlab/show/brane+scan and references therein.

- In early 1988, Nicolai, Sezgin and Tanii [5] independently put forward the same generalization of the Membrane at the End of the Universe idea, spelling out the doubleton and triplet lagrangian and transformation rules, in addition to the singleton. However, by insisting on only scalar supermultiplets as in [29] their list excluded the vector or tensor brane-scans of Table 3. In this case, as they point out, the spheres are just the parallelizable ones $S^1, S^3$ and $S^7$.

- The two factors appearing in the $p = 1$ case, $G_+ \times G_-$, are simply a reflection of the ability of strings to have left and right and movers on the worldsheet [30]. In this case, there are many candidate supergroups as shown in Table 1 so for $p = 0, 1$ we did not attempt a complete list of which of these would eventually be realized. In [3], we focused on Type IIA, Type IIB and heterotic strings with $\text{OSp}(n|2)_c \times \text{OSp}(8-n|2)_c$, $\text{OSp}(n|2)_c \times \text{OSp}(8-n|2)_c$ and $\text{OSp}(n|2)_c \times \text{Sp}(2,R)$, respectively, since the singleton CFTs (but not the supergravity $AdS_3$ solutions) had already been identified [30]. For concreteness the Type IIA case appears on the scan of Table 3.

- Even for $p \geq 2$ not all of the conformal algebras listed in Table 1 appear in the scan. For example, since none of our CFTs is self-interacting, we restricted $SU(2,2|N)$ to $N = 1, 2, 4$ since perturbatively $N = 3$ implies $N = 4$. But we now know there are nonperturbative interacting CFTs with just $N = 3$ [31, 32, 33, 34]. We also focused on $N = 1, 2, 4, 8$ in $OSp(N|4)$ since they corresponded to the division algebra $R,C,H,O$ interpretation of the four diagonal lines in the scalar branescan of Table 3.
3 Significance of the brane-scan

The significance of the $M2$, $D3$ and $M5$ and indeed the other configurations on the brane-scan became clearer thanks to four major developments:

- **Branes as solitons**
  The realization that string theory admits p-branes as solitons \[35, 36, 37, 38, 21, 20, 39, 40\]

- **M-theory**
  The realization that the Type IIA superstring in $D = 10$ could be interpreted \[41\] as a wrapped supermembrane in $D = 11$ \[11\]. The membrane is a 1/2 BPS solution of $D = 11$ supergravity \[42\], whose spacetime approaches Minkowski space far away from the brane but $AdS_4 \times S^7$ close to the brane, jumping to the full $OSp(4|8)$ in the limit \[43\]. Regarded as an extremal black-brane, this limit was also called the near-horizon limit. Moreover multi-brane solutions could be obtained by stacking $N$ branes on top of one another \[42\], yielding quantized 4-form flux. So $AdS_4 \times S^7$ could equally well be regarded as the large $N$ limit. A similar story applied to its magnetic dual fivebrane \[26\] as a solution of $D = 11$ supergravity. Moreover, the five string theories were merely different corners of an overarching M-theory \[44, 45, 46\] with $D = 11$ supergravity as its low-energy limit. The membrane and fivebrane were accordingly renamed M2 and M5.

- **D-branes**
  The realization that p-branes carrying RR charge, with a closed-string interpretation as solitons, admitted an alternative open string interpretation as Dirichlet-branes, surfaces of dimension $p$ on which open strings can end \[25\]. In particular the self-dual 3-brane, a solution of Type IIB supergravity with $AdS_5 \times S^5$ and $SU(2, 2|4)$ in the large N limit, was reinterpreted as a D3-brane and renamed accordingly.

- **AdS/CFT**
  The AdS/CFT conjecture \[47, 48, 49\] proposes that large N limits of certain conformal field theories in $d$ dimensions can be described in terms of supergravity (and string theory) on the product of $d+1$-dimensional AdS space with a compact manifold. Another vital ingredient, missing in the early days, was the non-abelian nature of the symmetries that appear when we stack $N$ branes on top of one another \[174\]. Examples include $N = 4$ Yang-Mills in $D = 4$ from $AdS_5 \times S^5$ and ABJM theory \[50\] from $AdS_4 \times S^7/Z_n$.

4 The missing ingredients $p \geq 2$

Notwithstanding the success with $M2$, $D3$ and $M5$, for quite some time the status of the other slots on the brane-scans remained obscure\[3\]. Here we perform a literature search and confirm

\[2\]In \[51\] we entertained the idea that they might arise from classical branes whose symmetry is enhanced when $\alpha'$ corrections are taken into account, but this did not pan out.
that all of the empty slots have now been filled, largely thanks to warped products and massive Type IIA, as shown below

- \( d=6 \) \( \text{OSp}(8^*|4), \text{OSp}(8^*|2) \) [52, 53, 54, 55, 56, 57]
- \( d=5 \) \( F^2(4) \) [58, 59, 60, 61, 62, 63, 64, 65]
- \( d=4 \) \( SU(2,2|N) \) \( N = 4, 2, 1; \) [20, 66, 67, 68, 69]
- \( d=3 \) \( \text{OSp}(N|4) \) \( N = 1, 2, 4, 8 \) [42, 70, 71, 72, 73, 74, 75]

Comments

- There are no \( AdS_7 \) solutions in Types IIA and IIB. In M all are locally isometric to \( AdS_7 \times S^4 \).
- There are no maximally supersymmetric \( AdS_6 \) backgrounds in M, IIA or IIB. There are no half BPS (16 supersymmetries) \( AdS_6 \) backgrounds in M and IIA with compact internal space.
- There are no such \( AdS_5 \) solutions that preserve \( >16 \) supersymmetries in IIA and D=11. In IIB, all supersymmetric solutions are locally isometric to \( AdS_5 \times S^5 \). This means that all backgrounds preserving 24 supersymmetries in IIB are locally \( AdS_5 \times S^5 \).
- There are no \( >16 \) \( AdS_4 \) supersymmetric solutions in IIA and IIB. In D=11 all \( >16 \) supersymmetric solutions are locally isometric to \( AdS_4 \times S^7 \). This means that all solutions with 20, 24, 28 are locally \( AdS_4 \times S^7 \).

5 \( p = 0, 1 \)

- \( d=2 \) [53, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 74, 89]
- \( d=1 \) [90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101]

Comment

- Not all of the algebras in Nahm’s list correspond to known solutions and indeed there may be some for which no solutions exist. A thorough and up-to-date summary maybe found in [89].
6 Conclusion

Thus not only the M2, D3 and M5 but all of the $p$-brane configurations on the $S^1 \times S^p$ boundary of $AdS_{(p+1)}$ with $p = (5, 4, 3, 2, 1)$ mentioned explicitly in the 1987 paper as shown in Table 3 have now been discovered: $\text{OSp}(\mathbb{N}|4) \ N = 8, 4, 2, 1$; $\text{SU}(2, 2|\mathbb{N}) \ N = 4, 2, 1$; $\text{F}^2(4)$; $\text{OSp}(8^*|\mathbb{N})$, $N = 4, 2$, as have most of the $(p = 0, 1)$ in Nahm’s list not mentioned explicitly. Orbifolds, orientifolds and S-folds also play a part providing examples not predicted: $\text{SU}(2, 2|3)$, $\text{OSp}(3, 4)$ and $\text{OSp}(5, 4)$ (but not $\text{OSp}(7, 4)$).

To be fair, if our colleagues did not take our vector and tensor brane-scans seriously in 1987, it may be because, in the Weinberg sense, we did not take them seriously enough ourselves.

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References

[1] M. J. Duff, “Supermembranes: The First Fifteen Weeks,” Class. Quant. Grav. 5 (1988) 189.
[2] E. Bergshoeff, M. J. Duff, C. N. Pope, and E. Sezgin, “Supersymmetric Supermembrane Vacua and Singletons,” Phys. Lett. B 199 (1987) 69–74.
[3] M. P. Blencowe and M. J. Duff, “Supersingletons,” Phys. Lett. B 203 (1988) 229–236.
[4] M. J. Duff and C. Sutton, “The Membrane at the End of the Universe,” New Sci. 118 (1988) 67–71.
[5] H. Nicolai, E. Sezgin, and Y. Tanii, “Conformally Invariant Supersymmetric Field Theories on $S^p \times S^1$ and Super p-branes,” Nucl. Phys. B 305 (1988) 483–496.
[6] E. Bergshoeff, M. J. Duff, C. N. Pope, and E. Sezgin, “Compactifications of the Eleven-Dimensional Supermembrane,” Phys. Lett. B 224 (1989) 71–78.
[7] M. J. Duff, C. N. Pope, and E. Sezgin, “A Stable Supermembrane Vacuum With a Discrete Spectrum,” Phys. Lett. B 225 (1989) 319–324.
[8] E. Bergshoeff, E. Sezgin, and Y. Tanii, “Stress Tensor Commutators and Schwinger Terms in Singleton Theories,” Int. J. Mod. Phys. A 5 (1990) 3599–3616.
[9] M. J. Duff, “Classical and Quantum Supermembranes,” 
*Class. Quant. Grav.* **6** (1989) 1577–1598

[10] P. Claus, R. Kallosh, J. Kumar, P. K. Townsend, and A. Van Proeyen, “Conformal theory of M2, D3, M5 and D1-branes + D5-branes,” *JHEP* **06** (1998) 004, arXiv:hep-th/9801206

[11] E. Bergshoeff, E. Sezgin, and P. K. Townsend, “Supermembranes and Eleven-Dimensional Supergravity,” *Phys. Lett. B* **189** (1987) 75–78.

[12] P. A. M. Dirac, “A Remarkable representation of the 3 + 2 de Sitter group,” *J. Math. Phys.* **4** (1963) 901–909.

[13] C. Fronsdal, “The Dirac Supermultiplet,” *Phys. Rev. D* **26** (1982) 1988.

[14] H. Nicolai and E. Sezgin, “Singleton Representations of Osp(N,4),” *Phys. Lett. B* **143** (1984) 389–395.

[15] W. Nahm, “Supersymmetries and their Representations,” *Nucl. Phys. B* **135** (1978) 149.

[16] A. Van Proeyen, “Tools for supersymmetry,” *Ann. U. Craiova Phys.* **9** (1999) no. I, 1–48, arXiv:hep-th/9910030.

[17] M. Gunaydin and D. Minic, “Singletons, doubletons and M theory,” *Nucl. Phys. B* **523** (1998) 145–157, arXiv:hep-th/9802047.

[18] N. Seiberg and E. Witten, “The D1 / D5 system and singular CFT,” *JHEP* **04** (1999) 017, arXiv:hep-th/9903224.

[19] A. Batrachenko, M. J. Duff, and J. X. Lu, “The Membrane at the end of the (de Sitter) universe,” *Nucl. Phys. B* **762** (2007) 95–111, arXiv:hep-th/0212186.

[20] G. T. Horowitz and A. Strominger, “Black strings and P-branes,” *Nucl. Phys. B* **360** (1991) 197–209.

[21] M. J. Duff and J. X. Lu, “The Selfdual type IIB superthreebrane,” *Phys. Lett. B* **273** (1991) 409–414.

[22] M. J. Duff and J. X. Lu, “Type II p-branes: The Brane scan revisited,” *Nucl. Phys. B* **390** (1993) 276–290, arXiv:hep-th/9207060.

[23] M. J. Duff, R. R. Khuri, and J. X. Lu, “String solitons,” *Phys. Rept.* **259** (1995) 213–326, arXiv:hep-th/9412184.

[24] J. Polchinski, “Dirichlet Branes and Ramond-Ramond charges,” *Phys. Rev. Lett.* **75** (1995) 4724–4727, arXiv:hep-th/9510017.

[25] J. Polchinski, “Tasi lectures on D-branes,” arXiv:hep-th/9611050.

[26] R. Gueven, “Black p-brane solutions of D = 11 supergravity theory,” *Phys. Lett. B* **276** (1992) 49–55.
[27] S. Beck, U. Gran, J. Gutowski, and G. Papadopoulos, “All Killing Superalgebras for Warped AdS Backgrounds,” JHEP 12 (2018) 047, arXiv:1710.03713 [hep-th].

[28] A. S. Haupt, S. Lautz, and G. Papadopoulos, “A non-existence theorem for N > 16 supersymmetric AdS$_3$ backgrounds,” JHEP 07 (2018) 178, arXiv:1803.08428 [hep-th].

[29] A. Achucarro, J. M. Evans, P. K. Townsend, and D. L. Wiltshire, “Super p-Branes,” Phys. Lett. B 198 (1987) 441–446.

[30] M. Gunaydin, B. E. W. Nilsson, G. Sierra, and P. K. Townsend, “Singletons and Superstrings,” Phys. Lett. B 176 (1986) 45–49.

[31] S. Ferrara, M. Porrati, and A. Zaffaroni, “N=6 supergravity on AdS(5) and the SU(2,2/3) superconformal correspondence,” Lett. Math. Phys. 47 (1999) 255–263, arXiv:hep-th/9810063.

[32] O. Aharony and M. Evtikhiev, “On four dimensional N = 3 superconformal theories,” JHEP 04 (2016) 040, arXiv:1512.03524 [hep-th].

[33] I. Garcia-Etxebarria and D. Regalado, “N = 3 four dimensional field theories,” JHEP 03 (2016) 083, arXiv:1512.06434 [hep-th].

[34] O. Aharony and Y. Tachikawa, “S-folds and 4d N=3 superconformal field theories,” JHEP 06 (2016) 044, arXiv:1602.08638 [hep-th].

[35] P. K. Townsend, “SUPERSYMMETRIC EXTENDED SOLITONS,” Phys. Lett. B 202 (1988) 53–57.

[36] A. Strominger, “Heterotic solitons,” Nucl. Phys. B 343 (1990) 167–184. [Erratum: Nucl.Phys.B 353, 565–565 (1991)].

[37] M. J. Duff and J. X. Lu, “A Duality between strings and five-branes,” Class. Quant. Grav. 9 (1992) 1–16.

[38] M. J. Duff, R. R. Khuri, and J. X. Lu, “String and five-brane solitons: Singular or nonsingular?,” Nucl. Phys. B 377 (1992) 281–294 arXiv:hep-th/9112023.

[39] C. G. Callan, Jr., J. A. Harvey, and A. Strominger, “Supersymmetric string solitons,” arXiv:hep-th/9112030.

[40] G. W. Gibbons, D. Kastor, L. A. J. London, P. K. Townsend, and J. H. Traschen, “Supersymmetric selfgravitating solitons,” Nucl. Phys. B 416 (1994) 850–880, arXiv:hep-th/9310118.

[41] M. J. Duff, P. S. Howe, T. Inami, and K. S. Stelle, “Superstrings in D=10 from Supermembranes in D=11,” Phys. Lett. B 191 (1987) 70.

[42] M. J. Duff and K. S. Stelle, “Multimembrane solutions of D = 11 supergravity,” Phys. Lett. B 253 (1991) 113–118.
[43] M. J. Duff, G. W. Gibbons, and P. K. Townsend, “Macroscopic superstrings as interpolating solitons,” *Phys. Lett. B* **332** (1994) 321–328, arXiv:hep-th/9405124.

[44] C. M. Hull and P. K. Townsend, “Unity of superstring dualities,” *Nucl. Phys. B* **438** (1995) 109–137, arXiv:hep-th/9410167.

[45] E. Witten, “String theory dynamics in various dimensions,” *Nucl. Phys. B* **443** (1995) 85–126, arXiv:hep-th/9503124.

[46] M. J. Duff, “M theory (The Theory formerly known as strings),” *Int. J. Mod. Phys. A* **11** (1996) 5623–5642, arXiv:hep-th/9608117.

[47] J. M. Maldacena, “The Large N limit of superconformal field theories and supergravity,” *Adv. Theor. Math. Phys.* **2** (1998) 231–252, arXiv:hep-th/9711200.

[48] S. S. Gubser, I. R. Klebanov, and A. M. Polyakov, “Gauge theory correlators from noncritical string theory,” *Phys. Lett. B* **428** (1998) 105–114, arXiv:hep-th/9802109.

[49] E. Witten, “Anti-de Sitter space and holography,” *Adv. Theor. Math. Phys.* **2** (1998) 253–291, arXiv:hep-th/9802150.

[50] O. Aharony, O. Bergman, D. L. Jafferis, and J. Maldacena, “N=6 superconformal Chern-Simons-matter theories, M2-branes and their gravity duals,” *JHEP* **10** (2008) 091, arXiv:0806.1218 [hep-th].

[51] M. J. Duff, “Near-horizon brane-scan revived,” *Nucl. Phys. B* **810** (2009) 193–209, arXiv:0804.3675 [hep-th].

[52] R. Gueven, J. T. Liu, C. N. Pope, and E. Sezgin, “Fine tuning and six-dimensional gauged N=(1,0) supergravity vacua,” *Class. Quant. Grav.* **21** (2004) 1001–1014, arXiv:hep-th/0306201.

[53] J. D. Edelstein, A. Garbarz, O. Miskovic, and J. Zanelli, “Stable p-branes in Chern-Simons AdS supergravities,” *Phys. Rev. D* **82** (2010) 044053, arXiv:1006.3753 [hep-th].

[54] F. Apruzzi, M. Fazzi, D. Rosa, and A. Tomasiello, “All AdS\(_7\) solutions of type II supergravity,” *JHEP* **04** (2014) 064, arXiv:1309.2949 [hep-th].

[55] D. Gaiotto and A. Tomasiello, “Holography for (1,0) theories in six dimensions,” *JHEP* **12** (2014) 003, arXiv:1404.0711 [hep-th].

[56] S. Cremonesi and A. Tomasiello, “6d holographic anomaly match as a continuum limit,” *JHEP* **05** (2016) 031, arXiv:1512.02225 [hep-th].

[57] C. Nunez, J. M. Penin, D. Roychowdhury, and J. Van Gorsel, “The non-Integrability of Strings in Massive Type IIA and their Holographic duals,” *JHEP* **06** (2018) 078, arXiv:1802.04269 [hep-th].

[58] A. Brandhuber and Y. Oz, “The D-4 - D-8 brane system and five-dimensional fixed points,” *Phys. Lett. B* **460** (1999) 307–312, arXiv:hep-th/9905148.
[59] O. Bergman and D. Rodriguez-Gomez, “5d quivers and their AdS(6) duals,”
\textit{JHEP} 07 (2012) 171, \url{arXiv:1206.3503 [hep-th]}

[60] Y. Lozano, E. Ó Colgáin, D. Rodriguez-Gómez, and K. Sfetsos, “Supersymmetric AdS$_6$
via T Duality,” \textit{Phys. Rev. Lett.} 110 (2013) no. 23, 231601
\url{arXiv:1212.1043 [hep-th]}

[61] E. D’Hoker, M. Gutperle, A. Karch, and C. F. Uhlemann, “Warped AdS$_6 \times S^2$ in Type
IIB supergravity I: Local solutions,” \textit{JHEP} 08 (2016) 046,
\url{arXiv:1606.01254 [hep-th]}

[62] E. D’Hoker, M. Gutperle, and C. F. Uhlemann, “Holographic duals for five-dimensional
superconformal quantum field theories,” \textit{Phys. Rev. Lett.} 118 (2017) no. 10, 101601
\url{arXiv:1611.09411 [hep-th]}

[63] E. D’Hoker, M. Gutperle, and C. F. Uhlemann, “Warped AdS$_6 \times S^2$ in Type IIB
supergravity III: Global solutions with seven-branes,” \textit{JHEP} 11 (2017) 200,
\url{arXiv:1706.00433 [hep-th]}

[64] Y. Lozano, N. T. Macpherson, and J. Montero, “AdS$_6$ T-duals and type IIB AdS$_6 \times S^2$
geometries with 7-branes,” \textit{JHEP} 01 (2019) 116, \url{arXiv:1810.08093 [hep-th]}

[65] D. Corbino, E. D’Hoker, and C. F. Uhlemann, “AdS$_2 \times S^6$ versus AdS$_6 \times S^2$ in Type
IIB supergravity,” \textit{JHEP} 03 (2018) 120, \url{arXiv:1712.04463 [hep-th]}

[66] D. Gaiotto and J. Maldacena, “The Gravity duals of N=2 superconformal field
theories,” \textit{JHEP} 10 (2012) 189, \url{arXiv:0904.4466 [hep-th]}

[67] R. Reid-Edwards and j. Stefanski, B., “On Type IIA geometries dual to N = 2 SCFTs,”
\textit{Nucl. Phys. B} 849 (2011) 549–572 \url{arXiv:1011.0216 [hep-th]}

[68] O. Aharony, L. Berdichevsky, and M. Berkooz, “4d N=2 superconformal linear quivers
with type IIA duals,” \textit{JHEP} 08 (2012) 131, \url{arXiv:1206.5916 [hep-th]}

[69] C. Nunez, D. Roychowdhury, S. Speziali, and S. Zacarias, “Holographic aspects of four
dimensional $\mathcal{N} = 2$ SCFTs and their marginal deformations,”
\textit{Nucl. Phys. B} 943 (2019) 114617, \url{arXiv:1901.02888 [hep-th]}

[70] E. D’Hoker, J. Estes, and M. Gutperle, “Exact half-BPS Type IIB interface solutions. I.
Local solution and supersymmetric Janus,” \textit{JHEP} 06 (2007) 021,
\url{arXiv:0705.0022 [hep-th]}

[71] E. D’Hoker, J. Estes, M. Gutperle, and D. Krym, “Exact Half-BPS Flux Solutions in
M-theory. I: Local Solutions,” \textit{JHEP} 08 (2008) 028 \url{arXiv:0806.0605 [hep-th]}

[72] M. Chiodaroli, E. D’Hoker, Y. Guo, and M. Gutperle, “Exact half-BPS string-junction
solutions in six-dimensional supergravity,” \textit{JHEP} 12 (2011) 086
\url{arXiv:1107.1722 [hep-th]}

[73] B. Assel, C. Bachas, J. Estes, and J. Gomis, “Holographic Duals of D=3 N=4
Superconformal Field Theories,” \textit{JHEP} 08 (2011) 087 \url{arXiv:1106.4253 [hep-th]}
[74] A. S. Haupt, S. Lautz, and G. Papadopoulos, “AdS₄ backgrounds with N > 16 supersymmetries in 10 and 11 dimensions,” *JHEP* **01** (2018) 087, arXiv:1711.08280 [hep-th].

[75] F. Marchesano, E. Palti, J. Quirant, and A. Tomasiello, “On supersymmetric AdS₄ orientifold vacua,” *JHEP* **08** (2020) 087, arXiv:2003.13578 [hep-th].

[76] C. Couzens, C. Lawrie, D. Martelli, S. Schafer-Nameki, and J.-M. Wong, “F-theory and AdS₃/CFT₂,” *JHEP* **08** (2017) 043, arXiv:1705.04679 [hep-th].

[77] Y. Lozano, N. T. Macpherson, C. Nunez, and A. Ramirez, “AdS₃ solutions in Massive IIA with small $\mathcal{N} = (4,0)$ supersymmetry,” *JHEP* **01** (2020) 129, arXiv:1908.09851 [hep-th].

[78] Y. Lozano, N. T. Macpherson, C. Nunez, and A. Ramirez, “1/4 BPS solutions and the AdS₃/CFT₂ correspondence,” *Phys. Rev. D* **101** (2020) no. 2, 026014, arXiv:1909.09636 [hep-th].

[79] Y. Lozano, N. T. Macpherson, C. Nunez, and A. Ramirez, “Two dimensional $\mathcal{N} = (0,4)$ quivers dual to AdS₃ solutions in massive IIA,” *JHEP* **01** (2020) 140, arXiv:1909.10510 [hep-th].

[80] Y. Lozano, N. T. Macpherson, C. Nunez, and A. Ramirez, “AdS₃ solutions in massive IIA, defect CFTs and T-duality,” *JHEP* **12** (2019) 013, arXiv:1909.11669 [hep-th].

[81] Y. Lozano, C. Nunez, A. Ramirez, and S. Speziali, “M-strings and AdS₃ solutions to M-theory with small $\mathcal{N} = (0,4)$ supersymmetry,” *JHEP* **08** (2020) 118, arXiv:2005.06561 [hep-th].

[82] F. Faedo, Y. Lozano, and N. Petri, “Searching for surface defect CFTs within AdS₃,” *JHEP* **11** (2020) 052, arXiv:2007.16167 [hep-th].

[83] F. Faedo, Y. Lozano, and N. Petri, “New $\mathcal{N} = (0,4)$ AdS₃ near-horizons in Type IIB,” arXiv:2012.07148 [hep-th].

[84] G. Dibitetto and N. Petri, “AdS₃ from M-branes at conical singularities,” arXiv:2010.12323 [hep-th].

[85] Y. Lozano and C. Núñez, “Field theory aspects of non-Abelian T-duality and $\mathcal{N} = 2$ linear quivers,” *JHEP* **05** (2016) 107, arXiv:1603.04440 [hep-th].

[86] Y. Lozano, N. T. Macpherson, J. Montero, and C. Nunez, “Three-dimensional $\mathcal{N} = 4$ linear quivers and non-Abelian T-duals,” *JHEP* **11** (2016) 133, arXiv:1609.09061 [hep-th].

[87] Y. Lozano, C. Nunez, and S. Zacarias, “BMN Vacua, Superstars and Non-Abelian T-duality,” *JHEP* **09** (2017) 008, arXiv:1703.00417 [hep-th].

[88] G. Itsios, Y. Lozano, J. Montero, and C. Nunez, “The AdS₅ non-Abelian T-dual of Klebanov-Witten as a $\mathcal{N} = 1$ linear quiver from M5-branes,” *JHEP* **09** (2017) 038, arXiv:1705.09661 [hep-th].
[89] N. T. Macpherson and A. Tomasiello, “$\mathcal{N} = (1, 1)$ supersymmetric $\text{AdS}_3$ in 10 dimensions,” [arXiv:2110.01627 [hep-th]]

[90] G. Dibitetto and N. Petri, “$\text{AdS}_2$ solutions and their massive IIA origin,” [JHEP 05 (2019) 107, arXiv:1811.11572 [hep-th]]

[91] J. P. Gauntlett, N. Kim, and D. Waldram, “Supersymmetric $\text{AdS}(3)$, $\text{AdS}(2)$ and Bubble Solutions,” [JHEP 04 (2007) 005 arXiv:hep-th/0612253]

[92] N. Kim, “Comments on $\text{AdS}_2$ solutions from M2-branes on complex curves and the backreacted Kähler geometry,” [Eur. Phys. J. C 74 (2014) no. 2, 2778, arXiv:1311.7372 [hep-th]]

[93] M. Chiodaroli, M. Gutperle, and D. Krym, “Half-BPS Solutions locally asymptotic to $\text{AdS}(3) \times S^3$ and interface conformal field theories,” [JHEP 02 (2010) 066, arXiv:0910.0466 [hep-th]]

[94] M. Chiodaroli, E. D’Hoker, and M. Gutperle, “Open Worldsheets for Holographic Interfaces,” [JHEP 03 (2010) 060 arXiv:0912.4679 [hep-th]]

[95] D. Corbino, E. D’Hoker, J. Kaidi, and C. F. Uhlemann, “Global half-BPS $\text{AdS}_2 \times S^6$ solutions in Type IIB,” [JHEP 03 (2019) 039 arXiv:1812.10206 [hep-th]]

[96] D. Corbino, “Warped $\text{AdS}_2$ and $\text{SU}(1,1|4)$ symmetry in Type IIB,” [arXiv:2004.12613 [hep-th]]

[97] G. Dibitetto, Y. Lozano, N. Petri, and A. Ramirez, “Holographic description of M-branes via $\text{AdS}_2$,” [JHEP 04 (2020) 037, arXiv:1912.09932 [hep-th]]

[98] Y. Lozano, C. Nunez, A. Ramirez, and S. Speziali, “New $\text{AdS}_2$ backgrounds and $\mathcal{N} = 4$ Conformal Quantum Mechanics,” [arXiv:2011.00005 [hep-th]]

[99] Y. Lozano, C. Nunez, A. Ramirez, and S. Speziali, “$\text{AdS}_2$ duals to ADHM quivers with Wilson lines,” [arXiv:2011.13932 [hep-th]]

[100] E. D’Hoker, J. Estes, and M. Gutperle, “Gravity duals of half-BPS Wilson loops,” [JHEP 06 (2007) 063 arXiv:0705.1004 [hep-th]]

[101] C. Bachas, E. D’Hoker, J. Estes, and D. Krym, “M-theory Solutions Invariant under $D(2, 1; \gamma) \oplus D(2, 1; \gamma)$,” [Fortsch. Phys. 62 (2014) 207–254 arXiv:1312.5477 [hep-th]]