Constrained Superfields from D3-Branes

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Hamburg February 15th, 2017

Based on:

R. Kallosh, B. Vercnocke, TW 1606.09245
B. Vercnocke, TW 1605.03961
E. Bergshoeff, K. Dasgupta, R. Kallosh, A. Van Proeyen, TW 1502.07627
R. Kallosh, TW 1411.1121

FWF
Der Wissenschaftsfonds.

Outline

- Introduction: D-branes and SUSY breaking
- The nilpotent chiral superfield
- Connection to dS vacua in string theory and other constrained multiplets from anti-D3-branes
- Conclusion

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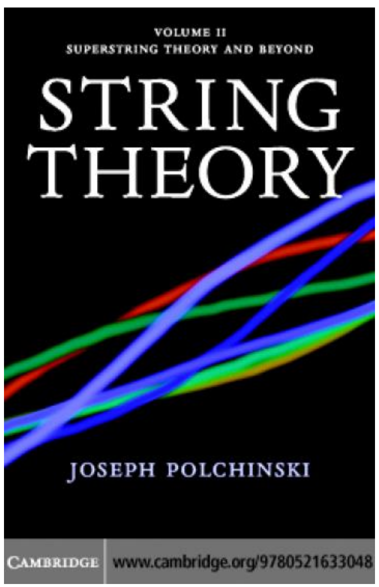
D-branes 102

Let us recall some facts about D-branes *in flat space*:

- The D-brane breaks half of the supersymmetry *spontaneously* and the other half is linearly realized



momentum is measured by the integral of the corresponding current over the world-sheet boundary,

$$\frac{1}{2\pi\alpha'}\int_{\partial M} ds\, \partial_n X'^9 \,, \tag{13.2.3}$$

which up to normalization is just the (0 picture) vertex operator for the collective coordinate, with zero momentum in the Neumann directions.

We conclude by analogy that the D-brane also spontaneously breaks 16 of the 32 spacetime supersymmetries, the ones that are explicitly broken by the open string boundary conditions. The integrals

$$\int_{\partial M} ds\, \mathscr{V}'_\alpha = -\int_{\partial M} ds\, (\beta^9 \tilde{\mathscr{V}}')_\alpha \,, \tag{13.2.4}$$

which measure the breaking of supersymmetry, are just the vertex op-

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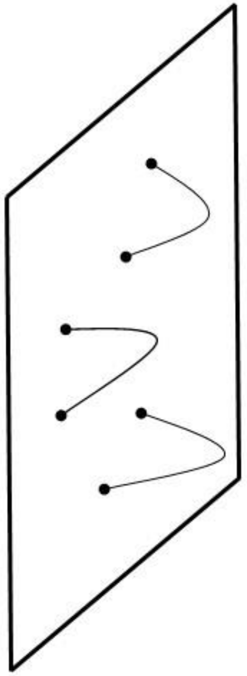
- Example: a D3-brane
- It preserve 16 linearly realized supercharges, i.e. $N = 4$ in 4d
- The worldvolume fields $A_\mu, \lambda^0, \phi^i, \lambda^i, i = 1, 2, 3$ can be package into an $N = 4$ multiplet



D-branes 102

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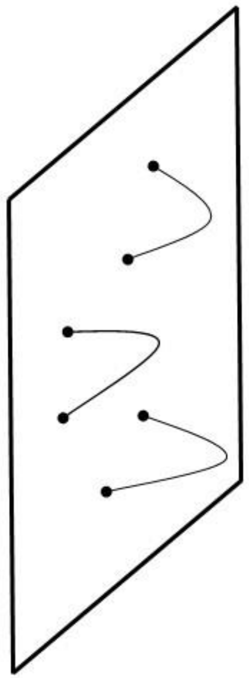
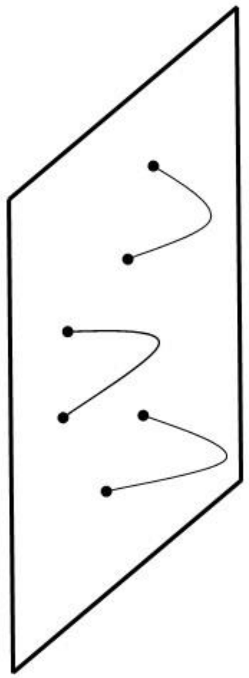
- <u>Example:</u> a D3-brane
- 16 supercharges are spontaneously broken at the string scale $\mathcal{O}(\alpha')$
- The Goldstone fermions aka Goldstinos are λ^0 and $\lambda^i, i = 1, 2, 3$



D-branes 102

Let us recall some facts about D-branes *in flat space*:

- The D-brane breaks half of the supersymmetry *spontaneously* and the other half is linearly realized
- The 16 *spontaneously* broken supersymmetries are non-linearly realized
- The D-brane action is invariant under 16 linear and 16 non-linear SUSY trafos
- Non-linear SUSY is very interesting and pretty old …



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The nilpotent chiral superfield

- SUSY 101: supersymmetry relates bosons and fermions

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Not necessarily!

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- If we break supersymmetry we expect a massless goldstone fermion χ, the goldstino
- Is the neutrino a goldstone particle?

Volkov, Akulov 1972, 1973

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Volkov, Akulov 1972, 1973

$$S_{VA} = -\int E^0 \wedge E^1 \wedge E^2 \wedge E^3, \qquad E^\mu = dx^\mu + \bar{\chi}\gamma^\mu d\chi$$

- Invariant under: $\delta_\epsilon \chi = \epsilon + (\bar{\chi}\gamma^\mu \epsilon)\partial_\mu \chi$

The nilpotent chiral superfield

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Not necessarily!

- If we break supersymmetry we expect a massless goldstone fermion χ, the goldstino
- Is the neutrino a goldstone particle? No, but interesting!

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- Invariant under: $\delta_\epsilon \chi = \epsilon + (\bar{\chi}\gamma^\mu \epsilon)\partial_\mu \chi$
- There is only one fermion!
- Supersymmetry is non-linearly realized
- Supersymmetry is spontaneously broken

The nilpotent chiral superfield

$$S_{VA} = -\int E^0 \wedge E^1 \wedge E^2 \wedge E^3$$

$$E^\mu = dx^\mu + \bar{\chi}\gamma^\mu d\chi = dx^\nu\left(\delta^\mu_\nu + \bar{\chi}\gamma^\mu\partial_\nu\chi\right)$$

- Invariant under: $\delta_\epsilon\chi = \epsilon + (\bar{\chi}\gamma^\mu\epsilon)\partial_\mu\,\chi$

$$S_{VA} = -\int d^4x(1 + \bar{\chi}\gamma^\mu\partial_\mu\chi + \cdots)$$

- The action is fixed by the kinetic term and the non-linear transformation:

$$\ldots \xrightarrow{\delta_\epsilon} \mathcal{O}(\chi^{n-1}) \xleftarrow{\delta_\epsilon} \mathcal{O}(\chi^n) \xrightarrow{\delta_\epsilon} \mathcal{O}(\chi^{n+1}) \xleftarrow{\delta_\epsilon} \mathcal{O}(\chi^{n+2}) \ldots$$

The nilpotent chiral superfield

- In $N = 1$ supersymmetry in 4d we can have a so called nilpotent chiral superfield

Volkov, Akulov 1972, 1973
Rocek; Ivanov, Kapustnikov 1978
Lindstrom, Rocek 1979
Casalbuoni, De Curtis, Dominici, Feruglio, Gatto 1989
Komargodski, Seiberg 0907.2441

- This can be thought of as a chiral superfield that squares to zero

$$S = s + \sqrt{2}\theta\chi + \theta^2 F, \qquad S^2 = 0$$

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$$s = \frac{\chi\chi}{2F} = \frac{\chi_1\chi_2}{F} \quad \Rightarrow \quad s\chi = 0 \text{ and } s^2 = 0$$

The nilpotent chiral superfield

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- These nilpotent chiral superfields consists only of fermions!
- Supersymmetry is non-linearly realized and spontaneously broken ($F \neq 0$)

- There are a variety of different actions but all are related to S_{VA} via non-linear field redefinitions

Kuzenko, Tyler 1009.3298, 1102.3043

The nilpotent chiral superfield

- The bosonic supergravity action for a single nilpotent field $s^2 = 0$ is very simple

Antoniadis, Dudas, Ferrara, Sagnotti 1403.3269

$$K = s\bar{s} = -\ln(1 - s\bar{s})$$
$$W = c_0 + c_1 s$$

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- The bosonic action is obtained as usual with the additional simplification that $s = \bar{s} = 0$

$$V = e^K (K^{s\bar{s}} D_s W \overline{D_s W} - 3|W|^2) = |c_1|^2 - 3|c_0|^2$$

1   1

$$D_s W \Big|_{s=0} = \partial_s W + W \cancel{\partial_s K} \Big|_{s=0} = c_1$$

0

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- Trivial to get $V > 0$, SUSY broken since $D_s W = \partial_s W = c_1$

$\Rightarrow$ It is trivial to get dS vacua in SUGRA!

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- χ is the Goldstino and gets eaten by the gravitino

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The nilpotent chiral superfield

- This nilpotent superfield also arises in string theory for example from anti-D3-branes in KKLT

McGuirk, Shiu, Ye 1206.0754
Ferrara, Kallosh, Linde 1408.4096
Kallosh, TW 1411.1121
Bergshoeff, Dasgupta, Kallosh, Van Proeyen, TW 1502.07627
Kallosh, Quevedo, Uranga 1507.07556
Bandos, Martucci, Sorokin, Tonin 1511.03024
Aparicio, Quevedo, Valandro 1511.08105
García-Etxebarria, Quevedo, Valandro 1512.06926
Dasgupta, Emelin, McDonough 1601.03409
Retolaza, Uranga 1605.01732
Vercnocke, TW 1605.03961
Kallosh, Vercnocke, TW 1606.09245
Bandos, Heller, Kuzenko, Martucci, Sorokin 1608.05908

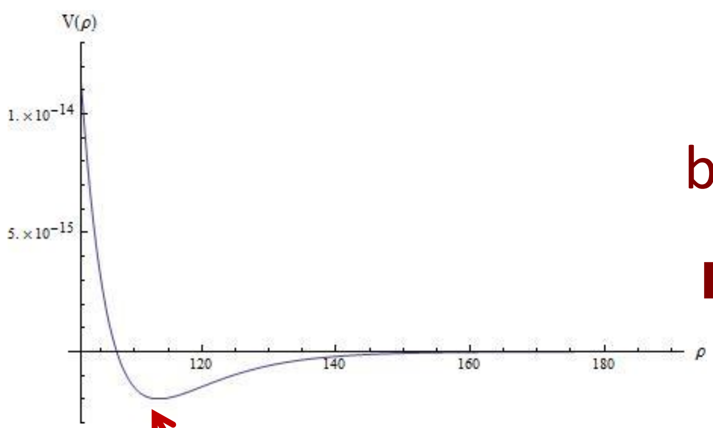
dS vacua in string theory

Kachru, Kallosh, Linde, Trivedi hep-th/0301240

Balasubramanian, Berglund, Conlon, Quevedo hep-th/0502058

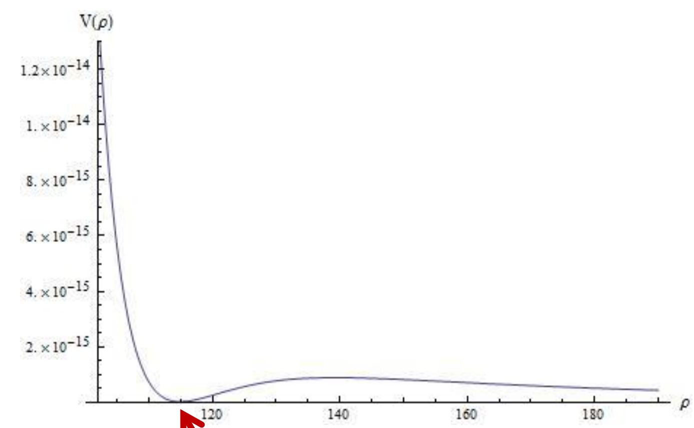
Conlon, Quevedo, Suruliz hep-th/0505076

dS vacua construction are often a two step procedure:



AdS vacuum

Adding an anti-D3-brane “uplift”



dS vacuum

dS vacua in string theory

- The uplifting term *seems* to explicitly break the 4D $N = 1$ supersymmetry:

$$V = e^{K}\left(K^{T\bar{T}} D_T W \overline{D_T W} - 3|W|^2\right) + \frac{\mu^4}{(T+\bar{T})^2}$$

$$K = -3\log(T+\bar{T})$$
$$W = W_0 - A\, e^{-aT}$$

dS vacua in string theory

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- How do we package the uplift term into K and W or a D-term?

The nilpotent chiral superfield

- A very interesting observation

Ferrara, Kallosh, Linde 1408.4096

$$K = -3\ln(T + \bar{T}) + s\bar{s}$$
$$W = W_0 + Ae^{-aT} + \mu^2 s$$

- The scalar potential for $s^2 = 0$ is

$$V = V_{KKLT} + \frac{\mu^4}{(T + \bar{T})^3}$$

The nilpotent chiral superfield

- Similarly for warping

Ferrara, Kallosh, Linde 1408.4096

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- The second term is exactly what is expected for an anti-D3-brane uplift!

- Seems to show a connection to D-branes

D-branes

Recall some facts about D3-branes *in CY_3 flux compactifications*:

- The CY_3 background preserves 8 supersymmetries
- The O3/O7 projection/fluxes break this down to 4d $N = 1$

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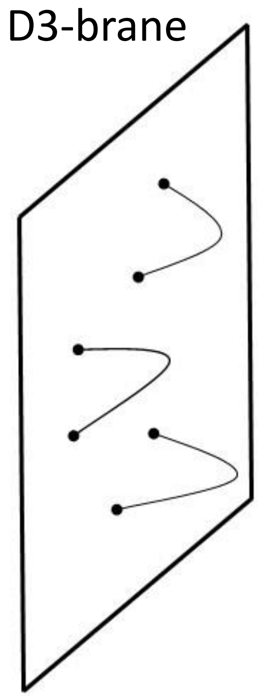

The D3 preserves this linear SUSY.

The worldvolume fields form $N = 1$ multiplets:

$$\left(A_\mu, \lambda^0\right)$$
$$(\phi^i, \lambda^i)$$

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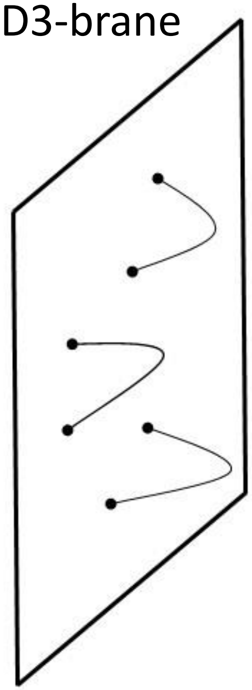

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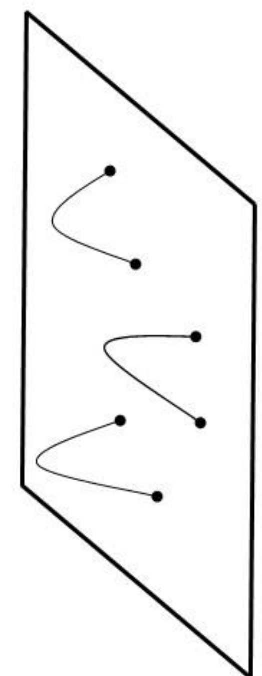
The anti-D3 breaks this linear SUSY spontaneously.

What happens to the worldvolume fields?

anti-D3-brane



More Constrained Multiplets

- Since the anti-D3-brane breaks supersymmetry spontaneously, we should be able to package all worldvolume fields into $N = 1$ multiplets

- The anti-D3-brane worldvolume fields are

$$\lambda^0, \quad \lambda^i, \quad A_\mu, \quad \phi^i, \quad i = 1,2,3$$

Goldstino

$$S^2 = 0 \qquad ? \qquad ? \qquad ?$$

More Constrained Multiplets

- There are many more constrained multiplets:

Komargodski, Seiberg 0907.2441
Dall'Agata, Ferrara, Zwirner 1509.06345
Ferrara, Kallosh, Thaler 1512.00545
Dall'Agata, Farakos 1512.02158
Ferrara, Kallosh, Van Proeyen, TW 1603.02653
Kallosh, Karlsson, Mosk, Murli 1603.02661
Dall'Agata, Dudas, Farakos 1603.03416

$$S\,Y^i = 0, \qquad S\,W_\alpha = 0, \qquad S(\Phi - \overline{\Phi}) = 0, \qquad \ldots$$

- Which ones arise from the worldvolume fields?

More Constrained Multiplets

- In a GKP background the λ^i are no longer goldstinos and get a mass

- The anti-D3-brane action in a GKP/KKLT background is

Vercnocke, TW 1605.03961

$$K = s\bar{s} + \delta_{i\bar{\imath}} Y^i \bar{Y}^{\bar{\imath}}$$
$$W = \mu^2 s + m_{ij} Y^i Y^j$$

$$S^2 = S\,Y^i = 0$$

with $\bar{m}_{\bar{\imath}\bar{\jmath}} \propto e^{\phi_0} G_{uv\bar{p}} \bar{\Omega}_{\bar{u}\bar{v}\bar{w}}\, g^{u\bar{u}} g^{v\bar{v}}\, e^{\bar{p}}_{\bar{\imath}}\, e^{\bar{w}}_{\bar{\jmath}}$

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More Constrained Multiplets

- Include all worldvolume fields of the anti-D3-brane

Kallosh, Vercnocke, TW 1606.09245

- Vector field A_μ and scalars ϕ^i can be package into

$$S\, W_\alpha = S\, \overline{D}_{\dot{\alpha}} \overline{H}^{\bar{\imath}} = 0$$

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Kallosh, Vercnocke, TW   1606.09245

- Vector field A_μ and scalars ϕ^i can be package into

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- Consistent with certain `truncated' D3-brane actions previously discussed in the literature

Cecotti, Ferrara   Phys. Lett. B 1987

Bagger, Galperin   hep-th/9608177

Bagger, Galperin   hep-th/9707061

Gonzalez-Rey, Park, Rocek   hep-th/9811130

Rocek, Tseytlin   hep-th/9811232

Ferrara, Porrati, Sagnotti   1411.4954

Ferrara, Sagnotti   1506.05730

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* These identifications are probably not unique.

More Constrained Multiplets

- Worldvolume fields (after field redefinitions) transform as

$$
\begin{aligned}
\delta_\epsilon \lambda^0 &= \epsilon + \left(\bar{\lambda}^0 \gamma^\mu \epsilon\right) \partial_\mu \lambda^0 \\
\delta_\epsilon A_\mu &= \left(\bar{\lambda}^0 \gamma^\nu \epsilon\right) F_{\mu\nu} \\
\delta_\epsilon \lambda^i &= \left(\bar{\lambda}^0 \gamma^\mu \epsilon\right) \partial_\mu \lambda^i \\
\delta_\epsilon \phi^i &= \left(\bar{\lambda}^0 \gamma^\mu \epsilon\right) \partial_\mu \phi^i
\end{aligned}
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- These are the expected transformation under non-linear supersymmetry

- They severely constrain the action

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$$

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See Susha's talk tomorrow!

SUSY breaking

- We break supersymmetry at the string scale:

$$m_{4d} \ll m_{KK} \ll m_{string} = m_{SUSY} \ll m_{Pl}$$

- In KKLT or LVS we reduce these scales via warping

$$m_{4d} \ll m_{KK}^{warped} \ll m_{string}^{warped} = m_{SUSY} \ll m_{Pl}$$

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Does it make sense to use or do we even have

4d $N = 1$ supergravity theory?

SUSY breaking

- Yes, the SUSY action correctly describes the physics for $E \ll m_{KK}$
- SUSY makes life simple and constrains the action

SUSY breaking

- Yes, the SUSY action correctly describes the physics for $E \ll m_{KK}$
- SUSY makes life simple and constrains the action
- We want almost vanishing cosmological constant

$$V_F = m_{SUSY}^4 - 3m_{\frac{3}{2}}^2\, m_{Pl}^2 \;\approx 0$$

$$m_{\frac{3}{2}} \sim \frac{m_{string}^2}{m_{Pl}} \ll m_{string}$$

- So we can have a 4d SUSY theory with gravitino

Conclusion

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- We have a SUSY description of the anti-D3-brane uplift

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- We have a SUSY description of the anti-D3-brane uplift
- There are actually many more constraint multiplets that arise from D-branes that spontaneously break SUSY:

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- We have a SUSY description of the anti-D3-brane uplift
- There are actually many more constraint multiplets that arise from D-branes that spontaneously break SUSY:

$$S^2 = S\, Y^i = S\, W_\alpha = S\, \overline{D}_{\dot{\alpha}} \overline{H}^{\bar{\imath}} = S(\Phi - \overline{\Phi}) = 0$$

THANK YOU!