Nilpotent multiplets in supergravity and anti-D3 branes

Antoine Van Proeyen

KU Leuven

College Station Texas,

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based on collaborations with
Eric Bergshoeff,
Keshav Dasgupta,
Dan Freedman,
Renata Kallosh,
Timm Wrase,

1. Intro: Cosmology and string theory

- In 1998 the Supernova Cosmology Project and the High-Z Supernova Search Team observed type Ia supernovae and found evidence for a positive cosmological constant

This discovery lead to the 2011 Nobel Prize for

Saul Perlmutter, Adam Riess and Brian Schmidt

- String theory: claiming to be the fundamental theory, should provide a theoretical framework to describe this.
- Problems:

  -the positive cosmological constant

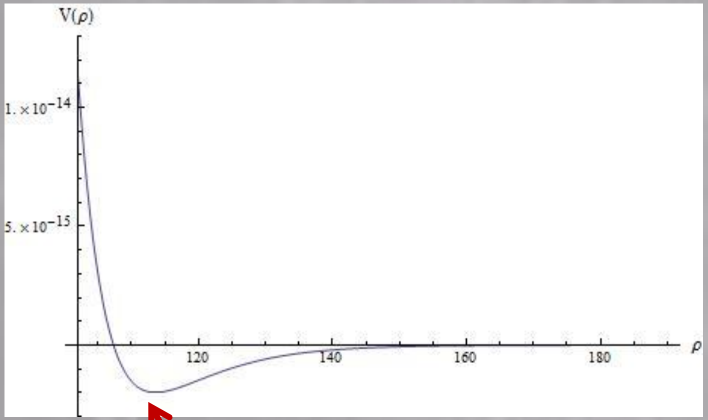
  -The slow-roll potential for inflation

  -String theory has many moduli, that should be stabilized

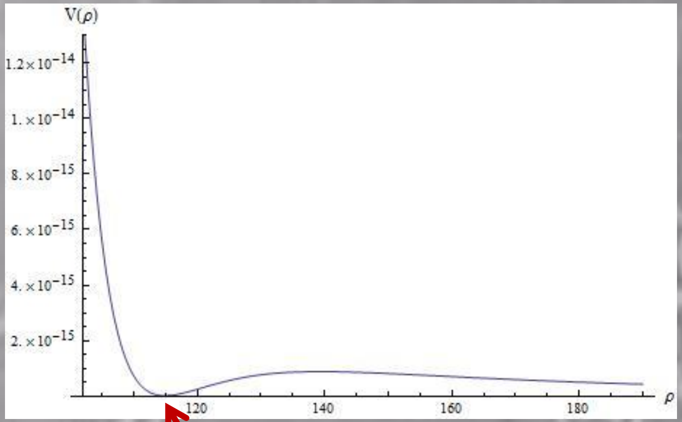
dS vacua in string theory

‘KKLT: Kachru, Kallosh, Linde, Trivedi hep-th/0301240

dS vacua construction with a two step procedure:



Adding an anti-D3-brane “uplift”



AdS vacuum

dS vacuum

Should be made precise: Kallosh, Wrase, 1411.112.
We (Bergshoeff, Dasgupta, Kallosh, AVP and Wrase) discuss the fermionic part to make connection with $\mathcal{N}$ =1 sugra description with a nilpotent multiplet.

String theory and inflation, some steps

- 2001: Giddings – Kachru – Polchinski (GKP):
  how a solution for string theory equations of motion can be used.
- We expect: inflation scale >> susy breaking scale
- Supersymmetry breaking in Supergravity and in String Theory can provide important lessons for Cosmology:
- Tools:
  - flux compactifications
    (Graña,Polchinsky , hep-th/0106014)
  - General supergravity models, e.g.
    "Superconformal Symmetry, Supergravity and Cosmology"
    (Kallosh, Kofman, Linde and AVP), hep-th/0006179
- New tool: nilpotent multiplets

Plan

1. Intro: Cosmology and string theory
2. Review on goldstinos in $\mathcal{N}$ =1 supersymmetry and supergravity
3. Basic facts on nilpotent superfields/multiplets
4. Nilpotent fields and cosmology
5. Nilpotent multiplets in supergravity or ‘V-A sugra’
6. Non-linear realizations from actions on branes
7. $\overline{\text{D3}}$ and dS
8. Conclusions

2. Review on goldstinos in $\mathcal{N}$ =1 supersymmetry and supergravity

- **Rigid supersymmetry:**
  - potential,
  - general form of goldstino
  - its susy transformation
- **Supergravity**:
  - potential,
  - Minkowski / de Sitter vacua,
  - mixing with gravitino

Textbook material.

Which textbook ?

Rigid supersymmetry

$$\mathcal{L} = [K(Z,\bar{Z})]_D + [W(Z)]_F + \left[f_{AB}(Z)\bar{\lambda}^A P_L \lambda^B\right]_F$$

notation: includes + c.c.

- *Chiral multiplets*, with lowest components Z^α.
- *Gauge multiplets*, with gauginos (left-handed part) $P_L\lambda^A$ (is $W_\alpha{}^A$ in superspace)
- Gauging determined by moment map $\mathcal{P}_A$.

$$\begin{aligned} \delta Z^\alpha &= \theta^A k_A^\alpha(Z) \\ k_{A,\alpha} &= g_{\alpha\bar{\beta}}\, k_A^{\bar{\beta}}(\bar{Z}) = \mathrm{i}\partial_\alpha \mathcal{P}_A(Z,\bar{Z}) \end{aligned}$$

Potential

$$\mathcal{L} = [K(Z,\bar{Z})]_D + [W(Z)]_F$$

- *Chiral multiplets*, with lowest components Z^α.
- Elimination of auxiliary fields F^α

$$F^\alpha = -g^{\alpha\bar{\beta}}\overline{W}_{\bar{\beta}} + \text{fermionic}$$

- Potential $V = g^{\alpha\bar{\beta}} W_\alpha \overline{W}_{\bar{\beta}}$
- Is of a general form

V = Σ_{fermions} (δ_s fermion) (metric) (δ_s fermion)

$$\delta_s P_L \chi^\alpha \equiv \frac{1}{\sqrt{2}} F^\alpha = -\frac{1}{\sqrt{2}} g^{\alpha\bar{\beta}}\overline{W}_{\bar{\beta}}$$

'fermion shifts'

$$\delta P_L \chi = P_L \epsilon\,(\delta_s P_L \chi) + \ldots$$

SUSY breaking and Goldstino

$V = \sum_{\text{fermions}} (\delta_s \text{ fermion}) (\text{metric}) (\delta_s \text{ fermion})$

- Unbroken susy: $F^\alpha = 0 \leftrightarrow W_\alpha(Z) = 0$
- Broken susy: there is a massless Goldstino: fermion in direction of susy breaking

$$P_L v = -\frac{1}{\sqrt{2}} P_L \chi^\alpha W_\alpha = \sum_{\text{fermions}} (\text{fermion})(\text{metric})(\delta_s \text{fermion})$$

- Transforms with a shift term

$$\delta_s P_L v = \sum_{\text{fermions}} (\delta_s \text{fermion})(\text{metric})(\delta_s \text{fermion}) = \tfrac{1}{2} g^{\alpha\bar\beta} W_\alpha \overline{W}_{\bar\beta} = \tfrac{1}{2} V\,.$$

$$\delta v = \tfrac{1}{2}\epsilon V + \ldots$$

$\mathcal{N}$=1 supergravity - matter

- Start from superconformal multiplets.
  Their structure is analogous to rigid susy
- Superconformal gauge fields: e_μ^a, ψ_μ, A_μ
- Chiral multiplets; including compensator X^I, Ω^I, F^I
- Actions built from *F*- and *D*-terms

$$\mathcal{L} = [N(X,\bar{X})]_D + [\mathcal{W}(X)]_F$$

Restrictions to be conformal invariant:

X^I have Weyl weight 1

D- terms : Weyl weight 2 ; F- terms : Weyl weight 3

$$\left\{X^I\right\} \to \{y, z^\alpha\}$$

$$I = 0,1,\ldots,n$$
$$\alpha = 1,\ldots,n$$

y is an overall scale that is gauge-fixed

z^α are physical scalars

Kähler potential $\mathcal{K}(z,\bar{z})$ determined by $N(X,\bar{X})$

Potential $V = V_F + V_D$

- As in rigid supersymmetry with superpotential $\mathcal{W}$ (X) field eqns: $F^I = -N^{I\bar{J}}\overline{\mathcal{W}}_{\bar{J}}$ $V_F = F^I N_{I\bar{J}} \bar{F}^{\bar{J}} = \mathcal{W}_I N^{I\bar{J}} \overline{\mathcal{W}}_{\bar{J}}$

However $N_{I\bar{J}}$ has a negative direction (compensator)

after 'diagonalization'

$$V_F = V_{F,-} + V_{F,+} = -3\kappa^2 \mathrm{e}^{\kappa^2 \mathcal{K}} W \overline{W} + \mathrm{e}^{\kappa^2 \mathcal{K}} \nabla_\alpha W g^{\alpha\bar{\beta}} \overline{\nabla}_{\bar{\beta}} \overline{W}$$

$$\nabla_\alpha W = \partial_\alpha W + \kappa^2 (\partial_\alpha \mathcal{K}) W$$

- Minkowski vacua possible if negative contribution cancels positive one
- 'No-scale models' (or 'flat potentials'): geometry such that positive contribution from one multiplet already cancels negative part, and contributions from other multiplets maintain this equilibrium.

Goldstino in supergravity

The physical fermions from the chiral multiplets

$$P_L \upsilon = \chi^\alpha \delta_s \chi_\alpha = -\frac{1}{\sqrt{2}} \chi^\alpha e^{\kappa^2 \mathcal{K}/2} \nabla_\alpha W$$

$$\delta \upsilon = \frac{1}{2} \epsilon V_+ + \dots$$

- Couples to the gravitino $\mathcal{L}_{mix} = -\bar{\psi} \cdot \gamma \upsilon$
- One can take a susy gauge $\upsilon = 0$ however, effective part of gravitino at low energy is the goldstino part.

S. Deser and B. Zumino, 'Broken supersymmetry and supergravity', PRL, 1977

3. Basic facts on nilpotent superfields/multiplets

- Non-linear realizations typically emerge in singular limits, when some multiplet members attain infinite masses.
- The mechanism has been widely explored over the years for the Akulov-Volkov model and also for other models of (partially) broken Supersymmetry,
  but only to a minor extent for Supergravity.
- Mostly for $\mathcal{N}$=1 and 2 where
  off-shell formulations are available.

Historical references

Volkov, Akulov 1972, 1973

Roček '*Linearizing the Volkov-Akulov model*', 1978

Ivanov, Kapustnikov, '*Relation Between Linear and Nonlinear Realizations of Supersymmetry*' 1978

Lindström, Roček, '*Constrained local superfields*', 1979

Samuel and Wess, 1983-84.

Cecotti, Ferrara '*Supersymmetric Born-Infeld lagrangians*', 1987

Casalbuoni, De Curtis, Dominici, Feruglio, Gatto, '*Non-linear realization of susy algebra from supersymmetric constraint*', 1989

Bagger and Galperin, '*A New Goldstone multiplet for partially broken supersymmetry*' hep-th/9608177

Komargodski, Seiberg, '*From linear susy to constrained superfields*' 0907.2441

Kuzenko, Tyler, '*Relating the Komargodski-Seiberg and Akulov-Volkov actions*', 1009.3298

The nilpotent superfield

$$\Phi = X + \frac{1}{\sqrt{2}}\bar{\theta}P_L\Omega + \frac{1}{4}\bar{\theta}P_L\theta F$$

$$\Phi^2 = X^2 + \sqrt{2}\bar{\theta}XP_L\Omega + \frac{1}{4}\bar{\theta}P_L\theta\left(2XF - \overline{\Omega}P_L\Omega\right)$$

Solve $\Phi^2=0$ with $X(\Omega,F) = \frac{\bar{\Omega}P_L\Omega}{2F} \equiv \frac{\Omega^2}{2F}$

Solves all components since $P_L\Omega$ has only two components.
$X(\Omega, F)$ still transforms as a chiral scalar

$$\delta\left(\frac{\bar{\Omega}P_L\Omega}{2F}\right) = \frac{1}{\sqrt{2}}\bar{\epsilon}P_L\Omega$$

Important: this is possible for multiplet with $F \neq 0$: multiplet that breaks susy, i.e. Ω is Goldstino

Following Komargodski, Seiberg, 0907.2441

Lagrangian of nilpotent model

$$\mathcal{L} = [X\bar{X}]_D + [f\,X]_F + \left[\Lambda X^2\right]_F$$

Lagrange multiplier for constraint

Number that determines vev of *F*: *susy breaking scale*

$$\mathcal{L}(\Omega, F) = \mathcal{L}_1(X(\Omega,F),\Omega,F)$$

$$X(\Omega,F) = \frac{\bar{\Omega}P_L\Omega}{2F} \equiv \frac{\Omega^2}{2F}$$

$$\begin{aligned}\frac{\delta\mathcal{L}}{\delta F} &= \frac{\delta\mathcal{L}_1}{\delta F} + \frac{\delta\mathcal{L}_1}{\delta X}\frac{\delta X}{\delta F}\\ &= \bar{F} + f - (\Box\bar{X})\frac{X}{F} = \bar{F} + f - \frac{\Omega^2}{2F^2}\Box\frac{\bar{\Omega}^2}{2\bar{F}}\end{aligned}$$

Solved iteratively : *F(Ω)* and

$$\mathcal{L}(\Omega, F(\Omega)) = -\frac{1}{2}\bar{\Omega}\not{\partial}\Omega - f^2 + \frac{1}{4f^2}\bar{\Omega}^2\Box\Omega^2 - \frac{1}{16f^6}\Omega^2\bar{\Omega}^2(\Box\Omega^2)(\Box\bar{\Omega}^2)\,,$$

Up to non-linear field redefinitions, this is the VA action

Kuzenko, Tyler, 1009.3298

4. Nilpotent fields and cosmology

- In general: scalar partners of goldstinos: sgoldstinos.
- After symmetry breaking:
  - weakly coupled:
    masses of the order of the susy breaking scale
  - strongly coupled:
    sgoldstinos not present in low E: effective description by nilpotent multiplets. See example anti-D3 later.
  - transformation of goldstino is as in Volkov-Akulov
- '*The Volkov-Akulov-Starobinsky supergravity*', Antoniadis, Dudas, Ferrara, Sagnotti, 1403.3269

Model of inflation uses a nilpotent superfield, and this leads to a VA type of action

Cosmology with nilpotent fields

- *Cosmology with nilpotent fields*,
  Ferrara, Kallosh, Linde, 1408.4096
- Inflaton multiplet Φ + multiplet with goldstino S
- difficult to stabilize scalar field s (sgoldstino)
- Replace by superfield with $S^2 = 0 \rightarrow$ no sgoldstino
- is simplification of models that already stabilize s.
  But gives also consistent action when this is not yet accomplished.
- More advanced model that stabilizes the other scalars :
  G. Dall'Agata and F. Zwirner,
  On sgoldstino-less supergravity models of inflation, 1411.2605
- All these analyses are mostly concerned with bosonic part
- To develop a fully consistent theory, we also need to analyze the fermionic part of the action.

5. Nilpotent multiplets in supergravity or 'V-A sugra'

With E. Bergshoeff, D. Freedman and R. Kallosh

- Goal: general supergravity actions including nilpotent multiplets
- Technical problem: the elimination of auxiliary field *F*, which is included in constrained expression of the scalars These scalars appear very non-linear

$$X(\Omega, F) = \frac{\bar{\Omega} P_L \Omega}{2\,F} \equiv \frac{\Omega^2}{2\,F}$$

$$\frac{\delta\mathcal{L}}{\delta F} = \frac{\delta\mathcal{L}_1}{\delta F} + \frac{\delta\mathcal{L}_1}{\delta X}\frac{\delta X}{\delta F}$$

- Conformal structure is helpful: restricts non-linearities, and one remains close to the equations of rigid susy.
- For now: an elementary model: sugra + 1 nilpotent multiplet

Conformal structure of action

$$\mathcal{L} = [N(X^0, X, \bar{X}^0, \bar{X})]_D + [\mathcal{W}(X^0, X)]_F + \left[\Lambda X^2\right]_F$$

Conformal weights: chiral multiplets: 1,
D-action: 2; *F*-action: 3

We choose here

$$N = -X^0 \bar{X}^0 + X\,\bar{X}\,, \qquad \mathcal{W} = m\left(\frac{X^0}{\sqrt{3}}\right)^3 + M\left(\frac{X^0}{\sqrt{3}}\right)^2 X$$

gives AdS — gives uplifting

Bosonic: $e^{-1}\mathcal{L} = \frac{1}{2}R - (|M|^2 - 3\,|m|^2)$

Technical tool

- A theorem for the elimination of F for an action of the form

$$\mathcal{L}(X,F) = (F+f)(\bar{F}+\bar{f}) - f\bar{f} + \bar{X}\,A\,X + X\bar{B} + B\bar{X} + C$$

Diff. operator (A)

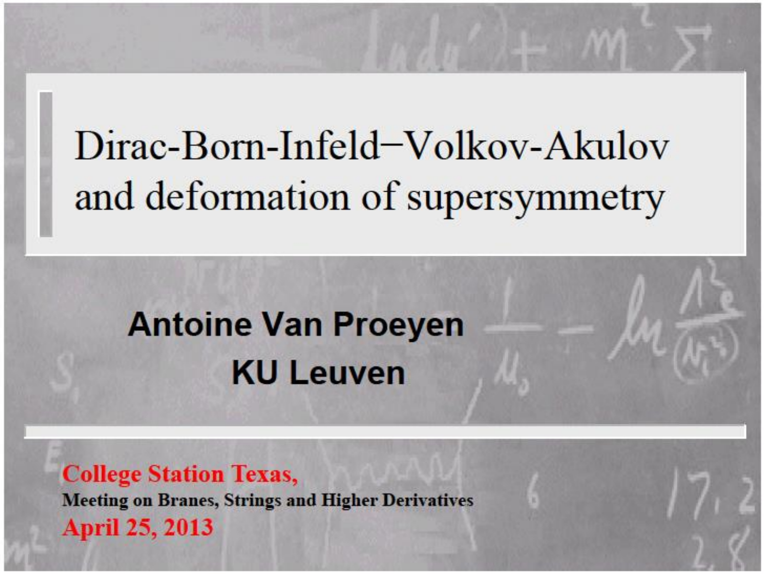
$$X(\Omega,F) = \frac{\bar{\Omega}P_L\Omega}{2F} \equiv \frac{\Omega^2}{2F}$$

- Importing the solution for *F* in the action
- Identifying the quantities *f, A, B, C.*
- *Gives a V-A type action.*

6. Non-linear realizations from actions on branes

- Non-linear realizations emerge from actions on branes.
- Dirac-Born-Infeld on bosonic part and Volkov-Alkulov action, describing a Goldstino (branes partially break susy)

Aganagic, C. Popescu and J. H. Schwarz, hep-th/9610249, hep-th/9612080
Bergshoeff, Kallosh, Ortín and Papadopoulos, hep-th/9705040
R. Kallosh, '*Volkov-Akulov theory and D-branes*', hep-th/9705118
Bergshoeff, Coomans, Kallosh, Shahbazi and AVP, 1303.5662



D-brane actions

$$S^{D3/\overline{D3}} = -T_3 \int d^4\sigma\, e^{-\phi} \sqrt{\det(-g_{\mu\nu} + \alpha' F_{\mu\nu})} \pm T_3 \int e^F C$$

- DBI term + WZ term

  related by κ symmetry

- Action determined by superspace geometry
- The bosonic worldvolume :vector A_μ and transverse scalars ϕ^i

  The fermionic fields: 10D Majorana-Weyl spinors θ^1, θ^2

- When bosonic fields vanish: VA type action for the fermions

  $S_{DBI} = -T_3 \int E^0 \wedge E^1 \wedge E^2 \wedge E^3$ where

  $E^a = \left(\delta^a_\mu + \bar{\theta}^1 \Gamma^a \partial_\mu \theta^1\right) dx^\mu$ when $\theta^2 = 0$

- Vacuum value $S_{DBI} = -T_3 \int d^4\sigma \sqrt{\det(-\eta_{\mu\nu})}$

Symmetry breaking on branes

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

this supersymmetry is non-linearly realized
(Goldstino VA action)

7. $\overline{\text{D3}}$ and dS

- A $\overline{\text{D3}}$ brane can provide contributions to supergravity leading to spontaneous supersymmetry breaking and to a positive value of the cosmological constant.
- DBI and WZ term are equal and add up to give a positive contribution (uplifting) (for D3: cancel)
- In $\mathcal{N}=1$ background: reduces to the VA action for one fermion (Goldstino)

dS D-brane physics → dS in effective *D*=4 sugra with nilpotent multiplet and spontaneous broken SUSY

Kallosh, Wrase, 1411.1121 (flat background: $\mathcal{N}=4$)
Bergshoeff, Dasgupta, Kallosh, AVP, Wrase 1502.07627

Our setup

- To simplify our life and make the connection to the nilpotent field fully explicit
  we restrict to a $\overline{\text{D3}}$ -brane on top of an O3-plane
- O3-plane projects out the scalar degrees of freedoms but leaves all the fermionic degrees of freedom

  Uranga hep-th/9912145
- The O3-plane breaks explicitly 16 supercharges.
  These are the supercharges that are linearly realized on the $\overline{\text{D3}}$
  so we are left with 16 non-linearly realized supercharges

The fermions

- IIB 10D Majorana-Weyl spinors θ^1, θ^2
- κ symmetry reduces to ½ .

  We choose $\theta^2 = \Gamma_{0123}\theta^1$.

  Choice θ^2=0 is not compatible with orientifolding

$$E^a = \left(\delta^a_\mu + \bar{\theta}^1 \Gamma^a \partial_\mu \theta^1\right) dx^\mu$$

In flat background

- Kallosh, Wrase, 1411.1121

$$S_{DBI} = -T_3 \int E^0 \wedge E^1 \wedge E^2 \wedge E^3 = |S_{CS}|$$

- This leads to

$$S^{D3} = 0, \qquad S^{\overline{D3}} = -2T_3 \int E^0 \wedge E^1 \wedge E^2 \wedge E^3$$

- Makes sense since for a D3 brane all world volume degrees of freedom are projected out
- This action preserves 16 non-linear realized supercharges $\delta_\zeta \theta^1 = \alpha^{-1}\zeta + \alpha \partial_\mu \theta^1 \bar{\theta}^1 \gamma^\mu \zeta$ and thus break $4D$ $\mathcal{N} = 4$ supersymmetry spontaneously

$$T_3 = \alpha^{-2} = f^2$$

Flux backgrounds

- Giddings, Kachru, Polchinski (GKP, 2001): warped flux backgrounds with 10= 4+ 6 split.
- Important for us: $G_{(3)} = F_{(3)} - \tau H_{(3)}$ splits in ISD (imaginary selfdual) + AISD (anti-imag.selfdual)

$$G_{(3)} = G_{(3)}^{\mathrm{ISD}} + G_{(3)}^{\mathrm{IASD}}$$

$$*_6 G_{(3)}^{\mathrm{ISD}} = \mathrm{i} G_{(3)}^{\mathrm{ISD}}$$

- Solutions with ISD $\neq 0$, and AISD=0.

$\mathcal{N}$=1 Supersymmetric GKP backgrounds

- Using analysis Graña, Polchinski and Gubser, 2000: susy background if 6*D* is Kähler with SU(3) holonomy: fluxes split in *(p,q)* holomorphic – antiholomorphic: ISD: implies that fluxes can be
  - (2,1) primitive: $G_{uv\bar{w}}$ but $G_{uv\bar{w}}J^{v\bar{w}} = 0$
  - (0,3) $G_{\overline{uvw}}$
  - (1,2) non-primitive $G_{u\overline{vw}}$ proportional to $J_{u\bar{v}}$ or $J_{u\bar{w}}$
- To preserve $\mathcal{N}$ =1 SUSY :

  ISD backgrounds can only have (2,1) primitive flux.

Fermionic action (up to quadratic order) for flux compactification

- Using results of
  - Marolf, Martucci and Silva, hep-th/0303209
  - Martucci, Rosseel, D. Van den Bleeken and AVP, hep-th/0504041
  - Bergshoeff, Kallosh, Kashani-Poor, Sorokin, Tomasiello, hep-th/0507069
- 10*D* MW 16-component fermions split in 4*D* Weyl fields
  - SU(3) singlet λ^o and triplet λ^i (*i*= 1,2,3)

$$\begin{aligned}\mathcal{L}_f^{\overline{\mathrm{D3}}} = {}& 2T_3 e^{4A_0-\phi}\Big[\bar\lambda_-^{\bar 0}\gamma^\mu\nabla_\mu\lambda_+^0 + \bar\lambda_-^{\bar\jmath}\gamma^\mu\nabla_\mu\lambda_+^i\delta_{i\bar\jmath} \\ &+ \tfrac12 m_0\bar\lambda_+^0\lambda_+^0 + \tfrac12\overline{m}_0\bar\lambda_-^{\bar 0}\lambda_-^{\bar 0} + m_i\bar\lambda_+^0\lambda_+^i + \overline{m}_{\bar\imath}\bar\lambda_-^{\bar 0}\lambda_-^{\bar\imath} + \tfrac12 m_{ij}\bar\lambda_+^i\lambda_+^j + \tfrac12\overline{m}_{\bar\imath\bar\jmath}\bar\lambda_-^{\bar\imath}\lambda_-^{\bar\jmath}\Big],\end{aligned}$$

where

$$m_0 = \frac{\sqrt2}{12}\mathrm{i}e^{\phi}\bar\Omega^{uvw}\bar G^{\mathrm{ISD}}_{uvw}, \qquad \text{from } (0,3) \text{ flux},$$

$$m_i = -\frac{\sqrt2}{4}e^{\phi}e_i^u\,\bar G^{\mathrm{ISD}}_{uv\bar w}J^{v\bar w}, \qquad \text{from non-primitive } (1,2) \text{ flux},$$

$$m_{ij} = \frac{\sqrt2}{8}\mathrm{i}e^{\phi}\left(e_i^w e_j^t + e_j^w e_i^t\right)\Omega_{uvw}g^{u\bar u}g^{v\bar v}\bar G^{\mathrm{ISD}}_{t\bar u\bar v}, \qquad \text{from primitive } (2,1) \text{ flux}.$$

$\mathcal{N}$=1 susy background

- Only primitive (2,1) flux: triplet get mass, and singlet remains massless
- In effective low E : $\mathcal{N}$=1 theory: only λ^o : $\overline{\text{D3}}$ breaks symmetry and λ^o is Goldstino with

$$\mathcal{L}_f^{\overline{\text{D3}}} = 2T_3 e^{4A_0-\phi}\Big[\bar\lambda^{\bar 0}_- \gamma^\mu \nabla_\mu \lambda^0_+ + \bar\lambda^{\bar\jmath}_- \gamma^\mu \nabla_\mu \lambda^i_+ \delta_{i\bar\jmath}$$
$$+ \tfrac{1}{2} m_0 \bar\lambda^0_+ \lambda^0_+ + \tfrac{1}{2} \overline{m}_0 \bar\lambda^{\bar 0}_- \lambda^{\bar 0}_- + m_i \bar\lambda^0_+ \lambda^i_+ + \overline{m}_{\bar\imath} \bar\lambda^{\bar 0}_- \lambda^{\bar\imath}_- + \tfrac{1}{2} m_{ij} \bar\lambda^i_+ \lambda^j_+ + \tfrac{1}{2} \overline{m}_{\bar\imath\bar\jmath} \bar\lambda^{\bar\imath}_- \lambda^{\bar\jmath}_-\Big],$$

where

~~$m_0 = \frac{\sqrt{2}}{12} \mathrm{i} e^{\phi} \bar\Omega^{uvw} \bar G^{\text{ISD}}_{uvw}$, from $(0,3)$ flux,~~

~~$m_i = \frac{\sqrt{2}}{4} e^{\phi} e^u_i \bar G^{\text{ISD}}_{uvw} J^{v\bar w}$, from non primitive $(1,2)$ flux,~~

$m_{ij} = \frac{\sqrt{2}}{8} \mathrm{i} e^{\phi} \left(e^w_i e^t_j + e^w_j e^t_i\right) \Omega_{uvw} g^{u\bar u} g^{v\bar v} \bar G^{\text{ISD}}_{t\bar u\bar v}$, from primitive $(2,1)$ flux.

$\overline{\text{D3}}$ breaking of $\mathcal{N}$=1

Summary:

- We know that the action for an $\overline{\text{D3}}$ -brane on top of an O3-plane in flat space is of VA type (just have extra triplet)
- This triplet gets a mass in a GKP background with (2,1) flux
- This VA action for a single 4*D* spinor is the same as the action for the nilpotent chiral superfield
- The susy breaking scale *f* is related to tension and warp factor.

8. Conclusions

- We make progress in using string theory for cosmology, using supergravity techniques
- SUSY breaking in KKLT can be spontaneous using a $\overline{\text{D3}}$ brane.
- In effective $\mathcal{N}$=1 4*D* supergravity: Nilpotent multiplets give interesting cosmology with de Sitter vacua and

  spontaneously broken supersymmetry
- These models are embeddable in string theory
- And if you want to know more soon: go to …

http://iks32.fys.kuleuven.be/indico/event/StringThUniverse_Leuven2015

I hope that you all come !