A NEW CLASS OF DE SITTER VACUA IN TYPE IIB LARGE VOLUME COMPACTIFICATIONS

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SUSY17, TIFR, MUMBAI-INDIA

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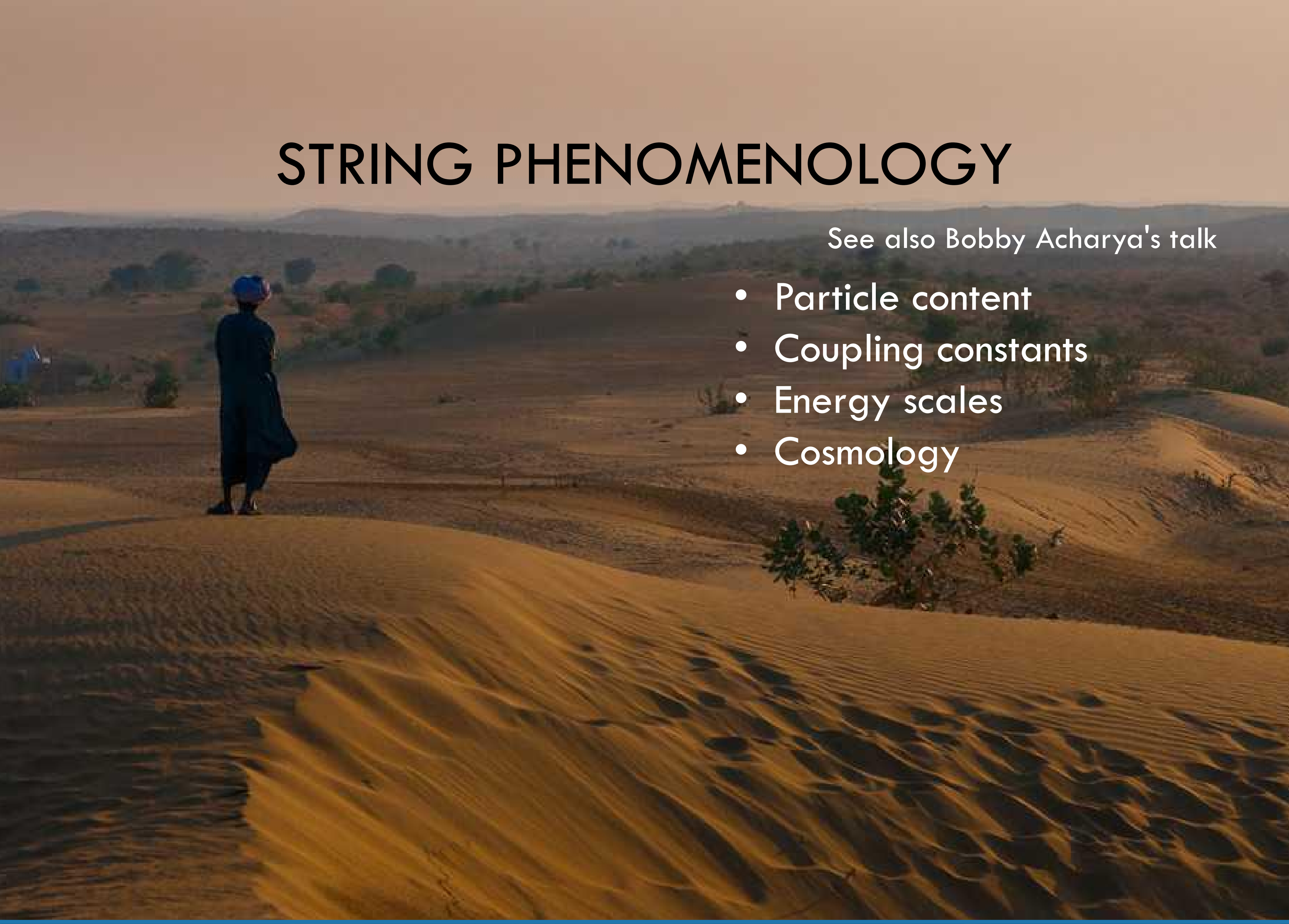
WORK IN COLLABORATION WITH M. C. D. MARSH (CAMBRIDGE U., DAMTP), B. VERCNOCKE (LEUVEN U.), T. WRASE (VIENNA, TECH. U.)



STRING PHENOMENOLOGY

See also Bobby Acharya's talk

- Particle content
- Coupling constants
- Energy scales
- Cosmology

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Good prospects for type IIB string flux compactifications with D-branes

Generalized electromagnetic fluxes to:

- Avoid massless exotic particles
- Control the scale of SUSY breaking
- <u>Finetune</u> the Cosmological constant

Can fluxes explain the full tune of the cosmological constant?

Yes!

In the context of Large Volume Compactifications we are able to analytically construct these novel vacua.

FLUX COMPACTIFICATIONS

The complex structure and axio/dilaton muduli acquire dynamics from fluxes

[Godins et al. '01]

$$W_0 = -\vec{N}^T \Sigma \vec{\Pi} \,. \qquad \Sigma = \begin{pmatrix} 0 & \mathbb{1} \\ -\mathbb{1} & 0 \end{pmatrix} .$$

Depending on the periods and flux vector

$$\vec{\Pi} = \begin{pmatrix} 1 \\ u^i \\ 2\mathcal{F} - u^j \mathcal{F}_j \\ \mathcal{F}_i \end{pmatrix} \qquad \vec{N} = -\begin{pmatrix} \int_{A^I} F_3 - S H_3 \\ \int_{B_I} F_3 - S H_3 \end{pmatrix}$$

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With the Kähler potencial

$$\tilde{K} = -\ln\left[-\mathrm{i}(S - \bar{S})\right] - \ln\left(\mathrm{i}\vec{\Pi}^\dagger \Sigma \vec{\Pi}\right)$$

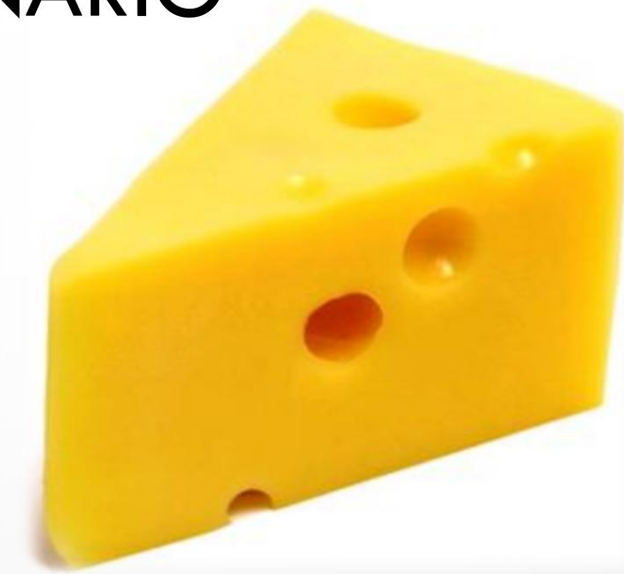
Standard procedure: find SUSY preserving solutions [KKLT '03]

$$\partial_S W_0 + \partial_S \tilde{K} W_0 = \partial_i W_0 + \partial_i \tilde{K} W_0 = 0$$

SUSY, and decoupling, ensure metastability

LARGE VOLUME SCENARIO

- Kähler moduli in Swiss-Cheese manifolds



$$W = W_0 + \sum_{s=1}^{N_{small}} A_s\, e^{\mathrm{i}a_s T^s}$$

$$K_{\mathrm{K}} = -2\ln\left[\mathcal{V} + \frac{\xi}{2}\left(-\mathrm{i}\frac{S-\bar{S}}{2}\right)^{\frac{3}{2}}\right]$$

$$\mathcal{V} = (\eta_b \tau^b)^{\frac{3}{2}} - \sum_{s=1}^{N_{\mathrm{small}}} (\eta_s \tau^s)^{\frac{3}{2}}$$

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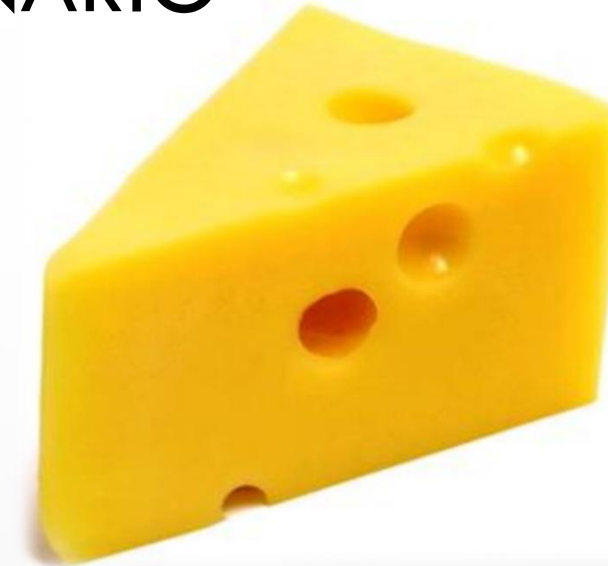

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Large volume expansión with $x_s = a_s \tau^s \gg 1$

[Quevedo et al. '05-on]

$$V_{\mathrm{LVS}} = \frac{a}{\mathcal{V}^3} - \frac{\sum_{s=1}^{N_{\mathrm{small}}} b_s x_s e^{-x_s}}{\mathcal{V}^2} + \frac{\sum_{s=1}^{N_{\mathrm{small}}} c_s \sqrt{x_s} e^{-2x_s}}{\mathcal{V}} \ldots$$

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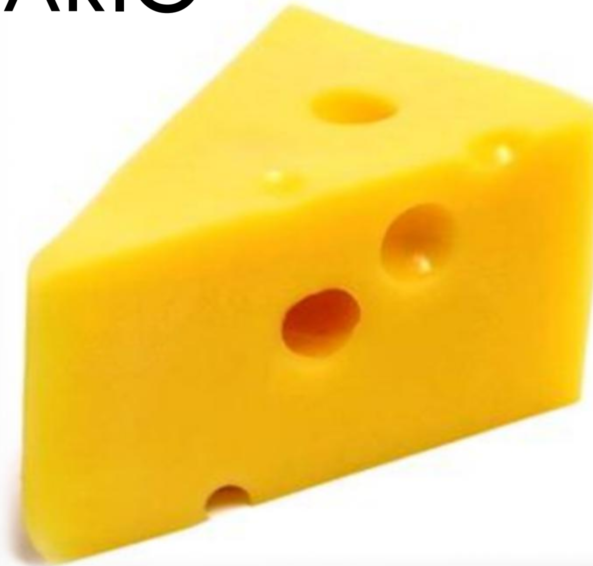

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Has a minimum at exponentialy large volume $\mathcal{V}_{\min} \approx \frac{b_s}{2c_s} e^{x_s} \sqrt{x_s} \,,$

$$V_{\mathrm{LVS}}|_{\min} \approx -\frac{1}{8\mathcal{V}_{\min}^3} \sum_s \frac{b_s^2}{c_s} \sqrt{x_s} \,.$$

NO-SCALE SUGRA NON-SUSY SOL'S

No-scale property

$$K(X,T) = K_X(X) + K_T(T) \qquad W(X,T) = W_X(X)$$

and

$$\dot{K}_T(\ddot{K}_T)^{-1}\dot{K}_T = 3$$

Then

$$F_T = \dot{K}_T W_X(X) \neq 0 \qquad V = e^K |W_X' + K_X' W_X|^2 \geq 0$$

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Look for non-SUSY sol's in the X sector [Marsh et al. '14]

$$F_X \sim \eta \ll 1 \quad \text{s.t.} \quad \langle V \rangle > 0$$

An almost flat mode

$$m_+^2 \sim 1 \qquad m_-^2 \sim \eta.$$

DECOUPLING IN LVS

Nearly factorizable models

[D.G. 15]

$$W(X,T) = W_X(X) + W_T(T) + \epsilon W_{mix}(X,T)$$

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This is the case in LVS with

$$\epsilon \sim 1/\mathcal{V}$$

For LVS

$$V = \frac{|F^X F_X|}{\mathcal{V}^2} + V_{LVS}$$

Thus Minkowski if

$$\eta \sim 1/\sqrt{\mathcal{V}} \gg \epsilon \sim 1/\mathcal{V}$$

The analysis for no-scale holds!

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Thus Minkowski if

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The analysis for no-scale holds!

Decoupling not destroyed for it is still suppressed!

FLUX VECTOR SPACE

From the parent basis of 3-forms $\{\Omega, \bar{\Omega}, D_i\Omega, \bar{D}_{\bar{\imath}}\bar{\Omega}\}$

[Candelas & de la Ossa. '91]

$$\{\vec{\Pi}, \vec{\Pi}^*, D_i\vec{\Pi}, \bar{D}_{\bar{\imath}}\vec{\Pi}^*\}$$

is a basis

With the projections

$$\vec{\Pi}^T \,\Sigma\, \vec{\Pi}^* = +\mathrm{i}e^{-K_{\mathrm{c.s.}}} \qquad D_i\vec{\Pi}^T \,\Sigma\, \bar{D}_{\bar{\jmath}}\vec{\Pi}^* = -\mathrm{i}K_{i\bar{\jmath}}e^{-K_{\mathrm{c.s.}}}$$

$$D_i\vec{\Pi} = \vec{\Pi}^T \,\Sigma\, \bar{D}_{\bar{\imath}}\vec{\Pi}^* = D_i\vec{\Pi}^T \,\Sigma\, D_j\vec{\Pi} = 0$$

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$$D_i\vec{\Pi} = \vec{\Pi}^T\,\Sigma\,\bar{D}_{\bar{\imath}}\vec{\Pi}^* = D_i\vec{\Pi}^T\,\Sigma\,D_j\vec{\Pi} = 0$$

Any vector in the flux space

$$\vec{V} = \mathrm{i}e^{K_{\mathrm{c.s.}}}\left((\vec{\Pi}^\dagger\Sigma\vec{V})\vec{\Pi} - (\vec{\Pi}^T\Sigma\vec{V})\vec{\Pi}^* - (K^{\bar{\jmath}l}\bar{D}_{\bar{\jmath}}\vec{\Pi}^\dagger\Sigma\vec{V})D_l\vec{\Pi} + (K^{j\bar{l}}D_j\vec{\Pi}^T\Sigma\vec{V})\bar{D}_{\bar{l}}\vec{\Pi}^*\right),$$

DECOMPOSING THE FLUX VECTOR

Denoting

$$F_A = D_A W = \partial_A W + K_A W \,,$$

$$Z_{AB} = D_A F_B = \partial_A F_B + K_A F_B - \Gamma^C_{AB} F_C$$

Then the Hodge decomposition reads

$$\vec{N} = \mathrm{i} e^{K_{\mathrm{c.s.}}} \left(\frac{\bar{F}_{\bar{S}}}{K_{\bar{S}}} \vec{\Pi} - W_0 \vec{\Pi}^* - \frac{\overline{Z}^{i}{}_{\bar{S}}}{K_{\bar{S}}} D_i \vec{\Pi} + F^{\bar{\imath}} \bar{D}_{\bar{\imath}} \vec{\Pi}^* \right) .$$

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(2,1) and primitive fluxes

$$\vec{N} = \mathrm{i} e^{K_{\mathrm{c.s.}}} \left(- \frac{\overline{Z}^{i}{}_{\bar{S}}}{K_{\bar{S}}} D_i \vec{\Pi} \right) .$$

STEPS TO NON-SUSY FLUX VACUA

1. Choose convenient moduli space point p
2. Choose a value for

$$\overline{Z}^{i}{}_{\bar{S}} \longrightarrow Z_{ij}$$

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3. Solve

$$v^{*I} Z_{IJ}|_p = -\lambda^* v_J \,,$$

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4. This fixes superpotential VEV

$$W_0|_p = \lambda$$

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5. Use this for "standard" LVS and determine $\mathcal{V}_0$.
6. The eigen value problen fixes the Goldstino direction. Take

$$F_I = \eta W v_I|_p$$

$$\eta \sim 1/\sqrt{\mathcal{V}_0} \ll 1$$

$$\vec{N} = \mathrm{i}e^{K_{\rm c.s.}} \left(\frac{\bar{F}_{\bar{S}}}{K_{\bar{S}}} \vec{\Pi} - W_0 \vec{\Pi}^* - \frac{\overline{Z}^{i}{}_{\bar{S}}}{K_{\bar{S}}} D_i \vec{\Pi} + F^{\bar{\imath}} \bar{D}_{\bar{\imath}} \vec{\Pi}^* \right) \Bigg|_p .$$

EXPLICIT EXAMPLE $\mathbb{CP}^4_{11169}$

Defined by $h^{1,1} = 2 \quad h^{2,1} = 272 \to 2$

$$\mathcal{F} = -\frac{3}{2}(u^1)^3 - \frac{3}{2}(u^1)^2 u^2 - \frac{1}{2}u^1(u^2)^2 + \frac{9}{4}(u^1)^2 + \frac{3}{2}u^1 u^2 + \frac{17}{4}u^1 + \frac{3}{2}u^2 - \mathrm{i}\zeta(3)\frac{135}{4\pi^3}\,.$$

$$\mathcal{V} = \frac{1}{9\sqrt{2}}\left(\left(-\mathrm{i}\frac{T^b - \bar{T}^b}{2}\right)^{3/2} - \left(-\mathrm{i}\frac{T^s - \bar{T}^s}{2}\right)^{3/2}\right) \qquad \xi = -\frac{\chi(CY_3)\zeta(3)}{2(2\pi)^3} \approx 1.31.$$

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Then with $p = \{S = u^1 = u^2 = 2\mathrm{i}\},$

$$A_s = 1 \qquad a_s = \frac{2\pi}{10}\,,$$

It is found

$$W_0|_p = -104, \qquad \mathcal{V}|_p \approx 6360 \qquad V|_p \approx -1.15 \times 10^{-11}$$

$$v_I \approx \begin{pmatrix} -0.196\mathrm{i} \\ +0.189\mathrm{i} \\ +0.0365\mathrm{i} \end{pmatrix}, \qquad \vec{f} \approx \begin{pmatrix} 0 \\ 6.93 \\ -17.8 \\ -5.03 \\ 4.55 \\ 10.4 \end{pmatrix}, \qquad \vec{h} \approx \begin{pmatrix} -0.114 \\ 0 \\ 0 \\ 0 \\ -13.8 \\ 1.85 \end{pmatrix}.$$

ACTUAL VACUUM

Moduli

$$S \approx 1.96\,\mathrm{i}\,, \quad u^1 \approx 2.03\,\mathrm{i}\,, \quad u^2 \approx 1.97\,\mathrm{i}\,,$$

$$\tau^s \approx 9.64\,, \quad \mathcal{V} \approx 11300\,.$$

Masses

m^2_{3+}	m^2_{3-}	m^2_{1+}	m^2_{2+}	m^2_{2-}	m^2_{1-}
1.61×10^{-5}	1.15×10^{-5}	3.56×10^{-7}	2.12×10^{-7}	2.20×10^{-8}	2.23×10^{-9}

$m^2_{\mathrm{Re}(T^s)}$	$m^2_{\mathrm{Im}(T^s)}$	$m^2_{\mathrm{Im}(T^b)}$	$m^2_{\mathrm{Re}(T^b)}$
1.18×10^{-5}	1.10×10^{-5}	7.06×10^{-12}	0

Cosmological constant

$$V \approx 9.03 \times 10^{-14}\,.$$

SOFT TERMS

- Visible sector realized in D-branes wrapping a cycle T_{SM}:
  - Decoupled from the original T^S.

$$\mathfrak{f} = c_1\, S + c_2\, T_{\rm SM}\,.$$

$$M_{1/2} \sim \frac{m_{3/2}}{\sqrt{\mathcal{V}_{\rm min}}} \sim m_{T^b}$$

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  - The no-scale ⟹ cancellation of the leading T^b contribution

Although F^S smaller the S contribution is comparable in general

$$K = \sum_\alpha h_\alpha(X^I,\, \bar{X}^{\bar{I}})\, e^{K/3} \kappa_\alpha\, (1 + \cdots)\, C^\alpha \bar{C}^{\bar{\alpha}} + \ldots\,,$$

$$M_{1/2}^2 \sim m_\alpha^2 \sim (A_{\alpha\beta\gamma})^2 \sim B\mu \sim \frac{m_{3/2}^2}{\mathcal{V}_{\rm min}} \sim m_{T^b}^2$$

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A degenerated spectrum!

Then given $m_{T^b} \geq 50 TeV$

no room for a WIMP scenario.

CONCLUSIONS

We report a new kind of dS vacua in the Large volume scenario:

- Important contributions from the SU sector to SUSY breaking.
- No extra ingredients like anti D-branes and a minimal set of fields.
- Are not deformations of standard LVS vacua.
- A sistematic step-by-step procedure is developed to construct such.
- The visible sector present a generic degenerate spectrum.

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Thank you!

SOME PREVIOUS HINTS

- Numerical Non-SUSY sols for the flux SU potential [Saltman-Silvertein'04]
- Numerical dS sols in STU models [Blabäck, Roest & Zavala '14]
- Random Matrix Models with dS vacua [Achucarro, Ortiz, Sousa'15]
- Aprox no-scale super gravities and dS vacua [Bercnocke, Marsh & Wrase'14]

For LVS

Thus Minkowski if

$$\eta \sim 1/\sqrt{\mathcal{V}} \gg \epsilon \sim 1/\mathcal{V}$$

The previous analysis holds!

For KKLT: up-lift naively requires

$$F^X \sim F^T \sim M_{SUSY}^2$$

such naively

$$m_-^2 \sim M_{SUSY}^2 \sim m_T^2$$

Working with both sectors separately is not justified!