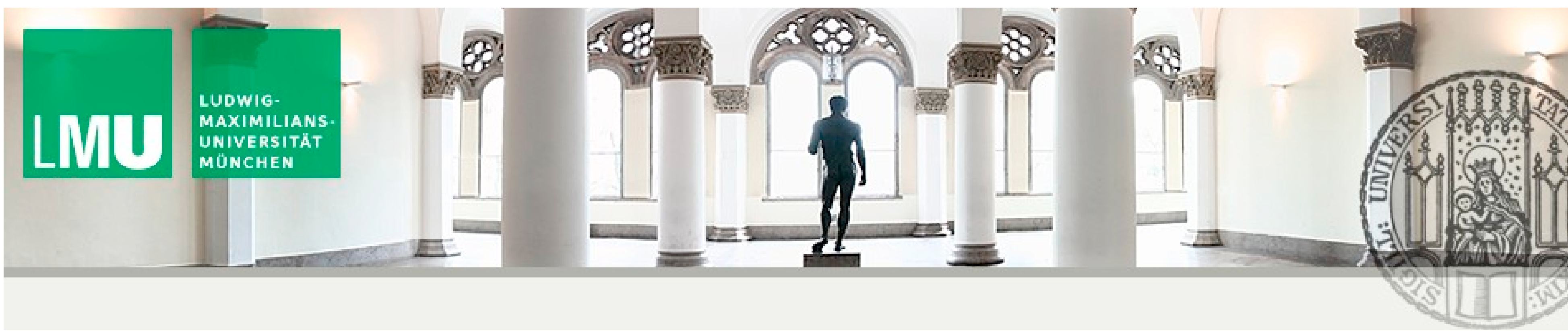
The Landscape of String theory

Dieter Lüst, LMU (ASC) and MPI München



$3^{\rm rd}$ RTN-workshop, Valencia

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The Landscape of String theory

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in collaboration with
Riccardo Appreda, Ralph Blumenhagen, Gabriel L. Cardoso, Mirjam Cvetic, Johanna Erdmenger, Florian Gmeiner, Viviane Grass, Michael Haack, Daniel Krefl, Gabriele Honecker, Costas Kounnas, Jan Perz, Marios Petropoulos, Susanne Reffert, Robert Richter, Christoph Sieg, Maren Stein, Stephan Stieberger Antoine van Proeyen, Dimitri Tsimpis, Timo Weigand and Marco Zagermann

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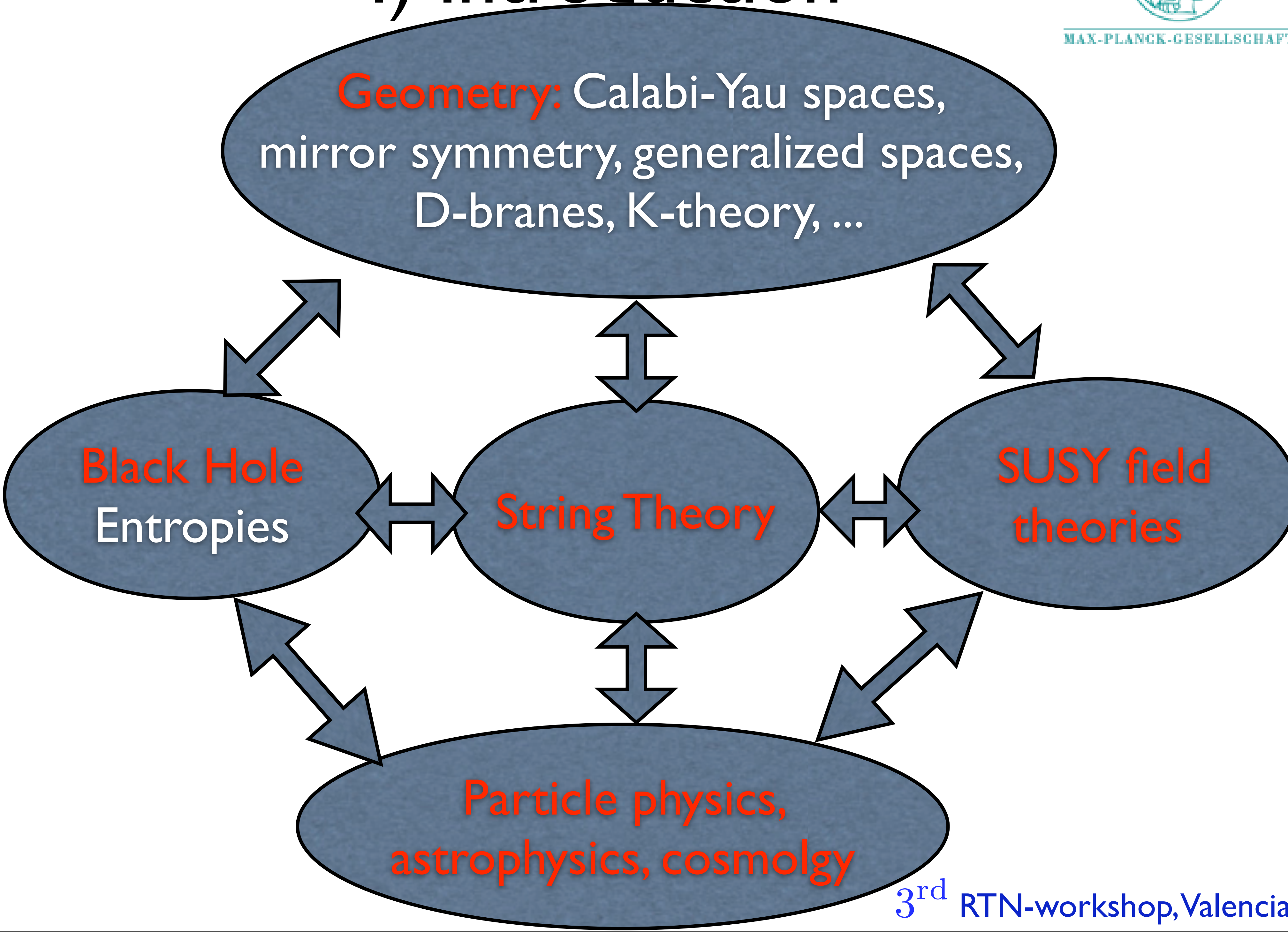
I) Introduction



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- Intermediate energies $(E \sim \mathcal{O}(\text{TeV}), \quad D = 4(6?))$:

  Perturbative (supersymmetric?) Standard Model (by compactification) with 3 quark families.

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- Low energies $(E \sim \mathcal{O}(\text{GeV})\,, \quad D = 4(5?))$

  Can string theory provide some non-perturbative informations for QCD?

Count the number of consistent string solutions

Vast landscape with $N_{sol} = 10^{500-1500}$ discrete vacua!

(Lerche, Lüst, Schellekens (1986), Douglas (2003))

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- Do not look randomly - look for green (promising) spots in the landscape ➡ model building, bottom up approach.

Outline

- Heterotic string compactifications
- Type II orientifolds models

  Intersecting brane models and their statistics

  D-instantons: non-perturbative couplings

- The string landscape: fluxes and branes

  AdS_2 flux vacua and black holes

  AdS_4 flux vacua and domain walls

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(Review: D. Lüst, arXiv:0707:2305)

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10 dimensions: gauge group $G_{10} = E_8 \times E_8, (SO(32))$

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4D chiral matter fields: $N_F = c_3(V)$

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$$H = SU(4) \implies G_4 = SO(10)$$

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Flipped SU(5): $H = SU(4) \times U(1) \quad \Longrightarrow \quad G_4 = SU(5) \times U(1)$

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☹ Moduli stabilization (bundle moduli!) with H-flux is difficult.

(Strominger (1985), Becker, Becker, Dasguta, Green (2003); Curio, Cardoso, Dall'Agata, Lüst, Krause (2003/04/05); Braun, He, Ovrut (2006))

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- Can be combined with background fluxes ➠ moduli stabilization (GKP) and dS-vacua (KKLT)

Perturbative type II orientifolds contain:

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- Closed string 6-dimensional background geometry:

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(diophantic equations with finite no. of solutions!)

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Geometrical, large radius regime:

IIA: special lagrangian submanifolds: D6 on 3-cycles at angles

⇕ Mirror symmetry (SYZ)

IIB: points, (complex lines), divisors, (CY) with gauge bundles:

D3 (D5) D7 (D9)

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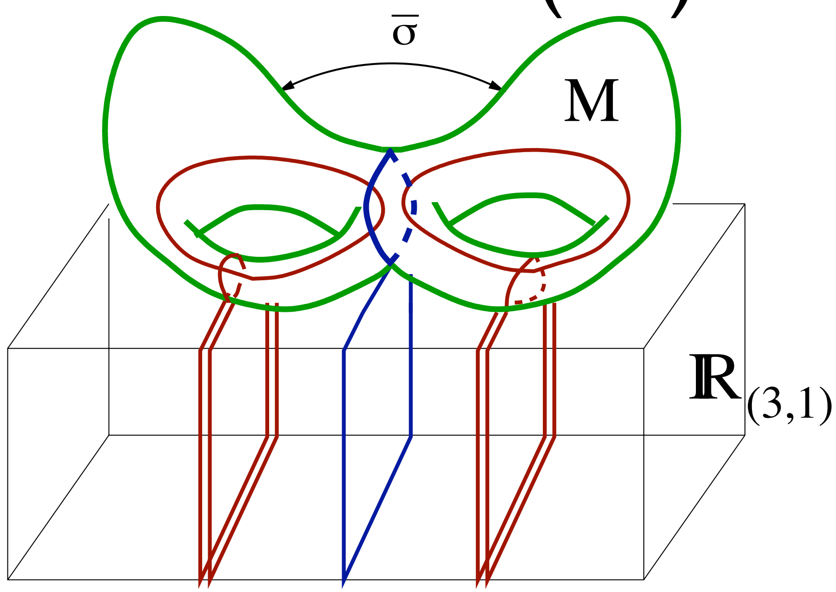

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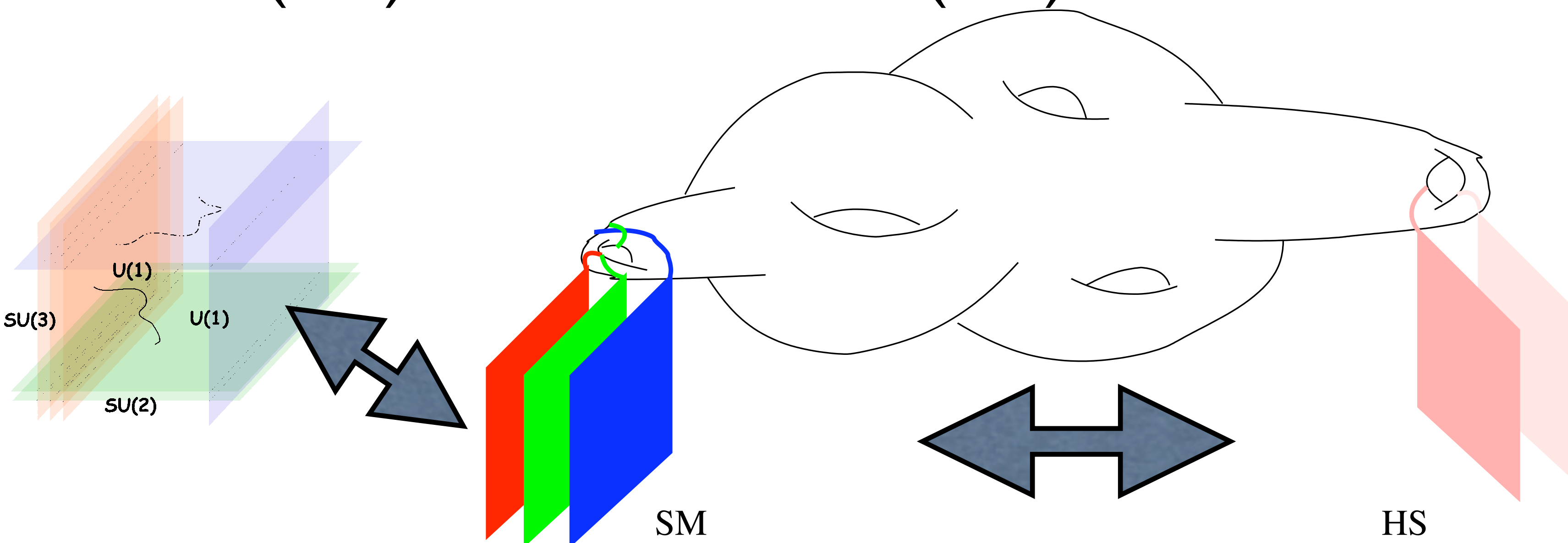

Soft SUSY breaking

How many orientifold models exist which come close to the (spectrum of the) MSSM?

(Blumenhagen, Gmeiner, Honecker, Lüst, Stein, Weigand, hep-th/0411173, hep-th/0510170, hep-th/0703011; related work: Dijkstra, Huiszoon, Schellekens, hep-th/0411129; Anastasopoulos, Dijkstra, Kiritsis, Schellekens, hep-th/0605226; Douglas, Taylor, hep-th/0606109; Dienes, Lennek, hep-th/0610319)

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Example: $\mathcal{M}_6 = T^6/(Z_2 \times Z_2)$ IIA orientifold:

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There exist about $1.66 \cdot 10^8$ susy D-brane models

on this orbifold (with restricted complex structure)!

(Finiteness of models was recently proven by D.T.)

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Restriction	Factor
gauge factor $U(3)$	0.0816
gauge factor $U(2)/Sp(2)$	0.992
No symmetric representations	0.839
Massless $U(1)_Y$	0.423
Three generations of quarks	2.92×10^{-5}
Three generations of leptons	1.62×10^{-3}
Total	1.3×10^{-9}

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Only one in a billion models gives rise to a MSSM like vacuum!

More results:

- D-brane statistics: (Gmeiner, Stein, hep-th/0603019; Gmeiner, Lüst, Stein, 0703011; Gmeiner, Honecker, arXiv:0708.2285)

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(i) Z6-orientifold: (exceptional, blowing-up 3-cycles!)

In total $3.4 \cdot 10^{28}$ susy D-brane models.

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- Explicit D-brane constructions:
there exist many models that come close to the MSSM.
Problem of exotic particles!

(Chen, Li, Mayes, Nanopoulos, hep-th/0703280; Chen, Li, Nanopoulos, hep-th/0604107; Blumenhagen, Plauschinn, hep-th/0604033; Bailin, Love, hep-th/0603172; Blumenhagen, Cvetic, Marchesano, Shiu, hep-th/0502095; Marchesano, Shiu, hep-th/0409132; Honecker, Ott, hep-th/0407181; .....)

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- Hidden sector: Moduli stabilization by fluxes.

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Take into account non-perturbative instanton corrections to the effective action!

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- Can generate new matter couplings (Majorana masses, Yukawa couplings) → see in a moment.

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IIA: special lagrangian submanifolds: E2 on 3-cycles

⇕ Mirror symmetry (SYZ)

IIB: points, (complex lines), divisors, (CY)

E(-1) (E1) E3 (E5)

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- Not all instantons can contribute to the effective action:

- F-terms: E(p)-brane is half-BPS:
  need two fermionic zero modes θ_i

- D-terms: E(p)-brane breaks all 4 supersymmetries:
  need four fermionic zero modes $\theta_i, \bar{\theta}_i$

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Instanton action:

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W_{np} must contain charged matter fields:

$$W_{np} \sim \prod \Phi_a e^{-S_E}$$

(U(1) selection rules will follow from fermionic zero modes.)

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Compute the 1-instanton Veneziano-Yankielowicz/ Affleck-Dine-Seiberg (VY/ADS) superpotential from string theory.

(N. Akerblom, R. Blumenhagen, D.L., E. Plauschinn, M. Schmidt-Sommerfeld)

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VY/ADS non-perturbative superpotential:

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$$W_{\rm n.p.} = \frac{1}{\det[\tilde{\Phi}_{ab}\Phi_{ab}]} \exp - \Big(f_{\rm a,tree} + f_{\rm a,1-loop}(M) \Big)$$

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From integration over bosonic zero modes, ADHM constraints.

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Possible generalizations:

- $SU(N_c),\ N_f \leq N_c - 1,$ due to gaugino condensation?
- Non-rigid cycles $(b_1(\Xi) \neq 0)$?

This corresponds to adjoint chiral fields in gauge theory, which must get a mass by fluxes.

Non-perturbative Yukawa couplings:

(R. Blumenhagen, M. Cvetic, D. Lüst, R. Richter, T. Weigand, arXiv:0707.1871)

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Consider two stack a and b of D6-branes:

$$G = U(5)_a \times U(1)_b = SU(5)_a \times U(1)_a \times U(1)_b$$

Open strings:

sector	number	$U(5)_a \times U(1)_b$ reps.	$U(1)_X$
(a', a)	$3 + (1, 1)$	$\mathbf{10}_{(2,0)}$	$\frac{1}{2}$
(a, b)	3	$\overline{\mathbf{5}}_{(-1,1)}$	$-\frac{3}{2}$
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(a', b)	1	$\mathbf{5}^H_{(1,1)} + \overline{\mathbf{5}}^H_{(-1,-1)}$	$(-1) + (1)$

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Abelian symmetries: $U(1)_a \times U(1)_b$

One anomalous linear combination: global symmetry

One anomaly free linear combination $U(1)_X$

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Two different cases:

$U(1)_X$ massive: Georgi-Glashow model

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These can be generated by E2-instantons:

The instanton has to wrap a rigid 3-cycle Ξ

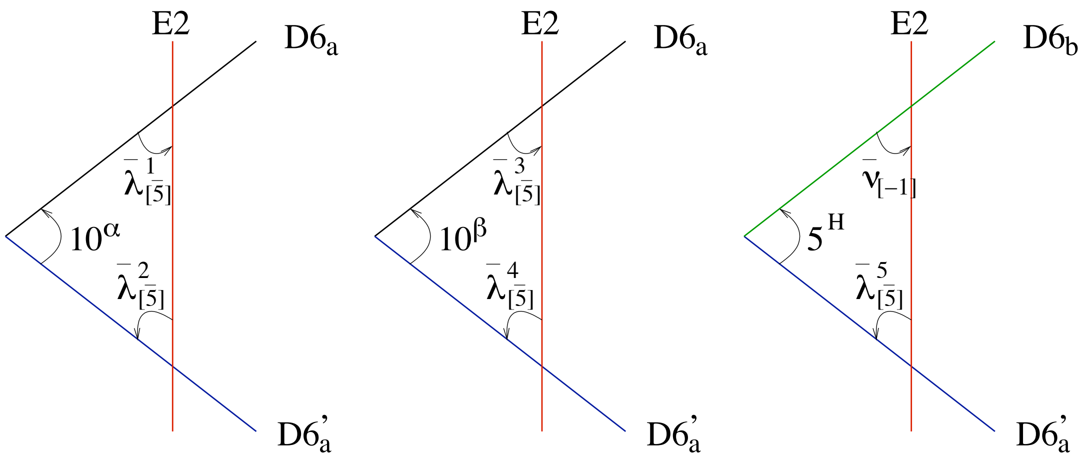
invariant under the orientfold projection $\Omega\bar{\sigma}$

and carrying gauge group $O(1)$

$U(1)_X$ charge of Yukawa coupling: one needs 6 fermionic zero modes:

Instanton intersection numbers:

$$[\Xi \cap \Pi_a]^+ = [\Xi \cap \Pi_b]^+ = 0, \quad [\Xi \cap \Pi_a]^- = [\Xi \cap \Pi_b]^- = 1$$



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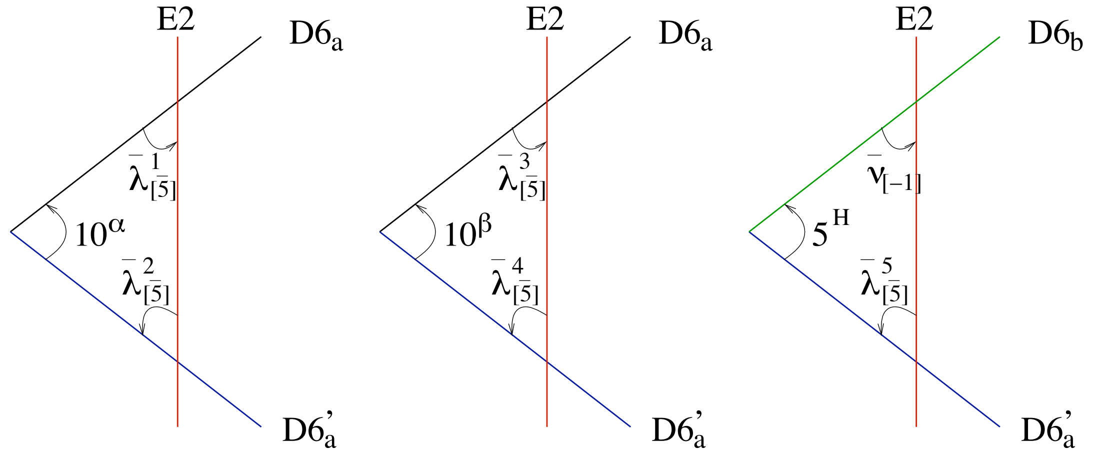

Instanton action: $\exp(-S_{inst}) = \exp\Big(C^{10}_\alpha \, 10^\alpha_{[ij]} \, \overline{\lambda}^i \overline{\lambda}^j + C^5 \, 5_m \, \overline{\lambda}^m \, \overline{\nu} \Big)$

Yukawa coupling: $W_Y = Y^{\alpha\beta}_{\langle \mathbf{10}\, \mathbf{10}\, \mathbf{5}_H \rangle} \, \epsilon_{ijklm} \, \mathbf{10}^\alpha_{ij} \, \mathbf{10}^\beta_{kl} \, \mathbf{5}^H_m \, e^{-S_{E2}} \, e^{Z'}$

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Two features of non-perturbative Yukawa coupling:

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Two features of non-perturbative Yukawa coupling:

(i) depend on complex structure moduli:

Suppression factor $\mathrm{Vol}_{E2}/\mathrm{Vol}_{D6} = (R_{E2}/R_{D6})^3$

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E2-instantons also relevant for doublet-triplet splitting, Majorana masses, masses for exotic states, ...

(Ibanez, Uranga, hep-th/0609213; Cvetic, Richer, Weigand, hep-th/0703028; Ibanez, Schellekens, Uranga, arXiv:0704.1079; Antusch, Ibanez, Macri, arXiv:07062132; Bianchi, Kiritsis, arXiv:0702015; Bianchi, Fucito, Morales, arXiv:0704.0784)

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String model buiding: What do we like to learn?

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(How good is the chain between fundamental theory and the data?)

Outline

- Heterotic string compactifications
- Type II orientifolds models

  Intersecting brane models and their statistics

  D-instantons: non-perturbative couplings

- The string landscape: fluxes and branes

  AdS_2 flux vacua and black holes

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(Weinberg, Bousso, Polchinski, Susskind, Linde, Schellekens, ...)

(Review: D. Lüst, arXiv:0707:2305)

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Compactification

There exist a huge number of lower dim. groundstates:

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How to make any prediction in string theory, i.e. how to determine the correct string vacuum state?

Moduli:

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String compactifications contain many massless moduli fields ϕ with flat potential:

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However undetermined moduli result in uncalculable couplings (and new forces)!

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In this way one can obtain a discrete set of vacua with either

- negative cosological constant, $\Lambda < 0$ (AdS vacua)
- zero cosmological constant, $\Lambda = 0$ (Minkowski vacua)
- positive cosmological constant, $\Lambda > 0$ (dS vacua)
- and various possibilities for gauge and matter fields

Effective moduli potential:

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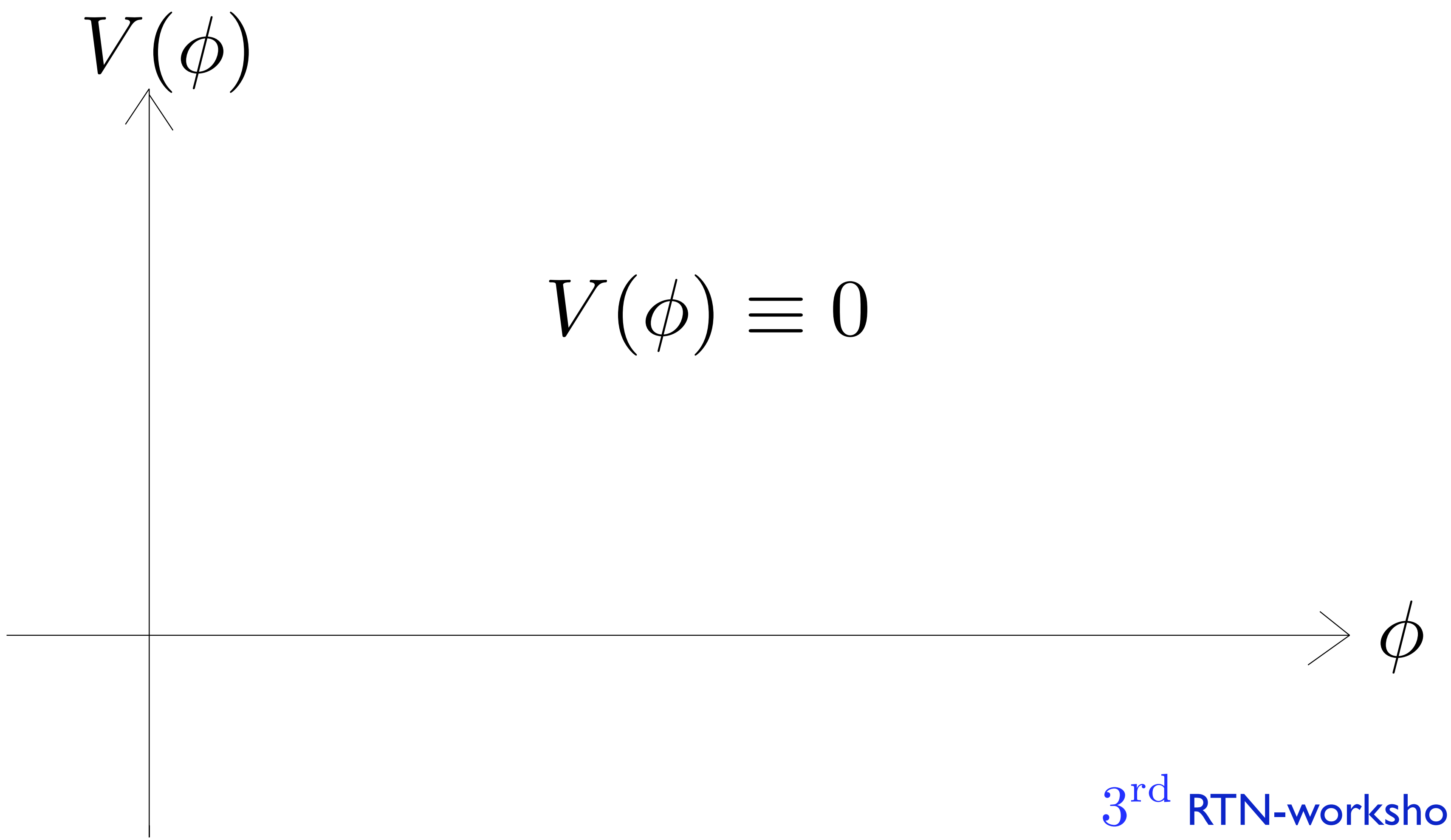
Flat moduli potential before turning on fluxes and non-perturbative effects:



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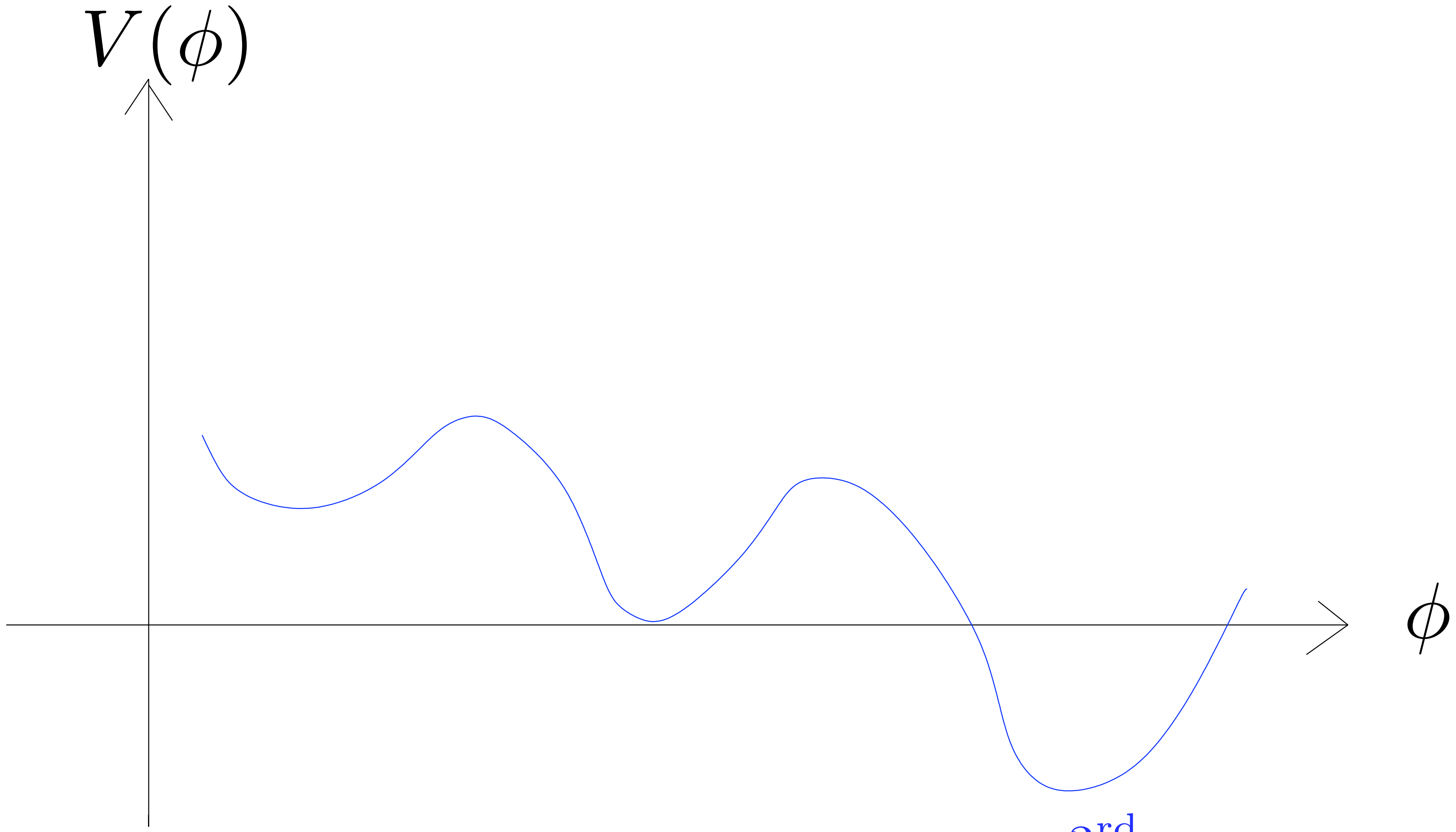

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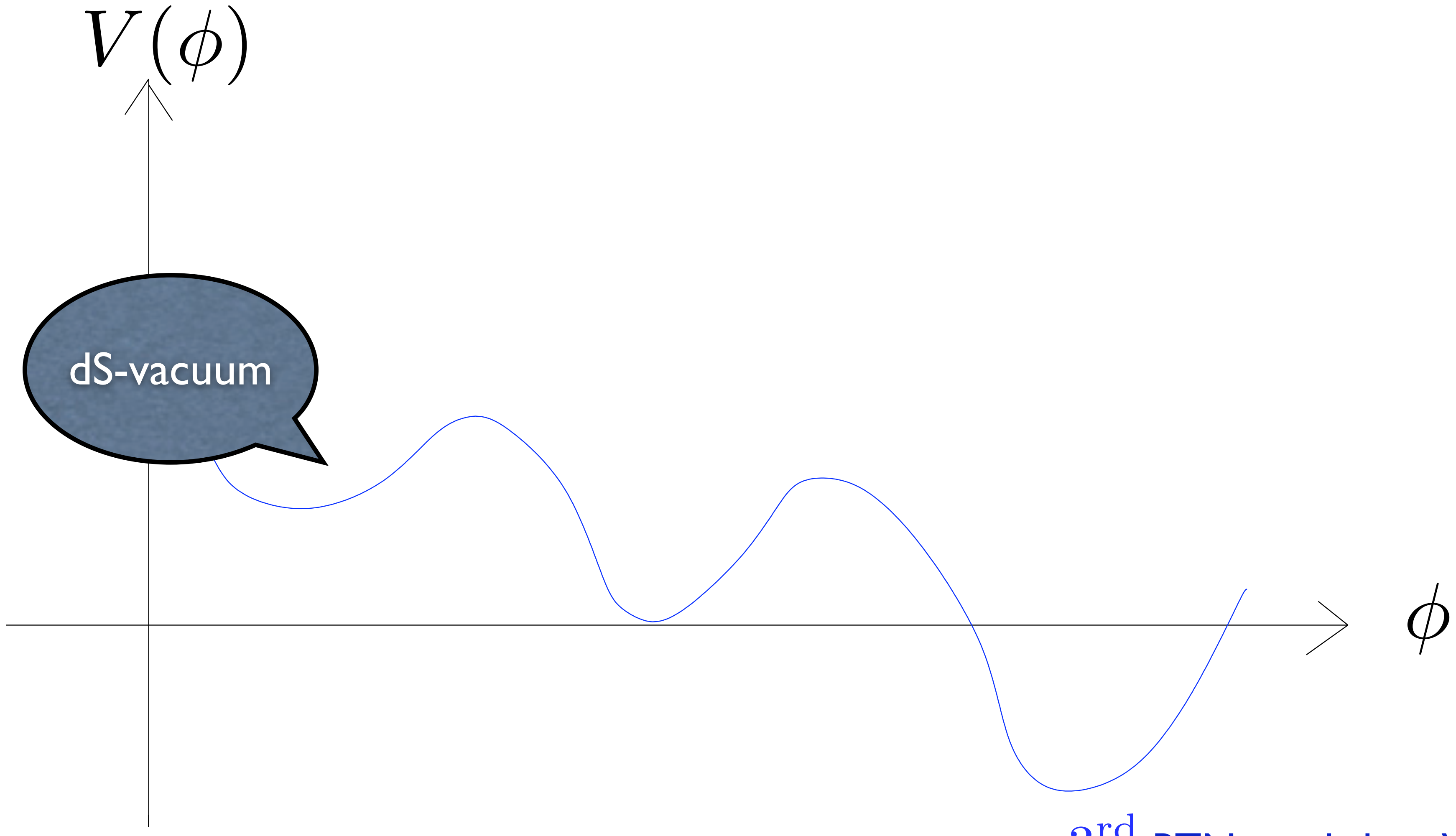

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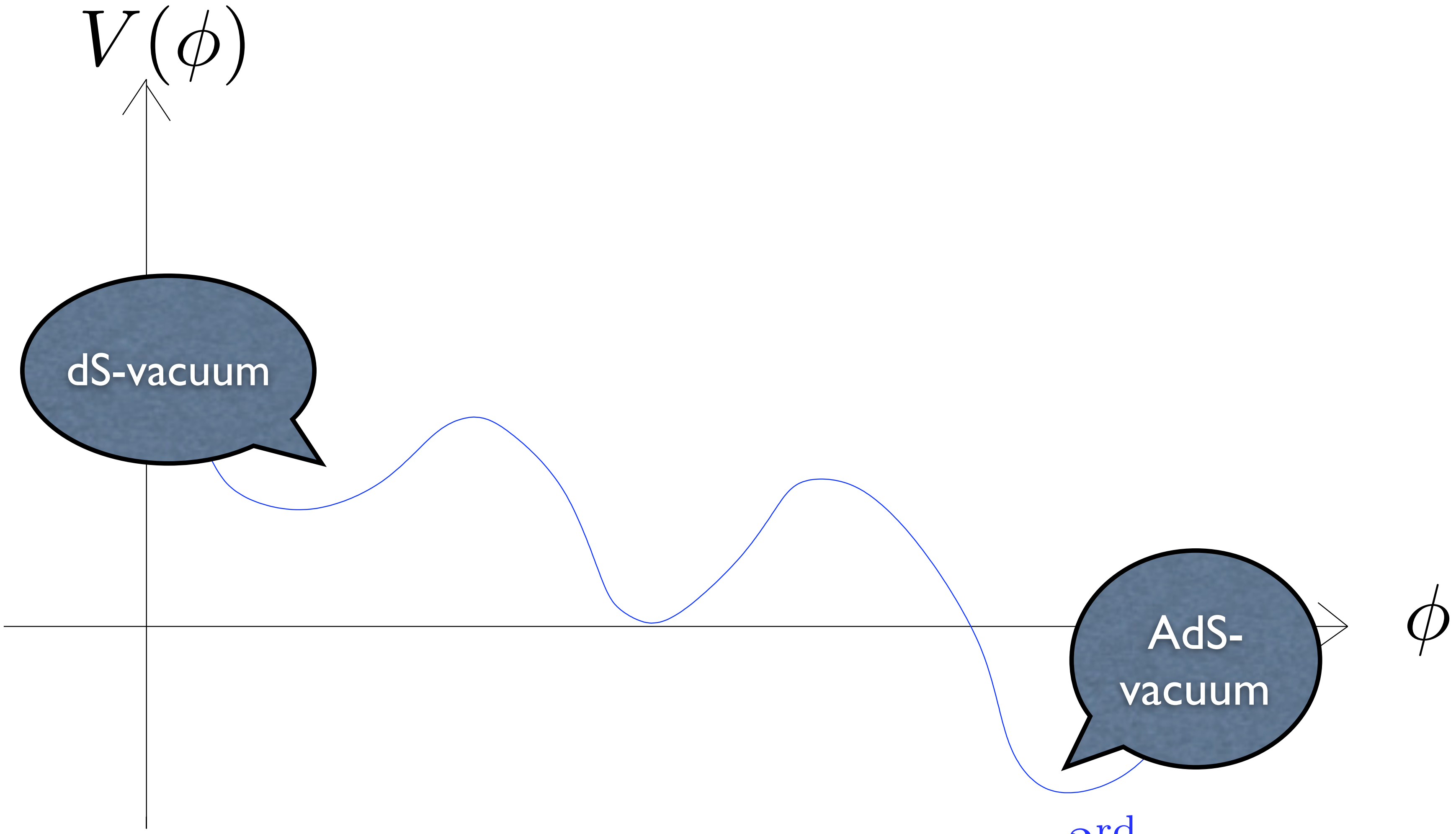

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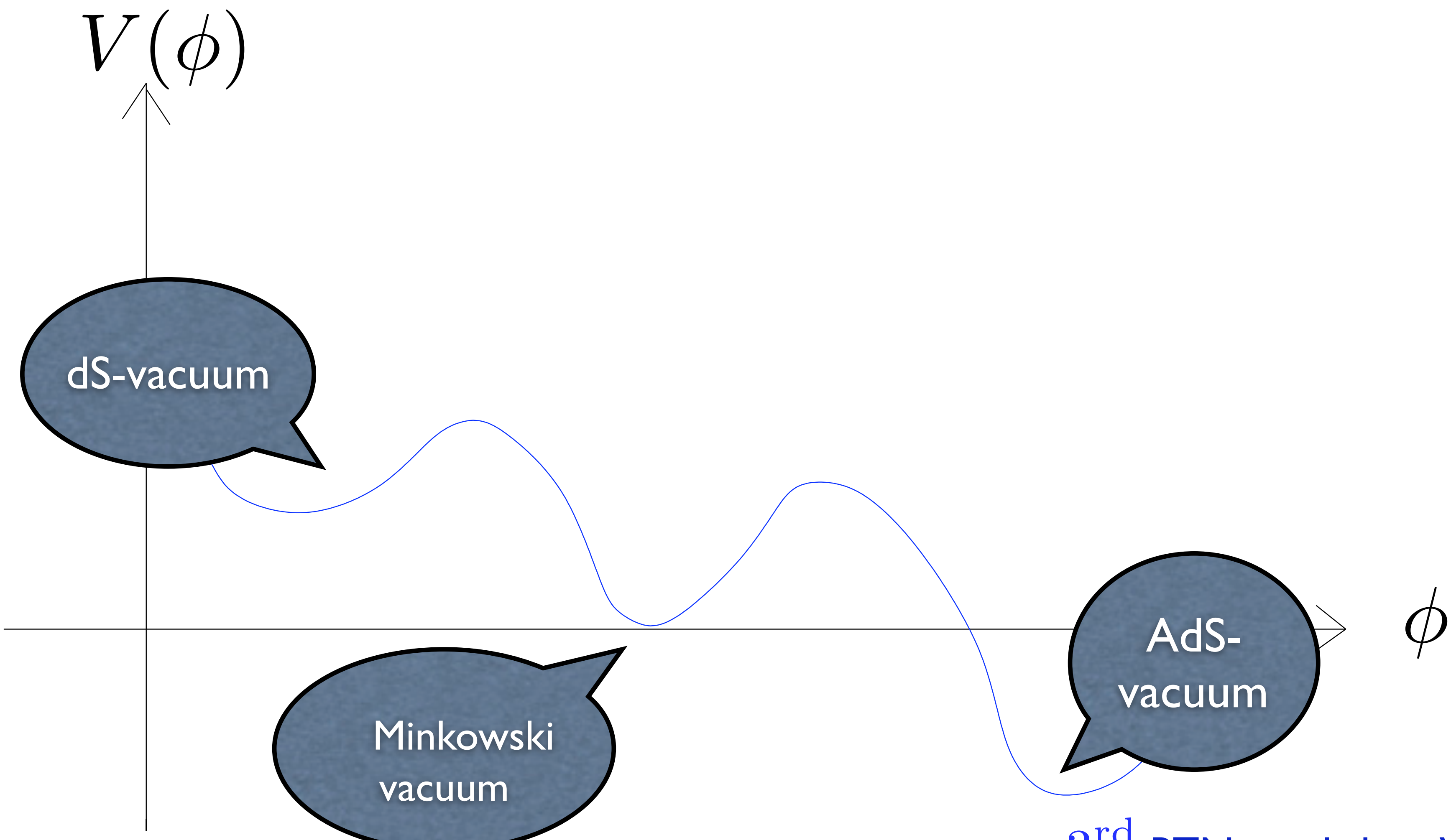

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Two possible solutions of the landscape problem:

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- String statistics (Anthropic answer): determine the fraction of vacua with good phenomenological properties:

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- Entropy of string vacua (Entropic answer): determine a wave function (probability function) in moduli space,

$$\psi(\phi)$$

and see if $|\psi|^2$ is peaked, i.e. has maxima with good phenomenological properties.

Wave function:

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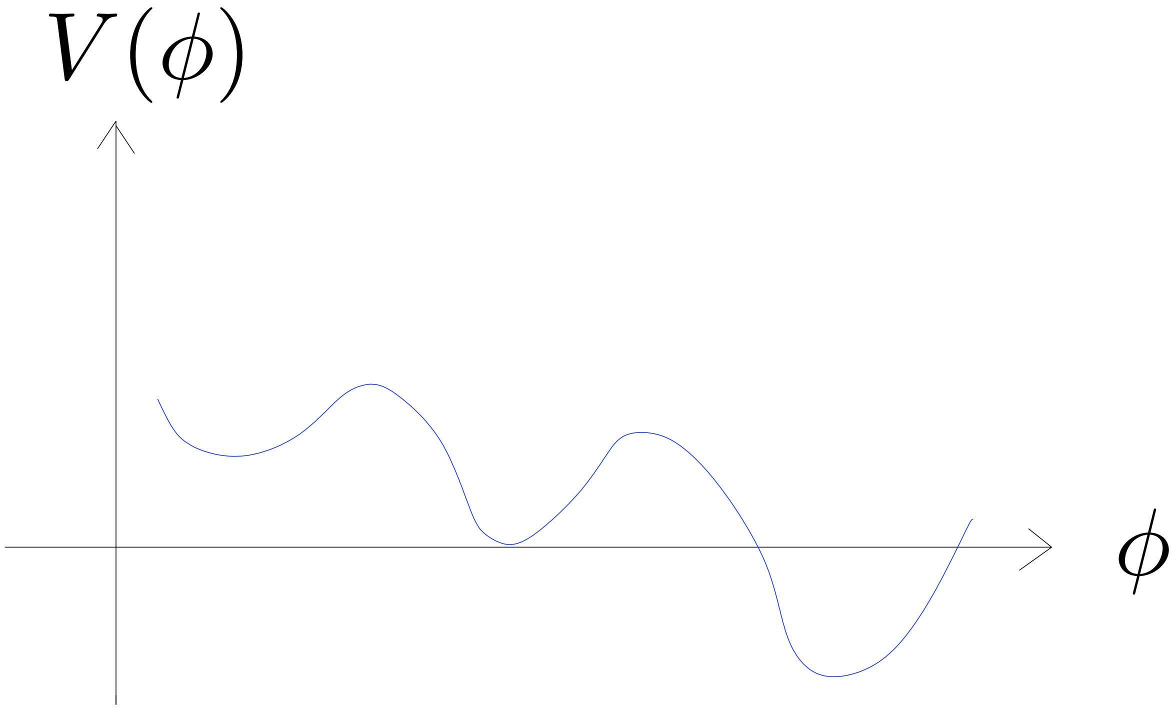
(i) Computation of transition amplitudes:

(Hartle, Hawking, Coleman, De Luccia, Linde, Vilenkin, ...)



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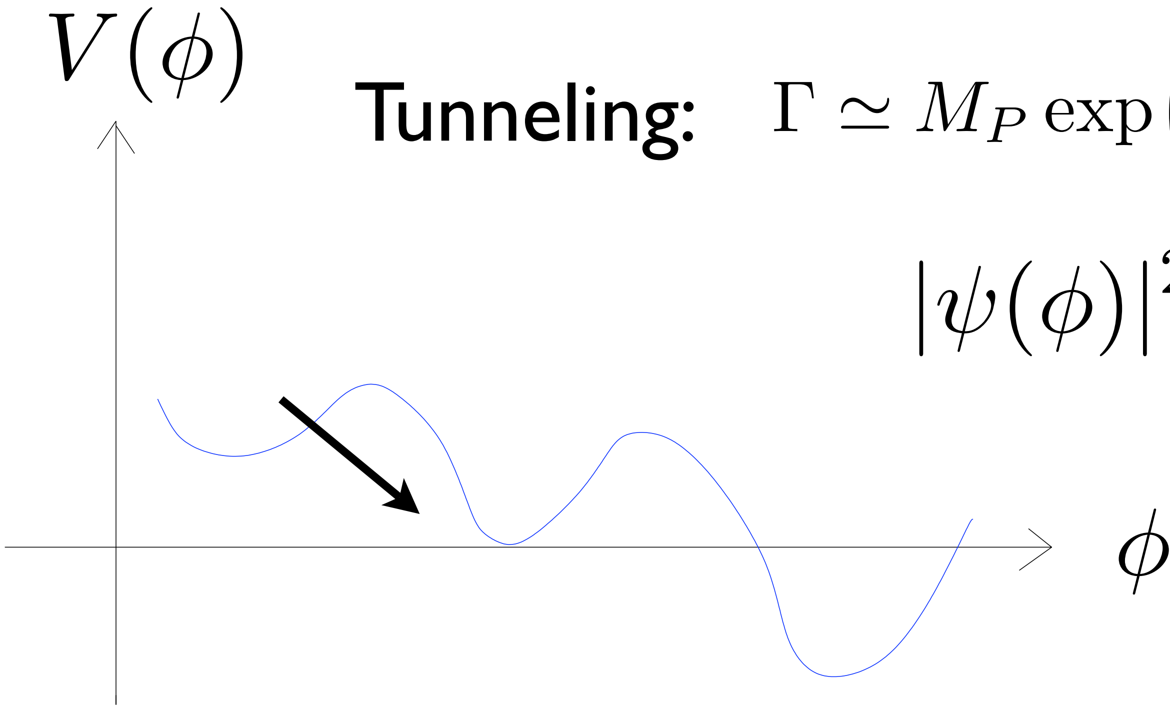

Tunneling: $$\Gamma \simeq M_P \exp\left(-\frac{24\pi^2 M_P^4}{\Lambda(\phi)}\right)$$

$$|\psi(\phi)|^2 \sim e^{-\Lambda(\phi)}$$

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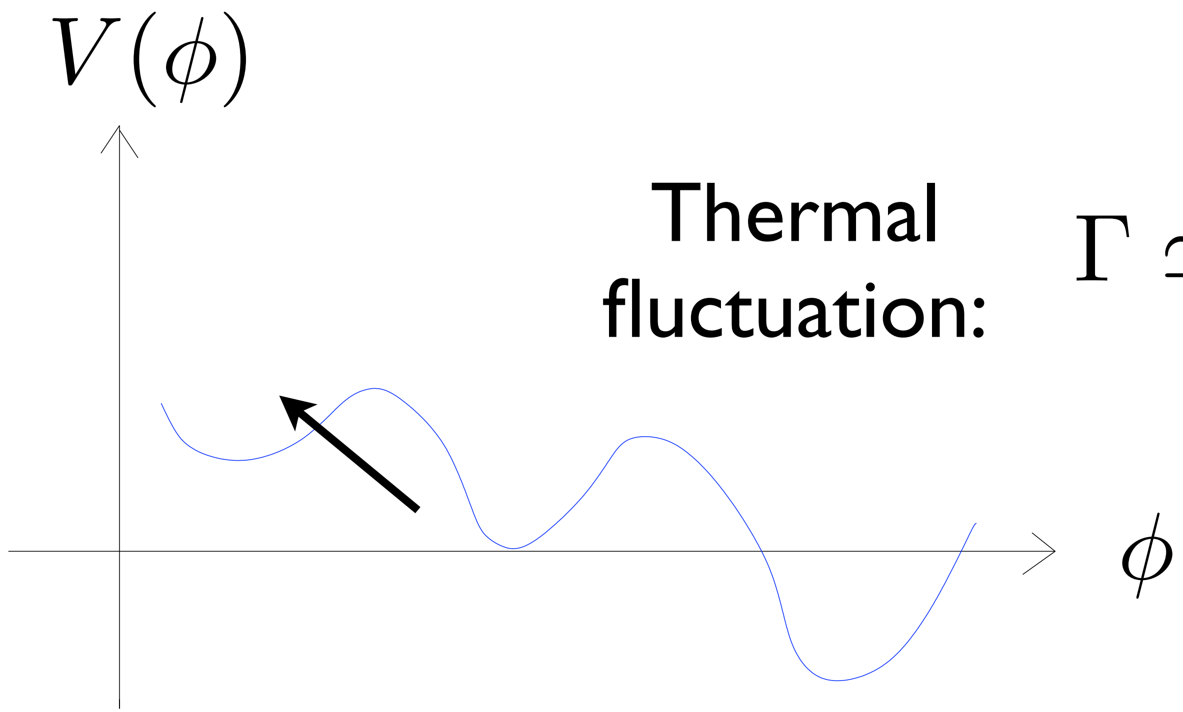

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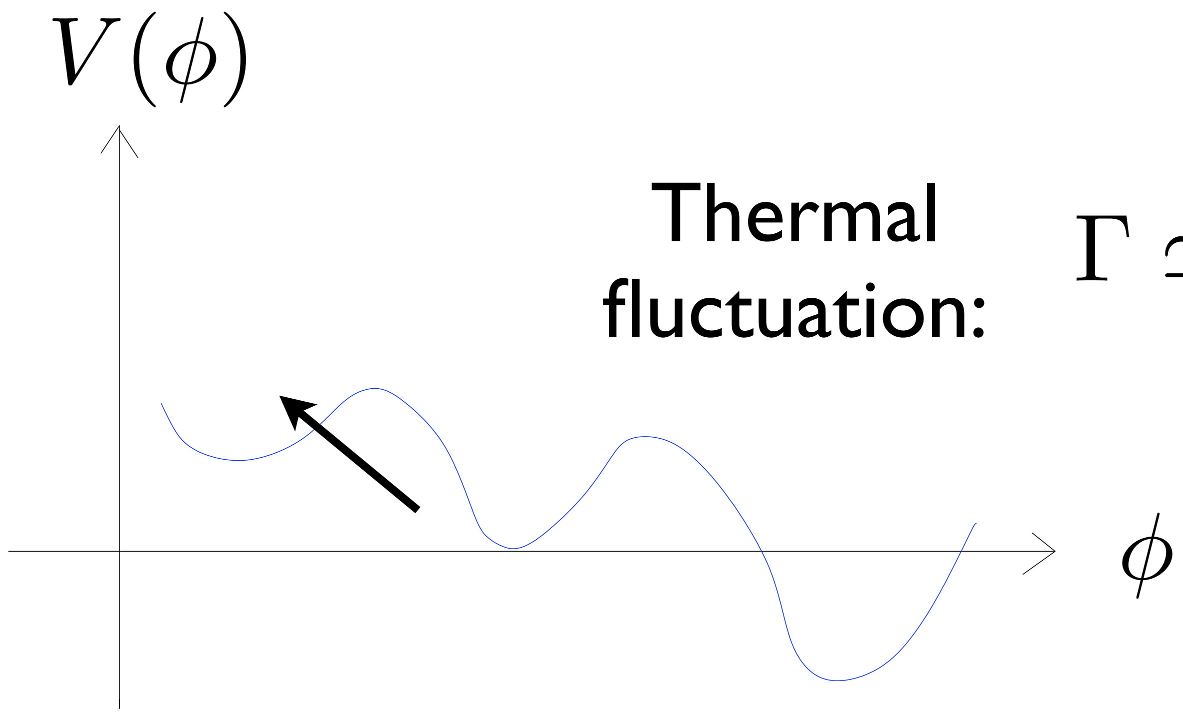

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(ii) „Stringy" computation of the entropy of string vacua:

$$|\psi(\phi)|^2 = e^{S_{\mathrm{string}}(\phi)}$$

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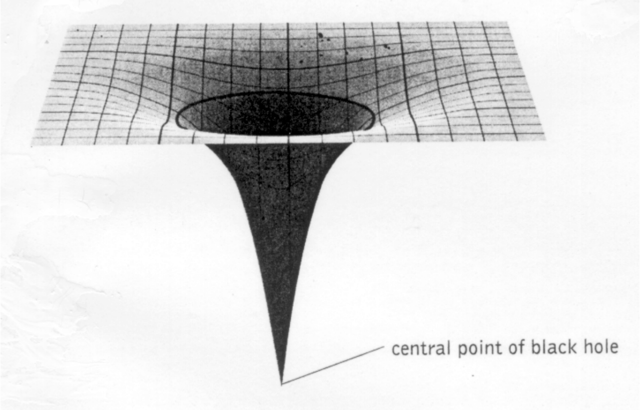

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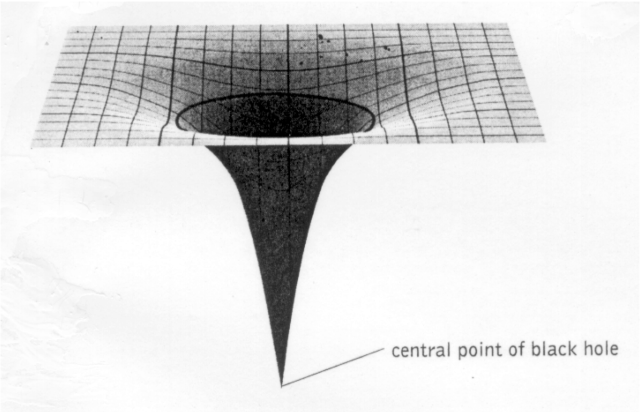

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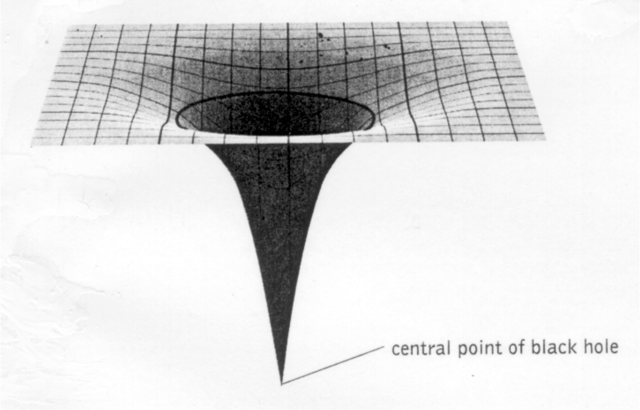

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Which one has the largest possible entropy?

Conjecture: (Ooguri, Vafa, Verline, hep-th/0502211)

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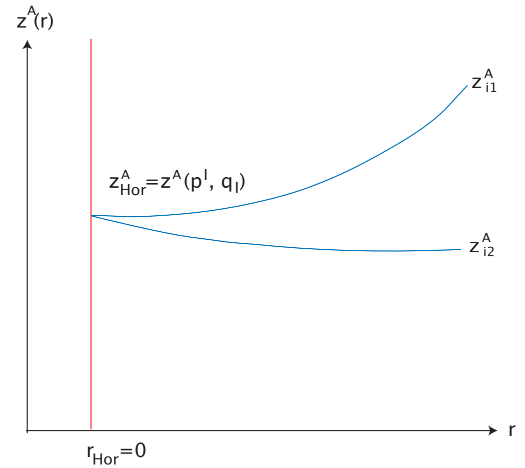

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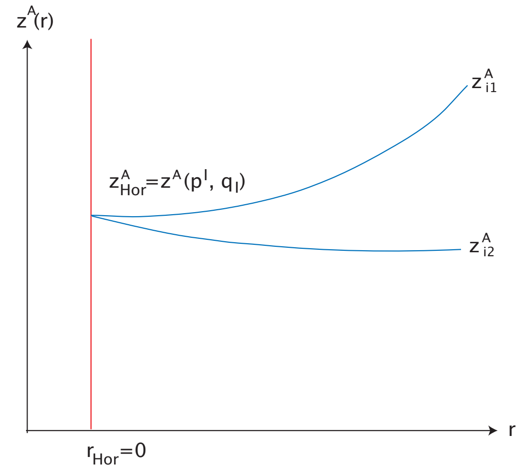

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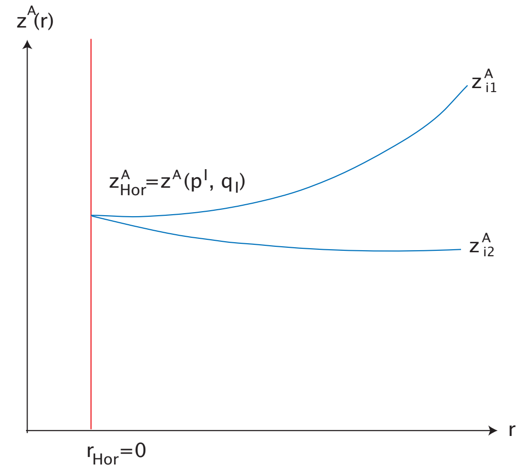

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(The black hole BPS conditions are very similar to the flux SUSY conditions, replacing the central charge Z by the superpotential W !)

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Example:

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Consider IIB on $S^2 \times CY$ with Ramond 5-form fluxes q_I and p^I through $S^2 \times \alpha_I(\beta_I) \quad (\alpha_I, \beta_I \subset CY)$

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Near horizon geometry ⇔ Vacuum geometry

$$AdS_2 \times S^2 \times CY$$

Application: entropy maximization

(Cardoso, Lüst, Perz, hep-th/0603211; related work: Gukov, Saraikin, Vafa, hep-th/0509109; Fiol, hep-th/0602103; Belluci, Ferrara, Marrani, hep-th/0602161

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Following the entropic principle infrared free theories seem to be preferred!

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- Heterotic string compactifications
- Type II orientifolds models

  Intersecting brane models and their statistics

  D-instantons: non-perturbative couplings
- The string landscape: fluxes and branes

  AdS_2 flux vacua and black holes

  AdS_4 flux vacua and domain walls

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(Related work: Cowdall, Lu, Pope, Stelle, Townsend, hep-th/9608173; Boonstra, Peeters, Skenderis, hep-th/9803231; Behrndt, Cardoso, Lüst, hep-th/0102128; Ceresole, Dall'Agata, Kallosh, Van Proeyen, hep-th/0104056; Behrndt, Cvetic, hep-th/0308045; Lüst, Tsimpis, hep-th/0412250; Ceresole, Dall'Agata, Giryavets, Kallosh, Linde, hep-th/0605266; .....)

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Metric fluxes (twisted tori)

$$W_{\rm geom}(S,T,U) = i \int_Y \Omega_c \wedge {\rm d}J = -\tilde{a}_i S T_i - \tilde{d}_{im} T_i U_m \, ,$$

The fluxes induce a C7 tadpole:

$$\tilde{N}_{\rm flux} = \int \left(C_7 \wedge \mathrm{d}F_2 + C_7 \wedge (\tilde{a}_0 H_3 + \mathrm{d}\bar{F}_2)\right) = \sum_{I=0}^{\tilde{h}^{1,1}} \tilde{a}_I \tilde{m}_I \, .$$

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$$|\gamma_i| T_i = \sqrt{\frac{5|\gamma_1\gamma_2\gamma_3|}{3\tilde{m}_0^2}}\,, \quad S = -\frac{2}{3\tilde{m}_0\tilde{a}_0}\gamma_i T_i\,, \quad \tilde{c}_m U_m = -\frac{2}{3\tilde{m}_0}\gamma_i T_i\,.$$

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IIB: No Kähler moduli: (LG description)

(Becker, Becker, Vafa, Walcher, hep-th/0611001)

Then all IIB moduli can be fixed by 3-form flux superpotential:

$$W_{\mathrm{IIB}} = \int_X \Omega \wedge \left(F_3^{\mathrm{R}} + S H_3^{\mathrm{NS}}\right) = i e_i U_i + i m_0 U_1 U_2 U_3 + i a_0 S$$

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Replace fluxes by (2+p)-dim. branes:

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2 common directions in uncompatified space

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⇕ T-duality

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$$0 = \left(\nabla_\mu + \tfrac{1}{4} H_\mu \mathcal{P} + \tfrac{e^\Phi}{16} \sum_n F_n \Gamma_\mu \mathcal{P}_n\right) \epsilon \,,$$

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- Non-vanishing C7 tadpole, same as for fluxes

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IIA Examples:

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(i) Not all moduli are stabilized:

Ramond 4-form flux superpotential:

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The corresponding sources are intersecting D4-branes:

	ξ^0	ξ^1	ξ^2	y^1	y^2	y^3	x^1	x^2	x^3	x^4
D4	$\otimes$	$\otimes$	$\otimes$				$\otimes$	$\otimes$		
D4′	$\otimes$	$\otimes$	$\otimes$						$\otimes$	$\otimes$

10 D metric and dilaton:

$$\mathrm{d}s^2_{10} = \frac{1}{\sqrt{H_1 H_2}}\,\eta_{\mu\nu}\mathrm{d}\xi^\mu \mathrm{d}\xi^\nu + \sqrt{H_1 H_2}\;\delta_{ij}\mathrm{d}y^i\mathrm{d}y^j + \sqrt{\frac{H_2}{H_1}}\sum_{a=1}^{2}(\mathrm{d}x^a)^2 + \sqrt{\frac{H_1}{H_2}}\sum_{a=3}^{4}(\mathrm{d}x^a)^2$$

$$\mathrm{e}^{-2\phi} = \sqrt{H_1 H_2}, \quad F_{x^3x^4y^iy^j} = -\delta^{kl}\varepsilon_{ijk}\partial_{y^l}H_1, \quad F_{x^1x^2y^iy^j} = -\delta^{kl}\varepsilon_{ijk}\partial_{y^l}H_2\ ,$$

where $4\pi H_\alpha = 1 + \dfrac{c_\alpha}{y} + \dfrac{d_\alpha}{2y^2}, \quad \alpha = 1, 2$

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H are not harmonic in overall transverse directions .

Smeared sources: $$j_\alpha := -\nabla^2 H_\alpha = c_\alpha\delta^3(y) - \frac{d_\alpha}{4\pi y^4}$$

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Near horizon limit $y \to 0$:

$$ds^2_{\rm NH} = \frac{y^2}{\sqrt{D_1 D_2}}\, \eta_{\mu\nu} d\xi^\mu d\xi^\nu \quad + \quad \sqrt{D_1 D_2}\, \frac{dy^2}{y^2} + \sqrt{D_1 D_2}\, d\Omega_2^2$$

Metric of $\mathrm{AdS}_4 \times S^2 \times T^4$ $+ \sqrt{\frac{D_2}{D_1}} \sum_{a=1}^{2} (dx^a)^2 + \sqrt{\frac{D_1}{D_2}} \sum_{a=3}^{4} (dx^a)^2$

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$$\mathrm{d}s_{10}^2 = \frac{1}{\sqrt{H_1 H_2}}\,\eta_{\mu\nu}\mathrm{d}\xi^\mu \mathrm{d}\xi^\nu + \sqrt{H_1 H_2}\;\delta_{ij}\mathrm{d}y^i \mathrm{d}y^j + \sqrt{\frac{H_2}{H_1}}\sum_{a=1}^{2}(\mathrm{d}x^a)^2 + \sqrt{\frac{H_1}{H_2}}\sum_{a=3}^{4}(\mathrm{d}x^a)^2$$

$$\mathrm{e}^{-2\phi} = \sqrt{H_1 H_2}, \quad F_{x^3 x^4 y^i y^j} = -\delta^{kl}\varepsilon_{ijk}\partial_{y^l} H_1, \quad F_{x^1 x^2 y^i y^j} = -\delta^{kl}\varepsilon_{ijk}\partial_{y^l} H_2\ ,$$

where $\quad 4\pi H_\alpha = 1 + \frac{c_\alpha}{y} + \frac{d_\alpha}{2y^2}, \qquad \alpha = 1,2$

H are not harmonic in overall transverse directions .

Smeared sources: $\quad j_\alpha := -\nabla^2 H_\alpha = c_\alpha \delta^3(y) - \frac{d_\alpha}{4\pi y^4}$

Near horizon limit $y \to 0$:

$$\mathrm{d}s_{\mathrm{NH}}^2 = \frac{y^2}{\sqrt{D_1 D_2}}\,\eta_{\mu\nu}\mathrm{d}\xi^\mu \mathrm{d}\xi^\nu \;+\; \sqrt{D_1 D_2}\,\frac{\mathrm{d}y^2}{y^2} + \sqrt{D_1 D_2}\;\mathrm{d}\Omega_2^2$$

Metric of $\mathrm{AdS}_4 \times S^2 \times T^4 \quad + \sqrt{\frac{D_2}{D_1}}\sum_{a=1}^{2}(\mathrm{d}x^a)^2 + \sqrt{\frac{D_1}{D_2}}\sum_{a=3}^{4}(\mathrm{d}x^a)^2$

String coupling $\quad g_s = \mathrm{e}^\phi \to 0 \quad$ Runaway behavior

(ii) All moduli are stabilized:

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The corresponding sources are intersecting D4, NS5 and D8-branes:

	ξ^0	ξ^1	ξ^2	y	x^1	x^2	x^3	x^4	x^5	x^6
D4	$\otimes$	$\otimes$	$\otimes$		$\otimes$	$\otimes$				
D4$'$	$\otimes$	$\otimes$	$\otimes$				$\otimes$	$\otimes$		
D4$''$	$\otimes$	$\otimes$	$\otimes$						$\otimes$	$\otimes$
NS5	$\otimes$	$\otimes$	$\otimes$		$\otimes$		$\otimes$		$\otimes$	
NS5$'$	$\otimes$	$\otimes$	$\otimes$		$\otimes$			$\otimes$		$\otimes$
NS5$''$	$\otimes$	$\otimes$	$\otimes$			$\otimes$		$\otimes$	$\otimes$	
NS5$'''$	$\otimes$	$\otimes$	$\otimes$			$\otimes$	$\otimes$			$\otimes$
D8	$\otimes$	$\otimes$	$\otimes$		$\otimes$	$\otimes$	$\otimes$	$\otimes$	$\otimes$	$\otimes$

Explicit form of the solution:

$$
\begin{aligned}
\mathrm{d}s_{10}^2 = &\quad \left\{H^{\mathrm{D8}}\left(\prod_{\alpha=1}^{3} H_\alpha^{\mathrm{D4}}\right)\right\}^{-\frac{1}{2}} \eta_{\mu\nu}\mathrm{d}\xi^\mu \mathrm{d}\xi^\nu \\
&+ \left(\prod_{\alpha=1}^{4} H_\alpha^{\mathrm{NS5}}\right)\left\{H^{\mathrm{D8}}\left(\prod_{\alpha=1}^{3} H_\alpha^{\mathrm{D4}}\right)\right\}^{\frac{1}{2}} \mathrm{d}y^2 \\
&+ \sqrt{\frac{H_2^{\mathrm{D4}}H_3^{\mathrm{D4}}}{H_1^{\mathrm{D4}}H^{\mathrm{D8}}}}\left\{H_3^{\mathrm{NS5}}H_4^{\mathrm{NS5}}\,(\mathrm{d}x^1)^2 + H_1^{\mathrm{NS5}}H_2^{\mathrm{NS5}}\,(\mathrm{d}x^2)^2\right\} \\
&+ \sqrt{\frac{H_1^{\mathrm{D4}}H_3^{\mathrm{D4}}}{H_2^{\mathrm{D4}}H^{\mathrm{D8}}}}\left\{H_2^{\mathrm{NS5}}H_3^{\mathrm{NS5}}\,(\mathrm{d}x^3)^2 + H_1^{\mathrm{NS5}}H_4^{\mathrm{NS5}}\,(\mathrm{d}x^4)^2\right\} \\
&+ \sqrt{\frac{H_1^{\mathrm{D4}}H_2^{\mathrm{D4}}}{H_3^{\mathrm{D4}}H^{\mathrm{D8}}}}\left\{H_2^{\mathrm{NS5}}H_4^{\mathrm{NS5}}\,(\mathrm{d}x^5)^2 + H_1^{\mathrm{NS5}}H_3^{\mathrm{NS5}}\,(\mathrm{d}x^6)^2\right\}; \\
\mathrm{e}^{2\phi} &= \left(\prod_{\alpha=1}^{4} H_\alpha^{\mathrm{NS5}}\right)\left(\prod_{\alpha=1}^{3} H_\alpha^{\mathrm{D4}}\right)^{-\frac{1}{2}}\left(H^{\mathrm{D8}}\right)^{-\frac{5}{2}}; \\
H_{x^2x^4x^6} &= -\partial_y H_1^{\mathrm{NS5}}\left(H^{\mathrm{D8}}\right)^{-1}; \quad H_{x^2x^3x^5} = -\partial_y H_2^{\mathrm{NS5}}\left(H^{\mathrm{D8}}\right)^{-1}; \\
H_{x^1x^3x^6} &= -\partial_y H_3^{\mathrm{NS5}}\left(H^{\mathrm{D8}}\right)^{-1}; \quad H_{x^1x^4x^5} = -\partial_y H_4^{\mathrm{NS5}}\left(H^{\mathrm{D8}}\right)^{-1}; \\
F_{x^3x^4x^5x^6} &= \partial_y H_1^{\mathrm{D4}}; \quad F_{x^1x^2x^5x^6} = \partial_y H_2^{\mathrm{D4}}; \\
F_{x^1x^2x^3x^4} &= \partial_y H_3^{\mathrm{D4}}; \quad F = -\partial_y H^{\mathrm{D8}}\left(\prod_{\alpha=1}^{4} H_\alpha^{\mathrm{NS5}}\right)^{-1}.
\end{aligned}
$$

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- Smeared (thick) branes:

$$H_\alpha^{\mathrm{D4}} = \begin{cases} c_\alpha^{\mathrm{D4}} y\{1 - \frac{1}{2}\left(\frac{y}{y_0}\right)\}, & y < y_0 \\ \frac{1}{2} c_\alpha^{\mathrm{D4}} y_0, & y \geq y_0 \end{cases}$$

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- Non-vanising tadpole: need (smeared) D6-branes and O6-plane.

T-dual type II B description:

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T-duality in x_1 direction:

$$W_{\rm IIB} = i(\tilde{e}_1 U_1 + \tilde{c}_2 U_2 + \tilde{c}_3 U_3 + \tilde{c}_1 T_1 + \tilde{e}_2 T_2 + \tilde{e}_3 T_3 + \tilde{m}_0 U_1 T_2 T_3 + \tilde{a}_0 S)$$

This includes geometrical fluxes.

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D3	$\otimes$	$\otimes$	$\otimes$			$\otimes$				
D5	$\otimes$	$\otimes$	$\otimes$		$\otimes$		$\otimes$	$\otimes$		
D5$'$	$\otimes$	$\otimes$	$\otimes$		$\otimes$				$\otimes$	$\otimes$
D7	$\otimes$	$\otimes$	$\otimes$			$\otimes$	$\otimes$	$\otimes$	$\otimes$	$\otimes$
NS5	$\otimes$	$\otimes$	$\otimes$		$\otimes$		$\otimes$		$\otimes$	
NS5$'$	$\otimes$	$\otimes$	$\otimes$		$\otimes$			$\otimes$		$\otimes$
KK	$\otimes$	$\otimes$	$\otimes$		$\bullet$	$\otimes$		$\otimes$	$\otimes$	
KK$'$	$\otimes$	$\otimes$	$\otimes$		$\bullet$	$\otimes$	$\otimes$			$\otimes$

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D5′	$\otimes$	$\otimes$	$\otimes$		$\otimes$				$\otimes$	$\otimes$
D7	$\otimes$	$\otimes$	$\otimes$			$\otimes$	$\otimes$	$\otimes$	$\otimes$	$\otimes$
NS5	$\otimes$	$\otimes$	$\otimes$		$\otimes$		$\otimes$		$\otimes$	
NS5′	$\otimes$	$\otimes$	$\otimes$		$\otimes$			$\otimes$		$\otimes$
KK	$\otimes$	$\otimes$	$\otimes$		$\bullet$	$\otimes$		$\otimes$	$\otimes$	
KK′	$\otimes$	$\otimes$	$\otimes$		$\bullet$	$\otimes$	$\otimes$			$\otimes$

Near horizon: $AdS_4 \times N$, (Nilmanifold)

Resume:

We found new supersymmetric brane solutions that correspond to AdS_4 flux vacua.

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Open problems:

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We found new supersymmetric brane solutions that correspond to AdS_4 flux vacua.

Open problems:

- Entropy count of brane configurations.
- Uplift to dS and its brane description.
- Characterization of brane configurations via generalized geometry.

Conclusions

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Thank you for organizing this conference!