Moduli Stabilization in Meta-Stable Heterotic String Vacua

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in collaboration with Marco Serone

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Go back to moduli stablization and SUSY breaking in flux-less, perturbative heterotic strings

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RT2: has a non-SUSY minimum, $F_T \neq 0$, but still AdS

RT3: has a SUSY AdS minimum in S and T !

SUSY breaking - add one more condensate: $SU(N)$ with N_f flavors $Q, \tilde{Q}$ such that $N < N_f < 3N/2$ - realizes ISS

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Dynamics of baryons $\varphi \sim Q^N$, $\tilde{\varphi} \sim \tilde{Q}^N$ & mesons $\Phi \sim Q\tilde{Q}$ below $\Lambda_{\rm ISS}$

$$W_{\rm ISS} = {\rm Tr}\, \tilde{\varphi}^t \Phi \varphi - \mu^2 {\rm Tr}\, \Phi + \frac{\det \Phi}{\Lambda_{\rm ISS}^{N-2}}$$

$\Phi \ll \mu \ll \Lambda_{\rm ISS}$: determinant piece negligible, SUSY-breaking vacuum at

$$\Phi_0 = \begin{pmatrix} Y_0 & 0_N \\ 0_N & \hat{\Phi}_0 \end{pmatrix} = 0 \quad , \quad \varphi_0 = \tilde{\varphi}_0 = \begin{pmatrix} \mu \\ 0_N \end{pmatrix}$$

$\mu \ll \Phi \ll \Lambda_{\rm ISS}$: trilinear piece negligible, SUSY vacuum at

$$\varphi_{\rm SUSY} = \tilde{\varphi}_{\rm SUSY} = 0 \quad , \quad \Phi_{\rm SUSY} = \frac{\mu}{\epsilon_{\rm ISS}^{(N-2)/N}} \mathbb{1}_{N_f} \quad , \quad \epsilon_{\rm ISS} = \frac{\mu}{\Lambda_{\rm ISS}}$$

embedding into heterotic supergravity - μ and $\Lambda_{\rm ISS}$ S-dependent

the full system is now:

$$W = W_{\rm RT} + W_{\rm ISS} \quad , \quad \mu^2(S) = e^{-\eta S} \quad , \quad \Lambda_{\rm ISS} = e^{-\frac{8\pi^2}{2N-1}S}$$

$$K = \underbrace{-3\ln(T+\bar{T}) - \ln(S+\bar{S})}_{K_{\rm RT}} + K_{\rm ISS}$$

$K_{\rm ISS}$ now essentially unknown, allow for S- and T-dependence, take

$$K_{\rm ISS} = \frac{\mathrm{Tr}\,\Phi^\dagger\Phi}{(T+\bar{T})^m(S+\bar{S})^n} + \frac{\mathrm{Tr}(\varphi^\dagger\varphi + \tilde{\varphi}^\dagger\tilde{\varphi})}{(T+\bar{T})^p(S+\bar{S})^q}$$

Study of full $V_F(S,T,\Phi,\varphi,\tilde{\varphi})$ is hard. Expand in powers of $\mu \ll 1$

$$V_F = V_s + V_w \quad \text{with :} \quad \mathrm{V_s} \gg \mathrm{V_w}$$

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$$V_s = e^{K_{\rm RT}}\left(K^{i\bar{j}}_{\rm RT} D_i W_{\rm RT}\overline{D_j W_{\rm RT}} - 3|W_{\rm RT}|^2 + N_c \mu^4(S)\right)$$

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Requiring Minkowski vacuum determines size of $W_{\rm RT}$

$$W_{\rm RT} \sim \mu_0^2 \equiv \mu^2(S_0) \quad \Rightarrow \quad m_{3/2} = e^{K/2}|W_0| \sim \mu_0^2$$

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see also [Dudas, Papineau & Pokorski; Abe et al.]

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The SUSY vacuum of ISS is still there - as it is AdS, the non-SUSY vacuum is meta-stable

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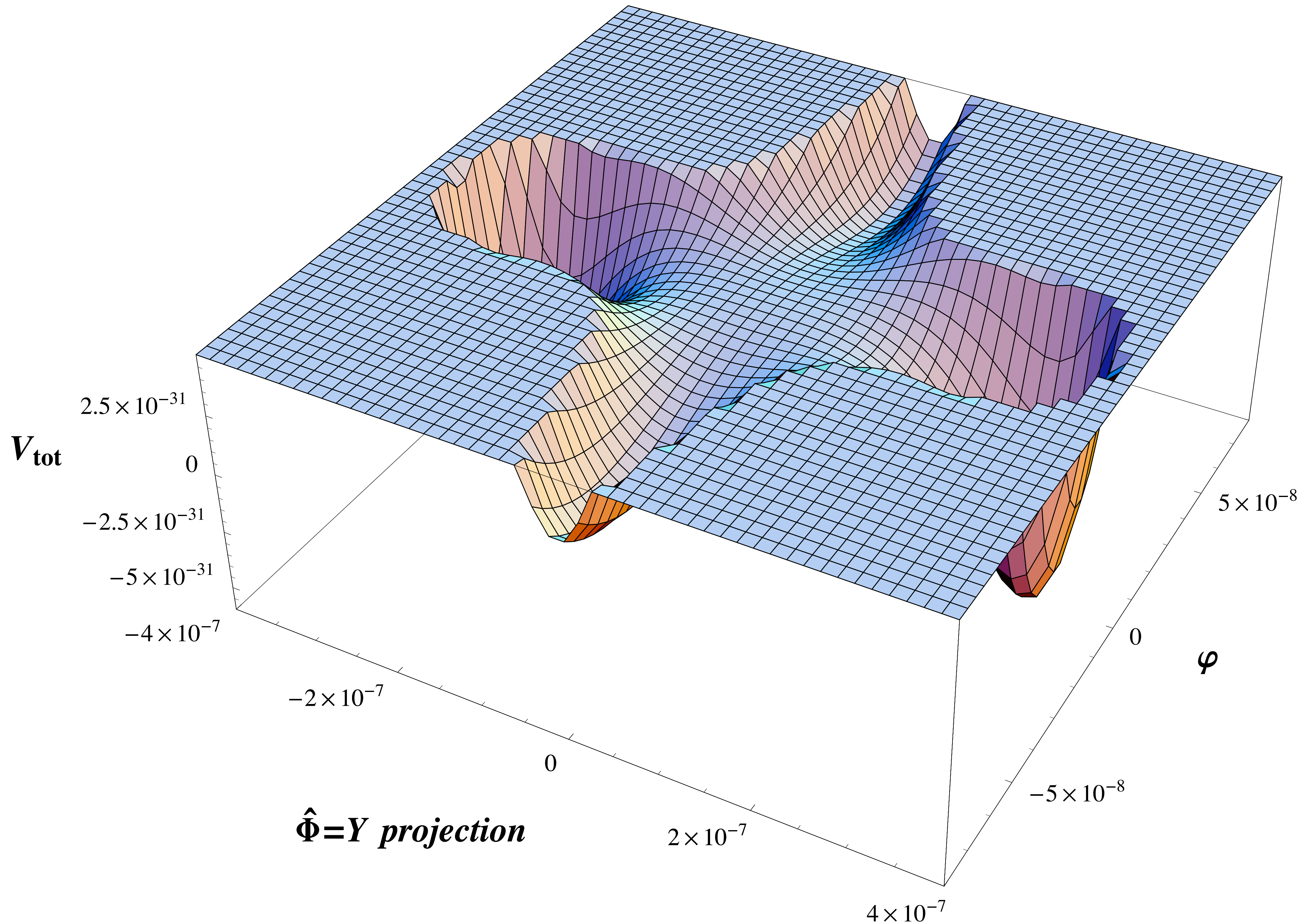

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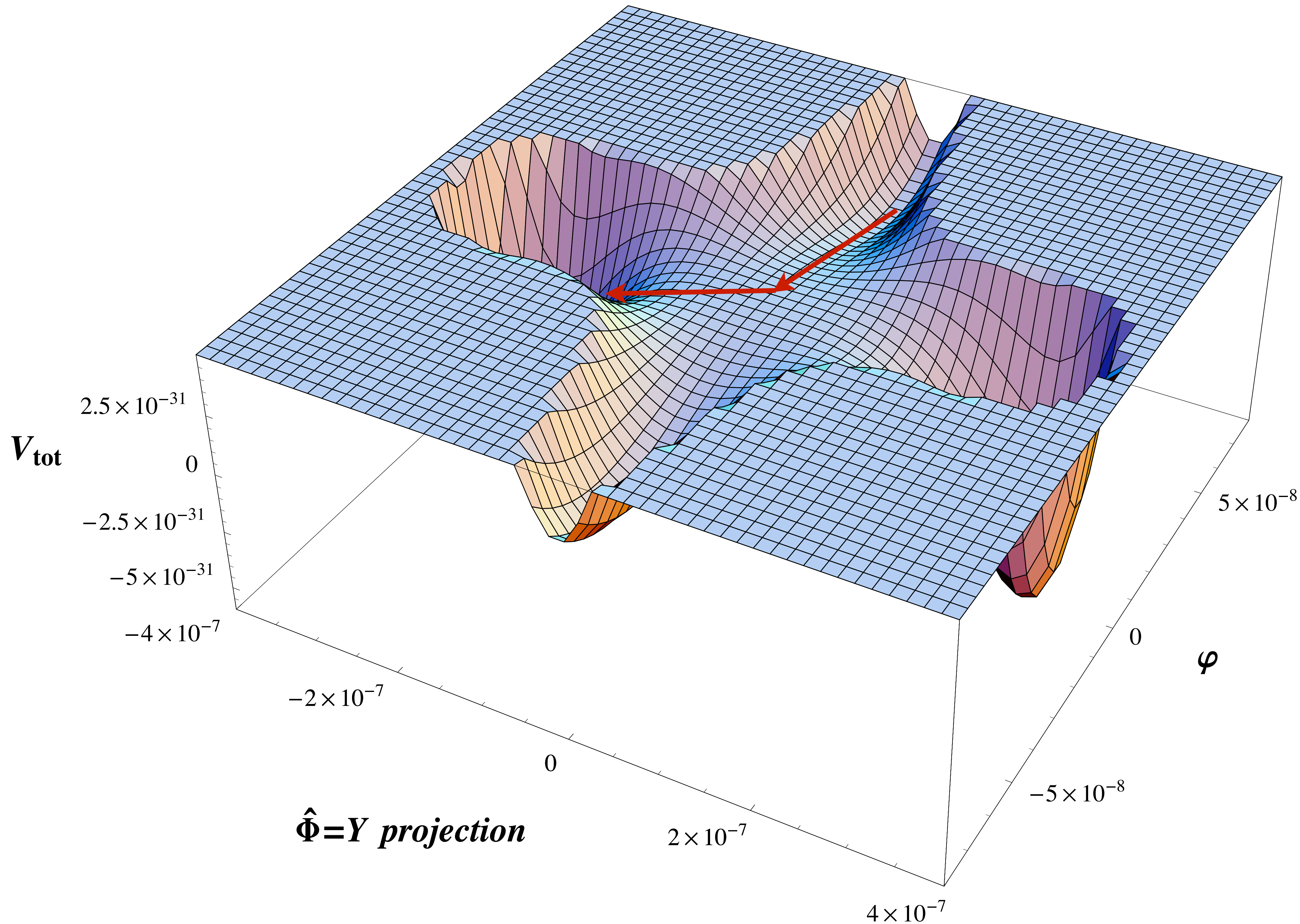

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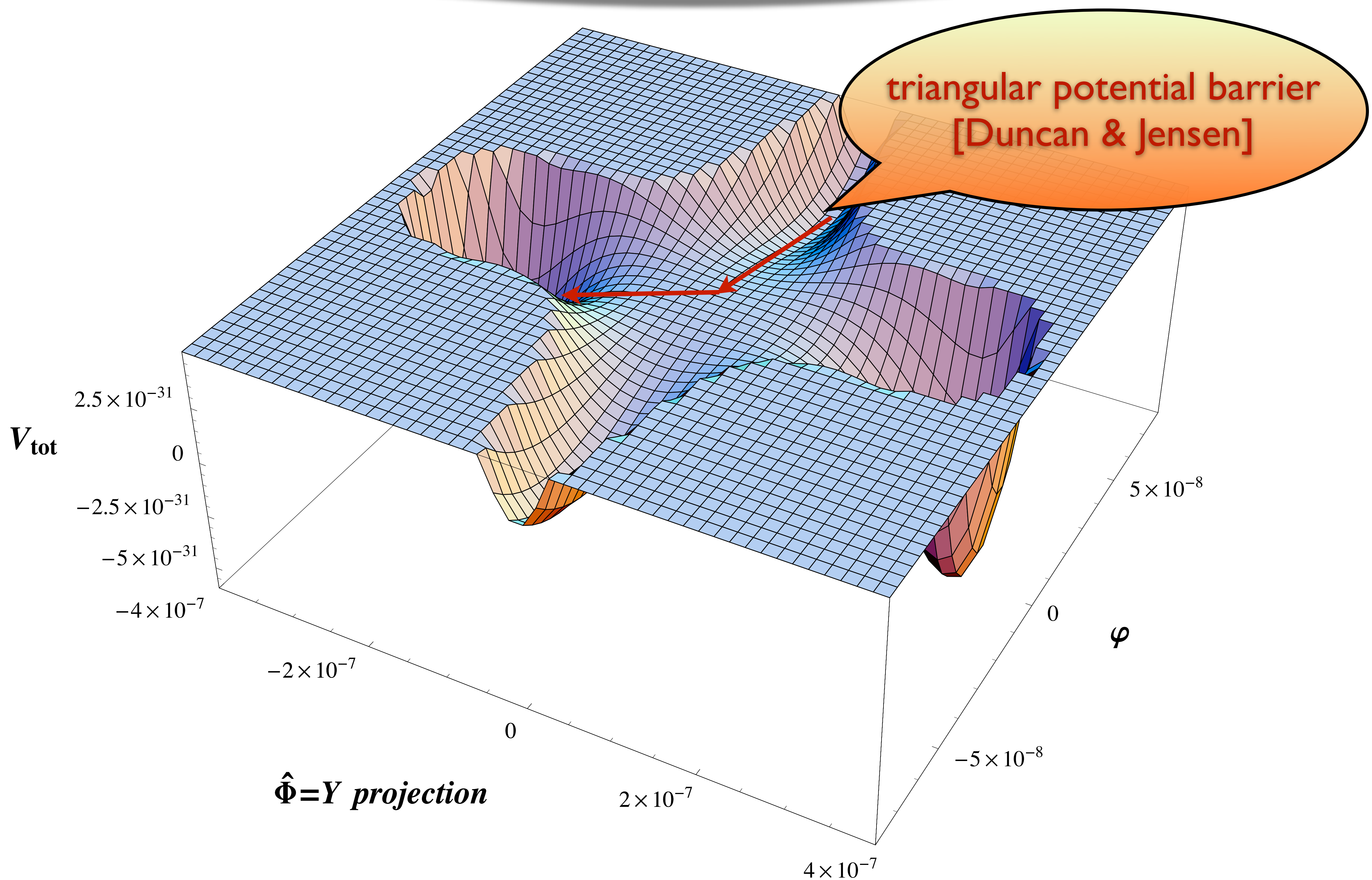

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- The Planck scale $M_{\rm Pl}$: sets the moduli VEVs
- Intermediate scale $\mu_0 \sim e^{-\eta S_0}$: meson/baryon masses, F-term scale
- low scale $\mu_0^2 \sim e^{-2\eta S_0}$: gravitino and moduli masses

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explained with dynamical mechanism
(retro-fitting) [Dine, Feng & Silverstein]

	RT3 $Sp(4)^2 \times SU(4)^2 \times G_{\mathrm{vis}}$	RT2 $SU(4) \times SU(5)^2 \times G_{\mathrm{vis}}$
A_1 A_2 A_3	$1/4$ 3 $1/1000$	$1/200$ 4 - - -
$\langle S \rangle$ $\langle T \rangle$ μ_0 $\sqrt{F_{\hat{\Phi}}}$ m_s m_t $m_{3/2}$	1.20 1.40 $1.2 \cdot 10^{11}$ GeV $2.4 \cdot 10^{11}$ GeV 3500 TeV 8.6 TeV 1.1 TeV	1.69 1.57 $1.0 \cdot 10^{11}$ GeV $2.3 \cdot 10^{11}$ GeV 2300 TeV 0.9 TeV 0.6 TeV
$\mathrm{C.C.}/3m_{3/2}^2$	-0.04	-0.03
ϵ_{ISS}	0.04	0.12

Conclusions

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- Closer look at moduli stabilization in the perturbative heterotic string at the supergravity level
- Non-perturbative gauge dynamics alone leads to moduli stabilization AND low energy SUSY breaking in a (nearly) Minkowski minimum
- open questions:
  - explicit heterotic string embedding (Z_6-II orbifolds ?)
  - dynamics of massive flavors responsible for the A_i
  - soft terms
  - D-terms, anomalous U(1)'s
  - inflation driven by the moduli / mesons?