Super no-scale models and moduli stability

Hervé Partouche

Ecole Polytechnique, Paris

In collaboration with Costas Kounnas (to appear soon)

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Outline

Introduction

• Strings unify gravity and gauge interactions at the quantum level.

• Particle physics : Start with classical 4D Minkowski space + implement perturbation theory to derive quantum dynamics.

• But from gravity point of view : Cosmological constant generated by quantum loops.

- Except if susy : perturbative $\Lambda = 0$
- If not susy at all : $\Lambda = \mathcal{O}(M_s^4)$

• Intermediate situation : **No-scale models** [Cremmer, Ferrara, Kounnas, Nanopoulos]

- At tree level : Minkowski space + susy spontaneously broken
- Potential $\mathcal{V}_{\text{tree}} \geq 0$ and admits $m_{3/2}$ as a modulus : flat direction

• Magnitude of the 1-loop effective potential $\mathcal{V}_{\text{1-loop}}$ is dictated by $m_{3/2}$.
For small $m_{3/2}$, does $\mathcal{V}_{\text{1-loop}}$ admit a small expectation value ?

• Generically, NO : runaway behavior of $m_{3/2}$, other moduli destabilized, magnitude of $\mathcal{V}_{\text{1-loop}}$ still too large,...

• To find a loophole, we consider a context where all computations can be done explicitly, in perturbation theory :

- **Heterotic string**
- **Coordinate Dependent Compactification**
  = "stringy Scherk-Schwarz mechanism", to break spontaneously susy and gauge symmetry :

$$m_{3/2} = \frac{M_s}{R}$$

where R is the characteristic size of the compact space involved in the susy breaking

• Taking R large, to have $m_{3/2}$ and hopefully $|\mathcal{V}_{\text{1-loop}}|$ small,

$\Longrightarrow$ Light towers of KK modes : They **dominate in $\mathcal{V}_{\text{1-loop}}$.**

• Choose a point in classical moduli space $\langle G_{IJ}\rangle$, $\langle B_{IJ}\rangle$, $\langle$Wilson lines$\rangle$,...

• Suppose there are no scales between 0 and $m_{3/2}$.

———	cM_s	: large Higgs, GUT or string scale
———	$m_{3/2}$	: towers of KK modes of mass $\propto m_{3/2}$
———	0	: n_B massless bosons and n_F massless fermions

$$\mathcal{V}_{\text{1-loop}} = \xi(n_F - n_B)m_{3/2}^4 + \mathcal{O}(e^{-cM_s/m_{3/2}})\ , \qquad \xi > 0$$

• General case : Some scales may be lower than $m_{3/2}$.

• Switch on small deviations collectively denoted Y, to $\langle G_{IJ}\rangle$, $\langle B_{IJ}\rangle$, $\langle$Wilson lines$\rangle$:

———	cM_s	: large Higgs, GUT or string scale
———	$m_{3/2}$	: towers of KK modes of mass $\propto m_{3/2}$
———	YM_s	: some of the $n_B + n_F$ states get a mass YM_s
———	0	

• **$n_B(Y)$ and $n_F(Y)$ interpolate between different integer values**, reached at distinct points in moduli space.

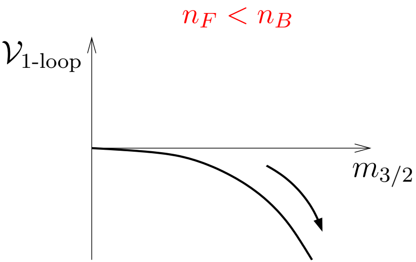
$\Longrightarrow$ **Expand in Y**

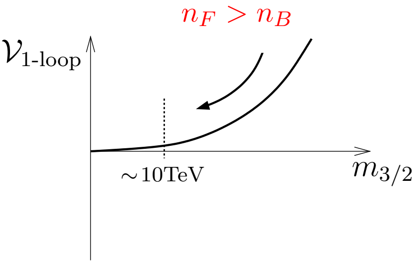
- **For $\mathcal{N} = 4 \to \mathcal{N} = 0$**

$$\mathcal{V}_{\text{1-loop}} = \xi(n_F - n_B)m_{3/2}^4 - b\,\tilde{\xi}\,m_{3/2}^2(YM_s)^2 + \cdots + \mathcal{O}(e^{-cM_s/m_{3/2}})$$

- The Y's are **Wilson lines of the non-Abelian gauge groups.**
- The b's are their **β-function coefficients.** $\tilde{\xi} > 0$.

- **Dominant term :**





$$\langle m_{3/2}\rangle^4 \gg \Lambda_{obs}$$

$$\mathcal{V}_{\text{1-loop}} = \xi(n_F - n_B)m_{3/2}^4 - b\,\tilde{\xi}\,m_{3/2}^2(YM_s)^2 + \cdots + \mathcal{O}(e^{-cM_s/m_{3/2}})$$

$\Longrightarrow$ define **"Super No-Scale Models" in string theory** by :

$\boldsymbol{n_F = n_B}$ [Kounnas, H.P.] [Abel, Dienes, Mavroudi]

$\Longrightarrow$ Standard Model needs hidden sector

- **Subdominant term :**
  - $b < 0 \Longrightarrow$ ***Y*** **stabilized at 0**
  - $b > 0 \Longrightarrow$ **Instability** [Kounnas, H.P.]

- **If there is no non-assymptotically free gauge group factor,**

$$\mathcal{V}_{\text{1-loop}} = \mathcal{O}(e^{-cM_s/m_{3/2}})$$

The **Stable Super No-Scale Models extend the notion of no-scale models to the 1-loop level :**

$\boldsymbol{\mathcal{V}_{\text{1-loop}} \geq 0}$ **and** $\boldsymbol{m_{3/2}}$ **is a flat direction.**

• Note that in Type II and orientifold theories, there exist non-susy models with

$$\mathcal{V}_{\text{1-loop}} = 0 \qquad i.e. \qquad N_F = N_B \text{ are any mass level !}$$

[Kachru, Kumar, Silverstein] [Harvey]
[Shiu, Tye] [Blumenhagen, Gorlich]
[Angelantonj, Antoniadis, Forger]
[Satoh, Sugawara, Wada]

When obtained *via* spontaneous breaking of susy, they are super no-scale models in a "strong sense".

• However

- $\mathcal{V}_{\text{2-loops}}$ has no reason to vanish. [Aoki, D'Hoker, Phong]
- When a perturbative heterotic dual is known, it is a conventional super no-scale models : $n_F = n_B$.

[Harvey] [Angelantonj, Antoniadis, Forger]

Outline

Example of $\mathcal{N} = 4 \to 0$ super no-scale model

- Start from $\mathcal{N} = 4$, $E_8 \times E_8$ heterotic string on $T^2 \times T^2 \times T^2$:

$$Z = \frac{1}{\tau_2 \eta^2 \bar{\eta}^2} \; \frac{\Gamma^{(1)}}{\eta^2 \bar{\eta}^2} \; \frac{\Gamma^{(2)}}{\eta^2 \bar{\eta}^2} \; \frac{\Gamma^{(3)}}{\eta^2 \bar{\eta}^2} \; (V_8 - S_8)\, (\bar{O}_{16} + \bar{S}_{16})\, (\bar{O}_{16} + \bar{S}_{16})$$

where the left-moving worldsheet fermions contribute

$$V_8 - S_8 = \sum_{a,b} (-1)^{a+b+ab} \, \frac{\theta\begin{bmatrix} a \\ b \end{bmatrix}^4}{\eta^4}$$

and the lattice is modular invariant

$$\Gamma^{(1)} = \sum_{\substack{m_1, m_2 \\ n_1, n_2}} q^{\frac{1}{2}|p_L|^2} \bar{q}^{\frac{1}{2}|p_R|^2} = \frac{\sqrt{\det G}}{\tau_2} \sum_{\substack{\tilde{m}_1, \tilde{m}_2 \\ n_1, n_2}} e^{-\frac{\pi}{\tau_2}(\tilde{m}_i + n_i \tau)(G+B)_{ij}(\tilde{m}_j + n_j \bar{\tau})}$$

- To break susy, couple lattice to the spin structure *via* a modular invariant sign, *e.g.*

$$(-1)^{\tilde{m}_1 a + n_1 b + \tilde{m}_1 n_1}$$

$$\Longrightarrow \quad \begin{cases} (-1)^{bn_1} & : \text{odd } n_1 \text{ reverse GSO} \\ \\ m_1 + \dfrac{a+n_1}{2} & : \text{shifts the KK masses} \end{cases}$$

- When the first T^2 is large, all massless states have $n_1 = 0$.

$\Longrightarrow$The massless fermions ($a = 1$) get a KK mass $\Longrightarrow n_F = 0$.
Cannot be super no-scale.

- We need to keep some fermions massless :

$$\bar{O}_{16} + \bar{S}_{16} = \frac{1}{2}\sum_{\gamma,\delta} \frac{\bar{\theta}\big[{}^{\gamma}_{\delta}\big]^8}{\bar{\eta}^8}\,, \quad \text{where } \gamma = 0 \Leftrightarrow \bar{O}_{16} \text{ and } \gamma = 1 \Leftrightarrow \bar{S}_{16}.$$

- Insert

$$(-1)^{\tilde{m}_1(a+\gamma+\gamma')+n_1(b+\delta+\delta')+\tilde{m}_1 n_1}$$

$$\Longrightarrow \begin{cases} \text{When } \gamma+\gamma' = 0 \text{ or } 2, \text{ nothing changes.} \\ \\ \text{When } \gamma+\gamma' = 1, \text{ roles of Bosons and Fermions reversed.} \end{cases}$$

$$Z = \frac{1}{\tau_2 \eta^2 \bar\eta^2} \; \frac{\Gamma^{(2)}}{\eta^2 \bar\eta^2} \; \frac{\Gamma^{(3)}}{\eta^2 \bar\eta^2} \; \frac{1}{\eta^2 \bar\eta^2} \quad \times$$

$$\Big[\; \Gamma^{(1)}\left[{}^{e}_{e}\right] \Big(V_8 (\bar O_{16} \bar O_{16} + \bar S_{16} \bar S_{16}) - S_8 (\bar O_{16} \bar S_{16} + \bar S_{16} \bar O_{16}) \Big)$$

$$+ \Gamma^{(1)}\left[{}^{e}_{o}\right] \Big(V_8 (\bar O_{16} \bar S_{16} + \bar S_{16} \bar O_{16}) - S_8 (\bar O_{16} \bar O_{16} + \bar S_{16} \bar S_{16}) \Big)$$

$$+ \Gamma^{(1)}\left[{}^{o}_{e}\right] \Big(O_8 (\bar V_{16} \bar C_{16} + \bar C_{16} \bar V_{16}) - C_8 (\bar V_{16} \bar V_{16} + \bar C_{16} \bar C_{16}) \Big)$$

$$+ \Gamma^{(1)}\left[{}^{o}_{o}\right] \Big(O_8 (\bar V_{16} \bar V_{16} + \bar C_{16} \bar C_{16}) - C_8 (\bar V_{16} \bar C_{16} + \bar C_{16} \bar V_{16}) \Big) \Big]$$

where $\Gamma^{(1)}\left[{}^{\text{parity of winding}}_{\text{parity of momentum } 2m_1 + a}\right]$

- $m^2_{3/2} = \dfrac{|U_1|^2 M_s^2}{\mathrm{Im}\, T_1 \, \mathrm{Im}\, U_1}$ where $\boldsymbol{T_1, U_1}$ **are the Kähler and complex structure of the first** $\boldsymbol{T^2}$**.**

- When $\mathrm{Im}\, T_1$ is large, the gauge group is

$$U(1)^2 \times G^{(2)} \times G^{(3)} \times SO(16) \times SO(16)$$

- The massless spectrum satisfies

$$n_B = 8\Big(244 + \dim G^{(2)} + \dim G^{(3)}\Big)\,, \qquad n_F = 8 \times 256\,.$$

12 missing bosons are obtained when T_2, U_2 and T_3, U_3 at the enhanced symmetry points

$$G^{(2)} \times G^{(3)} = SU(2)^4 \qquad \text{or} \qquad G^{(2)} \times G^{(3)} = SU(3) \times SU(2) \times U(1)$$

- At these points, the model develops a **super no-scale structure.**

Properties of the model

$$m_{3/2}^2 = \frac{|U_1|^2 M_s^2}{\operatorname{Im} T_1 \operatorname{Im} U_1}$$

- When $\operatorname{Im} T_1 > 1, \operatorname{Im} U_1 \sim 1$

$$m_{3/2} < M_s \ , \quad \mathcal{V}_{\text{1-loop}} = \mathcal{O}(e^{-cM_s/m_{3/2}}) \ : \quad \text{super no-scale regime}$$

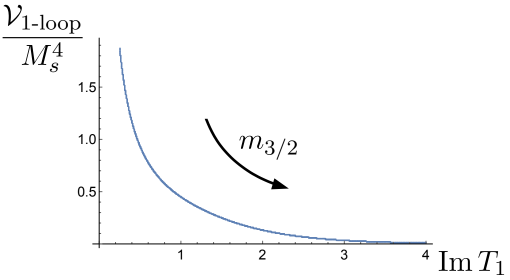
- When $\operatorname{Im} T_1$ decreases up to ~ 1

$$m_{3/2} \sim M_s \ , \qquad \mathcal{V}_{\text{1-loop}} \text{ is not small.}$$

Do we have an Hagedorn-like divergence of $\mathcal{V}_{\text{1-loop}}$?

- In $(-1)^{m_1 a}$ breaking, YES : $O_8 \bar{O}_{16} \bar{O}_{16} \Longrightarrow$ Tachyons
- In $(-1)^{m_1 (a+\gamma+\gamma')}$ breaking, NO: $O_8 \bar{V}_{16} \bar{V}_{16} \Longrightarrow$ Non-level matched

• For $\mathrm{Re}\, T_1 = 0$ and
$U_1 = T_2 = U_2 = T_3 = U_3 = i$:



• When $\mathrm{Im}\, T_1 \to 0$, the first T^2 shrinks,
which is equivalent to a dual theory in 6D, explicitly non susy.

So, when $m_{3/2} > M_s$, the model is better interpreted as a compactification of this non-susy theory down to 4 dimensions.

• The model is self-dual under

$$(T_1, U_1) \longrightarrow \left(-\frac{1}{U_1}, -\frac{1}{T_1}\right)$$

So, evolving T_1 from 0 (non susy) to $i\infty$(super no-scale)
$\Longleftrightarrow$ evolving U_1 from $i\infty$ (super no-scale) to 0 (non susy).

Outline

Moduli deformations

- The classical moduli space of the model is

$$\frac{SO(6,6+16)}{SO(6)\times SO(6+16)}$$

We consider the model at point where $T^2 \times T^2 \times T^2$, where the first torus is large and the last two are at an enhanced symmetry point where the model is **super no-scale**, *e.g.*

$$U(1)^2 \times SU(2)^4 \times SO(16)^2$$

We switch on an arbitrary marginal deformation of the classical theory around this point and compute $\mathcal{V}_{\text{1-loop}}$ to study the local stability :
Is the super no-scale point a minimum, maximum or saddle ?

- Compute $$\mathcal{V}_{\text{1-loop}} = -\frac{M_s^4}{(2\pi)^4}\int_{\mathcal{F}} \frac{d^2\tau}{2\tau_2^2}\, Z$$

Since T^2 is large, the winding states are super heavy $\Longrightarrow \mathcal{O}(e^{-\mathrm{Im}\, T_1})$.

We keep in Z all states s_0 with 0-winding and 0-momenta along the first T^2 and take into account their towers of KK modes

$$(-1)^{F_0}\,\frac{1}{\tau_2}\sum_{m_1,m_2}(-1)^{m_1}\,e^{-\pi\tau_2\frac{|U_1 m_1-m_2+\xi|^2}{\mathrm{Im}\,T_1\,\mathrm{Im}\,U_1}}\;q^{\frac{1}{4}M_{0L}^2}\;\bar{q}^{\frac{1}{4}M_{0R}^2}$$

$$(-1)^{F_0}\,\frac{\mathrm{Im}\,T_1}{\tau_2^2}\sum_{\tilde{m}_1,\tilde{m}_2}e^{-\frac{\pi\,\mathrm{Im}\,T_1}{\tau_2\,\mathrm{Im}\,U_1}|\tilde{m}_1+\frac{1}{2}+U_1\tilde{m}_2|^2}\,e^{2i\pi\frac{\mathrm{Im}[(\tilde{m}_1+\frac{1}{2}+U_1\tilde{m}_2)\bar{\xi}]}{\mathrm{Im}\,U_1}}\;q^{\frac{1}{4}M_{0L}^2}\;\bar{q}^{\frac{1}{4}M_{0R}^2}$$

$$\Longrightarrow\quad\int_{\mathcal{F}}d^2\tau\,(\,\cdots)=\int_{-1/2}^{1/2}d\tau_1\int_0^{+\infty}d\tau_2\,(\,\cdots)+\mathcal{O}(e^{-\sqrt{\mathrm{Im}\,T_1}})$$

$\Longrightarrow$ Only the level matched states contribute

Finally, $\quad q^{\frac{1}{4}M_{0L}^2}\,\bar{q}^{\frac{1}{4}M_{0R}^2}=e^{-2\pi\tau_2(N_L-\frac{1}{2}+\cdots)}$ with $\tau_2\geqslant\mathrm{Im}\,T_1$

$\Longrightarrow$ Lowest number $N_L=\frac{1}{2}$ dominates.

The oscillators states give $\mathcal{O}(e^{-\sqrt{\mathrm{Im}\,T_1}})$ contributions.

• For small moduli deformations : **Keep only the KK towers above the initially massless states s_0**

$$\mathcal{V}_{\text{1-loop}} = -\frac{M_{\rm s}^4}{(2\pi)^4} \sum_{s_0=1}^{n_B+n_F} (-1)^{F_0} \int_0^{+\infty} \frac{d\tau_2}{2\tau_2^3} \sum_{m_1,m_2} (-1)^{m_1}\, e^{-\pi\tau_2 M_L^2} + \mathcal{O}(e^{-c\sqrt{\operatorname{Im} T_1}})$$

where M_L is the mass of each KK mode, deformed by the worldsheet operators

$$y_I^i \partial X_i \bar\partial X^I\,,\ i, I = 1,\dots,6 \qquad \text{and} \qquad y_I^i \partial X_i \bar\partial \phi^I\,,\ I = 7,\dots,22\ :$$

$$M_L^2 = 2\left(|p_L^{(1)}|^2 + \sum_{i=3}^{6} (p_L^i)^2\right)$$

$$2|p_L^{(1)}|^2 = \frac{|U_1 m_1 - m_2 + \sum_{I=3}^{22} (i \operatorname{Im} U_1\, y_I^1 - y_I^2) Q^I|^2}{\operatorname{Im} T_1 \operatorname{Im} U_1}$$

$$2(p_L^i)^2 = \left(\frac{m_i + \operatorname{Re}\left[(iy_1^i - y_2^i)\bar Q^{(1)}\right] + \sum_{I=3\neq i}^{22} y_I^i Q^I}{R_i} + n_i R_i\right)^2$$

• The Q's are the charges of the KK modes, with respect to $U(1)^2 \times SU(2)^4 \times SO(16)^2$.

They can be neutral or in the Adjoint of one of the $SU(2)$'s, or Adjoint or Spinorial of one of the $SO(16)$'s.

$$\begin{aligned}\mathcal{V}_{\text{1-loop}} = & \frac{n_{\rm F}-n_{\rm B}}{16\pi^7}\,\frac{M_s^4}{(\operatorname{Im}T_1)^2}\,E_{(1,0)}(U_1|3,0)\left(1+\sum_{j=3}^{6}\left[2|Y^j|^2-\frac{3}{2}\rho_3(Y^j)^2-\frac{3}{2}\bar{\rho}_3(\bar{Y}^j)^2\right]\right)\\ & -\frac{3}{16\pi^5}\,\frac{M_s^4}{\operatorname{Im}T_1}\,E_{(1,0)}(U_1|2,0)\left(b_{SU(2)}\sum_{i=3}^{6}\left[\sum_{j=3}^{6}(Y_i^j)^2+2|Y_i|^2-\rho_2(Y_i)^2-\bar{\rho}_2(\bar{Y}_i)^2\right]\right.\\ & \left.+\,b_{SO(16)}\sum_{I=7}^{22}\left[\sum_{j=3}^{6}(Y_I^j)^2+2|Y_I|^2-\rho_2(Y_I)^2-\bar{\rho}_2(\bar{Y}_I)^2\right]\right)\\ & +\mathcal{O}(M_s^4\,Y^3)+\mathcal{O}\left(M_s^4\,e^{-c\sqrt{\operatorname{Im}T_1}}\right)\end{aligned}$$

where $$E_{(1,0)}(U|s,k)=\sum_{\tilde{m}_1,\tilde{m}_2}\frac{(\operatorname{Im}U)^s}{\left(\tilde{m}_1+\frac{1}{2}+\tilde{m}_2U\right)^{s+k}\left(\tilde{m}_1+\frac{1}{2}+\tilde{m}_2\bar{U}\right)^{s-k}}$$

$$\rho_s=\frac{E_{(1,0)}(U_1|s,1)}{E_{(1,0)}(U_1|s,0)}$$

$$\mathcal{V}_{\text{1-loop}} = \frac{n_{\rm F}-n_{\rm B}}{16\pi^7}\,\frac{M_s^4}{(\operatorname{Im}T_1)^2}\,E_{(1,0)}(U_1|3,0)\left(1+\sum_{j=3}^{6}\left[2|Y^j|^2-\frac{3}{2}\rho_3(Y^j)^2-\frac{3}{2}\bar\rho_3(\bar Y^j)^2\right]\right)$$

$$-\frac{3}{16\pi^5}\,\frac{M_s^4}{\operatorname{Im}T_1}\,E_{(1,0)}(U_1|2,0)\left(b_{SU(2)}\sum_{i=3}^{6}\left[\sum_{j=3}^{6}(Y_i^j)^2+2|Y_i|^2-\rho_2(Y_i)^2-\bar\rho_2(\bar Y_i)^2\right]\right.$$

$$\left.+\,b_{SO(16)}\sum_{I=7}^{22}\left[\sum_{j=3}^{6}(Y_I^j)^2+2|Y_I|^2-\rho_2(Y_I)^2-\bar\rho_2(\bar Y_I)^2\right]\right)$$

$$+\,\mathcal{O}(M_s^4\,Y^3)+\mathcal{O}\left(M_s^4\,e^{-c\sqrt{\operatorname{Im}T_1}}\right)$$

- **1st line $\propto m_{3/2}^4$**
  - It is not there in the **super no-scale models** but is there in the generic no-scale models.
  - The Y^j's are moduli that break the $T^2 \times T^4$ factorization and also deform the definition of $m_{3/2}$.
  - Their mass is $\propto \dfrac{m_{3/2}^2}{M_s}$

$$\mathcal{V}_{\text{1-loop}} = \frac{n_F - n_B}{16\pi^7} \frac{M_s^4}{(\operatorname{Im} T_1)^2} E_{(1,0)}(U_1|3,0)\left(1 + \sum_{j=3}^{6}\left[2|Y^j|^2 - \frac{3}{2}\rho_3(Y^j)^2 - \frac{3}{2}\bar{\rho}_3(\bar{Y}^j)^2\right]\right)$$

$$- \frac{3}{16\pi^5} \frac{M_s^4}{\operatorname{Im} T_1} E_{(1,0)}(U_1|2,0)\left(b_{SU(2)} \sum_{i=3}^{6}\left[\sum_{j=3}^{6}(Y_i^j)^2 + 2|Y_i|^2 - \rho_2(Y_i)^2 - \bar{\rho}_2(\bar{Y}_i)^2\right]\right.$$

$$\left. + b_{SO(16)} \sum_{I=7}^{22}\left[\sum_{j=3}^{6}(Y_I^j)^2 + 2|Y_I|^2 - \rho_2(Y_I)^2 - \bar{\rho}_2(\bar{Y}_I)^2\right]\right)$$

$$+ \mathcal{O}(M_s^4 Y^3) + \mathcal{O}\left(M_s^4 e^{-c\sqrt{\operatorname{Im} T_1}}\right)$$

- **2^{nd} and 3^{rd} lines $\propto m_{3/2}^2 M_s^2$**
  - The Y's are the **Wilson lines** of the four $SU(2)$'s and of the two $SO(16)$ along T^6.
  - Their masses are $\propto m_{3/2}$
  - $b_{SU(2)} = -\frac{8}{3} \times 2 < 0 \implies$ **Moduli stabilized at the origin.**
  - $b_{SO(16)} = +\frac{8}{3} \times 2 > 0 \implies$ **Tachyonic :** They condense. Go to **new vacuum where the $SO(16)$'s are broken to subgroups with $b \leq 0$.**

Stabilization

• The super no-scale models can be considered in a **cosmological scenario.**

• They are all **stable at early times, if finite temperature effects are taken into account.**

• At finite T,

$$\mathcal{V}_{\text{1-loop}} \longrightarrow \text{free energy}$$

$$(\text{mass})^2 \longrightarrow T^2 + (\text{mass})^2$$

• As the Universe expands, T decreases :

- **As long as $T > m_{3/2}$:** No tachyons $\Longrightarrow$ the models are **stable.**
- **When T crosses $m_{3/2}$: Higgs phase transition** take place.

Outline

$\mathcal{N} = 2 \to 0$ and $\mathcal{N} = 1 \to 0$ super no-scale models

- Consider $T^2 \times \frac{T^4}{\mathbb{Z}_2}$ or $\frac{T^2 \times T^2 \times T^2}{\mathbb{Z}_2 \times \mathbb{Z}_2}$ and implement the stringy Scherk-Schwarz mecanism along the first T^2.

In general, the untwisted sector and twisted sectors contribute to $n_F - n_B$, except is one $\mathbb{Z}_2$ is freely acting (no fixed point) :

$$\mathcal{V}_{\text{1-loop}} = \frac{1}{2}\,\mathcal{V}_{\text{1-loop}}^{\mathcal{N}=4\to 0} \quad \text{or} \quad \frac{1}{4}\,\mathcal{V}_{\text{1-loop}}^{\mathcal{N}=4\to 0}$$

- Without free $\mathbb{Z}_2$, there are large $\text{Im}\,T_1$ corrections of the KK modes to

$$\frac{16\,\pi^2}{g^2_{\text{YM}}(\mu)} = k\,\frac{16\,\pi^2}{g^2_{\text{string}}} + b\log\frac{M_s^2}{\mu^2} + b\left(\frac{\pi}{3}\,\text{Im}\,T_1 - \log\text{Im}\,T_1 + \mathcal{O}(1)\right)$$

When $b < 0$, a **fine tuning** of g_{string} is a priori required to cancel it.

With one free $\mathbb{Z}_2$, we have an underlying $\mathcal{N} = 4 \to \mathcal{N} = 2$

$\Longrightarrow$ No $\text{Im}\,T_1$ term : **No "Decompactification Problem"**

Conclusion

• The **Super No-Scale Models** are those which preserve the flatness of the effective potential at 1-loop (up to $\mathcal{O}(e^{-cM_s/m_{3/2}})$).

$\Longrightarrow$ **Bosons - Fermions degeneracy at the massless level.**

• Their **quantum stability** is guaranteed if :

- There are no Non-Asymptotically Free gauge groups ($b > 0$), in the $\mathcal{N} = 4 \to 0$ case.
- Or simply if finite T is greater than $m_{3/2}$.

• When such a model is stable, it makes sense to decouple gravity to obtain MSSM-like models in flat space and let the electroweak radiative breaking stabilize $m_{3/2}$. [Alvarez-Gaume, Polchinski, Wise] [Ibanez, Ross] [Ellis, Nanopoulos, Tamvakis] [Kounnas, Lahanas, Nanopoulos, Quiros] [Kounnas, Zwirner, Pavel]

• **Question :** Is the effective potential at genus $g \geq 2$ still flat ? Or do we have to impose more constraints to guaranty the flatness condition ?