Low-energy SUSY from the Heterotic String

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O.L., Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter

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Plan

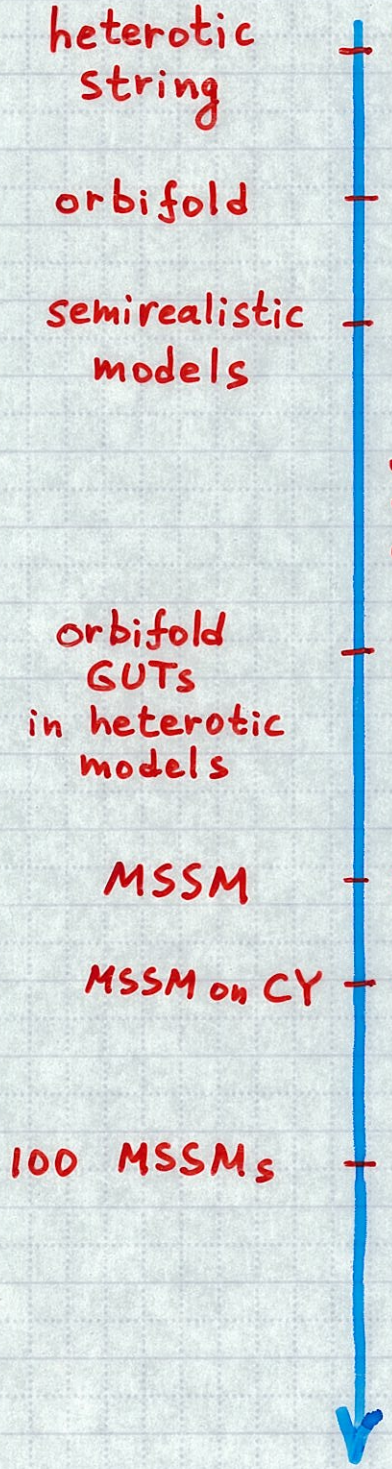
- where we stand in string model building

- local GUTs + minilandscape

- theory motivation for O(TEV) scales

Heterotic String Model Building

(bosonic formulation)



heterotic string — 1985 — Gross, Harvey, Martinec, Rohm

orbifold — —"— — Dixon, Harvey, Vafa, Witten

semirealistic models — 1987, 1988 — Ibañez, Nilles, Quevedo, Kim; Casas, Muñoz; Ross et al.

orbifold GUTs in heterotic models — 2004 — Kobayashi, Raby, Zhang; Förste, Nilles, Vaudrevange, Wingerter

MSSM — 2005 — Buchmüller, Hamaguchi, O.L., Ratz

MSSM on CY — —"— — Braun, He, Ovrut, Pantev; Bouchard, Donagi

100 MSSMs — 2006 — O.L., Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter

Also models by Kim, Kyae '06

Free fermionic constructions :

Cleaver, Faraggi, Nanopoulos '98

Basics

Heterotic string = 10 D superstring +
26 D bosonic

Gauge symmetry : $E_8 \times E_8$
(or $SO(32)$)

Compactification : orbifold
$T_2 \otimes T_2 \otimes T_2 \,/\, \mathbb{Z}_N$

A model is specified by :

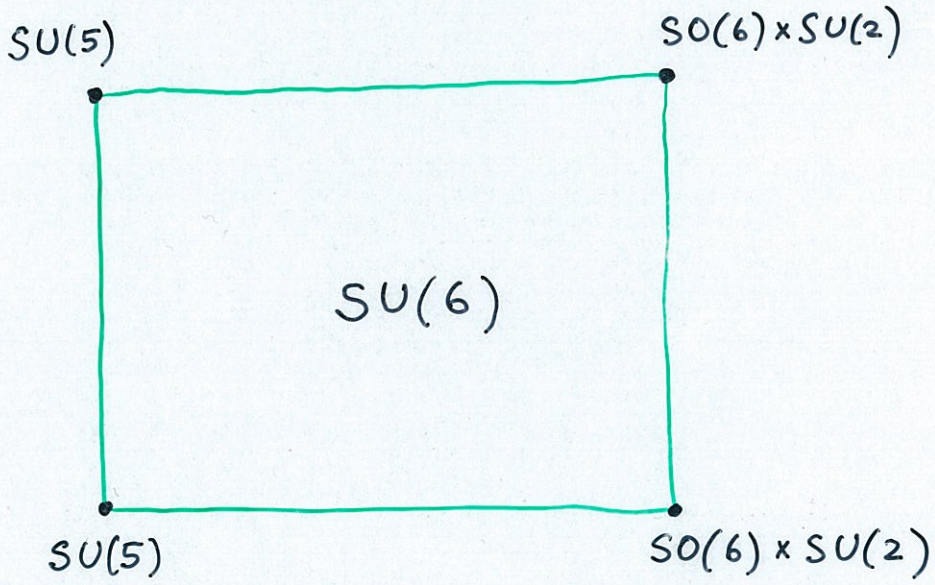
- twist $\theta = \left(\frac{-1}{2}, \frac{1}{3}, \frac{1}{6}\right), \ldots$
- lattice
- gauge shift V
- Wilson lines W_i

Orbifold GUT limits

Kobayashi, Raby, Zhang
2004

Förste, Nilles, Vaudrevange
Wingerter · 2004

$r_1 \gg r_2, r_3$



4D gauge group = intersection

fixed points ~ "branes"

Local GUT strategy

Buchmüller, Hamaguchi, O.L., Ratz '2005

① Choose gauge shift :

16-plet of SO(10) $\in T_1$

Reason: massless states from T_1 are automatically twist-invariant
⇒ complete 16-plets at low energies

② Choose Wilson lines :

4D gauge group = SM × ...

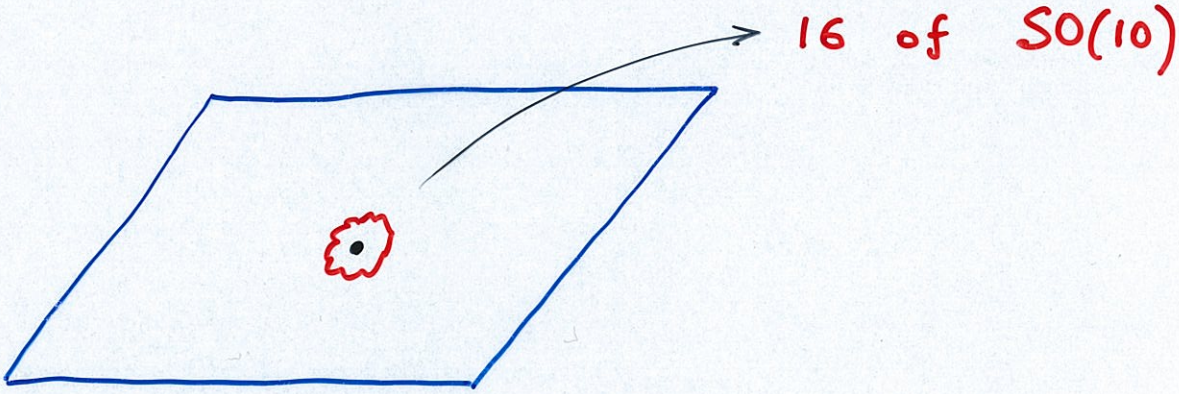
Remark : does not destroy ①

③ Choose Wilson lines :

SM ⊂ SU(5) → GUT $U(1)_Y$

Reason : standard hypercharge normalization ⇒ gauge coupling unification

Buchmüller, Hamaguchi, O.L., Ratz ' 2005



No 4D GUT, but

- complete 16-plets
- gauge coupl. unification

Bulk states partially projected out ⇒

- gauge group = SM
- split Higgses

Statistics

O.L., Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter 2006

	$V^1_{SO(10)}$	$V^2_{SO(10)}$	$V^1_{E_6}$	$V^2_{E_6}$
inequiv. models with 2 WL	10^4	10^4	10^3	10^3
SM gauge group $\subset SU(5) \subset SO(10)$	3563	1163	27	63
3 net (3,2)	1170	492	3	32
non-anomal. $U(1)_Y \subset SU(5)$	528	234	3	22
spectrum = 3 gener. + vector-like	128	90	3	2
heavy top	72	37	3	2
exotics decouple + gauginos condense	47	25	3	2
B-L ...				

$10^2/10^4$ are good !

→ "Fertile patch" of the Landscape

O.L., Nilles, Raby, Kamos-Sanch
Ratz, Vaudrevange, Wingerter
2006

Hidden - Observable sector correlations and ~~SUSY~~ SUSY

Phenomenology favours TeV ~~SUSY~~ SUSY masses :

- gauge coupling unification
- EW symmetry breaking
- hierarchy problem
- ...

What is special about the TeV scale?

(from the top-down perspective)

TeV soft masses are as good as

eV or 10^6 TeV

soft masses

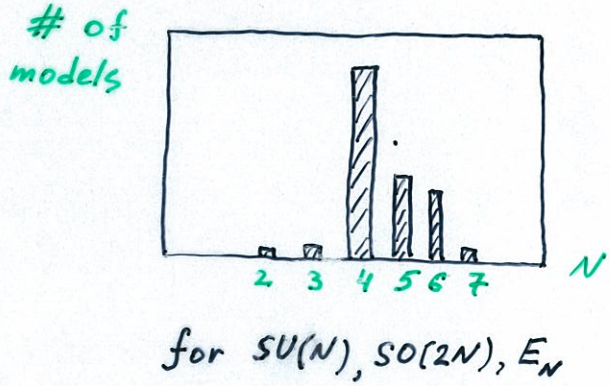
... OR ARE THEY?

observable sector ⟷ hidden sector

require:
3 generations,
no exotics,
$Y_t \sim 1$,
...

preferred:
pure SYM
SO(8), SU(5), ...

(see also Dienes '06,07)



for $SU(N)$, $SO(2N)$, E_N

The correlations are due to:

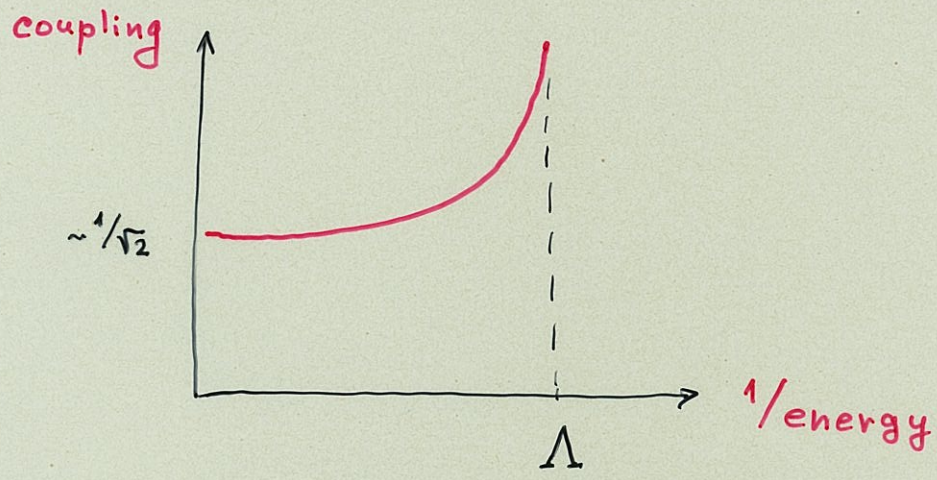
- modular invariance
- masslessness condition (twisted)
- GSO (twisted)

If SUSY is broken by gaugino condensation,

⇒ "prediction" for SUSY masses!

Gaugino condensation

Nilles '82
Ferrara, Girardello, Nilles '83
Dine et al. '85



$$\Lambda = M_{GUT}\, e^{-\frac{1}{2\beta}\cdot\frac{1}{g^2(M_{GUT})}}$$

$$\langle \lambda\lambda \rangle \sim \Lambda^3 \sim \langle W \rangle$$

$$m_{3/2} \sim \Lambda^3 / M_{Pl}^2$$

model-independent!

Example:

$$\begin{cases} W = d\, e^{-3S/2\beta} \\ K = -\ln(S+\bar{S}) + \Delta K_{np} \end{cases}$$

$$F_S \sim \frac{\langle \lambda\lambda \rangle}{M_{Pl}} \qquad (F_T = 0)$$

Binetruy, Gaillard, Wu '96
Casas '96
Gaillard, Nelson '07

Statistics of gaugino condensation

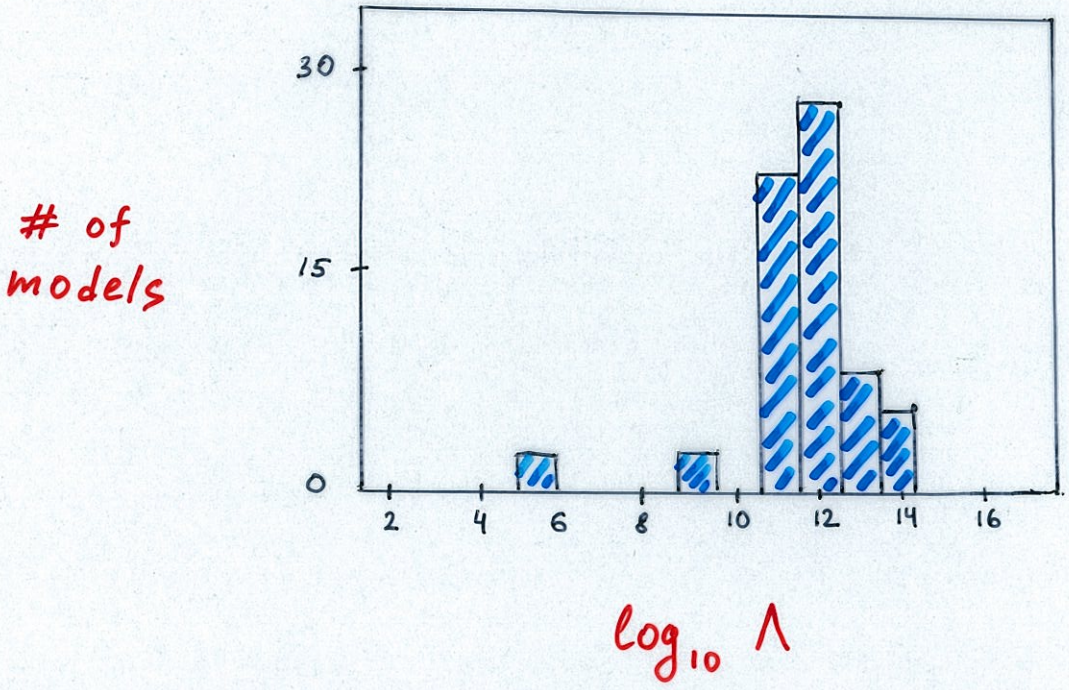
$\Lambda = M_{GUT}\, e^{-const/\beta}$

$\lambda^3 \sim \langle \lambda\lambda \rangle$

$m_{3/2} \sim \lambda^3 / M_{Pl}^2$

(Nilles, ...)

O.L., Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter 2006



intermediate scale $\Lambda \sim 10^{12}$ GeV is preferred !

$\Rightarrow$ theory motivation for TeV soft masses

Resulting picture:

observable sector:

O(1 GeV)

(⇒ nucleon/atom masses ~ GeV)

hidden sector:

$O(10^{12}-10^{13}\ \text{GeV})$

⇒ $EW \sim \Lambda^3/M_{Pl}^2$

Conclusion

- progress in the last 2 years
- 100 MSSM's
- THEORY motivation for TeV soft masses / EW scale