The μ problem and the NMSSM with strings

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In collaboration with

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Top-Down approach: From strings to the real world

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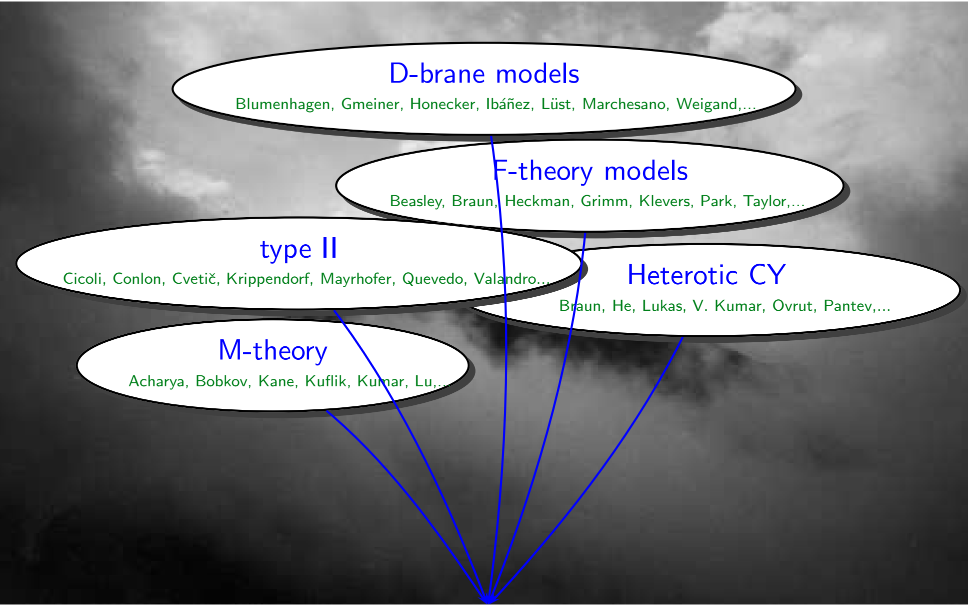
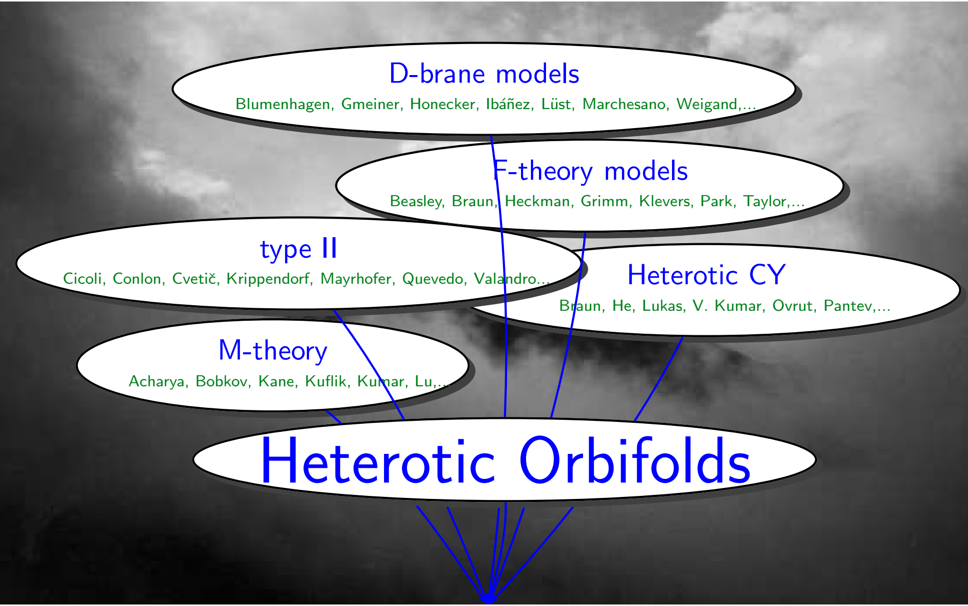


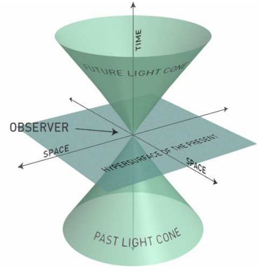
Top-Down approach: From strings to the real world



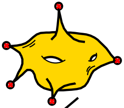
Heterotic

String

en 10D



$\times$



input: Orbifold

Geometry

Embedding

($\mathbb{Z}_N$, Lattice(s), Twist, Shifts,
Wilson lines, discrete torsion)

output: effective QFT in 4D

gauge symmetry $\mathcal{G}_{4D}$

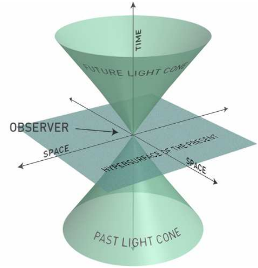
matter spectrum

further symmetries

$\rightarrow K, W, f_a$

$E_8 \times E_8$ heterotic orbifolds

Heterotic String en 10D



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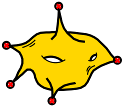

In this talk...

- get close to (N)MSSM
- solve some hierarchy issues

From minilandscape and further searches

☺ there are "fertile patches"

Our search:

- ~ 300 "MSSM"
- no charged exotics
- grand unification
- heavy top
- $m_{3/2}$ ~TeV
- seesaw
- R parity
- flavor symmetries
- QCD axion
- $\mu H_u H_d$ *with* $\mu \ll M_{Pl}$

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($m_{3/2}$ ~TeV through $\mu H_u H_d$ with $\mu \ll M_{Pl}$) } gift !! ☺

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- $\mu H_u H_d$ *with* $\mu \ll M_{Pl}$?

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($m_{3/2}$ ~TeV through $\mu H_u H_d$ with $\mu \ll M_{Pl}$?: gift !! ☺)

Hierarchies

from

R symmetries

$\mathrm{U}(1)_R$ symmetries

- Perturbative superpotential

$$\mathscr{W} \;=\; \sum c_{n_1\cdots n_M}\phi_1^{n_1}\cdots\phi_M^{n_M}$$

- vacuum with $\mathcal{N}=1$

$$-F_i^\dagger \;=\; \frac{\partial\mathscr{W}}{\partial\phi_i} \;=\; 0 \quad \text{in } \phi_j = \langle\phi_j\rangle \;\forall\; i,j$$

- $\mathrm{U}(1)_R$ symmetry

$$\mathscr{W} \;\to\; \mathrm{e}^{2\mathrm{i}\,\alpha}\,\mathscr{W} \qquad\qquad \phi_j \;\to\; \phi_j' \;=\; \mathrm{e}^{\mathrm{i}\,r_j\,\alpha}\,\phi_j$$

$$\mathscr{W}(\phi_i) \;\to\; \mathscr{W}(\phi_i') \;=\; \mathscr{W}(\phi_i) + \sum_j \underbrace{\frac{\partial\mathscr{W}}{\partial\phi_j}}_{=0}\,\Delta\phi_j$$

$$\Rightarrow \mathscr{W} \;=\; 0$$

$\mathrm{U}(1)_R$ symmetries

$\mathrm{U}(1)_R$ & $F = 0$ $\Rightarrow$ vacuum with $\langle \mathscr{W} \rangle = 0$

Consequences:

- $D\mathscr{W} = 0$ in sugra $\rightarrow$ $\langle V \rangle = 0$: Minkowski vacuum ☺
- does not matter if $\mathrm{U}(1)_R$ is exact or accidental ☺
- complements Nelson+Seiberg's theorem:

$\mathscr{W}$ with $\mathrm{U}(1)_R$ $\Rightarrow$
- SUSY vacuum with $\langle \mathscr{W} \rangle = 0$
- SUSY or non-SUSY vacuum

Nelson, Seiberg (1994)

accidental $\mathrm{U}(1)_R$

If $\mathrm{U}(1)_R$ is accidental, i.e. explicitly broken at order N:

1. $\langle \mathscr{W} \rangle \sim \langle \phi \rangle^{\geq N}$
2. $\mathscr{W}_{eff} = \langle \mathscr{W} \rangle + \mathscr{W}_{np}$
3. $m_{3/2} \sim \langle \mathscr{W} \rangle$
4. Goldstone mode η gets mass $m_\eta \sim m_{3/2}/\langle \phi \rangle^2$

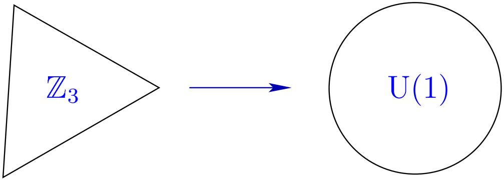
If e.g. $\langle \phi \rangle \sim \mathcal{O}(0.1)$:

- $N \sim \mathcal{O}(10) \quad \Rightarrow \quad$ hierarchically suppressed $m_{3/2}$ ☺
- η a bit heavier than the gravitino ☺

In string models

In heterotic orbifolds...

No global stringy $\mathrm{U}(1)$s allowed, but...



accidental symmetry $\mathrm{U}(1)_R$ broken at order $N \in [10, 20]$ ☺

Magnitude of $\langle\phi_i\rangle$ determined by

$$D_{\mathrm{FI}} = \xi + \sum_i q^i_{\mathrm{anom}} |\langle\phi_i\rangle|^2 \overset{!}{=} 0\,,\ \xi \sim \mathcal{O}(0.1) \text{ in Planck units}$$

$$\rightarrow \quad \langle\phi_i\rangle \sim \mathcal{O}(0.1)$$

Assume moduli stabilization here!

In heteroti orbifolds...

- $H_u H_d \supset \mathbf{1}$ (gauge and stringy symmetries)

Antoniadis, Gava, Narain, Taylor; Brignole, Ibáñez, Muñoz; Cvetič, Louis, Ovrut

$$\rightarrow \;\; K \supset -\log[(T+\bar{T})(U+\bar{U}) - (H_u + \bar{H}_d)(H_d + \bar{H}_u)]$$

$$\rightarrow \;\; \mu \sim \langle \mathscr{W} \rangle$$

Brümmer, Kappl, Ratz, Schmidt-Hoberg

In SUSY vacua

$$\langle \mathscr{W} \rangle \sim \mathcal{O}(10^{-20}) - O(10^{-10}) \quad \rightarrow \quad \mu \; suppressed! \;\; ☺$$

Assume moduli stabilization here!

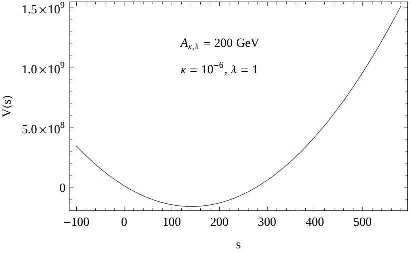
Stringy NMSSM

MSSM + singlet S, such that

$$W = W_{MSSM} + \lambda S H_u H_d + \frac{1}{3}\kappa S^3$$

$$V(s) = -2\lambda A_\lambda v_u v_d s + m_S^2 s^2 + (\kappa s^2 - \lambda v_u v_d)^2 + (\lambda v_d s)^2 + \frac{2}{3}\kappa A_\kappa s^3$$

E.g. in the PQ limit (slightly) broken ($\kappa \ll 1$)



$\rightarrow \quad \mu = \lambda\langle s\rangle \gtrsim$ 100 GeV

Heterotic NMSSMs

In heterotic orbifolds

- μ term *highly* suppressed
- one (or very few) massless S charged under other gauge $\mathrm{U}(1)$s
- renormalizable coupling $S\, H_u\, H_d$
- S^3 possible only at (large) non-renormalizable orders

$$\Rightarrow \quad \lambda = \text{cte.} + \langle s_{a_1} ... s_{a_n} \rangle, \qquad \kappa = \langle s_{b_1} ... s_{b_n} \rangle$$

NMSSMs heteróticos: generalidades

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$$\rightarrow \quad \langle s_i \rangle \sim \mathcal{O}(0.1)$$

$$\rightarrow \qquad \boxed{\kappa \ll 1, \qquad \lambda \lesssim \mathcal{O}(1)} \qquad ☺$$

Two possible NMSSM scenarios:

- $\lambda \sim 1,\; \kappa \ll 1$ PQ limit
- $\lambda,\; \kappa \ll 1$ "effective MSSM"

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In a sample heterotic model with a SUSY vacuum

$$W_{NMSSM} = S H_u H_d + \tfrac{1}{3} \langle s_i \rangle^6 S^3$$

In this and most heterotic NMSSM models

$\lambda \sim 1, \;\; \kappa \sim 10^{-6} \;\; \rightarrow$ límite con $m_{a_{PQ}} \sim 10^2$ MeV – GeV ☺

To take home...

In orbifolds with other appealing properties

- mecanism to yield hierarchies based on $\mathrm{U}(1)_R$ ✓
- consequence: $\mu \ll M_{Pl}$ ✓
- NMSSM less common than MSSMs
- S^3 coupling suppressed

  $\rightarrow$ PQ limit or "effective MSSM" ✓
- solutions to μ & fine-tuning problems of MSSM ✓
- R & PQ symmetries come from string theory (*not ad hoc*) ✓