F. Zwirner
University & INFN, Padova
& LPT-ENS, CNRS, Paris

No-scale supergravity models from string compactifications

30 years of Supergravity
IHP, Paris, 17 October 2006

Local vs. global supersymmetry breaking

$$V_{sugra} = ||F||^2 + ||D||^2 - ||H||^2$$

aux(chi.) aux(vec.) aux(grav.)

$$\Lambda_{SUSY}^4 = \langle ||F||^2 + ||D||^2 \rangle > M_{weak}^4$$

no sparticle observed

$$\Lambda_{cosm} = \langle V_{sugra} \rangle^{1/4} < M_{weak}^2 / M_P$$

limits on vacuum energy

phenomenology ➔

gravitational effects crucial for vacuum selection

only afterwards can one take the global limit

Generic problems of N=1 D=4 supergravity

•Classical vacuum energy

$$V_{cl} = O(m_{3/2}^2 M_P^2) \quad \overset{?}{\longrightarrow} \quad \langle V_{cl} \rangle \simeq 0$$

•($m_{3/2}/M_P$) hierarchy

$$m_{3/2} = O(M_P) \quad \overset{?}{\longrightarrow} \quad m_{3/2} < O(10^{-15} M_P)$$

•Stability of the classical vacuum

$$\Delta V = O(m_{3/2}^2 M_P^2) \quad \overset{?}{\longrightarrow} \quad \Delta V < O(m_{3/2}^4)$$

•Universality of squark/slepton mass terms
(or equivalent condition to suppress FCNC)

generic N=1, D=4 supergravity is not enough: too flexible
need some special N=1, D=4 supergravity

N=1 D=4 no-scale supergravity

simplest example:
one chiral multiplet
[Cremmer+Ferrara+
Kounnas+Nanopolulos 83]

$$K = -3\log(T+\overline{T})$$

$W = k \neq 0$ (T-independent)

Special no-scale properties:

$V \equiv 0$ classically flat potential $(G_T G^T \equiv 3)$

$F_T \neq 0 \ (\forall T)$ broken supersymmetry

$$m_{3/2}^2 = \frac{|k|^2}{(T+\overline{T})^3}$$ sliding scale Λ_{SUSY}

Spontaneously broken N=1 supersymmetry with
naturally vanishing classical vacuum energy!

Coupling to “matter” chiral multiplets C^i:

$$K \to K + \sum_i |C^i|^2 (T + \overline{T})^{n_i} + \ldots \quad W \to W + d_{ijk} C^i C^j C^k$$

still local minima of V with $\langle C^i \rangle = 0$ and all no-scale properties

e.g. $n_i = -1$ in the special case SU(1,N)/SU(N)xU(1) [Ellis-Kounnas-Nanopoulos ‘84]

universal supersymmetry-breaking mass terms:

$$\tilde{m}_i^2 = (1 + n_i) m_{3/2}^2 \quad A_{ijk} = (3 + n_i + n_j + n_k) m_{3/2}$$

similar formulae for gaugino masses

$$f_{ab} = \delta_{ab} T^{n_\lambda} \ \ (n_\lambda = 0, 1) \ \ \Rightarrow \ \ M_\lambda^2 = n_\lambda^2 m_{3/2}^2$$

and for the mass parameters in the Higgs sector

One possibility [Ellis-Kounnas-Nanopoulos ‘84] (“gaugino mediation”)
vanishing tree-level scalar masses, then generated
from gaugino masses via radiative corrections

Dynamical generation of the hierarchy:

assuming no terms $O[(m_{3/2}M_P)^2]$ in $V_{eff} = V_{cl} + \Delta V$ may allow for a dynamical generation of the hierarchy $m_{3/2} << M_P$ from interplay of gauge vs. Yukawa renormalization effects

[Ellis-Lahanas-Nanopoulos-Tamvakis ‘83; Ellis-Kounnas-Nanopoulos ‘83]

A point not to be overlooked [Kounnas-Pavel-F.Z. ‘94]

$$V_{cl} = O(H^4) + O(m_{3/2}^2\, H^2) + O(m_{3/2}^4)$$

The last term is also renormalized by gauge and Yukawa interactions and plays a role in the determination of $m_{3/2}$

$$m_{3/2}^2 \frac{\partial V_{eff}}{\partial m_{3/2}^2} = 2 V_{eff} + \frac{Str M^4}{64\pi^2} = 0$$

effective infrared fixed point of $V_{eff}[m_{3/2}(T), H_1, H_2]$

Problems of N=1, D=4 no-scale models

(I) unexplained origin of (special) K and W

In the simplest example K has a SU(1,1) duality:

$$T \to \frac{aT - ib}{icT + d} \quad C^i \to (icT + d)^{n_i} C^i \quad (ab - cd = 1)$$

should understand its origin as well as the one of W=k

(II) no control over UV quantum corrections

$$\Delta V = \frac{1}{32\pi^2} Str(M^2)\,\Lambda^2 + \frac{1}{64\pi^2} Str(M^4 \log \frac{M^2}{\Lambda^2}) + \dots$$

destabilization of the hierarchy if the effective cutoff is M_P

[Polchinski-Susskind ‘83; Nilles-Srednicki-Wyler ‘83; Lahanas ‘83]

More general no-scale models

if (in a suitable field basis)

$$G = K(\varphi^\alpha, \overline{\varphi}^{\overline{\alpha}}) - \log Y(z^a + \overline{z}^{\overline{a}}) + \log |W(\varphi^\alpha)|^2$$

$$(z^a + \overline{z}^{\overline{a}}) Y_a = 3Y \;\Rightarrow\; G^a G_a \equiv 3 \;\Rightarrow\; V_F = e^G G^\alpha G_\alpha \geq 0$$

and there are allowed field configurations such that

$$W \neq 0 \qquad G_\alpha = 0$$

we get more general realizations of no-scale models

Additional sectors C^i with $\langle C^i \rangle = 0$ can be added as before without spoiling the no-scale properties at classical level (perturbative treatment up to quadratic fluctuations in K)

Universal susy-breaking masses can be generated as before

Susy-breaking in string compactifications

D=10 superstrings have $N\geq 4$ supersymmetry in D=4 units:

- Some may be broken at the string scale
- Some may be broken at the compactification scale
- Some ($N\leq 1$) may be broken in the effective D=4 theory

Will concentrate here (motivated by the hierarchy problem) on spontaneously broken N=1 in the D=4 regime. Other viable possibilities will be discussed by other speakers.

Plan: discuss in a simple N=1 orbifold compactification

- Classical origin and no-scale properties of K
- Flux contributions to W and no-scale examples
- Consistency constraints from local symmetries
- Comments on quantum stability

String effective supergravities in D≥10

(describe for simplicity only bulk bosonic degrees of freedom)

- "M-theory" (D=11 ➔ N=8): $g_{\widehat{M}\widehat{N}} \quad A^{(3)}$
- Type-IIA (D=10 ➔ N=8):

  $g_{MN},\ \Phi,\ B_{MN};\ A^{(1)} \leftrightarrow A^{(7)},\ A^{(3)} \leftrightarrow A^{(5)},\ A^{(9)}$ non-dynamical
- Type-IIB (D=10 ➔ N=8):

  $g_{MN},\ \Phi,\ B_{MN};\ A^{(0)} \leftrightarrow A^{(8)},\ A^{(2)} \leftrightarrow A^{(6)},\ A^{(4)}$ self-dual
- Heterotic (D=10 ➔ N=4): $g_{MN},\ \Phi,\ B_{MN};\ A^{a}_{M}$ $E_8 x E_8$ SO(32)
- Type-I (D=10 ➔ N=4): $g_{MN},\ \Phi,\ A^{(2)} \leftrightarrow A^{(6)};\ A^{a}_{M}$ SO(32)

+ possible additional degrees of freedom localized on branes

orbifold/orientifold projections to N=1

Our illustrative example: Z_2 x Z_2 orbifold

	x^5	x^6	x^7	x^8	x^9	x^{10}
Z_2 :	$-$	$-$	$-$	$-$	$+$	$+$
Z_2' :	$+$	$+$	$-$	$-$	$-$	$-$

plus, for N=8 theories, additional orientifold projection

In all N=1 Z_2 x Z_2 theories in D=4, 7 closed untwisted moduli:

$$S = s + i\sigma \quad T_A = t_A + i\tau_A \quad U_A = u_A + i\nu_A \quad (A = 1,2,3)$$

with $$K = -\log(S+\overline{S}) - \sum_A \log(T_A + \overline{T}_A) - \sum_A \log(U_A + \overline{U}_A)$$

when all the remaining fields are consistently set to zero
identification in terms of D=10 fields model-dependent

Heterotic on $T^6/(Z_2 x Z_2)$

No-scale structure of K first noticed in SU(3) reduction [Witten '85]
also in similar N=1 orbifold reductions [Ferrara-Kounnas-Porrati '86, …]

Z_2 x Z_2 invariant untwisted bulk moduli:

$$e^{-2\Phi} = s\,(t_1 t_2 t_3)^{-1} \qquad g_{\mu\nu} = s^{-1}\,\widetilde{g}_{\mu\nu} \qquad B_{\mu\nu} \leftrightarrow \sigma$$

$$B_{56} = \tau_1 \qquad B_{78} = \tau_2 \qquad B_{910} = \tau_3$$

$$g_{i_A j_A} = \frac{t_A}{u_A}\begin{pmatrix} u_A^2 + \nu_A^2 & \nu_A \\ \nu_A & 1 \end{pmatrix} \qquad (A = 1,2,3)$$

Easy to include the untwisted fields from YM sector
$Z_2 x Z_2$ truncation of the underlying N=4 supergravity
[Ferrara-Kounnas-Girardello-Porrati '87; Antoniadis et al. '87]

$$K = -\log s - \sum_{A=1}^{3} \log(t_A u_A - \sum_{i=1}^{r_A} z_A^i z_A^i)$$

$$\frac{SU(1,1)}{U(1)} \times \prod_{A=1}^{3} \frac{SO(2,2+r_A)}{SO(2)\times SO(2+r_A)}$$

Z_2 x Z_2 invariant (bulk) fluxes:

$$\widetilde{H}_{579}\,,\ \widetilde{H}_{679}\,,\ \widetilde{H}_{589}\,,\ \widetilde{H}_{689}\,,\ \widetilde{H}_{5710}\,,\ \widetilde{H}_{6710}\,,\ \widetilde{H}_{5810}\,,\ \widetilde{H}_{6810}\,. \quad (8)$$

[Derendinger-Ibanez-Nilles ‘85; Dine-Rohm-Seiberg-Witten ‘85; Strominger ‘86; …]

$$\omega^{i_A}{}_{i_B i_C} \quad [(ABC) = (123), (231), (312)] \qquad (24)$$

(“geometrical fluxes” = Scherk-Schwarz twists)

Scherk-Schwarz ‘79; Rohm ‘84; Ferrara-Kounnas-Porrati-FZ ’89; …]

Effective superpotential from fluxes

$$\widetilde{H}_{i_A i_B i_C} \quad \longrightarrow \quad W \sim 1\,,\ i U_A\,,\ -U_A U_B\,,\ -i U_1 U_2 U_3$$

$$\omega^{i_A}{}_{i_B i_C} \quad \longrightarrow \quad W \sim i T_A\,,\ T_A U_B\,,\ i T_A U_B U_C\,,\ T_A U_1 U_2 U_3$$

Consistency conditions:

[Scherk-Schwarz’79] $\omega \cdot \omega = 0 \qquad \omega \cdot \widetilde{H} = 0$ [Kaloper-Myers’99]

(generalized Bianchi identities, here also N=4 Jacobi identities)

Comments on the heterotic case

Can also include also magnetic fluxes with suitably generalized consistency conditions [Kaloper-Myers '99] still related to the underlying N=4 gaugings

Twisted sectors can be included in K at quadratic order
[Ferrara-Girardello-Kounnas-Porrati '87]

Homogeneity properties of Kahler manifold

$$K^S K_S = 1 \qquad K^{i_A} K_{i_A} = 2 \;\; (A = 1, 2, 3)$$

Non-perturbative W from gaugino condensation may be present

$$\Delta W_{np} = W_0 \, e^{-k\, S} \qquad k = 3/(2\beta_0)$$

with H-flux gives a no-scale model [Dine-Seiberg-Rohm-Witten '85]

Also classical no-scale models, e.g.: $W = k\,(T_2\, U_2 + T_3\, U_3)$

Type-II on $T^6/(Z_2 x Z_2)$

classical Kahler potential for untwisted closed string moduli:
same as in heterotic, but different field identifications

IIA with O6/D6 [Derendinger-Kounnas-Petropoulos-FZ '04]

$$C^{(3)}_{6810} = \sigma\,, \quad C^{(3)}_{679|589|5710} = -\nu_{1|2|3}\,, \quad B_{56|78|910} = \tau_{1|2|3}$$

$$s = \sqrt{\frac{\hat{s}}{\hat{u}_1\,\hat{u}_2\,\hat{u}_3}}\,, \quad u_1 = \sqrt{\frac{\hat{s}\,\hat{u}_2\,\hat{u}_3}{\hat{u}_1}}\,, \quad u_2 = \sqrt{\frac{\hat{s}\,\hat{u}_1\,\hat{u}_3}{\hat{u}_2}}\,, \quad u_3 = \sqrt{\frac{\hat{s}\,\hat{u}_1\,\hat{u}_2}{\hat{u}_3}}$$

Kahler potential for untwisted open and closed string moduli
full non-linear result just derived for generic D6-brane angles
[Villadoro-FZ, hep-th/061mnnn]
highly non-trivial field redefinitions to reach Kahler field basis
no longer symmetric factorizable manifold as in heterotic
however, no-scale-friendly homogeneity properties do survive

$$K = -\log Y(z^k + \overline{z}^k) \qquad \sum_k (z^k + \overline{z}^k)\, Y_k = 7\, Y$$

Similarly for IIB with (O3/D3+O7/D7) or (O5/D5+O9/D9):
•Axions from invariant components of even-form potentials
•Field redefinitions now for dilaton (s) and Kahler moduli (t_A)
•D-branes at angles replaced by magnetized D-branes

No-scale models from type-II flux compactifications

Fluxes in IIB with O3/D3: $H_3 \quad F_3 \quad (\text{no } \omega_3,\ F_1,\ F_5\ !)$

$W(S, U_A)$ is generated, but no T-dependence!

Natural set-up for no-scale [Giddings-Kachru-Polchinski ‘01; …]

Fluxes in IIA with O6/D6: $\omega_3 \quad H_3 \quad F_0, F_2, F_4, F_6$

$W(S, T_A, U_A)$ can be generated (linear in U_A)

No-scale and other possibilities (susy-AdS, runaway, …)
depending on choice of fluxes [Derendinger-Kounnas-Petropoulos-FZ 04]

Consistency constraints [IIA O6/D6 for definiteness]

In type-II more general W than from N=4 gaugings
constraints from Bianchi Identities of local symmetries
gauged by either bulk or brane-localized vectors

In the type-IIA example under consideration:

$$\frac{1}{2}(\omega G^{(2)} + H G^{(0)}) = \sum_a N_a \mu_a \, [\pi_a]$$

[Villadoro, FZ '05 & '06]

$$\omega\, \omega = 0 \qquad \int_{\pi_a} H = 0 \qquad \omega\, [\pi_a] = 0$$

guarantee gauge-invariance of the effective action

(similar constraints also on non-perturbative W)

Still considerable freedom for model-building:
no-scale but also many other classical vacua

Some comments on quantum stability

No-scale models need quantum corrections to work but their structure can survive only very mild ones

Perturbative and non-perturbative quantum corrections in string compactifications are not under sufficient control yet to firmly establish or rule out the no-scale program

Scherk-Schwarz and flux supersymmetry breaking are non-local in some internal dimensions: the effective cutoff for the D=4 effective theory is not M_P or M_S but some M_C

[Rohm '84; Antoniadis'90]

Intriguing N=8 Str $M^n=0$ (n=0,2,4,6) relations found in some IIB orientifold Scherk-Schwarz compactifications

[deWit-Samtleben-Trigiante '02; D'Auria-Ferrara-Trigiante '04; …]

Conclusions

No-scale models may give us a clue to solve the big open problems with supersymmetry breaking

The required special properties the effective N=1 D=4 sugra must be understood from the microscopic theory

Still too early to say whether the no-scale hypotheses can be entirely fulfilled in N=1 string compactifications

What is encouraging is that the more we understand string compactifications the more ingredients seem to fit into place: but there are still too many open ends