Gravity Mediation: soft breaking terms in $N = 1$ supergravity

Hans Peter Nilles

Physikalisches Institut, Universität Bonn

Based on:

HPN, Phys. Lett. B115 (1982) 193; Nucl. Phys. B217 (1982) 366

Barbieri, Ferrara and Savoy, Phys. Lett. B119 (1982) 343

Chamseddine, Arnowitt and Nath, Phys. Rev. Lett. 49 (1982) 970

HPN, Srednicki and Wyler, Phys. Lett. B120 (1982) 346

Outline

- The goals of supersymmetric models
- Some “basic problems”
- How to hide the hidden sector
- Gaugino condensation
- Gravity mediation
- Solution to “basic problems”
- Embedding in heterotic string theory
- Modulus mediation
- The hidden wall in M-theory
- Mirage mediation

Goals of SUSY

Supersymmetric model building tries to achieve the following goals:

- explain the hierarchy between Planck scale and weak scale
- give soft supersymmetric breaking terms that are phenomenologically consistent
- explain $SU(2) \times U(1)$ breakdown as a consequence of supersymmetry breakdown

Goals of SUSY

Supersymmetric model building tries to achieve the following goals:

- explain the hierarchy between Planck scale and weak scale
- give soft supersymmetric breaking terms that are phenomenologically consistent
- explain $SU(2) \times U(1)$ breakdown as a consequence of supersymmetry breakdown

Around end of 1981 attempts in model building had to face some serious problems.

Some "basic problems"

Spontaneously broken SUSY needs to overcome some basic obstacles:

Some “basic problems”

Spontaneously broken SUSY needs to overcome some basic obstacles:

- positive m^2 for all scalar masses
  ($StrM^2 = 0$ for F-term breakdown at tree level)

Some “basic problems”

Spontaneously broken SUSY needs to overcome some basic obstacles:

- positive m^2 for all scalar masses
  ($StrM^2 = 0$ for F-term breakdown at tree level)
- question of nonvanishing gaugino masses (tree level)

Some "basic problems"

Spontaneously broken SUSY needs to overcome some basic obstacles:

- positive m^2 for all scalar masses
  ($StrM^2 = 0$ for F-term breakdown at tree level)
- question of nonvanishing gaugino masses (tree level)
- the appearance of a harmful R-axion

Some "basic problems"

Spontaneously broken SUSY needs to overcome some basic obstacles:

- positive m^2 for all scalar masses
  ($StrM^2 = 0$ for F-term breakdown at tree level)
- question of nonvanishing gaugino masses (tree level)
- the appearance of a harmful R-axion
- The cosmological constant $E_{\rm vac}$ is too large

Some "basic problems"

Spontaneously broken SUSY needs to overcome some basic obstacles:

- positive m^2 for all scalar masses
  ($Str M^2 = 0$ for F-term breakdown at tree level)
- question of nonvanishing gaugino masses (tree level)
- the appearance of a harmful R-axion
- The cosmological constant $E_{\rm vac}$ is too large

The last problem needs the consideration of supergravity!

MSSM

The minimal particle content of the susy extension of the standard model contains chiral superfields

- Q, U, D for quarks and partners
- L, E for leptons and partners
- H, $\bar{H}$ Higgs supermultiplets

MSSM

The minimal particle content of the susy extension of the standard model contains chiral superfields

- Q, U, D for quarks and partners
- L, E for leptons and partners
- H, $\bar{H}$ Higgs supermultiplets

with superpotential

$$W = QHD + Q\bar{H}U + LHE + \mu H\bar{H}.$$

Also allowed are

$$UDD + QLD + LLE.$$

R-parity

Proton stability in supersymmetric models requires a new symmetry, R-parity, that forbids dangerous operators (even of dimension 4):

- UDD and QLD are forbidden
- H and L can be distinguished
- superpartners of known particles are odd under R-parity
- superpartners are produced in pairs
- the good news is a stable particle (LSP)

R-parity

Proton stability in supersymmetric models requires a new symmetry, R-parity, that forbids dangerous operators (even of dimension 4):

- UDD and QLD are forbidden
- H and L can be distinguished
- superpartners of known particles are odd under R-parity
- superpartners are produced in pairs
- the good news is a stable particle (LSP)

But there is also bad news.

R-symmetry

If we consider the MSSM and postulate R-parity we get an enhancement to a continuous R-symmetry. This symmetry

- forbids gaugino masses,
- leads to a harmful axion in the case of spontaneous breakdown (by Higgs fields).

R-symmetry

If we consider the MSSM and postulate R-parity we get an enhancement to a continuous R-symmetry. This symmetry

- forbids gaugino masses,
- leads to a harmful axion in the case of spontaneous breakdown (by Higgs fields).

- Somehow this symmetry has to be broken
- and the axion has to be removed.

R-symmetry

If we consider the MSSM and postulate R-parity we get an enhancement to a continuous R-symmetry. This symmetry

- forbids gaugino masses,
- leads to a harmful axion in the case of spontaneous breakdown (by Higgs fields).

- Somehow this symmetry has to be broken
- and the axion has to be removed.

This needs new structure beyond the MSSM!

Hidden sectors

This also seems to be true for the unsatisfactory tree level mass relations:

- $StrM^2 = 0$ (Ferrara, Girardello, Palumbo, 1979)
- gaugino masses vanish at level of renormalizable couplings (dimension 5 operators are required)

Hidden sectors

This also seems to be true for the unsatisfactory tree level mass relations:

- $StrM^2 = 0$ (Ferrara, Girardello, Palumbo, 1979)
- gaugino masses vanish at level of renormalizable couplings (dimension 5 operators are required)

So the supersymmetry breakdown has to be somehow remote from the particles of the MSSM

- a “hidden sector”
- interacting weakly with the “observable sector”.

How to hide the hidden sector?

Attempts in the framework of spontaneously broken global supersymmetry were not very successful.

How to hide the hidden sector?

Attempts in the framework of spontaneously broken global supersymmetry were not very successful.

This was the reason for me to learn supergravity

- after all gravity exists
- the question of the vacuum energy can be solved
- Moreover, “dynamical” SUSY breakdown did not seem to work in the case of global supersymmetry

How to hide the hidden sector?

Attempts in the framework of spontaneously broken global supersymmetry were not very successful.

This was the reason for me to learn supergravity

- after all gravity exists
- the question of the vacuum energy can be solved
- Moreover, "dynamical" SUSY breakdown did not seem to work in the case of global supersymmetry

At that time supergravity was still quite young

(Cremmer, Julia, Scherk, van Nieuwenhuizen, Ferrara, Girardello, 1979)

How to obtain the small scale

Hidden sector gaugino condensation: $(\lambda\lambda) = \Lambda^3$

$$\Lambda \sim \mu \exp(-1/g^2(\mu)) << M_{\rm Planck}$$

leads to gravitino mass

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

(HPN, 1982)

How to obtain the small scale

Hidden sector gaugino condensation: $(\lambda\lambda) = \Lambda^3$

$$\Lambda \sim \mu \exp(-1/g^2(\mu)) << M_{\text{Planck}}$$

leads to gravitino mass

$$m_{3/2} \sim \Lambda^3 / M^2_{\text{Planck}}$$

(HPN, 1982)

SUSY breakdown requires nontrivial gauge kinetic function:

$$F_i = \exp(-K/2) D_i W + f_i(\lambda\lambda) + \dots$$

(Ferrara, Girardello, HPN, 1983)

Hidden sector gaugino condensation

Four-Fermi-terms

$$\frac{h}{M^2}(\lambda\lambda)(\chi\chi)$$

lead to gaugino masses

$$m_{1/2} = \frac{h}{M^2}(\Lambda^3) \sim m_{3/2}.$$

Hidden sector gaugino condensation

Four-Fermi-terms

$$\frac{h}{M^2}(\lambda\lambda)(\chi\chi)$$

lead to gaugino masses

$$m_{1/2} = \frac{h}{M^2}(\Lambda^3) \sim m_{3/2}.$$

Other soft terms are induced by radiative corrections.

In this simple scheme the gaugino mass might be the dominant soft parameter in the low energy spectrum.

Soft terms

Soft mass terms can be of the type

- $\phi\phi^*$ for complex scalar field ϕ
- $\phi^2 + \phi^{*2}$ (as in F-term breaking)

as well as

Soft terms

Soft mass terms can be of the type

- $\phi\phi^*$ for complex scalar field ϕ
- $\phi^2 + \phi^{*2}$ (as in F-term breaking)

as well as

- trilinear terms $\phi^3 + \phi^{*3}$
- gaugino masses $\chi\bar{\chi}$

which are forbidden by the (continous) R-symmetry

(Girardello, Grisaru, 1982)

Some “basic problems”

Remember, spontaneously broken SUSY needs to overcome some basic obstacles:

- positive m^2 for all scalar masses
  ($StrM^2 = 0$ for F-term breakdown at tree level)
- question of nonvanishing gaugino masses (tree level)
- the appearance of a harmful R-axion
- The cosmological constant E_{vac} is too large

Problems solved

Observe that (continuos) R-symmetry is broken explicitly through the presence of a nonvanishing gravitino mass

$$m_{3/2} = \exp(-K)W$$

- positive m^2 for scalar masses
- nonvanishing gaugino masses
- no R-axion
- the cosmological constant $E_{\rm vac}$ might vanish (e.g. as a result of some fine-tuning)

Message

Thus spontaneously broken supergravity solves the problems. The scheme consists of

- an observable sector containing the spectrum of the MSSM and
- a hidden sector that is responsible for supersymmetry breakdown,

coupled only through interactions of gravitational strength.

(HPN, 1982)

Message

Thus spontaneously broken supergravity solves the problems. The scheme consists of

- an observable sector containing the spectrum of the MSSM and
- a hidden sector that is responsible for supersymmetry breakdown,

coupled only through interactions of gravitational strength.

(HPN, 1982)

This is the scheme called gravity mediation (msugra)

Scale of Susy breakdown

The size of the soft terms is set by the gravitino mass

$$m_{3/2} \sim \Lambda^3/M^2_{\rm Planck} \sim F^2_{\rm SUSY}/M_{\rm Planck}$$

Scale of Susy breakdown

The size of the soft terms is set by the gravitino mass

$$m_{3/2} \sim \Lambda^3/M_{\rm Planck}^2 \sim F_{\rm SUSY}^2/M_{\rm Planck}$$

The soft terms could be smaller than $m_{3/2}$, but at most by a few orders of magnitude

Scale of Susy breakdown

The size of the soft terms is set by the gravitino mass

$$m_{3/2} \sim \Lambda^3/M^2_{\rm Planck} \sim F^2_{\rm SUSY}/M_{\rm Planck}$$

The soft terms could be smaller than $m_{3/2}$, but at most by a few orders of magnitude

We therefore expect $m_{3/2}$ to be in the (multi) TeV range and thus $F_{\rm SUSY}$ at the intermediate scale

$$F_{\rm SUSY} \sim 10^{11}{\rm GeV}.$$

Completing the action

Early 1982 the general coupling of N=1 supergravity to matter and gauge fields had not been worked out. In spring this was finally done (Cremmer, Ferrara, Girardello, van Proeyen, 1982)

and brought a surprise:

Completing the action

Early 1982 the general coupling of N=1 supergravity to matter and gauge fields had not been worked out. In spring this was finally done (Cremmer, Ferrara, Girardello, van Proeyen, 1982)

and brought a surprise:

$$StrM^2 = 2(N-1)m_{3/2}^2$$

in the presence of N chiral supermultiplets.

Masses of the scalar partners of quarks and leptons could be lifted even at tree level

Explicit models

Explicit models were considered by

(Barbieri, Ferrara, Savoy; Arnowit, Chamseddine, Nath, 1982)

The models assumed minimal kinetic terms for the scalar fields and a superpotential

$$W = h(z) + g(y_i),$$

where z denotes a hidden sector chiral superfield and y_i those of the observable sector.

Explicit models

Explicit models were considered by

(Barbieri, Ferrara, Savoy; Arnowit, Chamseddine, Nath, 1982)

The models assumed minimal kinetic terms for the scalar fields and a superpotential

$$W = h(z) + g(y_i),$$

where z denotes a hidden sector chiral superfield and y_i those of the observable sector.

Supersymmetry was broken in the way suggested by Polonyi

$W = mM(z + \beta M)$ with $\beta = 2 - \sqrt{2}$ for $E_{\text{vac}} = 0$

Explicit models II

Susy is broken in the hidden sector with a gravitino mass

$$m_{3/2} = m \exp(\frac{1}{2}(\sqrt{3}-1)^2)$$

so m should be chosen in the TeV range.

Explicit models II

Susy is broken in the hidden sector with a gravitino mass

$$m_{3/2} = m \exp(\frac{1}{2}(\sqrt{3} - 1)^2)$$

so m should be chosen in the TeV range.

The scalar masses of the y_i are all lifted to a common value of

$$m_0 = m_{3/2}.$$

The masses are degenerate because of the choice of common (minimal) kinetic terms.

General scheme

Parametrizing the hidden sector by:

$$< z_i >= b_i M \quad \text{and} \quad < h_i >= a_i^* m M$$

we can derive a general formula for the soft terms.

(HPN, Srednicki, Wyler, 1982)

General scheme

Parametrizing the hidden sector by:

$$< z_i >= b_i M \quad \text{and} \quad < h_i >= a_i^* m M$$

we can derive a general formula for the soft terms.

(HPN, Srednicki, Wyler, 1982)

The vacuum energy can be cancelled by an appropriate choice of of the a_i and b_i and all the soft terms can be computed.
The A-parameter (the coefficient of the trilinear scalar interactions) is given by

$$A = {b_i}^* (a_i + b_i)$$

msugra

This is known as the minimal sugra scheme. It is determined by the parameters

$$m_0, \quad A, \quad B \quad \text{and} \quad \mu$$

in the scalar sector.

msugra

This is known as the minimal sugra scheme. It is determined by the parameters

$$m_0, \quad A, \quad B \quad \text{and} \quad \mu$$

in the scalar sector.

The soft gaugino masses are generated at tree level if the theory has a nontrivial gauge kinetic function

$$m_{1/2} = \frac{\partial f}{\partial z_i} m_{3/2}$$

(Ferrara, Girardello, HPN, 1983)

String theory

This scheme has a natural embedding in the heterotic $E_8 \times E_8$ string theory.

- $SU(3) \times SU(2) \times U(1)$ from first E_8
- hidden sector gaugino condensation from subgroup of second E_8

String theory

This scheme has a natural embedding in the heterotic $E_8 \times E_8$ string theory.

- $SU(3) \times SU(2) \times U(1)$ from first E_8
- hidden sector gaugino condensation from subgroup of second E_8

An important role is played by the antisymmetric tensor field of 10d supergravity

- its field strength stabilizes the gaugino condensate

(Derendinger, Ibanez, HPN; Dine, Rohm, Seiberg, Witten,1985)

Flux and Chern-Simons terms

Antisymmetric tensor field B_{MN} in 10d supergravity (with field strength $H = dB$) is not gauge invariant.

Flux and Chern-Simons terms

Antisymmetric tensor field B_{MN} in 10d supergravity (with field strength $H = dB$) is not gauge invariant.

Need modification

$$H = dB + \alpha'(\omega^{\mathrm{YM}} - \omega^{\mathrm{L}})$$

with $\omega^{\mathrm{YM}} = AF + \frac{2}{3}A^3$ and $\omega^{\mathrm{L}} = \omega R + \frac{2}{3}\omega^3$

such that $dH = \mathrm{Tr}F^2 - \mathrm{Tr}R^2$.

(Green, Schwarz, 1984)

Flux and Chern-Simons terms

Antisymmetric tensor field B_{MN} in 10d supergravity (with field strength $H = dB$) is not gauge invariant.

Need modification

$$H = dB + \alpha'(\omega^{\mathrm{YM}} - \omega^{\mathrm{L}})$$

with $\omega^{\mathrm{YM}} = AF + \frac{2}{3}A^3$ and $\omega^{\mathrm{L}} = \omega R + \frac{2}{3}\omega^3$

such that $dH = \mathrm{Tr}F^2 - \mathrm{Tr}R^2$.

(Green, Schwarz, 1984)

The 4d potential contains the "perfect square" structure

$$\Big(dB + \alpha'(\omega^{\mathrm{YM}} - \omega^{\mathrm{L}}) - \alpha'(\lambda\lambda)\Big)^2$$

Chern-Simons terms

Observe that

- dB is quantized in units of the string scale,

  (Rohm, Witten, 1985)

- ω^{YM} and $(\lambda\lambda)$ are both "α' corrections".

Chern-Simons terms

Observe that

- dB is quantized in units of the string scale,

  (Rohm, Witten, 1985)

- ω^{YM} and $(\lambda\lambda)$ are both "α' corrections".

This led to the conjecture that

- the gaugino condensate is compensated by a Chern-Simons term,

  (Derendinger, Ibanez, HPN, 1986)

avoiding the quantization constraint.

Modulus Mediation

In such a scheme, the fields responsible for the breakdown of supersymmetry are moduli fields like

- the dilaton S
- or the Kähler moduli T.

This is why this scheme is often called modulus mediation.

Modulus Mediation

In such a scheme, the fields responsible for the breakdown of supersymmetry are moduli fields like

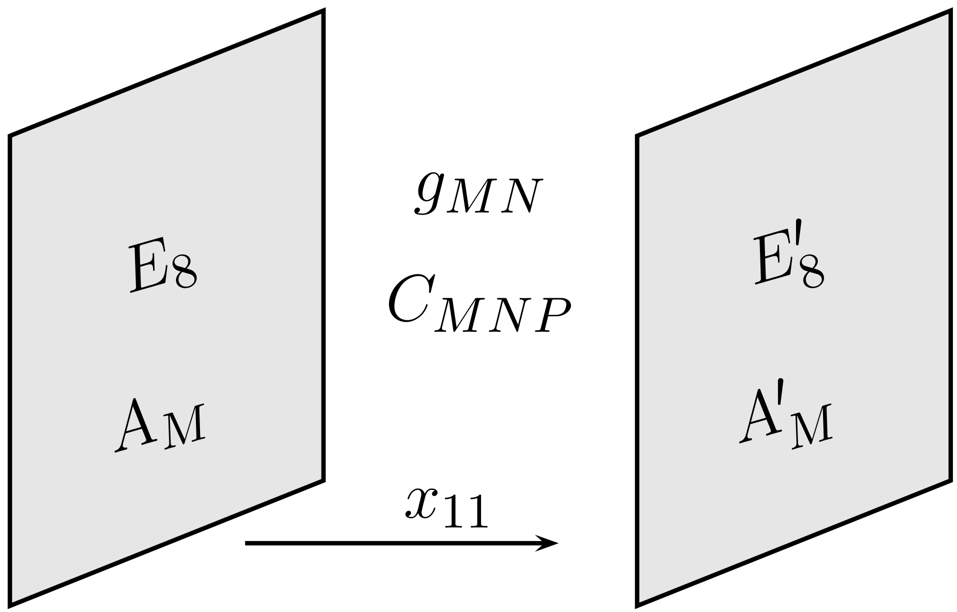
- the dilaton S
- or the Kähler moduli T.

This is why this scheme is often called modulus mediation.

It is the natural embedding of gravity mediation in the framework of string theory

Heterotic M-Theory

Further support for this conjecture comes from Heterotic M-theory (Horava, Witten, 1996)



with gravity multiplet in the bulk and $E_8 \times E_8$ on the branes

Chern-Simons terms im M-theory

- three index tensor field C_{NMP} lives in bulk
- again field strength $G = dC + \mathrm{Chern} - \mathrm{Simons}$
- gauge supermultiplets live on the boundaries (branes)

Chern-Simons terms im M-theory

- three index tensor field C_{NMP} lives in bulk
- again field strength $G = dC + \mathrm{Chern - Simons}$
- gauge supermultiplets live on the boundaries (branes)

- $C_{11,MN} \rightarrow B_{MN}$ and $G_{11,MNP} \rightarrow H_{MNP}$ with

Chern-Simons terms im M-theory

- three index tensor field C_{NMP} lives in bulk
- again field strength $G = dC + \mathrm{Chern-Simons}$
- gauge supermultiplets live on the boundaries (branes)

- $C_{11,MN} \to B_{MN}$ and $G_{11,MNP} \to H_{MNP}$ with

$$G = (dC) + \alpha' \sum_i \delta(x_{11} - x_{11}^i) \left(\omega_i^{\mathrm{YM}} - \frac{1}{2} \omega_i^{\mathrm{L}} \right)$$

Chern-Simons terms im M-theory

- three index tensor field C_{NMP} lives in bulk
- again field strength $G = dC + \mathrm{Chern-Simons}$
- gauge supermultiplets live on the boundaries (branes)

- $C_{11,MN} \rightarrow B_{MN}$ and $G_{11,MNP} \rightarrow H_{MNP}$ with

$$G = (dC) + \alpha' \sum_i \delta(x_{11} - x_{11}^i) \left(\omega_i^{\mathrm{YM}} - \frac{1}{2} \omega_i^{\mathrm{L}} \right)$$

- and $dG = \mathrm{Tr} F_1^2 + \mathrm{Tr} F_2^2 - \mathrm{Tr} R^2$

Chern-Simons terms im M-theory (II)

- Flux dC lives in the bulk
- Gauge fields and gauginos live on the branes

Chern-Simons terms im M-theory (II)

- Flux dC lives in the bulk
- Gauge fields and gauginos live on the branes

and this suggest a local compensation on the boundary

$$\left(\alpha'(\omega_i^{\mathrm{YM}} - \omega_i^{\mathrm{L}}) - \alpha'(\lambda_i\lambda_i)\right)^2$$

(HPN, Olechowski, Yamaguchi, 1997)

Chern-Simons terms im M-theory (II)

- Flux dC lives in the bulk
- Gauge fields and gauginos live on the branes

and this suggest a local compensation on the boundary

$$\left(\alpha'(\omega_i^{\mathrm{YM}} - \omega_i^{\mathrm{L}}) - \alpha'(\lambda_i \lambda_i)\right)^2$$

(HPN, Olechowski, Yamaguchi, 1997)

This suggests that

- supersymmetry is broken on a hidden brane
- the hidden sector becomes a hidden wall

The hidden wall

This suggestion of susy breakdown on a hidden wall fits perfectly in the picture of other string theories with D-branes and fluxes, e.g.

- moduli stabilization by H_3 and F_3 fluxes in Type IIB theory (Giddings, Kachru, Polchinski, 2002)
- T modulus fixed by gaugino condensation (Kachru, Kallosh, Linde, Trivedi, 2002)

The hidden wall

This suggestion of susy breakdown on a hidden wall fits perfectly in the picture of other string theories with D-branes and fluxes, e.g.

- moduli stabilization by H_3 and F_3 fluxes in Type IIB theory (Giddings, Kachru, Polchinski, 2002)
- T modulus fixed by gaugino condensation (Kachru, Kallosh, Linde, Trivedi, 2002)

So the message is:

- supersymmetry breaks at a hidden brane and is
- mediated by bulk moduli to the observable sector.

Signals of the scheme

Are there some model independent properties of the soft mass terms?

We always have

$$W = \text{something} - \exp(-X)$$

where "something" is small and X is moderately large

Signals of the scheme

Are there some model independent properties of the soft mass terms?

We always have

$$W = \text{something} - \exp(-X)$$

where "something" is small and X is moderately large

In fact

$$X \sim \log(M_{\text{Planck}}/m_{3/2})$$

providing a "little" hierarchy.

(Choi, Falkowski, HPN, Olechowski, 2005)

Mixed Modulus Anomaly Mediation

The contribution from "Modulus Mediation" is therefore suppressed by the factor

$$X \sim \log(M_{\text{Planck}}/m_{3/2})$$

Numerically this factor is given by: $X \sim 4\pi^2$.

Mixed Modulus Anomaly Mediation

The contribution from "Modulus Mediation" is therefore suppressed by the factor

$$X \sim \log(M_{\rm Planck}/m_{3/2})$$

Numerically this factor is given by: $X \sim 4\pi^2$.

Thus loop corrections known as "Anomaly Mediation" become competitive, leading to a Mixed Modulus-Anomaly-Mediation scheme.

For reasons that will be explained later we call this scheme

MIRAGE MEDIATION

(Loaiza, Martin, HPN, Ratz, 2005)

The little hierarchy

$$m_X \sim \langle X \rangle m_{3/2} \sim \langle X \rangle^2 m_{\rm soft}$$

leads to a number of encouraging consequences

(Choi, Falkowski, HPN, Olechowski, 2005)

The little hierarchy

$$m_X \sim \langle X \rangle m_{3/2} \sim \langle X \rangle^2 m_{\rm soft}$$

leads to a number of encouraging consequences

(Choi, Falkowski, HPN, Olechowski, 2005)

- moduli and gravitino are heavy
- relieves the Susy flavour and CP problems

The little hierarchy

$$m_X \sim \langle X \rangle m_{3/2} \sim \langle X \rangle^2 m_{\text{soft}}$$

leads to a number of encouraging consequences

(Choi, Falkowski, HPN, Olechowski, 2005)

- moduli and gravitino are heavy
- relieves the Susy flavour and CP problems

- distinct pattern of soft breaking terms.

(Endo, Yamaguchi, Yoshioka, 2005; Choi, Jeong, Okumura, 2005)

Mirage Unification

Mirage Mediation provides a

- characteristic pattern of soft breaking terms.

Mirage Unification

Mirage Mediation provides a

- characteristic pattern of soft breaking terms.

To see this, let us consider the gaugino masses

$$M_{1/2} = M_{\mathrm{modulus}} + M_{\mathrm{anomaly}}$$

as a sum of two contributions of comparable size.

Mirage Unification

Mirage Mediation provides a

- characteristic pattern of soft breaking terms.

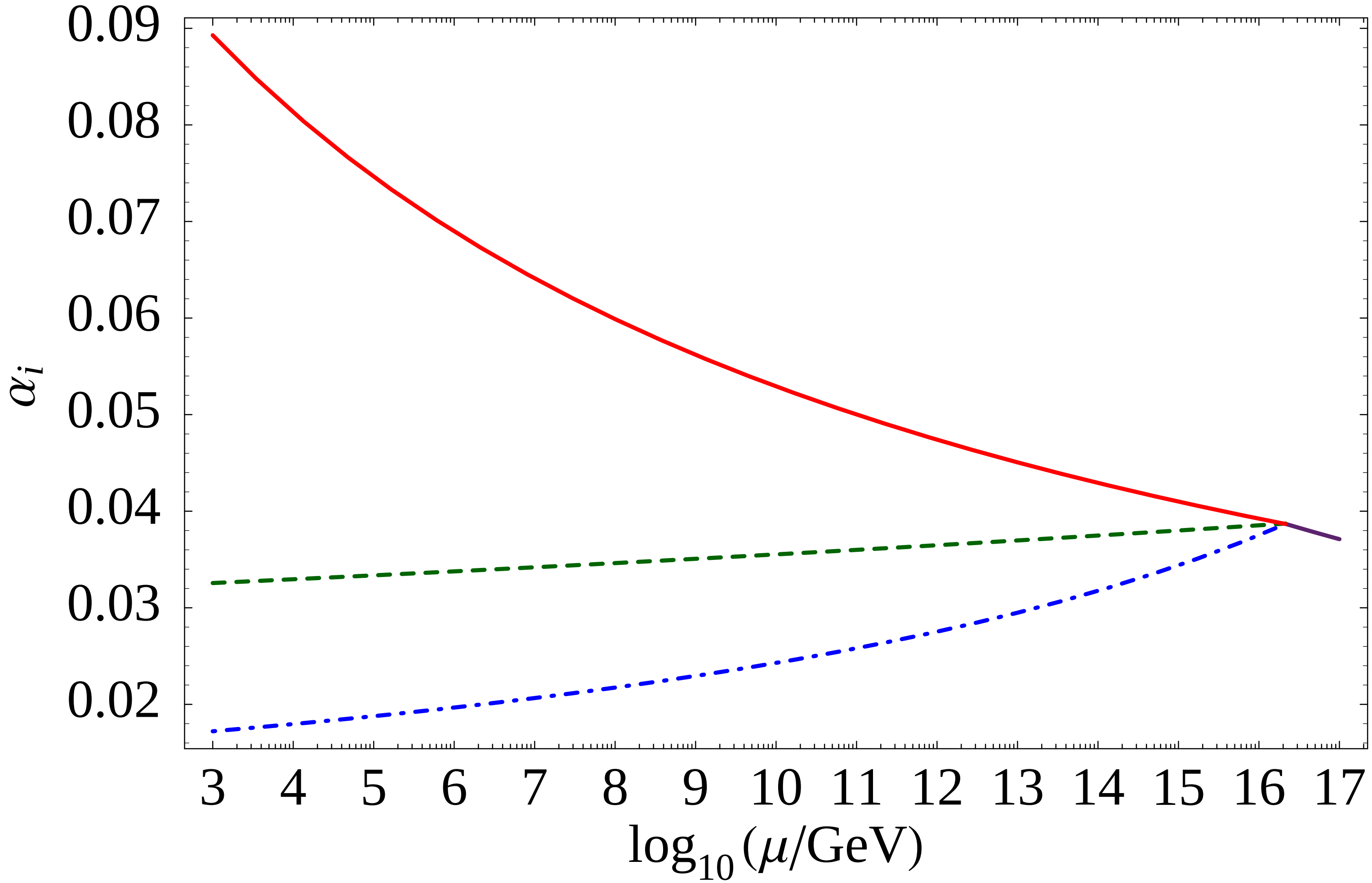
To see this, let us consider the gaugino masses

$$M_{1/2} = M_{\text{modulus}} + M_{\text{anomaly}}$$

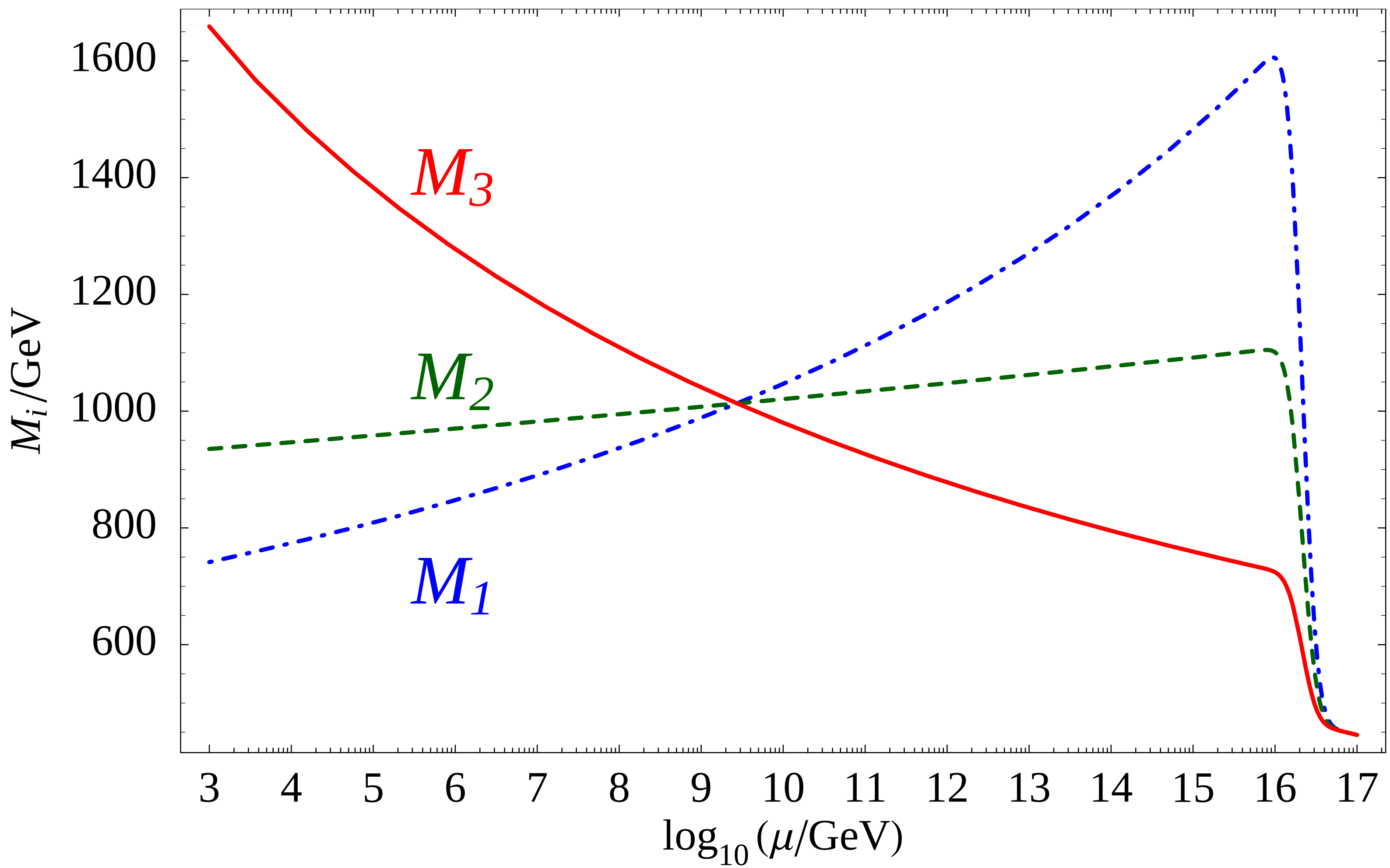
as a sum of two contributions of comparable size.

- M_{anomaly} is proportional to the β function, i.e. negative for the gluino, positive for the bino
- thus M_{anomaly} is non-universal below the GUT scale

Evolution of couplings



The Mirage Scale



(Lebedev, HPN, Ratz, 2005)

The Mirage Scale (II)

The gaugino masses coincide

- above the GUT scale
- at the mirage scale $\mu_{\rm mirage} = M_{\rm GUT} \exp(-8\pi^2/\alpha)$

The Mirage Scale (II)

The gaugino masses coincide

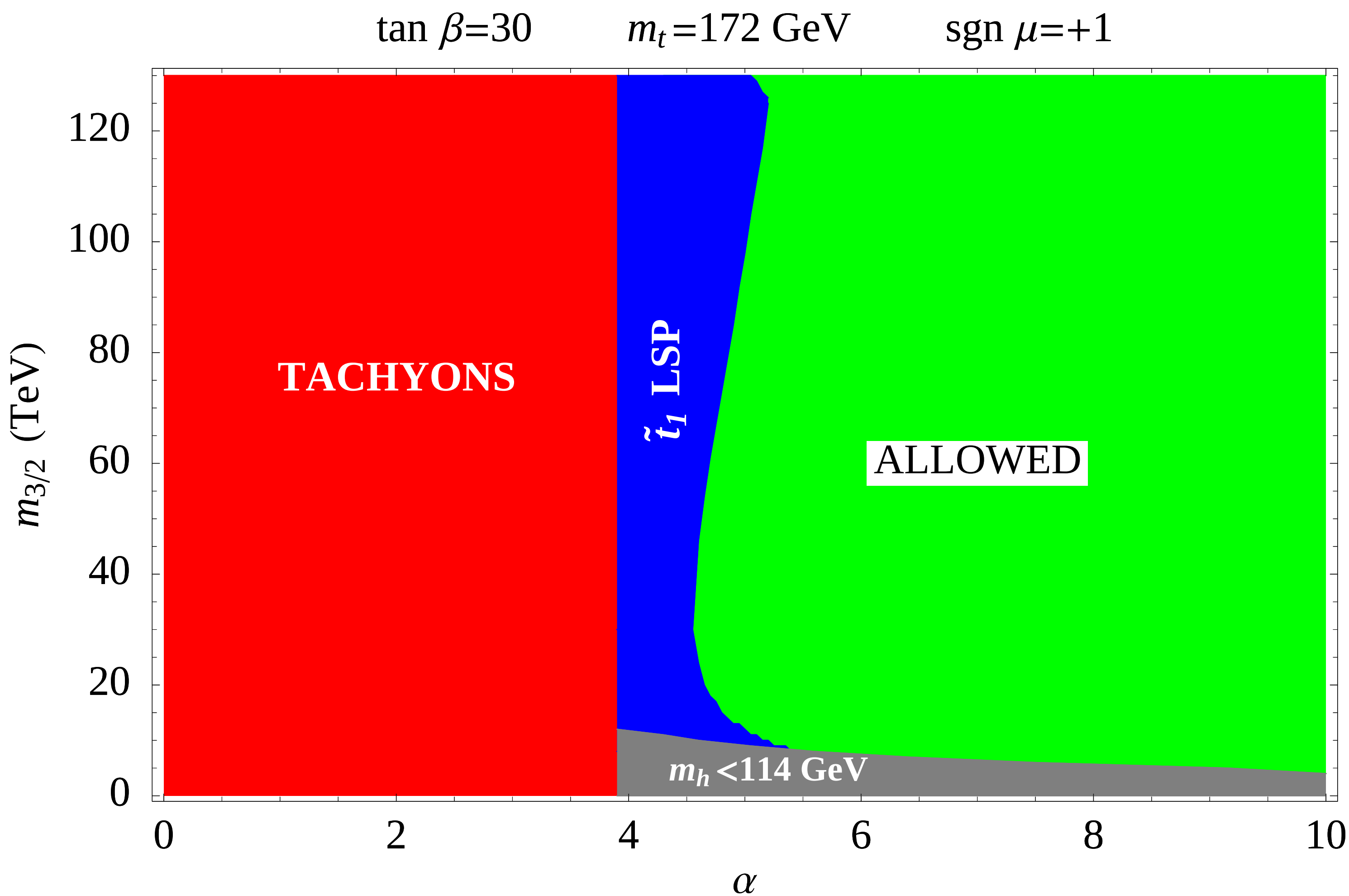
- above the GUT scale
- at the mirage scale $\mu_{\text{mirage}} = M_{\text{GUT}} \exp(-8\pi^2/\alpha)$

where α denotes the "ratio" of the contribution of modulus vs. anomaly mediation. We write the gaugino masses as

$$M_a = M_s(\alpha + b_a g_a^2) = \frac{m_{3/2}}{16\pi^2}(\alpha + b_a g_a^2)$$

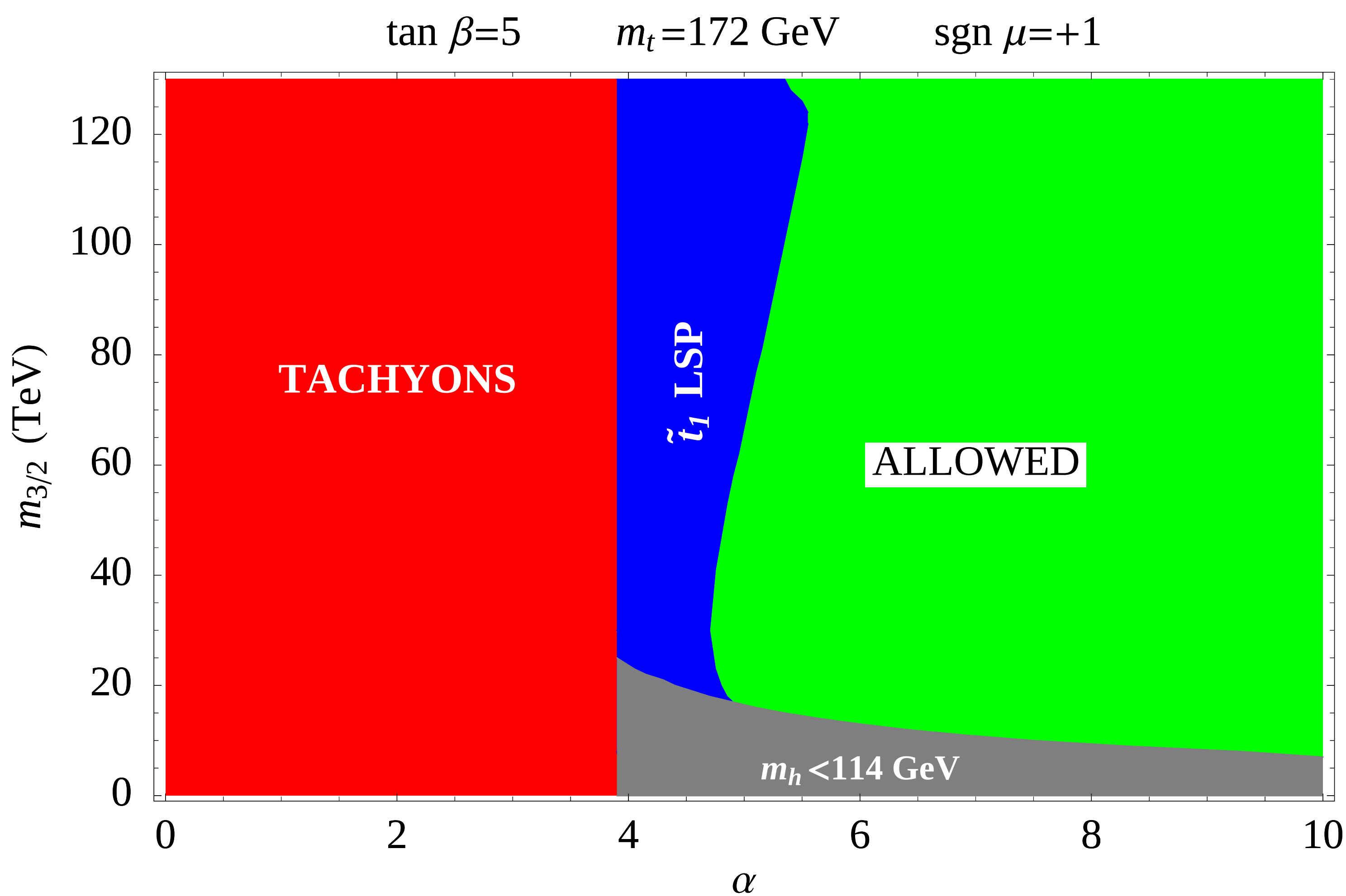
and $\alpha \to 0$ corresponds to pure anomaly mediation.

Constraints on the mixing parameter



(Löwen, HPN, Ratz, 2006)

Constraints on α



(Löwen, HPN, Ratz, 2006)

Conclusion

Gravity Mediation is a scheme that naturally overcomes the major problems of spontaneous Susy breakdown. It reqires

- a hidden sector that breaks supersymmetry,
- mediated to the observable sector
- by interactions of gravitational strength.

Conclusion

Gravity Mediation is a scheme that naturally overcomes the major problems of spontaneous Susy breakdown. It reqires

- a hidden sector that breaks supersymmetry,
- mediated to the observable sector
- by interactions of gravitational strength.

Suggestions for Susy breakdown are:

- gaugino condensation in the hidden sector,
- scalar field superpotentials.

Conclusion

Gravity Mediation is a scheme that naturally overcomes the major problems of spontaneous Susy breakdown. It reqires

- a hidden sector that breaks supersymmetry,
- mediated to the observable sector
- by interactions of gravitational strength.

Suggestions for Susy breakdown are:

- gaugino condensation in the hidden sector,
- scalar field superpotentials.

The scale of soft masses is set by the gravitino mass.

Conclusion

Gravity Mediation has a natural embedding in heterotic string theory:

- gaugino condensation in the hidden E_8
- stabilization by 3-form flux

Conclusion

Gravity Mediation has a natural embedding in heterotic string theory:

- gaugino condensation in the hidden E_8
- stabilization by 3-form flux

In heterotic M-theory

- the hidden sector becomes a hidden wall,
- and this generalizes to the brane world picture.

Conclusion

Gravity Mediation has a natural embedding in heterotic string theory:

- gaugino condensation in the hidden E_8
- stabilization by 3-form flux

In heterotic M-theory

- the hidden sector becomes a hidden wall,
- and this generalizes to the brane world picture.

These schemes are known under the name of

Modulus and/or Mirage Mediation.

Conclusion

The general scheme

- is consistent with all known data,
- provides a natural dark matter candidate and
- is testable by upcoming experiments.

Conclusion

The general scheme

- is consistent with all known data,
- provides a natural dark matter candidate and
- is testable by upcoming experiments.

We are waiting for

- LHC to confirm this picture.