Mirage Mediation

also known as MixedModulus-AnomalyMediation

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Based on work with K. Choi, A. Falkowski, M. Olechowski, S. Pokorski,

hep-th/0411066, hep-th/0503216

J. Martin, O. Loaiza, M. Ratz, hep-th/0509158

O. Lebedev, M. Ratz, hep-ph/0511320, hep-th0603047

Outline

- Basic questions: moduli stabilization and Susy breakdown: Fluxes and Gaugino Condensation
- A large and a little hierarchy
- Mirage Mediation
- Distinct pattern of soft terms
- Soft Susy breaking (flavour and CP)
- Dark matter candidates
- Avoiding cosmological (moduli) problems
- Some remarks on fine tuning
- Conclusions and outlook

Two Basic Questions

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Are the masses of moduli connected to Susy breakdown? Relevant moduli are

- Dilaton (S)
- Kähler (T_i) and complex structure moduli (Z_α)
- Other moduli are needed.
- They might come from Chern-Simons terms, additional matter fields.....

(Lebedev, HPN, Ratz, 2006)

Fluxes and gaugino condensation

Is there a general pattern of the soft mass terms?

We always have (from flux and gaugino condensate)

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

where "something" is small and X is moderately large.

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where "something" is small and X is moderately large.

In fact in this simple scheme

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

providing a "little" hierarchy.

(Choi, Falkowski, HPN, Olechowski, 2005)

Mixed Modulus Anomaly Mediation

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

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Thus the contribution due to "Anomaly Mediation" (suppressed by a loop factor) becomes 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

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

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- moduli and gravitino are heavy
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- distinct pattern of soft breaking terms.

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

Mirage Unification

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To see this, let us consider the gaugino masses

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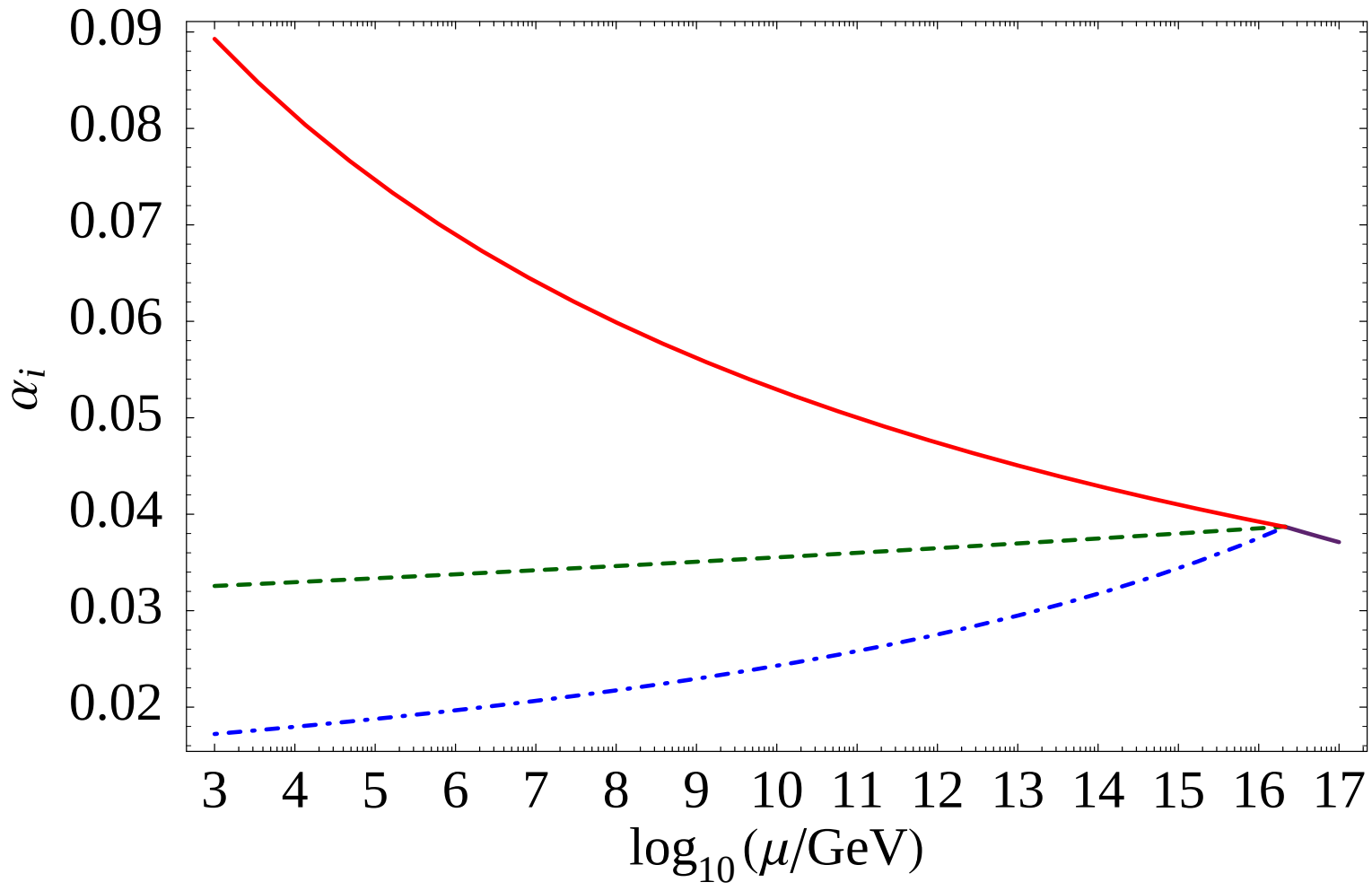
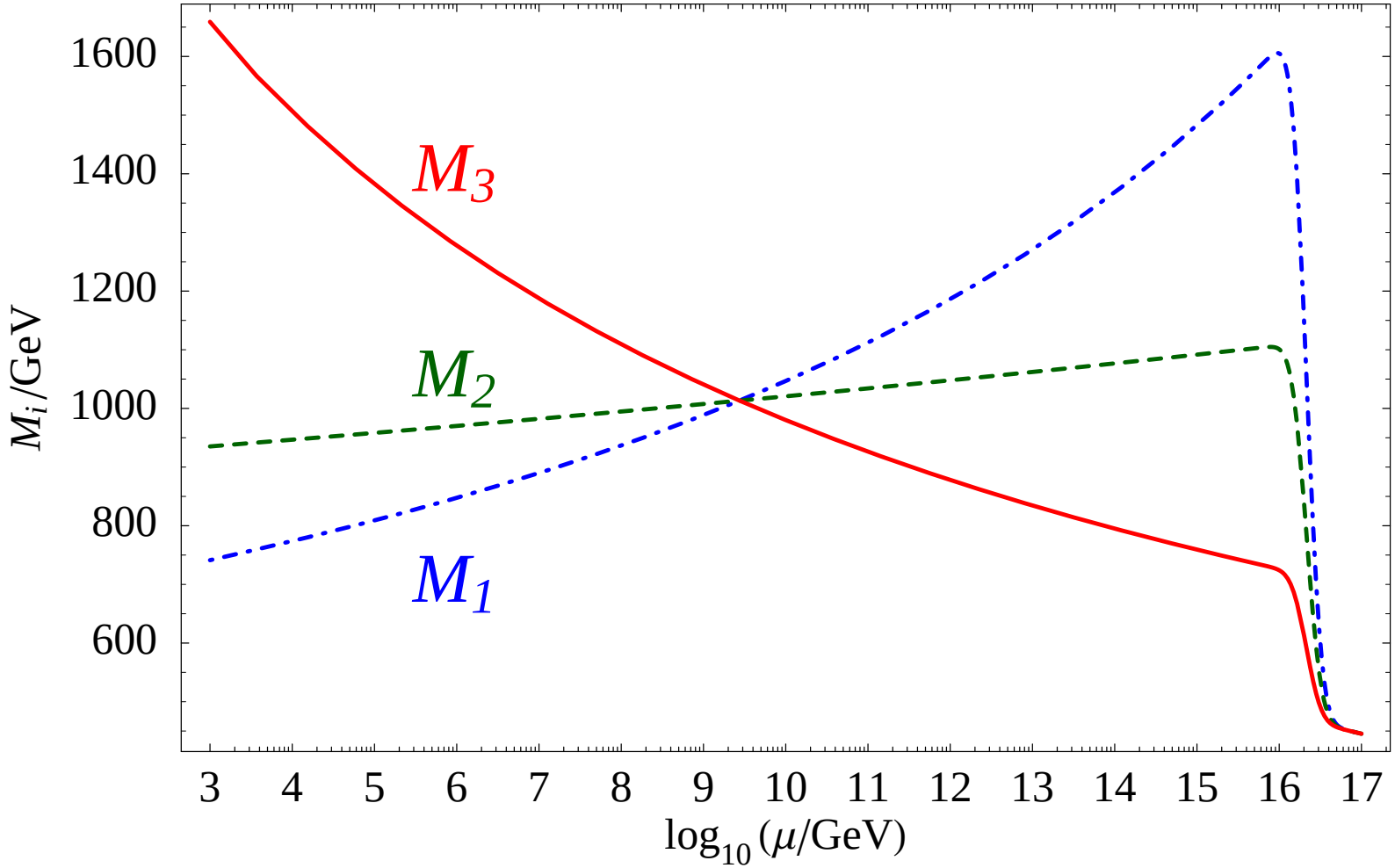
as a sum of two contributions of comparable size.

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

Evolution of couplings



The Mirage Scale



(Lebedev, HPN, Ratz, 2005)

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The gaugino masses coincide

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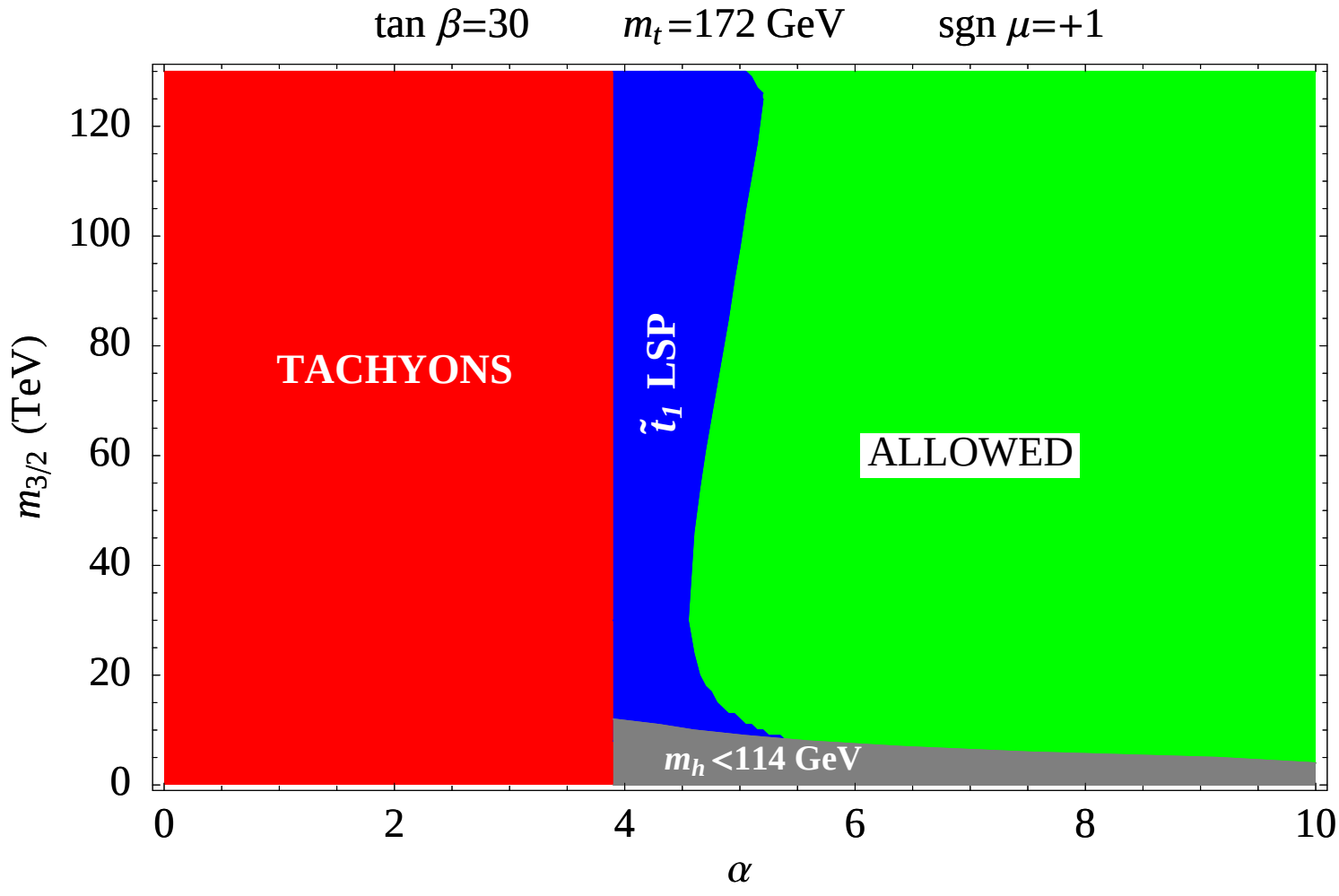
where α denotes the "ratio" of the contribution of modulus vs. anomaly mediation. We write the gaugino masses as

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

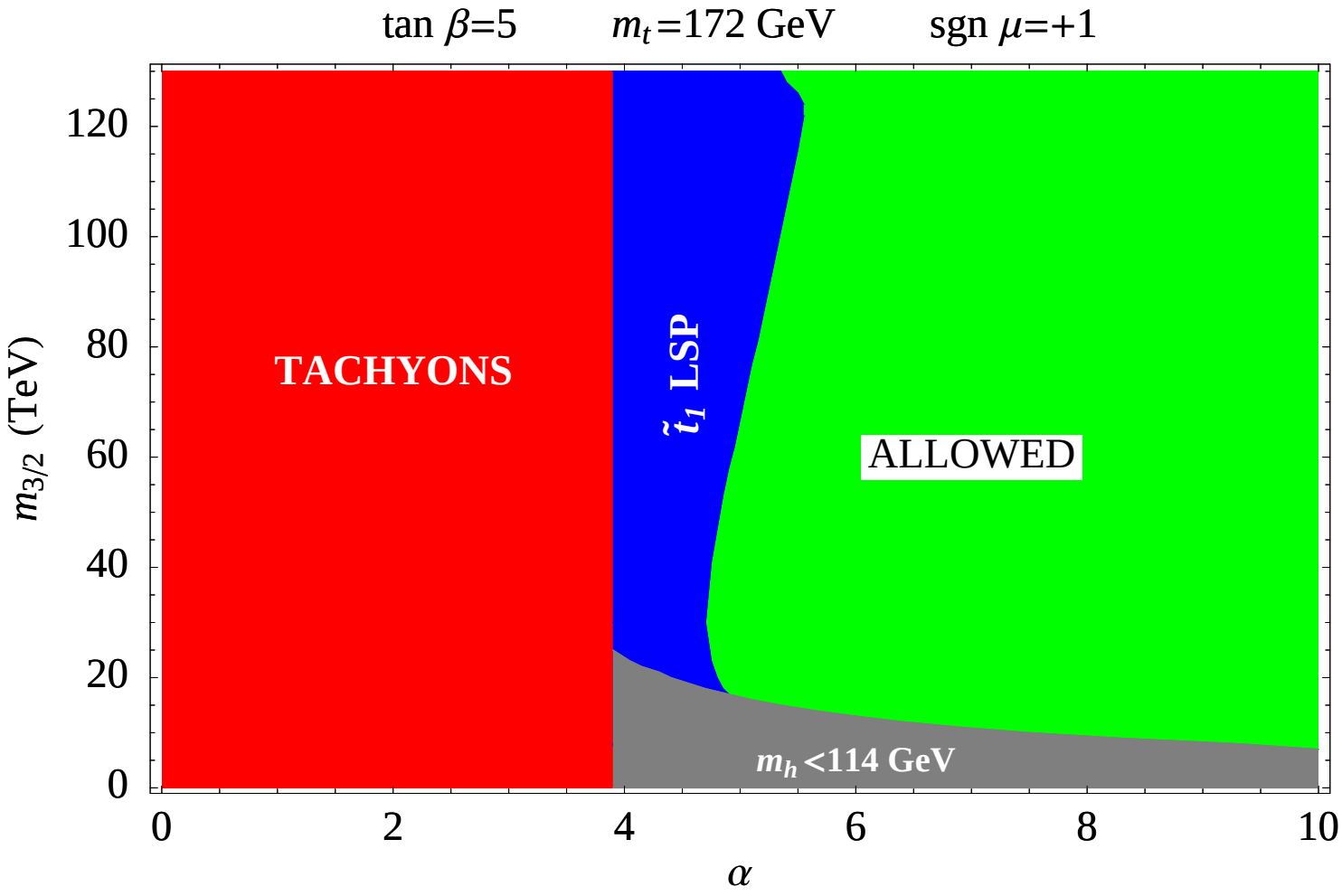
and $\alpha \to 0$ corresponds to pure anomaly mediation.

Constraints on the mixing parameter



(Löwen, HPN, Ratz, 2006)

Constraints on α



(Löwen, HPN, Ratz, 2006)

Constraints from cosmology

The scheme leads to

- neutralino Dark Matter

(Falkowski, Lebedev, Mambrini, 2005; Baer, Park, Tata, Wang, 2006)

Cosmological moduli problem revived through

- modulus decay into gravitini

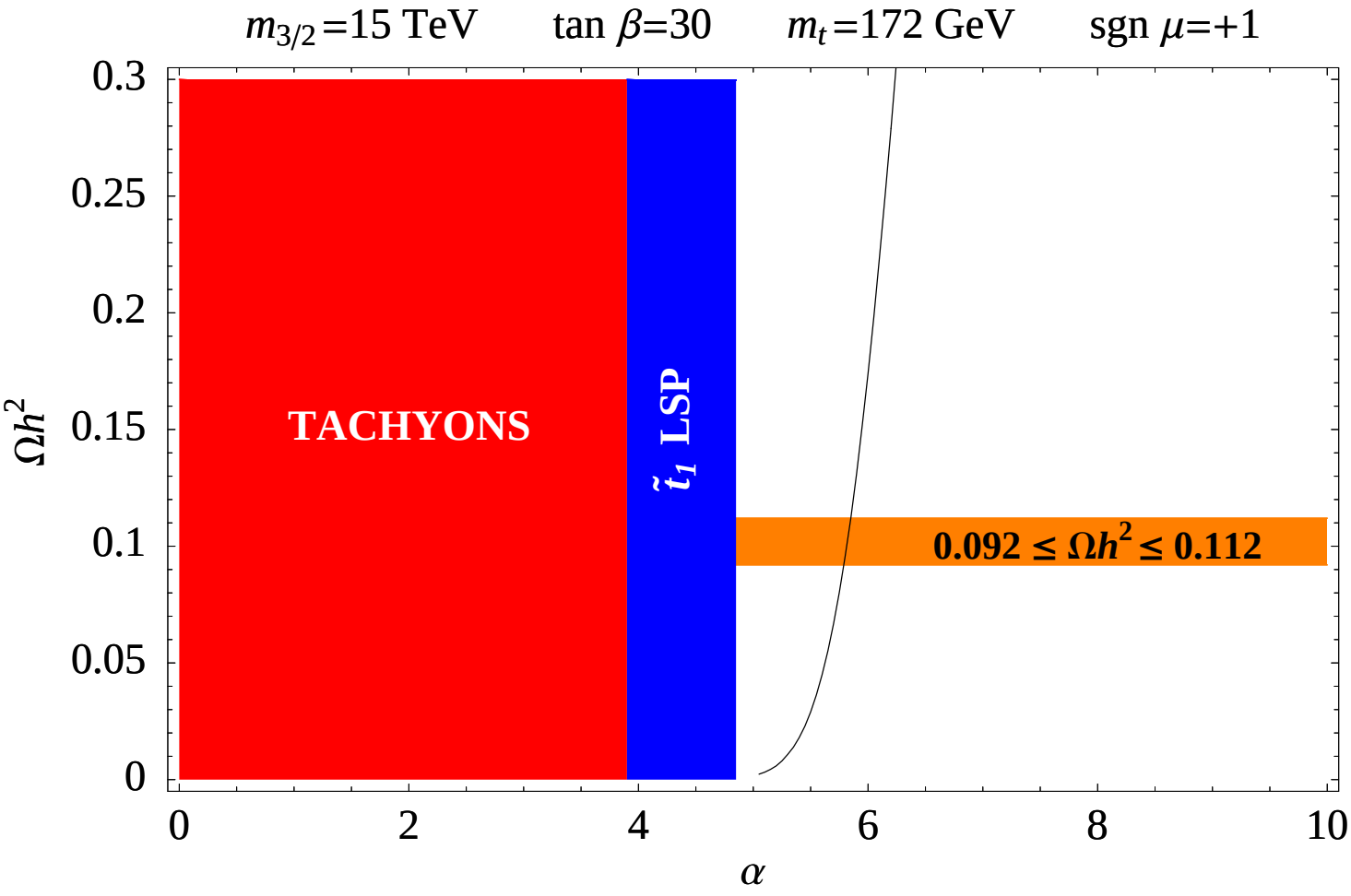
(Endo, Hamaguchi, Takahashi, 2006; Nakamura, Yamaguchi, 2006)

Seems to require the presence of

- additional light moduli

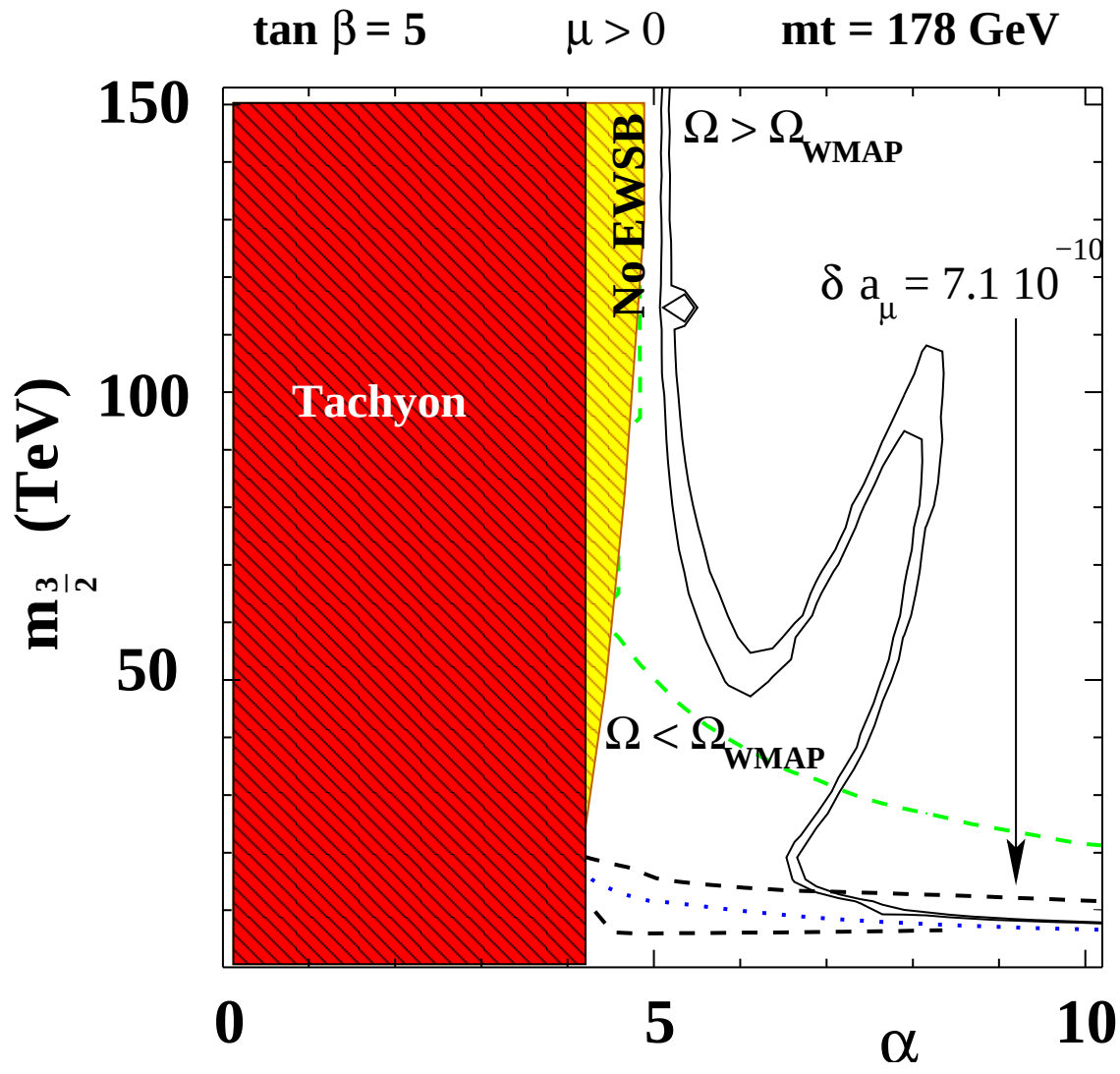
(Lebedev, HPN, Ratz, 2006; Dine, Kitano, Morisse, Shirman, 2006)

Dark Matter


$m_{3/2}$=15 TeV
tan β=30
m_t=172 GeV
sgn μ=+1
TACHYONS
$\tilde{t}_1$ LSP
$0.092 \leq \Omega h^2 \leq 0.112$
Ωh^2
α
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10

Dark Matter

(Falkowski, Lebedev, Mambrini, 2005)



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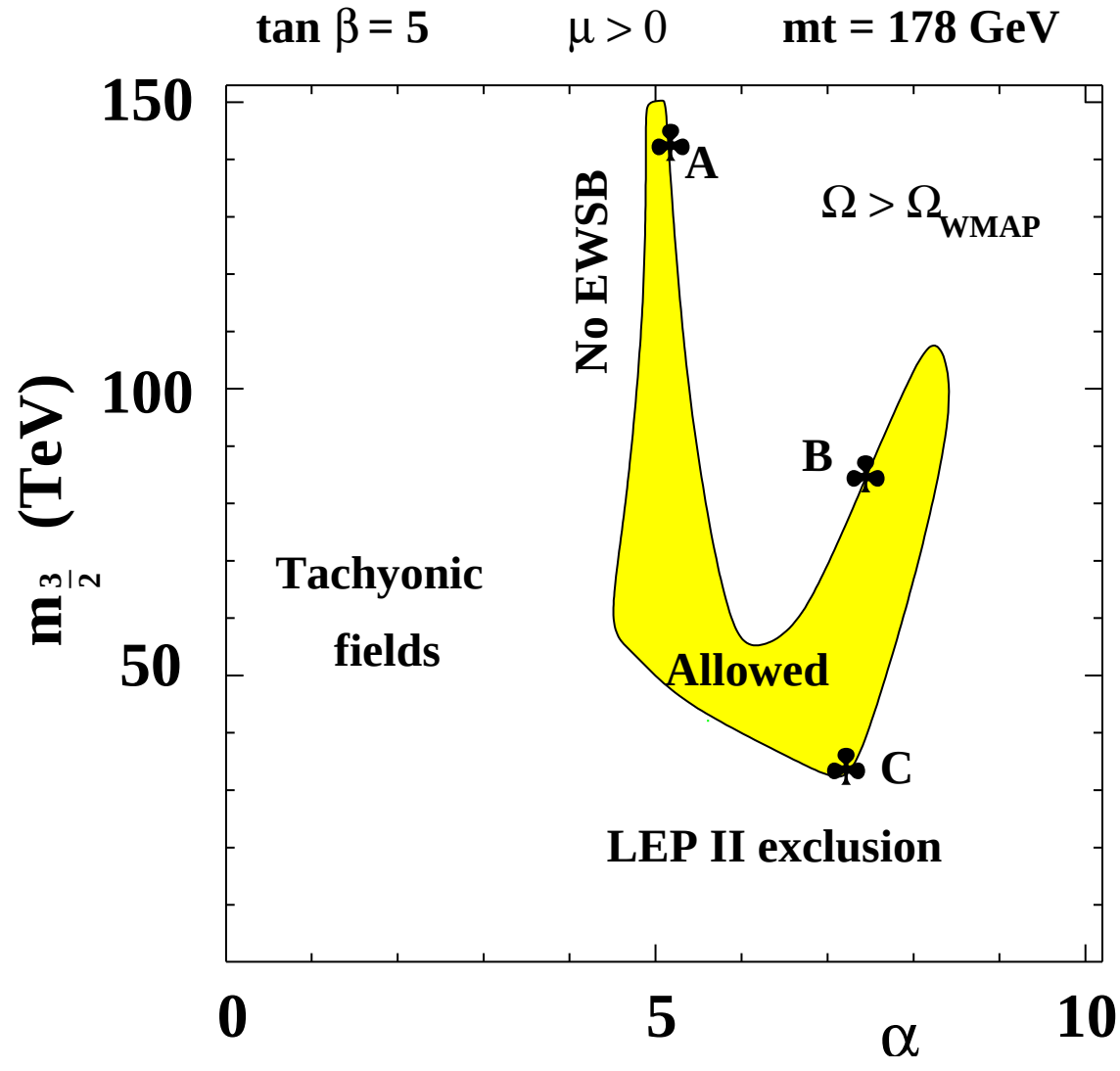

The “MSSM hierarchy problem”

The scheme predicts a rather high mass scale

- multi-TeV for the gravitino
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- multi-TeV for the gravitino
- rather high mass for the LSP-Neutralino

Thus we might worry about a fine-tuning to obtain

- the mass of the weak scale around 100 GeV from

$$\frac{m_Z^2}{2} = -\mu^2 + \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} \,,$$

and there are large corrections to $m_{H_u}^2$ .....

(Choi, Jeong, Kobayashi, Okumura, 2005)

The "MSSM hierarchy problem" solved?

The influence of the various soft terms is given by

$$m_Z^2 \simeq -1.8\,\mu^2 + 5.9\,M_3^2 - 0.4\,M_2^2 - 1.2\,m_{H_u}^2 + 0.9\,m^2_{q_{\rm L}^{(3)}} +$$
$$+ 0.7\,m^2_{u_{\rm R}^{(3)}} - 0.6\,A_t\,M_3 + 0.4\,M_2\,M_3 + \dots \ ,$$

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Mirage mediation improves the situation

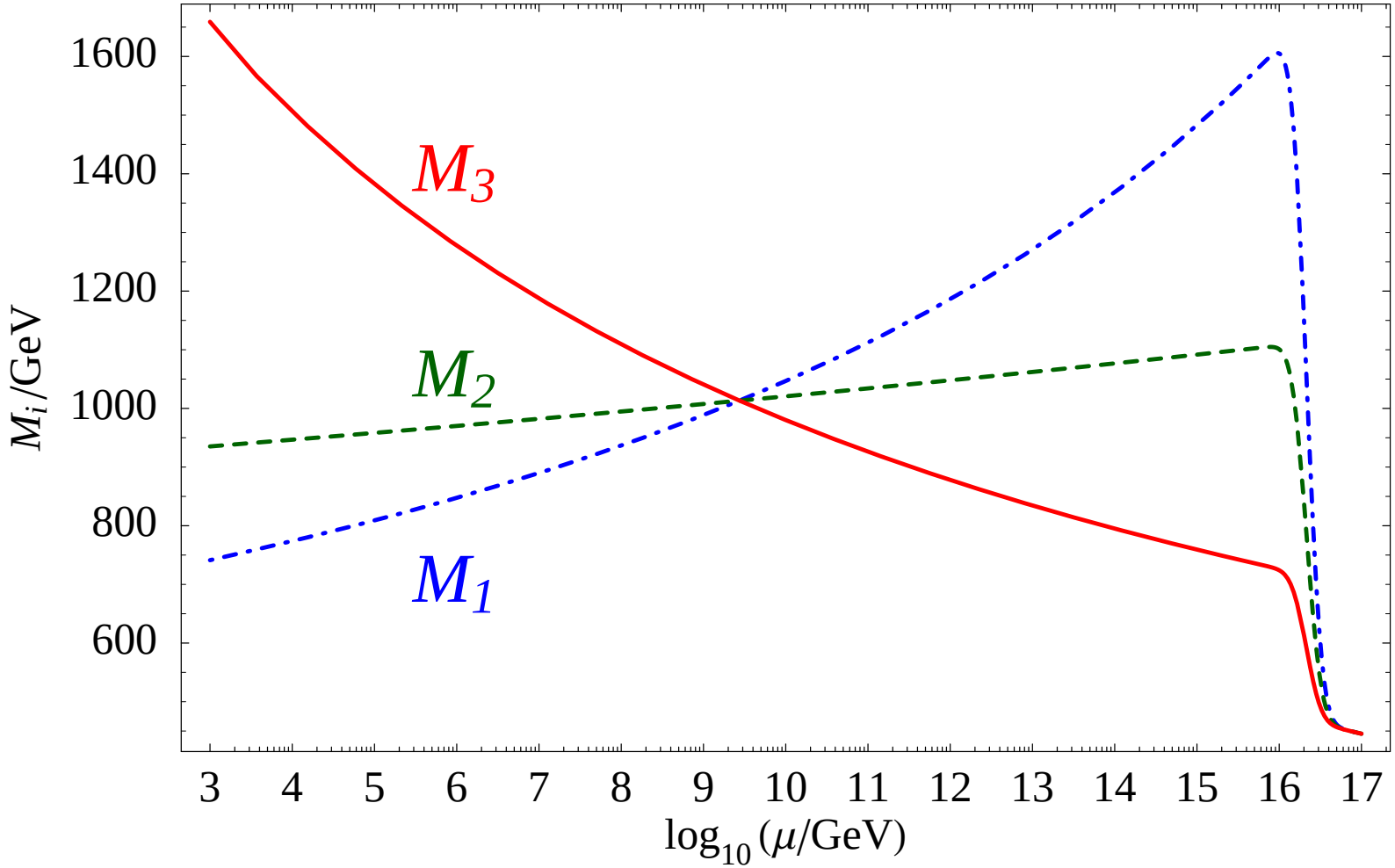
- especially for small α
- because of a reduced gluino mass

(Choi, Jeong, Kobayashi, Okumura, 2005)

- explicit model building required

(Lebedev, HPN, Ratz, 2005; Pierce, Thaler, 2006)

The Mirage Scale



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Explicit schemes

The different schemes depend on the mechanism of uplifting:

- uplifting with anti D3 branes

(Kachru, Kallosh, Linde, Trivedi, 2003)

  - $\alpha \sim 5$ in the original KKLT scenario leading to
  - a mirage scale of approximately 10^{11} GeV

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- de Sitter vacua from matter superpotentials

  (Lebedev, HPN, Ratz, 2006)

  - allows a continuous variation of α
  - leads to new contributions for sfermion masses

Conclusion

Mirage Mediation naturally appears in string theory models with background fluxes and gaugino condensation. It

- relieves cosmological problems of moduli and gravitino
- partially solves the Susy-flavour and CP problem
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It avoids

- the problems of conventional schemes like anomaly and modulus mediation
- gives a consistent picture with very few parameters

Conclusion

The source of Mirage Mediation is the appearance of a small parameter

$$X^{-1} \sim \log(m_{3/2}/M_{\rm Planck})$$

that leads to a (heavy) superpartner spectrum exhibiting

- a little hierarchy $m_X \sim \langle X \rangle m_{3/2} \sim \langle X \rangle^2 m_{\rm soft}$
- a rather heavy gravitino mass
- and an unusual relation between the gaugino masses.

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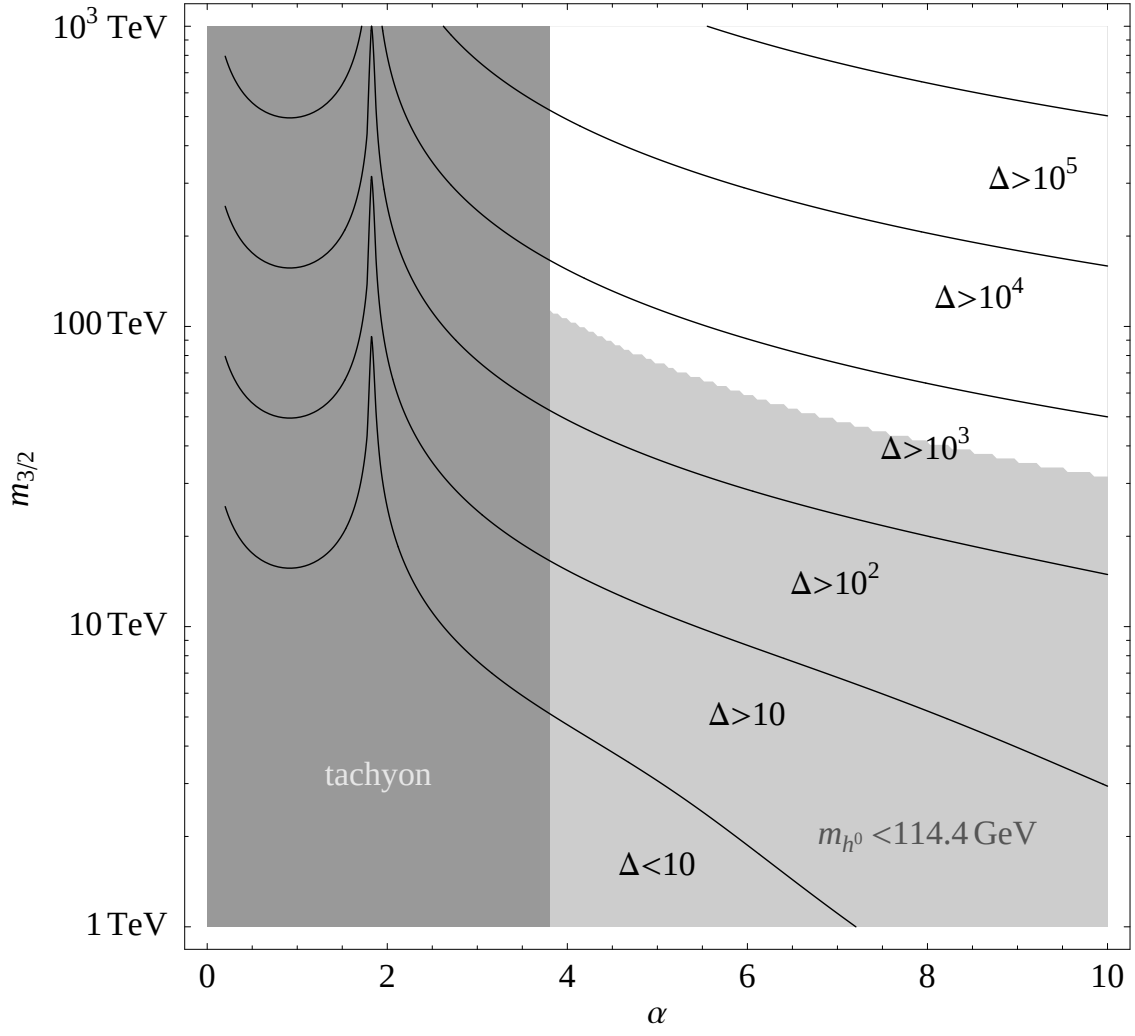
Mirage Mediation provides a distinct pattern of soft terms that could be tested at the LHC!

Sensitivity of the weak scale



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