Relic density in SO(10) SUSY GUT models

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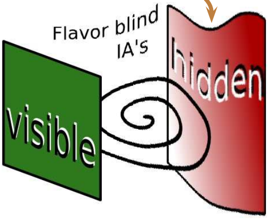
Outline

MSSM – Broken SUSY

SUSY breaking is supposed to be generated spontaneously

But: Exact method is not known! So:

- Supersymmetry is broken by hand by adding SUSY breaking terms
- The B- and L-breaking terms are prohibited by *R*-parity
  - $\longrightarrow$ *Lightest supersymmetric particle (LSP)* is absolutely stable



- Over hundred new *free* parameters from the SUSY breaking!

Must try to reduce the parameter space

Universality Assumptions

SUSY breaking is assumed to be universal at the GUT scale

- Most of the new parameters imply flavor mixing or large CP-violation → implies 'universality'

If one assumes that no flavor or CP-violation is generated:

Soft supersymmetry breaking universality

- 3 real independent gaugino masses
- 5 real squark and slepton squared masses
- 3 real scalar cubic coupling parameters
- 4 Higgs mass parameters

This is valid at the GUT scale

mSUGRA Parameters

Hidden-visible separation of superpotential (and [minimal] Kähler potential) gives a common mass scale for the squared masses, common mass for the trilinear and bilinear couplings.

But not for the gaugino masses!

1. $m_0, A_0, B_0 \leftarrow$ Common
2. $m_{1/2} \leftarrow$ Universal gaugino mass (for convenience)
3. $\mu \leftarrow$ Supersymmetric Higgs mass parameter (considered as fifth input parameter)

Usually people write $B_0\mu$, and after the rEWSB in mSUGRA, μ and $B_0 \Rightarrow$ sgn(μ) and $\tan\beta = \langle H_2^0 \rangle / \langle H_1^0 \rangle$.

SUSY SO(10) – Why?

1. It is fairly simple model for GUT (only SU(5) is simpler)
2. One family matter fermions can be put to one spinor rep of SO(10)
3. Representations of SO(10) are anomaly free
4. *R*-parity may result from some gauge symmetry breaking
5. More attractive breaking chains than SU(5)

Gives well specified non-universality for gauginos and the predictability is maintained!

Assume:

- that the breaking to the SM group takes place at M_{GUT}
- the gauge coupling unification

Gaugino Mass Terms

Masses come from the coupling of the

f_{ab} gauge kinetic function
W^a field strength superfield

$$\mathcal{L}_{g.k.} = \int d^2\theta \, f_{ab}(\Phi) W^a W^b$$

- The gauge kinetic function must be non-minimal. Then

$$\mathcal{L}_{g.k.} \supset \frac{\langle F_\Phi \rangle_{ab}}{M_P} \lambda^a \lambda^b + \text{H.C.},$$

$\langle F_\Phi \rangle \leftarrow$ is the *vev* for the F-term of Φ

Breaks SUSY

Non-singlet w.r.t. SO(10) – breaks SO(10)

Choice of Representations

The gauge multiplets are in the adjoint representation $\Rightarrow \langle F_\Phi \rangle$ transforms as a symmetric product of two adjoints

$$\langle F_\Phi \rangle_{ab} \, \lambda^a \lambda^b$$

(must be gauge invariant)

Therefore, Φ can belong to any of the (irreducible) representations of

$$(\mathbf{45} \otimes \mathbf{45})_{Symm} = \mathbf{1} \oplus \mathbf{54} \oplus \mathbf{210} \oplus \mathbf{770}.$$

The representations **54**, **210** and **770** give non-universal gaugino masses, while only the rep **1** gives the universal $m_{1/2}$!

Breaking Chains: SO(10) $\rightarrow H \rightarrow$ SM

The breaking of SO(10) to the SM must go through some intermediate gauge group *H*

$$\mathbf{54}: H = \begin{cases} SU(4)\times SU(2)\times SU(2) & \text{Pati–Salam} \\ SU(2)\times SO(7) & \\ SO(9) & \text{Universal gaugino masses} \end{cases}$$

$$\mathbf{210}: H = \begin{cases} SU(4)\times SU(2)\times SU(2) & \text{Massless gluino} \\ SU(3)\times SU(2)\times SU(2)\times U(1) & \text{Massless } SU(2)_L \text{ gauginos} \\ SU(3)\times SU(2)\times U(1)\times U(1) & \\ SU(5)\times U(1) & \text{'Flipped' } SU(5) \end{cases}$$

$$\mathbf{770} = \{\text{So many dimensions...}$$

Restrict the study to the three chosen representations

Ratios of the Gaugino Masses

Parameters are run down to the EW-scale using RGE's

Table: Ratios of the gaugino masses at the GUT and EW scales

F_Φ	H	M_1^{GUT}	M_2^{GUT}	M_3^{GUT}	M_1^{EW}	M_2^{EW}	M_3^{EW}
1		1	1	1	0.14	0.29	1
54	$SU(4)\times SU(2)\times SU(2)$	-1	-1.5	1	-0.14	-0.43	1
54	$SU(2)\times SO(7)$	1	-7/3	1	0.14	-0.7	1
210	$SU(5)\times U(1)$	-96/25	1	1	-0.53	0.29	1

Smallest of (M_1^{EW}, M_2^{EW}) characterizes the lightest neutralino

Note: Φ can also transform as a linear composition of any of the representations

Neutralinos Are Born at the EWSB

Neutralinos are combinations of gauginos and higgsinos

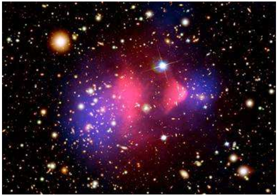
$$\boldsymbol{M}_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -c_\beta\, s_W\, m_Z & s_\beta\, s_W\, m_Z \\ 0 & M_2 & c_\beta\, c_W\, m_Z & -s_\beta\, c_W\, m_Z \\ -c_\beta\, s_W\, m_Z & c_\beta\, c_W\, m_Z & 0 & -\mu \\ s_\beta\, s_W\, m_Z & -s_\beta\, c_W\, m_Z & -\mu & 0 \end{pmatrix}$$

[$s_\beta = \sin\beta$, $c_\beta = \cos\beta$, $s_W = \sin\theta_W$, and $c_W = \cos\theta_W$]

Diagonalize $\boldsymbol{M}_{\tilde{\chi}^0} \Rightarrow$ Four neutralino masses

Relevant: Respective relations between M_1, M_2 and μ.
Remember: μ is determined by the EWSB

Dark Matter



Bullet cluster:
Blue = dark matter
Red = hot gas

Supersymmetric theories which preserve *R*-parity contain a natural candidate for the cold dark matter (CDM) particle.

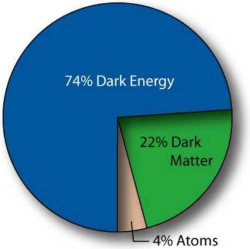
- A CDM candidate must be weakly interacting and massive (WIMP)

Neutralino!

- Usually the lightest neutralino is bino-like
  $\Rightarrow$ too high thermal relic density
- The non-universal gaugino masses changes the neutralino composition, possibly to wino (and higgsino)

Relic Density

1. Early universe: WIMP's in thermal equilibrium
2. Expansion & Cooling $\Rightarrow$ annihilation reduces density
3. Eventually, density is too low to maintain annihilation $\Rightarrow$ Freeze-out
4. From here on, the relic density depends only on expansion rate of the universe



Relic density Ωh^2 observed today can be calculated for each model.
($\Omega = \rho / \rho_c$ with $\rho_c =$ critical density to close the Universe)

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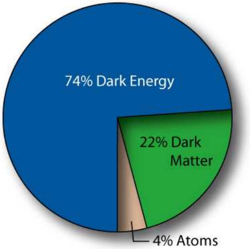

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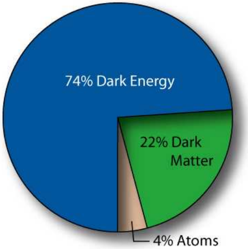

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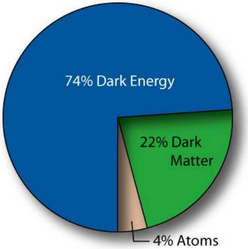

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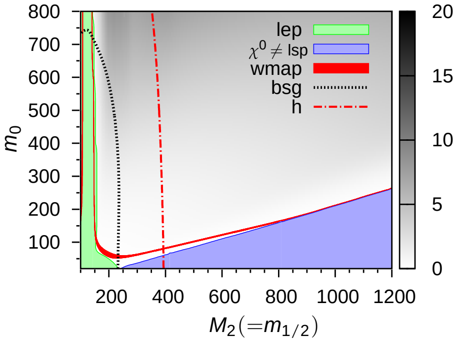

$\tan\beta = 10,\ \mathrm{sgn}(\mu) = +1,\ A_0 = 0$

$$\Omega_{CDM}h^2 = 0.11054^{+0.00976}_{-0.00956}$$

Three year WMAP data

Typical mSUGRA figure showing relic density stripe and collider constraints.

- The preferred relic density area is quite constrained
- Co-annihilation with $\tilde{\tau}$ helps to dilute the relic density
- Often the neutralino RD is overclosing the Universe

Rep 1

χ_1^0 is mainly bino-like

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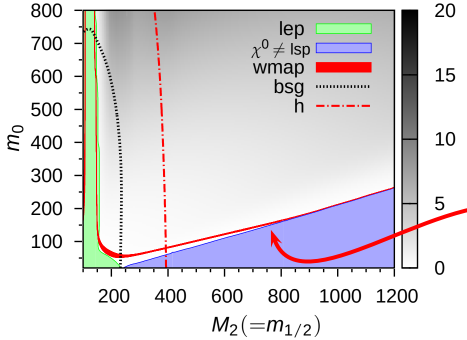

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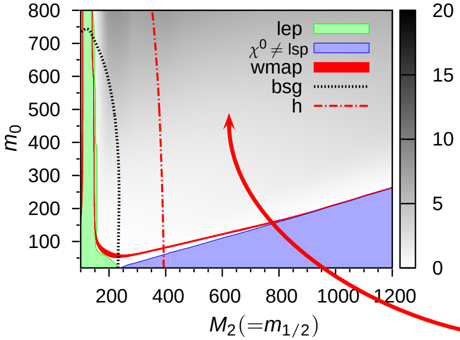

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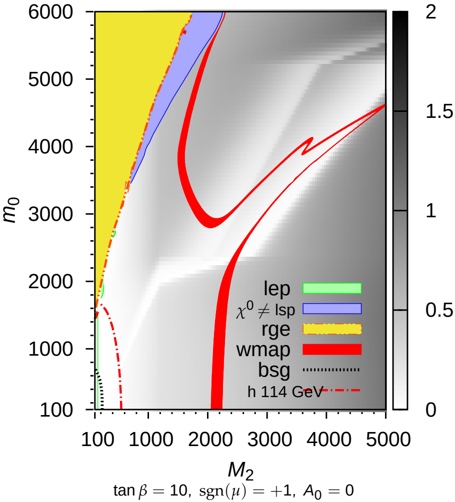

Rep 210 $\rightarrow$ SU(5)$\times$U(1) $\rightarrow$ SM

χ_1^0 is either wino or higgsino

- Allowed area quite wide (200 GeV at the widest!)
- Relic density moderate
- $\chi_1^\pm$ very close to χ_1^0 mass $\Rightarrow$ Minimum at co-annihilation region

Heavy spectrum $\Rightarrow$ might require some fine-tuning (or not, $\mu \sim 1$ TeV)

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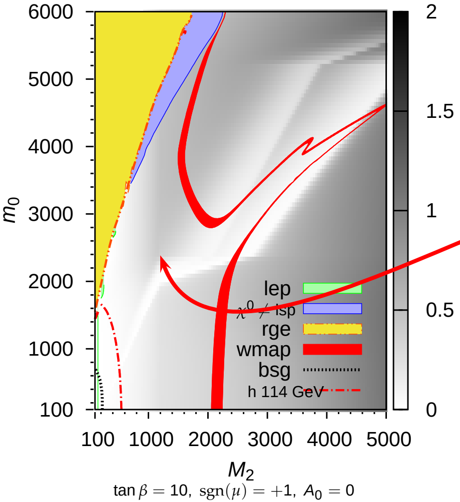

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χ^0_1 is either wino or higgsino

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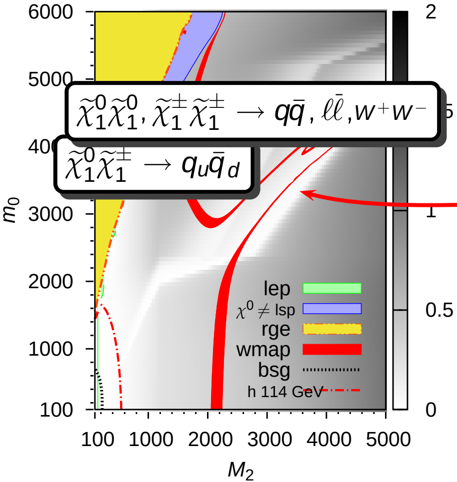

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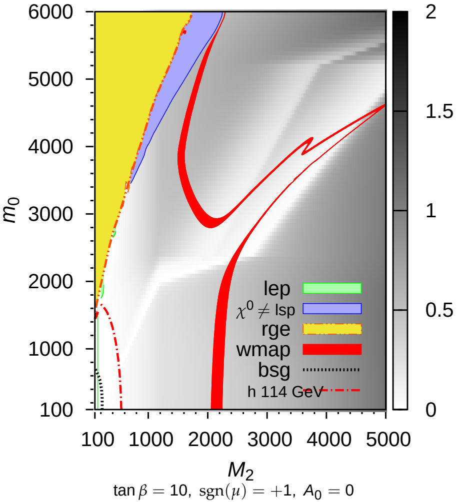

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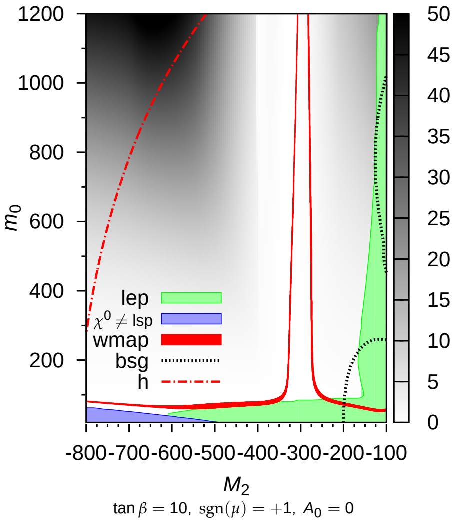
Pure SU(5) GUT: Rep 24 – Large Relic Density



For comparison, representation 24 from pure SU(5)

Rep 24 $(M^{EW}_{1:2:3}$ = -0.07 : -0.43 : 1)

χ^0_1 is bino-like

- Generally relic density very high
- Minimum: Z-peak

Many values of m_0 are allowed, but only for specified m_2

Most attractive of SU(5) representations

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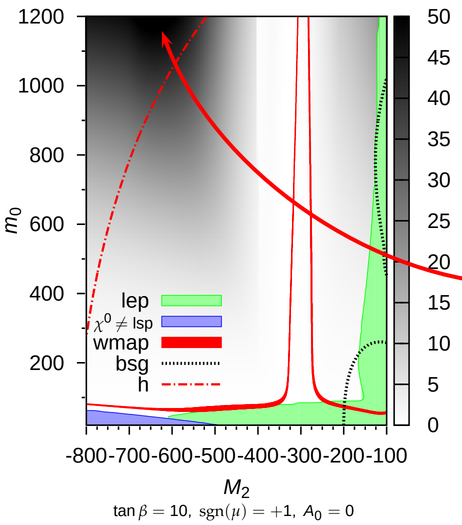

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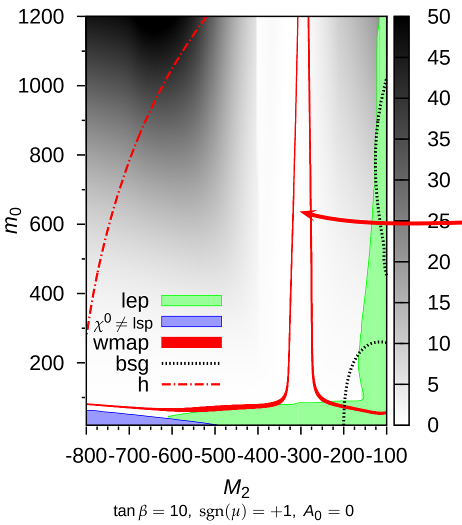

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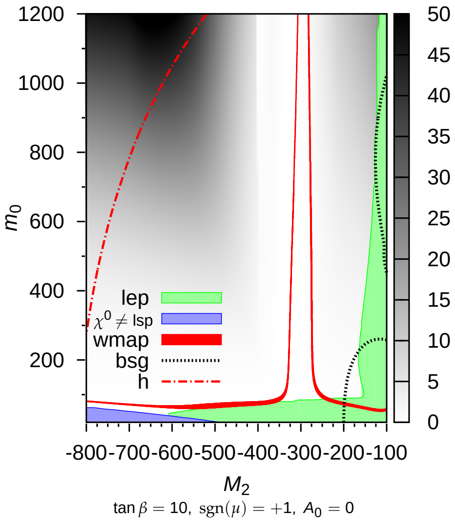

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Other SO(10) Representations – Rep 54

The two chains of the SO(10) 54 dim representation don't give such large relic density areas

- Both 54 dimensional reps give a narrow stripe for the preferred relic density
- Because χ_1^0 is mostly bino in SU(5)$\times$SO(2), the spectrum with preferred RD is quite light and conflicts with collider constraints in some parts of the parameter space (although the higgsino component keeps the overall RD low)
- In SU(4)$\times$SU(2)$\times$SU(2) more higgsino component is involved, and also co-annihilation with chargino is present at some points of parameter space, so the allowed region extends also to heavier spectrum

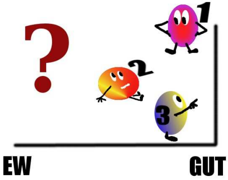
Summary

Specific GUT-models can

1. explain non-universal gaugino masses
2. help to dilute excess relic density

In SO(10) the 210-dimensional representation gives the largest relic density preferred parameter space

- It is important to realize that there is no automatically theoretical preference for the gaugino masses to be unified



Gaugino Non-Universality must be considered as a serious option
– Not a complication, but an opportunity!

end

4 Appendix
- Constraints

Constraints

For the relic density, the WMAP three year limits are used

$$\Omega_{CDM} h^2 = 0.11054^{+0.00976}_{-0.00956}.$$

The curve $m_h = 114$ GeV is depicted in the figures. For the shown parameter region, when otherwise experimentally allowed, Higgs is always heavier than 91 GeV, which is the Higgs mass limit in MSSM for $\tan\beta > 10$ assuming maximal top mixing.

The world average of

$$B(b \to s\gamma) = (355 \pm 24^{+9}_{-10} \pm 3) \times 10^{-6}$$

for the branching fraction for the decay $b \to s\gamma$ was used.