Neutralino dark matter in SO(10) SUSY GUT models

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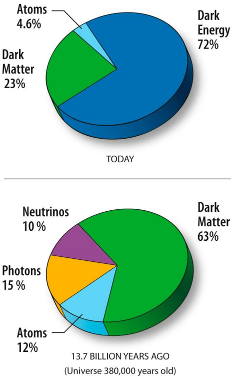
Outline

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



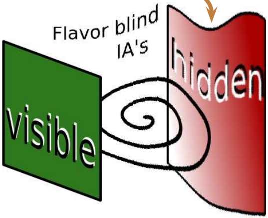
Relic density Ωh^2 observed today can be calculated for each model.
($\Omega = \rho / \rho_c$ with $\rho_c =$ critical density)

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

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. $M_1 = M_2 = M_3 \equiv m_{1/2} \leftarrow$ Universal gaugino mass (for convenience only!)
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 $\tan\beta = \langle H_2^0 \rangle / \langle H_1^0 \rangle$.

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 rEWSB

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

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

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

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

Break SUSY

$\langle F_\Phi \rangle \leftarrow$ actually comprises of the hidden sector singlets and the visible sector fields Φ_i associated with the GUT breakdown

Non-singlet – breaks the GUT symmetry

Choice of Representations

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

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

(must be gauge invariant)

The adjoint of SO(10) is **45**. Therefore, $\langle F_\Phi \rangle$ 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** may give non-universal gaugino masses, while the rep **1** only 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

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

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

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

Restrict the talk to the two chosen representations

Ratios of the Gaugino Masses: SO(10)

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

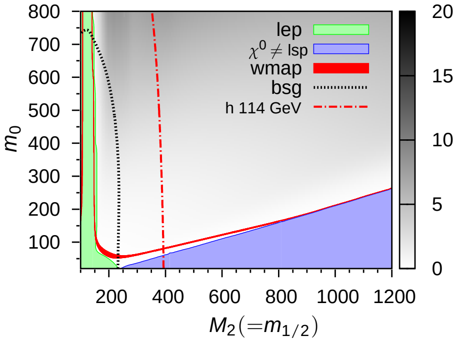
Table: Ratios of the gaugino masses at the GUT and EW scales

F_Φ	H	M_1^{GUT}	M_2^{GUT}	M_3^{GUT}	M_1^{EW}	M_2^{EW}	M_3^{EW}
1	(Singlet = mSUGRA)	1	1	1	0.14	0.29	1
54	$SU(4)\times SU(2)\times SU(2)$	-1	-1.5	1	-0.15	-0.44	1
210	$SU(5)\times U(1)$	-96/25	1	1	-0.56	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

SO(10): Rep 1 = mSUGRA



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

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

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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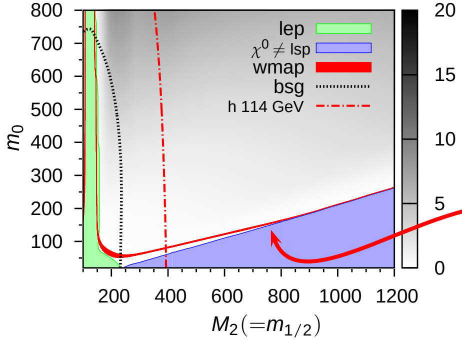

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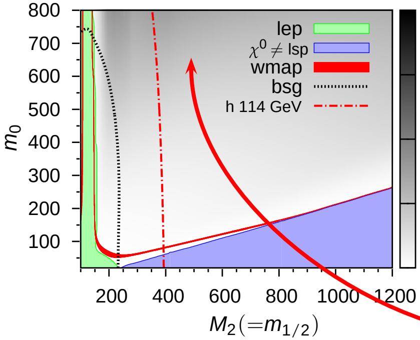

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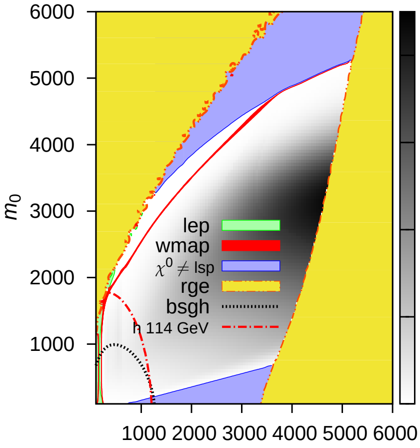
SO(10): Rep 54 – Pati–Salam



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Rep 54 $\rightarrow$ SU(4)$\times$SU(2)$\times$SU(2)

χ_1^0 tends to be bino

- Narrow stripe as usual with binos
- Some 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

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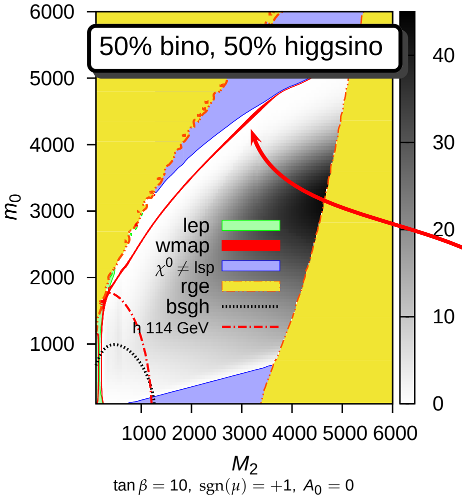

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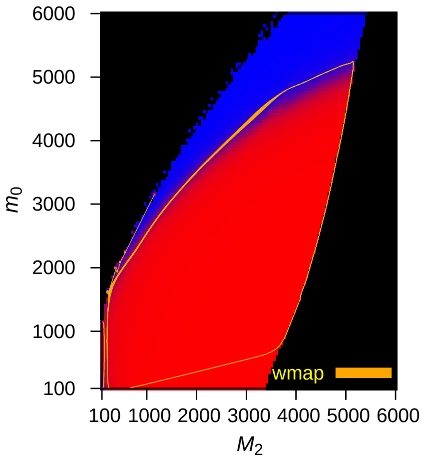

Bino- and higgsino components of $\tilde{\chi}_1^0$

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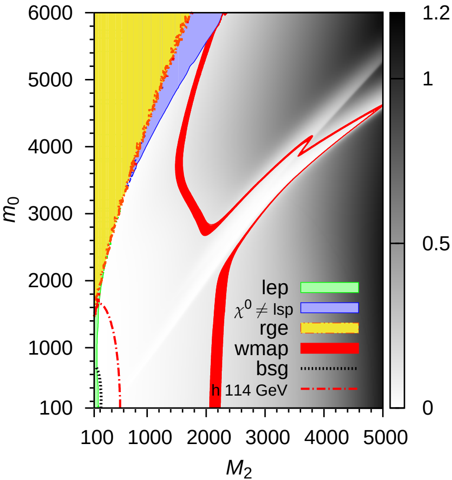
SO(10): Rep 210 – Wide Stripes



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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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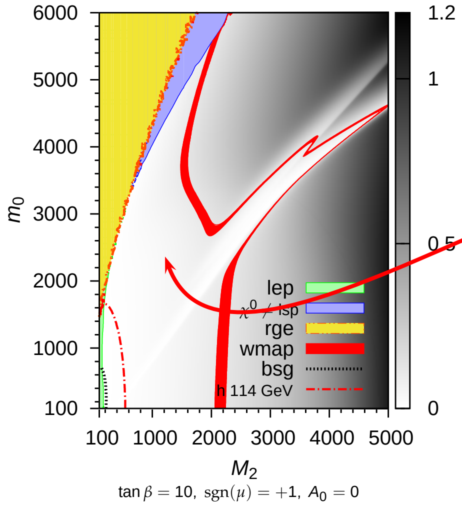

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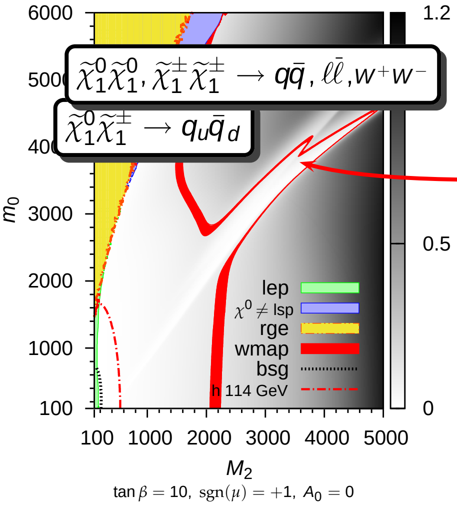

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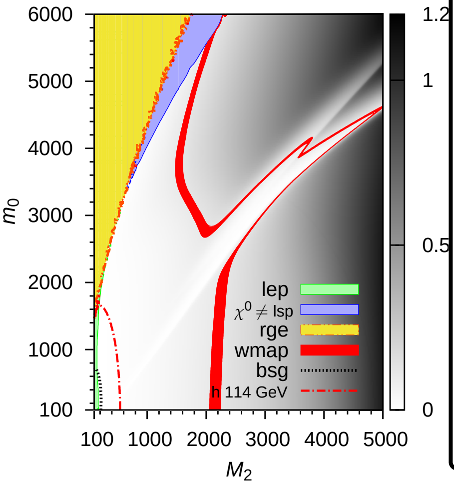

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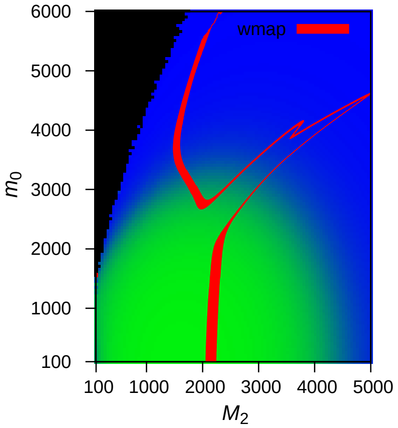


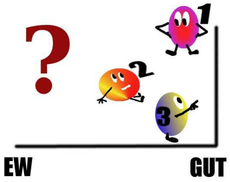
Wino- and higgsino components of $\tilde{\chi}_1^0$

Summary

Specific GUT-models can

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

The nature of the lightest neutralino changes significantly with the representation.



- 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.