Asymmetric Dark Matter in SUSY

Oscar Vives
Marco Ardu and Daniel Queiroz (WIP)

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IFIC INSTITUT DE FÍSICA CORPUSCULAR
CSIC
VNIVERSITAT DE VALÈNCIA

EXCELENCIA SEVERO OCHOA
GENERALITAT VALENCIANA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
UNIÓN EUROPEA
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- This requires a new dark sector, new dark interactions, new portal interaction and a new conserved quantum number.
- But . . . We already have all this in SUSY!!!

- Assume a SUSY spectrum with gravitino as LSP and stau as NLSP.
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Only the asymmetry (would) remains!!

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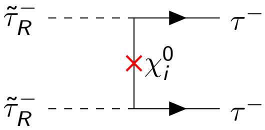

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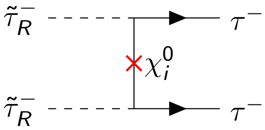

- $\tilde{\tau}_R^- \tilde{\tau}_R^- \to \tau_R^- \tau_R^-$ transfers stau asymmetry to SM fermions!!

- Decoupling at

$$z_b = \frac{m_{\tilde{\tau}}}{T_b} \approx 23 + \ln\left[\frac{m_{\tilde{\tau}}}{\mathrm{TeV}} \frac{(10\mathrm{TeV})^2}{M_{\tilde{B}}^2}\right] + 2\ln\left[\frac{M_{\tilde{B}_M}}{M_{\tilde{B}_D}}\right]$$

- And then, asymmetry

$$\frac{Y_{\tilde{\tau}} - \overline{Y_{\tilde{\tau}}}}{Y_\tau - \overline{Y_\tau}} \approx \frac{6\sqrt{\pi/2}\ z_b{}^{3/2} e^{-z_b}}{\pi^2} \simeq 10^{-10}$$

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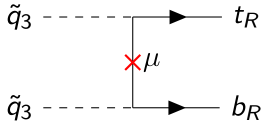

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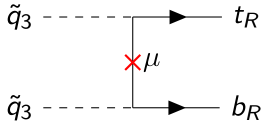

- Exact R-symmetry needed to protect the relation between baryon asymmetry and DM abundance.
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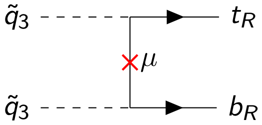

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$\Rightarrow$ Softly broken R-symmetry

Minimal R-symmetric Supersymmetric Standard Model (MRSSM)

- New adjoint chiral superfields: hypercharge singlet(s), weak triplet, color octet to get DIRAC gaugino masses.
- Additional scalar doublets $\hat{R}_d$ and $\hat{R}_u$ with R-charge 2 for R-symmetric Higgs masses.
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\begin{aligned}
W_{SBR} = {} & Y_u\, \hat{u}\, \hat{q}\, \hat{H}_u - Y_d\, \hat{d}\, \hat{q}\, \hat{H}_d - Y_e\, \hat{e}\, \hat{l}\, \hat{H}_d + \mu_D\, \hat{R}_d\, \hat{H}_d + \mu_U\, \hat{R}_u\, \hat{H}_u + \\
& + \lambda_D\, \hat{S}\, \hat{R}_d\, \hat{H}_d + \lambda_U\, \hat{S}\, \hat{R}_u\, \hat{H}_u + \Lambda_D\, \hat{R}_d\, \hat{T}\, \hat{H}_d + \Lambda_U\, \hat{R}_u\, \hat{T}\, \hat{H}_u + \\
& + \mu_S\, \hat{S}_1\, \hat{S}_2 + \kappa\, \hat{S}_1^3 + \lambda_1\, \hat{H}_u\, \hat{H}_d\, \hat{S}_1
\end{aligned}
$$

Field	Gen.	R	$(U(1)_Y, SU(2)_L, SU(3)_C)$
$\hat{q}$	3	1	$(\frac{1}{6}, 2, 3)$
$\hat{l}$	3	1	$(-\frac{1}{2}, 2, 1)$
$\hat{H}_d$	1	0	$(-\frac{1}{2}, 2, 1)$
$\hat{H}_u$	1	0	$(\frac{1}{2}, 2, 1)$
$\hat{d}$	3	1	$(\frac{1}{3}, 1, \overline{3})$
$\hat{u}$	3	1	$(-\frac{2}{3}, 1, \overline{3})$
$\hat{e}$	3	1	$(1, 1, 1)$
$\hat{S}$	1	0	$(0, 1, 1)$
$\hat{T}$	1	0	$(0, 3, 1)$
$\hat{O}$	1	0	$(0, 1, 8)$
$\hat{R}_d$	1	2	$(\frac{1}{2}, 2, 1)$
$\hat{R}_u$	1	2	$(-\frac{1}{2}, 2, 1)$
$\hat{S}_1$	1	2	$(0, 1, 1)$
$\hat{S}_2$	1	0	$(0, 1, 1)$

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- SUSY soft-breaking preserve R-symmetry (except B_κ),

$$-L_{soft} = \Big(\frac{1}{2}B_S S^2 + \frac{1}{2}B_T T^2 + \frac{1}{2}B_{S_1} S_1^2 + \frac{1}{2}B_{S_2} S_2^2 + B_{S_1 S_2} S_1 S_2 + \\ + \frac{1}{2}B_O O_\alpha O_\alpha + \frac{1}{3}B_\kappa S_1^3 + \text{h.c.}\Big) + m_S^2|S|^2 + m_{S_1}^2|S_1|^2 + \\ + m_{S_2}^2|S_2|^2 + m_t^2|T|^2 + m_O^2|O|^2 + B_\mu \; H_u H_d + B_d \; R_d H_d + \\ + B_u \; R_u H_u + m_{R_d}^2|R_d|^2 + m_{R_u}^2|R_u|^2 + B_\kappa \; S_1^3$$

- And Dirac gaugino masses,

$$-L_{Dirac} = M_D^B \tilde{B}\tilde{S} + M_D^{S_2} \tilde{B}\tilde{S}_2 + M_D^O \tilde{G}_\alpha \tilde{O}_\alpha + M_D^W \; \tilde{T}_i \tilde{W}_i$$

- with this Lagrangian ...

- Above the SUSY scale, chemical potentials determined by equilibrium conditions and conserved quantum numbers.
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- With Dirac masses, gauginos can have a non-vanishing chemical potential, μ_λ.
- R-symmetry breaking couplings $\rightarrow \mu_{S_1} = 0$.
- Yukawa, gaugino, trilinear couplings, superpotential masses, sphaleron interactions and hypercharge conservation fix $\mu_\lambda = 0$ and all the chemical potential in terms of three initial asymmetries, Y_{Δ_e}, Y_{Δ_μ}, Y_{Δ_τ}.
- We can relate the stau asymmetry, $Y_{\tilde{\tau}_R}$ with the initial $B/3 - L_\alpha$ (and baryon) asymmetries.

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- R-symmetry breaking only through S_1 interactions.
- Estimate through contribution to bino Majorana mass. (Work in progress...)
- In the presence of κ and B_κ.

$$M_{\tilde{B}} \sim \left(\frac{1}{16\pi^2}\right)^3 g_1^2\ \kappa^*\ B_\kappa\ \lambda_1^2 \sim 10^{-7}\ g_1^2\ \kappa^*\ B_\kappa\ \lambda_1^2 \sim 10^{-11}\ B_\kappa$$

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So... neglecting asymmetry removal ($B_\kappa = 0$)

Only $Y_{\Delta_\tau} \neq 0$

- Baryon asymmetry and stau asymmetry related to Y_{Δ_τ}.

$$Y_B \simeq \frac{21}{70}\, Y_{\Delta_\tau} \qquad\qquad Y_{\tilde{\tau}_R} \simeq -\frac{4}{7}\, Y_B \simeq -0.57\, Y_B$$

$\Longrightarrow$ Gravitino mass: $m_{3/3} \simeq 5 \times m_p\; Y_B / Y_{\tilde{\tau}_R} \simeq 9$ GeV

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- Similar results for $Y_{\Delta_{e,\mu}} \neq 0$.
- $\mathcal{O}(1)$ differences for other NLSP states.
- Larger gravitino masses possible for $B_\kappa \neq 0$ and partial asymmetry removal (less predictivity).

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- Avoid tachionic states.
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Parameter	**Value**	**Parameter**	**Value**
m_{SUSY}	2.2 TeV	λ	-0.3
$\tan\beta$	15	Λ	-0.3
M^D	3 TeV	λ_1	0.003
$M^D_{S_1 S_2}$	3 TeV	M_{DO}	5 TeV
M_{R_d}	35 TeV	B_O	-10^7 TeV^2
M_{R_u}	1 TeV	v_S	0.7 GeV
μ_d	3 TeV	v_T	-0.2 GeV
μ_u	4 TeV	κ	0.001
B_μ	4 TeV^2	B_κ	0 TeV

Spectrum generated with SARAH-4.15.2 and SPheno-4.0.5.

- $m_{\tilde{\tau}_R} = 1.7$ TeV, lifetime to gravitino, $\tau \sim 70$ sec
- Other sleptons $m_{\tilde{l}} \gtrsim 2$ TeV.
- Lightest neutralino $m_{\chi_1^0} = 1.77$ TeV, chargino $m_{\chi_1^+} = 3.77$ TeV.
- Heavy gluinos, squarks, $m_{\tilde{q}} \simeq 3.4$ TeV. $m_{\tilde{g}} = 13.6$ TeV.
- Higgs masses, $m_h = 122$ GeV, $m_H \simeq m_A \simeq m_{H^\pm} \simeq 3$ TeV.
- Exotic colored scalars, $m_{\sigma_O} = 5.8$ TeV, $m_{\phi_O} = 23$ TeV.

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$\Rightarrow$ Asymmetric Dark Matter with $m_{3/2} = 9$ GeV.

Conclusions

- Asymmetric dark matter in SUSY models possible in R-symmetric models.
- Small breaking of R-symmetry necessary to relate DM and baryon asymmetries.
- Breaking in singlet sector preserves stau asymmetry.
- Gravitino mass ~ 10 GeV with no asymmetry removal.
- Other NLSP possible, with different relations to the baryon asymmetry.