Discrete R symmetries and the GNMSSM

Kai Schmidt-Hoberg

UNIVERSITY OF OXFORD

based on

Ross, KSH
arXiv:1108.1284

Lee, Raby, Ratz, Ross, Schieren, KSH, Vaudrevange
arXiv:1009.0905; arXiv:1102.3595

DESY Theory Workshop 2011

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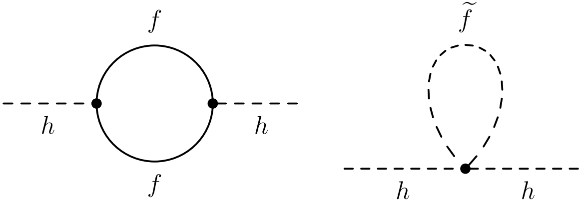

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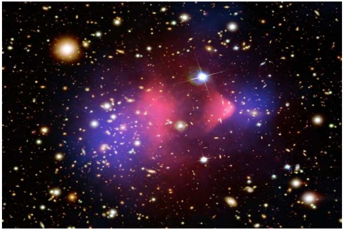

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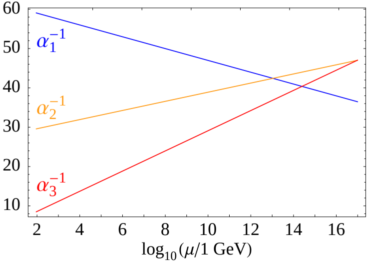

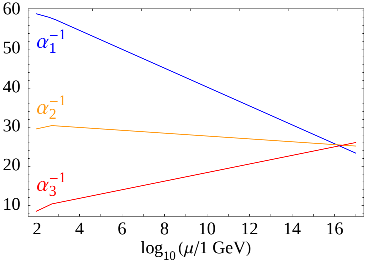

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- Proton decay
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$\Rightarrow$ Supersymmetry alone seems not to be enough!
Additional symmetries? Phenomenological Implications?

Outline

1. Discrete R symmetries for the (N)MSSM

2. The generalised NMSSM

MSSM superpotential

- The gauge-invariant superpotential terms of the MSSM include

$$
\begin{aligned}
\mathcal{W} \;=\;& \mu H_u H_d + \kappa_i L_i H_u \\
& + Y_e^{ij} H_d L_i E_j^c + Y_d^{ij} H_d Q_i D_j^c + Y_u^{ij} H_u Q_i U_j^c \\
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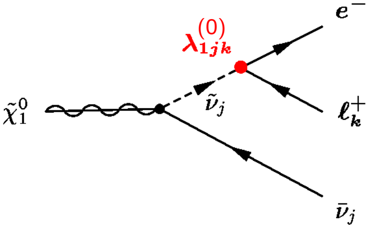

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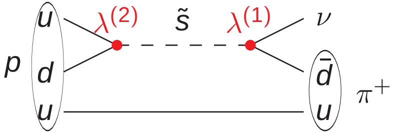

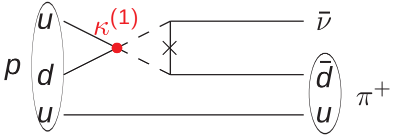

Superpotential and possible symmetries

Possible discrete symmetries:

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- forbidden by $\mathbb{Z}_3$ baryon triality   Ibanez & Ross
- forbidden by $\mathbb{Z}_6$ proton hexality $\cong$ matter parity $\times$ baryon triality

  Dreiner, Luhn & Thormeier

  Is there a symmetry which also forbids the μ term?

Discrete R symmetries

Yes! Ingredients:

1. discrete $\mathbb{Z}_M^R$ symmetries
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It can be shown that the Order M has to divide 24.

Viable symmetries for the MSSM:

M	$q_{\mathbf{10}}$	$q_{\overline{\mathbf{5}}}$	q_{H_u}	q_{H_d}	$q_{H_u}^{\mathrm{sh}}$	$q_{H_d}^{\mathrm{sh}}$	ρ	$A_0^R(\mathrm{MSSM})$
4	1	1	0	0	16	16	1	1
6	5	3	4	0	28	24	0	1
8	1	5	0	4	24	28	1	3
12	5	9	4	0	28	24	3	1
24	5	9	16	12	88	84	9	7

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- Unique $\mathbb{Z}_4^R$ which commutes with SO(10)

The $\mathbb{Z}_4^R$ case

$$\begin{aligned}\mathcal{W} = & \cancel{\mu}\, \underbrace{H_u\, H_d}_{0} + \cancel{\kappa_i}\, \underbrace{L_i\, H_u}_{1} \\ & + Y_e^{ij}\, \underbrace{H_d\, L_i\, E_j^c}_{2} + Y_d^{ij}\, \underbrace{H_d\, Q_i\, D_j^c}_{2} + Y_u^{ij}\, \underbrace{H_u\, Q_i\, U_j^c}_{2} \\ & + \cancel{\lambda_{ijk}^{(0)}}\, \underbrace{L_i L_j E_k^c}_{3} + \cancel{\lambda_{ijk}^{(1)}}\, \underbrace{L_i Q_j D_k^c}_{3} + \cancel{\lambda_{ijk}^{(2)}}\, \underbrace{U_i^c\, D_j^c\, D_k^c}_{3} \\ & + \kappa_{ij}^{(0)}\, \underbrace{H_u\, L_i\, H_u\, L_j}_{2} + \cancel{\kappa_{ijk\ell}^{(1)}}\, \underbrace{Q_i\, Q_j\, Q_k\, L_\ell}_{0} + \cancel{\kappa_{ijk\ell}^{(2)}}\, \underbrace{U_i^c\, U_j^c\, D_k^c\, E_\ell^c}_{0}\end{aligned}$$

The $\mathbb{Z}_4^R$ case

$$\mathcal{W} = \frac{1}{M_\mathrm{P}^2}\underbrace{\langle\mathcal{W}\rangle H_u\,H_d}_{2} + \cancel{\kappa_i}\underbrace{L_i\,H_u}_{1}$$

$$+\,Y_e^{ij}\underbrace{H_d\,L_i\,E_j^c}_{2} + Y_d^{ij}\underbrace{H_d\,Q_i\,D_j^c}_{2} + Y_u^{ij}\underbrace{H_u\,Q_i\,U_j^c}_{2}$$

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$$+\,\kappa_{ij}^{(0)}\underbrace{H_u\,L_i\,H_u\,L_j}_{2} + \frac{1}{M_\mathrm{P}^4}\underbrace{\langle\mathcal{W}\rangle Q_i\,Q_j\,Q_k\,L_\ell}_{2} + \frac{1}{M_\mathrm{P}^4}\underbrace{\langle\mathcal{W}\rangle U_i^c\,U_j^c\,D_k^c\,E_\ell^c}_{2}$$

- need $\langle\mathcal{W}\rangle \sim m_{3/2}M_\mathrm{P}^2$ to cancel cosmological constant
- $\mu \sim \langle\mathcal{W}\rangle/M_\mathrm{P}^2 \sim m_{3/2}$
- proton decay operators suppressed by $\langle\mathcal{W}\rangle/M_\mathrm{P}^4 \sim 10^{-15}/M_\mathrm{P}$
- matter parity exact

NMSSM

NMSSM superpotential:

$$\mathcal{W} \; = \; \mathcal{W}_{\text{MSSM}}^{\mu=0} + \lambda \, S \, H_u \, H_d + \kappa \, S^3$$

- Original motivation: Solve the μ problem: $\mu_{\text{eff}} = \lambda \, \langle S \rangle$
- Standard symmetry for the NMSSM: $\mathbb{Z}_3$

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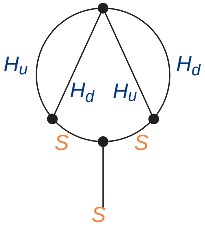
- still dimension five proton decay operators

In addition:

- domain wall problem   Abel, Sarkar & White
- tadpole problem (e.g. from $(H_u H_d)^2$ operator) Abel



The GNMSSM

- MSSM anomaly constraints also apply to the NMSSM
- $\mathbb{Z}_4^R$ and $\mathbb{Z}_8^R$ consistent with cubic term

- divergent tadpoles arise from even (odd) terms in the super (Kähler) potential $\Rightarrow$ Hierarchy problem not reintroduced Abel
- $\langle \mathcal{W} \rangle \sim m_{3/2} M_{\mathrm{P}}^2$; corresponding domain walls inflated away

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$$\begin{aligned} \Delta \mathcal{W}_{\mathbb{Z}_4^R} &= \langle \mathcal{W} \rangle + \langle \mathcal{W} \rangle^2 S + \langle \mathcal{W} \rangle \, S^2 + \langle \mathcal{W} \rangle \, H_u \, H_d \\ &\sim m_{3/2} \, M_\text{P}^2 + m_{3/2}^2 \, S + m_{3/2} \, S^2 + m_{3/2} \, H_u \, H_d \end{aligned}$$

- Phenomenological implications?

The Higgs in the GNMSSM

$$\mathcal{W}_{GNMSSM} = \mathcal{W}_{\text{Yukawa}} + (\mu + \lambda S) H_u H_d + \frac{1}{2}\mu_s S^2 + \frac{1}{3}\kappa S^3$$

Upper bound on the lightest Higgs mass (same as in NMSSM):

$$M_{11}^2 = M_Z^2(\cos^2(2\beta) + \delta \sin^4 \beta) + \lambda^2 v^2 \sin^2(2\beta)$$

- $\delta = \frac{3\,h_t^4}{g^2\,\pi^2} \ln \frac{M_{\tilde{t}}}{m_t}$ to leading order
- Including two-loop effects, $m_h^{\max} \sim 140$ GeV ($\lambda \sim 0.7$) Ellwanger

Difference to NMSSM?

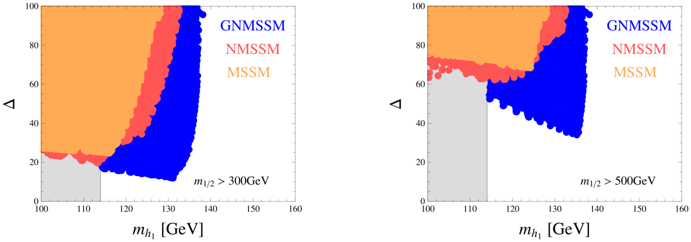
Look at fine-tuning! Standard definition Barbieri, Giudice

$$\Delta \equiv \max \text{Abs}\left[\Delta_p\right], \qquad \Delta_p \equiv \frac{\partial \ln v^2}{\partial \ln p} = \frac{p}{v^2}\frac{\partial v^2}{\partial p}$$

Fine-Tuning in the GNMSSM

A poor man's analysis:

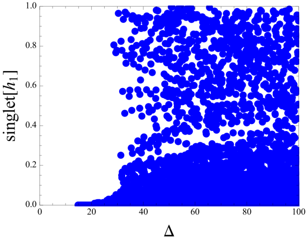
- determine the electroweak parameters of the GNMSSM in terms of the GUT parameters via average one-loop RGE running
- Calculate fine-tuning with respect to GUT parameters
- Scan over all GUT parameters and impose $\mu_{\text{eff}} > 100$ GeV, $m_{1/2} > 300$ (500) GeV

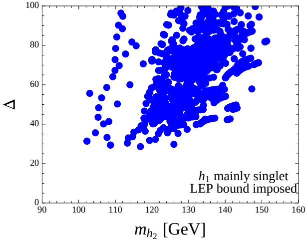


- So what if a Higgs at 141 GeV is found?

The second lightest Higgs

If the lightest Higgs is mainly singlet...

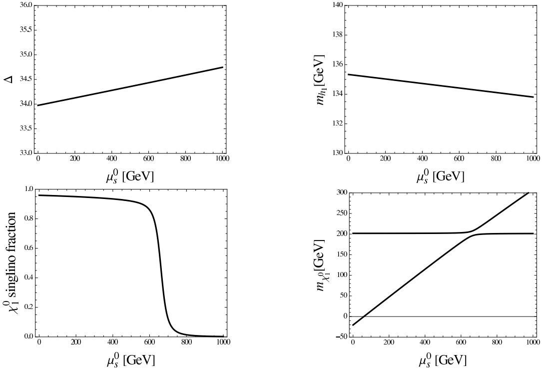




- Mainly MSSM Higgs can be above 150 GeV for $\Delta < 100$
- What about the LSP?

LSP and Higgs decays

Nature of lightest neutralino largely determined by μ_S



Fine-tuning rather insensitive to μ_S, two scenarios:

- μ_S smallish, LSP mainly singlino, Higgs could decay invisibly to $\tilde{s}\,\tilde{s}$
- μ_S largish, standard Higgs decays with rather large Higgs masses

Summary

- Found anomaly free discrete *R* symmetries for the (N)MSSM which
  - solve the μ problem
  - suppress dimension four and five proton decay operators
  - commute with GUTs
  - allow the Weinberg operator
  - solve the domain wall and tadpole problems of the NMSSM
- Interesting NMSSM like structure with additional mass terms emerges
- Minimal fine-tuning for rather large Higgs masses
- Details of the model remain to be studied

If you feel there is not much left to do for the (N)MSSM, try the GNMSSM! - Thank You!