Dark Matter in the GNMSSM

Kai Schmidt-Hoberg

based on

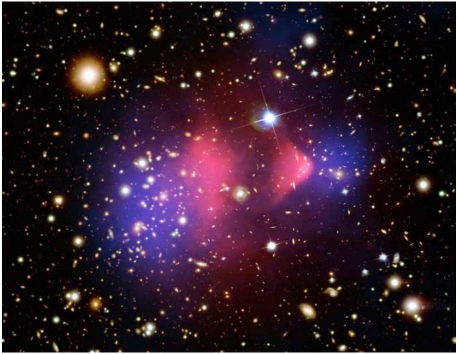
Ross, KSH, Staub
in preparation

Ross, KSH
arXiv:1108.1284

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

Motivation

- What is it? Is it related to the weak scale?



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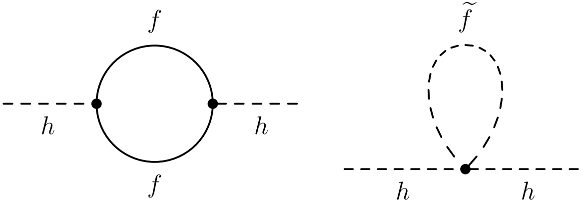

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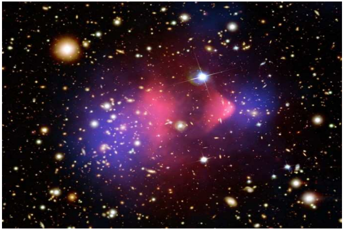

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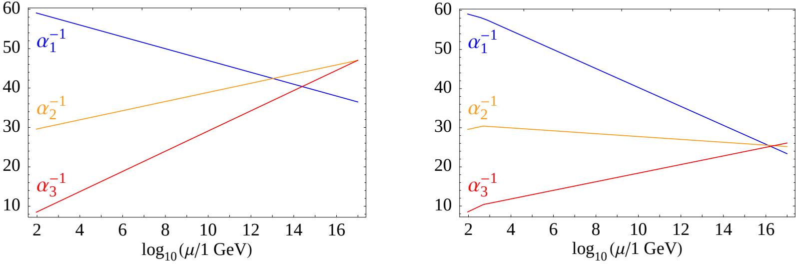

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$\Rightarrow$ Supersymmetry alone seems not to be enough!
Additional symmetries? Phenomenological Implications?

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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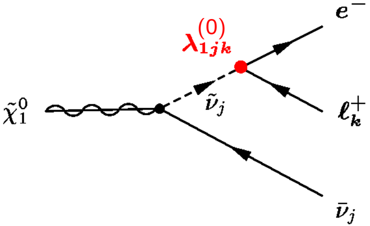

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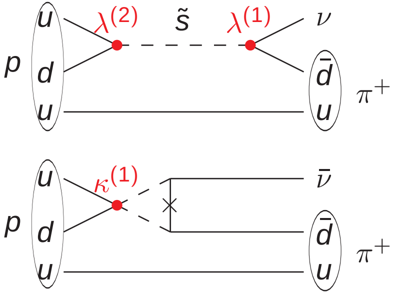

Superpotential and possible symmetries

Possible discrete symmetries:

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

- forbidden by $\mathbb{Z}_2$ matter parity   Farrar & Fayet; Dimopoulos, Raby, Wilczek

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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?

$\mathbb{Z}_N^R$ symmetries

Yes! A $\mathbb{Z}_4^R$ symmetry: Lee, Raby, Ratz, Ross, Schieren, KSH, Vaudrevange

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$$\begin{aligned}\mathcal{W} \;=\; & \frac{1}{M_\mathrm{P}^2}\underbrace{\langle\mathcal{W}\rangle H_u\,H_d}_{2} + \not{\kappa}_i \underbrace{L_i\,H_u}_{1} \\ & + Y_e^{ij}\underbrace{H_d\,L_i\,E_j^c}_{2} + Y_d^{ij}\underbrace{H_d\,Q_i\,D_j^c}_{2} + Y_u^{ij}\underbrace{H_u\,Q_i\,U_j^c}_{2} \\ & + \not{\lambda}_{ijk}^{(0)}\underbrace{L_i L_j E_k^c}_{3} + \not{\lambda}_{ijk}^{(1)}\underbrace{L_i Q_j D_k^c}_{3} + \not{\lambda}_{ijk}^{(2)}\underbrace{U_i^c\,D_j^c\,D_k^c}_{3} \\ & + \kappa_{ij}^{(0)}\underbrace{H_u\,L_i\,H_u\,L_j}_{2} + \frac{1}{M_\mathrm{P}^4}\underbrace{\langle\mathcal{W}\rangle Q_i\,Q_j\,Q_k\,L_\ell}_{2} + \frac{1}{M_\mathrm{P}^4}\underbrace{\langle\mathcal{W}\rangle U_i^c\,U_j^c\,D_k^c\,E_\ell^c}_{2}\end{aligned}$$

- 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 $\Rightarrow$ DM stable!

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: $\mu_{\text{eff}} = \lambda\, \langle S \rangle$
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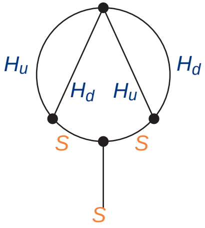
- still dimension five proton decay operators

In addition:

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



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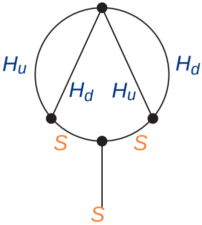

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- $\mathbb{Z}_4^R$ or $\mathbb{Z}_8^R$:
- divergent tadpoles arise from even (odd) terms in the super (Kähler) potential $\Rightarrow$ Hierarchy problem not reintroduced Abel
- $\langle \mathcal{W} \rangle \sim m_{3/2} M_{\text{P}}^2$; corresponding domain walls inflated away

The GNMSSM

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

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

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

- Including two-loop effects, $m_h^{\max} \sim 140$ GeV ($\lambda \sim 0.7$) Ellwanger

Difference to NMSSM?

Look at fine-tuning! Standard definition: Ellis, Enqvist, Nanopoulos, Zwirner

Barbieri, Giudice

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

Fine-Tuning in the GNMSSM

Implemented the GNMSSM into `SPheno` and `micrOMEGAs`

- Results depend on assumption about SUSY breaking sector
- The 'CGNMSSM': $m_0, m_{1/2}, A_0, B_0, \xi_s$ and $\lambda, \kappa, \mu, \mu_s$

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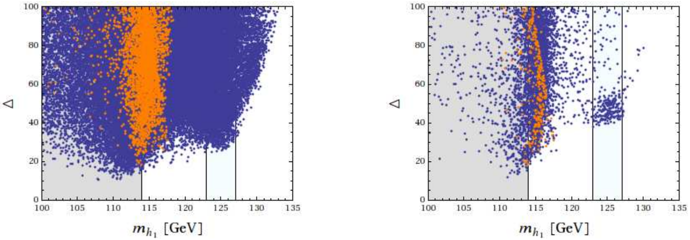
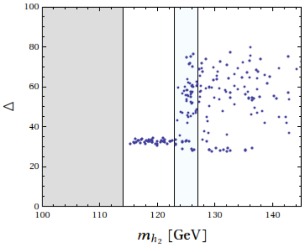


- Rather small fine-tuning for the interesting Higgs region
- In this simplest scenario μ_S is typically rather large, leading to an MSSM like phenomenology...

More general boundary conditions

- More general boundary conditions can be phenomenologically interesting
- second lightest Higgs 'MSSM like'



- light singlets and singlino
- interesting possibilities for Dark Matter

Summary

- GNMSSM based on anomaly free discrete R symmetries 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
- Small fine-tuning for rather large Higgs masses
- Universal SUSY breaking: MSSM-like phenomenology
- 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!