

Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM:

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential &

approach Conclusion

New Structures in Supergravity Mediation

A solution to the fine-tuning problem ?

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1/27



Outline

Supergravity

Breaking
Soni & Weldon
and Soft-Breaking
terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach Supergravity
 Supergravity Breaking
 Soni & Weldon and Soft-Breaking terms

2 Non-Soni-Weldon Solutions Hybrid fields and Hard-breaking terms A simple extension of NMSSM: S2MSSM

3 Radiative corrections induced by Hard-breaking terms
Hard-breaking terms as a solution to the Higgs mass fine-tuning
Coleman-Weinberg eff. potential & Diagrammatic approach

4 Conclusion



Outline

Supergravity

Supergravity Breaking Soni & Weldon and Soft-Breakin terms

Weldon Solution:

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach Supergravity
 Supergravity Breaking
 Soni & Weldon and Soft-Breaking terms

2 Non-Soni-Weldon Solutions Hybrid fields and Hard-breaking terms A simple extension of NMSSM: S2MSSM

3 Radiative corrections induced by Hard-breaking terms
Hard-breaking terms as a solution to the Higgs mass fine-tuning
Coleman-Weinberg eff. potential & Diagrammatic approach

4 Conclusion



Supergravity Breaking

upergravity

Supergravity Breaking

Soni & Weldon and Soft-Breaking terms

Weldon

Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

corrections induced by

Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion

Supergravity



Supergravity Breaking

Soni & Weldon and Soft-Breaking terms

Non-So

Solution

Hybrid fields and Hard-breaking terms

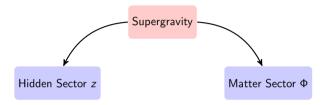
A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaki

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion





Supergravity Breaking

Soni & Weldon and Soft-Breaki terms

Non-So

Solution

Hybrid fields and Hard-breaking

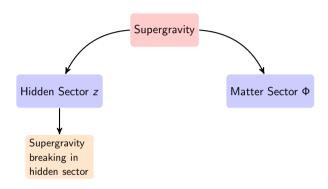
A simple extension of NMSSM: S2MSSM

corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion





Supergravity Breaking

Soni & Weldon and Soft-Breaking terms

Non-So

Solution

Hybrid fields and Hard-breaking

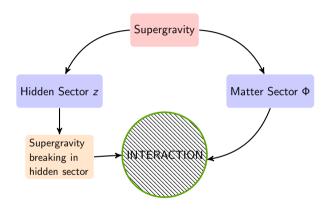
A simple extension of NMSSM: S2MSSM

corrections induced by Hard-breaking

terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion





Supergravity Breaking

Soni & Weldon and Soft-Breaki terms

Non-So

Solution

Hybrid fields ar Hard-breaking terms

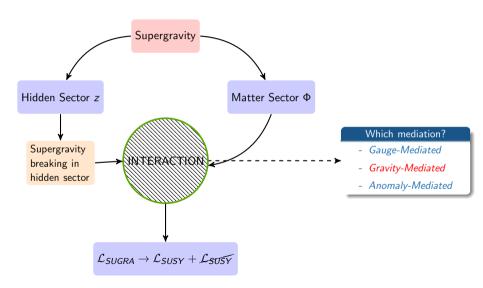
A simple extension of NMSSM: S2MSSM

corrections induced by Hard-breaking terms

terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion





Supergravity Breaking

Soni & Weldon and Soft-Breaki

Non-Sol Weldon

Hybrid fields ar Hard-breaking

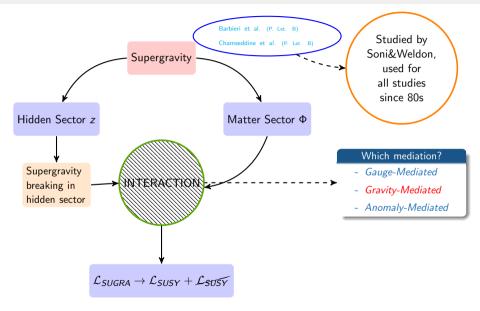
A simple extension of NMSSM:

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion





Supergravity Breaking

Soni & Weldon and Soft-Breaking terms

Weldon Solution

Hybrid fields at Hard-breaking terms

A simple extension of NMSSM:

Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential &

approach Conclusion

Soni & Weldon solutions

Soni & Weldon Phys.Lett. 126B (1983) 215-219 (1983)

Expansion of the fundamental functions of Supergravity as power of $m_{p\ell}$:

- Kähler potential K (describing kinetic terms)
- Superpotential W (describing Yukawa interactions,...)

$$V=\mathrm{e}^{rac{K}{m_{p\ell}^2}}\left(\mathcal{D}_I \mathcal{W} \mathcal{K}^I_{J*} \mathcal{D}^{J*} ar{\mathcal{W}} -rac{3}{m_{p\ell}^2} |\mathcal{W}|^2
ight)$$



Breaking
Soni & Weldon

and Soft-Breaking terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential &

Conclusion

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Requirment

At least one field from Hidden sector with $\langle z \rangle \sim \mathcal{O}(m_{p\ell})$ and $\langle \Phi \rangle \ll m_{p\ell}$ Visible sector fields interactions only present as $m_{p\ell}^{-n}$ with $n \geq 0$



Supergravity Breaking Soni & Weldon

Soni & Weldon and Soft-Breaking terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic

Conclusion

Soni & Weldon solutions

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Breaking
Soni & Weldon

and Soft-Breaking terms

Weldon Solution

Hybrid fields ar Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic

Conclusion

Soni & Weldon solutions

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$$W = m_{p\ell}^2 W_2(z) + m_{p\ell} W_1(z) + W_0(z, \Phi)$$

 $K = m_{p\ell}^2 K_2(z, z^{\dagger}) + m_{p\ell} K_1(z, z^{\dagger}) + K_0(z, z^{\dagger}, \Phi, \Phi^{\dagger})$



Soni & Weldon and Soft-Breaking

Non-Son Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion

Soni & Weldon solutions

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$$\mathcal{L}_{SUGRA} \Rightarrow \mathcal{L}_{SUSY} - V_{soft}$$

$$K = m_{p\ell}^2 K_2(z, z^{\dagger}) + m_{p\ell} K_1(z, z^{\dagger}) + K_0(z, z^{\dagger}, \Phi, \Phi^{\dagger})$$



ergravity

Supergravity Breaking Soni & Weldon

Soni & Weldon and Soft-Breaking terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

corrections induced by Hard-breakir

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic

Conclusion

Soni & Weldon solutions

Standard example : MSSM, NMSSM, ... If we take the NMSSM:

$$W_0 = \lambda(z)\hat{S}\hat{H}_u.\hat{H}_d + \frac{1}{3}\kappa(z)\hat{S}^3 + y_u(z)\hat{Q}.\hat{H}_u\hat{U} - y_d(z)\hat{Q}.\hat{H}_d\hat{D} - y_e(z)\hat{L}.\hat{H}_d\hat{E}$$
$$+ \frac{1}{2}\mu(z)\hat{S}^2 + \xi_F(z)\hat{S}$$
$$V = V_{SUSY} + V_{soft}$$



Supergravity Breaking Soni & Weldon

Soni & Weldon and Soft-Breaking terms

Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extens of NMSSM: S2MSSM

corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential &

Conclusion

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$$V = V_{SUSY} + V_{soft}$$

$$V_{Soft} = \sum_{I} m_{\Phi}^{2} \Phi^{I} \Phi_{I*}^{\dagger} + \left\{ a_{u}Q.H_{u}.U - a_{d}Q.H_{d}.D + a_{e}L.H_{d}.E + A_{\lambda}SH_{u}.H_{d} \right.$$
$$\left. - \frac{1}{2} \sum_{i} M_{i}\lambda_{i}\lambda_{i} + \frac{1}{3}A_{\kappa}S^{3} + \frac{1}{2}\mu'S^{2} + \xi_{S}S + \text{h.c.} \right\}$$



Supergravity Breaking Soni & Weldon and Soft-Breaking

terms Non-Soni-

Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extensi of NMSSM: S2MSSM

corrections induced by Hard-breaking

terms

Hard-breaking

terms as a solution

fine-tuning
Coleman-Weinberg
eff. potential &
Diagrammatic

Conclusion

Soni & Weldon solutions

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Squared Scalar Masses

$$V_{Soft} = \sum_{I} m_{\Phi}^{2} \Phi^{I} \Phi_{I^{*}}^{\dagger} + \left\{ a_{u}Q.H_{u}.U - a_{d}Q.H_{d}.D + a_{e}L.H_{d}.E + A_{\lambda}SH_{u}.H_{d} - \frac{1}{2} \sum_{i} M_{i}\lambda_{i}\lambda_{i} + \frac{1}{3}A_{\kappa}S^{3} + \frac{1}{2}\mu'S^{2} + \xi_{S}S + \text{h.c.} \right\}$$
Gauginos Masses

Trilinear terms

6 / 27



Outline

Supergravity

Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Non-Soni-Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Supergravity Breaking
Soni & Weldon and Soft-Breaking terms

2 Non-Soni-Weldon Solutions Hybrid fields and Hard-breaking terms A simple extension of NMSSM: S2MSSM

3 Radiative corrections induced by Hard-breaking terms
Hard-breaking terms as a solution to the Higgs mass fine-tuning
Coleman-Weinberg eff. potential & Diagrammatic approach

4 Conclusion



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Soni-Weldon: Just the tip of the iceberg?



Supergravity

Supergravity
Breaking
Soni & Weldon
and Soft-Breaking
terms

Non-Soni-Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach



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Find new solutions. One particular involve new type of fields.

Supergravity

Supergravity Breaking Soni & Weldon and Soft-Breaking

Non-Soni-Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach



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Hidden Sector z Coupling with $m_{p\ell}$ in W

Hybrid Field S

Matter field Φ with definition *à la* Soni Weldon

$$W = m_{p\ell} \Big[\hat{W}_0(z) + S^p \mu_p^* \hat{W}_1(z) \Big] + \Xi(\mathcal{U}, \Phi, z)$$

with $\mathcal{U} = \mu^p S^q - \mu^q S^p$

Soni & Weldon

Hybrid fields and Hard-breaking

terms as a solution Coleman-Weinberg eff. potential &



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We will focus on this new solution...

Supergravity
Supergravity

Breaking
Soni & Weldon
and Soft-Breakin
terms

Non-Soni-Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach



Properties of *S* field:

Supergravit

Supergravity Breaking Soni & Weldon and Soft-Breakin

Non-Soni Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breakir terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach



Properties of *S* field:

S Singlet under visible sector gauge group

Supergravity

Supergravity Breaking Soni & Weldon and Soft-Breakin

Non-Soni Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic

approach



Supergravity

Soni & Weldon and Soft-Breakin terms

Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM:

corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic

Conclusion

Non-Soni-Weldon-Solutions (NSWS)

Properties of *S* field:

- S Singlet under visible sector gauge group $W = m_{p\ell} \Big[\hat{W}_0(z) + S^p \mu_p^* \hat{W}_1(z) \Big] + \Xi(\mathcal{U}, \Phi, z)$
- Direct coupling Matter fields Φ / Hybrid fields S:
 - Through field $\mathcal{U}=\mu^1 S^2 \mu^2 S^1$ (Need at least 2 S) with μ^p also present in W



Soni & Weldon and Soft-Breaking terms

Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extensio of NMSSM:

corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic

Conclusion

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Supergravity Breaking

Soni & Weldon and Soft-Breaking terms

Non-Soni-Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach

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- Will lead to **Hard breaking terms** with the following properties:
 - M-suppressed with energy scale $M \ll m_{p\ell}$
 - Controlled by Gravitino mass $m_{\frac{3}{2}} = \frac{M^2}{m_{p\ell}} e^{\frac{1}{2}\left\langle z\right\rangle^2} (m_{\frac{3}{2}}^{NSW} < m_{\frac{3}{2}}^{SW})$
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- NMSSM+K(≥ 1) singlets-like with significant differences

Supergravity

Supergravity Breaking

Soni & Weldon and Soft-Breaking terms

Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach



SWS

upergravit

Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Non-Soni-Weldon

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential & Diagrammatic approach

Conclusion





Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Non-Soni-Weldon

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by

Hard-breaking terms as a solution to the Higgs mass

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion





S2MSSM

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pergravity

Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Non-Soni-Weldon

Hybrid fields and

terms
A simple extensi

A simple extension of NMSSM: S2MSSM

corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion



S2MSSM

ergravity

Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Non-Soni-Weldon

Hybrid fields and Hard-breaking

terms
A simple extension of NMSSM:

S2MSSM Radiative corrections

Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion







Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Non-Soni-Weldon

Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by

Hard-breaking terms as a solution to the Higgs mass

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion







Supergravity Breaking Soni & Weldon and Soft-Breaking

Non-Soni-Weldon

Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

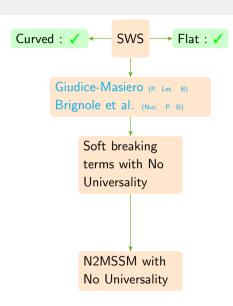
Radiative corrections induced by

Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential & Diagrammatic approach

Conclusion





Supergravity
Breaking
Soni & Weldon
and Soft-Breakin

Non-Soni-Weldon

terms

Hybrid fields

Hard-breaking terms

A simple extension of NMSSM: S2MSSM

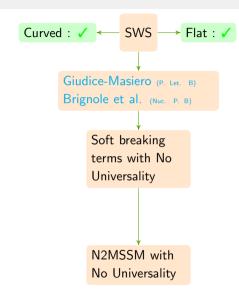
Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential & Diagrammatic approach

Conclusion

NSWS





S2MSSM

Flat : ✓ ← NSWS

Supergravity

Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Non-Soni-Weldon

Solutions

Hybrid fields and Hard-breaking terms

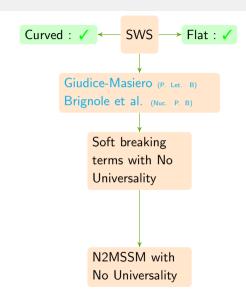
A simple extension of NMSSM: S2MSSM

Radiative corrections induced by

Hard-breaking terms as a solution to the Higgs mass

fine-tuning Coleman-Weinberg eff. potential & Diagrammatic

approach Conclusion





Supergravity

Supergravity Breaking Soni & Weldon

and Soft-Breal terms

Non-Soni-Weldon

Hybrid fields and Hard-breaking terms

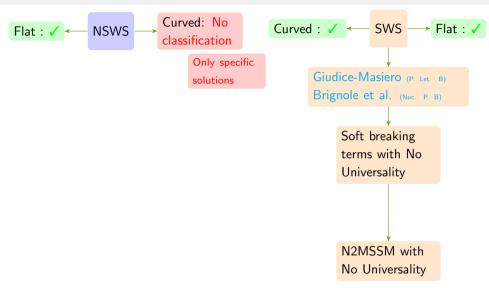
A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential & Diagrammatic approach

Conclusion



SWS : Soni-Weldon solutions NSW : Non-Soni-Weldon solutions



Supergravity

Supergravity Breaking Soni & Weldon

and Soft-Break

Weldon

Solutions

Hard-breaking terms

A simple extension of NMSSM: S2MSSM

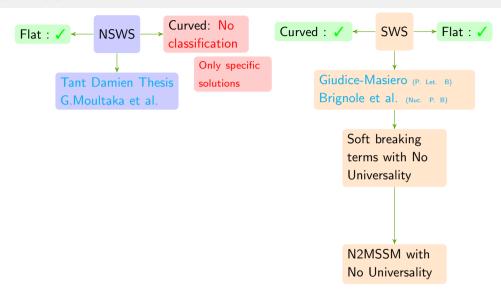
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Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential & Diagrammatic approach

Conclusion

S2MSSM



SWS : Soni-Weldon solutions NSW : Non-Soni-Weldon solutions



Supergravity

Supergravity Breaking Soni & Weldon

and Soft-Break terms

Non-Sor Weldon

Solution

Hybrid fields ar Hard-breaking terms

A simple extension of NMSSM: S2MSSM

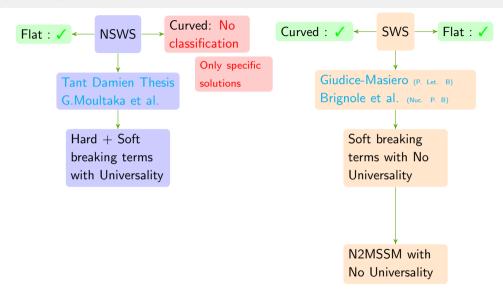
Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential & Diagrammatic approach

Conclusion

S2MSSM



SWS : Soni-Weldon solutions NSW : Non-Soni-Weldon solutions

Hybrid fields and Hard-breaking

A simple extension of NMSSM: S2MSSM

terms as a solution Coleman-Weinberg eff. potential &

approach

SWS: Soni-Weldon solutions

S2MSSM

Curved: No. Curved : ✓ ← Flat : 🗸 SWS Flat : ✓ ← **NSWS** classification Only specific Giudice-Masiero (P. Let. B) Tant Damien Thesis solutions Brignole et al. (Nuc. P. B) G.Moultaka et al. Hard + Soft Soft breaking Can we create a Non-Universal model breaking terms terms with No à la Brignole et al. and Giudice & with Universality Universality Masiero for NSWS ? S2MSSM with N2MSSM with Universality No Universality

NSW: Non-Soni-Weldon solutions

10 / 27

Terascale

C

Supergravity Breaking Soni & Weldon

Non-Son Weldon

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breakin terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion

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SWS : Soni-Weldon solutions

S2MSSM

NSW: Non-Soni-Weldon solutions

Terascale

Supergravity

Soni & Weldon and Soft-Break terms

Weldon

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breakin

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

Coleman-Weinbo eff. potential & Diagrammatic approach

Conclusion

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S2MSSM

NSW: Non-Soni-Weldon solutions



Supergravity

Supergravity Breaking Soni & Weldon

Non-Son Weldon

Hybrid fields and Hard-breaking

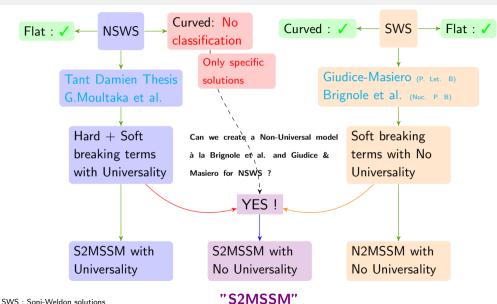
A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential & Diagrammatic approach

Conclusion



NSW : Non-Soni-Weldon solutions



Hybrid fields and Hard-breaking

A simple extension of NMSSM: S2MSSM

terms as a solution Coleman-Weinberg eff. potential &

S2MSSM

A simplest NSW model: **S2MSSM**

Fields content:

• Matter Sector Φ . S^1 and S^2

•
$$\mathcal{U} = \mu^1 S^2 - \mu^2 S^1$$

Hidden Sector z

N2MSSM-like (NMSSM + 1 gauge singlet) with significant differences!

$$W = m_{p\ell} \Big[\hat{W}_0(z) + S^p \mu_p^* \hat{W}_1(z) \Big] + \Xi(\mathcal{U}, \Phi, z)$$
 $K = m_{p\ell}^2 \hat{K}(z, z^\dagger) + S^p S_p^\dagger + \sum_I \Lambda_I(z, z^\dagger) \Phi_I^\dagger \Phi^I$

with:

$$\Xi(\mathcal{U}, \Phi, z) = \lambda(z)\mathcal{U}\hat{H}_{u}.\hat{H}_{d} + \kappa(z)\mathcal{U}^{3} + y_{u}(z)\hat{Q}.\hat{H}_{u}\hat{U} - y_{d}(z)\hat{Q}.\hat{H}_{d}\hat{D} - y_{e}(z)\hat{L}.\hat{H}_{d}\hat{E}$$



Supergravity
Supergravity
Breaking
Soni & Weldon
and Soft-Breaking
terms

Non-Soni-Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential &

Conclusion

SUPERGRAVITY BREAKING IN HIDDEN SECTOR

12 / 27





A simple extension of NMSSM: S2MSSM

terms as a solution Coleman-Weinberg eff. potential &

approach

SUPERGRAVITY BREAKING IN HIDDEN SECTOR

$$V_{soft} = m_{\phi_I}^2 \phi_I^{\dagger} \phi^I + (m_S^2)^q{}_p S_q^{\dagger} S^p + \left\{ \frac{1}{6} \hat{\kappa} \mathcal{U}^2 \langle \mathcal{U} \rangle + \frac{1}{6} A_{\kappa} \mathcal{U}^3 + A' \mathcal{U} H_u . H_d + C_p S^p + a_u Q . H_u U - a_e L . H_d E - a_d Q . H_d D + \lambda' \langle \mathcal{U} \rangle H_U . H_D + \text{h.c.} \right\}$$



Supergravit

Supergravity

Soni & Weldon and Soft-Breaki terms

Weldon

Hybrid fields ar Hard-breaking

A simple extension of NMSSM: S2MSSM

Radiativ

induced by
Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion

SUPERGRAVITY BREAKING IN HIDDEN SECTOR

$$\begin{split} V_{soft} &= m_{\phi_{I}}^{2} \phi_{I}^{\dagger} \phi^{I} + (m_{S}^{2})^{q}_{p} S_{q}^{\dagger} S^{p} + \left\{ \frac{1}{6} \hat{\kappa} \mathcal{U}^{2} \langle \mathcal{U} \rangle + \frac{1}{6} A_{\kappa} \mathcal{U}^{3} + A' \mathcal{U} H_{u}. H_{d} \right. \\ &\quad + C_{p} S^{p} + a_{u} Q. H_{u} \mathcal{U} - a_{e} L. H_{d} E - a_{d} Q. H_{d} D + \lambda' \langle \mathcal{U} \rangle H_{U}. H_{D} + \text{h.c.} \right\} \\ V_{hard} &= \frac{\left| m_{\frac{3}{2}} \right|^{2}}{M^{2}} \left(Q_{Ip}{}^{q} \phi_{I}^{\dagger} \phi^{I} S_{q}^{\dagger} S^{p} + Q_{r}^{\prime t} S_{p}^{\dagger} S^{p} S_{t}^{\dagger} S^{r} \right) \\ &\quad + \left\{ \frac{\left| m_{\frac{3}{2}} \right|^{2}}{M} \left(T_{Ip} \phi_{I}^{\dagger} \phi^{I} S^{p} + T' S_{p}^{\dagger} S^{p} S^{r} \right) \right. \\ &\quad + \frac{m_{\frac{3}{2}}^{\dagger}}{M^{\dagger}} \left(E^{q} \langle \mathcal{U} \rangle H_{u}. H_{d} + D_{u}^{q} Q. H_{u} \mathcal{U} - D_{e}^{q} L. H_{d} E - D_{d}^{q} Q. H_{d} D + \frac{1}{6} \hat{\kappa}^{q} \mathcal{U}^{3} + \right. \\ &\quad + \frac{1}{2} \hat{\kappa} a^{q} \mathcal{U}^{2} (\mathcal{U} + \langle \mathcal{U} \rangle) + D^{q} \mathcal{U} H_{u}. H_{d} + \hat{\lambda} \langle \mathcal{U} \rangle a^{q} H_{u}. H_{d} \right) S_{q}^{\dagger} + \text{h.c.} \right\} \end{split}$$



Supergravit

Supergravity
Breaking
Soni & Weldon
and Soft-Breaking

Non-Soni-Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential &

approach



Supergravit

Supergravity Breaking Soni & Weldon and Soft-Breakin

Weldon Solution

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breakin terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential &

approach

Differences with N2MSSM (NMSSM+1 singlet):

• S coupling parameters (λ, κ) not only doubled but correlated!



Supergravit

Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic

approach

- S coupling parameters (λ, κ) not only doubled but correlated!
- EW symmetry breaking conditions



Supergravit

Supergravity Breaking Soni & Weldon and Soft-Breaking

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion

- S coupling parameters (λ, κ) not only doubled but correlated!
- EW symmetry breaking conditions
- Mass spectrum



Supergravit

Supergravity Breaking Soni & Weldon and Soft-Breaking terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion

- S coupling parameters (λ, κ) not only doubled but correlated!
- EW symmetry breaking conditions
- Mass spectrum
- RGEs (effects from hard-breaking terms)



Outline

Supergravity Breaking

Supergravity
Breaking
Soni & Weldon
and Soft-Breakin
terms

Weldon Solutions

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

Coleman-Weinbe eff. potential & Diagrammatic approach 1 Supergravity
Supergravity Breaking
Soni & Weldon and Soft-Breaking terms

2 Non-Soni-Weldon Solutions Hybrid fields and Hard-breaking terms A simple extension of NMSSM: S2MSSM

3 Radiative corrections induced by Hard-breaking terms
Hard-breaking terms as a solution to the Higgs mass fine-tuning
Coleman-Weinberg eff. potential & Diagrammatic approach

4 Conclusion

Conclusion

Fine-tuning and V_{Hard}

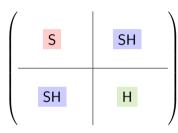


Breaking Soni & Weldon

A simple extension of NMSSM:

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential &



Constraints : $\langle V \rangle \approx 0, \langle \partial V \rangle = 0, \langle S \rangle \ll m_{p\ell}$

S: Singlet submatrix

H: Higgs submatrix



Supergravity

Supergravity

Soni & Weldon and Soft-Breaking terms

Non-Son Weldon

Hybrid fields an Hard-breaking

A simple extension of NMSSM:

Radiati

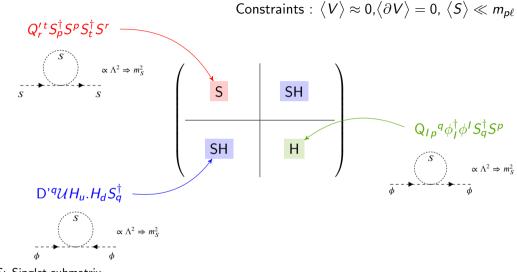
Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusio

Fine-tuning and V_{Hard}



- S: Singlet submatrix
- H: Higgs submatrix
- SH: Higgs / Singlet mixing (off-diagonal)



Supergravity

Supergravity Breaking

Soni & Weldon and Soft-Breakin terms

Weldon

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM:

Radiative correction induced I

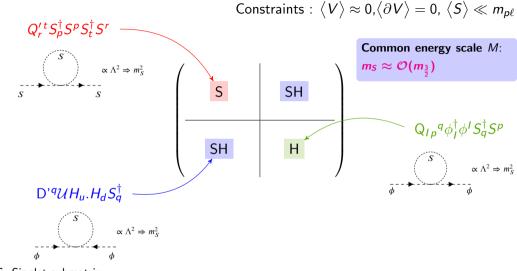
Hard-breaking

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Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusio

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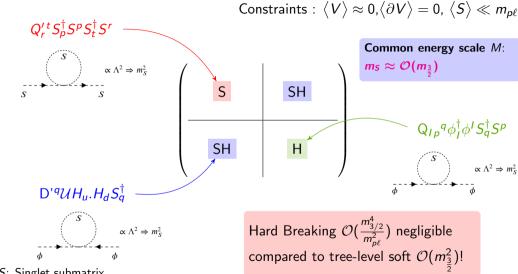


A simple extension of NMSSM:

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential &

Fine-tuning and V_{Hard}



S: Singlet submatrix

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15 / 27

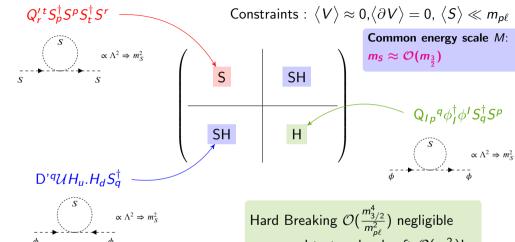


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Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential &

Fine-tuning and V_{Hard}



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compared to tree-level soft $\mathcal{O}(m_3^2)!$



A simple extension of NMSSM:

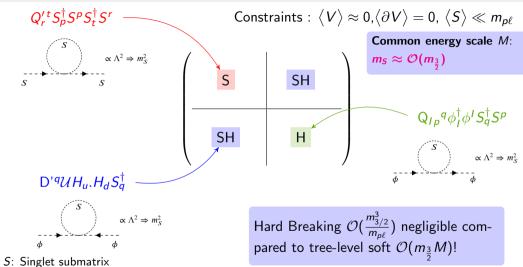
Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential &

H: Higgs submatrix

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Fine-tuning and V_{Hard}





Supergravity

Breaking
Soni & Weldon
and Soft-Breaking

Non-So

Solution

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

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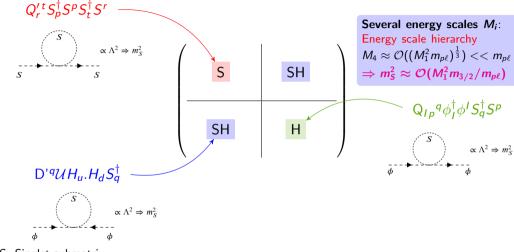
induced by Hard-breaking

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion

Fine-tuning and V_{Hard}



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Supergravity

Breaking
Soni & Weldon
and Soft-Breaking

Non-Sor Weldon

Hybrid fields a Hard-breaking

A simple extension of NMSSM: S2MSSM

Radiat

induced by Hard-breaking

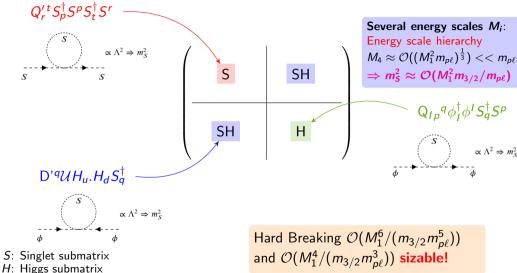
Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion

Fine-tuning and V_{Hard}

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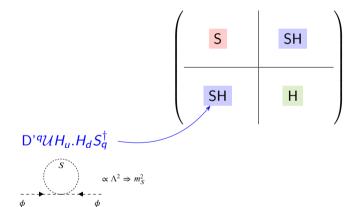
A simple extension

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential &

Seesaw mechanism and V_{Hard}

Let's take a look on Off-diagonal corrections...



S: Singlet submatrix

H: Higgs submatrix

SH: Higgs / Singlet mixing (off-diagonal)

approach Conclusion



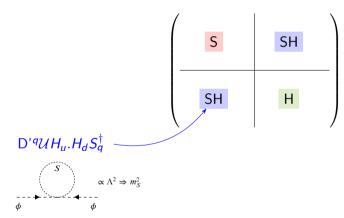
Soni & Weldon

A simple extension

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & approach

Let's take a look on Off-diagonal corrections...



If $SH \ll H, S$: $D'^q \mathcal{U} H_u . H_d S_a^{\dagger}$ (generated by λ in Ξ) can push Tree-Level mass:

S: Singlet submatrix

H: Higgs submatrix



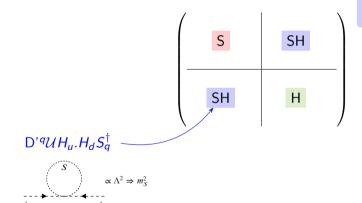
Soni & Weldon

A simple extension

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & approach

Let's take a look on Off-diagonal corrections...



If $SH \ll H$. S: $D'^q \mathcal{U} H_u . H_d S_a^{\dagger}$ (generated by λ in Ξ) can push Tree-Level mass:

$$m_H = m_H^{TL} - (\text{Corr.})^2$$

 $m_S = m_S^{TL} + (\text{Corr.})^2$

S: Singlet submatrix

H: Higgs submatrix



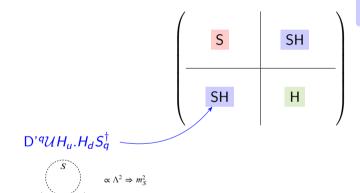
Soni & Weldon

A simple extension

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential &

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$$m_H = m_H^{TL} - (\text{Corr.})^2$$

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 $m_H = m_H^{TL} + (\text{Corr.})^2$
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Supergravity

Supergravity

Soni & Weldon and Soft-Breakin terms

Weldon

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

corrections induced by Hard-breaking terms

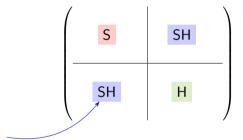
Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

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 $D'^q \mathcal{U} H_{\mu} H_d S_a^{\dagger}$

Let's take a look on Off-diagonal corrections...



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 $D'^q \mathcal{U} H_u. H_d S_q^{\dagger}$ can induce a see-saw mechanism and **possibly push upwards** m_h to **125** $GeV \rightarrow$ Reduce the fine-tuning?



Soni & Weldon

Hybrid fields and

A simple extension

Hard-breaking terms as a solution to the Higgs mass fine-tuning

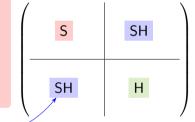
Coleman-Weinberg eff. potential &

Let's take a look on Off-diagonal corrections...

Example:

- $m_{3/2} \sim \mathcal{O}(1) \text{ TeV}$
- $M_1 \lesssim \mathcal{O}(10^{15}) \text{ GeV}$
- $M_4 \sim \mathcal{O}(10^{16}) \text{ GeV}$
- \Rightarrow 5 20% loop correc-

tion to λ



If $SH \ll H$. S: $D'^q \mathcal{U} H_u . H_d S_q^{\dagger}$ (generated by λ in Ξ) can push Tree-Level mass:

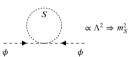
$$m_H = m_H^{TL} - (\text{Corr.})^2$$

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 $D'^q \mathcal{U} H_{\mu} H_d S_a^{\dagger}$



S: Singlet submatrix

H: Higgs submatrix

SH: Higgs / Singlet mixing (off-diagonal)

 $D'^q \mathcal{U} H_u \cdot H_d S_a^{\dagger}$ can induce a see-saw mechanism and possibly push upwards m_b to 125 GeV \rightarrow Reduce the fine-tuning?



Soni & Weldon

terms as a solution

Coleman-Weinberg eff. potential & Diagrammatic approach

$$\Delta V_{eff} = rac{1}{64\pi^2} \mathrm{STr} \mathcal{M}^4 \Bigg[\ln \left(\mathcal{M}^2/M^2
ight) - rac{3}{2} \Bigg] + rac{M^2}{32\pi^2} \mathrm{STr} \mathcal{M}^2$$



Soni & Weldon

Hard-breaking

A simple extension

terms as a solution

eff. potential & Diagrammatic approach

Coleman-Weinberg

1) Coleman-Weinberg (off-shell $p^2 = 0$)

$$\Delta V_{eff} = rac{1}{64\pi^2} \mathrm{STr} \mathcal{M}^4 \Bigg[\ln \left(\mathcal{M}^2/M^2
ight) - rac{3}{2} \Bigg] + rac{M^2}{32\pi^2} \mathrm{STr} \mathcal{M}^2$$

• No SUSY-breaking : $STr \mathcal{M}^2 = 0$: No corrections



Soni & Weldon

terms as a solution

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$$\Delta V_{eff} = rac{1}{64\pi^2} \mathrm{STr} \mathcal{M}^4 \Bigg[\ln \left(\mathcal{M}^2/M^2
ight) - rac{3}{2} \Bigg] + rac{M^2}{32\pi^2} \mathrm{STr} \mathcal{M}^2$$

- No SUSY-breaking : $STr \mathcal{M}^2 = 0$: No corrections
- Soft-SUSY-breaking : $STr\mathcal{M}^2 = 2(Tr(m_0^2) Tr(m_{1/2}^2))$: $STr\mathcal{M}^2$ Field independant! No corrections on mass matrix



Soni & Weldon

Hard-breaking

terms as a solution

Coleman-Weinberg eff. potential & Diagrammatic approach

$$\Delta V_{\it eff} = rac{1}{64\pi^2} {
m STr} \mathcal{M}^4 \Bigg[\ln \left(\mathcal{M}^2/M^2
ight) - rac{3}{2} \Bigg] + rac{M^2}{32\pi^2} {
m STr} \mathcal{M}^2$$

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- Soft-SUSY-breaking : $STr\mathcal{M}^2 = 2(Tr(m_0^2) Tr(m_{1/2}^2))$: $STr\mathcal{M}^2$ Field independant! No corrections on mass matrix
- Soft+Hard-breaking terms : $STr \mathcal{M}^2$ Field dependant \Rightarrow Will induce mass matrix corrections!



Supergravity

Supergravity Breaking

Soni & Weldon and Soft-Breakin terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning

Coleman-Weinberg eff. potential & Diagrammatic approach

$$\Delta V_{\it eff} = rac{1}{64\pi^2} {
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- No SUSY-breaking : $STr \mathcal{M}^2 = 0$: No corrections
- Soft-SUSY-breaking : $STr\mathcal{M}^2 = 2(Tr(m_0^2) Tr(m_{1/2}^2))$: $STr\mathcal{M}^2$ Field independent! No corrections on mass matrix
- Soft+Hard-breaking terms : STrM² Field dependant ⇒ Will induce mass matrix corrections !
- 2) Diagrammatic (on shell $p^2 = m^2$)...



Outline

Soni & Weldon

terms as a solution Coleman-Weinberg eff. potential & approach

A simple extension of NMSSM: S2MSSM

Conclusion

Conclusion



Conclusion

Supergravity

Breaking
Soni & Weldon
and Soft-Breakin
terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach Soni & Weldon: finds solutions to consistent Supergravity breaking

Leading to Soft-breaking terms

Used since 80's for all phenomenological studies

SWS is not the only possible solutions ⇒ Non-Soni-Weldon-Solutions

Leading to Hard-breaking terms M suppressed

• The simplest possible model involve a new type of field : "Hybrid field"

A simple model : S2MSSM (N2MSSM-like with significant differences)

Radiative corrections on Higgs mass from Hard-breaking terms

See-saw mechanism as a solution to fine-tuning problem

ullet V_{Hard} can possibly push upwards sfermions mass scale

 $\label{eq:LHC_loss} \mbox{LHC / Dark Matter / Cosmology} \Rightarrow \mbox{S.low.SUGRA project} \\ \mbox{(IPHC,L2C,LUPM,APC)}$

Conclusion



Soni & Weldon solutions

Supergravity

Supergravity
Breaking
Soni & Weldon

and Soft-Breaki

Weldon

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

corrections induced by

Hard-breaking terms

terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg

eff. potential & Diagrammatic approach

Conclusion

Assumptions:

$$K = \sum_{n=0}^{N} m_{p\ell}^{n} K_{n}(z, z^{\dagger}, \Phi, \Phi^{\dagger})$$

$$W = \sum_{n=0}^{M} m_{p\ell}^{n} W_{n}(z, \Phi)$$

Constraints on Matter Fields / Hidden Fields decoupling in $m_{p\ell} \to \infty$ limit :

$$K = m_{p\ell}^2 K_2(z, z^{\dagger}) + m_{p\ell} K_1(z, z^{\dagger}) + K_0(z, z^{\dagger}, \Phi, \Phi^{\dagger})$$
 $W = m_{p\ell}^2 W_2(z) + m_{p\ell} W_1(z) + W_0(z, \Phi)$



NSW Canonical solutions

Supergravity

Supergravity Breaking Soni & Weldon and Soft-Breakin

Non-Soni Weldon

Hybrid fields and Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breakin terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic

Conclusion

Canonical solutions:

$$K = m_{p\ell}^2 z z^\dagger + \Phi \Phi^\dagger + S_p^\dagger S^p$$
 $W = m_{p\ell} W_1(z, S) + W_0(z, S, \Phi)$

with:

$$W_1(z,S) = W_{1,0}(z) + \sum_{\rho \geq 1}^{k_1} W_{1,\rho}(z) \sum_{s \geq 1}^{n_\rho} \mu_{\rho_s}^* S^{\rho^s}$$

$$W_0(z, S, \Phi) = \sum_{q \ge 1}^{k_1} W_{0,q}(z) S^q + \Xi(\mathcal{U}_S^{pp_s}; \Phi, z)$$
 $\mathcal{U}_S^{pp_s} = \xi_{p_s} S^{p_s} - \xi^{p_s} S^{p_1} \quad \text{with} \quad \mu_{p_s} \xi_{p_s}(z) = \mu_{p_1} \xi^{p_s}(z)$



NSW Non-canonical solution

Supergravity

Supergravity Breaking Soni & Weldon

and Soft-Breaki terms

Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extensio of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic

Conclusion

An other non-Canonical solutions:

$$K = m_{p\ell}^2 K_2(z, z^{\dagger}, \Phi, \Phi^{\dagger}) + K_0(z, z^{\dagger}, \Phi, \Phi^{\dagger})$$

 $W = m_{p\ell}^2 W_2(z, \Phi) + W_0(z, \Phi)$

Decoupling Matter / Hidden for $m_{p\ell} \to \infty$ limit if :

- W_0 , K_0 are arbitrary functions
- W_2 , K_2 are arbitrary functions that should depend explicitly on Φ , Φ^{\dagger} , subject to a **no-scale-like** condition :

$$\partial_I \mathcal{G}_2 \left(\frac{\partial^2 \mathcal{G}_2}{\partial Z^I \partial Z^{J*}} \right)^{-1} \partial_{J*} \mathcal{G}_2 = 3 \; , \; ext{with} \; \mathcal{G}_2 = \mathcal{K}_2 + \ln \left| \frac{W_2}{m_{p\ell}} \right|^2$$



N2MSSM

N2MSSM = MSSM + 2 gauge singlets (NMSSM + 1 gauge singlet)

Phenomenological study in progress :

- RGEs (SARAH)
- Spectrum Generator (SPheno) + Work with Cyril Hugonie (LUPM) on NMSSMTools→N2MSSMTools
- Constraints coming from Higgs sector measurements (HiggsBounds & HiggsSignals)
- Constraints coming from Dark Matter (micrOmegas)

 \Rightarrow Recasting of $H \rightarrow aa$ analysis + Full space parameters scan

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Weldon Solutions

Hybrid fields an Hard-breaking terms

A simple extension of NMSSM: S2MSSM

Radiative corrections induced by Hard-breaking terms

Hard-breaking terms as a solution to the Higgs mass fine-tuning Coleman-Weinberg eff. potential & Diagrammatic approach

Conclusion



No-scale Supergravity

Soni & Weldon

terms as a solution Coleman-Weinberg eff. potential &

Fine-tuning problem on $\langle V \rangle$ for Cosmology

$$V=\mathrm{e}^{rac{K}{m_{p\ell}^2}}\Big(\mathcal{D}_IWK^I_{J*}\mathcal{D}^{J*}ar{W}-rac{3}{m_{p\ell}^2}|W|^2\Big)$$

A possible solution: **No-Scale Supergravity**

$$\mathcal{D}_{I}WK^{I}_{J*}\mathcal{D}^{J*}\bar{W} = \frac{3}{m_{\rho\ell}^{2}}|W|^{2}$$

V=0 at Tree-Level !

The gravitino mass is unfixed (no-scale) and is a free-parameter of the theory