Soft-terms in Sequestered dS Models

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Based on:

Aparicio, MC, Krippendorf, Maharana, Muia, Quevedo, JHEP 1411 (2014) 071

LVS SUSY breaking

- $W_0 \sim O(1)$ natural ⟶ SUSY breaking
- $\mathcal{V} \approx e^{1/g_s} >> 1$ for $g_s << 1$ ⟶ trust approximations
- Generate hierarchies naturally: $m_{3/2} \approx \dfrac{W_0 M_P}{\mathcal{V}} \approx M_P e^{-1/g_s} << M_P$
- Moduli masses of $O(m_{3/2})$ except for volume mode: $m_{\mathcal{V}} \approx \dfrac{m_{3/2}}{\sqrt{\mathcal{V}}} << m_{3/2}$
- Spontaneous SUSY breaking $F^{T_b} \approx \dfrac{M_P^2}{\mathcal{V}^{1/3}} \neq 0$ $F^{T_s} \approx \dfrac{M_P^2}{\mathcal{V}} \neq 0$
- Soft-terms depend on location and type of MSSM D-brane model

  i) D7-branes in geometric regime

  ⟶ Unsequestered models: $M_{soft} \approx m_{3/2}$ (up to loop factors)

  ii) D3-branes at singularities

  ⟶ Sequestered models: $M_{soft} << m_{3/2}$ (more than loop-suppressed)

- dS vacua without anti-branes

  i) non-zero F-terms of hidden matter fields induced by D-terms

  ii) non-perturbative effects at singularities

Visible sector

- D7s in geometric regime:

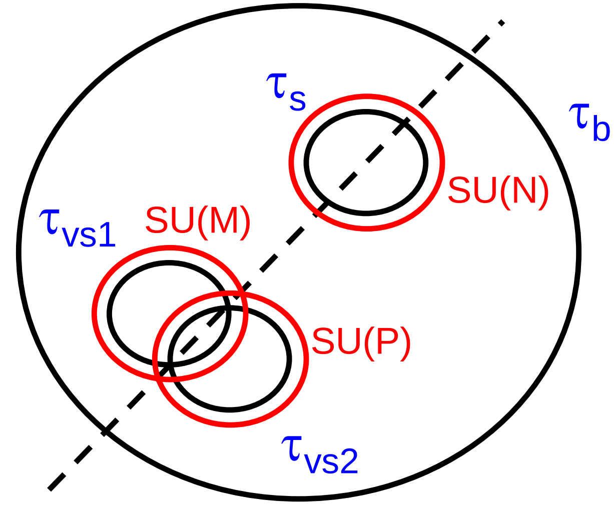
$$\mathcal{V} = \tau_b^{3/2} - \tau_s^{3/2} - (\alpha\tau_{vs1} + \beta\tau_{vs2})^{3/2}$$

i) D-terms fix $\tau_{vs1} \sim \tau_{vs2} \sim \tau_{vs}$

ii) NP + α' effects fix τ_b and τ_s at

$$\tau_b^{3/2} \approx e^{\tau_s} \qquad \tau_s \approx g_s^{-1}$$

iii) g_s effects fix τ_{vs}



- D3s at singularities:

$$\mathcal{V} = \tau_b^{3/2} - \tau_s^{3/2} - \tau_{vs1}^{3/2} - \tau_{vs2}^{3/2}$$

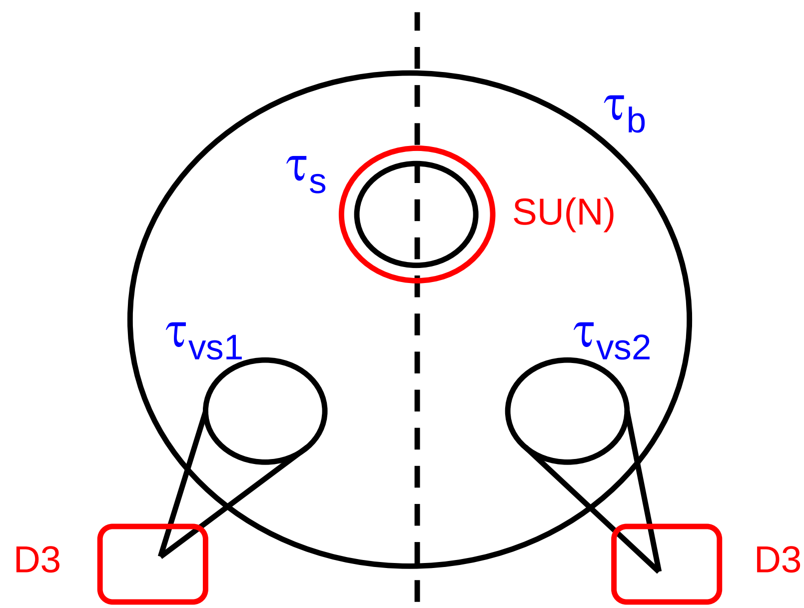
i) $\tau_{vs1} \longleftrightarrow \tau_{vs2}$ orientifold projection

→ get U(N) groups

ii) D-terms fix $\tau_{vs1} \sim \tau_{vs2} \longrightarrow 0$

iii) NP + α' effects fix τ_b and τ_s at

$$\tau_b^{3/2} \approx e^{\tau_s} \qquad \tau_s \approx g_s^{-1}$$



NB1 Non-perturbative effects for rigid cycles!

NB2 τ_{vs} fixed by D-terms or g_s effects

→ compatible with chirality!

Unsequestered models

- D7s in geometric regime ⟶ F-term of τ_{vs} is non-zero: $F^{vs} \sim m_{3/2} M_P \neq 0$
- Soft-terms and volume mode: $M_{soft} \approx \frac{M_P}{\mathcal{V}}$ $\quad m_{\mathcal{V}} \approx \frac{M_P}{\mathcal{V}^{3/2}}$
- Set either $M_{soft} \sim O(1)$ TeV (hierarchy problem) or $m_{\mathcal{V}} > O(50)$ TeV (cosm mod problem)

Energy scales for $\mathcal{V} \sim 10^{14}$:

$$M_P \approx 10^{18}\ \text{GeV}$$

$$M_s \approx m_{\tau_{vs1}} \approx m_{a_{vs1}} \approx M_P \mathcal{V}^{-1/2} \approx 10^{11}\ \text{GeV}$$

$$M_{KK} \approx M_P \mathcal{V}^{-2/3} \approx 10^{8}\ \text{GeV}$$

$$m_{\tau_s} \approx m_{a_s} \approx M_P \mathcal{V}^{-1} \ln \mathcal{V} \approx 100\ \text{TeV}$$

$$m_{3/2} \approx M_P \mathcal{V}^{-1} \approx 10\ \text{TeV}$$

$$M_{soft} \approx m_{\tau_{vs2}} \approx M_P \mathcal{V}^{-1} (\ln \mathcal{V})^{-1} \approx 1\ \text{TeV}$$

$$m_{\tau_b} \approx M_P \mathcal{V}^{-3/2} \approx 1\ \text{MeV}$$

$$m_{a_{vs2}} \approx \Lambda^2_{QCD} f^{-1}_{a_{vs2}} \approx 1\ \text{meV} \quad \text{for} \quad f_{a_{vs2}} \approx M_s$$

$$m_{a_b} \approx M_P e^{-\mathcal{V}^{3/2}} \approx 0$$

Energy scales for $\mathcal{V} \sim 10^{4}$:

$$M_P \approx 10^{18}\ \text{GeV}$$

$$M_s \approx m_{\tau_{vs1}} \approx m_{a_{vs1}} \approx 10^{16}\ \text{GeV}$$

$$M_{KK} \approx 10^{15}\ \text{GeV}$$

$$m_{\tau_s} \approx m_{a_s} \approx 5 \cdot 10^{14}\ \text{GeV}$$

$$m_{3/2} \approx 10^{14}\ \text{GeV}$$

$$M_{soft} \approx m_{\tau_{vs2}} \approx 10^{13}\ \text{GeV}$$

$$m_{\tau_b} \approx 10^{12}\ \text{GeV}$$

$$m_{a_{vs2}} \approx 1\ \text{neV} \quad \text{for} \quad f_{a_{vs2}} \approx M_s$$

$$m_{a_b} \approx 0$$

Sequestered models

- D3s at singularties → F-term of τ_{vs} is zero: $F^{vs} \propto \xi_{FI} \propto \tau_{vs} \to 0$
- Soft-terms (depending on matter Kahler metric and dS mechanism):

$$M_{1/2} \approx \frac{M_P}{\mathcal{V}^2} \qquad m_0 \approx \begin{cases} \frac{M_P}{\mathcal{V}^{3/2}} \approx m_\nu \\ \frac{M_P}{\mathcal{V}^2} \end{cases}$$

- Set $\mathcal{V}$ ~10^7 to get $M_{1/2}$ ~ O(1) TeV :

$$M_P \approx 10^{18}\ \text{GeV}$$

$$M_{GUT} \approx M_s \mathcal{V}^{1/6} \approx 10^{16}\ \text{GeV}$$

$$M_s \approx m_{\tau_{vs1}} \approx m_{a_{vs1}} \approx m_{\tau_{vs2}} \approx m_{a_{vs2}} \approx 10^{15}\ \text{GeV}$$

$$M_{KK} \approx 10^{14}\ \text{GeV}$$

$$m_{\tau_s} \approx m_{a_s} \approx 10^{12}\ \text{GeV}$$

$$m_{3/2} \approx 10^{11}\ \text{GeV}$$

1) TeV scale SUSY
2) Standard GUTs
3) Right inflationary scale
4) No CMP for τ_b
5) QCD axion from open string modes
6) Reheating driven by the decay of τ_b
7) T_{rh} ~ 1 GeV
8) Non-thermal dark matter → Aparicio's talk
9) Axionic dark radiation → Muia's talk

MSSM

$$m_{\tau_b} \approx 10^7\ \text{GeV}$$

$$M_{1/2} \approx m_0 \approx M_P \mathcal{V}^{-2} \approx 1\,\text{TeV}$$

↔

Split SUSY

$$m_{\tau_b} \approx m_0 \approx 10^7\ \text{GeV}$$

$$M_{1/2} \approx 1\,\text{TeV}$$

$$m_{a_{open}} \approx 1\,\text{meV} \quad \text{for} \quad f_{a_{open}} \approx M_s \sqrt{\tau_{vs}} << M_s$$

$$m_{a_b} \approx 0$$

EFT for sequestered models

- Kahler moduli (trading τ_{vs1} and τ_{vs2} for τ_{SM} and b)

$$T_b = \tau_b + i\psi_b\,, \quad T_s = \tau_s + i\psi_s\,, \quad T_{\rm SM} = \tau_{\rm SM} + i\psi_{\rm SM}\,, \quad G = b + ic$$

- Superpotential (moduli denoted as M and MSSM superfields as C)

$$W = W_{\rm flux}(U,S) + A_s(U,S)\, e^{-a_s T_s} + W_{\rm ds} + W_{\rm matter}$$

$$W_{\rm matter} = \mu(M) H_u H_d + \frac{1}{6} Y_{\alpha\beta\gamma}(M) C^\alpha C^\beta C^\gamma + \cdots$$

- Kahler potential

$$K = -2\ln\left(\mathcal{V} + \frac{\hat{\xi}}{2}\right) - \ln(2s) + \lambda_{\rm SM}\frac{\tau_{\rm SM}^2}{\mathcal{V}} + \lambda_b \frac{b^2}{\mathcal{V}} + K_{\rm ds} + K_{\rm cs}(U) + K_{\rm matter}$$

$$K_{\rm matter} = \tilde{K}_\alpha(M,\overline{M})\overline{C}^{\overline{\alpha}} C^\alpha + [Z(M,\overline{M}) H_u H_d + {\rm h.c.}]$$

$$\tilde{K}_\alpha = \frac{f_\alpha(U,S)}{\mathcal{V}^{2/3}}\left(1 - c_s\frac{\hat{\xi}}{\mathcal{V}} + \tilde{K}_{\rm ds} + c_{\rm SM}\tau_{\rm SM}^p + c_b b^p\right), \qquad p > 0$$

- Gauge kinetic functions

$$f_a = \delta_a S + \kappa_a T_{\rm SM}$$

D-term stabilisation

- Each del Pezzo singularity has 2 anomalous U(1)s
- T_{SM} and G get charged under these U(1)s
- D-term potential

$$V_D = \frac{1}{2\mathrm{Re}(f_1)}\left(\sum_\alpha q_{1\alpha}\frac{\partial K}{\partial C^\alpha}C^\alpha - \xi_1\right)^2 + \frac{1}{2\mathrm{Re}(f_2)}\left(\sum_\alpha q_{2\alpha}\frac{\partial K}{\partial C^\alpha}C^\alpha - \xi_2\right)^2$$

- FI-terms

$$\xi_1 = -\frac{q_1}{4\pi}\frac{\partial K}{\partial T_{\mathrm{SM}}} = -\frac{q_1\lambda_{\mathrm{SM}}}{4\pi}\frac{\tau_{\mathrm{SM}}}{\mathcal{V}}\,,$$
$$\xi_2 = -\frac{q_2}{4\pi}\frac{\partial K}{\partial G} = -\frac{q_2\lambda_b}{4\pi}\frac{b}{\mathcal{V}}\,.$$

- D = 0 fixes τ_{SM} and b in terms of visible matter fields
- Subleading F-terms from SUSY breaking fix C = 0 if scalars are non-tachyonic

$$\longrightarrow \quad \xi_1 = \xi_2 = 0 \quad \longrightarrow \quad \tau_{\mathrm{SM}} = b = 0$$

- Axions ψ_{SM} and c eaten up by anomalous U(1)s

F-term stabilisation

- Leading order: $\mathcal{V}^{-2}$

$$V_{\mathcal{O}(\mathcal{V}^{-2})} = \frac{1}{2s\mathcal{V}^2}\left[4s^2|D_S W_{\rm flux}|^2 + K^{U\overline{U}} D_U W_{\rm flux} D_{\overline{U}} \overline{W}_{\rm flux}\right]\Big|_{\xi=0}$$

$$D_S W_{\rm flux}|_{\xi=0} = 0\ , \qquad D_U W_{\rm flux}|_{\xi=0} = 0\ , \qquad \langle W_{\rm flux}\rangle \equiv W_0$$

- Subleading order: $\mathcal{V}^{-3}$

$$V_{\mathcal{O}(\mathcal{V}^{-3})} = \frac{1}{2s}\left[\frac{8}{3}(a_s A_s)^2\sqrt{\tau_s}\frac{e^{-2a_s\tau_s}}{\mathcal{V}} - 4a_s A_s W_0 \tau_s \frac{e^{-a_s\tau_s}}{\mathcal{V}^2} + \frac{3\hat{\xi} W_0^2}{4\mathcal{V}^3}\right]$$

- AdS minimum which breaks SUSY

$$e^{-a_s\tau_s} = \frac{3\sqrt{\tau_s}W_0}{4a_s A_s \mathcal{V}}\frac{(1-4\epsilon_s)}{(1-\epsilon_s)} \qquad \text{with} \qquad \epsilon_s \equiv \frac{1}{4a_s\tau_s} \sim \mathcal{O}\left(\frac{1}{\ln\mathcal{V}}\right) \ll 1$$

$$\tau_s^{3/2} = \frac{\hat{\xi}}{2}\left[1 + f_{\rm dS}(\epsilon_s)\right]$$

Subleading correction f_{dS} depends on dS mechanism

U and S shift

- Potential at O($\mathcal{V}^{-3}$) depends on U and S

  → shift of U and S minimum

$$D_S W \simeq D_S W_{\text{flux}}|_{\xi=0} - \frac{3\hat{\xi}W_0}{4s\mathcal{V}}\left[1+\epsilon_s s\partial_s \ln A_s(U,S)\right]$$

$$D_U W \simeq D_U W_{\text{flux}}|_{\xi=0} - \frac{3\hat{\xi}W_0}{4\mathcal{V}}\epsilon_s\partial_u\left[K_{\text{cs}}(U) + \ln A_s(U,S)\right]$$

- Parametrisation of the S-shift in terms of ω_S defined as

$$D_S W = -\frac{3\omega_S(U,S)}{4}\frac{\hat{\xi}W_0}{s\mathcal{V}}$$

- Parametrisation of the U-shift in terms of ω_U defined as

$$D_{U_i} W = -\frac{3\omega_{U_i}(U,S)}{4}\frac{\hat{\xi}W_0}{s\mathcal{V}} \qquad \Rightarrow \qquad D_{U_i} W = \frac{\omega_{U_i}(U,S)}{\omega_S(U,S)} D_S W \sim \mathcal{O}(\mathcal{V}^{-1})$$

Also S and U-moduli break SUSY!

dS case 1: hidden F-terms

- FW anomaly cancellation → non-zero flux on T_b → T_b gets a U(1)-charge
- D-term potential

$$V_D = \frac{1}{2\mathrm{Re}(f_b)}\left(\frac{q_\phi}{s}|\phi_{\rm ds}|^2 - \xi_b\right)^2 \qquad f_b = T_b \qquad \xi_b = -\frac{q_b}{4\pi}\frac{\partial K}{\partial T_b} = \frac{3q_b}{8\pi}\frac{1}{\mathcal{V}^{2/3}}$$

- Total scalar potential

$$V_{\rm tot} = V_D + V_F = \frac{1}{2\mathcal{V}^{2/3}}\left(\frac{q_\phi}{s}|\phi_{\rm ds}|^2 - \frac{3q_b}{8\pi\mathcal{V}^{2/3}}\right)^2 + \frac{1}{s}m_{3/2}^2|\phi_{\rm ds}|^2 + V_{\mathcal{O}(\mathcal{V}^{-3})}$$

- Minimum for $\phi_{\rm dS}$ at $\frac{q_\phi}{s}|\phi_{\rm ds}|^2 = \xi_b - \frac{m_{3/2}^2\mathcal{V}^{2/3}}{q_\phi}$
- Substitute in $V_{\rm tot}$

$$V_{\rm tot} = V_{D,0} + \frac{3q_b}{16\pi q_\phi}\frac{W_0^2}{s\mathcal{V}^{8/3}} + V_{\mathcal{O}(\mathcal{V}^{-3})} \qquad V_{D,0} = \frac{m_{3/2}^4\mathcal{V}^{2/3}}{2q_\phi^2} \sim \mathcal{O}\left(\mathcal{V}^{-10/3}\right) \text{ negligible}$$

- Minimising with respect to τ_s and $\mathcal{V}$

$$\langle V_{\rm tot}\rangle \simeq \frac{3W_0^2}{8sa_s^{3/2}\langle\mathcal{V}\rangle^3}\left[\delta\,\mathcal{V}^{1/3} - \sqrt{\ln\left(\frac{\langle\mathcal{V}\rangle}{W_0}\right)}\right] \qquad \delta = \frac{1}{18\pi}\frac{q_b\,a_s^{3/2}}{q_\phi} \simeq 0.02\left(\frac{q_b\,a_s^{3/2}}{q_\phi}\right)$$

- Tune W_0 so that $\langle V_{\rm tot}\rangle = 0$

Solutions for $W_0 \sim O(1)$ and $\mathcal{V} \sim 10^6 - 10^7$ as needed to get TeV scale SUSY!

dS case 2: non-perturbative effects

- New W from non-perturbative effects at singularities $W_{\rm dS} = A_{\rm dS}(U,S)\, e^{-a_{\rm dS}(S+\kappa_{\rm dS}T_{\rm dS})}$
- New Kahler modulus T_{dS} with $K_{\rm dS} = \lambda_{\rm dS}\dfrac{\tau_{\rm dS}^2}{\mathcal{V}}$
- Hidden D-term potential

$$V_D = \frac{1}{2{\rm Re}(f_{\rm h})}\left(\sum_i q_{{\rm h},i}|\phi_{{\rm h},i}|^2 - \xi_{\rm h}\right)^2 \qquad f_{\rm h} = S \qquad \xi_{\rm h} = -\frac{q_{\rm dS}}{4\pi}\frac{\partial K}{\partial T_{\rm dS}} = -\frac{q_{\rm dS}}{4\pi}\frac{\tau_{\rm dS}}{\mathcal{V}}$$

- Total scalar potential

$$V_{\rm tot} = \frac{1}{2s}\left(\sum_i q_{{\rm h},i}|\phi_{{\rm h},i}|^2 + \frac{q_{\rm dS}}{4\pi}\frac{\tau_{\rm dS}}{\mathcal{V}}\right)^2 + \frac{(\kappa_{\rm dS}a_{\rm dS}A_{\rm dS})^2}{s}\frac{e^{-2a_{\rm dS}(s+\kappa_{\rm dS}\tau_{\rm dS})}}{\mathcal{V}} + V_{\mathcal{O}(\mathcal{V}^{-3})}$$

- Minimum for τ_{dS} at $\dfrac{q_{\rm dS}}{4\pi}\dfrac{\tau_{\rm dS}}{\mathcal{V}} = -\sum_i q_{{\rm h},i}|\phi_{{\rm h},i}|^2 + \dfrac{a_{\rm dS}\kappa_{\rm dS}}{q_{\rm dS}}(\kappa_{\rm dS}a_{\rm dS}A_{\rm dS})^2\, e^{-2a_{\rm dS}s}$

- $s = g_s^{-1} \approx \tau_s \longrightarrow e^{-2a_{dS}s} \approx e^{-2a_s\tau_s} \approx \mathcal{V}^{-2}$ for $a_{dS} = a_s$

$\longrightarrow \tau_{dS} \approx |\phi_h|^2\mathcal{V} + \mathcal{V}^{-1} \approx \mathcal{V}^{-1} << 1$ for $|\phi_h| \le \mathcal{V}^{-1}$

- Substitute in V_{tot} $\qquad V_{\rm tot} = V_{D,0} + \dfrac{(\kappa_{\rm dS}a_{\rm dS}A_{\rm dS})^2}{s}\dfrac{e^{-2a_{\rm dS}s}}{\mathcal{V}} + V_{\mathcal{O}(\mathcal{V}^{-3})}$ $\qquad V_{D,0} \sim O(\mathcal{V}^{-4})$ negligible

- Tune fluxes so that $<V_{tot}>=0$ $\qquad \left(\dfrac{\kappa_{\rm dS}a_{\rm dS}A_{\rm dS}}{W_0}\right)^2 e^{-2a_{\rm dS}s} = \dfrac{9}{32}\dfrac{\epsilon_s\hat{\xi}}{\mathcal{V}^2}$

F-terms

- General expression of F-terms

$$F^I = e^{K/2} K^{I\bar{J}} D_{\bar{J}} W$$

- Relevant F-terms

$$\frac{F^{T_b}}{\tau_b} \simeq -2m_{3/2}\left(1 + \frac{x_{\rm dS}}{a_s^{3/2}\mathcal{V}\sqrt{\epsilon_s}}\right), \qquad \frac{F^{T_s}}{\tau_s} \simeq -6m_{3/2}\epsilon_s$$

$$\frac{F^S}{s} \simeq \frac{3\omega'_S(U,S)}{8a_s^{3/2}} \frac{m_{3/2}}{\mathcal{V}\epsilon_s^{3/2}}, \qquad F^{U_i} \simeq -\frac{K^{U_i\bar{U}_{\bar{j}}}}{2s^2} \frac{\omega_{\bar{U}_{\bar{j}}}(U,S)}{\omega'_S(U,S)} F^S \equiv \beta^{U_i}(U,S) F^S$$

$$F^G = F^{T_{\rm SM}} = 0$$

- dS case 1

$$\frac{F^{\phi_{\rm dS}}}{\phi_{\rm dS}} \simeq m_{3/2}$$

- dS case 2

$$F^{T_{\rm dS}} \simeq \frac{3}{4\sqrt{2}a_s^{3/4}} \frac{m_{3/2}}{\epsilon_s^{1/4}}$$

Local and ultra-local scenarios

- Physical Yukawa couplings

$$\hat{Y}_{\alpha\beta\gamma} = e^{K/2} \frac{Y_{\alpha\beta\gamma}(U,S)}{\sqrt{\tilde{K}_\alpha \tilde{K}_\beta \tilde{K}_\gamma}}$$

- Locality constraint

$$\tilde{K}_\alpha = h_\alpha(U,S)\, e^{K/3} \simeq \frac{h_\alpha(U,S)\, e^{K_{\rm cs}/3}}{(2s)^{1/3}\mathcal{V}^{2/3}} \left(1 - \frac{\hat{\xi}}{3\mathcal{V}} + \frac{1}{3}K_{\rm dS}\right) \qquad \tau_{\rm SM} = b = C^\alpha = 0$$

- Same volume scaling as matter Kahler metric

$$\tilde{K}_\alpha = \frac{f_\alpha(U,S)}{\mathcal{V}^{2/3}} \left(1 - c_s \frac{\hat{\xi}}{\mathcal{V}} + \tilde{K}_{\rm dS}\right) \equiv f_\alpha(U,S)\tilde{K} \qquad \tilde{K}_{\rm dS} = c_{\rm dS} K_{\rm dS} \qquad \tau_{\rm SM} = b = 0$$

- Soft-term computation depends on subleading corrections
- 2 limits:

i) Local limit: locality constraint holds only at leading order

→ $c_s \neq 1/3$ and $c_{dS} \neq 1/3$

ii) Ultra-local limit: locality constraint holds exactly

→ $$f_\alpha(U,S) = \frac{h_\alpha(U,S)\, e^{K_{\rm cs}/3}}{(2s)^{1/3}} \quad \text{and} \quad c_s = c_{\rm dS} = \frac{1}{3}$$

Gaugino masses

- General expression for gaugino masses

$$M_a = \frac{1}{2\mathrm{Re}\,(f_a)} F^I \partial_I f_a \qquad f_a = \delta_a S + \kappa_a T_{\mathrm{SM}}$$

- $F^{T_{SM}} = 0$ → universal gaugino masses generated by F^S

$$M_{1/2} = \frac{F^S}{2s} \simeq \frac{3\omega'_S(U,S)}{16 a_s^{3/2}} \frac{m_{3/2}}{\mathcal{V}\epsilon_s^{3/2}} \sim \mathcal{O}\left(m_{3/2} \frac{(\ln \mathcal{V})^{3/2}}{\mathcal{V}} \right) \ll m_{3/2}$$

- Loop-suppressed anomaly mediation contributions because of no-scale cancellation

$$M_{1/2}^{anom} \approx \frac{g^2}{16\pi^2} M_{1/2} << M_{1/2}$$

Scalar masses

- F-term contributions $$m_\alpha^2\big|_F = m_{3/2}^2 - F^I\overline{F}^{\overline{J}}\partial_I\partial_{\overline{J}}\ln\tilde{K}_\alpha$$

- Local limit: universal scalar masses generated by F^{T_b}

$$m_0^2\big|_F \simeq m_{3/2}^2 - \left(\frac{F^{T_b}}{2}\right)^2\partial_{\tau_b}^2\ln\tilde{K} \simeq \frac{5\left(c_s-\frac{1}{3}\right)}{\omega_S'}m_{3/2}M_{1/2} \sim \mathcal{O}\left(m_{3/2}^2\frac{(\ln\mathcal{V})^{3/2}}{\mathcal{V}}\right)$$

- Ultra-local limit: vanishing contribution from F^{T_b} for $c_s=1/3$ → m_0 generated by F^U and F^S

$$m_\alpha^2\big|_F = -M_{1/2}^2 s^2\left(\partial_s^2 + \beta^{U_i}\partial_{u_i}\partial_s + \beta^{U_i}\beta^{\overline{U}_j}\partial_{u_i}\partial_{u_j}\right)\ln h_\alpha(U,S) \sim \mathcal{O}\left(M_{1/2}^2\right)$$

- D-term contributions

$$m_\alpha^2\big|_D = \tilde{K}_\alpha^{-1}\sum_i g_i^2 D_i\partial_{\alpha\overline{\alpha}}^2 D_i - V_{D,0}$$

- dS case 1

$$m_0^2\big|_D = \frac{q_b}{2f_\alpha(U,S)}D_{\mathrm{dS}_1}\partial_{\tau_b}\tilde{K}_\alpha = \frac{m_{3/2}^2}{3s}|\phi_{\mathrm{dS}}|^2 = \frac{6\epsilon_s}{\omega_S'}m_{3/2}M_{1/2} \sim \mathcal{O}\left(m_{3/2}^2\frac{\sqrt{\ln\mathcal{V}}}{\mathcal{V}}\right)$$

dominant effect in ultra-local limit

- dS case 2

$$m_0^2\big|_D = \frac{q_{\mathrm{dS}}\mathcal{V}^{2/3}}{2sf_\alpha(U,S)}D_{\mathrm{dS}_2}\partial_{\tau_{\mathrm{dS}}}\tilde{K}_\alpha - V_{D,0} = \frac{c_{\mathrm{dS}}}{s}D_{\mathrm{dS}_2}q_{\mathrm{dS}}\frac{\tau_{\mathrm{dS}}}{\mathcal{V}} - V_{D,0} = (2c_{\mathrm{dS}}-1)\,V_{D,0}$$

subdominant effect in local limit since $V_{D,0} \sim O(\mathcal{V}^{-4})$

$$m_0^2\big|_D = 2\left(c_{\mathrm{dS}}-\frac{1}{3}\right)V_{D,0} = 0 \quad \text{for} \quad c_{\mathrm{dS}} = \frac{1}{3}$$

vanishing in ultra-local limit

A-terms

- Vanishing D-term contributions for C = 0
- F-term contribution

$$A_{\alpha\beta\gamma} = F^I \partial_I \left[K + \ln \left(\frac{Y_{\alpha\beta\gamma}(U,S)}{\tilde{K}_\alpha \tilde{K}_\beta \tilde{K}_\gamma} \right) \right] = F^I \partial_I \left[K - 3 \ln \tilde{K} + \ln \left(\frac{Y_{\alpha\beta\gamma}(U,S)}{f_\alpha f_\beta f_\gamma} \right) \right]$$

- Local limit

$$A_{\alpha\beta\gamma} = - \left[1 - s\beta^{U_i} \partial_{u_i} K_{\mathrm{cs}} - \frac{6}{\omega'_S} \left(c_s - \frac{1}{3} \right) - s\partial_{s,u} \ln \left(\frac{Y_{\alpha\beta\gamma}}{f_\alpha f_\beta f_\gamma} \right) \right] M_{1/2} \sim \mathcal{O}\left(M_{1/2} \right)$$

$$\partial_{s,u} \equiv \partial_s + \beta^{U_i} \partial_{u_i}$$

- Ultra-local limit

$$A_{\alpha\beta\gamma} = s\partial_{s,u} \ln \left(\frac{Y_{\alpha\beta\gamma}(U,S)}{h_\alpha h_\beta h_\gamma} \right) M_{1/2} \sim \mathcal{O}\left(M_{1/2} \right)$$

μ and Bμ from K

- Contributions from K

$$\hat{\mu} = \left(m_{3/2}Z - \overline{F}^{\overline{I}}\partial_{\overline{I}}Z\right)\left(\tilde{K}_{H_u}\tilde{K}_{H_d}\right)^{-1/2} \quad \text{and} \quad B\hat{\mu} = B\hat{\mu}|_F + B\hat{\mu}|_D$$

$$B\hat{\mu}|_F = \Big\{2m_{3/2}^2 Z - m_{3/2}\overline{F}^{\overline{I}}\partial_{\overline{I}}Z + m_{3/2}F^I\left[\partial_I Z - Z\partial_I \ln\left(\tilde{K}_{H_u}\tilde{K}_{H_d}\right)\right]$$
$$-F^I\overline{F}^{\overline{J}}\left[\partial_I\partial_{\overline{J}}Z - \partial_I Z\partial_{\overline{J}}\ln\left(\tilde{K}_{H_u}\tilde{K}_{H_d}\right)\right]\Big\}\left(\tilde{K}_{H_u}\tilde{K}_{H_d}\right)^{-1/2},$$

$$B\hat{\mu}|_D = \left(\tilde{K}_{H_u}\tilde{K}_{H_d}\right)^{-1/2}\left(\sum_i g_i^2 D_i\partial_{H_u}\partial_{H_d}D_i - V_{D,0}Z\right). \qquad Z = \gamma(U,S)\tilde{K}$$

- Local limit

$$\hat{\mu} = \frac{\gamma}{\sqrt{f_{H_u}f_{H_d}}}\left[\frac{6}{3\omega'_S}\left(c_s - \frac{1}{3}\right) - s\partial_{s,u}\ln\gamma\right]M_{1/2} \sim \mathcal{O}\left(M_{1/2}\right)$$

$$B\hat{\mu} = \frac{\gamma}{\sqrt{f_{H_u}f_{H_d}}}\frac{5\left(c_s - \frac{1}{3}\right)}{\omega'_S}m_{3/2}M_{1/2} \sim \mathcal{O}\left(m_{3/2}^2\frac{(\ln\mathcal{V})^{3/2}}{\mathcal{V}}\right)$$

- Ultra-local limit

$$Z \equiv z(U,S)\,e^{K/3} \qquad \hat{\mu} = -\frac{z\,s\partial_{s,u}\ln\gamma}{\sqrt{h_{H_u}h_{H_d}}}M_{1/2} \sim \mathcal{O}\left(M_{1/2}\right)$$

dS case 1: $$B\hat{\mu}|_D = \frac{z}{\sqrt{h_{H_u}h_{H_d}}}\, m_0^2|_D = \frac{z}{\sqrt{h_{H_u}h_{H_d}}}\frac{6\epsilon_s}{\omega'_S}m_{3/2}M_{1/2} \sim \mathcal{O}\left(m_{3/2}^2\frac{\sqrt{\ln\mathcal{V}}}{\mathcal{V}}\right)$$

dS case 2: $$B\hat{\mu} = \frac{z}{\sqrt{h_{H_u}h_{H_d}}}\sigma(U,S)\,M_{1/2}^2 \sim \mathcal{O}\left(M_{1/2}^2\right)$$

μ and Bμ from W

- Contributions from W

$$\hat{\mu} = \mu\, e^{K/2} \left(\tilde{K}_{H_u} \tilde{K}_{H_d}\right)^{-1/2} ,$$

$$B\hat{\mu} = \mu\, e^{K/2} \left[F^I \left(K_I + \partial_I \ln \mu - \partial_I \ln \left(\tilde{K}_{H_u} \tilde{K}_{H_d}\right)\right) - m_{3/2}\right] \left(\tilde{K}_{H_u} \tilde{K}_{H_d}\right)^{-1/2}$$

- Non-perturbative effects (μ=0 from reduction of D3-brane action)

$$\begin{cases} W \supset e^{-aT} H_u H_d \quad \Rightarrow \quad \mu_{\text{eff}} = e^{-aT} \\ W \supset e^{-b(S+\kappa T)} H_u H_d \quad \Rightarrow \quad \mu_{\text{eff}} = e^{-b(S+\kappa T)} \end{cases}$$

$$T = T_s \qquad a = n a_s \ \text{with}\ n > 0 \qquad b = n a_s$$

$$\longrightarrow \quad \hat{\mu} \simeq \frac{c_\mu(U,S)}{\mathcal{V}^{n+\frac{1}{3}}} \quad \text{and} \quad B\hat{\mu} \simeq \frac{c_B(U,S)}{\mathcal{V}^{n+\frac{4}{3}}}$$

model-dependent

- Higgs bilinear forbidden by anomalous U(1)s
- Gauge invariant operators from T-moduli or open string scalars ϕ

$$K \supset \left(\frac{\Phi}{\Lambda}\right)^m H_u H_d\,, \qquad W \supset \frac{\Phi^m}{\Lambda^{m-1}} H_u H_d$$

model-dependent

Summary of soft terms

$$M_{1/2} \approx c_{1/2} \frac{M_P}{\mathcal{V}^2} (\ln \mathcal{V})^{3/2}$$

$$A_{\alpha\beta\gamma} \approx c_{\alpha\beta\gamma} M_{1/2}$$

c's are flux-dependent coefficients
n>0 is a model-dependent parameter

$$m_0^2 \approx \begin{cases} c_0 M_{1/2}^2 \dfrac{\mathcal{V}}{(\ln \mathcal{V})^{3/2}} >> M_{1/2}^2 & \text{Local limit} \\ c_0 M_{1/2}^2 \dfrac{\mathcal{V}}{(\ln \mathcal{V})^{5/2}} >> M_{1/2}^2 & \text{Ultra-local dS}_1 \\ c_0 M_{1/2}^2 & \text{Ultra-local dS}_2 \end{cases}$$

- Local limit → Split SUSY
- Ultra-local dS_1 → Split SUSY
- Ultra-local dS_2 → Standard MSSM

$$\hat{\mu} \approx \begin{cases} c_\mu M_{1/2} & \text{from } K \\ c_\mu \dfrac{M_P}{\mathcal{V}^{n+1/3}} & \text{from } W \end{cases}$$

$$B\hat{\mu} \approx \begin{cases} c_B m_0^2 & \text{from } K \\ c_B \dfrac{M_P}{\mathcal{V}^{n+1/3}} & \text{from } W \end{cases}$$

RG running down to LHC scale, SUSY phenomenology, cosmological implications from dark matter and dark radiation studied in:

1) Allahverdi, MC, Dutta, Sinha, Phys.Rev. D88 (2013) 9, 095015
2) Aparicio, MC,Dutta, Krippendorf,Maharana, Muia,Quevedo, JHEP 1505 (2015) 098
3) MC, Conlon, Quevedo, Phys.Rev. D87 (2013) 4, 043520
4) Allahverdi, MC, Dutta, Sinha, JCAP 1410 (2014) 002
5) MC, Conlon, Marsh, Rummel, Phys.Rev. D90 (2014) 023540