Soft Supersymmetric Terms in Calabi-Yau compactifications with D-branes and Fluxes

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Universe made of space-time filling D-branes?

- Open strings ending on D-branes: matter.
  Can realize $SU(3) \times SU(2) \times U(1)$.
  Here one stack of D3-branes $\rightarrow U(N)$.

- Closed strings: moduli

1. Compactify on CY orientifold. Add N space-time filling D3-branes.

2. Add background fluxes.
   $\rightarrow$ Fix some moduli
   $\rightarrow$ Break SUSY spontaneosly in the bulk

Purpose:

- Understand low-energy theory of CY–compactifications with D-branes and O3-planes

- Break SUSY by fluxes. See how SU$\cancel{\text{S}}$Y is communicated to matter

Outline

- Find low-energy action for IIB on CY3-orientifold

$$
+\text{ D3-branes + flux}\;\begin{array}{l}\nearrow\quad W \;\;\text{Gukov,Vafa,Witten}\\ \rightarrow\; K \;\;\text{CY orientifold: Grimm and Louis}\\ \qquad\quad\;\; \text{+ D3-branes: GGJL}\\ \searrow\quad f_a\end{array}
$$

- Find soft SU~~S~~Y terms in matter (D3) action
- Check consistency with effective sugra description

Bulk

Thomas Grimm and Jan Louis, in preparation

Moduli of CY compactifications with orientifold planes
(neglect warping → large radius limit)

- Orientifold projection

  $\mathcal{O} = (-1)^{F_L}\,\Omega_p\,\sigma^*$

- Demand

  $\sigma^*\Omega = -\Omega \quad \Rightarrow \quad$ O3- or O7-planes

- Under σ^*:

$$H^{(p,q)} = H_+^{(p,q)} \oplus H_-^{(p,q)}$$

$H_+^{(1,1)} : \omega_\alpha$	$H_-^{(1,1)} : \omega_a$
$H_+^{(2,2)} : \tilde{\omega}^\alpha$	$H_-^{(2,2)} : \tilde{\omega}^a$
$H_+^{(2,1)} : \chi_\alpha$	$H_-^{(2,1)} : \chi_a$
$H_+^{(1,2)} : \tilde{\chi}^\alpha$	$H_-^{(1,2)} : \tilde{\chi}^a$
	$H_-^{(3,0)} : \Omega$

$$\begin{aligned}
(-1)^{F_L}\,\Omega_p\,\hat{\phi} &= \hat{\phi}, & (-1)^{F_L}\,\Omega_p\,\hat{l} &= \hat{l},\\
(-1)^{F_L}\,\Omega_p\,\hat{g} &= \hat{g}, & (-1)^{F_L}\,\Omega_p\,\hat{C}_2 &= -\hat{C}_2,\\
(-1)^{F_L}\,\Omega_p\,\hat{B} &= -\hat{B}, & (-1)^{F_L}\,\Omega_p\,\hat{C}_4 &= \hat{C}_4.
\end{aligned}$$

Spectrum of moduli

- $J_2 = v^\alpha \omega_\alpha + \cancel{v^a \omega_a}$
- $B_2 = \cancel{b^\alpha \omega_\alpha} + b^a \omega_a + \cancel{B}$
- $C_2 = \cancel{c^\alpha \omega_\alpha} + c^a \omega_a + \cancel{C}$
- $C_4 = D_2^\alpha \cancel{\wedge} \omega_\alpha + V_1^\alpha \wedge \chi_\alpha - U_{1\alpha} \cancel{\wedge} \tilde{\chi}^\alpha + C_1 \cancel{\wedge} \Omega + \bar{C}_1 \cancel{\wedge} \bar{\Omega} + \rho_\alpha \tilde{\omega}^\alpha + (..)^\alpha \cancel{(...)_a}$

$\mathcal{N}=2$	$\mathcal{N}=1$
$h^{(2,1)}$ vector multiplets $\{V_{1\mu}^{\alpha,a}, z^{\alpha,a}\}$	$h_+^{(2,1)}$ vector multiplets $\{V^\alpha\}$ $h_-^{(2,1)}$ chiral multiplets $\{z^{\hat{a}}\}$
$h^{(1,1)}$ hypermultiplets $\{v, \rho, b, c\}$	$h^{(1,1)}$ chiral multiplets $\{v^\alpha, \rho_\alpha\}$, $\{b^a, c^a\}$
universal hypermultiplet $\{\hat{\phi}, \hat{l}, B, C\}$	chiral multiplet $\{\hat{\phi}, C\}$
gravity multiplet $\{g_{\mu\nu}, C_{1\mu}, \bar{C}_{1\mu}\}$	gravity multiplet $\{g_{\mu\nu}\}$

KK compactification to 4D

$$S^{(4)}_{O3/O7} = \int_{\mathbb{M}_{3,1}} -\tfrac{1}{2}R * \mathbf{1} - \hat{K}_{I\bar{J}}\, dM^I \wedge *d\bar{M}^J + e^{\hat{K}}\left(\hat{K}^{I\bar{J}} D_I \hat{W} D_{\bar{J}} \hat{\bar{W}} - 3|\hat{W}|^2\right) + \dots$$

Kähler coordinates: $M^I = \{z^{\hat{a}}, \tau, G^a, T_\alpha\}$

$\tau = \hat{l} + ie^{-\hat{\phi}}$

$G^a = c^a - \tau b^a$

$T_\alpha = \frac{3i}{2}\rho_\alpha + \frac{3}{4}\mathcal{K}_\alpha - \frac{3i}{4(\tau-\bar{\tau})}\mathcal{K}_{\alpha bc} G^b (G-\bar{G})^c$

Intersection numbers

$\mathcal{K}_{\alpha\beta\gamma} = \int_{\mathcal{M}_6} \omega_\alpha \wedge \omega_\beta \wedge \omega_\gamma \,, \quad \mathcal{K}_{ab\gamma} = \int_{\mathcal{M}_6} \omega_a \wedge \omega_b \wedge \omega_\gamma$

$\mathcal{K}_\alpha \equiv \mathcal{K}_{\alpha\beta\gamma} v^\beta v^\gamma$

$\mathcal{K} \equiv \mathcal{K}_{\alpha\beta\gamma} v^\alpha v^\beta v^\gamma = 3!\mathrm{Vol}(\mathcal{M}_6)$

Kähler potential (in non Kähler coordinates)

$$\hat{K} = -\ln\left(-i\int \Omega \wedge \bar{\Omega}\right) - \ln(-i(\tau - \bar{\tau})) - 2\ln(\mathcal{K})$$

$\hat{K}_{I\bar{J}} = \frac{\partial^2 \hat{K}}{\partial M^I \partial \bar{M}^J} \equiv \mathcal{G}_{I\bar{J}} \quad \rightarrow \quad \mathcal{G}_{\hat{a}\hat{\bar{b}}} = -\frac{1}{\int \Omega\wedge\bar{\Omega}} \int \chi_{\hat{a}} \wedge \bar{\chi}_{\hat{\bar{b}}}$

Fluxes

Consider warped-metric

$$ds^2 = e^{2A}\tilde{g}_{\mu\nu}dx^\mu dx^\nu + e^{-2A}\tilde{g}_{mn}dy^m dy^n$$

And fluxes

$$F^{(5)}, \quad F^{(3)} \underset{\underset{G^{(3)} = F^{(3)} - \tau H^{(3)}}{\uparrow}}{\&} H^{(3)}, \quad F^{(1)} = 0 \;\; (\tau \text{ constant})$$

- Poincare invariance

$$\tilde{F}^{(5)} = d\chi^{(4)} + *d\chi^{(4)}\,, \qquad \chi^{(4)} = \alpha\, dx^0 \wedge dx^1 \wedge dx^2 \wedge dx^3$$

$$G^{(3)} : G_{mnp}(y)$$

- Bianchi identities

$$d\tilde{F}^{(5)} = e^{2A}\mu_3\rho_3 + H^{(3)} \wedge F^{(3)}$$

$$\Downarrow$$

$$\tilde{\nabla}^2\alpha = e^{2A}\mu_3\rho_3 + 2e^{-6A}\partial_m\alpha\,\partial^m e^{4A} + \frac{i\,e^{\hat{\phi}+2A}}{12}G_{mnp}(*_6\bar{G})^{mnp}$$

$$dF^{(3)} = dH^{(3)} = 0 \Rightarrow dG^{(3)} = 0$$

- Bianchi identity for $\tilde{F}^{(5)}$ - Tr (Einstein)$_{\mu\nu}$ equation

$$\tilde{\nabla}^2(\underset{\underset{\int_{\text{compact CY}} \ldots = 0}{\uparrow}}{e^{4A}} - \alpha) = e^{-6A}\left|\partial(\underset{\underset{\geq 0}{\uparrow}}{e^{4A}} - \alpha)\right|^2 + \frac{e^{2A}e^{\hat{\phi}}}{6}\left|*_6 \underset{\underset{\geq 0}{\uparrow}}{G^{(3)}} - iG^{(3)}\right|^2$$

Global tadpole cancellation condition: on compact CY

$$e^{4A} = \alpha \;\text{ and }\; *_6 G^{(3)} = iG^{(3)} \quad \rightarrow \quad G^{(3)}\text{: ISD}$$

$$dG^{(3)} = d *_6 G^{(3)} = 0 \quad \Rightarrow \quad G^{(3)} \text{ is harmonic}$$

$$\begin{array}{ll} *_6\Omega = -i\Omega & *_6\,\chi_{\hat{a}} = i\chi_{\hat{a}} \\ *_6\bar{\Omega} = i\bar{\Omega} & *_6\,\bar{\chi}_{\hat{a}} = -i\bar{\chi}_{\hat{a}} \end{array} \quad \Rightarrow \quad G^{(3)} \in \underset{\underset{\text{SUSY}}{\uparrow}}{H_-^{(2,1)}} \oplus \underset{\underset{\cancel{\text{SUSY}}}{\uparrow}}{H_-^{(0,3)}}$$

- ISD flux: "no-scale"

  Not very interesting phenomenologically

- Add IASD flux: $\not{\text{S}}$USY

  In compact manifolds EOM solved locally only

  IASD flux: *perturbation* over ISD

  EOM for $G^{(3)}$:

$$d\left[e^{4A}(*_6 G^{(3)} - iG^{(3)})\right] = 0 \Rightarrow e^{4A}(*_6 G^{(3)} - iG^{(3)}) \text{ is } \underset{\displaystyle \in H_-^{(1,2)} \oplus H_-^{(3,0)}}{\overset{\uparrow}{\text{harmonic}}}$$

$$\Downarrow$$

$$e^{4A}(*_6 G_3 - iG_3) = \frac{2i}{w}\left(\Omega \int \bar{\Omega} \wedge G^{(3)} + \mathcal{G}_w^{\hat{a}\hat{\bar{b}}}\ \bar{\chi}_{\hat{\bar{b}}} \int \chi_{\hat{a}} \wedge G^{(3)}\right)$$

$$w = \int e^{-4A} \Omega \wedge \bar{\Omega}$$

- 3-form flux generates superpotential for moduli $\hat{W}$

  $\hat{W} = \int \Omega \wedge G^{(3)}\ , \qquad \hat{W} \neq 0\ \Rightarrow\ G^{(3)}\ : (3,0)$

- From $\hat{W}$ we get a potential $\hat{V}$ for moduli

  $\hat{V} = e^{\hat{K}}\left(K^{I\bar{J}} D_I \hat{W} D_{\bar{J}} \hat{\bar{W}} - 3|W|^2\right)$

$$\hat{V} = ie^{\hat{K}}\left(\int \Omega \wedge \bar{G}^{(3)} \int \bar{\Omega} \wedge \underset{(3,0)}{\underset{\uparrow}{G^{(3)}}} + \mathcal{G}_w^{\hat{a}\hat{\bar{b}}} \int \chi_{\hat{a}} \wedge \underset{(1,2)}{\underset{\uparrow}{G^{(3)}}} \int \bar{\chi}_{\hat{\bar{b}}} \wedge \bar{G}^{(3)}\right)$$

- $\hat{V} \neq 0$ when IASD flux present

<u>Branes</u>. D3-brane action

$$S_{DBI+WZ} \begin{array}{l} \nearrow \text{ bosonic NA} \quad \text{Myers'99} \\ \searrow \text{ fermionic abelian} \end{array}$$

Cederwall et al '96
Bergshoeff Townsend '96
Aganagic, Popoescu Schwarz '96

Bosonic:

$$\boxed{\mathrm{S}^{\mathrm{sf}}_{\mathrm{DBI}} = -\mu_p \int_W^{p+1} \xi Tr e^{-\hat{\phi}} \sqrt{-\det\left(\varphi^*\left(E_{\mu\nu} + E_{\mu n}(\underline{Q^{-1} - \delta})^{nm} E_{m\nu}\right) + \ell F_{\mu\nu}\right) \underline{\det(Q^n{}_m)}}}$$

$Q^n{}_m = \delta^n{}_m + i\ell\left[\phi^n, \phi^k\right] E_{km} \rightarrow$ get $[\phi, \phi][\phi, \phi]$ term

$$\boxed{\mathrm{S}_{\mathrm{WZ}} = \mu_p \int_W Tr\left(\varphi^*(\underline{e^{i\ell \mathrm{i}_\phi \mathrm{i}_\phi}} \sum_n C^{(n)} e^B) e^{\ell F}\right)}$$

$\mathrm{i}_\phi \mathrm{i}_\phi C^{(2)} = -\phi^i \phi^j C_{ij} \rightarrow$ get couplings to all $C^{(n)}$

- $Tr\left(\mathrm{i}_\phi^{2k} C^{(p)}\right) = 0$ for $\left[\phi, C^{(0)}\right] = 0$, but $C^{(p)} = C^{(p)}(y_0) + \ell\phi^m \partial_m C^{(p)}(yo) + \ldots$

  $\Rightarrow Tr(\phi^i\phi^j\phi^k C_{ij}) \rightarrow \frac{\ell}{3} Tr(\phi^i\phi^j\phi^k F_{ijk}) + \ldots$

$$
\boxed{\begin{aligned}
&\mathcal{S}^{\mathrm{E}}_{\mathrm{D3}} = -\mu_3 \int_W d^4\xi \sqrt{-\det \hat{g}_{\mu\nu}} Tr\Big(-\tfrac{6\,\ell^2}{\mathcal{K}_w}\tilde{g}_{i\bar{j}}\mathrm{D}_\mu\phi^i \mathrm{D}^\mu \bar{\phi}^{\bar{j}} \\
&+\ \tfrac{18\ell^2}{\mathcal{K}_w^2} h_{mn}\phi^m\phi^n + \tfrac{9\,\ell^2}{\mathcal{K}_w^2} e^{\phi}\tilde{g}_{mn}\tilde{g}_{op}\left[\phi^m,\phi^o\right]\left[\phi^p,\phi^n\right] \\
&+\tfrac{3i\ell^2 e^{\phi}}{\mathcal{K}_w^2} e^{4A}\left((*_6 G_3 - iG_3)_{nmp} + h.c.\right)\phi^n\phi^m\phi^p \\
&\ \tfrac{\ell^2}{4} Re\left[-i\tau\,(F + i *_4 F)_{\mu\nu}(F + i *_4 F)^{\mu\nu}\right]\ \Big)
\end{aligned}}
$$

- $h_{mn} = \tilde{\nabla}_n\tilde{\nabla}_m(e^{4A} - \alpha)|_{y_0}$

$e^{4A} - \alpha = h(y)\ ,\ \ h(y_0) = 0\ ,\ \tilde{\nabla}_n h|_{y_0} = 0\ ,\ h_{mn} = \tilde{\nabla}_n\tilde{\nabla}_m h|_{y_0}$

EOM:

$$\tilde{\nabla}^2(e^{4A} - \alpha) = e^{-6A}\left|\partial(e^{4A} - \alpha)\right|^2 + \frac{e^{2A}e^{\hat{\phi}}}{6}\left|*_6 G^{(3)} - iG^{(3)}\right|^2$$

$$\tilde{g}^{mn}(y_0)h_{mn} = \frac{e^{2A}e^{\hat{\phi}}}{6}\left|*_6 G_3 - iG_3\right|^2_{y_0}$$

- $e^{4A}(*_6 G_3 - iG_3) = \frac{2i}{w}\left(\Omega\int\bar{\Omega}\wedge G_3 + \mathcal{G}_w^{\hat{a}\hat{\bar{b}}}\ \bar{\chi}_{\hat{\bar{b}}}\int\chi_{\hat{a}}\wedge G_3\right)$

$$V \sim \left(\textstyle\int\bar{\Omega}\wedge G_3\right)\Omega_{ijk}\,\phi^i\phi^j\phi^k + \mathcal{G}_w^{\hat{a}\hat{\bar{b}}}\ \left(\textstyle\int\chi_{\hat{a}}\wedge G_3\right)\bar{\chi}_{\hat{\bar{b}}i\bar{j}\bar{k}}\,\phi^i\phi^{\bar{j}}\phi^{\bar{k}}$$

Fermionic action.

Computed up to dim 3 expanding superfields in component fields M.G.

- Known fermionic action is abelian
- Add Tr (Abelian expression)
- Intrinsic NA terms $\mathcal{O}(\bar{\theta}[\phi,\theta]) \to$ higher order

$$\mathcal{S}^E_{ferm} = \frac{36\mu_3}{\mathcal{K}_w^2}\int_W d^4\xi\sqrt{-det\hat{g}_{\mu\nu}}e^{3A}$$

$$Tr\left(-\frac{\mathcal{K}_w^{1/2}}{2}\overline{\theta}\hat{\Gamma}^{\mu}D_{\mu}\theta + \frac{e^{\hat{\phi}/2}e^{A}}{48}Re[(*_6G_3 - iG_3)_{pqr}]\overline{\theta}\Gamma^{pqr}\theta\right)$$

$$\theta\,\epsilon\,\bar{1}6 \to (\bar{\mathbf{2}},\mathbf{4}) \oplus (\mathbf{2},\bar{\mathbf{4}})$$

$$\theta = a\,\psi^i \otimes \Omega_{ijk}\gamma^{jk}\chi + b\,\lambda \otimes \chi + \ h.c.$$

$$\tilde{D}_m\chi = 0$$

$$\boxed{\begin{aligned}\mathcal{L}^E_{ferm} &= \mu_3\ell^2 Tr\Big(-i\frac{6}{\mathcal{K}_w}\,\overline{\psi}^{\bar{i}}\hat{\gamma}^{\mu}D_{\mu}\psi^l\tilde{g}_{\bar{i}l} - ie^{-\hat{\phi}}\,\overline{\lambda}\hat{\gamma}^{\hat{\mu}}D_{\mu}\lambda \\ &+\frac{\sqrt{6}}{4}e^{\hat{K}/2}\Big[-\frac{e^{-\hat{\phi}}}{2}\int\bar{\Omega}\wedge G^{(3)}\ \lambda\lambda \\ &+27\frac{1}{w}\,\mathcal{G}_w^{\hat{a}\hat{\bar{b}}}\,\Omega^{\bar{s}\bar{k}\bar{l}}\,(\bar{\chi}_{\hat{\bar{b}}})_{\,i\bar{k}\bar{l}}\,\tilde{g}_{j\bar{s}}\int\chi_{\hat{a}}\wedge G^{(3)}\ \psi^i\psi^j\Big] + h.c\Big)\end{aligned}}$$

- Gaugino masses $m = e^{\hat{K}/2}\int\bar{\Omega}\wedge G^{(3)}$
- ψ^i-fermions mass matrix

  $\mu_{ij} = e^{\hat{K}/2}\frac{1}{w}\,\mathcal{G}_w^{\hat{a}\hat{\bar{b}}}\,\Omega^{\bar{s}\bar{k}\bar{l}}\,(\bar{\chi}_{\hat{\bar{b}}})_{\,i\bar{k}\bar{l}}\,\tilde{g}_{j\bar{s}}\int\chi_{\hat{a}}\wedge G^{(3)}$

Soft SUSY breaking in supergravity

Kaplunovsky and Louis
Brignole Ibañez and Muñoz

- Observable sector: $\phi^i, \psi^i \to \Phi^i$
- Moduli M^I

Expand for small ϕ

- $K(M, \bar{M}, \phi, \bar{\phi}) = \hat{K}(M, \bar{M})$

$+Z_{i\bar{j}}(M, \bar{M})\, \phi^i \bar{\phi}^{\bar{j}} + \left(\frac{1}{2}\, H_{ij}(M, \bar{M})\, \phi^i \phi^j + \text{h.c.} \right) + \ldots$

- $W(M, \phi) = \hat{W}(M) + \frac{1}{2}\, \tilde{\mu}_{ij}(M)\, \phi^i \phi^j + \frac{1}{3}\, \tilde{Y}_{ijk}(M)\, \phi^i \phi^j \phi^k + \ldots$
- $\mathrm{R}ef(M) = g^{-2}$

> SU~~SY~~ by some mechanism (for us flux) that gives vevs
> $$< F^I > = < e^{\hat{K}/2}\, \hat{K}^{I\bar{J}} \left(\partial_{\bar{J}} \hat{W} + \hat{W} \partial_{\bar{J}} \hat{K} \right) > \neq 0$$

In $\mathcal{L}$ constructed out of $K(M, \bar{M}, \phi, \bar{\phi}), W(M, \phi), f(M)$:

- Replace F^I by VEVs
- Take limit $M_{pl} \to \infty$, $m_{3/2} \sim M_{susy}^3 / M_{pl}^2$ fixed (flat limit)

Softly broken effective $\mathcal{N} = 1$ sugra theory with matter Φ^i

Effective theory

- $W^{(\mathrm{eff})} = \frac{1}{2}\,\mu_{ij}\,\phi^i\phi^j + \frac{1}{3}\,Y_{ijk}\,\phi^i\phi^j\phi^k$

  $\rightarrow \mu_{ij} = e^{\hat{K}/2}\tilde{\mu}_{ij} + m_{3/2}H_{ij} - F^{\bar{I}}\bar{\partial}_{\bar{I}}H_{ij}$

  $\rightarrow Y_{ijk} = e^{\hat{K}/2}\tilde{Y}_{ijk}$, $\qquad m_{3/2} = e^{\hat{K}/2}\hat{W}$

- $V^{(\mathrm{eff})} = \frac{1}{2}D^2 + Z^{i\bar{j}}\,(\partial_i W^{(\mathrm{eff})})(\partial_{\bar{j}}\bar{W}^{(\mathrm{eff})}) +$ $m^2_{i\bar{j},soft}\,\phi^i\bar{\phi}^{\bar{j}} + \frac{1}{3}\,A_{ijk}\phi^i\phi^j\phi^k + \frac{1}{2}\,B_{ij}\phi^i\phi^j + \text{h.c.}$

  $\rightarrow D = \frac{g}{\sqrt{2}}\,\bar{\phi}^{\bar{i}}Z_{\bar{i}j}\phi^j$

  $\rightarrow m^2_{i\bar{j},soft} =$
  $C^2|m_{3/2}|^2 Z_{i\bar{j}} - F^I F^{\bar{J}} R_{I\bar{J}i\bar{j}} + 2m_{3/2}(C^2-1)Z_{i\bar{j}}$

  $\rightarrow A_{ijk} = F^I D_I Y_{ijk}$

  $\rightarrow B_{ij} = F^I D_I \mu_{ij} - \bar{m}_{3/2}\mu_{ij}$

  $R_{I\bar{J}i\bar{j}} = \partial_I\partial_J Z_{i\bar{j}} - \Gamma^k_{Ii}Z_{k\bar{l}}\Gamma^{\bar{l}}_{\bar{J}\bar{j}}$, $\qquad \Gamma^l_{Ii} = Z^{l\bar{j}}\partial_I Z_{\bar{j}i}$

  $D_I Y_{ijk} = \partial_I Y_{ijk} + \frac{1}{2}\hat{K}_I Y_{ijk} - 3\Gamma^l_{Ii}Y_{ljk}$

  $D_I\mu_{ij} = \partial_I\mu_{ij} + \frac{1}{2}\hat{K}_I\mu_{ij} - 2\Gamma^l_{Ii}\mu_{lj}$

  $C^2 = 1 + \frac{V_0}{3|m|^2_{3/2}}$

- $m = \frac{1}{2}F^I\partial_I\,\ln(\mathrm{Re}f)$

From D3-action we read:

1) Flux independent terms

- Bosonic kinetic terms: $Z_{i\bar{\jmath}} D_\mu \phi^i D^\mu \phi^{\bar{\jmath}}$

$\rightarrow \frac{1}{\mathcal{K}_w} D_\mu \phi^i D^\mu \phi^{\bar{\jmath}} \tilde{g}_{i\bar{\jmath}} \Rightarrow Z_{i\bar{\jmath}} = \frac{\tilde{g}_{i\bar{\jmath}}}{\mathcal{K}_w} = -i \frac{v^\alpha (w_\alpha)_{i\bar{\jmath}}}{\mathcal{K}_{w\,\alpha\beta\gamma} v^\alpha v^\beta v^\gamma}$

$\rightarrow H_{ij}$

$K = \hat{K}(M, \bar{M}) + Z_{i\bar{\jmath}}(M, \bar{M})\, \phi^i \bar{\phi}^{\bar{\jmath}} + \frac{1}{2} H_{ij}(M, \bar{M})\, \phi^i \phi^j +$ h.c.

- Gauge kinetic term: $-\frac{1}{4} Re \left[f_{ab} (F + i * F)^a_{\mu\nu} (F + i * F)^{b\,\mu\nu} \right]$

$\rightarrow f_{ab} = -i \tau \delta_{ab}$

- Bosonic quartic term: $Z^{i\bar{\jmath}} (\partial_i W^{(\text{eff})})(\partial_{\bar{\jmath}} \bar{W}^{(\text{eff})})$

$\rightarrow \frac{e^{\hat{\phi}}}{\mathcal{K}_w^2} \tilde{g}_{i\bar{\jmath}} \tilde{g}_{k\bar{l}} [\phi^i, \phi^{\bar{\jmath}}][\phi^k, \phi^{\bar{l}}] \Rightarrow$

$$W^{(\text{eff})} = \frac{e^{\hat{\phi}/2}}{\mathcal{K}_w^{3/2}} \frac{\Omega_{ijk}}{\|\Omega\|} \phi^i \phi^j \phi^k = e^{\hat{K}/2} \underset{\substack{\uparrow \\ \widetilde{Y}_{ijk}}}{\Omega_{ijk}} \phi^i \phi^j \phi^k$$

- Bosonic/fermionic quadratic term: $Z^{i\bar{\jmath}} (\partial_i W^{(\text{eff})})(\partial_{\bar{\jmath}} \bar{W}^{(\text{eff})})$
  $\partial^2_{ij} W^{(\text{eff})} \psi^i \psi^j$

$\rightarrow$ No flux independent $\begin{matrix} \phi\phi \\ \psi\psi \end{matrix}$ term $\Rightarrow \tilde{\mu}_{ij} = 0$

2) Flux dependent terms

- Bosonic masses

$$M^2_{i\bar\jmath} = m^2_{i\bar\jmath,susy} + m^2_{i\bar\jmath,soft} = Z^{l\bar k}\mu_{il}\bar\mu_{\bar\jmath\bar k} + m^2_{i\bar\jmath,soft}$$

$$\tilde g^{i\bar\jmath} M_{i\bar\jmath} = \frac{\ell^2 e^{\hat\phi} e^{2A}}{\mathcal{K}_w^2}\left|*_6 G^{(3)} - i G^{(3)}\right|^2$$

$$= \frac{\ell^2 e^{\hat K}}{w}\Big[\|\Omega\|^2 \int \Omega\wedge\bar G^{(3)} \int\bar\Omega\wedge G^{(3)} + \mathcal{G}_w^{\hat a\hat{\bar b}}\mathcal{G}_w^{\hat c\hat{\bar d}} (\bar\chi_{\hat{\bar b}})_{i\bar k\bar l}\,(\chi_{\hat c})^{\widetilde{i\bar k\bar l}} \int\chi_{\hat a}\wedge G^{(3)} \int\bar\chi_{\hat{\bar d}}\wedge\bar G^{(3)}\Big]$$

$$\boxed{G^{(3)}\ :\ \text{(3,0) or (1,2)}}$$

- Fermionic masses

$$\mu_{ij} = \partial^2_{ij} W^{(\mathrm{eff})} \quad \text{(susy)}$$

$$\mu_{ij} = \frac{\ell^2 e^{\hat K/2}}{w}\,\mathcal{G}_w^{\hat a\hat{\bar b}}\,\Omega^{\bar s\bar k\bar l}\,(\bar\chi_{\hat{\bar b}})_{i\bar k\bar l}\,\tilde g_{j\bar s}\int\chi_{\hat a}\wedge G^{(3)}$$

$$\boxed{G^{(3)}\ :\ \text{(1,2)}}$$

- Gaugino masses

$$m \quad (\cancel{\text{susy}})$$

$$m = -\frac{\sqrt6}{8} e^{\hat K/2}\int\bar\Omega\wedge G^{(3)}$$

$$\boxed{G^{(3)}\ :\ \text{(3,0)}}$$

- Soft A-terms

$$A_{ijk} \quad (\cancel{\text{susy}})$$

$$A_{ijk} = \ell^2\, e^{\hat K}\int\bar\Omega\wedge G^{(3)}\ \ \Omega_{ijk}$$

$$\boxed{G^{(3)}\ :\ \text{(3,0)}}$$

- Soft B-terms

$$B_{ij} \quad (\cancel{\text{susy}})$$

$$B_{ij} = 0$$

Consistency

1) ISD flux: $*_6 G^{(3)} = iG^{(3)} \quad \Rightarrow \quad G^{(3)}$: (2,1) or (0,3)

$$M^{(\mathrm{D3})}, \mu^{(\mathrm{D3})}, m^{(\mathrm{D3})}, A^{(\mathrm{D3})}, B^{(\mathrm{D3})} = 0$$

- (2,1): SUSY

$$\hat{W} = 0,\ \partial_I \hat{W} = 0 \Rightarrow D_I \hat{W} = 0,\ F^I = 0,\ m_{3/2} = 0$$
$$\Downarrow$$
$$M^{(\mathrm{eff})}, \mu^{(\mathrm{eff})}, m^{(\mathrm{eff})}, A^{(\mathrm{eff})}, B^{(\mathrm{eff})} = 0 \quad \surd$$

- (0,3): SU~~SY~~, no-scale

$$\hat{W} \neq 0, F^{T_\alpha} \neq 0 \quad \text{but} \quad \hat{V} = 0 \text{ (no-scale)}$$

<u>Is $V^{(\mathrm{eff})} = 0$</u>?

$$\rightarrow \mu^{(\mathrm{eff})} = m_{3/2} H_{ij} - F^{\bar{I}} \bar{\partial}_{\bar{I}} H_{ij}. \qquad H_{ij} \begin{array}{l} \nearrow \frac{v^\alpha w_\alpha}{\mathcal{K}_w} \\ \searrow z^{\hat{a}} \end{array}$$

$$\mathrm{F}^{\bar{A}} \partial_{\bar{A}} H_{ij} = m_{3/2} H_{ij}, \quad A = \{\text{Kähler}, \tau\}$$

$$\mu^{(\mathrm{eff})} \overset{\Downarrow}{=} -\underset{\substack{\uparrow \\ \int \chi_a \wedge G^{(3)} \rightarrow G^{(3)} : (1,2)}}{F^{\bar{z}^{\hat{a}}}} \partial_{\bar{z}^{\hat{a}}} H_{ij} = 0 \quad \surd$$

$$\Rightarrow m^{(\mathrm{eff})}_{i\bar{j},susy} = 0 \quad \surd$$
$$B_{ij} = 0 \quad \surd$$

$$\rightarrow A^{(\mathrm{eff})}_{ijk} = e^{\hat{K}/2} F^I \left[(\partial_I + \hat{K}_I) \tilde{Y}_{ijk} - 3\Gamma^l_{Ii} \tilde{Y}_{ljk} \right] = 0 \quad \surd$$

$$\rightarrow m^{(\mathrm{eff})} = \tfrac{1}{2} F^I \partial_I ln(Ref) = -\tfrac{i}{2} e^{\hat{\phi}} \underset{\substack{\uparrow \\ \int \bar{\Omega} \wedge G^{(3)} \rightarrow G^{(3)} : (3,0)}}{F^\tau} = 0 \quad \surd$$

$$\rightarrow m^{(\mathrm{eff})}_{i\bar{j},soft} = 0 \quad \surd$$

2) ISD + AISD flux

$$M^{(\mathrm{D3})}, \mu^{(\mathrm{D3})}, m^{(\mathrm{D3})}, A^{(\mathrm{D3})} \quad \neq 0\,,\;\; B^{(\mathrm{D3})} = 0$$

$$\rightarrow \mu^{(\mathrm{eff})} = -F^{\bar{z}^{\hat{\bar{a}}}} \partial_{\bar{z}^{\hat{\bar{a}}}} H_{ij} = -e^{\hat{K}/2} \mathcal{G}_w^{\hat{a}\hat{\bar{b}}} \; \partial_{\bar{z}^{\hat{\bar{b}}}} H_{ij} \int \chi_{\hat{a}} \wedge G^{(3)}$$

$$= \frac{\ell^2 e^{\hat{K}/2}}{w} \, \mathcal{G}_w^{\hat{a}\hat{\bar{b}}} \, \Omega^{\bar{s}\bar{k}\bar{l}} \, (\bar{\chi}_{\hat{\bar{b}}})_{\,i\bar{k}\bar{l}} \, \tilde{g}_{j\bar{s}} \int \chi_{\hat{a}} \wedge G^{(3)} \qquad \surd$$