Non-linear supersymmetry and MSSM

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1. Non-linear SUSY and goldstino
2. Description of low energy couplings

   I.A.-Tuckmantel '04; Komargodski-Seiberg '09
3. Non-linear MSSM — I.A.-Dudas-Ghilencea-Tziveloglou '10
4. Extended supersymmetry and brane dynamics

   Bagger-Galperin '97; I.A.-Derendinger-Maillard '08

   Ambrosetti-I.A.-Derendinger-Tziveloglou '09 + '10

Non-linear supersymmetry $\Rightarrow$ goldstino mode χ

Volkov-Akulov '73

Why study goldstino interactions:

- Effective field theory of SUSY breaking at low energies $m_\chi << m_{susy}$

  e.g. gauge mediation dominant vs gravity mediation

  χ: longitudinal gravitino with $m_\chi \simeq \dfrac{m_{susy}^2}{M_{Planck}} \lesssim m_{soft} << m_{susy}$

  $M_{Planck} \to \infty$: SUGRA decoupled

  massless χ coupled to matter $\sim 1/m_{susy}$

- Brane dynamics: half SUSY of the bulk broken but NL realized

  $\Rightarrow$ strongly constrain coupling of brane to bulk fields

Non-linear SUSY transformations: [5]

$$\delta\chi_\alpha = \frac{\xi_\alpha}{\kappa} + \kappa\,\Lambda^\mu_\xi\,\partial_\mu\chi_\alpha \qquad \Lambda^\mu_\xi = -i\left(\chi\sigma^\mu\bar{\xi} - \xi\sigma^\mu\bar{\chi}\right)$$

κ: goldstino decay constant (SUSY breaking scale) $\quad \kappa = 1/\left(\sqrt{2}m^2_{susy}\right)$

Goldstino interactions: 3 formulations

- Standard realization

  Volkov-Akulov '73, Clark-Love '96, Clark-Lee-Love-Wu '98

- Superfield formalism Ivanov-Kapustnikov '78, Samuel-Wess '83

  Brignole-Feruglio-Zwirner '97, Luty-Ponton '98, I.A.-Tuckmantel '04

- Constrained superfields

  Rocek-Tseytlin '78, Lindstrom-Rocek '79, Komargodski-Seiberg '09

Standard realization

Define the 'vierbein': $E_\mu^a = \delta_\mu^a + \kappa^2\, t_\mu^a \qquad t_\mu^a = i\chi \overleftrightarrow{\partial}_\mu \sigma^a \bar{\chi}$

$\delta(\det E) = \kappa\, \partial_\mu \left(\Lambda_\xi^\mu \det E\right) \Rightarrow$ invariant action:

$$S_{VA} = -\frac{1}{2\kappa^2}\int d^4x \det E = -\frac{1}{2\kappa^2} - \frac{i}{2}\chi\sigma^\mu \overleftrightarrow{\partial}_\mu \bar{\chi} + \dots$$

Generalization to matter and gauge fields:

$$S_{eff} = \int d^4x \det E\, \mathcal{L}_{SM}(\phi)$$ invariant if $\delta\phi = \kappa\, \Lambda_\xi^\mu \partial_\mu \phi$ and so $\mathcal{L}_{SM}$

However problem with derivatives $\Rightarrow$ define SUSY covariant ones:

$$\mathcal{D}_a\phi \equiv \left(E^{-1}\right)_a^\nu D_\nu\phi \qquad \mathcal{F}_{ab} \equiv \left(E^{-1}\right)_a^\lambda \left(E^{-1}\right)_b^\rho F_{\lambda\rho}$$

$$\mathcal{L}_{eff} = \det E\, \mathcal{L}_{SM}(\phi, \mathcal{D}_\mu\phi) = \mathcal{L}_{SM}(\phi, D_\mu\phi) + \kappa^2\, t^{\mu\nu}\, T_{\mu\nu} + \dots$$

universal coupling to stress-tensor but NOT the most general inv action

Superfield formalism

Recipe: $\phi(x) \to \Phi(x, \theta, \bar{\theta}) \equiv \phi(\tilde{x})$ $\quad$ $\tilde{x}^\mu = x^\mu + \Lambda^\mu_\theta(\tilde{x})$ [3] [10]

$$= \phi(x) + \kappa \Lambda^\mu_\theta \partial_\mu \phi + \ldots \quad \Rightarrow$$

Goldstino (spinor) superfield: $\mathcal{G}_\alpha = \frac{\theta_\alpha}{\kappa} + \chi_\alpha(\tilde{x})$

space-time derivatives: use the 'vierbein' $E(\tilde{x})$

e.g. $\mathcal{F}_{ab}(x, \theta, \bar{\theta}) \equiv \left[\left(E^{-1}\right)_a^{\ \lambda} \left(E^{-1}\right)_b^{\ \rho} F_{\lambda\rho} \right] (\tilde{x})$

List of lowest dim operators

2 operators of dim 6 linear in χ [8]

$$S_1 = C_1 \int d^4x\ \kappa\, F_{\mu\nu} \psi \sigma^\mu \partial^\nu \bar{\chi} + h.c. \qquad S_2 = C_2 \int d^4x\ \kappa\, (\psi \partial_\alpha \chi) D^\alpha \phi + h.c.$$

Quadratic in χ: 1 operator of dim 7

$$S_7 = C_7 \int d^4x\ \kappa^{3/2} \phi_1 \phi_2\ \partial_\mu \chi J^{\mu\nu}_{(\frac{1}{2},0)} \partial_\nu \chi + h.c. \qquad J^{\mu\nu}_{(\frac{1}{2},0)} = \frac{i}{4} \sigma^{[\mu} \bar{\sigma}^{\nu]}$$

$+$ 5 operators of dim 8

$$S_3 = C_3 \int d^4x\, \kappa^2 (\psi_1 \partial^\mu \chi)(\bar{\psi}_2 \partial_\mu \bar{\chi}) + h.c. \quad S_4 = C_4 \int d^4x\, \kappa^2 (\psi_1 \psi_2)(\partial_\mu \chi \partial^\mu \chi) + h.c.$$

$$S_5 = C_5 \int d^4x\, \kappa^2 \phi_1 \overleftrightarrow{D}_\mu \phi_2 i \partial_\alpha \chi \sigma^\mu \partial^\alpha \bar{\chi} + h.c.$$

$$S_6 = C_6 \int d^4x\, \kappa^2 \partial^\alpha \chi \sigma^\mu \partial^\nu \bar{\chi} \partial_\alpha F_{\mu\nu} + h.c.$$

$$S_8 = C_8 \int d^4x\, \kappa^2 \phi_1 \phi_2 \phi_3 (\partial_\mu \chi J^{\mu\nu}_{(\frac{1}{2},0)} \partial_\nu \chi) + h.c.$$

D-brane examples

Type II (closed) strings on $4d$ Minkowski $M_4 \times X_6$ internal $6d$ manifold

X_6 flat $\Rightarrow N = 8$ SUSY ; X_6 Calabi-Yau $\Rightarrow N = 2$ SUSY

Single stack of N Dp-branes $\Rightarrow$ half SUSY is spontaneously broken $p \geq 3$

$(p-3)$ dims wrapped around cycles in $X_6 \Rightarrow 4d$ effective field theory

- Gauge group: $G = U(N)$ (generically)
- SUSY: half remains unbroken Q_e ; other half NL realized Q_o

  broken SUSY commutes with $G \Rightarrow$ goldstino $= U(1)$ gaugino of Q_e

Intersecting branes: all SUSY is generally broken except for special angles

e.g. $\theta_1 + \theta_2 + \theta_3 = 0$ for $X_6 = T^2 \times T^2 \times T^2$

goldstino becomes a combination of the 2 gauginos

1) Goldstino decay constant: sum of brane tensions

$$\frac{1}{2\kappa^2} = T_1 + T_2 \qquad T_i = \frac{M_s^4}{4\pi^2 g_i^2} N_i$$

2) Goldstino couplings: only 3 non-vanishing up to order κ^2 [6]

$$C_1 = \sqrt{2} \quad ; \quad C_2 = 2 \quad ; \quad C_3 = 2$$

- universal coefficients independent of brane-angles
- C_3: fixes the field theory ambiguity of 4-fermion operator

Brignole-Feruglio-Zwirner '97, I.A.-Benakli-Laugier '01

Constrained superfields

spontaneous global $S\!\!\!/USY$: no supercharge but still conserved supercurrent

$\Rightarrow$ superpartners exist in operator space (not as 1-particle states)

$\Rightarrow$ constrained superfields: 'eliminate' superpartners

Goldstino: chiral superfield X_{NL} satisfying $X_{NL}^2 = 0 \Rightarrow$ [21]

$$X_{NL}(y) = \frac{\chi^2}{2F} + \sqrt{2}\theta\chi + \theta^2 F \qquad y^\mu = x^\mu + i\theta\sigma^\mu\bar{\theta}$$

$$= F\Theta^2 \qquad \Theta = \theta + \frac{\chi}{\sqrt{2}F}$$

$$\mathcal{L}_{NL} = \int d^4\theta X_{NL}\bar{X}_{NL} - \frac{1}{\sqrt{2}\kappa}\left\{\int d^2\theta X_{NL} + h.c.\right\} = \mathcal{L}_{VA}$$

$$F = \frac{1}{\sqrt{2}\kappa} + \dots$$

Constrained matter superfelds

- Fermions: Q_{NL} satisfying $Q_{NL}X_{NL} = 0$ (eliminate sfermions) $\Rightarrow$

$$Q_{NL} = \sqrt{2}\left(\psi - \frac{F_Q\chi}{F}\right)\Theta + F_Q\Theta^2$$

- Complex scalars: H_{NL} with $X_{NL}\bar{H}_{NL} =$ chiral (eliminate 'higgsinos') [5]

$$\Rightarrow H_{NL} = H(\hat{y}) \qquad \hat{y} = y^\mu + i\sqrt{2}\theta\sigma^\mu\bar{\chi}(\hat{y})/\bar{F}(\hat{y})$$

- Gauge fields: V_{NL} convenient gauge choice: $X_{NL}V_{NL} = 0$

eliminate gauginos: $X_{NL}W_{NL} = 0$ field strength $W = -\frac{1}{4}\bar{D}^2 DV$

$$\Rightarrow V_{NL} = -\Theta\left(\sigma^m V_m + \frac{D}{|F|^2}\chi\bar{\chi}\right)\bar{\Theta} + \frac{1}{2}\Theta^2\bar{\Theta}^2 D + \text{derivatives}$$

Goldstino couplings to matter supermultiplets

Before: goldstino coupling to non-SUSY matter $E << m_{soft}, m_{susy}$

sparticle masses $1/\sqrt{\kappa}$

$\rightarrow$ constrained matter superfelds

However if $m_{soft} \lesssim E << m_{susy} \;\Rightarrow$ linear SUSY in matter sector

$\rightarrow$ goldstino coupling to ordinary matter superfields

constrained X_{NL} coupled to MSSM

Komargodski-Seiberg '09

Assumption in the following: gaugino, higgsino, slepton masses $<< m_{susy}$

results independent on squark masses $\Rightarrow$ can be much higher

Equivalence theorem $\Rightarrow$ leading goldstino couplings:

$$\sim \int \partial_\mu \chi \, J^\mu = - \int \chi \, \partial_\mu J^\mu \leftarrow \text{supercurrent}$$

Equations of motion: $\partial_\mu J^\mu \sim$ soft terms

$\rightarrow$ generalization to non-linear terms: superfield formalism

Usually parametrization of soft SU̸SY terms using auxiliary spurion:

$$S = m_{soft}\theta^2$$

Non-linear MSSM: replace $S \rightarrow \sqrt{2}\kappa m_{soft} X_{NL} = \frac{m_{soft}}{m_{susy}} X_{NL}$

F-auxiliary in X_{NL}: dynamical field with no derivatives to be solved

$$-\bar{F} = m_{susy}^2 + \frac{B\mu}{m_{susy}^2} h_1 h_2 + \frac{A_u}{m_{susy}^2} \tilde{u}_R \tilde{q} h_2 + \cdots$$

$\Rightarrow$ compact form for all goldstino couplings at linear and non-linear level

Non-linear MSSM

$$\mathcal{L} = \mathcal{L}_{SUSY} + \mathcal{L}_{X_{NL}} + \mathcal{L}_H + \mathcal{L}_m + \mathcal{L}_{AB} + \mathcal{L}_g$$

with

$$\begin{aligned}
\mathcal{L}_H &= \sum_{i=1,2} \frac{m_i^2}{m_{susy}^4} \int d^4\theta \; X_{NL}^\dagger X_{NL} \; H_i^\dagger \, e^{V_i} \, H_i \\
\mathcal{L}_m &= \sum_{\Phi} \frac{m_\Phi^2}{m_{susy}^4} \int d^4\theta \; X_{NL}^\dagger X_{NL} \, \Phi^\dagger e^V \, \Phi \quad ; \quad {\color{red}\Phi = Q, U^c, D^c, L, E^c} \\
\mathcal{L}_{AB} &= \frac{1}{m_{susy}^2} \int d^2\theta \, X_{nl} \, (A_u \, H_2 \, Q \, U^c + A_d \, Q \, D^c \, H_1 + A_e \, L \, E^c \, H_1) \\
&\quad + \frac{B\mu}{m_{susy}^2} \int d^2\theta \, X_{NL} \, H_1 \, H_2 + h.c. \\
\mathcal{L}_g &= \sum_{i=1}^{3} \frac{1}{8 g_i^2} \frac{m_{\lambda_i}}{m_{susy}^2} \int d^2\theta \, X_{NL} \, \mathrm{Tr} \, [\, W^\alpha \, W_\alpha]_i + h.c.
\end{aligned}$$

Phenomenological analysis

I.A.-Dudas-Ghilencea-Tziveloglou '10

Higgs potential is modified:

$$V = V_{MSSM} + 2\kappa^2 \left| m_1^2|h_1|^2 + m_2^2|h_2|^2 + B\mu h_1 h_2 \right|^2 + \mathcal{O}(\kappa^4) \quad \Rightarrow$$

$m_{1,2}, B\mu$: soft mass parameters, μ: higgsino mass

Classical value of light higgs mass can be increased above the LEP bound

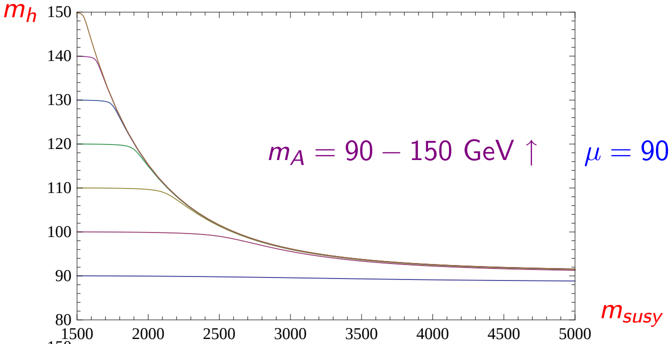
for $m_{susy} \sim$ a few TeV

large $\tan\beta$ limit: $m_h^2 = m_Z^2 + \dfrac{v^2}{2m_{susy}^2}(2\mu^2 + m_Z^2)^2 + \cdots$

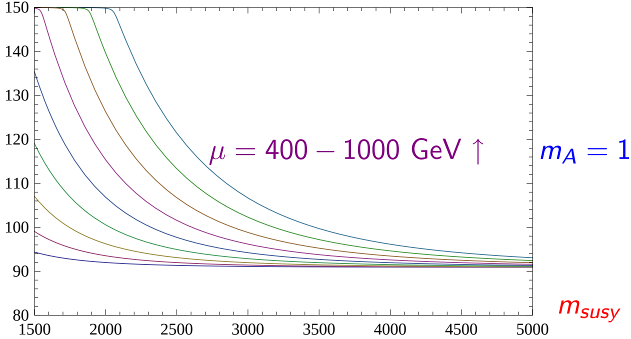
$\rightarrow$ e.g. $\mu = 900$ GeV, $m_{susy} = 2$ TeV $\quad \Rightarrow \quad m_h = 114.4$ GeV

Quartic higgs coupling increases for large soft masses $\Rightarrow$ [18]

MSSM 'little' fine tuning of the EW scale is alleviated



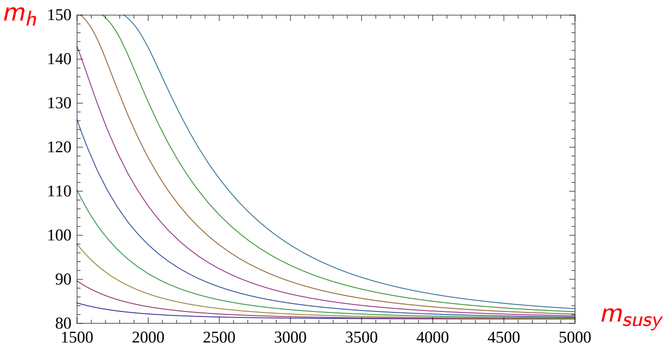
$\mu = 900$ GeV; $\tan\beta = 50$



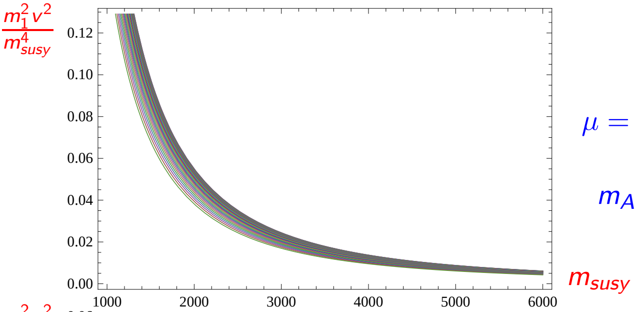
$m_A = 150$ GeV; $\tan\beta = 50$

Mild dependence on $\tan\beta$

$\mu = 400 - 1000$ GeV $\uparrow$ $\qquad$ $m_A = 150$ GeV; $\tan\beta = 5$

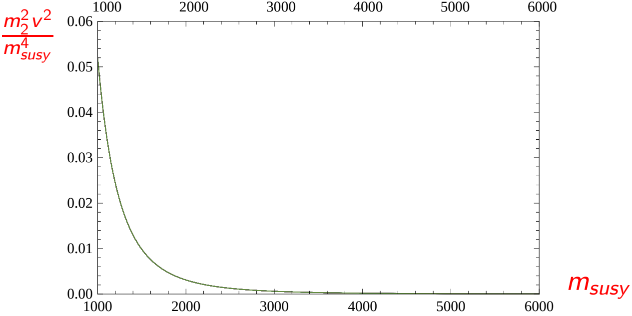


Validity of perturbative expansion: $m_i^2 v^2 / m_{susy}^4 << 1$



$\mu = 900$ GeV; $\tan\beta = 50$

$m_A = 90 - 650$ GeV $\uparrow$ [14]



Invisible decays of Higgs and Z boson

Other relevant couplings at order $\mathcal{O}(\kappa)$: $\frac{1}{m_{susy}^2}\times$

$$\left(m_1^2\,\chi\,\psi_{h_1^0}\,h_1^{0\,*}+m_2^2\,\chi\,\psi_{h_2^0}\,h_2^{0\,*}\right)+B\mu\,\left(\chi\,\psi_{h_2^0}\,h_1^0+\chi\,\psi_{h_1^0}\,h_2^0\right)+$$

$$\sum_{i=1,2}\frac{m_{\lambda_i}}{\sqrt{2}}\,\tilde{D}_i^a\,\chi\lambda_i^a+\sum_{i=1}^{2}\frac{m_{\lambda_i}}{\sqrt{2}}\,\chi\,\sigma^{\mu\nu}\,\lambda_i^a\,F_{\mu\nu,\,i}^a+h.c.$$

$\Rightarrow$ invisible higgs decay $h\rightarrow\chi+$ NLSP if NLSP is light enough

otherwise inverse decay studied in the past

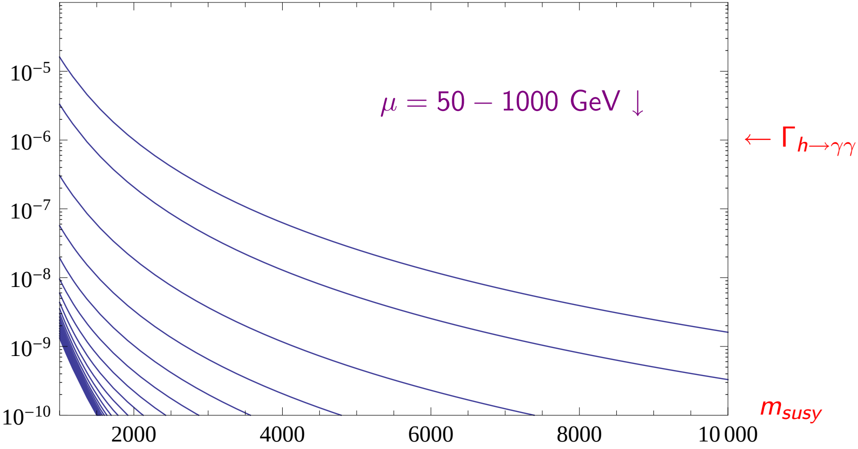
taking also into account the goldstino components of higgsinos/gauginos

from SUSY terms: $\sim h_i^0\lambda\tilde{h}_i^0$

Similarly $Z\rightarrow\chi+$ NLSP $\Rightarrow m_{susy}\gtrsim$ 400-700 GeV from Z-width

$\Delta\Gamma_Z\lesssim 2.3$ MeV

$\Gamma_{h\to\chi+\mathrm{NLSP}}$ $m_A = 150$ GeV; $\tan\beta = 50$; $(m_{\lambda_1}, m_{\lambda_2}) = (70, 150)$ GeV



NL extended supersymmetry $\quad N = 1_L + 1_{NL}$

Goldstino in multiplet of $N = 1$ SUSY: vector or chiral?

brane dynamics $\Rightarrow$ Maxwell goldstino multiplet

gauge chiral multiplet$\big|_{N=2}\, \mathcal{W} = (\text{vector } W + \text{chiral } X)_{N=1}$ [23]

$$\mathcal{W}(y,\theta,\tilde{\theta}) = X(y,\theta) + i\sqrt{2}\tilde{\theta}W(y,\theta) - \tilde{\theta}^2 \left[\tfrac{1}{4}\overline{DDX}(y,\theta) + \tfrac{1}{2\kappa}\right]$$

allow partial SUSY breaking $N = 2 \to N = 1$

$$\delta^* X = i\sqrt{2}\eta^\alpha W_\alpha \qquad \delta^* W_\alpha = \frac{i}{\sqrt{2}\kappa}\eta_\alpha + \ldots \leftarrow \text{linear SUSY}$$

$$\mathcal{L}^{N=2}_{Maxwell} = -\frac{1}{8}\int d^2\theta\, d^2\tilde{\theta}\, \mathcal{W}^2 + h.c. = \int d^2\theta \left[\frac{1}{2}W^2 - \frac{1}{4}X\overline{DDX} - \frac{1}{2\kappa}X\right] + h.c.$$

Partial SUSY breaking: non trivial prepotential $f(\mathcal{W})$

I.A.-Partouche-Taylor '96

DBI action

Non-linear $N = 2$ constraint: $\mathcal{W}_{NL}^2 = 0$

$$\Rightarrow \quad X^2 = 0 \quad , \quad XW_\alpha = 0 \quad , \quad WW - \frac{1}{2}X\overline{DDX} = \frac{1}{\kappa}X$$ [9]

$$X = \kappa W^2 - \kappa^3 \bar{D}^2 \frac{W^2\overline{W}^2}{1+A_+ + \sqrt{1+2A_+ + A_-^2}} \qquad A_\pm = \frac{\kappa^2}{2}\left(D^2W^2 \pm \bar{D}^2\overline{W}^2\right) = \pm A_\pm^*$$

$$\Rightarrow \mathcal{L}_{NL}^{N=2} = \frac{1}{4\kappa}\int d^2\theta X + h.c.$$

$$= \frac{1}{8\kappa^2}\left(1 - \sqrt{-\det(\eta_{\mu\nu} + 2\sqrt{2}\kappa F_{\mu\nu})}\right) + \ldots = \mathcal{L}_{\mathrm{DBI}} \leftarrow \text{D-brane}$$

The FI-term is also invariant under NL SUSY

$$\mathcal{L}_{FI} = \xi \int d^4\theta V; \quad W = -\frac{1}{4}\bar{D}^2 DV; \quad \delta^* V = \frac{i}{2\kappa}\left(\eta D + \bar{\eta}\bar{D}\right)\theta^2\bar{\theta}^2 + \ldots$$

$$\Rightarrow \mathcal{L}_{Max}^{NL} = \mathcal{L}_{NL}^{N=2} + \mathcal{L}_{FI}$$ [24]

Coupling to bulk hypermultiplets e.g. the universal dilaton

at least one isometry $\rightarrow$ single-tensor multiplet (RR 2-forms)

offers an off-shell formulation of matter (hyper) multiplet

$N = 2$ tensor $\mathcal{Y} = (\text{tensor } L + \text{chiral } \Phi)_{N=1}$ $\qquad D^2 L = \bar{D}^2 L = 0$

general action: $\mathcal{L}_{ST} = \int d^4\theta \mathcal{H}(L, \Phi, \bar{\Phi})$ with $\left(\partial_L^2 + 2\partial_\Phi \partial_{\bar{\Phi}}\right) \mathcal{H} = 0$

L supersymmetrizes the field-strength of a 2-index tensor $H = dB_2$

analog of $W = -\frac{1}{4}\bar{D}^2 DV$ for vector multiplet $F = dA$

To supersymmetrize the 2-index gauge potential B :

$L = D^\alpha \ell_\alpha + h.c.$ $\qquad \ell_\alpha$: chiral spinor superfield $\quad$ analog of V

$N = 2 \Rightarrow$ add auxiliary chiral superfield $Y \sim \theta^2 \epsilon \cdot C_4 \leftarrow$ 4-form

Single-tensor multiplet

$$\mathcal{Y}(y,\theta,\tilde\theta) = Y(y,\theta) + i\sqrt{2}\,\tilde\theta\,\ell(y,\theta) - \tfrac{i}{2}\tilde\theta^2\,\Phi(y,\theta)$$ [20]

Bononic field content:

$N=1$ superfield	Field	Gauge invariance	Number of fields
ℓ_α	$B_{\mu\nu}$	$\delta B_{\mu\nu} = 2\,\partial_{[\mu}\Lambda_{\nu]}$	$6_B - 3_B = 3_B$
	ℓ		1_B
Φ	Φ		2_B
	F_Φ		2_B (auxiliary)
Y	$C_{\mu\nu\rho\sigma}$	$\delta\, C_{\mu\nu\rho\sigma} = 4\,\partial_{[\mu}\Lambda_{\nu\rho\sigma]}$	$1_B - 1_B = 0_B$

coupling to $N=2$ vector $\mathcal{W}$ via Chern-Simons interaction:

$$\mathcal{L}_{CS} \sim g\int d^2\theta d^2\tilde\theta\,\mathcal{Y}\,\mathcal{W} = g\int d^2\theta\left(\ell^\alpha W_\alpha + \frac{1}{2}\Phi X - \frac{i}{2\kappa}Y\right) + h.c.$$

$\Rightarrow$ global SUSY limit of D-brane coupling to bulk hypermultiplets

$N = 2$ NL QED and novel super-higgs mechanism

General action: $\mathcal{L}_{tot}^{NL} = \mathcal{L}_{CS} + \mathcal{L}_{Max}^{NL}(W) + \mathcal{L}_{ST}(L, \Phi) \Rightarrow$ [21]

superhiggs mechanism without gravity:

Maxwell goldstino $\mathcal{W}_{NL}(W)$ is 'absorbed' by $N = 2$ tensor $\mathcal{Y}(L, \Phi)$

$\rightarrow N = 1$ massive vector (W, L) + massless chiral Φ:

- tensor of L + vector of $W \rightarrow$ massive vector
- scalar of $L \in$ same massive vector multiplet
- goldstino + fermion of $L \rightarrow$ Dirac spinor

System identical to Higgs phase of $N = 2$ NL QED (up to $\mathcal{L}_{ST}$)

$\Phi \sim Q_1 Q_2 \qquad L \sim |Q_1|^2 - |Q_2|^2 \qquad (Q_1, Q_2)$: charged hypermultiplet

adding mass-term $m \int d^2\theta\, \Phi \Rightarrow$ also Coulomb phase for $\xi = 0$

Vacuum structure of $N = 2$ NL QED

3 parameters: κ, ξ, m

- $m = 0$: Higgs phase and super-higgs without gravity

  $\langle Q_1 \rangle = v$ (real) arbitrary $\qquad \langle Q_2 \rangle = \sqrt{\xi + v^2}$
- $m \neq 0$, $\xi = 0$: Coulomb phase with $N = 2$ NL SUSY unbroken
- $m \neq 0$, $\xi \neq 0$: $N = 1$ (linear) SUSY is also broken

Ambrosetti-I.A.-Derendinger-Tziveloglou '09

Conclusions

Non-linear supersymmetry: powerful tool for studying:

- low energy SUSY breaking $E << m_{susy} \sim 1/\sqrt{\kappa}$

  Volkov-Akulov action and goldstino χ couplings to matter

  standard coupling to stress-tensor *not* the most general

- $m_{soft} \lesssim E << m_{susy}$: goldstino $\equiv$ spurion coupled to supermultiplets

  $\rightarrow$ Non-linear MSSM : narrow but interesting region

  - new quartic higgs coupling $\Rightarrow$ • can increase the higgs mass

    • reduce the MSSM fine tuning of the EW scale

- brane effective actions $\Rightarrow$ brane dynamics

  $N = 2$ NL SUSY $\Rightarrow$ DBI action and couplings to bulk fields

  vacuum structure of NL QED and superhiggs without gravity