GAUGE MEDIATION MASS PATTERN REVIEW

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OUTLINE

Supersymmetry and the MSSM
Mediation of supersymmetry breaking
Minimal Gauge Mediation
Semi Direct Gauge Mediation
Conclusions

$\mathcal{N} = 1$ Supersymmetry

Supersymmetry

Symmetry which maps bosons in fermions and viceversa

$$Q\,|\text{boson}>=|\text{fermion}> \qquad Q\,|\text{fermion}>=|\text{boson}>$$

$$\{Q_\alpha, Q^\dagger_{\dot\alpha}\} = 2\sigma^\mu_{\alpha\dot\alpha}P_\mu$$
$$\{Q_\alpha, Q_\beta\} = \{Q^\dagger_{\dot\alpha}, Q^\dagger_{\dot\beta}\} = 0$$
$$[P^\mu, Q_\alpha] = [P^\mu, Q^\dagger_{\dot\alpha}] = 0$$

- Irreducible representations of supersymmetry algebra are supermultiplets
- Supermultiplets contains bosons and fermions
- Superpartners have the same mass and quantum numbers
- Chiral superfields

$$\Phi = (\phi, \psi)$$

- Vector superfields

$$V_{Sfield} = (\lambda, A_\mu)$$

MSSM

- Matter and vector fields become supersymmetric

$$\text{Matter} \Rightarrow \text{ Chiral superfields } (\phi, \psi)$$

$$\text{Vector} \Rightarrow \text{Vector superfields } (\lambda, A^{\mu})$$

- Two Higgs chiral superfields

$$h \Rightarrow H_1, H_2$$

- Special ultraviolet finiteness properties (no quadratic divergencies)
- Address the hierarchy problem $M_{planck} \ggg M_{\text{weak}}$
- Better GUT unification
- Included in unification theories
  - Local supersymmetry includes gravity (Supergravity)
  - Superstring theory

SUPERSYMMETRY BREAKING

- Supersymmetry not realized at low energies

SUSY MUST BE BROKEN!!

- Soft susy breaking $\equiv$ No quadratic divergencies

SUPERSYMMETRY MUST BE BROKEN SOFTLY

$$\mathcal{L} = \mathcal{L}_{MSSM} + \mathcal{L}_{soft}$$

- $\mathcal{L}_{soft}$ = Soft terms

$m_{susy}\lambda_\alpha\lambda^\alpha$ Gaugino mass

$m_{susy}^2\phi^\dagger\phi$ Scalar mass

$A\phi^3$ A - term

$\vdots$

- Susy breaking scale m_{susy}
- Superpartners get masses of order m_{susy}

ASPECTS OF MSSM AND SOFT TERMS

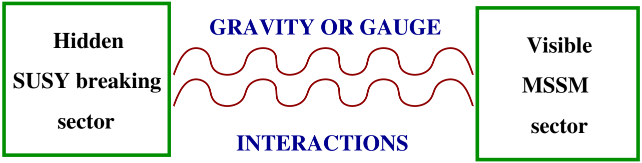
Z_2 SYMMETRY: R-PARITY

- Forbids lepton and baryon violating terms
- LSP stable $\Rightarrow$ Dark matter candidate

- 105 free parameters
- Flavour problem
- CP problem
- μ problem $\Rightarrow$ NMSSM

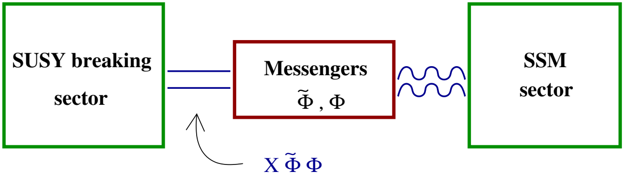
??? Scheme to predict structure of soft terms ???

Mediation of supersymmetry breaking



- Gravity Mediation
  - Effective Lagrangian description, Plank suppressed operators
  - Problem: Flavour violation, it leads to FCNC
- Gauge Mediation
  - No gravity
  - No Flavour Problem
  - Predictive for the soft terms
  - Problem: Landau Pole, μ, $B\mu$ ...
  - Low energy supersymmetry breaking
  - $\Rightarrow$ Dynamical Supersymmetry Breaking (strong dynamics in the hidden sector)

Minimal gauge mediation



- Supersymmetry breaking parametrized as $< X >= M + \theta^2 F_x$
- $\sqrt{F_x}$ susy breaking scale
- Introduce Messengers Φ and $\tilde{\Phi}$ in 5 and $\bar{5}$ of $SU(5)$ with

$$\Delta\mathcal{L}_{\text{mess}} = \int d^2\theta\, X\, \Phi\tilde{\Phi} \qquad < X >= M + \theta^2 F_x$$

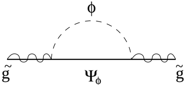
- Messengers mass matrix: split masses $m_\pm^2 = M^2 \pm |F_x|$, $M^2 \gg |F_x|$

$$\mathcal{L} \supset \begin{pmatrix} \phi & \tilde{\phi}^* \end{pmatrix} \begin{pmatrix} M^2 & F_x \\ F_x^* & M^2 \end{pmatrix} \begin{pmatrix} \phi^* \\ \tilde{\phi} \end{pmatrix}$$

- Susy breaking transmitted through loops of gauge and messengers fields

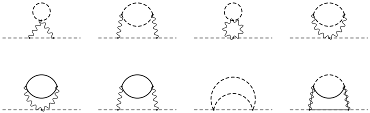
Soft masses in Minimal Gauge Mediation

- Loops generate soft susy breaking terms in the visible sector
- One loop gaugino masses



$$m_{\lambda,a} = \frac{\alpha_a}{4\pi}\frac{F_x}{M}$$

- Two loops scalar masses



$$m_{\phi_i}^2 = 2\left(\frac{F_x}{M}\right)^2 \left((\frac{\alpha_3}{4\pi})^2 C_3(i) + (\frac{\alpha_2}{4\pi})^2 C_2(i) + (\frac{\alpha_1}{4\pi})^2 C_1(i) \right)$$

Properties of gauge mediation

Model independent features

- Quite predictive in the mass spectrum
- No flavour problem
- Sum rules for scalar soft masses: $\mathrm{Tr} Y m^2 = 0$, $\mathrm{Tr}(B-L)m^2 = 0$

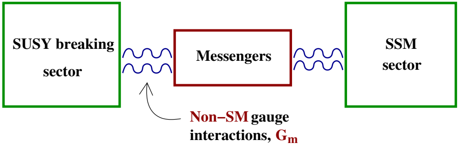
Most models of GMSB

- Gaugino mass unification: $\frac{m_{\lambda,1}}{\alpha_1} = \frac{m_{\lambda,2}}{\alpha_2} = \frac{m_{\lambda,3}}{\alpha_3}$
- Strongly int. sparticles heavier than weakly int.
- LSP: Gravitino

Some delicate issues

- μ and μ/B_μ problem
- Global $U(1)_R$ symmetry forbids gaugino mass term $m\lambda_\alpha\lambda^\alpha$ since $R[\lambda] = 1$
- Landau pole before GUT scale in models with many messengers
- Explain Hierarchy between susy br. scale and Planck scale (DSB)

SEMI DIRECT GAUGE MEDIATION



- Further assumption: Additional weakly coupled gauge group G_m
- Messengers couple to the susy br. sector only through G_m

$$\Phi_{a,i} \quad , \quad \tilde{\Phi}_{j,b} \qquad a,b \in G_m \qquad i,j \in G_{MSSM}$$

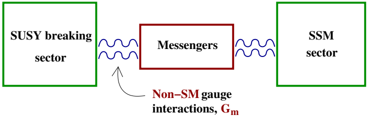
- Messengers do not partecipate to the susy breaking
- Tree level mass term for the messengers

$$W_{mess} = m_{mess}\Phi\tilde{\Phi}$$

- No Landau Pole problem (G_m can be a $U(1)$)

General Semi Direct GM

R.Argurio, M.Bertolini, G.Ferretti, A.M. arXiv:0912.0743



- Soft terms via loops of G_m, messengers and G_{MSSM}
- Perturbative computations in g_m and g_{SM}
- Gaugino masses expected at three loops
- Scalar masses at four loops
- Higher Susy breaking scale

Model Independent Analysis

- Gaugino mass screening
  - Three loop contribution sum to zero!!!
  - First non vanishing contribution at 5 loops
- Sfermion mass described in terms of two functions
  - One function $C(p^2/M^2)$ encodes hidden sector dynamics
  - Other function $K(p^2/m^2)$ encodes semi direct gauge mediation scheme
  - D term breaking in the hidden sector does not contribute

CONCLUSIONS

GAUGE MEDIATED THEORIES

- Promising for low energy supersymmetry breaking
- Address susy flavour problem
- Predictive soft mass spectrum

Martin: hep-ph/9709356; Giudice, Rattazzi: hep-ph/9801271

ISSUES FOR MODEL BUILDERS

- Model independent analysis
- Landau pole problem
- Dynamical Supersymmetry Breaking and $U(1)_R$ symmetry breaking
- Dark matter candidate
- μ and $B\mu$ problem

μ PROBLEM

μ PROBLEM

- Need μ term in Higgs superpotential

$$W = \mu H_1 H_2$$

- μ naturally of order UV scale $\mu \sim O(\Lambda_{UV})$
- We would like μ is of order EW scale
- $\Rightarrow$ We generate it with susy breaking $\mu \sim O(\Lambda_{SUSYbr})$

B_μ PROBLEM

B_μ PROBLEM

- We need μ both B_μ of the EW order in the scalar potential

$$V = \mu^2(h_1 h_1^\dagger + h_2 h_2^\dagger) + B_\mu(h_1 h_2 + \text{h.c.})$$

- Toy model: couple Higgs to susy breaking directly, small $\lambda \ll 1$

$$W = \lambda X H_1 H_2 \qquad\qquad < X >= x + \theta^2 F_x$$

- μ and B_μ terms are generated

$$\mu = \lambda x \qquad B_\mu = \lambda F_x$$

$$\Rightarrow \frac{B_\mu}{\mu} = \frac{F_x}{x} \sim 10 - 100 Tev \tag{1}$$

TOO LARGE

- (**??**) usual in gauge mediation scenario

R SYMMETRY AND LANDAU POLE

R SYMMETRY PROBLEM

$$R[\lambda] = 1$$

- Gaugino mass violates R symmetry (even discrete one)

$$\mathcal{L}_{gauginoM} = m_s \lambda_\alpha \lambda^\alpha$$

- Cannot be generated radiatively if R symmetry is preserved in susy breaking vacuum

LANDAU POLE PROBLEM

- In gauge mediation typically we add matter charged under gauge group of MSSM
- We have to control RG flow and preserve GUT
- Landau poles can arise before GUT scale

Dynamical supersymmetry breaking

Dynamical supersymmetry breaking

- Gauge group G in hidden sector drive susy breaking with strong dynamics effects (typically non perturbative ones)
- Lead to hierarchy between Λ_{SUSYbr} and Λ_{UV}

$$E_{vacuum} = \Lambda_{SUSYbr} = \Lambda_{UV}\ e^{-\frac{8\pi^2}{g^2(\Lambda_{UV})}}$$

Hidden sector is typically strongly coupled