# *Strongly Coupled Semi-Direct Mediation of Supersymmetry Breaking*


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# Contents

# 1. Introduction

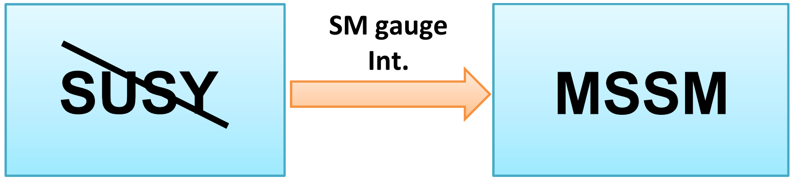
## Supersymmetry (SUSY)

*one of the most promising candidate*
*beyond the standard model.*

However,

*SUSY must be broken.*

***Gauge mediation*** *can naturally suppress FCNC.*



# *3 (main) types of gauge mediation*

***Minimal type*** $W = Xq\tilde{q},\ X = m + \theta^2 F$

Problem: *Color breaking minima often exist.*

***Direct type***

Gauging flavor symmetries of SUSY breaking sector and identifying them as SM gauge symmetries.

Problem: *Landau pole often exists.*

***Semi-direct type***

Messengers charged under hidden gauge group exist.

Problem: *gaugino mass is small (gaugino screening).*

## ***Gaugino screening***

Demonstrated *perturbatively*

**N. Arkani-Hamed, G. F. Giudice, M. A. Luty, and R. Rattazzi, arXiv:hep-ph/9803290.**

Little hierarchy between gaugino mass and scalar mass *(Naturalness problem occurs again).*

However, …

How about the case where ***messengers are strongly interacting and nonperturbative effects are important?***

**Leading order gaugino mass is generated by nonperturbative effects!**

# 2. Strongly coupled semi-direct mediation

**M. Ibe, Izawa K.-I., and Y. N., arXiv:0812.4089 [hep-ph], 0907.2970 [hep-ph].**

The model: *Supersymmetric QCD*

Gauge group: $SU(N)$

$Q, \tilde{Q}$ : Messengers, $\Phi, \tilde{\Phi}$ : SUSY breaking sector fields

The number of messengers: $N_f = N + 1$

→ SM gauge symmetries ($N = 4,\ N_f = 5$)

Superpotential: $W = X(\Phi\tilde{\Phi}) + \mu\,\mathrm{tr}Q\tilde{Q} + \kappa\,(\mathrm{tr}Q\tilde{Q})^2$

→ $X = m + \theta^2 F$

## *Messenger masses are smaller than dynamical scale.*

$$\mu \ll \Lambda_H \ll m$$

Integrating out $\Phi, \tilde{\Phi}$

➡ *Spurious dynamical scale*

: $$\Lambda = \Lambda_0(1+\theta^2 R) = m^{\frac{a}{b}} \Lambda_H^{1-\frac{a}{b}} \left(1+\theta^2 \frac{aF}{bm}\right)$$

$b = 3N - N_f = 2N - 1$

$a = N_\Phi$ for $N_\Phi$ pairs of (anti-)fundamentals $\Phi$ and $\tilde{\Phi}$.

$R \sim F/m \gtrsim 100\,\mathrm{TeV}$ : Characteristic mass scale of gauge mediation

## ***Low-energy effective theory***

$$W_{eff} = \frac{1}{\Lambda^b}(BM\tilde{B} - \text{det}M) + \mu\text{tr}M + \kappa(\text{tr}M)^2$$

$$(b = 3N - N_f = 2N - 1)$$

$$K_{eff} \simeq \left(\frac{\alpha^2|M|^2}{|\Lambda|^2} + \frac{\beta^2|B|^2}{|\Lambda|^{2(N-1)}} + \frac{\beta^2|\tilde{B}|^2}{|\Lambda|^{2(N-1)}}\right)$$

## ***SUSY breaking vacuum***

Minimizing the effective potential

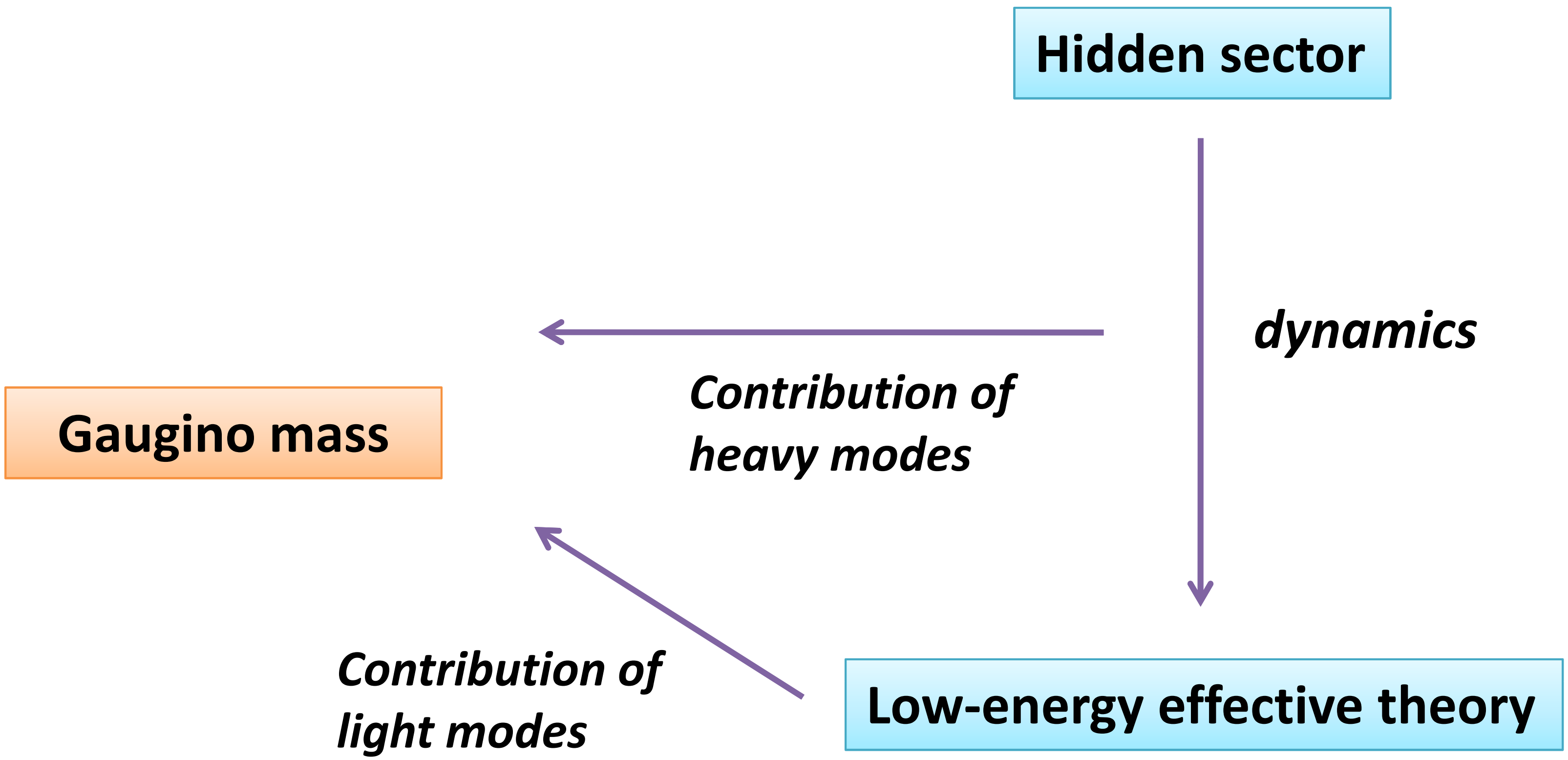
⇨ $\langle B\rangle = \langle\tilde{B}\rangle = 0, \ \langle M\rangle = (M_0 + \theta^2 M_1)\mathbf{1}$

*(No SM gauge symmetry breaking)*

$$\frac{M_1}{M_0} \simeq \frac{bR}{N}\left(1 + \frac{2\kappa\langle\text{tr}M\rangle}{N\mu}\right), \ \langle\text{tr}M\rangle \simeq N_f \sqrt[N]{\mu\Lambda_0^b}$$

# 3. Gaugino mass

*There are 2 contributions to gaugino mass…*



# *Contribution from light modes*

Low energy effective theory is weakly coupled.

➡ *Gaugino mass can be calculated perturbatively!*

The same calculation as minimal type.

$$\left[\, W = Xq\tilde{q},\ X = m + \theta^2 F \ \Rightarrow\ m_{1/2} \propto \frac{F}{m} \,\right]$$

$$W_{eff} \simeq \frac{1}{\Lambda_0^b}(1 - \theta^2 bR)\left(B\langle M\rangle\tilde{B} + \frac{1}{2}(M_0 + \theta^2 M_1)^{N-1}\mathrm{tr}\tilde{M}^2\right),\ \ \tilde{M} = M - \langle M\rangle$$

➡ $$\boxed{\delta m_{1/2} \simeq \frac{\alpha_{sm}}{2\pi} bR\left(\frac{\kappa\langle \mathrm{tr} M\rangle}{\mu} - 1\right)}$$

$\alpha_{sm}$ : SM gauge coupling

# ***Contribution from heavy modes***

Symmetries and transformation properties of fields:

| | $SU(N)$ | $SU(N_f)$ | $U(1)_R$ | $U(1)_A$ |
|---|---|---|---|---|
| $Q$ | $\mathbf{N}$ | $\mathbf{N}_f$ | $1-\frac{N}{N_f}$ | $1$ |
| $\tilde{Q}$ | $\overline{\mathbf{N}}$ | $\overline{\mathbf{N}}_f$ | $1-\frac{N}{N_f}$ | $1$ |
| $\mu$ | $\mathbf{1}$ | $\mathbf{1}$ | $2\frac{N}{N_f}$ | $-2$ |
| $\kappa$ | $\mathbf{1}$ | $\mathbf{1}$ | $-2+4\frac{N}{N_f}$ | $-4$ |
| $\Lambda^b$ | $\mathbf{1}$ | $\mathbf{1}$ | $0$ | $2N_f$ |

UV theory

| | $SU(N_f)$ | $U(1)_R$ | $U(1)_A$ |
|---|---|---|---|
| $B$ | $\mathbf{N}_f$ | $N-\frac{N^2}{N_f}$ | $N$ |
| $\tilde{B}$ | $\overline{\mathbf{N}}_f$ | $N-\frac{N^2}{N_f}$ | $N$ |
| $M$ | $\mathbf{adj}+\mathbf{1}$ | $2-2\frac{N}{N_f}$ | $2$ |

IR theory

$U(1)_A$–$SU(N_f)^2$ anomaly matching requires…

➡ ***Operator*** $(\ln\,\Lambda^b)\,\mathcal{W}^\alpha\mathcal{W}_\alpha$ ***in IR theory!***

$\mathcal{W}$ : SM gauge multiplet

➡ Gaugino mass: $m_{1/2} \simeq \frac{\alpha_{sm}}{2\pi} bR\frac{\kappa\langle \mathrm{tr} M\rangle}{\mu} \propto \Lambda_0^{\frac{b}{N}} R$

# 4. Conclusion

***<u>Strongly coupled semi-direct mediation</u>***

No SM gauge symmetry breaking.

No Landau pole problem.

Non-vanishing leading order gaugino mass.

$$: \; m_{1/2} \simeq \frac{\alpha_{sm}}{2\pi} b R \frac{\kappa \langle \mathrm{tr} M \rangle}{\mu} \;\propto\; \Lambda_0^{\frac{b}{N}} R$$

*One of the general frameworks with no phenomenological problems.*