R-symmetric Gauge Mediation and the MRSSM

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Based on work with
S. De Lope Amigo, P. Fox and E. Poppitz
arXiv:0809.1112, ...

A Puzzle

- With all the new operators, the MSSM has 124 parameters - and that's the MINIMAL model!
- Many of those parameters are flavor mixing angles and phases, implying large FCNC's and CP violation. This is called the **SUSY Flavor/CP Puzzle**.
- We need some principle to eliminate this flavor violation to avoid conflicts with observation and reduce the parameter space to something manageable for experiments.

A New Solution

- An R-symmetry rotates fields within a supermultiplet differently.
- Kribs, Poppitz, Weiner (arXiv:0712.2039) found that by imposing an additional R-symmetry to the MSSM you can have sizable flavor-violating operators while not generating large FCNC's or CP violation, as long as gluinos are heavy.
- We impose a $U(1)_R$ symmetry, although a discrete symmetry would work as well.

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  - No A-terms for the scalars; hence no left-right squark/slepton mixing.
  - No mu-term, but there is a B-term (complicated Higgs sector).

K-Kbar Mixing

Strongest constraint in SUSY flavor physics.

Parametrize mixing: $\delta_L \equiv \frac{m^2_{\tilde{Q}12}}{M^2_{\tilde{q}}}$ $\delta_R \equiv \frac{m^2_{\tilde{d}12}}{M^2_{\tilde{q}}}$

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The Low-Energy Effective Lagrangian is:

$$\mathcal{L}_{\text{eff}} = \frac{\alpha_s^2(M_{\tilde{g}})}{216}\left(\frac{M^2_{\tilde{q}}}{M^4_{\tilde{g}}}\right)\sum_n C_n(\mu)\mathcal{O}_n(\mu)$$

$$\begin{aligned}
\mathcal{O}_1 &= (\bar{d}^i_L \gamma^\mu s^i_L)(\bar{d}^j_L \gamma_\mu s^j_L) \\
\mathcal{O}_4 &= (\bar{d}^i_R s^i_L)(\bar{d}^j_L s^j_R) \\
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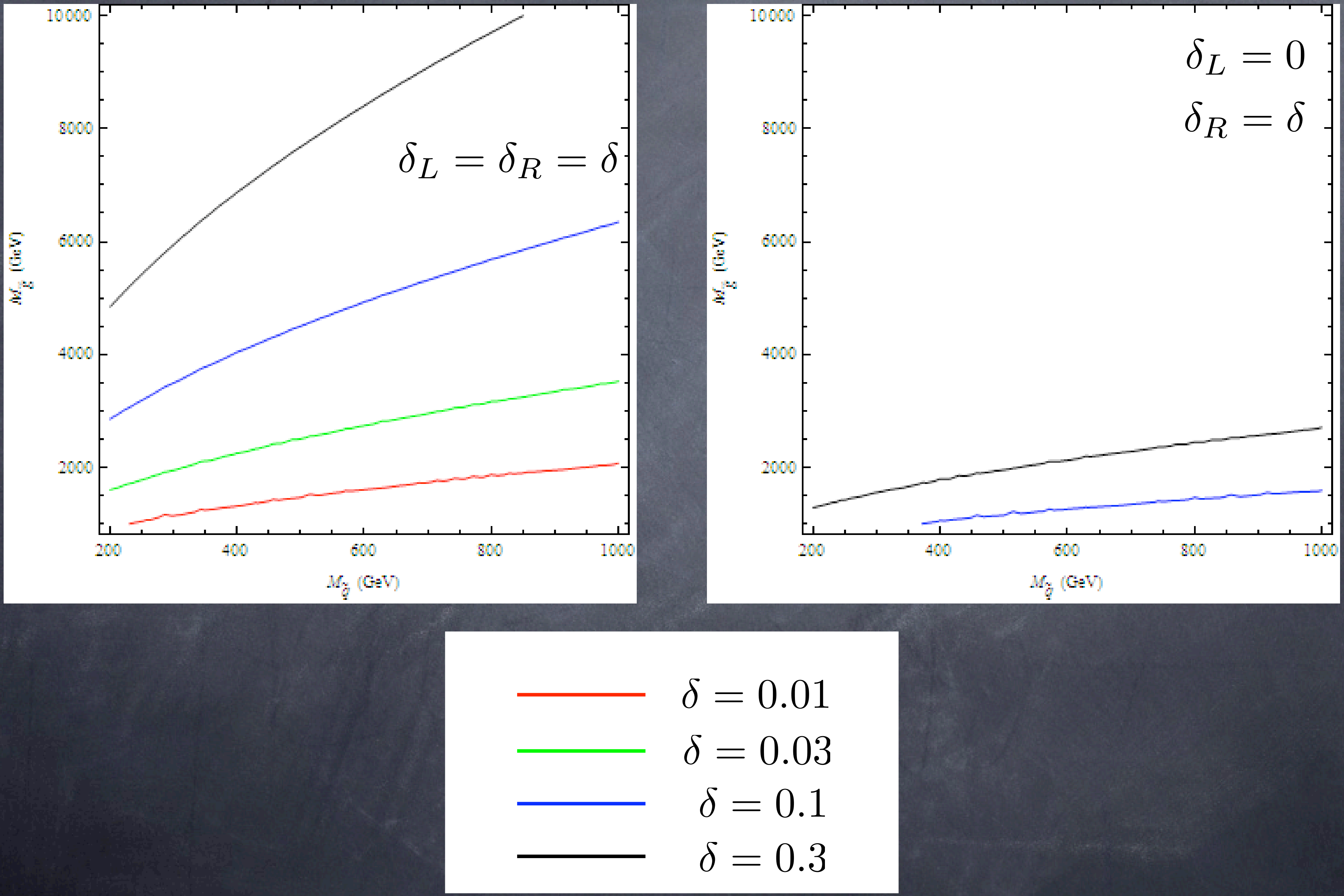
QCD Corrections computed in
A.B., S.-P. Ng, arXiv:0803.3811

K–Kbar Mixing



A Problem...

- Anytime you spontaneously break SUSY, you have a goldstino and a cosmological constant.
- When turning on supergravity, this goldstino is "eaten" by the gravitino (gauge field of SUSY) and it gains a mass which is R-violating (at least in N=1 SUSY).
- This mass term feeds into the MSSM through anomaly mediation, so it looks like this model can never be realized...

… A Solution!

- Gauge mediation has a very light gravitino, typically around 1 keV or so, rendering these troublesome effects irrelevant.
- Ordinary gauge mediation breaks the R-symmetry, but if we can find a framework where we can maintain the symmetry through a gauge-mediation-like mechanism, then we might realize the MRSSM naturally…

A Minimal Model

- Motivated originally by the ``ISS" Models, we need a SUSY-breaking **AND** an R-preserving messenger scalar mass, as well as an R-preserving chirality flip.
- We can seek to capture these effects in a minmal model with a pair of vector-like chiral messenger superfields, and a single chiral superfield in the adjoint representation of the gauge group:

$$W_{mess} = \sum_{i=1}^{N_{\rm mess}} \left(\Xi\, \bar{\varphi}^i \varphi^i + M_{\rm mess}\, \bar{\varphi}^i N^i + M_{\rm mess}\, \bar{N}^i \varphi^i + y\, \bar{\varphi}^i \Phi N^i - y\, \bar{N}^i \Phi \varphi^i \right)$$

The SUSY-breaking spurion is $\Xi = \theta^2 z M_{\rm mess}^2$

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Note: with all this matter, QCD will develop a Landau Pole Λ_3

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- IR ("Gauge Mediation") contributions.

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- $\Lambda \sim M_P$: UV operators are irrelevant; does not realize the large flavor-violating operators of the MRSSM, so we will not consider it here.
- $\Lambda \sim \frac{\Lambda_3}{4\pi}$: UV operators are important - this is the maximal size of the operators (using NDA). We will consider this case, but it could overestimate the size of these contributions.

UV Contributions

UV Dirac Gaugino Mass:

$$\int d^2\theta \, \frac{1}{\Lambda^3} \left(W^\alpha \Phi\right) \bar{D}^2 D_\alpha \left(\Xi^\dagger \Xi\right) \qquad m_{1/2} \sim M_{UV} \left(\frac{M_{UV}}{\Lambda}\right)$$

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UV Scalar Mass:

$$\int d^4\theta \, \frac{c_{ij}}{\Lambda^2} \left(\Xi^\dagger \Xi\right) Q_i^\dagger Q_j \qquad m_{0\;ij} \sim M_{UV}$$

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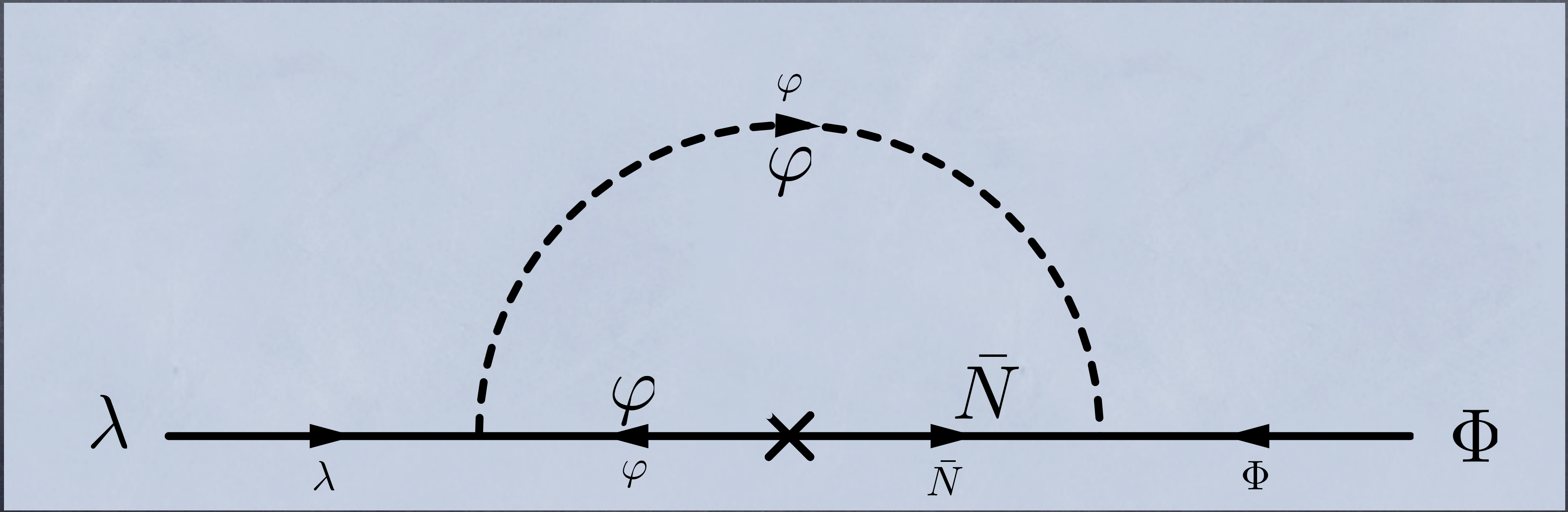

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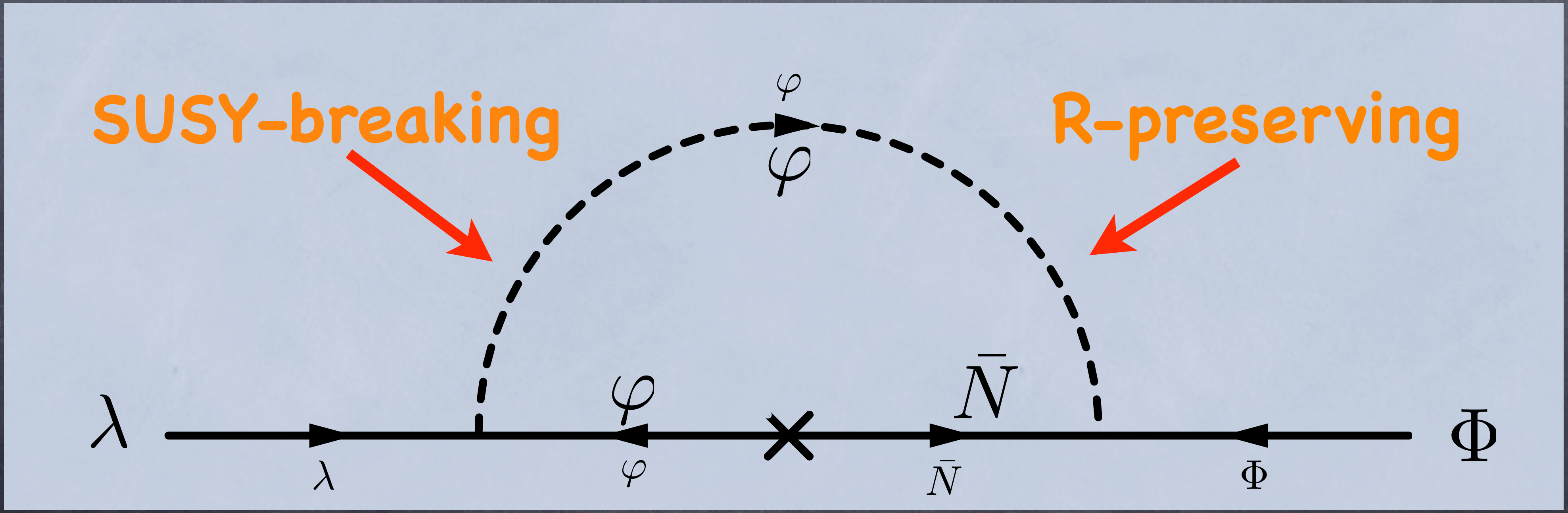

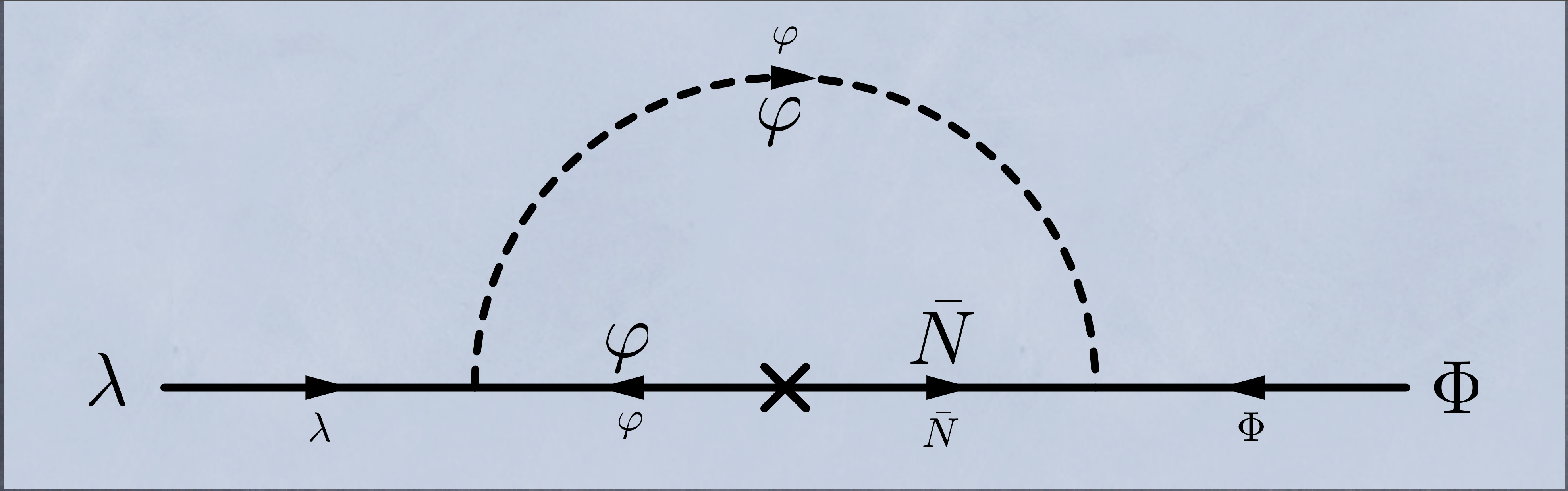

This diagram gives:

Yukawa dependent!

$$m_{1/2} = \frac{gy}{16\pi^2} M_{\rm mess} R(z) \cos\left(\frac{\langle \xi \rangle}{v}\right)$$

where we have the new function:

$$R(z) = \frac{1}{z}\left[(1+z)\log(1+z) - (1-z)\log(1-z) - 2z\right]$$

IR Contributions: Scalar Masses

Identical to Gauge Mediation with **one** messenger:

$$m_0^{(IR)2} = 2C_F^{(a)} \left(\frac{\alpha_a}{4\pi}\right)^2 M_{\rm mess}^2 F(z)$$

where F(z) is the usual GM function:

$$F(z) = (1+z)\left[\log(1+z) - 2\mathrm{Li}_2\left(\frac{z}{1+z}\right) + \frac{1}{2}\mathrm{Li}_2\left(\frac{2z}{1+z}\right)\right] + (z \to -z)$$

IR Contributions: Adjoint Scalar Masses

- Messenger loops will also generate masses for the adjoint scalars (at **ONE** loop!):

$$\begin{aligned} m_\phi^2 &= \frac{y^2}{16\pi^2} M_{\rm mess}^2 R_s(z) \\ B_\phi &= \frac{y^2}{16\pi^2} M_{\rm mess}^2 R(z) \end{aligned}$$

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- This leads to the prediction:

$$
\boxed{\frac{m_\phi}{m_{1/2}} \sim \frac{\sqrt{|B_\phi|}}{m_{1/2}} \sim \sqrt{\frac{4\pi}{\alpha}}}
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- Recall that the MRSSM needed gauginos heavier than squarks by a factor of 5. However:

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- This ratio function of z is strictly less than unity, so to make gauginos heavy requires a large Yukawa.

Benefits of The Generalized Model

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- Both the gaugino mass and the squark mass squared are proportional to N_{mess}. Thus the gaugino:squark mass ratio $\propto \sqrt{N_{\mathrm{mess}}}$.

Sample Spectrum 1

$M_{\rm mess} = 80\ \text{TeV}$ $N_{\rm mess} = 6$ $y = 3$ $z = 0.4$

$\tan\beta = 5$ $\tan\nu = 1$ $\lambda = 0$

All masses in GeV:

$M_1 = 257$ $M_2 = 370$ $M_3 = 612$

$m_{\tilde{e}} = 130$ $m_{\tilde{t}} = 986$ $|\mu| = 447$ $\sqrt{B_\mu} = 200$

$m_h = 80 \longrightarrow 134$ $\text{tuning} = 4\%$

$m_{\rm adj} = 4\ \text{TeV}$ $m_R = 312$

Sample Spectrum 2

$M_{\text{mess}} = 80 \text{ TeV} \qquad N_{\text{mess}} = 6 \qquad y = 3 \qquad z = 0.95$

$\tan\beta = 5 \qquad \tan\nu = 1 \qquad \lambda = 0$

All masses in GeV:

$M_1 = 2100 \qquad M_2 = 3000 \qquad M_3 = 4900$

$m_{\tilde{e}} = 296 \qquad m_{\tilde{t}} = 2200 \qquad |\mu| = 800 \qquad \sqrt{B_\mu} = 422$

$m_h = 54 \longrightarrow 152 \qquad \text{tuning} = 0.5\%$

$m_{\text{adj}} = 9 \text{ TeV} \qquad m_R = 693$

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- To satisfy flavor constraints, there is a tuning of the off-diagonal mass terms in the UV contribution.

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Thus: $c_D \sim 1$ for General Models

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- Using the results from $K-\bar{K}$ mixing:

$$m_0 = 1\text{TeV} \qquad \delta = 0.07$$

$$t = 2.7\%$$

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- RGM: A modified SUSY-breaking mediator that provides a new and unique spectrum, both through what it allows, and the nature of the mass spectrum.
- For RGM to realize MRSSM, it is possible but requires a better understanding of the UV theory to avoid tuning.

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The End!