Direct gaugino mediation

Andrey Katz

Daniel Green, AK, and Zohar Komargodski (arXiv:1008.2215)

Nathaniel Craig, Daniel Green, and AK (arXiv:1103.3708)

University of Maryland

May 16, 2011

SUSY Breaking 2011, CERN

Outline

SUSY at EW scale

What do we already know about SUSY?

- (almost) flavor blind
- does not have big CP phases
- either non-minimal or suffers from a little hierarchy problem

SUSY at EW scale

What do we already know about SUSY?

- (almost) flavor blind
- does not have big CP phases
- either non-minimal or suffers from a little hierarchy problem

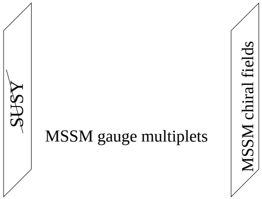
Flavor blindness and lack of CP-phases motivate specific mediation patterns of SUSY. In this talk I will concentrate on gauge and gaugino mediation, which are by construction perfectly flavor blind. I will also discuss some of their modifications, which are not flavor blind, but have good protection against excessive FCNCs.

Gaugino mediation

D.E. Kaplan, Kribs, Schmaltz (1999); Chacko, Luty, Nelson, Ponton(1999)

Gaugino mediation was proposed as extra-dimensional mediation pattern. This mediation scheme is flavor blind, there are no direct contact terms between the MSSM scalars and the SUSY-breaking sector.

Cartoon picture:



- Gauginos masses $\mathcal{L} \sim \int \frac{X W^\alpha W_\alpha}{M} d^2\theta$
- Scalar masses: suppressed at the mediation scale, get contributions from running
- flavor blind - true MFV

4D dynamical model with scalar screening?

- Gaugino mediation offers a nice mechanism of suppressing scalar masses compared to gaugino masses
- This mechanism can be realized in 4D via deconstruction $\Rightarrow$ fully calculable, on theoretically firm ground

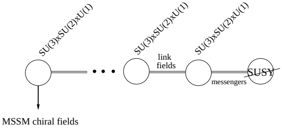
4D dynamical model with scalar screening?

- Gaugino mediation offers a nice mechanism of suppressing scalar masses compared to gaugino masses
- This mechanism can be realized in 4D via deconstruction $\Rightarrow$ fully calculable, on theoretically firm ground
- Can we build dynamical calculable model with the scalar mass screened?
- Can this screening compensate for the gaugino screening (which is a pervasive phenomenon in dynamical gauge-mediation models)?

Deconstructed Model

How do we deconstruct gaugino mediation?

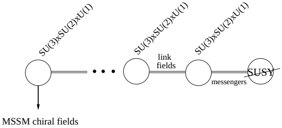
Cheng, D.E. Kaplan, Schmaltz, Skiba (2001); Csaki, Erlich, Grojean, Kribs (2001)



Deconstructed Model

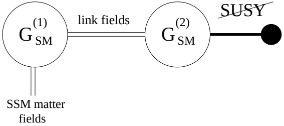
How do we deconstruct gaugino mediation?

Cheng, D.E. Kaplan, Schmaltz, Skiba (2001); Csaki, Erlich, Grojean, Kribs (2001)



At a scale v the link fields get VEVs, the gauge group is broken $SM^n \to SM$. The scalars are charged only under one gauge group and get no contributions above the scale v.

For any practical purpose we can replace this quiver by a simple two-site model:



Scales and regimes of the 2-site model

Scales of the two site model:

- M - messenger mass scale
- $\sqrt{F}$ - SUSY breaking scale
- v - breaking to the diagonal subgroup scale

Scales and regimes of the 2-site model

Scales of the two site model:

- M - messenger mass scale
- $\sqrt{F}$ - SUSY breaking scale
- v - breaking to the diagonal subgroup scale

$v \ll M$

- gaugino mass $m_\lambda \sim \frac{\alpha_2}{4\pi}\frac{F}{M}$
- above the scale v scalars get masses at 4 loops
- below the scale v: $m_{\tilde{f}}^2 \sim \left(\frac{\alpha_1}{4\pi}\right)^2 \left(\frac{v}{M}\right)^2 \left(\frac{F}{M}\right)^2$

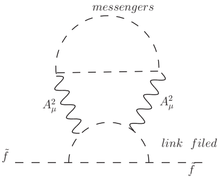
$v \gg M$

- the gauge group is broken to the diagonal at the scale v
- gaugino get mass $m_\lambda \sim \frac{\alpha_d}{4\pi}\frac{F}{M}$
- scalars are not screened $m_{\tilde{f}}^2 \sim \left(\frac{\alpha_d}{4\pi}\right)^2 \left(\frac{F}{M}\right)^2$

For $v \ll M$ we get scalar screening. The dominant contributions come from running and non-decoupling effects.

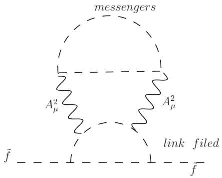
How imperfect is gaugino mediation in two-site model?

- Above the scale v – only 4-loop diagrams contribute to the scalar masses
- Three loop contribution mediated by link field cannot decouple. However one can show it is not log-enhanced, $m_{\tilde{f}}^2 \sim \frac{\alpha_1 \alpha_2^2}{(4\pi)^3} \left(\frac{F}{M}\right)^2$.

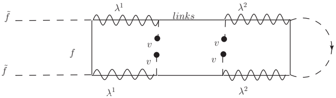


How imperfect is gaugino mediation in two-site model?

- Above the scale v – only 4-loop diagrams contribute to the scalar masses
- Three loop contribution mediated by link field cannot decouple. However one can show it is not log-enhanced, $m_{\tilde{f}}^2 \sim \frac{\alpha_1 \alpha_2^2}{(4\pi)^3} \left(\frac{F}{M}\right)^2$.



- Two loop diagrams are suppressed by v.



Some remarks about dynamical model

What do we mean by saying "dynamical model"?

- breaks SUSY dynamically
- has all necessary ingredients as integral parts of the model (link fields, messengers)

Some remarks about dynamical model

What do we mean by saying "dynamical model"?

- breaks SUSY dynamically
- has all necessary ingredients as integral parts of the model (link fields, messengers)

What ingredients we are looking for?

- SUSY breaking model with at least two flavor groups
- Two flavor groups are broken to the diagonal; breaking to the diagonal is the lowest scale in the theory
- Breaking to the diagonal occurs in the supersymmetric limit
- The messengers of SUSY-breaking are not charged under one of the flavor groups
- The messenger scale and the scale of breaking to the diagonal are parametrically separated

Dynamical model

It turns out that a simple and generic model can perform in the IR such a non-trivial dynamics.

- massive SQCD in free magnetic phase, namely $N_c < N_f < \frac{3}{2}N_c$
- add $(N_f - N_c) \equiv N$ masses m_1 and N_c masses m_2
- masses are important since the mass term in the UV $W \sim Q\tilde{Q}$ becomes dimension one operator in the IR $W \sim M$ signalling higgsing
- the flavor symmetry of the model is now $SU(N) \times SU(N_c)$
- add fields $S, \tilde{S}$, singlets under the color group and bifundamentals under the flavor group $SU(N) \times SU(N_c)$
- the most generic interaction terms one can write down is $W \sim SQ\tilde{Q} + \tilde{S}Q\tilde{Q}$ (with appropriate indices)
- assume that Yukawa interactions are order one, $\lambda \sim 1$

Claim: in the IR this simple theory reduces to the two-site model

SQCD w/ color singlets in the IR

The singlets and off-diagonal components of the meson are heavy at scale Λ. After integrating out heavy degrees of freedom there are no more $S, \tilde{S}$ fields and the meson is

$$M_{N_f \times N_f} = \begin{pmatrix} N_{N \times N} & 0 \\ 0 & M_{N_c \times N_c} \end{pmatrix}$$

SQCD w/ color singlets in the IR

The singlets and off-diagonal components of the meson are heavy at scale Λ. After integrating out heavy degrees of freedom there are no more $S, \tilde{S}$ fields and the meson is

$$M_{N_f \times N_f} = \begin{pmatrix} N_{N \times N} & 0 \\ 0 & M_{N_c \times N_c} \end{pmatrix}$$

The theory decoupled into two subsectors:

Sector 1

- includes $N_{N \times N}$ and magnetic quarks interacting with it
- global symmetry $SU(N)$

Sector 2

- Includes $M_{N_c \times N_c}$ and magnetic quarks
- global symmetry $SU(N_c)$

The sectors interact with one other through gauge interaction – magnetic group $SU(N)_m$

SUSY-breaking in SQCD w/ color singlets

The sector with $M_{N_c \times N_c}$ still has a rank condition (similar to the ISS) and breaks SUSY. After the SUSY is broken:

- the magnetic gauge group is completely higgsed
- the global symmetry group in the sector which breaks SUSY is $SU(N)_m \times SU(N_c) \to SU(N)_{diag} \times SU(N_c - N) \Rightarrow$ color-flavor locking

SUSY-breaking in SQCD w/ color singlets

The sector with $M_{N_c \times N_c}$ still has a rank condition (similar to the ISS) and breaks SUSY. After the SUSY is broken:

- the magnetic gauge group is completely higgsed
- the global symmetry group in the sector which breaks SUSY is $SU(N)_m \times SU(N_c) \to SU(N)_{diag} \times SU(N_c - N) \Rightarrow$ color-flavor locking
- another sector does not "know" that SUSY has been broken; the mass spectrum in that sector is supersymmetric
- the magnetic quarks in the SUSic sector were charged under $SU(N)_m$, after color-flavor locking occurred in the SUSY-breaking sector, they are charged under $SU(N)_{diag}$

Last step – breaking to the diagonal

The first sector does not break supersymmetry. However it has superpotential

$$W \sim \tilde{\chi} N \chi - \mu_1^2 N$$

Masses vs. higgsing

The last term in W is the mass-term in the UV. It causes the fields χ to get VEVs (not necessarily break SUSY) and higgs the symmetries they are charged under. Note that this mechanism of higgsing and the connection between the higgsing in the IR and mass terms in the UV is completely generic.

Last step – breaking to the diagonal

The first sector does not break supersymmetry. However it has superpotential

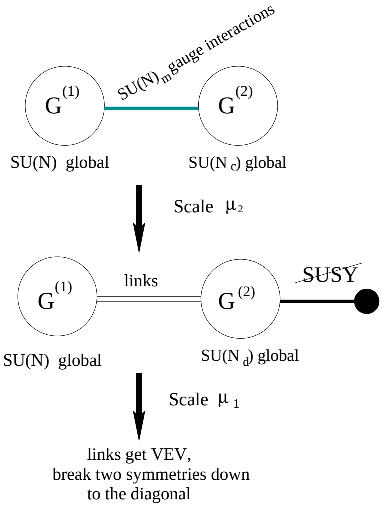
$$W \sim \tilde{\chi} N \chi - \mu_1^2 N$$

Masses vs. higgsing

The last term in W is the mass-term in the UV. It causes the fields χ to get VEVs (not necessarily break SUSY) and higgs the symmetries they are charged under. Note that this mechanism of higgsing and the connection between the higgsing in the IR and mass terms in the UV is completely generic.

When $\chi\tilde{\chi}$ get VEVs, they further break the flavor groups $SU(N)_{diag} \times SU(N)$ to the diagonal at the scale μ_1. If this is the lowest scale in the problem we get precisely a two-site model.

Partial summary



How do we get gaugino mediation?

- assume $\mu_1 \ll \mu_2$
- weakly gauge the global symmetries
- charge the SM fields under the "sector 1" gauge group

How do we get gaugino mediation?

- assume $\mu_1 \ll \mu_2$
- weakly gauge the global symmetries
- charge the SM fields under the "sector 1" gauge group

How can we break R-symmetry?

1. add small quartic to the superpotential $\Delta W_{el} \sim (Q\tilde{Q})^2$
2. assume that at least one of the quarks is massless
3. other solutions...

How do we get gaugino mediation?

- assume $\mu_1 \ll \mu_2$
- weakly gauge the global symmetries
- charge the SM fields under the "sector 1" gauge group

How can we break R-symmetry?

1. add small quartic to the superpotential $\Delta W_{el} \sim (Q\tilde{Q})^2$
2. assume that at least one of the quarks is massless
3. other solutions...

Phenomenology

The scalar mass suppression is a free parameter, therefore phenomenology of these models can interpolate between gauge mediation with suppressed gaugino masses (quite unnatural) all the way to gaugino mediation. For more discussion of soft mass calculation and spectra see talk by R. Auzzi.

Motivation: why should we think about variations?

1. We did not say anything about $\mu/B\mu$, usually it is hard to solve this problem within gauge mediation

Motivation: why should we think about variations?

1. We did not say anything about $\mu/B\mu$, usually it is hard to solve this problem within gauge mediation
2. We did not even try to address in any sense the flavor puzzle of the SM. However from the point of view of EW scale SUSY the μ problem and the SM flavor puzzle can be related. Both ask us to explain small numbers in the superpotential, which are technically natural.

Motivation: why should we think about variations?

1. We did not say anything about $\mu/B\mu$, usually it is hard to solve this problem within gauge mediation
2. We did not even try to address in any sense the flavor puzzle of the SM. However from the point of view of EW scale SUSY the μ problem and the SM flavor puzzle can be related. Both ask us to explain small numbers in the superpotential, which are technically natural.
3. The simple two-site model is a particular example of gauge mediation. One of the problem of gauge mediation is that it exacerbates the little hierarchy problem. The two-site model gives us a natural source of new contributions to the Higgs quartic – the D-terms of the broken generators. However they are numerically small. We will see why are they small and whether it is possible to change this.

Towards a simple single-sector model

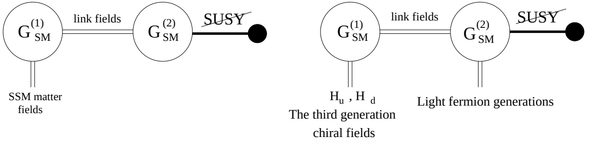
How can we explain the smallness of quark masses?

Simple solution: not all the scalars are charged under the LH SM. We can charge some of the fields under the RH group. If this is the case, some of the Yukawa couplings are forbidden at the renormalizable level.

Towards a simple single-sector model

How can we explain the smallness of quark masses?

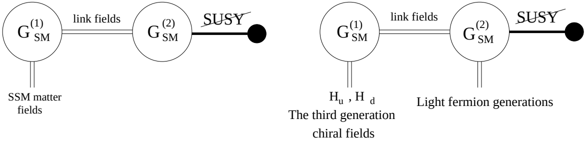
Simple solution: not all the scalars are charged under the LH SM. We can charge some of the fields under the RH group. If this is the case, some of the Yukawa couplings are forbidden at the renormalizable level.



Towards a simple single-sector model

How can we explain the smallness of quark masses?

Simple solution: not all the scalars are charged under the LH SM. We can charge some of the fields under the RH group. If this is the case, some of the Yukawa couplings are forbidden at the renormalizable level.



Corrections to the Higgs quartic

Corrections from the broken generators are proportional to g_1/g_2. In the simple two site model this ratio was small to ameliorate the Landau pole problem. But in our modification most of the SM matter is charged under SM_2, so it is natural to choose $g_1 > g_2$ to ameliorate this problem

Modified 2-site model

- It is not a model of gauge mediation, therefore we should not expect it to be flavor-blind

Modified 2-site model

- It is not a model of gauge mediation, therefore we should not expect it to be flavor-blind
- Tree level – only the third generation Yukawas are allowed
- We can write down other Yukawas with insertions of the link fields:

$$W \sim \frac{H_u \chi Q \bar{u}}{M_*}$$

This can explain why Yukawas and light generations quark masses are small

Modified 2-site model

- It is not a model of gauge mediation, therefore we should not expect it to be flavor-blind
- Tree level – only the third generation Yukawas are allowed
- We can write down other Yukawas with insertions of the link fields:

$$W \sim \frac{H_u \chi Q \bar{u}}{M_*}$$

  This can explain why Yukawas and light generations quark masses are small
- If we forbid tree-level μ-term, it is formed with insertion of the link fields:

$$W \sim \frac{\chi \tilde{\chi} H_u H_d}{M_*}$$

Quark masses, CKM matrix

Within two site model we can explain:

- why up to two angles in the CKM matrix are small
- why is the second generation lighter then the third generation
- one more small number should be put "by hand"

Quark masses, CKM matrix

Within two site model we can explain:

- why up to two angles in the CKM matrix are small
- why is the second generation lighter then the third generation
- one more small number should be put "by hand"

Define small parameter: $\epsilon \equiv \frac{\langle \chi \rangle}{M_*}$

Quark masses

$$m_d \sim \cos\beta \ (1, \epsilon, \epsilon)$$

$$m_u \sim \sin\beta \ (1, \epsilon, \epsilon)$$

CKM matrix

$$V_{CKM} = \begin{pmatrix} 1 & 1 & \epsilon^2 \\ 1 & 1 & \epsilon^2 \\ \epsilon^2 & \epsilon^2 & 1 \end{pmatrix}$$

Superpartners

Hierarchy of soft scalar masses

Light generations scalars get gauge-mediated contributions: $m_{lf}^2 \propto \left(\frac{\alpha}{4\pi}\right)^2 \left(\frac{F}{M}\right)^2$. Heavy generations scalars are lighter, their masses^2 are suppressed roughly by 1-loop. This spectrum, with light third generation superpartners starts resembling more minimal SUSY.

Superpartners

Hierarchy of soft scalar masses

Light generations scalars get gauge-mediated contributions: $m_{lf}^2 \propto \left(\frac{\alpha}{4\pi}\right)^2 \left(\frac{F}{M}\right)^2$. Heavy generations scalars are lighter, their masses^2 are suppressed roughly by 1-loop. This spectrum, with light third generation superpartners starts resembling more minimal SUSY.

Flavor and CP

Now rotate the squarks to the quark mass basis. We find off-diagonal terms, but they are small, $\mathcal{O}(\epsilon, \epsilon^2)$. There is no mixing between two first generations at the leading order. However $K - \bar{K}$ is so well measured, that it poses the main constraint. In general, if we assume an arbitrary phase in the RH squark masses matrix, we are forced to live in quite a narrow part of parameter space (ϵ_K). If for some reason this phase is aligned with the CKM phase, we have very mild constraints from $\Delta m_K, \Delta m_B$ and $b \to s\gamma$ which are all very easy to satisfy in big portions of parameter space.

Conclusions and Outlook

1. We showed that deconstructed gaugino mediation ansatz, even though it looks quite sofisticated, can be easily realized in dynamical models
2. We build an explicit dynamical model of 4D gaugino mediation
3. The spectrum of this model, depending on choice of parameters interpolates between low-scale gaugino to low-scale gauge mediation
4. "Mild" variations on deconstructed gaugino mediation can lead to models which can address the μ-problem and flavor-puzzle of the SM.
5. These model might have non-trivial predictions for collider experiments and B-factories.

SUSY vacuum structure with singlets

SUSY vacua are protected by holomorphy, therefore we can perform our analysis in regime $m \gg \Lambda$ and then analytically continue our results to the interesting region $m \ll \Lambda$.

SUSY vacuum structure with singlets

SUSY vacua are protected by holomorphy, therefore we can perform our analysis in regime $m \gg \Lambda$ and then analytically continue our results to the interesting region $m \ll \Lambda$.

One can write down the superpotential in a following form:

$$W = Q\mathcal{M}\tilde{Q}, \quad \mathcal{M} = \begin{pmatrix} m_1 \mathbf{1}_N & \lambda S \\ \lambda \tilde{S} & m_2 \mathbf{1}_{N_c} \end{pmatrix}$$

Below the scale where all the electric quarks are massive the theory is just pure SYM, due to gaugino condensate it develops superpotential $W_{eff} \sim \left(\det \mathcal{M} \Lambda^{3N_f - N_c}\right)^{1/N_c}$.

SUSY vacuum structure with singlets

SUSY vacua are protected by holomorphy, therefore we can perform our analysis in regime $m \gg \Lambda$ and then analytically continue our results to the interesting region $m \ll \Lambda$.

One can write down the superpotential in a following form:

$$W = Q\mathcal{M}\tilde{Q}, \quad \mathcal{M} = \begin{pmatrix} m_1 \mathbf{1}_N & \lambda S \\ \lambda \tilde{S} & m_2 \mathbf{1}_{N_c} \end{pmatrix}$$

Below the scale where all the electric quarks are massive the theory is just pure SYM, due to gaugino condensate it develops superpotential

$$W_{eff} \sim \left(\det \mathcal{M} \Lambda^{3N_f - N_c}\right)^{1/N_c}.$$

$$Q\tilde{Q} \sim \left(\det \mathcal{M} \Lambda^{3N_f - N_c}\right)^{1/N_c} \mathcal{M}^{-1} .$$

SUSY vacua and runaways

S - dependent SUSY vacua

The vacua should also satisfy $\partial_S \det \mathcal{M} = 0$.

- automatically works for $S = \tilde{S} = 0$ (since $\det\mathcal{M} = f(S\tilde{S})$), and $Q\tilde{Q} \sim \left(m_1^{N_f - N_c} m_2^{N_c} \Lambda^{3N_c - N_f}\right)^{1/N_c} \mathrm{diag}\left(\frac{1}{m_1}, \ldots, \frac{1}{m_2}, \ldots\right)$
- $\det\mathcal{M}$ is a polynomial in $S\tilde{S}$ of order N. Therefore we also expect to have new vacua at some isolated points at which $S, \tilde{S} \sim \mathcal{O}(m)$. At this vacua the meson is still far away from the origin.

SUSY vacua and runaways

S - dependent SUSY vacua

The vacua should also satisfy $\partial_S \mathrm{det}\mathcal{M} = 0$.

- automatically works for $S = \tilde{S} = 0$ (since $\mathrm{det}\mathcal{M} = f(S\tilde{S})$), and $Q\tilde{Q} \sim \left(m_1^{N_f - N_c} m_2^{N_c} \Lambda^{3N_c - N_f}\right)^{1/N_c} \mathrm{diag}\left(\frac{1}{m_1}, \ldots, \frac{1}{m_2}, \ldots\right)$
- $\mathrm{det}\mathcal{M}$ is a polynomial in $S\tilde{S}$ of order N. Therefore we also expect to have new vacua at some isolated points at which $S, \tilde{S} \sim \mathcal{O}(m)$. At this vacua the meson is still far away from the origin.

For large S we also find a runaway direction. The highest power of S in W_{eff} is 1. Along this branch of the theory some of the electric quarks still must be big.

SUSY is always restored far away from the origin and cannot affect the structure of the theory at small VEVs.

Spectrum of gaugino mediation

We can think about three different regimes: $\mu_2 \ll M$, $\mu_2 \sim M$, $\mu_2 \gg M$. The latter is phenomenologically uninteresting since $m_\lambda \sim M$. In other cases we get:

Spectrum of gaugino mediation

We can think about three different regimes: $\mu_2 \ll M$, $\mu_2 \sim M$, $\mu_2 \gg M$. The latter is phenomenologically uninteresting since $m_\lambda \sim M$. In other cases we get:

- $\mu_2 \ll M$ leads to gaugino mass suppression $m_\lambda \sim 0.1 \frac{\alpha}{4\pi} \frac{\mu_2^6}{M^5}$
- if $\mu_2 \sim M$ we get $m_\lambda \sim 0.1\ \mu_2$

Spectrum of gaugino mediation

We can think about three different regimes: $\mu_2 \ll M$, $\mu_2 \sim M$, $\mu_2 \gg M$. The latter is phenomenologically uninteresting since $m_\lambda \sim M$. In other cases we get:

- $\mu_2 \ll M$ leads to gaugino mass suppression $m_\lambda \sim 0.1 \frac{\alpha}{4\pi} \frac{\mu_2^6}{M^5}$
- if $\mu_2 \sim M$ we get $m_\lambda \sim 0.1\ \mu_2$

Scalar masses

At two loops are $m_{\tilde{f}}^2 \sim \left(\frac{\alpha}{4\pi}\right)^2 \mu_2^2$. This effect is not generic for any model of gaugino mediation, it is a relic of a particular messenger structure. On top of that we have three-loop effects which might be even more important, they come since the link fields acquire soft masses and they are estimated $\Delta m_{\tilde{f}} \sim \left(\frac{\alpha}{4\pi}\right)^3 \mu_2^2$.