A Holographic Perspective on Gauge Mediation

Paul McGuirk
University of Wisconsin-Madison

In collaboration with:
Gary Shiu (UW-Madison), Yoske Sumitomo (TIFR)
arXiv:0910.4581 and arXiv:0911.0019

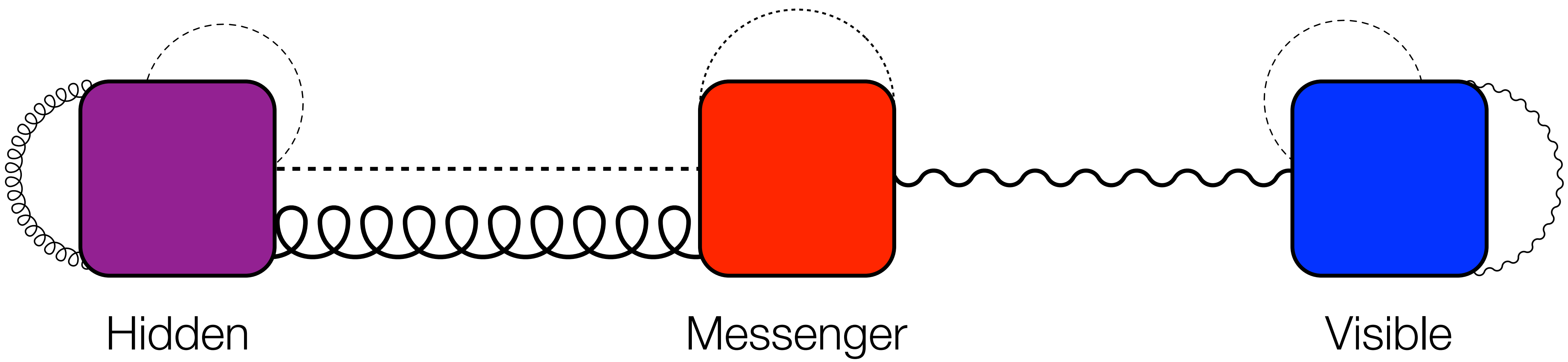
Presented at:
UW-Madison,
Pheno, May 10, 2010

Motivation

- Many BSM scenarios involve strong coupling.
- Strong-weak dualities can help to make problems tractable.
- Example (focus of this talk): A strongly coupled hidden sector in a GMSB scenario can be described using the gauge-gravity correspondence (a.k.a. AdS/CFT, holography)

Semi-Direct Gauge Mediation

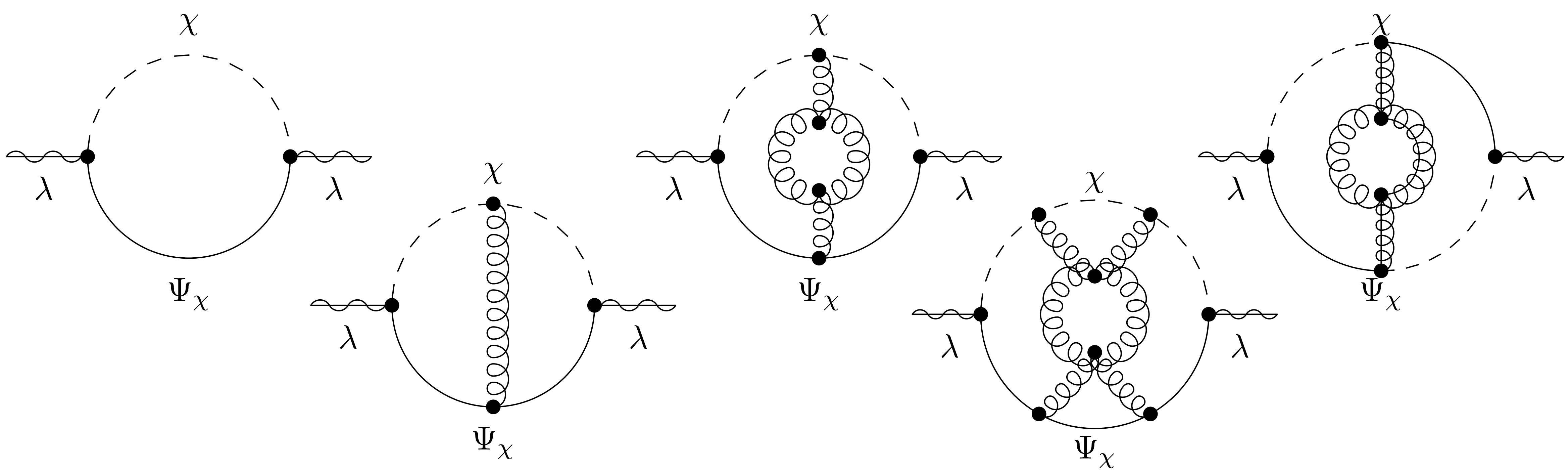
- Semi-direct gauge mediation [Seiberg, Volansky, Wecht] is a compromise between minimal and direct scenarios



- Messenger fields charged under hidden sector gauge group, but do not participate in dynamical breaking of SUSY.

Strong Coupling

- If the hidden sector has large ‘t Hooft coupling $\lambda = g^2 N$, visible sector soft terms receive important corrections at all orders (direct perturbation theory is hopeless!)



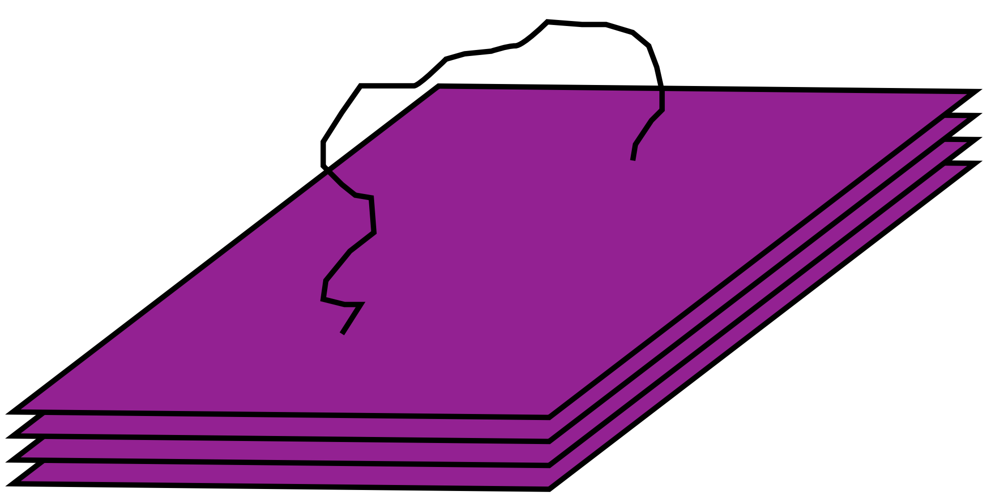
- If λ is large and g is small (so N is large), then the gauge-gravity correspondence is effective.

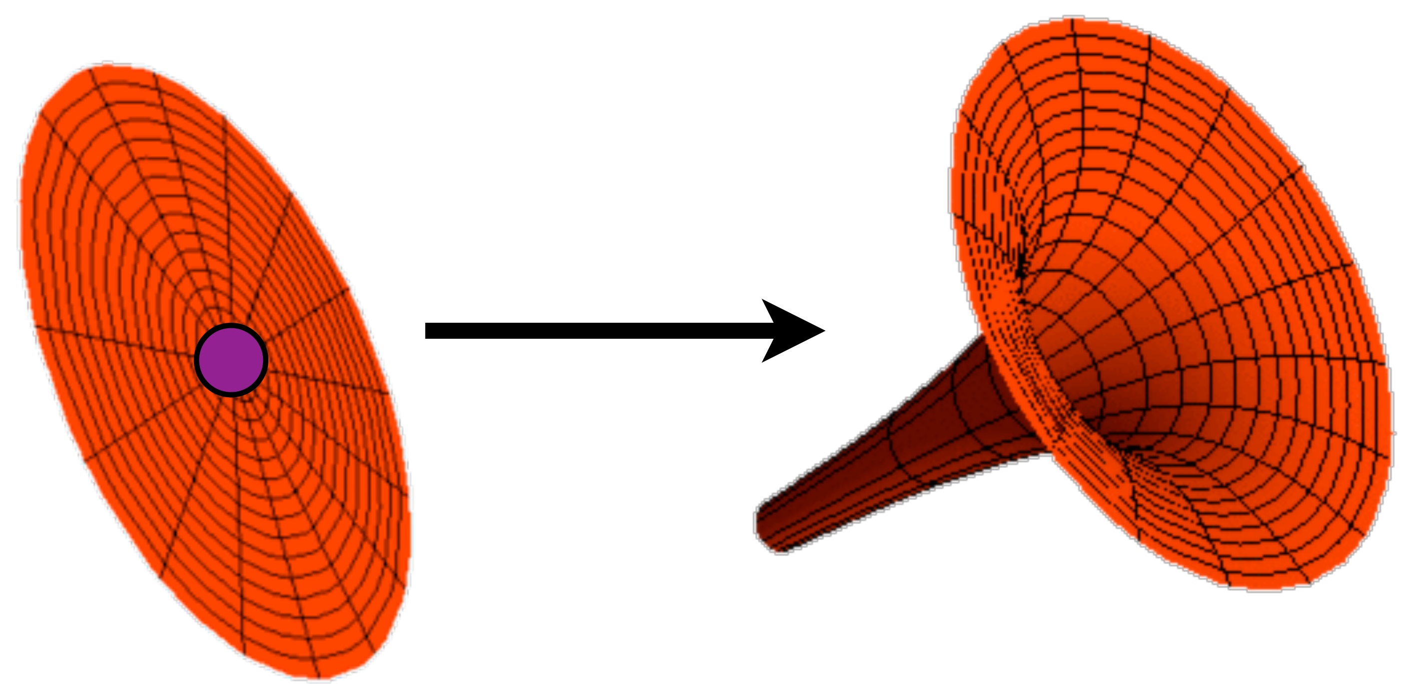
AdS/CFT

- Simplest example of gauge-gravity correspondence:

$\mathcal{N}=4 \quad \mathrm{SU}\,(N)$ SYM $\qquad \cong \qquad$ IIB SUGRA on $\mathrm{AdS}_5 \times \mathrm{S}^5$

EFT of D3-stack $\qquad\qquad$ SUGRA fields sourced by D3s





A Gravity Dual of Gauge Mediation

- To holographically describe gauge mediation [Benini, Dymarsky, Franco, Kachru, Simic, Verlinde]

	Gauge Side	Gravity Side
1	Choose a hidden sector	Choose a gravity background
2	Prepare a (metastable) non-SUSY state	Add $\overline{\text{D3}}$-branes
3	Introduce a flavor group with messenger “quarks”	Introduce D7-branes
4	Weakly gauge flavor group	Cutoff the geometry
5	Calculate soft terms using field theory	Calculate soft terms using string theory

A Gravity Dual of Gauge Mediation

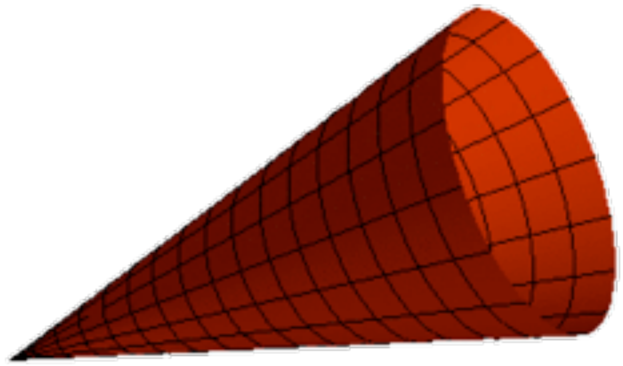
	Gauge Side	Gravity Side
1	Choose a hidden sector	Choose a gravity background
2	Prepare a (metastable) non-SUSY state	Add $\overline{\text{D3}}$-branes
3	Introduce a flavor group with messenger “quarks”	Introduce D7-branes
4	Weakly gauge flavor group	Cutoff the geometry
5	Calculate soft terms using field theory	Calculate soft terms using string theory

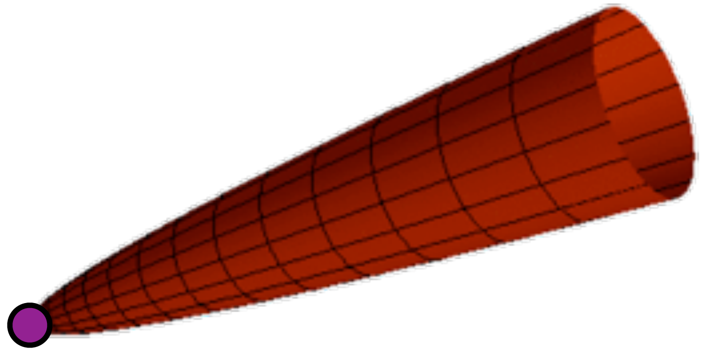
Klebanov-Strassler (Geometry)

- Finding the gravity dual of a particular gauge theory is difficult, but the inverse is sometimes easier.

- A particularly explicit example is Klebanov-Strassler found by placing M D5-branes on a deformed conifold singularity

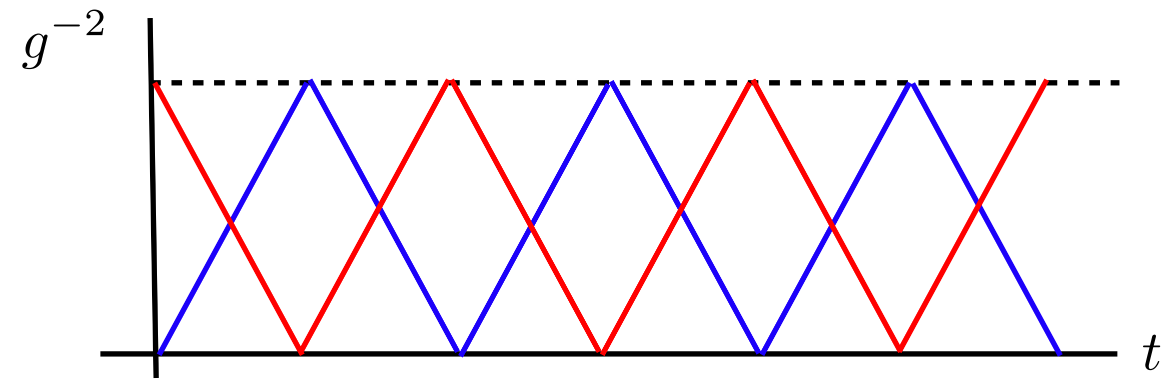
$$\sum_{i=1}^{4} z_i^2 = 0 \longrightarrow \sum_{i=1}^{4} z_i^2 = \varepsilon^2$$





Klebanov-Strassler (Gauge Theory)

- Dual gauge theory is $\mathcal{N}=1$ theory exhibiting a cascade of Seiberg dualities



$$\mathrm{SU}\left(N+M\right)\times\mathrm{SU}\left(N\right)\to$$
$$\to\mathrm{SU}\left(N\right)\times\mathrm{SU}\left(N-M\right)\to\cdots\to\mathrm{SU}\left(M\right)$$

- Confines at a scale $\Lambda_\varepsilon=\varepsilon^{2/3}$

- $\mathbb{Z}_2$ R-symmetry (enhances to $\mathbb{Z}_{2M}$ at small distances)

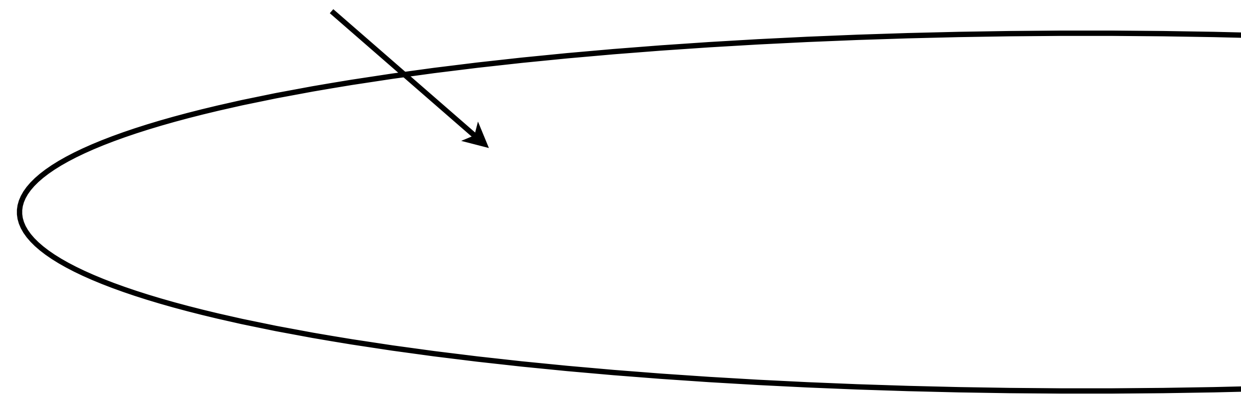
Dual Pictures

	$\mathrm{SU}(N)$	$N+M$
A_i	$\square$	$\overline{\square}$
B_i	$\overline{\square}$	$\square$

$$W = \lambda \epsilon^{ij} \epsilon^{kl} \mathrm{tr}\left(A_i B_k A_j B_l\right)$$

confinement at Λ_ε

KS warped solution



$$\sum z_i = \varepsilon^2$$

A Gravity Dual of Gauge Mediation

	Gauge Side	Gravity Side
1	Choose a hidden sector	Choose a gravity background
2	Prepare a (metastable) non-SUSY state	Add $\overline{\text{D3}}$-branes
3	Introduce a flavor group with messenger “quarks”	Introduce D7-branes
4	Weakly gauge flavor group	Cutoff the geometry
5	Calculate soft terms using field theory	Calculate soft terms using string theory

Adding $\overline{\text{D3}}$-branes

- $\overline{\text{D3}}$-branes differ by the sign of charge

$$S_{\text{D3}} = -\tau_3 \int *_4 1 + \mu_3 \int C_{(4)} \qquad S_{\overline{\text{D3}}} = -\tau_3 \int *_4 1 - \mu_3 \int C_{(4)}$$

- Adding $\overline{\text{D3}}$-branes to KS geometry breaks SUSY explicitly and entirely

- Dual of a metastable SUSY-breaking state in the KS theory [Kachru, Pearson, Verlinde; deWolfe, Kachru, Mulligan]

$\overline{\text{D3}}$ Backreaction

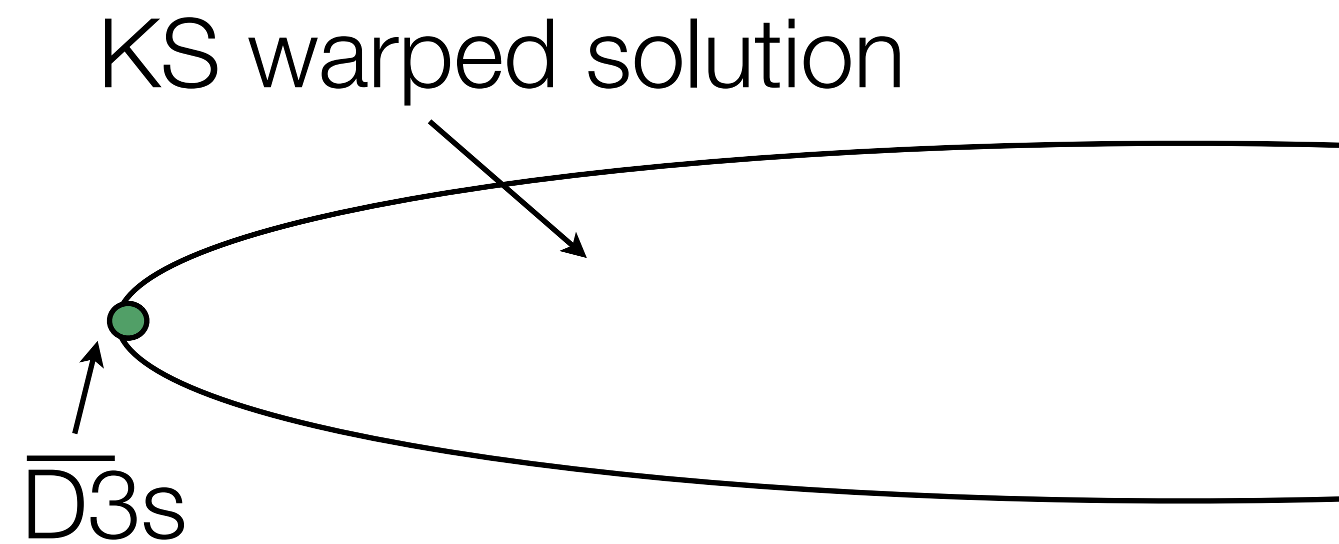
- $\overline{\text{D3}}$s will gravitate and alter the geometry. Needs to be calculated for getting soft terms.

- Can be treated as a perturbation if number of $\overline{\text{D3}}$s is small

- Solution known at large radius [DeWolfe, Kachru, Mulligan] and small radius [PM, Shiu, Sumitomo] (interpolation could use [Bena, Graña, Halmagyi])

Dual Pictures

	$\mathrm{SU}\,(N)$	$N+M$
A_i	$\square$	$\overline{\square}$
B_i	$\overline{\square}$	$\square$



$$W = \lambda \epsilon^{ij} \epsilon^{kl} \mathrm{tr}\,(A_i B_k A_j B_l)$$

$$Q\,|\Omega\rangle \neq 0$$

confinement at Λ_ε

$$\delta_\epsilon \Psi_\mu, \delta_\epsilon \psi_\Phi \neq 0$$

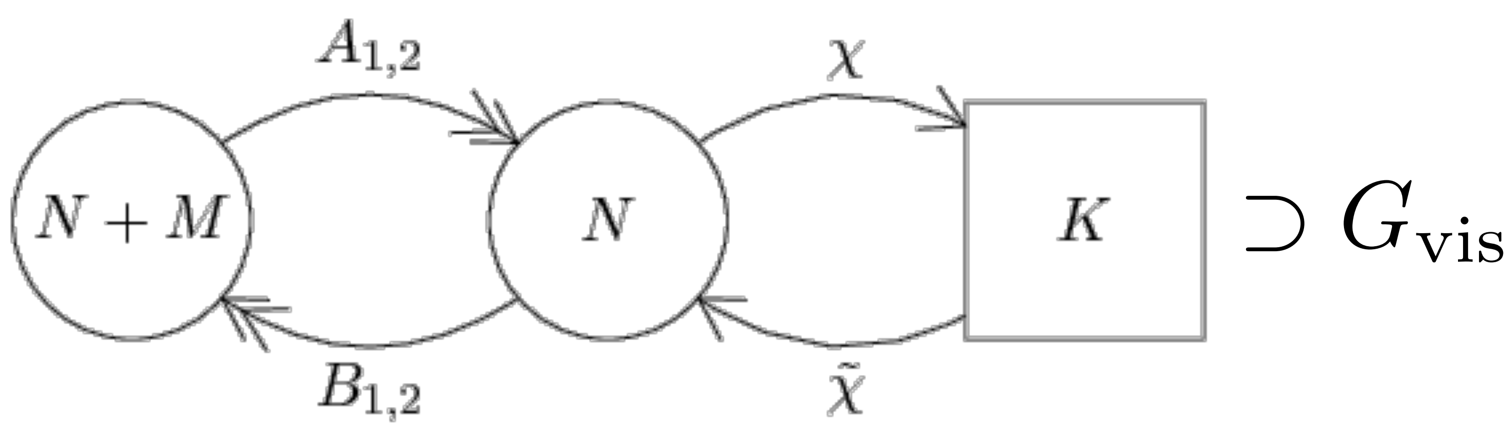
$$\sum z_i = \varepsilon^2$$

A Gravity Dual of Gauge Mediation

	Gauge Side	Gravity Side
1	Choose a hidden sector	Choose a gravity background
2	Prepare a (metastable) non-SUSY state	Add $\overline{\text{D3}}$-branes
3	Introduce a flavor group with messenger "quarks"	Introduce D7-branes
4	Weakly gauge flavor group	Cutoff the geometry
5	Calculate soft terms using field theory	Calculate soft terms using string theory

Adding Flavor

- Adding D7-branes to the geometry adds a flavor group with bifundamental “quarks” to the dual theory (group is weakly gauged by cutting off the geometry)



$$m_\chi = \mu^{2/3}$$

D7 location

- Quarks act as messengers in semi-direct gauge mediation

Dual Pictures

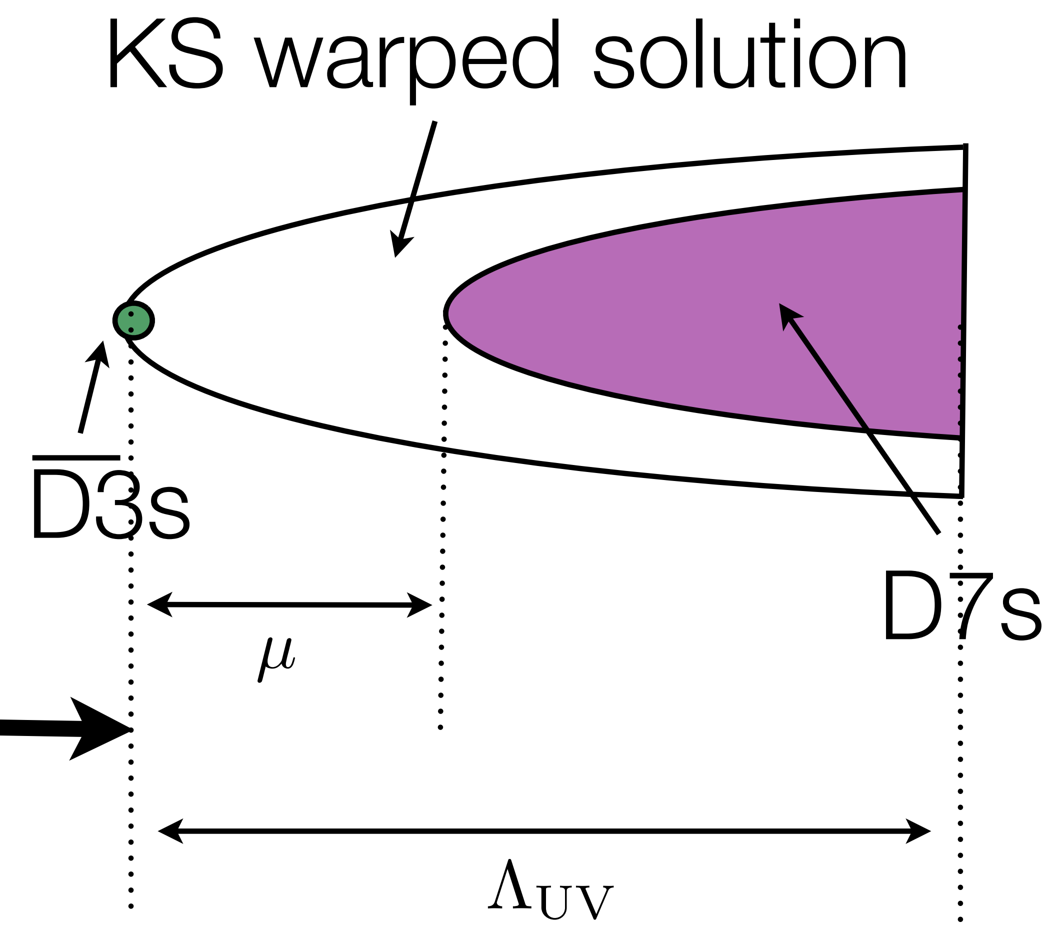
	$\mathrm{SU}(N)$	$N+M$	K
A_i	$\square$	$\overline{\square}$	
B_i	$\overline{\square}$	$\square$	
χ	$\overline{\square}$		$\square$
$\tilde{\chi}$	$\square$		$\overline{\square}$

$$\begin{aligned} W &= \lambda_1 \epsilon^{ij}\epsilon^{kl}\mathrm{tr}\left(A_i B_k A_j B_l\right) \\ &\quad +\tilde{\chi}^a \left(A_1 B_1 + A_2 B_2 - \mu\right)\chi_a \\ &\quad +\lambda_2 \tilde{\chi}\chi\tilde{\chi}\chi \end{aligned}$$

$$Q\left|\Omega\right\rangle \neq 0$$

confinement at Λ_ε

cutoff at Λ_{UV}



$$\delta_\epsilon \Psi_\mu, \delta_\epsilon \psi_\Phi \neq 0$$

$$\sum z_i = \varepsilon^2$$

A Gravity Dual of Gauge Mediation

	Gauge Side	Gravity Side
1	Choose a hidden sector	Choose a gravity background
2	Prepare a (metastable) non-SUSY state	Add $\overline{\mathrm{D3}}$-branes
3	Introduce a flavor group with messenger “quarks”	Introduce D7-branes
4	Weakly gauge flavor group	Cutoff the geometry
5	Calculate soft terms using field theory	Calculate soft terms using string theory

Gaugino Mass

- Messengers strongly coupled to hidden sector, so calculate soft terms holographically.

- Visible sector gaugino mass follows from dimensional reduction of classical D7 action

$$S_{\mathrm{D7}} = \tau_7 \int \mathrm{d}^8x\, \bar{\theta}\mathcal{O}\theta \to \int \mathrm{d}^4x\, m_{1/2}\lambda\lambda$$

- Non-SUSY perturbation of KS from $\overline{\text{D3}}$s contributes to $m_{1/2}$

Gaugino Mass (cont.)

- Two simplified regimes (mesonic contribution not included)

1. $m_\chi \gg \Lambda_\varepsilon \Rightarrow m_{1/2} = 0$ [Benini et al]

2. [PM, Shiu, Sumitomo]

$$m_\chi \approx \Lambda_\varepsilon \Rightarrow m_{1/2} \sim g_{\mathrm{vis}}^2 \frac{F^2}{m_\chi^3} \left(\left(\frac{m_\chi}{\Lambda_\varepsilon} \right)^{3/2} - 1 \right)^{3/2}$$

$$F = \sqrt{\lambda} \Lambda_{\mathcal{S}}^2$$

Hidden sector 't Hooft

vacuum energy
(proportional to tension of $\overline{\mathrm{D}}$3s)

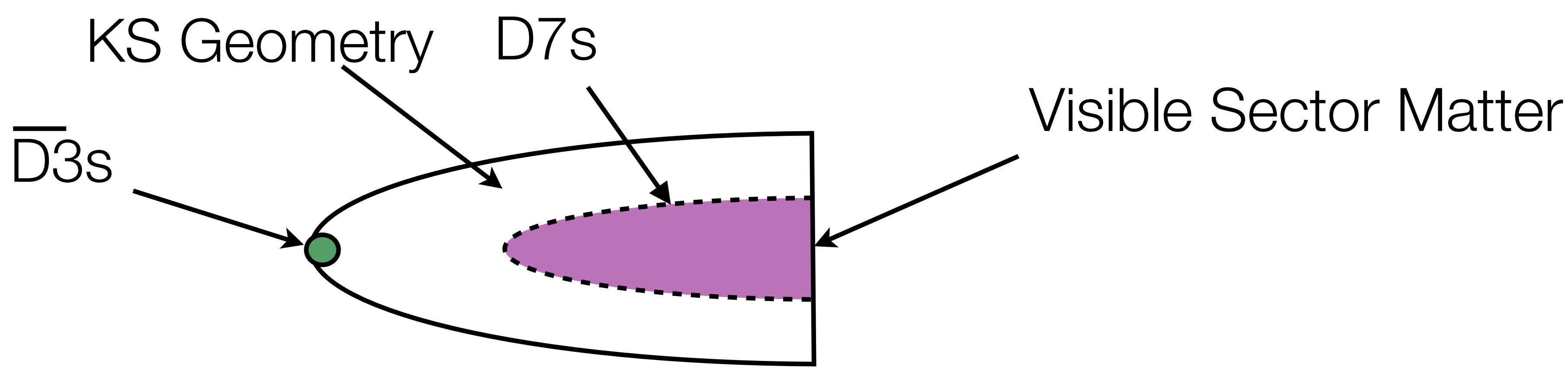
Gaugino Mass Comments

$$m_{1/2} \sim g_{\rm vis}^2 \frac{F^2}{m_\chi^3}\left(\left(\frac{m_\chi}{\Lambda_\varepsilon}\right)^{3/2} - 1\right)^{3/2} \qquad F = \sqrt{\lambda}\Lambda_{\mathcal{S}}^2$$

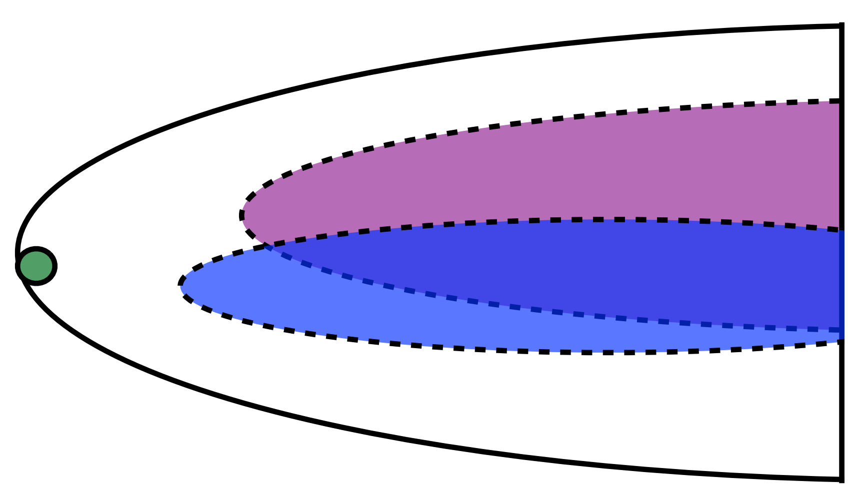
- $m_\chi \to \Lambda_\varepsilon$ limit cannot be trusted (singularity in geometry)
- F is non-perturbative in ‘t Hooft
- Suppression of gaugino mass typical in semi-direct GMSB (recall in mGMSB $m_{1/2} \sim g_{\rm vis}^2 \frac{F}{m_X}$)

Other Soft Terms

- Visible sector matter fields localized in UV (gaugino mediation)



- Could also realize on intersecting D7s (work in progress)



Concluding Remarks

- Holography provides a powerful tool to explore BSM physics

- Here, I gave an example of using the technique to calculate soft terms in GMSB with strongly coupled messengers

- Although calculations are classical, need to understand gravity background well and calculations are complicated (though still easier than strong coupling picture!)

A Gravity Dual of Gauge Mediation

	Gauge Side	Gravity Side
1	Choose a hidden sector	Choose a gravity background
2	Prepare a (metastable) non-SUSY state	Add $\overline{\text{D3}}$-branes
3	Introduce a flavor group with messenger “quarks”	Introduce D7-branes
4	Weakly gauge flavor group	Cutoff the geometry
5	Calculate soft terms using field theory	Calculate soft terms using string theory

Thanks!