Dynamical generation of the Peccei-Quinn scale in gauge mediation

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Based on arXiv:1504.07634 (Phys. Rev. D92 2015)
in collaboration with Guido Festuccia and Lorenzo Ubaldi

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What is the issue with Axions?

The axion decay constant f_a is the most important parameter in axion models

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Question: how does one build a model that generates sufficiently high scale f_a?

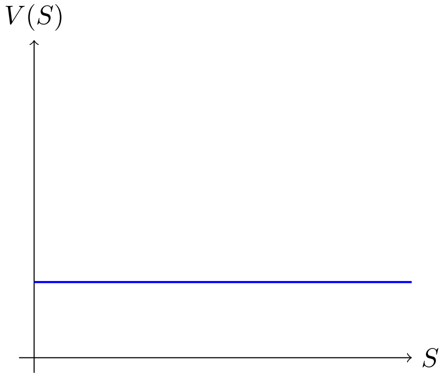
$\hookrightarrow$ Use supersymmetry breaking effects to trigger PQ-breaking

Asaka & Yamaguchi (1998)

Arkani-Hamed, Giudice, Luty & Rattazzi (1998)

The Basic Idea

- Saxion potential flat at tree-level



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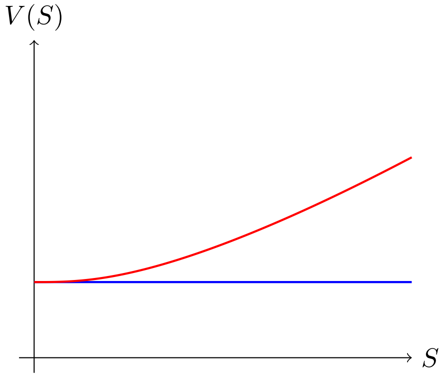
- Saxion potential flat at tree-level
- One-loop potential including SUSY breaking effects lifts flatness
- Logarithmic behaviour at large field values



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- Saxion potential flat at tree-level
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- Minimum at large S possible by:
  - (i) Introducing additional gauge interactions

    Carpenter, Dine, Festuccia & Ubaldi (2009)
  - (ii) Dominant two-loop contributions

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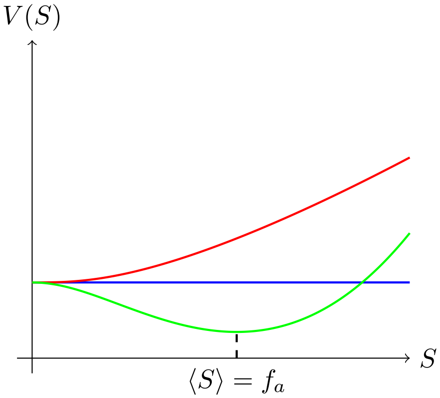

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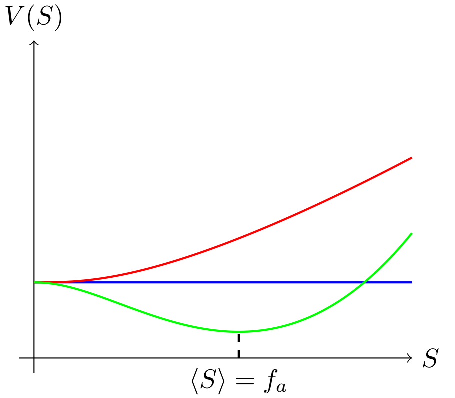


Claim: neither additional gauge interactions nor two-loop effects necessary!

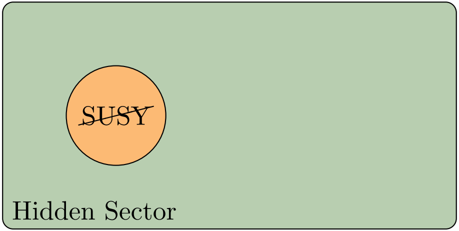
Building the Hidden Sector

Require:

- Global $\mathrm{U}(1)_R$

$\langle X \rangle = M + \theta^2 F$ F-term ~~SUSY~~

$$W_{\text{hidden}} = W_{\not{R}}(X)$$



Building the Hidden Sector

Require:

- Global $\mathrm{U}(1)_R$
- Gauged $\mathrm{SU}(5)$

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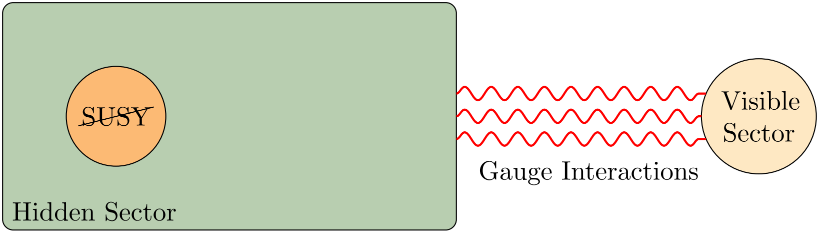
$\tilde{\Phi}_i,\ \Phi_j$ $\bar{\mathbf{5}} + \mathbf{5}$ Messengers

$$W_{\text{hidden}} = W_{\not{R}}(X) + \mathcal{M}_{ij}(X)\,\tilde{\Phi}_i \Phi_j$$



Building the Hidden Sector

Require:

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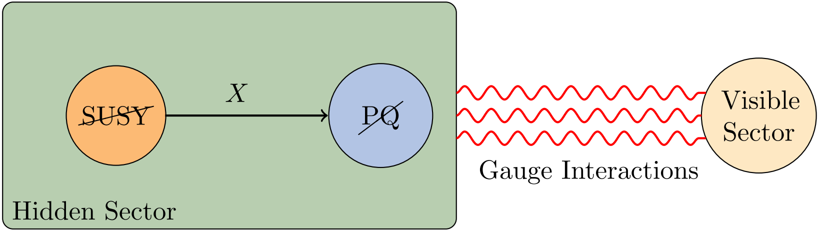
S		Axion supermultiplet



Classification Scheme

$$W_{\text{hidden}} = W_{\not{R}}(X) + \mathcal{M}_{ij}(X,S)\tilde{\Phi}_i\Phi_j$$

$$\mathcal{M}_{ij}(X,S) = X\lambda_{ij} + m_{ij} + S\delta_{ij}$$

	X	S	Φ_i	$\tilde{\Phi}_i$
$\mathrm{U}(1)_{\mathrm{R}}$	2	r_S	r_i	$\tilde{r}_i$
$\mathrm{U}(1)_{\mathrm{PQ}}$	0	p_S	p_i	$\tilde{p}_i$

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Charge assignments $\Longrightarrow$ determinant becomes a monomial in S and X

Cheung, Fitzpatrick & Shih (2008)

$$\det \mathcal{M} = X^n S^q G(\lambda, m, \delta)$$

Concrete Model

Model of type C

$$W = W_{\mathrm{PQ}}^{C} + W_R$$

$$W_R = X(\lambda \varphi_1 \varphi_{-1} + F) + m_1 \varphi_{-1} \varphi_3 + \frac{1}{2} m_2 \varphi_1^2$$

$$W_{\mathrm{PQ}}^{C} = X \lambda_x \tilde{\Phi}_1 \Phi_1 + S \lambda_s \left(\tilde{\Phi}_1 \Phi_2 + \tilde{\Phi}_2 \Phi_1 \right)$$

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Tree-level dynamics:

- Pseudo-moduli space of vacua ($\varphi_i = \Phi_i = \tilde{\Phi}_i = 0$, X & S arbitrary)
- Tachyons at small $S \Rightarrow$ moduli space of SUSY vacua ($\varphi_i = S = X = 0$)
- Runaway direction ($\Phi_i = \tilde{\Phi}_i = 0$ and $\varphi_3 \to \infty$)

The One-Loop Potential

CW-effective potential $V^{(1)}(X,S)$ expanding in F

$$\text{Form of } W \quad \Longrightarrow \quad V^{(1)}(X,S) = V^{(1)}_{\text{PQ}}(X,S) + V^{(1)}_{R}(X)$$

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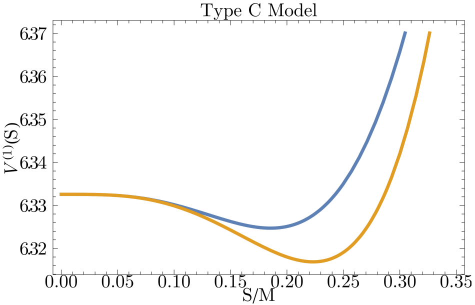
- $V^{(1)}_{R}(X)$ generates $\langle X\rangle = M$
- $V^{(1)}_{\mathrm{PQ}}(X,S)$ with $\langle X\rangle = M$ yields

$$\langle S\rangle \simeq \frac{\lambda_x}{\lambda_s}\, e^{-3/2} M \simeq M$$



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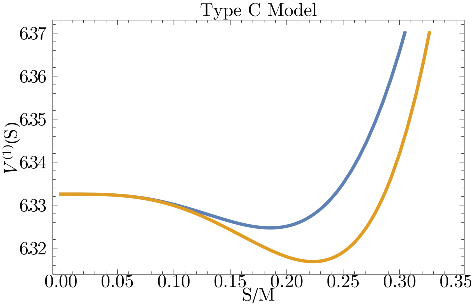

Constraints on parameters:

(i) Ensure minima sufficiently long-lived

(ii) New contributions to potential do not destroy SUSY breaking minimum

(iii) Pseudo-moduli decays do not interfere with standard cosmology

Summary & Outlook

Status:

- Explored simple models where $f_a = \langle S \rangle \simeq M$
- Established a simple classification scheme

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Outlook:

- Explore dynamics of models containing more than two sets of messengers
- Combine $V_{\text{PQ}}^{(1)}(X, S)$ and $V_R^{(1)}(X)$ without introducing gauge singlets

Backup Slides

Classification Scheme

$$\det \mathcal{M} = X^n S^q G(\lambda, m, \delta), \qquad \mathcal{M}_{ij}(X,S) = X\lambda_{ij} + m_{ij} + S\delta_{ij}$$

Type A: $\det m \neq 0$, $\det \lambda = \det \delta = 0$

Type B: $\det \lambda \neq 0$, $\det m = \det \delta = 0$

Type C: $\det \delta \neq 0$, $\det \lambda = \det m = 0$

Type D: $\det \lambda = \det m = \det \delta = 0$

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Type A features:

- $n = q = 0$
- Messengers stable about $X = S = 0$
- Tachyons at large X and S
- Vanishing gaugino masses at LO

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Type B features:

- $n = N$ and $q = 0$
- At large X, $m^2_{\Phi_i} \simeq \lambda X$
- Small X, $\det m = 0$
  - (i) $m^2_{\Phi_i} \simeq m$
  - (ii) $m^2_{\Phi_i} \simeq X^k$, $k \in \mathbb{Z}^+$
- Local minima found at finite X for massive messengers

Classification Scheme

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Type C features:

- $n = 0$ and $q = N$
- Small S, $\det \delta = 0$
  - (*i*) $m^2_{\Phi_i} \simeq \delta$
  - (*ii*) $m^2_{\Phi_i} \simeq S^k$, $k \in \mathbb{Z}^+$
- Vanishing gaugino masses at LO
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Type D features:

- $0 < n < N$ and $0 < q < 0$
- Messengers behaviour combination previous categories
- No tachons in region

$$X_{\min} < |X| < X_{\max} \quad S_{\min} < |S| < S_{\max}$$

- Possible models acquire one-loop VEV $\langle X \rangle \neq 0$, $\langle S \rangle \neq 0$