

Effective MSSM Baryogenesis

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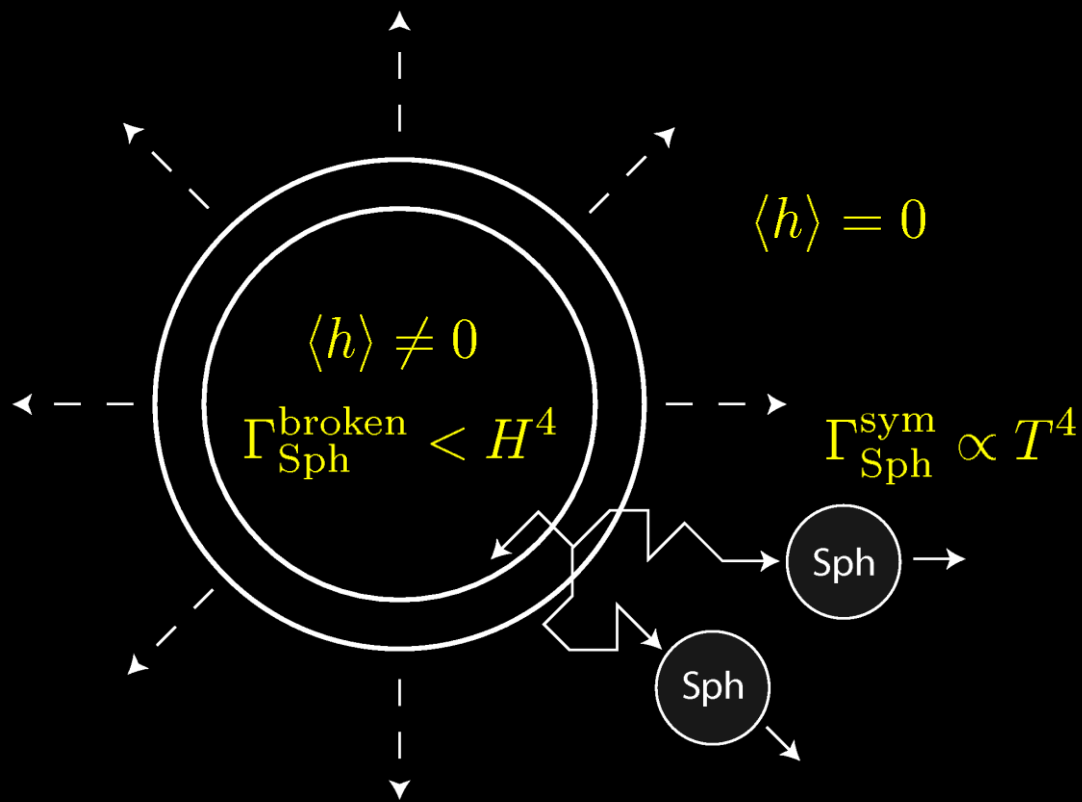
based on 1003.2447 with K.Blum, M. Losada, Y. Nir & S. Tulin

Outline

- The MSSM Higgs limits EW baryogenesis
- No « little hierarchy » from effective operators
- Impacts for CP violation and baryogenesis

(non-local) Electroweak Baryogenesis

Cohen, Kaplan, Nelson '92-94



this would explain why $\eta \equiv n_B/n_\gamma \simeq 6 \times 10^{-10} \gg 10^{-18}$

MSSM Baryogenesis is very marginal

- the MSSM higgs is too light ($m_U^2, m_Q^2 \gtrsim (0.5 - 1\text{TeV})^2$)

$$m_h^2 < m_Z^2 c_{2\beta}^2 + \frac{3y_t^4 v^2}{16\pi^2} \log m_{\tilde{t}}^2 / m_t^2 \quad \text{little hierarchy pb}$$

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- strong 1st order phase transition requires:
1/light RH-stop, 2/ small stop mixing

$$m_U^2 \lesssim 0, \quad m_Q^2 > (10 - 10^4 \text{TeV})^2 \quad (\tan \beta \lesssim 10) \quad \textit{big little hierarchy pb}$$

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- no stop CPV source, asymmetry only through higgsino source (w/ an $o(1)$ phase in tension with EDMs)

Hence the MSSM higgs is responsible for:

little hierarchy pb & frustrating baryogenesis in susy

Higgs mass beyond the MSSM (BMSSM)

Dine, Seiberg, Thomas '07

- MSSM is crying for new physics; what if it's heavy?

$$\mathcal{W} \supset \mu H_u H_d + \frac{1}{M} (\lambda_1 + \lambda_2 m_{\text{soft}} \theta^2) (H_u H_d)^2$$

$$(\epsilon_1 = \lambda_1 \mu^* / M, \quad \epsilon_2 = -\lambda_2 m_{\text{soft}} / M)$$

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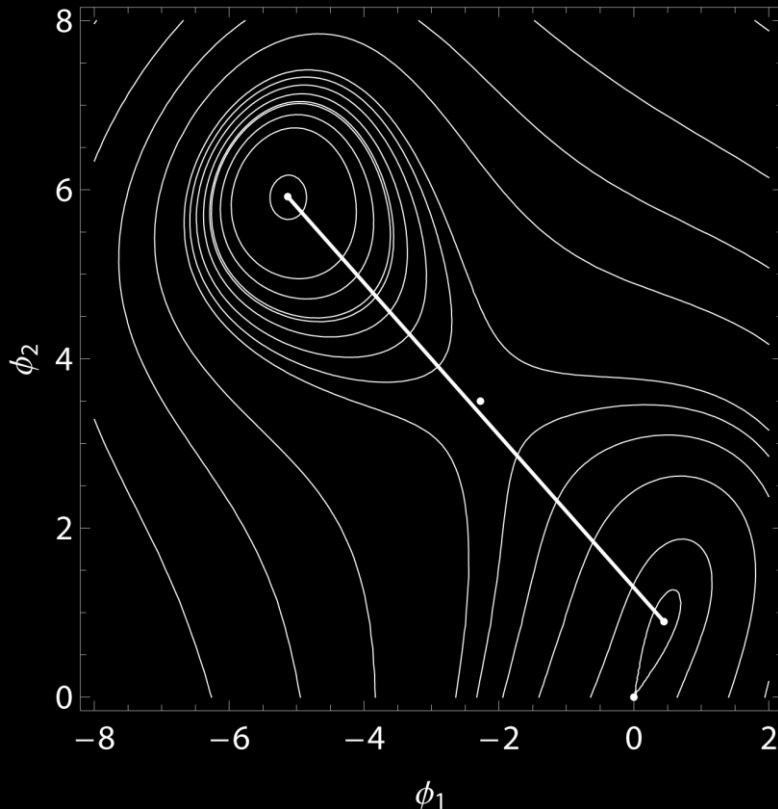
- new quartic couplings along the MSSM D-flat direction(s)

$$m_h^2 \lesssim m_Z^2 c_{2\beta}^2 + 16v^2 \left(\frac{-\epsilon_{1r}}{\tan \beta} + \frac{\epsilon_{2r}}{2 \tan \beta^2} \right) + \text{loops}$$

- LEP bound easily evaded w/ e.g. $|\epsilon_{1r}| \simeq 0.05 - 0.1$
- EFT truncated at $\mathcal{O}(1/M)$ valid only for $\tan \beta \lesssim 1/\epsilon \sim 10$

Vacuum stability constraint

Blum, CD, Hochberg '09



- new (remote) vacuum

$$\langle h \rangle \sim \sqrt{\mu M} < M$$

- safe from vacuum decay if

$$m_A \gtrsim |\mu|$$

- Higgs mass \sim **120-150** GeV
@**classical** level for

$$M \sim \mathcal{O}(\text{TeV})$$

CP violation in the BMSSM

- 7 MSSM CPV phases + 2 new phases from complex $\epsilon_{1,2}$
but not all physical, thanks to $U(1)_{PQ,R}$ field redefinitions

MSSM phases		BMSSM phases		VEV phase
ϕ_i	ϕ_f	ϑ_1	ϑ_2	θ
$\arg(M_i \mu / b)$	$\arg(A_f \mu / b)$	$\arg(\epsilon_1 / b)$	$\arg(\epsilon_2 / b^2)$	$\arg(b H_u H_d)$

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- in the BMSSM the VEV phase is non-zero at tree-level

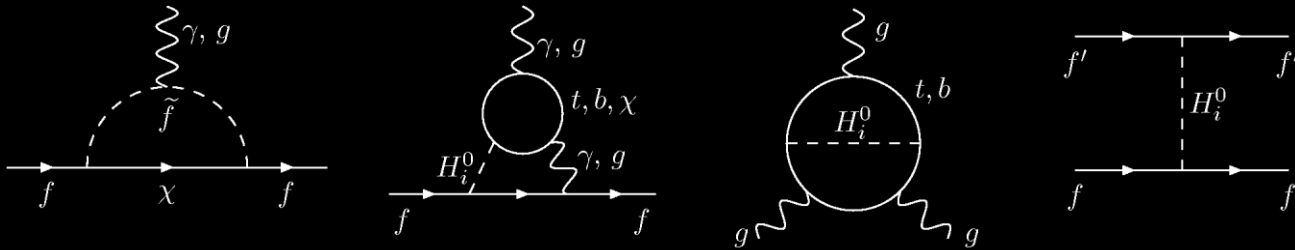
$$\partial V / \partial \theta = 0 \quad \leftrightarrow \quad \tan \theta = \frac{2 v^2 (\epsilon_{2i} s_{2\beta} - 2 \epsilon_{1i})}{s_{2\beta} (m_{H_{\pm}}^2 - m_W^2) + 2 v^2 (\epsilon_{2r} s_{2\beta} - 2 \epsilon_{1r})}$$

- at leading order : $\theta \propto \epsilon_{2i} \sin 2\beta - 2\epsilon_{1i}$

BMSSM allows for « *spontaneous baryogenesis* »

EDM bounds on BMSSM phases

- present sensitivities: $|d_{n, Tl, Hg}| < 3 \times 10^{-26}, 9 \times 10^{-25}, 2 \times 10^{-29} \text{ ecm}$



- EDMs dominated by (light) higgs-pseudoscalar mixing

$$m_{h_A}^2 \approx 4v^2 \epsilon_{1i} - 2v^2 \epsilon_{2i} \sin 2\beta \propto \theta, \quad m_{H_A}^2 \approx 2v^2 \epsilon_{2i} \cos 2\beta$$

all EDMs are roughly set by the VEV phase (at $T=0$)

(if all MSSM phases are turned off)

New CPV sources for baryogenesis

- baryon asymmetry computed from Schwinger-Dyson eq. in so-called closed time path formalism

$$\partial_t n_a - D_a \nabla^2 n_a = \sum_b \Gamma_{ab} n_b + S_a^{\text{CPV}} \quad a = t_{L,R}, \tilde{t}_{L,R}, \tilde{H}, H$$

(n_a chiral charge density, Γ_{ab} relaxation terms, S_a^{CPV} CPV sources)

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- in MSSM only $S_{\tilde{H}}^{\text{CPV}} \neq 0$ since real VEV + heavy LH-stop
- BMSSM baryogenesis can be top, stop, higgsino-driven

e.g. stop-driven BMSSM baryogenesis

- stop CPV source @leading order in VEV:

$$\begin{array}{c}
 y_t [A_t^* v_u^*(z) - \mu v_d(z)] \quad y_t [A_t v_u(z') - \mu^* v_d^*(z')] \\
 \otimes \quad \otimes \\
 | \quad | \\
 \hline
 \tilde{t}_R \quad \tilde{t}_L \quad \tilde{t}_R^*
 \end{array}$$

$$S_{\tilde{t}_R}^{\text{CPV}}(z) = \frac{3y_t^2 v(z)^2}{2\pi^2} \left[\mathcal{A}_{\text{MSSM}} \dot{\beta}(z) + \mathcal{B} \dot{\theta}(z) \right] \mathcal{I}$$

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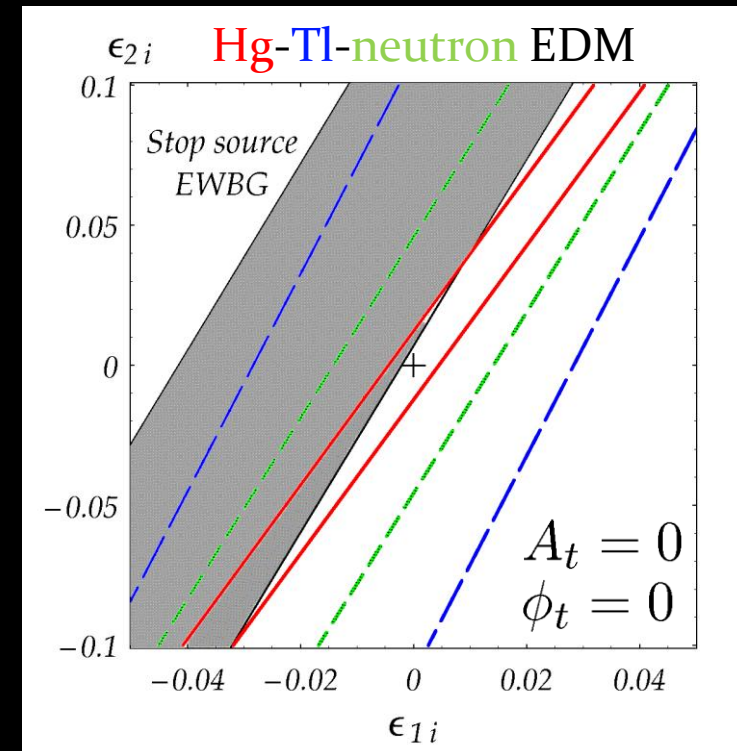
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linear approximation of gradients:

$$\dot{\beta}(z) \simeq \Delta\beta/L_w, \quad \dot{\theta}(z) \simeq \Delta\theta/L_w$$

$$\Delta\theta \simeq \theta(v_c/v)^2 \sim (0.2 - 0.5)\theta$$

new CPV controlled by T=0 VEV phase



Conclusions

- The MSSM little hierarchy problem significantly limits the EW baryogenesis in SUSY
- Evading LEP bound at tree-level, effective operators in the MSSM Higgs sector makes the generation of the baryon asymmetry much more natural by:
 - adding new CPV phases (leading to spontaneous EWBG)
 - resurrecting the stop source by allowing both stops to be light

