Affleck-Dine Baryogenesis from Type IIB Strings

Francesco Muia
University of Bologna
24/06/2016

Based on:
"Affleck-Dine Baryogenesis from Type IIB Strings"
R. Allahverdi, M. Cicoli & FM
arXiv: 1604.03120 [hep-th].

StringPheno 2016
Ioannina

Baryogenesis

Main problem:

attempt to dynamically generate the Baryon Asymmetry of the Universe (BAU).

$$\Delta_{\mathrm{B}} = \frac{n_{\mathrm{B}}}{s} = \left(\Omega_{\mathrm{B}} h^2\right) \frac{\rho_{\mathrm{crit}}}{s h^2 m_{\mathrm{p}}} \sim 10^{-10}$$

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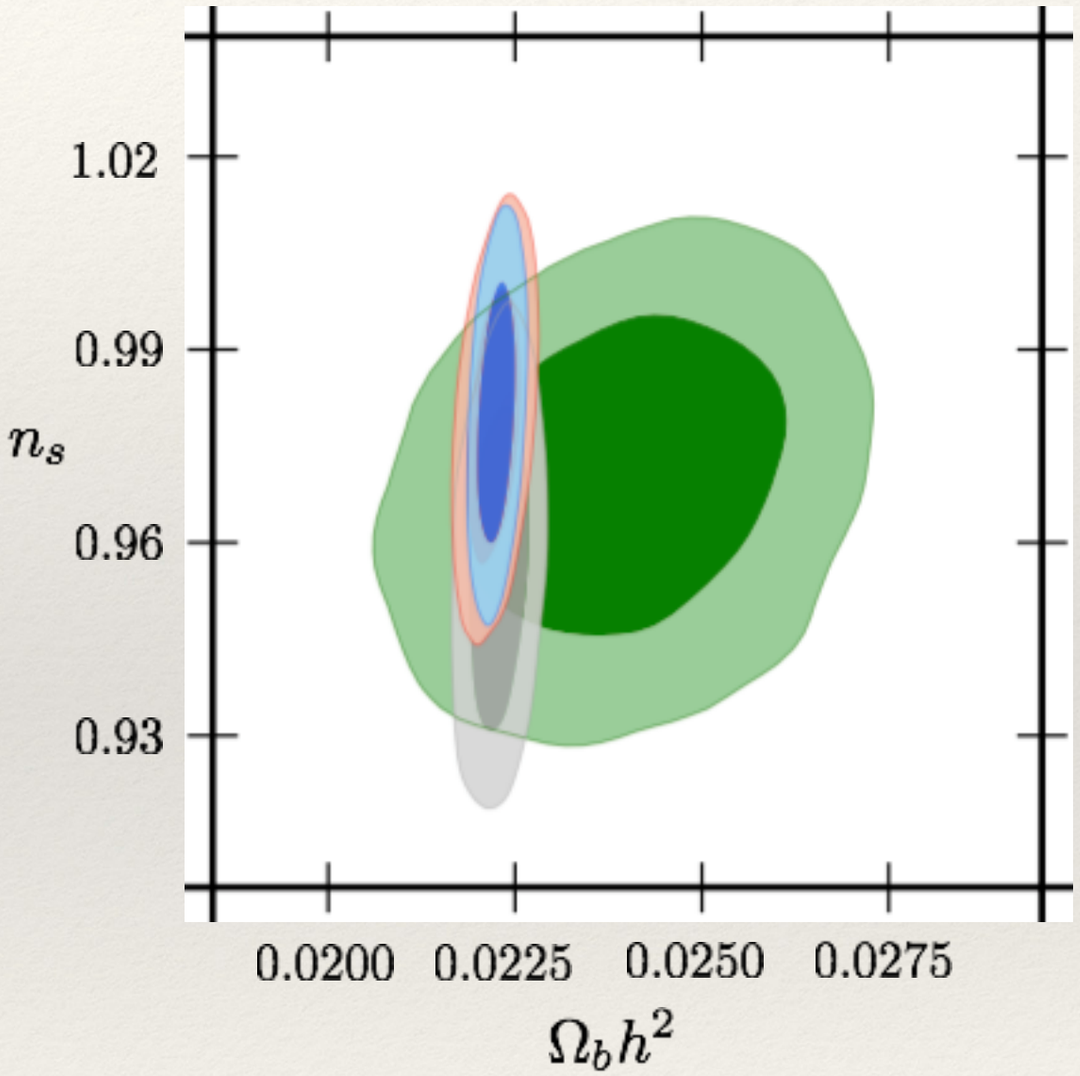

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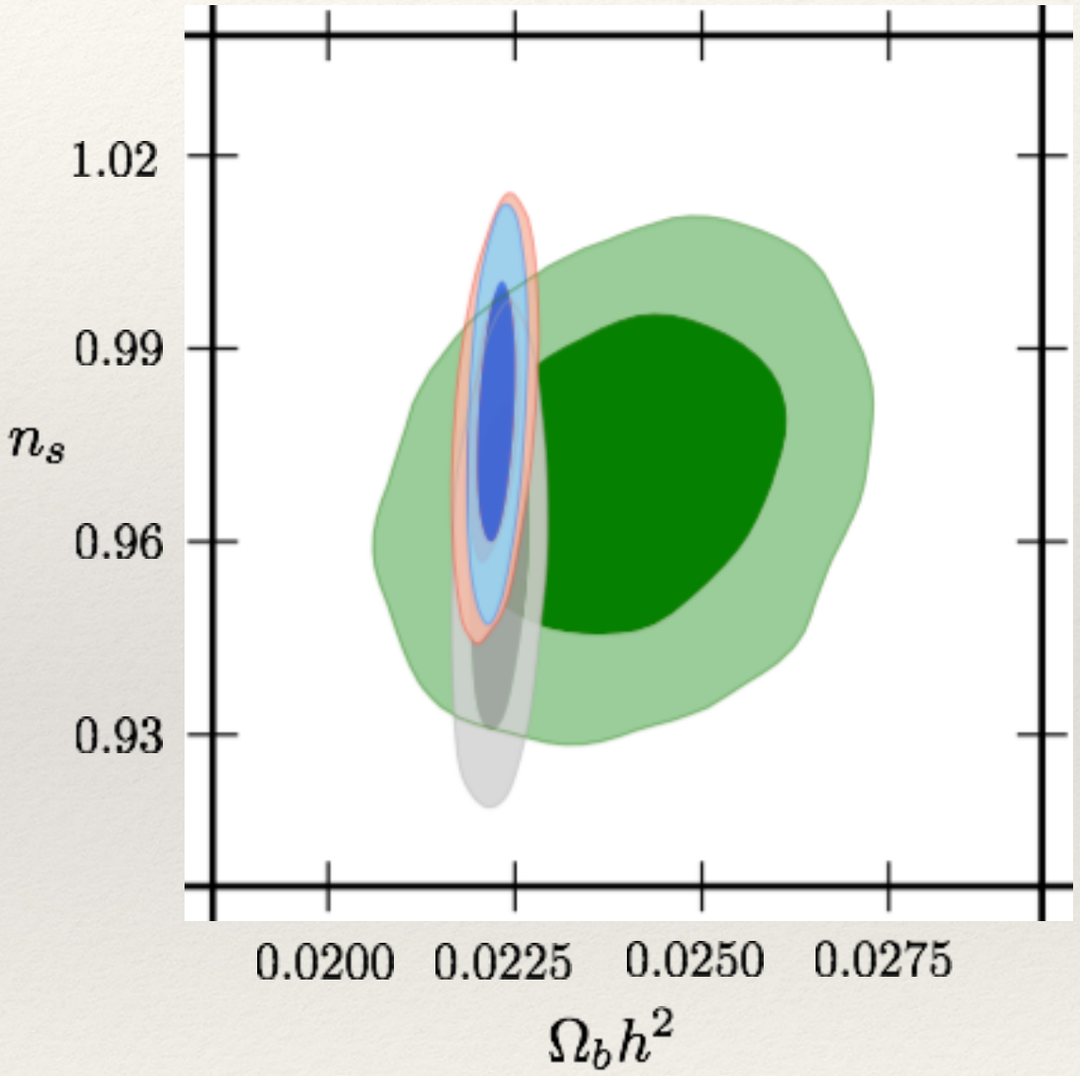

Sakharov conditions: [Sakharov, 1967]

1) B-violation;

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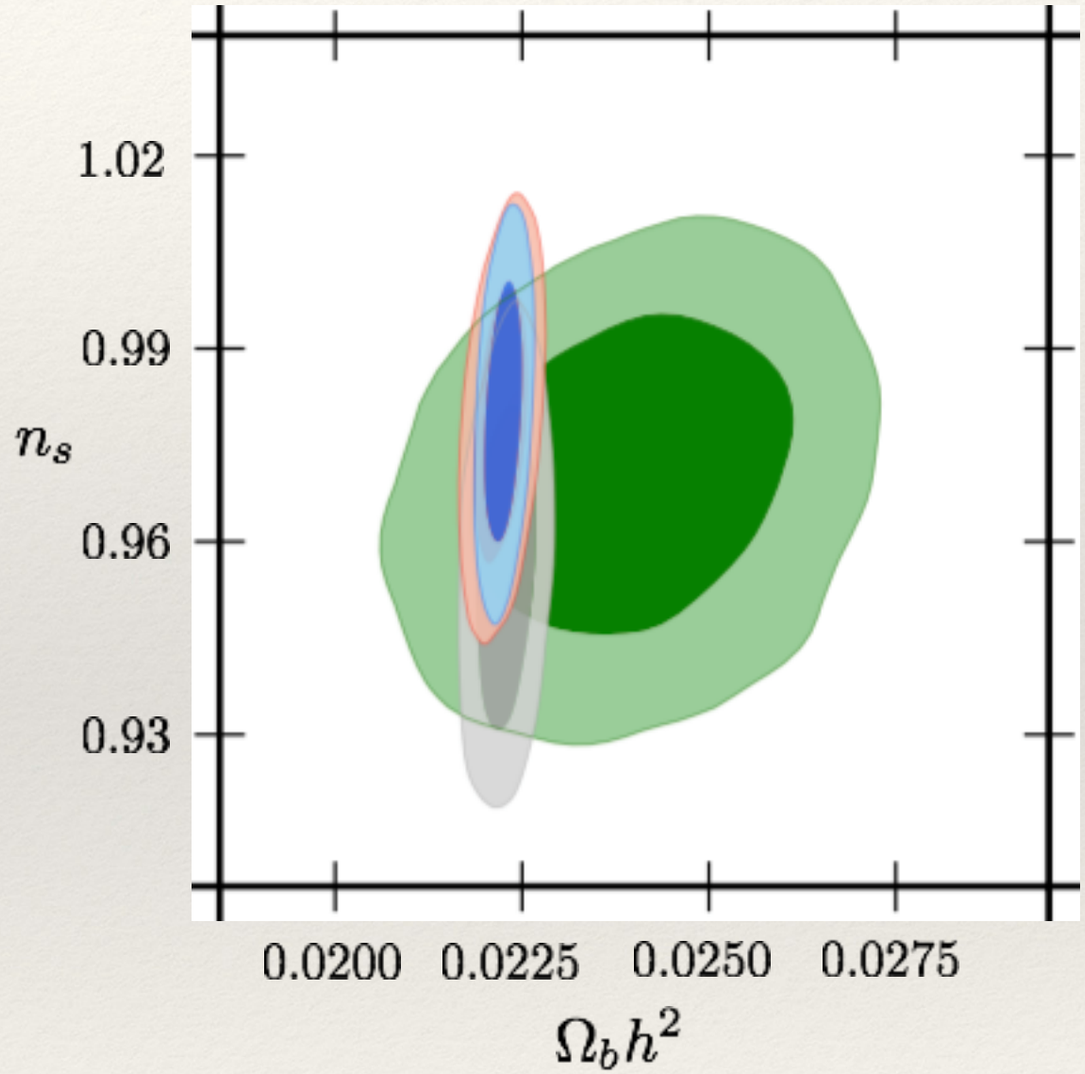

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Affleck-Dine mechanism

[Affleck & Dine, 1985]

A string theory embedding is missing.

Affleck-Dine Mechanism

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The MSSM contains many D-flat directions: $D^a = X^\dagger T^a X = 0\,.$

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Example: $L_i L_j \overline{e}_k \qquad L_i = \begin{pmatrix} \phi \\ 0 \end{pmatrix} \qquad L_j = \begin{pmatrix} 0 \\ \phi \end{pmatrix} \qquad \overline{e}_k = \phi$

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Many D-flat directions can also be F-flat.
(their potential does not receive any contribution from $W_{\rm MSSM}$)

$$W_{\rm MSSM} = \lambda_u\, Q\, H_u\, \overline{u} + \lambda_d\, Q\, H_d\, \overline{d} + \lambda_e\, L\, H_d\, \overline{e} + \mu\, H_u\, H_d$$

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Flat directions lifted by SUSY-breaking effects and non-renormalizable terms.

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The cosmological evolution depends crucially on the sign of $c_{\rm H}$:

- $c_{\rm H} > 0$: the field settles down to the origin.

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- $c_{\rm H} < 0$: the field becomes tachyonic during inflation.

  $\longrightarrow$ Affleck-Dine mechanism is enabled.

Affleck-Dine Mechanism

- ϕ tachyonic during inflation $\longrightarrow$ new minimum: $\phi_{\mathrm{inf}} = \left(\frac{H_{\mathrm{inf}} \Lambda^{k-3}}{\sqrt{k-1} c_{\mathrm{H}} \lambda_k} \right)^{\frac{1}{k-2}}$

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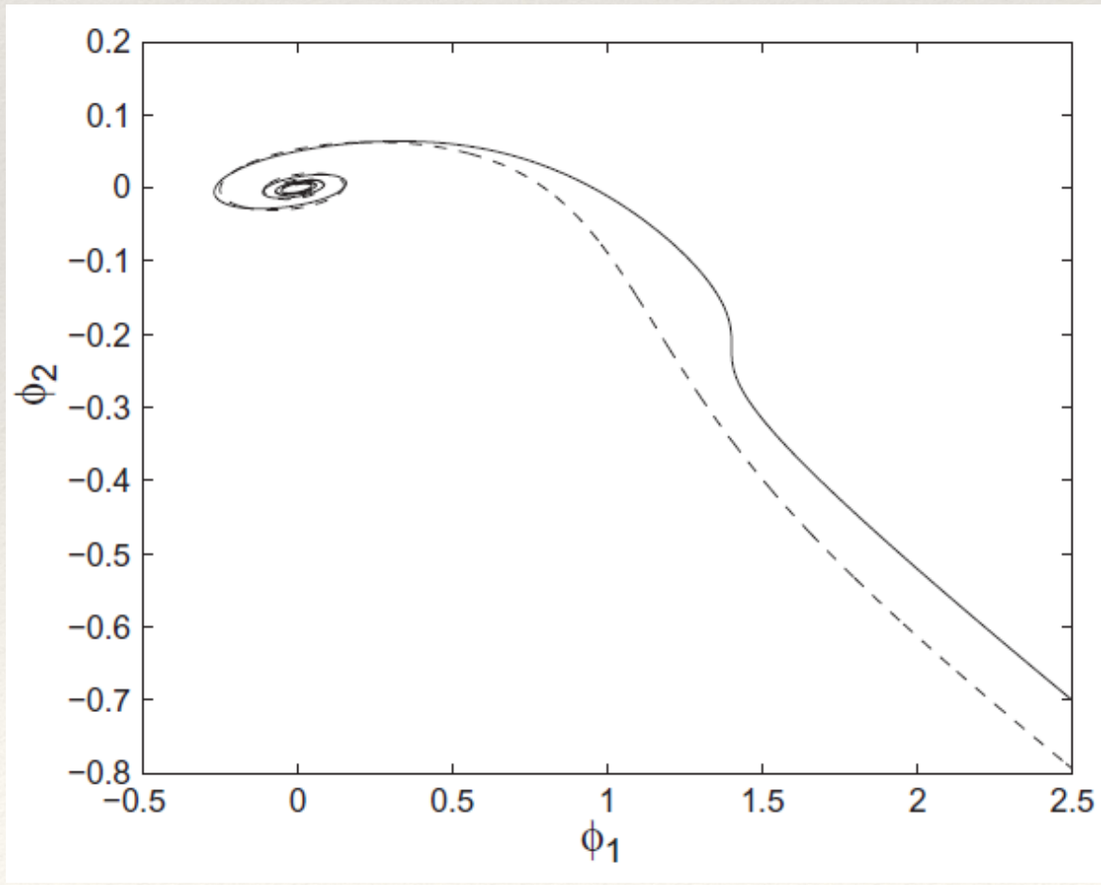

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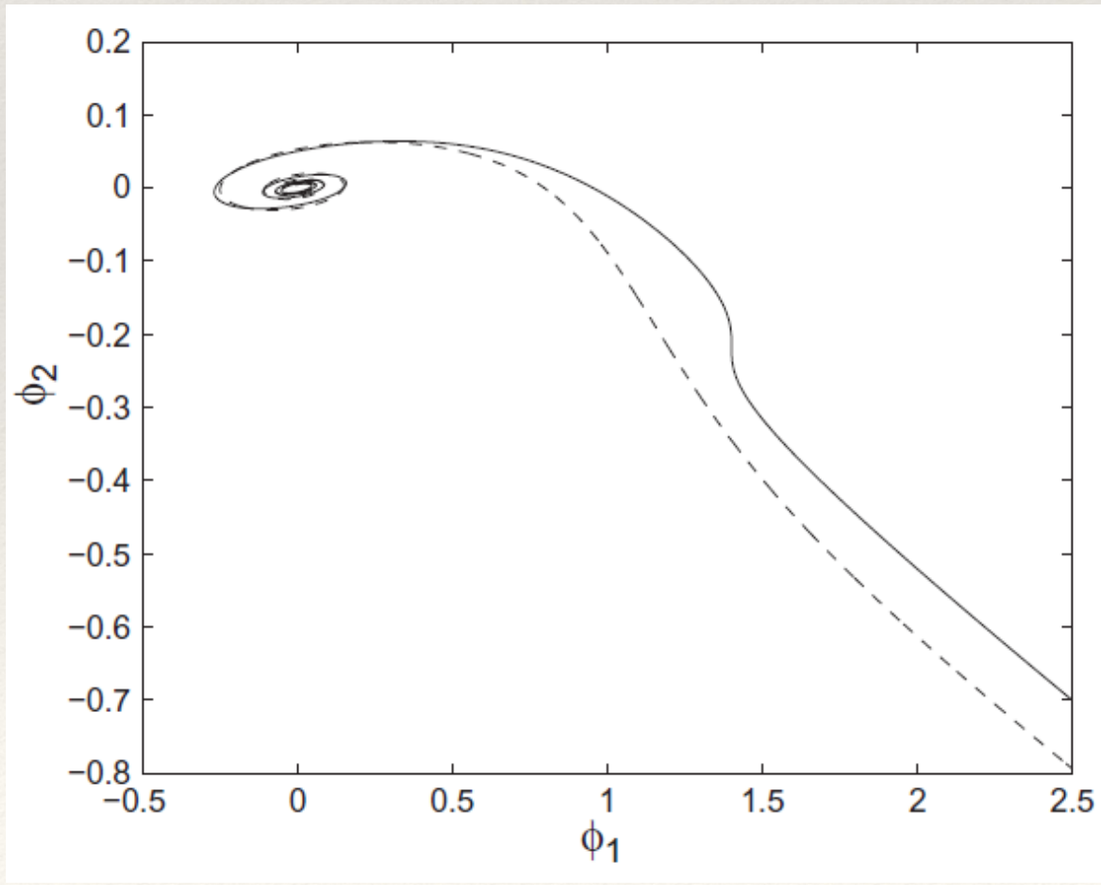

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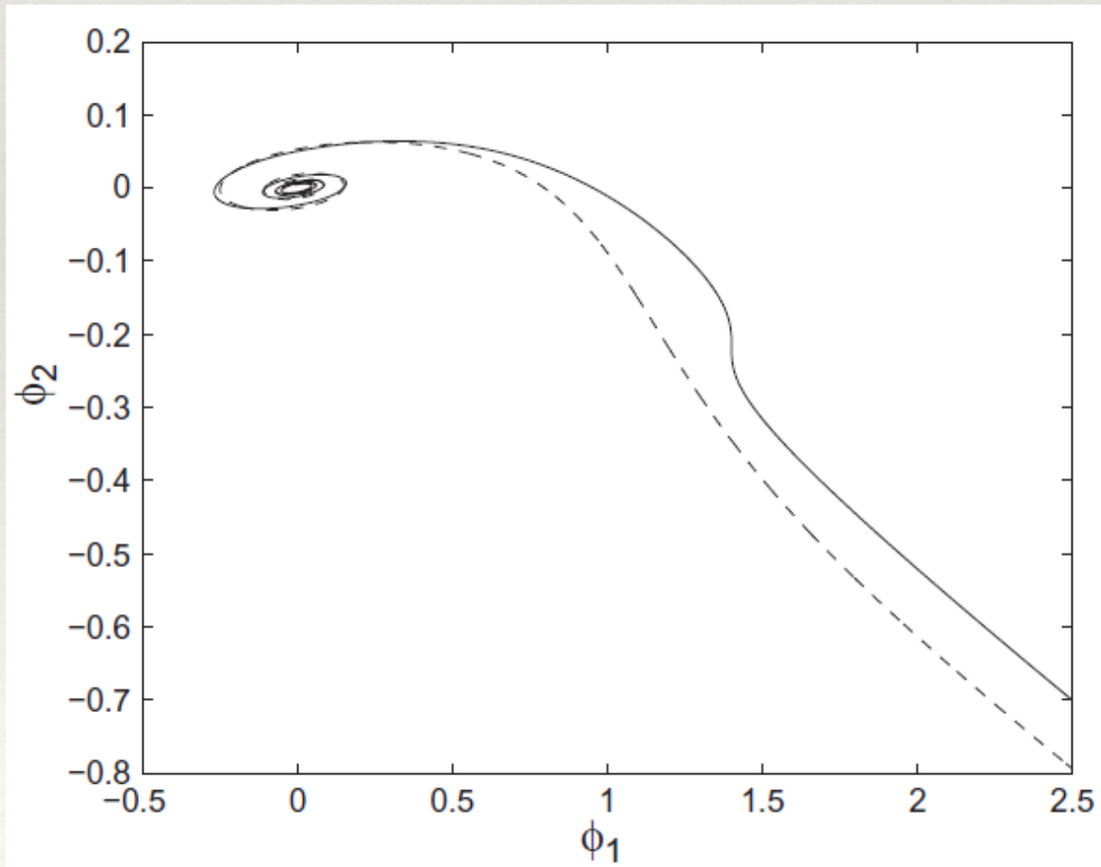

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Geometric constraints necessary to get inflation and AD baryogenesis.

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We look for a model with:

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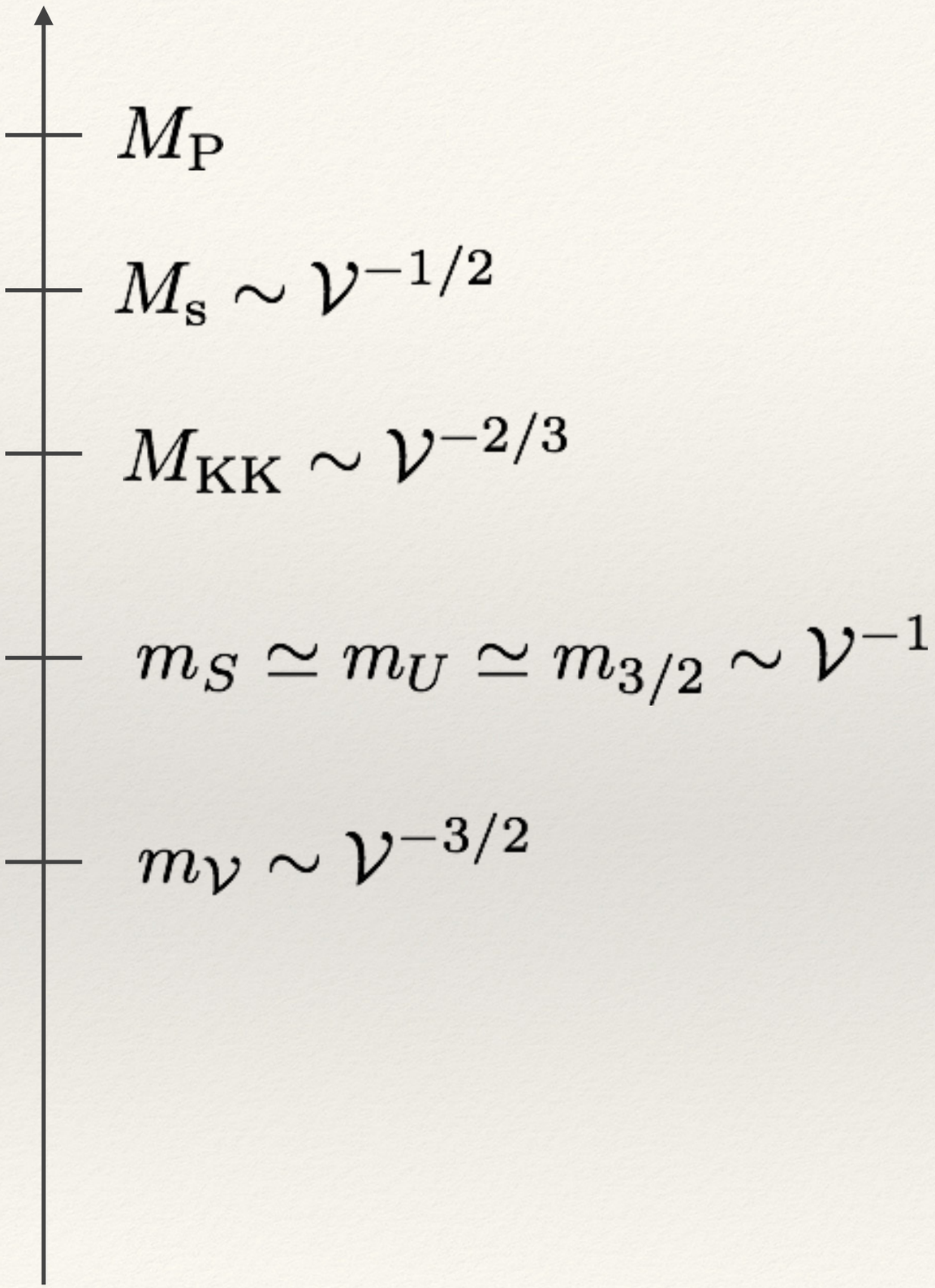

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$m_{\mathcal{V}} \sim \mathcal{V}^{-3/2}$ ⟶ Lightest modulus $\gtrsim 100\,\mathrm{TeV}$ (CMP)

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(non-thermal history)

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A. (*) holds exactly: ULTRALOCAL limit.
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low-energy MSSM-scenario

(gauginos and scalars have similar masses)

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$$m_0^2 = m_{3/2}^2 + V_0 - F^I F^{\overline{J}} \partial_I \partial_{\overline{J}} \log \tilde{K}_\alpha = \frac{2}{3} V_0 \equiv 2H_{\rm inf}^2 > 0$$

$$V_0 = |F|^2 - 3m_{3/2}^2$$

Affleck-Dine Baryogenesis is not compatible with low-energy SUSY in sequestered models!

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Split-SUSY scenario
(scalars hierarchically heavier than gauginos)

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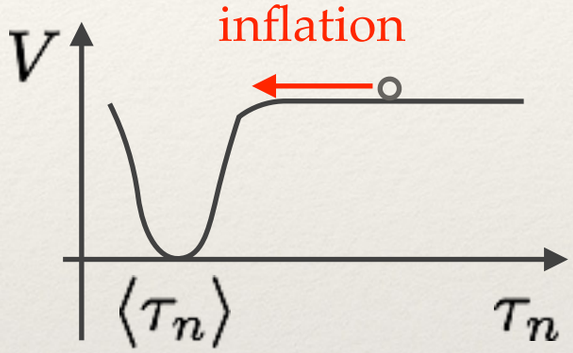

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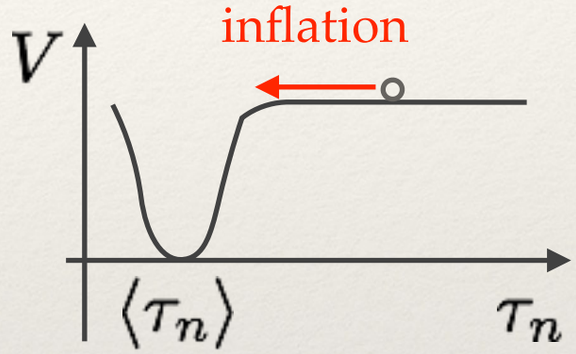

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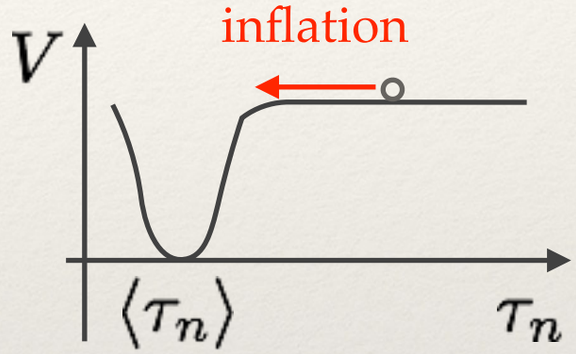

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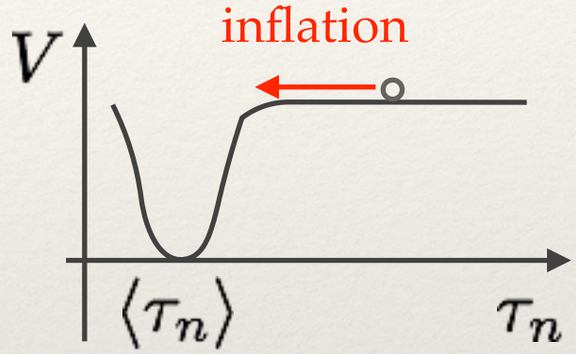

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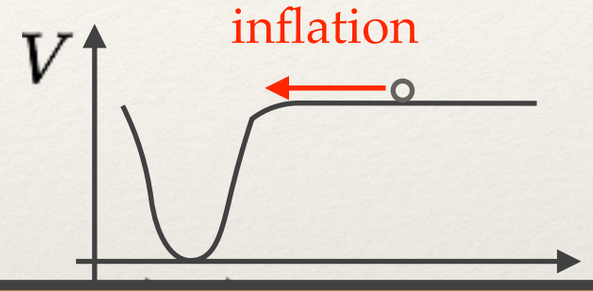

😐 **WARNING** 😐

Kähler Moduli Inflation suffers from an η-problem created by string loop corrections.
We assume that these are absent due to a suitable choice of the brane setup.

[see Shukla's talk]

reheats the universe.

- Small-field inflation: $r \lesssim 10^{-10}$.

SUSY-breaking

- F^{T_b} is the main source of SUSY-breaking: $F^{T_b} \gg F^i$.
- The interplay between no-scale structure and locality produce the SEQUESTERING.
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  * F^{T_b} is slightly larger during inflation:

$$F^{T_b} = -2\tau_b m_{3/2}\left(1+\mathcal{O}\left(\frac{\hat{\xi}/n}{\mathcal{V}\log\mathcal{V}}\right)\right)$$

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Scalar masses

LOCAL LIMIT

Assumption: the Kähler matter metric depends on the inflaton at sub-leading order.

$$\tilde{K}_\alpha = \frac{1}{\tau_b}\left(1 - 2c_n \frac{\tau_n^{3/2}}{\mathcal{V}}\right)$$

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Affleck-Dine Baryogenesis is possible!

Reheating

[Cicoli et al., 2016]

- Immediately after inflation τ_n gets very heavy: $m_{\tau_n} \simeq m_{3/2} \log \mathcal{V}$

τ_n decays quickly (I matter domination) $\longrightarrow$ $T_{\rm rh,inf} \simeq \sqrt{\Gamma M_{\rm P}} \sim M_{\rm P} \mathcal{V}^{-1}$

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- Since $m_\phi \simeq m_{\mathcal{V}} \sqrt{\log \mathcal{V}}$ the Affleck-Dine field ϕ starts oscillating at the end of inflation.

ϕ gives a mass of order $m \sim y\langle\phi\rangle$ to the fields to which it couples.

$\longrightarrow$ it decays once $y\langle\phi\rangle < m_\phi$.

ϕ decays well before the decay of the volume mode.

Generation of baryon asymmetry

[Cicoli et al., 2016]

The displacement of the volume mode at the end of inflation is $M_{\rm P}$.

The displacement of the Affleck-Dine field at the end of inflation is ϕ_0.

$$\frac{n_\phi}{n_\mathcal{V}} \simeq \frac{m_\phi}{m_\mathcal{V}} \left(\frac{\phi_0}{M_{\rm P}} \right)^2$$

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where $\dfrac{n_{\rm B}}{n_\phi} \sim \beta \sin\delta \dfrac{|A|}{m_\phi}$ and $\dfrac{n_\mathcal{V}}{s} = \dfrac{3T_{\rm rh}}{4m_\mathcal{V}}$

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Note: in sequestered models: $A \sim \mathcal{V}^{-2}$.

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number of small cycles: $n = 10$

$g_s \sim 0.1$

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	W_0	$\log_{10}\left(\mathcal{V}\vert_{\rm COBE}\right)$
(A)	1	5.14
(B)	10	6.15
(C)	100	7.15

$$\mathcal{A}^2_{\mathcal{R}}(\tau^*_n) \simeq \frac{g_s}{8\pi}\frac{3^4\hat{\xi}^3 W_0^4}{4^6 n^3\, a_n^4 A_n^2 (\tau^*_n)^{5/2}}\frac{e^{2a_n\tau^*_n}}{\mathcal{V}^6} \simeq 2.7\times 10^{-7}$$

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	M [GeV]	m_0 [GeV]
(A)	5.4×10^5	3×10^{10}
(B)	5.2×10^4	9.2×10^9
(C)	5×10^3	2.8×10^9

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$$M = \frac{F^S}{2s} \simeq \lambda(U,S)\frac{\hat{\xi} m_{3/2}}{\mathcal{V}}$$

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	$T_{\rm rh}\,[\mathrm{GeV}]$	$\phi_0/M_{\rm P}$
(A)	6.7×10^3	0.03
(B)	1.1×10^3	0.08
(C)	195	0.19

Discussion

DARK MATTER

- **Non-thermal production**: $200\,\mathrm{GeV} \lesssim T_{\mathrm{rh}} < T_f \longrightarrow m_{\mathrm{DM}} \gtrsim 4\,\mathrm{TeV}$

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$T_{\rm rh}$ is always too large to allow for a non-thermal production of DM!

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(RPV MSSM terms)

R-parity violating LSP decay proceeds via off-shell scalars:

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DARK RADIATION

- Sequestered models in the Split-SUSY scenario do not suffer from DR overproduction if the volume decay into MSSM scalars is allowed.

[Cicoli, FM, 2015]

Conclusions

We proposed a possible embedding of the Affleck-Dine mechanism in a string theory model with:

A. Chiral visible sector (extension of the MSSM, split-SUSY spectrum);

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Drawbacks:

1. The model crucially depends on the form of the sub-leading corrections to the Kähler matter metric. These corrections are not explicitly computable at the moment.
2. Kähler Moduli Inflation generically suffers from an η-problem, due to string loop corrections. We assume that this can be avoided by a suitable choice of the brane setup.

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Despite these issues, the model serves as a **proof-of-principle** to show that the Affleck-Dine mechanism can be embedded in string theory.

Thanks for the attention!

Sequestered models

- Type IIB with O3/O7 planes.

[Blumenhagen et al., 2009]
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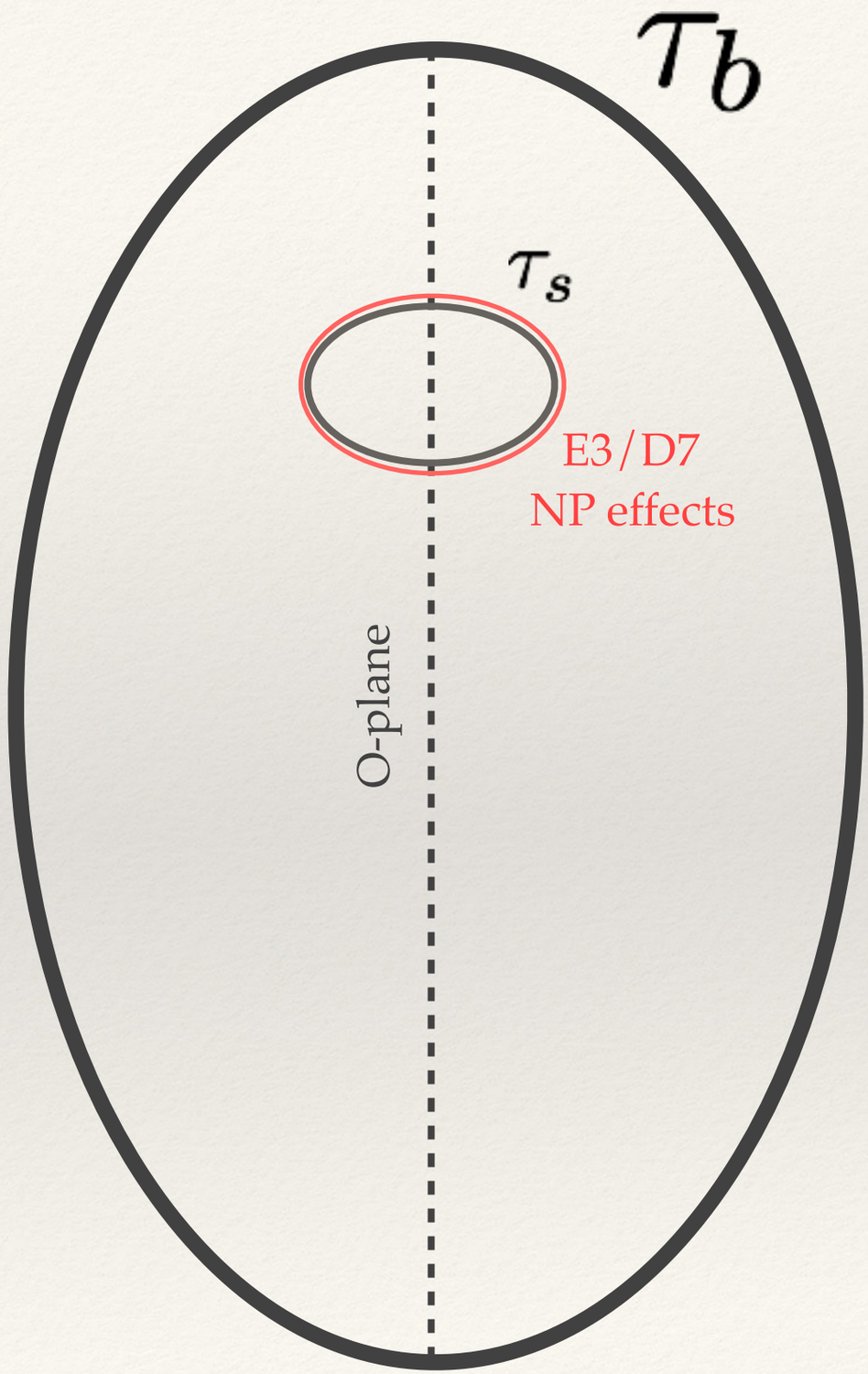
Minimum: $\langle\mathcal{V}\rangle \sim e^{1/g_s} \qquad \langle\tau_s\rangle^{3/2} \sim \frac{\hat{\xi}}{2} = \frac{\xi}{2g_s^{3/2}}$



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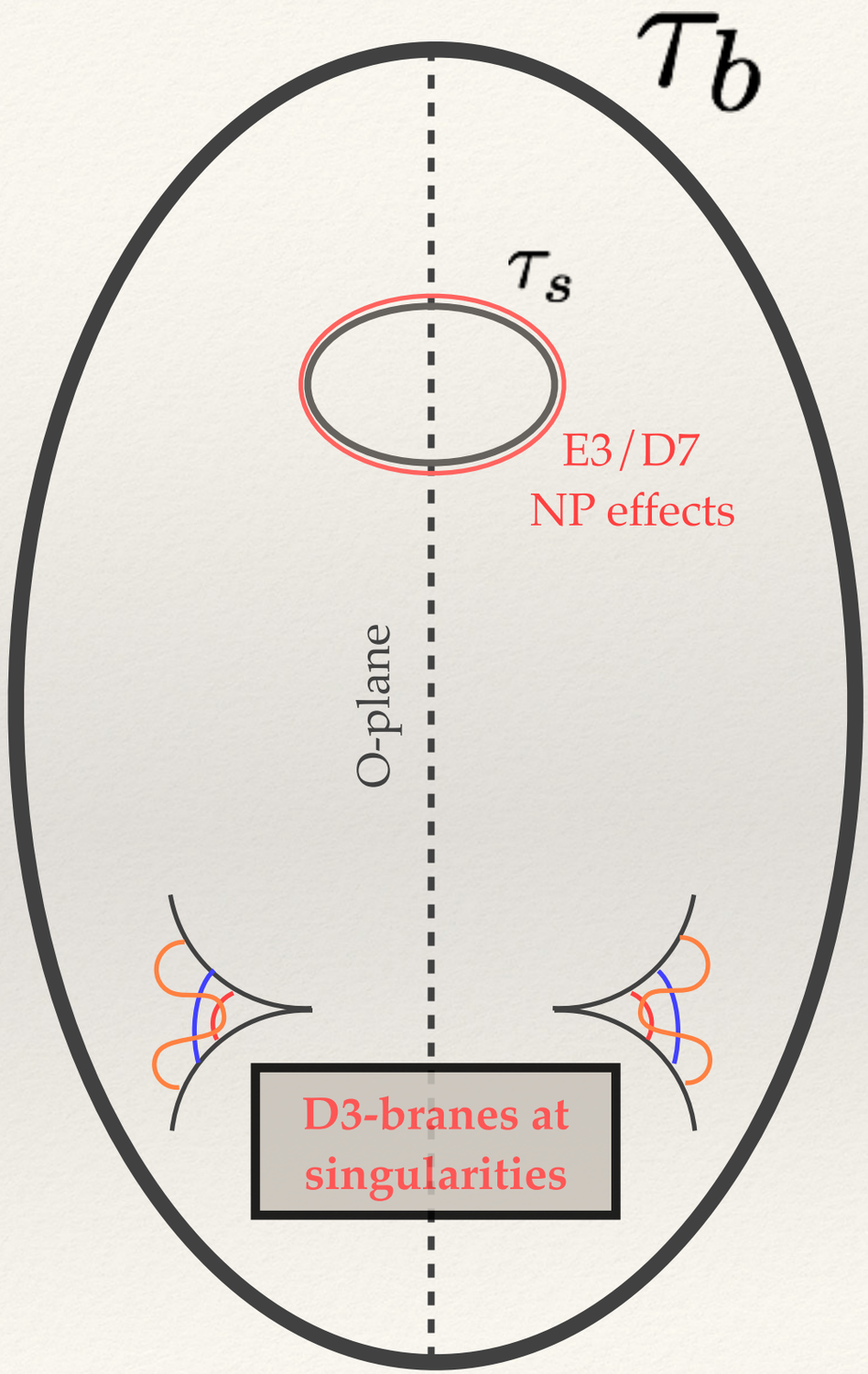
- D3-branes at singularity

↓

SEQUESTERING: $\boxed{m_{\rm soft}^2 \ll m_{3/2}^2 \sim \frac{W_0^2}{\mathcal{V}^2}}$



Affleck-Dine Mechanism

[Dine et al., 1996]
[Martin et al., 1996]

The MSSM contains many D-flat directions.

Ex: direction $L_i L_j \bar{e}_k \qquad L_i = \begin{pmatrix} \phi \\ 0 \end{pmatrix} \qquad L_j = \begin{pmatrix} 0 \\ \phi \end{pmatrix} \qquad \bar{e}_k = \phi$

$$D_1 = \frac{1}{2}\sum_i \left(L_i^{\uparrow *} L_i^{\downarrow} + L_i^{\downarrow *} L_i^{\uparrow} \right) \qquad D_2 = \frac{i}{2}\sum_i \left(L_i^{\uparrow *} L_i^{\downarrow} - L_i^{\downarrow *} L_i^{\uparrow} \right)$$

$$D_3 = \frac{1}{2}\sum_i \left(\left| L_i^{\uparrow} \right|^2 - \left| L_i^{\downarrow} \right|^2 \right) \qquad D_Y = \frac{1}{2}\sum_i \left(2\left|\bar{e}_i\right|^2 - \left| L_i^{\uparrow} \right|^2 - \left| L_i^{\downarrow} \right|^2 \right)$$

$$\longrightarrow \qquad V_D = \frac{g^2}{2}\left(D_1^2 + D_2^2 + D_3^2 \right) + \frac{g'^2}{2} D_Y^2 \equiv 0$$