# The Affleck-Dine dynamics of pangenesis

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# INTRODUCTION

- Pangenesis: Mechanism for jointly producing baryon asymmetry and dark matter abundance
- Dark and visible matter charged under separate global U(1)s ($B_{\mathrm{d}}$ and $(B-L)_{\mathrm{v}}$)
- In early universe, $X \equiv (B-L)_{\mathrm{v}} + B_{\mathrm{d}}$ broken $\Rightarrow$ X-charge asymmetry generated
- $B-L \equiv (B-L)_{\mathrm{v}} - B_{\mathrm{d}}$ always conserved $\Rightarrow$ Visible and dark asymmetries related $\Rightarrow$ Right DM abundance obtained for $m_{\mathrm{DM}} \approx (2-5)$ GeV

In this talk: Focus on Affleck-Dine dynamics to generate X-charge asymmetry

Based on work with Kallia Petraki and Ray Volkas (arXiv:1201.2200)

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# The Affleck-Dine mechanism

- SUSY theories often have 'flat directions' in scalar potential (in MSSM e.g. certain combinations of *u*- and *d*-type squarks)
- Beyond SUSY and renormalizable limit, FDs 'lifted' by
  - hidden-sector SUSY breaking:

$$V \supset m_s^2 |\Phi|^2 + \ldots$$

  - inflaton-induced SUSY breaking:

$$V \supset -cH^2 |\Phi|^2$$

  - thermal corrections (turn out to be not important)
  - higher-dimensional operators:

$$W_{\rm nr} = \frac{\Phi^d}{d\, M_*^{d-3}} \implies V \supset \left| \frac{\Phi^{d-1}}{M_*^{d-3}} \right|^2$$

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# Dynamics of the Affleck-Dine field

Let's focus on gauge mediation. Potential for AD field then given by

$$V_{\mathrm{AD}} = -c\,H^2|\Phi|^2 + \left|\frac{\Phi^{d-1}}{M_*^{d-3}}\right|^2 + m_{\mathrm{s}}^2 M_{\mathrm{m}}^2 \ln^2\left(1 + \frac{|\Phi|}{M_{\mathrm{m}}}\right) + \left(A\frac{\Phi^d}{d\,M_*^{d-3}} + \mathrm{h.c.}\right)$$

- During inflation: AD field stuck in minimum determined by inflaton-induced tachyonic mass and nonrenormalizable part
- After inflation: Hubble rate decreases ⇒ hidden-sector soft mass starts dominating ⇒ AD field begins oscillating around minimum
- At same time: $A$-term kicks AD field in radial direction

$$\Rightarrow \text{asymmetry } n_x = iq_x\left(\dot{\Phi}^*\Phi - \Phi^*\dot{\Phi}\right) \text{ generated}$$

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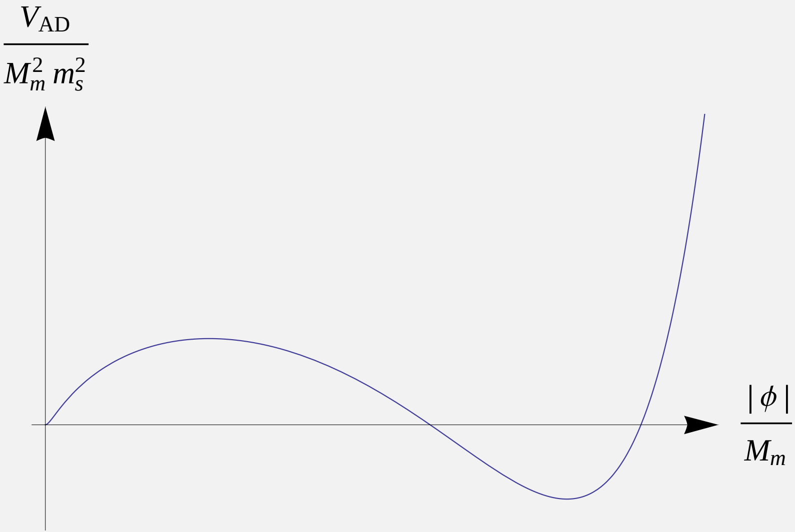

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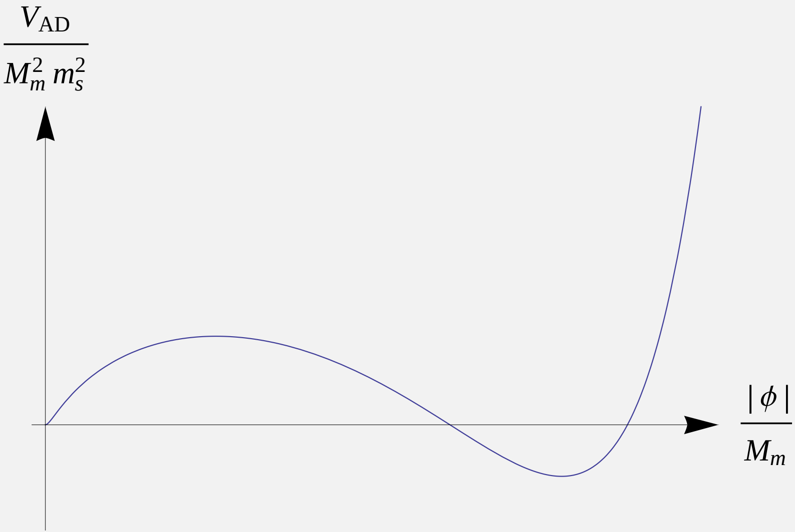

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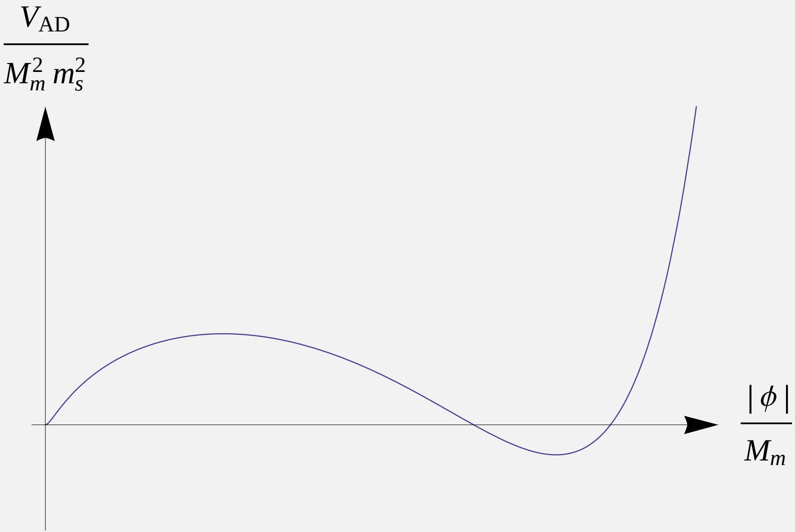

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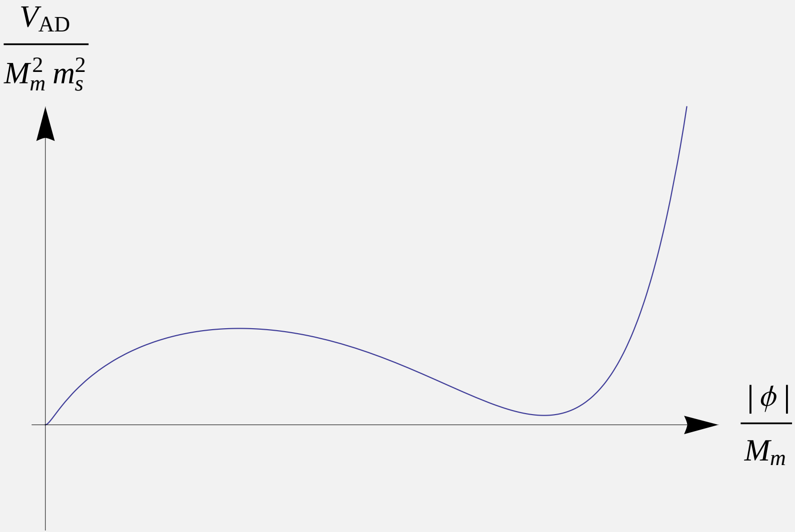

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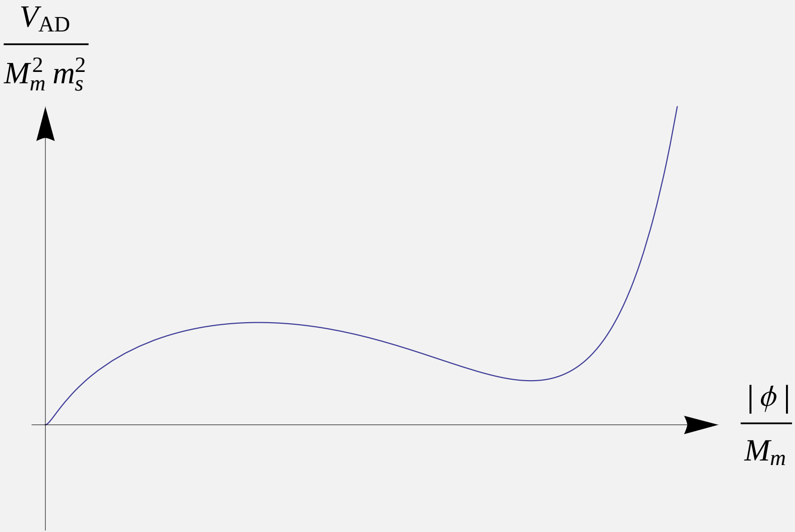

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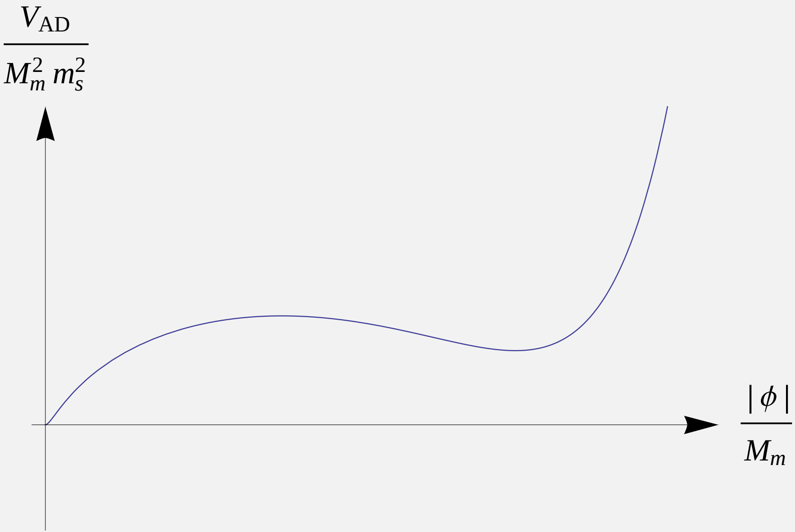

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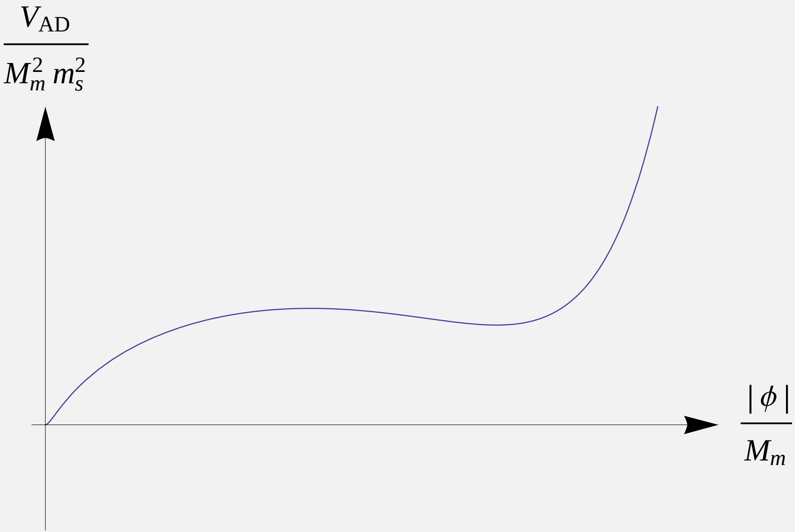

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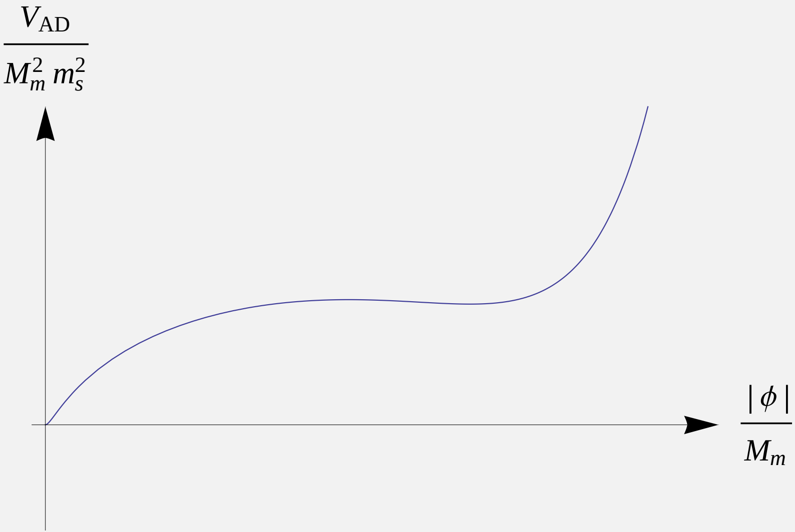

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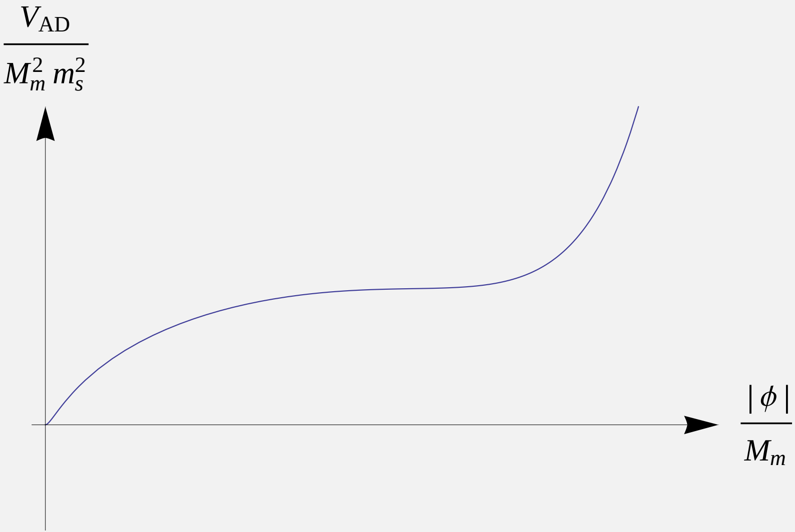

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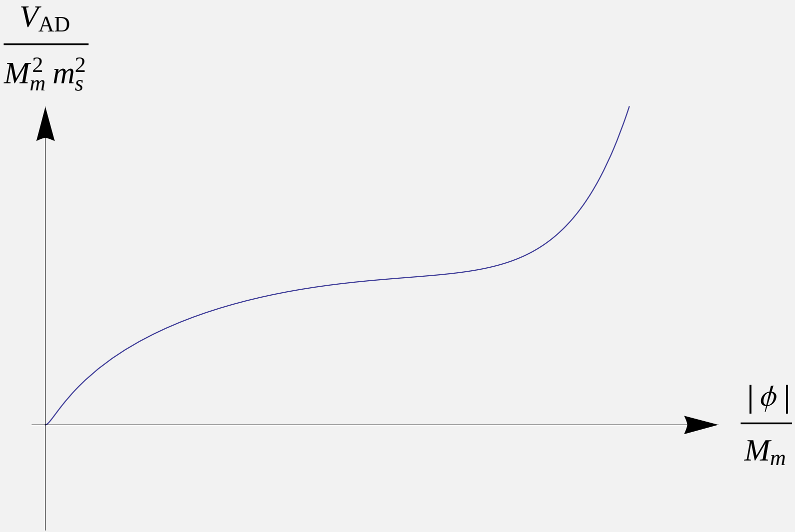

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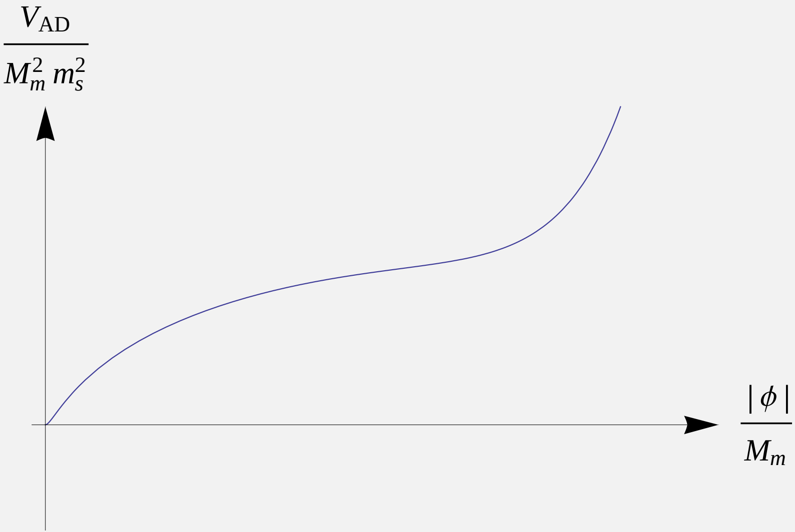

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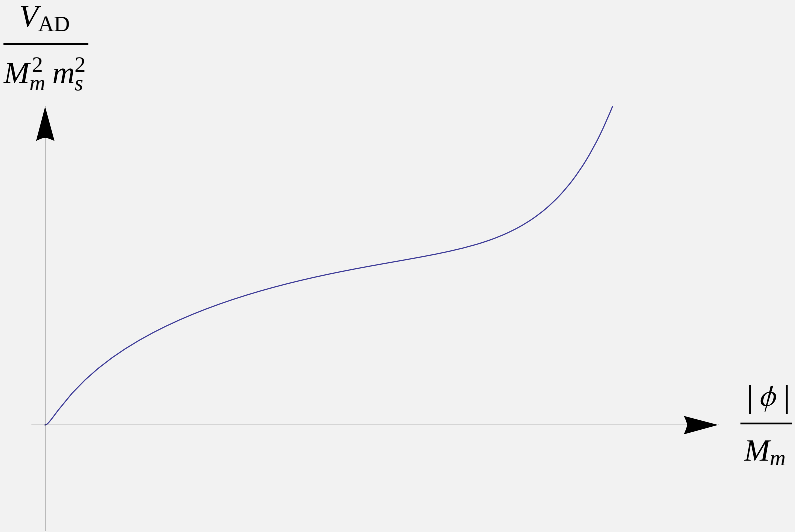

# PARAMETER SPACE ANALYSIS

- X-charge asymmetry generated during inflaton oscillations. charge-to-entropy ratio becomes constant at reheating:

$$\eta_X \approx \frac{q_X \sin\delta}{2} \frac{|A| T_R}{M_{\mathrm{P}}^2} \left(\frac{M_*}{H_{\mathrm{osc}}}\right)^{\frac{2(d-3)}{d-2}}$$

- Four free parameters: $T_R$, $M_{\mathrm{m}}$, $M_*$ and $d$. Requirement that $\eta_X \approx 10^{-9}$ leaves three. We choose $M_{\mathrm{m}}$, $M_*$ and $d$.
- In gauge mediation, gravitino is the LSP

$\Rightarrow$ Constraints on $T_R$ (and thus $M_*$, $M_{\mathrm{m}}$, $d$)

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# Constraints on the reheating temperature

BBN and avoiding overclosure require that

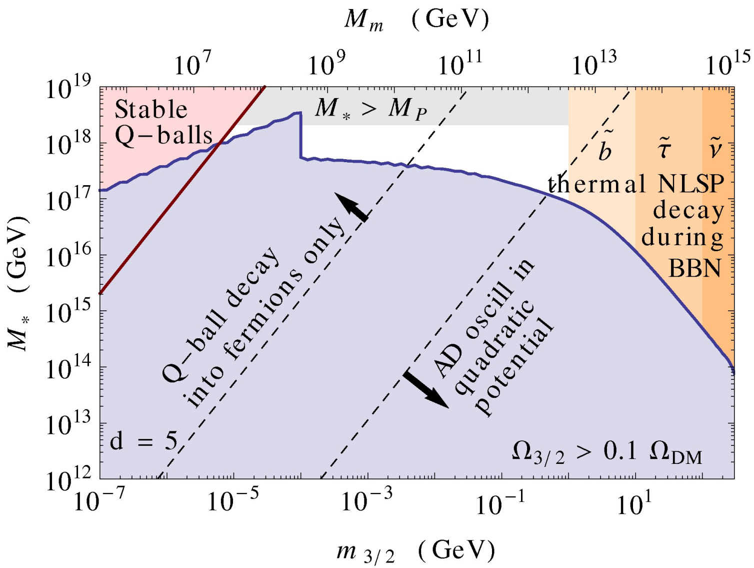
$$T_R \lesssim \begin{cases} 100\ \text{GeV}, & \text{for} \quad m_{3/2} \gtrsim \tilde{m} \\ 4 \cdot 10^7\ \text{GeV} \left(\dfrac{m_{3/2}}{1\ \text{GeV}}\right) & \text{for} \quad 100\ \text{keV} \lesssim m_{3/2} \lesssim \tilde{m} \\ 100\ \text{GeV}, & \text{for} \quad 100\ \text{eV} \lesssim m_{3/2} \lesssim 100\ \text{keV} \\ \text{no limit}, & \text{for} \quad m_{3/2} \lesssim 100\ \text{eV}\ , \end{cases}$$

where

$$\tilde{m} \equiv \begin{cases} 1\ \text{GeV}, & \text{for NLSP} = \tilde{b} \\ 10\ \text{GeV}, & \text{for NLSP} = \tilde{\tau} \\ 100\ \text{GeV}, & \text{for NLSP} = \tilde{\nu}\ . \end{cases}$$

# ALLOWED PARAMETER SPACE

d=5



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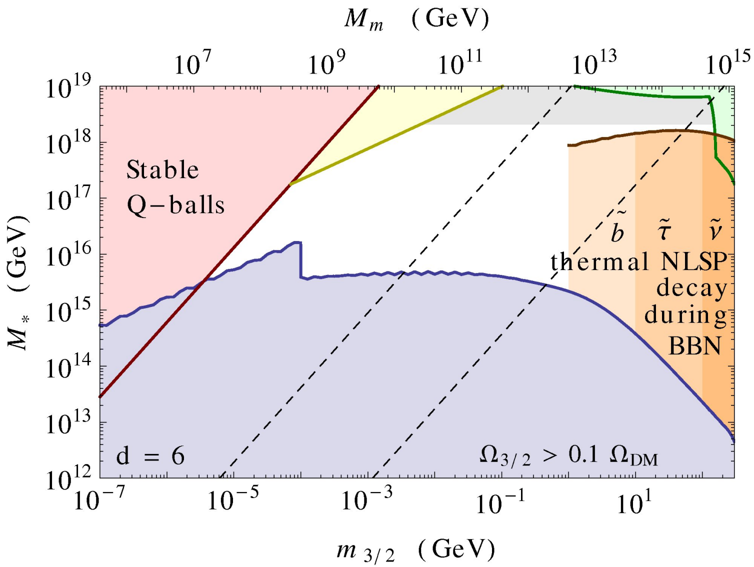

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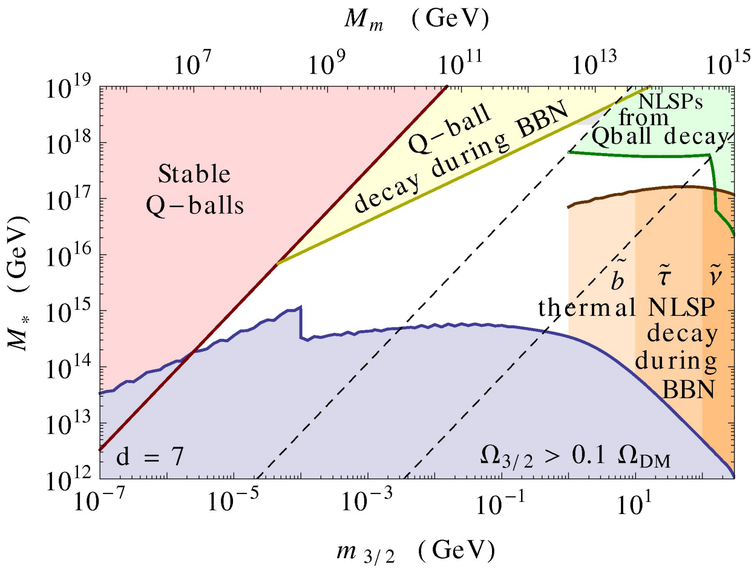

# Allowed parameter space

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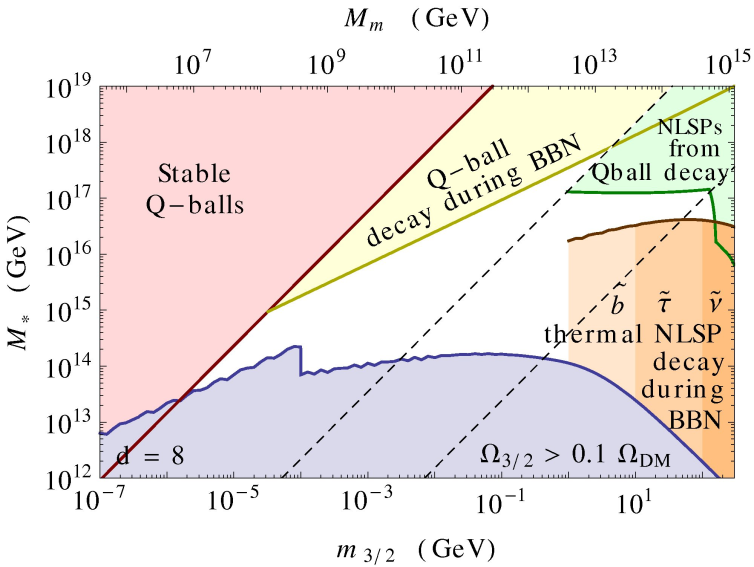

# CONSTRAINTS FROM $Q$-BALLS

- $Q$-balls: non-topological solitons, stabilized by charge under U(1)
- AD condensate is unstable under spatial perturbations

$\Rightarrow$ Fragments into $Q$-balls

- Average charge from numerical simulations:

$$Q \approx 10^{17} \left(\frac{m_{3/2}}{1\ \mathrm{GeV}}\right)^2 \left(\frac{500\ \mathrm{GeV}}{m_\mathrm{s}}\right)^4 \cdot \begin{cases} b^2 & \text{for } b \lesssim 1 \\ b^{\frac{4(d-2)}{d-1}} & \text{for } b \gtrsim 1\,, \end{cases}$$

where $b \equiv \left(m_\mathrm{s} M_*^{d-3} / M_\mathrm{m}^{d-2}\right)^{1/(d-2)}$

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# Constraints from $Q$-balls

- $Q$-balls can decay to particles with smaller mass-to-charge ratio. SM temperature at time of Q-ball decay:

$$T_Q \approx 250\ \text{GeV} \left(\frac{1\ \text{GeV}}{m_{3/2}}\right) \left(\frac{m_s}{500\ \text{GeV}}\right)^{\frac{5}{2}} \cdot \begin{cases} \frac{1}{b} & \text{for } b \lesssim 1 \\ b^{-\frac{5(d-2)}{2(d-1)}} & \text{for } b \gtrsim 1 \end{cases}$$

- Require decay before BBN:

$$T_Q \gtrsim 10\text{MeV}$$

- Q-ball decays produce gravitinos $\Rightarrow$ To avoid overclosure require:

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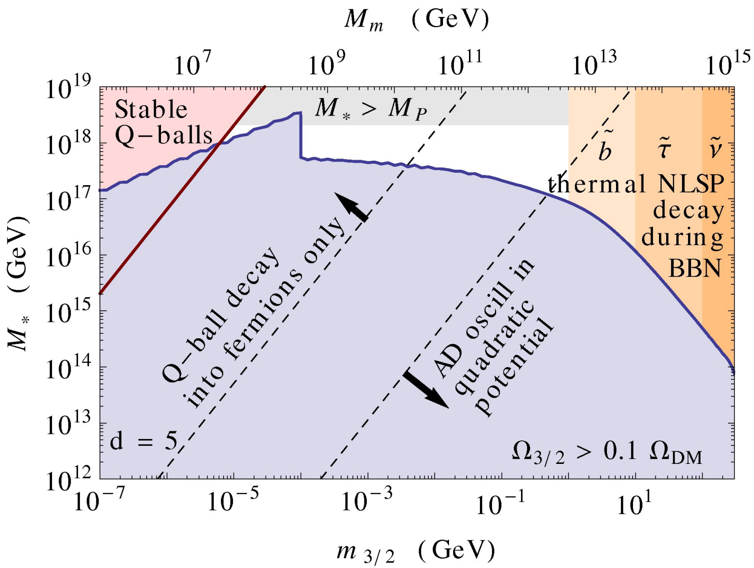

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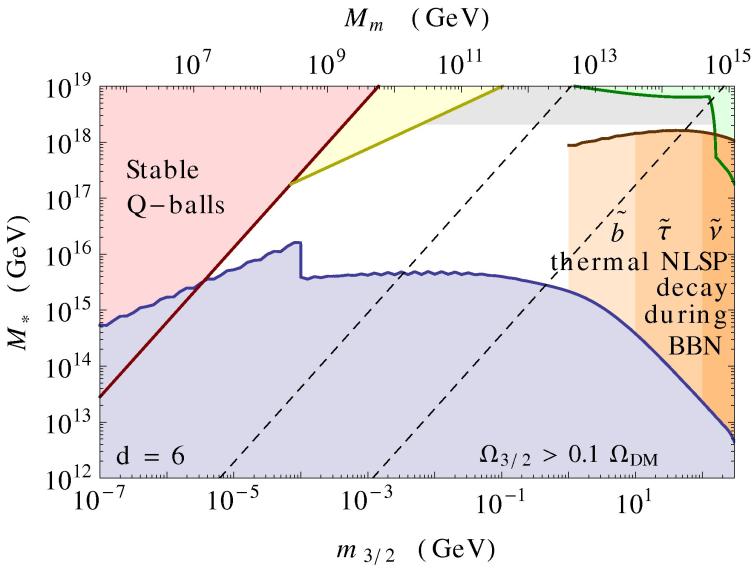

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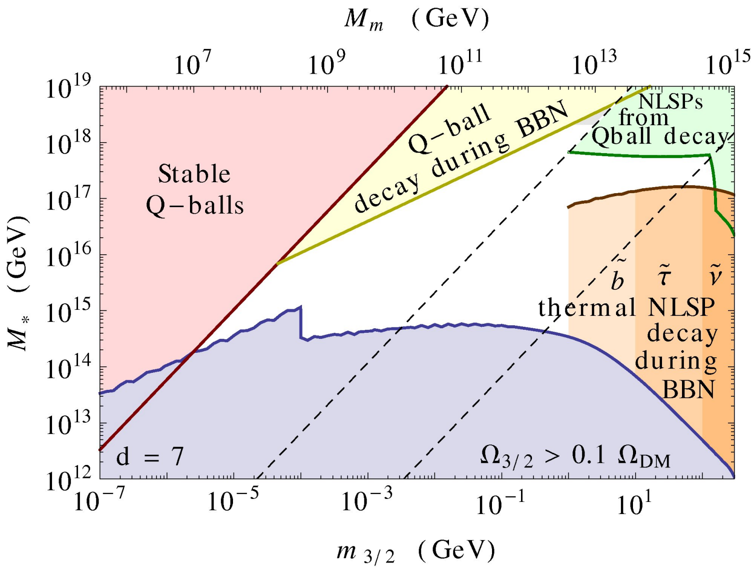

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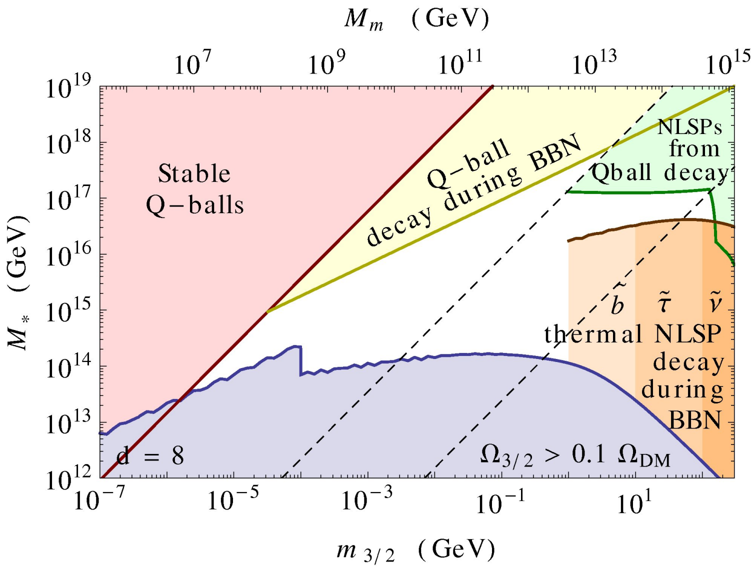

# CONCLUSIONS

- Have analysed parameter space for successful pangenesis
- Important constraints on this scenario from
  - Gravitino-bounds on reheating temperature
  - Formation and decay of $Q$-balls
- Ample parameter space still allowed
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