Cosmological Aspects of Spontaneous Baryogenesis

Takeshi Kobayashi (SISSA)

based on arXiv:1605.00670 w/Andrea De Simone

Dark Side of the Universe 2016

SAKHAROV'S THREE CONDITIONS FOR BARYOGENESIS

- baryon number violation
- C/CP violation
- non-equilibrium

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→ energy gap between baryon/antibaryon

→ baryogenesis even in equilibrium

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Cohen, Kaplan '87

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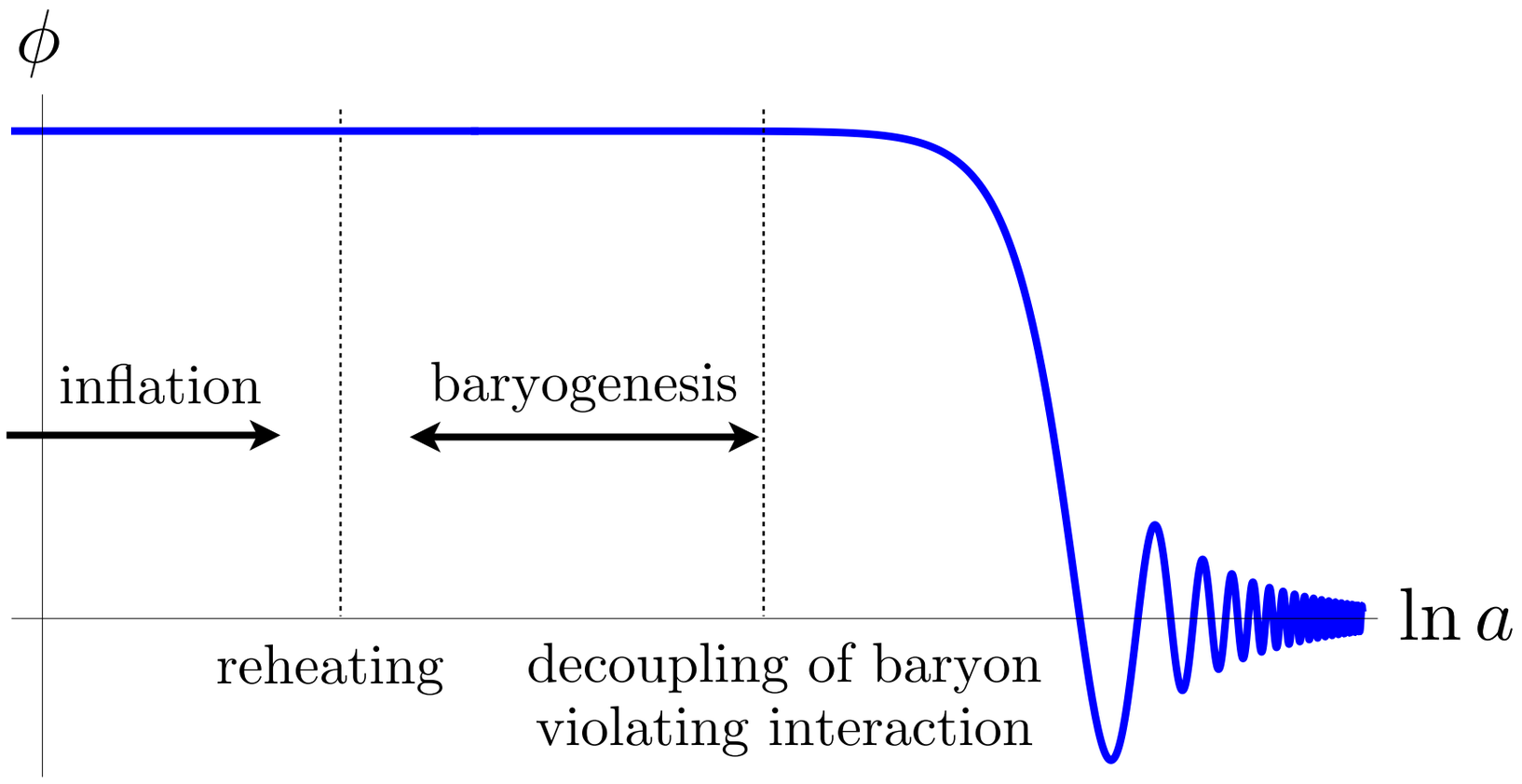
cosmic inflation sets a coherent $\dot{\phi}$

ϕ may be the Higgs, an axion-like field, etc.

Cohen, Kaplan '88 Dine, Huet, Singleton, Susskind '90 Dolgov, Freese '95

Kusenko, Pearce, Yang '14 Kusenko, Schmitz, Yanagida '15 ...

COSMOLOGY WITH SPONTANEOUS BARYOGENESIS



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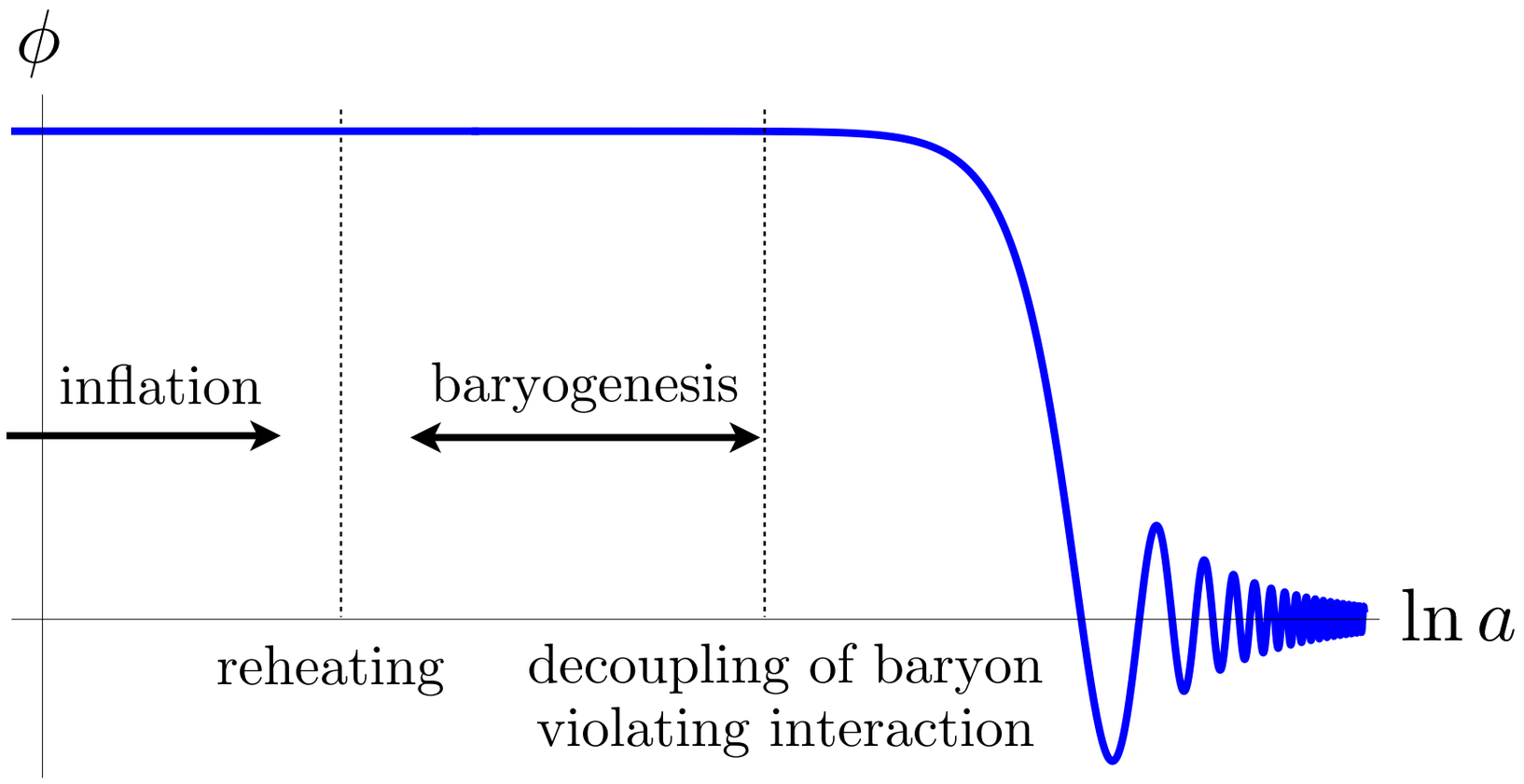
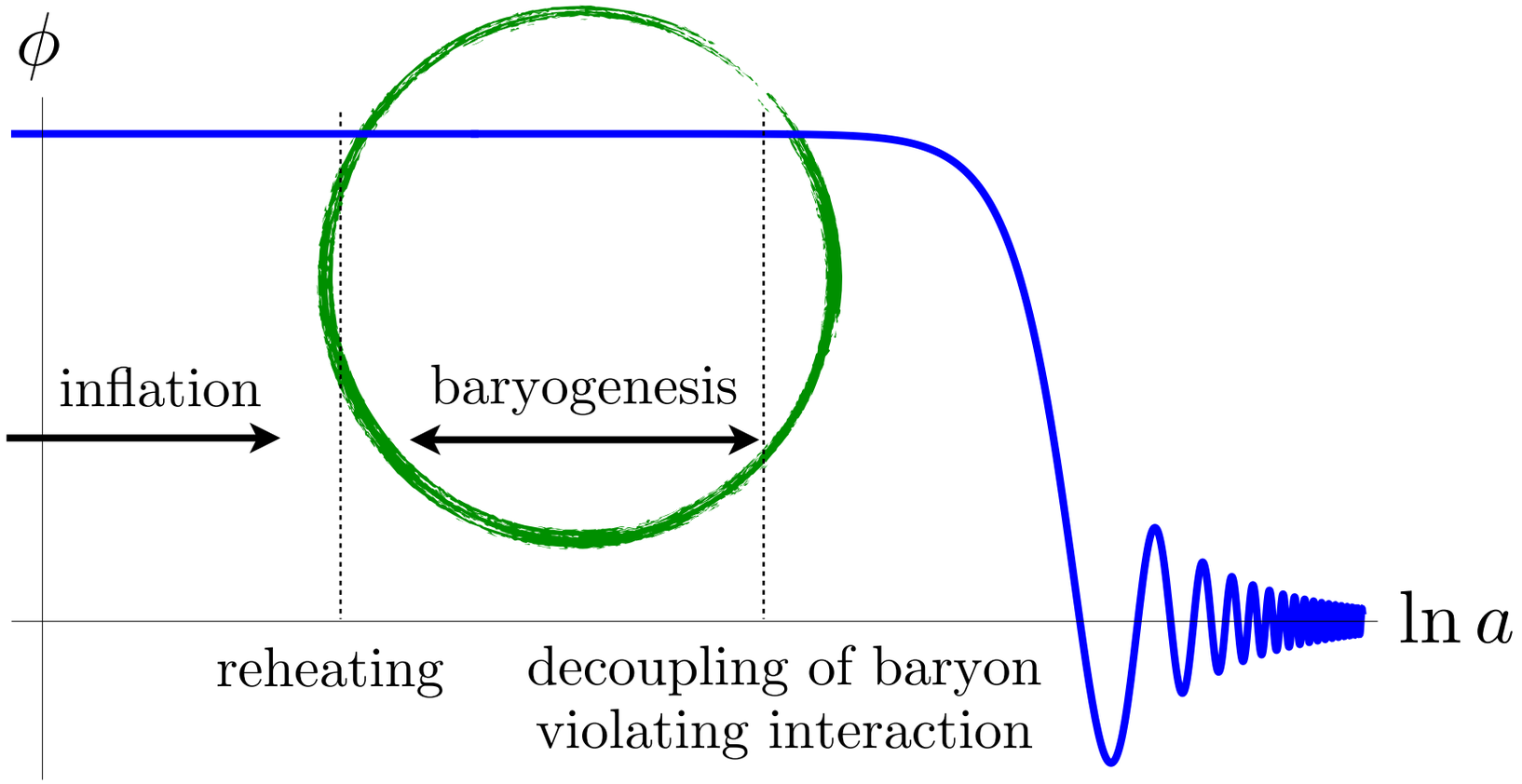


Embedding into the early universe calls for careful examinations.

BACKREACTION FROM BARYONS



$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 - V(\phi) - \frac{\partial_\mu\phi}{f} j_B^\mu + \cdots$$

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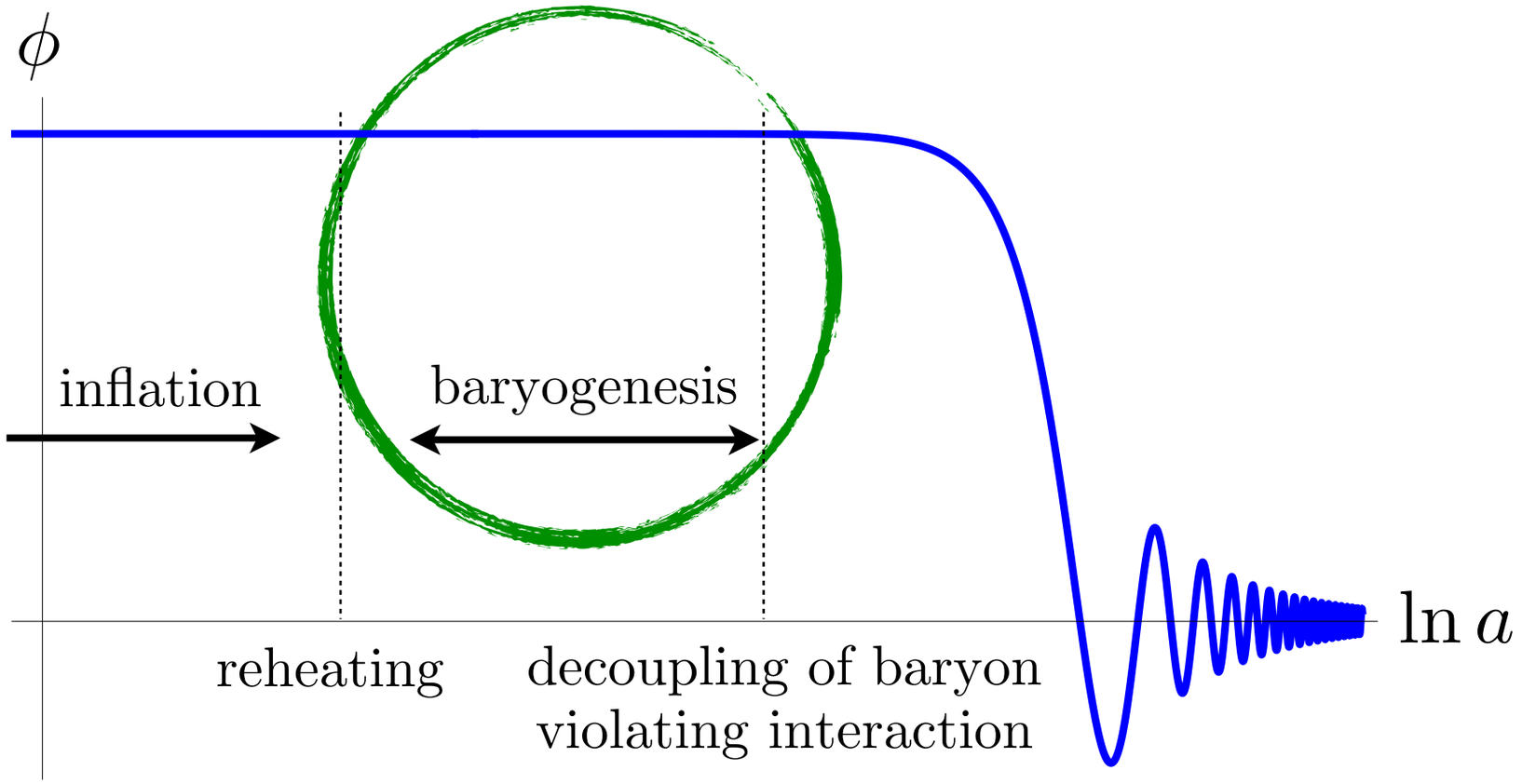
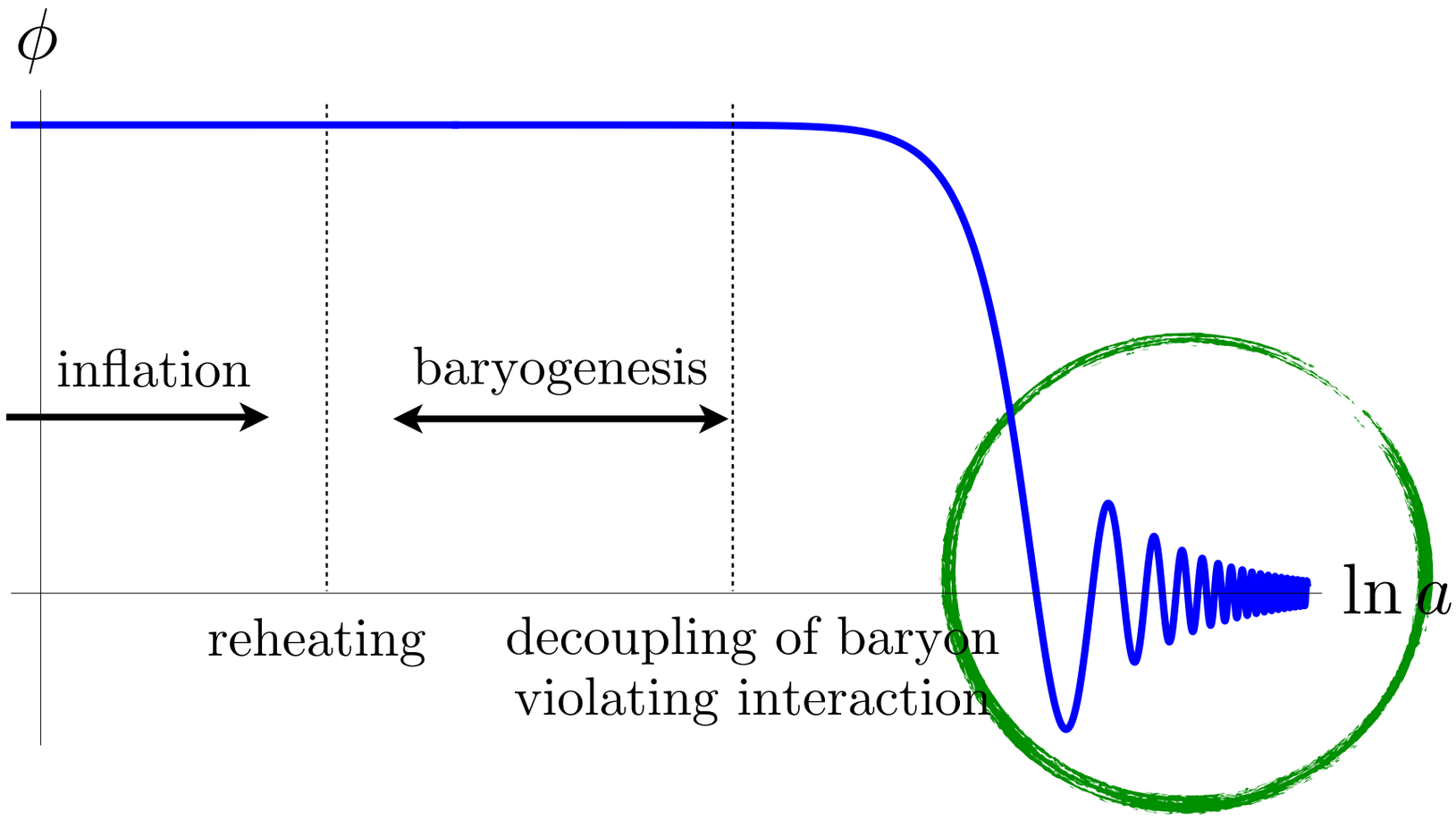


$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 - V(\phi) - \frac{\partial_\mu\phi}{f} j_B^\mu + \cdots$$

backreaction from baryons slows down $\dot{\phi}$
and suppress baryogenesis

FATE OF OSCILLATING ϕ



$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 - V(\phi) - \frac{\partial_\mu \phi}{f} j_B^\mu + \cdots \qquad \Gamma_\phi = \mathcal{O}(1)\frac{m_\phi^3}{f^2}$$

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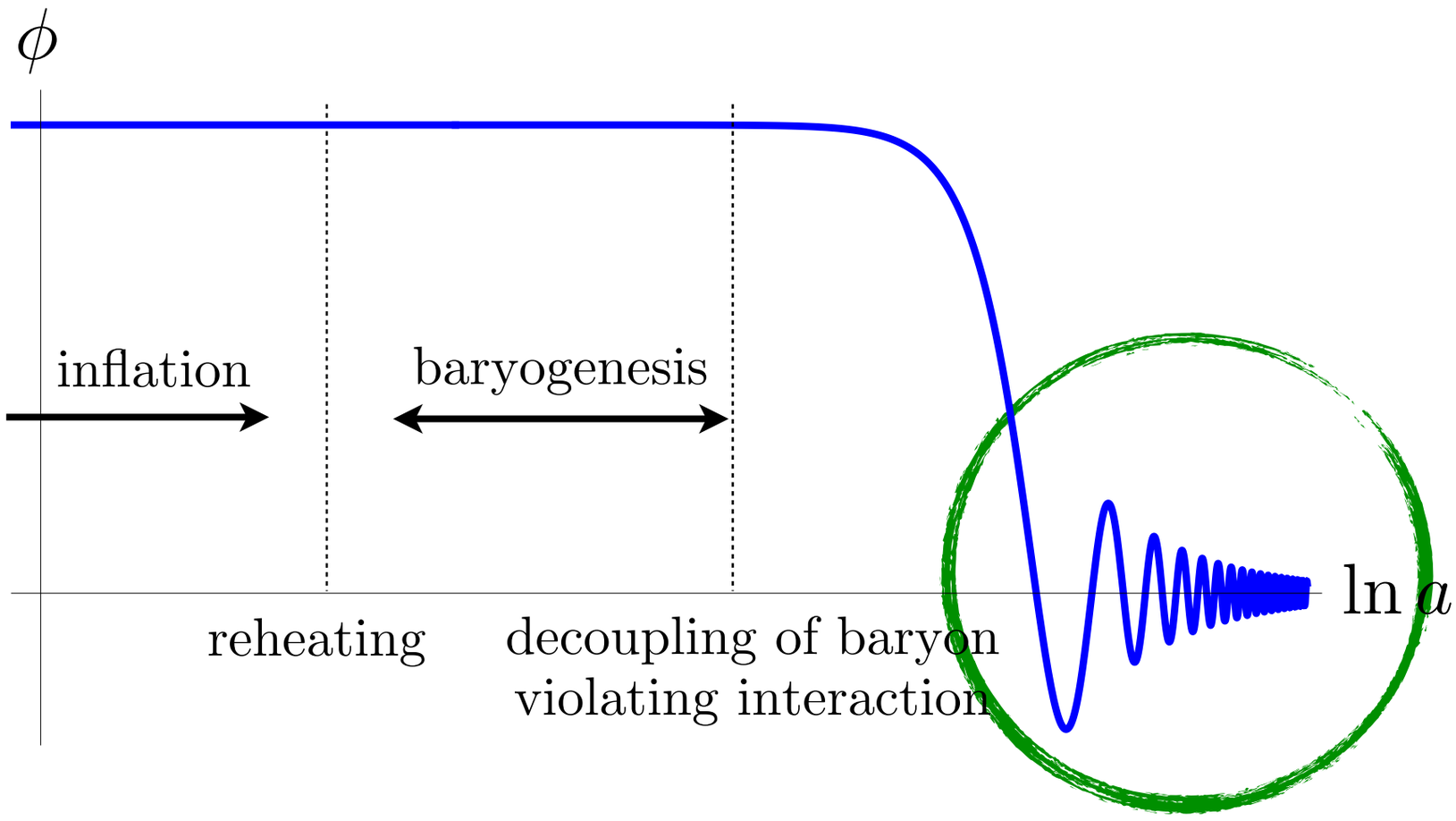
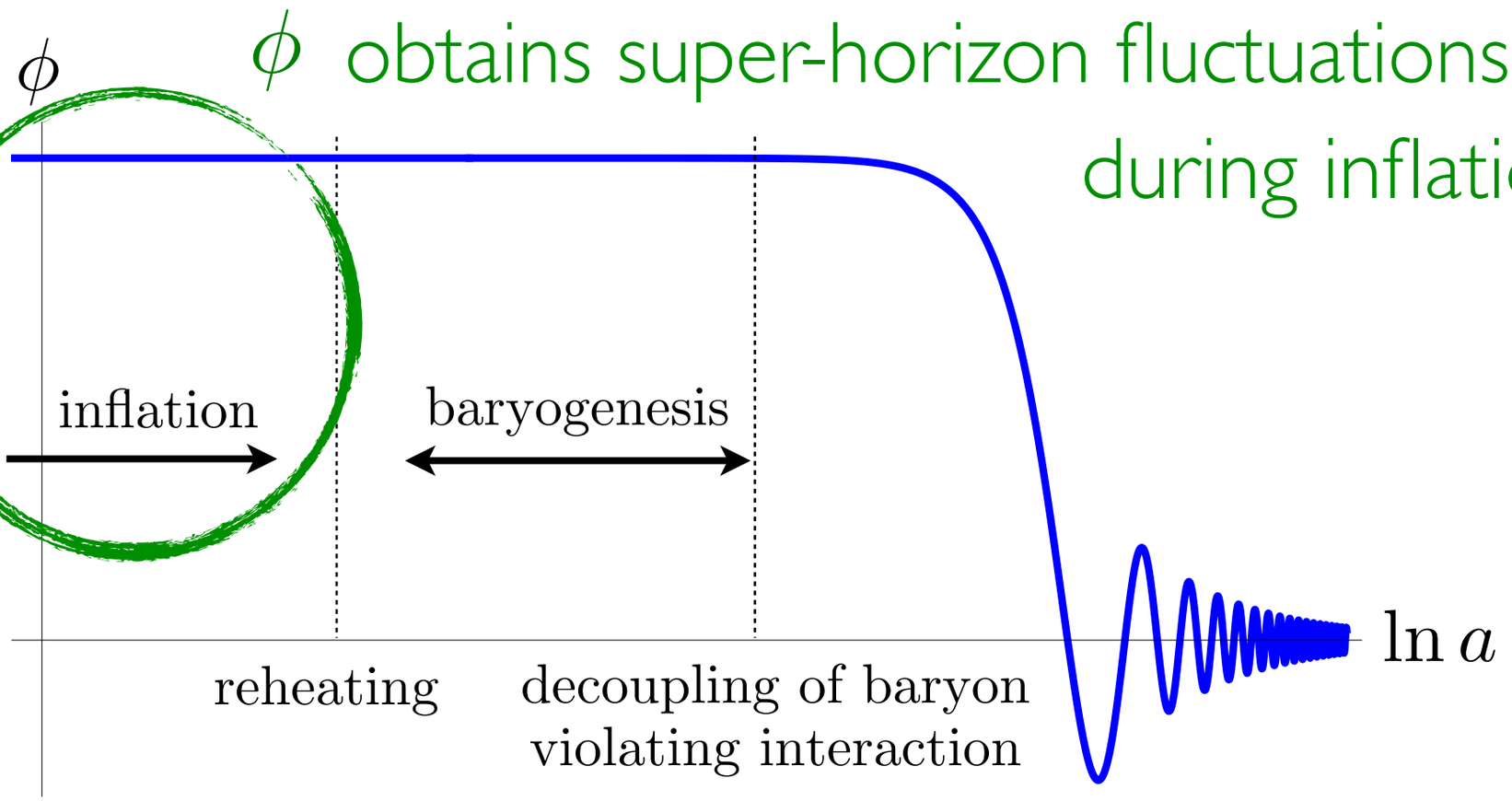


$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 - V(\phi) - \frac{\partial_\mu \phi}{f} j_B^\mu + \cdots \qquad \Gamma_\phi = \mathcal{O}(1)\frac{m_\phi^3}{f^2}$$

baryon asymmetry would be diluted
if ϕ dominates the universe before decay

BARYON ISOCURVATURE PERTURBATIONS



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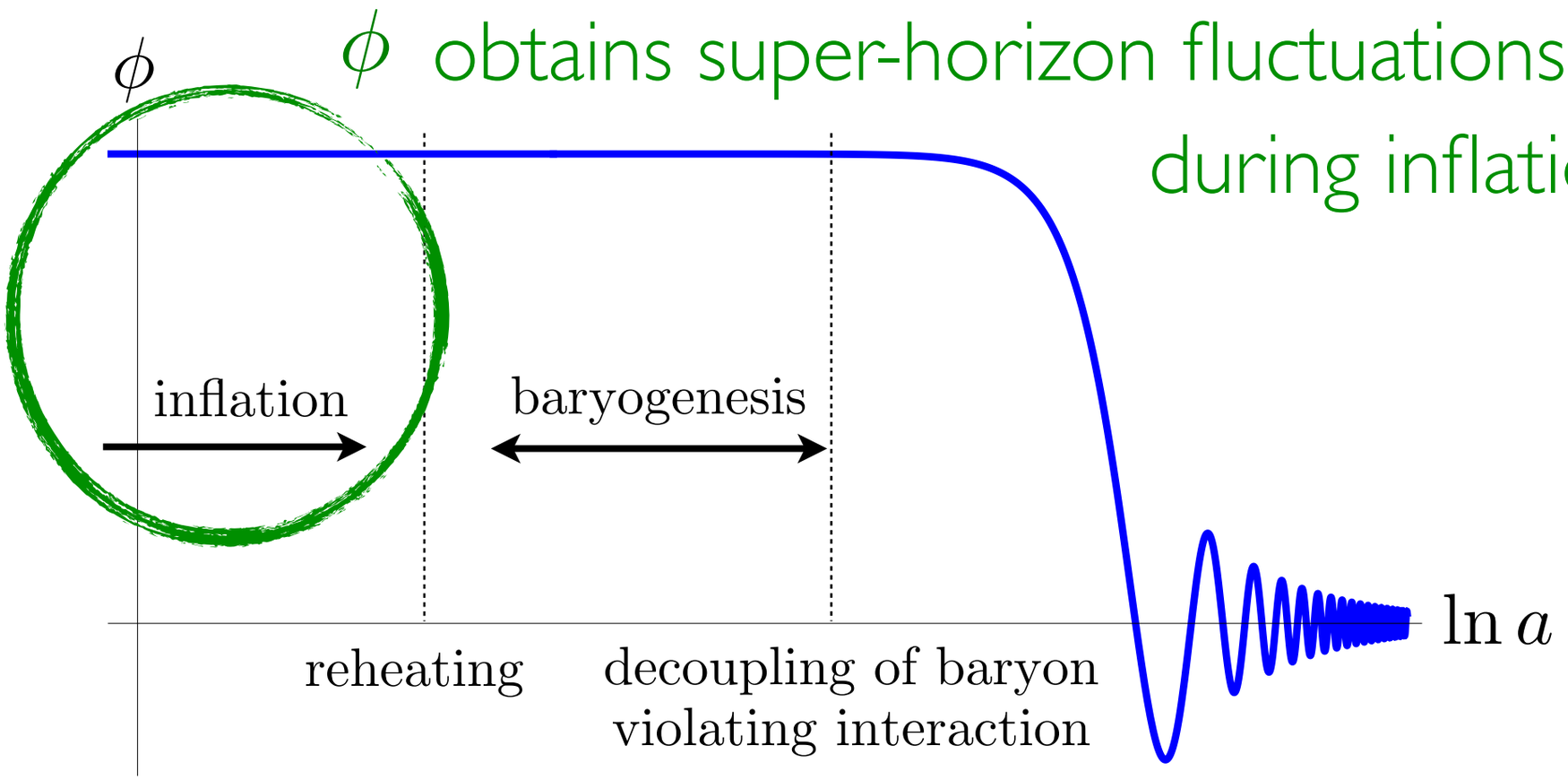
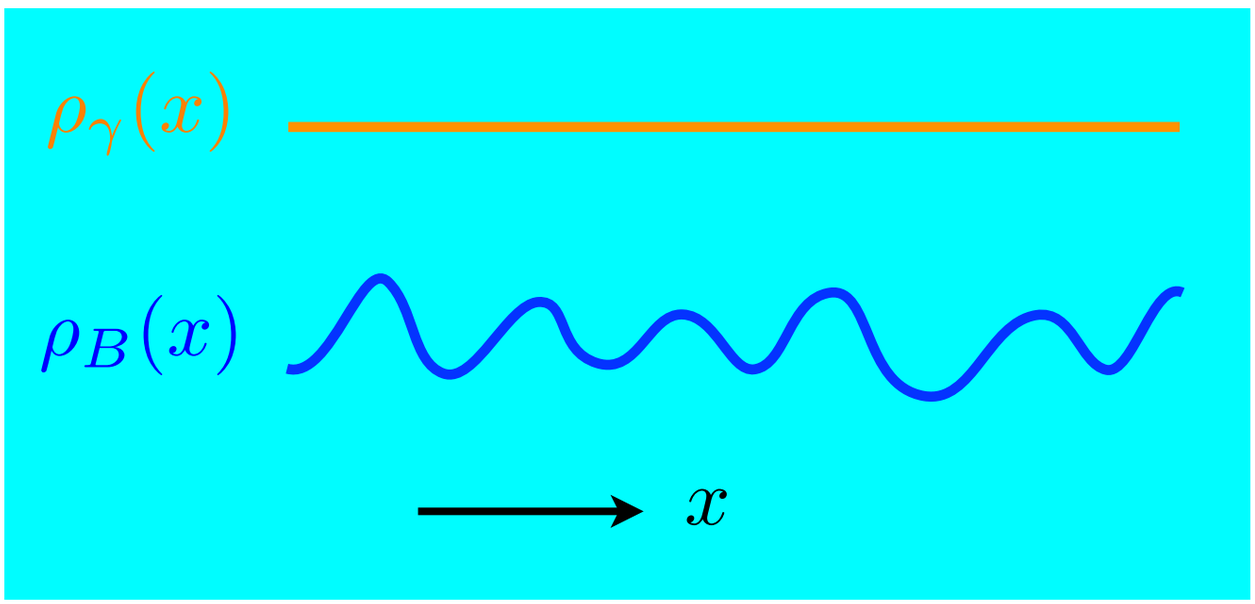




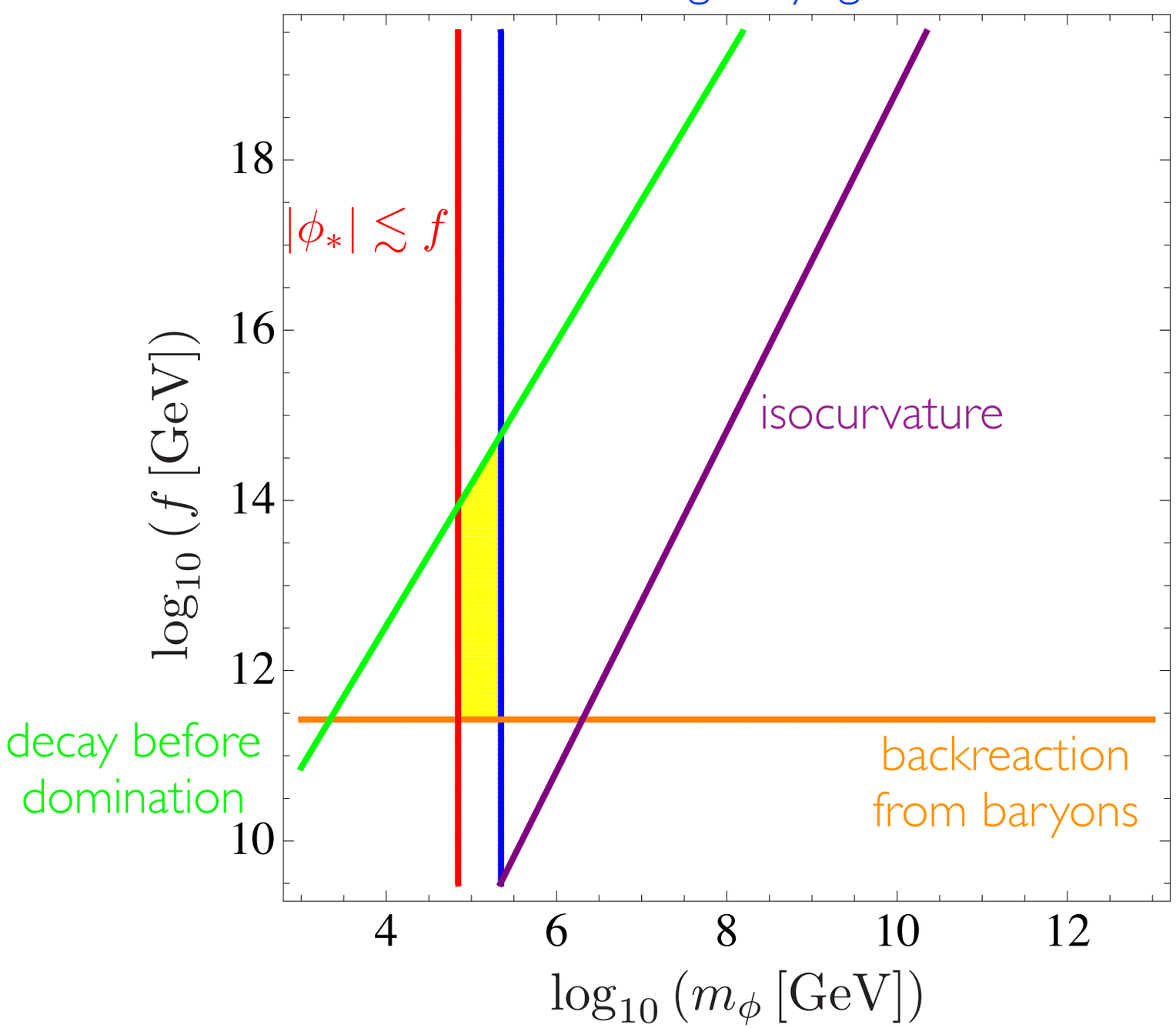
$$S_{B\gamma} = \frac{\delta\rho_B}{\rho_B} - \frac{3}{4}\frac{\delta\rho_\gamma}{\rho_\gamma}$$

$$\left(\frac{\Omega_B}{\Omega_{\rm CDM}}\right)^2 \mathcal{P}_{B\gamma}(k_*) \lesssim 0.040 \times \mathcal{P}_\zeta(k_*)$$

(95%C.L., TT,TE, EE + lowP) from Planck '15

PARAMETER SPACE OF MINIMAL MODEL

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m_\phi^2\phi^2 - \frac{\partial_\mu\phi}{f}j_B^\mu$$



$$H_{\rm inf} = 10^5\,{\rm GeV}$$

$$H_{\rm dec} = H_{\rm inf}$$

$$\Gamma_\phi \sim \frac{m_\phi^3}{f^2}$$

$$\phi_* \text{ set by } \frac{n_B}{s}$$

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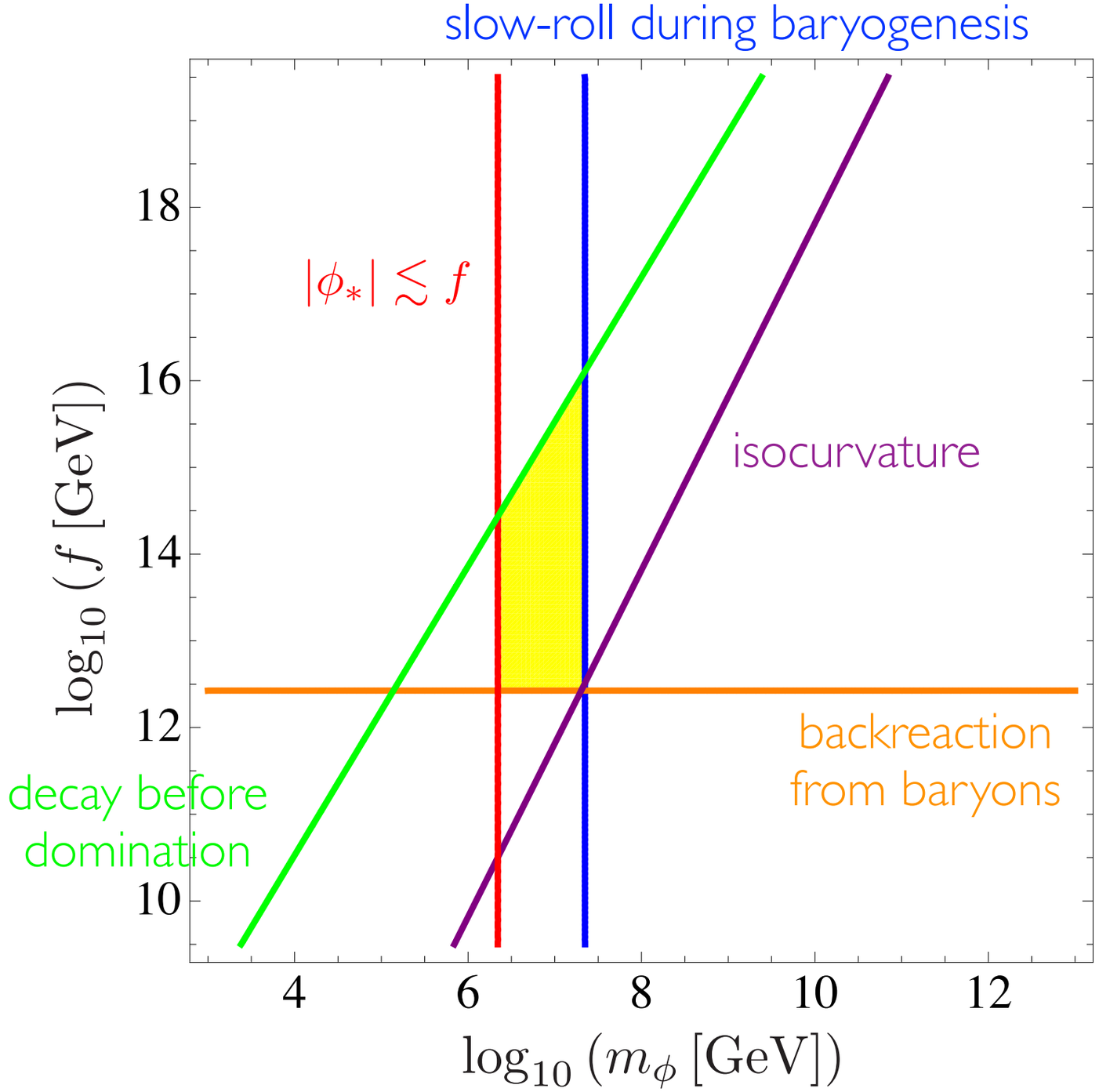

$$H_{\rm inf} = 10^7\,{\rm GeV}$$

$$H_{\rm dec} = H_{\rm inf}$$

$$\Gamma_\phi \sim \frac{m_\phi^3}{f^2}$$

$$\phi_* \text{ set by } \frac{n_B}{s}$$

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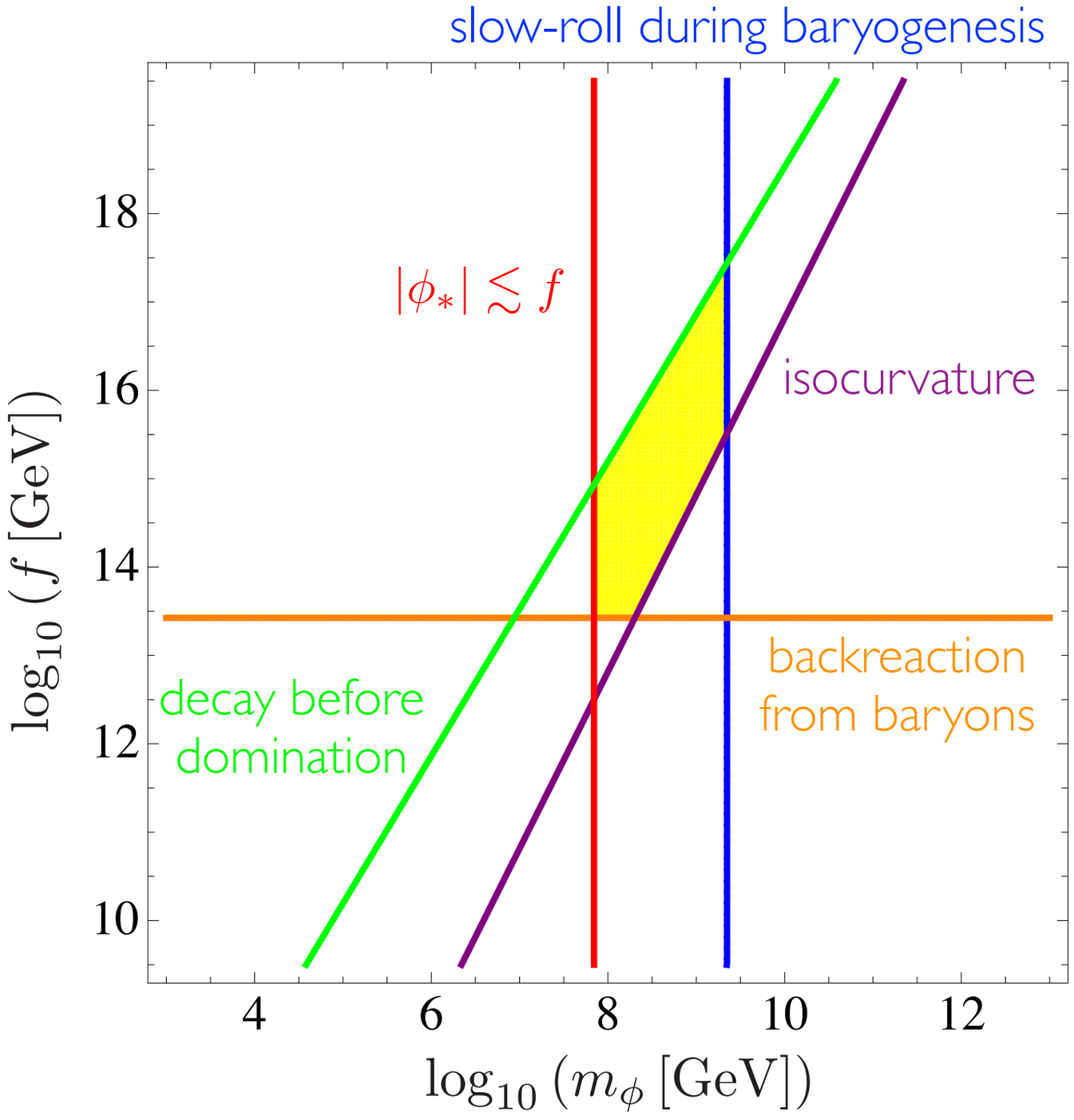

$$H_{\rm inf} = 10^9\,{\rm GeV}$$

$$H_{\rm dec} = H_{\rm inf}$$

$$\Gamma_\phi \sim \frac{m_\phi^3}{f^2}$$

$$\phi_* \text{ set by } \frac{n_B}{s}$$

PARAMETER SPACE OF MINIMAL MODEL

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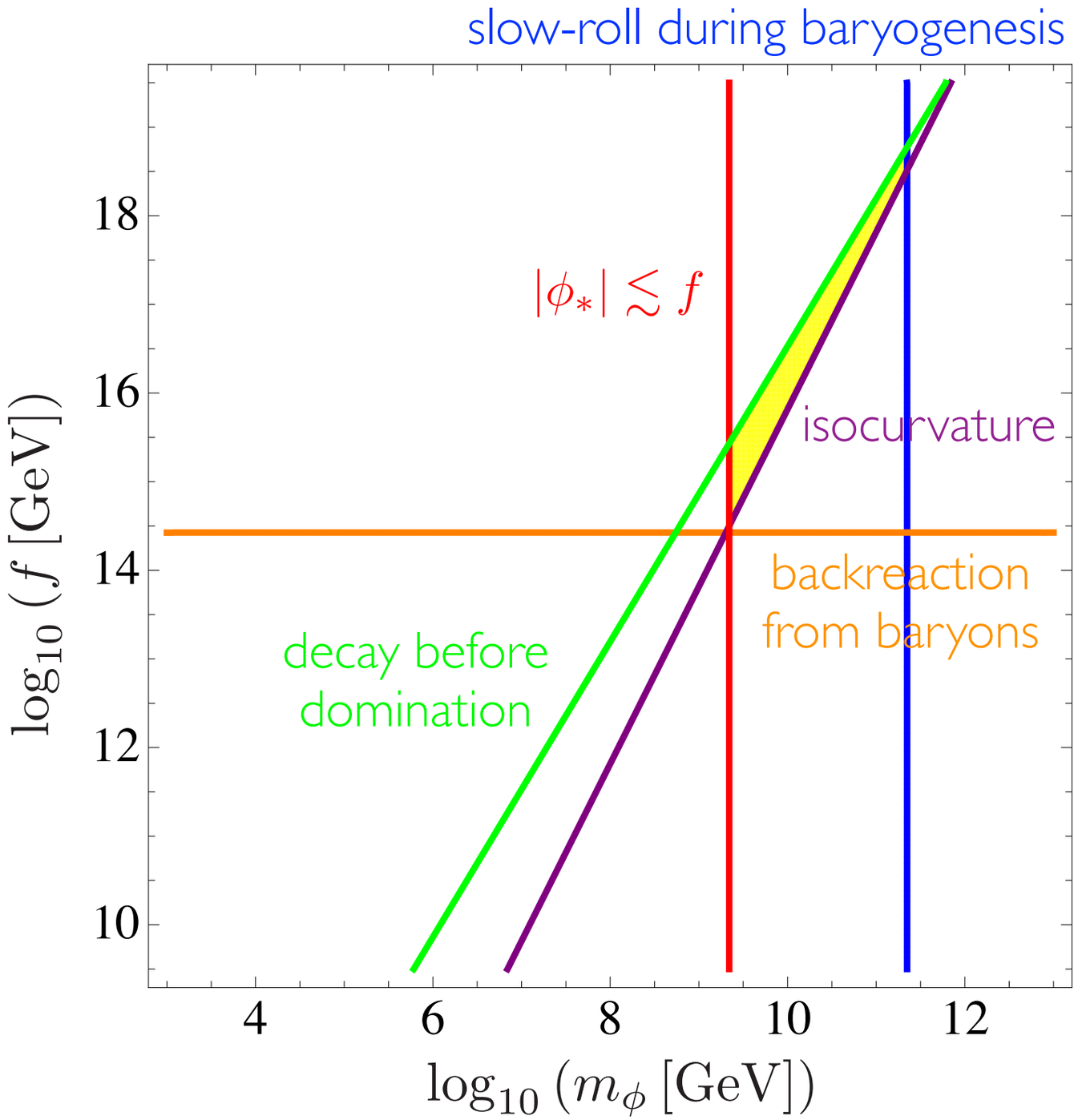

$$H_{\rm inf} = 10^{11}\,{\rm GeV}$$

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$$\Gamma_\phi \sim \frac{m_\phi^3}{f^2}$$

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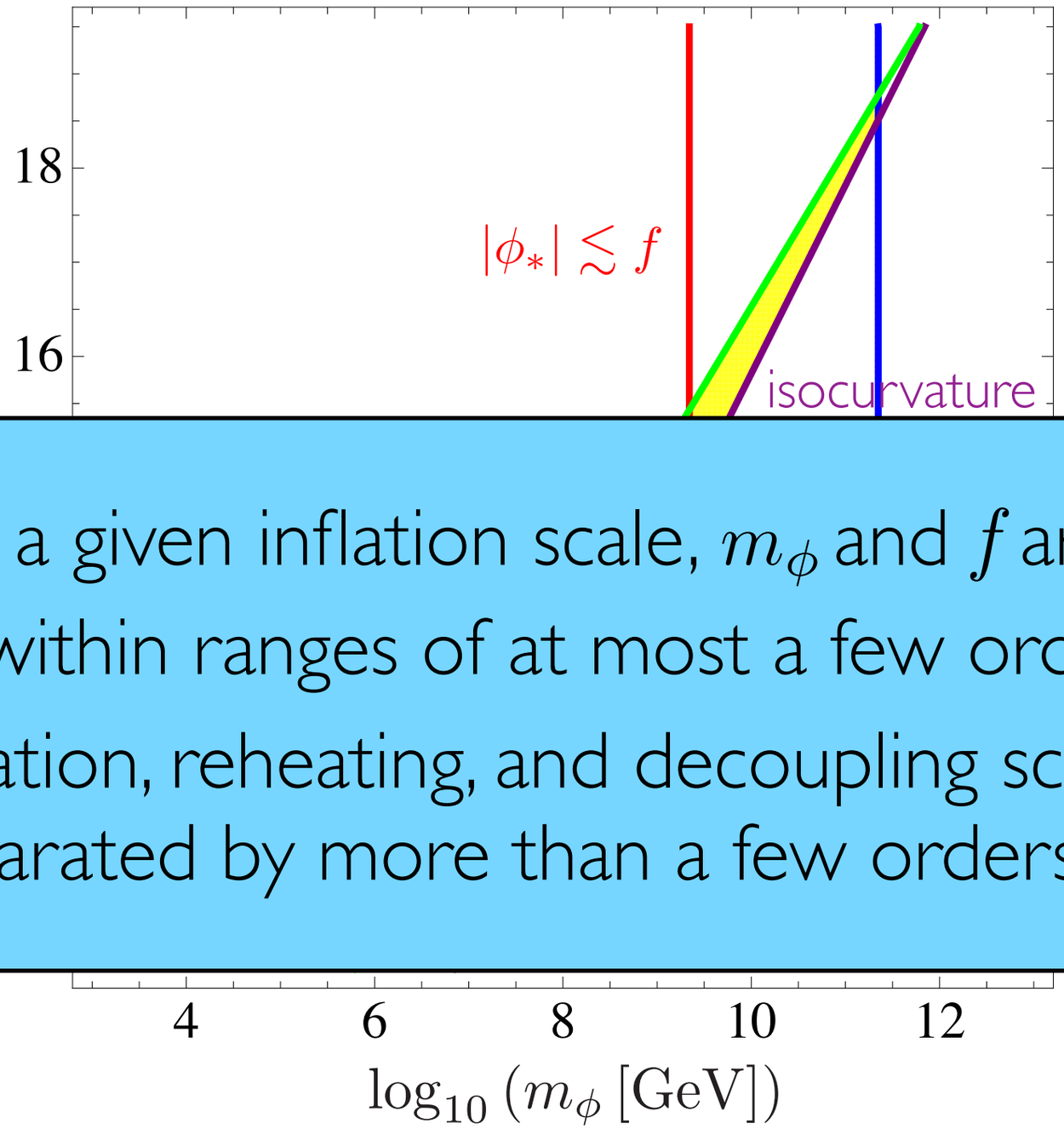
slow-roll during baryogenesis

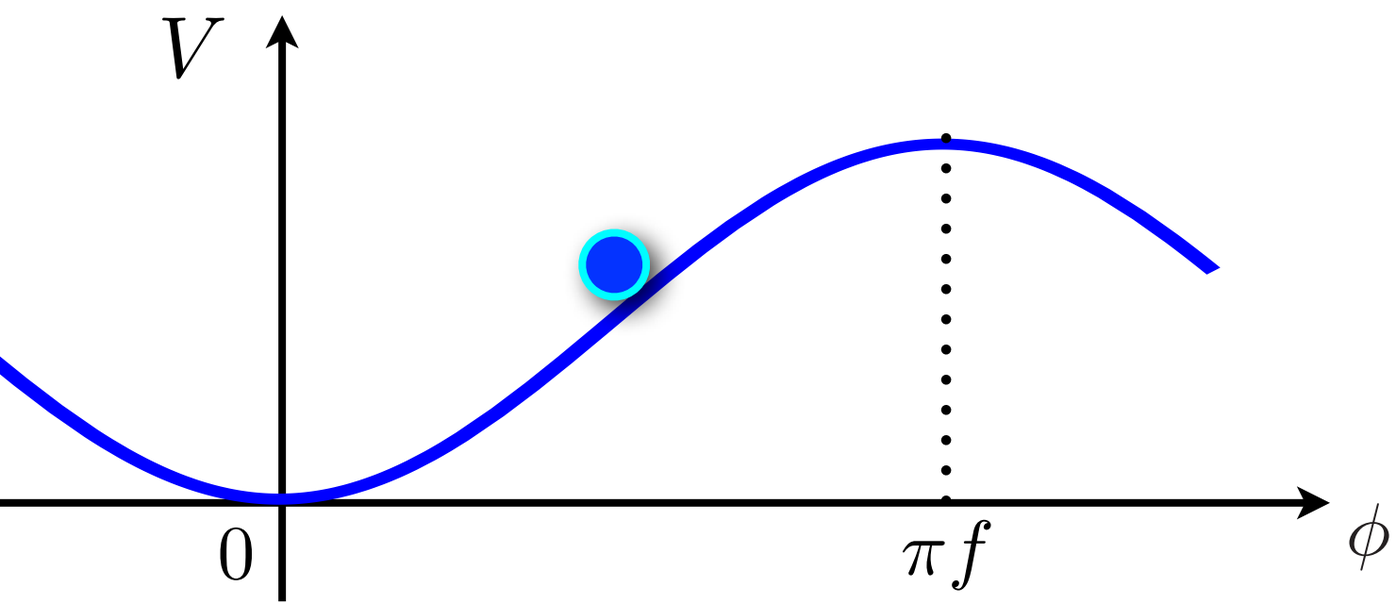


$$H_{\rm inf} = 10^{11}\,{\rm GeV}$$

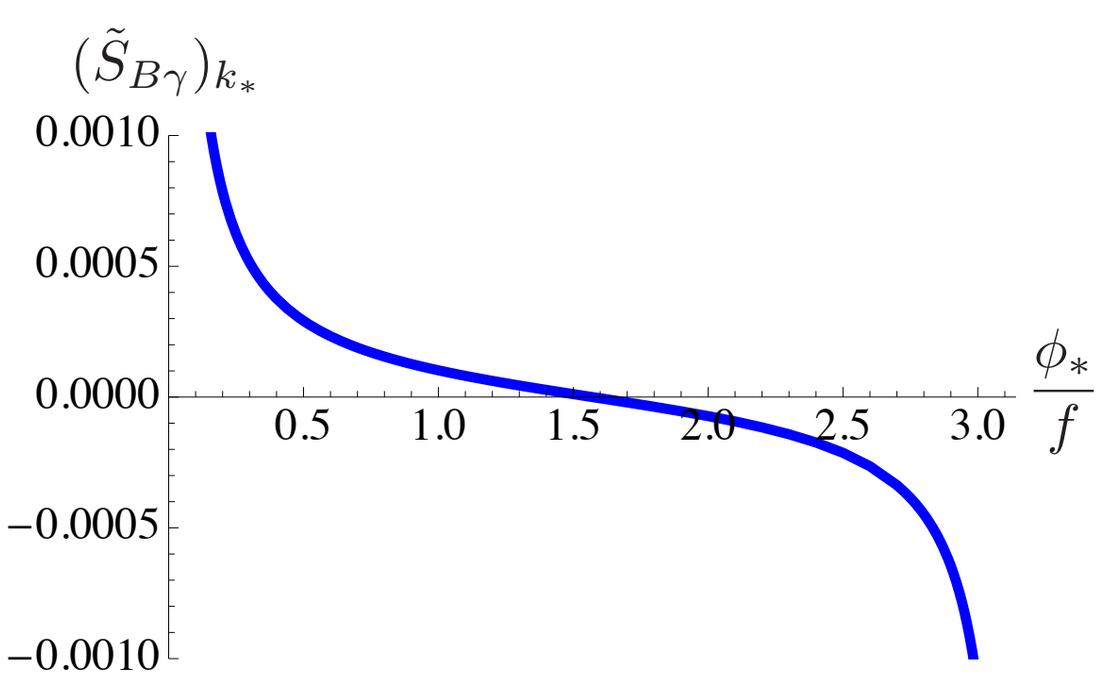
$$H_{\rm dec} = H_{\rm inf}$$

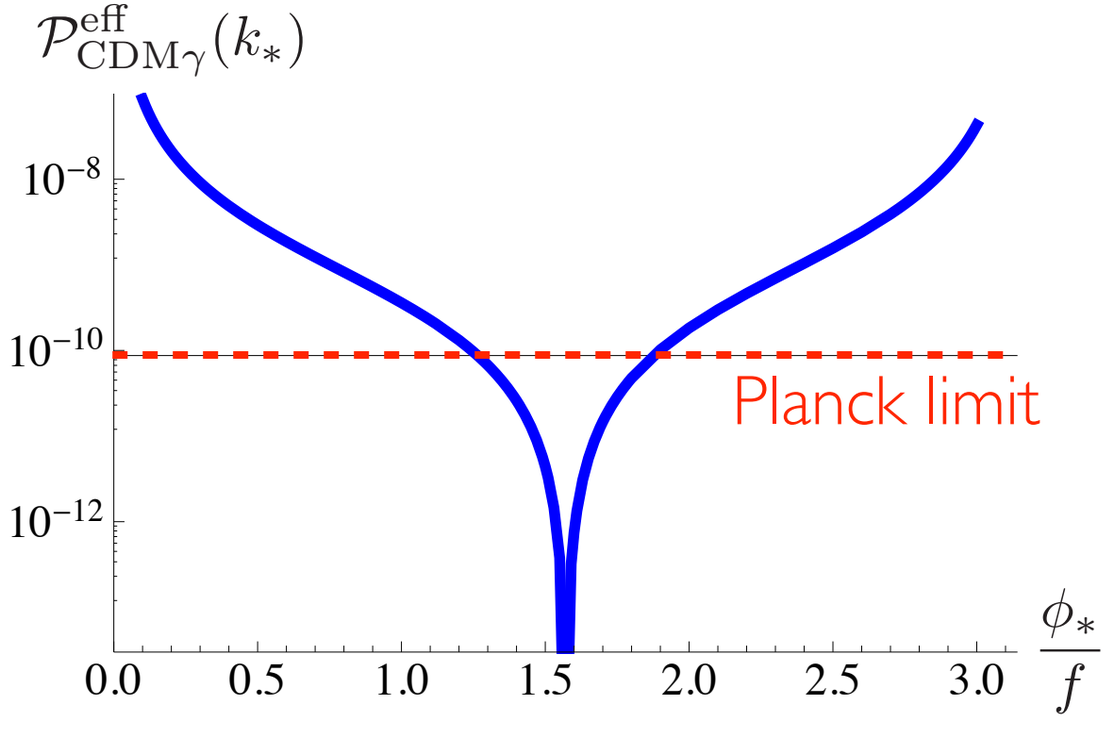
- For a given inflation scale, m_ϕ and f are constrained to lie within ranges of at most a few orders of magnitude.
- Inflation, reheating, and decoupling scales cannot be separated by more than a few orders of magnitude.

EXTENDED MODEL : SUPPRESSING BARYON ISOCURVATURE WITH A COSINE POTENTIAL



$$V(\phi) = m_\phi^2 f^2 \left[1 - \cos\left(\frac{\phi}{f}\right)\right]$$





$H_* = 1.0 \times 10^{12}\,\mathrm{GeV},\ H_{\rm dec} = 1.0 \times 10^{11}\,\mathrm{GeV},\ m_\phi = 2.2 \times 10^{9}\,\mathrm{GeV},\ f = 1.0 \times 10^{15}\,\mathrm{GeV}$

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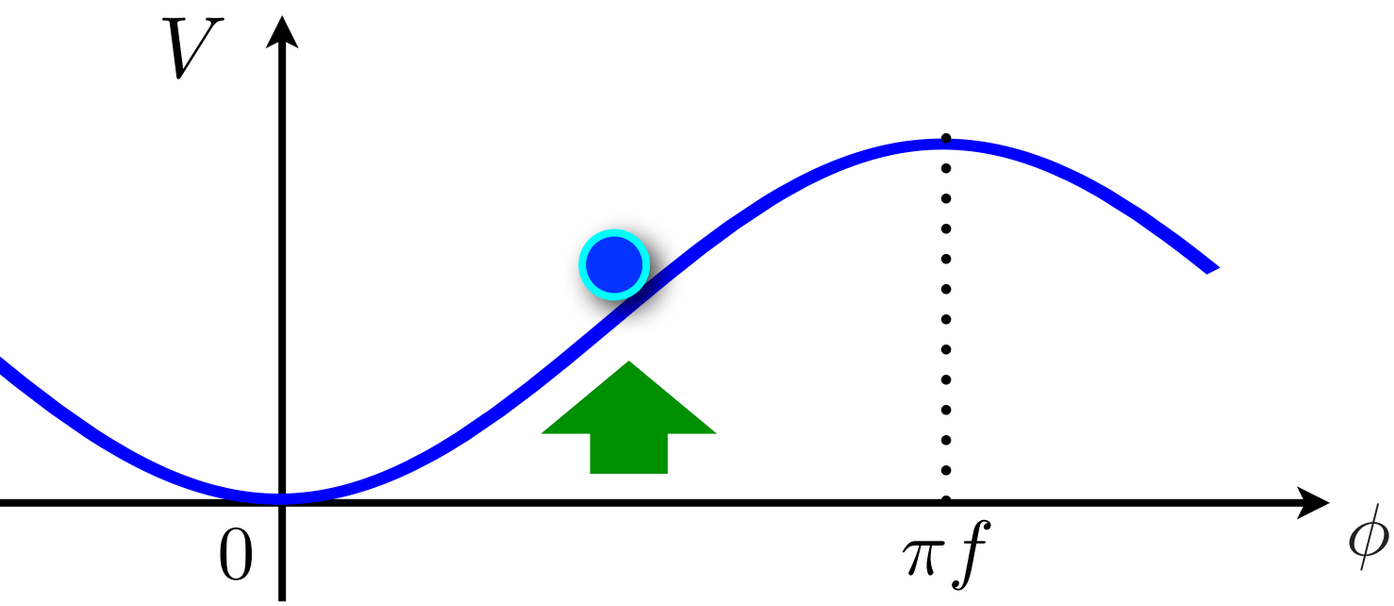

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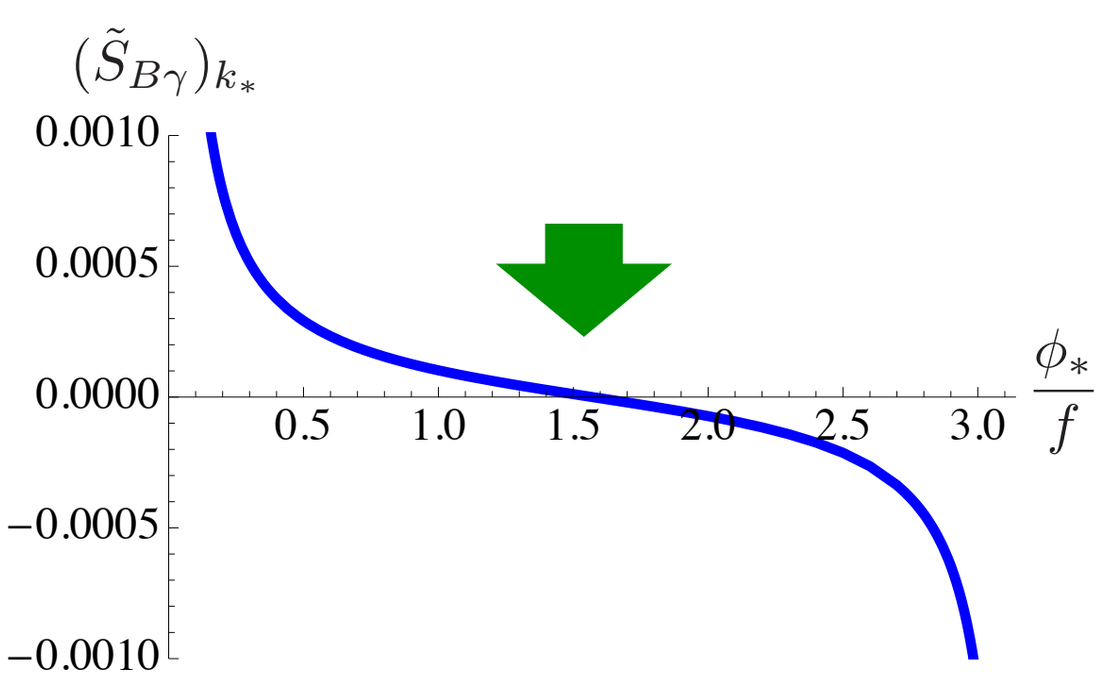

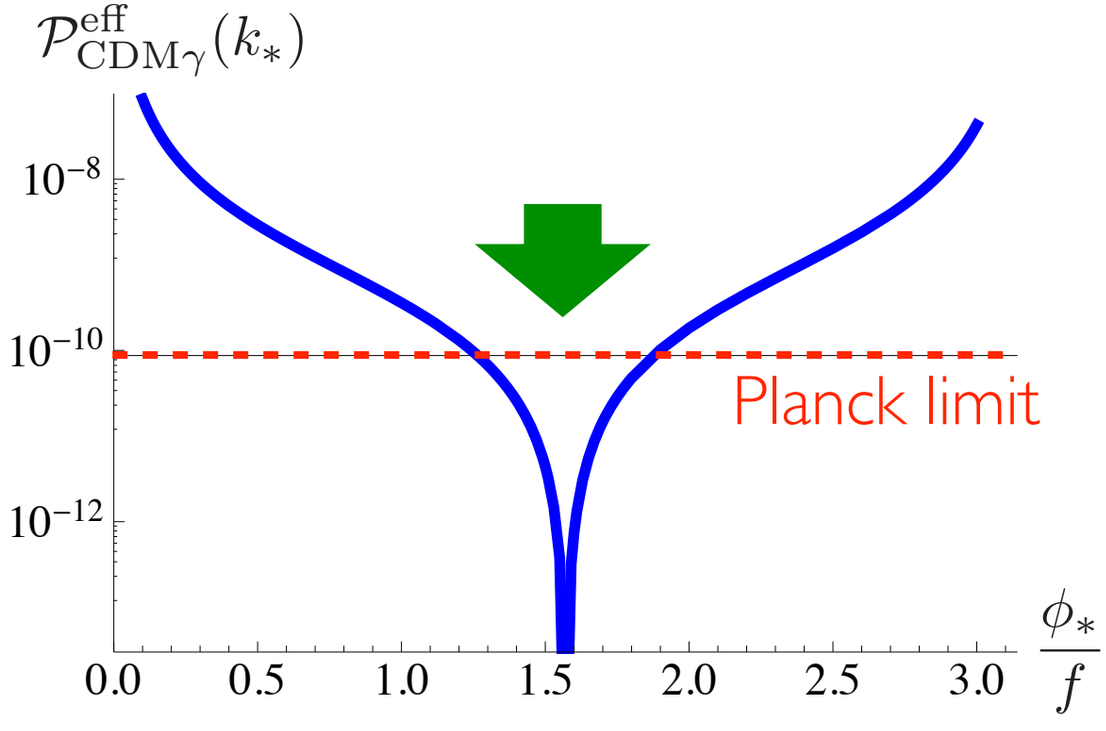

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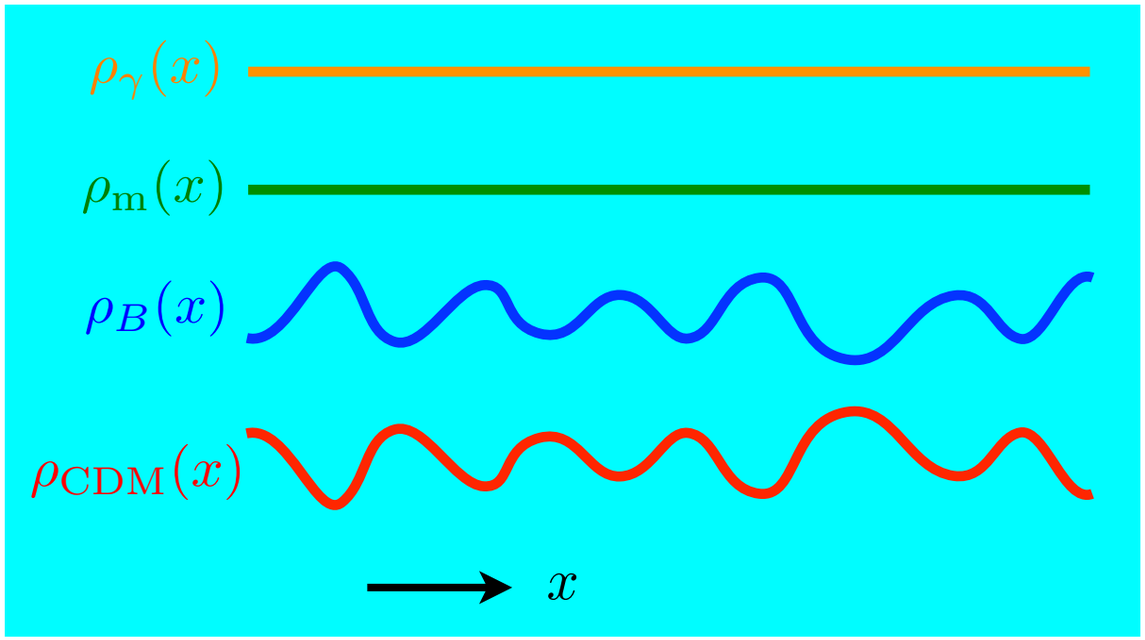
EXTENDED MODEL : COMPENSATED ISOCURVATURE WITH ϕ BEING DARK MATTER

If ϕ contributes to CDM, baryon iso. can be compensated by CDM iso.



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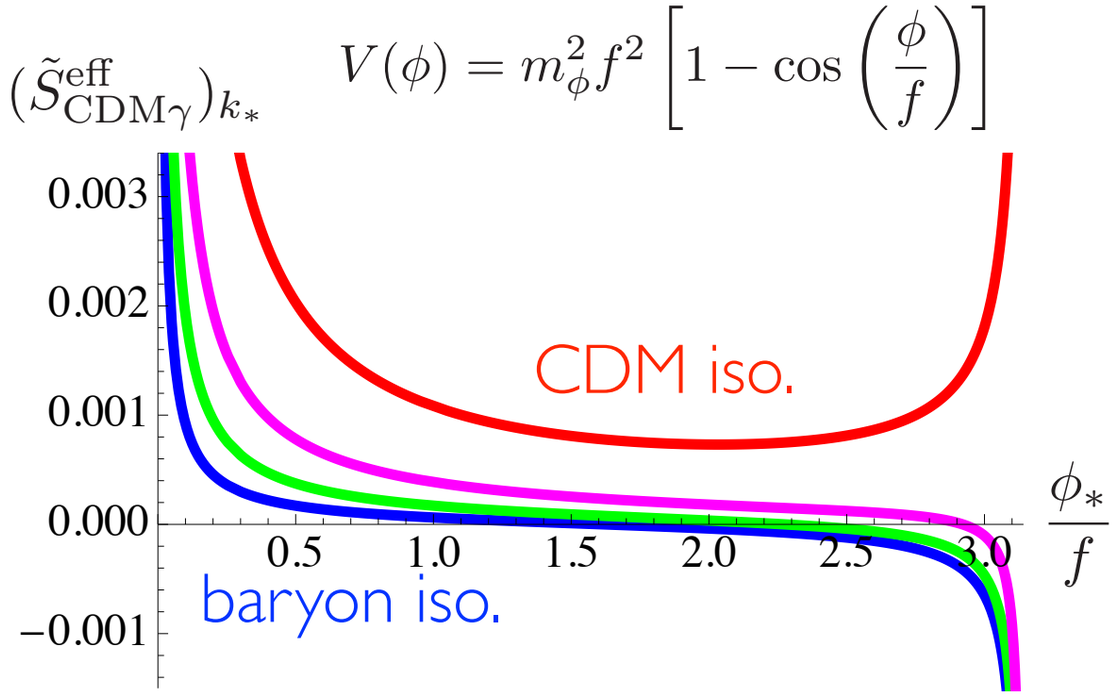

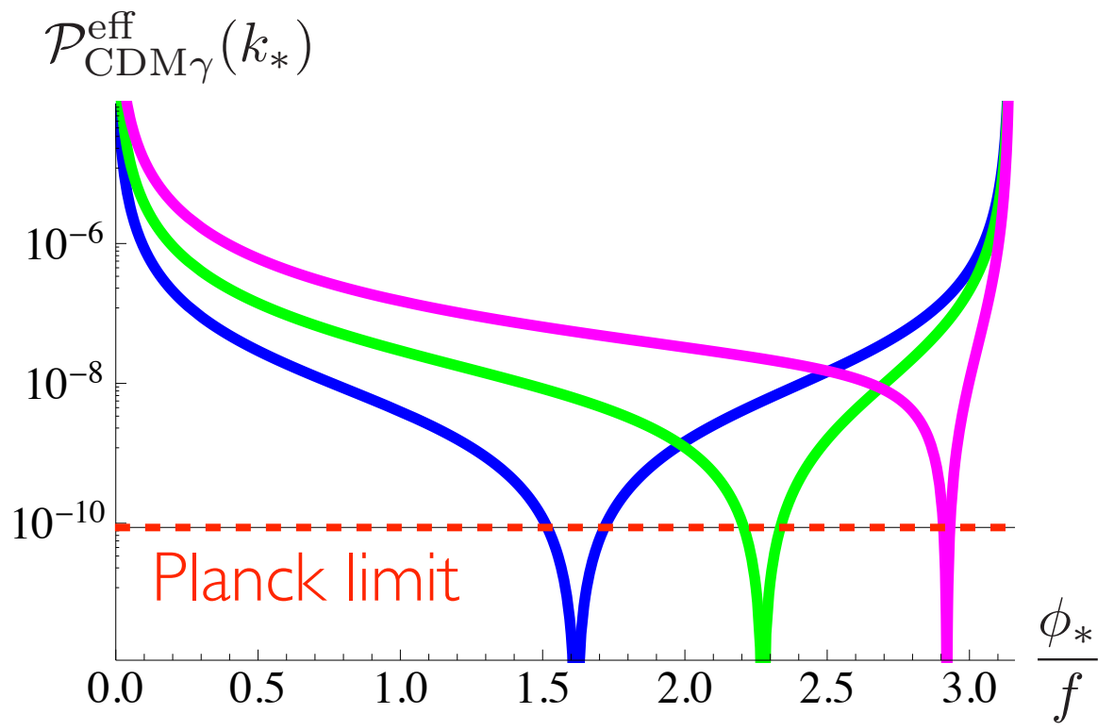

$H_* = 1.0 \times 10^7\,{\rm GeV},\ H_{\rm dec} = 1.0 \times 10^{-2}\,{\rm GeV},$
$m_\phi = 1.3 \times 10^{-2}\,{\rm GeV},\ f = 3.2 \times 10^9\,{\rm GeV}$

$$\frac{\Omega_\phi}{\Omega_{\rm CDM}} = 0,\quad 0.1,\quad 0.3$$

SUMMARY

- Cosmological considerations alone provide powerful constraints on spontaneous baryogenesis, especially for the minimal scenario with a quadratic scalar potential.

- Baryon isocurvature perturbation can be suppressed/ compensated in extended models.

- In general, any early universe scenario that exploits scalar condensates requires careful considerations.