Towards Constraining Affleck-Dine Baryogenesis

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arXiv:1108.4687

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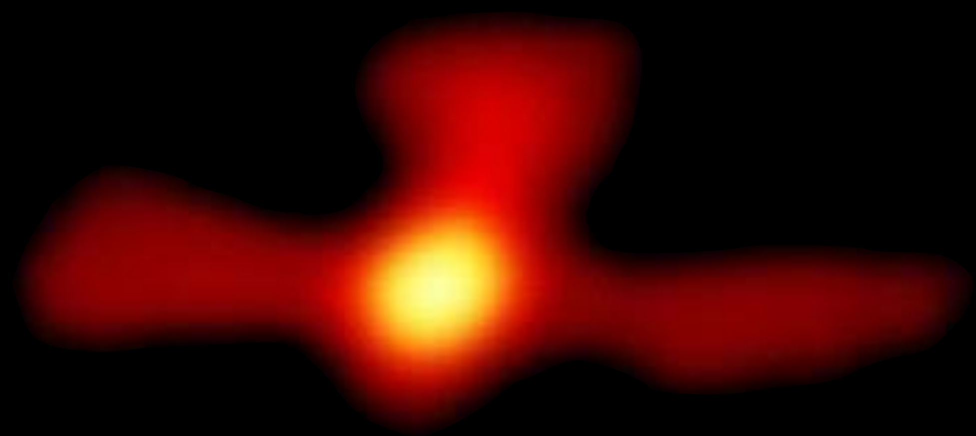
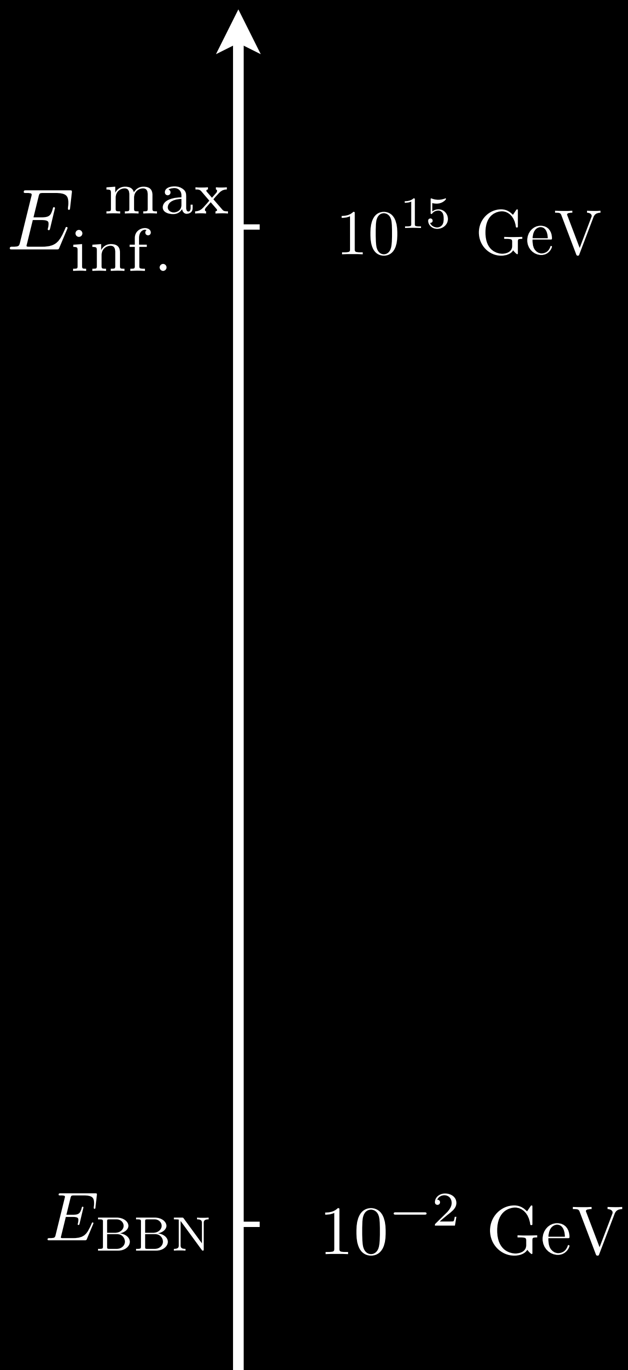
Laboratory for Elementary-Particle Physics

Matter

Antimatter

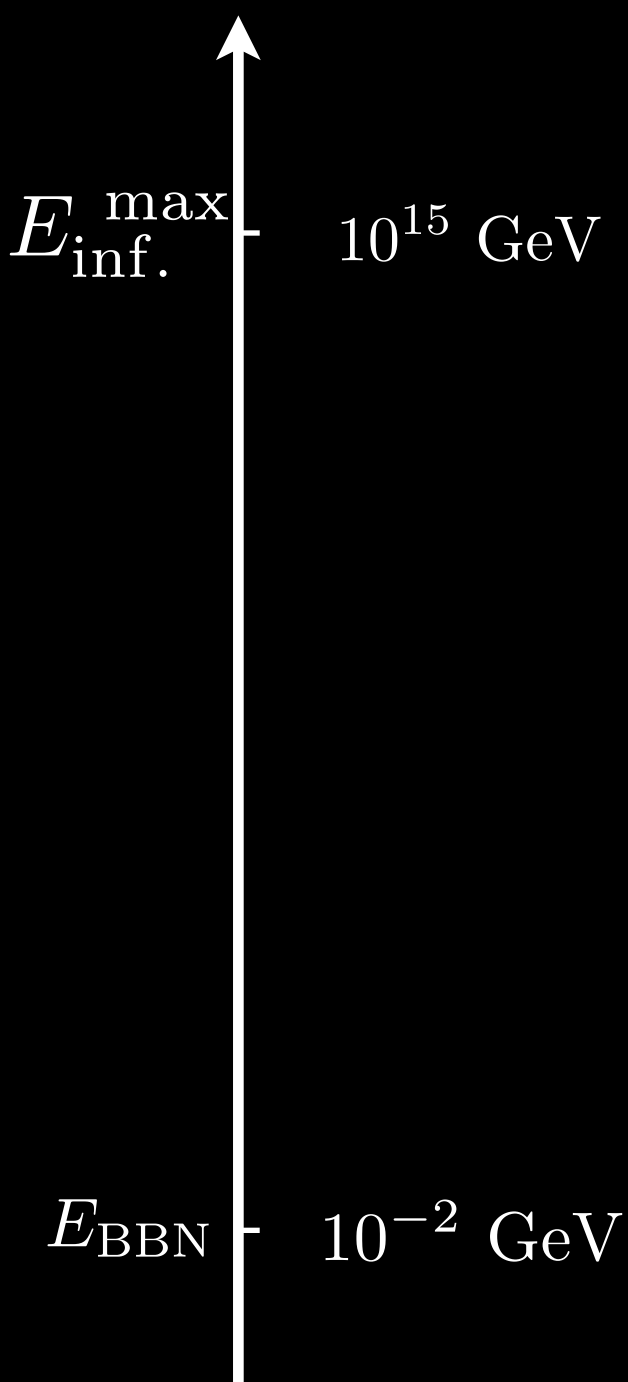


Baryogenesis



Suggested mechanisms:

- Affleck-Dine baryogenesis
- Leptogenesis
- GUT baryogenesis
- Electroweak baryogenesis
- ...



Baryogenesis

Suggested mechanisms:

- Affleck-Dine baryogenesis
- Leptogenesis
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- ...

Affleck-Dine Baryogenesis is UV-sensitive

Φ : Inflaton chiral superfield,

Ψ : "Baryonic" chiral superfield,

$$K \supset \frac{\beta}{M_{Pl}^2} \Phi^\dagger \Phi \Psi^\dagger \Psi$$

Affleck-Dine baryogenesis is *impossible* in some of the most successful models of inflation in string theory (brane inflation, volume modulus inflation, etc.).

Affleck-Dine Baryogenesis is robust

Observed: $$\frac{n_B}{n_\gamma} = 6.2 \cdot 10^{-10}\,,$$

Affleck-Dine estimate: $$\frac{n_B}{n_\gamma} \sim 10^{-10} \left(\frac{T_R}{10^9 \text{ GeV}} \right) \left(\# \right),$$

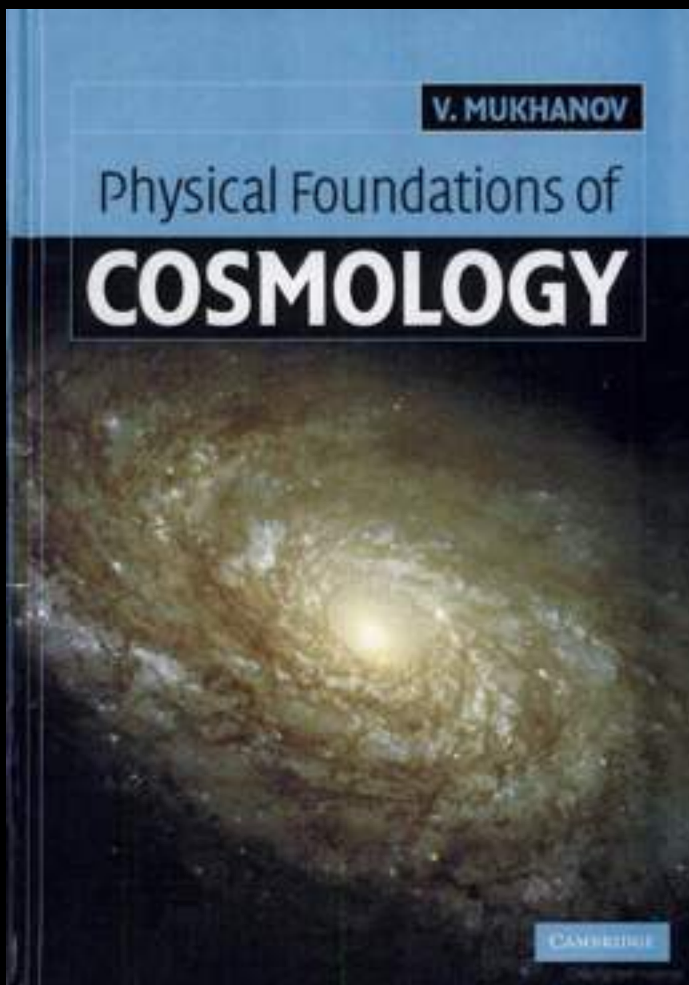
Correlated predictions:

- Supersymmetry
- Q-balls

$$\Omega_{DM} \sim \Omega_m$$

M. Dine and A. Kusenko,
Rev. Mod. Phys. **76** (2004) 1

... but how predictive?

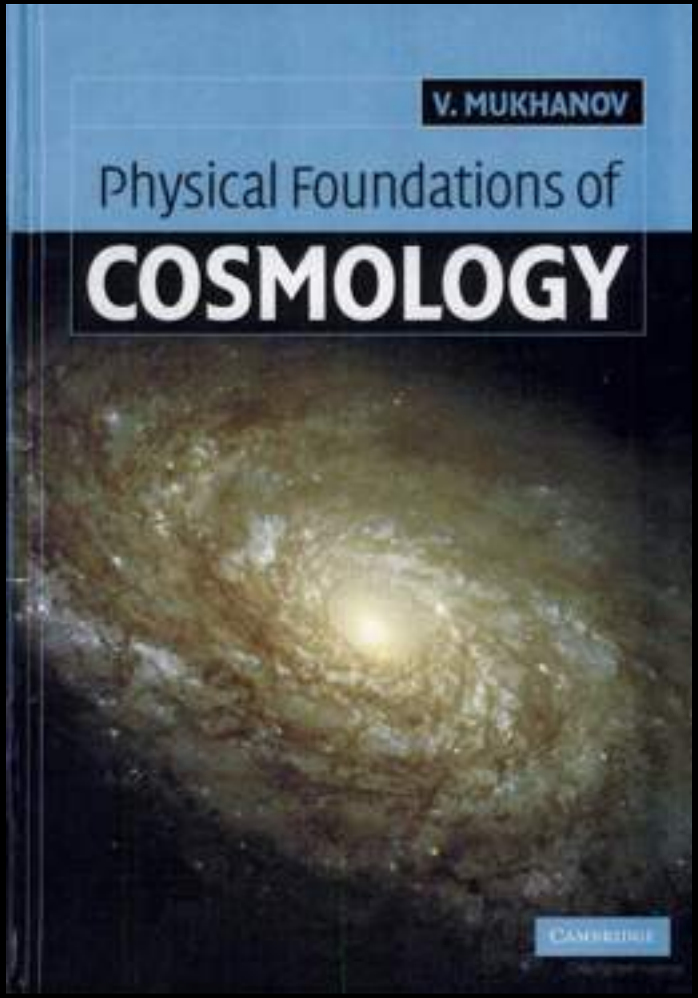


216 *The very early universe*

with complex λ_1, λ_2) become important, and a substantial baryon asymmetry can be produced. The scalar particles decay into ordinary quarks and leptons, transferring to them the generated baryon number. The Affleck–Dine mechanism can be implemented at nearly any energy scale, even below 200 GeV. By suitable choice of the parameters, one can explain almost any amount of baryon asymmetry. This makes the Affleck–Dine scenario practically unfalsifiable and it is a very unattractive feature of this scenario.

More exotic possibilities have also been considered. Among them are baryogenesis via black hole evaporation and leptogenesis with very weakly coupled right-handed Dirac neutrinos. Although at present the accepted wisdom favors leptogenesis, it is not clear which scenario was actually realized in nature. Therefore the main lesson of this section is that there exist many ways to "solve" the baryogenesis problem.

… but how predictive?



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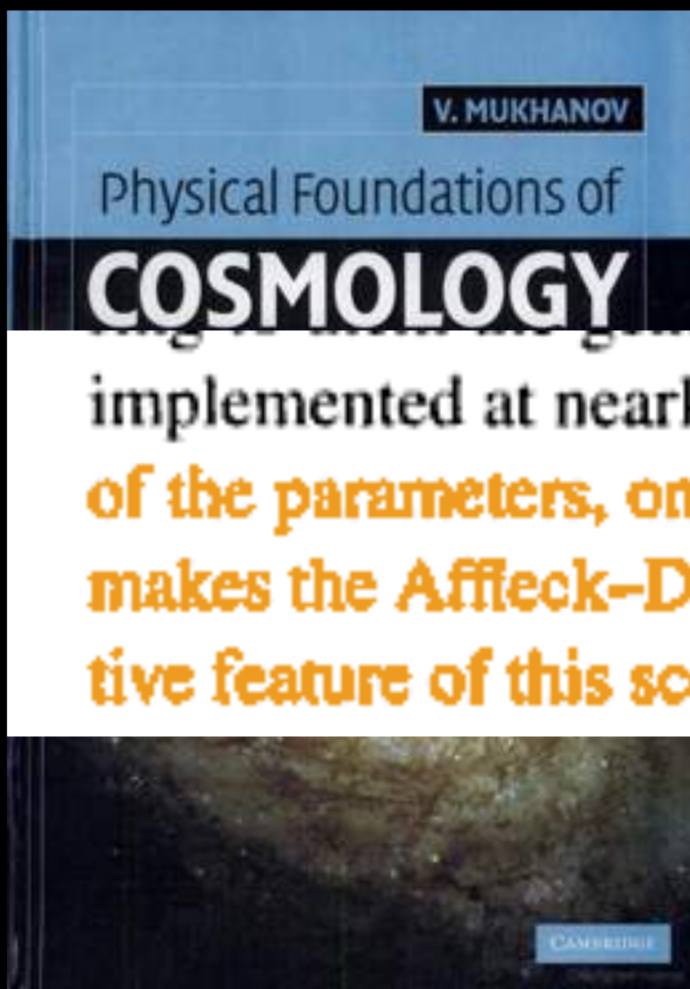

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Towards Constraining Affleck-Dine Baryogenesis

This talk:

- The Affleck-Dine Mechanism
- Geometric condition
- Affleck-Dine baryogenesis in brane inflation
- Possible constraints from precision cosmology

Affleck-Dine Baryogenesis

For a scalar field ψ charged under a global $U(1)$, transforming like

$\psi \to e^{i\alpha}\psi$, the corresponding charge is,

$$q = -i(\psi^* \dot{\psi} - \psi \dot{\psi}^*) \quad \sim \text{``}L_z\text{''} \,.$$

In particular, for q to be non-vanishing, ψ must have a time-dependent, non-vanshing vev (focus of this talk).

I. Affleck and M. Dine,
Nucl. Phys. B **249** (1985) 361.

Candidate Affleck-Dine fields

In global supersymmetry:

$$F_i = \partial_i W^{(\mathrm{ren})} = 0\,, \qquad D_a = 0\,,$$

$\langle \psi \rangle$ undetermined: "renormalizably flat direction".

Examples in the MSSM: $H_u H_d\,, H_u L_i\,, L_i L_j e_k\,, \bar{u}\bar{d}\bar{d}\,, \ldots$

T. Gherghetta, C. F. Kolda and S. P. Martin, Nucl. Phys. B **468** (1996) 37

Flat directions in the early universe

In supergravity:

$$V = V_F + V_D = e^{K/M_{Pl}^2}\left(K^{A\bar{B}}F_A\bar{F}_{\bar{B}} - 3\frac{|W|^2}{M_{Pl}^2}\right) + \frac{1}{2}\sum_i g_i^2 D_i^2 \,.$$

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A single flat direction is lifted by supersymmetric and supersymmetry breaking effects:

$$W = W^{\text{ren.}} + \frac{\lambda}{n}\frac{\Psi^n}{M_{Pl}^{n-3}}\,, \qquad K = \tilde{K} + \tilde{K}_{\psi\bar{\psi}}\psi\bar{\psi} + \ldots\,,$$

where $\tilde{K} = \tilde{K}(\phi, \bar{\phi})\,.$

Flat directions in the early universe

In supergravity:

For F-term inflation, the leading contributions to the scalar potential can be written:

$$V(\psi, \bar{\psi}) = -c_I H^2 |\psi|^2 + \left(a \frac{\lambda H \psi^n}{n M_{Pl}^{n-3}} + c.c. \right) + |\lambda|^2 \frac{|\psi|^{2n-2}}{M_{Pl}^{2n-6}} \, ,$$

M. Dine, L. Randall and S. D. Thomas, Nucl. Phys. B **458** (1996) 291

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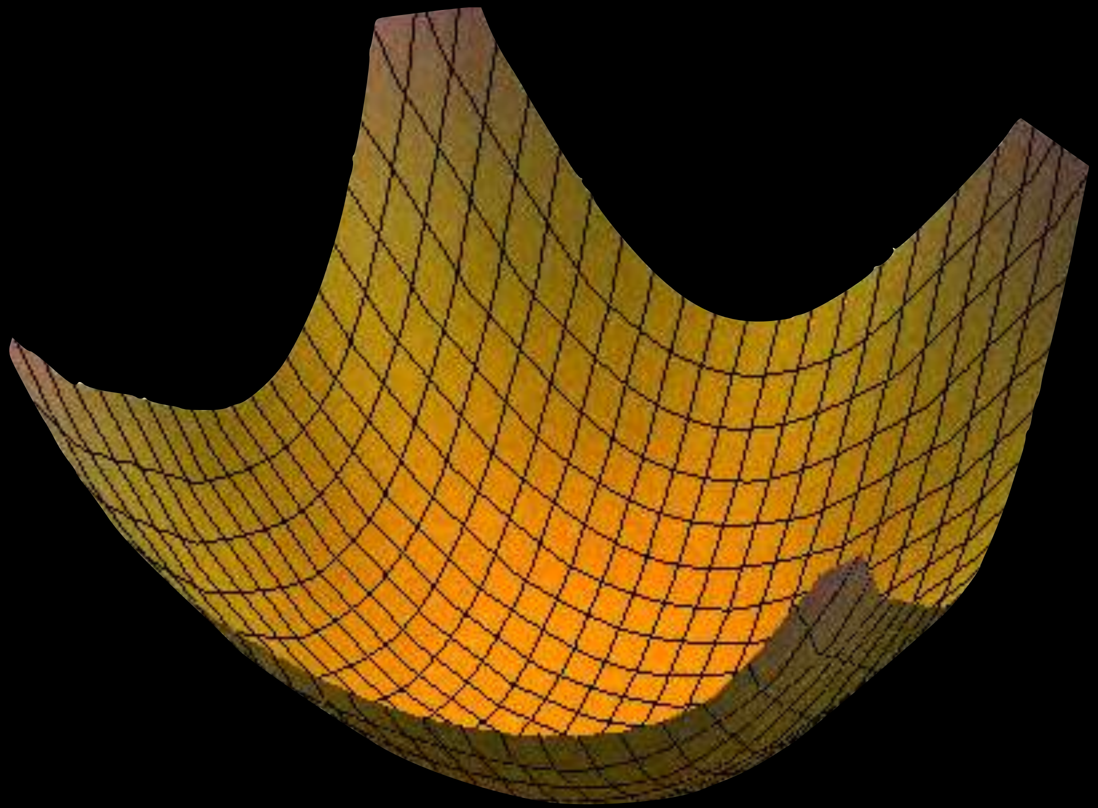
M. Dine, L. Randall and S. D. Thomas, Nucl. Phys. B **458** (1996) 291

Affleck-Dine Baryogenesis

In supergravity:

$c_I < 0$:



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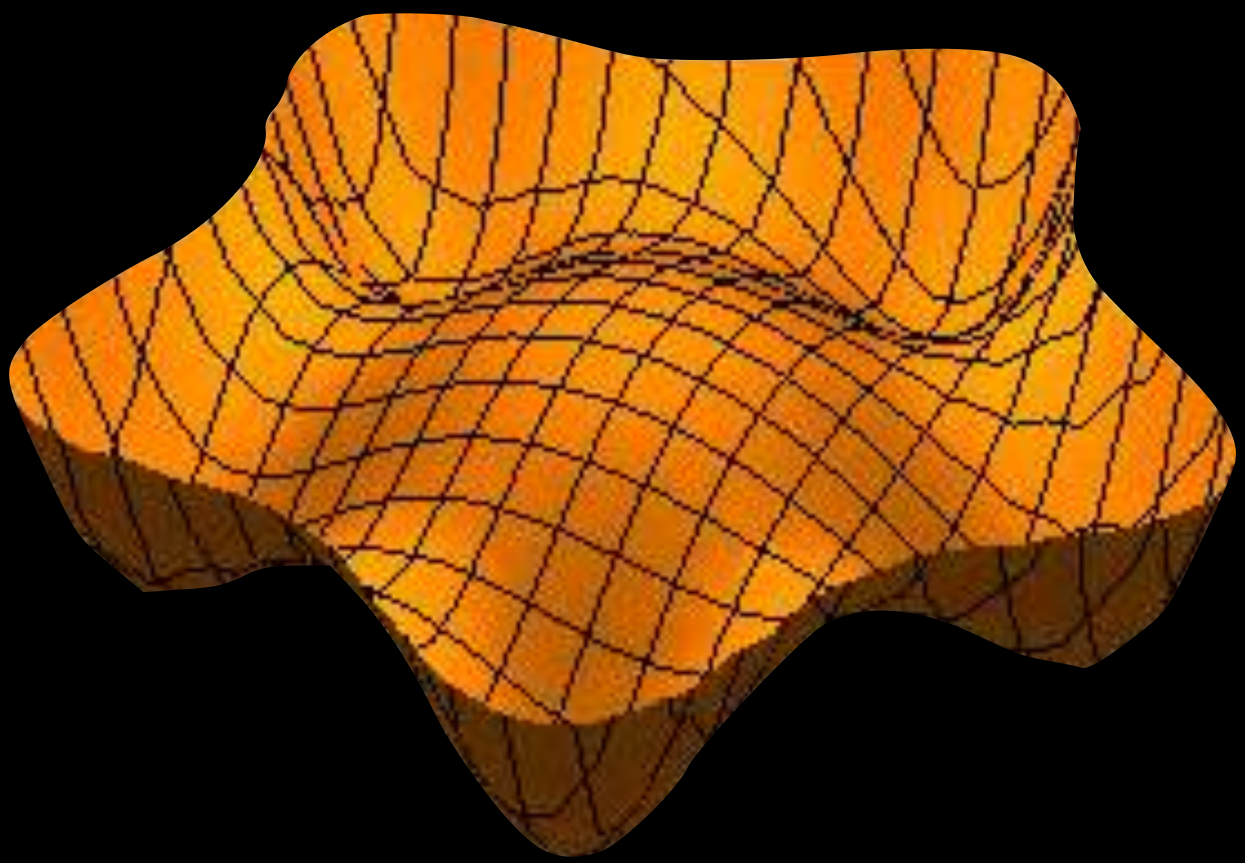
Affleck-Dine Baryogenesis

In supergravity:

$c_I > 0$:



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Affleck-Dine Baryogenesis

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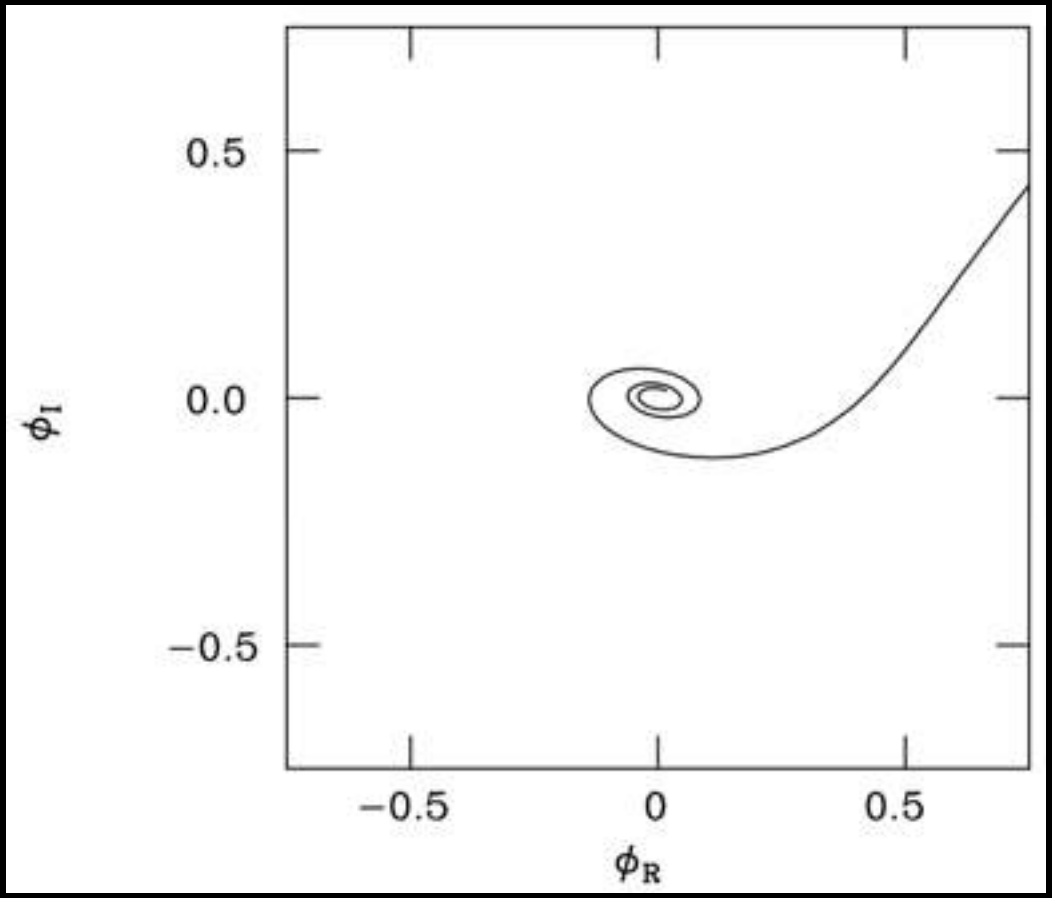


M. Dine, L. Randall and S. D. Thomas, Nucl. Phys. B **458** (1996) 291

Geometric Condition

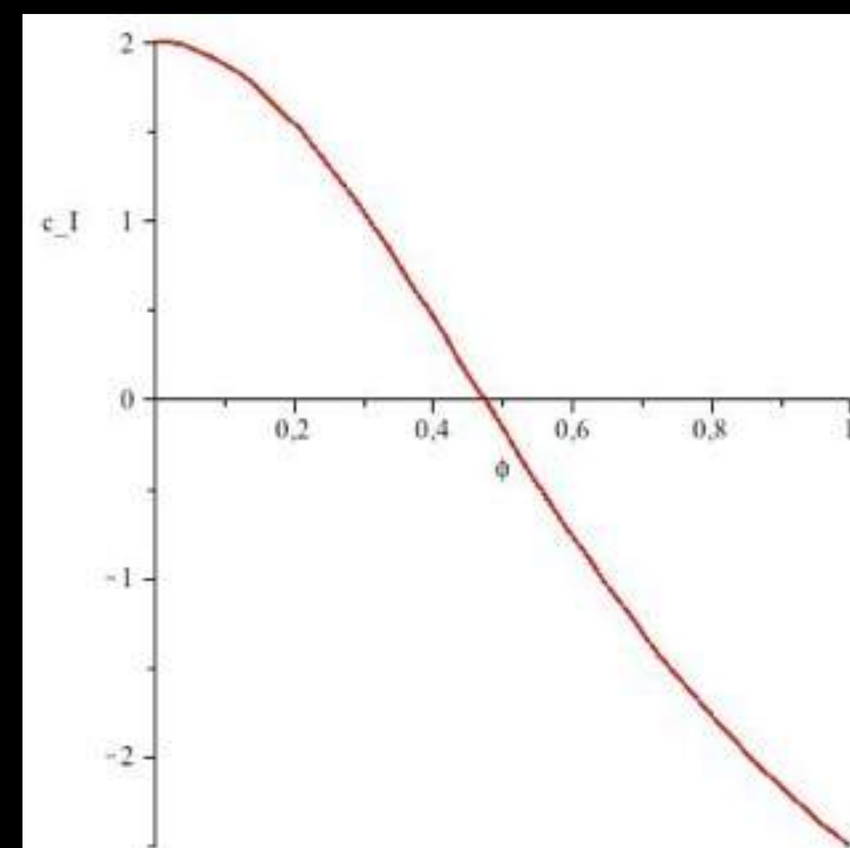
In supergravity:

$$c_I > 0 \ : \ V(\psi, \bar{\psi}) = -c_I H^2 |\psi|^2 + \left(a \frac{\lambda H \psi^n}{n M_{Pl}^{n-3}} + c.c. \right) + |\lambda|^2 \frac{|\psi|^{2n-2}}{M_{Pl}^{2n-6}} \, ,$$

Simplest model: $\beta > 0 \, ,$

$$K \supset \frac{\beta}{M_{Pl}^2} \Phi^\dagger \Phi \Psi^\dagger \Psi \, ,$$

requires a small field excursion of the inflaton from inflation and until $H \approx m_{\text{soft}} \, .$



Geometric Condition

In supergravity:

$$c_I > 0 \ : \quad V(\psi, \bar{\psi}) = -c_I H^2 |\psi|^2 + \left(a \frac{\lambda H \psi^n}{n M_{Pl}^{n-3}} + c.c. \right) + |\lambda|^2 \frac{|\psi|^{2n-2}}{M_{Pl}^{2n-6}} \, ,$$

During F-term inflation:

$$c_I = -3 \left(1 + B[\phi, \psi] + \left(\frac{m_{3/2}}{H} \right)^2 \left(\frac{1}{3} + B[\phi, \psi] \right) \right) \, .$$

Geometric Condition

Holomorphic Bisectional Curvature:

$$c_I = -3\left(1 + B[\phi,\psi] + \left(\frac{m_{3/2}}{H}\right)^2 \left(\frac{1}{3} + B[\phi,\psi]\right)\right) .$$

$$B[\phi,\psi] = -M_{Pl}^2 \tilde{K}^{\phi\bar{\phi}} \tilde{K}^{\psi\bar{\psi}} R_{\phi\bar{\phi}\psi\bar{\psi}} ,$$

For $m_{3/2} \ll H$ Affleck-Dine baryogenesis requires $B[\phi,\psi] < -1$.

For $m_{3/2} = H$ Affleck-Dine baryogenesis requires $B[\phi,\psi] < -\frac{2}{3}$.

Geometric Condition

Holomorphic Bisectional Curvature:

$$c_I = -3\left(1 + B[\phi,\psi] + \left(\frac{m_{3/2}}{H}\right)^2\left(\frac{1}{3} + B[\phi,\psi]\right)\right)\ .$$

$B[\phi,\psi]$ determines the inflaton-dependence of the function $c_I(\phi)$.

$B[\phi,\psi]$ appears elsewhere in the Lagrangian, and thus gives rise to definite correlated predictions of the scenario (more in paper).

The Affleck-Dine mechanism in string theory

Example: Brane-inflation with a sequestered visible sector.

In the 4D EFT:

$$V_{tot.} = V_F + V_{up} \, ,$$

$$c_I^{(tot.)} = c_I^{(F)} + c_I^{(up)} \, .$$

S. Kachru, R. Kallosh, A. D. Linde, J. M. Maldacena, L. P. McAllister and S. P. Trivedi, JCAP **0310** (2003) 013

The Affleck-Dine mechanism in string theory

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In the 4D EFT:

$$V_{tot.} = V_F + V_{up}\,,$$

$$c_I^{(tot.)} = c_I^{(F)} + c_I^{(up)}\,.$$

The gravitino mass is given by:

$$m_{3/2}^2 = (1+\beta)H^2\,,$$

S. Kachru, R. Kallosh, A. D. Linde, J. M. Maldacena, L. P. McAllister and S. P. Trivedi, JCAP **0310** (2003) 013

The Affleck-Dine mechanism in string theory

Example: Brane-inflation with a sequestered visible sector.

Sequestering: $$K = -3M_{Pl}^2 \ln\left(-\frac{1}{3}(f_{vis.} + f_{hid.})\right) \, ,$$

It follows that:

$$c_I^{(F)} = 2 + 2\beta \, ,$$

$$c_I^{(up)} = -4 - 2\beta \, ,$$

$$c_I^{(tot.)} = -2 \, .$$

The Affleck-Dine mechanism in string theory

Example: Brane-inflation with a sequestered visible sector.

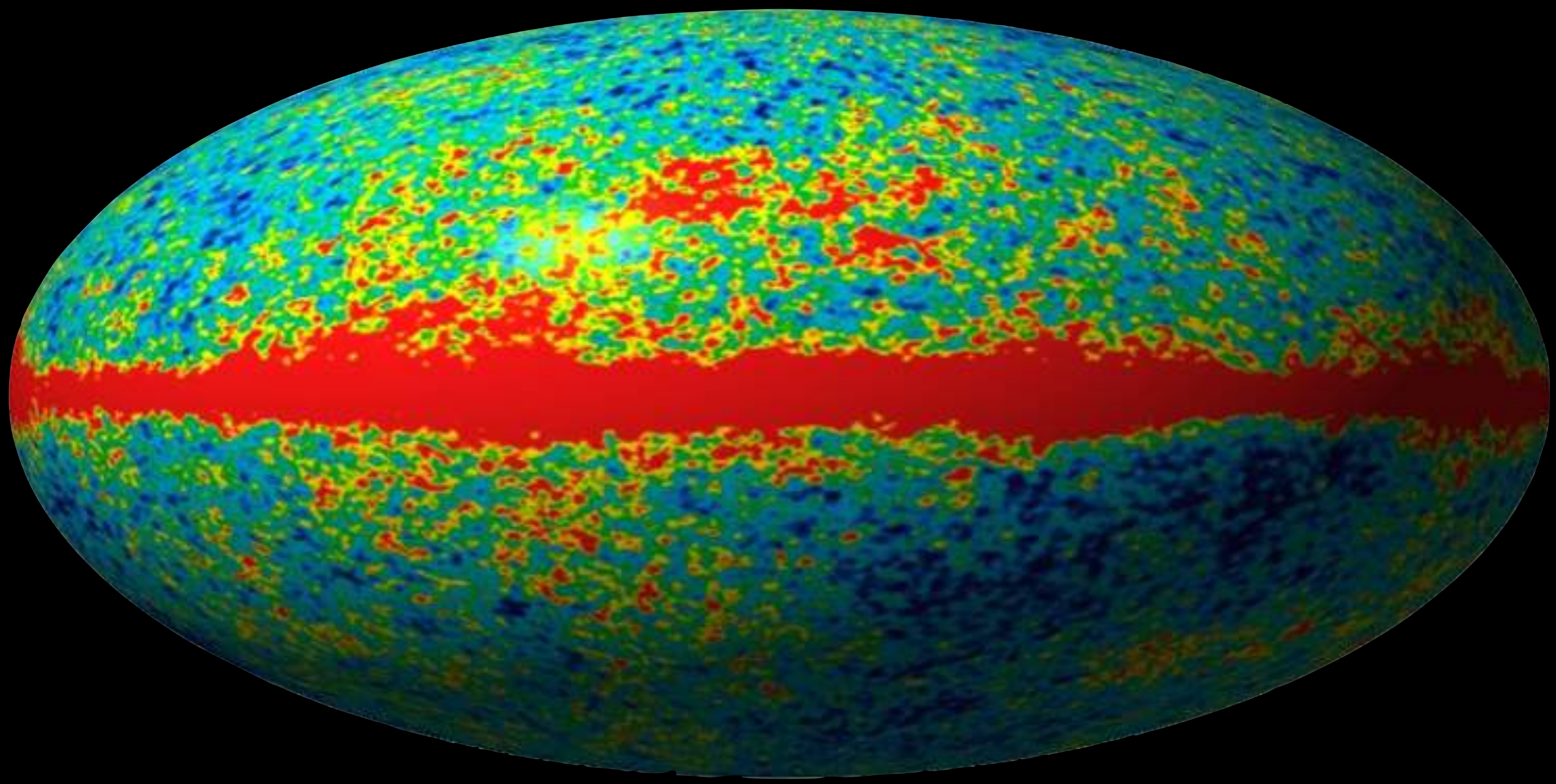
Sequestering: $$K = -3M_{Pl}^2 \ln\left(-\frac{1}{3}(f_{vis.} + f_{hid.})\right) \,,$$

It follows that:

Affleck-Dine baryogenesis is impossible
in brane inflation with a sequestered visible sector.

$$c_I^{(tot.)} = -2 \,.$$

Affleck-Dine baryogenesis and precision cosmology



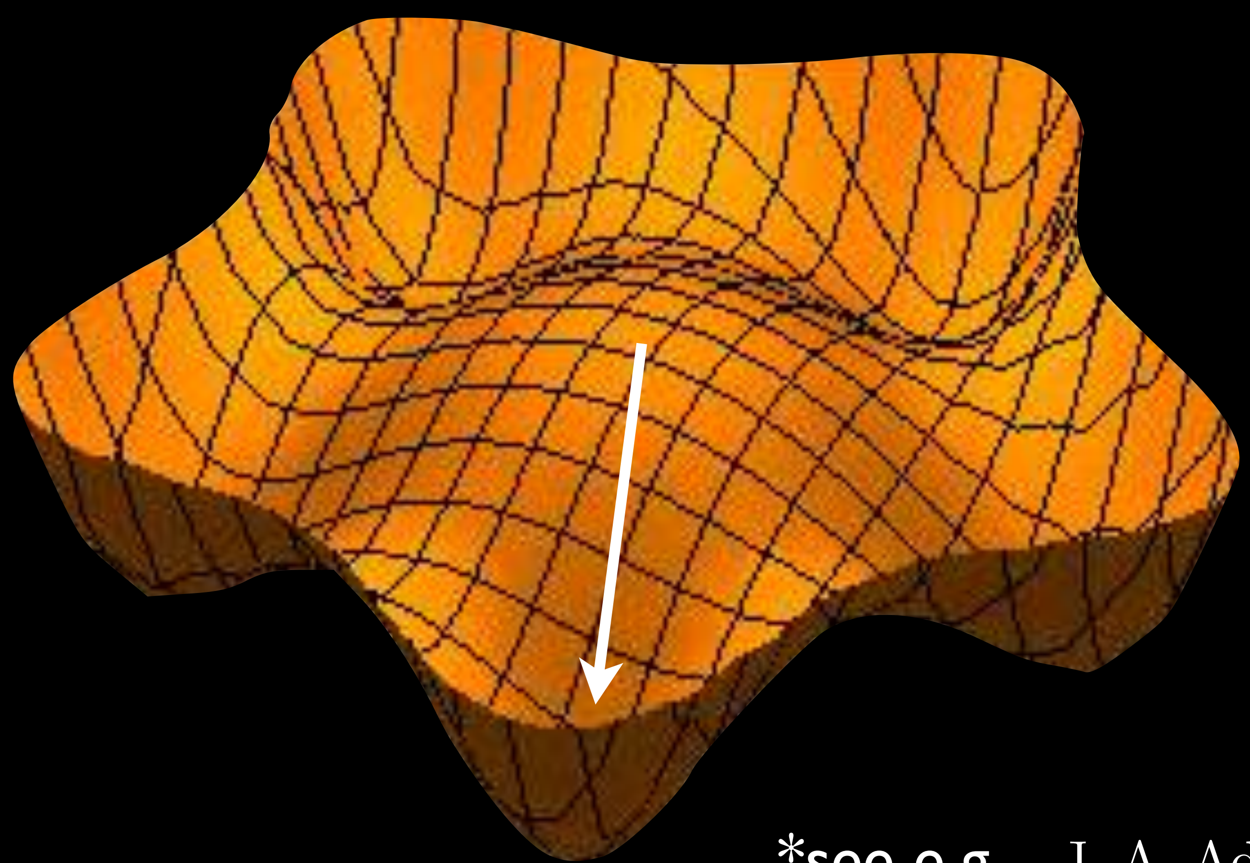
E. Komatsu *et al.* [WMAP Collaboration], Astrophys. J. Suppl. **192** (2011) 18

David Marsh, Cornell.

String Phenomenology, Madison, August 24, 2011.

The Affleck-Dine field backreacts on the inflaton potential

Flat directions moving during inflation affect the cosmological perturbations originating during this period. Transitions from the origin can occur for a variety of initial conditions (e.g. thermal IC*, triggering).



*see e.g. J. A. Adams, G. G. Ross and S. Sarkar, Nucl. Phys. B **503** (1997) 405

The Affleck-Dine field backreacts on the inflaton potential

Two interesting cases:

i) Transition happens before "observable inflation":

Natural if $N_{tot.} \gtrsim 90$.

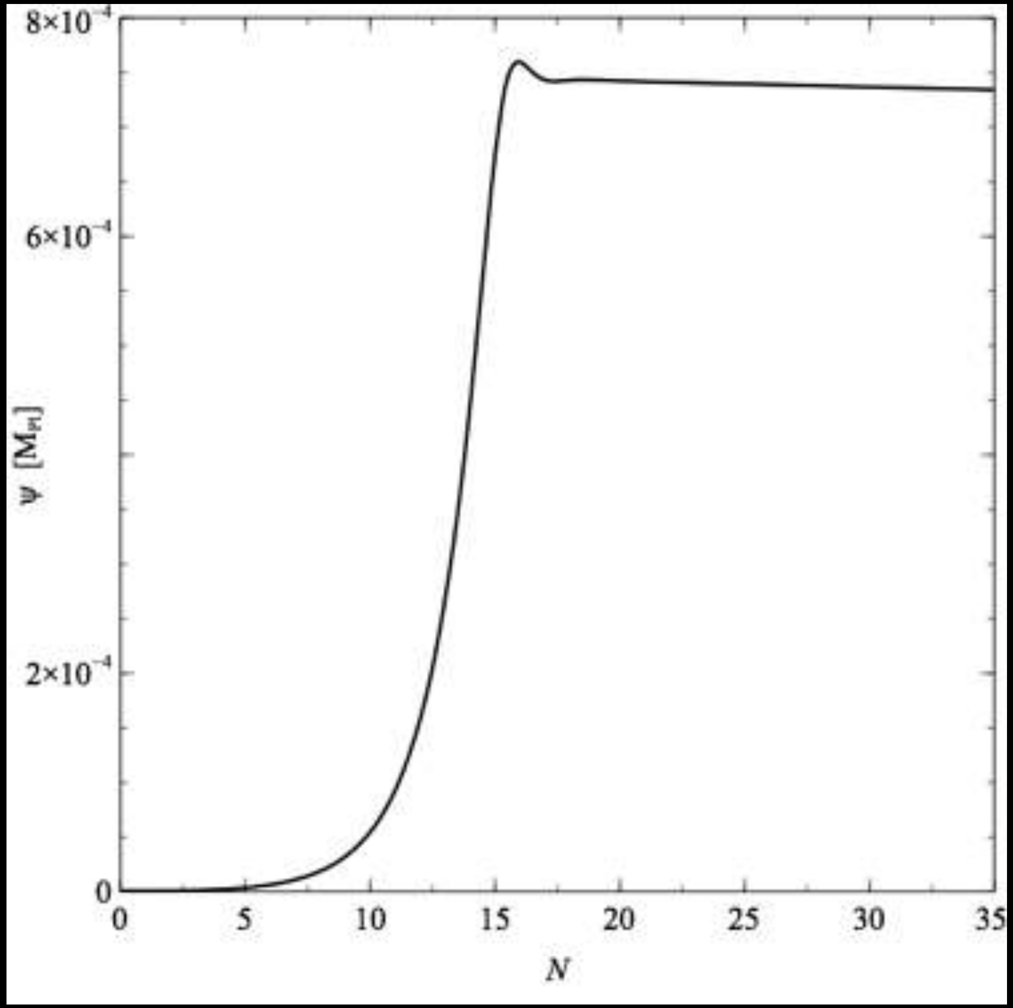
ii) Transitions happens during "observable inflation":

Tightly constrained:
A step in the inflaton potential can provide a (marginally significant) better fit to the TT-spectrum, as measured by WMAP.

Mapping the transitioning flat direction to a step

The transitioning flat direction can – as a first approximation – be integrated out, and mapped to an inflaton potential with a step:

$$V(\phi, \psi) = V_0(\phi) - c_I(\phi) H_I^2 \psi^2 + |\lambda|^2 \frac{\psi^{2n-2}}{M_{Pl}^{2n-6}}$$



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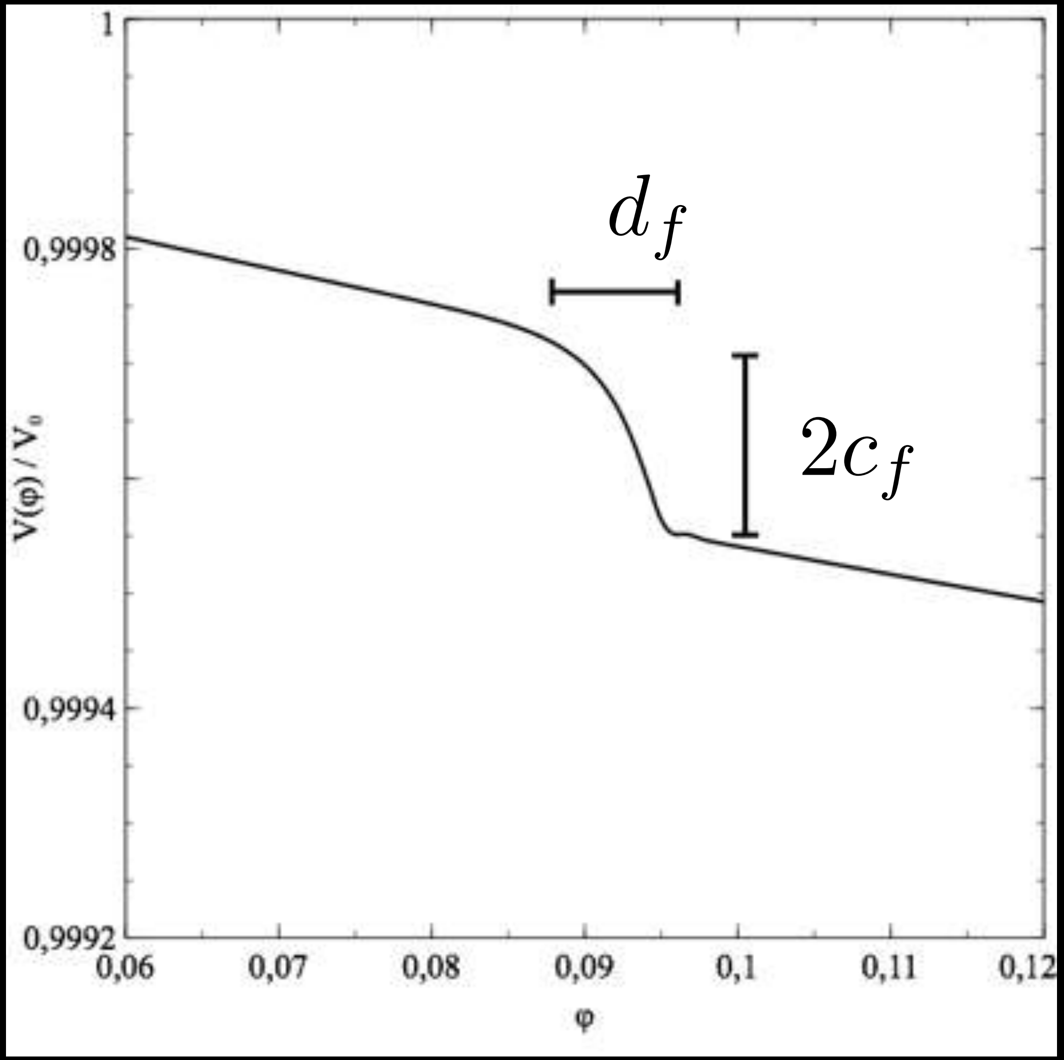
The transitioning flat direction can – as a first approximation – be integrated out, and mapped to an inflaton potential with a step:

$$V(\phi) = V_0(\phi)\left(1 - c_f \tanh\left(\frac{\phi - \phi_f}{d_f}\right)\right) ,$$



Towards constraining Affleck-Dine baryogenesis

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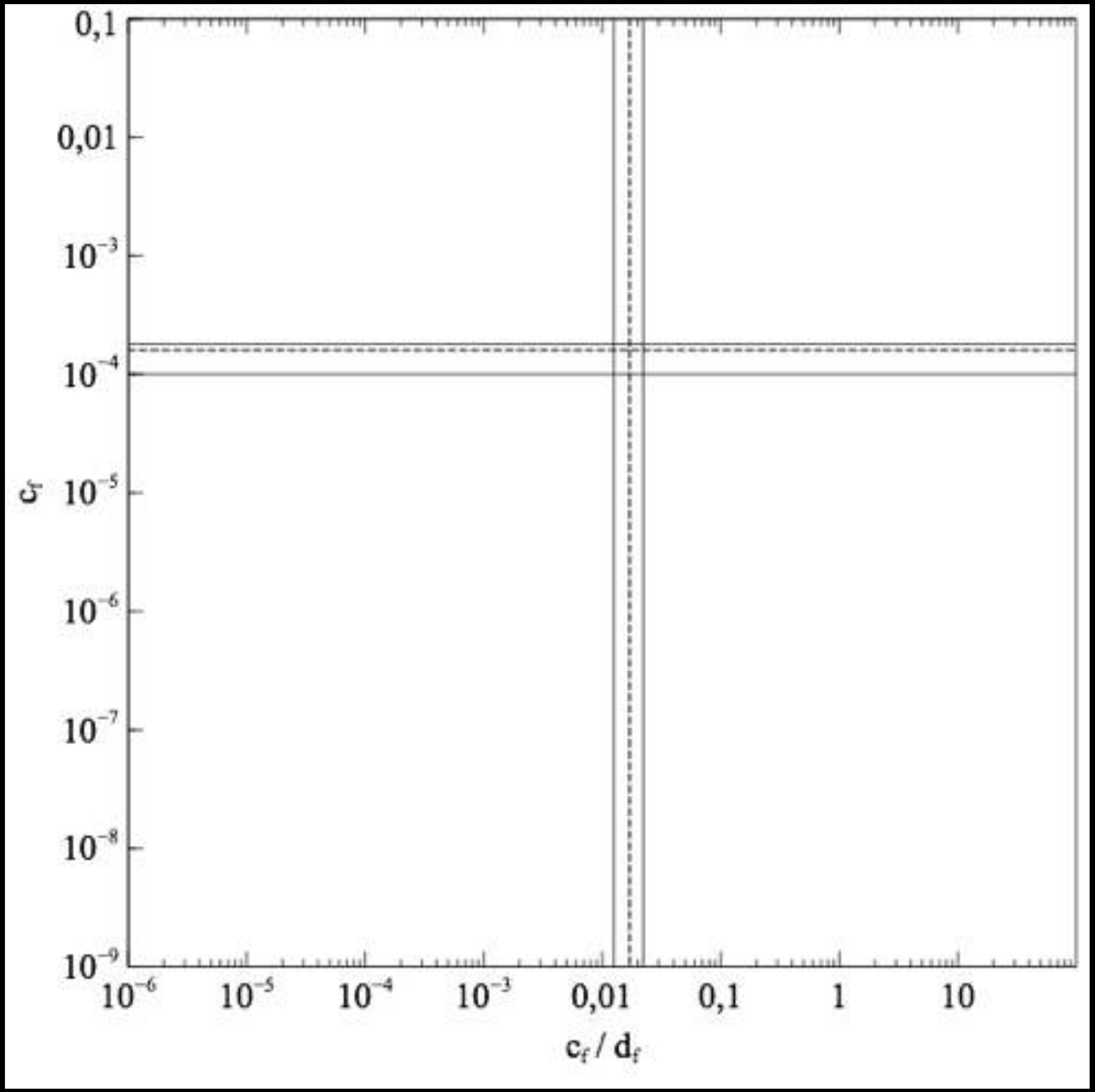

D. K. Hazra, M. Aich, R. K. Jain, L. Sriramkumar and T. Souradeep, JCAP **1010** (2010) 008

Towards constraining Affleck-Dine baryogenesis

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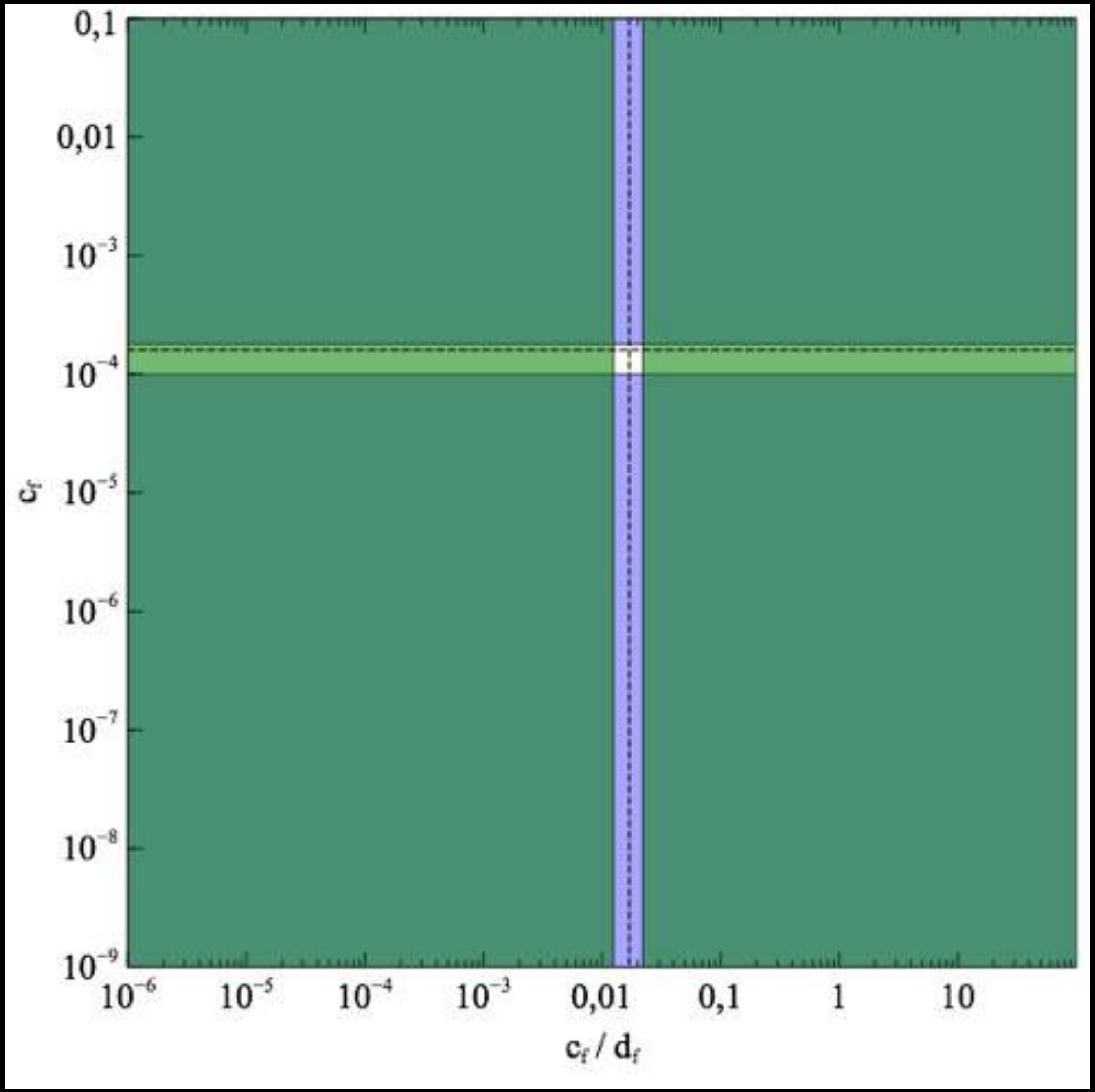

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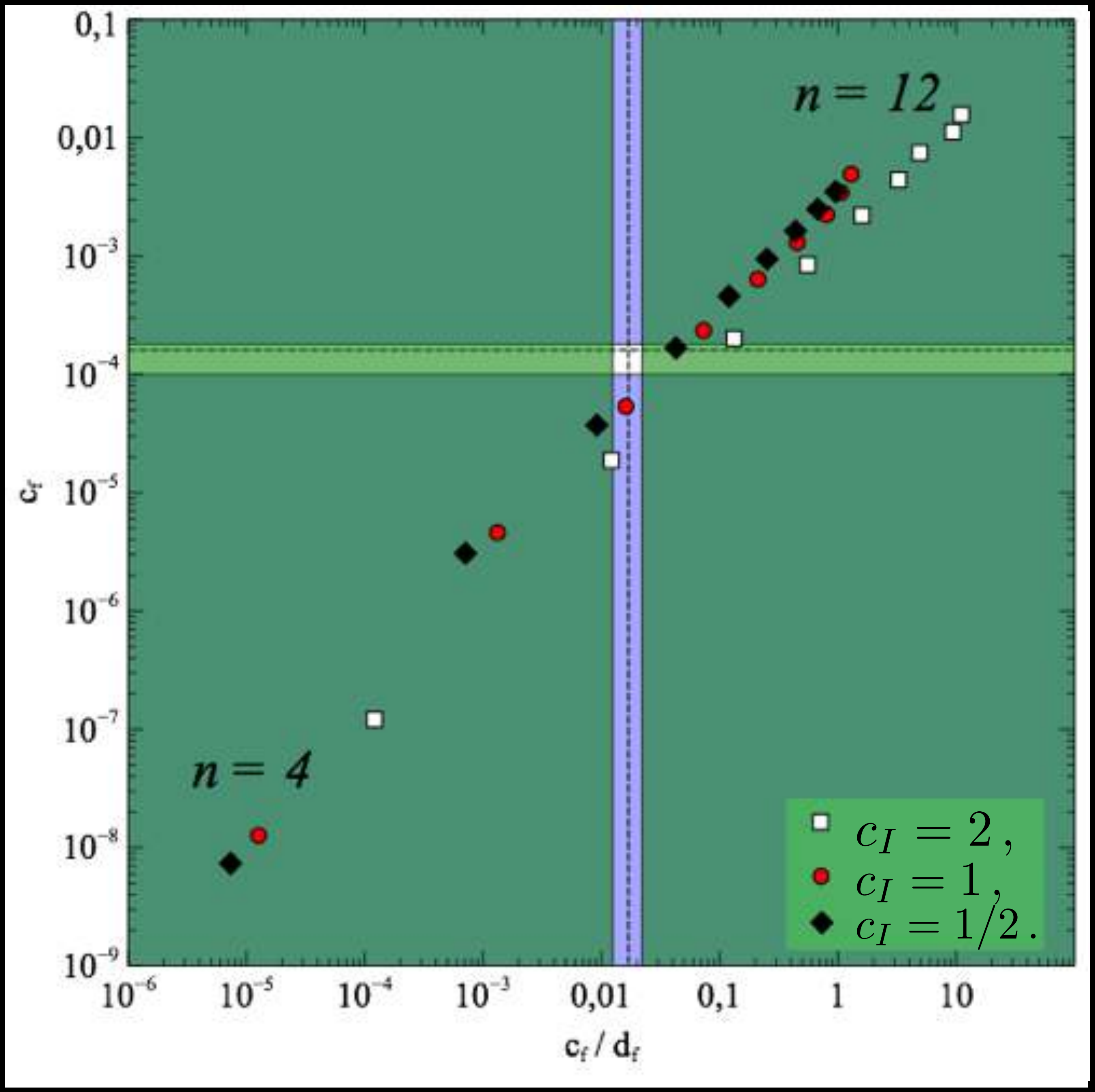

Here, $H_I \simeq 10^{-6}\ M_{Pl}$.

D. K. Hazra, M. Aich, R. K. Jain, L. Sriramkumar and T. Souradeep, JCAP **1010** (2010) 008

Towards constraining Affleck-Dine baryogenesis

Conclusions:

- No flat direction with $c_I \in [.5, 2]$ and any n falls within the 68% confidence contour.
- The improved fit for a potential with a step is only marginally significant:

Future observations will determine the significane of the features in the CMB.

Summary:

- Affleck-Dine baryogenesis is conditioned on a sufficiently negative holomorphic bisectional curvature.
- The constraint on the holomorphic bisectional curvature can not be satisfied in some well studied models of string inflation.
- The holomorphic bisectional curvature appears in a number of places in the supergravity Lagrangian, thus giving rise nontrivial correlations of the scenario.
- A subset of the models can be severely constrained by current WMAP data. Future precision cosmology experiments will determine the nature and significance of this constraint.