Affleck-Dine baryogenesis after D-term inflation and a solution to the baryon-DM coincidence problem

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Phys. Rev. D 91, 083512 [hep-ph/1502.03550]

DESY theory workshop 2015 @DESY

Introduction: motivation

Content of the Universe

Antibaryon : 0%

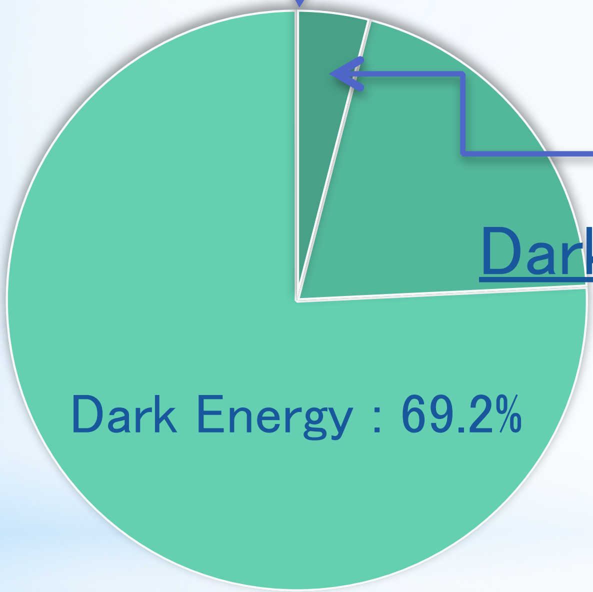
asymmetry

Baryon : 4.8%

Dark Matter : 26%

$$\frac{1}{5} = \mathcal{O}(1)$$

coincidence problem



Planck (2013)

- What is the origin of baryon asymmetry?
- Why is there the coincidnece between the energy density of baryon and DM?

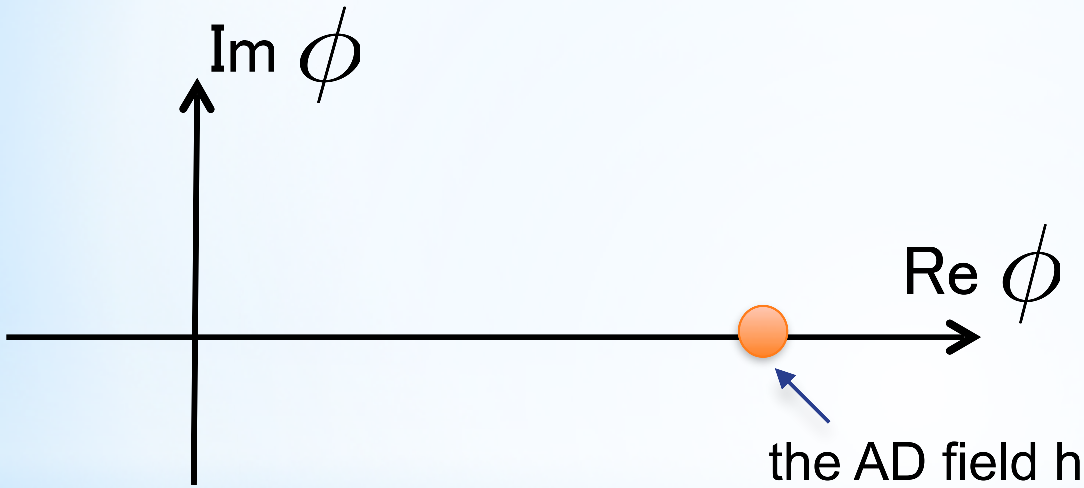
We have proposed a scenario to explain the coincidence by the Affleck-Dine baryogenesis and non-thermal production of DM after D-term inflation.

Introduction: Affleck–Dine mechanism

Affleck, Dine, 85
Dine, Randall, Thomas, 96

B–L flat direction (AD field ϕ) can generateg B–L asymmetry through the following dynamics:

e.g.,
$$\phi^2 = \frac{1}{2}(LH_u)$$
$$\phi^3 = \frac{1}{3}(u^c d^c d^c)$$



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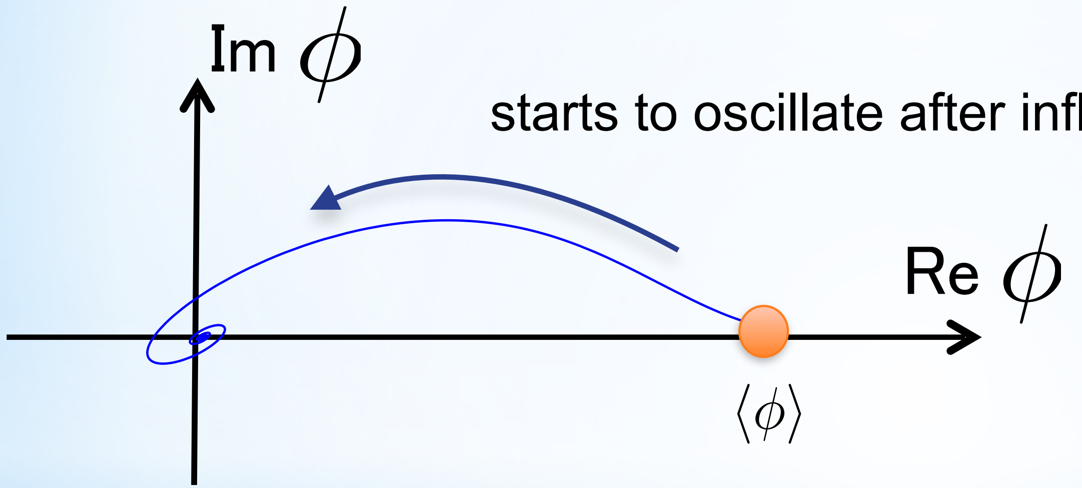

$$B = \int \mathrm{d}V \mathrm{Im}\left(\phi \partial_0 \phi^*\right)$$

$$Y_B \simeq \epsilon \frac{T_{\rm RH}}{H_{\rm osc}} \left(\frac{\langle\phi\rangle}{M_{\rm Pl}} \right)^2$$

observation: 10^{-10}

Introduction: Affleck–Dine mechanism

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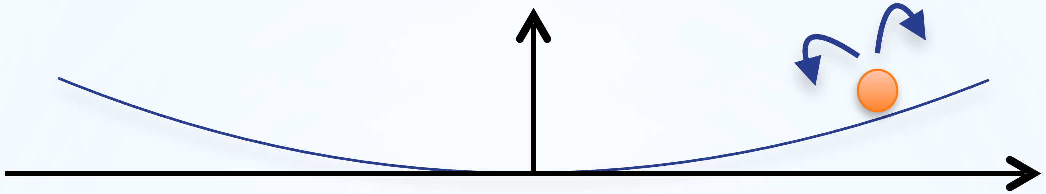
How does the AD field obtain a large VEV?

When inflation is driven by a D–term potential, it obtains a large VEV by the Howking–Moss instanton effect during inflation.



In the literature, they introduce higher dimensional Kahler potential:

$$K = |\phi|^2 + \frac{\tilde{c}}{M_{\rm Pl}} |I|^2 |\phi|^2$$

I : inflaton

After inflation, $\left\langle |F_I|^2 \right\rangle = \mathcal{O}(1) \times H^2(t) M_{\rm Pl}^2$, so that $V \supset -cH^2(t) |\phi|^2$.

The AD field starts to oscillate at the time of $H(t) \simeq m_{\rm soft}$.

$$Y_B \simeq \epsilon \frac{T_{\rm RH}}{H_{\rm osc}} \left(\frac{\langle \phi \rangle}{M_{\rm Pl}} \right)^2$$

with $H_{\rm osc} \simeq m_{\rm soft}$.

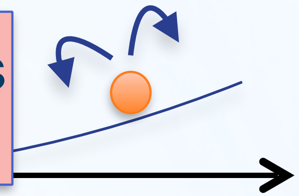
Introduction: Affleck–Dine mechanism

Kawasaki, M.Y. 15

How does the AD field obtain a large VEV?

When inflation is driven by a D–term potential, it obtains a large VEV by the Howking–Moss instanton effect during inflation.

We have found that the ADBG works even if this term is absent.



In the literature, they introduce higher dimensional Kahler potential:

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After inflation, $\left\langle |F_\psi|^2 \right\rangle = \mathcal{O}(1) \times H_{\rm inf}^2 M_{\rm Pl}^2$, so that $V \supset +cH^2(t)\,|\phi|^2$.

In this case, the Hubble–induced mass term is positive and the AD field starts to oscillate just after the end of inflation.

$$Y_B \simeq \epsilon \frac{T_{\rm RH}}{H_{\rm osc}} \left(\frac{\langle \phi \rangle}{M_{\rm Pl}} \right)^2$$ with $H_{\rm osc} \simeq m_{\rm soft} \rightarrow H_I$

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The result depends on the inflation parameter H_I,

Solution to the baryon–DM coincidence problem

Kawasaki, M.Y. 15

We can arrange D–term inflation models such that inflaton decays mainly into gravitinos at reheating.

If gravitino is heavier than 400 TeV, the gravitinos decay into MSSM particles before the BBN epoch.

The gravitino decay is a non–thermal source of DM and the result is

$$Y_{\rm DM} \approx \frac{T_{\rm RH}}{m_I}$$

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$$Y_{\rm DM} \approx \frac{T_{\rm RH}}{m_I}$$

This is similar to $Y_B \simeq \dfrac{T_{\rm RH}}{H_I}$ (where we assume $\langle \phi_{\rm osc} \rangle \approx M_{\rm Pl}$).

Therefore, the baryon–to–DM ratio is

$$\frac{\Omega_b}{\Omega_{\rm DM}} \simeq \frac{4}{69} \frac{m_p}{m_{\rm LSP}} \frac{m_I}{H_I}$$

$$\simeq 0.12 \lambda g^{-1} \left(\frac{m_{\rm LSP}}{400\ {\rm GeV}} \right)^{-1} \left(\frac{\sqrt{\xi}}{6.6 \times 10^{15}\ {\rm GeV}} \right)^{-1}$$

Summary

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We have pointed out that the Affleck–Dine baryogenesis works even when the Hubble–induced mass term is positive after D–term inflation.
The resulting baryon asymmetry is given by

$$Y_B \simeq 9 \times 10^{-11} \left(\frac{T_{\rm RH}}{4 \times 10^3 \text{ GeV}} \right) \left(\frac{H_I}{4 \times 10^{12} \text{ GeV}} \right)^{-1}$$

(where we assume $\langle \phi_{\rm osc} \rangle \approx M_{\rm Pl}$).

We have modified D–term inflation models such that inflaton decays mainly into gravitinos, which then decay into light SUSY particles as well as the SM particles.

The barion to DM ratio is then given by

$$\frac{\Omega_b}{\Omega_{\rm DM}} \simeq \frac{4}{69} \frac{m_p}{m_{\rm LSP}} \frac{m_I}{H_I} = \mathcal{O}(1)$$

back up slides

A new scenario of the ADBG

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We assume that the VEV of the AD field is of order the Planck scale.

There are some advantages in this assumption:

- We can explain the baryon–to–DM ratio
- We can avoid the bayon isocuvature constraint
- The back reaction of the AD field to the inflaton dynamics can be neglected because it has no F–term potential.
- Non–renormalizable Kahler potentials can be efficient and they kick the AD field in the complex plane.

note: the AD field never dominate the Universe because its effective mass decreases as $\propto H(t) \propto a^{-3/2}$.

A new scenario of the ADBG

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Comments:

We assume that the gravitino is heavier than 400 TeV and the DM mass is of order 10^2-3 GeV. This is motivated by split SUSY and pure gravity mediation models and by stabilization of Polonyi field.

Arkani-Hamed, Dimopoulos 04, Giudice, Romanino 04, Arkani-Hamed, Dimopoulos, Giudice, Romanino 04, Wells 04, Hall, Nomura 12, Ibe, Yanagida 11, Ibe, Matsumoto, Yanagida 12

Buchmuller, Domcke, Wieck 13

The thermal abundance of DM is diluted by the gravitino decay.

Q-balls may form after the ADBG, but in the new scenario their charges are so small that they evapolate into radiation soon.

D–term inflation model

D–term inflation model:

$$V = V_F + V_{1-\mathrm{loop}} + V_D$$

$$W = \lambda I \psi_+ \psi_-$$

$$V_D = \frac{g^2}{2}\left(|\psi_+|^2 - |\psi_-|^2 - \xi\right)^2$$

There are some advantageouses:

the energy scale is naturally of order the GUT scale,
which predicts the amplitude of CMB fluctuations consistent with the obaservations.

there is no Hubble induced mass term,
which guarantees the flatness of the inflaton potential.

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D−term inflation model

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$$V_D = \frac{g^2}{2}\left(|\psi_+|^2 - |\psi_-|^2 - \xi\right)^2$$

We introduce a shift symmetry and an approximate Z_2 symmetry for the inflaton field in the Kahler potential:

$$K = c_I(I + I^*) + \frac{1}{2}(I + I^*)^2$$

- The shift symmetry ensures the flatness of inflaton potential above the Planck scale.
- The Z_2 breaking term allows the inflaton decays into gravitinos.

D−term inflation model

D−term inflation model:

In the simplest model,

- the spectrul index is too blue tilted $n_s \simeq 0.98$
- cosmic strings form after inflation.

  The cosmic strings contribute to the CMB fluctuations,
  so that the string tension (which is related to the FI term)
  is bounded above by the observation of the CMB fluctuations.

We just assume that these problems are solved by some mechanism.

e.g., Buchmuller, Domcke, Schmitz 13, Buchmuller, Domcke, Kamada 13, etc..

D−term inflation model

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D−term inflation model:

$$V = V_F + V_{1-\mathrm{loop}} + V_D$$

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Nonthermal production of DM

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The inflaton decays mainly into gravitinos.

$$V = W_I (K_I W)^* + c.c. + \dots$$
$$\approx c m_I F_z z^* \psi_- + c.c.$$

SUSY breaking field

Then the Universe is dominated by relativistic gravitinos.
If the gravitino mass is larger than 400 TeV,
they decay into MSSM particles before the BBN epoch.

The gravitino decay is a non-thermal source of DM:

$$Y_{\rm DM} \approx \frac{T_{\rm RH}}{m_I}$$

A new scenario of the ADBG

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In the ordinary scenario of the ADBG,
the baryon asymmetry is given as

$$Y_B \simeq \epsilon \frac{T_{\rm RH}}{H_{\rm osc}} \left(\frac{\langle \phi \rangle}{M_{\rm Pl}} \right)^2$$

with $H_{\rm osc} \simeq m_{\rm soft}$.

In the case of the positive Hubble-induced mass term in D-term inflation models,
it is given by the same formula but with

$$H_{\rm osc} \simeq H_I \ .$$

e.g., $$Y_B \simeq 9 \times 10^{-11} \left(\frac{T_{\rm RH}}{4 \times 10^3 \ {\rm GeV}} \right) \left(\frac{H_I}{4 \times 10^{12} \ {\rm GeV}} \right)^{-1}$$

(where we assume $\langle \phi_{\rm osc} \rangle \approx M_{\rm Pl}$).

The result depends on an inflation parameter H_I,
which gives a scenario to solve the baryon–DM coincidence problem.