“Early universe phenomenology by scalar fields”

Kenji Kadota
Particle Astrophysics Center, Fermilab

- ‘D-term inflation and leptogenesis by a right-handed sneutrino’ (K.K. and J. Yokoyama ‘06)

- “Modular cosmology, thermal inflation, baryogenesis and predictions for particle accelerators” (D. Jeong, K.K.,W. Park and E. Stewart ‘03)

Overview:
Early universe phenomenology by scalar fields

What kinds of scalar fields are there?

$$\boxed{W = W_{MSSM} + W_{NEUTRINO}}$$

$$W_{MSSM} = \text{Yukawa} + \mu H_U H_D$$

$$W_{NEUTRINO} = MNN + NLH_U$$

Phenomenology by sneutrino and flat direction fields:

a) Inflation
b) Gravitino/moduli problem
c) Baryo/leptogenesis
d) Dynamical resolution to μ problem

Example I
Early universe phenomenology by scalar fields

$$W = W_{MSSM} + W_{NEUTRINO}$$

$$W_{NEUTRINO} = MNN + NLH_U$$

SUGRA inflation thru an example

(K.K. and J. Yokoyama '06.
'D-term inflation and leptogenesis by right-handed sneutrino')

FAQ for inflation model building

- Who is inflaton?

  Right-handed sneutrino
- How do you keep flatness?

  D-term dominates
- How about baryon asymmetry?

  Non-thermal leptogenesis from inflaton sneutrino decay
  with low-enough reheating temperature

'economical': sneutrino already in Lagrangian. Inflation, leptogenesis

Sneutrino inflation

a) Chaotic inflation by right-handed sneutrino

- Murayama,Suzuki, Yanagida &Yokoyama ('93, '94), Ellis,Raidal&Yanagida ('04)
- ➢ Requires M~10^{13}GeV to match CMB data

  $\Rightarrow$high reheating temperature $\Rightarrow$ Gravitino problem
- Gherghetta &Kane ('95) Baryon asymmetry not from inflaton sneutrino.

b) F-term hybrid inflation by right-handed sneutrino

- S. Antusch, M. Baster-Gil, S. King and Q. Shafi ('05)
- ➢ Fine-tuning necessary to keep flatness for F-term dominated SUGRA inflation (η-problem)

c) D-term hybrid inflation by right-handed sneutrino

- K.K. and Yokoyama (hep-ph/0512221) (Lin&McDonald (hep-ph/0604245))
- ➢ M~10^{10}GeV $\Rightarrow$low reheating temperature is possible
- ➢ D-term dominated inflation $\Rightarrow$ free from η-problem

Model:

SUSY model with U(1) gauge group under which the chiral superfields $\phi_\pm$ have the charges ±1.

$$\boxed{W \supset \lambda N_i N_i \phi_+ \phi_- + \frac{1}{2} M_i N_i N_i + h_{i,\alpha} N_i L_\alpha H_u}$$

(We can justify the above form of superpotential by R-parity)

$\lambda N_i N_i \phi_+ \phi_-$:

Note standard D-term inflation has the form of $\lambda N_i \phi_+ \phi_-$.

D-term Inflation Dynamics

- Big amplitude of N $\Rightarrow$

  All the fields except N stay at the origin during inflation.
- D-term dominates during inflation

$$V_D = \frac{1}{2} g^2 (\xi - |\phi_-|^2 + |\phi_+|^2)^2$$

$$= \frac{1}{2} g^2 \xi^2 \text{ during inflation. } (\xi \text{ is Fayet - Illiopoulos term})$$

- ϕ_- has mass of $m_{\phi_-}{}^2 = \dfrac{\lambda^2 N_1{}^4}{4} + \dfrac{M_1{}^2 N_1{}^4}{16} - g^2\xi$

$\Rightarrow$ Hybrid inflation

•By-product: Leptogenesis from sneutrino decay

•Several parameter constraints:

a)Cosmic string formation from U(1) breaking water-fall field.

$$\sqrt{\xi} \le 4.8 \times 10^{15}\,\mathrm{GeV}$$

b)F-I term dominates over F-terms. Relatively small $\mathrm{M}_1 < 10^{12}\,GeV$

c)e.g. $\mathrm{For}\ g = 0.1,\ \sqrt{\xi} = 4.8 \times 10^{15}\mathrm{GeV},\ \mathrm{M}_1 \sim 10^{10}\mathrm{GeV}$, $n \sim 0.99$

d) The decay thru Yukawa coupling.

Gravitino constraints: T_1 $< 10^{6\sim7}$GeV

Small Yukawa coupling of order electron Yukawa coupling $h \sim 10^{-6}$.

Example II
Early universe phenomenology by scalar fields

$$\boxed{W = W_{MSSM} + W_{NEUTRINO}}$$

$$W_{MSSM} = \text{Yukawa} + \mu H_U H_D$$

$\mu = \phi^2$

Model

$$W = W_{MSSM} + W_{NEUTRINO} + W_{FLATON}$$

$$W_{MSSM} = \text{Yukawa} + \mu H_U H_D$$

$\mu = \phi^2$

$$W_{FLATON} = \phi^4$$

Thermal Inflation

(Lyth&Stewart ‘96, Yamamoto ‘86)

$$\boxed{V = V_0 + (T^2 - m^2)|\phi|^2 + (A\phi^4 + h.c.) + |\phi|^6}$$

• Inflation for $\boxed{m \leq T \leq V_0^{1/4}}$

$\boxed{N \sim 5-10,\ T_R \sim GeV}$ (high enough for BBN)

- Finite temperature effects in presence of SUSY flat direction solves Polonyi/Moduli problem.

Affleck-Dine Baryo/Leptogenesis

Cosmological moduli problem

Thermal inflation , H ~ 10^{-25}

$\Rightarrow$ Baryon asymmetry production at low energy scale

Standard A-D mechanism in SUGRA
(Dine, Randall, Thomas ‘95)

$$\boxed{V = (m_{3/2}{}^{2} - H^{2})|S|^{2} + ((Am_{3/2} + aH)S^{4} + h.c.) + |S|^{6}}$$

Very low energy scale "Affleck-Dine" Leptogenesis after thermal inflation

(E. Stewart, M. Kawasaki and T. Yanagida '96 ,
D. Jeong, K.K.,W. Park and E. Stewart '03)

$$W = \text{Yukawa} + \phi^2 H_u H_d + LH_u\, LH_u /M + \phi^4$$

1. Relevant fields trapped at the origin (thermally)
2. LH_u starts rolling first away from the origin [assume: $m_L^2 + m_{Hu}^2 < 0$]
3. Flaton ϕ starts rolling away

- F-term $|\phi^2 H_u|^2$ gives LH_u positive mass squared
- Phase of LH_u changes due to cross terms

Summary: Early universe phenomenology by scalar fields

$$W = W_{MSSM} + W_{NEUTRINO}$$

Scalar field phenomenology:

a) Inflation

e.g. RH sneutrino

b) Baryo/leptogenesis

e.g. Inflaton sneutrino, A-D mechanism

c) Gravitino/moduli problem

e.g. Moduli fields, Thermal inflation

d) Dynamical resolution to μ problem

e.g. VEV of flat direction