“Early universe phenomenology by scalar fields”
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• ‘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?

\[ W = W_{\text{MSSM}} + W_{\text{NEUTRINO}} \]

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

\[ W_{\text{NEUTRINO}} = MNN + NLH_U \]

Phenomenology by sneutrino and flat direction fields:

a) Inflation
b) Gravitino/moduli problem
c) Baryo/leptogenesis
d) Dynamical resolution to \(\mu\) problem
Example I
Early universe phenomenology by scalar fields

\[ W = W_{\text{MSSM}} + W_{\text{NEUTRINO}} \]

\[ W_{\text{NEUTRINO}} = M_{\text{NN}} + N_{\text{LH}} U \]
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 $M \sim 10^{13}\text{GeV}$ to match CMB data
       ⇒ high reheating temperature ⇒ 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 ($\eta$-problem)

b) D-term hybrid inflation by right-handed sneutrino
     ➢ $M \sim 10^{10}\text{GeV} \Rightarrow$ low reheating temperature is possible
     ➢ D-term dominated inflation ⇒ free from $\eta$-problem
SUSY model with U(1) gauge group under which the chiral superfields $\phi_{\pm}$ have the charges $\pm 1$.

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

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

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

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

- \( \phi_- \) has mass of

\[ m_{\phi_-}^2 = \frac{\lambda^2 N_1^4}{4} + \frac{M_1^2 N_1^4}{16} - g^2 \xi \]

⇒ Hybrid inflation

- By-product: Leptogenesis from sneutrino decay
• Several parameter constraints:
  a) Cosmic string formation from U(1) breaking water-fall field.
    \[ \sqrt{\xi} \leq 4.8 \times 10^{15} \text{GeV} \]
  b) F-I term dominates over F-terms. Relatively small \( M_1 < 10^{12} \text{GeV} \)
  c) e.g. For \( g = 0.1 \), \( \sqrt{\xi} = 4.8 \times 10^{15} \text{GeV} \), \( M_1 \sim 10^{10} \text{GeV} \), \( n \sim 0.99 \)
  d) The decay thru Yukawa coupling.
    Gravitino constraints: \( T_1 < 10^{6-7} \text{GeV} \)
    Small Yukawa coupling of order electron Yukawa coupling \( h \sim 10^{-6} \).
Example II
Early universe phenomenology by scalar fields

\[ W = W_{\text{MSSM}} + W_{\text{NEUTRINO}} \]

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

\[ \mu = \phi^2 \]
\[ W = W_{\text{MSSM}} + W_{\text{NEUTRINO}} + W_{\text{FLATON}} \]

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

\[ W_{\text{FLATON}} = \phi^4 \]

\[ \mu = \phi^2 \]
Thermal Inflation

(Lyth&Stewart ‘96, Yamamoto ‘86)

\[ V = V_0 + (T^2 - m^2)|\phi|^2 + (A\phi^4 + h.c.) + |\phi|^6 \]

• Inflation for \[ m \leq T \leq V_0^{1/4} \]

\[ N \sim 5 - 10, \ T_R \sim GeV \] (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, $H \sim 10^{-25}$

$\Rightarrow$ Baryon asymmetry production at low energy scale

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

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

\[ W = \text{Yukawa} + \phi^2 H_u H_d + L H_u L H_u / M + \phi^4 \]

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

\[ W = W_{\text{MSSM}} + W_{\text{NEUTRINO}} \]

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 \( \mu \) problem
e.g. VEV of flat direction