Affleck-Dine Sneutrino Inflation

Jason L. Evans

[1] University of Minnesota, FTPI

JLE, Gherghetta, Peloso arXiv:1501.06560 [hep-ph]

Outline

Horizon and Flatness Problem

- Horizon problem

  Visible Universe is Homogenous and Isotropic

  CMB is homogenous on super horizon scales

- Flatness problem

  Universe is quite flat ($\Omega = 1$)
  $\Omega = 1$ is unstable fixed point

$$\Omega - 1 = -\frac{k}{(aH)^2} \sim -k \begin{cases} t^{2/3} & MD \\ t & RD \end{cases}$$

Inflation: Fixing Flatness and Horizon Problem

- Hubble radius shrinks during inflation

$$\frac{d}{dt}\left(\frac{1}{Ha}\right) = \frac{1}{H}\frac{d}{dt}\left(\frac{1}{a}\right) < 0$$

- Comoving horizon τ (i.e. conformal time)

$$\tau = \int_0^a d\ln a \left(\frac{1}{Ha}\right)$$

- Dominant Contribution to τ from early times
- Shrinking $(Ha)^{-1}$ also fixes flatness
  $\Omega = 1$ becomes attractor

$$\Omega - 1 = -\frac{k}{(aH)^2}$$

Quadratic chaotic inflation

- Quadratic chaotic inflation

$$V = \frac{1}{2} m^2 \phi^2$$

- Slow roll parameters ($\phi(t_I) \simeq 2\sqrt{N} M_P$)

$$\epsilon = \frac{M_P^2}{2} \left(\frac{V_{,\phi}}{V} \right)^2 = \frac{1}{2N} \qquad \eta = M_P^2 \frac{V_{,\phi\phi}}{V} = \frac{1}{2N}$$

- Power spectrum and spectral index ($m \sim 10^{13}$ GeV)

$$P_s = \frac{V^{1/2}}{2\sqrt{6}\pi\sqrt{\epsilon} M_P} \simeq \boxed{\frac{mN}{\sqrt{6}\pi}} \qquad n_s - 1 = 2\eta - 6\epsilon \simeq \boxed{-\frac{2}{N}}$$

$$r = 16\epsilon \simeq \boxed{\frac{8}{N}}$$

Large Field Inflation: SUGRA

- SUGRA specifies form of interactions

$$\mathcal{L} = K_i^{j^*} g^{\mu\nu} \partial_\mu \phi^i \partial_\nu \phi_j^* - V \qquad K_i^{j^*} = \frac{\partial^2 K}{\partial \phi^i \partial \phi_j^*}$$

$$V = e^{\frac{K}{M_P^2}} \left[\left(K^{-1}\right)_j^i \left(W^{*j} + \frac{K^j}{M_P^2} W^*\right)\left(W_i + \frac{K_i}{M_P^2} W\right) - 3\frac{|W|^2}{M_P^2}\right]$$

- Canonical Kähler potential

$$K = \phi^* \phi \qquad \rightarrow \qquad \mathcal{L} = g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi^* - V$$

- Potential exponentially steep for $\langle \phi \rangle > M_P$

$$V = e^{\frac{|\phi|^2}{M_P^2}} [\ldots]$$

- Majorana superfield create UBF ($W = m\phi^2$)

$$V = e^{\frac{K}{M_P}} \left[\ldots - 3 \frac{m^2}{M_P^2} |\phi^4| \right]$$

SUGRA Inflation: Shift-Symmetry

- Canonical shift symmetric Kähler

$$K = \frac{1}{2}\left|\phi + \phi^\dagger\right|^2 \qquad \rightarrow \qquad \mathcal{L} = g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi^* - V$$

- Exponentially steepening gone for ϕ_I

$$V = e^{\frac{K}{M_P^2}}[....] = e^{\frac{\phi_R^2}{M_P^2}}[....]$$

- Stabilizer field prevents UFB ($W = m\phi\chi$)

$$V \simeq e^{\frac{K}{M_P^2}}\left[... - 3\frac{m^2}{M_P^2}|\phi\chi|^2\right]$$

- Inflation possible along $\chi, \phi_R = 0$ and $\phi_I \neq 0$ flat direction

$$V \simeq \frac{m^2}{2}\phi_I^2$$

Sneutrino Chaotic Inflation

- Seesaw mechanism, $M_N \sim 10^{13}\mathrm{GeV} \gg M_D$

$$W = Y_N HLN + N^T M_N N \qquad \to \qquad W = \frac{HLY_N Y_N^T HL}{M_N}$$

- Shift symmetry and stabilizer field

$$K = \frac{1}{2}\left|N_3 + N_3^\dagger\right|^2 + |N_1|^2 + |N_2|^2 \qquad M_N = \begin{pmatrix} 0 & M & 0 \\ M & 0 & 0 \\ 0 & 0 & m \end{pmatrix}$$

Murayama, Suzuki, Yanagida, Yokoyama

- Inflation along flat direction $N_1 = N_2 = 0$ and $\mathrm{Re}(N_3) = 0$

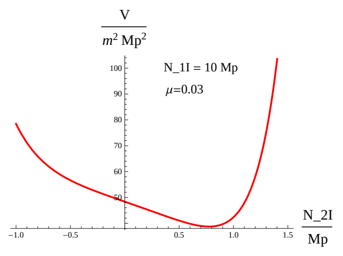
$$V \simeq \frac{M^2}{2}\mathrm{Im}(N_3)^2$$

More Natural Sneutrino Chaotic Inflation

- Generic Majorana mass matrix more natural ($W \supset M_{ij} N_i N_j$)
- Simplified two field sneutrino chaotic inflation

$$W = m \left(N_1 N_2 + \frac{\mu}{2} N_1^2 \right) \qquad K = \frac{1}{2} \left| N_1 + N_1^\dagger \right| + |N_2|^2$$

- For $\mu \neq 0$, $N_{2_I} \neq 0 \rightarrow$ two field inflation



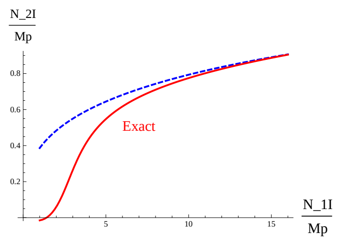
$$V = \frac{m^2}{2} N_{1_I}^2 e^{\frac{N_{2_R}}{M_P^2}} \left[1 + \mu^2 - \frac{3}{8} \frac{\mu^2}{M_P^2} N_{1_I}^2 \right.$$

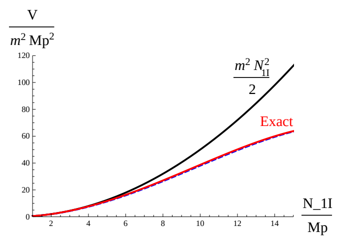
$$\left. - \mu \left(1 - \frac{2 M_P^2}{N_{1_I}^2} \right) \frac{N_{1_I} N_{2_I}}{M_P^2} + \dots \right]$$

Single Field Approximation

- N_{2_I} can be integrated out

$$N_{2_I} = \left(2\mu N_{1_I} M_P^2\right)^{1/3} - \frac{1}{6}\mu N_{1_I}$$





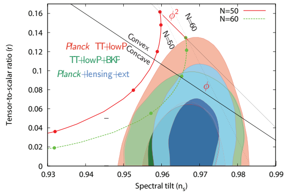
- Effective potential flatter

$$V = \frac{1}{2} m^2 N_{1_I}^2 \left[1 - \frac{3}{2^{5/3}} \left(\frac{\mu N_{1_I}}{M_P}\right)^{4/3} - \frac{13}{24} \left(\frac{\mu N_{1_I}}{M_P}\right)^2\right]$$

r and n_s for Generic Sneutrino Inflation

- Flatness of potential μ dependent

$$V = \frac{1}{2} m^2 N_{1_I}^2 \left[1 - \frac{3}{2^{5/3}} \left(\frac{\mu N_{1_I}}{M_P} \right)^{4/3} - \frac{13}{24} \left(\frac{\mu N_{1_I}}{M_P} \right)^2 \right]$$



- $\mu = [0, 0.01, 0.02, 0.03, 0.04]$
- $m \simeq 1.5 \times 10^{13}$
- 3 Neutrinos $\rightarrow$ flatter potential?

Affleck-Dine Baryogenesis

- Shift symmetry forbids rephasing of N_1

$$K = \frac{1}{2}\left(N_1 + N_1^\dagger\right)^2 + \ldots$$

- Rephasing $N_2 \rightarrow$ overall phase of W

$$W = m\left(N_1 N_2 + \frac{|\mu| e^{-i\phi}}{2} N_1^2\right)$$

$$N_2 \rightarrow N_2 e^{-i\phi}$$

- V independent of phase of W

$$V = e^{\frac{K}{M_P^2}}\left[\left(K^{-1}\right)_j^i \left(W^{*j} + \frac{K^j}{M_P^2} W^*\right)\left(W_i + \frac{K_i}{M_P^2} W\right) - 3\frac{|W|^2}{M_P^2}\right]$$

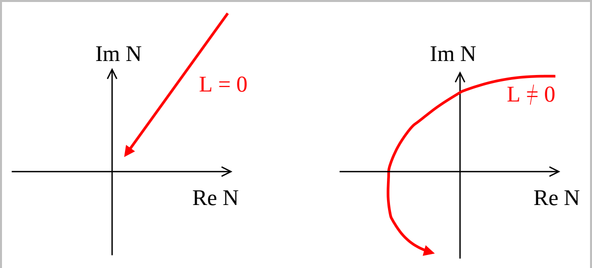
- Gravitino mass prevent removal of phase

$$W = m_{3/2} M_P^2 + m e^{-i\phi}\left(N_1 N_2 + \frac{|\mu|}{2} N_1^2\right)$$

Affleck-Dine Baryogenesis: Continued

- Lepton number ⇔ angular momentum
- The evolution of snuetrino fields can carry lepton number

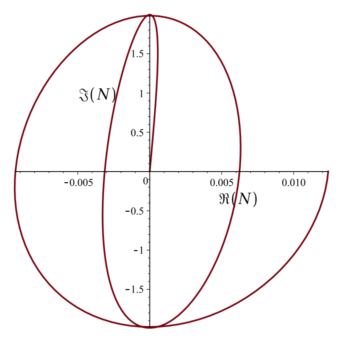
$$n_L = J_L^0 = i\left[N_i^* \frac{dN_i}{dt} - N_i \frac{dN_i^*}{dt}\right] = [N_{i_R}, N_{i_I}, 0] \times \frac{d}{dt}[N_{i_R}, N_{i_I}, 0]$$



- Converted to lepton asymmetry by decays to SM fields

Affleck-Dine From CP Violating Mass

- Eventually, mass term dominates vev evolution
- $M_{N_{1_I}} \neq M_{N_{1_R}} \rightarrow$ different evolution for N_{i_I} and N_{i_R}

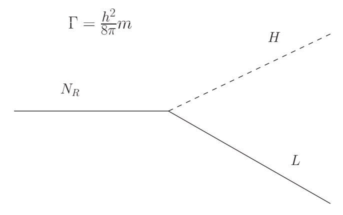


- Lepton asymmetry oscillates
- Frequency of osc. $\Delta m \propto \mu$
- $\Gamma_N \gg$ osc. frequency
- Prompt decay suppresses n_L

$$n_L \simeq \frac{\mu_I}{4\mu_R^{2/3}} \frac{m_{3/2}}{m} \sqrt{\frac{M_P}{\Gamma}}$$

- $n_B \simeq n_L$ due to sphaleron

Reheating and Gravitino Problem



- $Y_{N_R} \sim 0.1$ set by inflaton mass
- High Reheat temp., $H \sim \Gamma$

$$T_R \simeq 4 \times 10^{13}\mathrm{GeV}\frac{h}{0.1}\sqrt{\frac{m}{10^{13}\mathrm{GeV}}}$$

- Thermal bath overproduces gravitinos

$$Y_{3/2} = 2.3 \times 10^{-9}\left(\frac{T_R}{10^{13}\mathrm{GeV}}\right)$$

- Gravitino decay to LSP overclose universe

$$\omega_{LSP}h^2 = 64\left(\frac{T_R}{10^{13}\mathrm{GeV}}\right)\left(\frac{m_{\tilde{\chi}_1^0}}{100\mathrm{GeV}}\right)$$

Preventing Overclosure

- Really light DM can fix problem.

$$\omega_{LSP} h^2 = 6.4 \times 10^{-2} \left(\frac{T_R}{10^{13}\mathrm{GeV}} \right) \left(\frac{m_{\tilde{\chi}_1^0}}{100\mathrm{MeV}} \right)$$

- *R*- parity violation makes LSP unstable

$$W = \lambda_{ijk} \bar{U}\bar{U}\bar{D} + \lambda'_{ijk} L \cdot L\bar{E} \ldots$$

- Gravitino decays before LSP freezeout

$$m_{3/2} \gtrsim 10^7 \ \mathrm{GeV} \left(\frac{m_{LSP}}{100 \ \mathrm{GeV}} \right)^{2/3}$$

Conclusions

- Seesaw sneutrino scale similar to inflation scale
- Quadratic chaotic inflation is basically ruled out
- Multifield sneutrino chaotic inflation reduces r
- Baryon asymmetry can be generated from AD mechanism
- Reheat problem unavoidable, but ...