Seesaw and NMSO(10)GUT Inflation

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Idea of Inflation

- Initial conditions problems :Horizon problem, Flatness problem, monopole problem.
- The temperature variation in Cosmic Microwave Background Radiation (CMB) measured by Wilkinson Microwave Anisotropy Probe (WMAP) bears evidence of small density fluctuations in the early universe.
- The Universe at present is the result of Large Scale Structure formed from these fluctuations which grew via gravitational instability.
- Primordial inflation can be the simplest dynamics which can explain the origin of these fluctuations.

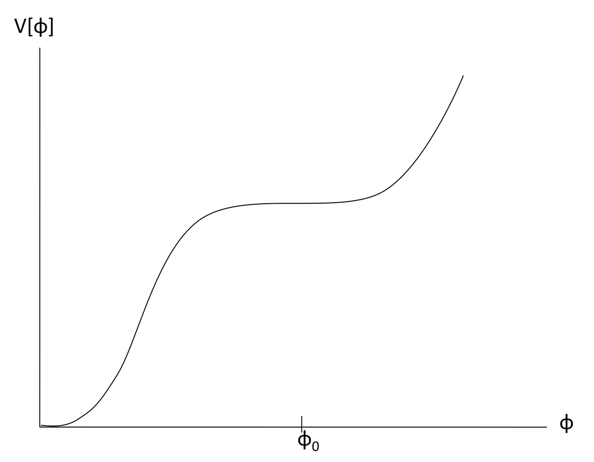
Constraints on a inflationary model

- Inflation Data: Power spectrum of curvature (density, scalar) perturbations : $P_R = (2.1977 \pm 0.103) \times 10^{-9}$, spectral index $n_s = .958 \pm 0.008$ and scale invariance $kdn_s/dk \simeq 0$. These are the values at a representative "pivot" scale $k_{pivot} \sim (500Mpc)^{-1}$.
- Standard thermal history : Inflation, Reheating, radiation domination, matter domination, present $\Lambda_{CDM} \rightarrow$ Number of efolds remaining when representative scale $k_{pivot} < aH$(comoving Horizon): $N_{pivot} \sim 50 \pm 5$.
- Many inflation models manage to fulfil these constraints, But a connection of the inflaton field(s) with known Particle physics is a natural desire to have a reheating into the SM degrees of freedom required for the success of Big Bang Nucleosynthesis.

Generic Renormalizable Inflection point inflation

- A generic renormalizable inflection point inflation model can be formulated in terms of a single complex field φ. This can be extremized w.r.t. angular d.o.f. and have a form:

$$V = \frac{h^2}{12}\phi^4 - \frac{Ah}{6\sqrt{3}}\phi^3 + \frac{M^2}{2}\phi^2$$



The inflection point is

$$\phi_0 = \frac{\sqrt{3}M}{h}(1 - \Delta + O(\Delta^2)) : \quad V''(\phi_0) = 0$$

- The slow roll inflection point inflation demands a strong fine tuning condition on potential parameters as: A = 4M(1-Δ) Where Δ(fine tuning parameter) ≈ 0.
- In [1] we showed that an accurate analytic solution for potential parameters M, h and Δ around $n_s^0 = 0.967, N_C^0 = 50.006$ gives

$$h^2 \sim 10^{-24.95\pm0.17}(\frac{M}{GeV}) \quad ; \quad \Delta \sim 10^{-28.17\pm.13}(\frac{M}{GeV})^2$$

Supersymmetric Seesaw Inflaton Toy model

- $SIMSSM \times U(1)_{B-L} \oplus S[1,1,1,-2] \oplus \{\Theta_i\}$
- $< S >= \bar{\sigma}/\sqrt{2} \Rightarrow M_{\nu^c}$ ($10^6 - 10^{12}$ GeV) via $W = 3\sqrt{2}f_{AB}S\nu_A^c\nu_B^c + ...$
- Additional fields Θ_i fix the vev of S in MSLRMs and MSGUTs
- Neutrino Dirac Coupling: $L_A[1,2,0,-1] = (\nu, e)_A^T$ and Higgs $H[1,2,1/2,0] : W = y_{AB}^{\nu}N_A L_B H + ...$
- NLH Flat direction Inflaton ϕ rolls out of minimum corresponding to

$$SU(3) \times SU(2) \times U(1)_R \times U(1)_{B-L} \rightarrow SIMSSM$$
$$\tilde{N} = \tilde{\nu} = h_0 = \frac{\varphi}{\sqrt{3}} = \phi e^{i\theta}; \quad \phi \geq 0, \quad \theta \in [0, 2\pi)$$

- From Seesaw model GRIPI potential follows :

$$V_{tot} = f^2\left((2 + 9\tilde{y}^2)\phi^4 - (\tilde{A}_0 + 12)\tilde{y}\bar{\sigma}\phi^3 + (\tilde{A}_0 + \tilde{m}_0^2 + 4)\bar{\sigma}^2\phi^2\right)$$

- Seesaw models $m_\nu^D > 1MeV$, $M_{\nu^c} > 10^6$ GeV $>> M_S \sim 10$ TeV. $\tilde{A}_0, \tilde{m}_0 \sim O(M_S/M_{\nu^c}) << 1$, So play no role in fine tuning.
- For $M_{\nu^c} \simeq 10^6 - 10^{12} \Rightarrow \tilde{y} = y/f \simeq 4/3$: For $M_{\nu^c} \sim 10^6$ GeV, $\tilde{y}$ differs from 1.333 only at the second decimal place, so $\tilde{y}^2$ can be approximated as:

$$\tilde{y}_0^2 = \frac{64}{9}\frac{4 + \tilde{A}_0 + \tilde{m}_0^2}{16 - 8\tilde{A}_0 - 32\tilde{m}_0^2 + \tilde{A}_0{}^2}$$

Merits of Susy Seesaw inflation scenario

- In [2] Dirac Neutrino-Inflation connection is studied. The D-flat direction, NLH in the νMSSM$\times U(1)_{B-L}$ connects tiny y_ν required for Dirac m_ν to inflation.
- Dirac mass case: a high degree of fine tuning between A and M ($\Delta \simeq 10^{-24} - 10^{-20}$).
- $A, M \sim M_S$(Susy breaking scale) receive dominant contributions from soft Susy breaking terms so radiatively unstable.
- A very small neutrino Yukawa $\simeq 10^{-12}$.
- In our case the inflation scale is determined by heavy right handed neutrino mass $\simeq 10^6 - 10^{12}GeV$, So the fine tuning parameter $\Delta \simeq 10^{-16} - 10^{-4}$.
- Seesaw makes small majorana neutrino mass natural instead of lowered by fine tuning yukawa coupling to 10^{-12} to lower Dirac mass.
- The Susy breaking terms $<< M_{\nu^c}$, so have no role to play in fine tuning.
- Fine tuning condition is determined in terms of superpotential parameters of neutrino mass, so radiatively stable.

NMSO(10)GUT Inflation

- Spinor Representation of SO(10) GUT contains right handed neutrino and explains the neutrino mass via Type-I Seesaw so natural home for SSI.
- The superpotential which determines the inflation parameters is given as

$$W = 2\sqrt{2}(h_{AB}h_1 - 2\sqrt{3}f_{AB}h_2 - g_{AB}(h_5 + i\sqrt{3}h_6))\bar{\nu}_A L_B + \bar{h}^T\mathcal{H}(<\Omega>)h$$
$$+4\sqrt{2}f_{AB}\bar{\sigma}\bar{\nu}_A\bar{\nu}_B + W_\Omega(\Omega)$$

- The ansatz for flat direction is

$$\tilde{\nu}_1 = \frac{\phi}{\sqrt{3 - 2|\alpha_4|^2}} \qquad H_1^0 = \frac{\phi}{\sqrt{3 - 2|\alpha_4|^2}} \qquad \tilde{\bar{\nu}}_3 = \frac{\phi\sqrt{1 - 2|\alpha_4|^2}}{\sqrt{3 - 2|\alpha_4|^2}}$$

- The mass of inflaton $\sim M_{\nu_3^c} \sim 10^{12}GeV$, $h^2 \sim 10^{-13}$ and fine tuning parameter $\Delta \sim 10^{-4}$.

$$V_0 \approx \frac{M^4}{h^2} \sim M^3 \times 10^{25} \sim 10^{61}GeV^4$$

BICEP2 results: Twist in the Tale

- B-mode polarization in CMB ⇒ presence of primordial gravitational waves and direct evidence of inflation.
- The large value of tensor to scalar fluctuations parameter $r = .2^{+.07}_{-.05}$.
- The whole scenario of IFI models has changed.
- From Lyth bound we have

$$V_0^{\frac{1}{4}} = \left(\frac{r}{.1}\right) \times 2 \times 10^{16}GeV$$

- With such a large value of r this condition can be satisfied with inflaton mass $\simeq 10^{13.5-13.7}$.
- The right handed neutrino mass in NMSGUT is not able to account for such large value of r.

Solution for problem in SO(10) NMSGUT inflation

- In NMSO(10)GUT we have 6 × 6 Higgs mass matrix. The fine tuning condition Det M_H=0 gives the light MSSM Higgs and rest 5 are heavy O(10^{16} GeV).
- Since Higgs is part of inflaton condensate any Higgs out of 6 can contribute.
- Our new ansatz for inflaton is

$$\tilde{\nu}_A = \eta_A\phi \qquad H_i^0 = \zeta_i\phi \qquad \tilde{\bar{\nu}}_A = \rho_A\phi$$

- For $|\eta_1| = |\rho_1| = |\zeta_1| \sim 1$ and $|\eta_{2,3}|, |\eta_{2,3}|, |\zeta_{2-6}| \sim O(\epsilon)$ where $\epsilon = 10^{-2}$ we can have

$$M = 10^{13.5-13.7}GeV; , \quad h^2 = 10^{-11.5}$$

- For such a large values of inflaton mass the trilinear term comes out to be very small.
- We don't need the fine tuning of potential parameters to achieve the slow roll conditions.
- The quartic coupling h $\sim 10^{-5.7}$ is larger than old case of NMSO(10)GUT inflation case so easily achievable.
- $\omega = \frac{\phi_0}{M_{pl}} \approx 10$ is required to have sufficient efolds (same as Lyth bound).

Connection of Baryon stability with Inflation in NMSO(10)GUT

- In [3] we showed that matter Yukawa couplings of NMSO(10)GUT are subject to significant GUT scale threshold corrections.
- Threshold corrections lower the required SO(10) Yukawas so much that $\Gamma_{d=5}^{\Delta B \neq 0}$ is suppressed to less than 10^{-34} yrs!
- The same lowered Yukawa will also determine the quartic coupling $h \sim 10^{-5.7}$.

Summary

- The latest BICEP results make it possible to realize Inflation Within NMSO(10)GUT which seemed to be difficult earlier.
- We are searching for a complete solution of NMSO(10)GUT parameters which satisfy the inflation conditions along with full SM fermion fitting.
- Till now we are able to achieve a fit with $\chi^2 \sim 5 - 6$ and compatible with BICEP latest results.

References

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2. Allahverdi,Kusenko and Mazumdar, JCAP **07** (2007), 018
3. C. S. Aulakh, I. Garg and C. K. Khosa, Nucl. Phys. B **882**, 397 (2014) [arXiv:hep-ph/1311.6100].