MSSM Inflation

Rouzbeh Allahverdi
Perimeter Institute

IPMLHP 06

hep-ph/0605035

Collaboration with:

Juan Garcia-Bellido (Madrid),
Kari Enqvist (Helsinki),
Anupam Mazumdar (NORDITA)

Outline:

- Inflation
- MSSM flat directions
- MSSM Inflation
- Predictions of the model.
- Summary and future directions.

Inflation:

To solve the flatness, isotropy and relic problems:

$a \propto \exp(Ht)$; $H = \text{const.}$

Basic predictions:

$\Omega \simeq 1$, almost scale invariant perturbations $\rightarrow$ confirmed by CMB experiments (WMAP3 most recently).

Scalar field ϕ (inflaton), potential $V(\phi)$:

Slow-roll parameters: $\varepsilon = \frac{1}{2} M_P^2 \left(\frac{V'}{V}\right)^2$

$$\eta = M_P^2 \left(\frac{V''}{V}\right)$$

$$\varepsilon, \eta \ll 1 \Rightarrow \frac{1}{2}\dot{\phi}^2 \ll V(\phi) \Rightarrow P = -\rho \Rightarrow a \propto \exp(Ht)$$

$$H^2 = \frac{V}{3M_P^2}$$

Categorizing models of inflation:

Large field, small field, hybrid.

Embedding inflation in particle physics $\rightarrow$ many attempts, no realistic implementation.

Examples: hybrid inflation in $SU(5)$, $SO(10)$, sneutrino inflation, ...

Major difficulties: singlet fields, super-planckian VEV.

MSSM Flat Directions:

MSSM flat directions: $V=0$ in the limit of unbroken supersymmetry.

Classified by gauge-invariant monomials:

$$H_u L \rightarrow \quad H_u = \begin{bmatrix} v \\ 0 \end{bmatrix} \; ; \; L = \begin{bmatrix} 0 \\ v \end{bmatrix}$$

$$\phi = \frac{1}{\sqrt{2}} (H_u^1 + L^2) \rightarrow V(\phi) = 0$$

Nearly 300 flat directions in MSSM, linear combinations of slepton, squark and Higgs fields.

Flat directions lifted by:

soft supersymmetry breaking, higher-order terms in superpotential and/or kähler potential.

$$W \sim \frac{\lambda_n}{n} \frac{\Phi^n}{M_p^{n-3}} \qquad (n>3)$$

$$V = \frac{1}{2} \underbrace{m_0^2}_{\text{soft mass}} \phi^2 + \underbrace{\frac{A\lambda_n}{M_p^{n-3}}}_{\text{A-term}} \phi^n \cos(n\theta + \theta_A) + \frac{\lambda_n^2 \phi^{2(n-1)}}{M_p^{2(n-3)}}$$

Weak scale supersymmetry: $m_0, A \sim O(\text{TeV})$

If:

$$n^2 A^2 \geq 8(n-1)(2n-3)\, m_0^2$$

There are n minima at:

$$\phi_0 \sim (m_0 M_p^{n-3})^{\frac{1}{n-2}} \quad ; \quad n\theta + \theta_A = (2k+1)\pi$$

MSSM Inflation:

If ϕ is stuck at a secondary minimum, it will lead to inflation.

But no graceful exit, just as old inflation.

However, if:

$$n^2 A^2 = 8(n-1)(2n-3)\, m_0^2$$

the barrier will disappear → a saddle point appears.

$$V'(\phi_0) = V''(\phi_0) = 0 \quad ; \quad V'''(\phi_0) \sim \frac{m_0^2}{\phi_0}$$

$$V \sim m_0^2 \phi_0^2 + \frac{m_0^2}{\phi_0} (\phi - \phi_0)^3$$

$\varepsilon, \eta \ll 1 \Rightarrow$ (ultra) slow-roll inflation

- $\phi_0 - \phi_1 \sim \left(\frac{m_0 \phi_0^4}{M_P^3}\right)^{\frac{1}{2}}$: quantum jumps dominate → eternal inflation.
- $\phi_2 - \phi_1 \sim \frac{\phi_0^3}{M_P^2}$: classical slow roll dominates → relevant for observation

Model Predictions:

$$H_{inf} \sim \frac{m_0 \phi_0}{M_P}$$

$$N_e = \frac{1}{M_P^2} \int_{\phi_1}^{\phi_2} \frac{V}{V'}\, d\phi \sim \frac{\phi_0}{(m_0 M_P)^{1/2}}$$

$$\left(\frac{\delta\rho}{\rho}\right)_k = \left(\frac{H^2}{\dot\phi}\right)_{k=H_{inf}} \sim \frac{m_0 M_P}{\phi_0^2} N_{COBE}^2$$

$$n_s = 1 + 2\eta - 6\epsilon = 1 - \frac{4}{N_{COBE}}$$

For $m_0 \sim 1$ TeV, $\phi_0 \sim 10^{15}$ GeV (flat direction lifted by $n=6$ operators):

$H_{inf} \sim 1$ GeV ; $N_e \sim 10^3$; $N_{COBE} \sim 46$;

$\frac{\delta\rho}{\rho} \sim 10^{-5}$; $n_s \sim 0.92 \rightarrow$ well within 2σ of WMAP3+ SDSS

Running of n_s negligible, but close to the upper bound from CMB+LSS data.

$H_{inf} \sim 1$ GeV :

- Negligibe gravity waves.
- No supergravity η-problem.
- No moduli problem.

The inflaton candidate:

udd, LLe flat directions (lifted at $n=6$ level).

Flat directions lifted at $n<6$ or $n>6$ don't work.

Summary:

- Explicit model of inflation within MSSM: no singlets, subplanckian VEV. Closest realization to particle physics so far.
- Low scale of inflation, large number of e-foldings, negligible gravity waves.
- No η-problem, no moduli problem.
- Predictions for the spectral index and its running can be soon tested.
- udd, LLe flat directions as the inflaton → part of the inflaton potential can be tested at colliders.

Further Work (in progress):

Particle physics side:

- tuning issue (landscape picture?).
- running of the soft terms (relating m_0, A to gaugino masses).
- adding RH (s)neutrinos (extending the gauge group).

Cosmology side:

- inflaton decay and reheating.
- baryogenesis and dark matter production.
- initial condition for inflation.
- successful inflation in a secondary minimum (dynamical mechanism for transition to a saddle point).