# MSSM inflation

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# Outline

- Consider flat directions of the MSSM as inflaton candidates
- Known gauge couplings!
- Low inflationary scale, very flat potential required
- Constraints on the underlying supergravity model that determines the potential
- Try to find sugra models where the constraints are satisfied

# Flat directions

- Supersymmetric vacuum degenerate, potential vanishes along flat directions
- Flatness lifted by susy breaking and non-renormalizable terms in the potential

# MSSM inflation

- $d = 6$ flat directions **LLe** and **udd** candidates for the inflaton [1]
- After susy breaking the potential to lowest order becomes

$$V(\phi) = \frac{1}{2}m^2|\phi|^2 - \frac{A\lambda}{6}|\phi|^6 + \lambda^2|\phi|^{10}$$

- If $A^2 = 40m^2$ , saddle point at $|\phi_0| \sim (m/M_P)^{1/4}M_P$

$\Longrightarrow$ Inflation with:

$$\zeta \sim \left(\frac{m}{M_P}\right)^{1/2} N_*^2, \quad n_s \sim 1 - 4/N_*$$

- Low scale $H \sim 1\ \mathrm{GeV}$, $A^2 = 40m^2$ must hold very precisely

[1] [Allahverdi, Enqvist, Garcia-Bellido, Mazumdar]

# What fixes $A^2 = 40m^2$ ?

- Sugra: $V = e^G(G^M G_M - 3), \quad G = K + \ln|W|^2$
- Consider a model with [2]

$$
\begin{aligned}
W &= \hat{W} + \frac{\hat{\lambda}}{6}\phi^6 \\
K &= \hat{K}(h_m, h_m^*) + \hat{Z}_2(h_m, h_m^*)|\phi|^2 + \hat{Z}_4(h_m, h_m^*)|\phi|^4 + \dots
\end{aligned}
$$

- $V = e^G(G^M G_M - 3) = \frac{1}{2}m^2|\phi|^2 - \frac{A\lambda}{6}|\phi|^6 + \lambda^2|\phi|^{10} + \mathcal{O}(|\phi_0|^{12})$
- $A^2 = 40m^2$ reads $(K_m = \partial_{h_m}K, K^m = (K_{m\bar{n}})^{-1}K_{\bar{n}})$

$$
\begin{aligned}
&|\hat{K}^m\hat{K}_m - 6\hat{Z}_2^{-1}\hat{K}^{\bar{m}}\hat{Z}_{2\bar{m}} + 3|^2 \\
&= 20(\hat{K}^m\hat{K}_m + \hat{K}^m\hat{K}^{\bar{n}}(\hat{Z}_2^{-2}\hat{Z}_{2m}\hat{Z}_{2\bar{n}} - \hat{Z}_2^{-1}\hat{Z}_{2m\bar{n}}) - 2)
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[2] [K. Enqvist, L. Mether, SN],[SN]

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# Kähler potentials that yield $A^2 = 40m^2$

- Solved by:

$$K = \sum_m \beta_m \ln(h_m + h_m^*) + \kappa \prod_m (h_m + h_m^*)^{\alpha_m} |\phi|^2 + \ldots$$

$$\alpha(36\alpha + 16 - 12\beta) + (\beta + 7)^2 = 0 \ , \quad \alpha = \sum \alpha_m \ , \ \beta = \sum \beta_m$$

- Includes for example the values

| $\beta = \sum \beta_m$ | $\alpha = \sum \alpha_m$ |
|---|---|
| $-7$ | $0$ |
| $-7$ | $-\frac{25}{9}$ |
| $-11$ | $-\frac{1}{9}$ |
| $-11$ | $-4$ |

# Higher order corrections

- Saddle point can be removed by higher order corrections

$$V = \underbrace{\frac{1}{2}m^2|\phi|^2 - \frac{A\lambda}{6}|\phi|^6 + \lambda^2|\phi|^{10}}_{\text{Leading order part } \mathcal{O}(|\phi_0|^{10})} + \mathcal{O}(|\phi_0|)^{12}$$

- Corrections $|\phi_0|^{12}$ and $|\phi_0|^{14}$ crucial, $|\phi_0|^{16}$ affects the spectral index

# Kähler potentials for the MSSM inflation

- Potential flat enough close to $|\phi_0|$ if [3]

$$K = \hat{K} + \hat{Z}_2|\phi|^2 + \mu\hat{Z}_2^2|\phi|^4 + \nu\hat{Z}_2^3|\phi|^6 + \rho\hat{Z}_2^4|\phi|^8 + \dots$$

where $\hat{K} = \sum_m \beta_m \ln(h_m + h_m^*)$, $\hat{Z}_2 = \kappa\prod_m (h_m + h_m^*)^{\alpha_m}$ and

| $\beta = \sum \beta_m$ | $\alpha = \sum \alpha_m$ | $\gamma = \sum \alpha_m^2/\beta_m$ | $\delta = \sum \alpha_m^3/\beta_m^2$ |
|---|---|---|---|
| $-7$ | $0$ | $\frac{1}{4} - 3\mu$ | $\delta$ |
| $-7$ | $-\frac{25}{9}$ | $-\frac{46}{81} - \frac{22}{9}\mu$ | $-\frac{2414}{16767} - \frac{628}{1863}\mu - \frac{2804}{207}\mu^2 + \frac{162}{23}\nu$ |
| $-11$ | $-\frac{1}{9}$ | $\frac{28}{81} - \frac{26}{9}\mu$ | $\frac{6556}{69255} - \frac{3736}{7695}\mu - \frac{12596}{855}\mu^2 + \frac{162}{19}\nu$ |
| $-11$ | $-4$ | $-\frac{7}{8} - \frac{5}{2}\mu$ | $-\frac{339}{1600} - \frac{73}{200}\mu - \frac{1371}{100}\mu^2 + \frac{36}{5}\nu$ |

[3] [Enqvist, Mether, SN],[SN]

- An example of the solutions:

$$K = -\ln\Big(\prod_m (h_m + h_m^*)^{-\beta_m} - \kappa \prod_m (h_m + h_m^*)^{\alpha_m - \beta_m} |\phi|^2\Big)$$

with

$$\beta_m = -1,\ \alpha_1 = 1,\ \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = -\frac{1}{4},\ \alpha_6 = \alpha_7 = 0$$

# Conclusions

- MSSM inflation can be realized "naturally" in certain supergravity models
- Flat inflaton potential not accidental but a direct consequence of the supergravity model
- Requires a specific Kähler potential, to some extent motivated by various string theory compactifications
- Many open questions: initial conditions[4], dynamics of the moduli fields[5], loop corrections...

[4] [Allahverdi, Dutta, Mazumdar]
[5] [Lalak, Turzynski]