Large-Field Inflation and Super-Symmetry Breaking

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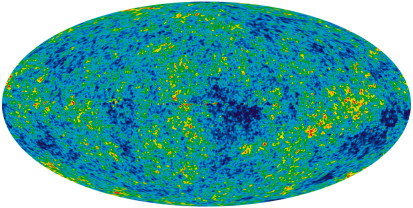
Outline

- Chaotic Inflation in Super Gravity
- Inflation and Supersymmetry Breaking
- Minimal SUSY breaking Set Up : Bound on the Gravitino Mass
- O'Rafeartaigh Attempt
- Moduli Stabilization ?

Introduction



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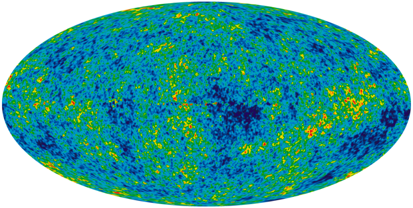

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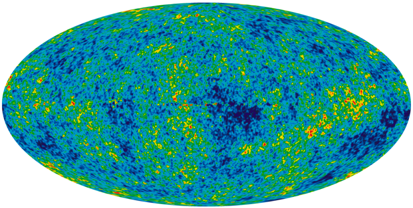

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- **Flatness Problem :** Need initial kinetic energy to cancel potential energy with very, very high fine tuning..

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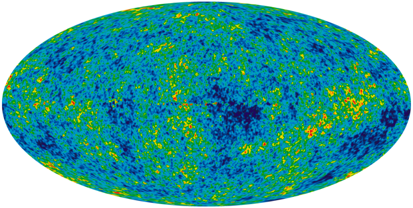


- **Horizon Problem :** Need $\delta\epsilon/\epsilon \sim 10^{-4}$ on 10^{84} initial patches !
- **Flatness Problem :** Need initial kinetic energy to cancel potential energy with very, very high fine tuning..
- **Inflation idea :** Source a period of acceleration for the universe expansion !

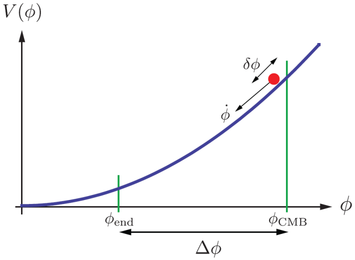
Introduction

$\ddot{a} = -\frac{4\pi}{3} G(\epsilon + 3p)$:

Ask that $\epsilon \sim -p$

One scalar field ϕ :

$$\epsilon = \frac{1}{2}\dot{\phi}^2 + V(\phi)$$
$$p = \frac{1}{2}\dot{\phi}^2 - V(\phi)$$



Chaotic Inflation : $V(\phi) = m^2\phi^2$

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$$

Lyth Bound : $\frac{\Delta\phi}{M_P} = \mathcal{O}(1) \times \left(\frac{r}{0.01}\right)^{1/2}$

$$r \sim 0.1 \Rightarrow \Delta\phi \sim 10 M_P$$

Standard set up

Idea : Provide a shift symmetry for ϕ in the Kähler :

i.e. Inv. under $\phi \to \phi + ic$

+

Simplest attempt : Add a stabilizer field S

Simplest attempt : $$W = mS\phi$$

$$K = \frac{1}{2}(\phi + \bar{\phi})^2 + |S|^2 - \xi|S|^4$$

- ξ : needed to stabilize S, arising through raditative corrections
- *Inflaton* : $\varphi \equiv \sqrt{2} \cdot Im(\phi)$

Integrating out S gives effectively : $V_{eff}(\varphi) \simeq m^2\varphi^2$

SUSY Breaking

Super-symmetry needs to be broken...

~~SUSY~~ sector		Inflation sector
Polonyi field	O'Raifeartaigh	Chaotic
$W \supset fX$	$W = fX + mS\phi + \frac{h}{2}S^2X$	$W = mS\phi$ + Shift sym.

Idea : Build explicit models $\longrightarrow$ ~~SUSY~~ + Inflation

+ Impose effective chaotic inflation

Inflaton + Polonyi field

$$\begin{cases} W &= mS\phi + fX + W_0 \\ K &= \frac{1}{2}(\phi + \bar{\phi})^2 + S\bar{S} + X\bar{X} - \xi_1 (X\bar{X})^2 - \xi_2 (S\bar{S})^2 \end{cases}$$

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- Only gravitational interactions

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- $\varphi \equiv \sqrt{2} \cdot Im(\phi)$ is the inflaton
- ξ_1 needed to stabilize X with high mass **in the ground state**
- ξ_2 needed to stabilize S with high mass **during inflation**
- $\chi \equiv \sqrt{2} \cdot Im(S)$ shifted during inflation, due to ~~SUSY~~

Inflaton + Polonyi field

SUGRA scalar potential :

$$V = e^K \left\{ |mS + (\phi + \bar{\phi})W|^2 + K^{-1}_{S\bar{S}}|m\phi + K_S W|^2 + K^{-1}_{X\bar{X}}|f + K_X W|^2 - 3|W|^2 \right\}$$

Fields stabilization :

- **End of Inflation**

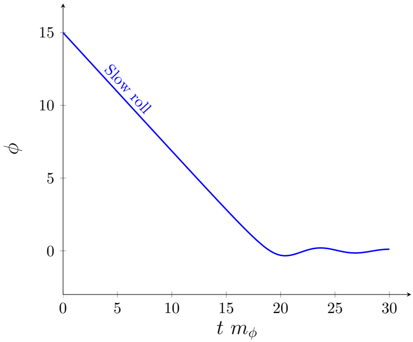
  $\langle\phi\rangle = \langle S\rangle = 0\,,\qquad \langle X\rangle \simeq \frac{1}{2\sqrt{3}\xi_1}$ and $m_{3/2} \simeq W_0 \simeq \frac{f}{\sqrt{3}}$

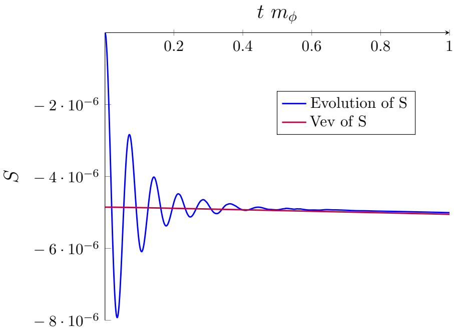
- **During Inflation**

  $\hookrightarrow$ φ can take high values, other vev's at 0, except :

$$\sqrt{2} \cdot Im(S) \equiv \chi \simeq -\frac{2mW_0\varphi}{f^2 - 2W_0^2 + m^2 + 2m^2\varphi^2\xi_2}$$

Inflaton + Polonyi field





$m = 6 \times 10^{-6}$, $f = 10^{-8}$, and $\xi_1 = \xi_2 = 10$

Bound on the gravitino mass

- Need to estimate ξ_1, ξ_2 :

  Heavy modes couplings $W_{\text{heavy}} \supset \lambda_1 S\psi_1^2 + \lambda_2 X\psi_2^2 + \text{mass terms}$

  $$K_{\text{1-loop}} \simeq S\bar{S}\left[1 - \frac{\lambda^2}{16\pi^2}\log\left(1 + \frac{\lambda^2 S\bar{S}}{M^2}\right)\right] \simeq S\bar{S} - \frac{\lambda^4}{16\pi^2 M^2}(S\bar{S})^2$$

  $$\lambda \sim \mathcal{O}(1) \text{ and } M \sim M_{GUT} \Rightarrow \xi_1, \xi_2 \sim \mathcal{O}(10) M_P^{-2}$$

Bound on the gravitino mass

Which dependance in f ?

$\hookrightarrow$ Integrate out heavy fields (Stabilizer & Polonyi) to their vevs

$$V_{eff}(\varphi) = f^2 - 3W_0^2 + \frac{1}{2}m^2\varphi^2\left(1 - \frac{4W_0^2}{f^2 - 2W_0^2 + m^2 + 2m^2\varphi^2\xi_2}\right)$$

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High values of f $\longrightarrow$ negativity of the potential !

Bound on the gravitino mass

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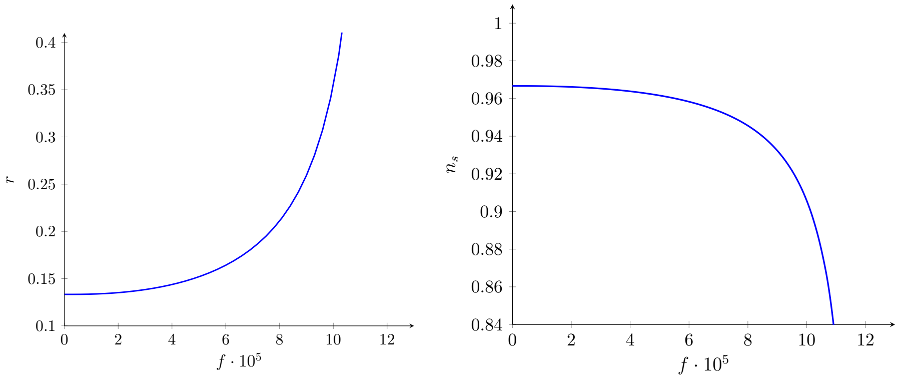
High values of $f \longrightarrow$ negativity of the potential !

- Case $f < m$: $W_0 \simeq \frac{f}{\sqrt{3}}$
- Case $f > m$: $W_0 \simeq \frac{f}{\sqrt{3}}$ + corrections

Anyway, problems expected at least for $m^2 \lesssim m_{3/2}^2 \lesssim \frac{2m^2}{3}\varphi^2\xi_2$

Bound on the gravitino mass

Observables



$$m = 6 \times 10^{-6} \text{ and } \xi_1 = \xi_2 = 10$$

$$m_{3/2} \lesssim H$$

Extended scenario

Can we circumvent the bound ?

$\rightarrow$ Possible extension :

$$\begin{cases} W &= mS\phi + MX\phi + fX + W_0 \\ K &= \frac{1}{2}(\phi+\bar{\phi})^2 + S\bar{S} + X\bar{X} - \xi_1 (X\bar{X})^2 \end{cases}$$

- Only one quartic coupling needed : field X automatically stabilized
- M assumed to be real $\rightarrow$ new parameter $\delta \equiv M/m$
- Inflaton mass : $V = \frac{1}{2}m^2\varphi^2 \longrightarrow V = \frac{1}{2}(m^2 + M^2)\varphi^2$

Extended scenario : gravitino bound

- Vevs are shifted slightly : fields can be integrated out
- gravitino mass becomes :

$$m_{3/2} \simeq W_0 \simeq \frac{m}{\sqrt{m^2 + M^2}} \frac{f}{\sqrt{3}}$$

- Effective Inflaton potential :

$$V(\varphi) = \frac{1}{2}(1+\delta^2)m^2\varphi^2 \left(1 - \frac{8f^2}{f^2(2+8\delta^2+6\delta^4) + 3m^2(1+\delta^2)^2(2+\delta^2\varphi^2)}\right) + f^2\left(1 - \frac{1}{1+\delta^2}\right),$$

$\hookrightarrow$ **Negative contribution for high values of f...**

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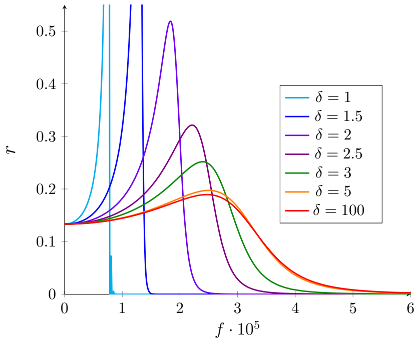

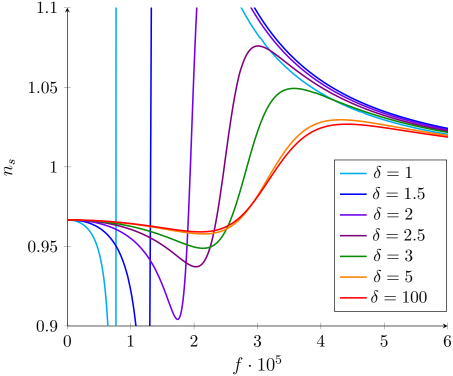

$m = 6 \times 10^{-6}$ and $\xi_1 = \xi_2 = 10$

Best case : $\delta \sim 4 \Rightarrow m_{3/2} \lesssim 8 \times 10^{12}$ GeV $\ll H$

(recall ξ_2 has been dropped...)

O'Raifeartaigh ?

Possible to combine inflation with an O'Raifeartaigh ~~SUSY~~ sector ?

$$W = X(f + \frac{1}{2}hS^2) + mS\phi + W_0$$

$$K = \frac{1}{2}(\phi + \bar{\phi})^2 + S\bar{S} + X\bar{X}$$

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Problem : large cross terms $V \supset m\varphi X\bar{S} + \text{c.c.}$

$\longrightarrow$ Tachyonic masses : $m^2_{\text{tach}} \sim -m\varphi \sim -H$

O'Raifeartaigh ?

Issues ?

- Add quartic terms for S and X with high ξ_1, ξ_2 coefficients

$$\xi_1, \xi_2 \gg \frac{1}{M_{GUT}^2}$$

$\longrightarrow$ not possible to achieve through loops... (string theory ?)

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- Completely decouple inflation from $\not{S}\not{U}\not{S}\not{Y}$ sector

$$W = W_{\mathrm{O'R}}(\chi_i) + mS\phi$$

O'Raifeartaigh ?

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- Completely decouple inflation from ~~SUSY~~ sector

$$W = W_{\mathrm{O'R}}(\chi_i) + mS\phi$$

- Use Non-linear supersymmetry with goldstino superfield

$$X = \frac{\psi_X \psi_X}{2F_X} + \sqrt{2}\theta\psi_X + \theta^2 F_X \quad , \qquad X^2 = 0$$

O'Raifeartaigh ?

With

$$K = \frac{1}{2}(\phi+\bar{\phi})^2 + S\bar{S} + X\bar{X} - \xi|S|^4$$

$$W = X\left(f + \frac{1}{2}hS^2\right) + mS\phi + W_0\,, \quad \text{and} \quad X^2 = 0$$

Integrating out heavy fields

$$V(\varphi) = f^2 - 3W_0^2 + \frac{1}{2}m^2\varphi^2\left(1 - \frac{4W_0^2}{f^2 - 2W_0^2 - hf + m^2 + 2\xi m^2\varphi^2}\right)$$

Constraint on the gravitino :

- If $|hf| > m^2 \Rightarrow m_{3/2} < m$
- If $|hf| < m^2 \Rightarrow m_{3/2} < H$

Moduli stabilization

No-scale structure

$$W = W_{\rm mod}(\rho) + W_{\rm inf}(\phi, X) \qquad (0.1)$$

$$W_{\rm inf}(\phi, X) = \frac{1}{2} m\phi^2 + fX + W_0$$

$$K = -3\log(\rho + \bar{\rho}) + \frac{1}{2}(\phi + \bar{\phi})^2 + X\bar{X} - \xi_1 (X\bar{X})^2$$

$$V = e^K \left\{ \frac{(\rho+\bar{\rho})^2}{3} |\partial_\rho W|^2 - (\rho+\bar{\rho})(\partial_\rho W \overline{W} + \overline{\partial_\rho W} W) + K^{\alpha\bar{\alpha}} D_\alpha W D_{\bar{\alpha}} \overline{W} \right\}$$

- Seems to cancel negative unbounded terms
- Actually unboundness from below still present after integrating out the modulus in its supersymmetric vacuum...

Conclusion

- Supersymmetry breaking very hard to achieve
- Simple models without field interactions are possible to handle
- Stringent bound on the gravitino mass in such cases :
  $m_{3/2} \lesssim H$
- Inflaton difficult to integrate in an O'Raifeartaigh set up
- Moduli stabilization does not cure undboundness from below problems..