Rescuing (very) low scale SUSY breaking in sgoldstino-less inflation models

Lucien Heurtier

Based on arXiv:1601.03397 and arXiv:1705.06788

In collaboration with R. Argurio, D. Coone, E. Dudas, A. Mariotti, C. Wieck, M. Winkler

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Goal

↪ How to describe consistently sgoldstinoless inflation?

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Goal

↪ How to describe consistently sgoldstinoless inflation?

↪ How to accomodate low scale SUSY breaking in such models?

↪ Can one make Inflation face phenomenology at low energies?

See Dries Coone's talk this afternoon!

Supergravity Set up

$$\text{Scalar potential}: \; V = e^K \left[D_\alpha W \overline{D^\alpha W} - 3|W|^2 \right],$$

- η-problem : Appropriate choice of the Kähler potential

  $\hookrightarrow$ Use of shift symmetry : $K = K(|\phi + \overline{\phi}|^2)$

- Negative term $-3|W|^2$ can render the potential unbounded from below

  $\hookrightarrow$ Use of stabilizers : $W = m\phi^2 \rightarrow W = mS\phi$

- Any ~~SUSY~~ sectors can back react on the inflation potential

  $\hookrightarrow$ Constraint on the SUSY breaking scale

SUSY breaking backreaction

Chaotic Inflation
+
~~SUSY~~ sector
(Polonyi, Moduli, O'Raifeartaigh,...)

Models with stabilizer
$W \supset mS\phi + \ldots$

$f \ll H$

Models without stabilizer
$W \supset m\phi^2 + \ldots$

$f \gg H$

[Buchmüller, Dudas, **L.H.**, Wieck '14]
[Buchmüller, Dudas, **L.H.**, Westphal, Wieck, Winkler '15]

- Plateau-Inflation : De-plateau-ization due to soft terms backreaction
- Natural Inflation unconstrained by SUSY breaking effects

[Dudas, Wieck '15]

Sgoldstino-less inflation

Nilpotent Inflation : How to be smart AND lazy?

- SUGRA inflation involves many scalar fields
- Stabilization of these is challenging
- SUSY breaking strongly constrained

$\hookrightarrow$ **Nilpotent Inflation : Eliminate one scalar + Relax constraints on SUSY breaking !**

Sgoldstino-less inflation

Ingredient? **Constrained superfield :** $S^2 = 0$

- Introduced to match linearly vs. non linearly realized SUSY and SUGRA [Roček '78],[Lindström, Roček '79]

- String theory set up's built with the use of $\overline{\text{D3}}$ branes exhibit such non linear SUSY [Kallosh, Wrase '14],[Bergshoeff, Dasgupta, Kallosh, Van Proeyen, Wrase '15],[Kallosh, Quevedo, Uranga '15]

- Nilpotency constraint reproduced effectively in the limit of infinite sgoldstino mass [Komargodski, Seiberg '09],[Kallosh, Karlsson, Murli '15]

However, the limit $m_{sg} \to \infty$ difficult to explicitely realize...

Sgoldstino-less Inflation

Strategy :

- Write a Lagrangian containing the goldstino superfield

$$\begin{aligned} K &= \mathcal{K}(\phi, S, X_i)\,, \\ W &= \mathcal{W}(\phi, S, X_i)\,, \end{aligned}$$

- Compute the scalar potential

$$V = e^K \left[D_\alpha W \overline{D^\alpha W} - 3|W|^2 \right] \quad \text{with} \quad \alpha = \phi, S, X_i\,.$$

- Use the constraint $S^2 = 0$ to obtain

$$V_{sg-less}(\varphi, x_i) = V(\varphi, s = 0, x_i)\,.$$

Sgoldstino-less Inflation

- [Ferrara, Kallosh, Linde '14]

$$K = -\frac{(\Phi - \bar{\Phi})^2}{2} + S\bar{S}\,, \quad W = Sf(\Phi) + uplifting\,, \quad S^2 = 0$$

- [Kallosh, Linde, Scalisi '15]

$$K = -\frac{(\Phi - \bar{\Phi})^2}{2} + S\bar{S}\,, \quad W = Sf(\Phi) + g(\phi)\,, \quad S^2 = 0$$

where $g(0) = m_{3/2}$ in the vacuum and $V(0) = f^2(0) - 3g^2(0)$ can be tuned as desired.

- [Dall'Agata, Zwirner '15]

$$K = -\frac{(\Phi - \bar{\Phi})^2}{2} + S\bar{S}\,, \quad W = f(\Phi)(1 + \sqrt{3}S)\,, \quad S^2 = 0$$

where $V(\Phi) = |f'(\Phi)|^2$ and $m_{3/2}^2 = |f(\Phi)|^2$

Nilpotency constraint: out of the blue?

Heavy sector + SUSY breaking sector

$$K = |S|^2 - \frac{c}{\Lambda^2}|S|^4 \,,$$
$$W = f\, S \,.$$

where

$$S = s + \sqrt{2}\theta\psi_s + \theta^2 F_s \,.$$

Limit $c \to \infty$: Integrate out the scalar s

$$\frac{\delta\mathcal{L}}{\delta s^*} = 0 \quad \Rightarrow \quad s = \frac{\psi_s\psi_s}{2F_s} \quad \Rightarrow \quad s^2 = 0 \quad \textbf{and} \quad S^2 = 0 \,.$$

Effective formulation

Towards a UV completion...

$$\boxed{\text{Heavy sector}} \longrightarrow \boxed{\text{Kähler corrections}} \longrightarrow \boxed{S^2=0}$$

$$W \supset \lambda S X^2 \qquad K \supset \frac{-\lambda^4}{16\pi^2}\frac{|S|^4}{m_X^2} \qquad ???$$

- Hypothesis (1) "Heavy sector" : $m_X \to \infty$
- Hypothesis (2) "S Nilpotent" : $m_X \to 0$ or $\lambda \to \infty$

Realistic set up : λ, m_X finite $\longrightarrow$ hypotheses in tension...

Dall'Agata & Zwirner model

$$K = \frac{1}{2}(\Phi + \overline{\Phi})^2 + |S|^2 \,,$$
$$W = f(\Phi)(1 + \sqrt{3}S) \,,$$

[Dall'Agata, Zwirner '14]

$S^2 = 0 \quad \Rightarrow \quad V(\phi) = |f'(\phi)|^2$ and $m^2_{3/2} \approx |f(\phi)|^2$

Chaotic : $f(\phi) = f_0 - \frac{m}{2}\phi^2,$

Starobinsky : $f(\phi) = f_0 - i\sqrt{V_0}\left(\phi + i\frac{\sqrt{3}}{2}e^{2i\phi/\sqrt{3}}\right).$

During Inflation :

$$\phi > 1 \;\Rightarrow\; m^2_{3/2} > V(\phi)$$

After Inflation :

$$\phi = 0 \;\Rightarrow\; m_{3/2} = f_0$$

Behind the magic

Decouple the sgoldstino manually :

$$K = \frac{1}{2}(\Phi + \overline{\Phi})^2 + |S|^2 - \frac{1}{\Lambda^2}|S|^4 \,,$$
$$W = f(\Phi)(1 + \delta S) \,,$$

- Heavy sector : New scale $\Lambda \gg H$
- Parameter δ tuned to cancel the cosmological constant

$V_0(\phi) = |f'(\phi)|^2 \rightarrow s = Re(S)$ dynamical with mass $m_s^2 = 12 \frac{m_{3/2}^2}{\Lambda^2}$

and $V = V_0 + m_{3/2}^2 \Lambda^2 + \sqrt{3}\left(2V_0 - 4m_{3/2}^2\right) s + m_s^2 s^2 \,.$

If $m_s \gg H$, s stabilized to $\langle s \rangle = \frac{2m_{3/2}^2 - V_0}{m_{3/2}^2} \frac{\Lambda^2}{4\sqrt{3}} \approx 0$, corrections under control and $V \approx V_0$... [Dudas, **L.H.**, Wieck, Winkler '16]

A UV complete models

Towards UV completion :

Inflation: **Susy breaking:** **Heavy sector:**

ϕ S $X\,,Y$

$$W = f(\Phi)(1+\delta S)+\lambda S X^2 + MXY\,,$$

$$K = \frac{1}{2}(\Phi+\overline{\Phi})^2 + |S|^2 + |X|^2 + |Y|^2\,.$$

Minkowski vacuum:

$$\delta = \sqrt{3}\left(1+\frac{2\pi^2 M^2}{\lambda^4}\right) + \mathcal{O}(M^4)\,.$$

Two UV complete models

- Scalar fields x, y and $Im(s)$ stabilized to the origin
- Mass of the sgoldstino $s = Re(S)$ given by loop corrections

$$\Delta K = -|S|^4/\Lambda^2 \qquad \text{with} \qquad \Lambda = \frac{2\sqrt{3}\pi}{\lambda^2} M$$

Nilpotent limit : $M \longrightarrow 0$

- However, tachyonic directions in the heavy sector arise in such a limit :

$$m^2_{Im(x)} \simeq M^2 - 2\sqrt{3}\lambda m_{3/2}$$

Successful inflation : $\Lambda \sim 0.1 M_p$

[Dudas, **L.H.**, Wieck, Winkler '16]

Recap

- Sgoldstinoless theories assume the sgoldstino to decouple during inflation
- Realising such a decoupling involves a heavy sector at an energy scale Λ
- Such scale is constrained to be high enough to ensure validity of the EFT and low enough to ensure the sgoldstino decoupling

$$m_s^2 \sim \frac{m_{3/2}^2}{\Lambda^2}$$

- Too low values of Λ lead to tachyonic directions and/or fatal correction to the inflaton potential...

What about low scale SUSY breaking?

- ⋆ **Sgoldstino-less models :** $m_{3/2}$ and m_s completely decoupled.
- ⋆ **UV complete models :** $m_s \sim m_{3/2}/\Lambda$ and $\Lambda \gtrsim 0.1$
- ⋆ **Requiring (very)low scale susy breaking:**

$$\text{Say}: \; m_{3/2} \approx \mathrm{keV} \Rightarrow m_s \lesssim 10\mathrm{keV}!!!$$

Idea : $\Lambda \longrightarrow \Lambda(\phi)$!

During Inflation : $\Lambda(\phi \sim M_p) \sim \mathcal{O}(0.1-1)$

After Inflation : $\Lambda(0) = \Lambda_0 \ll 0.1 \;\Rightarrow\; m_s \gg m_{3/2}$.

$$K = -\alpha\frac{3}{2}\log\left(\frac{(1-\phi\bar{\phi})^2}{(1+\phi^2)(1+\bar{\phi}^2)}\right)+S\bar{S}-\frac{(S\bar{S})^2}{\Lambda_{\rm eff}^2}\,, \qquad W = f(\phi)S+h(\phi)$$

where we take

$$\Lambda_{\rm eff}^2(\phi) = |\Lambda_0 + g\phi|^2$$

$$f(\phi) = f_0 - \frac{m_f}{M_p}\phi^2\,, \quad h(\phi) = h_0 - \frac{m_h}{M_p}\phi^2\,,$$

Minkowski vacuum :

$$h_0^2 \ \approx\ \frac{f_0^2}{3}\left(1-\frac{\Lambda_0^2}{3}+\mathcal{O}(\Lambda_0^4)\right)$$

Shift of s :

$$\langle s\rangle \ =\ \frac{(\varphi^2-2)^2 f'h' + 24\alpha fh}{6\sqrt{2}\alpha\left(-\frac{(\varphi^2-2)^2}{12\alpha}(f'^2+h'^2)+\frac{4f^2}{\Lambda_{\rm eff}^2}-2h^2\right)}$$

UV completion : Gauge Mediated SUSY Breaking

- Starting from previous UV example :

$$W = f(\phi)S + h(\phi) + \lambda SX^2 + (M+g\phi)XY$$

- In the context of GMSB, copies of charged messengers

$$W = f(\phi)S + h(\phi) + \lambda SX\tilde{X} + (M+g\phi)(X\tilde{Y} + Y\tilde{X}) + m_y Y\tilde{Y}$$

→ (slightly) Broken R-symmetry : restored SUSY vacua far from the origin

→ Additional couplings can lead to tachyonic directions in the X, Y sector

→ Consistency conditions $m_s, \langle s \rangle \ll \Lambda_{eff}$ lead to a bunch of constraints among which $m_h \ll m_f$.

A complete set up for :

⋆ Accomodating inflation in a realistic SUSY breaking scenario

[R. Argurio, D. Coone, L.H., A. Mariotti '17]

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A model in which inflation faces directly phenomenology !

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Conclusion

- SUSY breaking can be challenging to accommodate with inflationary scenarios
- Nilpotent set up seducing from many aspects but uses strong assumptions on the sgoldstino decoupling
- UV attempts to release such decoupling strongly constrained
- Simple set up don't allow very low supersymmetry breaking
- A way out : Make the heavy sector ϕ-dependant
- Extremely constrained : tachyons, EFT validity...
- Allow to build GMSB scenarios and confront constraints from both primordial cosmology and LHC datas...

Thanks for your attention

Back up

↪ **Integrate out the messengers :**

Loop corrections :

$$K_{1-\mathrm{loop}} = -\frac{N_m \lambda^4 (SS^\dagger)^2}{12(4\pi)^2 |M + g\Phi|^2} ,$$

and

$$\Lambda_{eff} = \Lambda_0 + g\Phi = \frac{2\sqrt{3}(4\pi)}{\sqrt{N_m}\lambda^2}(M + g\Phi)$$

Tachyons in the Inflationary sector :

$$m_h > \lambda_f \frac{f_0}{M}$$