~~On constrained superfields and inflation~~

Constrained Superfields in Dynamical Background

Takahiro Terada

ibS 기초과학연구원 Institute for Basic Science

TT, “Minimal Supergravity Inflation without Slow Gravitino”, PRD 103 (2021) 125022, arXiv:2104.05731 [hep-th]
S. Aoki and TT, “Constrained Superfields in Dynamical Background”, arXiv:2111.04511 [hep-th]

Dark World to Swampland 2021, The 6th IBS-IFT-MultiDark Workshop

Outline

- Introduction
  - Catastrophic Production of Slow Gravitinos cf. [Talk by E. Dudas]
  - Minimal Supergravity Inflation without Slow Gravitino
- Constrained Superfields in Dynamical Background
  - UV completion: Derivation from a UV model
  - Inflation with a Stabilizer Field

Minimal Supergravity Inflation

[Ferrara, Kallosh, Thaler, 1512.00545], [Carrasco, Kallosh, Linde, 1512.00546]

- Orthogonal nilpotent superfields $\mathbf{X}$ and $\mathbf{A}$:

$$\mathbf{X}^2 = \mathbf{X}(\mathbf{A} + \bar{\mathbf{A}}) = 0$$ cf. [Talk by E. Dudas] [Talk by F. Quevedo]

Stabilizer superfield $\mathbf{X} = X + \sqrt{2}\theta\chi^X + \theta\theta F^X$

Inflaton superfield $\mathbf{A} = A + \sqrt{2}\theta\chi^A + \theta\theta F^A$

- The only independent dynamical degrees of freedom are

χ^X (stabilizino) and $\mathrm{Im}\,A$ (inflaton).

The physical spectrum:
(real) inflaton, (massive) gravitino, and graviton.

See also [Kahn, Roberts, Thaler, 1504.05958], [Dall'Agata, Farakos, 1512.02158], [Delacretaz, Gorbenko, Senatore, 1610.04227], [Cribiori et al., 1611.01490].

- The model is specified by

$$K(\mathbf{A}, \bar{\mathbf{A}}, \mathbf{X}, \bar{\mathbf{X}}) = \bar{\mathbf{X}}\mathbf{X} + \frac{1}{2}(\mathbf{A} + \bar{\mathbf{A}})^2,$$

$$W(\mathbf{A}, \mathbf{X}) = f(\mathbf{A})\mathbf{X} + g(\mathbf{A}).$$

- The scalar potential is

$$V(A) = |f(A)|^2 - 3|g(A)|^2.$$

Note that there is no $\partial g/\partial A$ term because of the constraint.

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Catastrophic Production of Slow Gravitinos

[Hasegawa, Mukaida, Nakayama, Terada, Yamada, 1701.03106], [Kolb, Long, Mcdonough, 2102.10113; 2103.10437]

Longitudinal gravitino Lagrangian

$$\mathscr{L} = -\frac{1}{2}\overline{\psi^\ell}\left(\gamma^0\partial_0 - \widehat{c}_{3/2}\left(\vec{\gamma}\cdot\overrightarrow{\nabla}\right) + a\,\widehat{m}_{3/2}\right)\psi^\ell$$

$$\widehat{c}_{3/2} \equiv \frac{p_{\rm SB} - \gamma^0 p_W}{\rho_{\rm SB}} \qquad \widehat{m}_{3/2} \equiv \frac{3Hp_W + m_{3/2}\left(\rho_{\rm SB} + 3p_{\rm SB}\right)}{2\rho_{\rm SB}}$$

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Inflaton potential & gravitino sound speed

For simplicity, we are assuming $p_W = 0$ so that $c_{3/2}$ is real.

Phase-space distribution (neglecting backreaction; $m_{3/2} \to 0$ limit)

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Catastrophic gravitino production

$$a^3 n_{3/2} \sim 2\int_0^\Lambda \mathrm{d}k\,\frac{4\pi k^2}{(2\pi)^3}\,f_{3/2}(\vec{k}, t) \sim \Lambda^3$$

… or breakdown of the effective theory.

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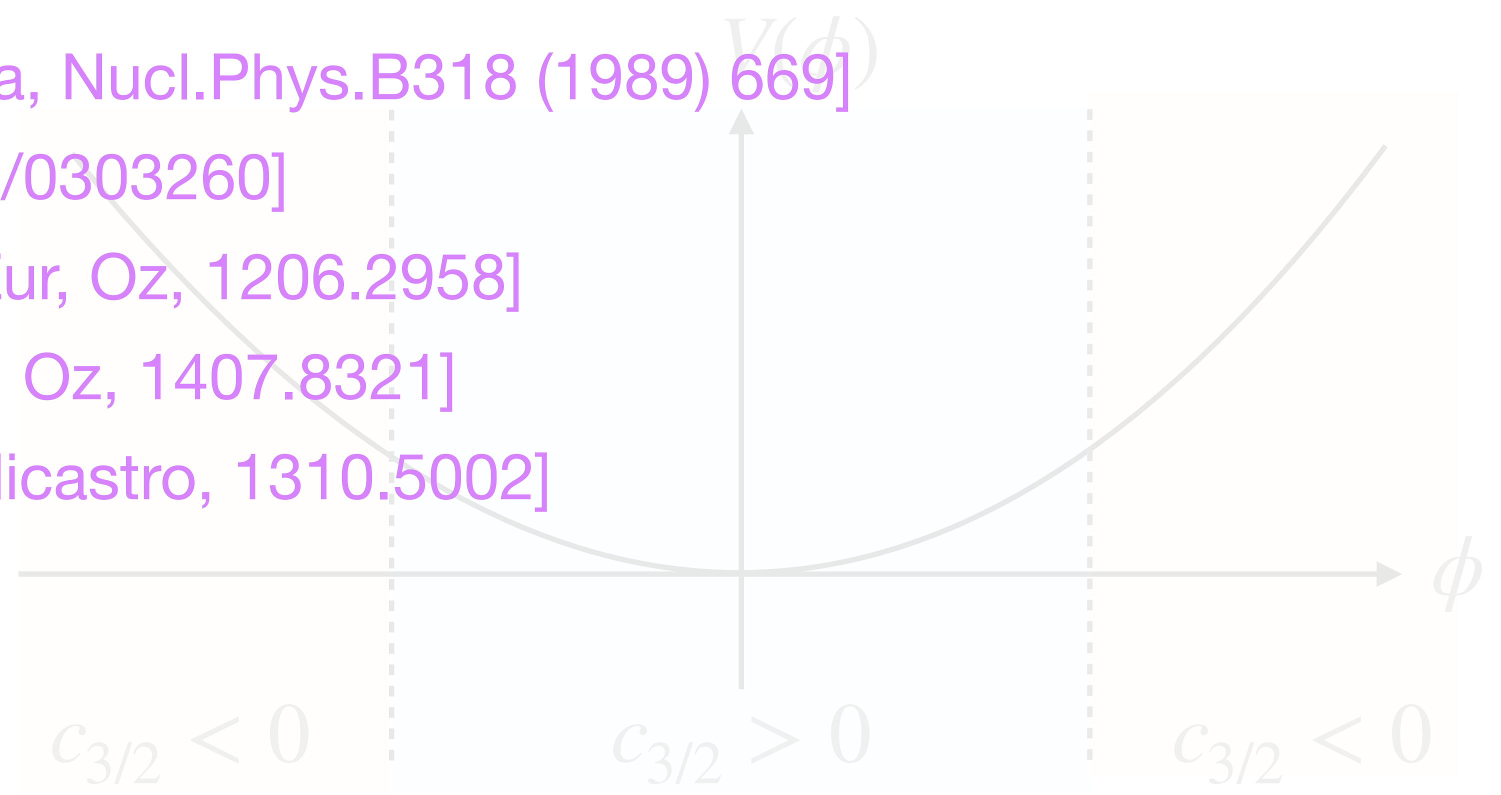
[Lebedev, Smilga, Nucl.Phys.B318 (1989) 669]
[Kratzert, hep-th/0303260]
[Hoyos, Keren-Zur, Oz, 1206.2958]
[Benakli, Darmé, Oz, 1407.8321]
[Benakli, Oz, Policastro, 1310.5002]



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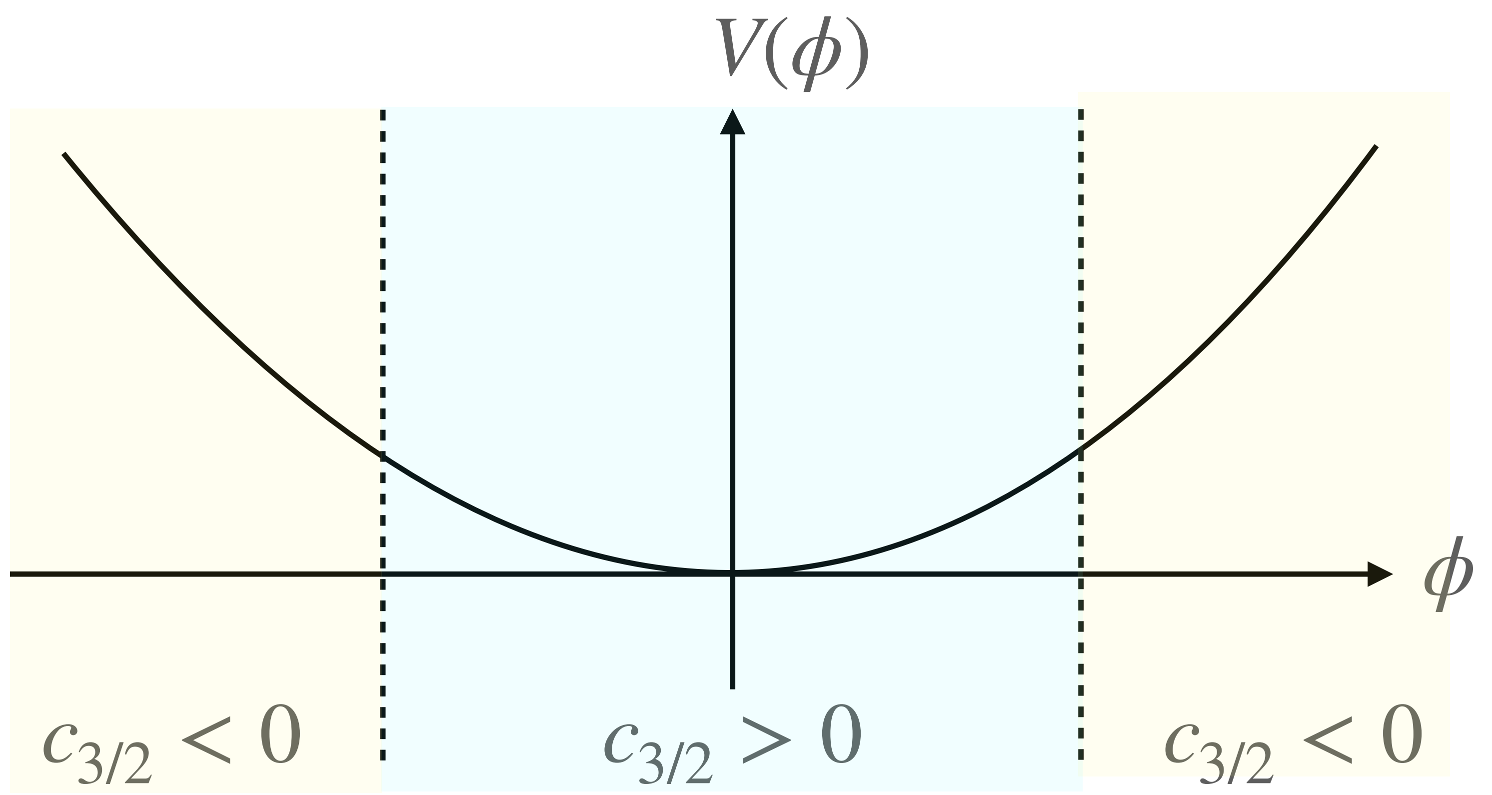

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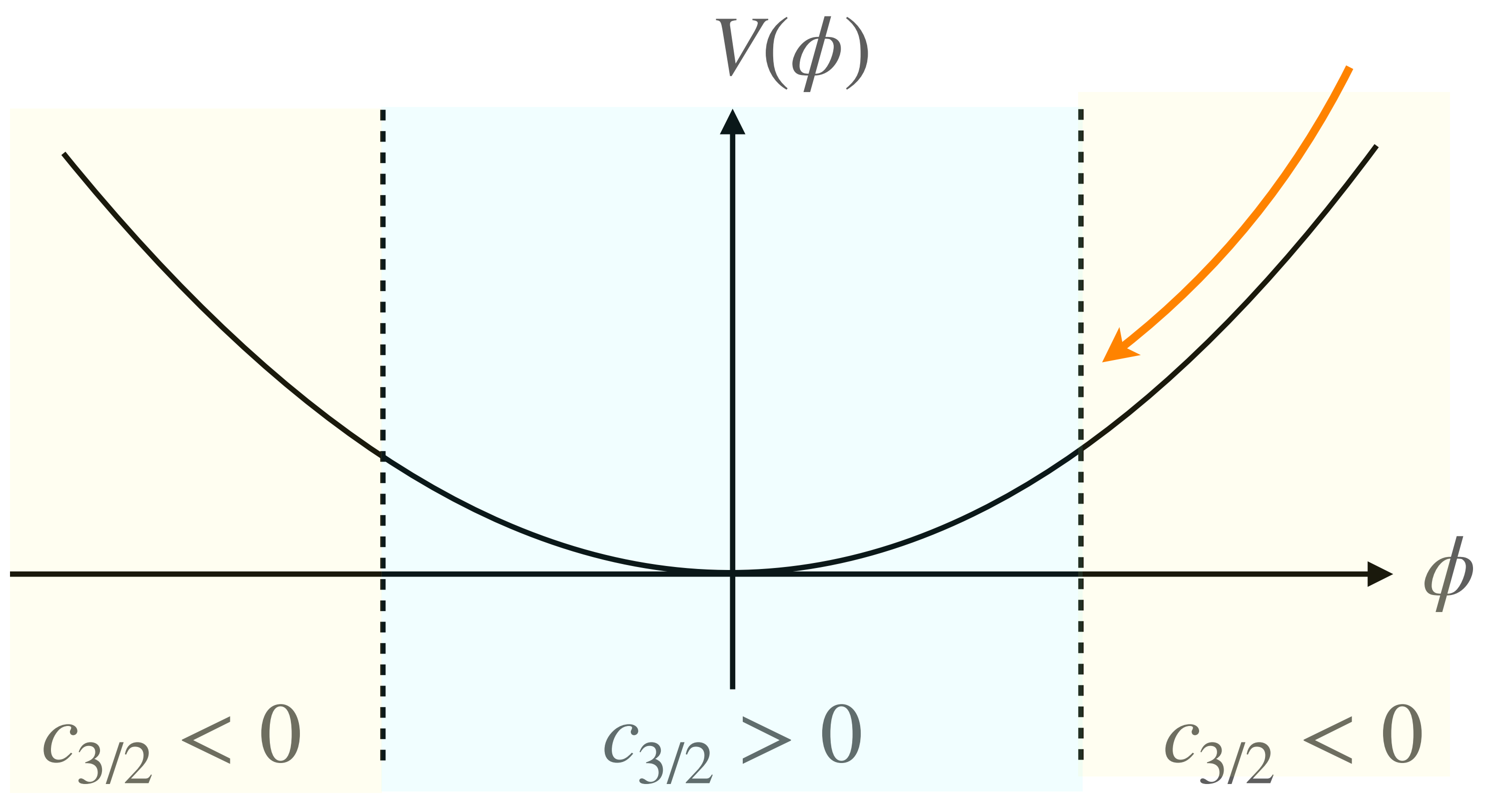

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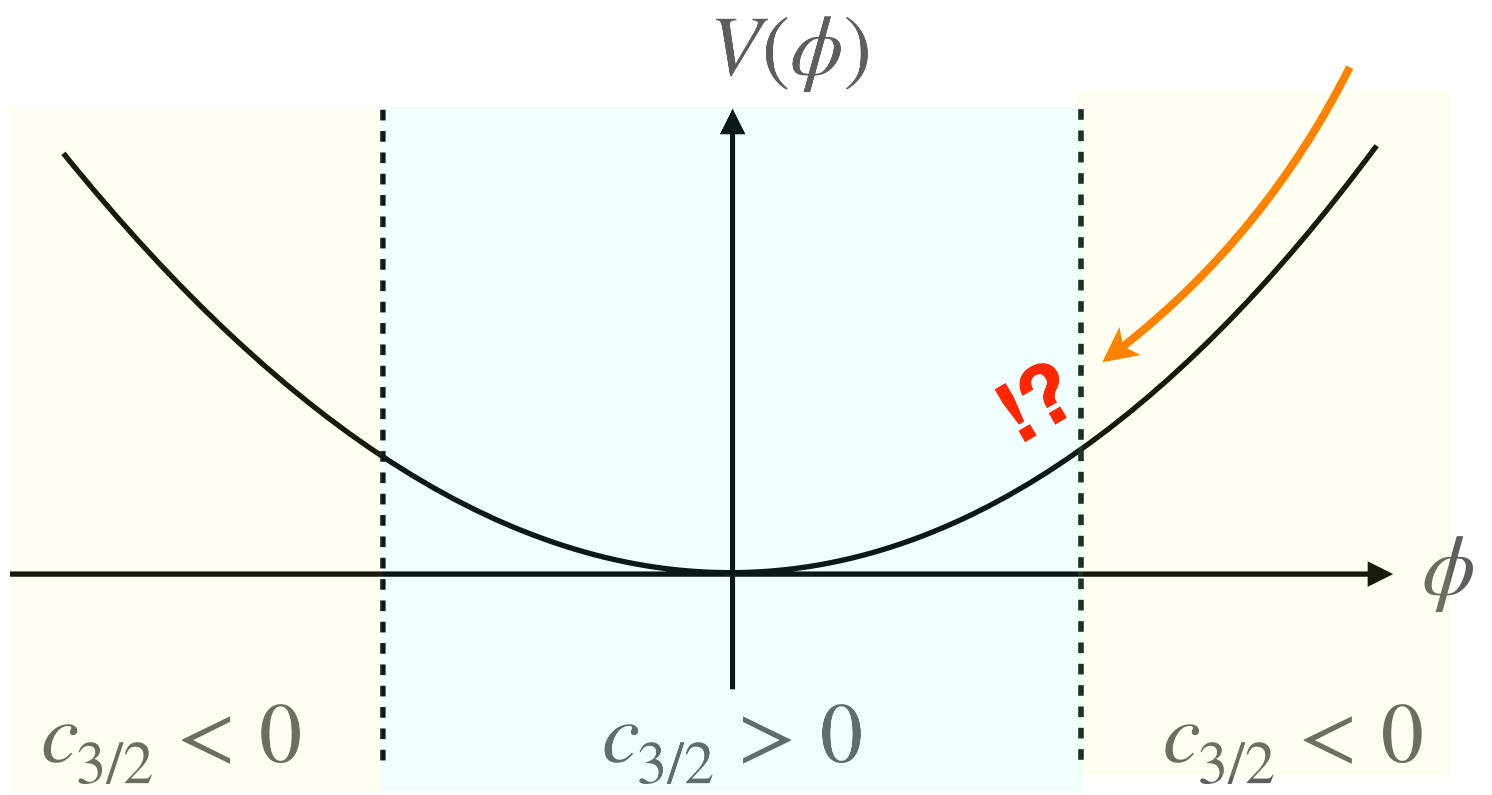

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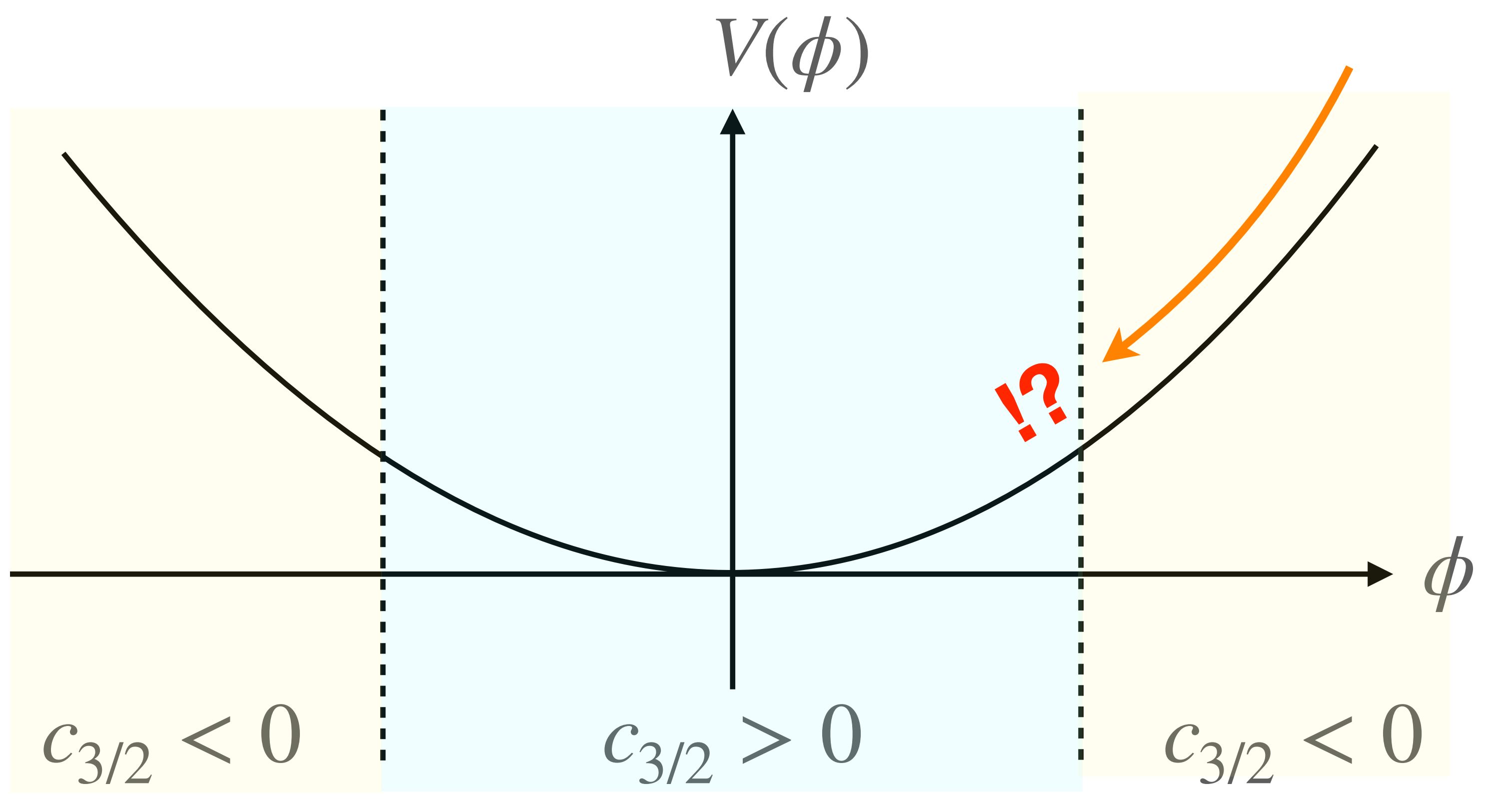

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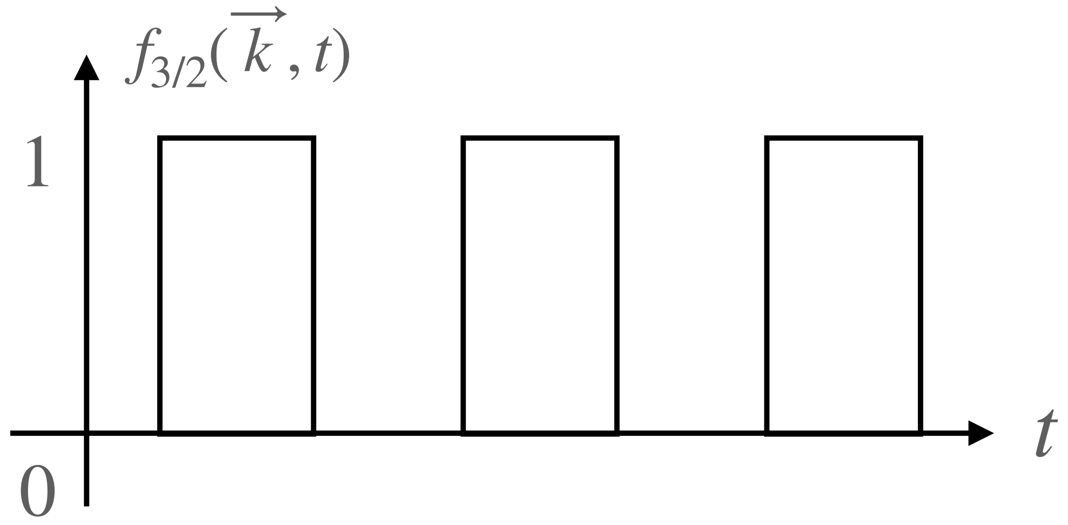

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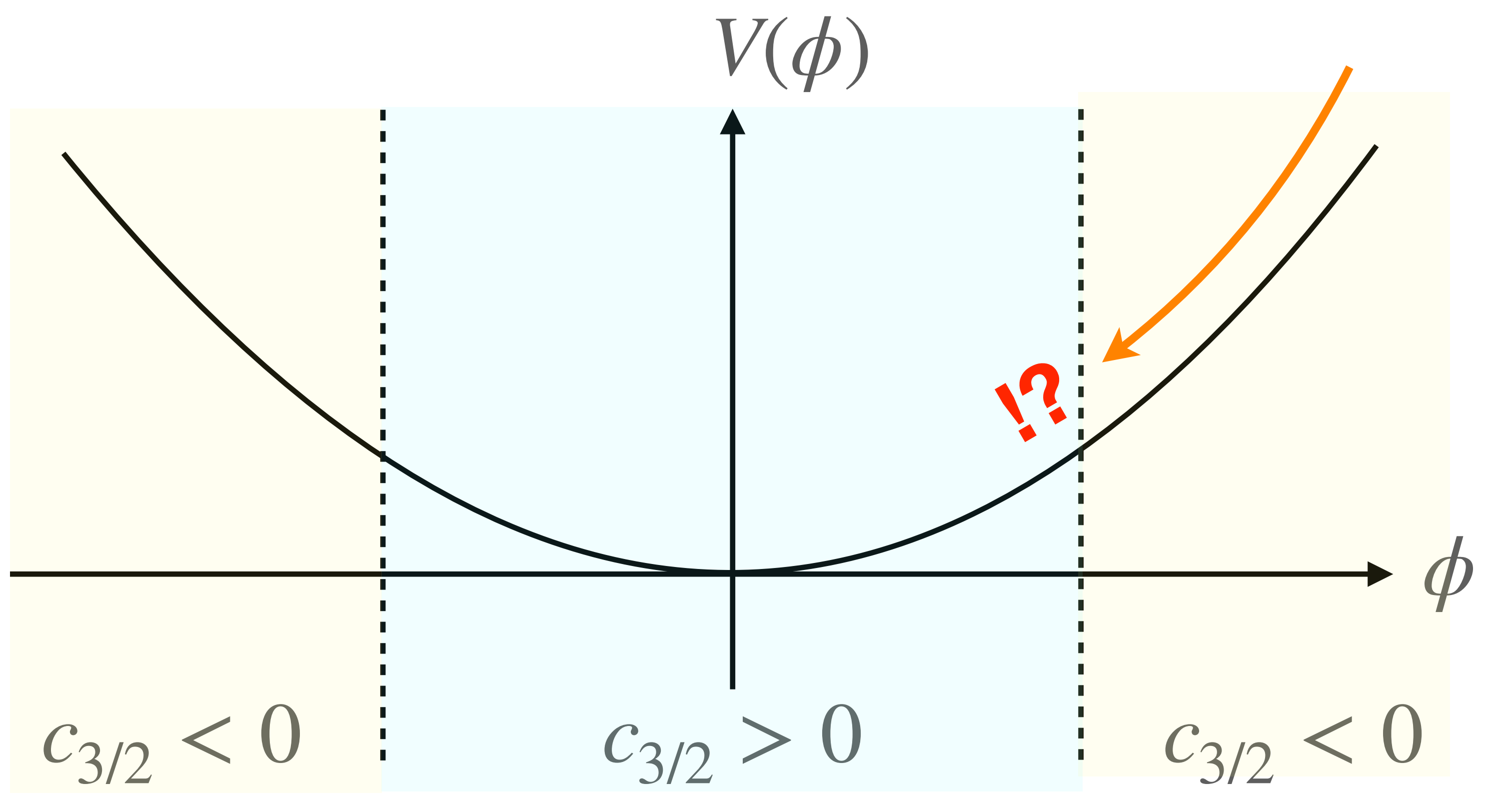

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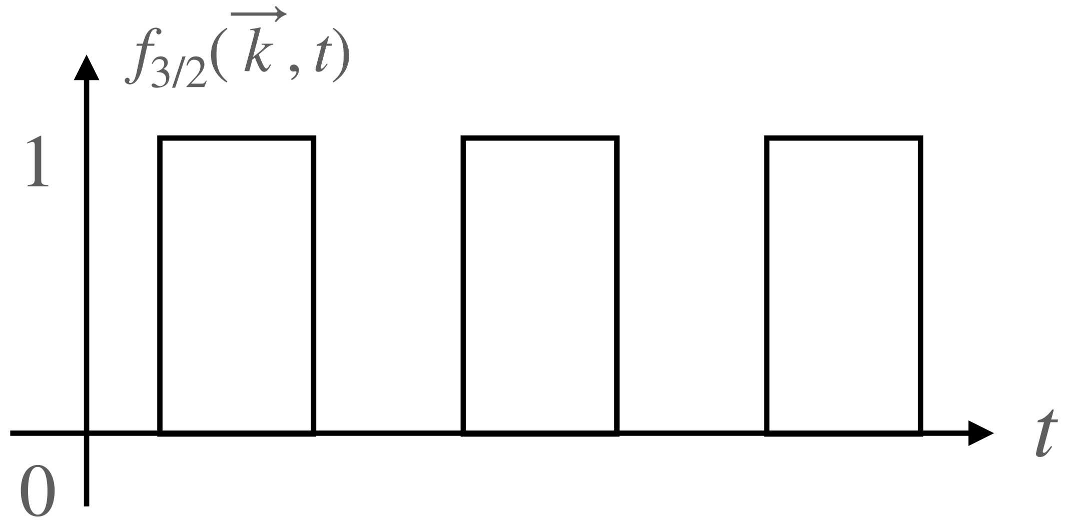

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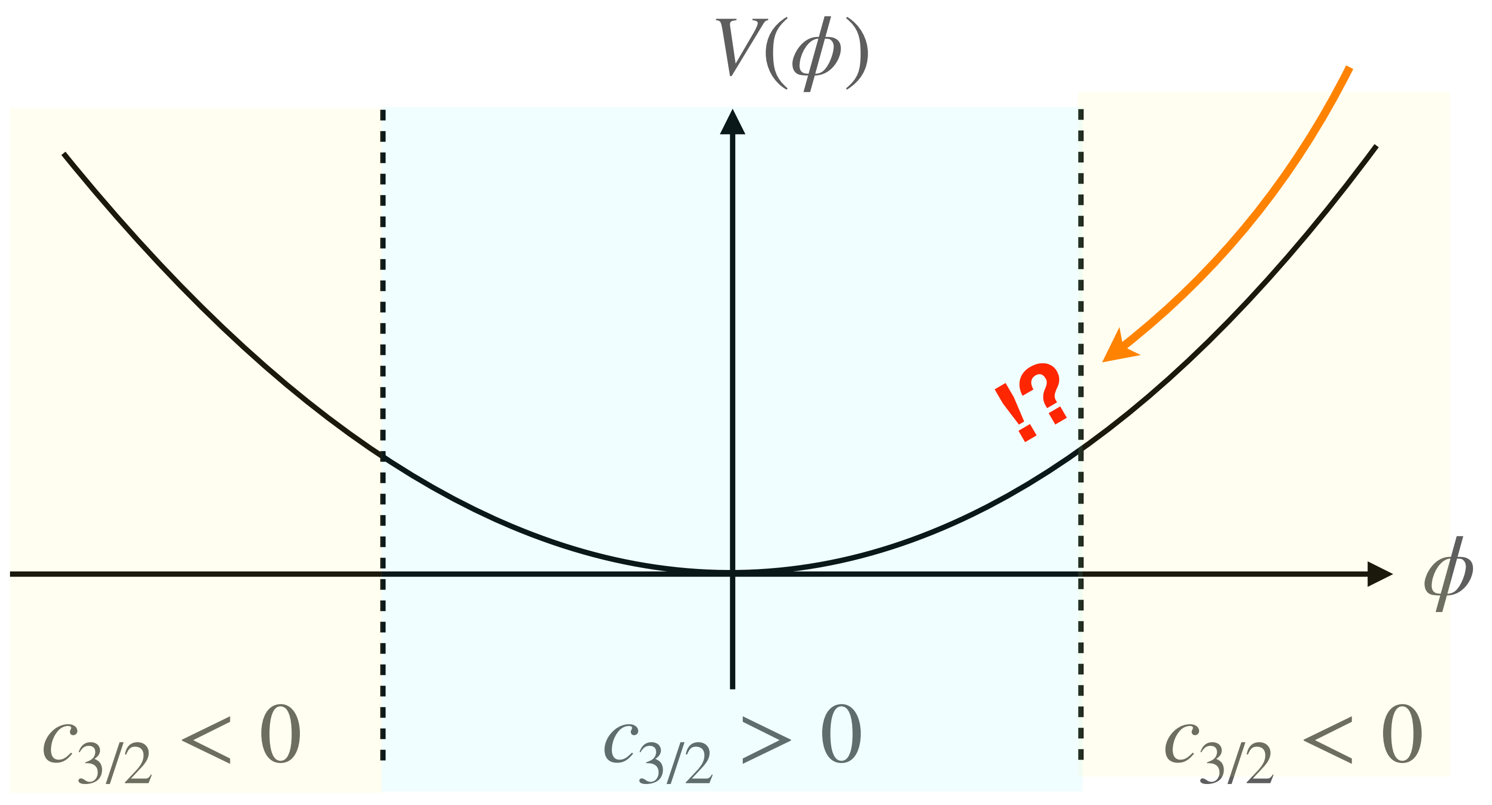

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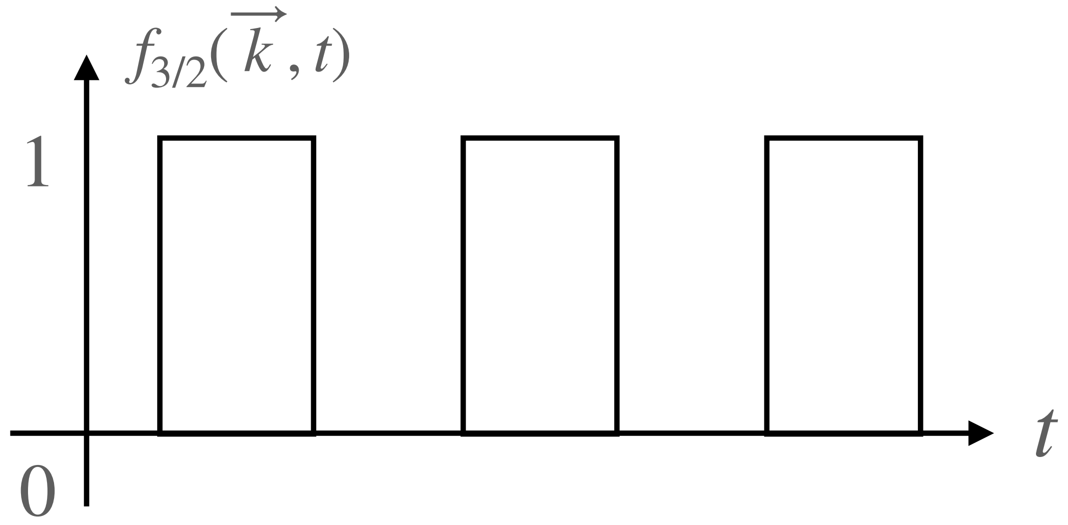

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What is the essence of the anomalous/catastrophic production?

In the standard case without constraints, the fermion gradient terms can be diagonalized:

$$\mathscr{L}_{\rm grad} = -\frac{1}{2}\begin{pmatrix}\overline{\psi^{\ell}} & \overline{v_{\perp}}\end{pmatrix}\left(i\vec{\gamma}\cdot\vec{k}\right)\widehat{\mathscr{C}_{3/2}}\begin{pmatrix}\psi^{\ell} \\ v_{\perp}\end{pmatrix}$$

For multi-(super)fields, $|\hat{c}_{3/2}|^2 \neq 1$, in general.

[Kallosh, Kofman, Linde, Van Proeyen, hep-th/9907124; hep-th/0006179]
[Giudice, Tkachev, Riotto, hep-ph/9907510; hep-ph/9911302]
[Nilles, Peloso, Sorbo, hep-ph/0102264; hep-th/0103202]
[Ema, Mukaida, Nakayama, Terada, 1609.04716]
[Dalianis, Farakos, 1705.06717]
[Dudas, Garcia, Mambrini, Olive, Peloso, Verner, 2104.03749]
[Antoniadis, Benakli, Ke, 2105.03784]

$$\widehat{\mathscr{C}_{3/2}} = \begin{pmatrix} -\hat{c}^{\dagger}_{3/2} & \alpha_i e^{-2\gamma^0\theta_i}\widetilde{O}_{iJ} \\ \widetilde{O}^{\rm T}_{Ii}\alpha_i e^{-2\gamma^0\theta_i} & \widetilde{O}^{\rm T}_{Ii}e^{-2\gamma^0\theta_i}\widetilde{O}_{iJ}\end{pmatrix}$$

The whole matrix satisfies $|\widehat{\mathscr{C}_{3/2}}|^2 = 1$ and can be diagonalized into the unit matrix.

The anomalous/catastrophic gravitino production can be interpreted as
the brute-force intervention to the diagonalization process by the constraints.
→ Inflatino (or other relevant fermions) should not be removed from the spectrum.

Alternative Superfield with Same D.O.F.

[Komargodski, Seiberg, 0907.2441], [Aldabergenov, Chatrabhuti, Isono, 2103.11217]

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This also implies $(\mathbf{A} + \bar{\mathbf{A}})^3 = 0$.

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$$\mathbf{\Phi} = \Phi + \sqrt{2}\theta\chi^\Phi + \theta\theta F^\Phi$$

$$(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3 = 0$$

Minimal Supergravity Inflation w/o Slow Gravitinos

[Terada, 2104.05731]

Inflation

e.g.) shift-symmetric Kähler potential

$$K(\mathbf{\Phi}, \bar{\mathbf{\Phi}}) = \frac{1}{2}(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2$$

with the constraint $(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3 = 0.$

There are several methods to construct inflation potentials in supergravity with a single chiral superfield.

[Ketov, Terada, 1406.0252; 1408.6524; 1509.00953; 1606.02817],
[Roest, Scalisi, 1503.07909], [Linde, 1504.00663],
[Ferrara, Roest, 1608.03709]

See also [Goncharov, Linde, PLB 139 (1984) 27], [Izawa, Shinbara, 0710.1141],
[Achucarro, Mooji, Ortz, Postma, 1203.1907],
[Alvarez-Gaume, Gomez, Jimenez, 1001.0010; 1101.4948]

Gravitino property

$$\mathscr{L} = -\frac{1}{2}\overline{\psi^\ell}\left(\gamma^0\partial_0 - \hat{c}_{3/2}\left(\vec{\gamma}\cdot\vec{\nabla}\right) + a\,\widehat{m}_{3/2}\right)\psi^\ell$$

$$\hat{c}_{3/2} \equiv \frac{p_{\rm SB} - \gamma^0 p_W}{\rho_{\rm SB}} \qquad \widehat{m}_{3/2} \equiv \frac{3Hp_W + m_{3/2}\left(\rho_{\rm SB} + 3p_{\rm SB}\right)}{2\rho_{\rm SB}}$$

$$\rho_{\rm SB} \equiv \rho + 3m_{3/2}^2 M_{\rm P}^2 \qquad p_{\rm SB} = p - 3m_{3/2}^2 M_{\rm P}^2 \qquad p_W \equiv 2\dot{m}_{3/2} M_{\rm P}^2$$

In our model,

$$|\hat{c}_{3/2}|^2 = (p_{\rm SB}^2 + p_W^2)/\rho_{\rm SB}^2 = 1.$$

Gravitino is not slow.

No catastrophic production.

Minimal Supergravity Inflation w/o Slow Gravitinos

[Terada, 2104.05731]

Inflation

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There are several methods to construct inflation potentials in supergravity with a single chiral superfield.

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In our model, $|\,\hat{c}_{3/2}|^2 = \left(p_{\rm SB}^2 + p_W^2\right)/\rho_{\rm SB}^2 = 1.$

Gravitino is not slow.

No catastrophic production.

UV completion?

From UV to IR: Nilpotent Superfield

[Casalbuoni, De Curtis, Dominici, Feruglio, and Gatto, PLB 220 (1989) 569]
See also [Dudas et al., 1106.5792], [Antoniadis et al., 1110.5939], [Antoniadis et al., 1210.8336]

UV model:

$$K(\mathbf{S}, \bar{\mathbf{S}}) = \bar{\mathbf{S}}\mathbf{S} - \frac{1}{\Lambda^2}(\bar{\mathbf{S}}\mathbf{S})^2, \qquad W(\mathbf{S}) = f\mathbf{S}.$$

Superfield expansion:

$$\mathbf{S} = S + \sqrt{2}\theta\chi + \theta\theta F$$

Lagrangian:

$$\mathscr{L} = K_{S\bar{S}}\left(-\partial^\mu \bar{S}\partial_\mu S - \frac{i}{2}\left(\chi\sigma^\mu D_\mu \bar{\chi} - D_\mu\chi\sigma^\mu\bar{\chi}\right) + F\bar{F}\right) + \left(\left(W_S - \frac{1}{2}K_{S\bar{S}\bar{S}}\bar{\chi}\bar{\chi}\right)F - \frac{1}{2}W_{SS}\chi\chi\right) + \mathrm{h.c.} + \frac{1}{4}K_{SS\bar{S}\bar{S}}\chi\chi\bar{\chi}\bar{\chi}$$

Equation of motion for S:

$$S\bar{F}F = \frac{1}{2}\bar{F}\chi\chi - i\partial_\mu\left(\chi\sigma^\mu\bar{\chi}S\right) - \frac{1}{2}\bar{S}\,\Box\,(S^2) + iS\chi\sigma^\mu\partial_\mu\bar{\chi} + \mathscr{O}(\Lambda^2)$$

→ nontrivial solution: $S = \dfrac{\chi\chi}{2F}$. This is equivalent to $\mathbf{S}^2 = 0$.

From UV to IR: “Axion” Superfield

UV model:

$$K(\mathbf{\Phi}, \bar{\mathbf{\Phi}}) = \frac{1}{2}(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2 - \frac{1}{4!\Lambda^2}(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^4$$

[Ketov, Terada, 1406.0252; 1408.6524]

Superfield expansion:

$$\mathbf{\Phi} = \Phi + \sqrt{2}\theta\chi + \theta\theta F$$

$$\Phi \equiv \frac{1}{\sqrt{2}}(\phi + i\varphi)$$

Equation of motion for ϕ:

$$\sqrt{2}\phi\left(-\frac{1}{2}\partial^\mu\varphi\partial_\mu\varphi + \bar{F}F - \frac{i}{2}\left(\chi\sigma^\mu\partial_\mu\bar{\chi} - \partial_\mu\chi\sigma^\mu\bar{\chi}\right)\right)$$
$$= \frac{\bar{F}}{2}\chi\chi + \frac{F}{2}\bar{\chi}\bar{\chi} + \frac{1}{\sqrt{2}}\chi\sigma^\mu\bar{\chi}\partial_\mu\varphi - \frac{1}{\sqrt{2}}\phi^2\Box\phi - \frac{1}{\sqrt{2}}\phi\partial^\mu\phi\partial_\mu\phi$$

Solution:

$$\phi = \frac{1}{\sqrt{2}\left(\bar{F}F - \frac{1}{2}\partial^\mu\varphi\partial_\mu\varphi\right)}\left(\frac{\bar{F}}{2}\chi\chi + \frac{F}{2}\bar{\chi}\bar{\chi} + \frac{1}{\sqrt{2}}\chi\sigma^\mu\bar{\chi}\partial_\mu\varphi\right) + \cdots$$

▲ SUSY breaking by axion kinetic energy

This is equivalent to

$$(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3 = 0.$$

[Komargodski, Seiberg, 0907.2441],
[Aldabergenov, Chatrabhuti, and Isono, 2103.11207]

From UV to IR: "Stabilizer" Inflation Models

UV model:

$$K = \frac{1}{2}(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2 + \bar{\mathbf{S}}\mathbf{S} - \frac{1}{4\Lambda_S^2}(\bar{\mathbf{S}}\mathbf{S})^2 - \frac{1}{2\Lambda_{S\phi}^2}(\bar{\mathbf{S}}\mathbf{S})(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2 - \frac{1}{4!\Lambda_\phi^2}(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^4$$

Shift symmetry, R-symmetry, and $\mathbf{Z}_2$ symmetry ensure this form.

[Kawasaki, Yamaguchi, Yanagida, hep-ph/004243; hep-ph/0011104], [Kallosh, Linde, 1008.3375], [Kallosh, Linde, Rube, 1011.5945]

$$\begin{aligned}
0 =& -\frac{1}{\Lambda_S^2}S\left(F^S\bar{F}^{\bar{S}} - \frac{i}{2}\left(\chi^S\sigma^\mu\partial_\mu\bar{\chi}^{\bar{S}} + \bar{\chi}^{\bar{S}}\bar{\sigma}^\mu\partial_\mu\chi^S\right)\right) - \frac{1}{\Lambda_{S\phi}^2}S\left(F^\Phi\bar{F}^{\bar{\Phi}} - \frac{i}{2}\left(\chi^\Phi\sigma^\mu\partial_\mu\bar{\chi}^{\bar{\Phi}} + \bar{\chi}^{\bar{\Phi}}\bar{\sigma}^\mu\partial_\mu\chi^\Phi\right)\right) \\
&- \frac{\sqrt{2}}{\Lambda_{S\phi}^2}\phi\left(F^S\bar{F}^{\bar{\Phi}} - \frac{i}{2}\left(\chi^S\sigma^\mu\partial_\mu\bar{\chi}^{\bar{\Phi}} + \bar{\chi}^{\bar{\Phi}}\bar{\sigma}^\mu\partial_\mu\chi^S\right)\right) + \left(-\frac{1}{\Lambda_{S\phi}^2}\phi^2 - \frac{1}{\Lambda_S^2}\bar{S}S\right)\Box S - \frac{\sqrt{2}}{\Lambda_{S\phi}^2}S\phi\Box\Phi \\
&- \frac{1}{\Lambda_S^2}\bar{S}\partial^\mu S\partial_\mu S - \frac{2\sqrt{2}}{\Lambda_{S\phi}^2}\phi\partial^\mu S\partial_\mu\Phi - \frac{1}{\Lambda_{S\phi}^2}S\partial^\mu\Phi\partial_\mu\Phi \\
&- \frac{i}{\Lambda_S^2}\chi^S\sigma^\mu\bar{\chi}^{\bar{S}}\partial_\mu S - \frac{i}{\Lambda_{S\phi}^2}\chi^S\sigma^\mu\bar{\chi}^{\bar{\Phi}}\partial_\mu\Phi - \frac{i}{\Lambda_{S\phi}^2}\chi^\Phi\sigma^\mu\bar{\chi}^{\bar{\Phi}}\partial_\mu S \\
&- \frac{i}{2\Lambda_S^2}S\partial_\mu(\chi^S\sigma^\mu\bar{\chi}^{\bar{S}}) - \frac{i}{\sqrt{2}\Lambda_{S\phi}^2}\phi\partial_\mu(\chi^S\sigma^\mu\bar{\chi}^{\bar{\Phi}}) - \frac{i}{2\Lambda_{S\phi}^2}S\partial_\mu(\chi^\Phi\sigma^\mu\bar{\chi}^{\bar{\Phi}}) \\
&+ \frac{1}{2\Lambda_{S\phi}^2}F^S\bar{\chi}^{\bar{\Phi}}\bar{\chi}^{\bar{\Phi}} + \frac{1}{2\Lambda_S^2}\bar{F}^{\bar{S}}\chi^S\chi^S + \frac{1}{\Lambda_{S\phi}^2}\bar{F}^{\bar{\Phi}}\chi^\Phi\chi^S, \qquad (21)
\end{aligned}$$

$$\begin{aligned}
0 =& -\frac{\sqrt{2}}{\Lambda_\phi^2}\phi\left(F^\Phi\bar{F}^{\bar{\Phi}} - \frac{i}{2}\left(\chi^\Phi\sigma^\mu\partial_\mu\bar{\chi}^{\bar{\Phi}} + \bar{\chi}^{\bar{\Phi}}\bar{\sigma}^\mu\partial_\mu\chi^\Phi\right)\right) - \frac{\sqrt{2}}{\Lambda_{S\phi}^2}\phi\left(F^S\bar{F}^{\bar{S}} - \frac{i}{2}\left(\chi^S\sigma^\mu\partial_\mu\bar{\chi}^{\bar{S}} + \bar{\chi}^{\bar{S}}\bar{\sigma}^\mu\partial_\mu\chi^S\right)\right) \\
&- \frac{1}{\Lambda_{S\phi}^2}S\left(F^\Phi\bar{F}^{\bar{S}} - \frac{i}{2}\left(\chi^\Phi\sigma^\mu\partial_\mu\bar{\chi}^{\bar{S}} + \bar{\chi}^{\bar{S}}\bar{\sigma}^\mu\partial_\mu\chi^\Phi\right)\right) - \frac{1}{\Lambda_{S\phi}^2}\bar{S}\left(F^S\bar{F}^{\bar{\Phi}} - \frac{i}{2}\left(\chi^S\sigma^\mu\partial_\mu\bar{\chi}^{\bar{\Phi}} + \bar{\chi}^{\bar{\Phi}}\bar{\sigma}^\mu\partial_\mu\chi^S\right)\right) \\
&- \frac{1}{\sqrt{2}\Lambda_\phi^2}\phi\left(\partial^\mu\phi\partial_\mu\phi - \partial^\mu\varphi\partial_\mu\varphi\right) - \frac{1}{\sqrt{2}\Lambda_{S\phi}^2}\partial^\mu\phi\partial_\mu(\bar{S}S) \\
&- \frac{i}{\sqrt{2}\Lambda_{S\phi}^2}\partial^\mu\varphi(\bar{S}\partial_\mu S - S\partial_\mu\bar{S}) - \frac{1}{\sqrt{2}\Lambda_{S\phi}^2}\phi\left(\partial^\mu S\partial_\mu S + \partial^\mu\bar{S}\partial_\mu\bar{S}\right) \\
&- \frac{1}{\sqrt{2}}\left(\frac{1}{\Lambda_{S\phi}^2}S\bar{S} + \frac{1}{\Lambda_\phi^2}\phi^2\right)\Box\phi - \frac{1}{\sqrt{2}\Lambda_{S\phi}^2}\phi(\bar{S}\Box S + S\Box\bar{S}) \\
&+ \frac{1}{\sqrt{2}\Lambda_\phi^2}\chi^\Phi\sigma^\mu\bar{\chi}^{\bar{\Phi}}\partial_\mu\varphi + \frac{1}{\sqrt{2}\Lambda_{S\phi}^2}\chi^S\sigma^\mu\bar{\chi}^{\bar{S}}\partial_\mu\varphi - \frac{i}{2\Lambda_{S\phi}^2}\chi^\Phi\sigma^\mu\bar{\chi}^{\bar{S}}\partial_\mu S + \frac{i}{2\Lambda_{S\phi}^2}\chi^S\sigma^\mu\bar{\chi}^{\bar{\Phi}}\partial_\mu\bar{S} \\
&+ \frac{1}{2\Lambda_\phi^2}\left(F^\Phi\bar{\chi}^{\bar{\Phi}}\bar{\chi}^{\bar{\Phi}} + \bar{F}^{\bar{\Phi}}\chi^\Phi\chi^\Phi\right) + \frac{1}{\Lambda_{S\phi}^2}\left(F^S\bar{\chi}^{\bar{S}}\bar{\chi}^{\bar{\Phi}} + \bar{F}^{\bar{S}}\chi^S\chi^\Phi\right). \qquad (22)
\end{aligned}$$

◀ Equations of motion for S and ϕ are long.

They have all possible combinations of fermion bilinear terms.

($\chi^\Phi\chi^\Phi, \chi^\Phi\chi^S, \chi^S\chi^S, \chi^\Phi\sigma^\mu\bar{\chi}^{\bar{\Phi}}, \chi^\Phi\sigma^\mu\bar{\chi}^{\bar{S}}, \chi^S\sigma^\mu\bar{\chi}^{\bar{S}}$, and their conjugates.)

From UV to IR: “Stabilizer” Inflation Models

UV model:

$$K = \frac{1}{2}(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2 + \bar{\mathbf{S}}\mathbf{S} - \frac{1}{4\Lambda_S^2}(\bar{\mathbf{S}}\mathbf{S})^2 - \frac{1}{2\Lambda_{S\phi}^2}(\bar{\mathbf{S}}\mathbf{S})(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2 - \frac{1}{4!\Lambda_\phi^2}(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^4$$

Shift symmetry, R-symmetry, and $\mathbf{Z}_2$ symmetry ensure this form.

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& - \frac{i}{\Lambda_S^2}\chi^S\sigma^\mu\bar{\chi}^{\bar{S}}\partial_\mu S - \frac{i}{\Lambda_{S\phi}^2}\chi^S\sigma^\mu\bar{\chi}^{\bar{\Phi}}\partial_\mu\Phi - \frac{i}{\Lambda_{S\phi}^2}\chi^\Phi\sigma^\mu\bar{\chi}^{\bar{\Phi}}\partial_\mu S \\
& - \frac{i}{2\Lambda_S^2}S\partial_\mu(\chi^S\sigma^\mu\bar{\chi}^{\bar{S}}) - \frac{i}{\sqrt{2}\Lambda_{S\phi}^2}\phi\partial_\mu(\chi^S\sigma^\mu\bar{\chi}^{\bar{\Phi}}) - \frac{i}{2\Lambda_{S\phi}^2}S\partial_\mu(\chi^\Phi\sigma^\mu\bar{\chi}^{\bar{\Phi}}) \\
& + \frac{1}{2\Lambda_{S\phi}^2}F^S\bar{\chi}^{\bar{\Phi}}\bar{\chi}^{\bar{\Phi}} + \frac{1}{2\Lambda_S^2}\bar{F}^{\bar{S}}\chi^S\chi^S + \frac{1}{\Lambda_{S\phi}^2}\bar{F}^{\bar{\Phi}}\chi^\Phi\chi^S, \qquad (21)
\end{aligned}$$

◀ Equations of motion for S and ϕ are long.

They have all possible combinations of fermion bilinear terms.

($\chi^\Phi\chi^\Phi, \chi^\Phi\chi^S, \chi^S\chi^S, \chi^\Phi\sigma^\mu\bar{\chi}^{\bar{\Phi}}, \chi^\Phi\sigma^\mu\bar{\chi}^{\bar{S}}, \chi^S\sigma^\mu\bar{\chi}^{\bar{S}}$, and their conjugates.)

This implies a bunch of quintic constraints as follows.

$$(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^5 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^4\mathbf{S} = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3\mathbf{S}^2 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3\mathbf{S}\bar{\mathbf{S}} = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2\mathbf{S}^3 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2\mathbf{S}^2\bar{\mathbf{S}}$$
$$= (\mathbf{\Phi} + \bar{\mathbf{\Phi}})\mathbf{S}^4 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})\mathbf{S}^3\bar{\mathbf{S}} = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})\mathbf{S}^2\bar{\mathbf{S}}^2 = \mathbf{S}^5 = \mathbf{S}^4\bar{\mathbf{S}} = \mathbf{S}^3\bar{\mathbf{S}}^2 = 0$$

$(\mathbf{X} + \bar{\mathbf{X}})^5 = 0$ in $\mathcal{N} = 2$ SUSY [Aldabergenov, Antoniadis, Chatrabhuti, and Isono, 2111.02205]

From UV to IR: “Stabilizer” Inflation Models

UV model:

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$$W = \mathbf{S} f(\mathbf{\Phi})$$

Without the $1/\Lambda_{S\phi}^2$ term, $S = \frac{1}{2F^S}\chi^S\chi^S + \cdots$ and $\phi = \frac{1}{-\partial^\nu\varphi\partial_\nu\varphi}\chi^\Phi\sigma^\mu\bar{\chi}^{\bar{\Phi}}\partial_\mu\varphi + \cdots$. → $\mathbf{S}^2 = 0$ and $(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3 = 0$.

When $\Lambda_S^2 = \Lambda_{S\phi}^2 = \Lambda_\phi^2$, the denominators are regular, $\phi, S \propto \frac{1}{2F^S\bar{F}^{\bar{S}} - \partial^\mu\varphi\partial_\mu\varphi}$.

▲ SUSY breaking by inflaton kinetic energy

$$(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^5 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^4\mathbf{S} = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3\mathbf{S}^2 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3\mathbf{S}\bar{\mathbf{S}} = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2\mathbf{S}^3 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2\mathbf{S}^2\bar{\mathbf{S}}$$
$$= (\mathbf{\Phi} + \bar{\mathbf{\Phi}})\mathbf{S}^4 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})\mathbf{S}^3\bar{\mathbf{S}} = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})\mathbf{S}^2\bar{\mathbf{S}}^2 = \mathbf{S}^5 = \mathbf{S}^4\bar{\mathbf{S}} = \mathbf{S}^3\bar{\mathbf{S}}^2 = 0$$

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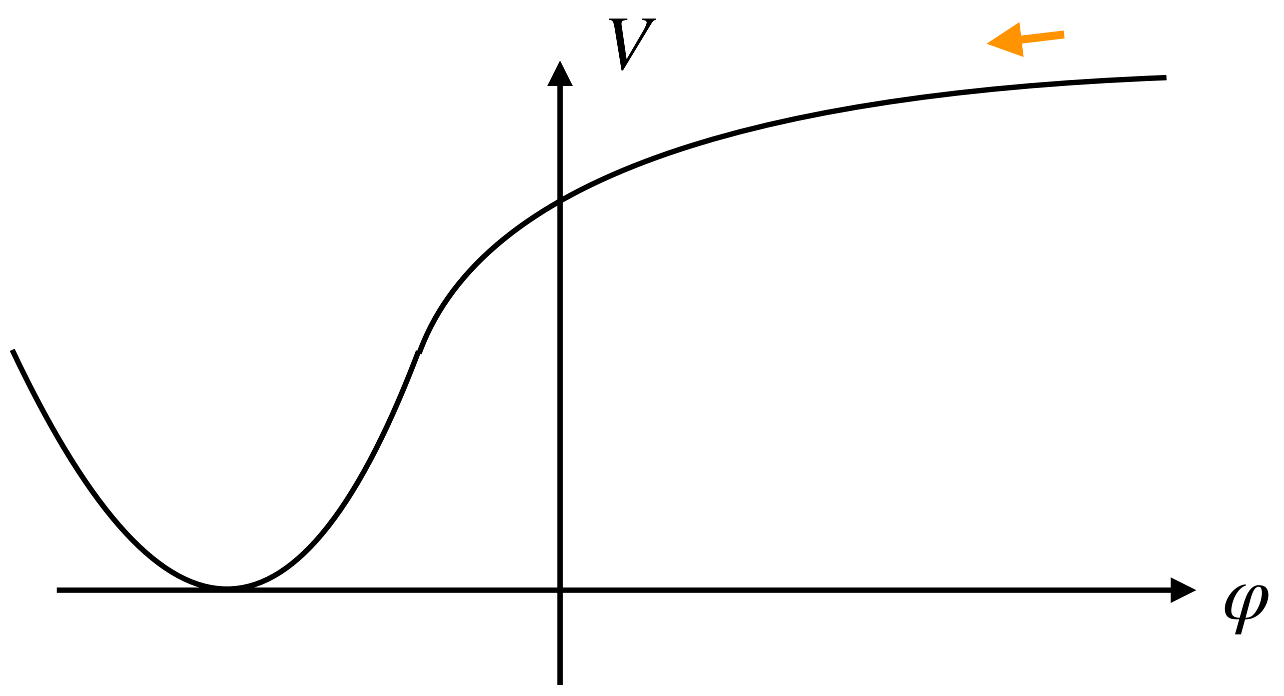
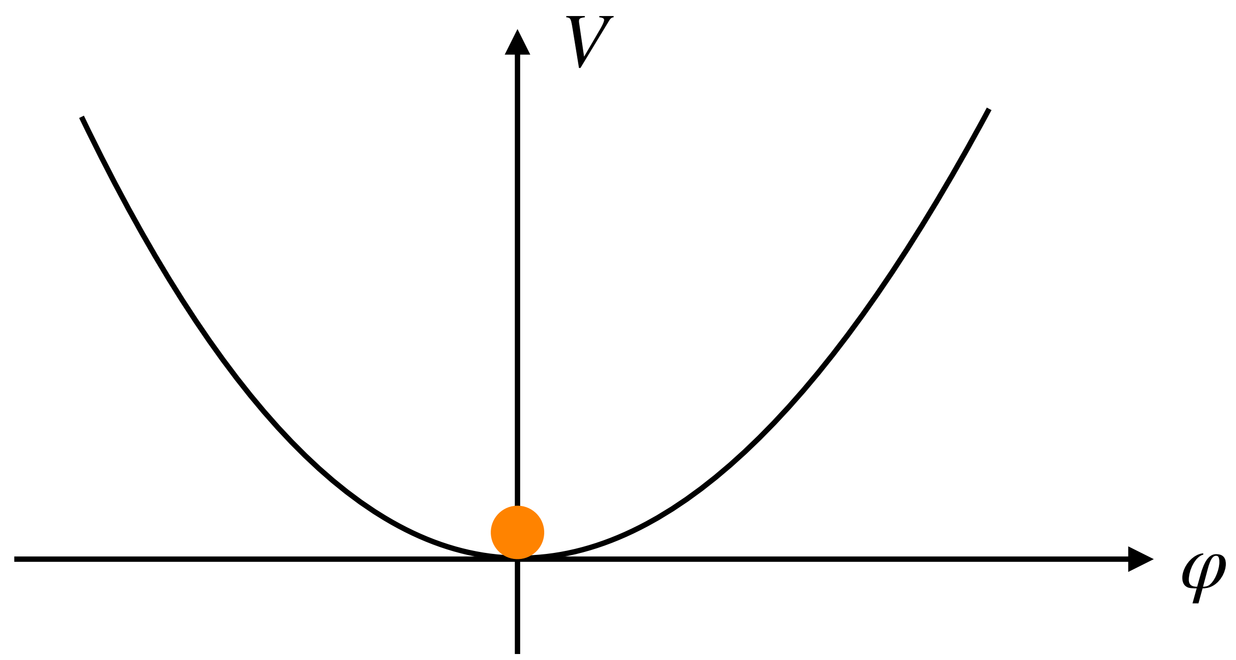
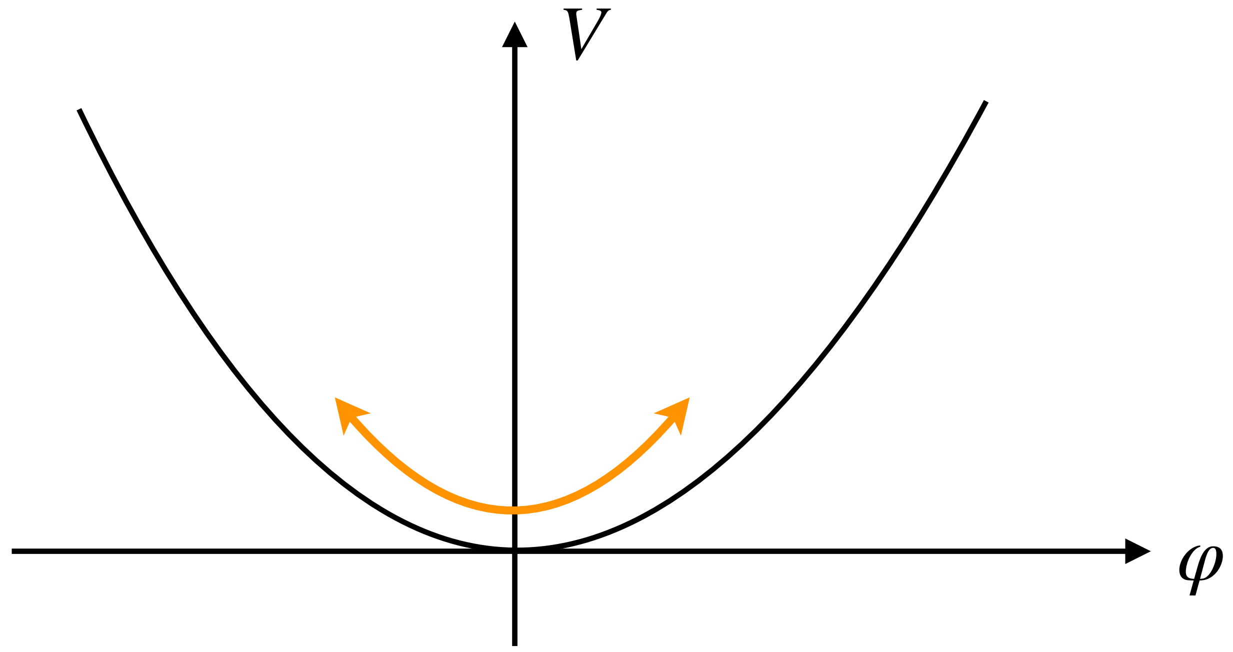


Inflation,
quintessence, dark energy

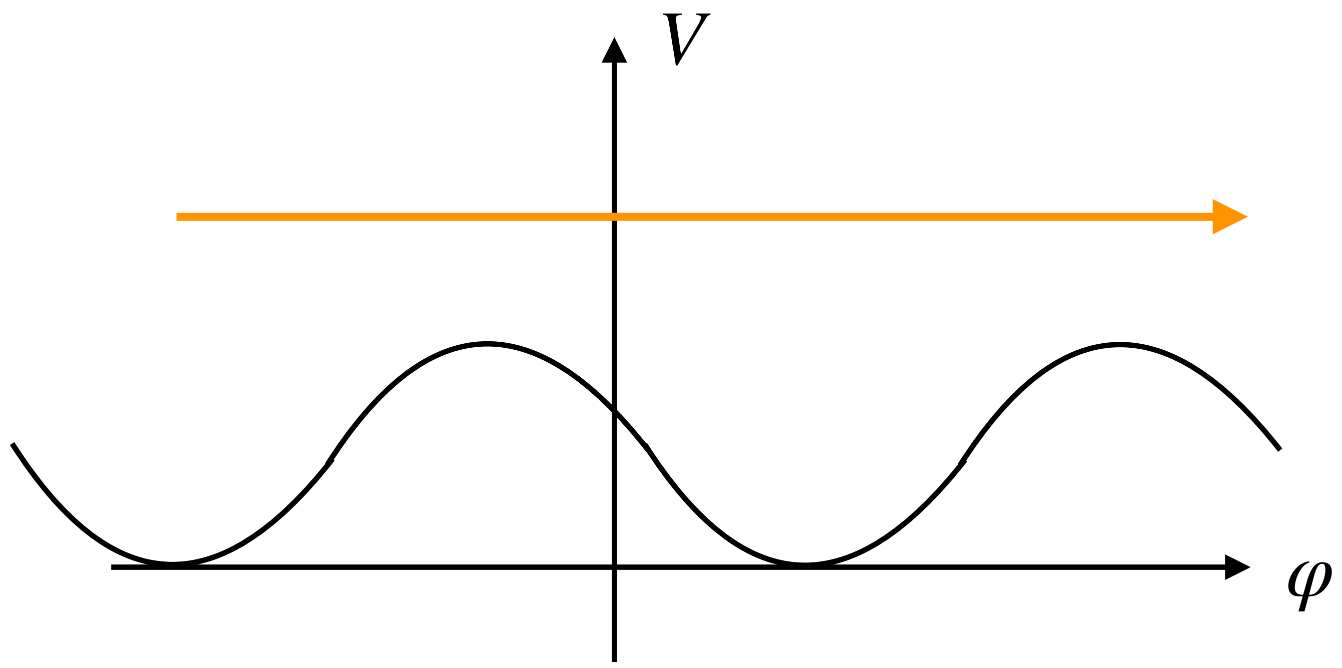


SUSY breaking in vacuum

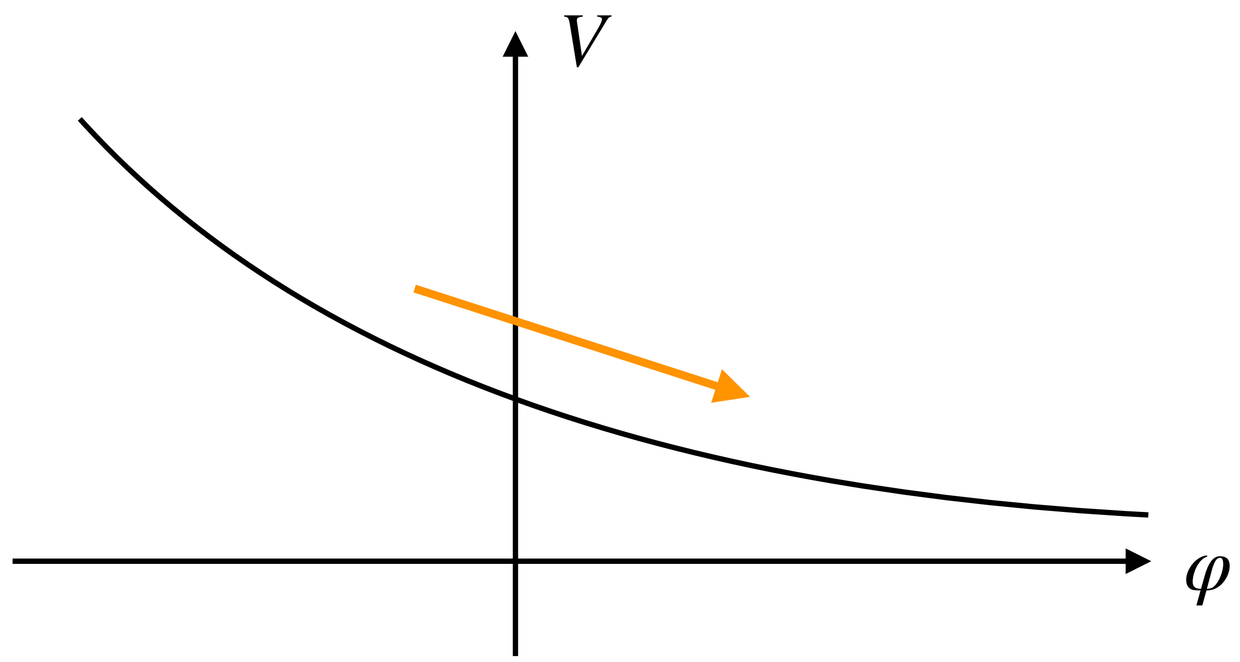


Inflaton oscillation, preheating,
axion misalignment, curvaton

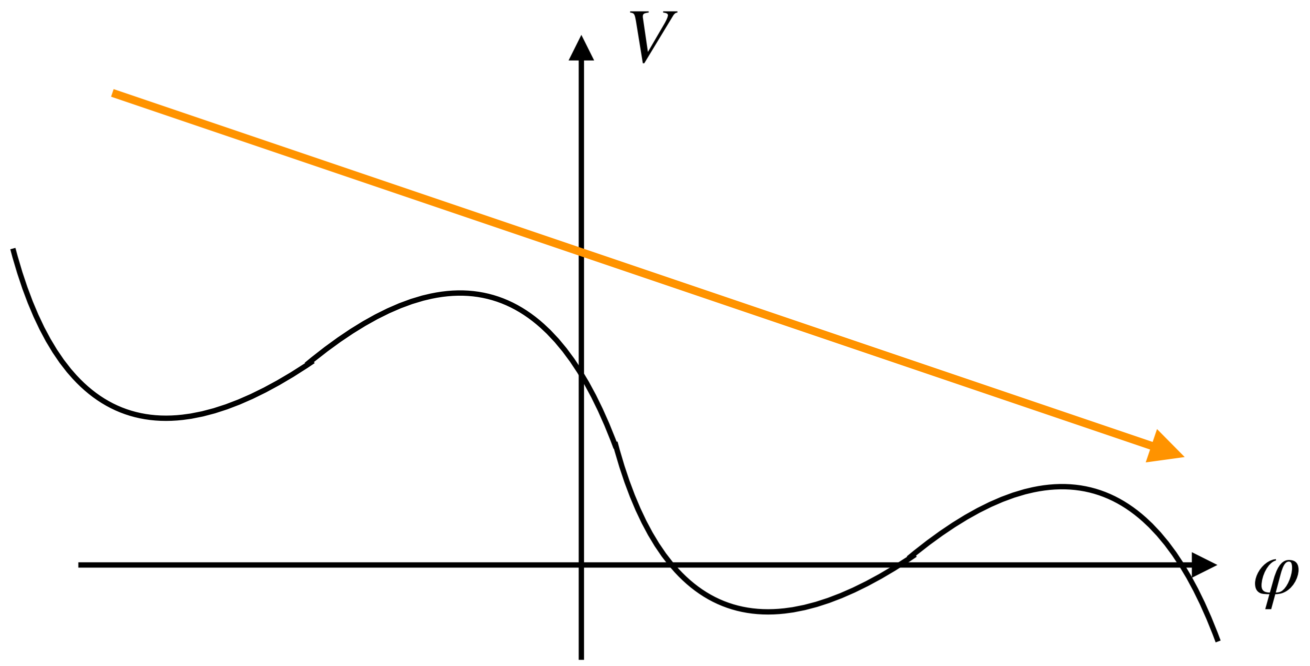
Cosmological Applications



axion kinetic misalignment



Kination



cosmological relaxation

Cosmological Implications

For $\Lambda_S^2 = \Lambda_{S\phi}^2 = \Lambda_\phi^2$,

$$\phi, S \propto \frac{1}{2F^S\bar{F}^{\bar{S}} - \partial^\mu\varphi\partial_\mu\varphi} \simeq \frac{1}{\rho}$$

Effective mass & coupling constants oscillates less.

Preheating (non-adiabatic particle production) suppressed?

For $\Lambda_S^2, \Lambda_{S\phi}^2 \ll M_{\rm P}^2$,

$$m_S^2 = \frac{|F^S|^2}{\Lambda_S^2} + \frac{1}{\Lambda_{S\phi}^2}\left(-\frac{1}{2}\partial^\mu\varphi\partial_\mu\varphi + |F^\Phi|^2\right) \gg H^2$$

The stabilizer can be consistently decoupled.

$$m_{3/2} = W \propto S \simeq 0$$

Gravitino production significantly suppressed?

[Ema, Mukaida, Nakayama, Terada, 1609.04716]

Conclusion

- Starting from UV setups with positive Kähler curvature and shift symmetry, we *derived* constrained superfields valid also in dynamical/cosmological backgrounds.

- Examples:
  - Cubic constraint for an “axion”-like superfield
  - Quintic constraints for inflation models with a stabilizer field

- The same method can apply to a wide variety of cosmological scenarios.

Conclusion

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Appendix

Equivalence

[Komargodski, Seiberg, 0907.2441], [Aldabergenov, Chatrabhuti, Isono, 2103.11217]

Orthogonal nilpotent superfields $\mathbf{X}$ and $\mathbf{A}$ can be packaged into $\mathbf{\Phi} = \log\left(\frac{1}{\sqrt{2}}\mathbf{X} + e^{\mathbf{A}}\right)$.

$$K = \frac{1}{2}(\mathbf{\Phi} + \bar{\mathbf{\Phi}})^2 = \frac{1}{2}(\mathbf{A} + \bar{\mathbf{A}})^2 + \mathbf{X}\bar{\mathbf{X}}$$

$$W(\mathbf{\Phi}) = W(\mathbf{A}) + \frac{1}{\sqrt{2}}\mathbf{X}W'(\mathbf{A})e^{-\mathbf{A}}$$

where we have used $\mathbf{X}^2 = \mathbf{X}(\mathbf{A} + \bar{\mathbf{A}}) = 0$, which implies $(\mathbf{A} + \bar{\mathbf{A}})^3 = (\mathbf{\Phi} + \bar{\mathbf{\Phi}})^3 = 0$.

The specific structure of the superpotential ensures that the gravitino speed is equal to the speed of light.

[Hasegawa, Mukaida, Nakayama, Terada, Yamada, 1701.03106], [Aoki, Terada, 2111.04511]

Gauge Field/D-term

$$\int \mathrm{d}^2\theta\, h_{AB}(\mathbf{\Phi})\mathbf{W}^A\mathbf{W}^b$$

The gauge kinetic function can be linear in the inflaton, $h(\mathbf{\Phi}) \sim 1 + \mathbf{\Phi}/M$, which breaks the shift symmetry only non-perturbatively.

This can lead to a new contribution, $\phi \sim \dfrac{i}{m_\phi^2}\dfrac{\Lambda^2}{M}\left(\lambda\sigma^\mu D_\mu\bar{\lambda} + \bar{\lambda}\bar{\sigma}^\mu D_\mu\lambda\right) + \cdots$.

The quadratic term, $h(\mathbf{S}) \sim 1 + \mathbf{S}^2/M^2$, leads to a holomorphic mass term, which cannot be a dominant contribution.

Anyway, new contributions are subdominant unless $M \lesssim \Lambda(\ll M_\mathrm{P})$.

Supergravity

Equation of motion for a complex scalar field X in supergravity

$$
\begin{aligned}
0 =& K_{\bar{X}i\bar{j}} \left(-\frac{i}{2} \left(\chi^i \sigma^\mu (\partial_\mu - iA_\mu) \bar{\chi}^{\bar{j}} + \bar{\chi}^{\bar{j}} \bar{\sigma}^\mu (\partial_\mu + iA_\mu) \chi^i \right) + F^i \bar{F}^{\bar{j}} \right) + K_{\bar{X}i} \Box \Phi^i + K_{\bar{X}ij} \partial^\mu \Phi^i \partial_\mu \Phi^j \\
&+ i K_{\bar{X}ij\bar{k}} \chi^j \sigma^\mu \bar{\chi}^{\bar{k}} \partial_\mu \Phi^i + \frac{i}{2} K_{\bar{X}i\bar{j}} \partial_\mu (\chi^i \sigma^\mu \bar{\chi}^{\bar{j}}) - \frac{1}{2} K_{\bar{X}i\bar{j}\bar{k}} F^i \bar{\chi}^{\bar{j}} \bar{\chi}^{\bar{k}} - \frac{1}{2} K_{\bar{X}\bar{i}jk} \bar{F}^{\bar{i}} \chi^j \chi^k + \frac{1}{4} K_{\bar{X}ij\bar{k}\bar{\ell}} \chi^i \chi^j \bar{\chi}^{\bar{k}} \bar{\chi}^{\bar{\ell}} \\
&+ \left(e^{K/2} \bar{D}_{\bar{i}} \bar{W} \right)_{\bar{X}} \bar{F}^{\bar{i}} - \frac{1}{2} m_{\bar{i}\bar{j}\bar{X}} \bar{\chi}^{\bar{i}} \bar{\chi}^{\bar{j}} \\
&+ 3 e^K W \bar{D}_{\bar{X}} \bar{W} - \frac{1}{2} m_{ij\bar{X}} \chi^i \chi^j + \left(e^{K/2} D_i W \right)_{\bar{X}} F^i - \frac{1}{4M_{\mathrm{P}}^2} K_{\bar{X}i\bar{k}} K_{j\bar{\ell}} \chi^i \chi^j \bar{\chi}^{\bar{k}} \bar{\chi}^{\bar{\ell}} \\
&- \frac{K_{i\bar{j}}}{2M_{\mathrm{P}}^2} \chi^i \sigma^\mu \bar{\chi}^{\bar{j}} K_{\bar{X}i} \partial_\mu \Phi^i - \frac{1}{4M_{\mathrm{P}}^2} K_{i\bar{j}} K_{\bar{X}} \partial_\mu \left(\chi^i \sigma^\mu \bar{\chi}^{\bar{j}} \right) - \frac{1}{4M_{\mathrm{P}}^2} \left(K_{i\bar{j}k} \partial_\mu \Phi^k + K_{i\bar{j}\bar{k}} \partial_\mu \bar{\Phi}^{\bar{k}} \right) K_{\bar{x}} \chi^i \sigma^\mu \bar{\chi}^{\bar{j}} \\
&+ \frac{i}{4M_{\mathrm{P}}^2} K_{\bar{X}i} \partial_\nu \Phi^i \left(\bar{\psi}_\mu \bar{\sigma}^{[\mu} \sigma^\nu \bar{\sigma}^{\rho]} \psi_\rho - \psi_\mu \sigma^{[\mu} \bar{\sigma}^\nu \sigma^{\rho]} \bar{\psi}_\rho \right) + \frac{i}{8M_{\mathrm{P}}^2} K_{\bar{X}} \partial^\mu \left(\bar{\psi}_\mu \bar{\sigma}^{[\mu} \sigma^\nu \bar{\sigma}^{\rho]} \psi_\rho - \psi_\mu \sigma^{[\mu} \bar{\sigma}^\nu \sigma^{\rho]} \bar{\psi}_\rho \right) \\
&- \frac{1}{2M_{\mathrm{P}}^2} K_{\bar{X}} m_{3/2} \psi_\mu \sigma^{\mu\nu} \psi_\nu - e^{K/2} \left(\bar{W}_{\bar{X}} + \frac{1}{2} K_{\bar{X}} \bar{W} \right) \bar{\psi}_\mu \bar{\sigma}^{\mu\nu} \bar{\psi}_\nu \\
&+ \frac{2\sqrt{2}}{M_{\mathrm{P}}} \left(-K_{\bar{X}ij} \psi_\mu \sigma^{\mu\nu} \chi^i \partial_\nu \Phi^j + K_{\bar{X}i\bar{j}} \bar{\psi}_\mu \bar{\sigma}^{\mu\nu} \bar{\chi}^{\bar{j}} \partial_\nu \Phi^i \right) - \frac{2\sqrt{2}}{M_{\mathrm{P}}^2} K_{i\bar{X}} \partial_\nu \left(\psi_\mu \sigma^{\mu\nu} \chi^i \right) \\
&+ \frac{i}{\sqrt{2} M_{\mathrm{P}}} \bar{\psi}_\mu \bar{\sigma}^\mu \left(\left(e^{K/2} D_i W \right)_{\bar{X}} \chi^i + i K_{\bar{X}i\bar{j}} \sigma^\nu \partial_\nu \Phi^i \bar{\chi}^{\bar{j}} \right) \\
&+ \frac{i}{\sqrt{2} M_{\mathrm{P}}} \psi_\mu \sigma^\mu \left(\left(e^{K/2} \bar{D}_{\bar{j}} \bar{W} \right)_{\bar{X}} \bar{\chi}^{\bar{j}} - i K_{\bar{X}ij} \bar{\sigma}^\nu \partial_\nu \Phi^j \chi^i \right) + \frac{1}{\sqrt{2} M_{\mathrm{P}}} K_{i\bar{X}} \partial_\nu \left(\psi_\mu \sigma^\mu \bar{\sigma}^\nu \chi^i \right) \\
&+ K_{\bar{X}i\bar{j}} \left(-\frac{i}{16} e^{-1} \epsilon^{\mu\nu\rho\sigma} \left(\psi_\mu \sigma_\nu \bar{\psi}_\rho + \bar{\psi}_\mu \bar{\sigma}_\nu \psi_\rho \right) \bar{\chi}^{\bar{j}} \bar{\sigma}_\sigma \chi^i - \frac{1}{2} \bar{\psi}_\mu \bar{\chi}^{\bar{j}} \psi^\mu \chi^i \right),
\end{aligned}
\tag{67}
$$

minor extension of the global SUSY result

Genuine supergravity effects

There are new contributions at the fermion quartic order.
We do not find new contributions at the quadratic order.