Seminario de Gravitación y Teoría de Campos 11/01/2018

Flipped No-Scale Inflation

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Based mostly on 1704.07331, with

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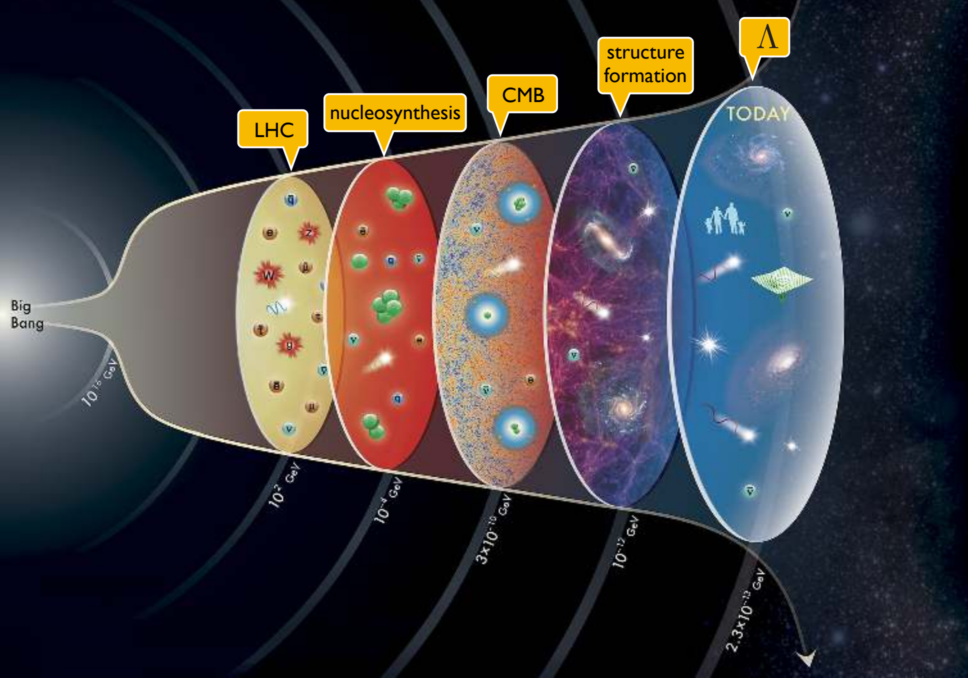
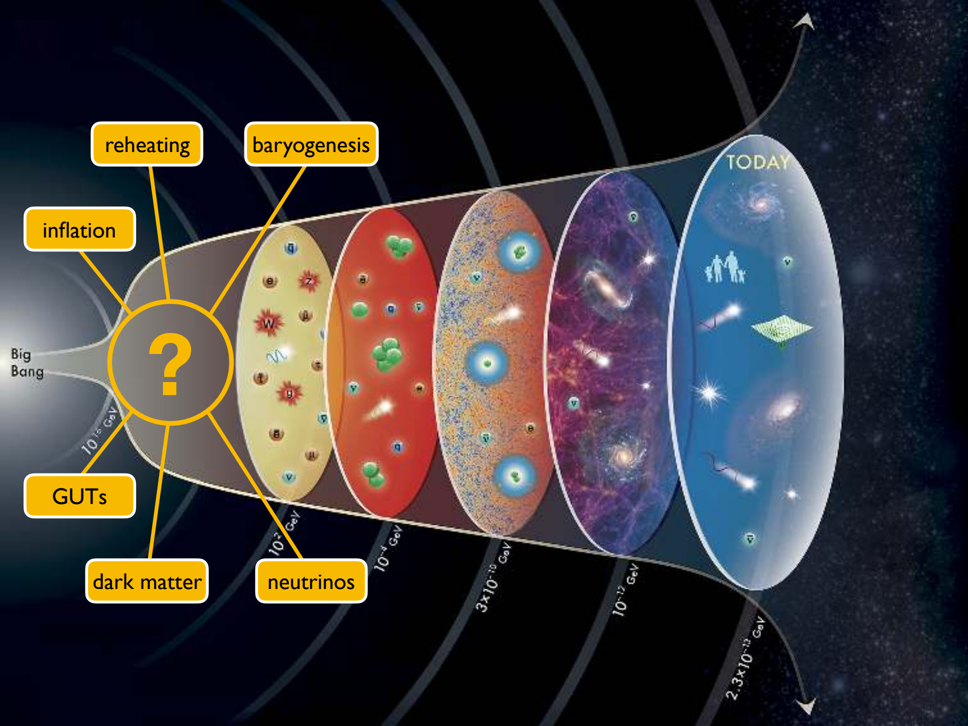
RICE

- Motivation
- No-scale Inflation
- Flipped-$SU(5\,)$
- Results
- Conclusion

Motivation


LHC
nucleosynthesis
CMB
structure formation
Λ
TODAY
Big Bang
10^{15} GeV
10^{2} GeV
10^{-4} GeV
$3x10^{-10}$ GeV
10^{-12} GeV
$2.3x10^{-13}$ GeV



reheating

baryogenesis

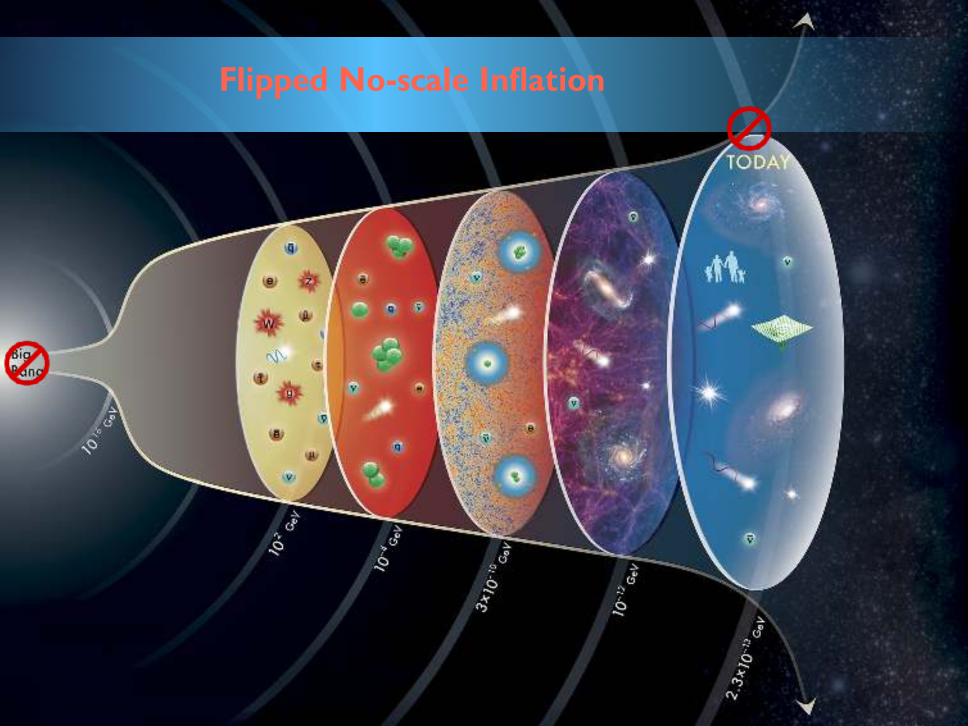
inflation

GUTs

dark matter

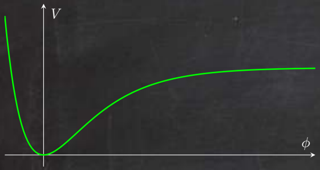
neutrinos

Flipped No-scale Inflation



No-Scale Inflation

Cosmological inflation is the early period of accelerated expansion, $a \sim e^{Ht}$



$$\mathcal{S} = \int d^4x \sqrt{-g} \left[\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right]$$

$$ds^2 = dt^2 - a(t)^2 d\mathbf{x}^2$$

$$\downarrow$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$H^2 \equiv \left(\frac{\dot{a}}{a} \right)^2 = \frac{1}{3} \left(\frac{\dot{\phi}^2}{2} + V(\phi) \right)$$

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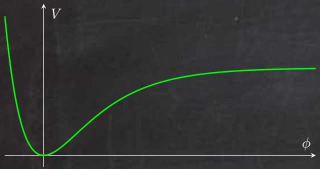
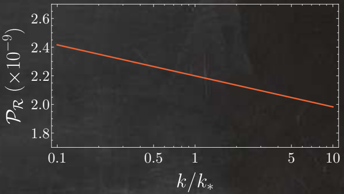


$$\xrightarrow{\substack{\phi \to \phi + \delta\phi \\ g \to g + \delta g}}$$



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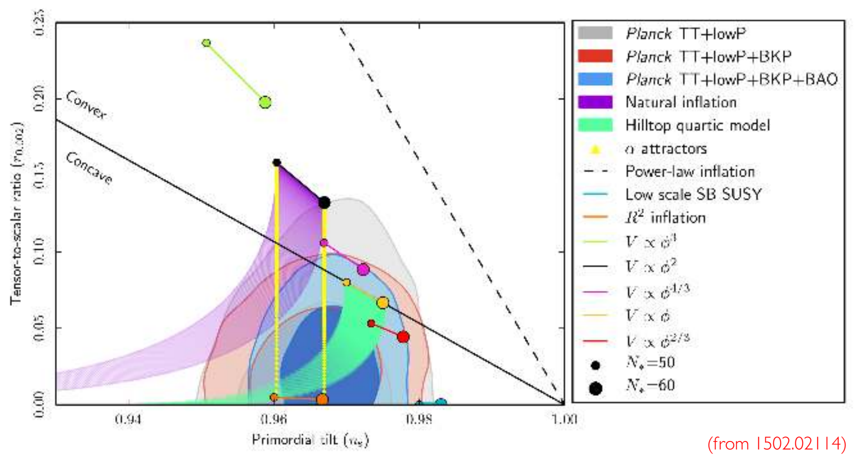
$$\mathcal{P}_{\mathcal{R}} = \underbrace{\frac{H^4}{4\pi^2 \dot{\phi}^2}}_{A_S} \left(\frac{k}{aH} \right)^{n_s - 1}$$

$$\mathcal{P}_{\mathcal{T}} = \underbrace{\frac{2}{\pi^2} H^2}_{A_T} \left(\frac{k}{aH} \right)^{n_T}$$

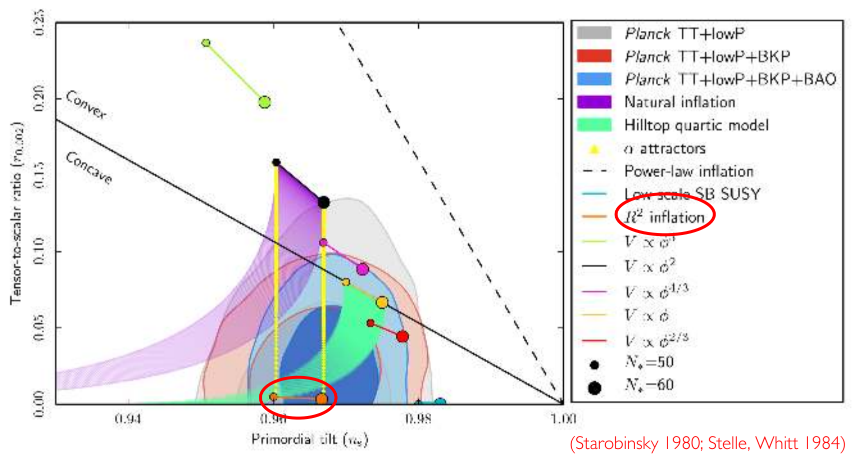
No-Scale Inflation



(from 1502.02114)

$$\ln(10^{10} A_S) = 3.094 \pm .034\,, \qquad n_s = 1 + \frac{d\ln \mathcal{P}_{\mathcal{R}}}{d\ln k}\,, \qquad r = \frac{\mathcal{P}_T}{\mathcal{P}_{\mathcal{R}}}$$

No-Scale Inflation



(Starobinsky 1980; Stelle, Whitt 1984)

$$\mathcal{S} = \frac{1}{2}\int d^4x\sqrt{-g}\left(-R+\frac{R^2}{6m^2}\right)$$

$$= \int d^4x\sqrt{-\tilde{g}}\left[-\frac{\tilde{R}}{2}+\frac{1}{2}(\partial_\mu\phi)^2-\frac{3}{4}m^2\left(1-e^{-\sqrt{2/3}\phi}\right)^2\right] \qquad (\tilde{g}\to\Omega(\phi)g)$$

Why isn't this it?

- The observed A_S requires $m \simeq 10^{-5} M_P$! What is ϕ then?
- For elementary ϕ, flatness of the potential will be destroyed by radiative corrections
- Unnatural initial conditions (homogeneity in $\sim 10^3$ Hubble radii *before* inflation)
  (Dalianis, Farakos 1502.01246)

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Naturalness through (super)symmetry!

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Naturalness through (super)symmetry!

It is the (single) extension of Poincaré symmetry, which connects bosons and fermions

$$\{Q_\alpha, Q_\beta\} = \{\bar{Q}_{\dot\alpha}, \bar{Q}_{\dot\beta}\} = 0\,, \quad \{Q_\alpha, \bar{Q}_{\dot\alpha}\} = 2\sigma^\mu_{\alpha\dot\alpha} P_\mu\,,$$

$$Q\,|\mathrm{Boson}\rangle = |\mathrm{Fermion}\rangle\,, \quad Q\,|\mathrm{Fermion}\rangle = |\mathrm{Boson}\rangle$$

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Particles are arranged in irreps of the superalgebra (supermultiplets)

Chiral superfields:	matter (Higgs) + susy partners	$\Phi \supset (\phi, \psi, F)$
Vector superfields:	gauge bosons + susy partners	$V^a \supset (A^a_\mu, \lambda^a, D^a)$

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Radiative corrections are multiplicative

$\Delta m_\phi^2 \sim$

Λ^2 $+$

$(-)\Lambda^2$

Local supersymmetry = supersymmetry + gravity = supergravity

$$e^{-1}\mathcal{L} = -\frac{R}{2} - \frac{e^{-1}}{2}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_5\gamma_\nu\tilde{D}_\rho\psi_\sigma$$

The coupling of supergravity to matter is in general complicated 🔗

For chiral fields it is determined by the (real) Kähler potential $K(\Phi, \bar{\Phi})$ and the (holomorphic) superpotential $W(\Phi)$ through

$$G = K + \ln|W|^2 \,.$$

Coupling to gauge fields is determined by the gauge kinetic function $f_{ab}(\Phi)$.

In the global limit ($M_P \to \infty$), renormalizable theories have quadratic K, cubic W and $f_{ab} = \delta_{ab}$.

🔗(Cremmer, Ferrara, Girardello & Van Proeyen, 1983)

Local supersymmetry = supersymmetry + gravity = supergravity

$$
\begin{aligned}
e^{-1}\mathcal{L} \;=\; & -\frac{R}{2} - \frac{e^{-1}}{2}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_5\gamma_\nu\tilde{D}_\rho\psi_\sigma + \frac{i}{2}e^{G/2}\bar{\psi}_{\mu\mathrm{L}}\sigma^{\mu\nu}\psi_{\nu\mathrm{R}} + \frac{e^{-1}}{8}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho\left(G^iD_\sigma\phi_i - G_iD_\sigma\bar{\phi}^i\right)\\
& + G^i_jD_\mu\phi_iD^\mu\bar{\phi}^j - e^G(G_i(G^{-1})^i_jG^j - 3) - \frac{1}{4}(\mathrm{Re}\,f_{ab})F_{a\,\mu\nu}F^{\mu\nu}_b + \frac{i}{4}(\mathrm{Im}\,f_{ab})F_{a\,\mu\nu}\tilde{F}^{\mu\nu}_b\\
& - \frac{g^2}{2}(\mathrm{Re}\,f^{-1}_{ab})G^i(T_a)^j_i\phi_jG^k(T_b)^l_k\phi_l + \Bigg[\frac{i}{2}G^i_j\bar{\chi}_{i\mathrm{R}}\gamma^\mu D_\mu\chi^j_{\mathrm{R}} + \frac{i}{2}\bar{\chi}_{i\mathrm{R}}\not{D}\phi_j\chi^k_{\mathrm{R}}\left(-G^{ij}_k + \frac{1}{2}G^i_kG^j\right)\\
& + \frac{1}{\sqrt{2}}G^j_i\bar{\psi}_{\mu\mathrm{R}}\not{D}\bar{\phi}^i\gamma^\mu\chi_{j\mathrm{L}} + \frac{1}{2}\,\mathrm{Re}\,f_{ab}\left(\frac{i}{2}\bar{\lambda}_a\not{D}\lambda_b - \frac{1}{4}\bar{\lambda}_a\gamma^\mu\sigma^{\nu\rho}\psi_\mu F_{b\,\nu\rho} - \frac{i}{2}G^iD^\mu\phi_i\bar{\lambda}_{a\mathrm{R}}\gamma_\mu\lambda_{b\mathrm{R}}\right)\\
& + \frac{1}{8}\,\mathrm{Im}\,f_{ab}\;\mathrm{e}^{-1}D_\mu(\mathrm{e}\bar{\lambda}_a\gamma_5\gamma^\mu\lambda_b) - \frac{i}{4\sqrt{2}}(f_{ab})^{,i}\;\bar{\chi}_{i\mathrm{L}}\sigma^{\mu\nu}F_{a\,\mu\nu}\lambda_{b\mathrm{R}} + \frac{i}{\sqrt{2}}e^{G/2}G^i\bar{\psi}_{\mu\mathrm{L}}\gamma^\mu\chi_{i\mathrm{L}}\\
& + \frac{1}{2}e^{G/2}(-G^{ij} - G^iG^j + G^{ij}_k(G^{-1})^k_lG^l)\bar{\chi}_{i\mathrm{R}}\chi_{j\mathrm{L}} + \frac{i}{16}G^j_i\bar{\chi}_{i\mathrm{L}}\gamma_\sigma\chi_{j\mathrm{L}}(\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho - i\bar{\psi}^\mu\gamma^5\gamma_\sigma\psi_\mu)\\
& + \left(\frac{1}{8}G^{ij}_{kl} - \frac{1}{8}G^{ij}_m(G^{-1})^m_nG^n_{kl} - \frac{1}{16}G^i_kG^j_l\right)\bar{\chi}_{i\mathrm{R}}\chi_{j\mathrm{L}}\bar{\chi}^k_{\mathrm{L}}\chi^l_{\mathrm{R}} + \frac{1}{4}e^{G/2}(\bar{f}_{ab})_{,j}(G^{-1})^j_kG^k\bar{\lambda}_{a\mathrm{L}}\lambda_{b\mathrm{R}}\\
& - \frac{g}{2}G^i(T_a)_{ij}\phi_j\bar{\psi}_{\mu\mathrm{R}}\gamma^\mu\lambda_{a\mathrm{R}} - ig\sqrt{2}G^j_i(T_a)_{jk}\phi_k\bar{\lambda}_{a\mathrm{L}}\chi^i_{\mathrm{R}} - \frac{i}{2\sqrt{2}}g(\mathrm{Re}\,f_{ab})^{-1}(f_{bc})^{,k}G^i(T_a)_{ij}\phi_j\bar{\chi}_{k\mathrm{R}}\lambda_{c\mathrm{L}}\\
& + \frac{3}{32}[(\mathrm{Re}\,f_{ab})\bar{\lambda}_{a\mathrm{R}}\gamma_\mu\lambda_{b\mathrm{R}}]^2 + \frac{i}{16}(\mathrm{Re}\,f_{ab})\bar{\lambda}_a\gamma^\mu\sigma^{\rho\sigma}\psi_\mu\bar{\psi}_\rho\gamma_\sigma\lambda_b - \frac{1}{32}(G^{-1})^k_l(f_{ab})^{,l}(\bar{f}_{cd})_{,k}\bar{\lambda}_{a\mathrm{R}}\lambda_{b\mathrm{L}}\bar{\lambda}_{c\mathrm{L}}\lambda_{d\mathrm{R}}\\
& + \frac{1}{4\sqrt{2}}(f_{ab})^{,i}\left(\bar{\chi}_{i\mathrm{R}}\sigma^{\mu\nu}\lambda_{a\mathrm{L}}\bar{\psi}_{\nu\mathrm{R}}\gamma_\mu\lambda_{b\mathrm{R}} + \frac{i}{2}\bar{\psi}_{\mu L}\gamma^\mu\chi_{i\mathrm{L}}\bar{\lambda}_{a\mathrm{L}}\lambda_{b\mathrm{L}}\right) + \frac{1}{16}\bar{\chi}_{i\mathrm{R}}\gamma^\mu\chi^j_{\mathrm{R}}\bar{\lambda}_{d\mathrm{L}}\gamma_\mu\lambda_{c\mathrm{L}}\Big[G^i_j(\mathrm{Re}\,f_{cd})\\
& + \frac{1}{2}\mathrm{Re}\,\left(f^{-1}_{ab}(f_{ac})^{,i}(\bar{f}_{bd})_{,j}\right)\Big] + \frac{1}{128}\bar{\chi}_{i\mathrm{R}}\sigma_{\mu\nu}\chi_{j\mathrm{L}}\bar{\lambda}_{c\mathrm{R}}\sigma^{\mu\nu}\lambda_{d\mathrm{L}}\,\mathrm{Re}\,\left(f^{-1}_{ab}(f_{ac})^{,i}(f_{bd})^{,j}\right)\\
& - \frac{1}{16}\bar{\chi}_{i\mathrm{R}}\chi_{j\mathrm{L}}\bar{\lambda}_{c\mathrm{R}}\lambda_{d\mathrm{L}}\left(2G^{ij}_k(G^{-1})^k_l(f_{cd})^{,l} - 2(f_{cd})^{,ij} + \frac{1}{2}\mathrm{Re}\,f^{-1}_{ab}(f_{ac})^{,i}(\bar{f}_{bd})_{,j}\right) + \mathrm{h.c.}\Bigg]
\end{aligned}
$$

Local supersymmetry = supersymmetry + gravity = supergravity

$$e^{-1}\mathcal{L} = -\frac{R}{2} - \frac{e^{-1}}{2}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_5\gamma_\nu\tilde{D}_\rho\psi_\sigma + \boxed{\frac{i}{2}e^{G/2}\bar{\psi}_{\mu\mathrm{L}}\sigma^{\mu\nu}\psi_{\nu\mathrm{R}}} + \frac{e^{-1}}{8}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho\left(G^iD_\sigma\phi_i - G_iD_\sigma\bar{\phi}^i\right)$$

$$+ G^i_jD_\mu\phi_iD^\mu\bar{\phi}^j - e^G(G_i(G^{-1})^i_jG^j - 3) - \frac{1}{4}(\mathrm{Re}\, f_{ab})F_{a\,\mu\nu}F^{\mu\nu}_b + \frac{i}{4}(\mathrm{Im}\, f_{ab})F_{a\,\mu\nu}\tilde{F}^{\mu\nu}_b$$

$$- \frac{g^2}{2}(\mathrm{Re}\, f^{-1}_{ab})G^i(T_a)^j_i\phi_jG^k(T_b)^l_k\phi_l + \Bigg[\frac{i}{2}G^i_j\bar{\chi}_{i\mathrm{R}}\gamma^\mu D_\mu\chi^j_\mathrm{R} + \frac{i}{2}\bar{\chi}_{i\mathrm{R}}\not{D}\phi_j\chi^k_\mathrm{R}\left(-G^{ij}_k + \frac{1}{2}G^i_kG^j\right)$$

$$+ \frac{1}{\sqrt{2}}G^j_i\bar{\psi}_{\mu\mathrm{R}}\not{D}\bar{\phi}^i\gamma^\mu\chi_{j\mathrm{L}} + \frac{1}{2}\,\mathrm{Re}\, f_{ab}\left(\frac{i}{2}\bar{\lambda}_a\not{D}\lambda_b - \frac{1}{4}\bar{\lambda}_a\gamma^\mu\sigma^{\nu\rho}\psi_\mu F_{b\,\nu\rho} - \frac{i}{2}G^iD^\mu\phi_i\bar{\lambda}_{a\mathrm{R}}\gamma_\mu\lambda_{b\mathrm{R}}\right)$$

$$+ \frac{1}{8}\,\mathrm{Im}\, f_{ab}\ \mathrm{e}^{-1}D_\mu(\mathrm{e}\bar{\lambda}_a\gamma_5\gamma^\mu\lambda_b) - \frac{i}{4\sqrt{2}}(f_{ab})^{,i}\ \bar{\chi}_{i\mathrm{L}}\sigma^{\mu\nu}F_{a\,\mu\nu}\lambda_{b\mathrm{R}} + \frac{i}{2}e^{G/2}G^i\bar{\psi}_{\mu\mathrm{L}}\gamma^\mu\chi_{i\mathrm{L}}$$

$$+ \frac{1}{2}e^{G/2}(-G^{ij} - G^iG^j \quad\quad \epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho - i\bar{\psi}^\mu\gamma^5\gamma_\sigma\psi_\mu)$$

$$+ \left(\frac{1}{8}G^{ij}_{kl} - \frac{1}{8}G^{ij}_m(G^{-1} \quad\quad \bar{f}_{ab})_{,j}(G^{-1})^j_kG^k\bar{\lambda}_{a\mathrm{L}}\lambda_{b\mathrm{R}}\right.$$

$$- \frac{g}{2}G^i(T_a)_{ij}\phi_j\bar{\psi}_{\mu\mathrm{R}}\gamma^\mu\lambda_{a\mathrm{R}} - ig\sqrt{2}G^j_i(T_a)_{jk}\phi_k\bar{\lambda}_{a\mathrm{L}}\chi^i_\mathrm{R} - \frac{i}{2\sqrt{2}}g(\mathrm{Re}\, f_{ab})^{-1}(f_{bc})^{,k}G^i(T_a)_{ij}\phi_j\bar{\chi}_{k\mathrm{R}}\lambda_{c\mathrm{L}}$$

$$+ \frac{3}{32}[(\mathrm{Re}\, f_{ab})\bar{\lambda}_{a\mathrm{R}}\gamma_\mu\lambda_{b\mathrm{R}}]^2 + \frac{i}{16}(\mathrm{Re}\, f_{ab})\bar{\lambda}_a\gamma^\mu\sigma^{\rho\sigma}\psi_\mu\bar{\psi}_\rho\gamma_\sigma\lambda_b - \frac{1}{32}(G^{-1})^k_l(f_{ab})^{,l}(\bar{f}_{cd})_{,k}\bar{\lambda}_{a\mathrm{R}}\lambda_{b\mathrm{L}}\bar{\lambda}_{c\mathrm{L}}\lambda_{d\mathrm{R}}$$

$$+ \frac{1}{4\sqrt{2}}(f_{ab})^{,i}\left(\bar{\chi}_{i\mathrm{R}}\sigma^{\mu\nu}\lambda_{a\mathrm{L}}\bar{\psi}_{\nu\mathrm{R}}\gamma_\mu\lambda_{b\mathrm{R}} + \frac{i}{2}\bar{\psi}_{\mu L}\gamma^\mu\chi_{i\mathrm{L}}\bar{\lambda}_{a\mathrm{L}}\lambda_{b\mathrm{L}}\right) + \frac{1}{16}\bar{\chi}_{i\mathrm{R}}\gamma^\mu\chi^j_\mathrm{R}\bar{\lambda}_{d\mathrm{L}}\gamma_\mu\lambda_{c\mathrm{L}}\Big[G^i_j(\mathrm{Re}\, f_{cd})$$

$$+ \frac{1}{2}\mathrm{Re}\,\left(f^{-1}_{ab}(f_{ac})^{,i}(\bar{f}_{bd})_{,j}\right)\Big] + \frac{1}{128}\bar{\chi}_{i\mathrm{R}}\sigma_{\mu\nu}\chi_{j\mathrm{L}}\bar{\lambda}_{c\mathrm{R}}\sigma^{\mu\nu}\lambda_{d\mathrm{L}}\,\mathrm{Re}\,\left(f^{-1}_{ab}(f_{ac})^{,i}(f_{bd})^{,j}\right)$$

$$- \frac{1}{16}\bar{\chi}_{i\mathrm{R}}\chi_{j\mathrm{L}}\bar{\lambda}_{c\mathrm{R}}\lambda_{d\mathrm{L}}\left(2G^{ij}_k(G^{-1})^k_l(f_{cd})^{,l} - 2(f_{cd})^{,ij} + \frac{1}{2}\mathrm{Re}\, f^{-1}_{ab}(f_{ac})^{,i}(\bar{f}_{bd})_{,j}\right) + \mathrm{h.c.}\Bigg]$$

local susy broken if

$$m_{3/2} = \langle e^{G/2}\rangle \neq 0$$

Local supersymmetry = supersymmetry + gravity = supergravity

$$
\begin{aligned}
e^{-1}\mathcal{L} \;=\; & -\frac{R}{2} - \frac{e^{-1}}{2}\epsilon^{\mu\nu\rho\sigma}\bar\psi_\mu\gamma_5\gamma_\nu\tilde D_\rho\psi_\sigma + \frac{i}{2}e^{G/2}\bar\psi_{\mu\mathrm{L}}\sigma^{\mu\nu}\psi_{\nu\mathrm{R}} + \frac{e^{-1}}{8}\epsilon^{\mu\nu\rho\sigma}\bar\psi_\mu\gamma_\nu\psi_\rho\left(G^iD_\sigma\phi_i - G_iD_\sigma\bar\phi^i\right)\\
& + G^i_jD_\mu\phi_iD^\mu\bar\phi^j - e^G(G_i(G^{-1})^i_jG^j - 3) - \frac{1}{4}(\mathrm{Re}\, f_{ab})F_{a\,\mu\nu}F^{\mu\nu}_b + \frac{i}{4}(\mathrm{Im}\, f_{ab})F_{a\,\mu\nu}\tilde F^{\mu\nu}_b\\
& - \frac{g^2}{2}(\mathrm{Re}\, f^{-1}_{ab})G^i(T_a)^j_i\phi_jG^k(T_b)^l_k\phi_l + \Bigg[\frac{i}{2}G^i_j\bar\chi_{i\mathrm{R}}\gamma^\mu D_\mu\chi^j_{\mathrm{R}} + \frac{i}{2}\bar\chi_{i\mathrm{R}}\not{D}\phi_j\chi^k_{\mathrm{R}}\left(-G^{ij}_k + \frac{1}{2}G^i_kG^j\right)\\
& + \frac{1}{\sqrt2}G^j_i\bar\psi_{\mu\mathrm{R}}\not{D}\bar\phi^i\gamma^\mu\chi_{j\mathrm{L}} + \frac{1}{2}\,\mathrm{Re}\, f_{ab}\,\left(\frac{i}{2}\bar\lambda_a\not{D}\lambda_b - \frac{1}{4}\bar\lambda_a\gamma^\mu\sigma^{\nu\rho}\psi_\mu F_{b\,\nu\rho} - \frac{i}{2}G^iD^\mu\phi_i\bar\lambda_{a\mathrm{R}}\gamma_\mu\lambda_{b\mathrm{R}}\right)\\
& + \frac{1}{8}\,\mathrm{Im}\, f_{ab}\;\mathrm{e}^{-1}D_\mu(\mathrm{e}\bar\lambda_a\gamma_5\gamma^\mu\lambda_b) - \frac{i}{4\sqrt2}(f_{ab})^{,i}\;\bar\chi_{i\mathrm{L}}\sigma^{\mu\nu}F_{a\,\mu\nu}\lambda_{b\mathrm{R}} + \frac{i}{\sqrt2}e^{G/2}G^i\bar\psi_{\mu\mathrm{L}}\gamma^\mu\chi_{i\mathrm{L}}\\
& + \boxed{\frac{1}{2}e^{G/2}(-G^{ij} - G^iG^j + G^{ij}_k(G^{-1})^k_lG^l)\bar\chi_{i\mathrm{R}}\chi_{j\mathrm{L}}} + \frac{i}{16}G^j_i\bar\chi_{i\mathrm{L}}\gamma_\sigma\chi_{j\mathrm{L}}(\epsilon^{\mu\nu\rho\sigma}\bar\psi_\mu\gamma_\nu\psi_\rho - i\bar\psi^\mu\gamma^5\gamma_\sigma\psi_\mu)\\
& + \left(\frac{1}{8}G^{ij}_{kl} - \frac{1}{8}G^{ij}_m(G^{-1})^m_nG^n_{kl} - \frac{1}{16}G^i_kG^j_l\right)\bar\chi_{i\mathrm{R}}\chi_{j\mathrm{L}}\bar\chi^k_{\mathrm{L}}\chi^l_{\mathrm{R}} + \frac{1}{4}e^{G/2}(\bar f_{ab})_{,j}(G^{-1})^j_kG^k\bar\lambda_{a\mathrm{L}}\lambda_{b\mathrm{R}}\\
& - \frac{g}{2}G^i(T_a)_{ij}\phi_j\bar\psi_{\mu\mathrm{R}}\gamma^\mu\lambda_{a\mathrm{R}} - ig\sqrt2G^j_i(T_a)_{jk}\phi_k\bar\lambda_{a\mathrm{L}}\chi^i_{\mathrm{R}} - \frac{i}{2\sqrt2}g(\mathrm{Re}\, f_{ab})^{-1}(f_{bc})^{,k}G^i(T_a)_{ij}\phi_j\bar\chi_{k\mathrm{R}}\lambda_{c\mathrm{L}}\\
& + \frac{3}{32}[(\mathrm{Re}\, f_{ab})\bar\lambda \qquad\qquad {}^{,l}(\bar f_{cd})_{,k}\bar\lambda_{a\mathrm{R}}\lambda_{b\mathrm{L}}\bar\lambda_{c\mathrm{L}}\lambda_{d\mathrm{R}}\\
& + \frac{1}{4\sqrt2}(f_{ab})^{,i}\,(\qquad\qquad {}_{d\mathrm{L}}\gamma_\mu\lambda_{c\mathrm{L}}\left[G^i_j(\mathrm{Re}\, f_{cd})\right.\\
& + \frac{1}{2}\mathrm{Re}\,\left(f^{-1}_{ab}(f \qquad\qquad {}^{,j}\right)\\
& - \frac{1}{16}\bar\chi_{i\mathrm{R}}\chi_{j\mathrm{L}}\bar\lambda_{c\mathrm{R}}\lambda_{d\mathrm{L}}\left(2G^{ij}_k(G^{-1})^k_l(f_{cd})^{,l} - 2(f_{cd})^{,ij} + \frac{1}{2}\mathrm{Re}\, f^{-1}_{ab}(f_{ac})^{,i}(\bar f_{bd})_{,j}\right) + \mathrm{h.c.}\Bigg]
\end{aligned}
$$

chiral fermion masses

$$\mathcal{M}^{ij} = W^{ij} - \frac{2}{3}\frac{W^iW^j}{W} + \mathcal{O}\left(M_P^{-2}\right)$$

Local supersymmetry = supersymmetry + gravity = supergravity

$$
\begin{aligned}
e^{-1}\mathcal{L} \;=\; & -\frac{R}{2} - \frac{e^{-1}}{2}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_5\gamma_\nu\tilde{D}_\rho\psi_\sigma + \frac{i}{2}e^{G/2}\bar{\psi}_{\mu\mathrm{L}}\sigma^{\mu\nu}\psi_{\nu\mathrm{R}} + \frac{e^{-1}}{8}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho\left(G^iD_\sigma\phi_i - G_iD_\sigma\bar{\phi}^i\right) \\
& + \boxed{G^i_jD_\mu\phi_iD^\mu\bar{\phi}^j - e^G(G_i(G^{-1})^i_jG^j - 3)} - \frac{1}{4}(\mathrm{Re}\,f_{ab})F_{a\,\mu\nu}F^{\mu\nu}_b + \frac{i}{4}(\mathrm{Im}\,f_{ab})F_{a\,\mu\nu}\tilde{F}^{\mu\nu}_b \\
& - \frac{g^2}{2}(\mathrm{Re}\,f^{-1}_{ab})G^i(T_a)^j_i\phi_jG^k(T_b)^l_k\phi_l + \Bigg[\frac{i}{2}G^i_j\bar{\chi}_{i\mathrm{R}}\gamma^\mu D_\mu\chi^j_\mathrm{R} + \frac{i}{2}\bar{\chi}_{i\mathrm{R}}\not{D}\phi_j\chi^k_\mathrm{R}\left(-G^{ij}_k + \frac{1}{2}G^i_kG^j\right) \\
& + \frac{1}{\sqrt{2}}G^j_i\bar{\psi}_{\mu\mathrm{R}}\not{D}\bar{\phi}^i\gamma^\mu\chi_{j\mathrm{L}} + \frac{1}{2}\,\mathrm{Re}\,f_{ab}\left(\frac{i}{2}\bar{\lambda}_a\not{D}\lambda_b - \frac{1}{4}\bar{\lambda}_a\gamma^\mu\sigma^{\nu\rho}\psi_\mu F_{b\,\nu\rho} - \frac{i}{2}G^iD^\mu\phi_i\bar{\lambda}_{a\mathrm{R}}\gamma_\mu\lambda_{b\mathrm{R}}\right) \\
& + \frac{1}{8}\,\mathrm{Im}\,f_{ab}\;\mathrm{e}^{-1}D_\mu(\mathrm{e}\bar{\lambda}_a\gamma_5\gamma^\mu\lambda_b) - \frac{i}{4\sqrt{2}}(f_{ab})^{,i}\;\bar{\chi}_{i\mathrm{L}}\sigma^{\mu\nu}F_{a\,\mu\nu}\lambda_{b\mathrm{R}} + \frac{i}{\sqrt{2}}e^{G/2}G^i\bar{\psi}_{\mu\mathrm{L}}\gamma^\mu\chi_{i\mathrm{L}} \\
& - \frac{1}{16}\bar{\chi}_{i\mathrm{R}}\chi_{j\mathrm{L}}\bar{\lambda}_{c\mathrm{R}}\lambda_{d\mathrm{L}}\left(2G^{ij}_k(G^{-1})^k_l(f_{cd})^{,l} - 2(f_{cd})^{,ij} + \frac{1}{2}\mathrm{Re}\,f^{-1}_{ab}(f_{ac})^{,i}(\bar{f}_{bd})_{,j}\right) + \mathrm{h.c.}\Bigg]
\end{aligned}
$$

chiral scalars

$$
\begin{aligned}
e^{-1}\mathcal{L} \;&=\; K^i_j\partial_\mu\,\phi\partial^\mu\phi - e^K\left[(K^{-1})^j_i(K^iW + W^i)(K_j\bar{W} + \bar{W}_j) - 3|W|^2\right] \\
&\sim\; \partial_\mu\phi\,\partial^\mu\phi - \underbrace{e^{\phi^2}}_{\text{too steep}}\Big[\underbrace{\lambda_0 + \lambda_1\phi + \cdots + \lambda_8\phi^8}_{\text{‘holes’ of depth } \sim\, -M_P^4}\Big]
\end{aligned}
$$

Consider no-scale $SU(N,1)/SU(N) \times U(1)$ supergravity

$$K = -3\ln\left(T + \bar{T} - \frac{1}{3}\sum_i |\phi_i|^2\right) + \cdots$$

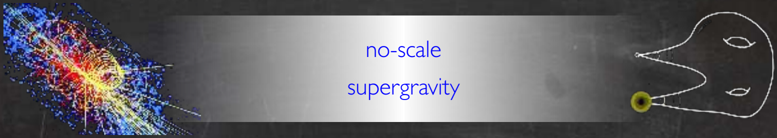
(Cremmer, Ferrara, Kounnas & Nanopoulos, 1983)

No-Scale Inflation

Consider no-scale $SU(N,1)/SU(N) \times U(1)$ supergravity

$$K = -3\ln\left(T + \bar{T} - \frac{1}{3}\sum_i |\phi_i|^2\right) + \cdots$$

- It is the EFT of orbifold compactifications of strings



low energy physics, $E \ll M_P$

$E \lesssim M_P$

string dynamics, $E \gtrsim M_P$

- A sliding gravitino mass, $m_{3/2}^2 = \langle T + \bar{T}\rangle^{-3}$. Soft susy-breaking parameters are radiatively determined

$$m_0 = A = B = 0\,, \quad m_{1/2} \neq 0$$

(Witten, 1985)

- Global-like potential, $V = e^{2K/3}|W^i|^2$. Minimum for $W^i = 0 \quad \Rightarrow \quad V_0 = 0$.

- Global-like potential, $V = e^{2K/3}|W^i|^2$. Minimum for $W^i = 0 \quad \Rightarrow \quad V_0 = 0$.
- With cubic W, no-scale inflation → Starobinsky-like inflation ⚭

Cecotti, 1987

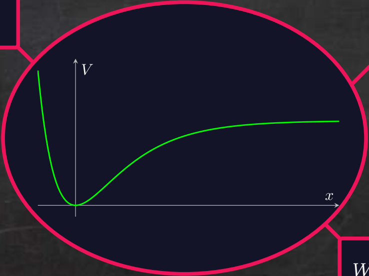
$$W = \sqrt{3}m\phi(T - 1/2)$$

$$\text{Re } T = \frac{1}{2}e^{\sqrt{2/3}x}$$

Ellis, Nanopoulos, Olive, 2013

$$W = m\left(\frac{\phi^2}{2} - \frac{\phi^3}{3\sqrt{3}}\right)$$

$$\phi = \sqrt{3}\tanh(x/\sqrt{6})$$



$$W = \sqrt{3}m\phi\left(1 + \phi/\sqrt{3}\right)(T - 1/2)$$

$$\phi = \sqrt{3}\tanh(x/\sqrt{6})$$

⚭(conjectured)

No-Scale Inflation

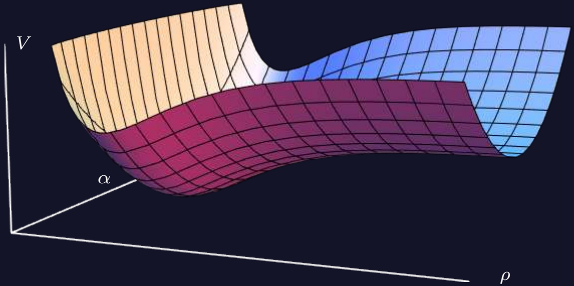
- Global-like potential, $V = e^{2K/3}|W^i|^2$. Minimum for $W^i = 0 \quad \Rightarrow \quad V_0 = 0$.
- With cubic W, no-scale inflation → Starobinsky-like inflation

Ellis, MG, Nanopoulos, Olive, 1405.0271

$$K = -3\ln(T+\bar{T}) + \frac{|\varphi|^2}{(T+\bar{T})^3}$$

$$W = \sqrt{3}m\phi(T-1/2)$$

$$T = \frac{1}{2}e^{-\sqrt{2/3}\rho} + \frac{i}{\sqrt{6}}\alpha$$



Flipped $SU(5)$

Supersymmetry improves Grand Unification. We choose Flipped $SU(5)$:

'Regular' $SU(5)$	Flipped $SU(5)$
$\Psi_i = \mathbf{10}_i \quad \ni \{u^c, Q, e^c\}_i$ $\Phi_i = \bar{\mathbf{5}}_i \quad \ni \{d^c, L\}_i$ $\nu_i^c = \mathbf{1}_i$ $\Sigma = \mathbf{24}$ $h = \mathbf{5}$ $\bar{h} = \bar{\mathbf{5}}$	$F_i = (\mathbf{10}, 1)_i \quad \ni \{d^c, Q, \nu^c\}_i$, $\bar{f}_i = (\bar{\mathbf{5}}, -3)_i \quad \ni \{u^c, L\}_i$, $\ell_i^c = (\mathbf{1}, 5)_i \quad \ni \{e^c\}_i$, $H = (\mathbf{10}, 1)$, $\bar{H} = (\overline{\mathbf{10}}, -1)$, $h = (\mathbf{5}, -2)$, $\bar{h} = (\bar{\mathbf{5}}, 2)$
$SU(5) \xrightarrow{\Sigma} SU(3)_C \times SU(2)_L \times U(1)_Y$ $\xrightarrow{h} SU(3)_C \times U(1)_{\mathrm{EM}}$	$SU(5) \times U(1)_X \xrightarrow{H} SU(3)_C \times SU(2)_L \times U(1)_Y$ $\xrightarrow{h} SU(3)_C \times U(1)_{\mathrm{EM}}$
$Y = T_{24} = \frac{1}{\sqrt{60}}\mathrm{diag}(2,2,2,-3,-3)$	$Y = \frac{1}{\sqrt{15}} T_{24} + \frac{1}{5} Q_X$

(Barr, 1982; Derendinger, Kim & Nanopoulos, 1984)

Flipped $SU(5)$

$\mathbb{Z}_2$-symmetric ($H \to -H$) superpotential

$$W = \lambda_1^{ij} F_i F_j h + \lambda_2^{ij} F_i \bar{f}_j \bar{h} + \lambda_3^{ij} \bar{f}_i \ell_j^c h + \lambda_4 H H h + \lambda_5 \bar{H} \bar{H} \bar{h}$$
$$+ \lambda_6^{ia} F_i \bar{H} \phi_a + \lambda_7^{a} h \bar{h} \phi_a + \lambda_8^{abc} \phi_a \phi_b \phi_c + \mu^{ab} \phi_a \phi_b$$

with $\phi_0, \ldots, \phi_3$ singlets.

No-scale Kähler potential

$$K = -3 \ln \left[T + \bar{T} - \frac{1}{3} \left(|\phi_a|^2 + |\ell^c|^2 + f^\dagger f + h^\dagger h + \bar{h}^\dagger \bar{h} + F^\dagger F + H^\dagger H + \bar{H}^\dagger \bar{H} \right) \right]$$

D-term for SM singlets

$$V_{\rm gauge} = \left(\frac{3}{10} g_5^2 + \frac{1}{80} g_X^2 \right) \left(|\tilde{\nu}_i^c|^2 + |\tilde{\nu}_H^c|^2 - |\tilde{\nu}_{\bar{H}}^c|^2 \right)^2$$

(Antoniadis, Ellis, Hagelin & Nanopoulos, 1987)

Flipped $SU(5)$

$\mathbb{Z}_2$-symmetric ($H \to -H$) superpotential

$$W = \lambda_1^{ij} F_i F_j h + \lambda_2^{ij} F_i \bar{f}_j \bar{h} + \lambda_3^{ij} \bar{f}_i \ell^c_j h + \lambda_4 H H h + \lambda_5 \bar{H} \bar{H} \bar{h}$$
$$+ \lambda_6^{ia} F_i \bar{H} \phi_a + \lambda_7^{a} h \bar{h} \phi_a + \lambda_8^{abc} \phi_a \phi_b \phi_c + \mu^{ab} \phi_a \phi_b$$

with $\phi_0, \ldots, \phi_3$ singlets.

No-scale Kähler potential

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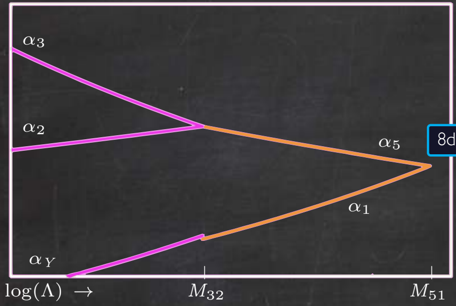
D-term for SM singlets

$$V_{\rm gauge} = \left(\frac{3}{10} g_5^2 + \frac{1}{80} g_X^2 \right) \left(|\tilde{\nu}_i^c|^2 + \underbrace{|\tilde{\nu}_H^c|^2 - |\tilde{\nu}_{\bar{H}}^c|^2}_{\substack{\text{GUT broken along flat-direction} \\ \langle \tilde{\nu}_H^c \rangle = \langle \tilde{\nu}_{\bar{H}}^c \rangle \neq 0}} \right)^2$$

(Antoniadis, Ellis, Hagelin & Nanopoulos, 1987)

Flipped $SU(5)$



8d SO(10) ?

$$\alpha_3(M_{32}) = \alpha_2(M_{32}) \\ = \alpha_5(M_{32}) = 0.0374$$

$$\frac{25}{\alpha_1(M_{32})} = \frac{1}{\alpha_5(M_{32})} + \frac{24}{\alpha_X(M_{32})}$$

- Yukawa unification: $f_u(M_{32}) = f_\nu(M_{32})$
- Doublet-triplet SM Higgs splitting: $HHh \quad \Rightarrow \quad \langle \nu_H^c \rangle d_H^c h_3\,;$ not for h_2
- No dimension 5 proton decay operators (Li, Nanopoulos & Walker, 1003.2570)

$$\tau(p \rightarrow e^+\pi^0) = 4.6 \times 10^{35} \times \left(\frac{M_{32}}{10^{16}\ \text{GeV}}\right)^4 \times \left(\frac{0.0374}{\alpha_5(M_{32})}\right)^2 \ \text{yrs}$$

No-Scale Flipped Inflation

Case I: segregated inflaton

Let $S = \phi_0$ be the inflaton. If other singlets don't vanish, potential will be deformed,

$$e^{-2K/3}\frac{\partial V}{\partial\bar{\phi}^a} = \sum_b W^b\left(\frac{2}{3}K_a\bar{W}_b + \bar{W}_{ab}\right)$$

$$\begin{aligned} W^i &= 3\lambda_8^{00i}S^2 + 2\sum_j(\mu^{ij} + 3\lambda_8^{0ij}S)\phi_j + 3\sum_{j,k}\lambda_8^{ijk}\phi_j\phi_k\,,\\ W^0 &= m(S - S^2/\sqrt{3}) + 6S\sum_j\lambda_8^{00j}\phi_j + 3\sum_{j,k}\lambda_8^{0jk}\phi_j\phi_k\,,\\ \bar{W}_{ab} &= 2\bar{\mu}_{ab} + 6\bar{\lambda}_{8\;0ab}\bar{S} + 6\sum_j\bar{\lambda}_{8\;abj}\bar{\phi}^j \end{aligned}$$

If μ^{ab} and λ_8^{0ab} are *simultaneously* diagonalizable, and $S = \phi_0^D$, then

$$\phi_i = 0$$

during inflation

No-Scale Flipped Inflation

Case I: segregated inflaton

With

$$\mu^{00} = m/2\,, \qquad \lambda_8^{000} = -m/3\sqrt{3}\,,$$

then

$$V = \frac{3}{4}m^2\left(1 - e^{-\sqrt{2/3}\,s}\right)^2\,, \qquad s = \sqrt{6}\tanh^{-1}(S/\sqrt{3})$$

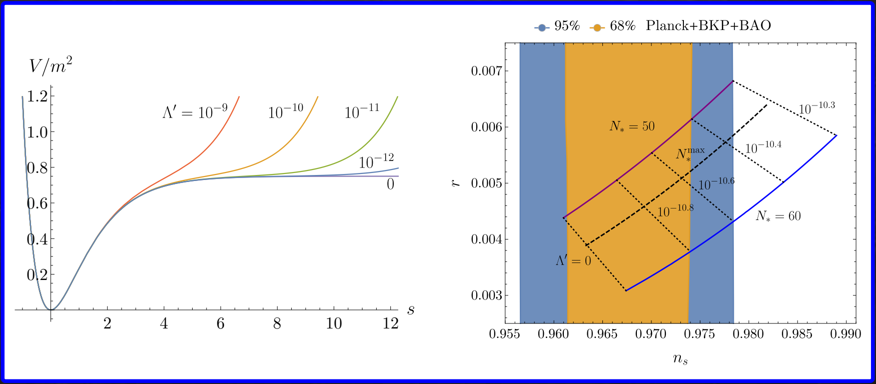
No isocurvature:

$$\frac{\partial^2 V}{\partial\phi_i \partial\bar{\phi}^j} = \frac{2}{3}e^K m^2 |S - S^2/\sqrt{3}|^2 \delta^i_j + \cdots \simeq \frac{1}{8}m^2 e^{\sqrt{2/3}s}\delta^i_j + \cdots \gg H^2$$

Case II: mass hierachy

If only $\mu^{ab} = \mathrm{diag}\left(m/2, \mu^1, \mu^2, \mu^3\right)$, $\lambda_8^{00i} \ll \lambda_8^{0ij} < \mu^i \leq M_{\mathrm{GUT}}$

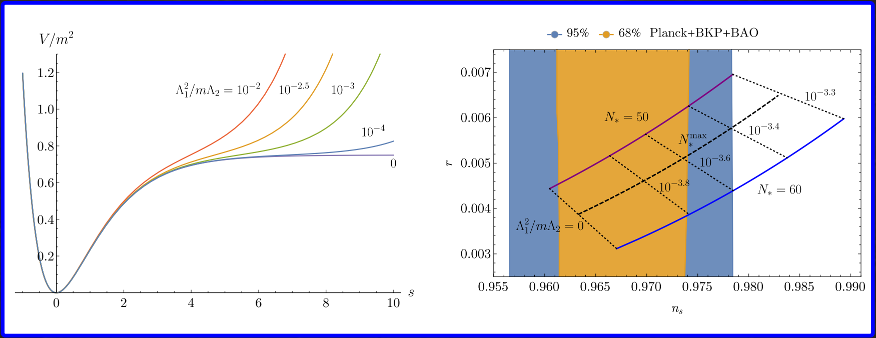
$$V \simeq \frac{3}{4} m^2 \left(1 - e^{-\sqrt{2/3}\, s}\right)^2 + 81\, m \sinh^4(s/\sqrt{6}) \left(\tanh(s/\sqrt{6}) - 1\right) \sum_i \underbrace{\left[\mu_i^{-1} (\lambda_8^{00i})^2 + \mathrm{h.c.}\right]}_{-\Lambda'}$$



Case III: all light singlets $(-3\sqrt{3}\,\lambda_8^{000} = 2\mu^{00} = m$ off-diagonally$)$

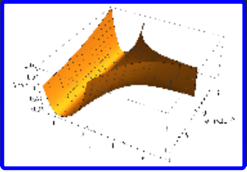
With $\lambda_8^{00i}S \sim \mu^{0i} \sim \Lambda_1,\, \lambda_8^{0ij}S \sim \mu^{ij} \sim \Lambda_2$

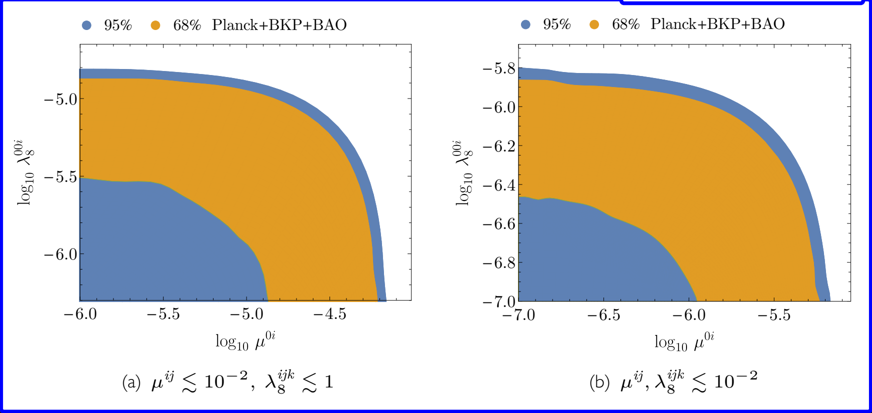
$$\langle\phi_i\rangle_{\rm inf} \sim \Lambda_1/\Lambda_2\,, \qquad \Delta V \sim m\frac{\sqrt{3}\Lambda_1^2}{8\Lambda_2}\,e^{\sqrt{2/3}\,s}$$



Case III: all light singlets $(-3\sqrt{3}\,\lambda_8^{000} = 2\mu^{00} = m$ off-diagonally)

Full numerical





(a) $\mu^{ij} \lesssim 10^{-2},\ \lambda_8^{ijk} \lesssim 1$

(b) $\mu^{ij}, \lambda_8^{ijk} \lesssim 10^{-2}$

Case III: all light singlets

Perturbed initial conditions

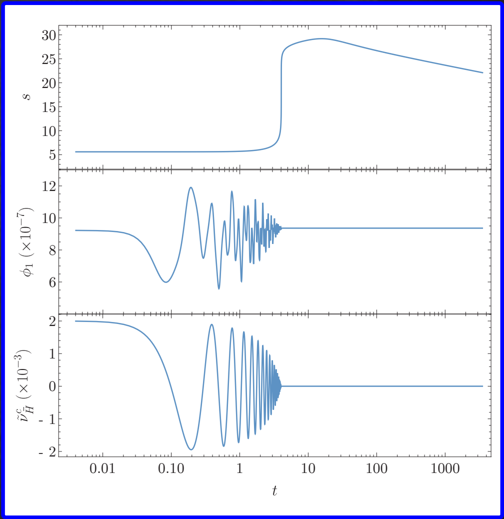
$$\ddot{\Psi}^{\alpha}+3H\dot{\Psi}^{\alpha}+\underbrace{\Gamma^{\alpha}_{\beta\gamma}\dot{\Psi}^{\beta}\dot{\Psi}^{\gamma}}_{\alpha = S}+K^{\alpha\bar{\beta}}\frac{\partial V}{\partial\bar{\Psi}^{\bar{\beta}}} = 0$$

$$-\frac{1}{2\sqrt{3}}\sinh(\sqrt{2/3}\,s)\left(\dot{\phi}_i^2+(\dot{\tilde{\nu}}^c)^2+(\dot{\tilde{\nu}}^c_{\bar{H}})^2\right)$$

$$+\cdots$$

Generic initial conditions at $V \sim 1$

(MG, Nagaraj & Nanopoulos, upcoming)



Neutrino Masses

From now on we assume $\lambda_6^{i0} \neq 0$ and $\lambda_7^0 = 0$ (most interesting case)

$i \neq 1$:

$$\mathcal{L}_{\rm mass}^{(\nu)} = -\frac{1}{2}\left(\nu_i \quad \nu_i^c \quad \tilde{\phi}_i\right)\begin{pmatrix} 0 & \lambda_2^{ij}\langle h\rangle & 0 \\ \lambda_2^{Tij}\langle h\rangle & 0 & \lambda_6^{ij}\langle H\rangle \\ 0 & \lambda_6^{Tij}\langle H\rangle & 2\mu^{ij} \end{pmatrix}\begin{pmatrix} \nu_j \\ \nu_j^c \\ \tilde{\phi}_j \end{pmatrix} + \text{h.c.}$$

$$m_{\nu_i} \sim \mu\left(\frac{\lambda_2\langle h\rangle}{\lambda_6\langle H\rangle}\right)^2$$

$$m_{N_\pm} \sim \frac{1}{2}\left[\mu \pm \sqrt{\mu^2 + (4\lambda_6\langle H\rangle)^2}\right]$$

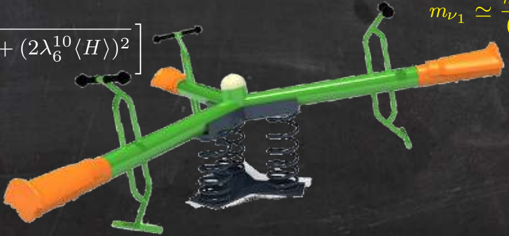
Neutrino Masses

From now on we assume $\lambda_6^{i0} \neq 0$ and $\lambda_7^0 = 0$ (most interesting case)

$i = 1$:

$$\mathcal{L}^{(\nu)}_{\text{mass}} = -\frac{1}{2} \begin{pmatrix} \nu_1 & \nu_1^c & \tilde{S} \end{pmatrix} \begin{pmatrix} 0 & \lambda_2^{11}\langle h \rangle & 0 \\ \lambda_2^{11}\langle h \rangle & 0 & \lambda_6^{10}\langle H \rangle \\ 0 & \lambda_6^{10}\langle H \rangle & m \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_1^c \\ \tilde{S} \end{pmatrix} + \text{h.c.}$$

$$m_{N_1 \pm} = \frac{1}{2}\left[m \pm \sqrt{m^2 + (2\lambda_6^{10}\langle H \rangle)^2} \right]$$



$$m_{\nu_1} \simeq \frac{m(\lambda_2^{11}\langle h \rangle)^2}{(\lambda_6^{10}\langle H \rangle)^2}$$

Reheating

Decay of the segregated inflaton. $\theta = (S, \nu^c)$ mixing angle

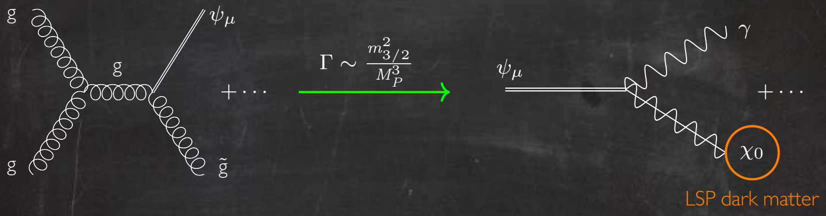
$$\Gamma(s \to L_j \tilde{h}_u) = \Gamma(s \to \tilde{L}_j h_u) \simeq \frac{|\lambda_2^{1j} \sin\theta|^2}{8\pi} m_{N_1} \, \_$$

Reheating

Decay of the segregated inflaton. $\theta \;=\; (S, \nu^c)$ mixing angle

$$\Gamma(s \to L_j \tilde{h}_u) = \Gamma(s \to \tilde{L}_j h_u) \simeq \frac{|\lambda_2^{1j} \sin\theta|^2}{8\pi} m_{N_1} \;–$$

Light gravitino produced in thermalized plasma



$$\begin{array}{ccc} \Omega_{\text{cold}} h^2 = 0.12 & & \\ + & \Rightarrow & |\lambda_2^{1j} \sin\theta| \;\lesssim\; 2.7 \times 10^{-5} \Delta \left(\dfrac{100\,\text{GeV}}{m_{\text{LSP}}}\right) \\ \text{BBN} & & \end{array}$$

(Ellis, MG, Nanopoulos, Olive & Peloso, 1512.05701)

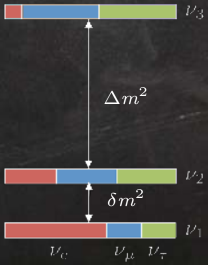
Reheating

Decay of the segregated inflaton. $\theta = (S, \nu^c)$ mixing angle

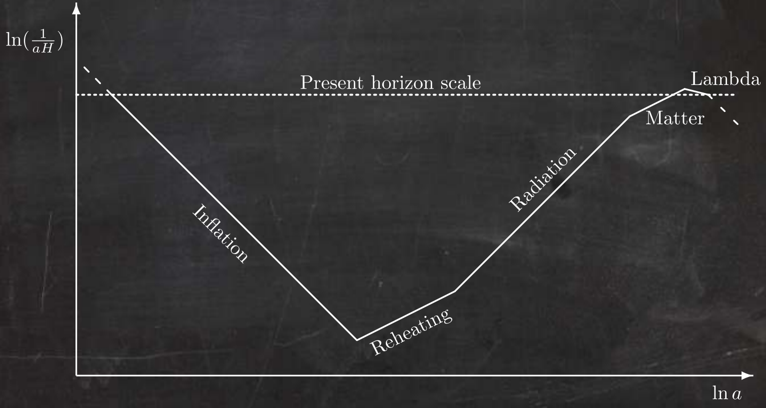
$$\Gamma(s \to L_j \tilde{h}_u) = \Gamma(s \to \tilde{L}_j h_u) \simeq \frac{|\lambda_2^{1j} \sin\theta|^2}{8\pi} m_{N_1}$$

Light neutrino mass spectrum

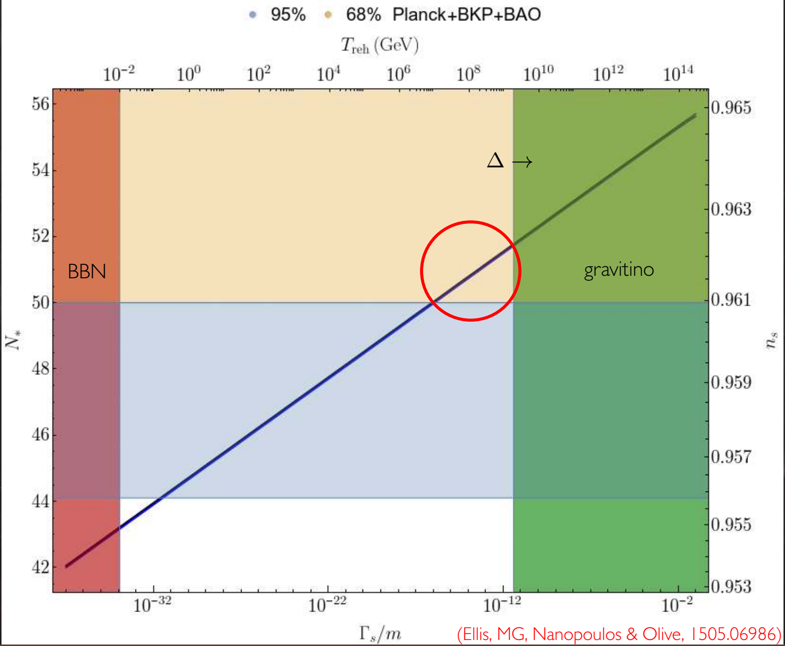
$$\begin{aligned} m_{\nu_1} &\simeq 10^{-9} \times \left(\frac{m}{3\times 10^{13}\,\mathrm{GeV}}\right)\left(\frac{|\lambda_6^{10}|}{10^{-3}}\right)^{-2}\left(\frac{\langle H\rangle}{10^{16}\,\mathrm{GeV}}\right)^{-2}\,\mathrm{eV} \\ m_{\nu_2} &\simeq |\delta m^2|^{\frac{1}{2}} \simeq 9\times 10^{-3}\,\mathrm{eV} \\ m_{\nu_3} &\simeq |\Delta m^2|^{\frac{1}{2}} \simeq 5\times 10^{-2}\,\mathrm{eV} \end{aligned}$$



$$N_* = \ln\left(\frac{\rho_{\rm reh}^{1/4} a_{\rm reh}}{\sqrt{3} a_0 H_0}\right) - \ln\left(\frac{k_*}{a_0 H_0}\right) + \frac{1}{4}\ln\left(\frac{V_*^2}{M_P^4 \rho_{\rm end}}\right) + \frac{1 - 3w_{\rm int}}{12(1+w_{\rm int})}\ln\left(\frac{\rho_{\rm reh}}{\rho_{\rm end}}\right)$$

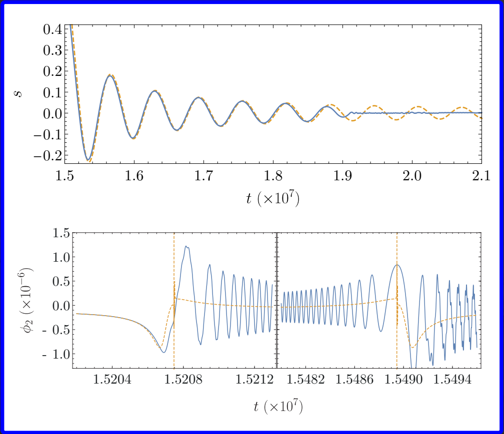


(Liddle & Leach, astro-ph/0305263)



(Ellis, MG, Nanopoulos & Olive, 1505.06986)

Decay of the non-segregated inflaton



Localized, non-adiabatic events

↓

stochastic particle production

Brownian-motion inspired methods

(Amin & Baumann, 1512.02637)
(Amin, MG, Xie & Wen, 1706.02319)
(MG *et.al.*, upcoming)

The GUT phase transition

Whatever happened to the GUT-breaking field?

$$V_F \simeq \frac{3}{4}m^2\left(1-e^{-\sqrt{2/3}s}\right)^2 + \frac{1}{8}m^2 e^{\sqrt{2/3}s}|\tilde{\nu}^c_{\bar{H}}|^2 + \cdots$$

$\Rightarrow \quad SU(5)\times U(1)_X$ broken *after* inflation

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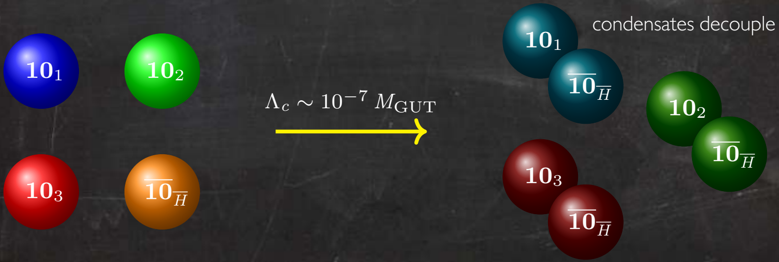
$\Rightarrow$ $SU(5) \times U(1)_X$ broken *after* inflation

Asymptotic freedom of $SU(5)$ takes care of this!

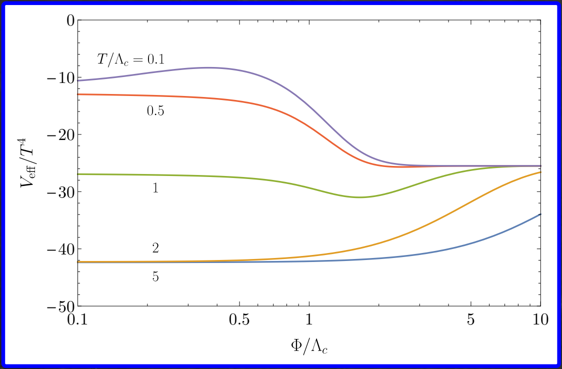
$$g^2(\Lambda_c)(C_c - C_1 - C_2) \simeq 4$$

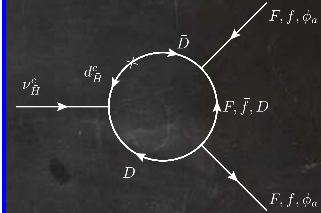


condensates decouple

(Kogut, 1983; Campbell, Ellis, Hagelin, Nanopoulos & Olive, 1987)

1-loop T-dependent effective potential





$T_{\rm reh} > \Lambda_c \quad \Rightarrow$ adiabatic evolution of Φ until $|m_\Phi| > T_\Phi$

$$\Delta \simeq 8\times 10^3 \, \lambda_{1,2,3,7}^{-2} \left(\frac{g_{d\Phi}}{43/4}\right)^{1/4} \left(\frac{915/4}{g_{\rm dec}}\right) \left(\frac{\langle\Phi\rangle}{5\times 10^{15}\,{\rm GeV}}\right) \left(\frac{10\,{\rm TeV}}{m^2_{F,\bar f,\ell^c,\tilde\phi_a}/|m_\Phi|}\right)^{1/2}$$

Baryogenesis

Leptogenesis from inflaton decays, $s \to L\,\tilde{h}_u\,,\ \tilde{L}\,h_u$

$$\frac{n_L}{s} \sim \frac{\epsilon}{\Delta} f \frac{T_R}{m}$$

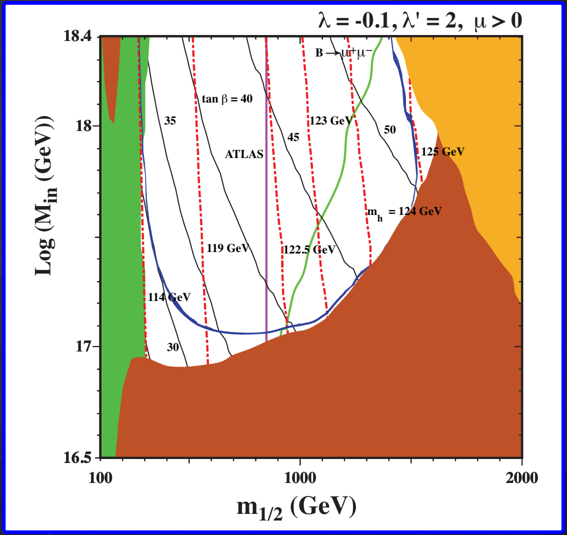
$$\epsilon \simeq -\frac{3}{4\pi}\frac{1}{\left(U^\dagger_{\nu^c}(\lambda_2^D)^2\,U_{\nu^c}\right)_{11}}\sum_{i=2,3}\mathrm{Im}\left[\left(U^\dagger_{\nu^c}(\lambda_2^D)^2\,U_{\nu^c}\right)^2_{i1}\right]\frac{m}{M_N}$$

$$\frac{n_L}{s} \simeq 3.8\times 10^{-11}\,\delta f\lambda^2_{1,2,3,7}\lambda_6^{-2}\left(\frac{43/4}{g_{d\Phi}}\right)^{1/4}\left(\frac{915/4}{g_{\rm reh}}\right)^{1/4}\left(\frac{g_{\rm dec}}{915/4}\right)\left(\frac{y}{10^{-5}}\right)$$
$$\times\left(\frac{5\times 10^{15}\ \mathrm{GeV}}{\langle\Phi\rangle}\right)^2\left(\frac{m^2_{F,\bar{f},\ell^c,\tilde{\phi}_a}/|m_\Phi|}{10\ \mathrm{TeV}}\right)^{1/2}\left(\frac{m}{3\times 10^{13}\mathrm{GeV}}\right)^{1/2}$$

Close to the EW phase transition $L \to B$ through sphaleron interactions

EW Phenomenology

Planck
+
dark matter
+
leptogenesis
+
neutrino masses
+
flavor
+
Higgs mass
+
LHC
+
⋮



(Ellis, Nanopoulos & Olive, 1310.4770; Li, Maxin & Nanopoulos, 1705.07973)

Conclusion

- The no-scale flipped $SU(5) \times U(1)$ framework is capable of satisfying the many different types of constraints, from CMB measurements to neutrino masses
- Significant flexibility $\rightarrow$ take as proof-of-concept
- Many interesting open questions (no-scale $\Leftrightarrow$ Starobinsky-like, initial conditions, stochastic preheating, $\ldots$)
- Not the only working model ($SO(10)$ in Ellis, MG, Nanopoulos & Olive, 1609.05849)

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Thank you