Constraining multifield inflation and supersymmetry breaking in no-scale supergravity

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In collaboration with
K. A. Olive, J. Ellis, D. V. Nanopoulos

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SUSY 2015
Lake Tahoe, 28 August 2015

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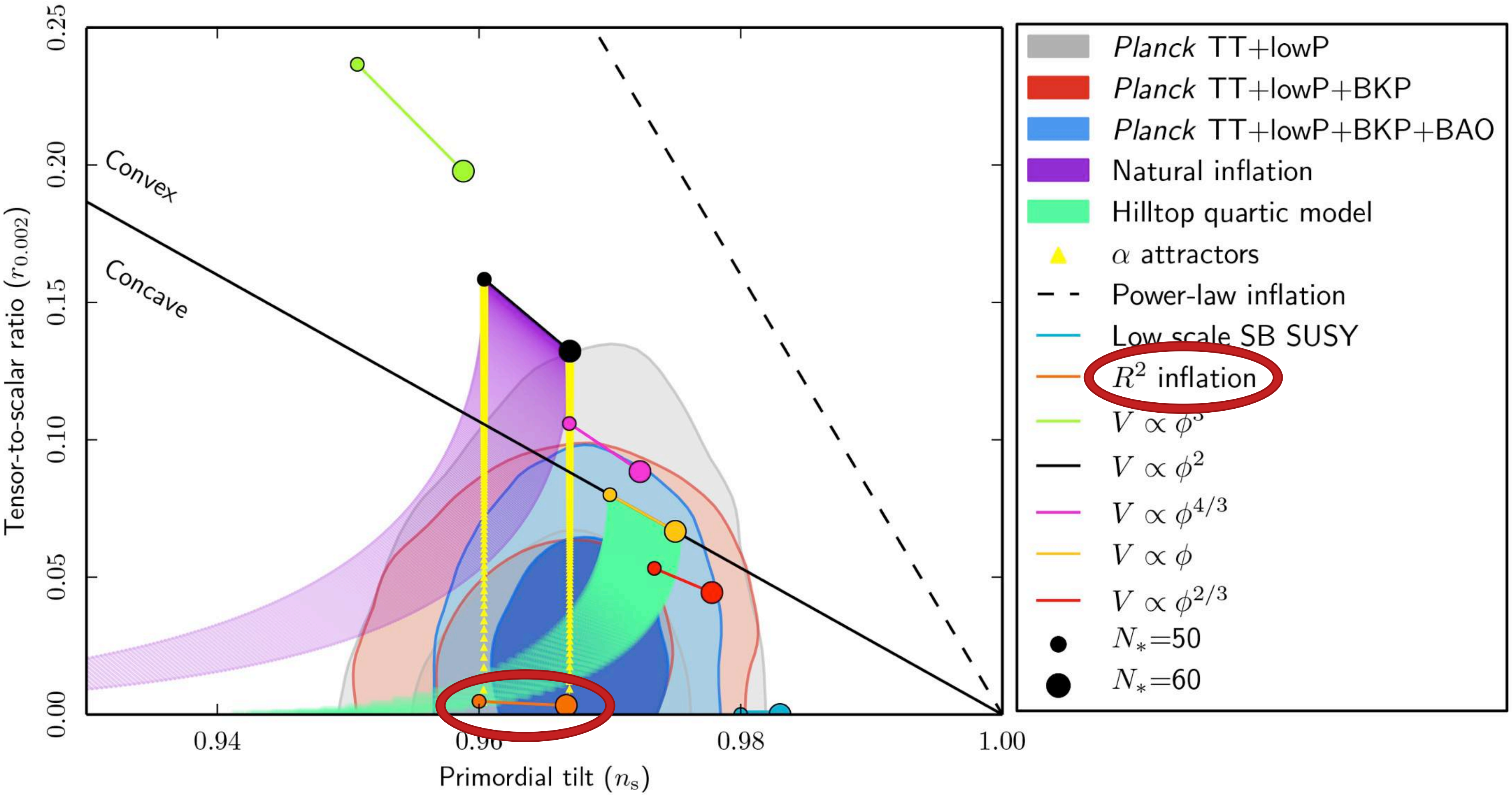
Planck 2015 results



P.A.R. Ade *et. al.* (Planck): arXiv: 1502.02114

Planck 2015 results

A.A. Starobinsky, 1980 (Phys.Lett.B 91, 99)

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

$$\downarrow$$

$$\tilde{g}_{\mu\nu} = (1 + x/3m^2)g_{\mu\nu}\,, \quad x' = \sqrt{\frac{3}{2}}\ln\left(1 + \frac{x}{3m^2}\right)$$

$$\downarrow$$

$$= \int d^4x\sqrt{-\tilde{g}}\left[\frac{\tilde{R}}{2} + \frac{1}{2}(\partial_\mu x')^2 - \underbrace{\frac{3}{4}m^2\left(1 - e^{-\sqrt{2/3}x'}\right)^2}_{\text{Starobinsky potential}}\right]$$

$$n_s \approx 0.961 \,-\, 0.968$$

$$r \approx 0.0030 \,-\, 0.0042$$

Starobinsky inflation in (no-scale) supergravity:

Scalar potential for (uncharged) chiral superfields

$$V = e^K (K^{i\bar{j}} D_i W \bar{D}_{\bar{j}} \bar{W} - 3|W|^2)$$

where $D_i = K_i W + W_i$

- Cecotti (1987)

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

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

$$\phi = 0\,,\ \ \mathrm{Re}\,T = \frac{1}{2} e^{\sqrt{2/3}x}$$

Phys.Lett.B 190,86

- Ellis, Nanopoulos, Olive (2013)

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

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

$$T = \frac{1}{2}\,,\ \ \phi = \sqrt{3}\tanh(x/\sqrt{6})$$

(arXiv: 1306.3214)

Starobinsky inflation in (no-scale) supergravity:

Scalar potential for (uncharged) chiral superfields

$$V = e^K \left(K^{i\bar{j}} D_i W \bar{D}_{\bar{j}} \bar{W} - 3|W|^2 \right)$$

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~~SU(2,1)~~

$$K = -3 \ln \left(T + \bar{T} - \frac{|\phi|^2}{3} + \frac{|\phi|^4}{\Lambda^2} \right) \qquad \phi = 0\,, \ \mathrm{Re}\, T = \frac{1}{2} e^{\sqrt{2/3}x}$$

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Phys.Lett.B 190,86

- Ellis, Nanopoulos, Olive (2013)

~~SU(2,1)~~

$$K = -3 \ln \left(T + \bar{T} - \frac{|\phi|^2}{3} + \frac{(T + \bar{T} - 1)^4 + d(T - \bar{T})^4)}{\Lambda^2} \right)$$

$$W = m \left(\frac{\phi^2}{2} - \frac{\phi^3}{3\sqrt{3}} \right) \qquad T = \frac{1}{2}\,, \ \phi = \sqrt{3} \tanh(x/\sqrt{6})$$

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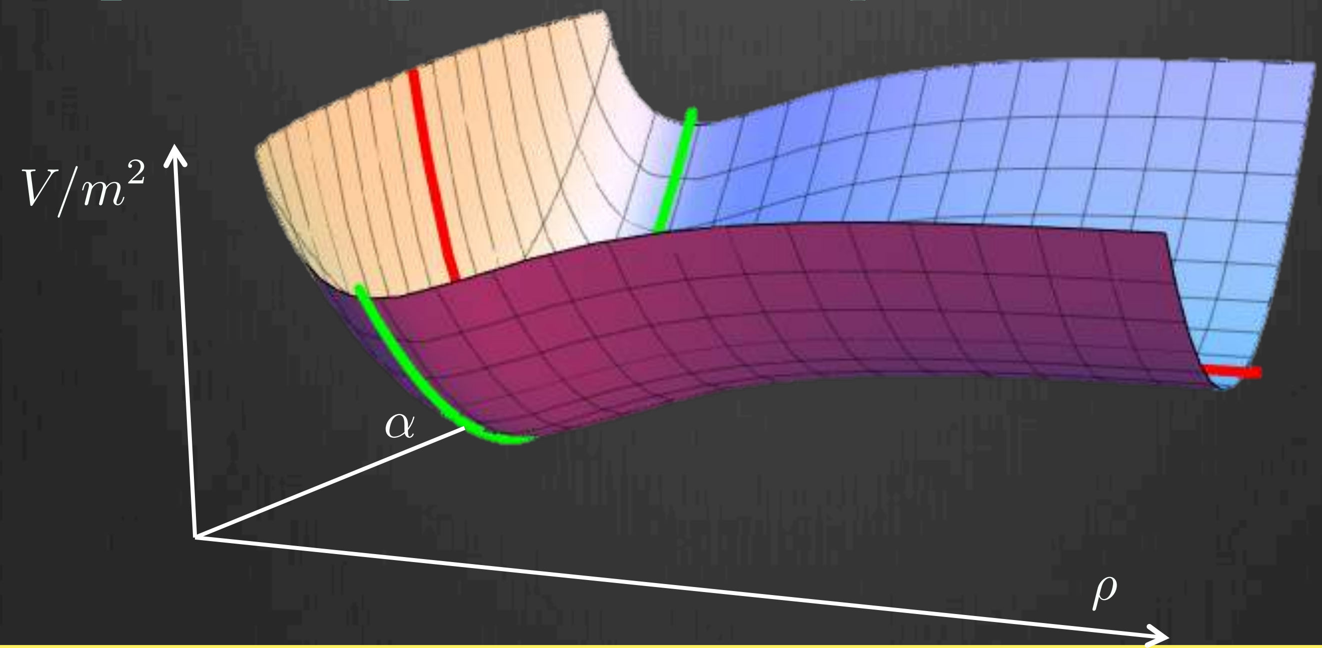
- Ellis, G, Nanopoulos, Olive (2014)

$$K = -3\ln(T+\bar{T}) + \frac{|\varphi|^2}{(T+\bar{T})^3}\,, \qquad T = \frac{1}{2}e^{-\sqrt{2/3}\rho} + \frac{i}{\sqrt{6}}\alpha$$

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

$$V \propto e^{|\varphi|^2/(T+\bar{T})^3}$$

$$\mathcal{L} = \frac{1}{2}\partial_\mu\rho\partial^\mu\rho + \frac{1}{2}e^{2\sqrt{\frac{2}{3}}\rho}\partial_\mu\alpha\partial^\mu\alpha - \frac{3}{4}m^2\left(1-e^{-\sqrt{\frac{2}{3}}\rho}\right)^2 - \frac{1}{2}m^2\alpha^2$$



(arXiv: 1405.0271)

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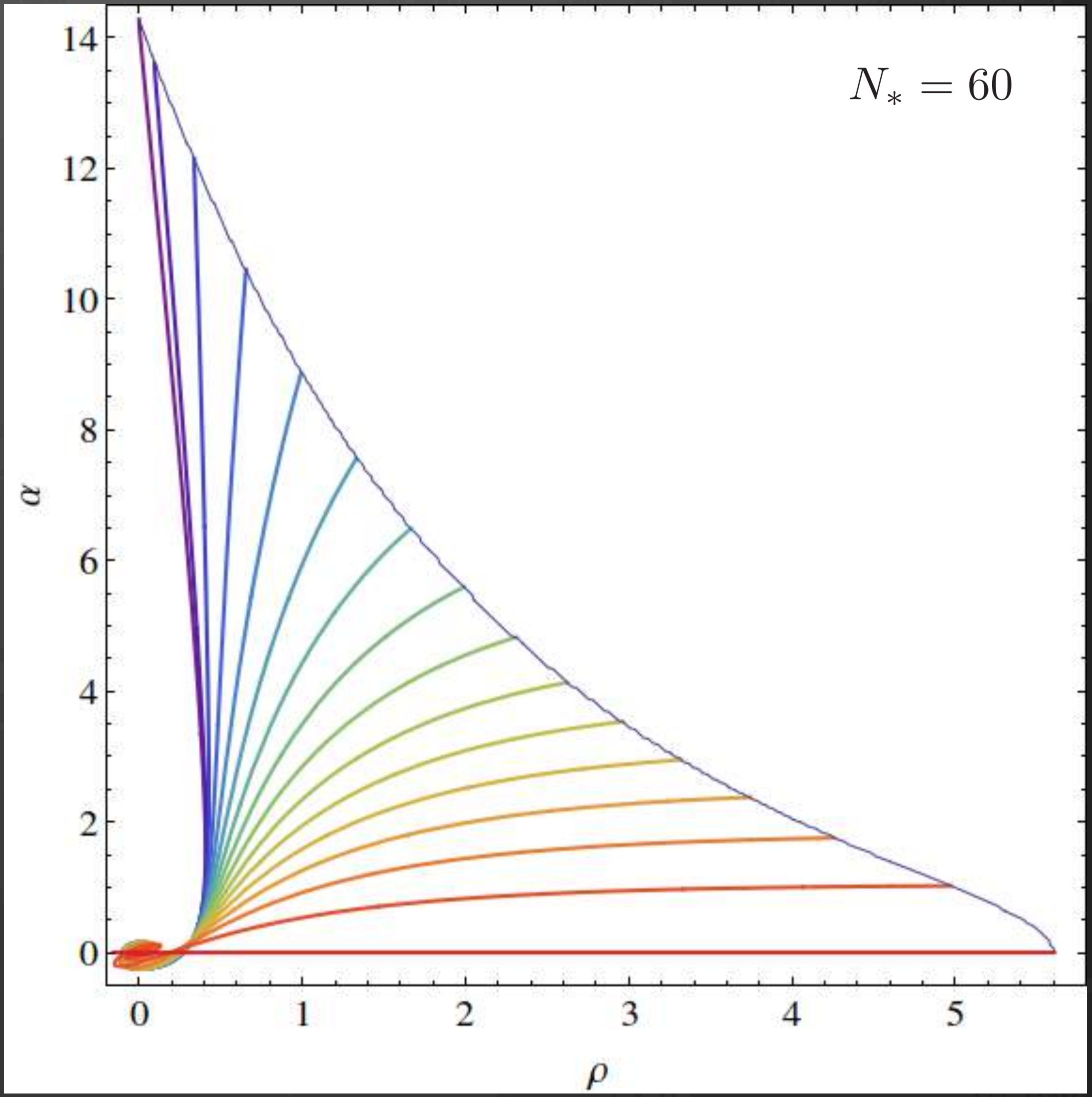

Starobinsky inflation in (no-scale) supergravity:

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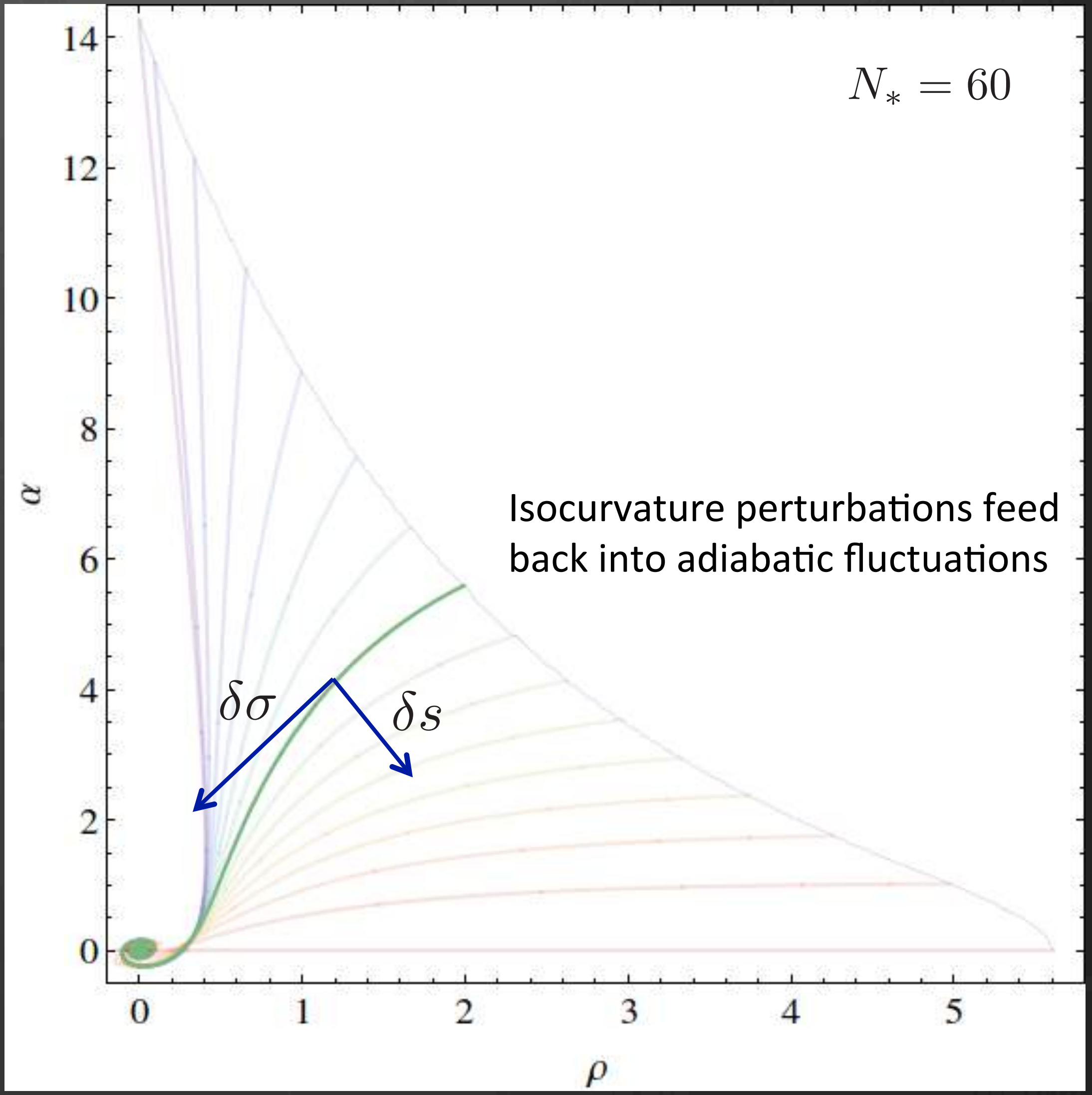


Two-field effects:

Rewrite $T = \frac{1}{\sqrt{2}}(\chi + i\zeta)$

$$\mathcal{L}_{\rm kin} \;=\; \frac{1}{2}f(\chi,\zeta)\,\left[(\partial_\mu\chi)^2 + (\partial_\mu\zeta)^2\right] \;=\; \frac{3}{4\chi^2}\left[(\partial_\mu\chi)^2 + (\partial_\mu\zeta)^2\right]$$

Background:

$$\ddot{\chi} + 3H\dot{\chi} + \frac{1}{2}f^{-1}\left[(\dot{\chi}^2 - \dot{\zeta}^2)f_\chi + 2\dot{\chi}\dot{\zeta}f_\zeta\right] + f^{-1}V_{,\chi} \;=\; 0$$
$$\ddot{\zeta} + 3H\dot{\zeta} + \frac{1}{2}f^{-1}\left[(\dot{\zeta}^2 - \dot{\chi}^2)f_\zeta + 2\dot{\chi}\dot{\zeta}f_\chi\right] + f^{-1}V_{,\zeta} \;=\; 0$$
$$H^2 \;=\; \frac{1}{3}\left[\frac{1}{2}f(\dot{\chi}^2 + \dot{\zeta}^2) + V\right]$$

Adiabatic and isocurvature decomposition:

$$\dot{\sigma} = \sqrt{f(\dot{\chi}^2 + \dot{\zeta}^2)} \quad \Rightarrow \quad \begin{aligned} \mathbf{e}_\sigma &= (\dot{\chi}/\dot{\sigma}, \dot{\zeta}/\dot{\sigma}) \\ \mathbf{e}_s &= (\dot{\zeta}/\dot{\sigma}, -\dot{\chi}/\dot{\sigma}) \end{aligned} \quad \Rightarrow \quad \begin{aligned} \delta\sigma &= \frac{f}{\dot{\sigma}}(\chi\delta\chi + \zeta\delta\zeta) \\ \delta s &= \frac{f}{\dot{\sigma}}(\chi\delta\zeta - \zeta\delta\chi) \end{aligned}$$

J. Ellis, MG, D. Nanopoulos, K. Olive, 2015 (arXiv: 1409.8197)

Two-field effects:

Gauge invariant perturbations:

$$Q_\sigma = \delta\sigma + \frac{\dot\sigma}{H}\Psi$$
$$Q_s = \delta s$$

$$\ddot{Q}_\sigma + 3H\dot{Q}_\sigma + 2\frac{V_s}{\dot\sigma}\dot{Q}_s + \left(\frac{k^2}{a^2} + C_{\sigma\sigma}\right)Q_\sigma + C_{\sigma s}Q_s = 0$$
$$\ddot{Q}_s + 3H\dot{Q}_s - 2\frac{V_s}{\dot\sigma}\dot{Q}_\sigma + \left(\frac{k^2}{a^2} + C_{ss}\right)Q_s + C_{s\sigma}Q_\sigma = 0$$

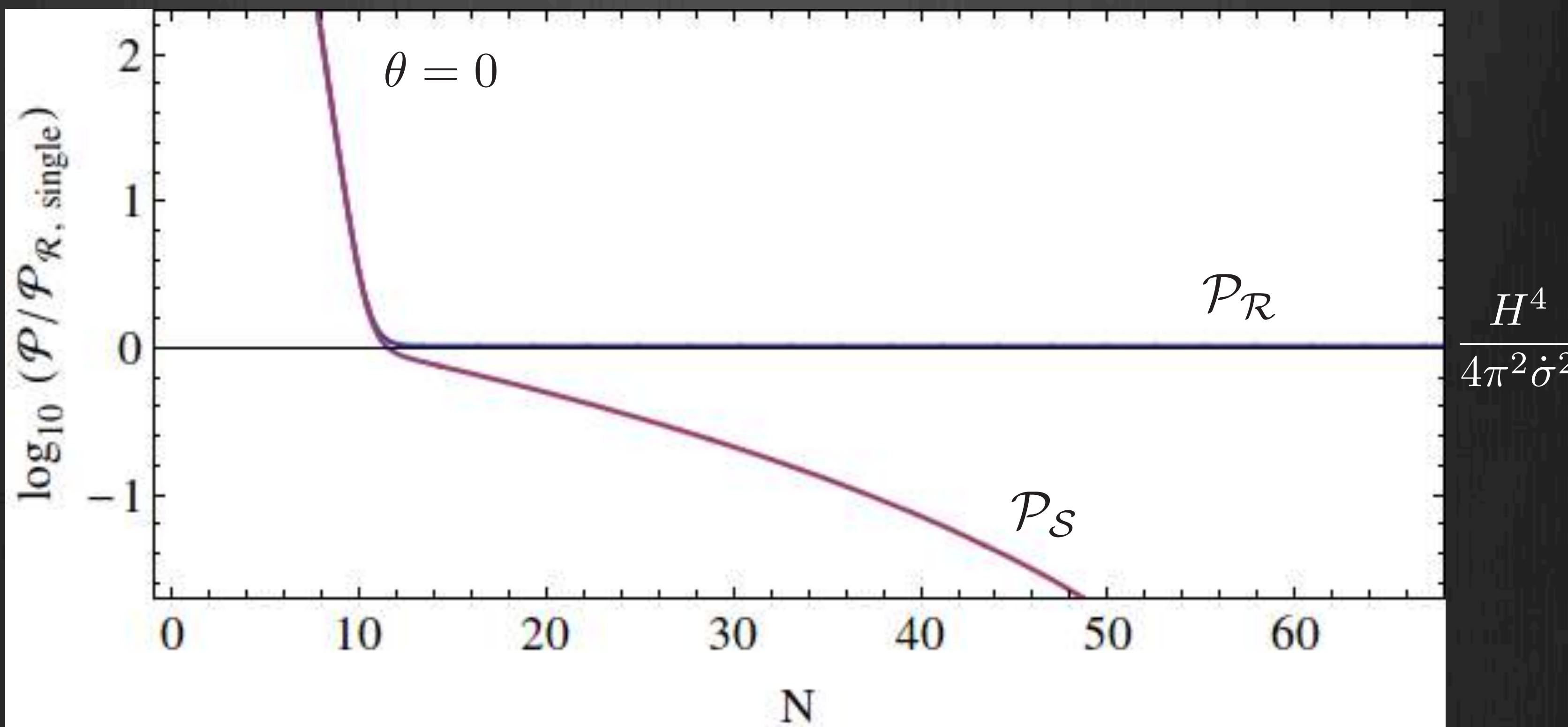
$$C_{\sigma\sigma} = V_{\sigma\sigma} - \left(\frac{V_s}{\dot\sigma}\right)^2 + \frac{2\dot\sigma}{H}V_\sigma + 3\dot\sigma^2 - \frac{\dot\sigma^4}{2H^2} - \frac{f_\chi\dot\chi + f_\zeta\dot\zeta}{2f\dot\sigma}V_\sigma - \frac{f_\zeta\dot\chi - f_\chi\dot\zeta}{2f\dot\sigma}V_s$$
$$C_{\sigma s} = 6H\frac{V_s}{\dot\sigma} + 2\frac{V_sV_\sigma}{\dot\sigma^2} + 2V_{\sigma s} + \frac{\dot\sigma V_s}{H} - \frac{f_\chi\dot\chi + f_\zeta\dot\zeta}{f\dot\sigma}V_s + \frac{f_\zeta\dot\chi - f_\chi\dot\zeta}{f\dot\sigma}V_\sigma$$
$$C_{s\sigma} = -6H\frac{V_s}{\dot\sigma} - 2\frac{V_\sigma V_s}{\dot\sigma^2} + \frac{\dot\sigma V_s}{H}$$
$$C_{ss} = V_{ss} - \left(\frac{V_s}{\dot\sigma}\right)^2 + \frac{f_\chi\dot\chi + f_\zeta\dot\zeta}{2f\dot\sigma}V_\sigma + \frac{f_\zeta\dot\chi - f_\chi\dot\zeta}{2f\dot\sigma}V_s + \frac{\dot\sigma^2}{2f^2}\left(\frac{f_\chi^2}{f} + \frac{f_\zeta^2}{f} - f_{\chi\chi} - f_{\zeta\zeta}\right)$$

Two-field effects:

Curvature and entropy perturbations, and power spectrum:

$$\mathcal{R} = \frac{H}{\dot\sigma} Q_\sigma \,, \qquad \langle \mathcal{R}(k)\bar{\mathcal{R}}(k')\rangle = \frac{2\pi^2}{k^3}\mathcal{P}_\mathcal{R}\,\delta(k-k')$$

$$\mathcal{S} = \frac{H}{\dot\sigma} Q_s \,, \qquad \langle \mathcal{S}(k)\bar{\mathcal{S}}(k')\rangle = \frac{2\pi^2}{k^3}\mathcal{P}_\mathcal{S}\,\delta(k-k')$$



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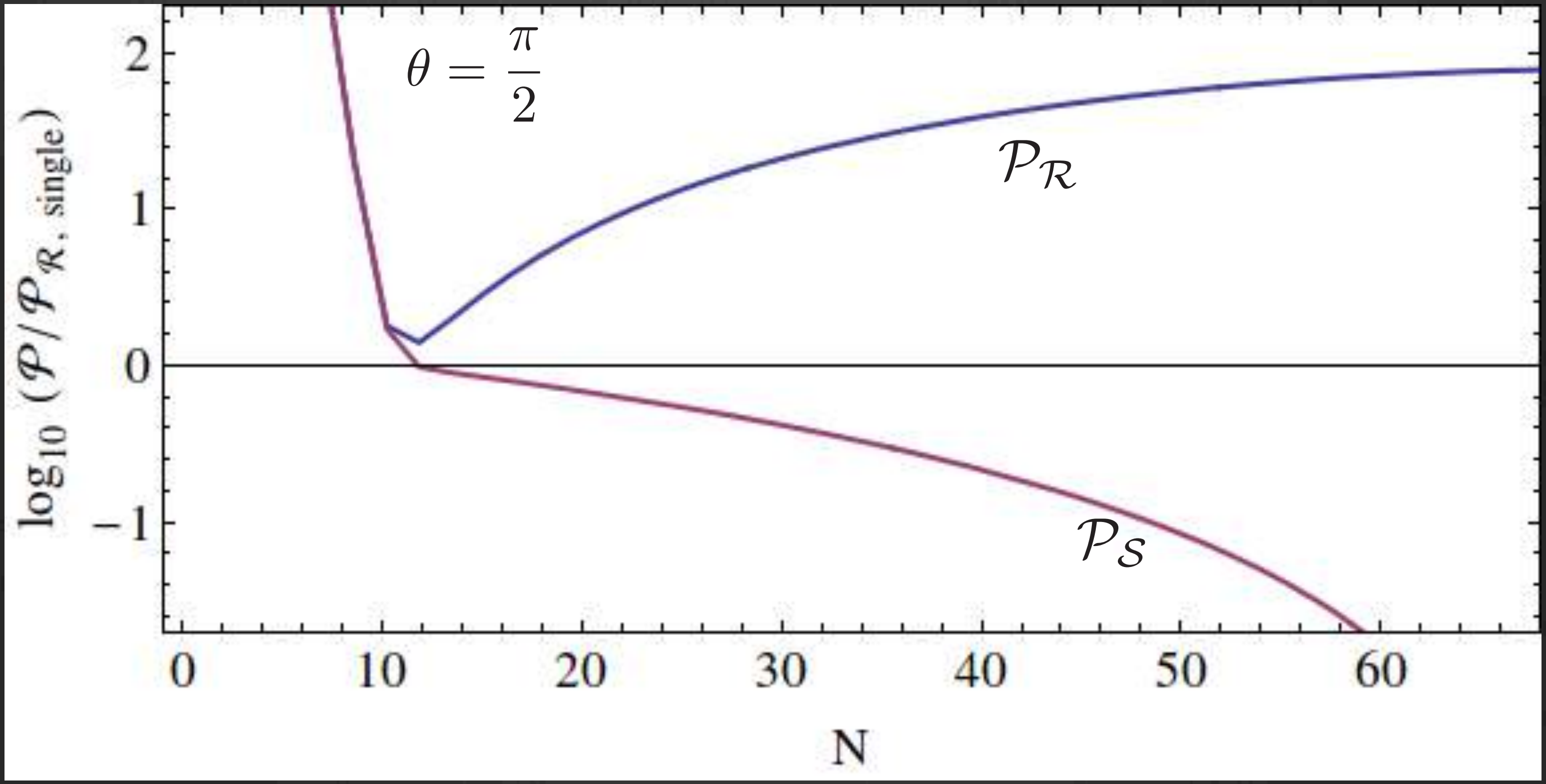
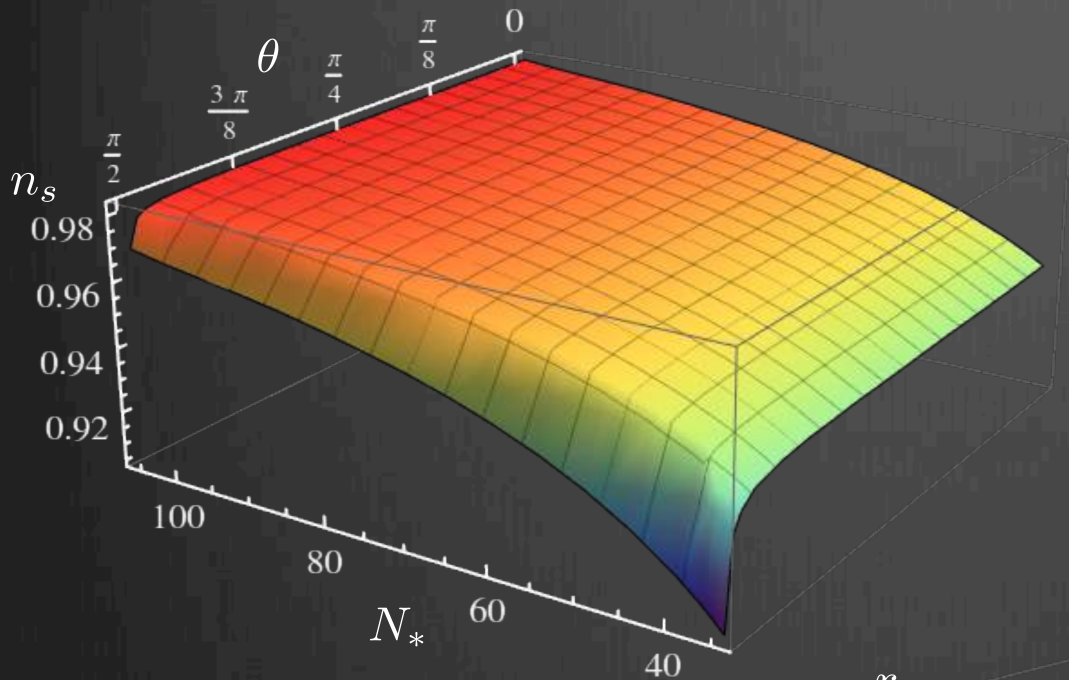


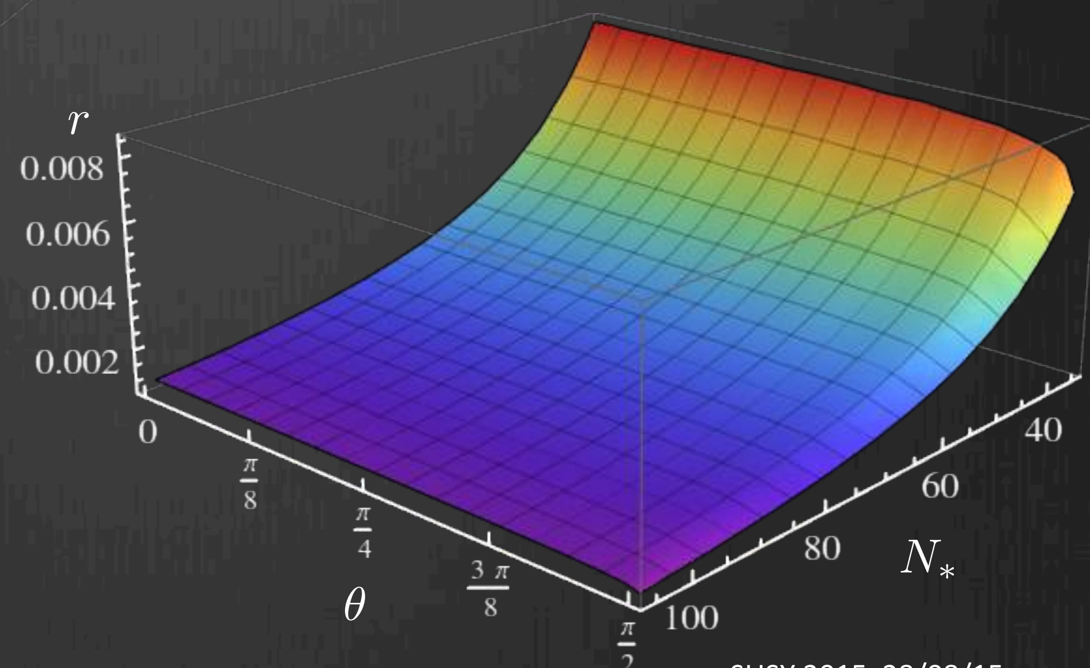
$$\frac{H^4}{4\pi^2\dot{\sigma}^2}$$

Two-field effects:



$$n_s = 1 + \frac{d\log \mathcal{P}_\mathcal{R}}{d\log k}$$

$$r = \frac{\mathcal{P}_T}{\mathcal{P}_\mathcal{R}}$$



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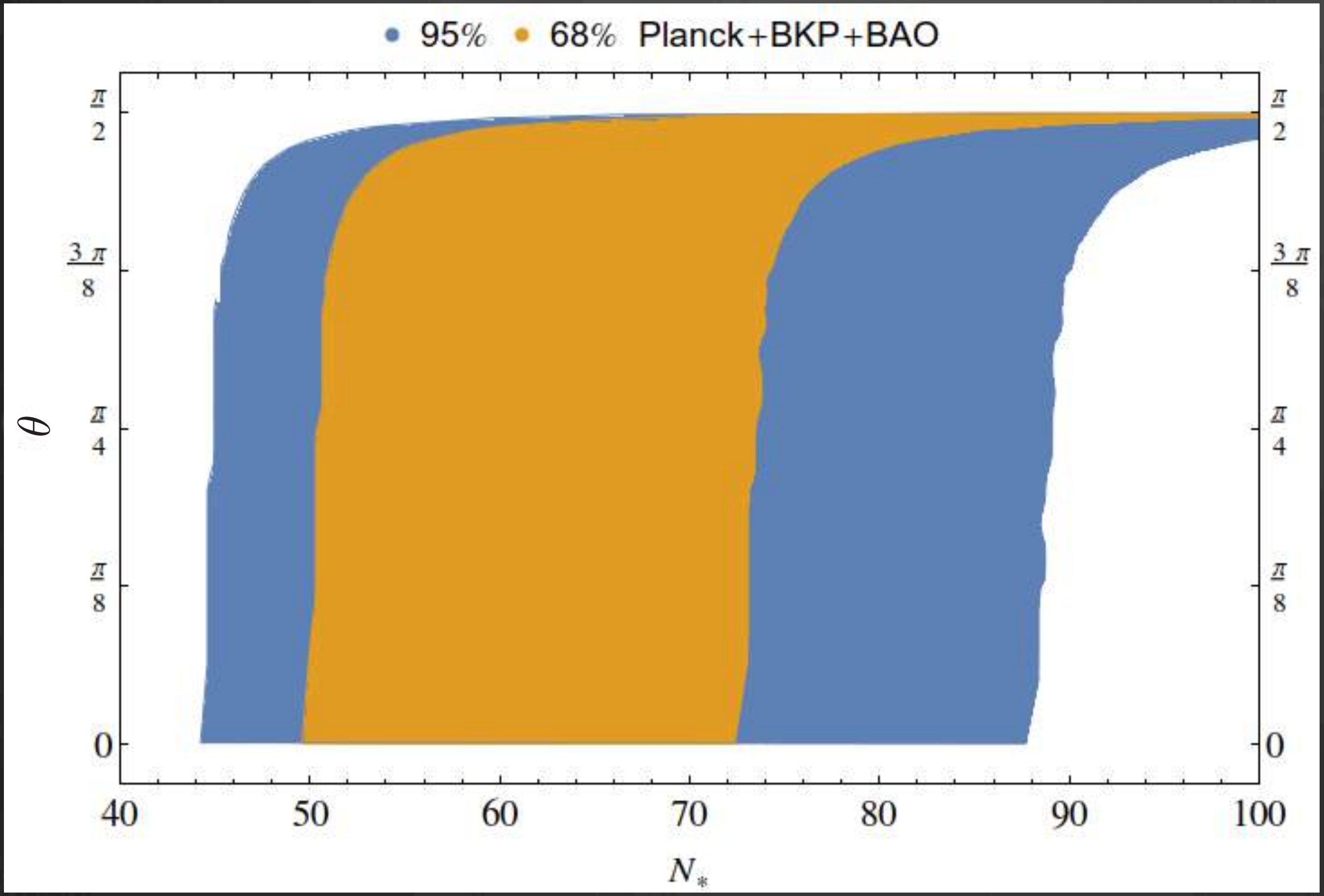


$$|f_{NL}| \lesssim 0.04$$

No-scale phenomenology

Kähler potential from string compactifications (S, U_j fixed)

$$K = -3\ln\left(T+\bar{T}-\underbrace{\frac{1}{3}\sum_j|\phi_j|^2}_{\text{Untwisted}}\right)+\underbrace{\sum_a\frac{|\varphi_a|^2}{(T+\bar{T})^{n_a}}}_{\text{Twisted}}$$

Generic, phenomenological superpotential

$$\begin{aligned} W &= W_{\rm inf}(T,\phi_1)+W_M(T,\phi_i,\varphi_a;\mu) \\ &= W_{\rm inf}(T,\phi_1)+(T+1/2)^{\alpha}W_3(\phi_i)+(T+1/2)^{\beta}W_2(\phi_i) \\ &\qquad +(T+1/2)^{\gamma}W_3(\varphi_a)+(T+1/2)^{\delta}W_2(\varphi_a)+\mu \end{aligned}$$

J. Ellis, MG, D.V. Nanopoulos and K.A. Olive, 2015 (arXiv: 1503.08867)

No-scale phenomenology

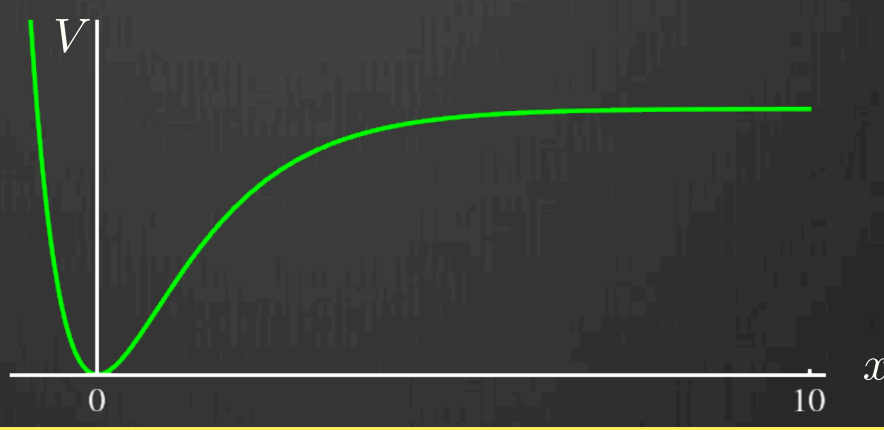
$$K = -3\ln\left(T+\bar{T}-\frac{1}{3}\sum_j|\phi_j|^2\right)+\sum_a\frac{|\varphi_a|^2}{(T+\bar{T})^{n_a}}$$

Untwisted matter inflaton ϕ_1 (WZ)

$\mu \to \mu$

Susy breaking minimum: $T = 1/2\,, \quad \phi_i = \varphi_a = 0 \quad \Rightarrow \quad m_{3/2} = \mu$

$$\phi_i : \begin{cases} m_0 = 0\,, \\ B_0 = -\beta m_{3/2}\,, \\ A_0 = -\alpha m_{3/2}\,, \end{cases} \qquad \varphi_i : \begin{cases} m_0 = (1-n_a)^{1/2} m_{3/2}\,, \\ B_0 = 2\left(1-n_a-\frac{\delta}{2}\right) m_{3/2}\,, \\ A_0 = 3\left(1-n_a-\frac{\gamma}{3}\right) m_{3/2}\,, \end{cases}$$



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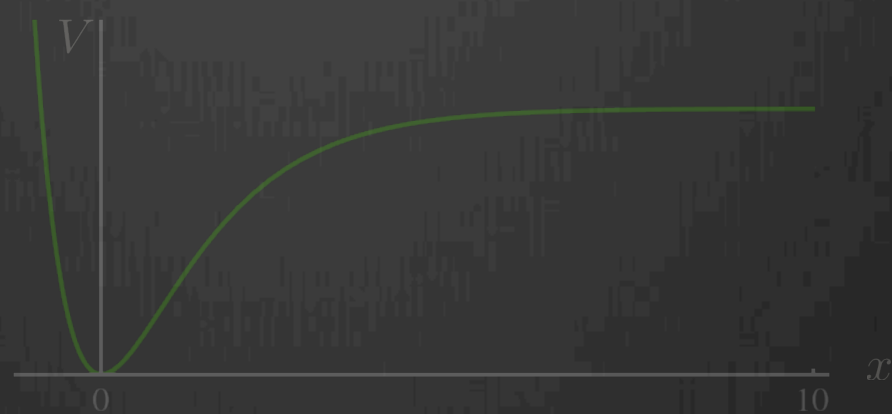
No-scale



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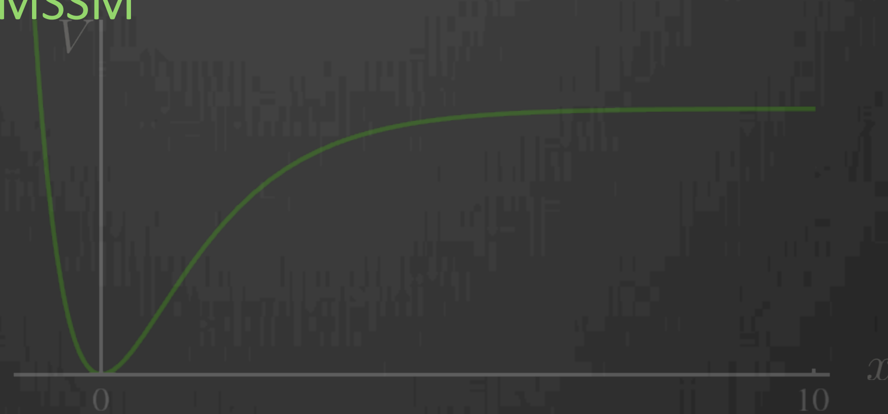
No-scale CMSSM



Untwisted matter inflaton ϕ_1 (WZ)

$$\mu \rightarrow \mu$$

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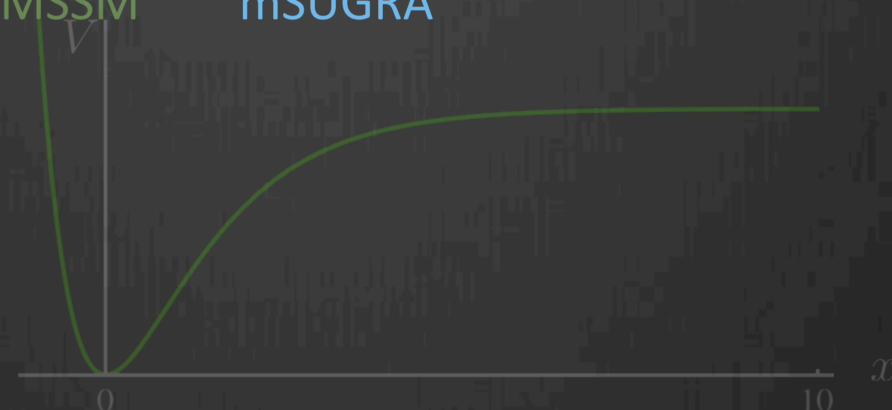
No-scale CMSSM mSUGRA



$$K = -3\ln\left(T + \bar{T} - \frac{1}{3}\sum_j |\phi_j|^2\right) + \sum_a \frac{|\varphi_a|^2}{(T+\bar{T})^{n_a}}$$

Untwisted matter inflaton ϕ_1 (WZ)

$$\mu \to \mu$$

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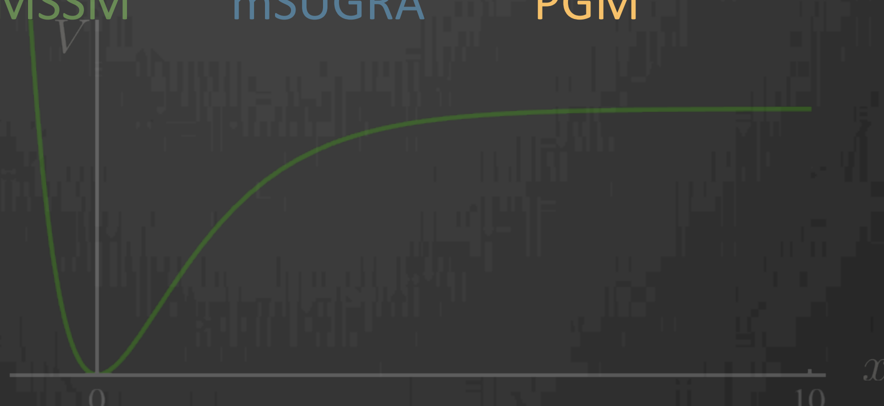
No-scale CMSSM mSUGRA PGM



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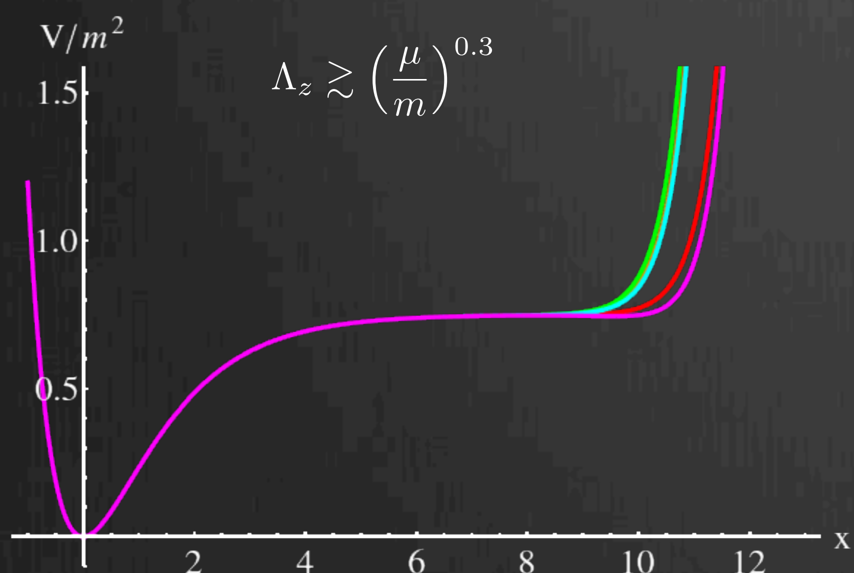
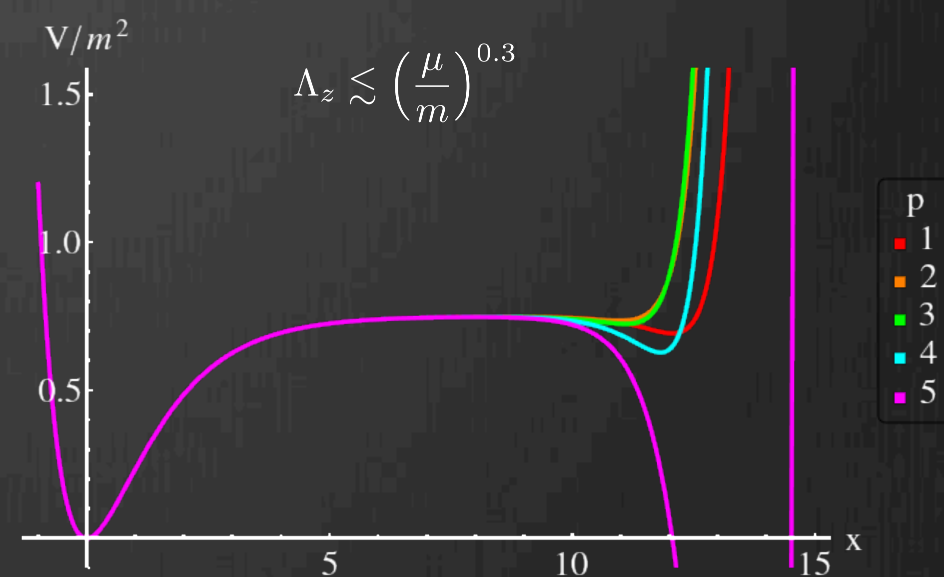
Untwisted matter inflaton ϕ_1 (WZ)

$$\mu \to \mu(z+\nu)(T+1/2)^p \qquad K \supset z\bar{z}-\frac{(z\bar{z})^2}{\Lambda_z^2}$$

Susy breaking minimum:

$$T=1/2\,,\quad \phi_i=\varphi_a=0\,,\quad z\simeq -\frac{(p^2-6p+3)\Lambda_z^2}{4(3p(6-p))^{1/2}}\,,\quad \nu\simeq\left(\frac{3}{p(6-p)}\right)^{1/2}$$





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Susy breaking minimum:

$$T=1/2\,,\quad \phi_i=\varphi_a=0\,,\quad z\simeq-\frac{(p^2-6p+3)\Lambda_z^2}{4(3p(6-p))^{1/2}}\,,\quad \nu\simeq\left(\frac{3}{p(6-p)}\right)^{1/2}$$

$$\phi_i:\begin{cases}m_0=\frac{1}{3}((6-p)p)^{1/2}m_{3/2}\,,\\ B_0=-\frac{1}{3}(p-\beta(p-3))m_{3/2}\,,\\ A_0=\frac{1}{3}\alpha(p-3)m_{3/2}\,,\end{cases}$$

$$\varphi_a:\begin{cases}m_0=\frac{1}{3}(9-n_a(p-3)^2)^{1/2}m_{3/2}\,,\\ B_0=\frac{1}{3}(6+2n_a(p-3)+p(\delta-3)-3\delta)m_{3/2}\,,\\ A_0=-\frac{1}{3}(3-3n_a-\gamma)(p-3)m_{3/2}\,.\end{cases}$$

Untwisted matter inflaton ϕ_1 (WZ)

Decay:

Segregated inflation and matter sectors, $W_1 = W_{1\alpha} = W_{1\alpha\beta} = \cdots = 0$

$$\Rightarrow \quad \Gamma(\phi_1 \to \text{matter}) = 0$$

No inflaton – modulus mixing, $W_{1TT} = 0$

$$\Rightarrow \quad \Gamma(\phi_1 \to T\,T) = 0$$

$$\Gamma(\phi_1 \to \psi_{3/2}\psi_{3/2}) = 0$$

No gauge kinetic function dependence, $\partial f_{\alpha\beta}/\partial\phi_1 = 0$

$$\Rightarrow \quad \Gamma(\phi_1 \to gg) = \Gamma(\phi_1 \to \tilde{g}\tilde{g}) = 0$$

Untwisted matter inflaton ϕ_1 (WZ)

Decay:

ϕ_1 as heavy singlet sneutrino, $\Delta W = y_\nu H_u L \phi_1$

$$\Rightarrow \quad \Gamma(\phi_1 \to H_u^0\tilde{\nu}, H_u^+\tilde{f}_L) = m\frac{|y_\nu|^2}{16\pi}$$

Inflaton – modulus mixing, $\Delta W = \zeta(T-1/2)^2\phi_1$

$$\Rightarrow \quad \Gamma(\phi_1 \to T\,T) = \Gamma(\phi_1 \to \psi_{3/2}\psi_{3/2}) = m\frac{|\zeta|^2}{72\pi}$$

$$\Gamma(\phi_1 \to gg) = (p-3)^2\frac{|\zeta\cdot f'(T)|^2}{216\pi\langle \mathrm{Re}\, f\rangle^2}\left(\frac{N_G}{12}\right)\left(\frac{m_{3/2}}{m}\right)^2 m$$

$$= \left(\frac{m}{m_{3/2}}\right)^2 \Gamma(\phi_1 \to \tilde{g}\tilde{g})$$

$$K = -3\ln\left(T+\bar{T}-\frac{1}{3}\sum_j|\phi_j|^2\right)+\sum_a\frac{|\varphi_a|^2}{(T+\bar{T})^{n_a}}$$

Volume modulus inflaton T (Cecotti, EGNO)

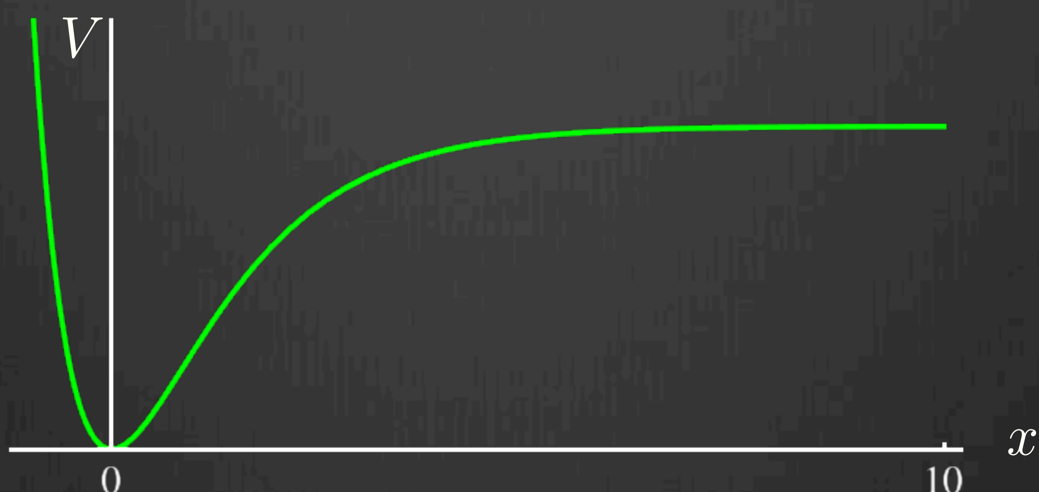
$$\mu \to \mu(z+\nu)$$

$$K \supset z\bar{z} - \frac{(z\bar{z})^2}{\Lambda_z^2}$$

Susy breaking minimum:

$$T \simeq \frac{1}{2}+\frac{2}{3}\left(\frac{\mu}{m}\right)^2\,,\quad \phi_1(\varphi_1)\simeq\frac{\mu}{m}\,,\quad z\simeq\frac{\Lambda_z^2}{\sqrt{12}}\,,\quad \nu\simeq\frac{1}{\sqrt{3}}\quad\Rightarrow\quad m_{3/2}=\mu/\sqrt{3}$$

Universal soft parameters: $m_0 = m_{3/2}\,,\quad B_0=-m_{3/2}\,,\quad A_0=0$



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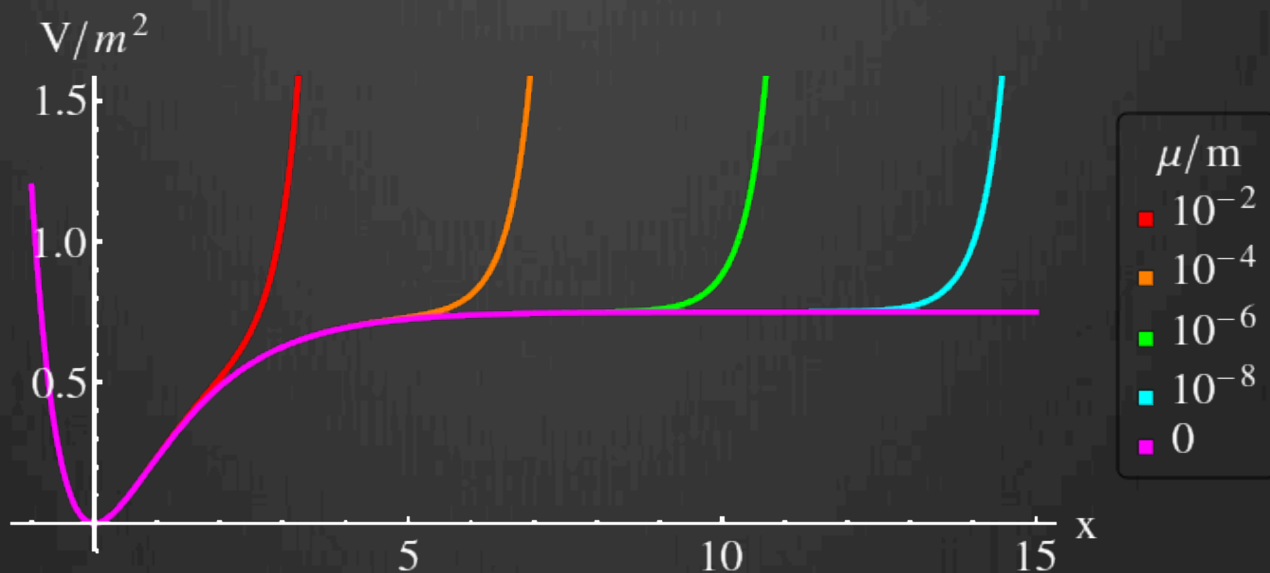


No-scale phenomenology

Volume modulus inflaton T (Cecotti, EGNO)

$$\mu \to \mu\left(\nu + z/\sqrt{3}\right)^3 \qquad K = -3\ln\left(T+\bar{T}-\frac{1}{3}z\bar{z}-\cdots\right)+\cdots$$

Susy breaking minimum:

$$T \simeq \frac{1}{2} + \left(\frac{\mu}{m}\right)^2 , \quad \phi_1(\varphi_1) \simeq \sqrt{3}\frac{\mu}{m} , \quad z \propto \sqrt{3}\left(\frac{\mu}{m}\right)^2 , \quad \nu = 1 \quad \Rightarrow \quad m_{3/2} = \mu$$

$$\phi_i \;:\; m_0 = 0 , \qquad B_0 = -m_{3/2} , \quad A_0 = 0$$
$$\varphi_a \;:\; m_0 = m_{3/2} , \quad B_0 = -m_{3/2} , \quad A_0 = 0$$

No modular weight dependence, $\langle D_T W\rangle = 0$

Volume modulus inflaton T (Cecotti, EGNO)

Coupling to matter (untwisted $n_i\equiv 1$):

$$\mathcal{L}=\frac{n_I}{\sqrt{3}}\delta T\Phi_I\partial_\mu\partial^\mu\bar{\Phi}^I-\frac{in_I}{2\sqrt{3}}\delta T\bar{\chi}_{IL}\gamma^\mu\partial_\mu\chi_L^I$$
$$+\frac{in_I}{2\sqrt{3}}\bar{\chi}_{IL}(\partial\!\!\!/\delta T)\chi_L^I+\frac{\sqrt{3}}{2}W^{IJ}\,\delta T\bar{\chi}_{IL}\chi_{JR}+\frac{\sqrt{3}}{2}W^{IJK}\,\delta T\Phi_K\bar{\chi}_{IL}\chi_{JK}$$
$$-\frac{B_J^I}{\sqrt{3}}\delta T\Phi_I\bar{\Phi}^J-\frac{B_K^{IJ}}{2\sqrt{3}}\delta T\Phi_I\Phi_J\bar{\Phi}^K-\frac{B_{JK}^I}{2\sqrt{3}}\delta T\Phi_I\bar{\Phi}^J\bar{\Phi}^K$$
$$-\frac{B_L^{IJK}}{6\sqrt{3}}\delta T\Phi_I\Phi_J\Phi_K\bar{\Phi}^L-\frac{B_{JKL}^I}{6\sqrt{3}}\delta T\Phi_I\bar{\Phi}^J\bar{\Phi}^K\bar{\Phi}^L-\frac{B_{KL}^{IJ}+C_{KL}^{IJ}}{4\sqrt{3}}\delta T\Phi_I\Phi_J\bar{\Phi}^K\bar{\Phi}^L$$
$$+\text{h.c.}+\mathcal{O}\left(\frac{m_{3/2}}{m}\right)+\cdots$$

$$B_{J_1J_2\ldots}^{I_1I_2\ldots}=\left[(n_a-3)W^{I_1I_2\ldots a}\bar{W}_{aJ_1J_2\ldots}-2W^{I_1I_2\ldots k}\bar{W}_{kJ_1J_2\ldots}\right]$$
$$C_{KL}^{IJ}=-(3+(n_I+n_J-3)(n_K+n_L-3))W^{IJ}\bar{W}_{KL}+(n_I+n_M-3)\delta_L^IW^{JM}\bar{W}_{MK}$$

$$K = -3\ln\left(T+\bar{T}-\frac{1}{3}\sum_j|\phi_j|^2\right)+\sum_a\frac{|\varphi_a|^2}{(T+\bar{T})^{n_a}}$$

Volume modulus inflaton T (Cecotti, EGNO)

Decays to matter:

$$\Gamma(T\to\bar{\chi}_I\chi_J) = (n_I+n_J-3)^2\frac{|W^{IJ}|^2 m}{192\pi M_P^2}$$

$$\Gamma(T\to\Phi_I\bar{\Phi}^J) = (n_I+n_L-3)^2\frac{|W^{IL}\bar{W}_{LJ}|^2}{48\pi m M_P^2}$$

$$\Gamma(T\to\Phi_I\bar{\Phi}^J\bar{\Phi}^K) = (n_I+n_L-3)^2\frac{|W^{IL}\bar{W}_{LJK}|^2 m}{12(8\pi)^3 M_P^2}$$

$$\boxed{\Gamma(T\to\bar{\chi}_I\chi_J\Phi_K) = (n_I+n_J+n_K-3)^2\frac{|W^{IJK}|^2 m^3}{36(8\pi)^3 M_P^2}}$$

$$\Gamma(T\to\Phi_I\Phi_J\bar{\Phi}^K) = (n_I+n_J+n_L-3)^2\frac{|W^{IJL}\bar{W}_{LK}|^2 m}{12(8\pi)^3 M_P^2}$$

$$\boxed{\Gamma(T\to\Phi_I\Phi_J\bar{\Phi}^K\bar{\Phi}^M) = (n_I+n_J+n_L-3)^2\frac{|W^{IJL}\bar{W}_{LKM}|^2 m^3}{72(8\pi)^5 M_P^2}}$$

Volume modulus inflaton T (Cecotti, EGNO)

Decays to matter:

$$\Gamma(T \to \tilde{t}_R \tilde{t}_L \bar{\tilde{t}}_R \bar{\tilde{t}}_L) = (2n_t + n_H - 3)^2 \frac{|y_t|^4 m^3}{8(8\pi)^5 M_P^2}$$

$$\Gamma(T \to H_u^0 t_L \bar{t}_R,\ \tilde{t}_L \tilde{H}_u^0 \bar{t}_R,\ \bar{\tilde{t}}_R t_L \tilde{H}_u^0) = (2n_t + n_H - 3)^2 \frac{|y_t|^2 m^3}{12(8\pi)^3 M_P^2}$$

T-dependent gauge kinetic function $f_{\alpha\beta} = f(T)\delta_{\alpha\beta}$

$$\Gamma(T \to gg) = \frac{|f'(T)|^2}{32\pi \langle \mathrm{Re}\, f\rangle^2} \left(\frac{N_G}{12}\right) \frac{m^3}{M_P^2}$$

All other rates suppressed by powers of $\dfrac{m_{3/2}}{m}$

CMB + Reheating for Starobinsky

$$N_* = 66.9 - \ln\left(\frac{k_*}{a_0 H_0}\right) + \frac{1}{4}\ln\left(\frac{V_*^2}{M_P^4 \rho_{\rm end}}\right) + \frac{1-3w_{\rm int}}{12(1+w_{\rm int})}\ln\left(\frac{\rho_{\rm reh}}{\rho_{\rm end}}\right) - \frac{1}{12}\ln g_{\rm reh}$$

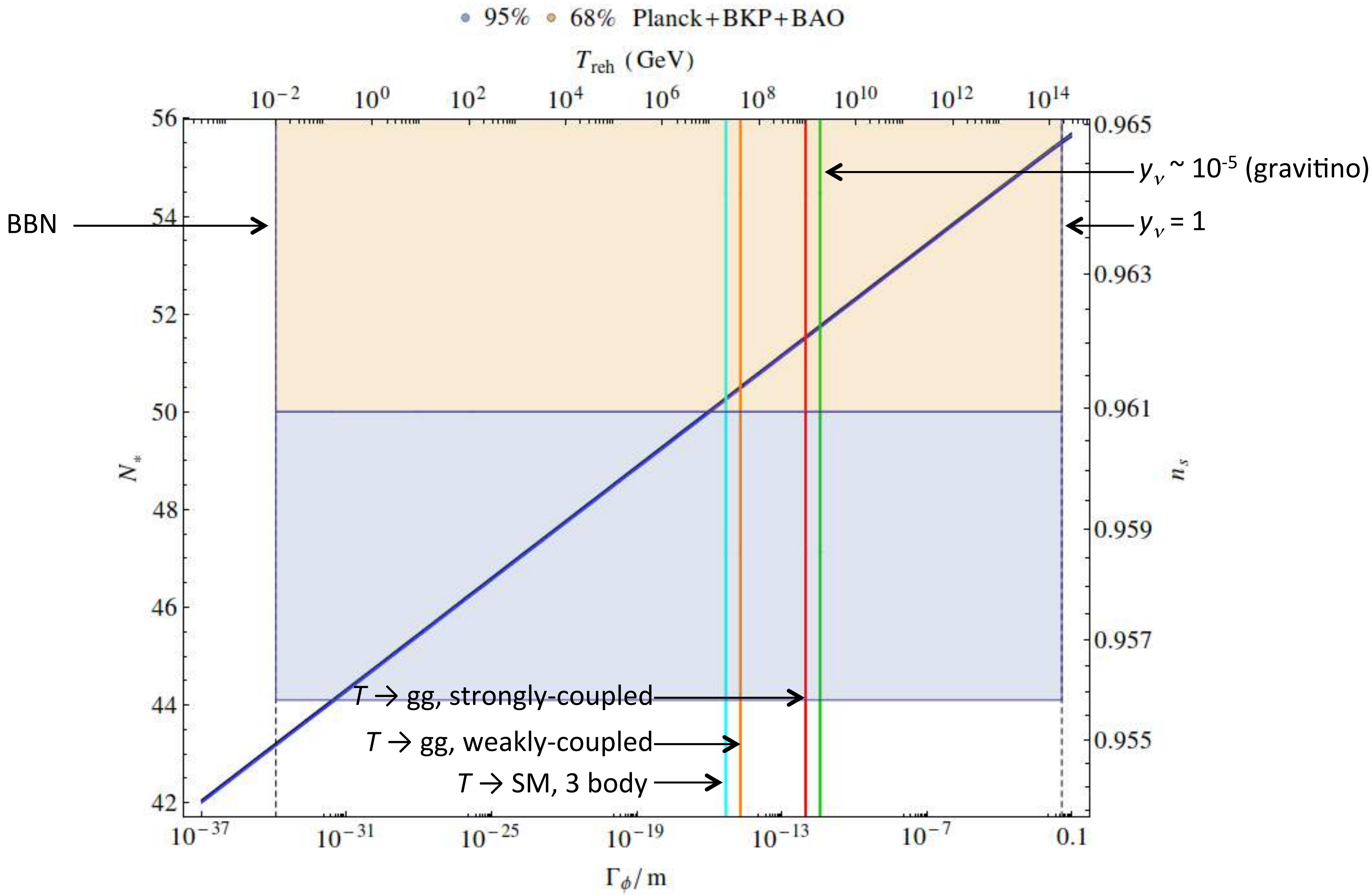
$$= 68.66 - \ln\left(\frac{k_*}{a_0 H_0}\right) + \frac{1}{4}\ln(A_{S*}) - \frac{1}{2}\ln\left(N_* - \sqrt{\frac{3}{8}}\frac{\phi_{\rm end}}{M_P} + \frac{3}{4}e^{\sqrt{\frac{2}{3}}\frac{\phi_{\rm end}}{M_P}}\right)$$

$$+ \frac{1-3w_{\rm int}}{12(1+w_{\rm int})}\left[2\ln\left(\frac{\Gamma}{m}\right) - 1.832\right] - \frac{1}{12}\ln g_{\rm reh}$$

$$w_{\rm int} = \frac{1}{N_{\rm reh} - N_{\rm end}}\int_{N_{\rm end}}^{N_{\rm reh}} w(n)\,dn \approx \frac{0.743}{\ln(3.40\,m/\Gamma)}$$

A. Liddle, S. Leach, 2003 (astro-ph/0305263)
J. Ellis, MG, D.V. Nanopoulos and K.A. Olive, 2015 (arXiv: 1505.06986)

CMB + Reheating for Starobinsky



Conclusion

- Stabilization not necessary in the presence of twisted matter
- Two-field effects reduce tensor-to-scalar ratio to Planck-compatible values
- Various mechanisms for supersymmetry breaking, via the volume moduli and the Polonyi mechanism
- Patterns of soft supersymmetry breaking for the untwisted and twisted matter sectors are different
- Rapid inflaton decay favored by data, $\frac{\Gamma_\phi}{m} \gtrsim 10^{-16}$; possible for sneutrino untwisted matter inflaton
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Thank you