Supersymmetry and Inflation

Supersymmetry and Inflation

or

Why are we still doing what we did in the 80’s?

Supersymmetry and Inflation

or

Why are we still doing what we did in the 80's?

- SuperCosmology
- Why Supersymmetry and Inflation
- Why Supergravity and inflation
- Why No-Scale Supergravity
- Planck and $R+R^2$ inflation
- Supergravity models
- Stabilization
- Phenomenology

SuperCosmology

Nanopoulos, Tamvakis

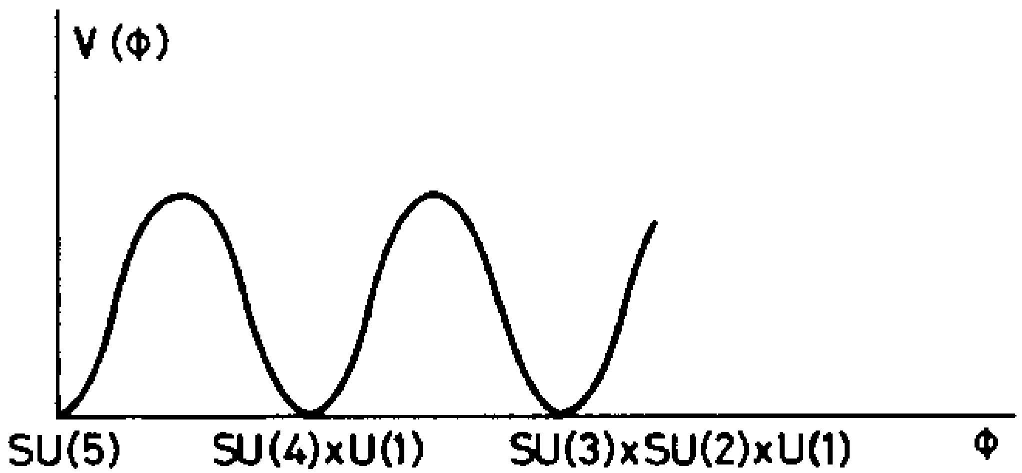


Fig 1 The effective potential at zero temperature.

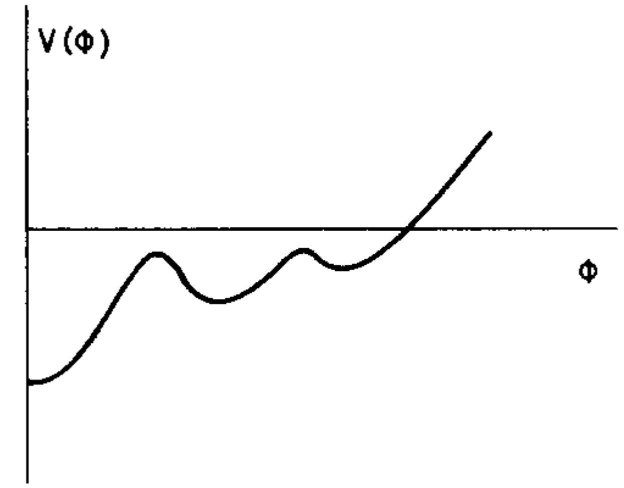


Fig 2. The effective potential at very high temperature

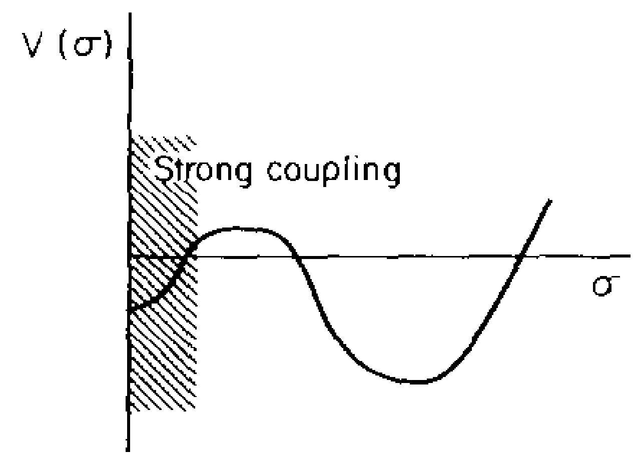


Fig. 2. The potential at $T \sim \Lambda_{SU(5)}$ with a barrier height of the order $\sim(10^{10}\ \mathrm{GeV})^4$. Strong coupling phenomena affect a region (shaded comparable to the dimensions of the barrier.

Nanopoulos, Olive, Tamvakis

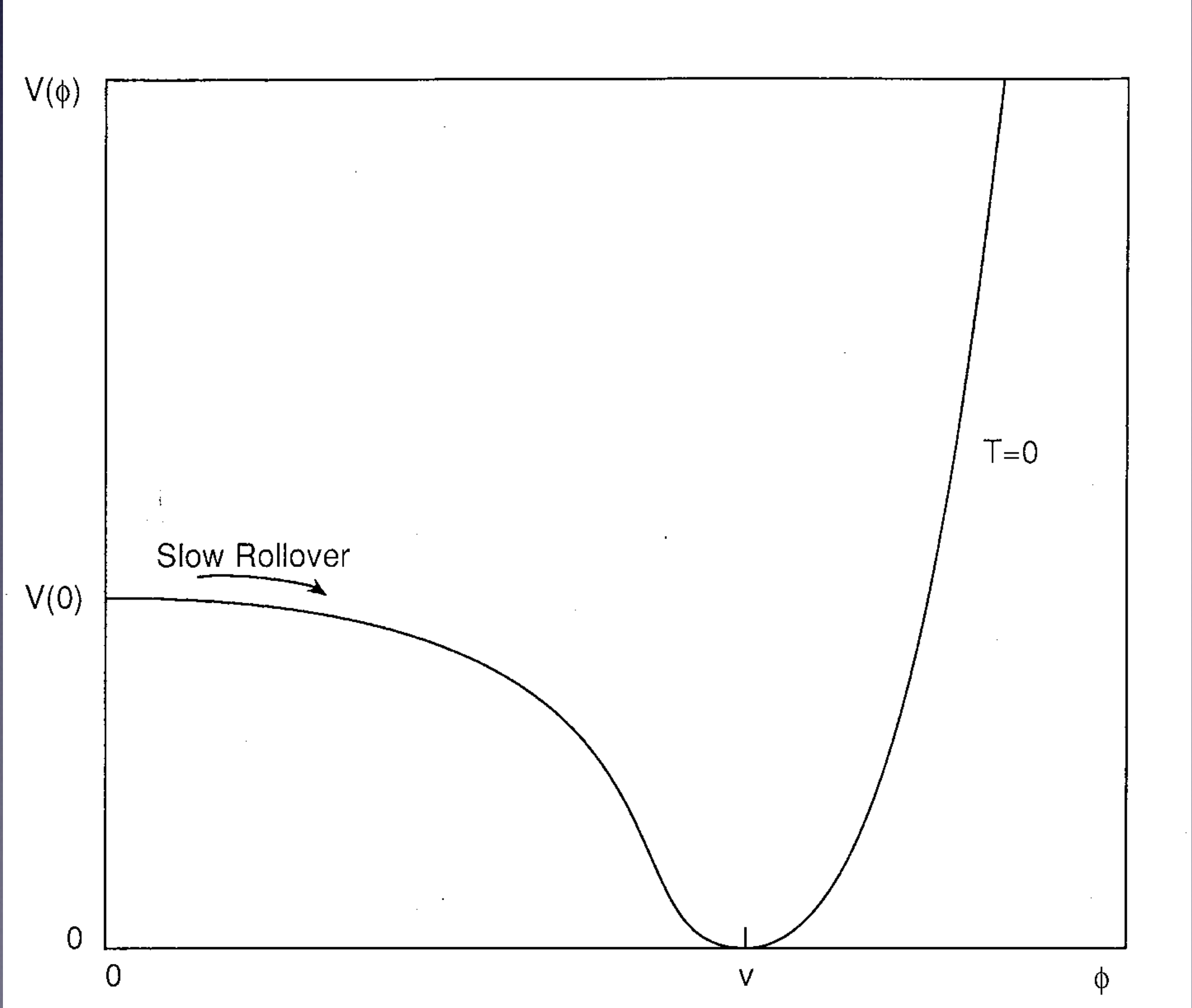
Old New Inflation

Great idea based on 1-loop corrected SU(5) potential for the adjoint:

$$V(\sigma) = A\sigma^4(\ln\frac{\sigma^2}{v^2} - \frac{1}{2})$$

$$A = \frac{5625}{1024\pi^2}g_5^4$$

Linde; Albrecht, Steinhardt



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Linde; Albrecht, Steinhardt

Problems:

- Vacuum structure
- destabilization through quantum fluctuations
- fine tuning (require curvature to be << M_X)
- density fluctuations - $\delta\rho/\rho \sim 100\ g_5^2$

How SUSY can help

Exact Susy - $V_{1\text{-loop}} = 0$

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$$A = \frac{1}{64\pi^2 v^4}\left(\sum_B g_B m_B^4 - \sum_F g_F m_F^4\right) = 0$$

How SUSY can help

Exact Susy - $V_{1\text{-loop}} = 0$

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Too flat!

How SUSY can help

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Too flat!

Broken Susy - $A = \dfrac{75}{32\pi^2 v^2} g_5^2 m_s^2$

fixes fine-tuning, $\delta\rho/\rho$, etc. - but isn't really a model

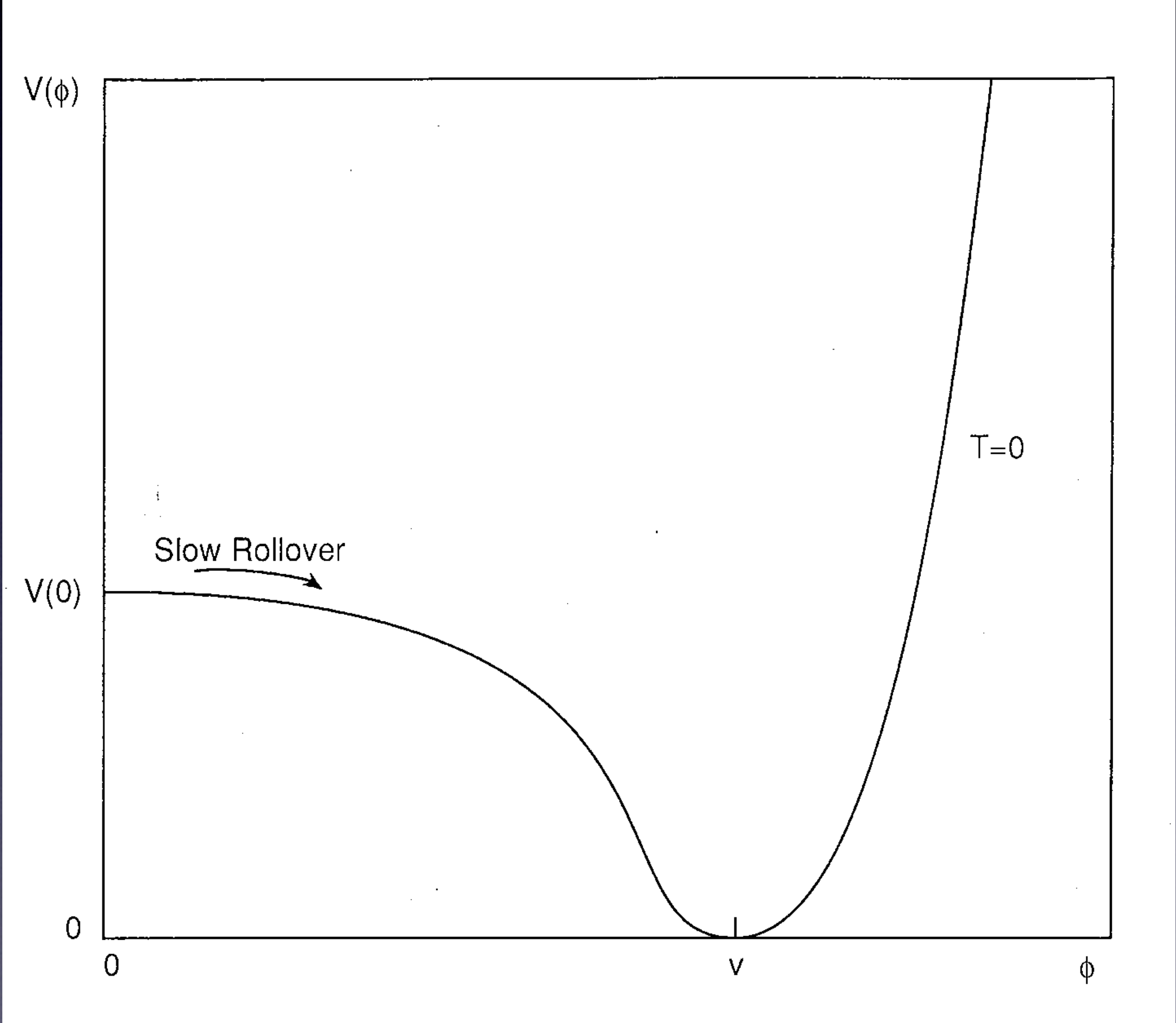
Ellis, Nanopoulos, Olive, Tamvakis

Primordial Supersymmetric Inflation

Ellis, Nanopoulos, Olive, Tamvakis

Supersymmetry

⬇



Primordial ➡

Also, $\delta\rho/\rho \propto a\, M_P/\mu$

$\rightarrow a \sim 10^{-6}$ for $\mu \sim M_P$ (primordial inflation)

Supergravity

Constructing Models $W = \mu^2 \sum_n \lambda_n \phi^n$

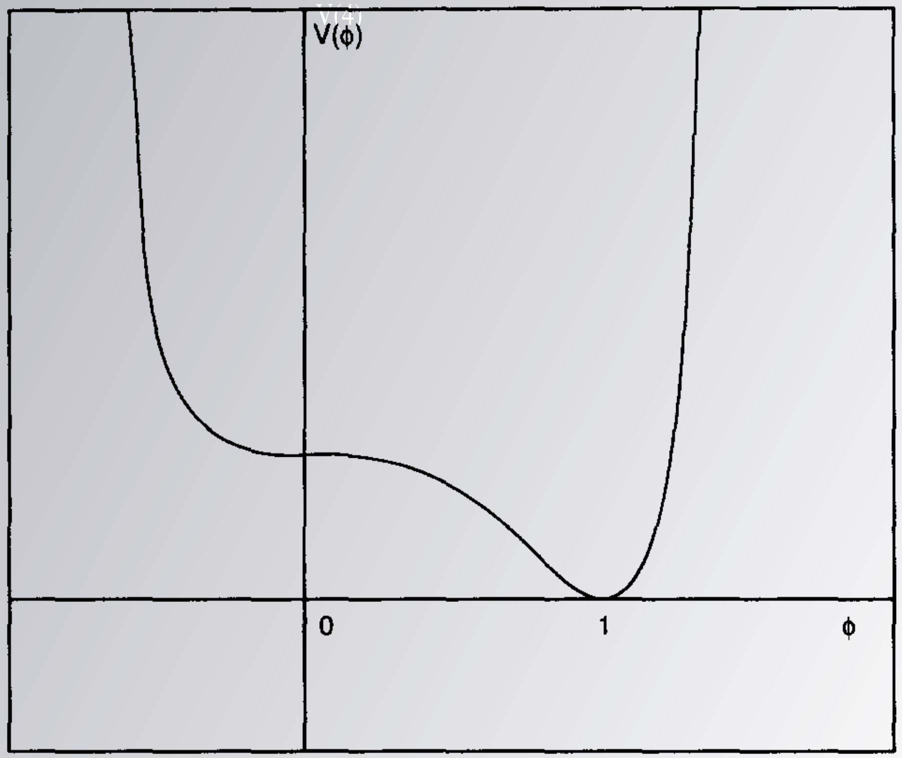
Nanopoulos, Olive, Srednicki, Tamvakis

μ^2 fixed by amplitude of density fluctuations, $\lambda_n \sim O(1)$

Simplest example, $W = \mu^2 (1-\phi)^2$

Holman, Ramond, Ross

$$\begin{aligned} V &= \mu^4 e^{|\phi|^2} \Big[1 + |\phi|^2 - (\phi^2 + \phi^{*2}) - 2|\phi|^2(\phi + \phi^*) \\ &\quad + 5|\phi^2|^2 + |\phi|^2(\phi^2 + \phi^{*2}) - 2|\phi^2|^2(\phi+\phi^*) + |\phi^3|^2 \Big] \\ &\simeq \mu^4 (1 - 4\phi^3 + \frac{13}{2}\phi^4 + \cdots \end{aligned}$$



Introduction of the Inflaton

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AFTER PRIMORDIAL INFLATION

D.V. NANOPOULOS, K.A. OLIVE and M. SREDNICKI
CERN, Geneva, Switzerland

Received 25 April 1983

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We consider the history of the early universe in the locally supersymmetric model we have previously discussed. We pay particular attention to the requirement of converting the quanta of the field which drives primordial inflation (inflatons) to ordinary particles which can produce the cosmological baryon asymmetry without producing too many gravitinos. An inflaton mass of about 10^{13} GeV (a natural value in our model) produces a completely acceptable scenario.

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$$f_B = (a_3/M)\,XY\bar{H}H + a_4 M\bar{\theta}\theta + (a_5/M)\,\bar{\theta}\Sigma^2 H + (a_c/M)\,\bar{H}\Sigma^2\theta + a_7\mu Y^2 + a_8 Y^3 + \text{Yukawa couplings}\,, \tag{4}$$

ϕ is the inflaton field, an SU(5) singlet which acquires a vacuum expectation value (VEV) $v = \langle 0|\phi|0\rangle \simeq M = M_P/(8\pi)^{1/2} \approx 2.4 \times 10^{18}$ GeV and drives inflation. X and z are also SU(5) singlets while Σ is an SU(5) **24**.

Construction of Supergravity Models

Cremmer et al. (1979)

$$\mathcal{L}_{\mathrm{aux}} = -\frac{9}{\phi} e \left|\tfrac{1}{2} g^* - \tfrac{1}{6}\left(\tfrac{1}{3} J_{,zz} + \tfrac{1}{9} J_{,z}^2\right) \phi \bar{\chi}(1+\gamma_5)\chi\right|^2$$

$$-\frac{3}{\phi J_{,zz^*}} \left| \tfrac{1}{2} g^* \left(\frac{g^*_{,z^*}}{g^*} - J_{,z^*} \right) - \tfrac{1}{6}\left(J_{,zzz^*} + \tfrac{2}{3} J_{,z} J_{,zz^*}\right) \bar{\chi}(1+\gamma_5)\chi\phi \right|^2$$

$$-\frac{e}{4\phi}\left[\tfrac{1}{2}\phi_{,zz^*}\bar{\chi}\gamma_\mu\gamma_5\chi - (\phi_{,z^*}\partial_\mu z^* - \phi_{,z}\partial_\mu z) - \tfrac{1}{2}\bar{\psi}_\mu \hat{\phi}_{,z}\gamma_5\chi\right]^2 .$$

K = -J; $-3e^{J/3} = \phi$

W = g/2

G = K + ln|W|^2

$$\mathcal{L}' = -e\phi_{,zz^*}|\partial_\mu z|^2 - e\phi_{,zz^*}\bar{\chi}\not{D}\chi + \tfrac{1}{6} e\phi R(\omega(e))$$

$$-\tfrac{1}{2} e\bar{\chi}\gamma_5\gamma^\mu\chi(\phi_{,zz^*z^*}\partial_\mu z^* - \phi_{,zzz^*}\partial_\mu z)$$

$$+ e\phi_{,zz^*}\bar{\psi}_\mu \partial_\nu \hat{z}^* \gamma^\nu\gamma^\mu\chi - \tfrac{4}{3} e\bar{\chi}\hat{\phi}_{,z}\sigma^{\mu\nu}D_\mu\psi_\nu$$

$$+ \tfrac{1}{6}\phi\bar{\psi}_\mu\gamma_5\gamma_\nu D_\rho\psi_\sigma\epsilon^{\mu\nu\rho\sigma} + \tfrac{1}{8}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho$$

$$\times(\phi_{,z^*}\partial_\sigma z^* - \phi_{,z}\partial_\sigma z) - \tfrac{1}{8} e\phi_{,zz^*}\bar{\psi}_\rho\gamma_5\gamma_\nu\psi^\rho\bar{\chi}\gamma_5\gamma^\nu\chi$$

$$-\tfrac{1}{16}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho\bar{\chi}\gamma_\sigma\gamma_5\chi\phi_{,zz^*} + \tfrac{1}{6} e\bar{\chi}\hat{\phi}_{,z}\psi_\mu\bar{\psi}\cdot\gamma\psi^\mu$$

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$$- \frac{3}{\phi J_{,zz^*}} \left| \tfrac{1}{2} g^* \left(\frac{g^*_{,z^*}}{g^*} - J_{,z^*} \right) - \tfrac{1}{6}\left(J_{,zzz^*} + \tfrac{2}{3} J_{,z} J_{,zz^*}\right) \bar{\chi}(1+\gamma_5)\chi\phi \right|^2$$
$$- \frac{e}{4\phi}\left[\tfrac{1}{2}\phi_{,zz^*}\bar{\chi}\gamma_\mu\gamma_5\chi - (\phi_{,z^*}\partial_\mu z^* - \phi_{,z}\partial_\mu z) - \tfrac{1}{2}\bar{\psi}_\mu \hat{\phi}_{,z}\gamma_5\chi\right]^2 .$$

$$\mathcal{L}' = -e\phi_{,zz^*}|\partial_\mu z|^2 - e\phi_{,zz^*}\bar{\chi}\not{D}\chi + \tfrac{1}{6} e\phi R(\omega(e))$$
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$$+ e\phi_{,zz^*}\bar{\psi}_\mu \partial_\nu \hat{z}^* \gamma^\nu\gamma^\mu\chi - \tfrac{4}{3} e\bar{\chi}\hat{\phi}_{,z}\sigma^{\mu\nu}D_\mu\psi_\nu$$
$$+ \tfrac{1}{6}\phi\bar{\psi}_\mu\gamma_5\gamma_\nu D_\rho\psi_\sigma\epsilon^{\mu\nu\rho\sigma} + \tfrac{1}{8}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho$$
$$\times (\phi_{,z^*}\partial_\sigma z^* - \phi_{,z}\partial_\sigma z) - \tfrac{1}{8} e\phi_{,zz^*}\bar{\psi}_\rho\gamma_5\gamma_\nu\psi^\rho\bar{\chi}\gamma_5\gamma^\nu\chi$$
$$- \tfrac{1}{16}\epsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho\bar{\chi}\gamma_\sigma\gamma_5\chi\phi_{,zz^*} + \tfrac{1}{6} e\bar{\chi}\hat{\phi}_{,z}\psi_\mu\bar{\psi}\cdot\gamma\psi^\mu$$

$K = -J$; $-3e^{J/3} = \phi$

$W = g/2$

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

Construction of Supergravity Models

Conformal transformation to Einstein Frame

Cremmer et al.

$$\tfrac{1}{6}e\phi R \to -\tfrac{1}{2}eR - \tfrac{3}{4}e(\partial_\mu(\log\phi))^2$$

essentially $(\partial_\mu K)^2$

so that

$$\mathcal{L}_{kin} = \frac{1}{2\kappa^2}\tilde{R} - \frac{1}{\kappa^2}K_i^j(\partial_\mu\phi^i)(\partial^\mu\phi_j^*)$$

with $$e^{2\Omega} = e^{-K/3} = -\frac{\phi}{3}$$

and

$$V = e^G[G_i(G^{-1})^i_j G^j - 3]$$

Construction of Supergravity Models

Cremmer et al.

Minimal Supergravity

$$\phi = -3e^{-zz^*/3} \qquad K = zz^*$$

or no-scale

$$\phi = z + z^* \qquad K = -3\ln(z + z^*)$$

or any $\phi_{z,z^*} = 0$

leading to V = 0!

No-Scale Supergravity

Natural vanishing of cosmological constant (tree level) with the supersymmetry scale not fixed at lowest order. (Also arises in generic 4d reductions of string theory.)

Cremmer, Ferrara, Kounnas, Nanopoulos; Ellis, Kounnas, Nanopoulos; Lahanas, Nanopoulos

$$K = -3\ln(T + T^* - \phi^i {\phi_i}^*/3)$$

$$V = e^{\frac{2}{3}K}\left|\frac{\partial W}{\partial \phi^i}\right|^2$$

Globally supersymmetric potential once K (canonical) picks up a vev

No-Scale Supergravity

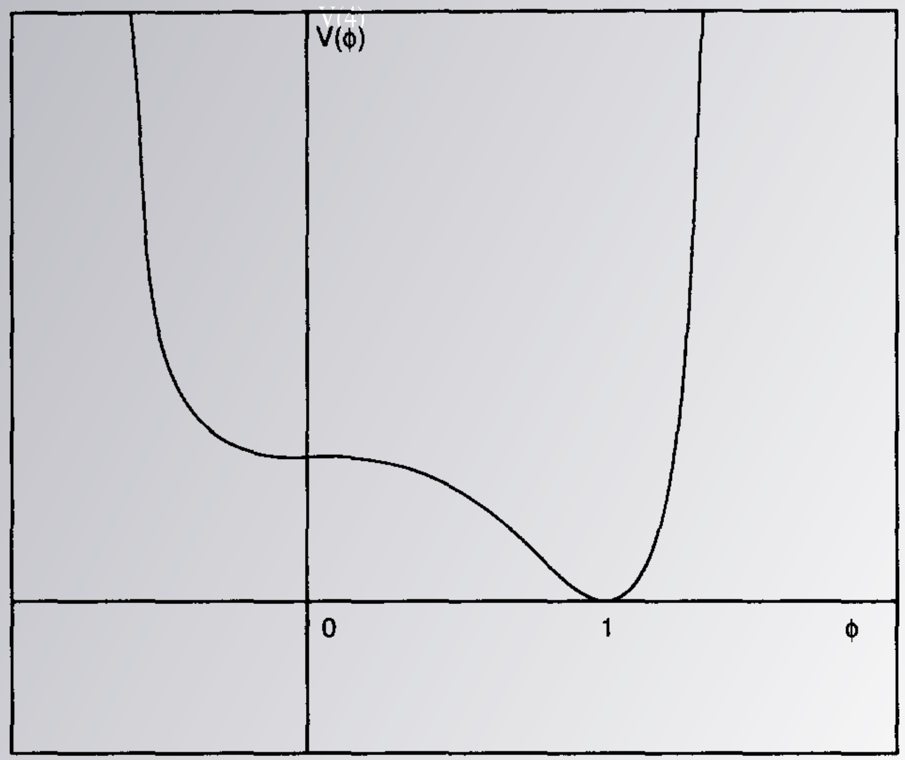
Ellis, Enqvist, Nanopoulos, Olive, Srednicki

Constructing Models $$W = \mu^2 \sum_n \lambda_n \phi^n$$

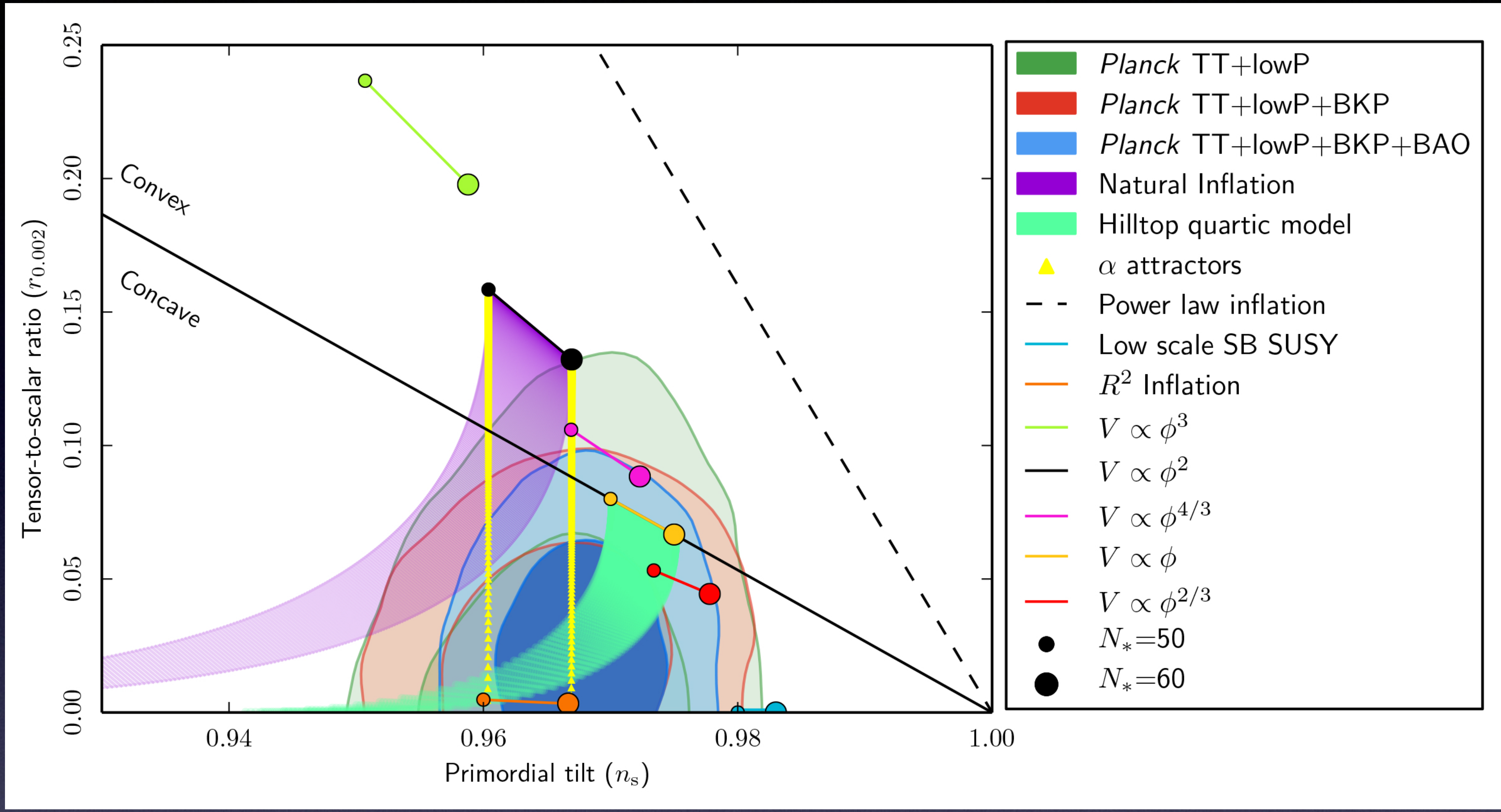
μ^2 fixed by amplitude of density fluctuations, $\lambda_n \sim O(1)$

Simplest example, $$W = \mu^2(\phi - \phi^4/4)$$

$$V = \mu^4 |1 - \phi^3|^2$$



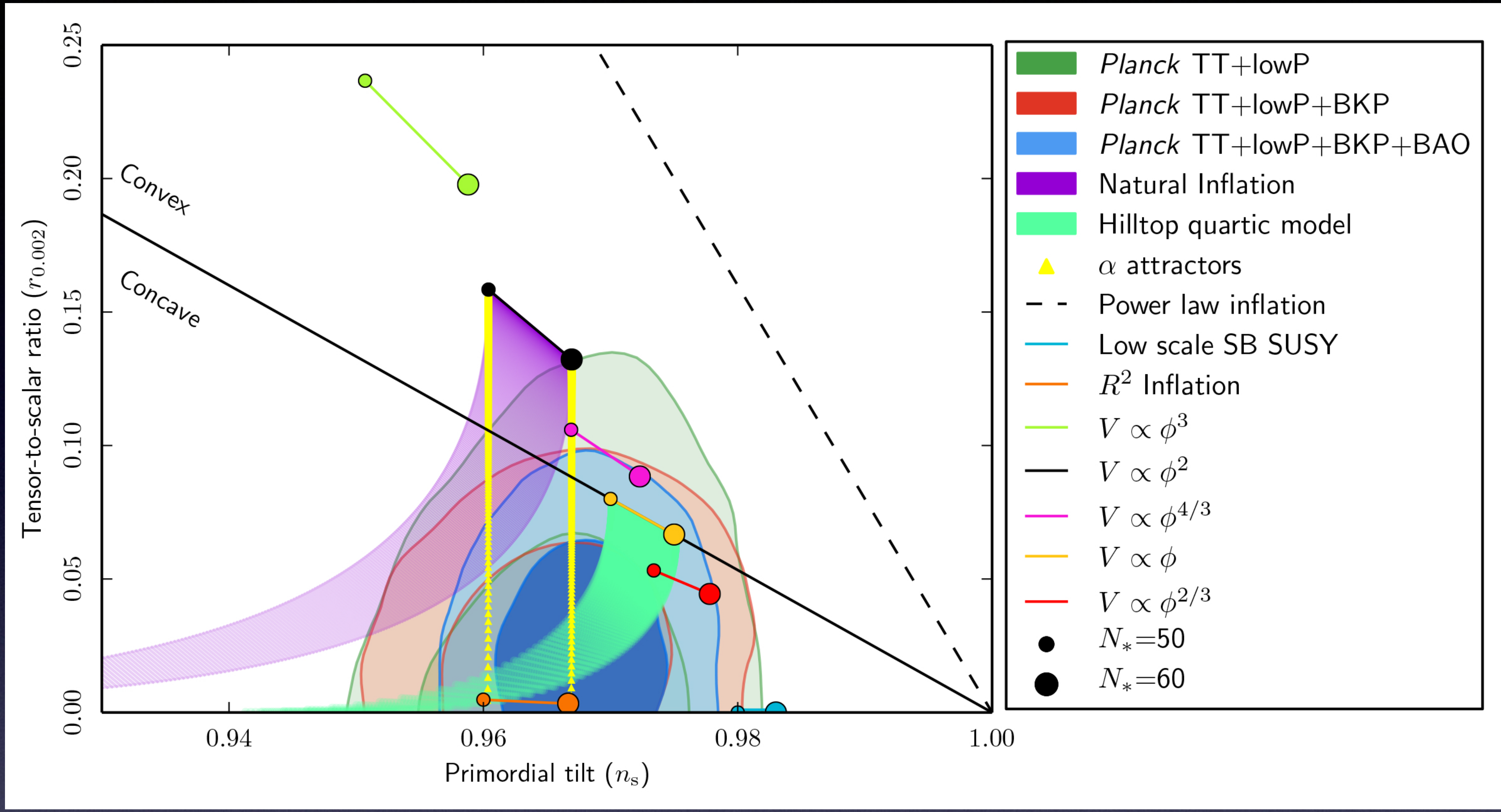
Planck Results



$$\epsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2 \qquad \eta = \frac{V''}{V} \qquad n_s = 1 - 6\epsilon + 2\eta \qquad r = 16\epsilon$$

Trouble for simple supergravity
and no-scale models:

Planck Results



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Trouble for simple supergravity and no-scale models:

$$\epsilon \simeq \frac{1}{72N^4} \ll 1$$

$$\eta \simeq -\frac{1}{2N}$$

not OK

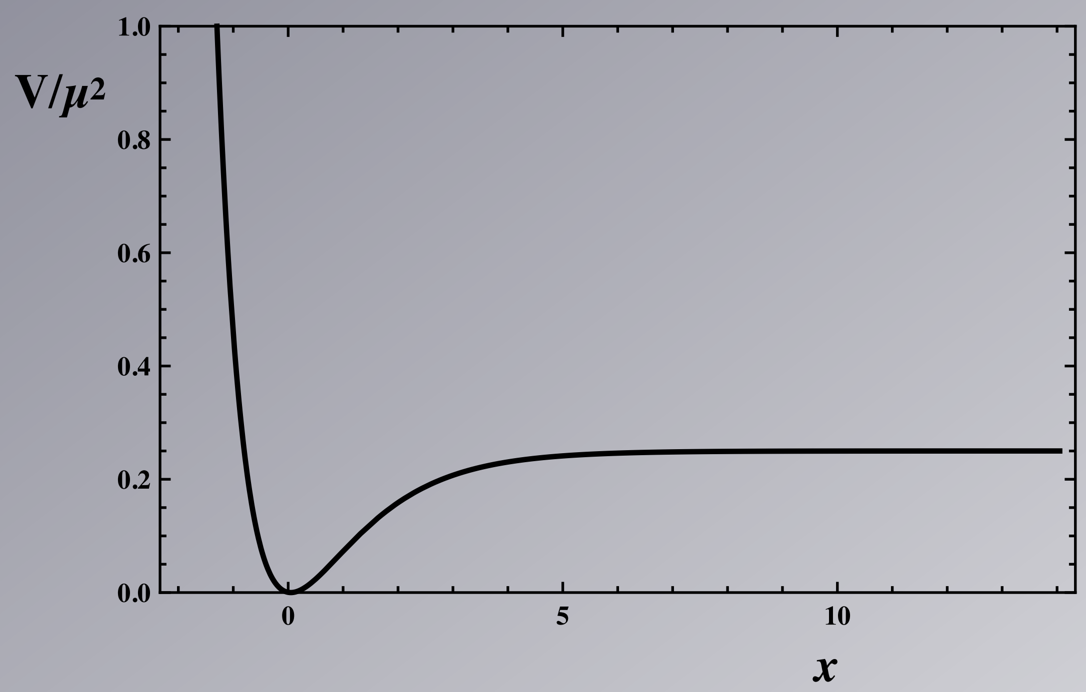
$$n_s \sim .933$$

Planck-friendly Models R+R^2 Inflation

Starobinsky

$$V = \frac{3}{4}M^2(1 - e^{-\sqrt{2/3}\varphi'})^2$$
$$= \mu^2 e^{-\sqrt{2/3}x}\sinh^2(x/\sqrt{6})$$

$x=\varphi/M_P$, $\mu^2 = 3M^2$



Slow Roll parameters:

$$\epsilon = \frac{1}{3}\mathrm{csch}^2(x/\sqrt{6})e^{-\sqrt{2/3}x},$$
$$\eta = \frac{1}{3}\mathrm{csch}^2(x/\sqrt{6})\left(2e^{-\sqrt{2/3}x} - 1\right)$$

μ is set by the normalization of the quadrupole

$$A_s = \frac{V}{24\pi^2\epsilon} = \frac{\mu^2}{8\pi^2}\sinh^4(x/\sqrt{6})$$

$\Longrightarrow$ $\mu = 2.2 \times 10^{-5}$ for N = 55

$x_i = 5.35$

R^2 Gravity

$$\mathcal{A} = \frac{1}{2}\int d^4x\sqrt{-g}\alpha R^2$$

Rewrite as:

$$\mathcal{A} = \frac{1}{2}\int d^4x\sqrt{-g}\left(2\alpha\Phi R - \alpha\Phi^2\right)$$

transform to Einstein frame $\tilde{g}_{\mu\nu} = e^{2\Omega}g_{\mu\nu} = \frac{2\alpha\Phi}{\mu^2}g_{\mu\nu}$

$$\mathcal{A} = \frac{1}{2}\int d^4x\sqrt{-\tilde{g}}\left(\mu^2\tilde{R} - 6\mu^2\partial^\mu\Omega\partial_\mu\Omega - \frac{\mu^4}{4\alpha}\right)$$

Finally leading to

$$\mathcal{A} = \frac{1}{2}\int d^4x\sqrt{-\tilde{g}}\left(\mu^2\tilde{R} - \partial^\mu\phi\partial_\mu\phi - \frac{\mu^4}{4\alpha}\right)$$

deSitter!

Buchdahl (1968,1978)
Bicknell (1974)

R+R² Gravity

$$\mathcal{A} = \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\left(R+\tilde{\alpha}R^2\right)$$

Starobinsky

$$\tilde{\alpha} = \alpha/M_P^2$$

transform to Einstein frame $\quad \tilde{g}_{\mu\nu} = e^{2\Omega}g_{\mu\nu} = \left(1+2\tilde{\alpha}\Phi\right)g_{\mu\nu}$

Leading to

$$\mathcal{A} = \frac{1}{2\kappa^2}\int d^4x\sqrt{-\tilde{g}}\left[\tilde{R} - \kappa^2\partial^\mu\phi\partial_\mu\phi - \frac{1}{4\tilde{\alpha}}\left(1-e^{-\sqrt{\frac{2}{3}}\kappa\phi}\right)^2\right]$$

$$\tilde{\alpha} = 1/6M^2$$

$$V = \frac{3}{4}M^2(1-e^{-\sqrt{2/3}\varphi'})^2$$

R+R^2 Gravity with conformally coupled fields

Ellis, Nanopoulos, Olive

$$\mathcal{A} = \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\left[\delta R + \tilde{\alpha}R^2 - 2\kappa^2\sum_{i=1}^{N-1}\left(\partial^\mu\phi^i\partial_\mu\phi_i^\dagger + \frac{1}{3}|\phi^i|^2 R\right)\right]$$

transform to Einstein frame $\quad \tilde{g}_{\mu\nu} = e^{2\Omega}g_{\mu\nu} = (\delta + 2\tilde{\alpha}\Phi - \frac{\kappa^2}{3}\sum_{i=1}^{N-1}|\phi^i|^2)g_{\mu\nu}$

Leading to

$$\mathcal{A} = \frac{1}{2\kappa^2}\int d^4x\sqrt{-\tilde{g}}\left[\tilde{R} - 6\partial^\mu\Omega\partial_\mu\Omega - \sum_{i=1}^{N-1}\frac{2\kappa^2\partial^\mu\phi^i\partial_\mu\phi_i^\dagger}{\left(\delta + 2\tilde{\alpha}\Phi - \frac{\kappa^2}{3}\sum_{i=1}^{N-1}|\phi^i|^2\right)} - \frac{\tilde{\alpha}\Phi^2}{\left(\delta + 2\tilde{\alpha}\Phi - \frac{\kappa^2}{3}\sum_{i=1}^{N-1}|\phi^i|^2\right)^2}\right]$$

No-scale Supergravity

Ellis, Nanopoulos, Olive

$$K = -3\ln\kappa\left(T + T^\dagger\right)$$

$$2\tilde{\alpha}\Phi \;=\; \kappa(T + T^\dagger)$$

giving

$$\mathcal{L}_{kin} = -\frac{3}{(T+T^\dagger)^2\kappa^2}\partial^\mu T\partial_\mu T^\dagger = -\frac{1}{12\kappa^2}(\partial_\mu K)^2 - \frac{3}{4}e^{2K/3}|\partial_\mu(T - T^\dagger)|^2$$

$$K = -6\Omega\,.$$

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$$K = -6\Omega\,.$$

Choose superpotential $\quad W = T^3 - \dfrac{\mu^3}{12\alpha}$

$$V(T,T^\dagger) = \frac{\mu^4}{4\alpha}\frac{T^2+{T^\dagger}^2}{(T+T^\dagger)^2}\,.$$

No-scale Supergravity: Minkowski, dS, AdS

Ellis, Nagaraj, Nanopoulos, Olive

Can be generalized to multiple moduli

$$K \;=\; -3\,\alpha \ln(\phi + \phi^\dagger)\,,$$

Ellis, Kounnas, Nanopoulos (1983)

$$\begin{array}{llcl}
1) & W & = & a \qquad \text{and} \qquad \alpha = 1\,, \\
2) & W & = & a\,\phi^{3\alpha/2}\,, \\
3) & W & = & a\,\phi^{3\alpha/2}(\phi^{3\sqrt{\alpha}/2} - \phi^{-3\sqrt{\alpha}/2})\,.
\end{array}$$

In General,

Minkowski: $W \;=\; a\,\phi^n \qquad n_\pm \;=\; \frac{3}{2}(\alpha \pm \sqrt{\alpha})$

dS: $a_1 a_2 > 0$

AdS: $a_1 a_2 < 0$

$$W \;=\; a_1 \phi^{n_-} - a_2 \phi^{n_+}$$

$$V = \frac{3}{2} a_1 a_2$$

No-scale Supergravity with matter

$$K = -3\ln\left(T + T^\dagger - (\sum_{i=1}^{N-1}|\phi^i|^2)/3\right)$$

giving

$$\mathcal{L} = -\frac{1}{12\kappa^2}(\partial_\mu K)^2 - e^{K/3}|\partial_\mu\phi^i|^2 - \frac{3}{4}e^{2K/3}|\partial_\mu(T - T^\dagger)$$
$$+ \sum_1^{N-1}\frac{1}{3}\kappa(\phi_i^*\partial_\mu\phi^i - \phi^i\partial_\mu\phi_i^*)|^2 - V$$

$$V = \frac{\hat{V}}{(T + T^* - |\phi|^2/3)^2}$$

with

$$\hat{V} \equiv \left|\frac{\partial W}{\partial\phi}\right|^2 + \frac{1}{3}(T + T^*)|W_T|^2 + \frac{1}{3}\left(W_T(\phi^* W_\phi^* - 3W^*) + \text{h.c.}\right)$$

No-Scale models revisited

Can we find a model consistent with Planck?

Ellis, Nanopoulos, Olive

Start with WZ model: $$W = \frac{\hat{\mu}}{2}\Phi^2 - \frac{\lambda}{3}\Phi^3$$

Assume now that T picks up a vev: 2<Re T> = c

$$\mathcal{L}_{eff} = \frac{c}{(c - |\phi|^2/3)^2}|\partial_\mu \phi|^2 - \frac{\hat{V}}{(c - |\phi|^2/3)^2}$$

Redefine inflaton to a canonical field χ

$$\hat{V} = |W_\Phi|^2$$

$$\phi = \sqrt{3c}\tanh\left(\frac{\chi}{\sqrt{3}}\right)$$

$$\lambda = \hat{\mu}/\sqrt{3}$$

Classes of R+R² in No-Scale Supergravity

So is the inflaton T or ϕ?

Ellis, Nanopoulos, Olive

1) T-fixed (ϕ-inflaton) or y_2-fixed y_1-inflaton

Starobinsky potential found when

$$\hat{V} \;=\; M^2|\phi|^2|1-\phi/\sqrt{3}|^2$$

with field redefinition $$(y_i,\phi) \;=\; \sqrt{3}\tanh\left(\frac{\chi}{\sqrt{3}}\right)$$

Classes of R+R^2 in No-Scale Supergravity

So is the inflaton T or ϕ? Ellis, Nanopoulos, Olive

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Starobinsky potential found when

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with field redefinition $$(y_i,\phi) \;=\; \sqrt{3}\tanh\left(\frac{\chi}{\sqrt{3}}\right)$$

2) ϕ-fixed (T-inflaton)

Starobinsky potential found when

$$\hat{V} = 3M^2|T-1/2|^2 \quad \text{or} \quad \hat{V} = 12M^2|T|^2|T-1/2|^2$$

with field redefinition $$T \;=\; \frac{1}{2}e^{2\chi/\sqrt{3}}$$ or T $\rightarrow$ 1/(4T)

Classes of R+R² in No-Scale Supergravity

Utilizing the no-scale symmetry, we can write

Ellis, Nanopoulos, Olive

$$K = -3\ln\left(1 - \frac{|y_1|^2 + |y_2|^2}{3}\right)$$

$$y_1 = \left(\frac{2\phi}{1+2T}\right) \; ; \; y_2 = \sqrt{3}\left(\frac{1-2T}{1+2T}\right)$$

or

$$T = \frac{1}{2}\left(\frac{1 - y_2/\sqrt{3}}{1 + y_2/\sqrt{3}}\right) \; ; \; \phi = \left(\frac{y_1}{1 + y_2/\sqrt{3}}\right)$$

with

$$W(T,\phi) \to \widetilde{W}(y_1, y_2) = \left(1 + y_2/\sqrt{3}\right)^3 W$$

Classes of R+R^2 in No-Scale Supergravity

Example 1:

$$W = M\left[\frac{\phi^2}{2} - \frac{\phi^3}{3\sqrt{3}}\right]$$

Ellis, Nanopoulos, Olive

$$W = M\left[\frac{y_1^2}{2}\left(1+\frac{y_2}{\sqrt{3}}\right) - \frac{y_1^3}{3\sqrt{3}}\right]$$

Example 2:

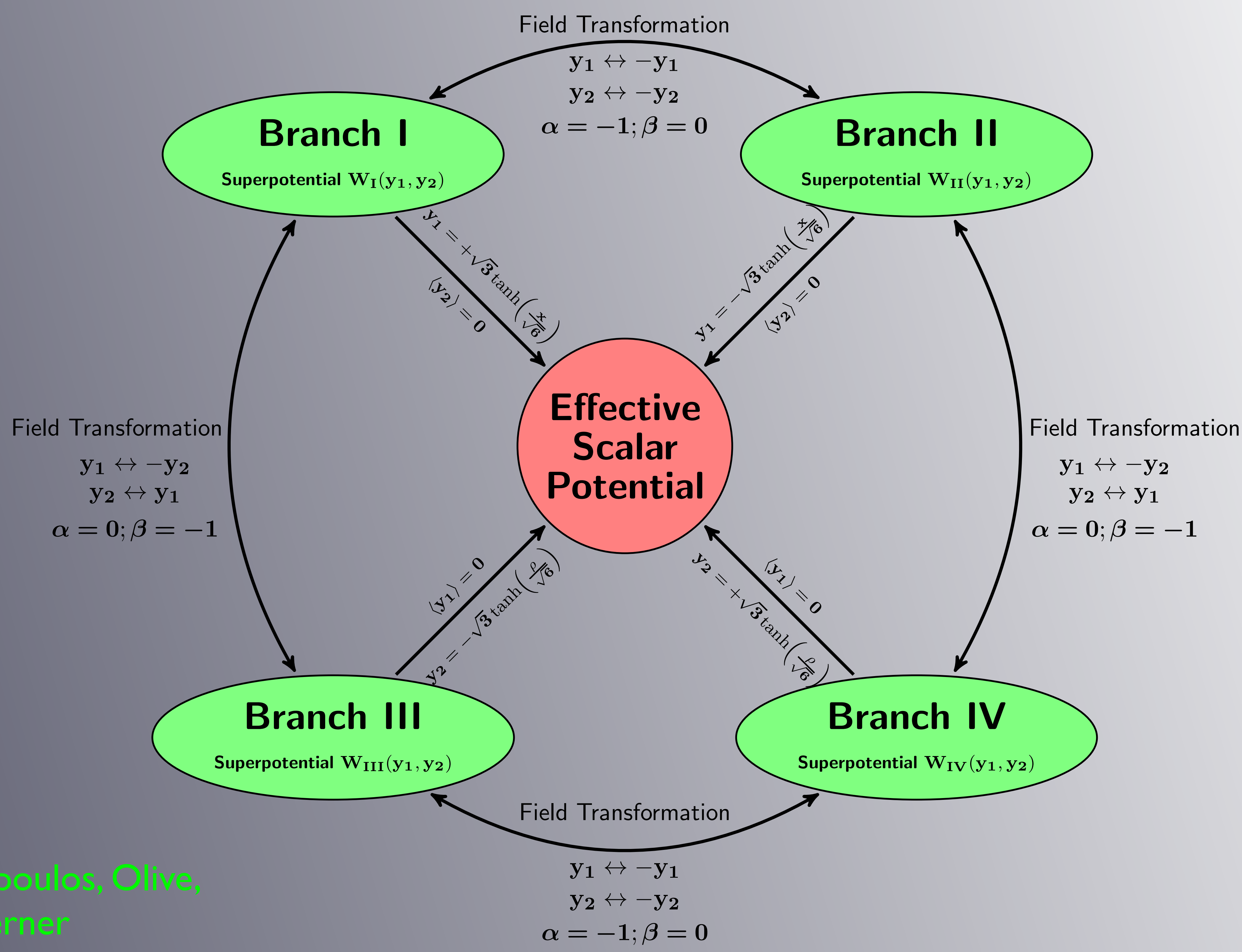
$$W = \sqrt{3}M\phi(T - 1/2)$$

Cecotti; Linde, Kallosh

$$W = My_1y_2(1 + y_2/\sqrt{3})$$

SU(2,1)/SU(2)xU(1) tansformations

$$y_1 \to \alpha y_1 + \beta y_2, \qquad y_2 \to -\beta^* y_1 + \alpha^* y_2 \,.$$



Ellis, Nanopoulos, Olive, Verner

Classes of R+R² in No-Scale Supergravity

Ellis, Nanopoulos, Olive, Verner

Branch 1 solution

$$W(y_1, y_2) \quad = \quad a y_1 + b y_1^2 + c y_1^3 + d y_2 + e y_2 y_1 + f y_2 y_1^2 + g(y_1, y_2)$$

$$a = 0, \qquad c = +\frac{b\left(\sqrt{1-4b^2}-2\right)}{3\sqrt{3}}, \qquad d = 0, \qquad e = \pm\sqrt{1-4b^2}, \qquad f = \mp\frac{\sqrt{1-4b^2}+2b^2}{\sqrt{3}},$$

Example 1: $b = 1/2 \quad \Rightarrow \quad W \ = \ M\left[\frac{\phi^2}{2} - \frac{\phi^3}{3\sqrt{3}}\right]$

Then $b = 0$ followed by

$\alpha = 0$ and $\beta = -1$ or $y_1 \to -y_2$ and $y_2 \to y_1$

$\Rightarrow \quad W \ = \sqrt{3} M \phi (T - 1/2)$:Example 2

SUSY breaking and LE phenomenology

Ellis, Garcia, Nanopoulos, Olive

Can add Polonyi terms,
calculate A-terms, B-terms, soft masses etc

or

Ellis,, Nanopoulos, Olive, Verner

$$K - 3\,\alpha\, \ln \left[T + T^{\dagger} - \frac{\phi\phi^{\dagger}}{3} - \frac{X^{i} X_{i}^{\dagger}}{3} \right]$$

$$W \;=\; W_{I}(T,\phi) + W_{SM}(X,\phi) + W_{dS}(T,\phi)$$

SUSY breaking and LE phenomenology

Ellis,, Nanopoulos, Olive, Verner

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

$$W_{SM} = \mu X^i X^j + \lambda X^i X^j X^k + y\phi X^i X^j$$

$$W_{dS} = a_1\left(2T - \frac{\phi^2}{3}\right)^{n_-} - a_2\left(2T - \frac{\phi^2}{3}\right)^{n_+}$$

$$n_- = 0 \qquad n_+ = 3 \qquad \alpha = 1$$

SUSY Breaking

$$F_T = -e^{G/2}K_{ij^*}G^j = -m_{3/2}(K_T + W_T/W)/3 = (a_1 + a_2) \neq 0$$

$$m_{3/2} = a_1 - a_2 \qquad \Rightarrow \qquad a_1 \sim a_2 \sim M^3 \sim 10^{-15} M_P$$

Inflation and LE phenomenology

Ellis,, Nanopoulos,
Olive, Verner

Λ ignore

$$V = 12a_1a_2 + 12a_2M\left(\frac{\phi^2}{2} - \frac{\phi^3}{3\sqrt{3}}\right) + 3M^2\left(\frac{\phi}{\sqrt{3}+\phi}\right)^2 .$$

inflation

$$\mathrm{Re}\,\phi = \sqrt{3}\tanh\left(x/\sqrt{6}\right),$$

untwisted matter

$$V_{SM} = \sum_i |W_{X^i}|^2 + 2a_2\mu\left(X^iX^j + h.c.\right) + 12a_1a_2\,,$$

$B_0 = 2\ a_2$

twisted matter

$$\begin{aligned} V = & \sum_i |W_{X^i}|^2 + (a_1 - a_2)^2 \sum_i |X^i|^2 \\ & + (2a_1 + 4a_2)\mu(X^iX^j + h.c.) \\ & + 3(a_1 + a_2)\left[\lambda X^iX^jX^k + y\phi X^iX^j + h.c.\right] \\ & + 12a_1a_2\,, \end{aligned}$$

$B_0 = 2a_1 + 4\ a_2$

$A_0 = 3(a_1 + a_2)$

More:

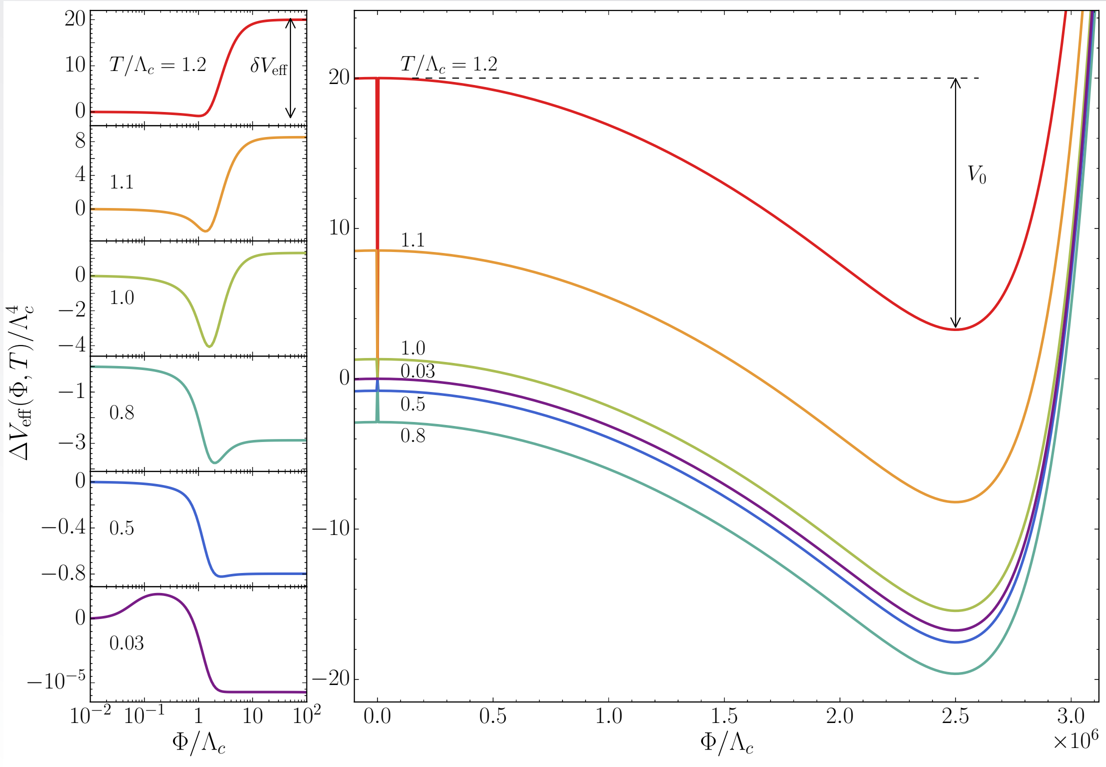
Reheating after inflation — Ellis, Garcia, Nanopoulos, Olive

Combining with SO(10) GUTs — Ellis, Garcia, Nagata, Nanopoulos, Olive

relates inflation to neutrino masses

Combining with Flipped SU(5) — Ellis, Garcia, Nagata, Nanopoulos, Olive

realization of superCosmology



More:

Reheating after inflation

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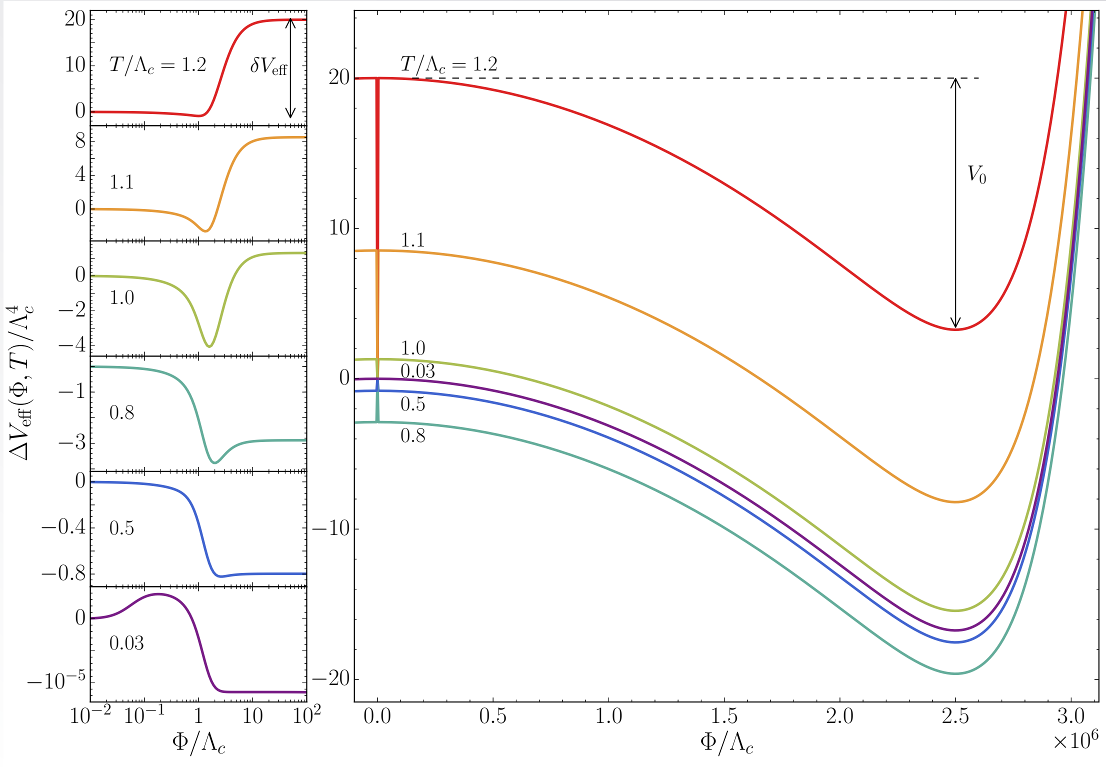

Even in retirement:
DVN is “cooking with gas”

Summary

- In the early 80's and beyond, supersymmetry appeared to be a cure-all for phenomenological and cosmological problems
- The introduction of the inflaton and supersymmetry to inflation model building is now commonplace
- The Starobinsky model of inflation can be realized with either modulus T or 'matter' field ϕ with a simple WZ superpotential.
- The latter lends itself nicely to equating the inflaton with a right-handed sneutrino
- Can easily integrate low energy susy phenomenology