Chaotic inflation and baryogenesis in supergravity in the light of BICEP2 results

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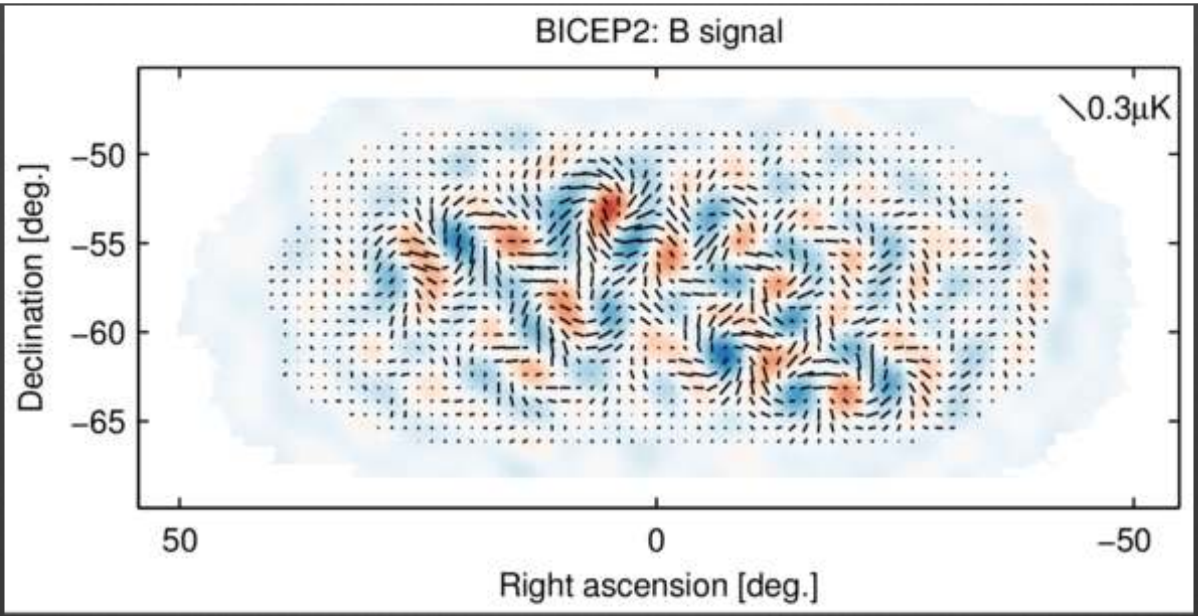
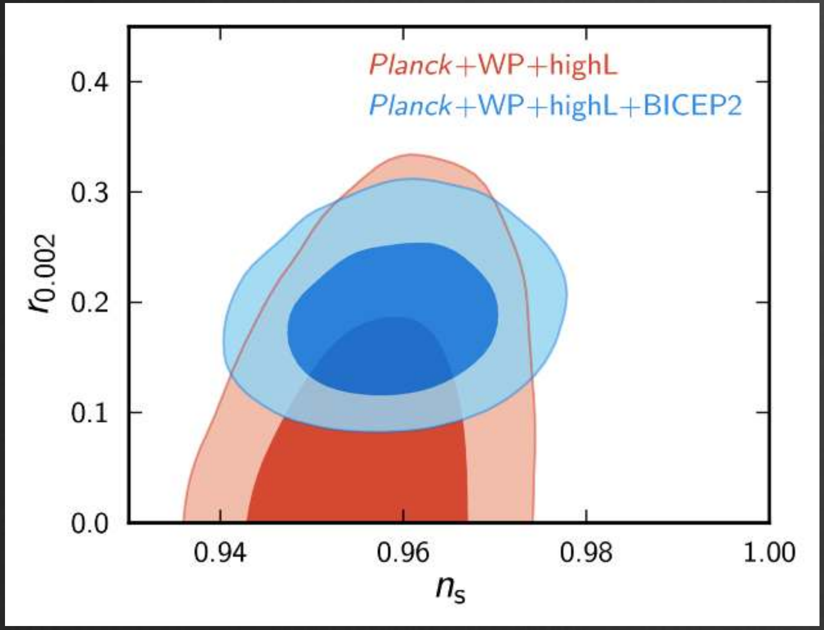
In collaboration with
K. A. Olive, J. Ellis, D. V. Nanopoulos

J. Ellis, MAGG, D. V. Nanopoulos and K. A. Olive, JCAP 1405 (2014) 037
J. Ellis, MAGG, D. V. Nanopoulos and K. A. Olive, arXiv: 1405.0271
MAGG and K. A. Olive, JCAP 1309 (2013) 007

SUSY 2014
Manchester, UK, 22 July 2014

Detection of tensor modes by BICEP2





$$r = 0.16^{+0.06}_{-0.05}$$ (after dust subtraction)

$$r < 0.11$$ Planck at 95% CL

$$n_s = 0.960 \pm 0.008$$

P.A.R. Ade *et. al.* (BICEP2): arXiv: 1403.3985

BICEP2 results are consistent with single field quadratic inflation

$$\epsilon = \frac{M_P}{2}\left(\frac{V'}{V}\right)^2 \ , \quad \eta = M_P^2\left(\frac{V''}{V}\right) \ , \quad N = \int_{\phi_i}^{\phi_f}\left(\frac{V}{V'}\right) d\phi$$

$$V = \mu^{4-n}\phi^n \quad \begin{cases} n_s = 1 - 6\epsilon + 2\eta = 1 - n(n+2)\dfrac{M_P^2}{\phi^2} \\ r = 16\epsilon = 8n^2\dfrac{M_P^2}{\phi^2} \\ N = \dfrac{1}{2n}\dfrac{\phi^2}{M_P^2} \end{cases}$$

ϕ-independent relations $\quad (N = 50 \pm 10)$

$$n = \frac{rN}{4} \longrightarrow \boxed{n = 2.0^{+0.9}_{-0.8}}$$

$$n = 2[N(1-n_s) - 1] \longrightarrow \boxed{n = 2.0 \pm 1.1}$$

Inflation in Supergravity $(M_P = 1)$

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 $D_i = K_i W + W_i$

How can we obtain a quadratic potential?

With canonical Kähler potential, $K = |\phi|^2 + \cdots$

$$V(\phi) \sim e^{|\phi|^2}$$ $\Rightarrow$ too steep, no inflation

[Affleck-Dine] baryogenesis difficult to realize: $m^2_{\text{eff}}(\chi) \sim H^2$

Single (complex) field:

S.V. Ketov, T. Terada, 2014 (arXiv: 1406.0252)

- Shift symmetry of the Kähler potential $\phi \longrightarrow \phi + iC$

$$K = \frac{1}{2}(\phi + \bar{\phi})^2 - \zeta(\phi + \bar{\phi} - 2\phi_0)^4$$

- Polonyi-like superpotential

$$W = \alpha + \beta\phi$$

$$\Rightarrow \qquad V = e^{2\phi_0^2}|\beta|^2(4\phi_0^2 - 3)(\mathrm{Im}\,\phi)^2$$

- α must be tuned to yield a vanishing cosmological constant

$$\alpha \sim m_\phi \qquad \Rightarrow \qquad m_{3/2} \sim m_\phi \sim 10^{13}\,\mathrm{GeV}\,!$$

Two fields:

M. Kawasaki, M. Yamaguchi, T. Yanagida 2000 (hep-ph/0004243)
R. Kallosh, A. Linde, 2010 (arXiv:1008.3375)

- Shift symmetry of the Kähler potential

$$K = -\frac{1}{2}(\phi - \bar{\phi})^2 + S\bar{S}$$

$$W = S f(\phi)$$

$$\Rightarrow \quad V = |f(\mathrm{Re}\,\phi)|^2$$

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- *S* coupled to flat direction $\chi \Rightarrow$ drive Affleck-Dine mechanism

MAGG, K.A. Olive, 2013 (arXiv: 1306.6119)

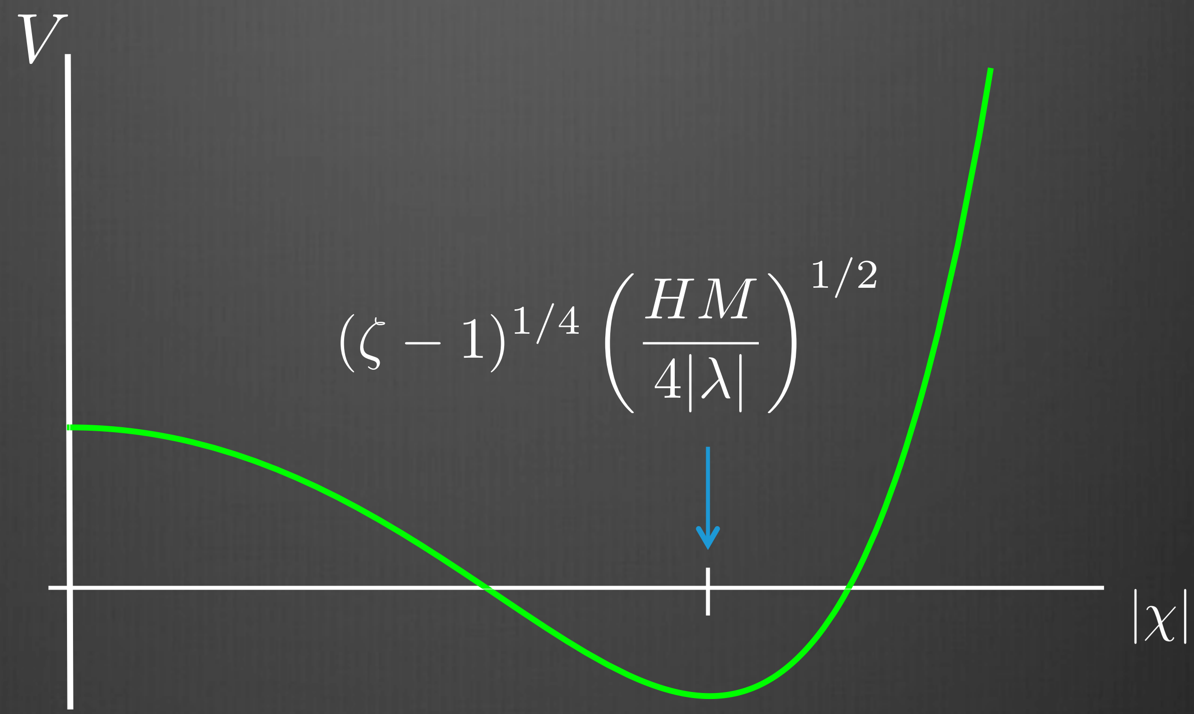
$$K_{\mathrm{AD}} = |\chi|^2 + \zeta |S|^2 |\chi|^2$$

$$W = \frac{\lambda}{M}\chi^4$$

$$V = 3H^2 + \left[m_{3/2}^2 + 3(1-\zeta)H^2\right]|\chi|^2 + A m_{3/2}\left(\frac{\lambda}{M}\chi^4 + h.c.\right) + 16\frac{|\lambda|^2}{M^2}|\chi|^6 + \cdots$$

Two fields: $K = -\frac{1}{2}(\phi - \bar{\phi})^2 + |S|^2 + |\chi|^2 + \zeta |S|^2 |\chi|^2, \; W = S f(\phi) + \frac{\lambda}{M}\chi^4$

$H \gg m_{3/2}$:

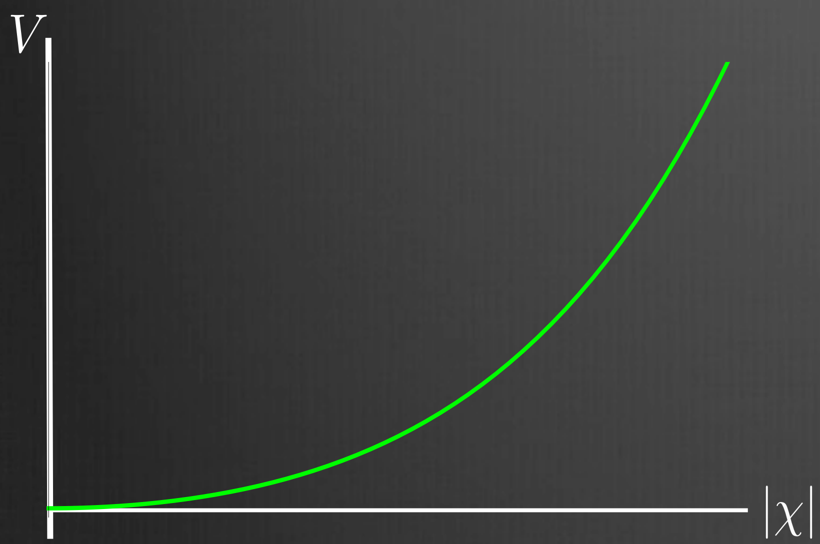


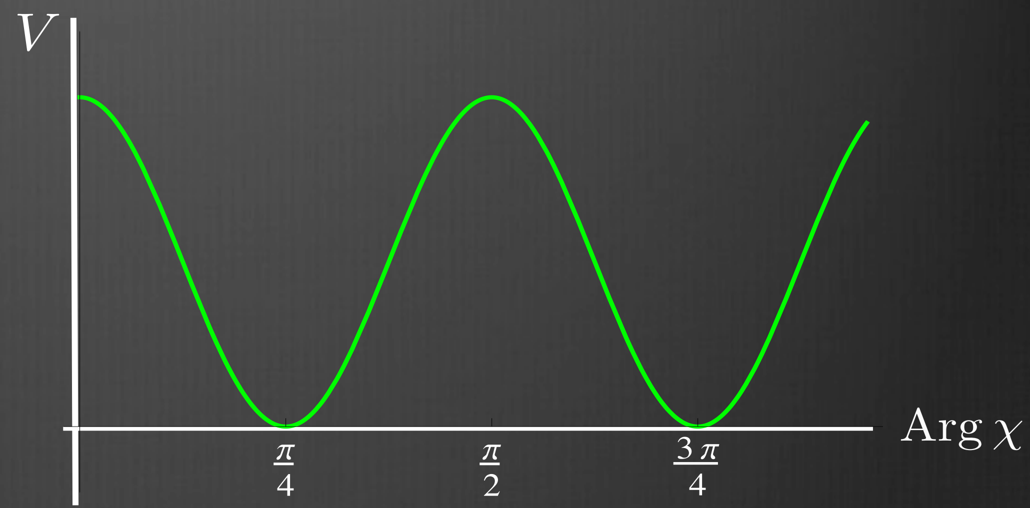
$$V = 3H^2 + \left[m_{3/2}^2 + 3(1-\zeta)H^2 \right] |\chi|^2$$

$$+ A m_{3/2} \left(\frac{\lambda}{M} \chi^4 + h.c. \right) + 16 \frac{|\lambda|^2}{M^2} |\chi|^6 + \cdots$$

Two fields: $K=-\frac{1}{2}(\phi-\bar{\phi})^2+|S|^2+|\chi|^2+\zeta|S|^2|\chi|^2,\ W=Sf(\phi)+\frac{\lambda}{M}\chi^4$

$$\frac{H}{\sqrt{3(\zeta-1)}}<m_{3/2}:$$

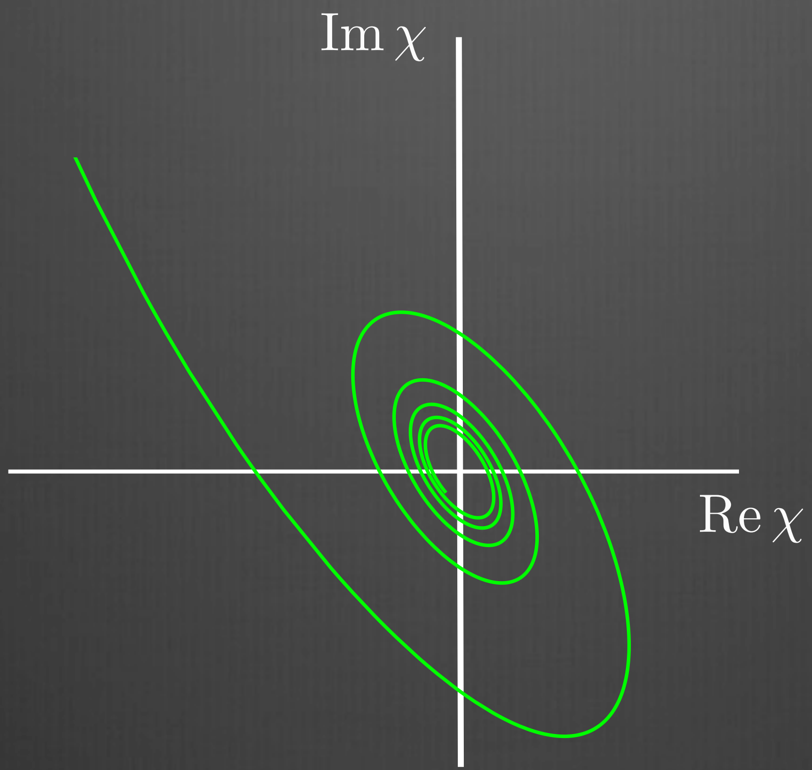




$$V=3H^2+\left[m_{3/2}^2+3(1-\zeta)H^2\right]|\chi|^2$$
$$+Am_{3/2}\left(\frac{\lambda}{M}\chi^4+h.c.\right)+16\frac{|\lambda|^2}{M^2}|\chi|^6+\cdots$$

Two fields: $K = -\frac{1}{2}(\phi - \bar{\phi})^2 + |S|^2 + |\chi|^2 + \zeta |S|^2 |\chi|^2,\ W = Sf(\phi) + \frac{\lambda}{M}\chi^4$

$$H < \frac{2}{3} m_{3/2} :$$



$$\frac{n_B}{s} \sim \frac{10^{-9}}{|\lambda|} \frac{M}{M_P}$$

$$V = 3H^2 + \left[m_{3/2}^2 + 3(1-\zeta)H^2 \right] |\chi|^2$$
$$+ A m_{3/2} \left(\frac{\lambda}{M}\chi^4 + h.c. \right) + 16 \frac{|\lambda|^2}{M^2} |\chi|^6 + \cdots$$

No-scale Supergravity

- Single field also leads to phenomenological problems
  At least two fields are necessary

- Full *SU(2,1)/SU(2)×U(1)* symmetry

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

- String inspired models with modular weights

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

J. A. Casas, 1997 (hep-ph/9802210)

SU(2,1)/SU(2)×U(1)

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

J. Ellis, D.V. Nanopoulos and K.A. Olive, 2013 (arXiv: 1307.3537)

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

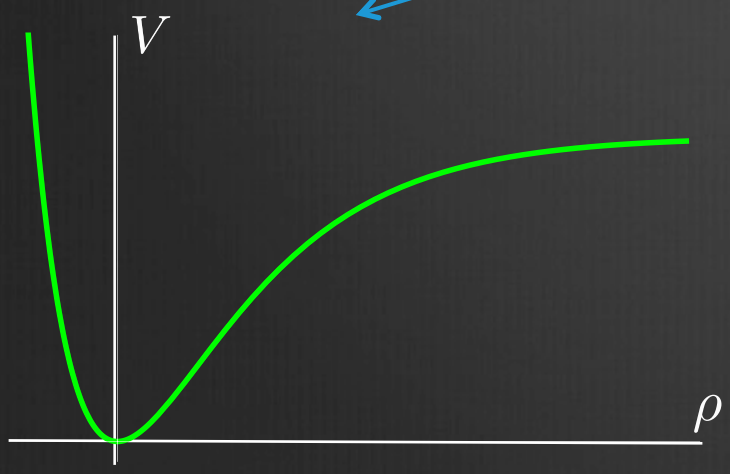
at $\phi = 0\ , \quad T = \frac{1}{2}e^{-\sqrt{\frac{2}{3}}\rho} + \frac{i}{\sqrt{6}}\sigma$

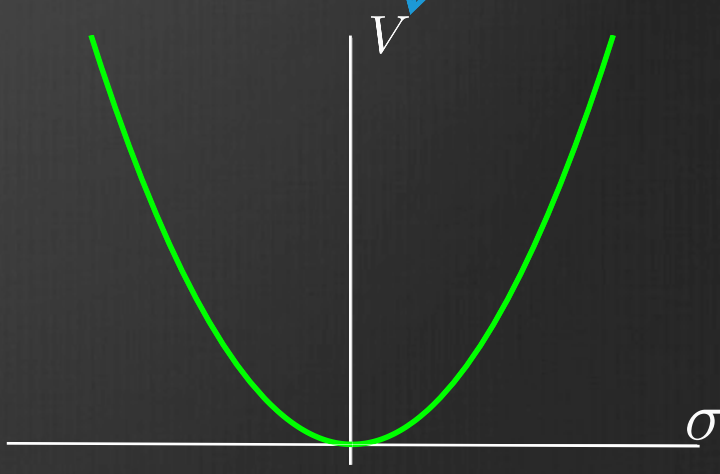
S. Ferrara, A. Kehagias and A. Riotto, 2014 (arXiv: 1403.5531)

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

$R + R^2$

$\rho = 0$





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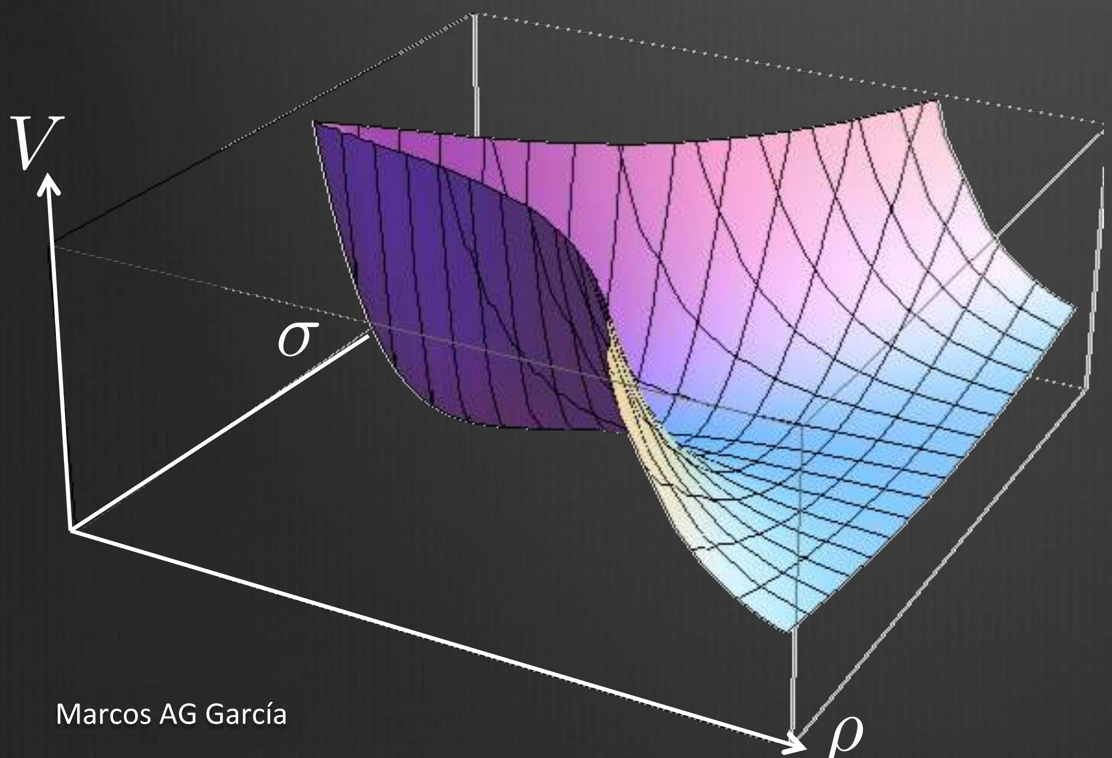

Needs stabilization!

SU(2,1)/SU(2)×U(1)

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

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

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$$K = -3\log\left(T+\bar{T}-\frac{|\phi|^2}{3}-\frac{(T+\bar{T})^n}{\Lambda^2}+\frac{|\phi|^4}{\Lambda_\phi^2}\right)$$

Forces $\rho = 0$

Forces $\phi = 0$

$SU(2,1)/SU(2)\times U(1)$

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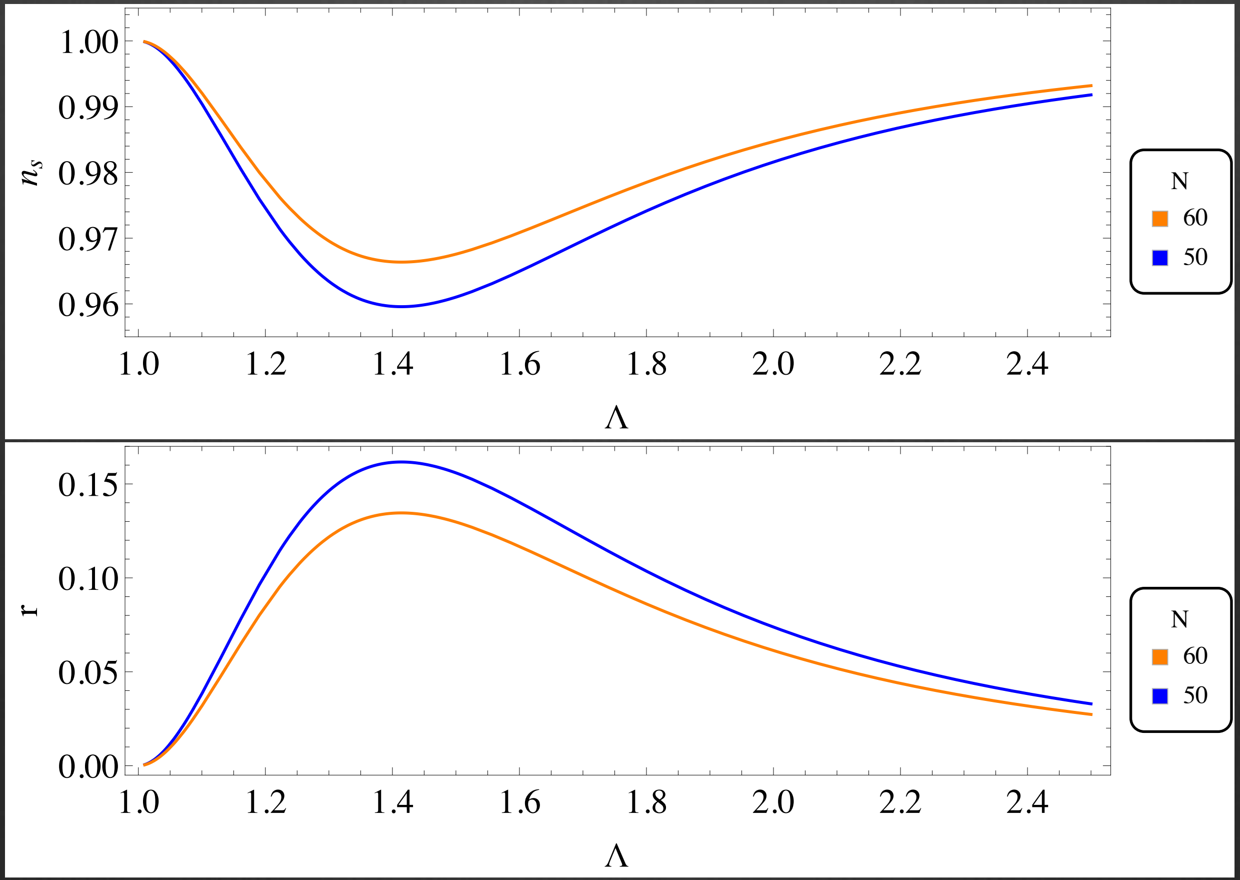

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$$K = -3\log\left(T+\bar{T}-\frac{|\phi|^2}{3}\right)$$

J. Ellis, D.V. Nanopoulos and K.A. Olive, 2013 (arXiv: 1305.1247)

- Modulus ϕ as inflaton $W = W(\phi) \;\Rightarrow\; V = \dfrac{|W_\phi|^2}{(T+\bar{T}-|\phi|^2/3)^2}$

- Planck-compatible potentials are "easy" to obtain

$$W = \frac{1}{2}m\phi^2\left(1-\frac{2}{3\sqrt{3}}\phi\right) \;\Rightarrow\; W_\phi = m\phi(1-\phi/\sqrt{3}) \;\Rightarrow\; V = \frac{3}{4}m^2(1-e^{-\sqrt{\frac{2}{3}}x})^2$$

$$\phi = \sqrt{3}\tanh\left(\frac{x+iy}{\sqrt{6}}\right)$$

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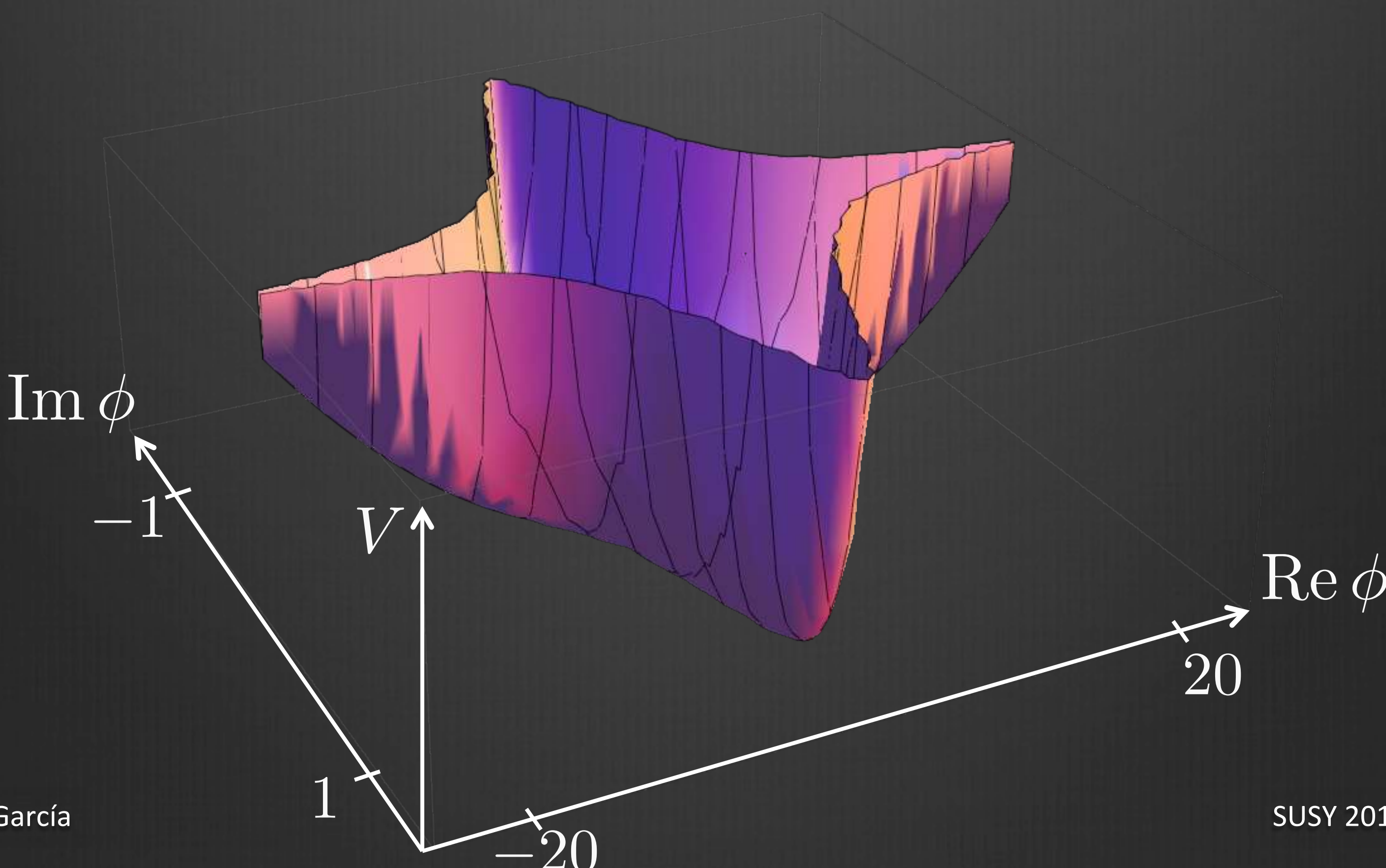
- Possible to reverse-engineer *W* for quadratic inflation, but…

$$W = \frac{m}{18}\left[9 - 3\phi^2 - 2\sqrt{3}\phi(\phi^2 - 9)\tanh^{-1}\left(\frac{\phi}{\sqrt{3}}\right) + 18\log\left(1 - \frac{\phi^2}{3}\right)\right]$$

$$K = -3\log(T+\bar{T}) + |\phi|^2$$

- Field ϕ as inflaton: $$W = e^{-\frac{\phi^2}{2}}\left(\tilde{m} - \frac{m}{2}\phi^2\right)$$

- At T=1/2, $$V = m^2(\mathrm{Re}\,\phi)^2$$



Zero modular weight $K = -3\log(T+\bar{T}) + |\phi|^2$

- Field ϕ as inflaton: $$W = e^{-\frac{\phi^2}{2}}\left(\underbrace{\cancel{\tilde{m}}}_{m_{3/2}} - \frac{m}{2}\phi^2\right)$$

- $\phi \to -\phi$ symmetry and $m \sim 2\times 10^{13}\,\mathrm{GeV}$, consistent with

$$\phi \Leftrightarrow \tilde{N}$$ (Type I seesaw)

⇒Leptogenesis

- Stabilization for *T*: $$K = -3\log\left(T+\bar{T}+\frac{(T+\bar{T}-1)^4+(T-\bar{T})^4}{\Lambda^2}\right)$$

$$\Rightarrow \quad m_T = 12\tilde{m}/\Lambda \gg m_{3/2}$$

No dilution of n_B/s
No moduli problem

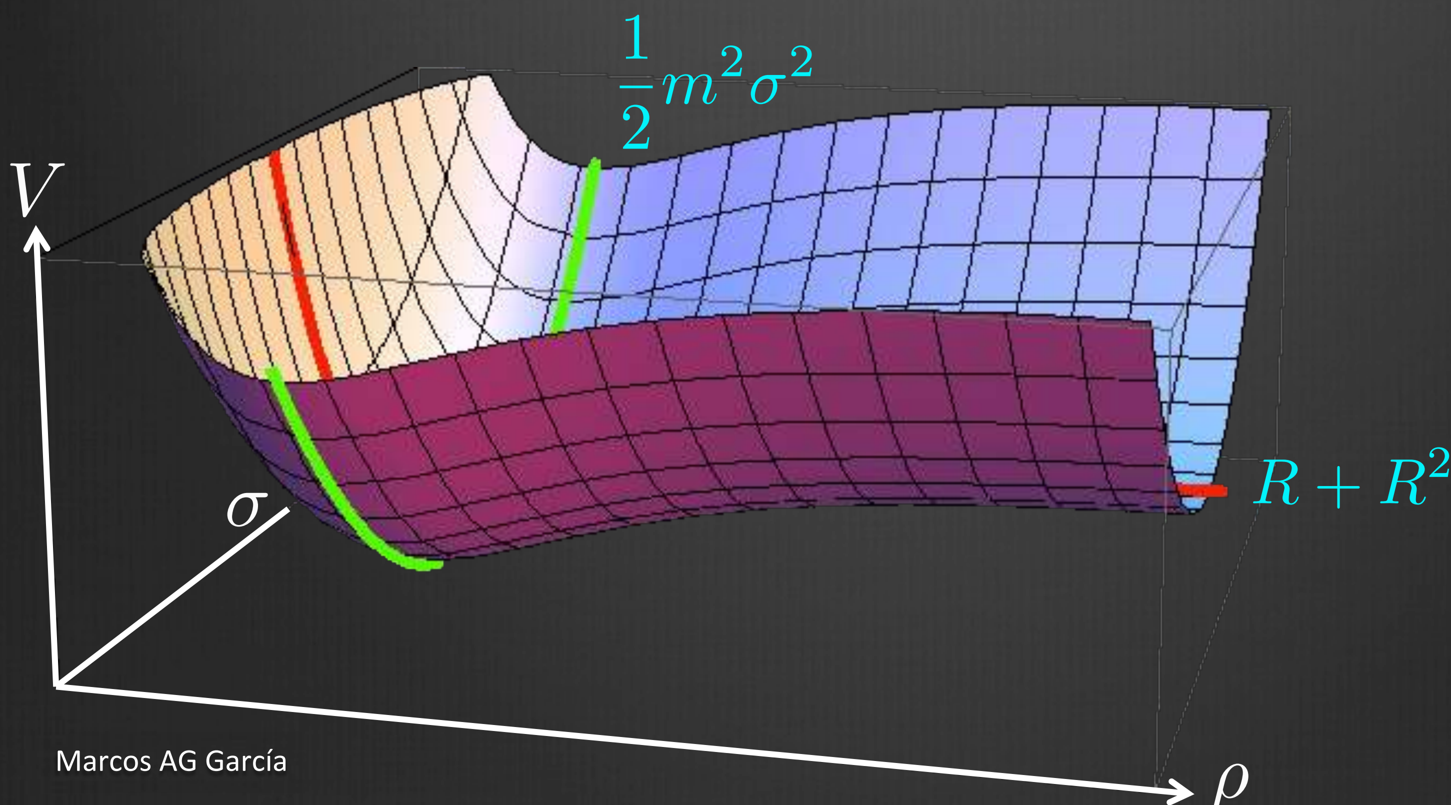
J.L. Evans, MAGG, K.A. Olive, 2014 (arXiv: 1311.0052)

Modular weight = 3

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

- Modulus T as inflaton: $W = \sqrt{3}m\phi(T-1/2)$
- ϕ is constrained by exponential factor $V \propto e^{|\phi|^2/(T+\bar{T})^3}$

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



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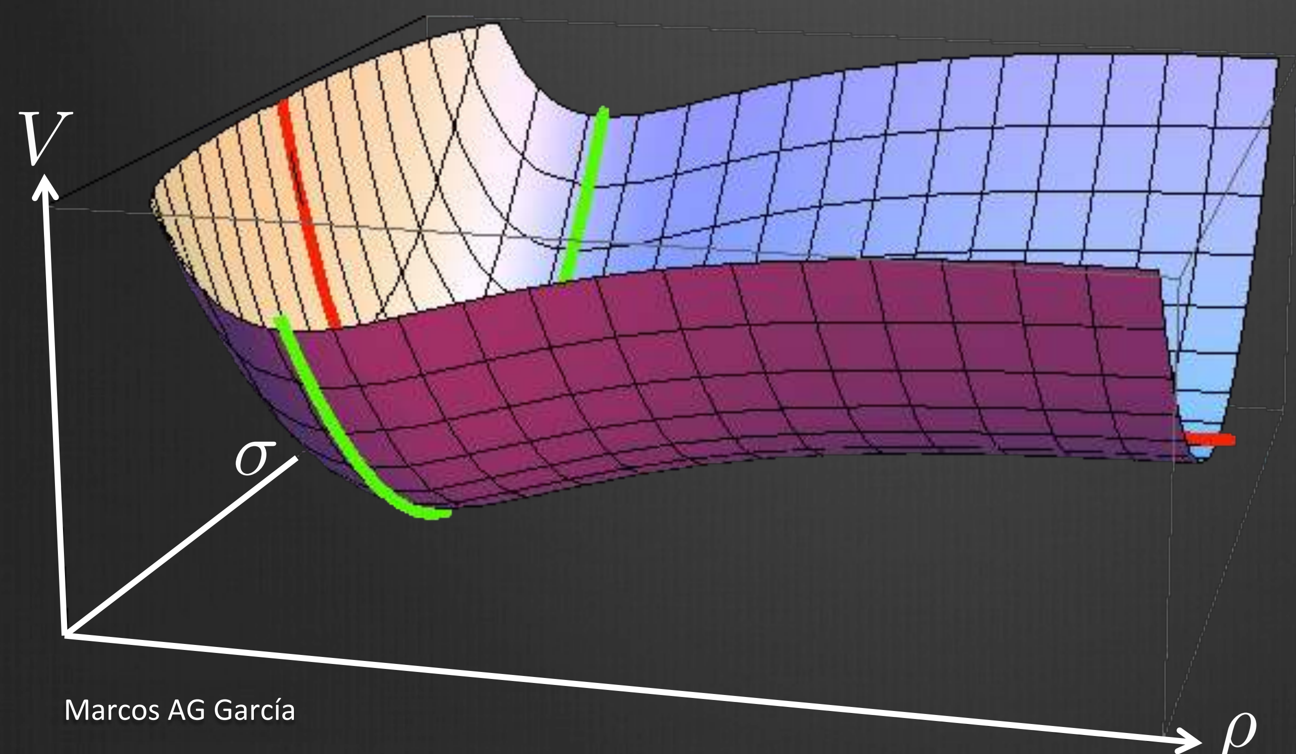
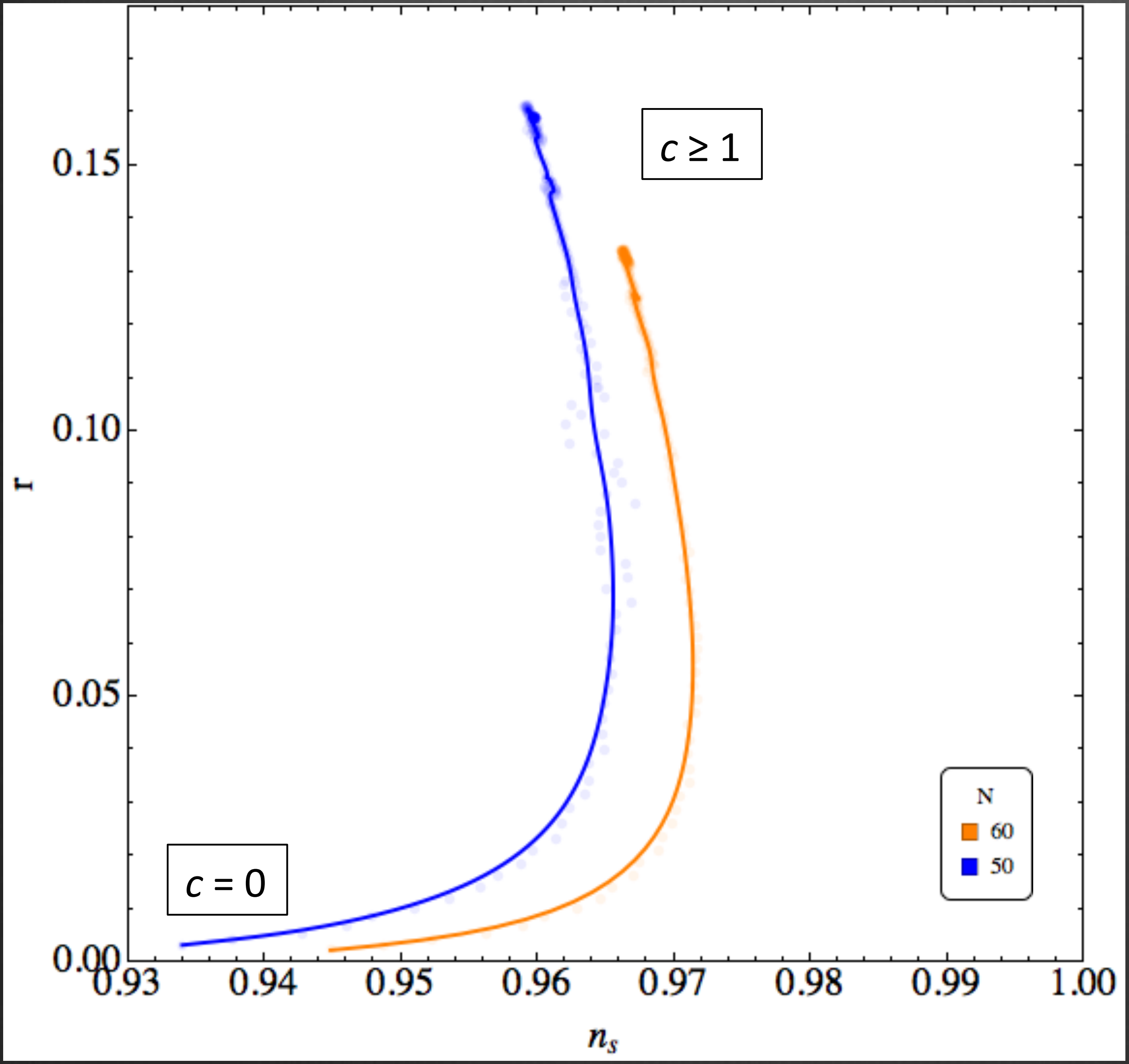


Has an isocurvature 'problem'

Modular weight = 3

$$W = \sqrt{3} m \phi (T - 1/2), \quad K = -3 \log(T + \bar{T}) + \frac{|\phi|^2}{(T + \bar{T})^3}$$



$$\Delta K = -c(T + \bar{T})^2$$

~~Has an isocurvature 'problem'~~

Conclusion

- A variety of BICEP2-compatible inflationary models can be built
- Non-generic: *W* must be of an specific form, and stabilization is needed
- Stabilization: - Constraint inflationary trajectory
  - Effectively single field (no isocurvature perturbations)
- Baryogenesis: - Affleck-Dine
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Thank you