False vacuum energy dominated inflation with large r and the importance of κ_s

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  ...but galactic dust contamination may have been underestimated.
- If observed B-modes would be due to primordial gravitational waves

  $\Rightarrow$ large tensor-to-scalar ratio:

  $$r \equiv A_{\rm t}/A_{\rm s} \sim \mathcal{O}(0.1)$$

  and consequently

  $$E_{\rm inf} = (V_*)^{1/4} \simeq 2 \times 10^{16}\,\text{GeV} \sim M_{\rm GUT}$$

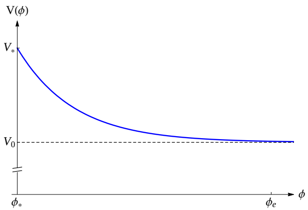
  Just by coincidence? Or is there some deeper physics reason?

Consider inflationary potential to be of the form

$$V(\phi) = V_0 + \tilde{V}(\phi),$$

with $\min[\tilde{V}(\phi)] = 0$ and

$$V_* \equiv V(\phi_*) = V_0 + \tilde{V}(\phi_*)\,.$$



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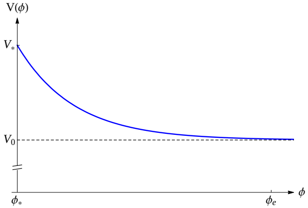
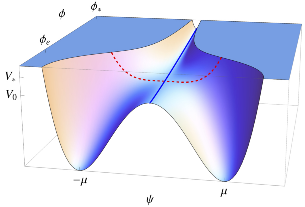
If $\tilde{V}(\phi) \ll V_0$ throughout inflation

$$V_0 \leftrightarrow M_{\rm GUT}.$$





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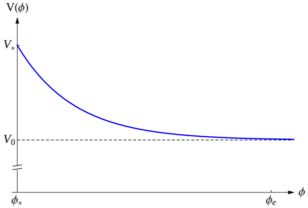

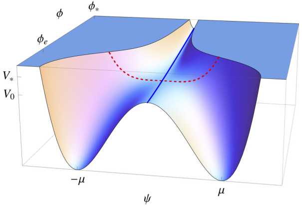

If $\tilde{V}(\phi) \ll V_0$ throughout inflation

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Question:

Requiring $r \sim \mathcal{O}(0.1)$, how large can V_0/V_* be for single-field slow-roll inflation?

Primordial spectra of curvature and tensor perturbations $\mathcal{P}_{\mathcal{R}}$ and $\mathcal{P}_{\mathrm{t}}$ can be parametrized as:

$$\mathcal{P}_{\mathcal{R}}(k) = A_{\mathrm{s}} \left(\frac{k}{k_*}\right)^{n_{\mathrm{s}}-1+\frac{\alpha_{\mathrm{s}}}{2}\ln(k/k_*)+\frac{\kappa_{\mathrm{s}}}{6}\ln^2(k/k_*)+\dots},$$

$$\mathcal{P}_{\mathrm{t}}(k) = r\, A_{\mathrm{s}} \left(\frac{k}{k_*}\right)^{-r/8+\dots}.$$

The observables can be expressed in terms of the slow-roll parameters

$$\varepsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2, \quad \eta = \frac{V''}{V}, \quad \xi^2 = \frac{V'V'''}{V^2}, \quad \sigma^3 = \frac{V'^2V''''}{V^3}$$

evaluated at horizon crossing $\phi = \phi_*$:

$$r = 16\varepsilon_*, \qquad n_{\mathrm{s}} = 1 - 6\varepsilon_* + 2\eta_* + 2q_1\xi_*^2 + 2q_2\sigma_*^3 + \dots,$$

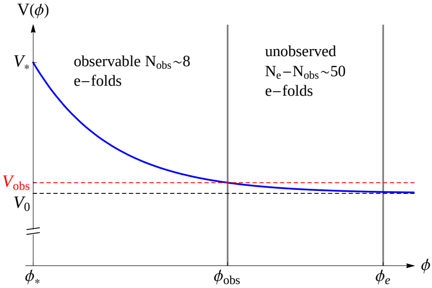
$$\alpha_{\mathrm{s}} = -2\xi_*^2 - 2q_1\sigma_*^3 + \dots, \qquad \kappa_{\mathrm{s}} = 2\sigma_*^3 + \dots,$$

with $q_1 \simeq 1.063$ and $q_2 \simeq 0.209$.

How to estimate the maximum amount of V_0 domination?

Way of proceeding:

1. Use that observables are related to the slow-roll parameters at horizon exit to reconstruct $V(\phi) = V_0 + \tilde{V}(\phi)$ around ϕ_* in terms of $r, n_s, \alpha_s, \ldots$.
2. Observable spectrum reliably constrains the potential only for the first $N_{obs} \sim 8$ e-folds of inflation
   $\Rightarrow$ **compute $V_{obs} > V_0$ as upper bound on V_0**



Assuming that all higher-order runnings beyond κ_s are zero for the first N_{obs} e-folds one can write:

$$V = V_* \left[1 + \frac{V'}{V}\bigg|_* \phi + \frac{1}{2}\frac{V''}{V}\bigg|_* \phi^2 + \frac{1}{6}\frac{V'''}{V}\bigg|_* \phi^3 + \frac{1}{24}\frac{V''''}{V}\bigg|_* \phi^4 \right]$$

$$\Lsh\ V = V_* \left[1 - \sqrt{2\varepsilon_*}\phi + \frac{1}{2}\eta_*\phi^2 - \frac{1}{6}\frac{\xi_*^2}{\sqrt{2\varepsilon_*}}\phi^3 + \frac{1}{24}\frac{\sigma_*^3}{2\varepsilon_*}\phi^4 \right]$$

$$\Lsh\ \frac{V}{V_*} = 1 - \sqrt{\frac{r}{8}}\phi + \left[\frac{n_s - 1}{4} + \frac{3}{32}r + \frac{q_1}{4}\alpha_s + \frac{q_1^2 - q_2}{4}\kappa_s \right]\phi^2 + \sqrt{\frac{8}{r}}\frac{\alpha_s + q_1\kappa_s}{12}\phi^3 + \frac{\kappa_s}{6r}\phi^4 \qquad (1)$$

Next steps:

- derive constraints on parameter space using Planck+BICEP2 data
- to compute V_{obs}: evaluate (1) after N_{obs} e-folds, by scanning *classical slow-roll* trajectories

We derived the joint constraints on ΛCDM + r + $\alpha_{\rm s}$ + $\kappa_{\rm s}$ using the likelihood data from Planck+BICEP2 and scanned inflationary trajectories for the ranges

$$\begin{aligned} r = 0.1 \quad &\text{and} \quad r = 0.2\,, \\ n_{\rm s} \quad &= \quad 0.96\,, \\ -0.060 \leq \quad &\alpha_{\rm s} \quad \leq 0.045\,, \\ -0.025 \leq \quad &\kappa_{\rm s} \quad \leq 0.090\,. \end{aligned}$$

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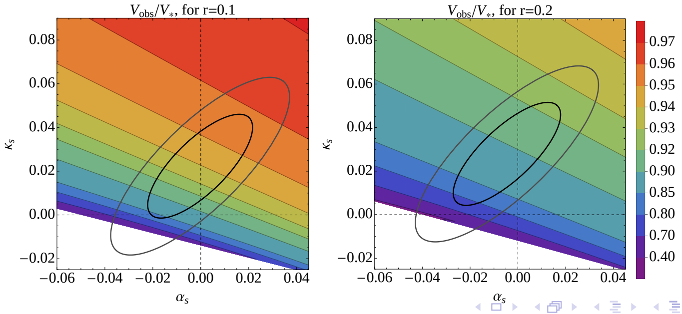


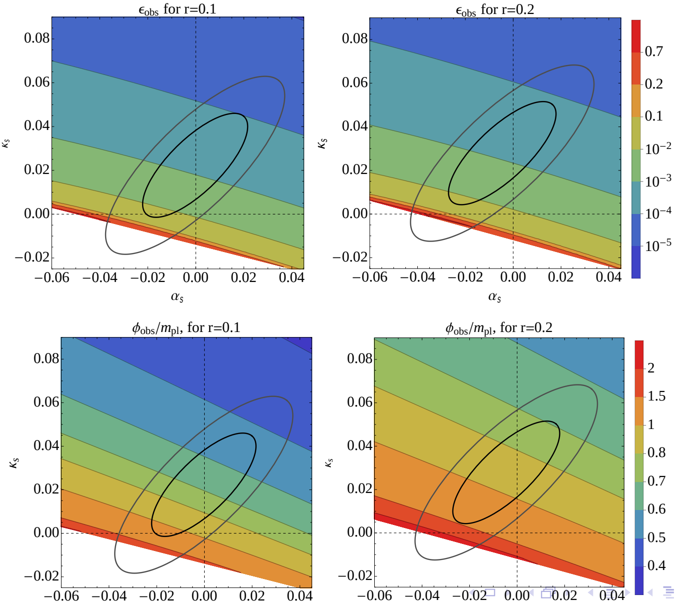
Question:

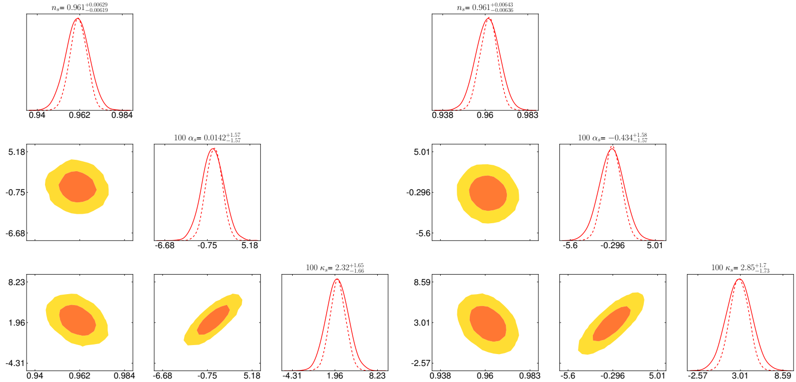
Requiring $r \sim \mathcal{O}(0.1)$, how large can V_0/V_* be for single-field slow-roll inflation?

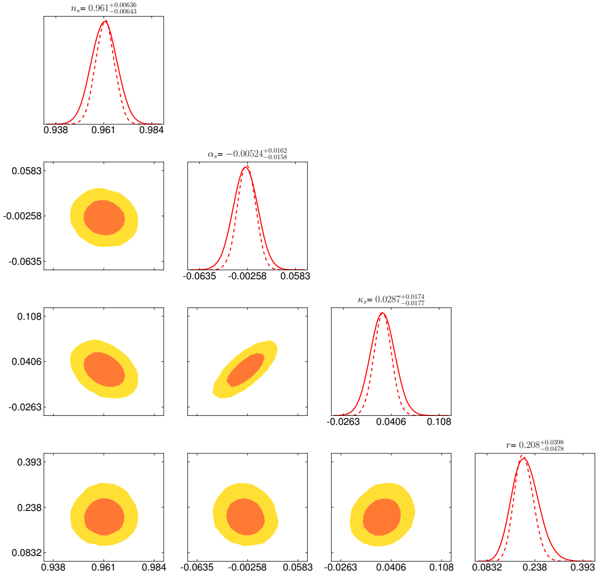
Summary & Conclusion:

- Within the scope of a *potential reconstruction around* ϕ_* we have studied the *compatibility of* V_0 *domination with large* $r \sim \mathcal{O}(0.1)$.
- We computed $V(\phi)$ after the first $N_{\rm obs} \sim 8$ *e*-folds, $V_{\rm obs} > V_0$, to estimate an upper bound on V_0/V_*.
- For $\kappa_{\rm s} = 0$: $V_0/V_* < 90\%$.
  For $\kappa_{\rm s} > 0$ maximum amount can increase up to $V_0/V_* \simeq 96\%$.
- We derived the joint constraints on ΛCDM + r + $\alpha_{\rm s}$ + $\kappa_{\rm s}$ to correctly constrain our parameter space. Our constraints can also be used to study other models of inflation with $\kappa_{\rm s} \neq 0$.

Backup


ϵ_{obs} for r=0.1
ϵ_{obs} for r=0.2
0.7
0.2
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
ϕ_{obs}/m_{pl}, for r=0.1
ϕ_{obs}/m_{pl}, for r=0.2
2
1.5
1
0.8
0.7
0.6
0.5
0.4
κ_s
α_s
0.08
0.06
0.04
0.02
0.00
−0.02
−0.06
−0.04
−0.02
0.00
0.02
0.04


n_s= 0.961$^{+0.00629}_{-0.00619}$
0.94
0.962
0.984
100 α_s= 0.0142$^{+1.57}_{-1.57}$
5.18
-0.75
-6.68
100 κ_s= 2.32$^{+1.65}_{-1.66}$
8.23
1.96
-4.31
-4.31
1.96
8.23
n_s= 0.961$^{+0.00643}_{-0.00636}$
0.938
0.96
0.983
100 α_s= $-0.434^{+1.58}_{-1.57}$
5.01
-0.296
-5.6
100 κ_s= 2.85$^{+1.7}_{-1.73}$
8.59
3.01
-2.57


$n_s = 0.961^{+0.00636}_{-0.00643}$
$\alpha_s = -0.00524^{+0.0162}_{-0.0158}$
$\kappa_s = 0.0287^{+0.0174}_{-0.0177}$
$r = 0.208^{+0.0398}_{-0.0478}$
0.938
0.961
0.984
-0.0635
-0.00258
0.0583
-0.0263
0.0406
0.108
0.0832
0.238
0.393

	r fitted	$r = 0.1$ fixed	$r = 0.2$ fixed
n_s	$0.961^{+0.006}_{-0.006}$	$0.961^{+0.006}_{-0.006}$	$0.961^{+0.006}_{-0.006}$
α_s	$-0.005^{+0.016}_{-0.016}$	$0.000^{+0.016}_{-0.016}$	$-0.004^{+0.016}_{-0.016}$
κ_s	$0.029^{+0.017}_{-0.018}$	$0.023^{+0.017}_{-0.017}$	$0.029^{+0.017}_{-0.017}$
r	$0.208^{+0.040}_{-0.048}$	0.1	0.2
A_s	$\left(2.28^{+0.06}_{-0.07}\right) \times 10^{-9}$	$\left(2.27^{+0.6}_{-0.7}\right) \times 10^{-9}$	$\left(2.28^{+0.06}_{-0.07}\right) \times 10^{-9}$
ω_b	$0.0223^{+0.0003}_{-0.0003}$	$0.0223^{+0.0003}_{-0.0003}$	$0.0223^{+0.0003}_{-0.0003}$
ω_{cdm}	$0.1170^{+0.0014}_{-0.0014}$	$0.1172^{+0.0014}_{-0.0014}$	$0.1170^{+0.0014}_{-0.0014}$
H_0	$\left(68.71^{+0.66}_{-0.69}\right) \frac{\text{km}}{\text{s Mpc}}$	$\left(68.53^{+0.65}_{-0.67}\right) \frac{\text{km}}{\text{s Mpc}}$	$\left(68.72^{+0.66}_{-0.68}\right) \frac{\text{km}}{\text{s Mpc}}$
τ_{reio}	$0.110^{+0.014}_{-0.015}$	$0.109^{+0.014}_{-0.015}$	$0.110^{+0.014}_{-0.016}$

Table : Cosmological parameter constraints for Planck + BICEP2 + BAO at 68% CL with the primordial spectrum expanded around the pivot scale $k_* = 0.05$ Mpc^{-1}.