A study in the non-canonical domain of Goldstone inflation

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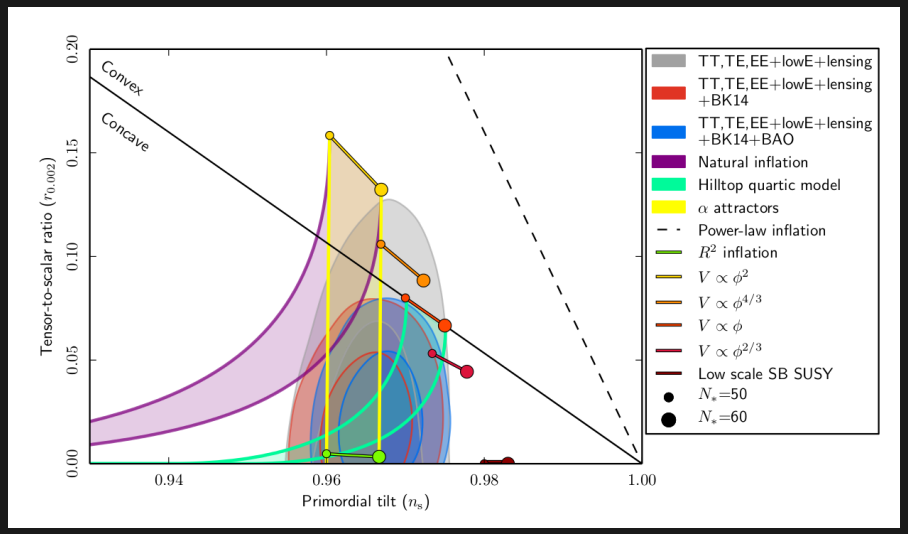
Motivation

- Precision era in cosmology → Theoretically motivated models of cosmological inflation are under stringent constraints.



- Natural inflation $V(\phi) = \Lambda^4(1 + \cos(\phi/f))$ is at verge of getting strongly disfavoured by Planck 2018.
- Sub-Planckian breaking scale doest not give enough e-folds.

[1] Croon et.al., arXiv:1503.08097

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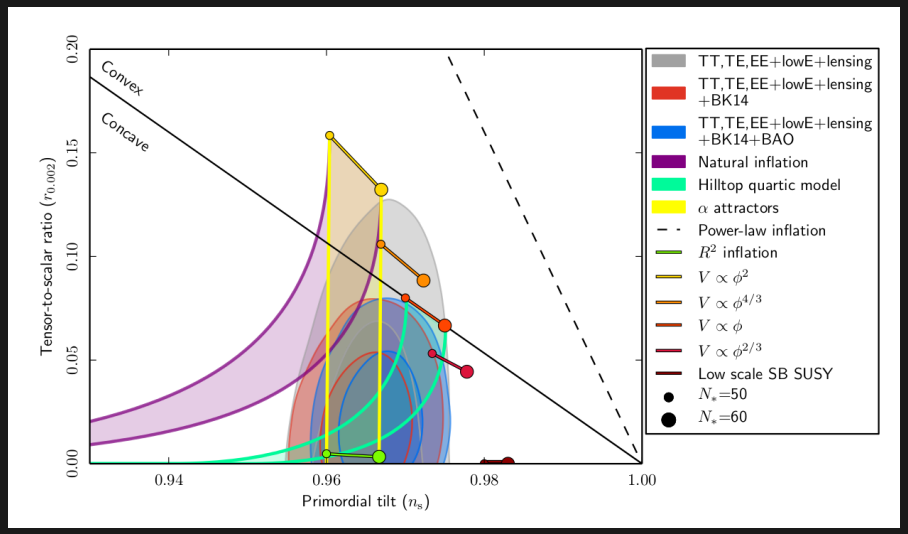

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- Natural inflation is a limiting case of a much more generalised Lagrangian: Goldstone inflation[1].

$$V(\phi) = \Lambda^4(C_\Lambda + \alpha\cos(\phi/f) + \beta\sin^2(\phi/f)).$$

- Fine tuning needed to fit canonical Goldstone inflation with 2015 Planck.
- Motivations to study non-canonical regime comes from string theory.
- General Lagrangian:

$$\mathcal{L} = K(X,\phi) - V(\phi), \qquad X \equiv \frac{1}{2}\partial_\mu\phi\partial^\mu\phi$$

- $K(X,\phi) = K_{nc}(\phi)K_{kin}(X)$.

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Case 1: K_{nc} switched on, $K_{kin}(X) = X$

- Choice: $K_{nc}(\phi) = V(\phi)/\Lambda^4$.

$$\ddot{\phi} + 3H\dot{\phi} + \frac{K_{nc,\phi}}{2K_{nc}}\dot{\phi}^2 + \frac{V_{,\phi}}{K_{nc}} = 0$$

$$\epsilon_V = \frac{M_{Pl}^2}{2K_{nc}}\left(\frac{V_{,\phi}}{V}\right)^2$$

$$\eta_V = \frac{M_{Pl}^2}{V}\left(\frac{V_{,\phi\phi}}{K_{nc}} - \frac{V_{,\phi}K_{nc,\phi}}{2K_{nc}^2}\right)$$

$$N = \frac{1}{M_{Pl}}\int_{\phi_i}^{\phi_e}\frac{V}{V_{,\phi}\sqrt{K_{nc}}}d\phi$$

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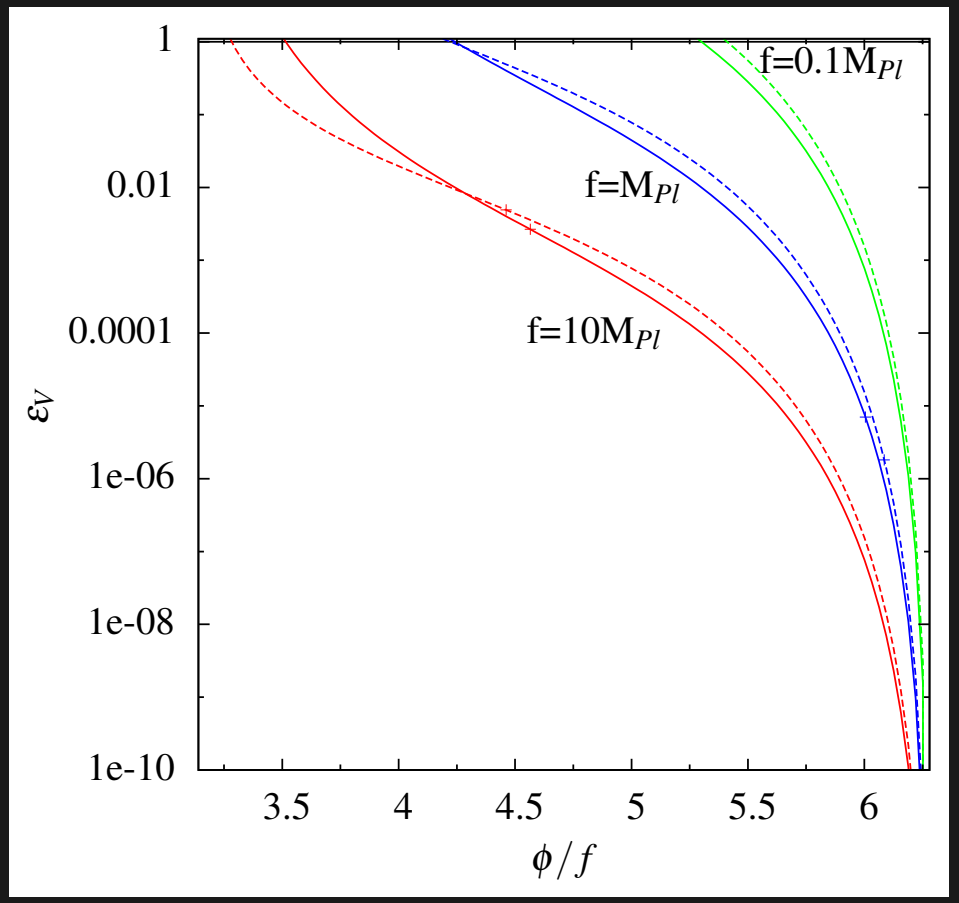

$r = 16\epsilon_V$.

- Non-canonical kinetic term provides friction.

Case 2: $K_{kin}(X)$ switched on, $K_{nc}(\phi) = 1$

- Choice: $K_{kin}(X) \equiv K_0 X^n$.

$$\ddot{\phi} + \frac{3H}{2n-1}\dot{\phi} + \frac{V_{,\phi}}{(2n^2-n)K_0 X^{n-1}} = 0$$

$$\epsilon_V = \frac{1}{2}\alpha_{kin}(n)\left(\frac{{V_{,\phi}}^{2n}}{V^{(3n-1)}}\right)^{\frac{1}{2n-1}}$$

$$\eta_V = \alpha_{kin}(n)\left(\frac{V^{(2n-1)}_{,\phi\phi}}{V^n V^{(2n-2)}_{,\phi}}\right)^{\frac{1}{2n-1}}$$

$$N = \int_{\phi_e}^{\phi_i} \frac{1}{\alpha_{kin}(n)}\sqrt{V}\left(\frac{\sqrt{V}}{V_{,\phi}}\right)^{\frac{1}{2n-1}} d\phi$$

$$\alpha_{kin}(n) = \left(\frac{6^{n-1}}{nK_0}\right)^{\frac{1}{2n-1}}$$

Dependence of ϵ_V, η_V and N on K_0,α and Λ.
For NI with kinetic term: $\epsilon_V \propto \frac{1}{(K_0\alpha\Lambda^4)^{1/3}}$.

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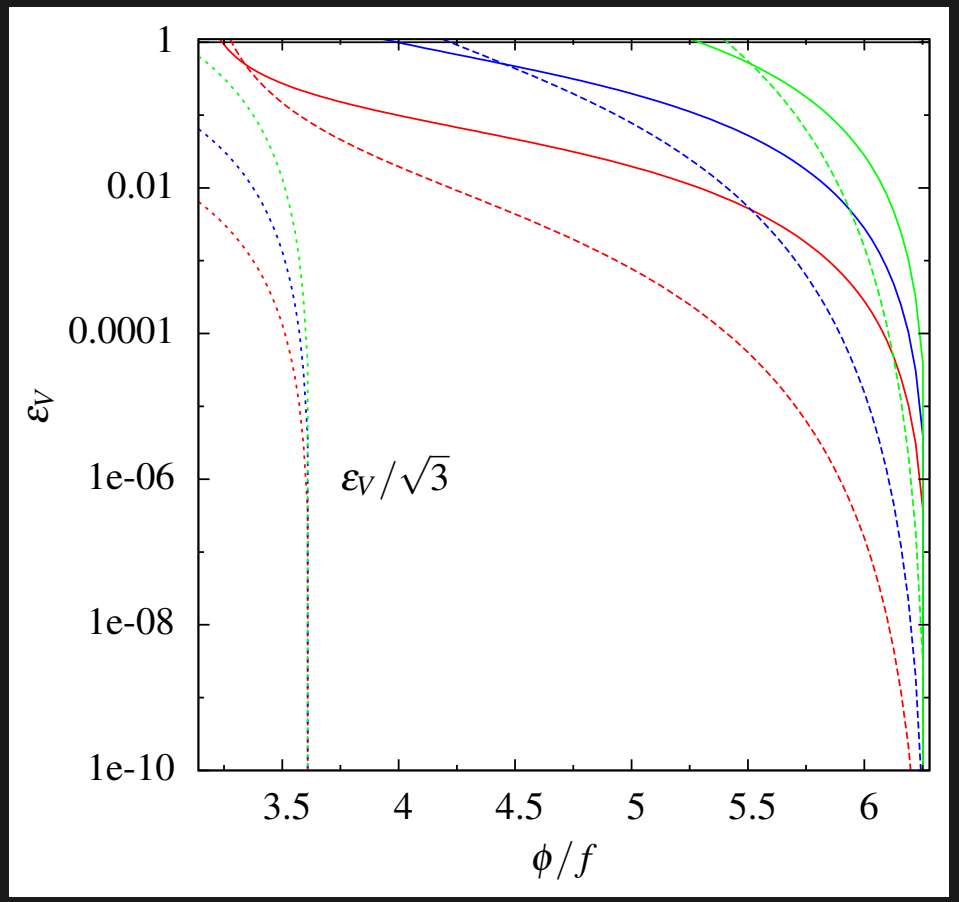
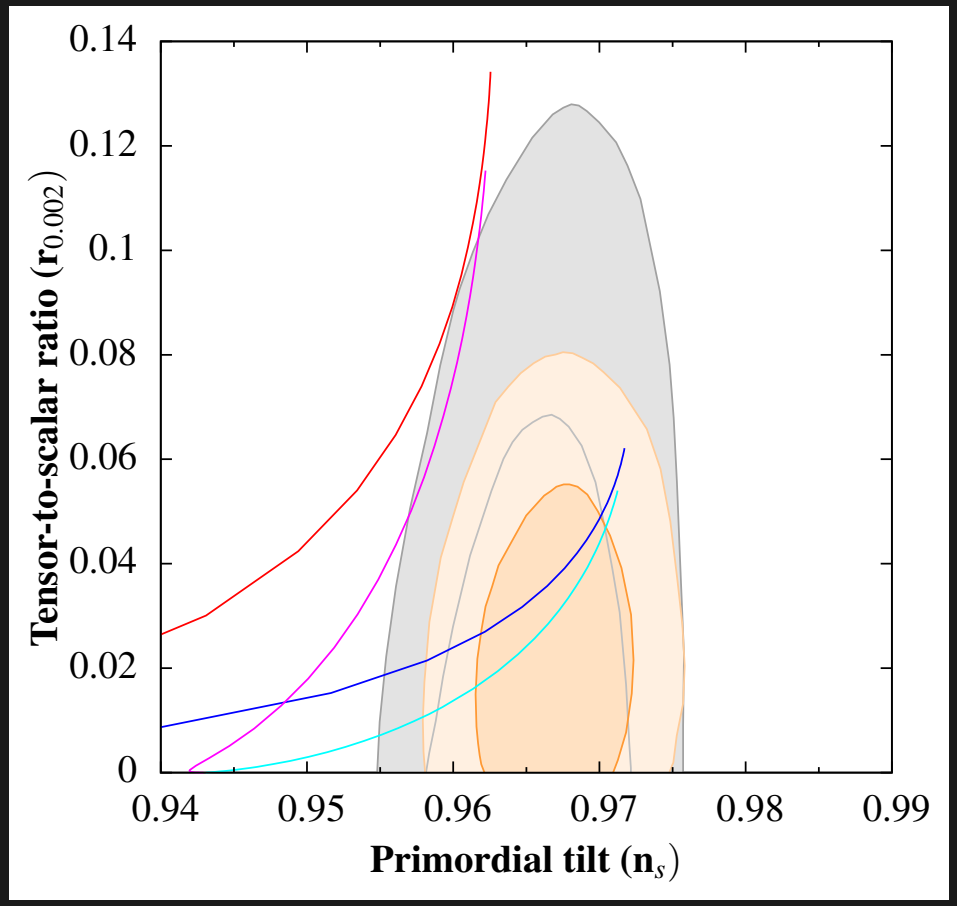
$c_s = \frac{1}{\sqrt{2n-1}}$, $r = 16 c_s \epsilon_V$.
$n = 2$



Comparison of Canonical and Non-canonical regime

- $C_\Lambda = 1$, $\beta/\alpha = 0.5$
- Data combinations used:
  1. Planck TT,TE,EE+lowE+lensing data (2018)
  2. Planck TT,TE,EE+lowE (2018)+lensing+BK14+BAO.



Varying β (Case 1)

- $C_\Lambda = 1$,
- $\beta/\alpha = 0, 0.25, 0.5, 0.75$ in red, cyan, magenta and green.
- Data combinations used:
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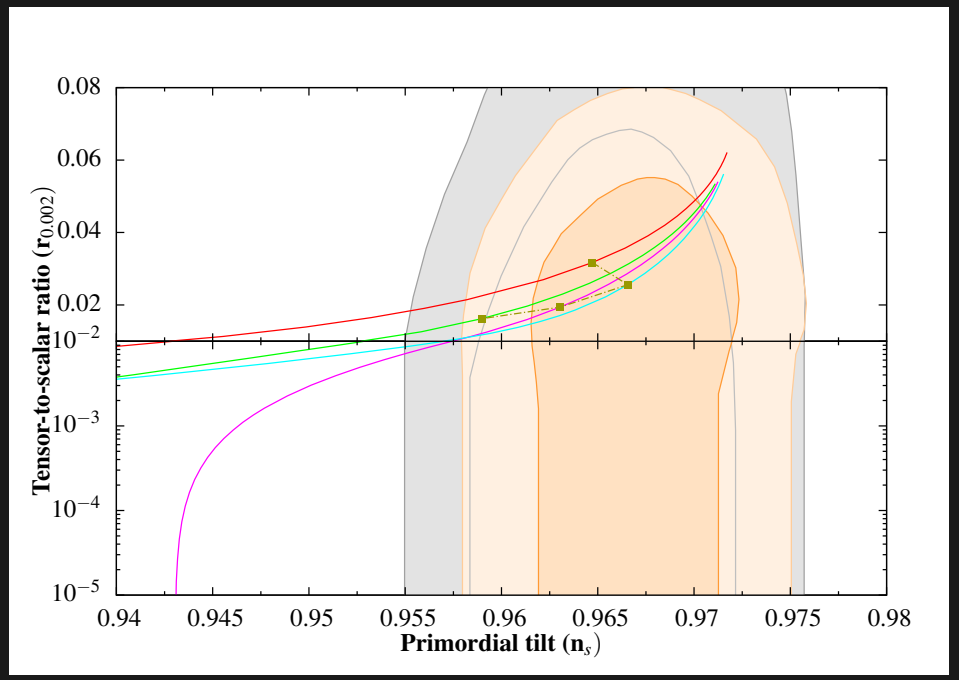
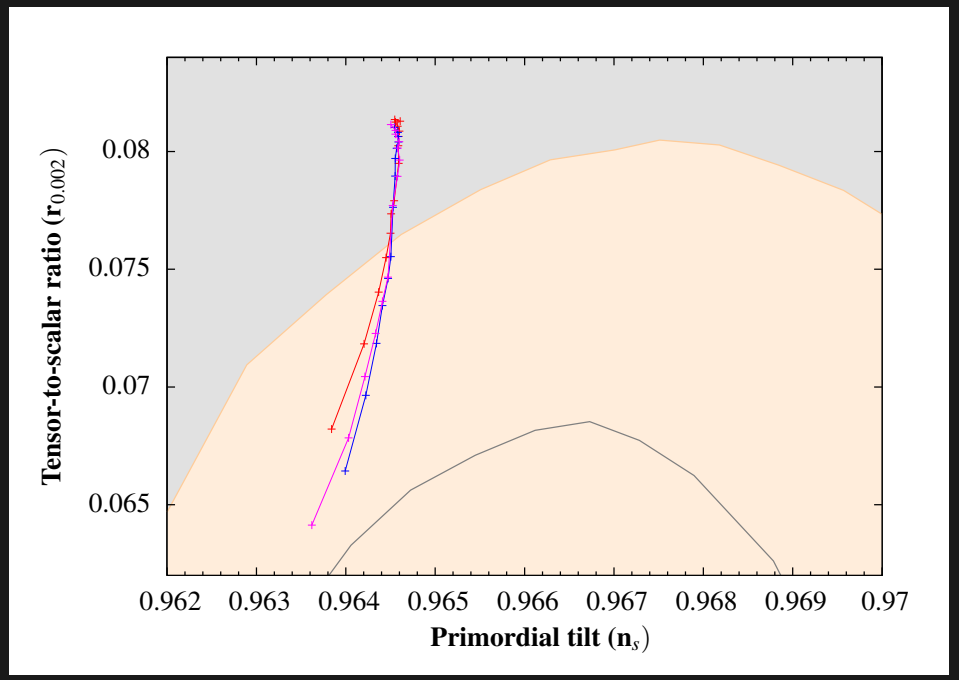


Varying β (Case 2)

- $C_\Lambda = 1$,
- $\beta/\alpha = 0, 0.2, 0.5$ in red, magenta and blue.
- Lowest point is for $f = 0.5 M_{Pl}$.
- Data combinations used:
  1. Planck TT,TE,EE+lowE+lensing data (2018)
  2. Planck TT,TE,EE+lowE (2018)+lensing+BK14+BAO.
- Inside 96% confidence limit of Planck 2018 (dataset 2 above) for sub-Planckian f.



Comparison

- $C_\Lambda = 1, f = 5M_{Pl}$.
- $\beta/\alpha = 0, 0.2, 0.5$ in red, magenta and blue.
- Canonical , Non-canonical and Kinetic (L2R).
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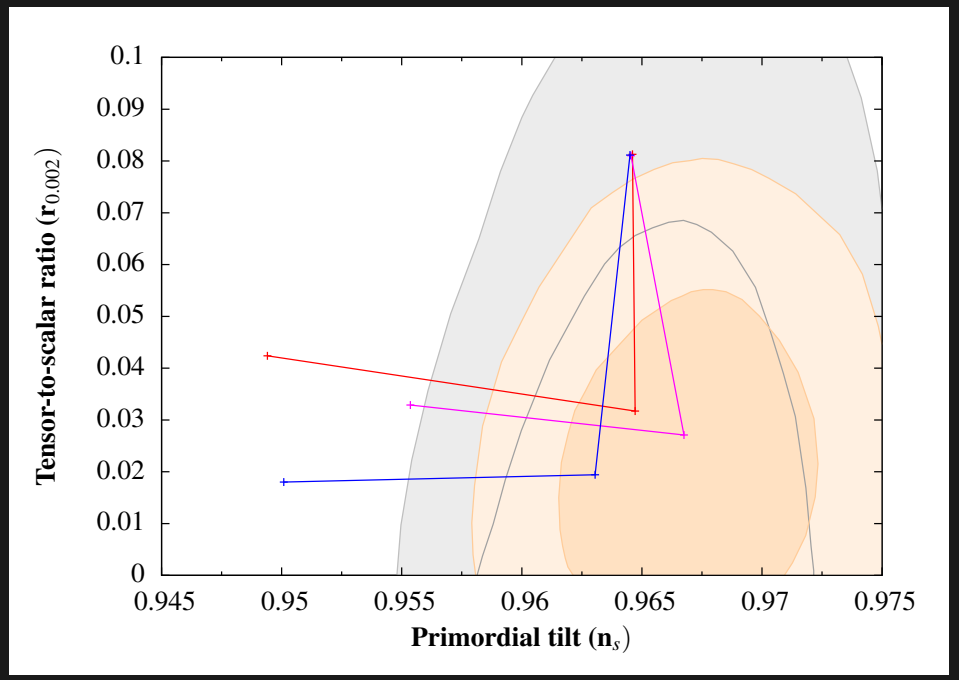

Discussions

- Implementation of Goldstone inflation in the non-canonical regime drives the tensor-to-scalar ratio r to a lower value for Case 1.
- For Case 1, inflation at sub-Planckian breaking scales corresponds to points outside the CMB observations by Planck 2018.
- For Case 2, r stays at high values and sub-Planckian breaking scale corresponds to points in n_s-r plane that are within 2σ of current observations.$\rightarrow$ Future detection of early universe tensor modes can easily verify.

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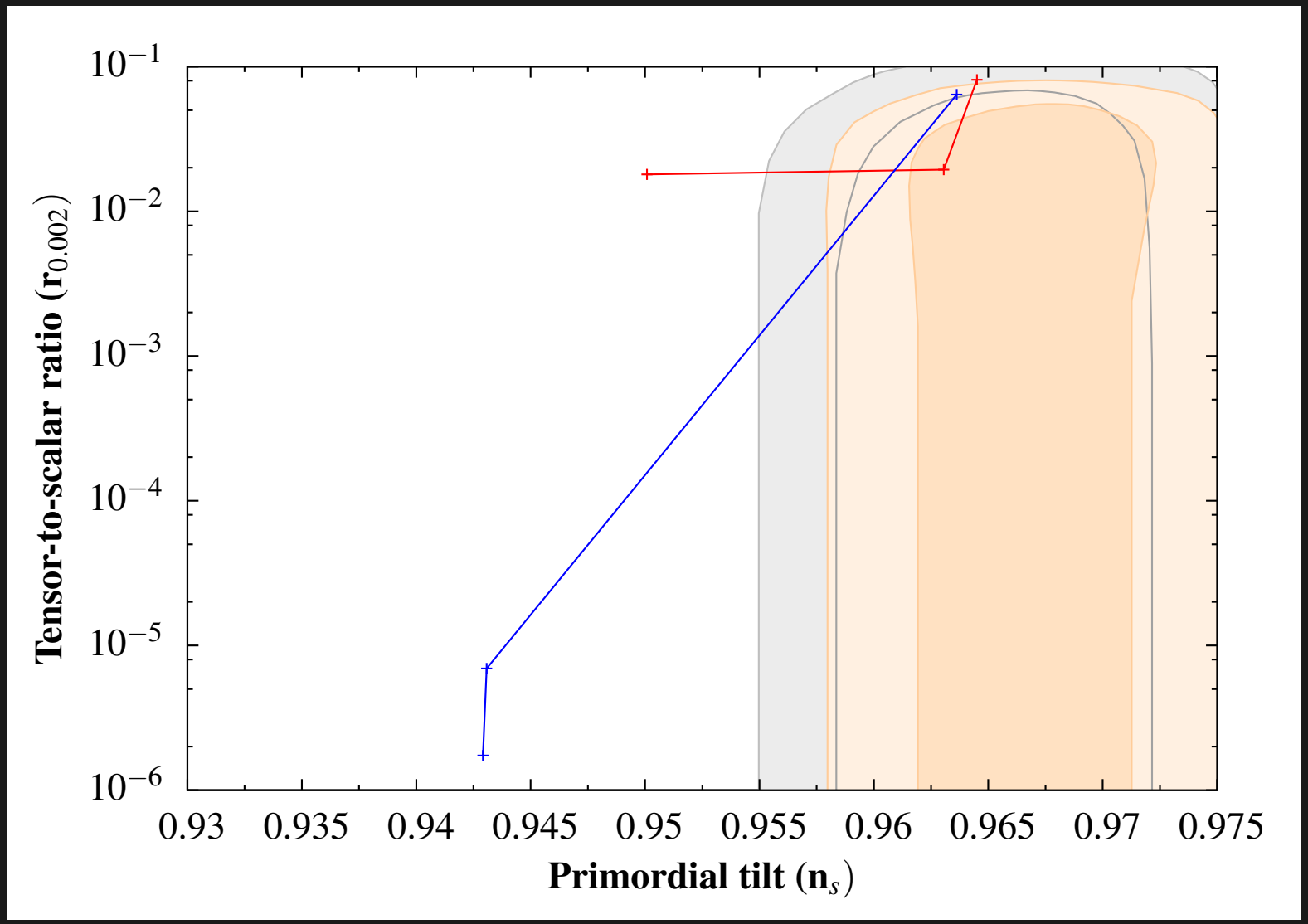
Extra



Red: $f = 5M_{Pl}$, Blue: $f = 0.5M_{Pl}$.