dS vacua and inflation

Timm Wrase

Lecture 5

Recap lecture 4

- The string compactification from above with fluxes for $\{\phi^I\} = \{S, T, U, N\}$ gives after compactification

$$K = -3\log\big(-i(T - \bar{T})\big) + N\bar{N}$$

$$W = W_0 + \mathrm{Ae}^{\mathrm{iaT}} + \mu\, N \equiv W_{KKLT} + \mu\, N$$

$$\begin{aligned} D_N W &= \partial_N W + W \partial_N K = \mu + W\bar{N} = \mu\,, \\ D_T W &= \partial_T W + W \partial_T K = \partial_T W_{KKLT} - \frac{3}{T - \bar{T}} W_{KKLT} \equiv D_T W_{KKLT} \end{aligned}$$

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We see that supersymmetry is now broken since $D_N W = \mu \neq 0$

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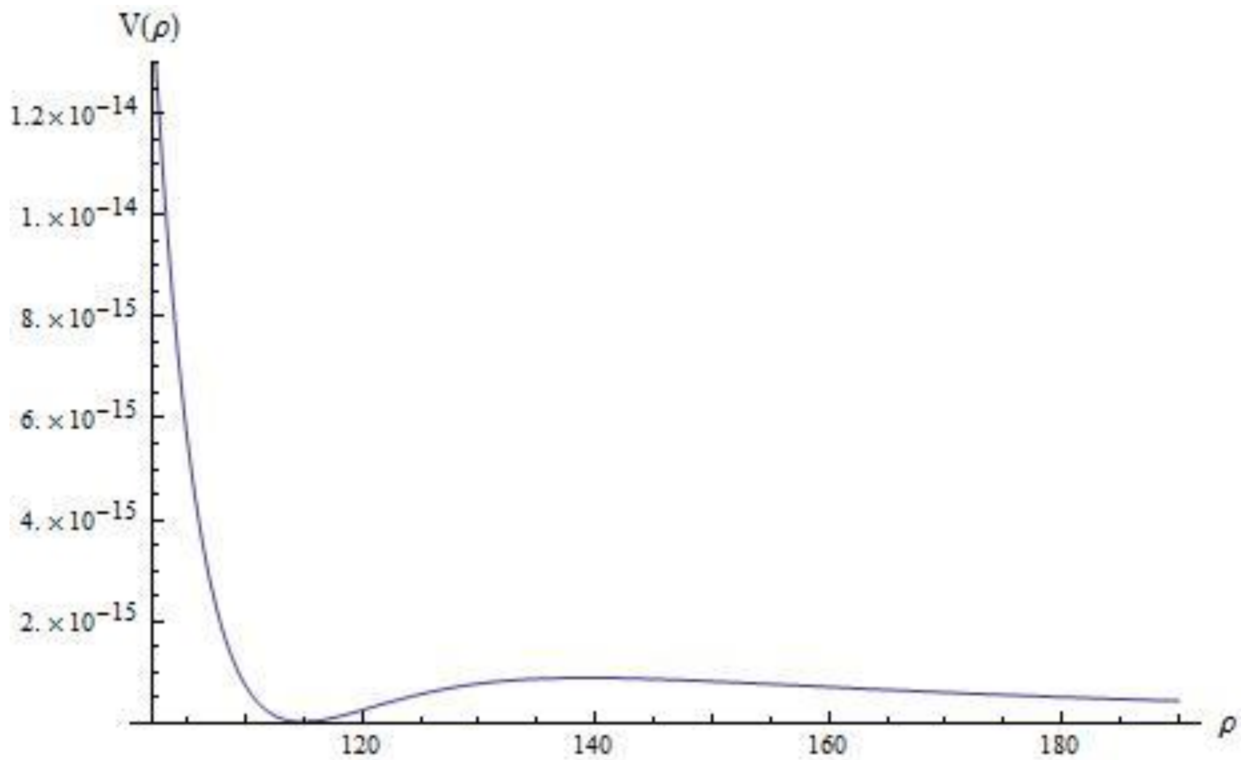
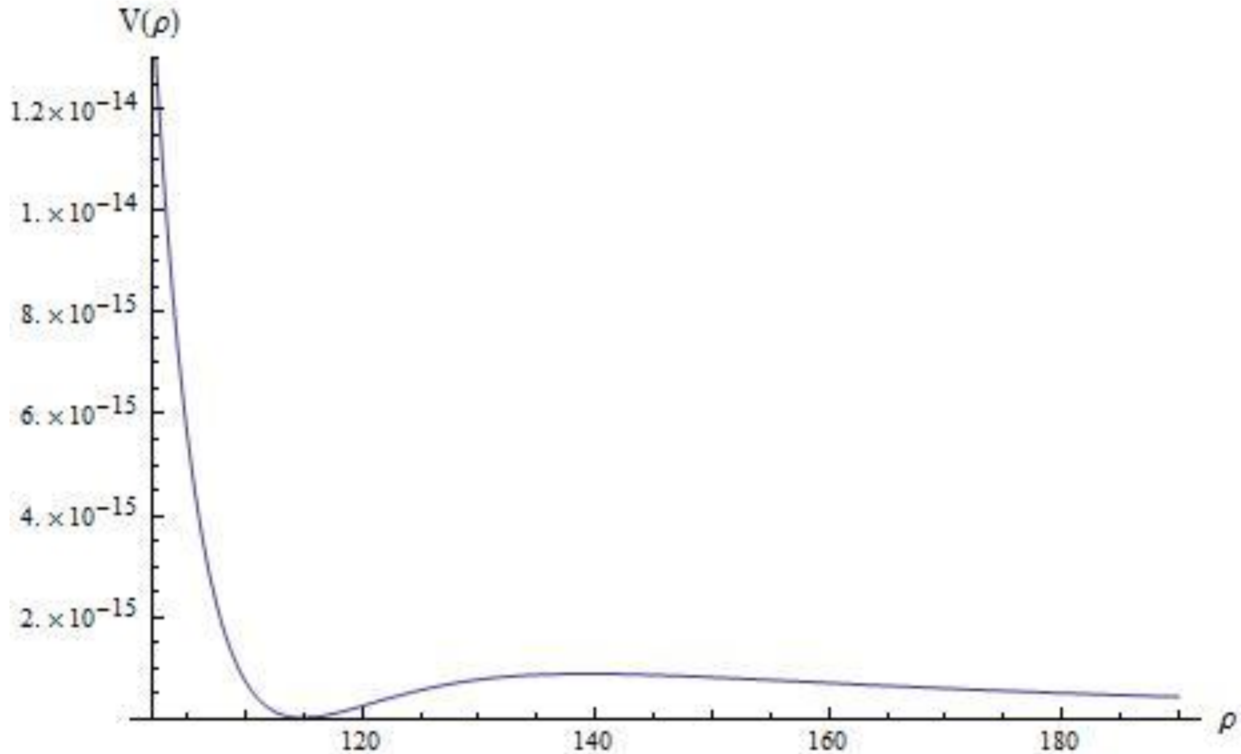
Recap lecture 4



- For an appropriate choice of μ we find $V_{min} > 0$

Recap lecture 4



- For an appropriate choice of μ we find $V_{min} > 0$
- One can in principle fine-tune $V_{min} \approx 10^{-120}$

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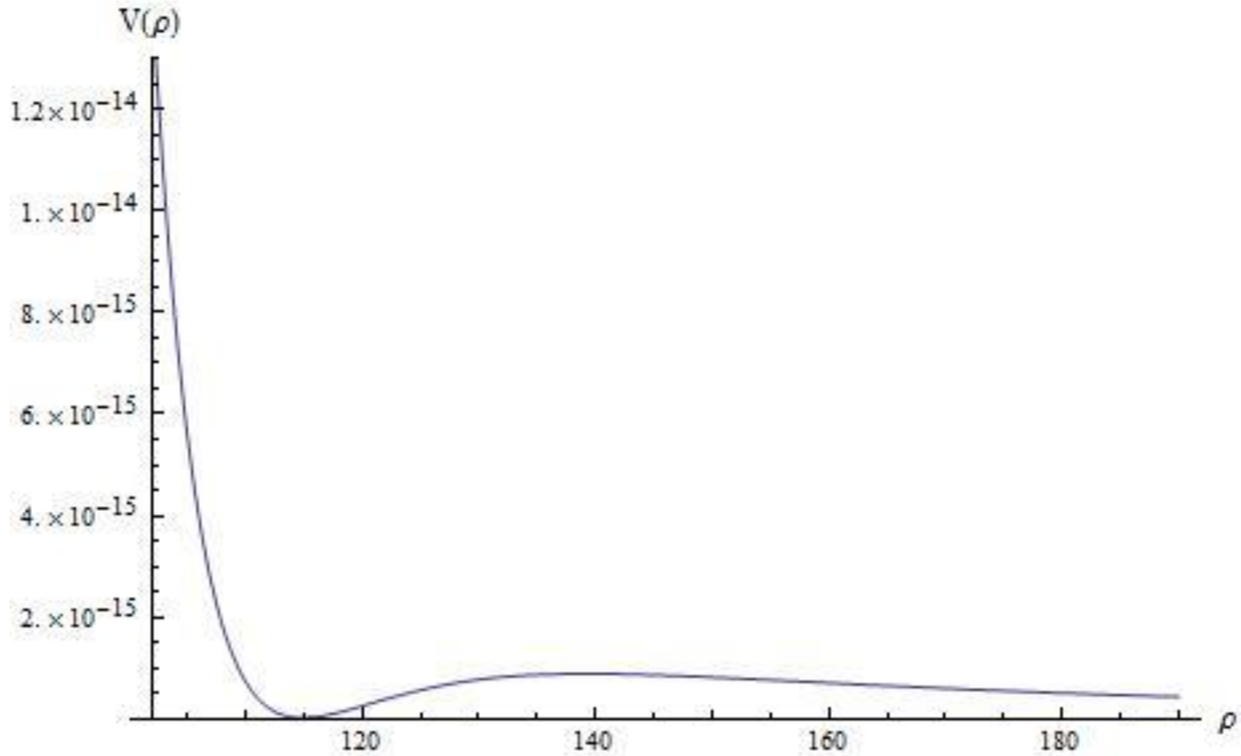

- For an appropriate choice of μ we find $V_{min} > 0$
- One can in principle fine-tune $V_{min} \approx 10^{-120}$
- SUSY breaking scale $D_N W = \mu$ independent of V_{min}

The scalar potential

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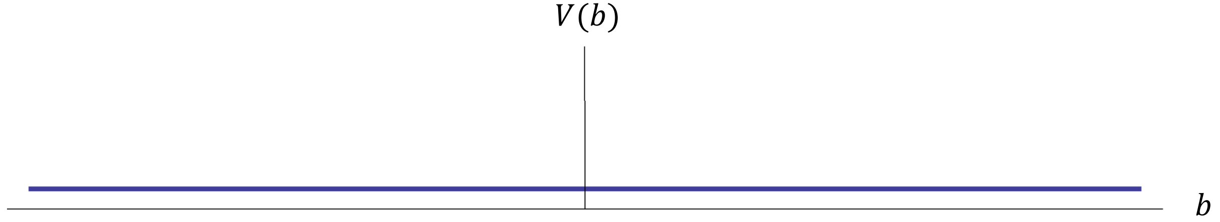
- In the absence of the non-perturbative corrections $b = Re(T)$ was a flat direction



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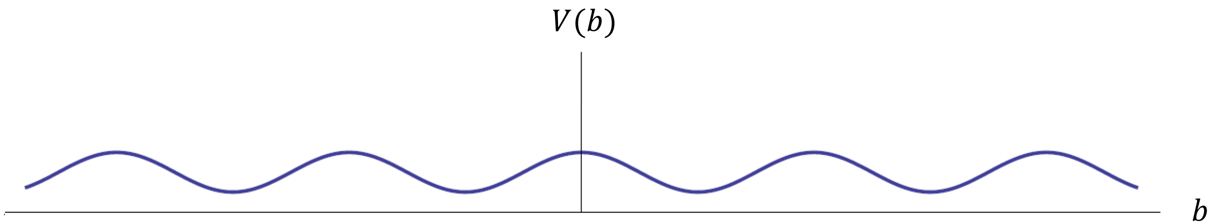

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$$V(\rho, b) = \frac{4aA^2\rho e^{-2a\rho}(a\rho+3) + 12aA\rho W_0 e^{-a\rho}\cos(ab) + 3\mu^2}{24\rho^3} \qquad T = b + \mathrm{i}\rho$$

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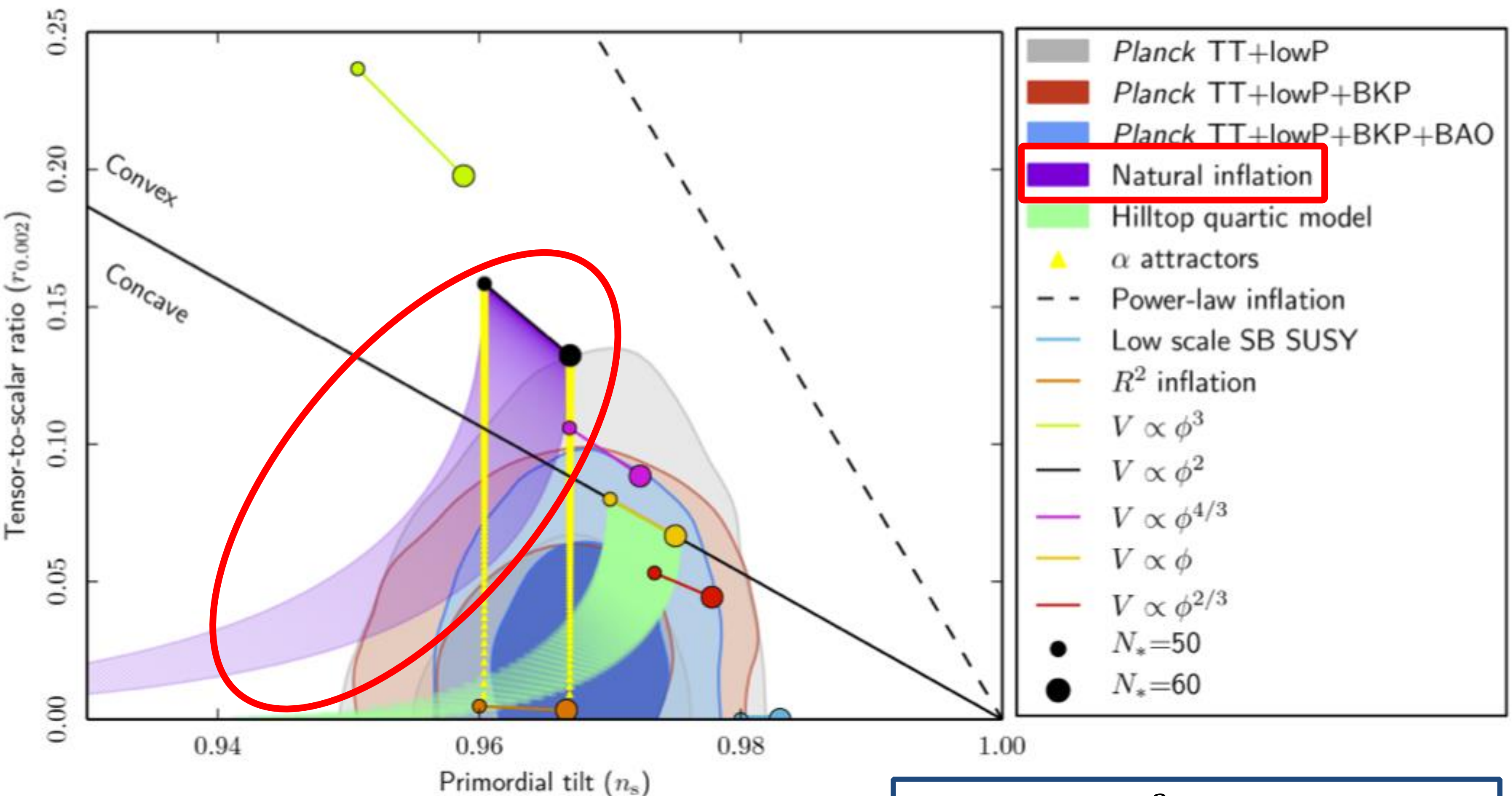
Looks like a good candidate for natural inflation

Planck 2015

$r \approx 16\epsilon_V$



$$n_s \approx 1 - 6\epsilon_V + 2\eta_V$$

$$\epsilon_V = \frac{M_P^2}{2}\left(\frac{V'}{V}\right)^2, \qquad \eta_V = M_P^2\frac{V''}{V}$$

Natural inflation

$$V(b) = \lambda^4 \left(1 + \cos\left(\frac{b}{f}\right)\right)$$

- In order to match onto observations we need $f > M_P = 1$ but not by that much so $f \approx 10\ M_P = 10$ or a little bit larger would be sufficient

- However, in controlled regimes of string theory the axion decay constant f seems to be always smaller than $M_P = 1$

Banks, Dine, Fox, Gorbatov hep-th/0303252
Svrcek, Witten hep-th/0605206

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Natural inflation from string theory?

N-inflation

- Another proposal to extend the axion decay constant requires a large number $N \gg 1$ of scalars

Liddle, Mazumdar, Schunck astroph/9804177

Dimopoulos, Kachru, McGreevy, Wacker hep-th/0507205

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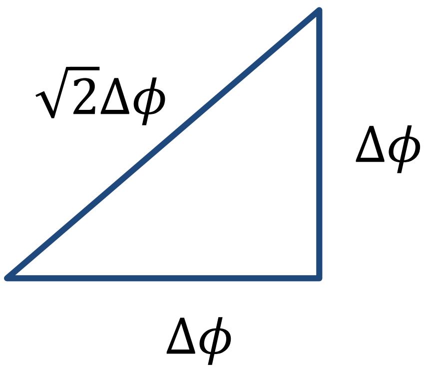
- String theory compactifications can certainly have many scalars with $N \approx O(100 - 1000)$

- The idea is essentially ``Pythagoras theorem'':



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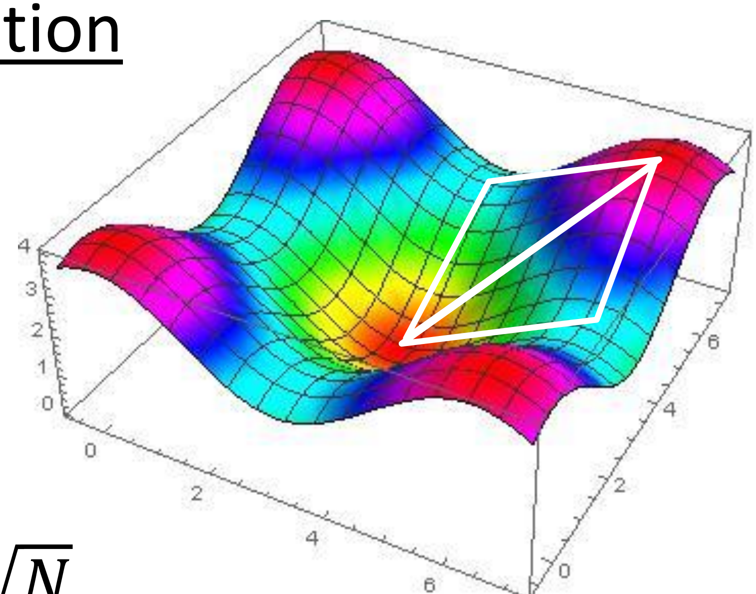

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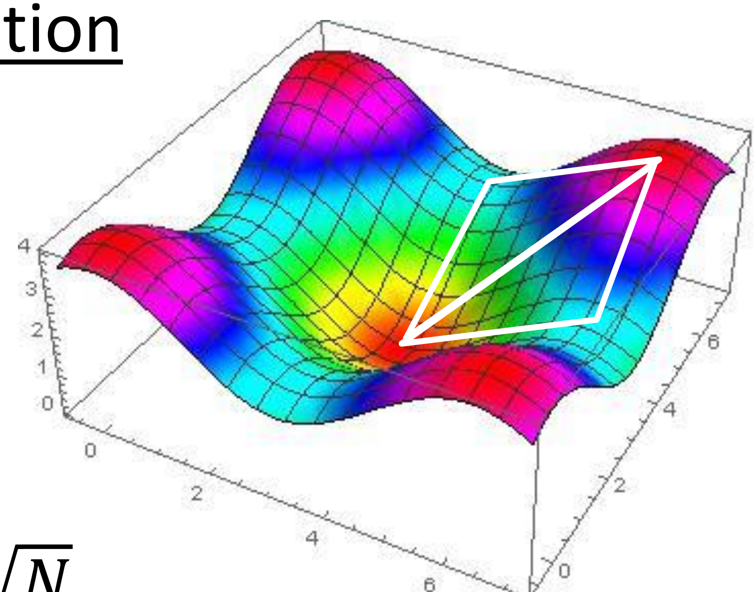

- The idea is essentially ``Pythagoras theorem''
- If we displace N identical scalars by the same amount we get an enhancement by $\sqrt{N}$
- We usually expect f to be not that much smaller than M_p so that we can have $\sqrt{N}f \approx 10\ M_P$

Natural inflation from string theory?

Alignment

- It is possible to get a super Planckian f, if one considers a model with two scalars that both have sub-Planckian f's

Kim, Niles, Peloso hep-ph/0409138

$$V = \lambda_1^4 \left[1 + \cos\left(\frac{b_1}{f_1} + \frac{b_2}{f_2}\right)\right] + \lambda_2^4 \left[1 + \cos\left(\frac{b_1}{g_1} + \frac{b_2}{g_2}\right)\right]$$

$$f_1, f_2, g_1, g_2 < M_P$$

Natural inflation from string theory?

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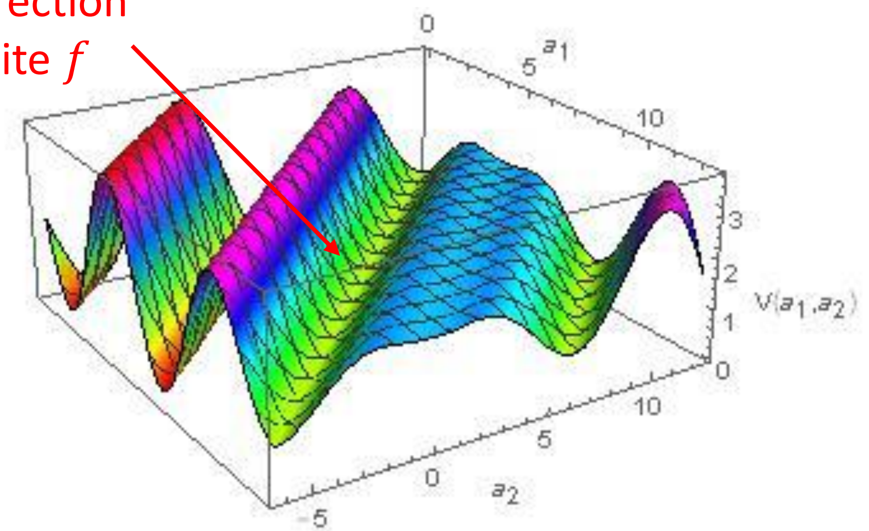

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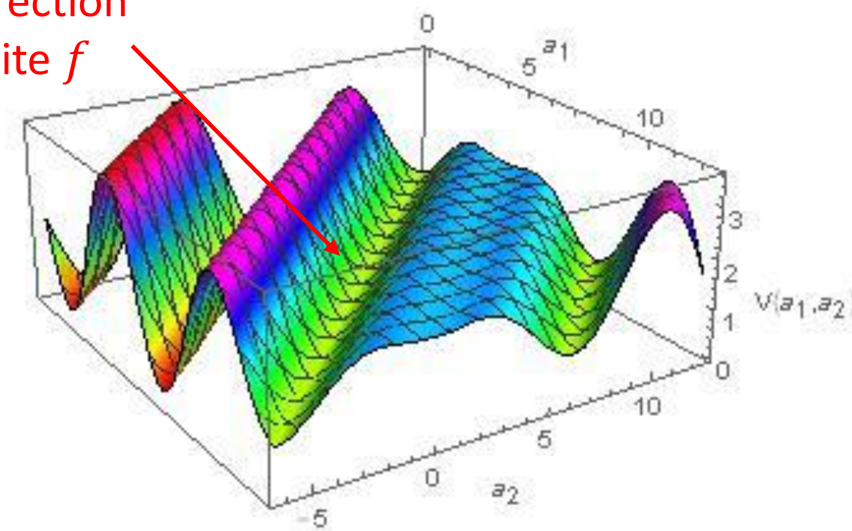
flat direction
= infinite f



Natural inflation from string theory?

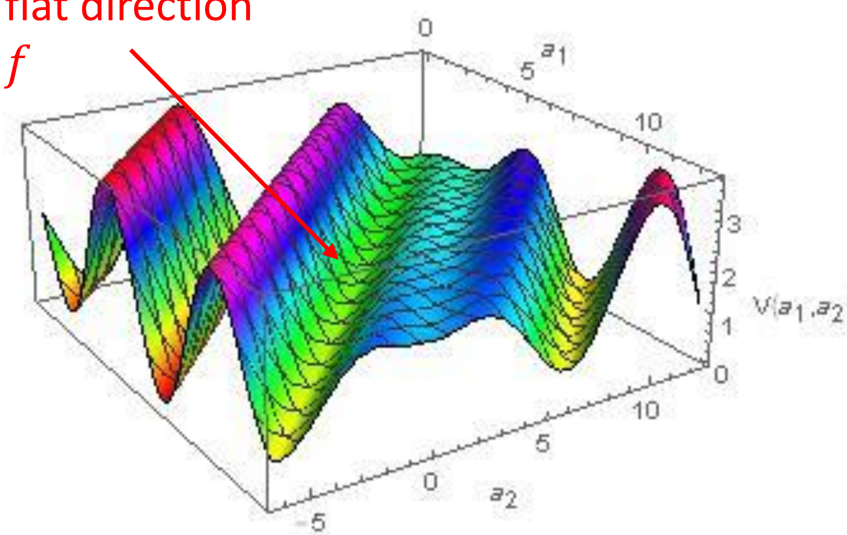
Alignment

$$V = \lambda_1^4\left[1+\cos\left(\frac{b_1}{f_1}+\frac{b_2}{f_2}\right)\right]+\lambda_2^4\left[1+\cos\left(\frac{b_1}{g_1}+\frac{b_2}{g_2}\right)\right]$$

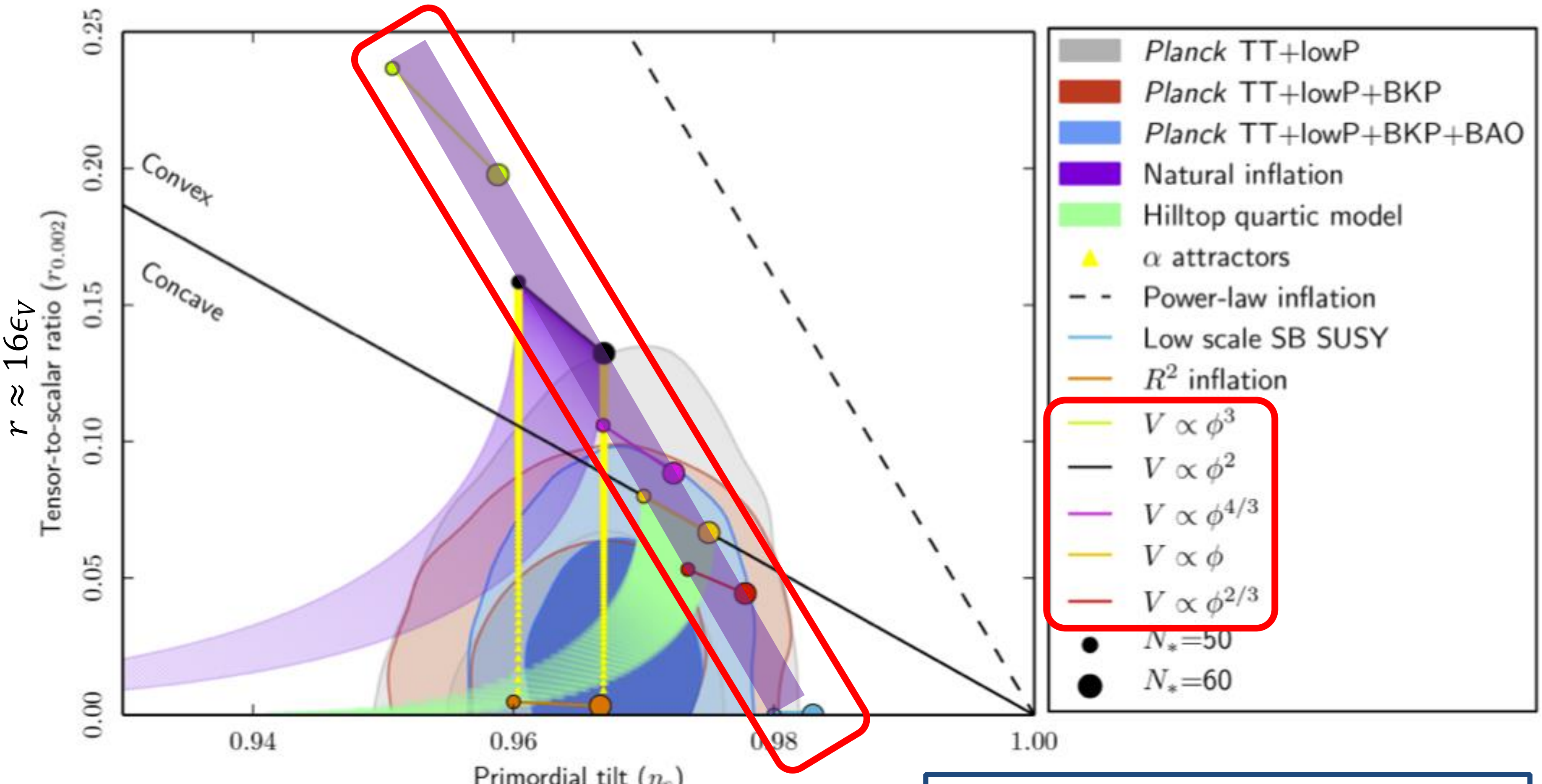
If $\frac{f_1}{f_2} \approx \frac{g_1}{g_2}$, then we can define $b = b_1 + \frac{f_1}{f_2}\, b_2 = b_1 + \frac{g_1}{g_2}\, b_2$

The direction orthogonal to a is the inflaton and can have arbitrarily large f

almost flat direction
= large f



Axion monodromy inflation



$$n_s \approx 1 - 6\epsilon_V + 2\eta_V$$

$$\epsilon_V = \frac{M_P^2}{2}\left(\frac{V'}{V}\right)^2, \qquad \eta_V = M_P^2 \frac{V''}{V}$$

Axion monodromy inflation

flux quanta (can be chosen)

Example:

$$V \sim M_{pl}^4 \frac{g_s^4}{L^{12}} \left(\frac{Q_1^2}{u^3} + \frac{Q_2^2}{L^4} u\, b^4 \right)$$

one extra scalar field

axion = inflaton

Axion monodromy inflation

Example:

$$V \sim M_{pl}^4 \frac{g_s^4}{L^{12}} \left(\frac{Q_1^2}{u^3} + \frac{Q_2^2}{L^4} u\, b^4 \right)$$

two term stabilization of u

Axion monodromy inflation

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$$\partial_u V = 0 \quad \Rightarrow \qquad u = \frac{3^{1/4} L}{b} \sqrt{\frac{Q_1}{Q_2}} \propto \frac{1}{b}$$

Axion monodromy inflation

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Flattening: $\quad V \propto b^4 \qquad \to \qquad V \propto b^3$

Axion monodromy inflation

Generic feature in these models:

- One or more fields adjust their value during inflation and thereby flatten the scalar potential

$$V(b,\phi^I) = \sum_{n=0}^{p_0} c_n(\phi^I)\, b^n \xrightarrow{\phi^I = \phi^I_{\min},\, b >> 1} \tilde{c}(\phi^I_{\min})\, b^p, \quad \boxed{p \leq p_0}$$

Axion monodromy inflation

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- There is some freedom in choosing fluxes to control the flattening

- We find $p = 3, 2, \frac{4}{3}, 1, \frac{2}{3}$ in some string models

Axion monodromy inflation

In string theory: $V(\phi) \propto \phi^p, p = 3, 2, \frac{4}{3}, 1, \frac{2}{3}$