Higgs-otic inflation in String Theory

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Ibáñez, Valenzuela, [arXiv:1404.5235 [hep-th]].
Ibáñez, Marchesano, Valenzuela, [arXiv:1411.5380 [hep-th]]
Bielleman, Ibáñez, Pedro, Valenzuela, [arXiv:1505.00221 [hep-th]]

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Higgs-otic inflation

Scalar particle responsible for non-abelian symmetry breaking while attaining large field inflation.

- Identify the inflaton with a position modulus of a system of D7-branes. [Hebecker et al.]
- Potential generated by turning on closed string fluxes.
- Effective action = DBI + CS action of the brane.
- Transplanckian field range: F-term monodromy inflation. [Marchesano,Shiu,Uranga]

Most obvious candidate: **MSSM Higgs boson**

✓ Reheating

✓ Minimal coupling to gravity

✓ Potential dominated by the soft mass: High SUSY breaking scale

$$V \simeq \frac{1}{2} m_H^2 H^2 \Rightarrow M_{SS} \sim m_H \simeq 10^{11} - 10^{13}\mathrm{GeV}$$

$$m_{h_{SM}} \sim 0$$

(consistent with density scalar perturbations, the experimental Higgs mass and detectable gravitational waves)

Higgs-otic inflation in Type IIB

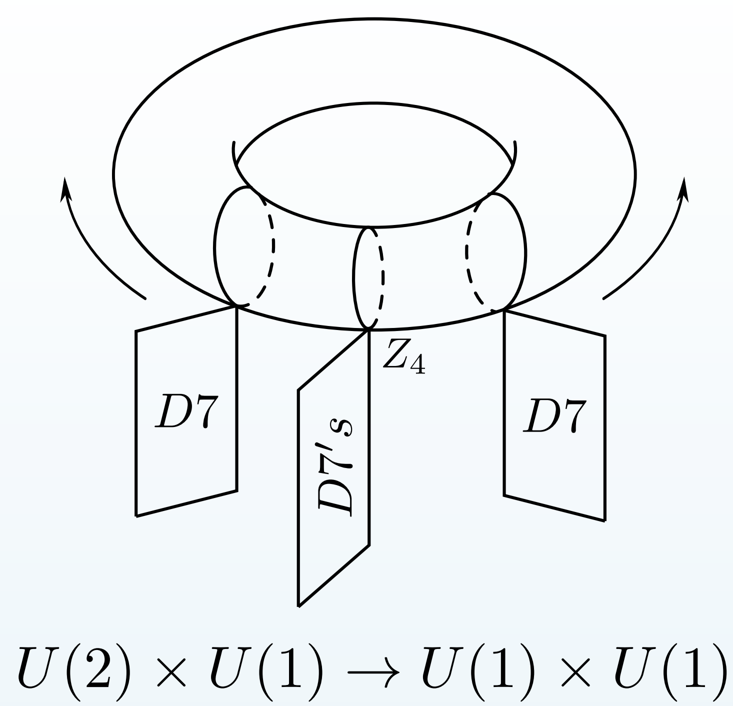
6 D7-branes at $(\mathbf{C^2} \times \mathbf{T^2})/Z_4$

$$(z_1, z_2, z_3) \to (\alpha z_1, \alpha z_2, \alpha^2 z_3)$$
$$\gamma = diag(\alpha \mathbf{1_3}, \alpha^2 \mathbf{1_2}, \mathbf{1})$$
$$\alpha = exp(i2\pi/4)$$

Gauge group: $U(3) \times U(2) \times U(1)$

Matter fields: $2(3, \overline{2}) \; + \; 2(1, \overline{3}) \; + \; \underbrace{(1, 2) + (1, \overline{2})}$

vector pair: H_u , H_d



One U(2)-brane + U(1)-brane can leave the singularity in opposite directions respecting the Z_2 twist on the torus.

Inflaton = Position moduli of the D7 wandering branes

Inflation comes along with EW gauge symmetry breaking

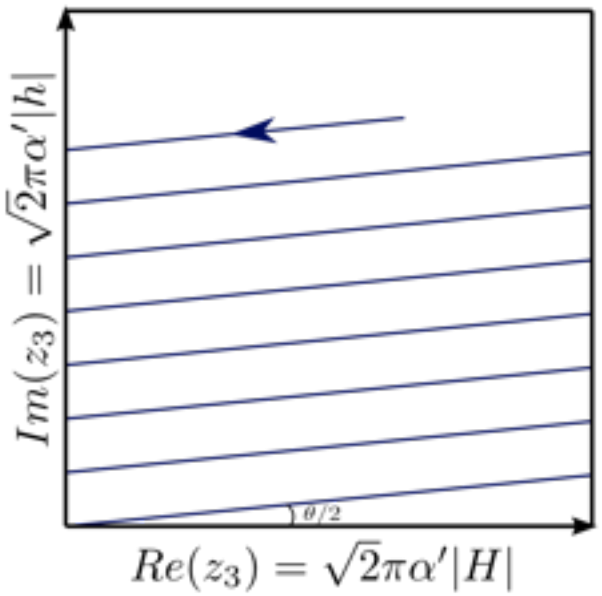
Higgs-otic inflation in Type IIB

D-flat direction: $V_D \propto (|H_u|^2 - |H_d|^2)^2$

Angular coordinates:

$$H_u = H_d^* e^{i\theta} \ , \ |H_u| = |H_d| = \sigma$$

$$z_3^2 = (2\pi\alpha')^2 \sigma^2 e^{i\theta}$$



$$H \simeq \frac{1}{\sqrt{2}}(H_u + H_d^*) \simeq \text{Heavy higgs}$$

$$h \simeq \frac{1}{\sqrt{2}}(H_u - H_d^*) \simeq \text{SM higgs}$$

Two real fields parametrize the position of the D7 wandering branes

Periodic moduli space: $z_3 \to z_3 + 2\pi R n$

The physics repeats itself $\left\{ \begin{array}{l} \text{- no new couplings} \\ \text{- no transplanckian masses} \end{array} \right.$

e.g. $M_{W,Z} \simeq \frac{1}{2\pi\alpha'}|z_3 - \underbrace{2\pi R\omega}_{\text{winding}}| < M_{KK}$ even if $\underbrace{|z_3| > \pi R}_{\text{transplanckian}}$

Higgs-otic inflationary potential

Addition of ISD 3-form closed string fluxes

- Non-vanishing potential energy $\longrightarrow$ monodromy
- Inflaton potential $\longrightarrow$ Inserting fluxes in the DBI+CS action (exact in α')

➡ Expand DBI+CS action

$$S_{DBI} = -\mu_7 \int d^8\xi \, \mathrm{STr} \left[e^{-\phi} \sqrt{-\det \left(P[E_{\mu\nu}] + \sigma F_{\mu\nu} \right)} \right]$$

$$S_{CS} = -\mu_7 \int d^8\xi \, \mathrm{STr} \left[-C_6 \wedge B_2 + C_8 \right]$$

in the presence of background fluxes $\begin{cases} G \equiv G_{(0,3)} & \text{(non-susy)} \\ S \equiv G_{(2,1)} & \text{(susy)} \end{cases}$

keeping all terms in Φ (large field)

$\downarrow$

position modulus D7-brane $\quad z_3 = 2\pi\alpha' \langle \Phi \rangle$

Higgs-otic inflationary potential

$$\boxed{S = \int d^4x \, \mathrm{STr}\left[\left(1 + \frac{\xi}{2} V(\Phi, \bar{\Phi})\right) D_\mu \Phi D^\mu \bar{\Phi} - V(\Phi, \bar{\Phi}) \right]}$$

$\xi = (V_4 \mu_7 g_s)^{-1}$

Non-canonical kinetic terms

Scalar potential: $V = \frac{g_s}{2} Tr|G^* \Phi - S\bar{\Phi}|^2$

Taking the trace: $\Phi = \begin{pmatrix} 0 & H_u \\ H_d & 0 \end{pmatrix}$

$$|\hat{G}|^2 = |G|^2 + |S|^2$$

$$V = m_H^2 |H|^2 + m_h^2 |h|^2 \rightarrow V = g_s |\hat{G}|^2 \sigma^2 (1 - A cos\theta)$$

$$A = \frac{2G^* S^*}{|G|^2 + |S|^2}$$

2-field chaotic inflation with non-canonical kinetic terms

- $A = 0 \rightarrow G = 0 \text{ or } S = 0 \longrightarrow V = g_s |\hat{G}|^2 \sigma^2$
- $A = 1 \rightarrow G = \pm S^* \longrightarrow V = \frac{g_s}{2} |\hat{G}|^2 H^2$
- $A \approx 0.83 \rightarrow det(m^2_{\text{Higgs}}(M_{ss})) = 0$ (running from Mc to Mss)

Single field limits

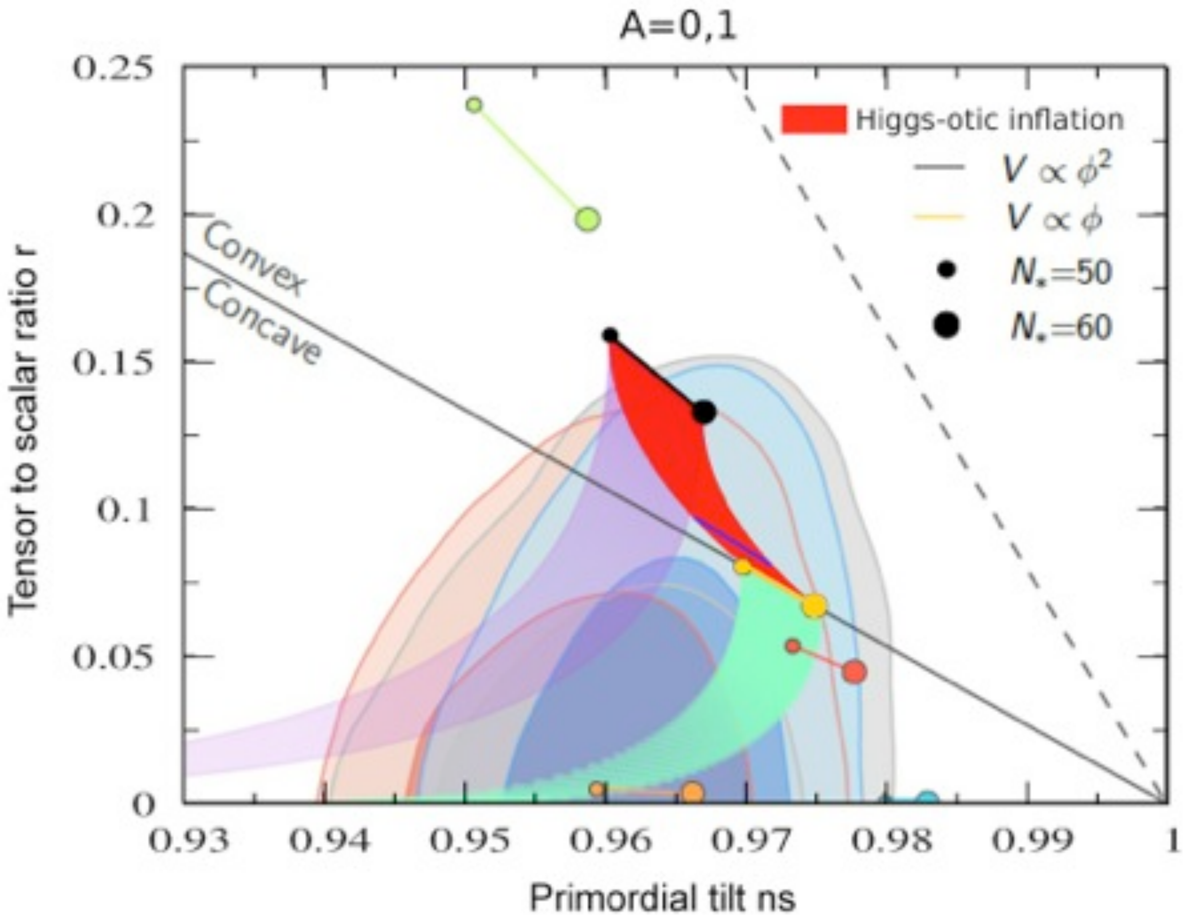
- $A = 0 \to G = 0$ or $S = 0 \longrightarrow V = g_s|\hat{G}|^2\sigma^2$
- $A = 1 \to G = \pm S^* \longrightarrow V = \frac{g_s}{2}|\hat{G}|^2 H^2$

After field redefinition to get canonical kinetic terms: $\varphi = \sigma, H$

$$\varphi' = \int f^{1/2} d\varphi = ... \to_{\varphi\to\infty} \varphi^2$$

$$V \to \mu_7 g_s V_4 |\hat{G}|\varphi$$

linear for large field



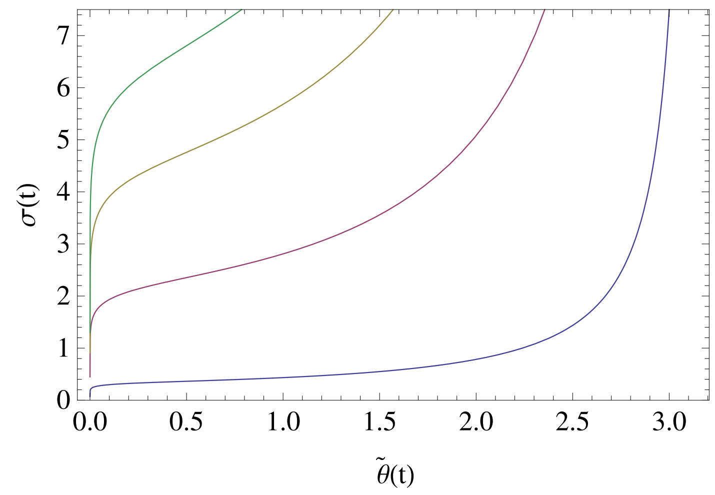
Potential interpolating between quadratic and lineal depending on the SUSY breaking scale

α' corrections $\Longrightarrow$ Flattening of the potential

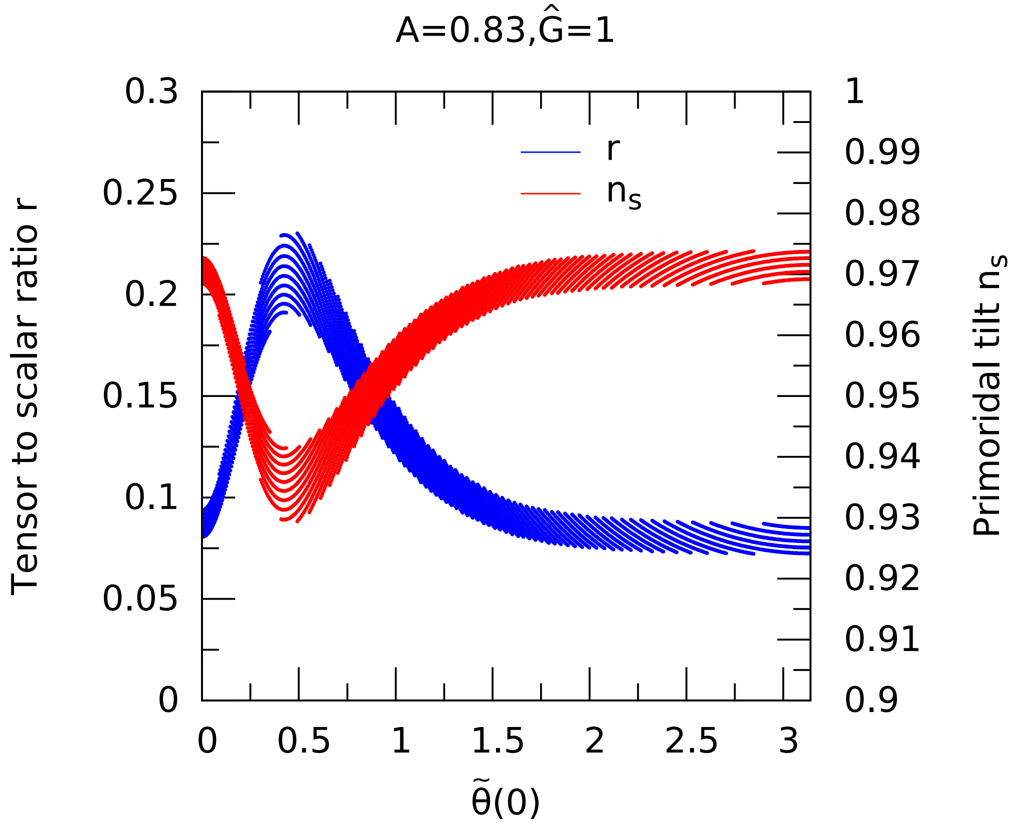
Higgs-otic limit (Two-field model)

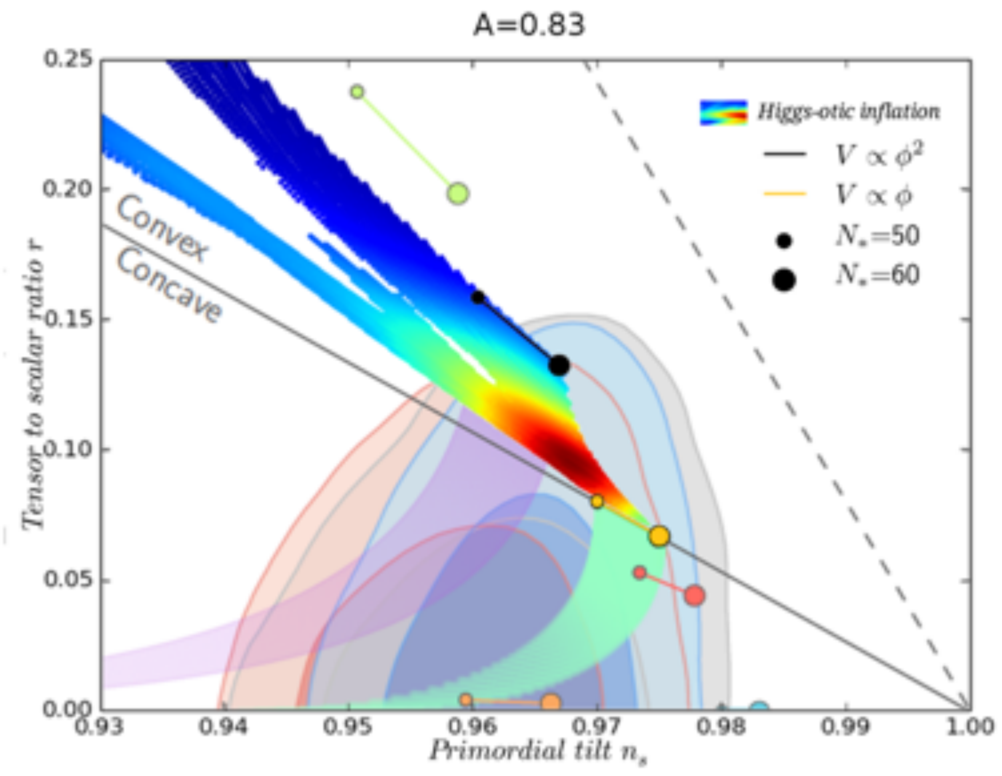
- $A \approx 0.83 \rightarrow det(m^2_{\rm Higgs}(M_{ss})) = 0$ (light SM Higgs!)

Depending on the initial conditions the trajectory and cosmological observables differ



Only adiabatic perturbations:





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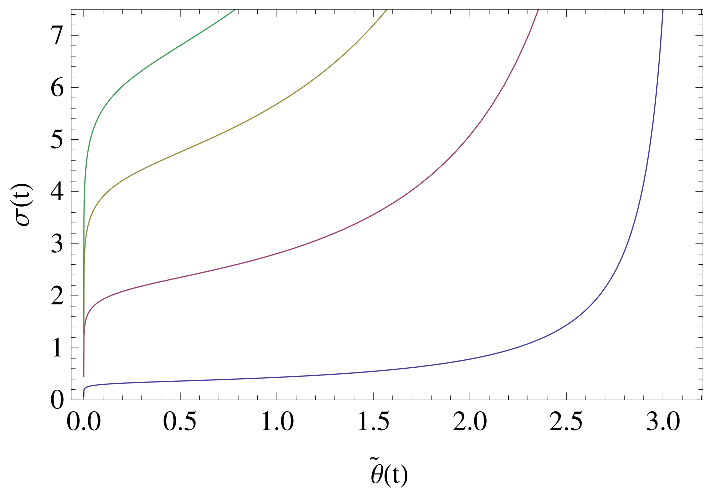
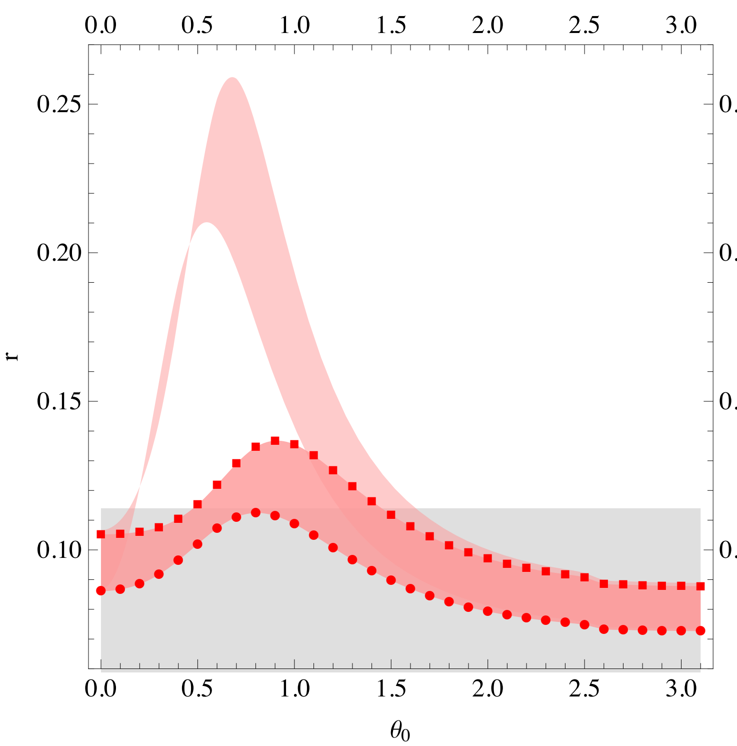
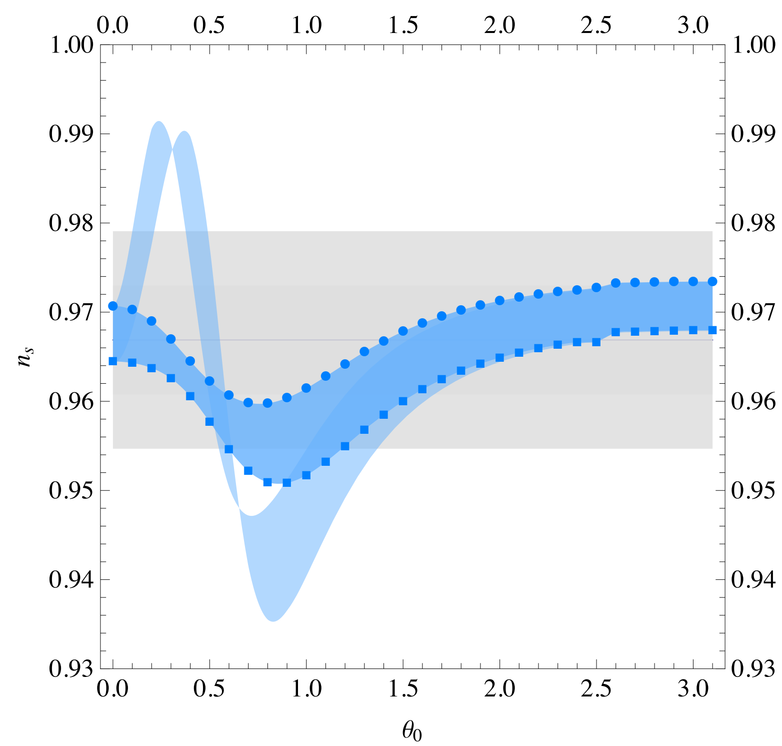


Adiabatic and isocurvature perturbations: Sharper predictions!





see Pedro's talk [Bielleman,Ibáñez,Pedro,Valenzuela]

Supergravity description

$$\boxed{\begin{aligned} K &= -log[(S+S^*)(U_3+U_3^*) - |H_u + H_d^*|^2] - 3log[T+T^*] \\ W &= W_0(U_3,S) + \mu H_u H_d \end{aligned}}$$

Structure determined by the $SL(2,Z)_{U_3}$ symmetry of T^2

Same result than DBI+CS action **for small field**:

$$V = (|M|^2 + |\hat{\mu}|^2)(|H_u|^2 + |H_d|^2) - 2M\hat{\mu}H_uH_d + hc.$$

$$H \simeq \frac{1}{\sqrt{2}}(H_u + H_d^*)$$

$$V = (|M| + |\hat{\mu}|)^2|H|^2 + (|M| - |\hat{\mu}|)^2|h|^2$$

$$h \simeq \frac{1}{\sqrt{2}}(H_u - H_d^*)$$

with $$M = -\frac{W_0^*}{\sqrt{st^3}} = \frac{g_s}{2}G^* \qquad \hat{\mu} = \frac{W_0 + \mu s}{\sqrt{st^3}} = \frac{g_s}{2}S^*$$

Explicit mu-term

Giudice-Masiero
$F^t \propto W_0 \neq 0$

It does not capture α' corrections $\longrightarrow$ Supergravity description not enough

Parametric control

- Only scalar potential is invariant under modular symmetries, so one expects higher corrections to appear as powers of the potential

$$\delta V = \mathcal{O}\left(V_0^n\right)$$

- This is consistent with DBI result which is exact in α'

$$\boxed{\text{Effect of higher order corrections} \longrightarrow \text{Flattening of the potential}}$$

- Action can be reduced to a Kaloper-Sorbo 4d effective lagrangian

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From DBI: $\mu_7 \int \frac{1}{2}\mathcal{F}_2 \wedge *_8 \mathcal{F}_2 = \mu_7 \int \frac{1}{2}\sigma^2 F_6 \wedge *_8 F_6 + \sigma B_2 \wedge F_6 + \ldots$

$$\int |F_4|^2 \Longleftarrow \boxed{\int_{\mathbb{R}^{1,3}} d^4x |dC_3|^2}$$

KS coupling $\int \phi F_4 \Longleftarrow \boxed{-g_s \int_{\mathbb{R}^{1,3}} d^4x\ \phi(G^* dC_3 - S^* d\bar{C}_3) + \text{c.c.}}$

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$$\mathcal{L}_{KS} = -\frac{1}{2}\int d^4x[(\partial\phi)^2 + |F_4|^2 - \mu\phi *_4 F_4] \longrightarrow \text{massive 4d scalar}$$

[Kaloper,Sorbo]

Underlying gauge invariance protects inflaton potential from dangerous UV corrections

$$\cancel{\delta V = \mathcal{O}\left(c_n \frac{\phi^n}{M_{UV}^{n-4}}\right)} \quad \text{forbidden} \qquad \delta V = V_0 \left(\frac{V_0}{M_{UV}^4}\right)^n \text{allowed}$$

Although $\phi > M_{UV}$, if $V_0 < M_{UV}$ UV corrections are under control.

[Kaloper,Sorbo] [Dvali] [Dudas]

Conclusions

- Higgs-otic inflation: MSSM Higgs identified with the inflaton in a large field inflation setup and high scale SUSY breaking.
- Realised in string theory by identifying the inflaton with a D7 position moving over a 2-torus.
- ISD fluxes induce a scalar potential which can be computed from the DBI+CS action.
- Result: 2-field chaotic inflation with specific non-canonical kinetic terms leading to a linear behaviour at large field.
- Quantum corrections appear as powers of the potential $\longrightarrow$

  $\longrightarrow$ under control $\longrightarrow$ flattening of the potential

Thank you!