The Inflaton as a MSSM Higgs and Open String Modulus Monodromy Inflation

Irene Valenzuela

Instituto de Física Teórica
UAM-CSIC, Madrid

European Research Council
SPLE Advanced Grant

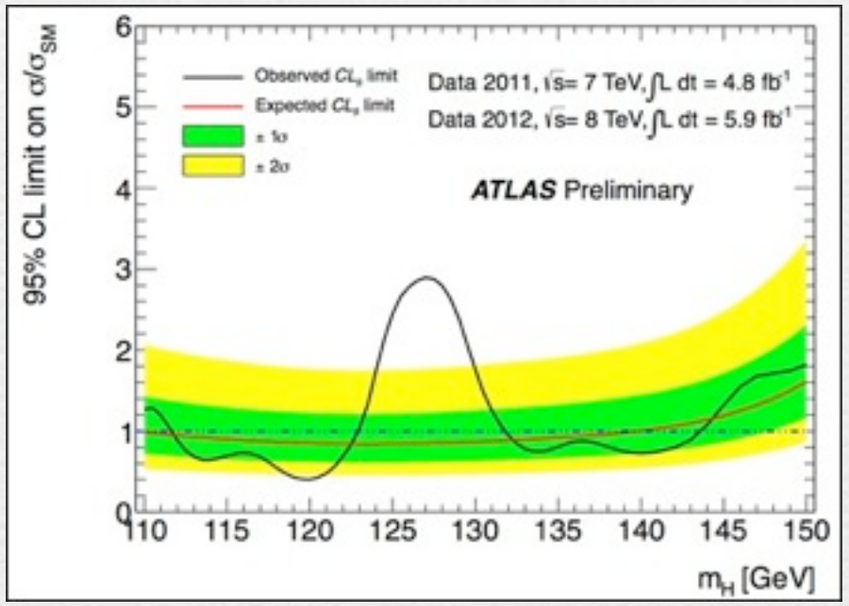
In collaboration with L.E. Ibáñez

String Phenomenology 2014, ICTP, Trieste, July 2014

Two big discoveries...

Higgs boson

(ATLAS and CMS, 2012)

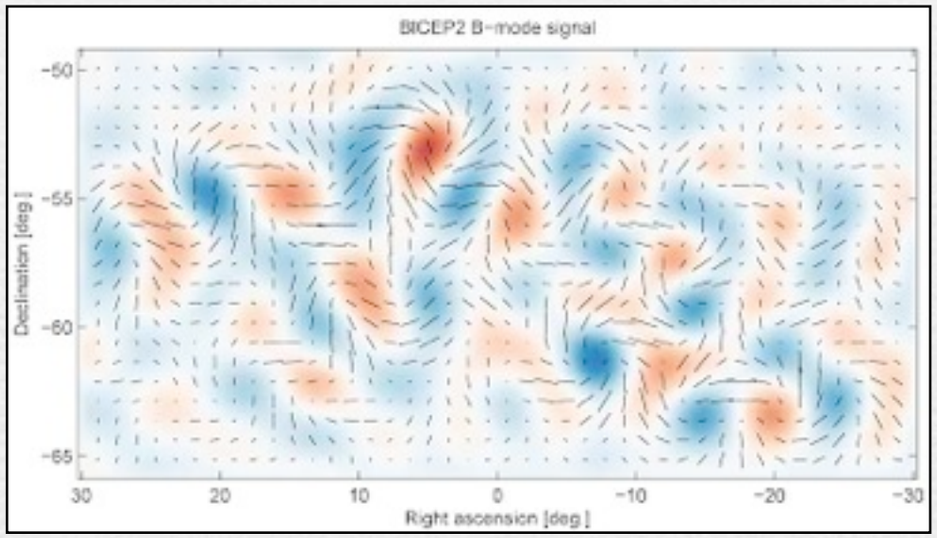


Responsible for SSB of EW interactions

Inflation

(BICEP2, 2014)

(still to be confirmed...)



Parametrized by a scalar particle rolling down a potential.

Higgs boson ? = Inflaton

Reheating ✓

Inflaton = MSSM Higgs boson

Problems of usual Higgs inflation:

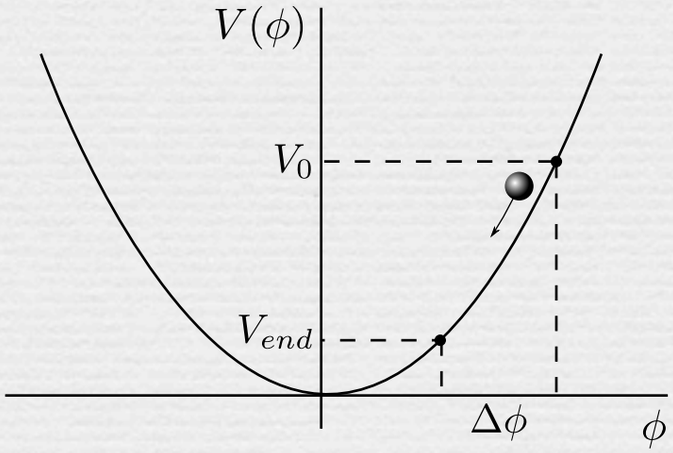
- Only quartic potential: not flat enough.
- Quartic coupling could vanish before inflation.
- Too small tensor-to-scalar ratio r.
- ...

Bezrukov,'13
Barbon,Espinosa'09

All of them solved if SUSY is broken at a high scale.

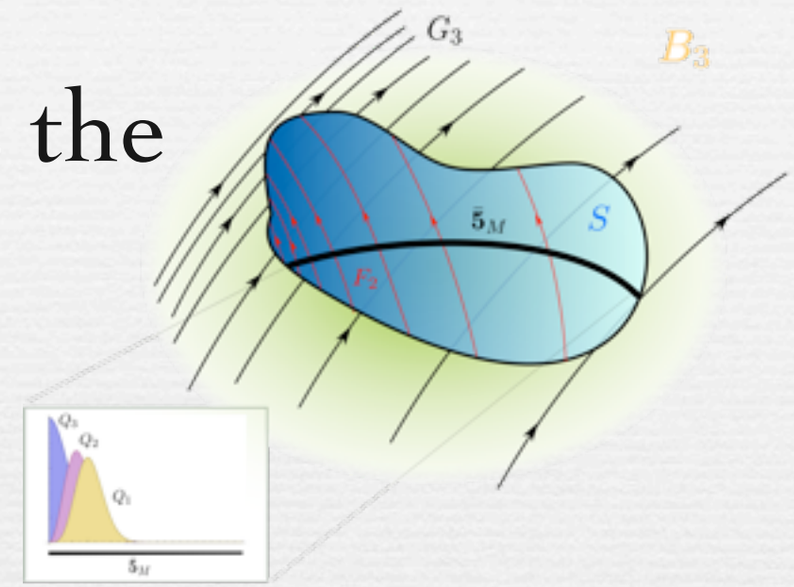
Potential dominated by the SUSY breaking terms $\sim \mathcal{O}(10^{13}\ \mathrm{GeV})$

First approx.: $V_H \simeq m_+^2 H^2$



SUSY breaking in Type IIB/F-Theory

Assumption: Closed string fluxes as the main source of SUSY breaking



- Non-vanishing auxiliary field for some closed string moduli.

Type IIB (CY):

$$\left.\begin{aligned} K &= -\log(S+S^*) - 3\log(T+T^*) \\ W &= \int G_3 \wedge \Omega \end{aligned}\right\} \Rightarrow \begin{aligned} F^S &\propto \int G_3^* \wedge \Omega = 0 \\ F^T &\propto \int G_3 \wedge \Omega \neq 0 \end{aligned}$$

- Important for moduli stabilization.

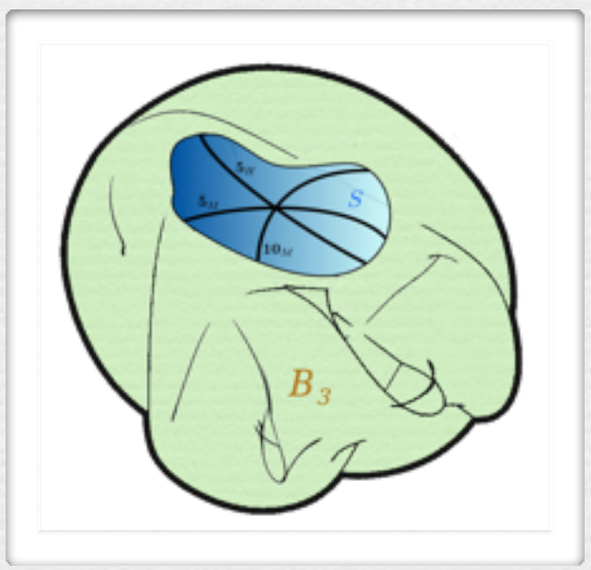
Size of soft terms: $M_{SS} \simeq \frac{g_s^{1/2}}{\sqrt{2}} G_3$

Scale of SUSY breaking

Size of soft terms: $M_{SS} \simeq \frac{g_s^{1/2}}{\sqrt{2}} G_3$

- Quantization of fluxes: $\frac{1}{2\pi\alpha'} \int_{\gamma_j} G_3 \in 2\pi\mathbb{Z} \to G_3 \sim \frac{\alpha' f}{\mathrm{Vol}(B_3)^{1/2}}$

- Scales in IIB/F-theory:



$$\left.\begin{aligned} M_p^2 &\sim \frac{1}{\alpha'^4 g_s^2}\, Vol(B_3) \\ M_{GUT} &\sim Vol(S_4)^{-1/4} \\ \alpha_{GUT}^{-1} &\sim \frac{1}{\alpha'^2 g_s}\, Vol(S_4) \end{aligned}\right\} \quad \boxed{M_{SS} \simeq f \frac{M_{GUT}^2}{\alpha_G^{1/2} M_p}}$$

$f \sim O(1) \Rightarrow M_{SS} \sim 10^{13}\mathrm{GeV}$

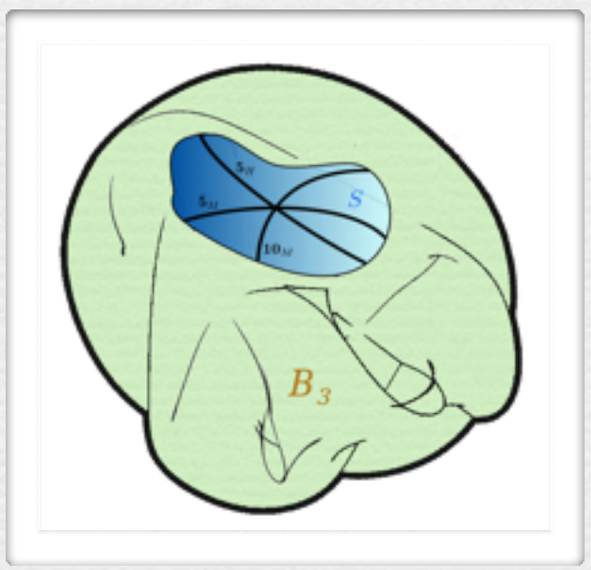
Intermediate SUSY breaking scale

Scale of SUSY breaking

Size of soft terms: $M_{SS} \simeq \frac{g_s^{1/2}}{\sqrt{2}} G_3$

- Quantization of fluxes: $\frac{1}{2\pi\alpha'} \int_{\gamma_j} G_3 \in 2\pi\mathbb{Z} \to G_3 \sim \frac{\alpha' f}{\mathrm{Vol}(B_3)^{1/2}}$

- Scales in IIB/F-theory:



$$\left.\begin{aligned} M_p^2 &\sim \frac{1}{\alpha'^4 g_s^2} Vol(B_3) \\ M_{GUT} &\sim Vol(S_4)^{-1/4} \\ \alpha_{GUT}^{-1} &\sim \frac{1}{\alpha'^2 g_s} Vol(S_4) \end{aligned}\right\} \quad \boxed{M_{SS} \simeq f \frac{M_{GUT}^2}{\alpha_G^{1/2} M_p}}$$

$f \sim O(1) \Rightarrow M_{SS} \sim 10^{13}\mathrm{GeV}$

$f \sim O(10^{-10}) \Rightarrow M_{SS} \sim 1\mathrm{TeV}$

Low energy SUSY implies a huge fine-tuning of the closed string fluxes...

MSSM Higgs Inflation

Inflaton/Higgs potential generated by breaking SUSY at a high scale.

- Density scalar perturbations:

$$\left(\frac{\delta\rho}{\rho}\right) \sim \left(\frac{V}{M_p^4\epsilon}\right)^{1/2} \sim 10^{-5} \Rightarrow m_+ \sim 10^{12} - 10^{13}\mathrm{GeV}$$

Consistent with closed string fluxes as the main source of SUSY breaking. ✓

- Big tensor-to-scalar ratio: $r \approx 0.1 - 0.2$ BICEP2 ✓

(If confirmed...)

Lyth bound: $\frac{\Delta\phi}{M_p} \gtrsim \left(\frac{r}{0.01}\right)^{1/2} \Rightarrow$ Transplanckian field range?

MSSM Higgs Inflation in String Theory (Type IIB)

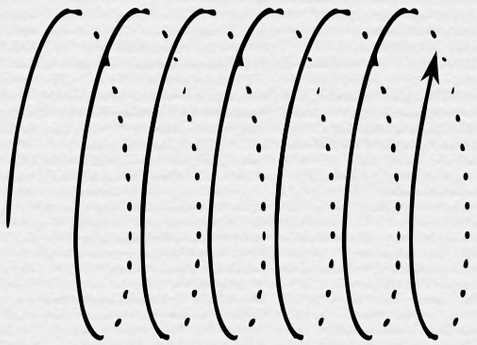
1) Identify the Higgs field with an open string modulus
   ↳ position modulus of a system of D7-branes

2) Transplanckian field range: **Monodromy inflation**

Silverstein et al.'08-'10
Kaloper,Sorbo'11

- Discrete periodicity
  ↳ the spectrum repeats itself.

- Closed string fluxes
  ↳ generate the monodromy.



Marchesano,Shiu,Uranga'14 Hebecker et al.'14

3) Inflation potential: dimensionally reduce DBI+CS for large field in the presence of closed string fluxes.

Toy model with D7-branes at singularities

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

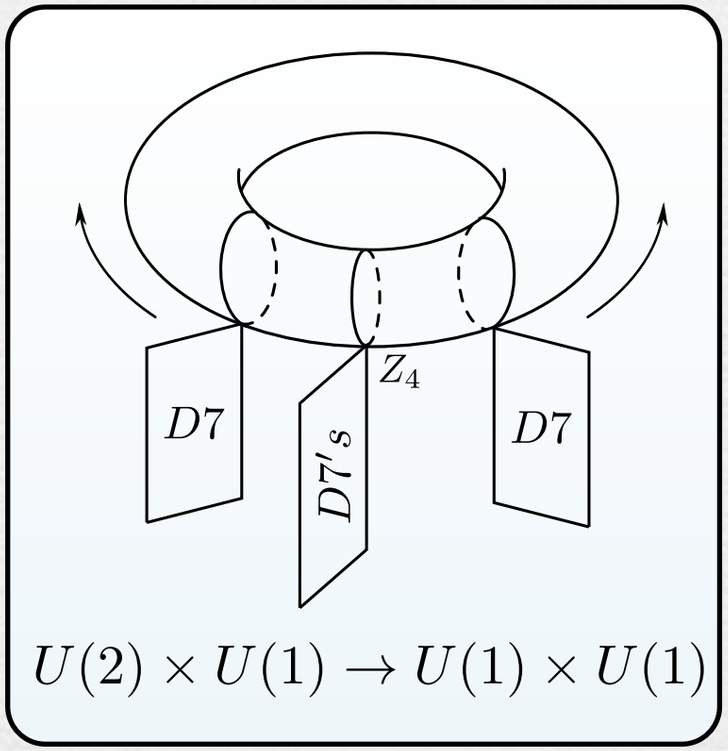
$(z_1, z_2, z_3) \to (\alpha z_1, \alpha z_2, \alpha^2 z_3)$

$\gamma = diag(\alpha \mathbf{1_3}, \alpha^2 \mathbf{1_2}, \mathbf{1})$

$\alpha = exp(i2\pi/4)$

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

Matter fields: $2(3, \overline{2}) \; + \; 2(1, \overline{3}) \; + \; \underbrace{(1, 2) + (1, \overline{2})}_{\text{vector pair: } H_u \,,\, H_d}$



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

$$z_3 = 2\pi\alpha' \langle H_u + H_d^* \rangle \neq 0$$

$\hookrightarrow$ Inflaton

Inflation comes along with gauge symmetry breaking

Gauge symmetry breaking:

2 complex doublets Hu,Hd
(**8** real scalars)

$\longrightarrow$

3 Goldstone bosons
3 scalars $(H^{\pm}, h)$
} N=1 massive vector multiplets

2 left $(H, A) \rightarrow$ massless complex field $H_u + H_d^*$

- Discrete shift symmetry:

$$z_3 \rightarrow z_3 + 2\pi R n \quad \text{with} \quad z_3 = 2\pi\alpha' \langle H_u + H_d^* \rangle$$

- Massive states ($W^{\pm}, Z$ and the scalars $H^{\pm}, h$)

$$M \simeq |H_u + H_d^*| < \frac{R}{\alpha'}$$

The physics repeats itself (no new couplings appear with trans-Planckian excursions)

Monodromy

Addition of $G_{(0,3)}$ ISD closed string fluxes

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

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

DBI action in the presence of a background for $B_{12} = \frac{g_s \sigma}{2i} G^*_{(0,3)} \phi$

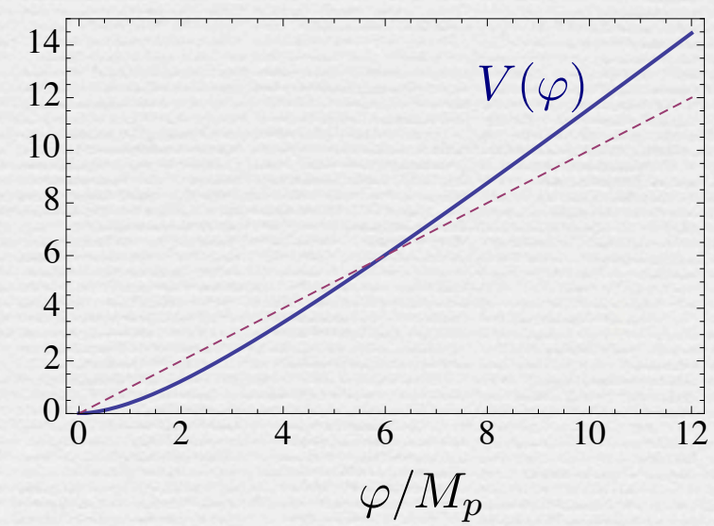
$$S_{DBI} \approx \mu_7 g_s V_4 \int d^4\xi \;\; \theta^{1/2}(1 + Z\sigma^2 \partial_\mu \phi \partial_\mu \bar{\phi} + \dots)$$

where $\theta = 1 + \frac{1}{2}|\tilde{G}||\phi|^2 + \frac{1}{4}|\tilde{G}|^2|\phi|^4$

$$V(\varphi) = \mu_7 g_s V_4 \theta^{1/2}(\varphi) \propto \begin{cases} |\hat{G}|^2|\varphi|^2 & \text{for small field} \\ |\hat{G}||\varphi| & \text{for large field} \end{cases}$$

where $\varphi \equiv H_u + H_d^*$

Ibáñez,Valenzuela
to appear



Supergravity description

Kahler potential

$$K = -log[(S+S^*)(U_3+U_3^*) - \frac{\alpha'}{2}(H_u+H_d^*)(H_u^*+H_d)]$$

Modulus/dilaton dominance $\longrightarrow$ $V \propto |H_u + H_d^*|^2$

Continous shift symmetry:

$$H_u - H_d^* \to H_u - H_d^* + c \quad , \quad c \in \mathbf{C}$$

Consequence of the $SL(2,Z)$ symmetry of T^2

- This field can not be the inflaton since it is frozen at zero vev by the Z_2 twist. $\langle h \rangle = \langle H_u - H_d^* \rangle = 0$
- All corrections to V should be $\propto \mathcal{O}(H_u + H_d^*)^n$

(in agreement with DBI action)

Control over higher dimensional operators

We have control over perturbative corrections in α'

(DBI+CS action is exact in α')

What about corrections in gs?

- Discrete shift symmetry in $H = H_u + H_d^*$

  (physics repeats itself)

- N=2 underlying substructure (Higgs sector form an N=2 hypermultiplet)

Hubble constant

η-problem $\longrightarrow$ De-Sitter vacuum: $m^2 \sim H^2 \sim \mathcal{O}(10^{14}\ \mathrm{GeV})$

Requires fine-tuning, but we already need a fine-tuning to have a light SM Higgs...

$$\boxed{\eta - \text{problem} \equiv \text{EW hierarchy problem}}$$

End of inflation: $\langle H \rangle = 0$ (gauge symmetry restored)

Inflaton: $H = H_u + H_d^* \rightarrow m_H^2 \simeq \frac{g_s}{2}|G|^2$

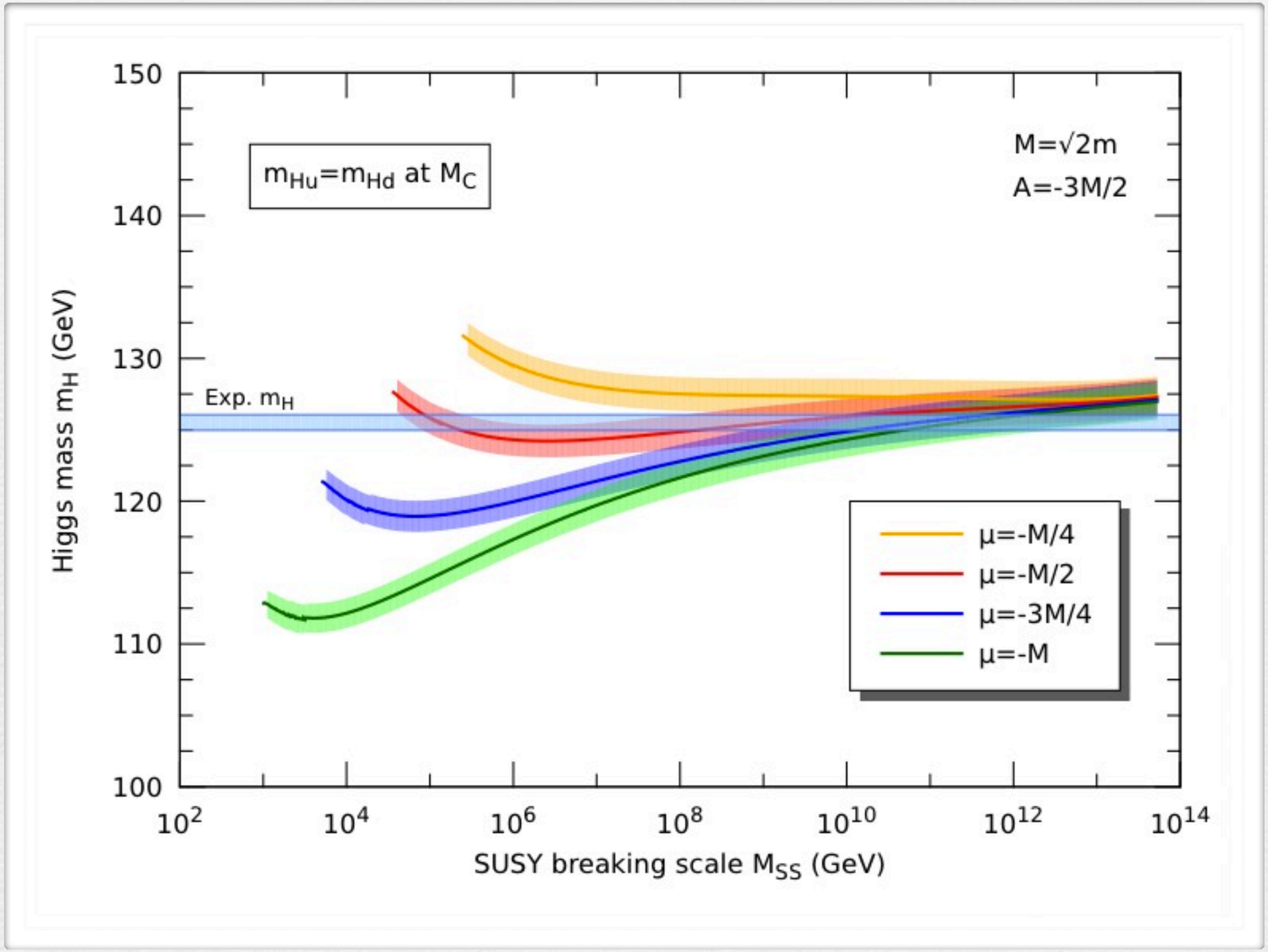
SM Higgs: $h = H_u - H_d^* \rightarrow m_h^2 \simeq 0$

Now h is the lightest field and will play the role of the SM Higgs boson.

(The massive states decouple at high energies)

$$V_{SM} = m_-^2 h^2 + \frac{g^2 + g_1^2}{8} cos^2 2\beta |h|^4$$

$$\left.\begin{array}{l} \text{Shift symmetry} \rightarrow \lambda \approx 0 \rightarrow tan\beta \approx 1 \\ \text{High SUSY breaking scale} \end{array}\right\} m_h(EW) \simeq 126 \text{ GeV}$$

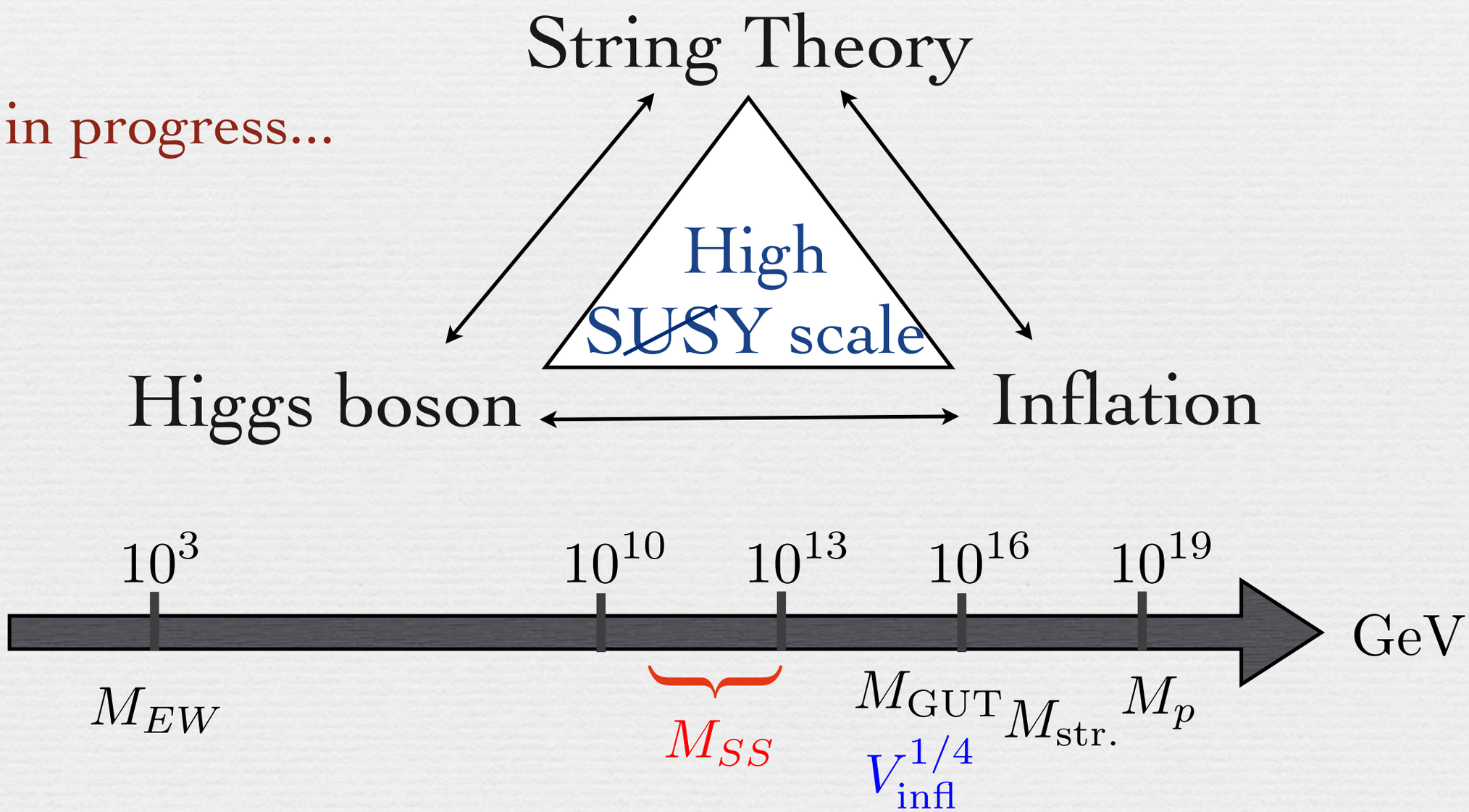


For $M_{SS} \gtrsim 10^{10}$ GeV $\longrightarrow$ $\boxed{m_H = 126 \pm 3 \text{ GeV}}$

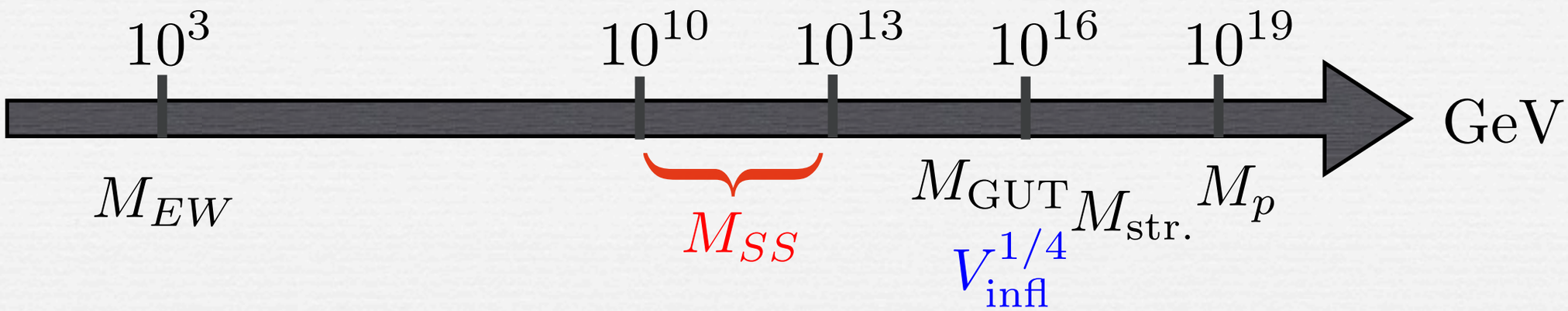
Conclusions

- Inflation and EW symmetry breaking driven by the Higgs sector.
- Hierarchy problem can be translated to conditions on the fluxes and local geometry (anthropic origin in a string landscape like the cosmological constant?)

Work in progress...



Thank you very much!



Intermediate SUSY breaking scale

- Natural for String Theory.
- Fine-tuning on the Higgs mass.
- No SUSY particles so far at LHC.
- Role of SUSY: to stabilize the SM vacuum.
- High scale of inflation: $V_{\rm infl}^{1/4} \simeq 2 \times 10^{16} \left(\frac{r}{0.2}\right)^{1/4}$ GeV

$V_{\rm infl}$ could be generated by breaking SUSY.

$$V_{SS} \simeq (m_{3/2} M_p)^2 \Rightarrow M_{SS} \simeq \frac{V_0^{1/2}}{M_p} \simeq 10^{13}\text{GeV}$$

Higgs mass fine-tuning

Higgs mass matrix:

$$m^2_{\text{Higgs}} = \frac{g_s}{8}\begin{pmatrix} 2|G_{(0,3)}|^2 + \frac{1}{4}|S_{(0,2)}|^2 & -G_{(0,3)}S_{(0,2)} \\ -G^*_{(0,3)}S^*_{(0,2)} & 2|G_{(0,3)}|^2 + \frac{1}{4}|S_{(0,2)}|^2 \end{pmatrix} + \mathcal{O}(\langle F_2\rangle^2)$$

$$+ \mathcal{O}(S_{(2,0)}, G_{(3,0)}) + \ldots$$

In general

$$det(m^2_{\text{Higgs}}) \neq 0 \text{ at } M_{GUT}$$

but due to the running

$$det(m^2_{\text{Higgs}}) = 0 \text{ at } M_{SS}$$

$$B^2 = m_u^2 m_d^2$$

Fine-tuning condition at Mss.