# de Sitter vacua and supersymmetry breaking in 6d flux compactifications

based on 1603.00654 and 1606.?????

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# Motivation

**Evidence for**:

- Positive cosmological constant
- Supersymmetry breaking at rather high scale ($m_{3/2} > \mathcal{O}(\text{TeV})$)

Hard to achieve this in full string theory

**Realize with:**

**6d supergravity in flux background**

- (Metastable) **de Sitter** vacua
- **F and D term SUSY breaking** at compactification scale
- Full **moduli stabilization**
- Fermion and boson **masses**

# The model

Setup: Minimal **6d supergravity** with

- **U(1) gauge symmetry**
- **Charged hypermultiplet** (charge $q$)
- One **tensor multiplet** (Lagrangian description)

(Part of) bosonic action, [Nishino, Sezgin '84]:

$$S_B = \int \left( \frac{M_6^2}{2}(R - d\phi \wedge *d\phi) - \frac{1}{4M_6^4 g_6^4} e^{2\phi}\, H \wedge *H - \frac{1}{2g_6^2} e^{\phi} F \wedge *F \right),$$

Compactified on:

$$T^2/\mathbb{Z}_2 \textbf{ orbifold with } \textbf{N units of flux}$$

# Anomaly cancellation

**Cancellation** of **anomalies** by 6d Green-Schwarz mechanism [Green, Schwarz '84], similar to heterotic string theory:

$$H = dB - X_3^0\,, \quad \text{with} \quad X_3^0 = -A \wedge F$$

6d bulk and fixed point anomalies (e.g. [Erler '93], [Scrucca, Serone '04])

$$\mathcal{A} = \Lambda F \wedge \left(\tfrac{\beta}{2} F \wedge F + \alpha \delta_{\mathcal{O}} F \wedge v_2\right)$$

canceled by the additional term in the action

$$S_{GS} = -\int \left(\tfrac{\beta}{2} A \wedge F + \alpha \delta_{\mathcal{O}} A \wedge v_2\right) \wedge dB\,, \quad \alpha = \tfrac{q^3}{(2\pi)^2}\,, \quad \beta = -\tfrac{q^4}{(2\pi)^3}$$

Also accounts for **flux induced anomaly** in 4d effective action

# Effective 4d action

Can be written in $\mathcal{N} = 1$ supergravity language in 4d (internal length scale $L$ and 4d bare coupling $g$)

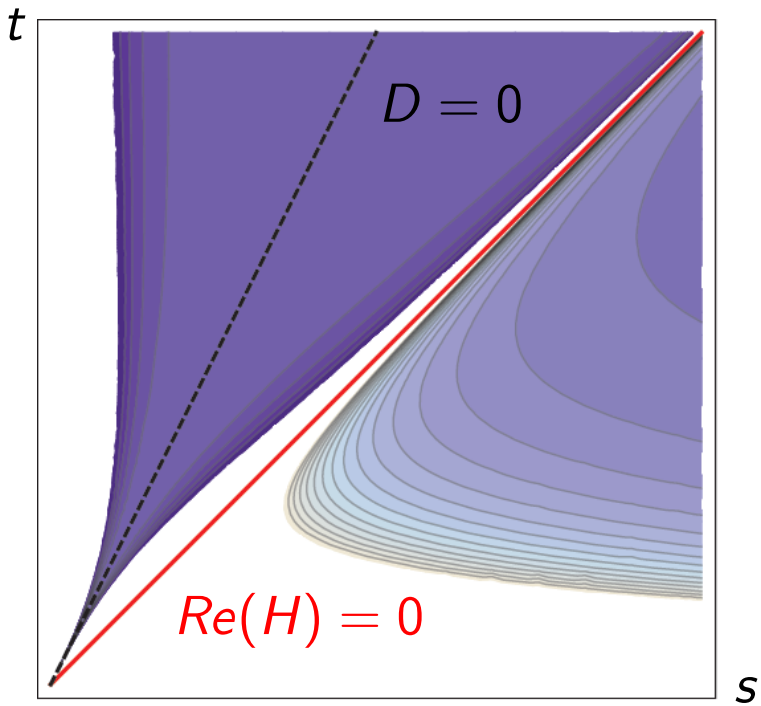
- **Moduli** in three chiral multiplets
  - $S = \frac{1}{2}(s + ic)$ , with $s = r^2 e^{\phi}$, $c$ dualized $B_{\mu\nu}$
  - $T = \frac{1}{2}(t + ib)$ , with $t = r^2 e^{-\phi}$, $b$ internal components $B_{56}$
  - $U = \frac{1}{2}(\tau_2 + i\tau_1)$ , complex structure
- **Gauged shift symmetry** for $S$ and $T$ (different direction)
  - $X^T = i\frac{4\pi N}{q\ell^2}$ , with $\ell = gLM_P$
  - $X^S = -ig^2\alpha(N + 1)$
- **Modified gauge kinetic function**: $H = 2\left(S - \frac{1}{(2\pi)^3} g^2 \ell^2 T\right)$
- **No-scale** Kähler potential:

$$K = -\ln(S + \overline{S} + iX^S V) - \ln(T + \overline{T} + iX^T V) - \ln(U + \overline{U})$$

# D-term potential

**Moduli** $s$ and $t$ **constrained** to region with $Re(H) > 0$:

The **D-term** potential $V_D = \frac{g^2}{2Re(H)} D^2$ is **strictly positive**




Run-away direction, need to **add superpotential** (negative contributions to potential)

# Superpotential

**Gauge invariant superpotential** define **gauge invariant field** combination:

$$Z = -iX^T S + iX^S T$$

Typical **superpotential** created by **non-perturbative effects** [Kachru, Kallosh, Linde, Trivedi '03] (gaugino condensation, worldsheet instantons)

$$\boxed{W = W(Z, U) = W_0 + W_1 e^{-aZ} + W_2 e^{-\tilde{a}U}}$$

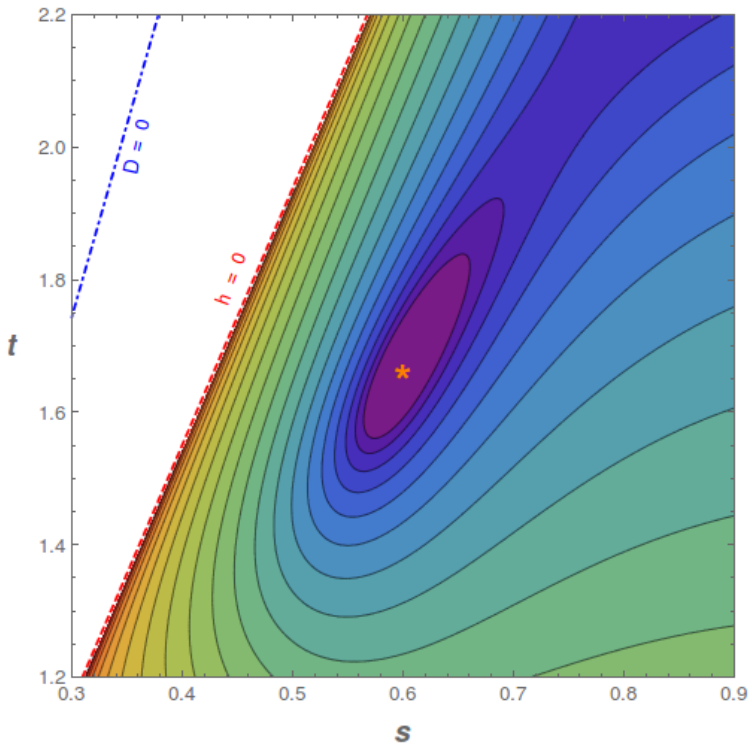
with $W_1\,, W_2\,, a\,, \tilde{a} > 0$ and $W_0 < 0$

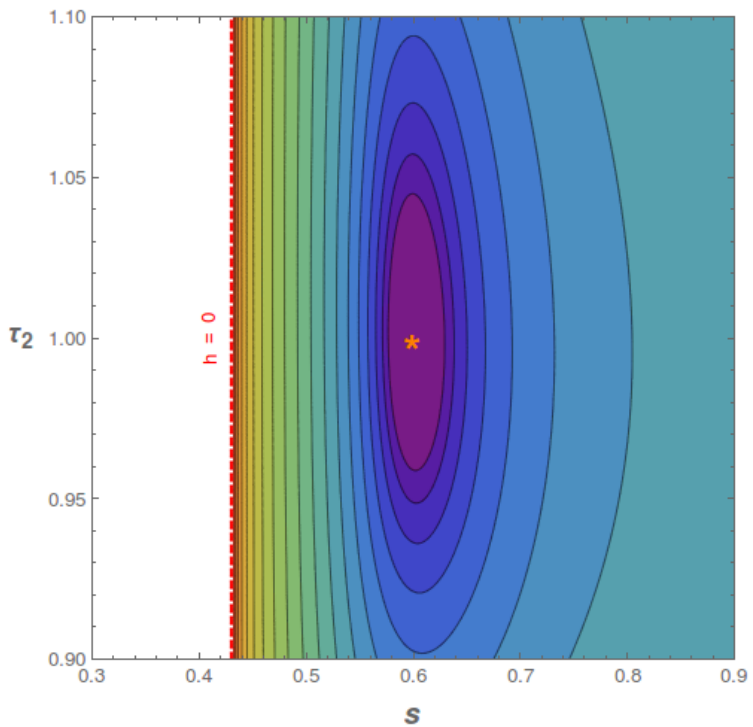
To find parameters invert problem:

- Fix D-term parameters and moduli vevs
- Solve minima equations to fix superpotential parameters

# Examples

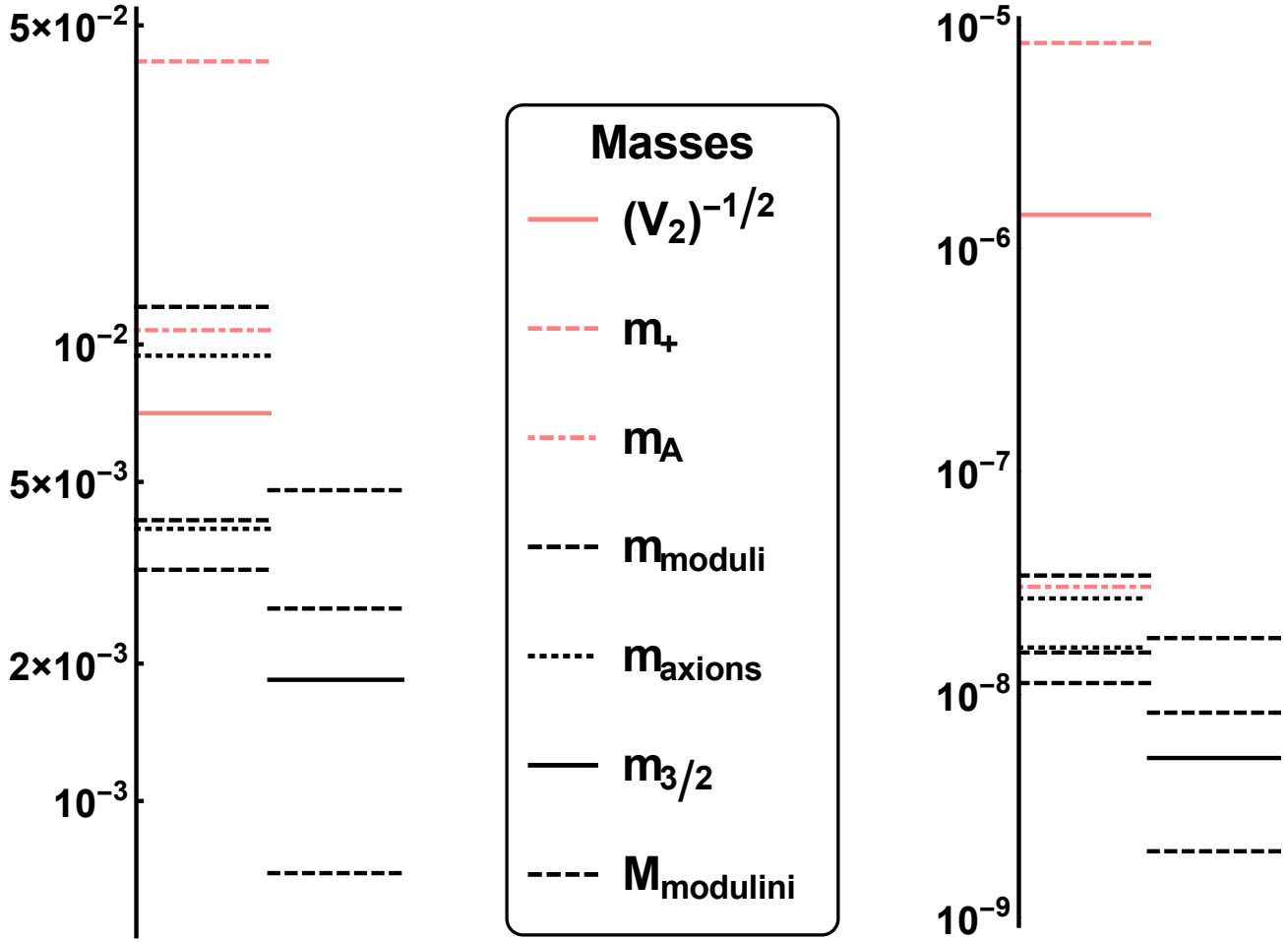
| | GUT scale | intermediate |
|---|---|---|
| $L$ | 200 | $10^6$ |
| $g$ | 0.2 | $4 \times 10^{-3}$ |
| $W_{0,1,2}$ | $\mathcal{O}(10^{-2})$ | $\mathcal{O}(10^{-6})$ |
| $(s, t, \tau_2)$ | $\left(\frac{3}{5}, \frac{5}{3}, 1\right)$ | $\left(\frac{6}{5}, \frac{5}{6}, 1\right)$ |



# Mass spectra

**Fermion and boson masses:** (for above examples, in Planck units)



# Conclusion and outlook

**Conclusion:**

**Minkowski** and **de Sitter** minima from **6d flux compactification**:

- **Killing vectors of opposite sign** (flux and anomaly cancellation)
- **Modified gauge kinetic function** (opposite sign)
- Stabilization by **nonperturbtive superpotential**

**Outlook:**

- Embedding into **string theory**
- Implement **grand unification** (running coupling, flux spectrum)
- Realize **inflation** with (one of the) moduli