D A   S U N A N K A
R A B B I   N A K A
F A R A   K O M A I

# Numerical Moduli Stabilisation towards Calabi-Yau Data Exploration

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# All In All

- **Calabi-Yau** data (CYD) $\rightarrow$ 1411.1418
  **Aim:** phenomenology-based classification
- **How?** Bayes factors & Jeffreys' scale w.r.t. **LVS AdS**
  **Via:** Multi modular fields stabilisation & nested sampling
- **Outlook:** Machine-learn the Calabi-Yau data,
  **Guide:** phenomenology, stringy remnants $\rightarrow$ 1801.03503
- **This talk:** $P_{11169}$ AdS vs dS scenarios comparison
  Based on: explorations towards minimal $V_0$

# $P_{11169}$ Effective Potential

**$4D$ Compactification**

+ fluxes + non-pertubative effects + $\alpha'$-corrections

generates super, Kähler, and $N = 1$, $D = 4$ scalar potentials

$$
\begin{aligned}
W &= W_0 + A_i e^{-a_i T_i}, \quad i = 1, 2 \\
K &= -2 \log(\mathcal{V} + \frac{\xi}{2}) + 2 \log g_s + K_{cs}, \\
V &= e^K \left[ K^{i\bar{j}} D_i W D_{\bar{j}} \overline{W} - 3|W|^2 \right] \\
\text{where } D_i W &= \partial_i W + (\partial_i K) W, \quad K^{i\bar{j}} = (\partial_i \partial_{\bar{j}} K)^{-1}
\end{aligned}
$$

LVS: two moduli stabilised & break SUSY at large volume

**Parameters, $\theta$:** $\{g_s, W_0, a_i, A_i\}$

**Possible Scenarios:** $\mathcal{H}_0 \equiv$ **Anti-de Sitter or**

$\mathcal{H}_1 \equiv$ **de Sitter (withou upliftment)**

# Numerical Moduli Stabilisation

**Given** $\theta$**, Find** $T_i$ at (deepest) minimum of $V(\theta, T_i)$
Genetic **or** Dlib C++ Library minimisation algorithm

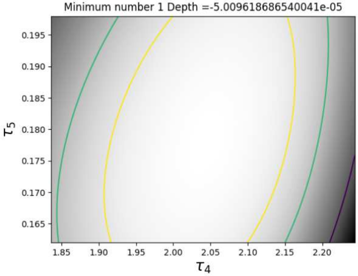


Figure: Deepest of 6 minima found using Genetic algorithm. A check for Dlib minimiser used.

# Bayesian Inference Machinery

**Apply** towards Calabi-Yau data pheno-based classification

- **Bayes: evidence**, Z × **posterior** = **prior** × **likelihood**

$$p(d|\mathcal{H}) \times p(\theta|d,\mathcal{H}) = p(\theta|\mathcal{H}) \times p(d|\theta,\mathcal{H})$$

$$Z = p(d|\mathcal{H}) = \int p(d|\theta,\mathcal{H}) p(\theta|\mathcal{H})\, d\theta \quad \text{[MultiNest]}$$

**Consider:** $d \equiv$ cosmological constant($\Lambda$) is very small

**Likelihood** function, $\mathcal{L}(\theta) = p(d|\theta,\mathcal{H})$
With $V_0$ from numerical moduli stabilisations, get $Z$ using

$$\log \mathcal{L} \sim -|V_0| \quad \text{or, alternatively,} \quad \mathcal{L} \sim \exp^{-(V_0-\Lambda)^2}$$

# Bayesian Inference Machinery

- **Comparison:** Bayes factor, $K = \frac{\mathcal{Z}_0}{\mathcal{Z}_1}$

- **Jeffreys' scale:**

| Bayes factors, K | Comparison Remarks | Classification |
|---|---|---|
| 1 to 3.2 | Inconclusive | 1 |
| 3.2 to 10 | Weak | 2 |
| 10 to 100 | Moderate | 3 |
| $>$ 100 | Decisive | 4 |

Table: Jeffreys' scale for the interpretation of Bayes factors. Classification, say w.r.t. LVS AdS. 0, comparison not possible. 5, 6 or 7, compared geometry wins weakly, moderately or decisively respectively.

# LVS de Sitter vs Anti-de Sitter [preliminary]

| $P_{11169}$ parameters, $\theta$ | Range |
|---|---|
| $g_s$ | $10^{-3}$ - 0.3 |
| $W_0$ | $10^{-11}$ -$10^2$ |
| $a_{1,2}$ | $2\pi/10$ - $2\pi$ |
| $A_{1,2}$ | $10^{-1}$ - $10^1$ |

| Scenario | $log_e Z$ | K | Class |
|---|---|---|---|
| AdS | $-0.366$ | - | reference hypothesis |
| dS | $-3 \times 10^{-14}$ | $3 \times 10^3$ | 7 |

**de Sitter** vacua are obtainable without need for uplit terms

# Summary & Outlook

- **Demonstrated:**
  **Multi moduli stabilisation** is within reach [dedicated to Joe Polchinski]

- **Proposed:** reference point model/CY. Only Λ used.
  **Extend** to include inflaton or particle physics constraints

- **Classification:** Bayes factors-based. Something else ?

- **de Sitter Vacua:** found many, without uplifting terms.

**Thanks for Listening!**