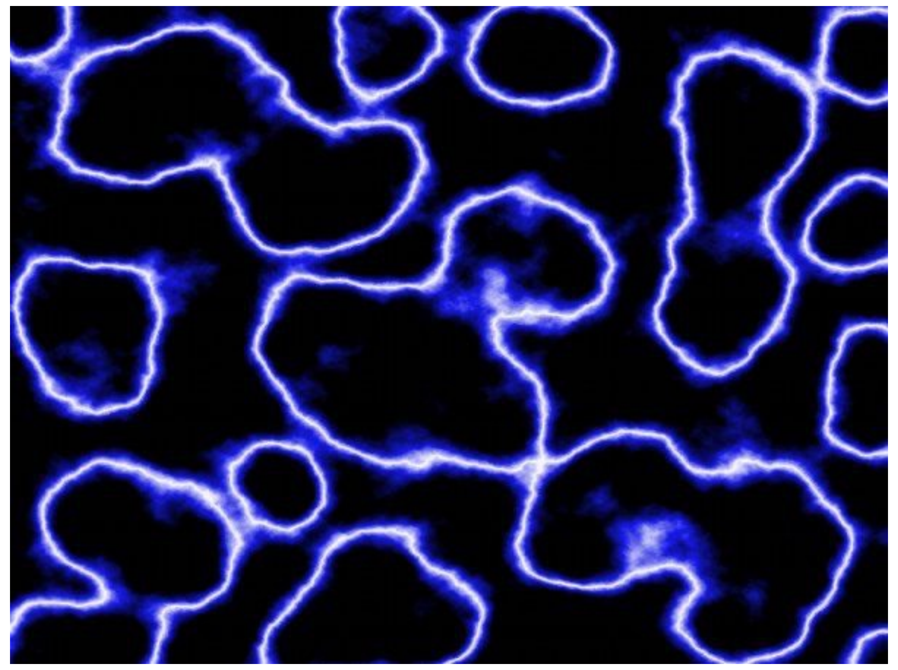
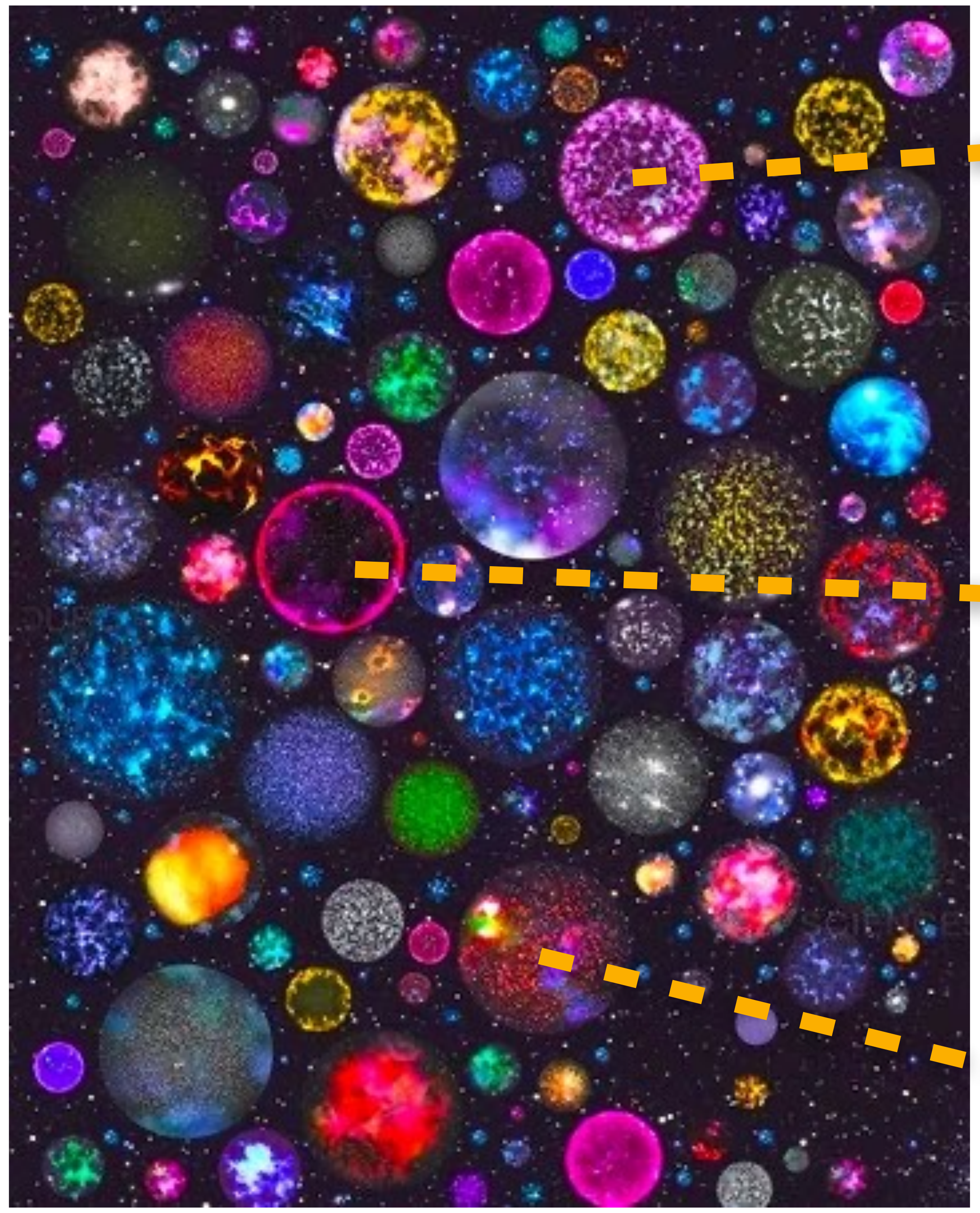
Deciphering the Structure of EFTs from String Theory using JAX and Reinforcement Learning



String Theory

Compactification

Equations of motion



String Landscape

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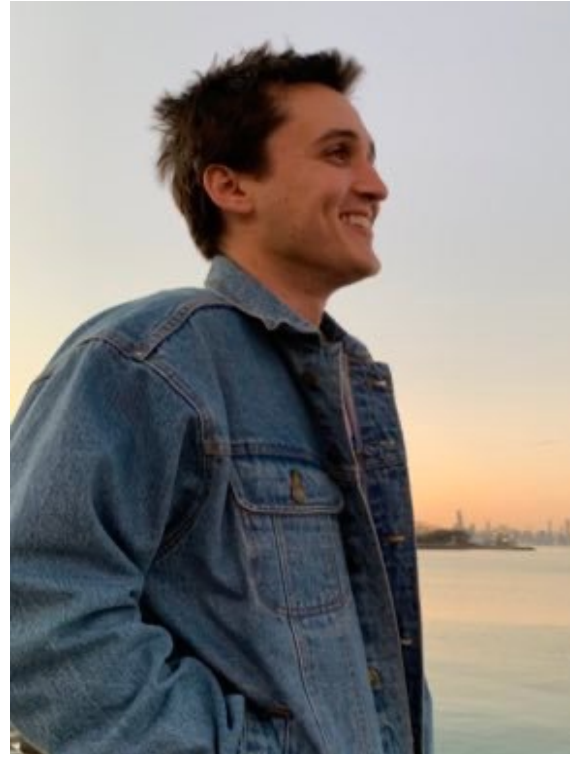
Cornell University

ML4Jets, Hamburg

November 9, 2023

Papers and Team



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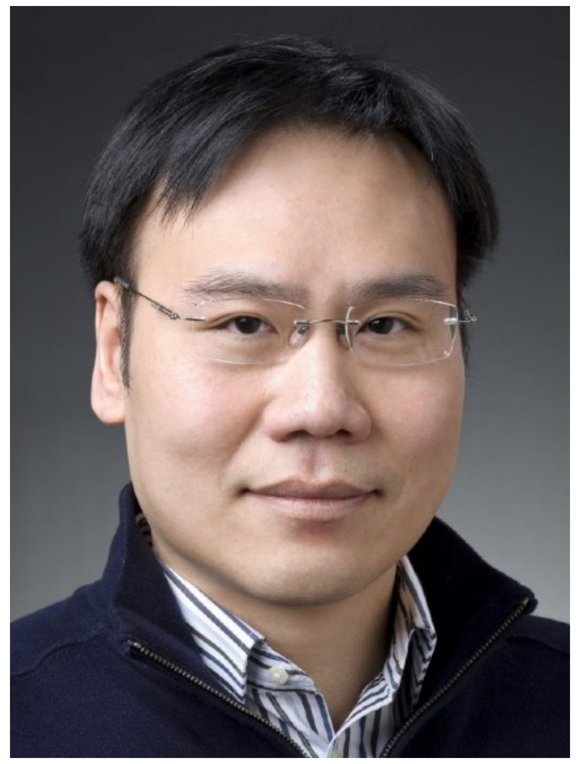

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Based on work with:

- Dubey, Krippendorf 2306.06160
- Ebelt, Krippendorf 2307.15749
- Krippendorf 2308.15525
- Ebelt, Krippendorf, Tovey wip

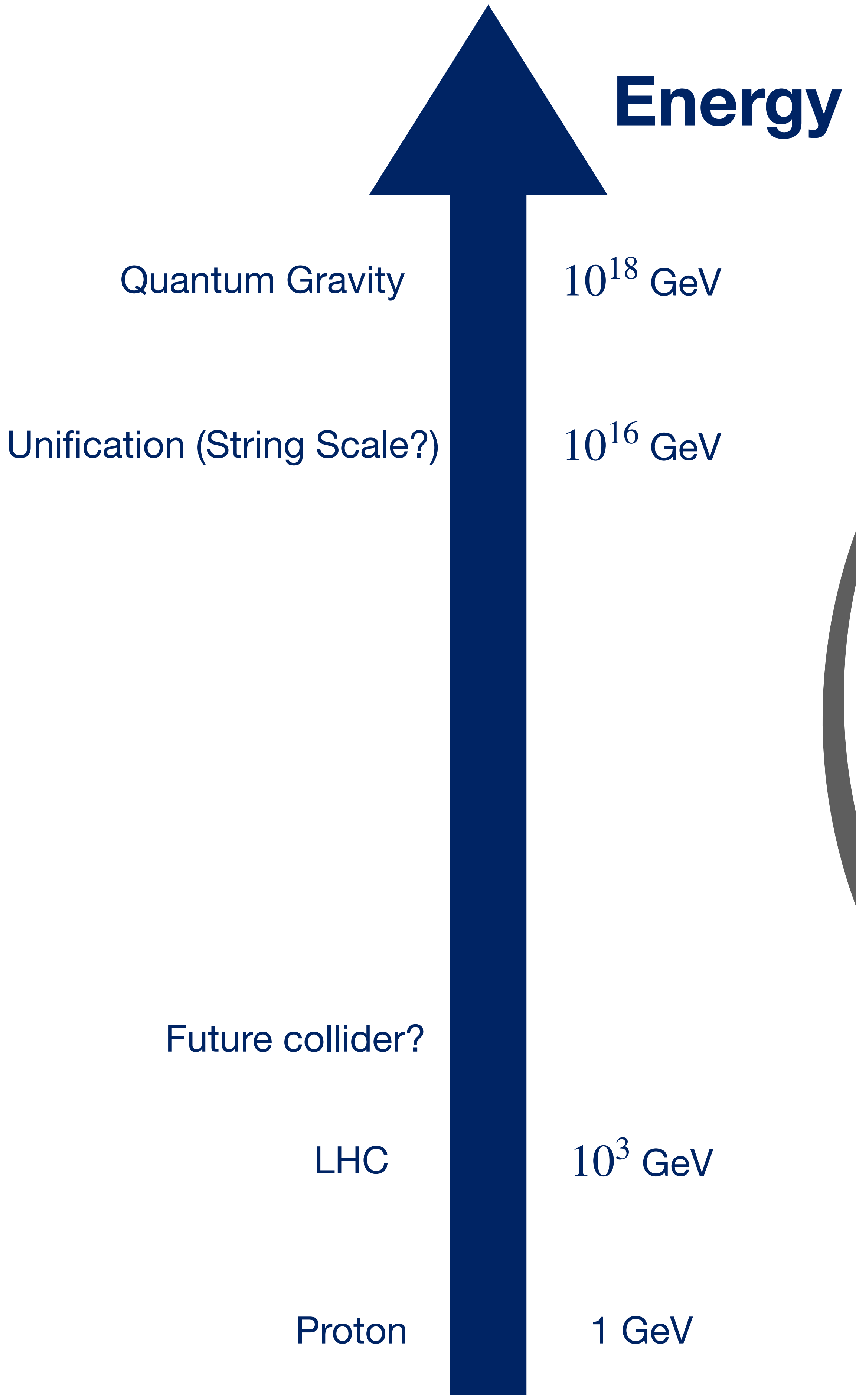
See also earlier work with:

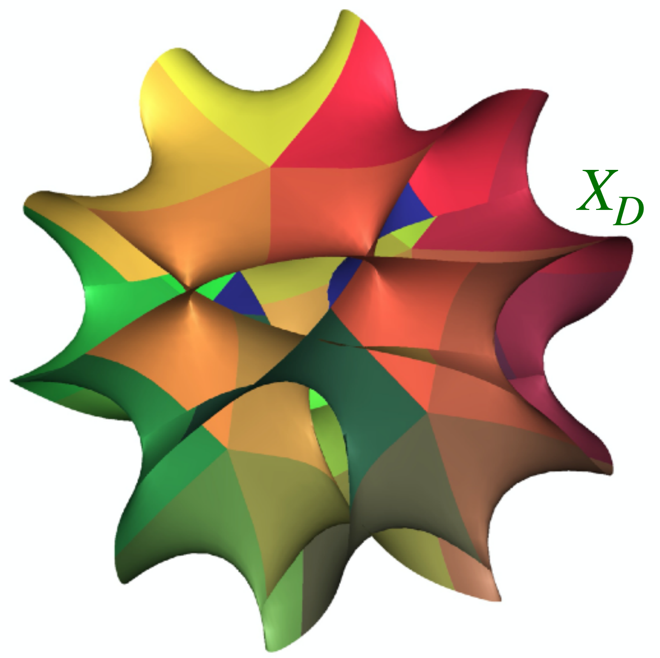
- Cole, Shiu 1907.10072
- Cole, Krippendorf, Shiu 2111.11466

Motivation: which BSM physics does string theory predict?

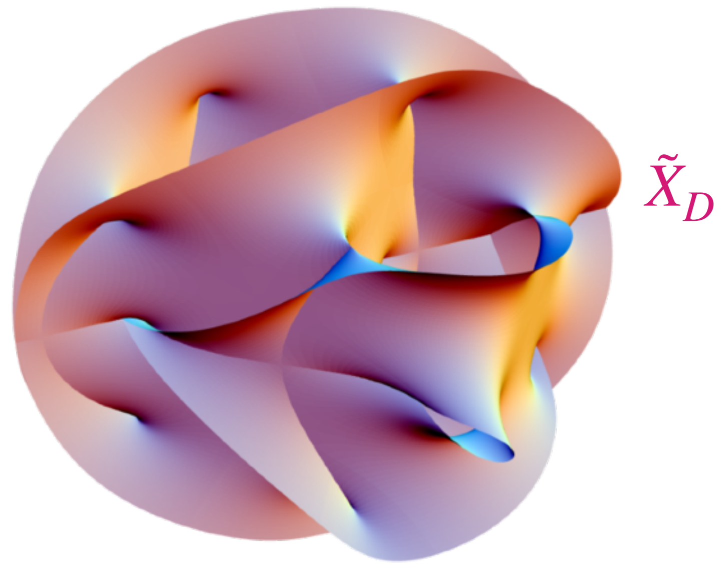
Problem: Physics from many background geometries

String theory predicts spacetime to be 10 dimensional…





$M_{4+D} = A_4 \times X_D$

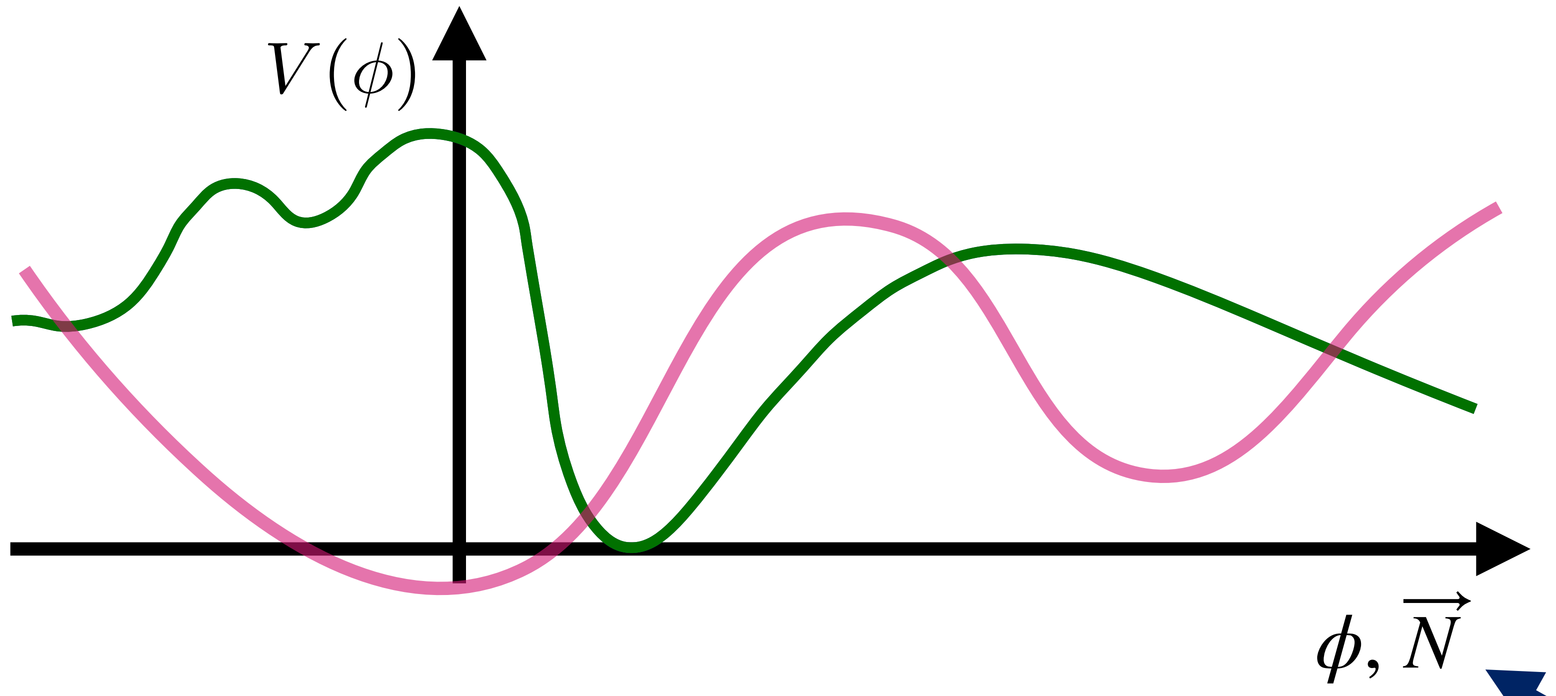


$M_{4+D} = A_4 \times \tilde{X}_D$

Different Geometries

Challenge for string theory:

As many as $10^{272,000}$ solutions **[Taylor et al. 1511.03209]**, but only a few are phenomenologically interesting!



String landscape

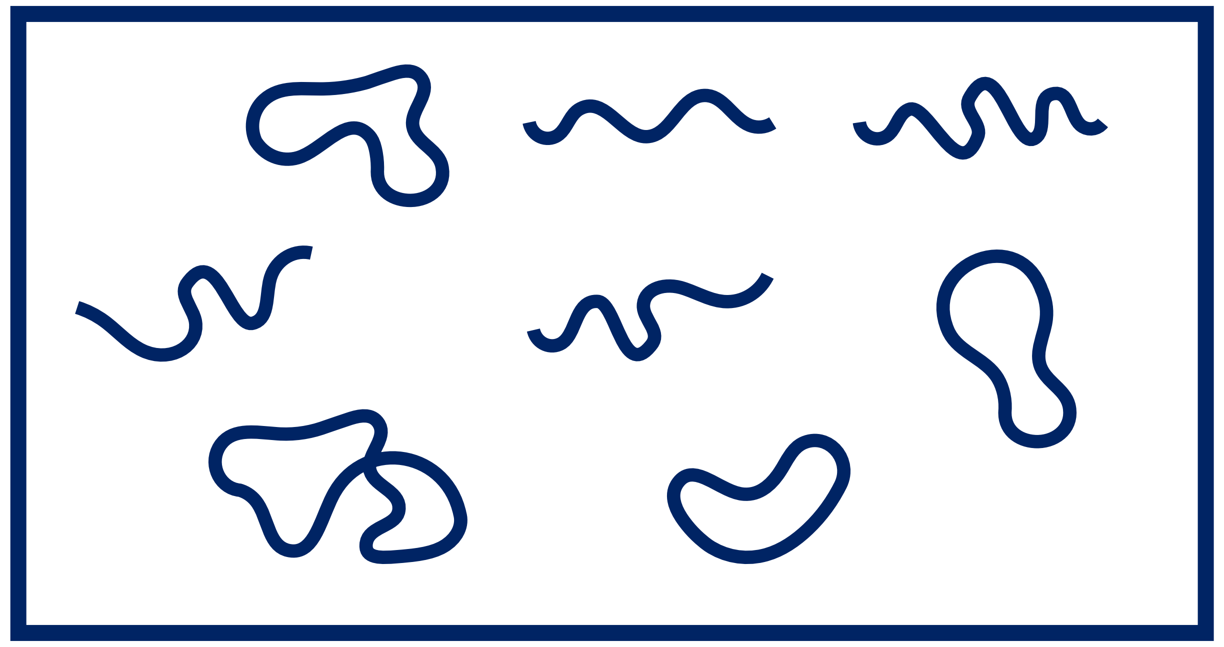
discrete parameters from background fields

Different physics at low energies (spectra, scales, cosmological evolution)

Objective: numerically construct effective field theories from string theory

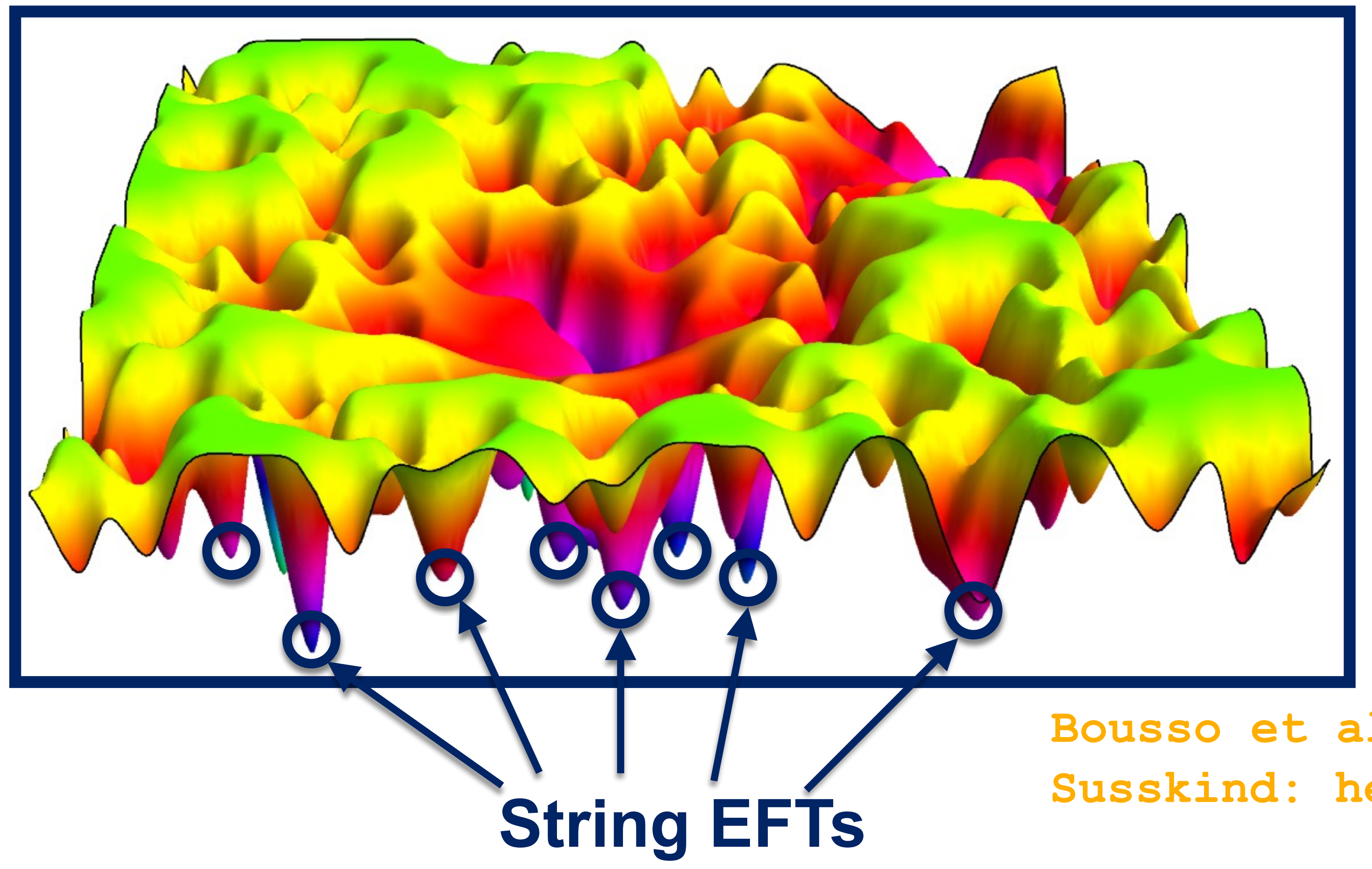
Problem: The landscape is terribly vast and complicated

String theory



equations of motion

String landscape



Bousso et al.: hep-th/0004134
Susskind: hep-th/0302219

String theory input:
$\vec{N} = (N_1, \ldots, N_h) \in \mathbb{Z}^h$

fluxes
=
generalised electromagnetic charges

solve equations of motion
=
minimising potential:
$\nabla_\phi V(\vec{N}, \vec{\phi}) = 0$

Field values in the “vacuum“
$\vec{\phi} = (\phi_1, \ldots, \phi_{h/2}) \in \mathbb{R}^{h/2}$

Physical observables
$W_0(\vec{N}, \vec{\phi})$

e.g. cosmological constant

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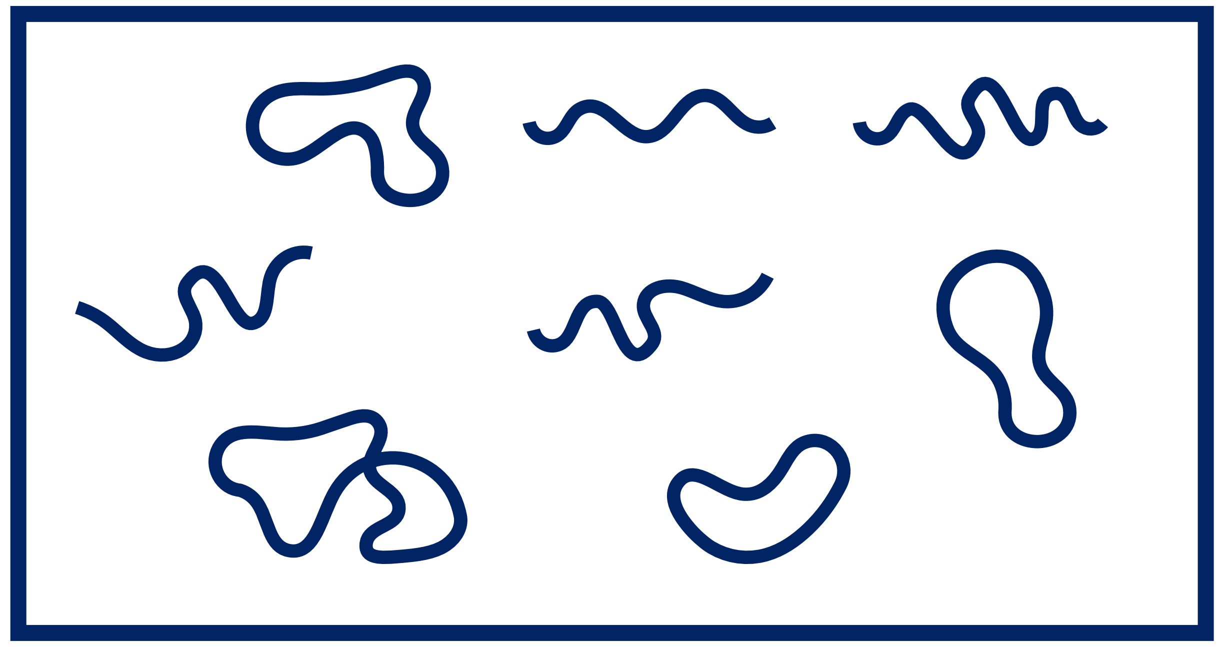
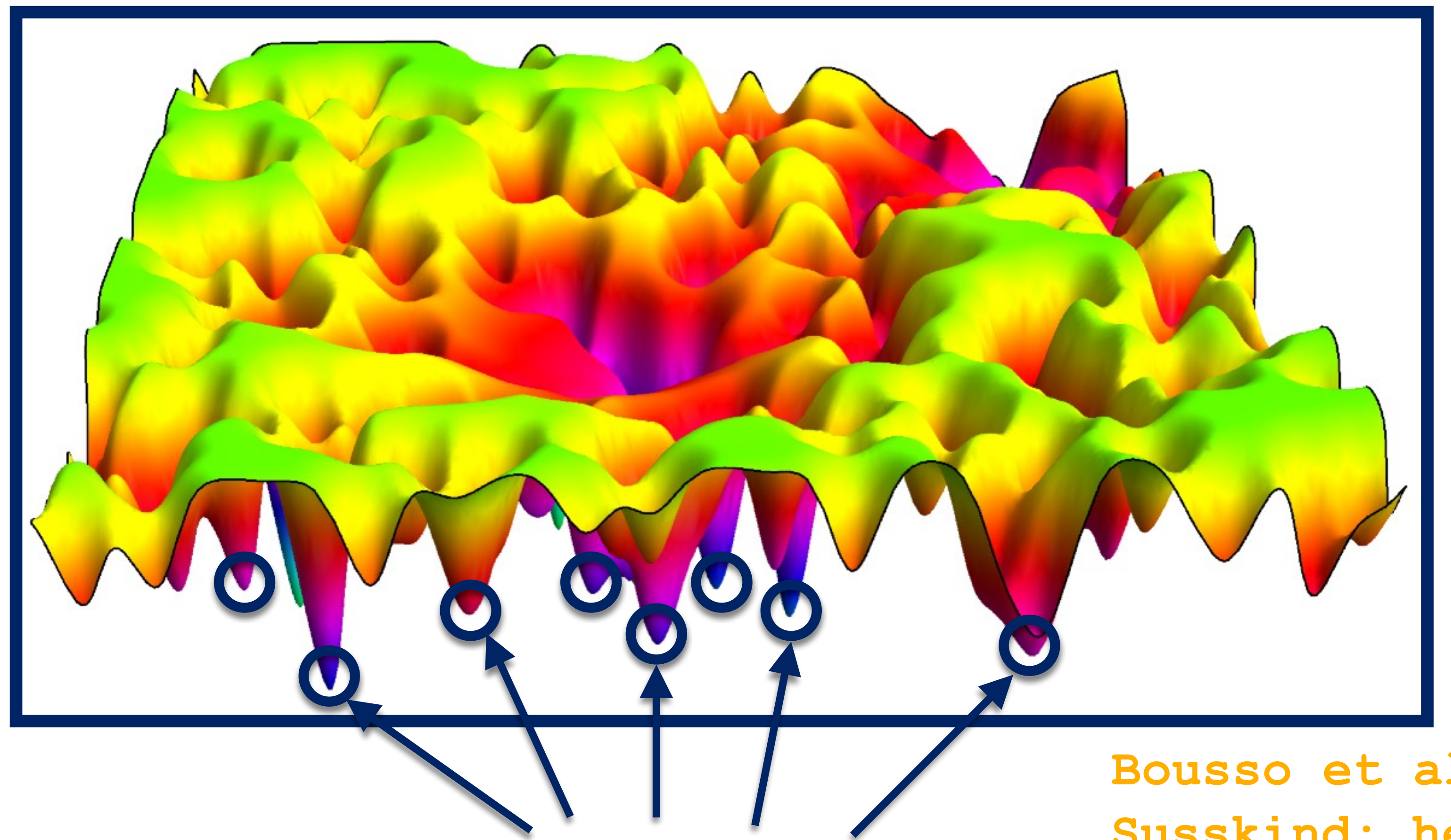
String theory



equations of motion →

String landscape



Bousso et al.: hep-th/0004134
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For many years, we couldn't even do this properly…

String theory input:
$\overrightarrow{N} = (N_1, \ldots, N_h) \in \mathbb{Z}^h$

fluxes
=
generalised electromagnetic charges

→ solve equations of motion
=
minimising potential:
$\nabla_\phi V(\overrightarrow{N}, \overrightarrow{\phi}) = 0$

→ ? → ?

e.g. cosmological ?

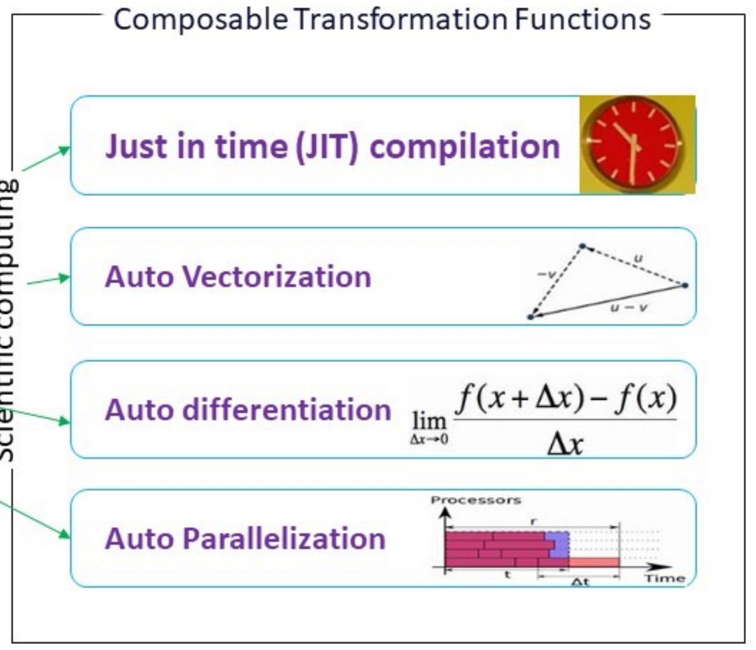
Most geometries have $h \gtrsim \mathcal{O}(100)$ leading to complex system of equations!

JAXVacua - A framework for constructing string effective field theories

Objective: Numerical framework to determine and evaluate EFT (e.g. scalar potential, Hessian, spectrum etc.) with only minimal input by using auto-differentiation

Demirtas, Rios-Tascon, McAllister 2211.03823

Bradbury et al. 2008



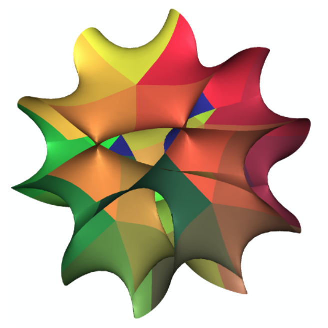
Optimisation targets:

$\partial_I V = 0$

$\langle V \rangle = 0$ **SUSY**

$\langle V \rangle > 0$ **non-SUSY**

Topological data



Prepotential

F

Only hardcoded input!

auto-diff

EFT properties

$V\,, \partial_I \partial_J V\,, M_{3/2}\,, \ldots$

Based on work with:

- A. Dubey, S. Krippendorf 2306.06160
- J. Ebelt, S. Krippendorf 2307.15749
- S. Krippendorf 2308.15525

Benchmarking our performance at $h = 12$:

100 nodes each with 32 cores to find **24,882 solutions** in **75,000 hours**

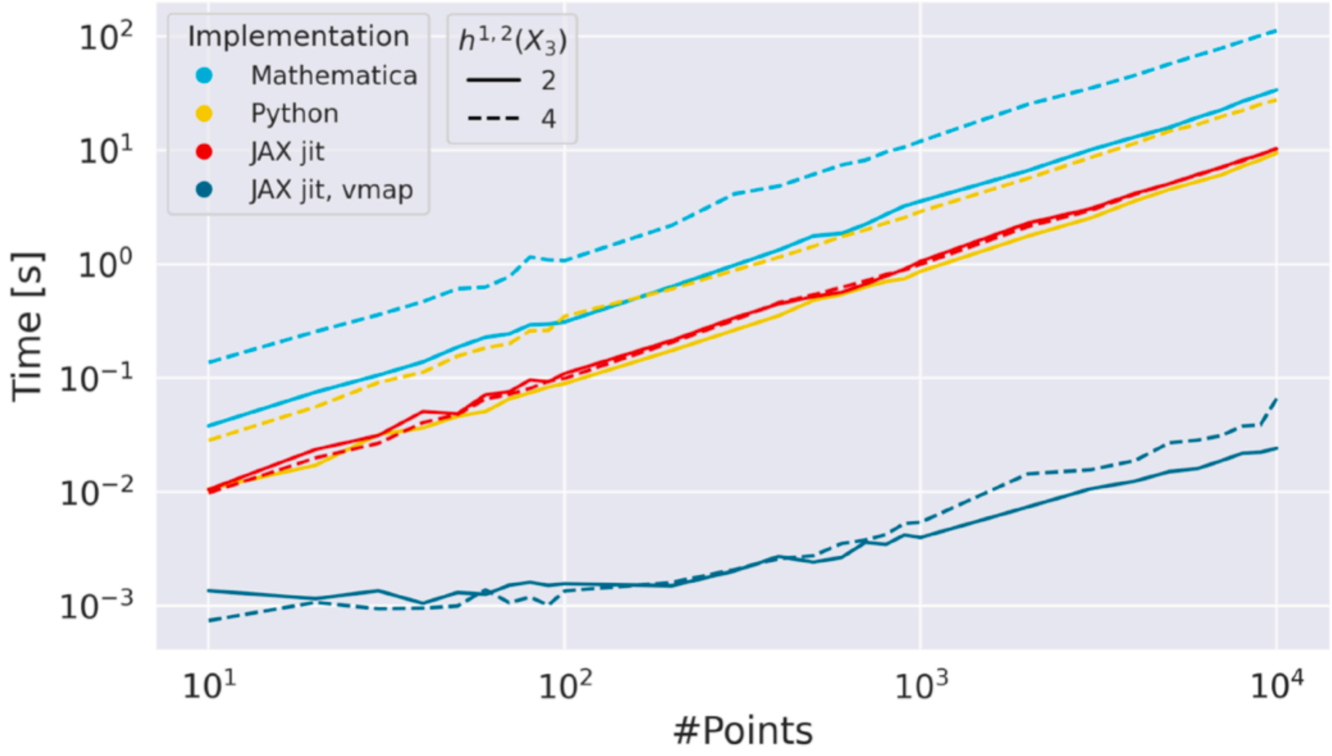
[Martinez-Pedrera et al. 1212.4530]

VS.

4 cores with 5GB of memory **33,019 solutions** in **45 minutes**

[Dubey, Krippendorf, AS 2306.06160]

Timing for evaluating ∇W



Orders of magnitude speed improvements!

Abhishek Dubey (Master student LMU)

Julian Ebelt (Master student LMU)

Sven Krippendorf LMU

Building up systematic databases of string theory EFTs

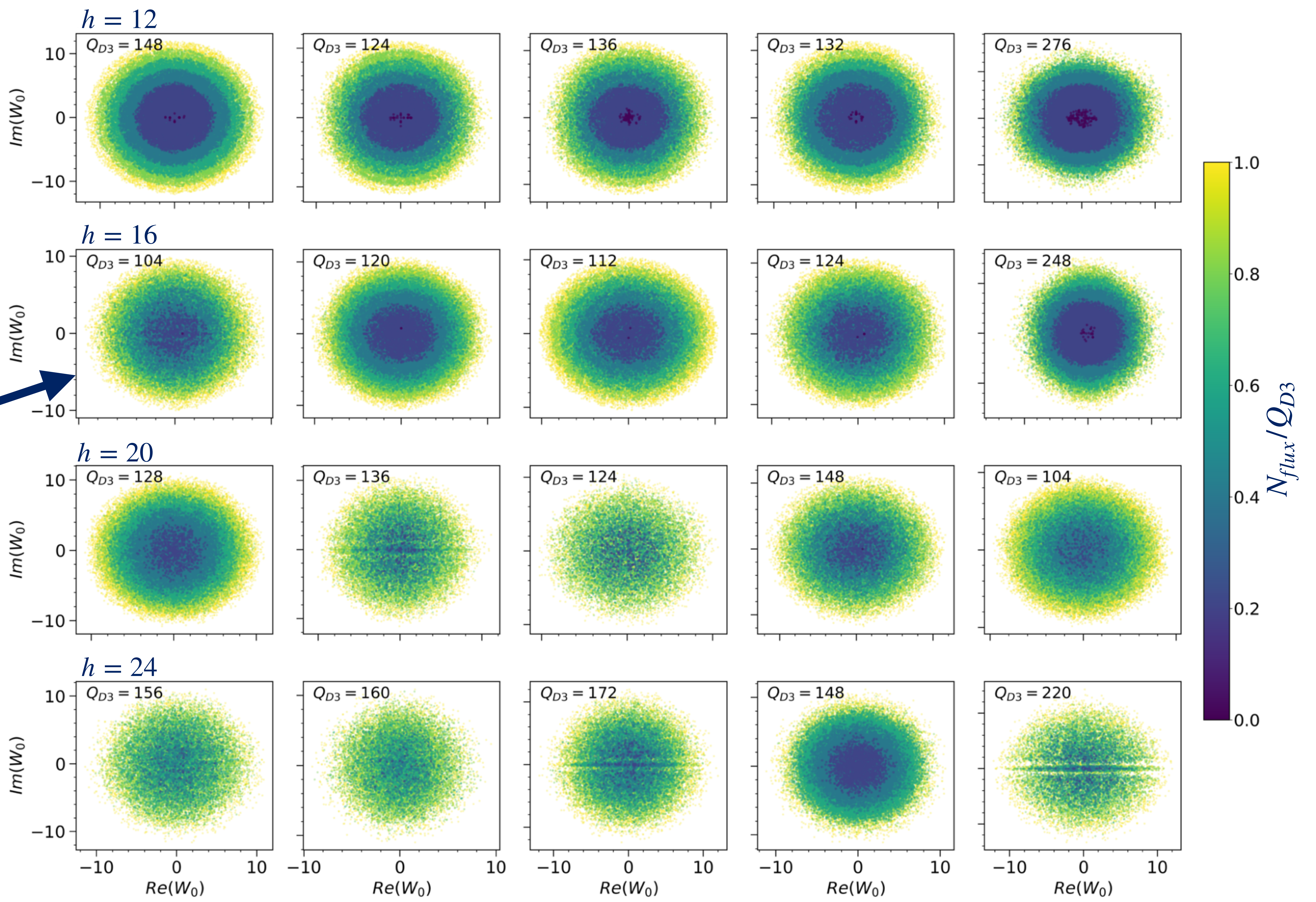
Based on ArXiv: 2307.15749

Observation: Universality across geometries

Probe distributions of EFT quantities in the string landscape:

We focus on the distribution of W_0 which determines e.g. the gravitino mass and the cosmological constant

We study 20 geometries with $h = 12, 16, 20, 24$ and construct at least $\mathcal{O}(10^5)$ EFTs for each

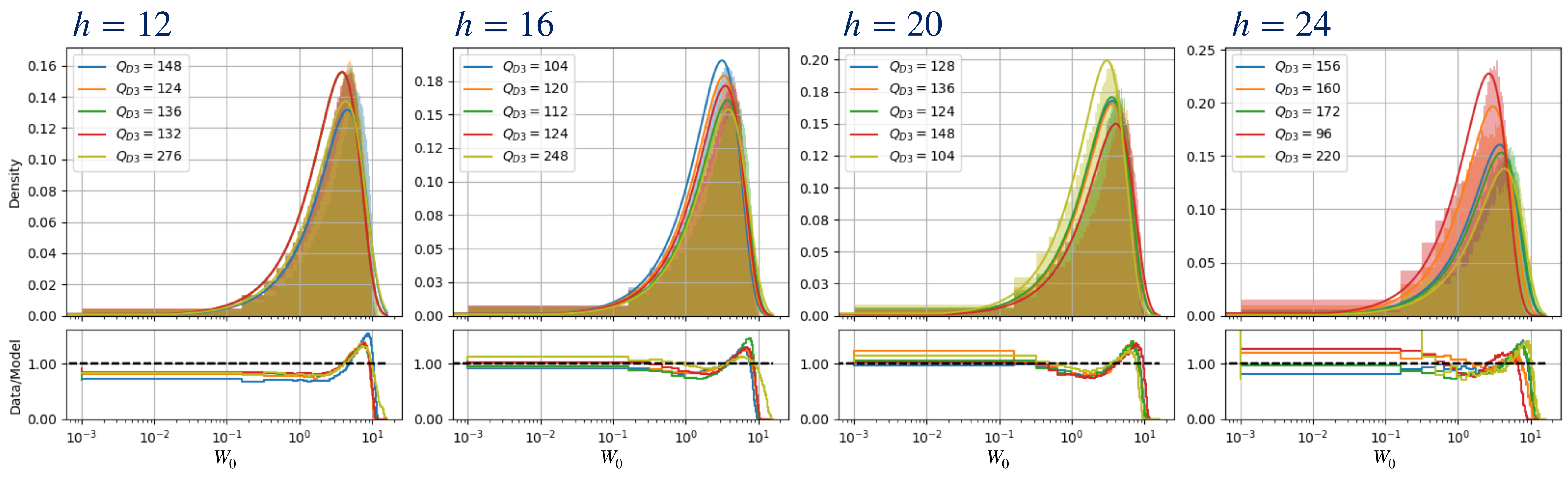


However, not any choice of fluxes is allowed due to Gauss' law:

$$N_{flux} \leq Q_{D3}$$

LHS = **total charge** induced by fluxes.

RHS = **localised sources** which are charged.

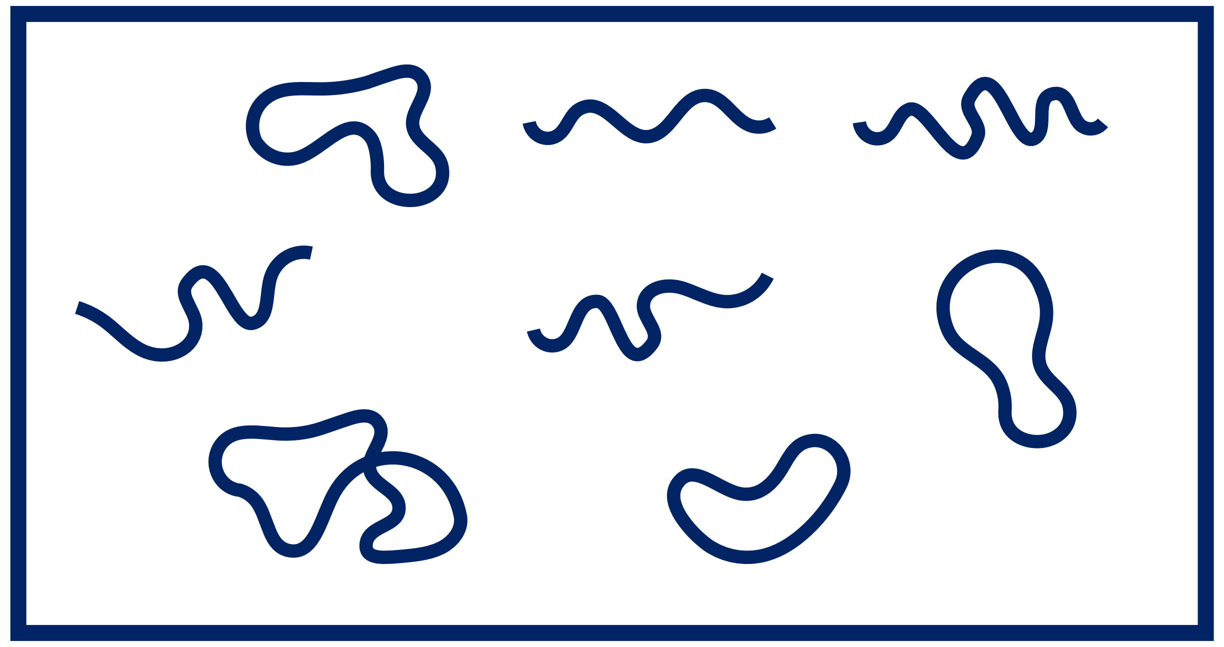


We find that a normal distribution is a good fit, though there are hints at deviations (work in progress)

Objective: numerically construct effective field theories from string theory

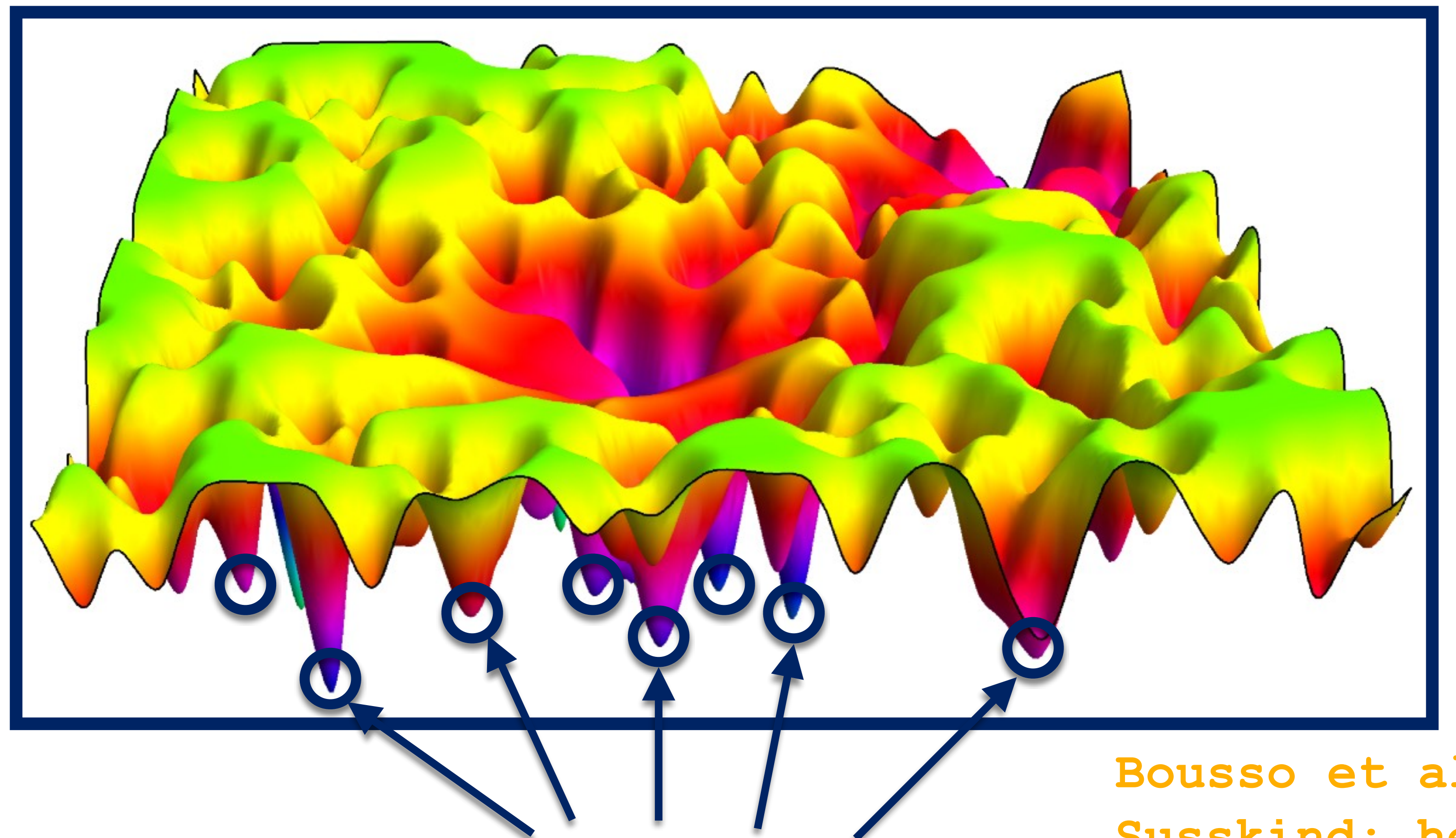
Problem: The landscape is terribly vast and complicated

String theory



equations of motion

String landscape



String EFTs

Bousso et al.: hep-th/0004134
Susskind: hep-th/0302219

We can do this now…

String theory input:
$\overrightarrow{N} = (N_1, \ldots, N_h) \in \mathbb{Z}^h$

fluxes
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solve equations of motion
=
minimising potential:
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Physical observables
$W_0(\overrightarrow{N}, \overrightarrow{\phi})$

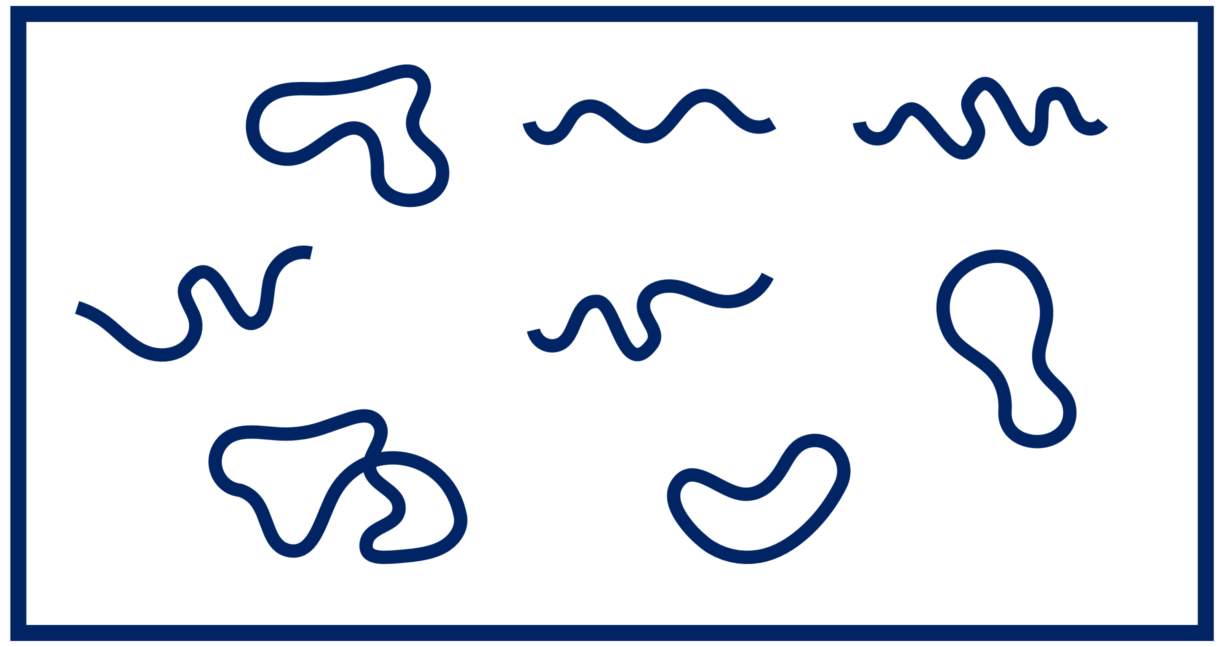
e.g. cosmological constant

As many as $10^{272,000}$ solutions [Taylor et al. 1511.03209],
but only a few are phenomenologically interesting!

Objective: numerically construct string EFTs with interesting properties

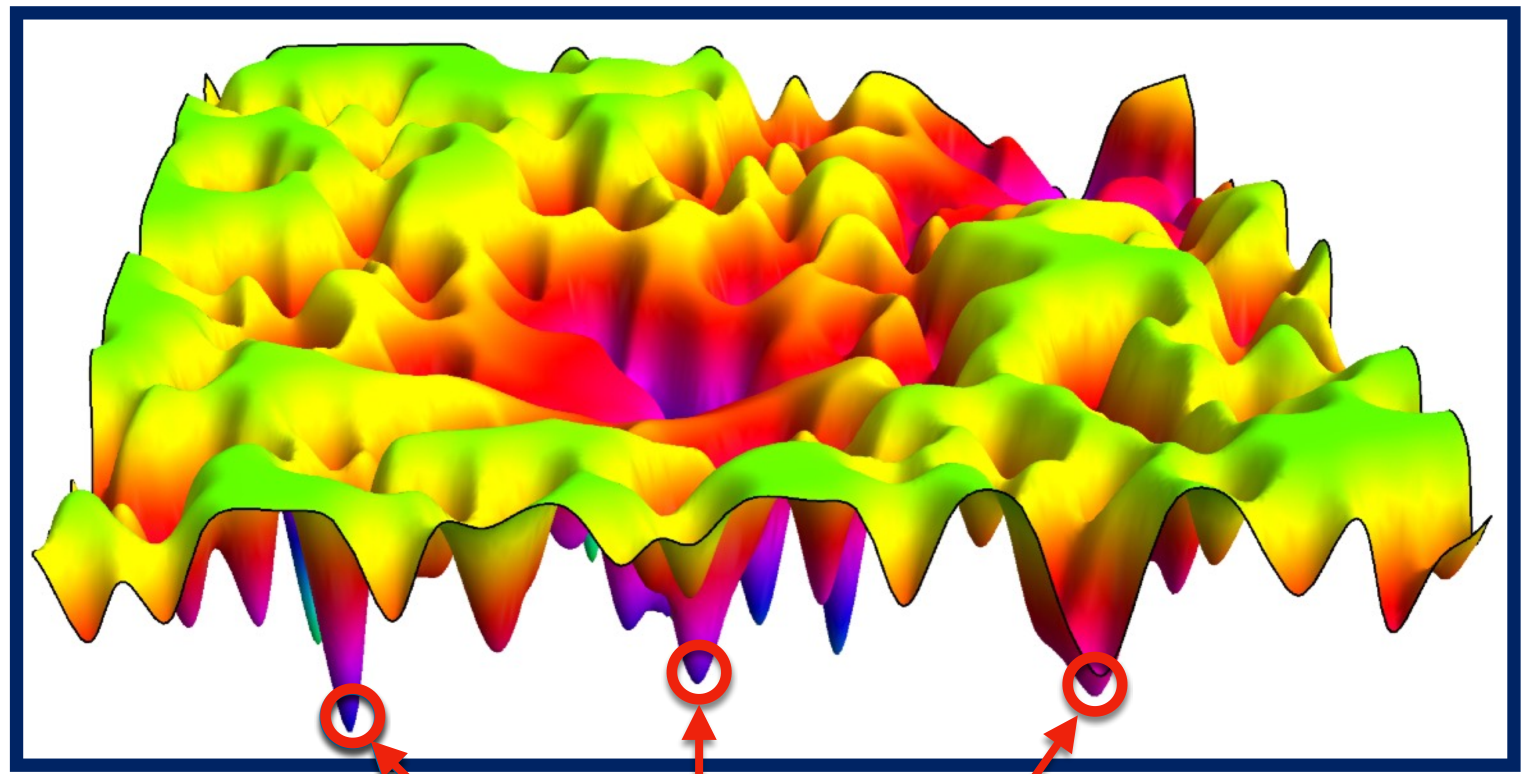
Problem: The landscape is terribly vast and complicated

String theory



Find string solutions with given properties!

String landscape



Special string EFTs

Bousso et al.: hep-th/0004134
Susskind: hep-th/0302219

Solve inverse problem: $W_0^* \to \vec{N}$

String theory input:
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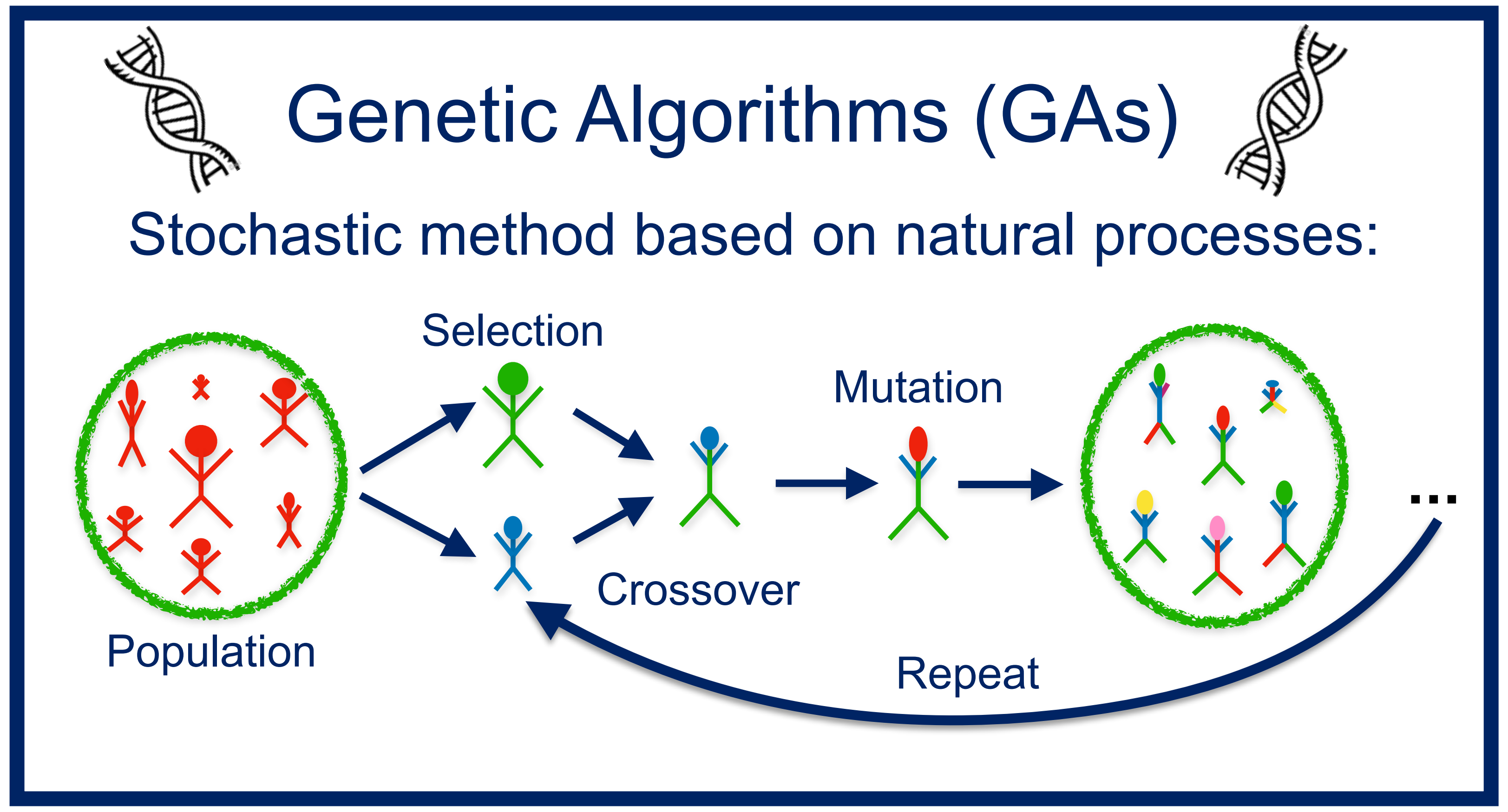
As many as $10^{272,000}$ solutions [Taylor et al. 1511.03209], but only a few are phenomenologically interesting!

Understanding the local structure of the string landscape

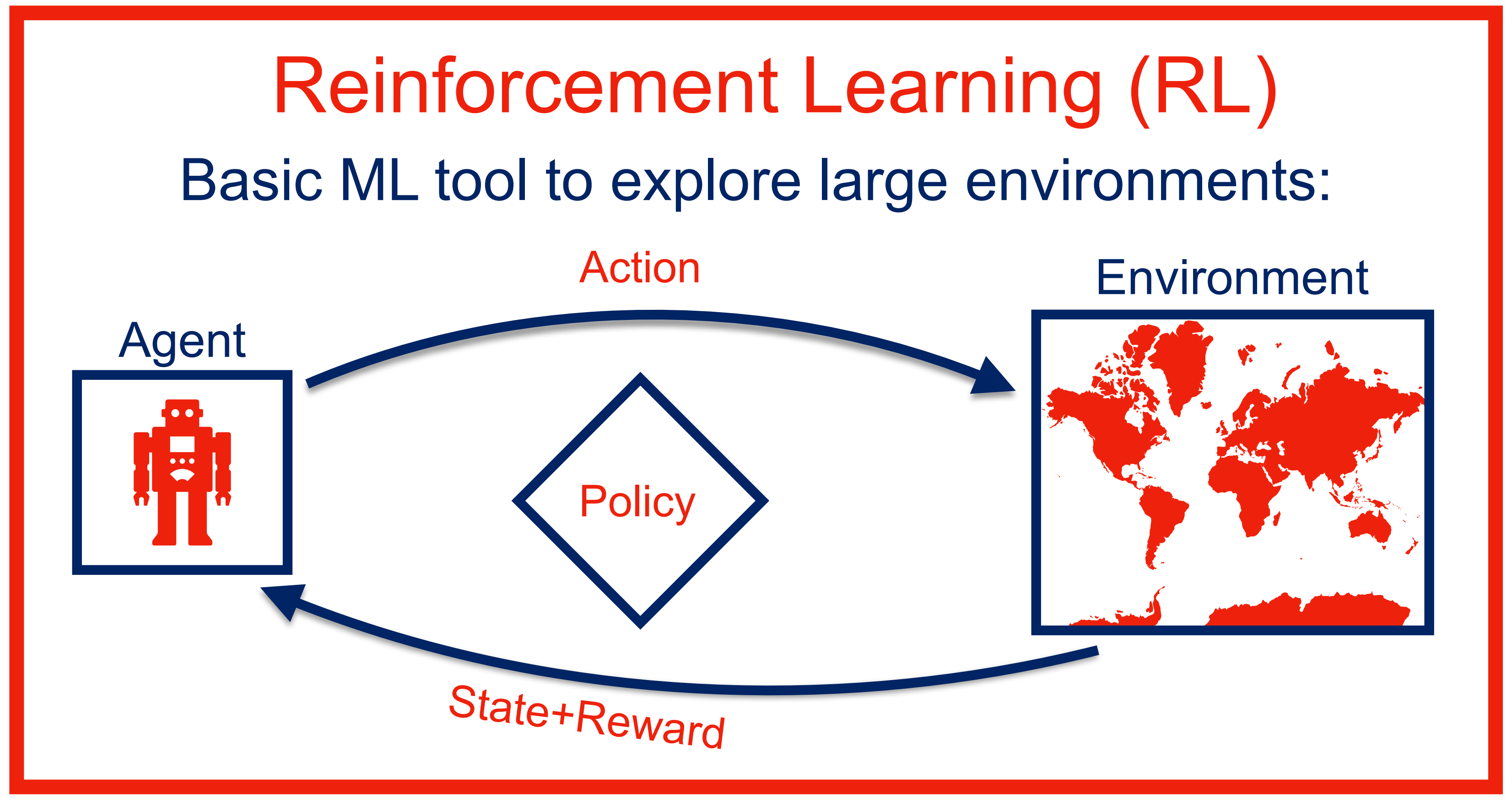
Based on ArXiv: 2111.11466

Looking at simple toy models with $h = 8$ from [DeWolfe et al. hep-th/0411061]

NEURAL INFORMATION PROCESSING SYSTEMS



vs.



[Cole, AS, Shiu: 1907.10072]

[Krippendorf, Kroepsch, Syvaeri: 2107.04039]

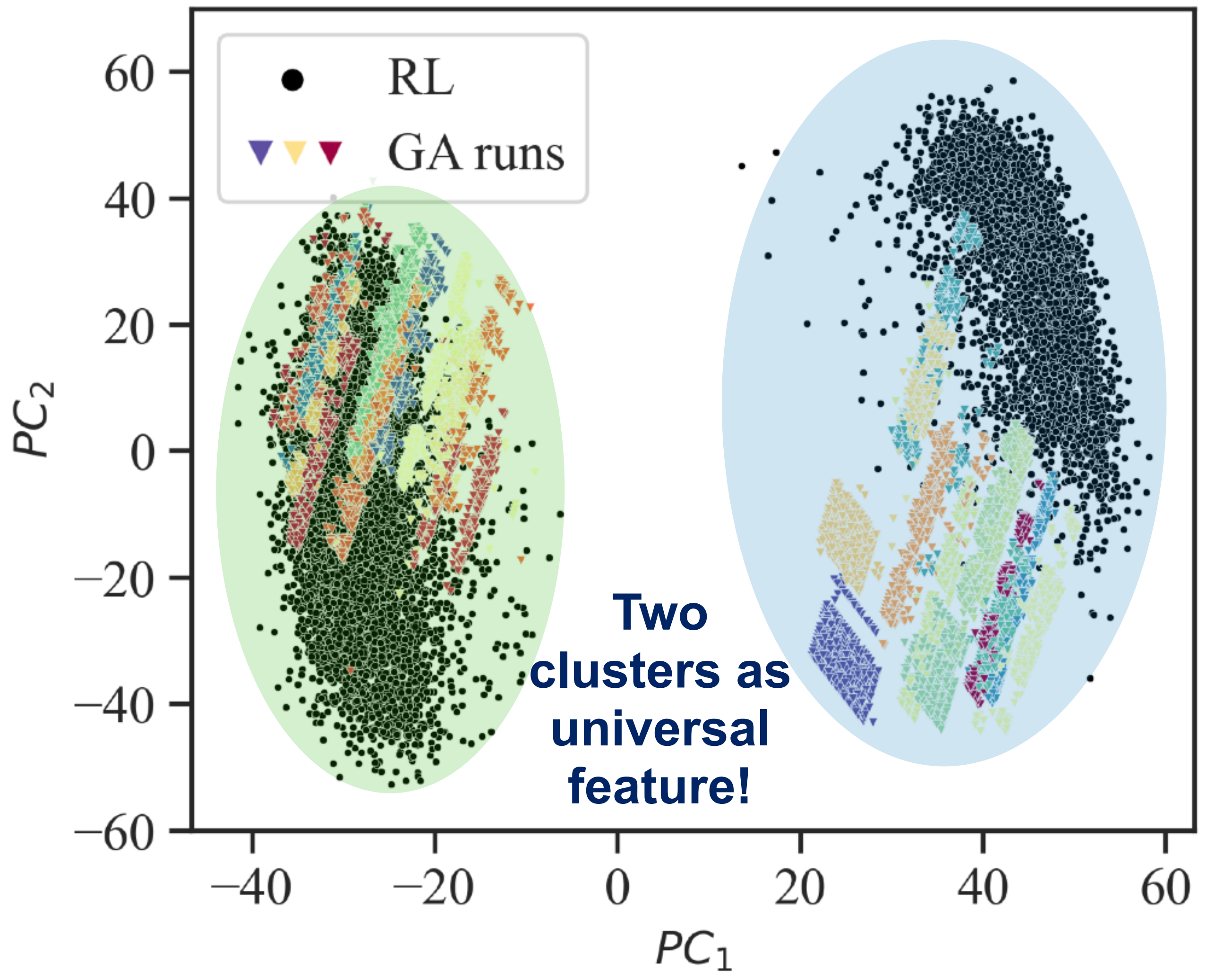
Solve inverse problem

$$W_0(\vec{N}, \vec{\phi}) = W_0^* \;\rightarrow\; \vec{N}$$

Is there **STRUCTURE** in the solutions?

Yes, we performed a **Principal Component Analysis (PCA)** on the output of flux vectors in $\mathbb{Z}^8$

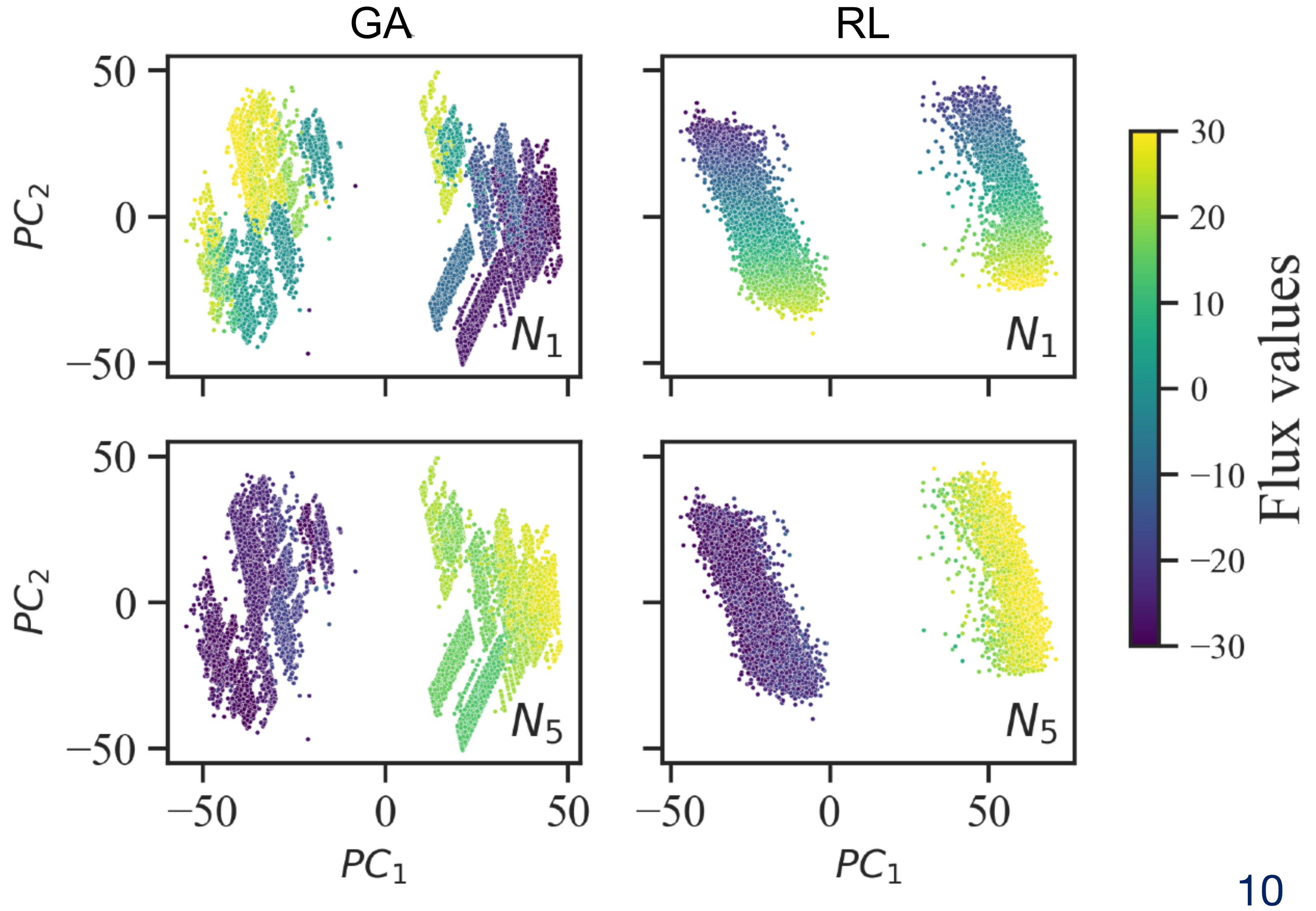
PCA on combined output



Scaling with respect to N_1 reveals difference in GA/RL output

Hint for discrete symmetry $N_5 \rightarrow -N_5$

PCA on individual output

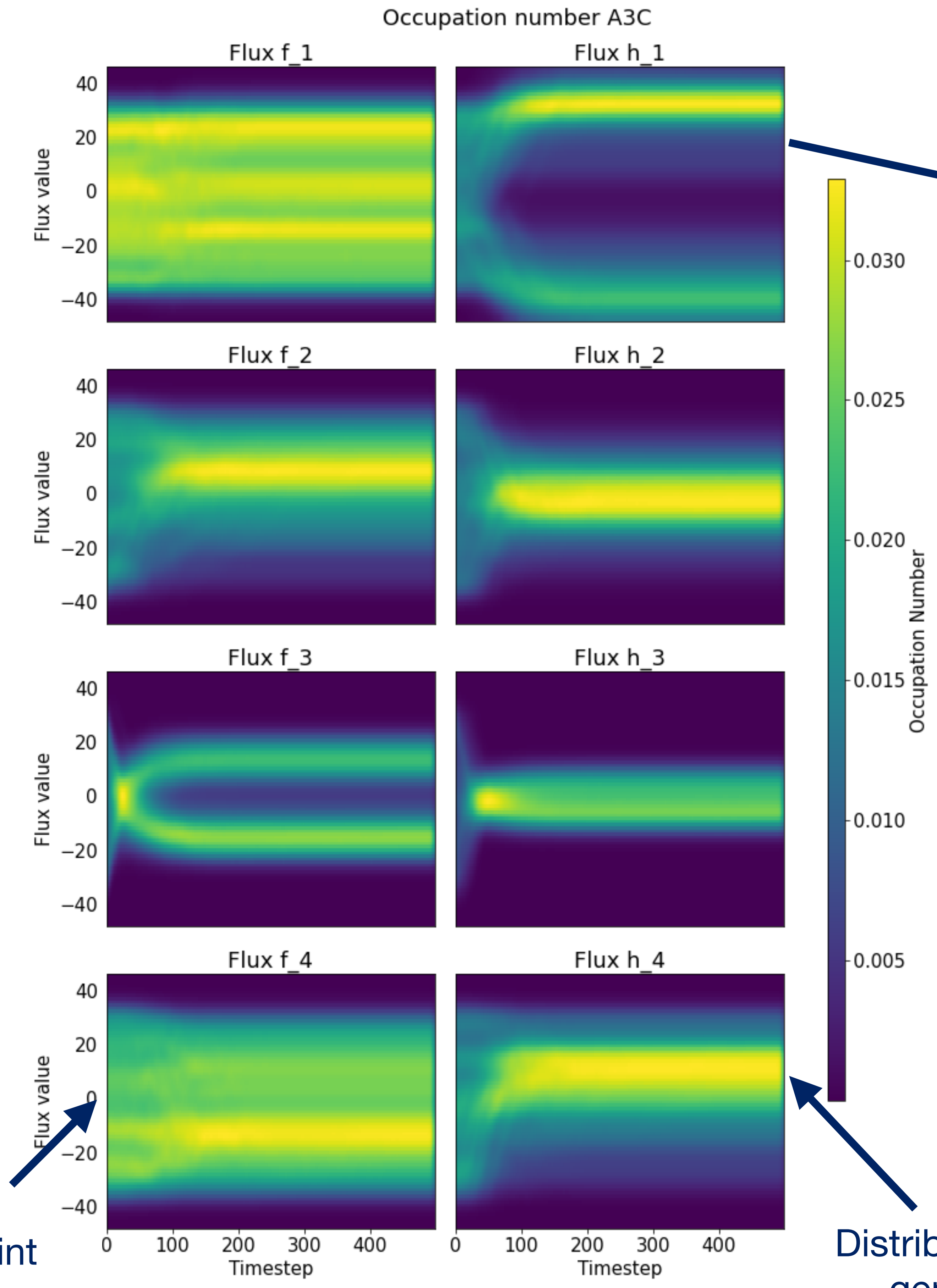


Numerical model building in string theory

Ebelt, Krippendorf, AS, Tovey: work in progress

ML methods for models with many scalar fields $h \gg 1$

So far, only limited number of EFTs could be studied systematically. The time is ripe to charter the landscape more broadly using **ML as a guiding tool**.



Random starting point

Distribution of samples generated by RL

Time evolution from RL

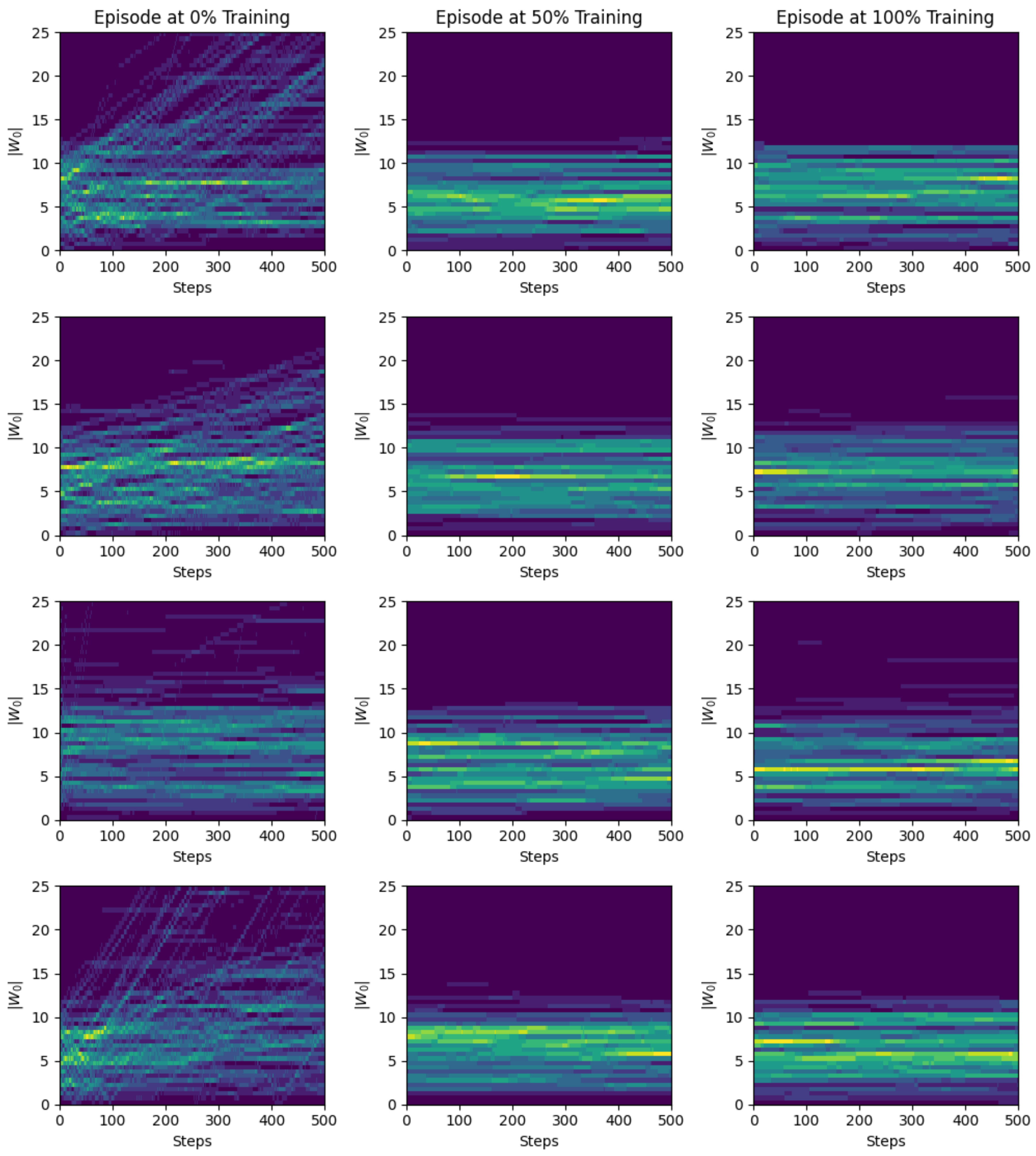
[Krippendorf, Kroepsch, Syvaeri: 2107.04039]

Solutions flow from random starting points to particular regions in parameter space!

	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8
N_1	1	0.17	0.11	-0.27	-0.23	0.3	0.5	0.14
N_2	0.17	1	0.34	-0.07	-0.27	0.22	0.37	0.76
N_3	0.11	0.34	1	0.21	-0.97	-0.18	0.88	0.18
N_4	-0.27	-0.07	0.21	1	-0.21	-0.59	0.06	-0.02
N_5	-0.23	-0.27	-0.97	-0.21	1	0.15	-0.93	-0.13
N_6	0.3	0.22	-0.18	-0.59	0.15	1	0.02	0.1
N_7	0.5	0.37	0.88	0.06	-0.93	0.02	1	0.21
N_8	0.14	0.76	0.18	-0.02	-0.13	0.1	0.21	1

We want to understand and quantify these emergent structures in our upcoming work!

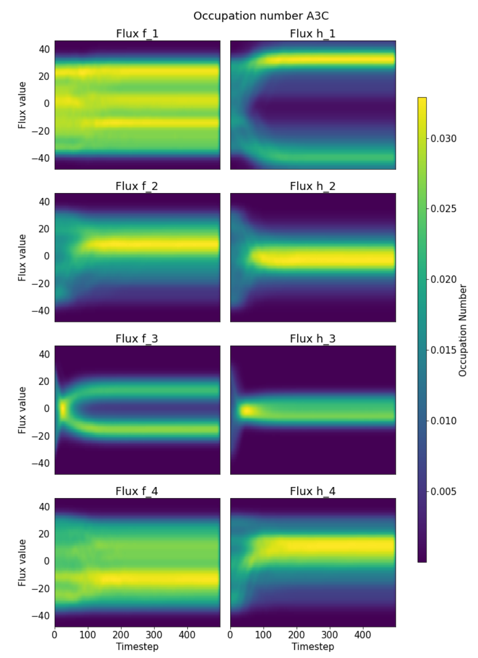
Test runs for RL for model with $h = 12$



SwarmRL using JAX

Tovey et al.: 2307.00994

Conclusions



RL: $W_0^* \to \vec{N}$

String theory input:
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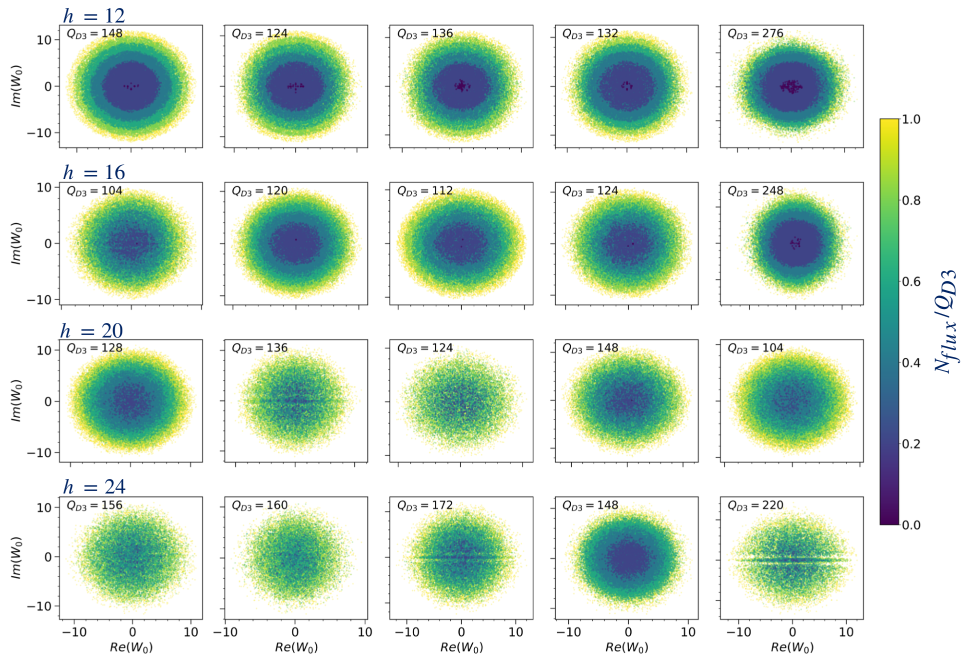
JAXVacua



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Physical observables
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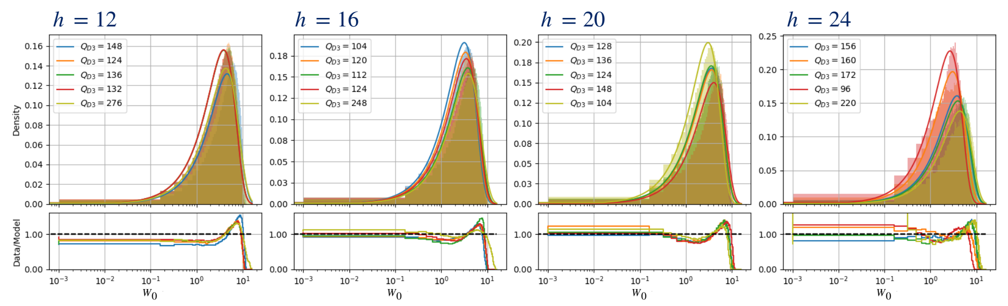

Examples of physics questions:

- Are there solutions with large scale separation?
- Universal structures across geometries?
- Phenomenology of non-supersymmetric solutions?


Thank you!