String Cosmology

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MPI Project Review

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PhD students	Mario Flory, Charlotte Sleight, Ann-Kathrin Straub, Max Newrzella, Henk Bart, Piotr Witkowski
Guest students	Prieslei Goulart, Yago Bea Besada
Master students	Abhiram Kidambi, Nina Miekley, Yunpu Ma

Holographic Kondo effect, Higher Spins, Information geometry, Entanglement entropy, Steady state formation,…

String Theory

Thomas Grimm

PostDocs Diego Regalado, Irene Valenzuela

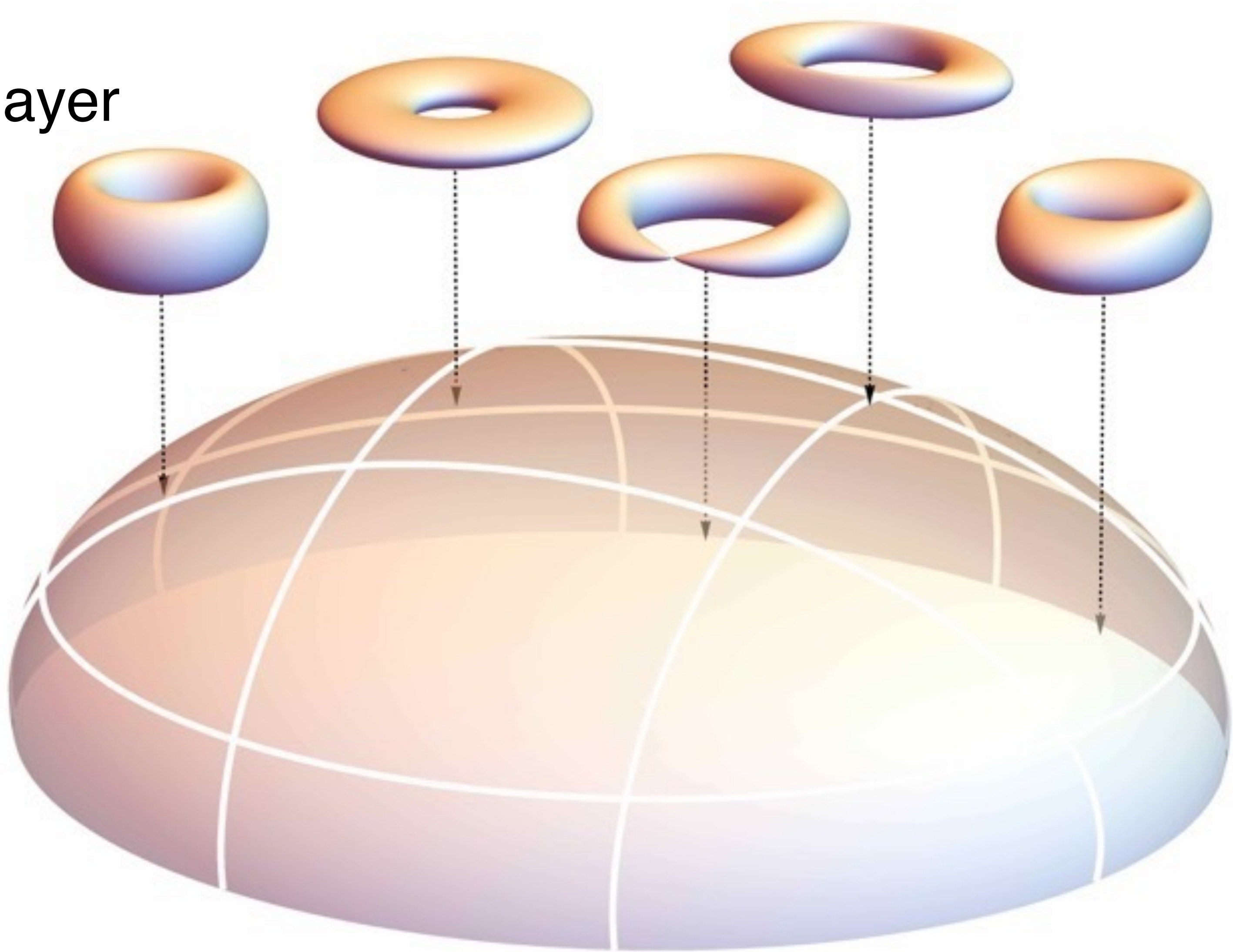
Phd students Andreas Kapfer, Sebastian Greiner, Pierre Corvilain

Master student Kilian Mayer

F-Theory,

Effective Actions,

String Cosmology



String Theory

<u>Dieter Lüst, Ralph Blumenhagen, Stephan Stieberger</u>

PostDocs	Inaki Garcia-Extebarria, Vic Feng, Cesar Damian
Phd students	Rui Sun, Michael Fuchs, Florian Wolf, Georg Puhlfürst, me, Pascal du Bosque, Benjamin Schulz, Valenti Vall Camell
Master student	Yuta Sekiguchi

Non-geometry, Amplitudes, String Cosmology,
String Phenomenology, …

String Cosmology
and
Large Field Inflation

String Theory

Dieter Lüst, Ralph Blumenhagen, Stephan Stieberger

Inaki Garcia-Extebarria, Vic Feng, Cesar Damian

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Kilian Mayer

String Cosmology

and

Large Field Inflation

Large field inflation

tensor to scalar ratio

$$r = \frac{\Delta_t^2(k)}{\Delta_s^2(k)}$$

inflationary
gravitational
waves

Large field inflation

tensor to scalar ratio

$$r = \frac{\Delta_t^2(k)}{\Delta_s^2(k)}$$

→ inflationary gravitational waves

Lyth bound

$$\frac{\Delta\phi}{M_{pl}} = \mathcal{O}(1)\sqrt{\frac{r}{0.01}}$$

Large field inflation

observations: **$r < 0.11$**

if tensor to scalar ratio large $r > 0.01$

$$\frac{\Delta\phi}{M_{pl}} = \mathcal{O}(1)\sqrt{\frac{r}{0.01}}$$

inflaton runs over superplanckian field ranges

$$\Delta\phi > M_{pl}$$

high inflation scale → UV completion

Large field inflation

when inflaton runs over superplanckian field ranges,

planck-suppressed corrections contribute

$$\mathcal{L}(\phi) = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m^2\phi^2 + \sum_{i=1}^{\infty} c_i \phi^{2i} \Lambda^{4-2i}$$

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axionic shift symmetry

Large field inflation = axion inflation

2 different approaches

- natural inflation, aligned inflation, N-flation,…

  discrete shift symmetry

- axion monodromy inflation

  slightly broken shift symmetry

Axions

continuous shift symmetry

$$\phi(x) \to \phi(x) + const.$$

non-perturbative effects break this to a

discrete shift symmetry

axion decay constant determines periodicity of the axion

$$\mathcal{L} \supset \frac{1}{2}(\partial\phi)^2 + \Lambda^4 \cos(\frac{\phi}{f}) \qquad \Rightarrow \phi(x) \to \phi(x) + 2\pi f$$

Natural inflation and co.

periodic inflaton potential

$$V(\phi) = \Lambda^4 (1 - \cos\frac{\phi}{f})$$

superplanckian axion decay constant needed

Natural inflation and co.

periodic inflaton potential

$$V(\phi) = \Lambda^4 (1 - \cos \frac{\phi}{f})$$

superplanckian axion decay constant needed

open question:

are effectively superplanckian decay constants forbidden in string theory?

weak gravity conjecture

Axion monodromy inflation

- shift symmetry broken in a controlled way

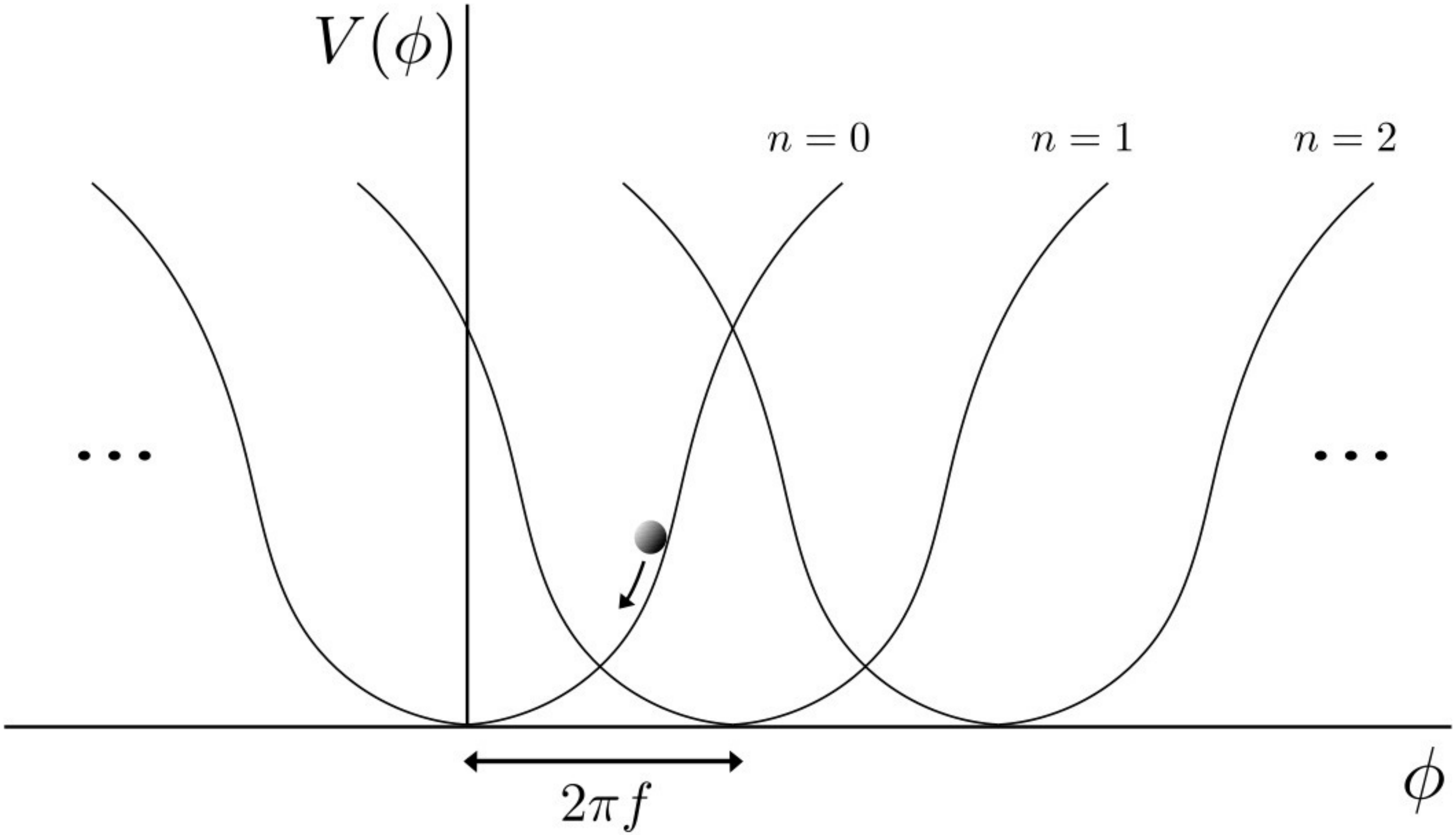
  by branes or fluxes

- field space enlarged such that the inflaton can run over

  superplanckian field ranges

- each cycle protected by shift symmetry
- polynomial inflaton potential

Axion monodromy inflation



Axion inflation in string theory

string theory contains many scalar fields

not observed → heavy ↘

“moduli“

e.g. Kahler and complex structure moduli
parametrising the internal space

Axion inflation in string theory

string theory contains many scalar fields

not observed → heavy

many of them axionic → use 1 as inflaton

to build viable single field inflationary models

inflaton has to be lighter than other scalar fields

Moduli stabilisation in string theory

example:

kinetic term for B-field

$$H = dB$$

$$\int d^4y\sqrt{-g}\int d^6x\, H \wedge \star_6 H$$

generates potential for moduli

Moduli stabilisation in string theory

example:

kinetic term for B-field

flux

$$H = dB$$

$$\int d^4y\sqrt{-g}\int d^6x\, H \wedge \star_6 H$$

generates potential for moduli

depends on fields which describe the internal space

Moduli stabilisation in string theory

or in 4D language

$$K = -2\log(V) - \log(S + \overline{S}) - \log(\Omega \wedge \overline{\Omega})$$

Moduli stabilisation in string theory

or in 4D language

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function of moduli **T** describing the volume of the internal space

Moduli stabilisation in string theory

or in 4D language

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function of moduli **T**
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Moduli stabilisation in string theory

or in 4D language

$$K = -2\log(V) - \log(S+\overline{S}) - \log(\Omega \wedge \overline{\Omega})$$

function of moduli **T** describing the volume of the internal space

describes the string coupling

function of moduli **U** describing the shape of the internal space

Moduli stabilisation in string theory

or in 4D language

$$K = -2\log(V) - \log(S + \overline{S}) - \log(\Omega \wedge \overline{\Omega})$$

function of moduli **T** describing the volume of the internal space

describes the string coupling

function of moduli **U** describing the shape of the internal space

$W(S, T_j, U_i)$ superpotential depending on moduli and fluxes

axion e.g. Im(S)

Moduli stabilisation in string theory

or in 4D language

K and W generate the scalar potential

$$V = e^K (|DW|^2 - 3|W|^2)$$

which in our case depends on

the axionic inflaton

and

other closed string moduli

Moduli stabilisation in string theory

minimise

$$V(\chi_i, \phi)$$

with moduli χ_i and axionic inflaton ϕ

- such that inflaton hierarchically lightest state
- no tachyons
- all saxions get a mass
- minimum de Sitter
- effective potential $V(\phi)$ suitable for inflation

Moduli stabilisation in string theory

minimise

$$V(\chi_i, \phi)$$

with moduli χ_i and axionic inflaton ϕ

- such that inflaton hierarchically lightest state

↓

not so easy!

procedure to get a light axion
and to control backreaction needed

Moduli stabilisation in string theory

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Moduli stabilisation in string theory

minimise

$$V(\chi_i, \phi)$$

with moduli χ_i and axionic inflaton ϕ

also very challenging

in string theory

- minimum de Sitter

consider D-terms, Anti-Branes,…

Moduli stabilisation in string theory

furthermore:

- mass hierarchy has to be fulfilled

$$M_{pl} > M_{string} > M_{KK} > M_{moduli} > H_{inf} > M_{axion}$$

- vevs of some moduli have to be large

Moduli stabilisation in string theory

[Blumenhagen, Damian, Font, Fuchs, DH, Plauschinn, Sekiguchi, Sun, Wolf]

Our results:

- challenging to get an hierarchically light axion

  we had to use a 4D effective theory

  where the uplift to string theory is unclear

$\mathcal{N} = 2$ gauged supergravity

motivated by T-duality

……

Non-geometric fluxes

metric
and
B-field

new dofs
to describe

?

$$H = dB \longleftrightarrow \omega = e\,de \longleftrightarrow Q \longleftrightarrow R$$

geometric fluxes

non-geometric fluxes

Moduli stabilisation in string theory

[Blumenhagen, Damian, Font, Fuchs, DH, Plauschinn, Sekiguchi, Sun, Wolf]

Our results:

- challenging to get an hierarchically light axion

  we had to use a 4D effective theory

  where the uplift to string theory is unclear

- mass hierarchy not fulfilled

$$M_{pl} > M_{string} > M_{KK} > M_{moduli} > H_{inf} > M_{axion}$$

if we insist on integer fluxes

Summary

- observations do not yet tell us whether there is

  small or large field inflation

- the latter might be challenging to realise in string theory
- since both kind of large field inflation models face challenges
- e.g. weak gravity conjecture and moduli stabilisation
- further research is needed to clarify what is allowed