A Flux-Scaling Scenario for High-Scale Moduli Stabilization in String Theory

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IMPRS Workshop on June 30, 2015

based on: Nucl.Phys. B897 (2015) 500-554
Blumenhagen, Font, Fuchs, Herschmann, Plauschinn, Sekiguchi, **Wolf**

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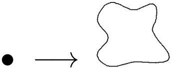
What is String Phenomenology?

String Theory:



- fundamental objects: strings instead of particles
- there are 5 superstring theories in 10d

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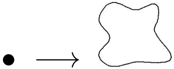

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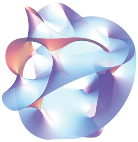
String Phenomenology:

String Theory in 10d	$\xrightarrow{\text{Compactification}}$	Standard Model in 4d



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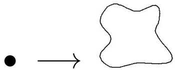

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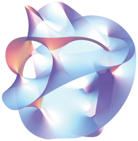
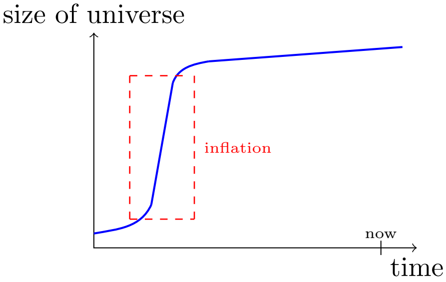


Here: type IIB string theory with orientifold projection

What is Inflation?

Inflation $\equiv$

very early time period of accelerated expansion of the universe [Guth, Linde, Starobinsky, Steinhardt, Mukhanov, ... '80s]



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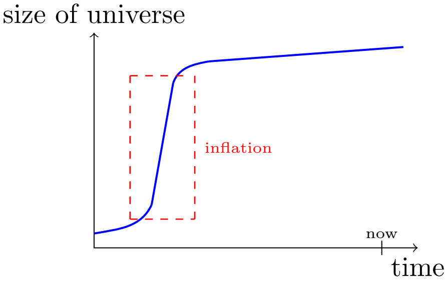

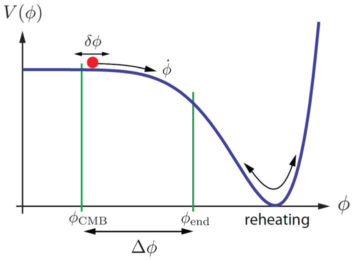

Described by scalar inflaton field ϕ with certain potential $V(\phi)$.

Motivation from Inflation

Initially [BICEP2 '14] observed a large tensor-to-scalar ratio: $r = 0.2$.

Lyth bound: $$\frac{\Delta\phi}{M_{\text{Pl}}} = O(1)\sqrt{\frac{r}{0.01}}$$

- study large-field inflation ($\Delta\phi > M_{\text{Pl}}$)
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Possible approach: F-term axion monodromy inflation [Hebecker, Kraus, Witkowski '14; Blumenhagen, Plauschinn '14; Marchesano, Shiu, Uranga '14;]

Need: axion that is parametrically lighter than all other moduli

(Include Kähler moduli: extension of [Blumenhagen, Herschmann, Plauschinn '14])

Motivation from String Phenomenology

Important Task:

Massless 'moduli' fields in 10d → (Moduli Stabilization) → Very heavy fields in 4d

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Objective for realizing single-field F-term axion monodromy inflation in the context of moduli stabilization:

- vacua: non-supersymmetric + tachyon-free
- all saxionic moduli stabilized with one axion Θ enabling inflation
- controllable mass hierarchies

$$M_{\rm Pl} > M_{\rm s} > M_{\rm KK} > M_{\rm mod} > H_{\rm inf} > M_{\Theta}$$

Moduli Space

Moduli $\equiv$ deformations of Calabi-Yau (CY) metric preserving CY properties

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Moduli of type IIB orientifold compactifications [Grimm '04]:

modulus	name
$S \;= s + i\,c$	axio-dilaton
$U^i = v^i + i\,u^i$	complex structure
$T_\alpha = \tau_\alpha + i\,\rho_\alpha + \dots$	Kähler
$G^a = S\,b^a + i\,c^a$	axionic odd

Moduli space described by Kähler potential:

$$K = -\log \underbrace{\left(-i\int \Omega \wedge \overline{\Omega}\right)}_{\text{complex structure}} - \log\left(S + \overline{S}\right) - 2\log \underbrace{\mathcal{V}}_{\text{volume}}$$

Fluxes and Moduli Stabilization

Type IIB superstring theory in 10d contains a NS-NS 2-form B_2 and R-R 2-form C_2.

Flux $\equiv$ field strength with non-trivial vacuum expectation value

- combine the 3-form fluxes $H = \langle dB_2 \rangle$ and $\mathfrak{F} = \langle dC_2 \rangle$:

$$G_3 \; = \; \mathfrak{F} - iSH$$

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Fluxes generate (F-term) scalar potential fixing the moduli vevs and thereby giving a large mass to the moduli:

$$V_F \;=\; \frac{M_{\rm Pl}^4}{4\pi}\, e^K \Big(K^{I\bar{J}} D_I W D_{\bar{J}} \overline{W} - 3\big|W\big|^2 \Big)$$

with Kähler potential K and Gukov-Vafa-Witten superpotential W.

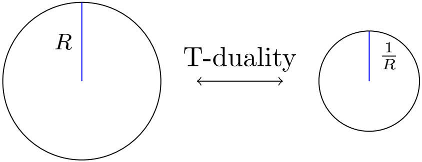
$\longrightarrow$ Moduli Stabilization

Geometric and Non-Geometric Fluxes

New fluxes from string dualities:

T-duality:

Compactification on T-dual circles yields the same physics!



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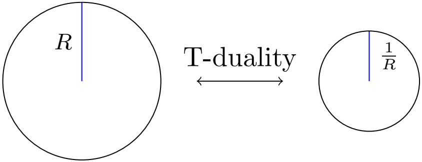

Apply to flux compactification [Grana, Louis, Waldram '06; Benmachiche, Grimm '06; Wecht '07; Shelton, Taylor, Wecht '07]:

$$
\begin{array}{ccccccc}
H_{abc} & \overset{T_c}{\longleftrightarrow} & f^c_{ab} & \overset{T_b}{\longleftrightarrow} & Q^{bc}_a & \overset{T_a}{\longleftrightarrow} & R^{abc} \\
\downarrow & & \downarrow & & \downarrow & & \downarrow \\
\text{NS-NS flux} & & \text{geometric} & & \text{non-geom.} & & \text{non-geom.}
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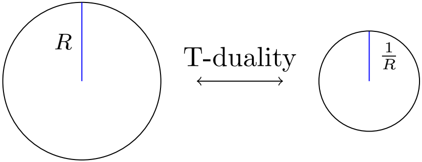

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H_{abc}	f^c_{ab}	Q^{bc}_a	R^{abc}
$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
NS-NS flux	geometric	non-geom.	non-geom.

Note: S-duality completion leads to P-flux [Aldazabal et al. '06, '10]

Flux-Scaling Scenario

A simple example ($q \in \mathbb{Z}$ denotes non-geometric flux):

$$W = i\tilde{\mathfrak{f}} + i\,h\,S + i\,q\,T \quad \text{and} \quad K = -3\log(T+\overline{T}) - \log(S+\overline{S})$$

$$\Longrightarrow V = \frac{M_{\text{Pl}}^4}{4\pi\cdot 2^4}\left[\frac{(hs-\tilde{\mathfrak{f}})^2}{s\tau^3} - \frac{6hqs+2q\tilde{\mathfrak{f}}}{s\tau^2} - \frac{5q^2}{3s\tau} + \frac{1}{s\tau^3}\,(hc+q\rho)^2\right]$$

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Extrema of V:

solution	(s,τ,θ)	non-susy	tachyon-free	Λ
1	$(-\frac{\tilde{\mathfrak{f}}}{2h}, -\frac{3\tilde{\mathfrak{f}}}{2q}, 0)$	no	no	AdS
2	$(\frac{\tilde{\mathfrak{f}}}{8h}, \frac{3\tilde{\mathfrak{f}}}{8q}, 0)$	✓	no	AdS
3	$(-\frac{\tilde{\mathfrak{f}}}{h}, -\frac{6\tilde{\mathfrak{f}}}{5q}, 0)$	✓	✓	AdS

Flux-Scaling Scenario

- mass eigenvalues of moduli:

$$M^2_{\text{mod},i} = \mu_i \, \frac{hq^3}{\tilde{\mathfrak{f}}^2} \, \frac{M^2_{\text{Pl}}}{4\pi \cdot 2^4} \qquad \text{with} \qquad \mu_i \approx (6.2, 1.7\,; 3.4, 0)$$

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- various other models with additional fluxes

Conclusion and Outlook

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- systematic analysis of non-susy, stable minima of the scalar potential generated by type IIB orientifolds on CY including non-geometric fluxes
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Open question:

- multi-field inflation: trajectory and non-Gaussianity?
- dS vacua or dS uplift?
- uplift to full string theory?
- include some Kaluza-Klein and string states?

Thank you!