Natural inflation and moduli stabilization in heterotic orbifolds

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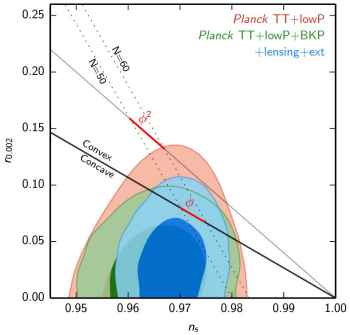
Based on [work in progress with Clemens Wieck]

Motivation

Motivation - Large field models

Necessity of large field models

- Field range $\Delta\varphi \approx 20\sqrt{r} \quad \rightsquigarrow \quad r \gtrsim 0.002 \Rightarrow \Delta\varphi > M_{\mathrm{Pl}}$
- Joint Planck/BICEP analysis favors $r \approx 0.05$
  $\Rightarrow \Delta\varphi \approx 5 M_{\mathrm{Pl}}$ at 1.8σ
  $\Rightarrow H \sim M_{\mathrm{GUT}}^2 \sim 10^{-4} \ldots 10^{-5}$
- Better results expected soon



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Challenges for string theory

- Large field models problematic to realize in string theory
  Reason: Inflaton candidates (moduli) live in compact space
  $\Rightarrow$ field range bounded and sub-Planckian
- Need moduli stabilization at high scale ($\gtrsim H$)
  - to work in single field inflation
  - to avoid Polonyi problem/not spoil BBN

Introduction

Large field inflation in string theory

Axion monodromy inflation

- Initially proposed by [Silverstein,Westphal,McAllister]
- Mechanism:
  - Start with **periodic inflaton**
  - Scalar potential **slightly breaks periodicity**
- Many string theoretic realizations [Palti,Weigand; Marchesano,Shiu, Uranga; Blumenhagen,Plauschinn; Hebecker,Kraus,Witkowski; . . .]

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Aligned axion inflation

- Initially proposed by [Kim,Nilles,Peloso]
- Mechanism:
  - Two **axions** with **almost aligned** axion decay constant
  - **Slight misalignment** gives almost-flat direction with effective trans-Planckian decay constant
- Many string theoretic realizations [Kappl,Krippendorf,Nilles;Long, McAllister,McGuirk;Ali,Haque,Jejjala;Tye,Wong;Ben-Dayan,Pedro,Westphal;. . .]

Short comment on recent results

Trans-Planckian field range

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- Arguments based on weak gravity conjecture/ E-brane instantons in type II
- Corresponding effect in heterotic?
  - Euclidean NS5 branes wrapping orbifolds?
  - relations to orbifold curvature singularities?
  - effects calculable in this setup?
  - worthwhile/interesting to study
- Results too recent to say more. . .

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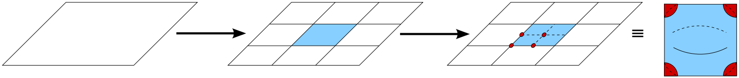
3. Need **near alignment**
   $\Rightarrow$ Both **effects related**:
   - Both governed by **modular forms** (Dedekind eta function)
   - Near alignment from **fixed modular weights** of Kähler and superpotential

Inflation and moduli stabilization in heterotic orbifolds

Recap: (Factorizable toroidal Abelian) Heterotic orbifolds



[Dixon,Harvey,Vafa,Witten]

Orbifold data

- $\theta : (z_1, z_2, z_3) \mapsto (e^{2\pi i v_1} z_1, e^{2\pi i v_2} z_2, e^{2\pi i v_3} z_3)$

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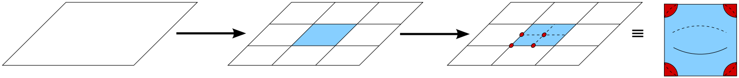

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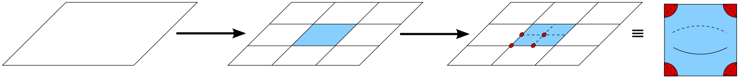

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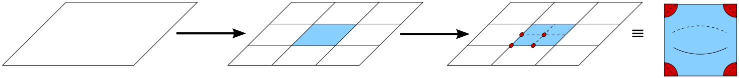

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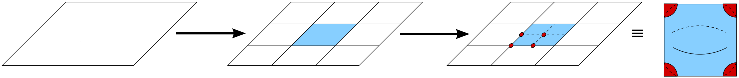

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- **Exact CFT** description ⇒ **Calculability**
- Known to yield **good** particle **pheno**
  [Blaszczyk,Buchmuller,Hamaguchi,Kim,Kyae,Lebedev,Nilles,Raby, Ramos-Sanchez,Ratz,FR,Trapletti,Vaudrevange,...]

Modular symmetry

Modular transformation

- Target space inherits modular symmetry
- Kähler parameters T_i transform under SL(2,$\mathbb{Z}$):
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Dedekind η-function

- $\eta(T) = e^{-\frac{\pi T}{12}} \prod_{r=1}^{\infty}\left(1 - e^{-2\pi r T}\right) \approx e^{-\frac{\pi T}{12}}$ for big T
- $\eta(T) \to (icT + d)^{\frac{1}{2}}\, \eta(T)$ (up to phase)

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Superpotential from WS instantons

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- More complicated modular forms possible [Hamidi,Vafa; Lauer,Mas,Nilles]

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  - Only T_i that belong to torus without fixed points; just fixed planes enter
  - For these, $c_i = N_i/N$ where N is orbifold order and N_i is the twist order that leaves i^{th} torus invariant
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Superpotential from gaugino condensation

- $$W \supset B\, e^{\frac{-24\pi^2}{\beta} f(S,T)} = B(\Phi_\alpha)\, \exp\left(\frac{-24\pi^2}{\beta} S\right)\, \exp\left(-\frac{\pi}{12} \sum_i \tilde{c}_i b_i^{\mathcal{N}=2}\right)$$

Superpotential

Schematic form of combined superpotential

$$W \supset A(\Phi)\; e^{-(n_1 T_1 + n_2 T_2)} + B(\Phi)\; e^{\frac{-24\pi^2}{\beta} S}\; e^{-(\beta_1 T_1 + \beta_2 T_2)}$$

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Typical values of β_i

- Depend on particle content, typically $\sim -2\pi/12$
- Calculated using `orbifolder` [Nilles,Ramos-Sanchez,Vaudrevange,Wingerter]

Alignment & moduli stabilization using GC+instantons

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     Racetrack for S from multiple GC or from anom. U(1)
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  3. Use F-term stabilizer fields and FI-terms to stabilize S and T_i
     [Wieck,Winkler;Kappl,Nilles,Winkler]

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- GC term highly suppressed:
  - for realistic $S \sim 2 \quad \Rightarrow \quad e^{-\frac{48\pi^2}{\beta}}$
  - smallish $\langle S \rangle \simeq 1.5$ and/or largish gauge groups (SU(6), SO(10), E_6) preferred

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- Thus [de Carlos,Casas,Munoz] and [Dundee,Raby,Westphal] problematic

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Challenges

- $W \supset e^{\frac{-24\pi^2}{\beta}S}\; e^{-(\beta_1 T_1+\beta_2 T_2)}$
  One of the racetrack terms for T_i from GC term
- GC term highly suppressed:
  - for realistic $S \sim 2 \quad \Rightarrow \quad e^{-\frac{48\pi^2}{\beta}}$
  - smallish $\langle S\rangle \simeq 1.5$ and/or largish gauge groups (SU(6), SO(10), E_6) preferred
- Thus [de Carlos,Casas,Munoz] and [Dundee,Raby,Westphal] problematic
- $W \supset \chi_1[C\; e^{-\frac{24\pi^2}{\beta}S}\; e^{-(\beta_1 T_1+\beta_2 T_2)} - B_1(\langle\chi\rangle)]$
  $+\; \chi_2[A_2(\langle\chi\rangle)e^{-S} - B_2(\langle\chi\rangle)]$
  - Need $\langle\chi_1\rangle \neq 0$ since it corresponds to mesonic mass term
  - has to be around Hubble scale to avoid BBN problems
  - Get high-scale SUSY breaking $\sim \langle\chi_1\rangle B_1(\langle\chi\rangle)$

Alignment & moduli stabilization using two instantons

Moduli stabilization with two WS Instantons

$$W \supset \chi_1[A_1(\langle\chi\rangle)e^{-S} - B_1(\langle\chi\rangle)] + \chi_2[A_2(\langle\Phi\rangle)e^{-\pi/12(2T_1+2T_2)} - B_2(\langle\chi\rangle)]$$
$$+ \chi_3[A_3(\langle\Phi\rangle)e^{-\pi/12(6T_1+4T_2)} - B_3(\langle\chi\rangle)]$$

- FI-Terms force VEVs ~ 0.1 to untw. χ_i and tw. Φ_i fields

$\chi_{1,2,3}$	S	T_1	T_2	A_1	A_2	A_3	B_1	B_2	B_3
0	1.8	1.05	1.25	$7 \cdot 10^{-4}$	$2 \cdot 10^{-3}$	$1 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$2 \cdot 10^{-5}$

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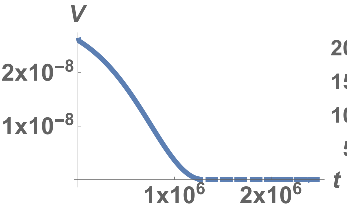

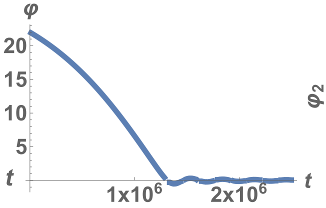

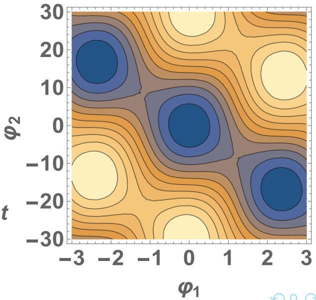

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Moduli stabilization and inflation

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- Stabilization
  - for **GC+WS instantons tension**
  - for **2 WS instantons easier**

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Thank you for your attention!