Natural inflation and moduli stabilization in heterotic orbifolds

Fabian Ruehle

Deutsches Elektronensynchrotron DESY
Hamburg

String Pheno 2015
06/09/2015

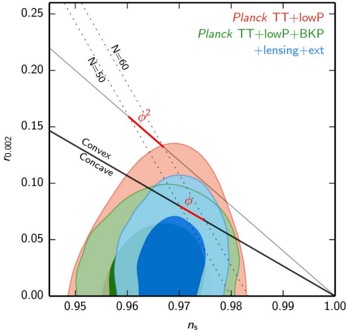
Based on [1503.07183] with Clemens Wieck

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 $r \approx 0.05$
  $\Rightarrow \Delta\varphi \approx 5M_{\mathrm{Pl}}$ at 1.8σ, $\quad H \sim M_{\mathrm{GUT}}^2 \sim 10^{-4}\ldots 10^{-5}$
- Better results expected soon



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Challenges for trans-Planckian inflation

- Inflaton candidates (moduli) live in compact space
  $\Rightarrow$ field range bounded and sub-Planckian
- Need to worry about corrections to the inflaton potential
  $\Rightarrow$ Axionic shift symmetry can protect you (see however [Montero,Uranga,Valenzuela;Brown,Cottrell,Shiu,Soler] & [Bachlechner,Long,McAllister;Hebecker,Mangat,Rompineve,Witkowski])
- Need moduli stabilization at high scale ($\gtrsim H$)
  - to work in single field inflation
  - to avoid Polonyi problem/not spoil BBN

Introduction

KNP inflation + moduli stabilization

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   Kähler: $T_i| = t_i + \mathrm{i}\tau_i$, Complex structure: $U_i| = u_i + \mathrm{i}\omega_i$

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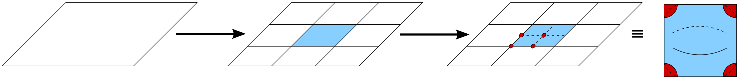
3. Need **near alignment**
   $\Rightarrow$ Both **effects related**:
   - Both governed by **modular forms** (Dedekind eta function)
   - Near alignment from **fixed modular weights** of Kähler and superpotential

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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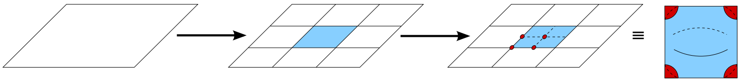

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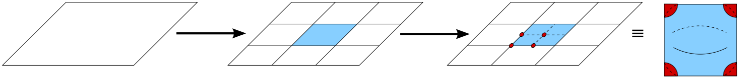

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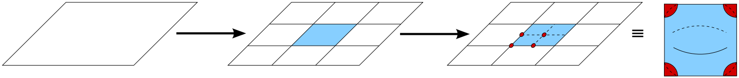

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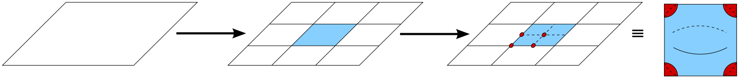

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- Known to yield **good** particle **pheno**

  [Blaszczyk,Buchmüller,Hamaguchi,Kim,Kyae,Lebedev,Nilles,Raby, Ramos-Sanchez,Ratz,FR,Trapletti,Vaudrevange,...]

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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)

Superpotential

- $W \supset A(\Phi_\alpha)\, \exp\left(-\frac{\pi}{12} \sum_i [-2(1 + \sum_\alpha m^i_\alpha) T_i]\right)$
- More complicated modular forms possible [Hamidi,Vafa; Lauer,Mas,Nilles]

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Superpotential from gaugino condensation

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

Anomalous U(1), GS mechanism and FI term

Target space gauge anomaly

- $E_8 \times E_8$ broken to non-Abelian GGs & multiple U(1)'s

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Superpotential from anomalous U(1)

- $W \subset C(\Phi_\alpha)\ \exp[-\sum_\alpha \frac{q_\alpha}{\delta_{\mathrm{GS}}} S]$

Alignment & moduli stabilization using GC+instantons

Challenges

- Full analysis involved [Parameswaran,Ramos-Sanchez,Zavala]
- $W \supset A(\Phi)e^{\frac{-24\pi^2}{\beta}S}\ e^{-(\beta_1 T_1+\beta_2 T_2)} + B(\Phi)\ e^{-(b_1 T_1+b_2 T_2)} + C(\Phi)\ e^{\frac{-q}{\delta_{\mathrm{GS}}}S}$
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- $$W \supset \chi_1 [C\, e^{-\frac{24\pi^2}{\beta} S}\, e^{-(\beta_1 T_1 + \beta_2 T_2)} - B_1]$$
  $$+ \chi_2 [A_2 e^{-(b_1 T_1 + b_2 T_2)} - B_2] + \chi_3 [A_3 e^{-\frac{q}{\delta_{\mathrm{GS}}} S} - B_3]$$
  - 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 $\sim \langle \chi_1 \rangle B_1$

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Untwisted fields χ, twisted fields $\varphi^{(k)}$

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$$K = -\ln(S+\overline{S}) - \ln(T_1+\overline{T}_1 - |\chi_A|^2) - \ln(T_2+\overline{T}_2 - |\chi_B|^2) + f(T, U)|\Phi_\alpha|^2$$

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Superpotential

$$\begin{aligned} W \supset\ & \chi_A\left[\chi_1\chi_2 e^{-q/\delta_{\mathrm{GS}}S} - \chi_3\chi_4\right] \\ & + \chi_B\left[\chi_5\varphi^{(1)}\varphi^{(1)}\varphi^{(4)} e^{-\pi/12(2T_1+2T_2)} - \chi_6\chi_7\right] \\ & + \chi_C\left[\varphi^{(1)}\varphi^{(3)}\varphi^{(4)}\varphi^{(4)} e^{-\pi/12(6T_1+4T_2)} - \chi_8\chi_9\right] \end{aligned}$$

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Moduli stabilization with two WS Instantons

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

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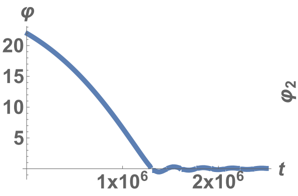

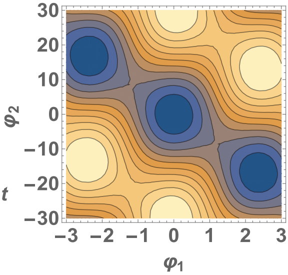

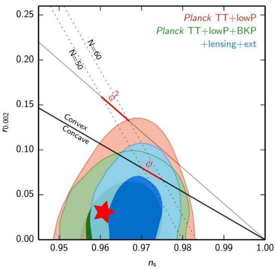

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- Several axions present (partner of geometric moduli) w/ shift symmetry from SL$(2,\mathbb{Z})$

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- Several axions present (partner of geometric moduli) w/ shift symmetry from $\mathrm{SL}(2,\mathbb{Z})$
- Naturally enter w/ **same function** in non-perturbative terms
  - in **instantonic couplings** to ensure **modular covariance** of W
  - in **gaugino condensation** from **1-loop correction** to f

Conclusion

Moduli stabilization and inflation

- Experimental results suggest large field inflation at large Hubble scale
- **Ingredients**
  - Several different **non-perturbative terms** in superpotential
  - **Near alignment** $\rightarrow$ small hierarchy between decay constants

Realization in heterotic orbifolds

- Several axions present (partner of geometric moduli) w/ shift symmetry from SL(2,$\mathbb{Z}$)
- Naturally enter w/ **same function** in non-perturbative terms
  - in **instantonic couplings** to ensure **modular covariance** of W
  - in **gaugino condensation** from **1-loop correction** to f
- Stabilization
  - for **GC+WS instantons tension**
  - for **2 WS instantons easier**

Conclusion

Thank you for your attention!