HARMONIC HYBRID INFLATION

F. Carta, N. Righi, Y. Welling and A. Westphal

arXiv: 2007.04322

XVI Avogadro Meeting – 22.12.2020

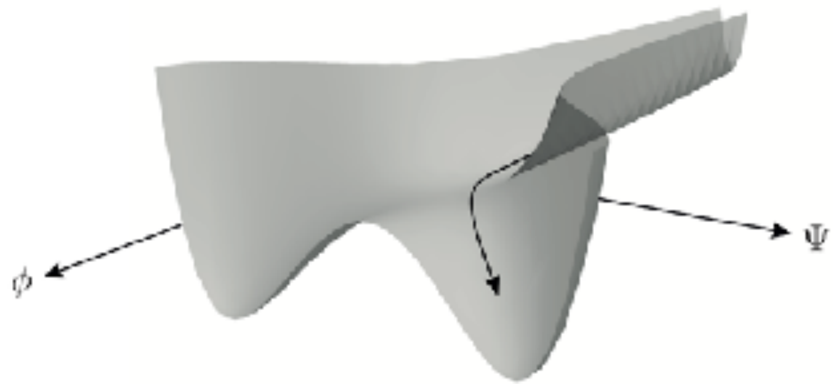
HYBRID INFLATION *Linde '93*

$$V(\phi, \Psi) = V_0 + \Delta V(\phi) + V(\Psi) + \frac{1}{2} g \phi^2 \Psi^2$$

- ϕ → inflaton
- Ψ → waterfall field

$m_\phi < m_\Psi$

- slow-rolling phase: $V(\Psi) = 0$, $V_0 > \Delta V(\phi)$ → $\Delta\phi_{60} \lesssim M_{pl}$
- $\phi > \phi_c$, Ψ frozen: single-field slow roll inflation
- $\phi \gtrsim \phi_c$, Ψ light: 2-field dynamics
- $\phi < \phi_c$, Ψ tachyonic: inflation ends rapidly
  - → tachyonic preheating
  - → or parametric resonance



from Baumann, McAllister '15

→ potentially oscillons?
→ PGW spectrum has peaks

... WITH TWO AXIONS

Ross, German '10 hybrid inflation with 1 axion

Why Axions ?

- equipped with continuous shift symmetry → the potential is stable against radiative corrections → good inflaton candidates from bottom-up
- ubiquitous presence in string theory → usually come with very light masses and → good inflaton candidates from top-down

$$f \lesssim M_{pl}$$

+

$$\Delta\phi_{60} \lesssim M_{pl}$$

(from the vacuum energy domination)

⇒

- ✓ SDC *Ooguri, Vafa '06*
- ✓ WGC *Arkani-Hamed, Motl, Nicolis, Vafa '06*

HARMONIC HYBRID INFLATION

perfect hybrid

$$V = \Lambda_1^4 \left[1 - \cos\left(c_1\phi_1 + c_2\phi_2\right)\right] + \\ + \Lambda_2^4 \left[1 - \cos\left(c_1\phi_1 - c_2\phi_2\right)\right] + \\ + \Lambda_3^4 \left[1 - \cos\left(c_2\phi_2\right)\right]$$

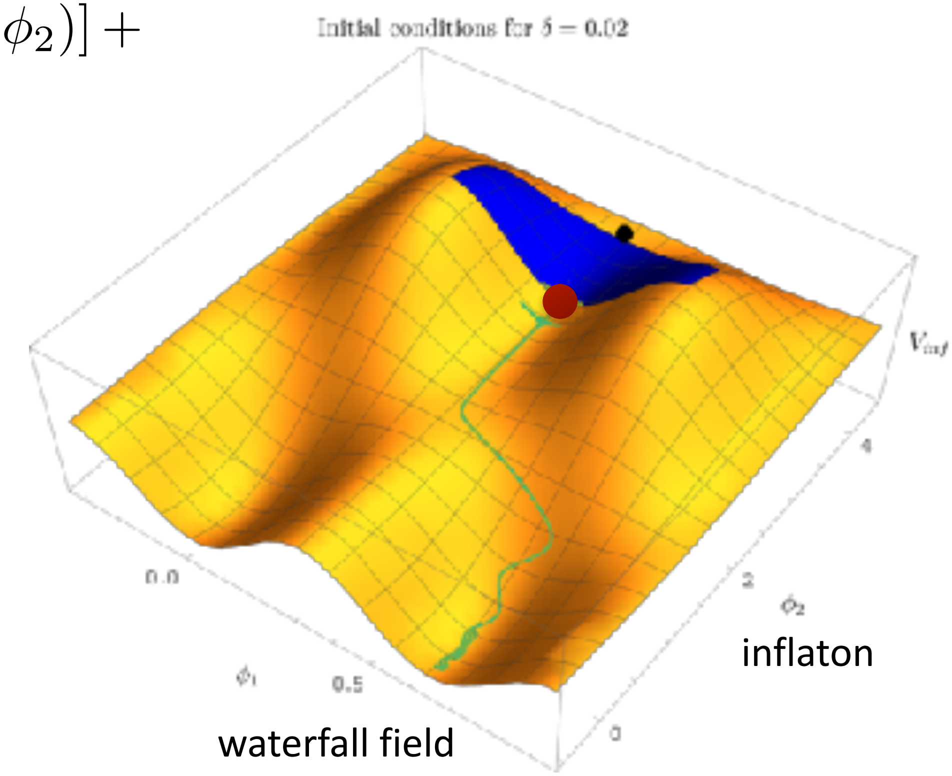
remaining freedom:

- relative phase of last term
- introduce a symmetry breaking effect to avoid DW formation

↓

✗ may preclude tachyonic preheating

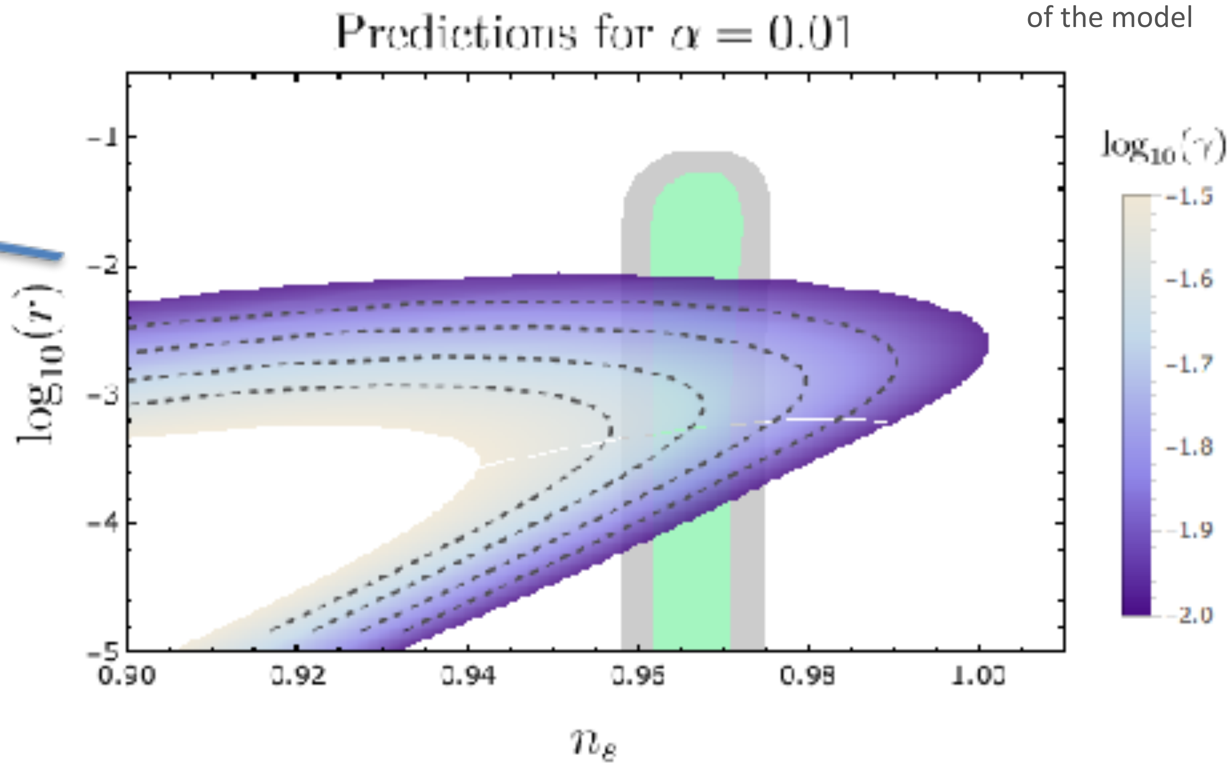
✓ but parametric resonances can still be there, need a dedicated study



NUMERICAL PREDICTIONS

detectable in the near future

parameters
of the model



POSSIBLE STRING THEORY REALISATIONS

IIB compactified to 4D on an orientifolded CY_3 : scalar d.o.f.

$$\begin{cases} G^a = c^a - \tau b^a & a = 1, \cdots, h^{1,1}_- \\ T_i = \tau_i + i \underbrace{\int_{D_i^+} C_4}_{\theta_i} & i = 1, \cdots, h^{1,1}_+ \end{cases}$$

POSSIBLE STRING THEORY REALISATIONS

IIB compactified to 4D on an orientifolded CY_3 : scalar d.o.f.

$$\begin{cases} G^a = c^a - \tau b^a & i = 1, \cdots, h^{1,1}_+ \\ T_i = \tau_i + i \underbrace{\int_{D_i^+} C_4}_{\theta_i} & a = 1, \cdots, h^{1,1}_- \end{cases}$$

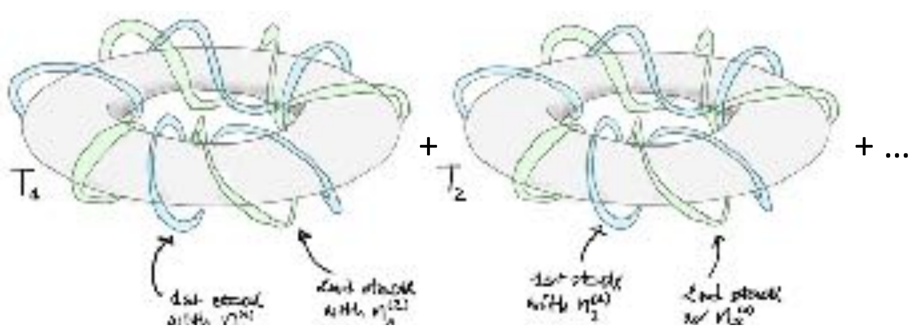
Long, McAllister, Mc Guirk '14

1) $h^{1,1}_- = 0$ ⇨ θ_i axions

+ stacks of D7 branes multiply-wrapping some of the 4-cycles

↓

$$W_{np} = A_j e^{-a_j n_i^j T_i} \qquad j = \text{stack}$$

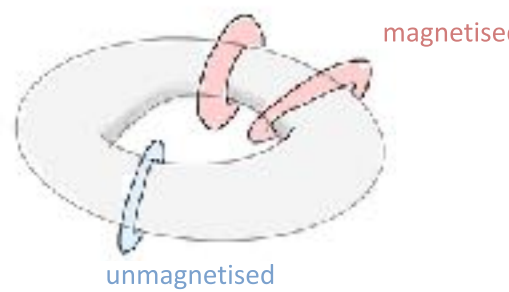


2) $h^{1,1}_- > 0$ ⇨ c^a axions

+ some of the stacks of D7 branes are magnetised

↓

$$W_{np} = A_j e^{-a_j (T_j + i k_{jab} F_j^a (G^b + \frac{\tau}{2} F_j^b))}$$



C_4 AXIONS

- LVS embedding: $\mathcal{V} \sim \alpha\tau_b^{3/2} - \beta\tau_s^{3/2} - \gamma\tau_{s_1}^{3/2} - \delta\tau_{s_2}^{3/2}$

cf. *Blumenhagen et al '07, Cicoli et al '12, …*

non pert. corrections to the superpotential

$$W = W_0 + A_s e^{-a_s T_s} + A_{s_2} e^{-a_{s_2} T_{s_2}} + \\ + A_{s_1} e^{-a_{s_1}\left(n^1_{s_1} T_{s_1} + n^2_{s_1} T_{s_2}\right)} + A_{s_2} e^{-a_{s_2}\left(n^1_{s_2} T_{s_1} - n^2_{s_2} T_{s_2}\right)}$$

C_4 AXIONS

LVS embedding: $\mathcal{V} \sim \alpha \tau_b^{3/2} - \beta \tau_s^{3/2} - \gamma \tau_{s_1}^{3/2} - \delta \tau_{s_2}^{3/2}$

cf. *Blumenhagen et al '07, Cicoli et al '12, …*

non pert. corrections to the superpotential

$$W = W_0 + A_s e^{-a_s T_s} + A_{s_2} e^{-a_{s_2} T_{s_2}} + \\ + A_{s_1} e^{-a_{s_1}\left(n_{s_1}^1 T_{s_1} + n_{s_1}^2 T_{s_2}\right)} + A_{s_2} e^{-a_{s_2}\left(n_{s_2}^1 T_{s_1} - n_{s_2}^2 T_{s_2}\right)}$$

potential for

- θ_{s_2} → inflaton
- θ_{s_1} → waterfall

$$V\left(\theta_{s_1}, \theta_{s_2}\right) = \Lambda_3^4 \cos\left(a_{s_2}\theta_{s_2}\right) + \\ + \Lambda_1^4 \cos\left[a_{s_1}\left(n_{s_1}^1 \theta_{s_1} + n_{s_1}^2 \theta_{s_2}\right)\right] + \\ + \Lambda_2^4 \cos\left[a_{s_2}\left(n_{s_2}^1 \theta_{s_1} - n_{s_2}^2 \theta_{s_2}\right)\right]$$

C_4 AXIONS

LVS embedding: $\mathcal{V} \sim \alpha\tau_b^{3/2} - \beta\tau_s^{3/2} - \gamma\tau_{s_1}^{3/2} - \delta\tau_{s_2}^{3/2}$

cf. *Blumenhagen et al '07, Cicoli et al '12, …*

non pert. corrections to the superpotential

$$W = W_0 + A_s e^{-a_s T_s} + A_{s_2} e^{-a_{s_2} T_{s_2}} + \\ + A_{s_1} e^{-a_{s_1}\left(n^1_{s_1} T_{s_1} + n^2_{s_1} T_{s_2}\right)} + A_{s_2} e^{-a_{s_2}\left(n^1_{s_2} T_{s_1} - n^2_{s_2} T_{s_2}\right)}$$

potential for

θ_{s_2} → inflaton

θ_{s_1} → waterfall

$$V(\theta_{s_1}, \theta_{s_2}) = \Lambda_3^4 \cos\left(a_{s_2}\theta_{s_2}\right) + \\ + \Lambda_1^4 \cos\left[a_{s_1}\left(n^1_{s_1}\theta_{s_1} + n^2_{s_1}\theta_{s_2}\right)\right] + \\ + \Lambda_2^4 \cos\left[a_{s_2}\left(n^1_{s_2}\theta_{s_1} - n^2_{s_2}\theta_{s_2}\right)\right]$$

Constraints on the free parameters of the pheno model and *viceversa*

e.g. maximizing $\Delta\phi_2$ while keeping a subplanckian *f* gives $n^2_{s_i} = \frac{N_{s_i}}{2\pi}$

C_2 AXIONS

- consider $h^{1,1}_{-} = 2$, $h^{1,1}_{+} = 3$
- assume τ_i , θ_i , b^a stabilised at a higher scale than c^a
- both $\Sigma^{(-)}_{1,2}$ intersect with $D^{(+)}_{1,2}$ while only $\Sigma^{(-)}_{2}$ intersects with $D^{(+)}_{3}$

C_2 AXIONS

- consider $h^{1,1}_- = 2$, $h^{1,1}_+ = 3$
- assume τ_i , θ_i , b^a stabilised at a higher scale than c^a
- both $\Sigma^{(-)}_{1,2}$ intersect with $D^{(+)}_{1,2}$ while only $\Sigma^{(-)}_2$ intersects with $D^{(+)}_3$

$$\mathcal{V} \sim \left(\tau_{D_1} + k^{D_1}_{ab} b^a b^b\right)^{3/2} - \left(\tau_{D_2} + k^{D_2}_{ab} b^a b^b\right)^{3/2} - \left(\tau_{D_3} + k^{D_3}_{22} (b^2)^2\right)^{3/2}$$

potential for

- c^2 → inflaton
- c^1 → waterfall

$$V = \Lambda^4_{D_1} \cos\left[\left(a_{D_1} k^{D_1}_{11} F^1_{D_1} + a_{D_1} k^{D_1}_{21} F^2_{D_1}\right) c^1 + \left(a_{D_1} k^{D_1}_{12} F^1_{D_1} + a_{D_1} k^{D_1}_{22} F^2_{D_1}\right) c^2\right] + $$
$$+ \Lambda^4_{D_2} \cos\left[\left(a_{D_2} k^{D_2}_{11} F^1_{D_2} + a_{D_2} k^{D_2}_{21} F^2_{D_2}\right) c^1 + \left(a_{D_2} k^{D_2}_{12} F^1_{D_2} + a_{D_2} k^{D_2}_{22} F^2_{D_2}\right) c^2\right] + $$
$$+ \Lambda^4_{D_3} \cos\left(a_{D_3} k^{D_3}_{22} F^2_{D_3} c^2\right)$$

Constraints on the free parameters + easier to include the symmetry breaking

CONCLUSIONS

- new model of 2-field inflation with peculiar observable features (in the near future)
- potentially easily embeddable in string theory
- interplay of the free parameters from the string model and the effective model: prediction of the firsts in function of the second and/or *viceversa*

Outlook

- analysis of dynamics after inflation / oscillons formation
- explicit and full string theory embedding
- possible realisation with thraxions

Thank you!

BACKUP I: THRAXIONS

Hebecker, Leonhardt, Moritz, Westphal '18

Thraxions: "C_2 - axions" present in CY compactifications with multi-throat regions

- ➪ periodic cosine potential due to the compactness of the CY
- ➪ $M_{pl} \gtrsim f_{thraxions} > f_{axions}$