

From String Data to Cosmology and Particle Physics

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Outline

- 1 Flux Compactification
- 2 String Data
- 3 De Sitter in String Landscape and Global Embedding

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Recent News in Flux Compactification

- Perturbative superstring provides a quantum gravity theory in 10D.
- From string to the real world: $10D \rightarrow 4D$
- What we want: $4D \mathcal{N} = 1$ Supersymmetry with chiral spectrum

Recent News in Flux Compactification

- Perturbative superstring provides a quantum gravity theory in 10D.
- From string to the real world: 10D $\rightarrow$ 4D
- What we want: 4D $\mathcal{N} = 1$ Supersymmetry with chiral spectrum
- Best under control: $\mathcal{N} = 1$ Flux Compactification
- Considering the flux, the geometry of the CY reacts back mildly by acquiring a non-trivial warp factor as $\mathcal{M}_4 \times X_6$:

$$ds^2 = h(y)^{-1/2} g_{\mu\nu}(x) dx^\mu dx^\nu + h(y)^{1/2} g_{mn}(y) dy^m dy^n$$

where $h(y) \equiv e^{2A(y)}$ is the **warp factor**, $\mu, \nu = 1, \dots, 4$,
 $m, n = 5, \dots, 10$.

Moduli Stabilization

- 1 Find a compactified space X_6 , such as $\mathcal{M}_4$ satisfy maximal Symmetry, i.e. $\mathcal{M}_4 = \{dS_4, AdS_4, \textit{Minks}\}$.
Chiral $\mathcal{N} = 1$ SUSY in 4D $\Rightarrow X_6$ be (orientifold) Calabi-Yau manifold

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(Fifth force experiments and the standard paradigm of early cosmology, i.e. Big Bang Nucleosynthesis.)
- 3 The existence of deformations of the underlying geometry (Moduli) .
The size (Kähler) and shape (complex) of the internal manifold is dynamically determined by the vacuum expectation values of moduli (Moduli Stabilization).

$$g \rightarrow g + \delta g \quad s.t. \quad R_{m\bar{n}}(g + \delta g) = 0. \quad \text{for } CY$$

For Kähler manifold, under proper gauge $\nabla(\delta g) = 0$, it decouples

- Kähler moduli: $\delta g_{m\bar{n}} = i v^i (\hat{D}_i)_{m\bar{n}}, \quad i = 1, \dots, h^{1,1}(X)$
- Complex moduli: $\delta g_{mn} = \frac{i}{||\Omega||^2} \bar{U}^a (\bar{\chi}_a)_{m\bar{p}\bar{q}} \Omega_n^{\bar{p}\bar{q}}, \quad a = 1, \dots, h^{2,1}(X)$

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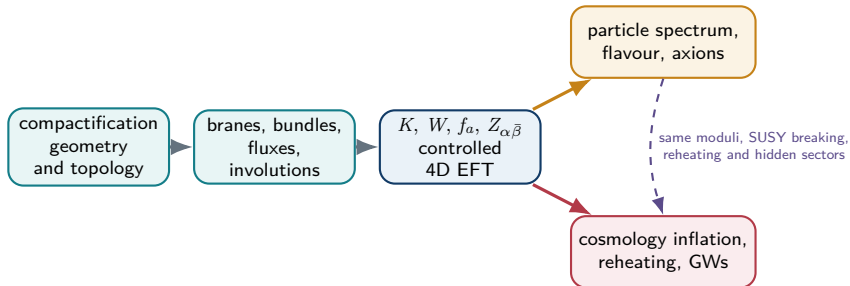
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- 4 Get the effective theory of these moduli (chiral spectrum). Based on some concrete model study the particle physics and cosmology.
Hard to achieve either of the two goals, more challenging to realize them simultaneously.

Combine two string pheno branches

- The **modern question** is not merely whether a SM spectrum or an inflationary potential exists. It is whether the construction survives **global consistency**, **moduli stabilization**, **quantum corrections**, and **canonical normalization** all the way to observables.



- Heterotic string, Orientifold Type IIA/B, F-theory/M-theory (**Yi-Nan's talk**) and Non-geometry compactification

4D $\mathcal{N} = 1$ flux compactification: Heterotic String

- Heterotic string on CY_3 + gauge bundles Candelas, Horowitz, Strominger, Witten, Donaldson, Uhlenbeck, Yau, ...,

Algorithmic approach: Spectrum: Monad line-bundle model-building
 $SU(5) \times S(U(1)^5)$: $V = \bigoplus_{a=1}^5 L_a$, $c_1(V) = 0$. Anderson, Gray, He, Lukas, Palti, Ovrut 08-12' ...

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Moduli Stabilisation? cicoli, Alwis, Westpha 13', Gray, Parsianl 18' Ibarra, Svanes 24' ...

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Numerical/ ML: Physical Yukawa coupling (HYM connection/ bundle-valued harmonic forms) on selected CY3, bundle constructions, and restricted loci in moduli space.

Donaldson 05', Douglas, Karp, Lukic, Reinbacher 07', ...Cui, Gray 19', Anderson, Gerdes, Gray, Krippendorf, Raghuram, Ruehle, 20', ..., Constantin, Taliente, Harvey, Lukas, Ovrut, 24', Butbaia, Pena, Tan, Berglund, Hübsch, Jejjala, Mishra, 24', Constantin, Leung, Lukas, Nutricati 25', Yip, Mininno, Shiu, 26'

ML: moduli-dependent metric Constantin, Lukas, Nutricati, 26'

ML: Non-Abelian vector bundles Mishra, Tan 25'

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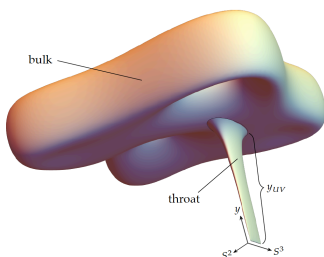
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- Heterotic on non-Kähler $SU(3)$ -structure manifolds with H -flux

Strominger, Hull, ..., Candelas, De La Ossa, Becker, Becker, Dasgupta, Green, Svanes ..., Lázari, Lotay, Earp, Svanes 24', Wu 26'

4D $\mathcal{N} = 1$ flux compactification: Orientifold Type IIB

- Type IIB is $\mathcal{N} = 2$. Break half SUSY to get $\mathcal{N} = 1 \Rightarrow$ **Orientifold CY3**
- Open string modes: **flux** and **D-brane**, introduce **O-plane** for **tadpole cancellation**.
- **Complex, dilaton moduli** decoupled with Kähler moduli and can be stabilized by Gukov-Vafa-Witten superpotential. **Gukov, Vafa, Witten 99'** **Kähler moduli** can be stabilized by (non-)perturbative effects (KKLT, Large Volume scenario). **Kachru, Kallosh, Linde, Trivedi 03', Jockers, Grimm, Louis, 04', Balasubramanian, Berglund, Colon, Quevedo 05'**
- The GKP geometry with strongly warped throat in Type IIB is locally described by **Klebanov-Strassler (KS)** solution.
Klebanov, Strassler, 00' Giddings, Karchru, Polchinski 01'



- The fluxes number is given by fluxes warpping on two 3-cycles at the conifold :
 $M = \int_A H_3, \quad K = \int_B F_3$, The throat carries $N = K \cdot M$ units of D3-brane charge contribute to tadpole.

4D $\mathcal{N} = 1$ flux compactification: Orientifold Type IIA

- With flux, Kähler moduli couples with complex, dilaton moduli [Grimm, Louis, 04'](#)
- DGKT shows fluxes can stabilize all closed-string geometric moduli in supersymmetric AdS_4 vacua [DeWolfe, Giriyavets, Kachru, Taylor 05'](#).
- Realize large volume, small coupling and [AdS-KK scale separation](#) simultaneously

$$L_{AdS} \gg L_{KK}, \quad M_{KK} L_{AdS} \gg 1, \quad M_{KK} \gg E \gg M_{AdS}, m_{moduli}$$

Swampland Distance Conjecture [Shiu, Tonioni, Hemelryck, Riet 22'](#)

[Strong](#)/Weak/Refined AdS Distance Conjecture [Coudarchet 23'](#)

CFT dual of DGKT? big spectrum gap of single-trace operators

Holographic decoupling [Bedroya, Steinhardt 25'](#) [Apers 26'](#)

- 10D description: the smeared solutions were related to half-flat geometries, localized O6 backreaction $\rightarrow$ torsional $SU(3)$ or $SU(3) \times SU(3)$ structure
[Grana, Minasian, Petrini, Tomasiello, 06'](#), [Benini 06'](#), [Junghans 20'](#)
- New scale-separated AdS families have been constructed on $SU(3)$ -structure spaces, while dynamical D6/open-string modes have begun to be included in gauged-supergravity analyses. [Carrasco, Coudarchet, Marchesano, Prieto 23'](#), [Cho, Kim 23'](#), [Balaguer, Bevilacqua, Dibitto, Melgarejo, Sudano 24'](#)
- [Questions](#): general O6 localization, special-Lagrangian D6 sectors, simultaneous open/closed-string stabilization, lack of dS uplift.

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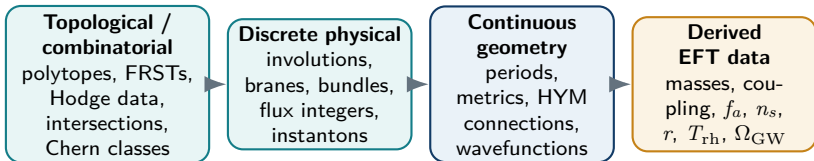
What is String Data?

Physical Quantity	Topology of Calabi-Yau
The particle spectrum	Moduli of geometry/intersection curve ...
# of generations of particle spectrum	Bundle-valued cohomology/Quiver ...
# of survive non-perturbative correction	Hodge number/Divisors ...
Holomorphic Yukawa coupling	Intersection number/(CY metric*) ...
# of tadpole	brane configuration/flux* ...
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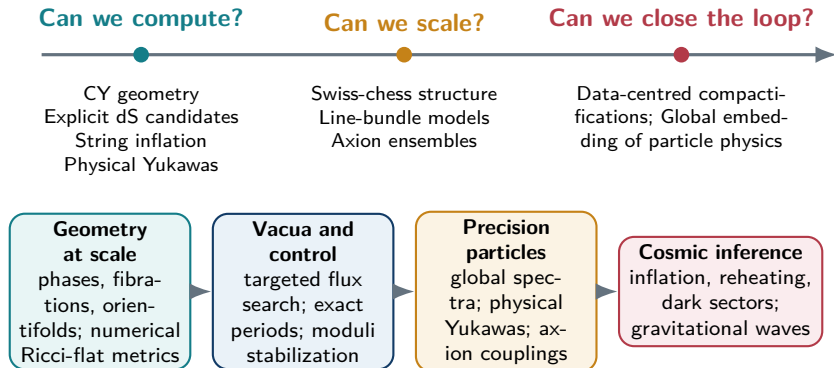
- Proper **String Vacuum** $\Leftrightarrow$ Proper **Geometry Configuration** + ...



- Exact data** are often integer-valued and exhaustively certifiable: intersection rings, indices, tadpoles, anomaly conditions and cohomology dimensions.
- Physical numbers** usually require continuous geometry: matter metrics, normalized wavefunctions, thresholds and a stabilized point in moduli space.

When does a compactification result become a prediction

Which compactification data survives exact consistency, dynamical control and normalization strongly enough to become an observable?



Calabi-Yau Database: Toric

Complicated	Construct? Property?
Abstract	Metric? Scattering Amplitude?
Tremendous	Finite?

- Toric Calabi-Yau Borisov, Batyrev, Cox, Hosono, Klemm, Theisen, Yau 90s', Kreuzer, Skarke 02'
 - Hypersurface $\hookrightarrow$ 473,800,776 reflexive polyhedra in 4D
Kreuzer, Skarke, 02', Altman, Gray, He, Jejjala, Nelson, 14'...
 $CY_3: \mathcal{O}(10^{10}) \leq \# \leq \mathcal{O}(10^{920}), \mathcal{O}(10^{296})$
Demirtas, Long, McAllister, 20' Gendler, MacFadden, McAllister, Moritz, Nally, Schachner, Stillman 23' MacFadden, Orevkov, Stepniczka 26'
FRST triangulation: SAGE, SINGULAR, PALP, CYTools ...
Q-learning/ NTFE Demirtas, Rios-Tascon, McAllister 22' Berglund, Butbaia, He, Heyes, Hirst, Jejjala 25', MacFadden 26'
vex triangulation Huang, Taylor 19', MacFadden, Sheridan 25'
 - Complete Intersection?
- Fibration Structure organize dualities, F-theory limits, anisotropic hierarchies and fibre-modulus inflation.
Genus-one/elliptic fibrations in KS 2.265×10^9 Abbasi, Nally, Taylor, 25', with flux (See Yi-Nan's Talk)

Calabi-Yau Database: CICY

- Complete Intersection Calabi-Yau (CICY)
 - Complete intersection hypersurfaces $\hookrightarrow$ Product of projective spaces
7,890 configuration matrices for CY3 Hubsch/Candelas/Dale/Lutaken/
Schimmrigk/Green 80s'...
 - 921,497 configuration matrices for CY4 Gray/Haupt/Lukas 14'...
 - Generalized Complete Intersection Calabi-Yau Manifolds (gCICY)
Anderson, Apruzzi, XG, Gray, Lee 15', Berglund, Hübsch 16', Garbagnati, Geemen 17'
 $gCICY_3$: (1, 1), (2, 1)-type, $\# \geq 4000$ Wei, XG, Wang, 22'

$$X_{\text{CICY}} = \left[\begin{array}{c} \mathbb{P}^2 \\ \mathbb{P}^4 \end{array} \left\| \begin{array}{ccc} 1 & 1 & 1 \\ 3 & 1 & 1 \end{array} \right. \right], \quad X_{g\text{CICY}} = \left[\begin{array}{c} \mathbb{P}^1 \\ \mathbb{P}^1 \\ \mathbb{P}^5 \end{array} \left\| \begin{array}{cc} 1 & 1 \\ 1 & 1 \\ 3 & 1 \end{array} \right| \begin{array}{cc} -1 & 1 \\ 1 & -1 \\ 1 & 1 \end{array} \right]$$

- Fibration structure and Favorable CICY: When toric divisor classes on the Calabi-Yau hypersurface X are all descended from ambient space $\mathcal{A}$. 139,597 genus-one fibration and 30,974 K3 fibration. Anderson, XG, Gray, Lee 17'
- Finiteness? For CICY3 and toric hypersurface, all non-fibered CY coming from fibered geometry shrinking a divisor Anderson, Gray, Nally, Taylor 26'

Orientifold Calabi-Yau

- Based in the **favorable** CICY database, orientifold CICYs has been studied recently **Carta, Moritz, Westphal 20'**, more general $\mathbb{Z}_n$ free quotient of CICY was considered, **Gray, Wang 21'** **Cui, XG, Wang 25'**
- In toric CY, **exchange involution** was first studied systematically for $h^{1,1} \leq 4$ ($\# \sim \mathcal{O}(10^3)$) **XG, Shukla 13'** and for $h^{1,1} \leq 6$ with fully classification of **exchange involutions, fixed locus, free action**. **Altman, Carifio, XG, Nelson 21'**
Up to $h^{1,1} \leq 12$, Identify 156,709 proper divisor exchange involutions. All possible **single, double, and triple** reflections for $h^{1,1} \leq 6$ and part of them for $7 \leq h^{1,1} \leq 12$. In total, we construct 3.2×10^9 orientifold CY3. **Cao, Gao, XG, 24'** . (<https://github.com/GroupofXG/anewcydatabase/>)
- Among total 646903 CYs with $h^{1,1}(X) \leq 6$, only 5% of them admits a proper **divisor exchange orientifold**. Suitable for **Machine Learning** to extend our result to higher $h^{1,1}$ to search and classify orientifold CYs. **XG, Zhou 21'** **Cao, XG**
- Orientifold CY with single reflections **Crino, Quevedo, Schachner, Valandro 23'** and the orientifold structure from polytope aspects **Moritz 23'** were considered recently.

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Two Aspects of String Phenomenology

Two longstanding problems of realistic string model building

- **Global Issues:** Complete compact Calabi-Yau compactification with, **moduli stabilization**, **tadpole cancellation** and **Freed-Witten anomaly cancellation**, **SUSY breaking**, realizing **dS solution and cosmology** ...
- **Local Issues:** Local sets of lower dimensional D-branes, which are localised in some area of the Calabi-Yau and reproduce **chiral spectrum**, **tree-level Yukawa couplings**, **gauge couplings** ...

However, it is fair to say that models developed so far are still far from being realistic.

Toy Model for de-Sitter space I

- The generic result of a compactification with volume $\mathcal{V}$ with some positive-energy source is:

$$\mathcal{S}_4 \sim \mathcal{V} \left(R_4 - \frac{(\partial \mathcal{V})^2}{\mathcal{V}^2} - E \right)$$

- After Weyl-rescaling to the Einstein frame and introducing the canonical field $\phi = \ln(\mathcal{V})$:

$$\mathcal{S}_4 \sim \left(R_4 - (\partial \phi)^2 - E e^{-\phi} \right)$$

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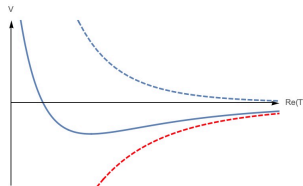
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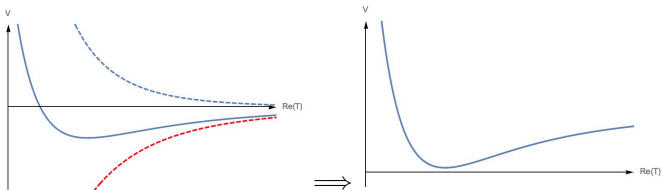
$V = E e^{-\phi}$, so the simplest compactifications lead to: $V'/V \sim \mathcal{O}(1)$.

- Combining two such runaway potentials with different sign allows in principle for AdS solutions. (Flux and D-brane potential (positive charge) and O-plane potential (negative charge))



Toy Model for de-Sitter space II

- At least 3 potential terms with different falloff and appropriate coefficients are needed to get dS. ($\overline{D3}$ /T-brane/nilpotent chiralfield uplift potential)

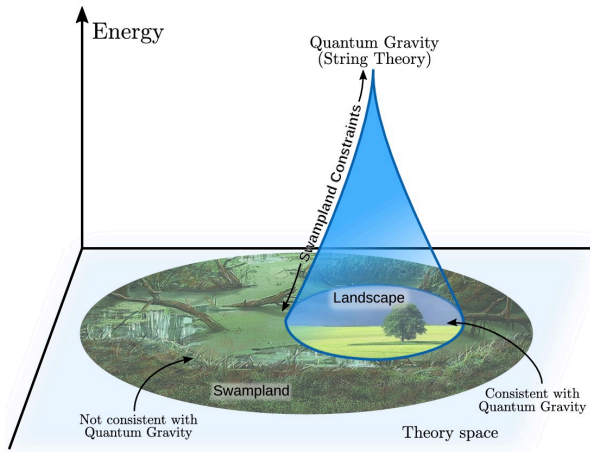


- If all parameters are $\mathcal{O}(1)$, this can never happen in parametric control.
- Swampland conjecture:** A potential $V(\phi)$ for scalar fields in a low energy EFT of any consistent QG must satisfy:

$$V'/V \gtrsim \mathcal{O}(1)$$

Oogru/ Palti/Shiu/Vafa

String Swampland Conjecture



KKLT and LVS

KKLT/LVS $\Rightarrow$ meta-stable dS vacua in 3-steps:

- Stabilize complex and dilaton moduli of orientifold CYs by fluxes, leading to a non-SUSY Minkowski minimum ($W = W_0 \neq 0, V = 0$). Gukov/Vafa/Witten
- Stabilize Kähler moduli by all possible perturbative and non-perturbative corrections.

$$K = K_{tree} + K_p + K_{np} \quad W = W_{tree} + W_{np}$$

leads to corrections of the $\mathcal{N} = 1$ scalar potential:

$$\delta V = \delta V_p + \delta V_{np}$$

- $g_s M \gtrsim 1$ for small curvature at KS tip (SUGRA control)
Klebanov/Strassler, Kachru/Pearson/Verlinde(KPV), Klebanov/Herzog/Ouyang
- $g_s M^2 \gtrsim 12$ for metastability of the $\overline{D3}$ (polarization of $\overline{D3}$ into NS5)
KPV, Bena/Dudas/Grana/Lust, Blumenhagen,Klawer,Schlechter 19 '
- Debate on the metastability of the $\overline{D3}$ in view of flux-backreaction.
Bena, Grana 11', Danielsson, Van Riet, Sethi 19' ...
- **Singular-Bulk Problem:** If the de-Sitter space exist, generically, the regime of KKLT is enforcing the warping factor $h(y) < 0$ in a large portion of the CY geometry, making the geometry largely singular.
Carta,Moritz,Westphal 20', XG, Hebecker, Junghans 20'
- Parameter **Tadpole Constraint** region in LVS
Bena,Blaback,Grana,Lust 20, Junghans 22, XG,Hebecker,Schreyer,Venken 22'

Type IIB orientifolds: flux vacua and de Sitter

$$(X, \sigma; F_3, H_3; D7/E3) \longrightarrow (S, U) \text{ fixed} \longrightarrow T_i \text{ stabilised} \longrightarrow \text{dS}.$$

- In **large-complex-structure** region, small W_0 and a strongly warped throat can support a string vacua. Demirtas, Kim, McAllister, Moritz 19' 20' Five explicit compactifications yield thirty metastable positive-energy minima at leading EFT order, including fluxes, ED3 effects and warped KS throats. McAllister, Moritz, Nally, Schachner 24'.
- The main unresolved issue is **parametric control**: the explicit candidates have $g_s M = O(1)$, while warping, localisation and subleading α' and g_s corrections are not yet fully controlled.
- Exact periods and modern search algorithms enable systematic enumeration or targeted generation of flux vacua with prescribed W_0 , tadpoles and mass hierarchies Chauhan, Cicoli, Krippendorff, Maharana, Piantadosi, Schachner 25' Walden, Larfors, 25'.
- A subsequent analysis argues that classical warping and mixed terms can compete with **F-term uplift** in the KKLT-like regimes studied, while LVS- like large-volume suppression can be parametrically more favorable. Hebecker, Lüst, Schachner, Schreyer 25'.
- Explicit leading-order candidates now exist; full parametric and numerical control has no community-wide closure.

Non-perturbative contribution to superpotential

Perturbative α'^3 correction to Kähler potential ($\tau = \text{Re}(T)$)

$$W = W_0 + A_s e^{-a_s T_s}, \quad K = -2 \ln \left(\mathcal{V} + \frac{\xi}{2g_s^{3/2}} \right) = -2 \ln \left(\tau_b^{3/2} - \kappa_s \tau_s^{3/2} - \frac{\chi(X) \zeta(3)}{4(2\pi)^3 g_s^{3/2}} \right)$$

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This yields the pure LVS scalar potential

$$V_{LVS} \sim \frac{g_s \sqrt{\tau_s} e^{-2a_s \tau_s}}{\mathcal{V}} - \frac{g_s \tau_s W_0 e^{-a_s \tau_s}}{\mathcal{V}^2} + \frac{\xi W_0^2}{\sqrt{g_s} \mathcal{V}^3}$$

which is minimized by

$$\mathcal{V} = \frac{3\kappa_s |W_0| \sqrt{\tau_s}}{4a_s |A_s|} e^{a_s \tau_s}, \quad \tau_s = \frac{\xi^{2/3}}{(2\kappa_s)^{2/3} g_s} + \mathcal{O}(1),$$

leading to an AdS vacuum at exponentially large volume

$$V_{\text{AdS}} = -\frac{3\kappa_s g_s \sqrt{\tau_s} |W_0|^2}{8a_s \mathcal{V}^3}.$$

LVS expansion balance the perturbative and non-perturbative correction

$$\delta V_{\alpha'} \sim \delta V_{np} \sim \mathcal{O}\left(\frac{1}{\mathcal{V}^3}\right)$$

Typical String Moduli Inflation

$$V = V_{\text{LVS}}(\mathcal{V}, \tau_s, \dots) + V_{up} + V_{\text{inf}}(\tau_\phi)$$

- **Blow-up inflation:** $0.96 \leq n_s \leq 0.967$, $r \leq 10^{-10}$

Conlon/Quevedo 06, Bansal/Brunelli/Cicoli/Hebecker/Kuespert 24

$$\mathcal{V} \sim \tau_b^{3/2} - \tau_\phi^{3/2} - \tau_s^{3/2} \quad V_{\text{inf}} \sim V_0(1 - ae^{-b\hat{\phi}}) \quad \text{with} \quad \hat{\phi} \sim \ln \tau_\phi^{3/4}$$

- **Fiber inflation:** $0.965 \leq n_s \leq 0.97$, $0.005 \leq r \leq 0.007$.

Conlon/Burgess/Quevedo 08

$$\mathcal{V} \sim \sqrt{\tau_f} \tau_b - \tau_s^{3/2} \quad V_{\text{inf}} \sim V_0(1 - ae^{-b\hat{\phi}}) \quad \text{with} \quad \hat{\phi} \sim \ln \tau_f$$

- **Poly-instanton inflation:** $0.95 \leq n_s \leq 0.97$, $r \leq 10^{-5}$

Cicoli/Pedro/Tasinato 11, Blumenhagen/XG/Rahn/Shukla 12,12

$$\mathcal{V} \sim \tau_b^{3/2} - \tau_s^{3/2} - (\tau_s + \tau_w)^{3/2} \quad V_{\text{inf}} \sim V_0(1 - a\hat{\phi}e^{-a\hat{\phi}})$$

- Cosmological validity control, Large volume expansion control, Deformation control, Heavy moduli control, Kähler cone control

Parameter Control of Quantum correction

- Searching for LVS in orientifold CY Gray, He, Jejjala, Jurke, Nelson Simon 12', Altman, He, Jejjala, Nelson 17' ...
- It is well known that loop corrections is **danger** for these inflation and we need to consider them in detail. Conlon, Quevedo 06, Cicoli, Burgess, Quevedo 08
- From the ten-dimensional viewpoint, Type IIB orientifold corrections arise from classical warping, **genuine loop correction**, and local operators, reproducing BBHL and BHP-type scalings and generating possible logarithmic Kähler-potential corrections. Ciupke, Louis, Westphal 15, XG, Hebecker, Schreyer, Venken 22'
- The impact of **genuine loop correction** on blow-up inflation was considered recently. Bansal, Brunelli, Cicoli, Hebecker, Kuespert 24
- Fibre inflation is sensitive to the orientifold projection and D-brane configuration, and identify a controlled new mechanism in which generalized α' -loop corrections stabilise the fibre modulus and drive slow-roll inflation when the conventional BHP loop channels are absent. Li, XG, Wang 26'

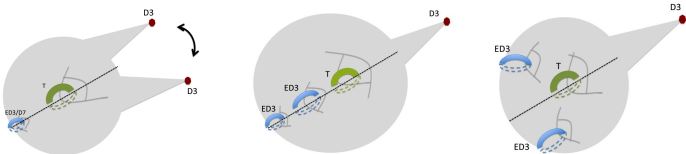
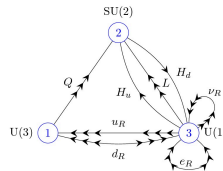
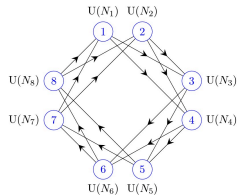
Orientifold CY: Particle Physics

- **Global embedding:** Combine particle physics together with moduli stabilisation and string cosmology. Important to solve the **chirality issue**.

Blumenhagen/Moster/Plauschinn 07', Balasubramanian/Berglund/Braun/Garcia-Etxebarria 12', Grimm/Weigand/Kerstan 11', Cicoli/Mayrhofer/Valandro/Quevedo/Krippendorff/Shukla 12'16'17'21' . . .

$$W = \prod_i \Phi_{ab} e^{-S_E}$$

- Fluxed Instanton: requiring $h_-^{1,1}(X) \neq 0$
- D-brane at singularity Picture from Wijnholt, Intriligator/Seiberg, Cicoli et al.



Type IIB orientifolds: visible sectors

geometry and branes $\longrightarrow$ moduli stabilisation $\longrightarrow$ inflation, particles and reheating.

- Visible sectors arise from D3-branes at singularities or magnetised D7-branes, subject to chirality, D7/D3 tadpoles, Freed–Witten constraints and massless hypercharge. [Bera, Chakraborty, Leontaris, Shukla 24'](#)
- An explicit K3-fibred orientifold combines a chiral D7 sector, Whitney brane, closed-string moduli stabilisation, warped uplift and viable Fibre Inflation [Cicoli, Grassi, Lacombe, Pedro 24'](#).
- Orientifold ensembles are increasingly connected directly to axions, dark photons, dark radiation, cosmic birefringence and inflaton visible/hidden decay channels [Sheridan, Carta, Gendler, Jain, Marsh, McAllister, Righi, Rogers, Schachner 25'](#).
- String compactifications generically contain light axions and moduli. A field with $m \sim H_0$ and a sufficiently flat potential may realise quintessence, while heavier stable axions can constitute cold, fuzzy or superheavy dark matter through misalignment or gravitational production. [Cicoli, Alwis, Maharana, Muia, Quevedo 18'](#), [Ling, Long, McDonough, Hayes 25'](#)

Missing benchmark

No single compactification yet combines a fully realistic Standard Model, physical Yukawas and soft terms with controlled dS/inflation, reheating and late-time cosmology.

Thanks for your attention!