A CICY scan for orientifolds

Federico Carta

DESY

25th of June 2019

Based on...

- A. Braun, F.C., J. Moritz, A. Westphal (to appear)

Related work:

- Y. Gao, P. Shukla, 2013
- R. Altman, 2017

Introduction

- Type II model building on $CY3$ needs O-planes for $\mathcal{N} = 1$ and tadpole cancellation
- Distinct types of $O7$-planes.
  1. $z \to -z$. Always leading to $h^{11}_{-} = 0$
  2. $z_i \to z_j$. Potentially leading to $h^{11}_{-} > 0$
- Every CY3 admits orientifolds of the first type. But **not all** admit orientifolds of the second type.
  Ex. Take a CY3 with $h^{11} = 2$ and D_1, D_2 different topology. Can't swap them!
- Natural question. Which CY3 can have non-trivial h^{11}_{-}?
- Pheno applications as h^{11}_{-} counts B_2 and C_2 axions.

Complete intersection CYs

- We focus on the database of complete intersection Calabi-Yaus. (CICY)
- K polynomial equations in $\mathbb{P}^{n_1} \times ... \times \mathbb{P}^{n_r}$
- Described by a configuration matrix:

$$\left[\begin{array}{c|ccc} \mathbb{P}^{n_1} & m_1^1 & \cdots & m_1^K \\ \vdots & \vdots & & \vdots \\ \mathbb{P}^{n_r} & m_r^1 & \cdots & m_r^K \end{array}\right] \tag{1}$$

- Threefold condition. $\sum_{i=1}^{r} n_r - K = 3$
- CY condition. $\sum_{j=1}^{K} m_i^j = n_i + 1$
- Classified. 7890 (P. Candelas et al.)

Favorable and non-favorable

- A CICY is ***favorable*** if all the divisors descend from the ambient space divisors
- Only $\sim$ 50% of the original CICYs list are favorable.
  Ex.

$$X = \left[\begin{array}{c|ccc} \mathbb{P}^2 & 2 & 0 & 1 \\ \mathbb{P}^1 & 1 & 1 & 0 \\ \mathbb{P}^3 & 0 & 1 & 3 \end{array} \right] \quad (2)$$

  $h^{11}(X) = 6$ so not favorable.
- Find *another* configuration matrix for the same CY, such that now it has a favorable description. (A. Anderson, Y. Gao, J. Gray, S. Lee, 2017)

Swapping ambient space divisors

- All configuration matrices in the original list admit a favorable description a part from 48 of them.
- For favorable CICYs we can see the $\mathbb{Z}_2$ action already at the level of the ambient space
- A $\mathbb{Z}_2$ action corresponding to a $O7$ plane has a codimension 1 fixed locus.
- Corresponds to swapping two $\mathbb{P}^1$s in the ambient space.
- Let us look how two different $\mathbb{P}^1$ can appear.

Swapping ambient space divisors

$$\begin{bmatrix} M & \vec{v}_1 & \vec{w}_2 & \vec{v}_2 & \vec{w}_2 \\ 0\cdots 0 & 1 & 1 & 0 & 0 \\ 0\cdots 0 & 0 & 0 & 1 & 1 \end{bmatrix}, \quad \begin{bmatrix} M & \vec{v}_1 & \vec{w} & \vec{v}_2 \\ 0\cdots 0 & 1 & 1 & 0 \\ 0\cdots 0 & 0 & 1 & 1 \end{bmatrix},$$

$$\begin{bmatrix} M & \vec{v} & \vec{w} \\ 0\cdots 0 & 1 & 1 \\ 0\cdots 0 & 1 & 1 \end{bmatrix}, \begin{bmatrix} M & \vec{v}_1 & \vec{v}_2 \\ 0\cdots 0 & 2 & 0 \\ 0\cdots 0 & 0 & 2 \end{bmatrix},$$

$$\begin{bmatrix} M & \vec{v} \\ 0\cdots 0 & 2 \\ 0\cdots 0 & 2 \end{bmatrix}, \quad \begin{bmatrix} M & \vec{v} & \vec{w} \\ 0\cdots 0 & 2 & 0 \\ 0\cdots 0 & 1 & 1 \end{bmatrix},$$

$$\begin{bmatrix} M & \vec{w} & \vec{v}_2 & \vec{v}_2 \\ 0\cdots 0 & 2 & 0 & 0 \\ 0\cdots 0 & 0 & 1 & 1 \end{bmatrix}.$$

Dropping cases

$$
\begin{bmatrix} M & \vec{v}_1 & \vec{w}_2 & \vec{v}_2 & \vec{w}_2 \\ 0\cdots 0 & 1 & 1 & 0 & 0 \\ 0\cdots 0 & 0 & 0 & 1 & 1 \end{bmatrix}, \quad
\begin{bmatrix} M & \vec{v}_1 & \vec{w} & \vec{v}_2 \\ 0\cdots 0 & 1 & 1 & 0 \\ 0\cdots 0 & 0 & 1 & 1 \end{bmatrix},
$$

$$
\begin{bmatrix} M & \vec{v} & \vec{w} \\ 0\cdots 0 & 1 & 1 \\ 0\cdots 0 & 1 & 1 \end{bmatrix}, \quad
\begin{bmatrix} M & \vec{v}_1 & \vec{v}_2 \\ 0\cdots 0 & 2 & 0 \\ 0\cdots 0 & 0 & 2 \end{bmatrix},
$$

$$
\begin{bmatrix} M & \vec{v} \\ 0\cdots 0 & 2 \\ 0\cdots 0 & 2 \end{bmatrix}, \quad
\begin{bmatrix} M & \vec{v} & \vec{w} \\ 0\cdots 0 & 2 & 0 \\ 0\cdots 0 & 1 & 1 \end{bmatrix},
$$

$$
\begin{bmatrix} M & \vec{w} & \vec{v}_2 & \vec{v}_2 \\ 0\cdots 0 & 2 & 0 & 0 \\ 0\cdots 0 & 0 & 1 & 1 \end{bmatrix}.
$$

Results for $O7$s

The CICYs in the $1+1$ class are

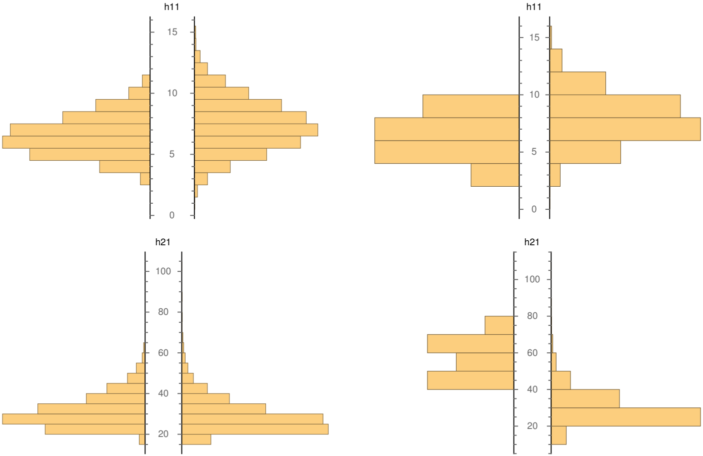
$$\Delta_{1+1} = \{289, 343, 357, 380, 713, 718, 782, 783, 1116, 1133, 1156, 1199, 1200, 1201, 1202, 1250, 1260, 1262, 1279, 1280, 1296, 1298, 1344, 1383, 1384, 1737, 1738, 1743, 1776, 1777, 1778, 1810, 1811, 1852, 1853, 1854, 1855, 1877, 1884, 1959, 2050, 2051, 2339, 2340, 2341, 2404, 2430, 2431, 2523, 2524, 2534, 2535, 2536, 2544, 2545, 2559, 2560, 2567, 2569, 2570, 2588, 2589, 2590, 2596, \ldots\}$$

The CICYs in the 2 class are

$$\Delta_2 = \{6829, 6925, 7459, 7709, 7731, 7830, 7859, 7862, 7880\}$$

In total 329 cases. 4.17% of the CICY list. All of them have $h^{11}_- = 1$

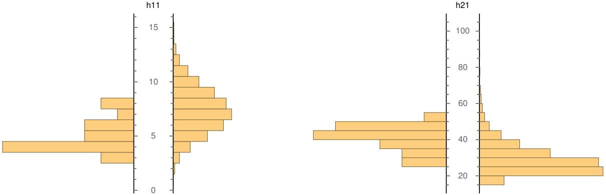
Results for $O7$s



$1+1$ $\qquad\qquad$ 2

Results for $O5$s

- Swapping two $\mathbb{P}^2$.

class	#	some properties	$h^{1,1}_-$
3	1	$\begin{bmatrix} 3 \\ 3 \end{bmatrix}^{7884}_{(2,83)}$	1
$2+1$	3	$\begin{bmatrix} 0 & 2 \\ 2 & 1 \\ 2 & 1 \end{bmatrix}^{7727}_{(3,51)}, \begin{bmatrix} 1 & 1 \\ 2 & 1 \\ 2 & 1 \end{bmatrix}^{7831}_{(3,60)}, \begin{bmatrix} 0 & 2 \\ 1 & 2 \\ 1 & 2 \end{bmatrix}^{7870}_{(3,69)}$	1
$1+1+1$	19		1

Results for $O5$s

- Swapping two $\mathbb{P}^1 \times \mathbb{P}^1$.

class	#	some properties	$h^{1,1}_-$
$(2,2)$	1	$\begin{bmatrix} 2 \\ 2 \\ 2 \\ 2 \end{bmatrix}^{7862}_{(4,68)}$	2
$(2,1+1)$	0	-	-
$(1+1,1+1)$	1	$\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 1 \\ 1 & 1 \\ 1 & 1 \end{bmatrix}^{7447}_{(5,45)}$	2

Results for $O3$s

- Codimension 3 fixed locus. We can:
  1. Swap two copies of $\mathbb{P}^3$
  2. Swap two copies of $\mathbb{P}^2 \times \mathbb{P}^1$
  3. Swap two copies of $\mathbb{P}^1 \times \mathbb{P}^1 \times \mathbb{P}^1$

$$\begin{bmatrix} 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}^{7626}_{(3,47)}, \begin{bmatrix} 0 & 0 & 0 & 2 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}^{7647}_{(3,47)}, \begin{bmatrix} 2 & 1 & 1 \\ 2 & 1 & 1 \end{bmatrix}^{7863}_{(2,66)} \tag{3}$$

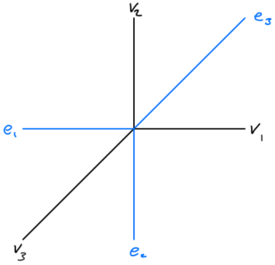
with $h^{1,1}_{-} = 1$, and

$$\begin{bmatrix} 0 & 1 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}^{7582}_{(4,46)} \tag{4}$$

with $h^{1,1}_{-} = 2$.

The 48 non-favorable cases

- 33 out of 48 admit a description as a single hypersurface in $dP_n \times dP_m$, or $\mathbb{P}^1 \times \mathbb{P}^1 \times \mathbb{P}^n$
- 15 out of 48 describe the Schön manifold
- Now it is favorable, but not CICY.
- For $n = 0, 1, 2, 3$, dP_n is toric.



- Look for $\mathbb{Z}_2$ action of the ambient space
- From the fan of dP_3 for example, we see

$$\begin{cases} v_1 \to v_2 \\ e_1 \to e_2 \end{cases} \tag{5}$$

Conclusions

- For favorable CICY, we performed the full scan.
- For the $O7$ case, $h^{11}_{-} = 0, 1$. We find 329 non-trivial cases. $\sim \mathbf{4}\%$
- For the $O5$ case, $h^{11}_{-} = 0, 1, 2$. Only 25 non-trivial cases.
- For the $O3$ case, $h^{11}_{-} = 0, 1, 2$. Only 4 non-trivial cases.
- For non-favorable CICYs, $h^{11}_{-} > 1$ might be possible.
- More work is needed for the non-favorable cases.

Thank you for your attention.

Funding acknowledgement:

This work is supported by the ERC Consolidator Grant STRINGFLATION under the HORIZON 2020 grant agreement no. 647995.