Heterotic—IIA duality and degenerations of K3 surface

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April 23, '16, Southeast Regional Meeting

based on 1604.xxxxx (appeared yesterday)

* away until Aug. '16

- Duality Het $\Longleftrightarrow$ IIA @6D

T^4 Narain K3

$$\mathrm{Isom}(\mathrm{II}_{4,20})\backslash O(4,20;\mathbb{R})/O(4)\times O(20)$$

Seiberg '88, Aspinwall Morrison '94, Vafa Witten '94 …

- 6D eff. theories w/ (1,1) SUSY
  fibred adiabatically over $\mathbb{P}^1$ $\longrightarrow$ 4D N=2 SUSY.

$$\mathrm{Het}/\text{"}T^2\times\text{"K3} \Longleftrightarrow \mathrm{IIA}/\text{K3-fib.}CY_3 = M$$

Kachru Vafa '95 Klemm Lerche Mayr '95
Ferrara et.al. '95, Vafa Witten '95, …….

- fibre adiabatically over $\mathbb{P}^1$
  - first step: specify a lattice polarization of K3 (IIA).

$$[U \oplus \Lambda_S] \otimes \mathbb{C} \quad \oplus \quad \Lambda_T \otimes \mathbb{C} \subset \mathrm{II}_{4,20} \otimes \mathbb{C}$$

	$[U \oplus \Lambda_S] \otimes \mathbb{C}$	$\Lambda_T \otimes \mathbb{C}$	
$(k^8 + ik^9)$	"fixed" over $\mathbb{P}^1$		$(B + iJ)[K3]$
$(k^6 + ik^7)$		vary over $\mathbb{P}^1$	$\Omega(\mathrm{K3})$

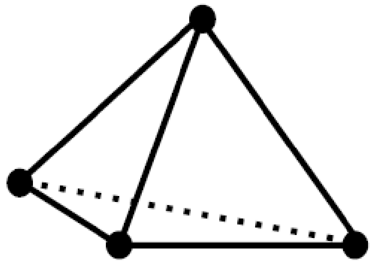
  - second: two aspects to study
    - further discrete choices in fibration. Part I
    - degeneration of fibre. not adiabatic. Part II

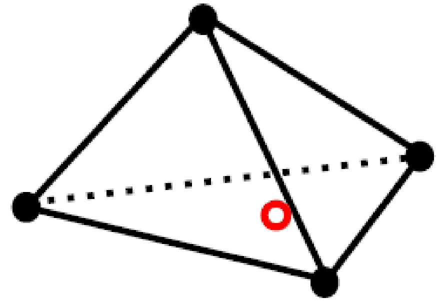
Part I:
Duality Dictionary of Discrete Data

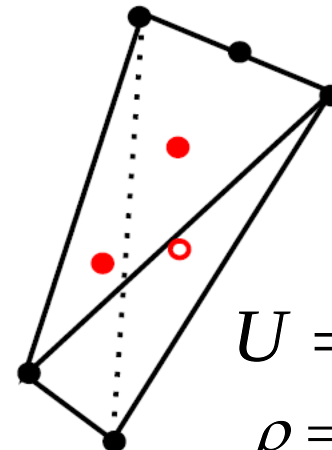
- Multiple choices of lattice-pol. K3 fibration

toric data (polytopes)

$\tilde{\Delta}_{K3} =$

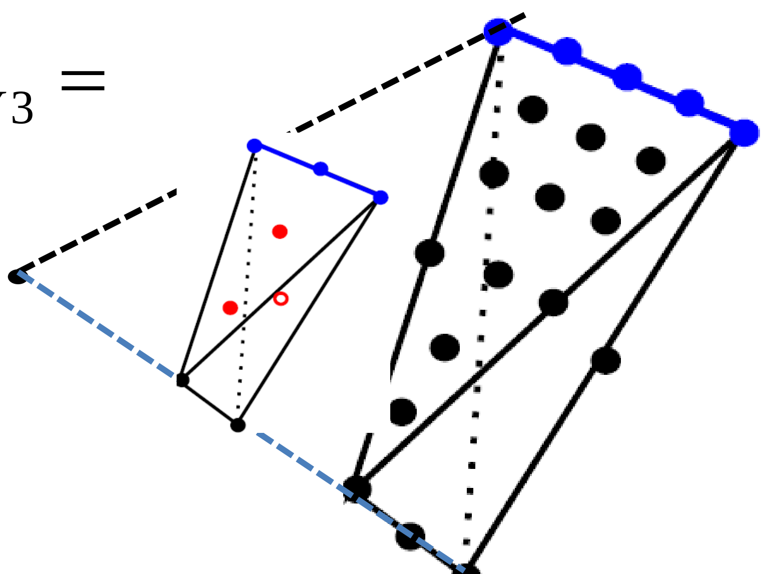






$\Lambda_S =$ $\langle +4 \rangle$ $\rho = 1$ $\langle +2 \rangle$ $\rho = 1$ $U = \mathrm{II}_{1,1}$ $\rho = 2.$

$\tilde{\Delta}_{CY3} =$



Choose any one from

$$2\tilde{\Delta}_{K3} \cap \mathbb{Z}^{\oplus 3}$$

For $h^{1,1}(M) = \rho + 1,$ blue points only.

Candelas Font '96

• Multiple choices of lattice-pol. K3 fibration

toric data (polytopes)

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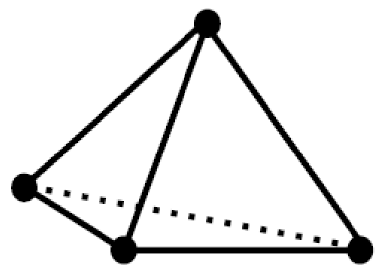

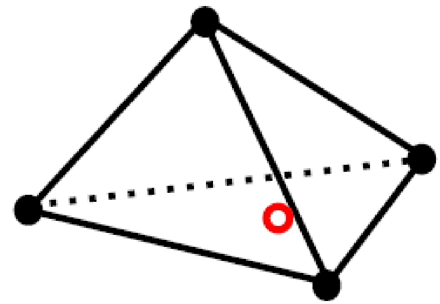

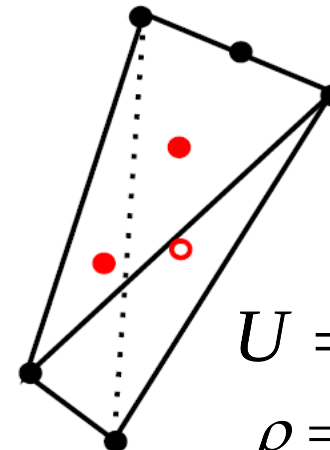

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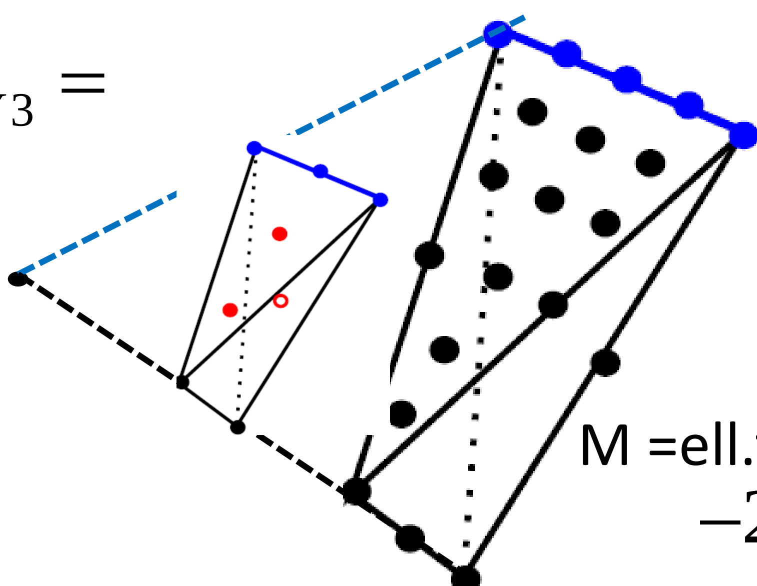

M =ell.fibr. over F_n
$-2 \leq n \leq +2.$

Choose any one from

$2\tilde{\Delta}_{K3} \cap \mathbb{Z}^{\oplus 3}$

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Candelas Font ‘96

- Multiple choices of lattice-pol. K3 fibration

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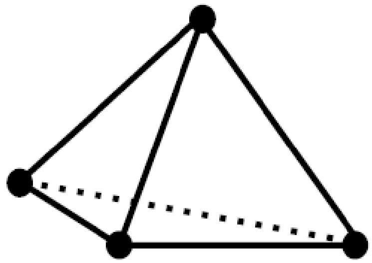

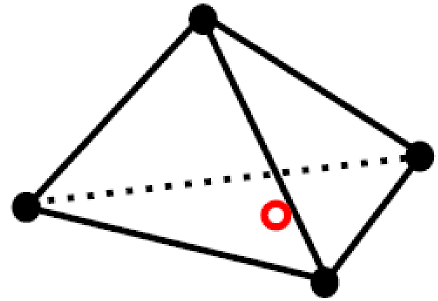

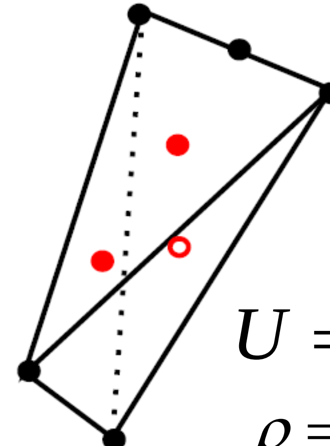

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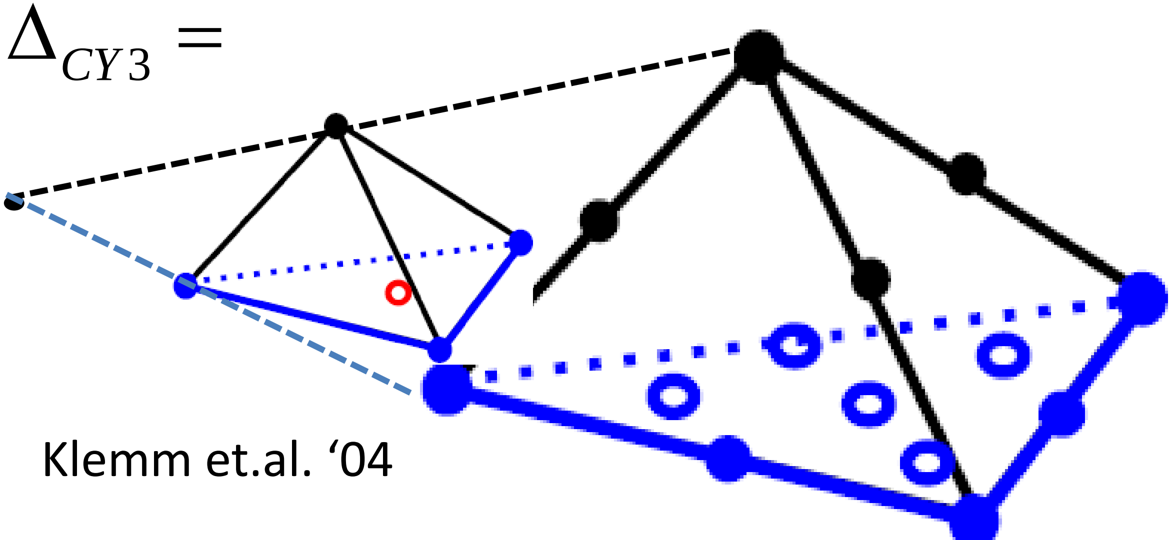

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For $h^{1,1}(M) = \rho + 1$, blue points only.

Klemm et.al. '04

Candelas Font '96

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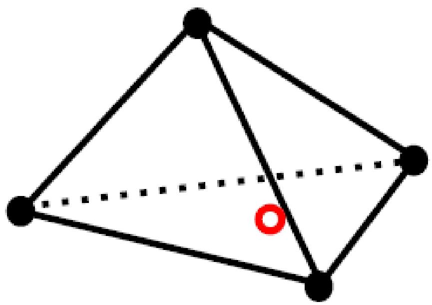


$$h^{1,1} + 1 = \#(vect) = 3$$
$$h^{2,1} + 1 = \#(hypr) = 129.$$

Kachru Vafa '95

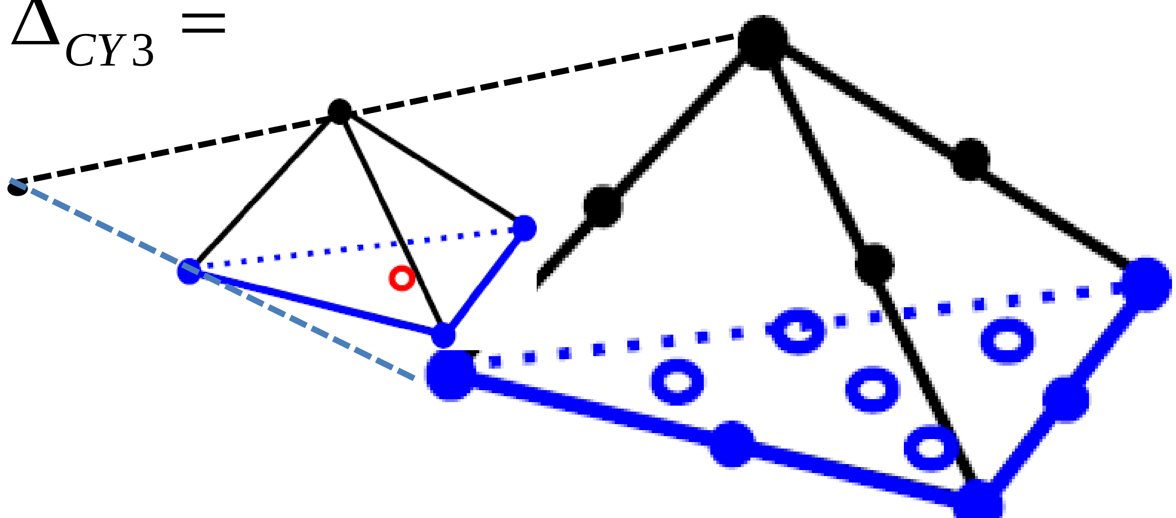
$\Lambda_S = \langle +2 \rangle$

$\rho = 1$

Type IIA on CY3 ⟺ Het on "T2 x" K3 instanton 4+10+10

GW-inv of vert. classes + **<div.div.div.> intersection** ⟺ Het 1-loop threshold

$\tilde{\Delta}_{CY3} =$



Kaplunovsky et.al.,
Antoniadis et.al. '95
Klemm et.al. '04

which one is dual?

- Multiple choices of lattice-pol. K3 fibration
  - 4319 choices (Λ_S, Λ_T) as toric hypersurface

Kreuzer Skarke '98

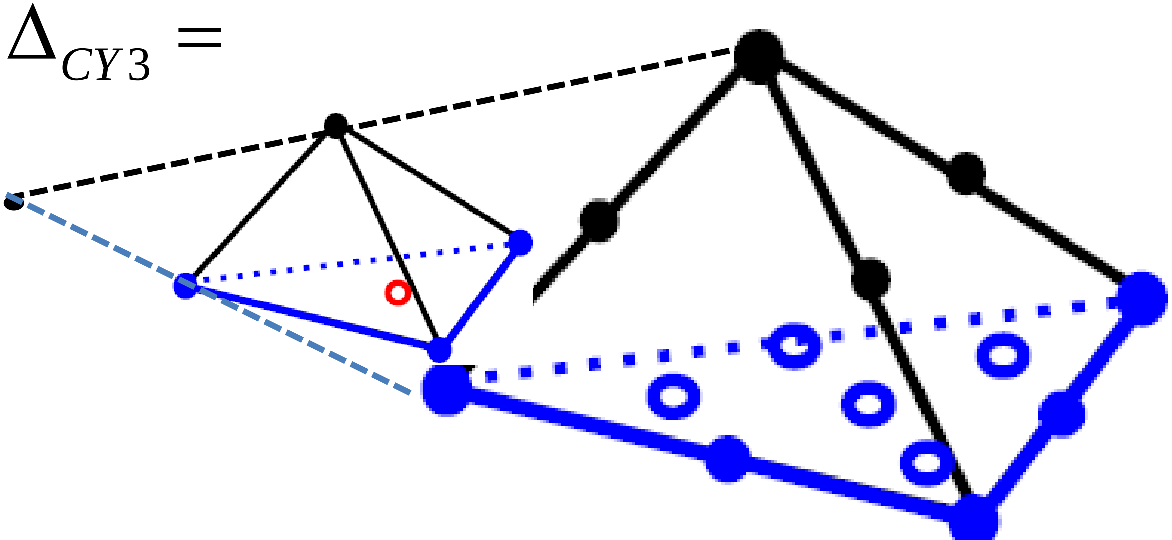
  - 3117 of them admit Λ_S-K3 fibration

    with $h^{1,1}(M) = \rho + 1$,

  - 1983 of them come with multiple choices,
    - sometimes the same $h^{2,1}$, sometimes not.

A. Braun

$\tilde{\Delta}_{CY3} =$

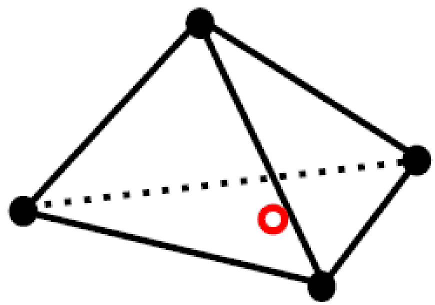


...... in Type IIA language

- In the case of deg.2-K3 fibration

Braun TW '16

$\tilde{\Delta}_{K3} =$



exploit detailed info. of
hyper –mult. moduli space

$$y^2 = F^{(6)}(X_2, X_3, X_4).$$

each coefficient → polynomial on $\mathbb{P}^1$

right DOFs for $E_8 \times E_8$ or not?

$\Lambda_S = \langle +2 \rangle \quad \rho = 1$

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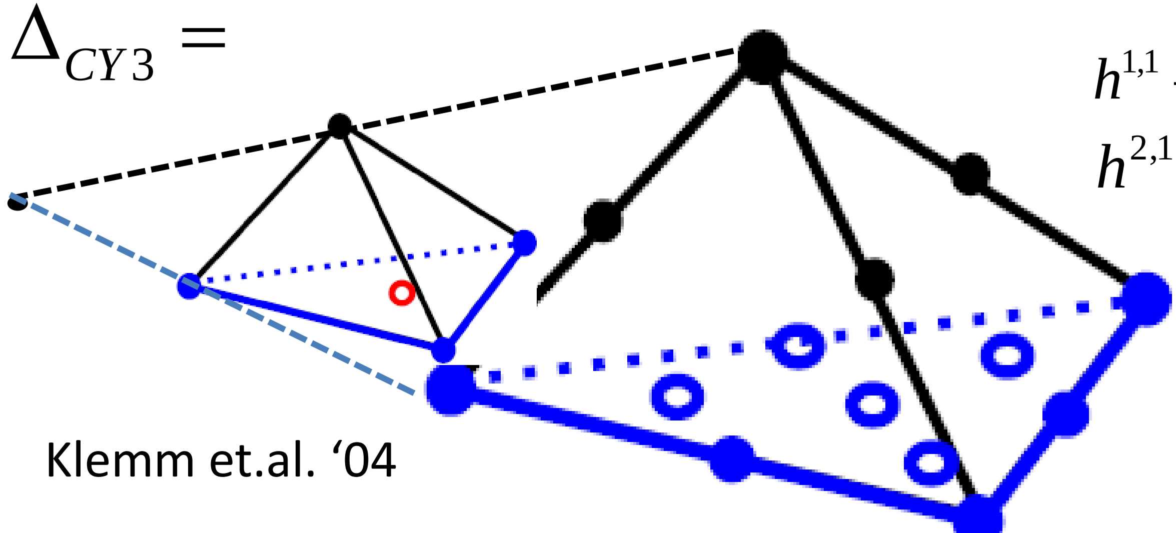
instanton 4+10+10

$\tilde{\Delta}_{CY3} =$



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Klemm et.al. '04

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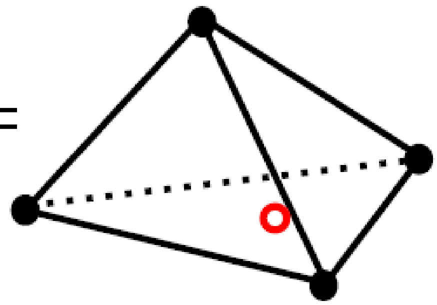

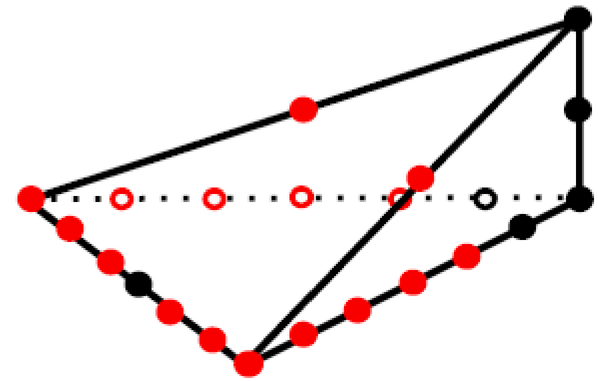

$= \Delta_{K3}$

coeff. w/ scaling

$(\varepsilon_\eta)^r (\varepsilon_K)^d$

⇕

section of

$\mathcal{O}_B(r\eta + dK_B)$

$$\begin{aligned} y^2 = \;& (a'_1 x_4^5 x_3 + a'_2 x_4^4 x_3^2 + a'_3 x_4^3 x_3^3 + a'_4 x_4^2 x_3^4 + a'_5 x_4 x_3^5 + a'_6 x_3^6) \\ & + (b'_1 x_4^3 x_3^2 + b'_2 x_4^2 x_3^3 + b'_3 x_4 x_3^4 + b'_4 x_3^5) + (c'_1 x_4 x_3^3 + c'_2 x_3^4) \\ & + x_4^6 + b_0 x_4^4 x_3 + c_0 x_4^2 x_3^2 + d_0 x_3^3 \\ & + (b_1 x_4^3 + b_2 x_4^2 + b_3 x_4 + b_4) x_3 + (c_1 x_4 + c_2) x_3^2 \\ & + (a_1 x_4^5 + a_2 x_4^4 + a_3 x_4^3 + a_4 x_4^2 + a_5 x_4 + a_6), \end{aligned}$$

$$\begin{aligned} a_{r=1,\cdots,6} &\in \Gamma(\mathbb{P}^1_A; \mathcal{O}(12 + r(I_v - 12))), \\ b_{r=1,\cdots,4} &\in \Gamma(\mathbb{P}^1_A; \mathcal{O}(8 + r(I_v - 12))), \\ c_{r=1,2} &\in \Gamma(\mathbb{P}^1_A; \mathcal{O}(4 + r(I_v - 12))), \end{aligned}$$

Braun TW ‘16

- In the case of deg.2-K3 fibration

Braun TW ‘16

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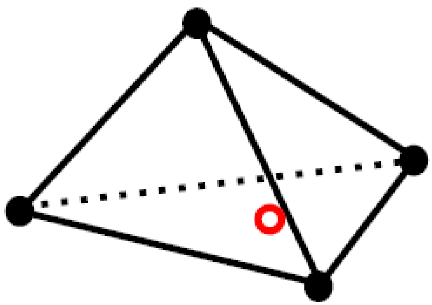

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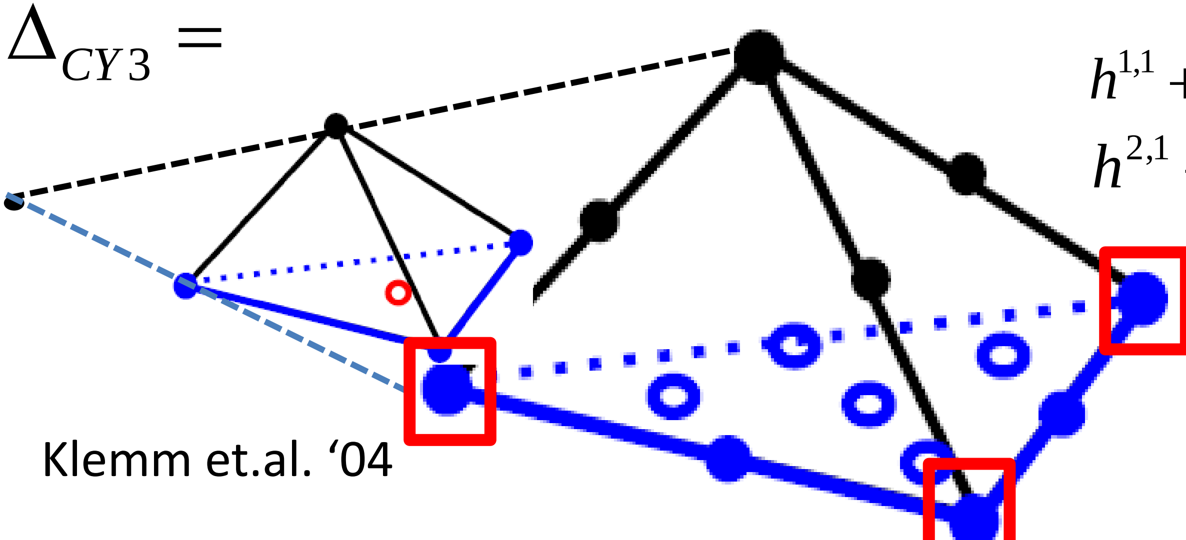

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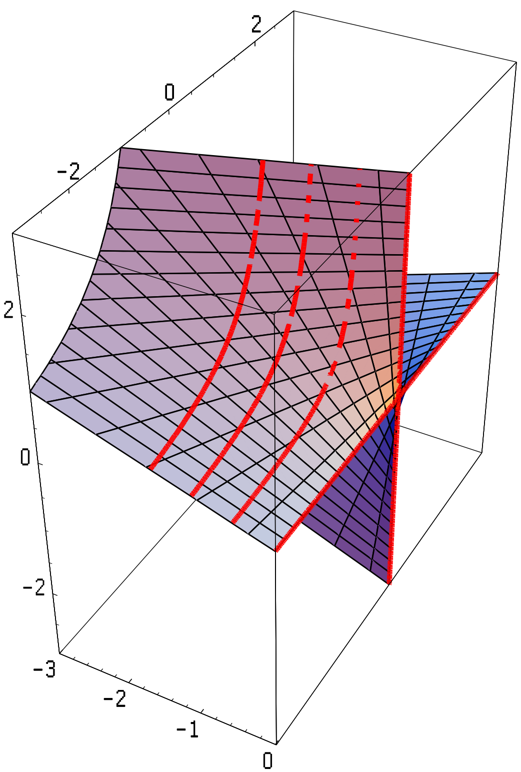
Klemm et.al. ‘04

Others do not allow free 4+10+10 instanton interpret’n.

Part II: degenerations of K3 and solitons

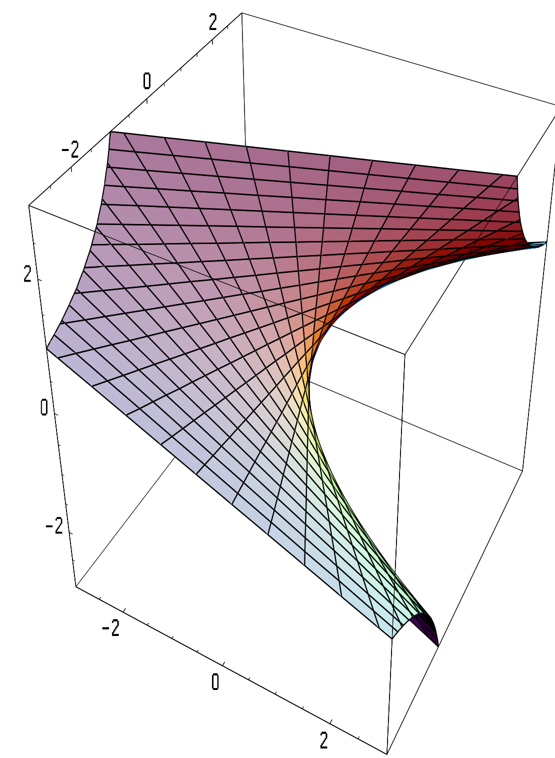


An example of degeneration

$$X = \{(x, y, t) \mid xy = t\}$$

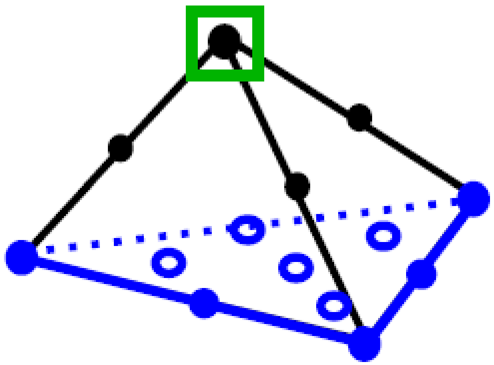
$$\downarrow$$

$$t \in \mathbb{C}$$



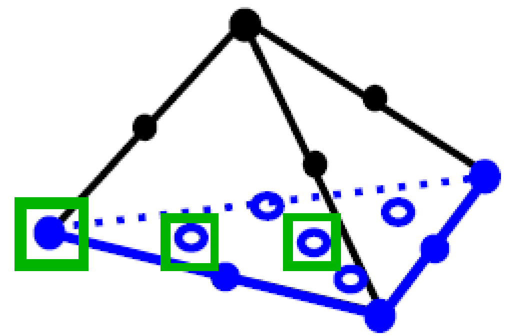
Friedman ’84, …., Davis et.al. ’13, Braun TW ‘16

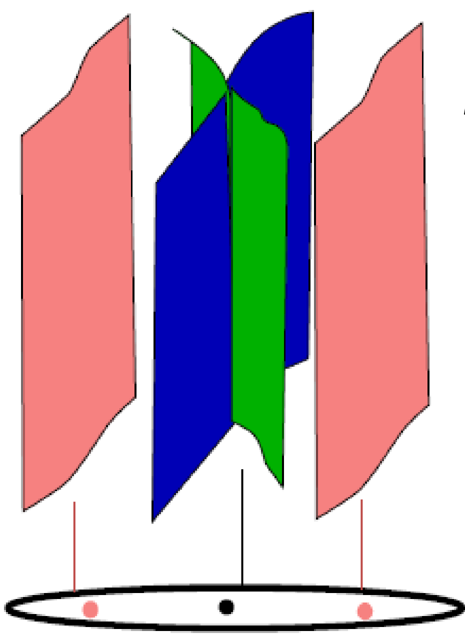
- Type IIA / M = deg-2 K3 fibr. over $\mathbb{P}^1$



Add point(s) from

$$2\tilde{\Delta}_{K3} \cap \mathbb{Z}^{\oplus 3}$$

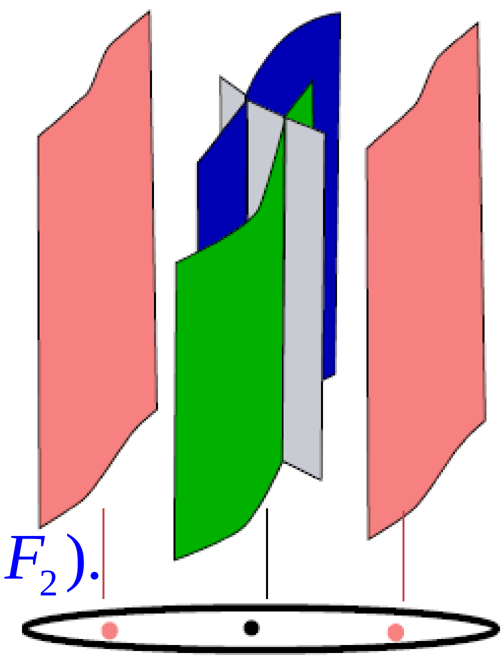




$$S_0 = \mathbb{P}^2 \cup \mathrm{Bl}^{18}(\mathbb{P}^2)$$

ruled surface
over ell. curve C

$$S_0 = dP_7 \cup \mathbb{P}[\mathcal{O}_C \oplus \mathcal{L}] \cup \mathrm{Bl}^{10}(F_2).$$

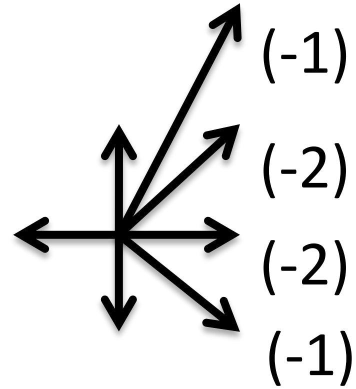


- Generalization

of IIA / CY_3 = ell.K3 fibr. over $\mathbb{P}^1$

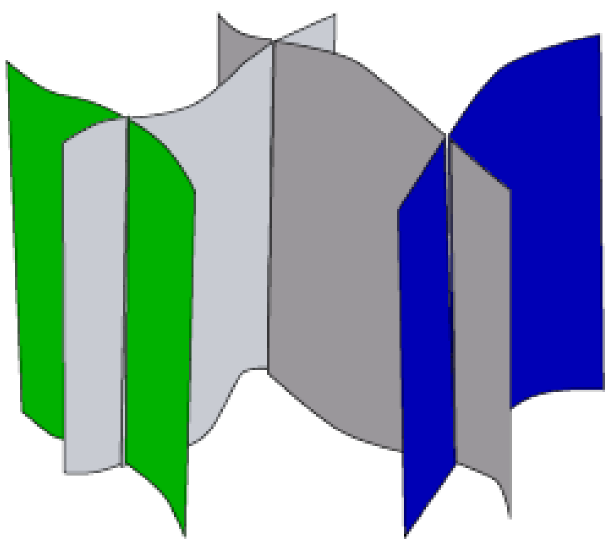
with degeneration

$= \text{ell.fibr. over Bl}^k(F_n)$



$= Bl^k(F_n)$

$S_0 = \text{RES} \cup (\text{T}^2 \times \mathbb{P}^1)^{k-1} \cup \text{RES}$



(-1) — (-2) — (-2) — (-1)

Dual to Het / T2 x K3
with k NS 5-branes

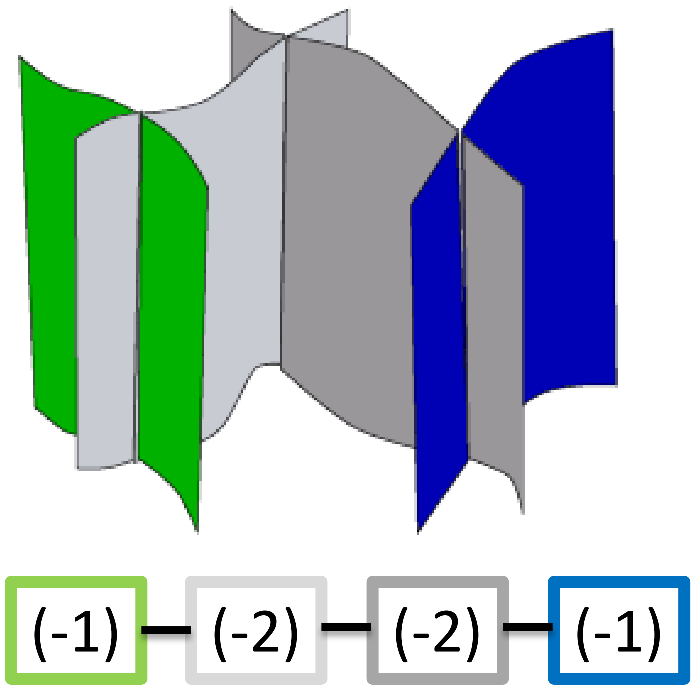
Ganor Hanany '96 Morrison Vafa '96

- Generalization

IIA / $CY_3 = \Lambda_S$ pol. K3 fibr. over $\mathbb{P}^1$ with degeneration

Type II degeneration of lattice-pol. K3 surface

$$S_0 = \mathrm{RES} \cup (\mathrm{T}^2 \times \mathbb{P}^1)^{k-1} \cup \mathrm{RES}$$



generic fibr. S_t degen. to

$$S_0 = V_0 \cup V_1 \ldots V_{k-1} \cup V_k$$

rational surfaces

$\mathbb{P}^1$-fibr over ell. curve

Clemens—Schmid exact sequence

monodromy

$$T : \Lambda_T(S_t) \to \Lambda_T(S_t)$$

$$T =: \exp[N], \qquad N^2 = 0.$$

Kulikov , Persson, Pinkham, Friedman,
Morrison, Looijenga, Saha, Scattone, ….

Type II degeneration of lattice-pol. K3 surface

generic fibr. S_t degen. to

$$S_0 = V_0 \cup V_1 \ldots V_{k-1} \cup V_k$$

rational surfaces

$\mathbb{P}^1$-fibr over ell. curve

$$\Lambda_T$$

$$[\text{rank } 4] \oplus R \cong [\text{transc. lattice}]$$

Clemens—Schmid exact sequence

monodromy

$$T : \Lambda_T(S_t) \to \Lambda_T(S_t)$$

$$T =: \exp[N], \qquad N^2 = 0.$$

$$\Delta \begin{pmatrix} 1 \\ -\tau \\ \rho\tau - a^2 \\ \rho \end{pmatrix} = N \bullet \begin{pmatrix} 1 \\ -\tau \\ \rho\tau - a^2 \\ \rho \end{pmatrix}, \qquad \Delta\rho = 1.$$

Het dual: soliton,
monodromy in Narain moduli

- back to examples. (deg-2 K3 fibre)

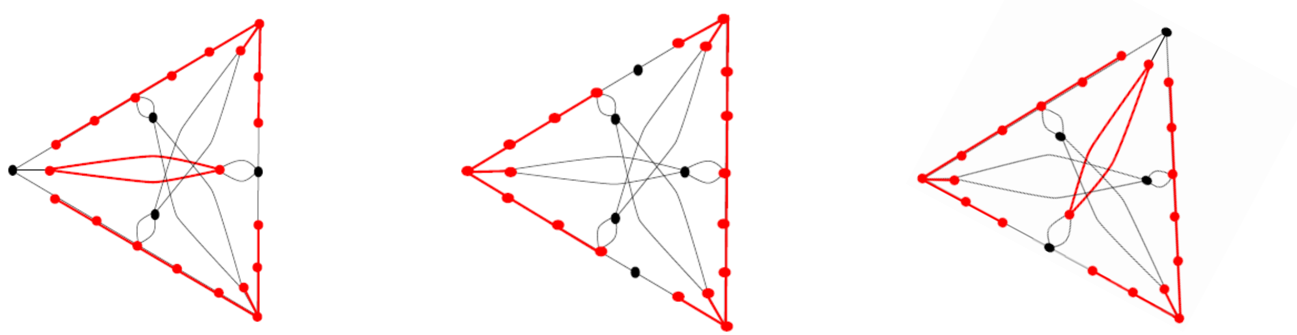
degen. to $S_0 = dP_7 \cup \mathbb{P}[\mathcal{O}_C \oplus \mathcal{L}] \cup \mathrm{Bl}^{10}(F_2).$ $\quad R = (E_7 + D_{10}); \mathbb{Z}_2,$

degen. to $S_0 = \mathbb{P}^2 \cup \mathrm{Bl}^{18}(\mathbb{P}^2)$ $\quad \Rightarrow \quad R = A_{17}; \mathbb{Z}_3.$

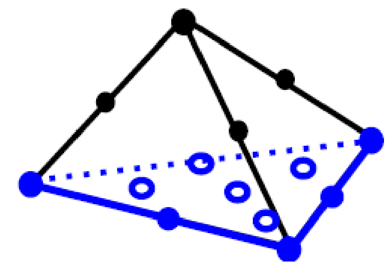
degen. to $S_0 = dP_8 \cup \mathbb{P}[\mathcal{O}_C \oplus \mathcal{L}] \cup V_2(\chi = 13)$ $\quad R = E_8^{\oplus 2} \oplus A_1$

all fall into 4 classes for deg2 K3 Type II degen. $\quad [\mathrm{rank}\ 4] \oplus R \cong \Lambda_T$

- Het interpretation: defects in $\mathbb{P}^1$ = corridor branches
  - NS 5-brane: $\Lambda_S = U, \ R = E_8 + E_8,$
  - 1st eg. above: $\Lambda_S = <+2>, \ R = (E_7 + D_{10}); \mathbb{Z}_2.$



- More varieties in degeneration of K3 surface
  - Type III: dual graph = triangulation of sphere
    - monodromy $T = \exp[N], \quad N^3 = 0.$
    - construction: Davis et.al. '13
    - more hyper-moduli -tuned solitons.



  - non semi-stable: reducible fibre with $m \neq 1.$
    - turned into semi-stable, after base change of order k
    - $T^k = \exp[N], \quad N^3 = 0.$ would-be Type II or III.

- Lattice polarization: which pair of solitons can be BPS together.