Type IIB flux compactifications with $h^{1,1} = 0$

Timm Wrase

LEHIGH UNIVERSITY

July 8th, 2022

Becker, Gonzalo, Walcher, TW in progress
Bardzell, Gonzalo, Rajaguru, Smith, TW 2203.15818
Becker, Becker, Walcher 0706.0514
Becker, Becker, Vafa, Walcher hep-th/0611001

Swampland Conjectures

- There are no 4d dS vacua in string theory

Danielsson, Van Riet 1804.01120

Obied, Ooguri, Spodyneiko, Vafa 1806.08362

…

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Gautason, Van Hemelryck, Van Riet 1810.08518

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- No 4d Minkowski vacua without massless scalars

Gautason, Van Hemelryck, Van Riet 1810.08518

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- There are no (SUSY?) 4d AdS vacua in string theory

D. Lüst, Palti, Vafa 1906.05225

Buratti, Calderon, Mininno, Uranga 2003.09740

…

Demirtas, Kim, McAllister, Moritz, Rios-Tascon 2107.09064

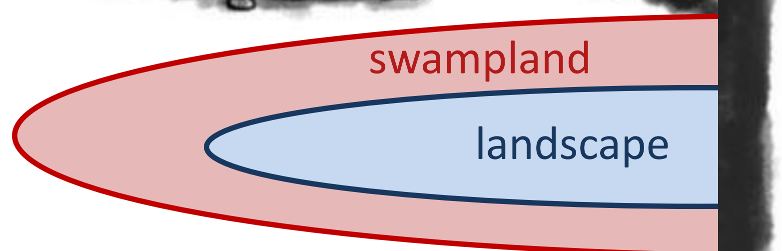
…

Swampland Conjectures

- Have not studied string theory in its fully generic form but usually only in certain regions: *large volume, weak coupling, with supersymmetry, ….*

- Try to understand larger parts of the string landscape

- Not easy $\Rightarrow$ incremental steps



Outline

- Review of flux compactifications in type IIA and IIB
- 4d $\mathcal{N} = 1$ Minkowski vacua from type IIB with $h^{1,1} = 0$
- 4d $\mathcal{N} = 1$ AdS vacua from type IIB with $h^{1,1} = 0$
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Type II Flux Compactifications

Type IIA

All moduli stabilized: $h^{2,1} = 0$

Type IIB

All moduli stabilized: $h^{1,1} = 0$

- Type IIA and type IIB on CY_3 related by mirror symmetry
- Extends to spaces with $h^{2,1} = 0$ that are dual to *spaces* with $h^{1,1} = 0$

$$
\begin{array}{ccccccc}
 & & & 1 & & & \\
 & & 0 & h^{1,1} & 0 & & \\
 & 1 & h^{2,1} & & h^{1,2} & 1 & \\
 & & 0 & h^{1,1} & 0 & & \\
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- Type IIA and type IIB on CY_3 related by mirror symmetry
- Extends to spaces with $h^{2,1} = 0$ that are dual to *spaces* with $h^{1,1} = 0$
- $h^{1,1} = 0$ seems to imply absence of an underlying geometry (which is fine for string theory)
- Actually, string frame volume is fixed by an orbifold to an $O(1)$ value and cannot fluctuate

Type IIB Flux Compactifications

- Flux compactifications with $h^{1,1} = 0$ where originally studied in 2006 and 2007

Becker, Becker, Vafa, Walcher hep-th/0611001

Becker, Becker, Walcher 0706.0514

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- Recently revisited in the swampland context

Ishiguro, Otsuka 2104.15030

- Given the plethora of recent swampland conjectures a further and closer look is warranted

Bardzell, Gonzalo, Rajaguru, Smith, TW 2203.15818

Becker, Gonzalo, Walcher, TW in progress

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Becker, Becker, Vafa, Walcher hep-th/0611001

Becker, Becker, Walcher 0706.0514

- The authors were guided by trying to find the dual of a $\frac{T^6}{\mathbb{Z}_3 \times \mathbb{Z}_3}$ type IIA flux compactification with $h^{2,1} = 0$

DeWolfe, Giryavets, Kachru, Taylor hep-th/0505160

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DeWolfe, Giryavets, Kachru, Taylor hep-th/0505160

- They study Landau-Ginzburg models that are dual to rigid Calabi-Yau manifolds

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- IIB H-flux in $W^{IIB} = \int (F_3 - \tau H_3) \wedge \Omega$ becomes $H_{ijk} \;\rightarrow\; H_{ijk}, f^{i}_{jk}, Q^{ij}_{k}, R^{ijk}$ under mirror symmetry

$\Rightarrow$ IIB setup contains DGKT but is more generic

Type IIB Flux Compactifications

- Focus on $1^9/\mathbb{Z}_3$ model, where $\mathbb{Z}_3$ is a ‘quantum symmetry’ (not geometric and fixes Kähler moduli, $h^{1,1} = 0$)

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- Model is mirror dual of geometric $T^6/\mathbb{Z}_3 \times \mathbb{Z}_3$ with $h^{2,1} = 0$

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- Model is mirror dual of geometric $T^6/\mathbb{Z}_3 \times \mathbb{Z}_3$ with $h^{2,1} = 0$
- They work out/discuss how to include D3-branes, O3-planes and fluxes that give Kähler and superpotential
- Find SUSY and AdS Minkowski vacua
- Discuss also 2^6 model which allows for larger O3 charge

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The effective 4d superpotential

- Type IIB compactifications with $h^{1,1} = 0$ one has

$$W(U_a, \tau) = \int (H_{RR} - \tau\, H_{NS}) \wedge \Omega(U_a), \qquad a = 1, \dots, h^{2,1}$$

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- Restricting to the bulk moduli of the underlying torus and setting the three bulk complex structure moduli equal, $U = U_1 = U_2 = U_3$:

$$W = W_{RR}(U) - \tau\, W_{NS}(U)$$
$$W_{RR}(U) = f_0 + 3f_1 U + 3f^1 U^2 + f^0 U^3$$
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- Generically, $h^{2,1} = 63$ complex structure moduli and τ
- Can solve the full LG model at the Fermat point

Supersymmetric Minkowski vacua

- Superpotential in 4d $\mathcal{N} = 1$ not protected and can receive corrections $\Rightarrow$ No Minkowski vacua for $\mathcal{N} < 2$?

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- These models have 4d $\mathcal{N} = 1$ Minkowski vacua due to powerful non-renormalization theorems!

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Becker, Becker, Walcher 0706.0514

- Appear in simple *and* full fledged models where all moduli are taken into account
- Actually, there are infinite families of such vacua!

Bardzell, Gonzalo, Rajaguru, Smith, TW 2203.15818

Supersymmetric Minkowski vacua

Solve $\partial W = W = 0$:

$$f^0 = -4, \qquad f^1 = 0, \qquad f_1 = 0, \qquad f_0 = 4,$$
$$h^0 = -3 - h_0, \qquad h^1 = 1, \qquad h_1 = -1$$

$$U = e^{\frac{2\pi i}{3}}, \qquad \tau = \frac{(6 + 4h_0) + i\, 2\sqrt{3}}{3 + h_0(3 + h_0)}$$

Tadpole: $N_{flux} = \int F_3 \wedge H_3 = 12$ independent of $h_0 \in \mathbb{Z}$

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$$Im(U) = \frac{\sqrt{3}}{2}$$

Never at large complex structure
but no corrections

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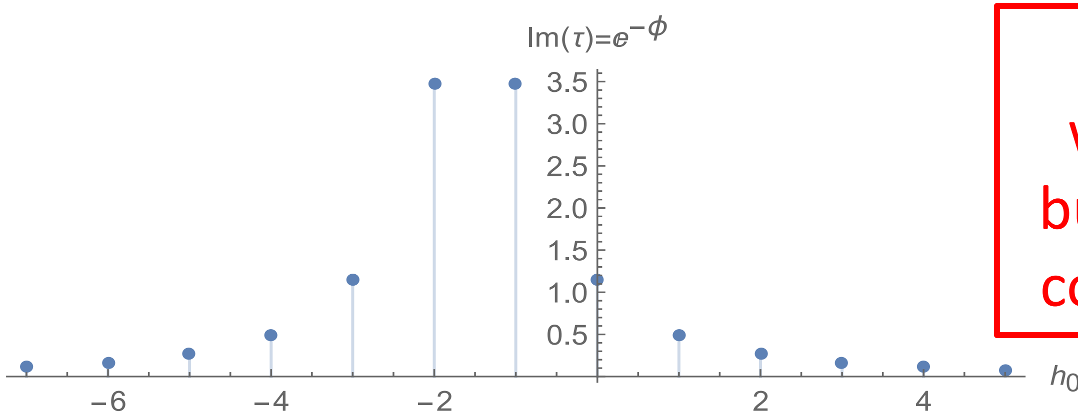

Never really weakly coupled but no string loop corrections to W!

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- However, $\partial W = W = 0$ implies fluxes are ISD
- Tadpole $N_{flux} = \int F_3 \wedge H_3 = \frac{1}{2} N_{O3} = \begin{cases} 12 \text{ for } 1^9 \text{model} \\ 40 \text{ for } 2^6 \text{model} \end{cases}$

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- Potential interesting connection to tadpole conjecture

Bena, Blåbäck, Graña, S. Lüst 2010.10519
Marchesano, Prieto, Wiesner 2105.09326
Plauschinn 2109.00029
Bena, Blåbäck, Graña, S. Lüst 2010.10519
S. Lüst 2109.05033
Gao, Hebecker, Schreyer Venken 2202.04087
Crinò, Quevedo, Schachner, Valandro 2204.13115
Graña, Grimm, van de Heisteeg, Herraez, Plauschinn 2204.05331

Preliminary results*

- Can calculate number of stabilized moduli for previous solutions

Becker, Gonzalo, Walcher, TW   in progress

- For 1^9 with tadpole 12 old Minkowski solution have

$$\approx \text{ 10 massive complex scalars} \ll h^{2,1} + 1 = 64$$

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- For 2^6 with tadpole 40 found solutions with

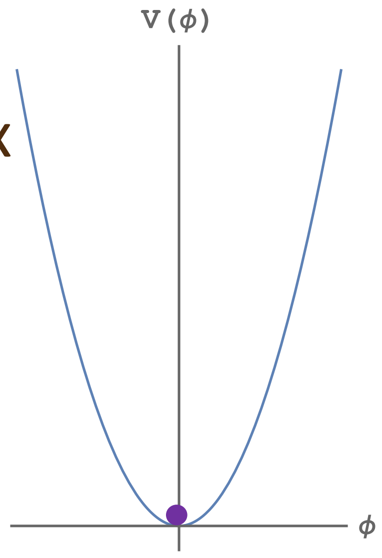
  85 massive complex scalars $\approx h^{2,1} + 1 = 91$

- So far no example where all scalars are massive

Stabilized vs massive fields

- Massive fields have non-vanishing Hessian matrix

$$V(\phi) = \frac{1}{2} m^2 \phi^2 \quad \Rightarrow \quad m^2 = \partial_\phi^2 V(\phi)\Big|_{\phi=0}$$



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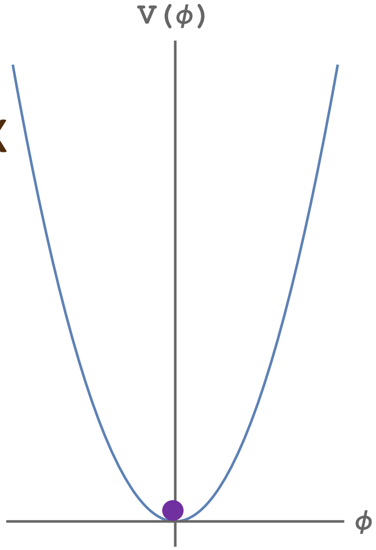

$$V(\phi) = \frac{1}{2} m^2 \phi^2 \quad \Rightarrow \quad m^2 = \partial_\phi^2 V(\phi)\Big|_{\phi=0}$$

- However, massless fields can also be stable

$$V(\phi) = \phi^4 \quad \Rightarrow \quad m^2 = \partial_\phi^2 V(\phi) = 12\,\phi^2\Big|_{\phi=0} = 0$$

- Calculate ϕ^4 terms to see whether all massless fields are stabilized

Becker, Gonzalo, Walcher, Wrase in progress

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Non-renormalization theorems

- Let us first look at the superpotential W

Becker, Becker, Vafa, Walcher hep-th/0611001

Becker, Becker, Walcher 0706.0514

- In a type IIB model all α' corrections for complex structure are contained in the Landau-Ginzburg

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- W does not receive string loop correction (neither perturbative nor non-perturbative). Variety of reasons presented (analogue to geometric case)

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- In a type IIB model all α' corrections for complex structure are contained in the Landau-Ginzburg
- W does not receive string loop correction (neither perturbative nor non-perturbative). Variety of reasons presented (analogue to geometric case)
- No D3-brane instantons since $h^{1,1} = 0$
- No D(-1)-brane instantons in decompactification limit consistent with recent results

Kim 2201.04634

Non-renormalization theorems

- The above no-go theorems do not apply to K

Becker, Becker, Vafa, Walcher hep-th/0611001

Becker, Becker, Walcher 0706.0514

- For SUSY AdS vacua we solve

$$D_i W = \partial_i W + W\,\partial_i K = 0$$

so we need to understand corrections to K

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so we need to understand corrections to K

- Corrections to $\partial_i K = K_i$ are Kähler transformation that do not change the equations $D_i W = 0$

- However, for example masses could receive corrections

The effective 4d SUGRA action

- Type IIB compactifications with $h^{1,1} = 0$ one has

$$K = -4\log(\tau - \bar{\tau}) - \log\left(-i\int \Omega \wedge \bar{\Omega}\right)$$
$$W = \int (H_{RR} - \tau H_{NS}) \wedge \Omega$$

- The factor of 4 is a small volume correction and can be derived using mirror symmetry

Becker, Becker, Walcher 0706.0514

$$K^{IIA} = -\log(e^{-4D}) - \log(vol_6)$$
$$= -\log\left(e^{-4\phi}(vol_6)^2\right) - \log(vol_6)$$

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- Due to the factor of 4 no ISD fluxes required

Ishiguro, Otsuka 2104.15030

$$D_\tau W = D_{U_a} W = 0 \quad \not\Rightarrow \quad \int F_3 \wedge H_3 \geq 0$$

- Tadpole: $N_{D3} + \int H_3 \wedge F_3 = N_{O3}/2, \quad N_{D3} = 0,1,2,3, \ldots$

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- Restricting to the bulk moduli

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- Easy to find many infinite families of SUSY AdS vacua

Bardzell, Gonzalo, Rajaguru, Smith, TW 2203.15818

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- Including families with $N_{D3} \to \infty, \quad \int H_3 \wedge F_3 \to -\infty$
- Gauge group $U(N_{D3})$ with arbitrary rank?

(similar to M-theory on $AdS_7 \times S^4/\mathbb{Z}_k$)

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- Including families with $N_{D3} \to \infty, \quad \int H_3 \wedge F_3 \to -\infty$
- No scale separated AdS solutions except for DGKT dual

(Integer conformal dimension only for DGKT dual)

Summary

- Type IIB with $h^{1,1} = 0$: new class of string compactifications to check swampland conjectures
- Provide trustworthy result even at strong coupling
- Infinite families of 4d $\mathcal{N} = 1$ Minkowski vacua (stable?)
- Several new infinite families of AdS vacua with interesting properties

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THANK YOU!