Towards classical dS vacua?

Timm Wrase

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

INSTITUTE FOR THEORETICAL PHYSICS

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FWF
Der Wissenschaftsfonds.

dS extrema and the swampland

Recent papers call for a paradigm change

Brennan, Carta, Vafa 1711.00864
Danielsson, Van Riet 1804.01120
Obied, Ooguri, Spodyneiko, Vafa 1806.08362
Agrawal, Obied, Steinhardt, Vafa 1806.09718

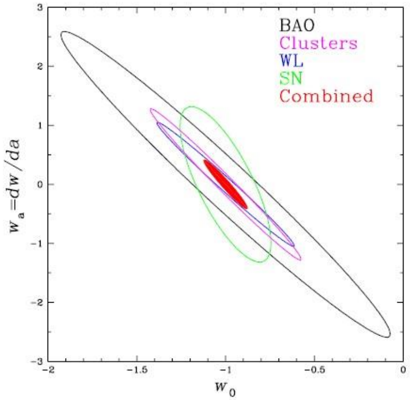
$$|\nabla V| \geq c\, V \quad \text{for} \quad c \sim O(1)$$

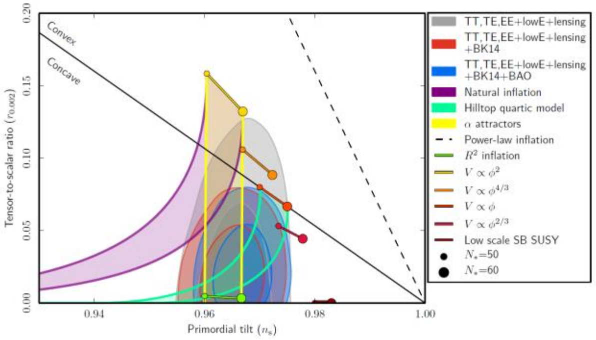
Inflation	$\Rightarrow$	string gas cosmology, bouncing cosmology, …
dS vacua	$\Rightarrow$	quintessence

dS extrema and the swampland

Current experiments search for signatures of inflation and quintessence, etc.

We as string theorist should explore all possible ways of explaining existing and potential future observations.





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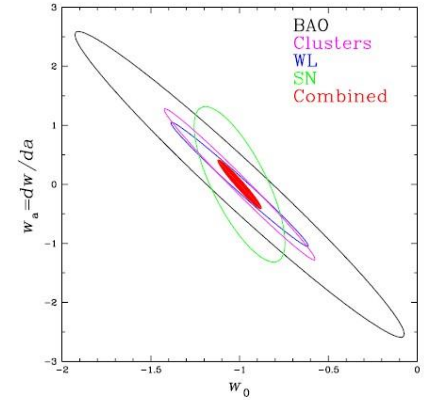

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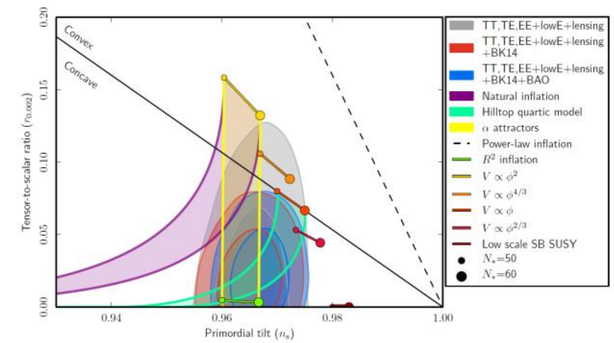

What about the dS swampland conjecture?

1. We can scrutinize existing constructions to spell out explicitly shortcomings (KKLT, LVS, …)

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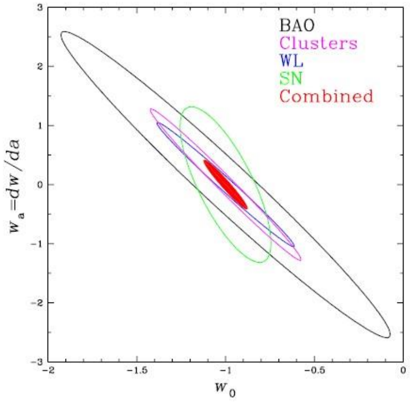

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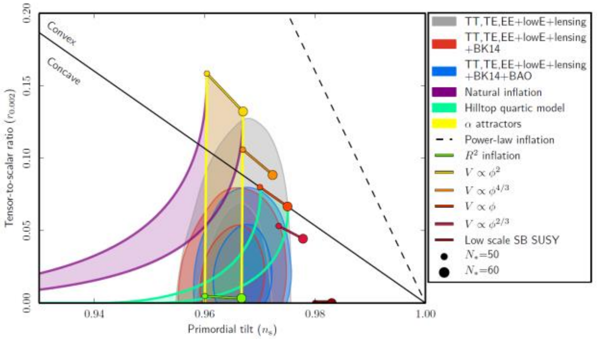

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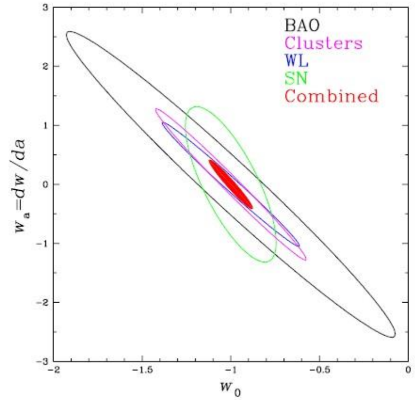

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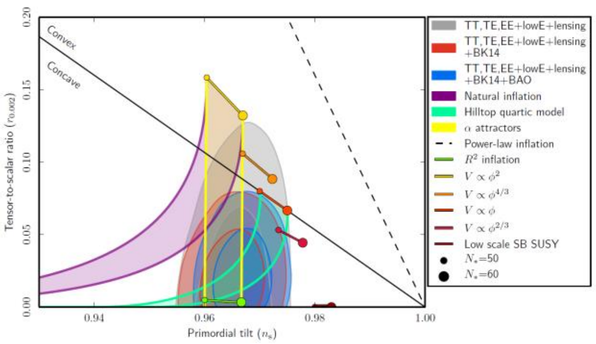

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Type IIA on CY_3

- Using fluxes F_0, F_2, F_4 and H_3 together with O6-planes, one can stabilize all moduli *classically* in AdS_4

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

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- However, it is impossible to have dS vacua

Hertzberg, Kachru, Taylor, Tegmark 0711.2512

$$\rho = (vol_6)^{\frac{1}{3}}, \qquad \tau = e^{-\phi}\sqrt{vol_6}$$

$$V(\rho,\tau) = \frac{A_H}{\rho^3\tau^2} + \sum_p \frac{A_{F_p}}{\rho^{p-3}\tau^4} - \frac{A_{O6}}{\tau^3}, \qquad \text{all } A_* > 0,$$

$$-\rho\frac{\partial V}{\partial\rho} - 3\tau\frac{\partial V}{\partial\tau} \geq 9\,V$$

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$$0 \neq \nabla V \sim -\rho\frac{\partial V}{\partial \rho} - 3\tau\frac{\partial V}{\partial \tau} \geq 9\,V > 0$$

Type IIA on group/coset spaces

- Considering compactifications on spaces with *curvature* changes things

summarized in Wrase, Zagermann 1003.0029

Curvature	No-go, if	No no-go in IIA with	No no-go in IIB with
$V_{R_6} \sim -R_6 \leq 0$	$q+p-6 \geq 0,\ \forall p,q,$ $\epsilon \geq \frac{(3+q)^2}{3+q^2} \geq \frac{12}{7}$	O4-planes and H, F_0-flux	O3-planes and H, F_1-flux
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Table 1 The table summarizes the conditions that are needed in order to find a no-go theorem in the (ρ,τ)-plane and the resulting lower bound on the slow-roll parameter ϵ. The third and fourth column spell out the minimal ingredients necessary to evade such a no-go theorem.

- Oq-planes and F_p fluxes (for lowest q and p)

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- Once curvature is included, dS vacua cannot be excluded and have been searched for

Flauger, Robbins, Paban, TW 0812.3886
Caviezel, Koerber, Körs, Lüst, TW, Zagermann 0812.3551
Danielsson, Haque, Shiu, Van Riet 0907.2041
Caviezel, TW, Zagermann 0912.3287
Danielsson, Koerber, Van Riet 1003.3590

- No dS vacua have been found but dS critical points with $|\nabla V| = 0, V > 0$ have been constructed

Junghans 1603.08939
Junghans, Zagermann 1612.06847

Type IIA on group/coset spaces

- Existing dS critical points are not phenomenologically interesting but prove of concept against above no-go

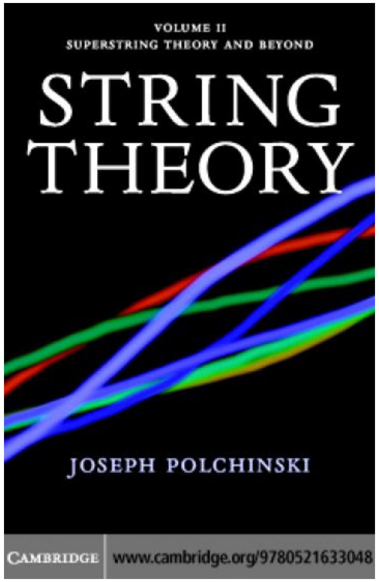
Flauger, Robbins, Paban, TW 0812.3886
Caviezel, Koerber, Körs, Lüst, TW, Zagermann 0812.3551

<u>Many subtleties:</u>

Danielsson, Haque, Koerber, Shiu, Van Riet, TW 1103.4858
Roupec, TW 1807.09538

  – Integrated EOMs for intersecting O6-planes
  – Neglect potential blow-up modes from orbifolding
  – What are the moduli?
  – Mass parameter in type IIA
  – Flux quantization

Anti-branes and dS supergravity



momentum is measured by the integral of the corresponding current over the world-sheet boundary,

$$\frac{1}{2\pi\alpha'}\int_{\partial M} ds\,\partial_n X'^9 \,, \tag{13.2.3}$$

which up to normalization is just the (0 picture) vertex operator for the collective coordinate, with zero momentum in the Neumann directions.

We conclude by analogy that the D-brane also spontaneously breaks 16 of the 32 spacetime supersymmetries, the ones that are explicitly broken by the open string boundary conditions. The integrals

$$\int_{\partial M} ds\,\mathscr{V}^{I}_{\alpha} = -\int_{\partial M} ds\,(\beta^9\tilde{\mathscr{V}}^{I})_{\alpha} \,, \tag{13.2.4}$$

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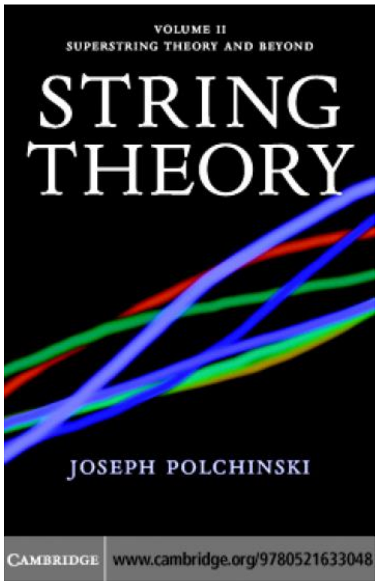

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- Anti-branes break supersymmetry spontaneously, so we should be able to describe them within SUGRA
- The last few years have seen the development of the so called dS SUGRA that involves a nilpotent multiplet $S^2 = 0$

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- Take any standard flux compactification to 4d $N = 1$
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- Now let us add (pseudo-calibrated) anti-Dp-branes

Lüst, Marchesano, Martucci, Tsimpis 0807.4540

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Kallosh, Wrase 1808.09427

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$$K^{new} = K^{old} + K_{S\bar{S}}(\phi^i, \bar{\phi}^i)\, S\bar{S}$$
$$W^{new} = W^{old} + \mu^2\, S$$

- $K_{S\bar{S}}(\phi^i, \bar{\phi}^i)$ worked out for anti-Dp-branes with p=3,5,6,7,9
- $\mu^4 = T_{Dp}$ is the brane tension

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Kallosh, Wrase 1808.09427

KKLT and LVS with anti-D3-brane uplift

$$K^{new} = K^{old} + (T + \bar{T})^n\, S\bar{S}$$
$$W^{new} = W^{old} + \mu^2\, S$$

- $n = 0$ unwarped, $n = -1$ warped anti-D3-brane
- $\mu^4 = T_{D3}$ is the brane tension

Anti-D6-branes in massive IIA

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Kallosh, Wrase 1808.09427

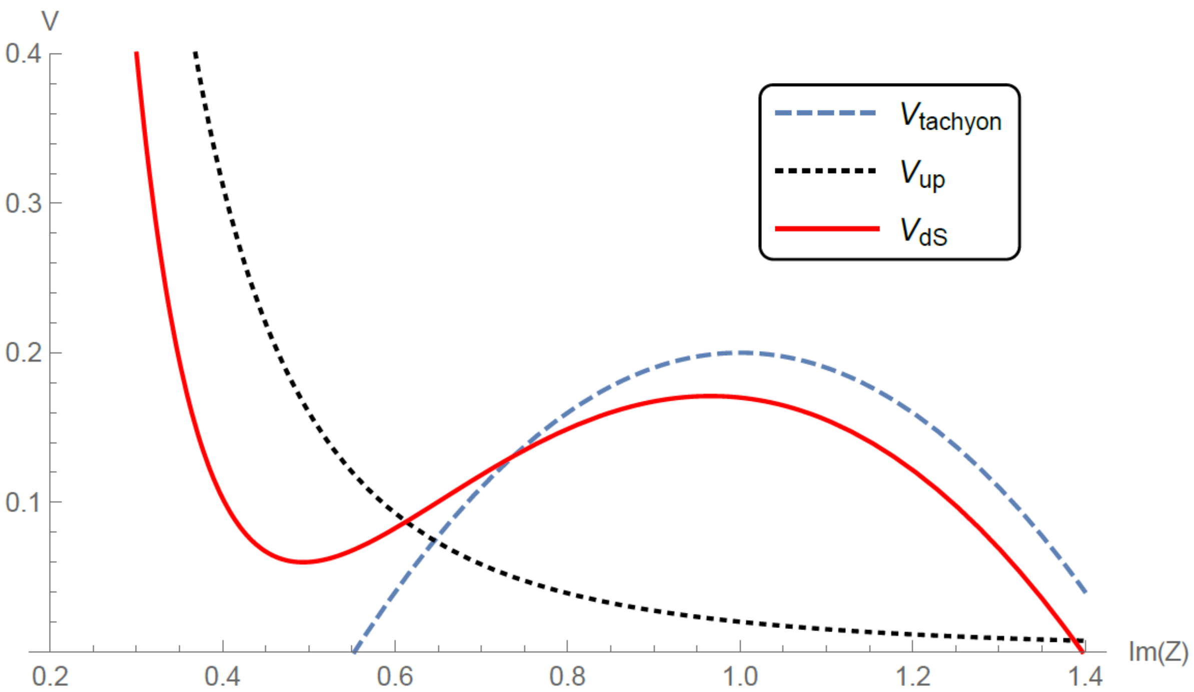
$$K^{new} = K^{old} + \frac{i}{8vol_6\, N_{\overline{D6},K}(Z^K - \bar{Z}^K)} S\bar{S}$$
$$W^{new} = W^{old} + \mu^2\, S$$

- $\mathrm{K} = 0,1, \dots, h^{2,1}$ labels the 3-cycles wrapped by $N_{\overline{D6},K}$ anti-branes
- $\mu^4 = T_{D6}$ is the brane tension

Anti-D6-branes in massive IIA

- Obstinate tachyon always (?) along 3-cycle moduli
- These 3-cycles can be wrapped by anti-D6-branes

$$V_{dS} = -m^2(Im(Z)-1)^2 + \frac{N_{\overline{D6}}}{Im(Z)^3}$$



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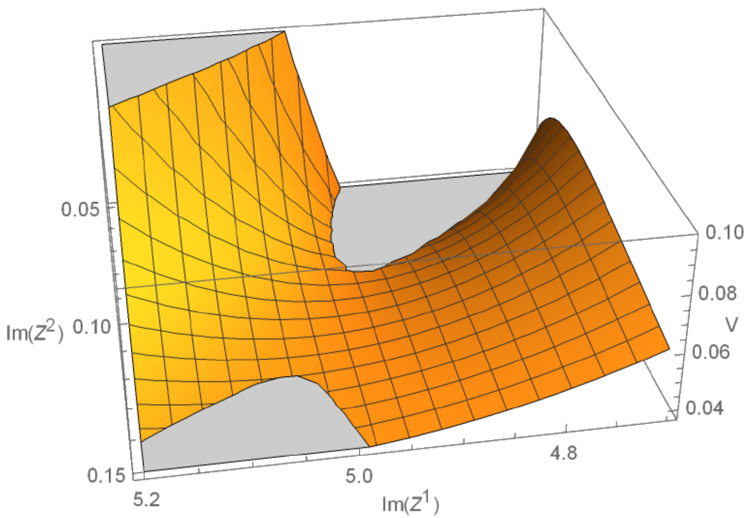

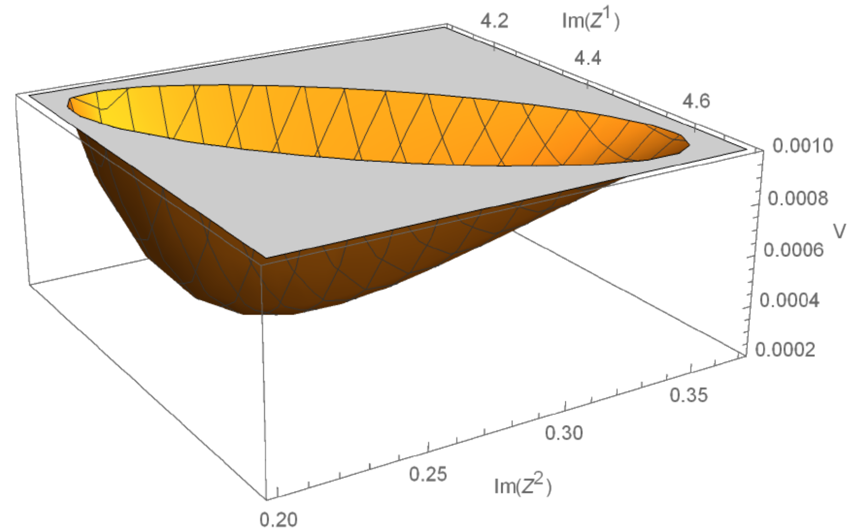

- Checked explicitly in the simplest example $S^3 \times S^3/Z_2 \times Z_2$
- Obstinate tachyon is now gone
- dS solutions at slightly shifted values, do not seem to be trustworthy in this example (small volume, large coupling)

Conclusion

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THANK YOU!

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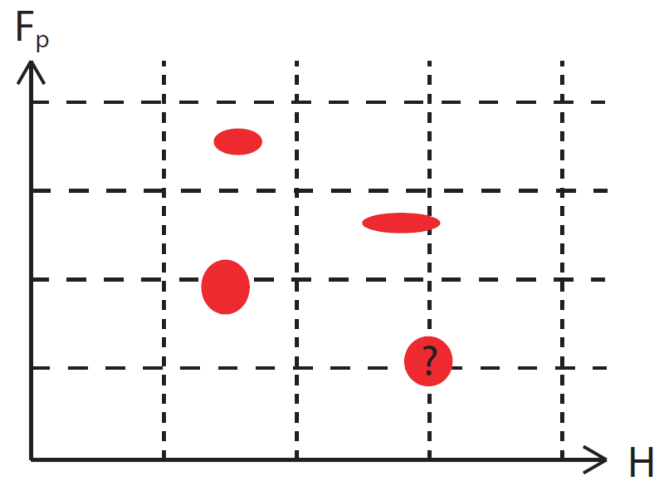
Are dS critical points compatible with flux quantization?



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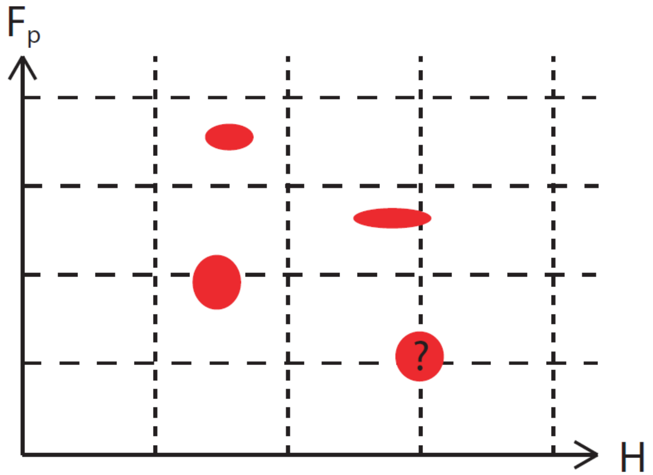

- Fluxes appear also in tadpole
- For $S^3 \times S^3/Z_2 \times Z_2$ flux quantization plus tadpole lead to small volume and large string coupling i.e. flux quantization kills model! But there are many more examples…

Danielsson, Haque, Koerber, Shiu, Van Riet, TW 1103.4858

- This model has a very limited parameter space