Suggestions for dS Discussion

(Geometry & Swampland Workshop, Banff, 2022)

Generalities

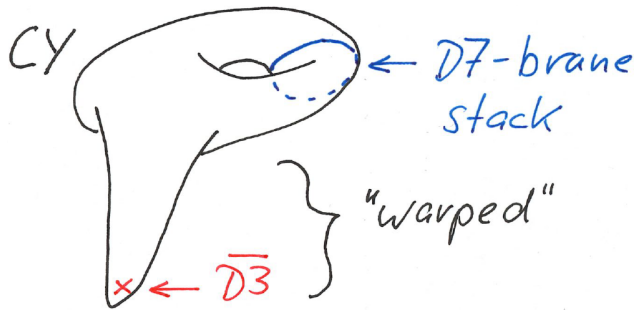
- String theory is beautiful mathematical physics.
  It provides and a nice toy-model for quantum gravity.

- Is it more than that?
  Is it the quantum gravity theory of our real world?

- If we want to claim that it is, we must answer the question about stringy dS (or realistic stringy quintessence) in a positive way.

- Just creating more no-go theorems will not suffice!

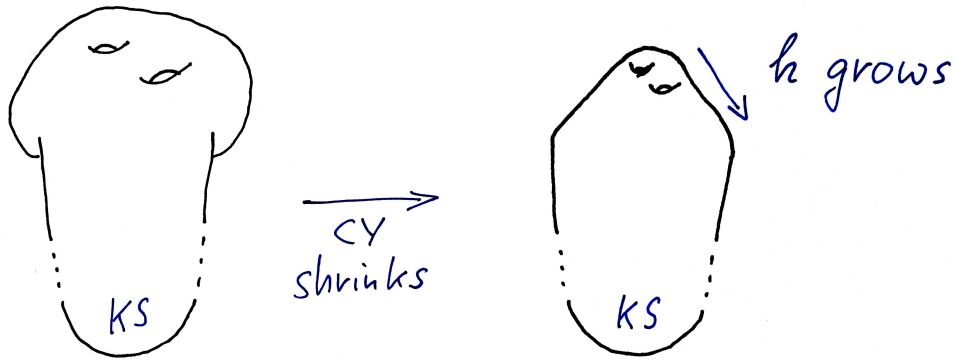
KKLT



- $K = -3\ln(T + \overline{T})$
  $W = W_0 + e^{-T}$.

(Potential) Issues:

- Do we still question the $\overline{D3}$-uplift in principle?
  What's the minimal flux M?
- The (singular) λ^4 gaugino term on the D7 is still only a proposal!
- Must resolve
  Throat Gluing /
  Singular Bulk problems!



... still KKLT

- Small W_0 by tuning / by large-z model building?
  Gain (duality-based) control over singular bulk?
  Does ($h^{1,1} \gg 1$) + (control over small 2-cycles) save us?

LVS

- $\tau \rightarrow \tau_b, \tau_s,$ modestly large: $\tau_s \sim \xi/g_s$
  exponentially large: $\mathcal{V} \sim \exp(2\pi\tau_s)$

  (Potential) Issues:

- Well-known: Loop and α' corrections in general.

- Recently emphasised: log-field-redefinitions;
  Flux enhanced corrections $\sim KM/\mathcal{V}^{2/3}$ in connection with lower bound on M ('LVS singular-bulk problem')

Stringy quintessence

- General difficulty: The most obvious idea of 'rolling to decompactification' fails: V too steep, $M_{\cancel{SUSY}}$ too low and, even worse, it keeps changing. Also: 5th force!

- One of the leading candidates:
  Ratio τ_i/τ_j in LVS at very large, fixed $\mathcal{V}$.

  (Potential) Issues:

- Light-volume problem

- F-term problem

- Inflationary constraints (cf. KL problem)

Yet more KKLT: complex structure moduli stabilisation with fluxes: are we starting from a vacuum with no moduli?

Tadpole

$$Q_{\text{flux.}} \quad \leq \quad \frac{\chi(CY_4)}{24} \sim \frac{1}{4} h^{3,1}$$

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Tadpole conjecture

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KKLT, LVS: based on type IIB on CY

Other ways of getting dS

Go away from CY, negatively curved manifolds

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Few examples → group manifolds

→ Einstein manifolds

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KKLT more robust…?

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Plan

A few words and questions on:

- Classical de Sitter string backgrounds
- Swampland conjectures and quantum gravity arguments

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Classical de Sitter string backgrounds

Existence: in 10d supergravity?

No de Sitter solution in heterotic string at tree level g_s and all orders α'.
Search in type IIA/B supergravities, with orientifolds O_p-planes and (anti-) D_p-branes.

Difficult (few ingredients only): many **no-go theorems**
$\rightarrow$ tell us where to look
$\hookrightarrow$ few 10d supergravity **de Sitter solutions found**

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Example: de Sitter solutions with 6d group manifold, constant fluxes, smeared intersecting O_6/D_6 sources (4 sets)
$\rightarrow$ consistent truncation: 4d gauged supergravity

Claim: de Sitter solutions need at least 3 intersecting O_p/D_p sets, i.e. **at most $\mathcal{N} = 1$** EFT in 4d.

Existence: in string theory?

Are these 10d supergravity de Sitter solutions **classical string backgrounds?**

Check: small g_s, large 6d volume/lengths, bounded/fixed number of O_p, flux quantization, lattice/compactness

$\rightarrow$ no tested example survives:
no known classical de Sitter string background

$\hookrightarrow$ bad luck or a deep string theory statement?

(reminiscent of difficulties in other approaches)

Classical regime = asymptotics of field/moduli space **(really?)**

Arguments (swampland conjectures + else):
no de Sitter solution in the asymptotics of field space

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Question of **parametric control**: there exists a parameter λ in the solution, such that classicality can be as good as desired (to the asymptotics: $\lambda \to \infty$): $g_s \sim \frac{1}{\lambda}$, $\text{vol}_6 \sim l_s^6 \times \lambda^n$ (like DGKT)

$\hookrightarrow$ claim: **no** classical de Sitter sol. with parametric control

But a classical de Sitter solution in a **bounded region** of field space?
Not the asymptotics, no parametric control?

Quantum gravity and de Sitter

Swampland de Sitter conjectures

$$\mathcal{S} = \int \mathrm{d}^4x\sqrt{|G_4|}\left(\frac{M_p^2}{2}\mathcal{R}_4 - \frac{1}{2}g_{ij}(\phi)\partial_\mu\phi^i\partial^\mu\phi^j - V(\phi)\right)$$

Several versions

"Consensus" version: Trans-planckian censorship conj. (TCC)

TCC bound: $M_p \left\langle \frac{|\partial_\phi V|}{V} \right\rangle_{\phi\to\infty} \geqslant c \geqslant \sqrt{\frac{2}{3}}$

no de Sitter solution in the asymptotics

Quantitative agreement with supergravity no-go theorems

De Sitter extrema possible in field space "bulk"

$\rightarrow$ bound on lifetime

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Relations to other conjectures: **swampland web**:
- Instability of AdS non-susy
- AdS distance conjecture (AdS no-scale sep. $\leftrightarrow$ dS instability)
- Distance conjecture

"Model independent" arguments against de Sitter

Swampland conjectures:

- Non-susy solution: unstable/absent
- Entropy-based arguments in quasi de Sitter
- No trans-planckian mode
- No eternal inflation
- ...

Older general arguments:

- QFT in curved/de Sitter spacetime $\rightarrow$ quantum gravity?
- De Sitter holography? (but 2d JT gravity, higher spins?)
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Why do we need a de Sitter spacetime?
→ inflation, quintessence, else...
(reheating positive minimum?)

Questions

- Smearing/backreacted O_p/D_p? (for AdS as well)
- Consistent truncation versus low energy EFT ?
- Asymptotics of field space/parametric control or bounded region?
- Stability: unstable or metastable?
- Generalized geometry, DFT: field/moduli space hints?
- General arguments against / do we need de Sitter sol.?
- Non-geometric fluxes?

Summary: dS Discussion

- KKLT: $\overline{D3}$; 10d gaugino cond. ; sing. bulk ;
  small W_0 ; small 2-cycle ; tadpole
- LVS: loop & α' corr. ; log-field-redefintions ;
  flux-enhanced α' effect ; sing. bulk? ; tadpole
- Quintessence: light-volume ; F-term-problem ;
  (KL-type) inflationary constraints
- Classical: smeared/backreacted Op/Dp ;
  consistent truncation/low energy EFT ;
  field space: asymptotics, par. control/bounded region
- Quant. Grav.: general arg. against ; need de Sitter?