# Landscape, Swampland and de Sitter

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including recent work with F. Denef / T. Wrase / Y. Hamada / G. Shiu / P. Soler

## Outline

- Landscape vs. Swampland – a brief introduction.
- The $|V'|/V$ de Sitter conjecture and its problems.
- The 'refined' and the 'asymptotic' de Sitter conjecture (and potential loopholes).
- Stringy de Sitter models: KKLT and its issues.
- Towards a 10d understanding of KKLT.

# String Compactifications

- String theory provides an (essentially unique) and UV-complete field theory in 10d:

$$S = \int_{10} \mathcal{R} - |F_{\mu\nu\rho}|^2 + \cdots$$

- At the very least, this is a useful toy-model for a well-defined gravitational theory.

- One may go for more by compactifying on Calabi-Yaus (6d spaces with vanishing Ricci tensor).

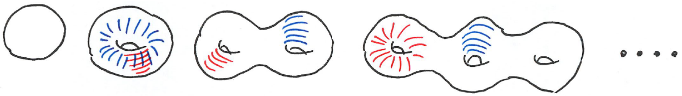
- One ends up with

  (A) unrealistic moduli-space field theories ($\mathcal{N} = 2$ SUSY)

  (B) very flat and poorly controlles field spaces ($\mathcal{N} = 1$ SUSY)
  [it remains unclear how $\Lambda \sim 10^{-120}$ can occur].

# String compactifications: flux landscape

- The extra ingredient of fluxes induces an exponentially large landscape of discrete solutions.



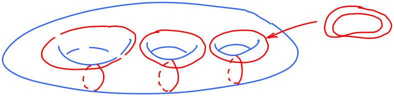
Bousso/Polchinski '00, Giddings/Kachru/Polchinski '01 (GKP)
Kachru/Kallosh/Linde/Trivedi '03 (KKLT), Denef/Douglas '04
Balasubramanian/Berglund/Conlon/Quevedo '05 (LVS)

- Key to the historical number $10^{500}$ (by now rather $10^{300.000}$) is not the abundance of Calabi-Yaus ($\sim 10^9$), but the discrete flux choice:

$$\oint_{3-cycle} F_{\mu\nu\rho} \in \mathbb{Z}$$

## String compactifications: flux landscape

- To understand the discreteness ('flux quantization'), one may think of the twisting of a gauge-theory $U(1)$ bundle:

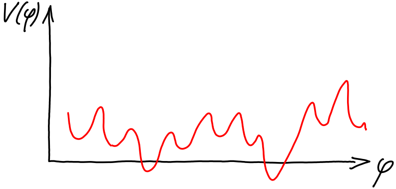


- Typical CYs have $\mathcal{O}(300)$ 3-cycles.
- Each can carry some integer number of flux of $F_{\mu\nu\rho}$ , $H_{\mu\nu\rho}$.
- With, for example, $N_{flux} \in \{-10, \ldots, 10\}$ on gets

$$(2 \times 20)^{300} \;\sim\; 10^{500} \text{ possibilities.}$$

## String compactifications: flux landscape

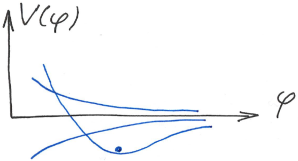
- One may visualize the emerging situation like (just with $\varphi \;\to\; \{\varphi_1, \cdots, \varphi_N\}$):

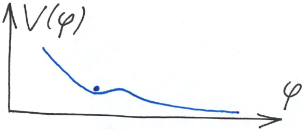



But ususally this only works for
the shape ('complex structure') moduli,
the size ('Kahler') moduli remain flat.

## String compactifications: flux landscape

- The size moduli (let's say just the volume) get a (much smaller) potential from quantum corrections.
- While the simplest solutions are runaway or SUSY-AdS, there is (in my opinion) evidence for meta-stable de-Sitter vacua .....



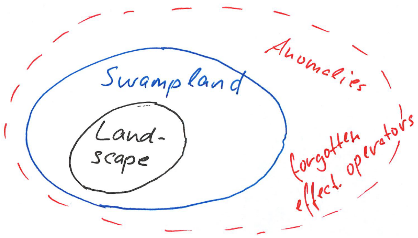



# Landscape vs. Swampland

- Before coming to de Sitter, let us clarify the concepts of Landscape and Swampland:

  **Landscape:** Any EFT obtained from string theory as above.

  Swampland: Any other naively consistent EFT (always including gravity).

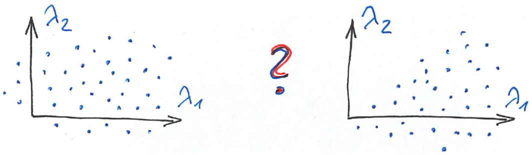



- The existence of a swampland is, of course, one key possibility of how the string landscape could be predictive.

## Landscape vs. Swampland

- In a way, this *existence* might however be almost trivial: The landscape is discrete, the space of EFTs is continuous.
  $\Rightarrow$ Almost any EFT is in the Swampland.

- What is less obvious is the presence of well-defined 'empty' regions in the field-parameter space:




- Thus, this presence of unaccessible regions in parameter space might be the more useful 'swampland' definition.

- Another twist: Demand 'consistency in quantum gravity' (not necessarily string theory). This is of course poorly defined....

# Concrete 'Swampland Criteria'

- Specific quantum-gravity consistency citeria have been discussed since a long time ....

  No exact global symmetries

  Completeness

  see e.g. Banks/Seiberg '10 and refs. therein

  [the charge lattice is fully occupied]

  The swampland distance conjecture

  [infinite distances in moduli space come with exponentially light states]

  Vafa '05, Ooguri/Vafa '06

  The weak gravity conjecture

  Arkani-Hamed/Motl/Nicolis/Vafa '06

- If any of those criteria were relevant experimentally...
  $\rightarrow$ unique opportunity to confront quantum gravity & reality!

## Example: Weak Gravity Conjecture

- 'Gravity is the weakest force':

$$m \lesssim g M_P \qquad \text{for the (lightest) charge particle}$$

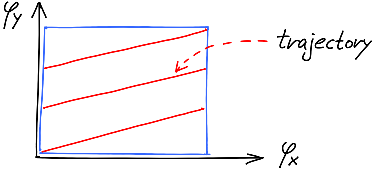
- Generalization to axions (0-forms gauge fields):

$$S_{inst} \lesssim \frac{1}{f} M_P \qquad \text{or} \qquad f \lesssim \frac{M_P}{S_{inst}} \lesssim M_P$$

- General problem: Might be avoidable in low-energy EFT through 'model building':

Through special potential (KNP)

Or through flux choice (Higgsing)
AH/Mangat/Rompineve/Witkowski
See also Saraswat for $U(1)$ version of this



## De Sitter swampland conjectures

- One possible constraint is clearly $\Lambda_{cosm.} \leq 0$.

- Indeed, a longstanding unease about the status of de Sitter space in quantum gravity exists.

Woodard, Danielsson, Van Riet, Bena, Grana, Sethi, Dvali, ...

The motivations are diverse, e.g. ...

- Backreaction of perturbations leaving the horizon.
- Possible problems with an interpretation of the 'inside-horizon region' as the full QM system.

(Personally, I do not fully understand this unease.)

- In string theory, dS space can only be metastable (one may always decay to the many Mink. or AdS vacua).

## The $|V'|/V$ de Sitter conjecture

- Recently, a very strong version of the doubts concerning (even metastable) dS vacua has been put forward:

  $|V'|/V > c$ (in Planck units and with $c \sim \mathcal{O}(1)$)

  Obied/Ooguri/Spodyneiko/Vafa
  Agrawal/Obied/Steinhardt/Vafa '18

- Intriguingly, this does not immediately clash with late cosmology:

  Indeed, a simple quintessence model with $V \sim e^{-c\varphi}$ and $c \sim \mathcal{O}(1)$ can satisfy the conjecture and replace $\Lambda_{cosm.}$.

  A lot of phenomenological work (both late-time and inflation) has followed ....

## The $|V'|/V$ de Sitter conjecture

- Let us briefly pause and (attempt to) explain how such an incredibly strong conjecture might be motivated.

- The generic result of a compactification with volume $\mathcal{V}$ (and some positive-energy source in the compact space) is

$$\mathcal{L} \sim \mathcal{V}\left[\mathcal{R}_4 - \frac{(\partial\mathcal{V})^2}{\mathcal{V}^2} - E\right] .$$

- After Weyl-rescaling to the Einstein frame and introducing the canonical field $\varphi = \ln(\mathcal{V})$, one finds

$$\mathcal{L} \sim \left[\mathcal{R}_4 - (\partial\varphi)^2 - E\, e^{-\varphi}\right] .$$

- The exponent is usually $\mathcal{O}(1)$, so the simplest compactifications do indeed obey the $|V'|/V$ conjecture.

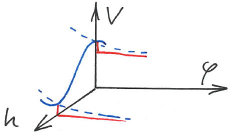
## The $|V'|/V$ dS conjecture and the Higgs

- However, if this were unavoidable, we would be in deep trouble.

  Denef/AH/Wrase '18

- Indeed, in presence of the SM, an additive quintessence contribution does not save the conjecture:

$$V = \lambda(h^2 - v^2)^2 \ + \ \Lambda_{cosm.}\, e^{-c\varphi}$$




  clearly violates the conjecture at $h = v$.

- An (apparent) remedy is also easily found:

$$V = \left[\lambda(h^2 - v^2)^2 \ + \ \Lambda_{cosm.}\right] e^{-c\varphi}$$

- But: Extreme tuning and equivalence principle violation now arise (especially if one generalizes from Higgs to pion).

  see also subsequent work by Cicoli/.../Quevedo; Murayama/Yamazaki/Yanagida; Marsh; ....

  and especially Choi/Chway/Shin '18

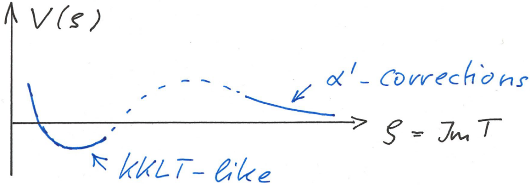
# The $|V'|/V$ dS conjecture and the Higgs (summary)

- The $|V'|/V$ conjecture might fall (has fallen?) on phenomenological grounds.
- As a logical possibility, the conjecture may still hold in string theory (which hence does not describe the real world!).
- However, critical points at $V > 0$ may exist even in ST.

see work by Lüst, Wrase, Andriot, Shiu, Danielsson, Van Riet, ....

- As a particularly simple, recent argument uses the potential..

Conlon '18



## The 'refined' dS Swampland conjecture

- One may say 'the conjecture is *really* about forbidding metastable de Sitter' (sacrificing $|V'|/V$).
- Such formulations have indeed been proposed:

Garg/Krishnan, Ooguri/Palti/Shiu/Vafa

One of the two must always hold:

$$|V'|/V > c_1 \qquad \text{or} \qquad V''/V < -c_2\,.$$

- In words: No continued exponential expansion.
- Technically, this puts us 'back to square one': The old debate about realizing de Sitter (or just inflation) in string theory.
- Such a critical debate is clearly needed (see below), but at this time I do not see strong *new* reasons against dS.

## The 'asymptotic' dS Swampland conjecture

- One of the above papers gave arguments against 'asymptotic' de Sitter vacua.

  Ooguri/Palti/Shiu/Vafa

- Here asymptotic means at asymptotically large field distance, corresponding e.g. to 'large volume'.

The argument is:

- By the Swampland distance conjecture:
  large $\varphi \quad \Rightarrow \quad$ tower of light states at $m \sim e^{-\varphi}$.
- New assumption: This number of states behaves as $n(\varphi)\, e^{-\varphi}$ with $n(\varphi)$ monotonic.
- New assumption: Those states should saturate dS entropyy $S \sim R_{dS}^2 \sim 1/V$.
- Accepting all of this does indeed imply that $V$ decays exponentially at $\varphi \to \infty$.

## The ‘asymptotic’ dS Swampland conjecture

- Clearly, many highly non-trivial new assumptions are invoked.
- In fact, one may argue much more directly:

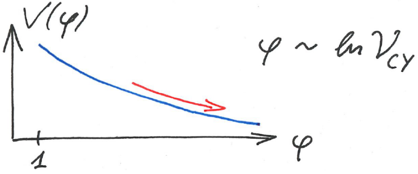
  Large $\varphi \quad \Rightarrow \quad$ many light states  
  Reece, AH/Wrase

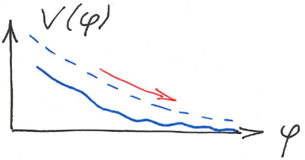
  Many light states $\Rightarrow$ low cutoff $\Lambda$ (species bound).

  Low cutoff $\Rightarrow$ small potential ($V \sim 1/R_{dS}^2 \lesssim \Lambda^2$).

- But: This gives only an upper bound, wiggles and hence minima not ruled out (closely related: flux vacua at $\varphi \to \infty$).

  AH/Wrase, Junghans



## dS Swampland conjectures: intermediate summary

- The above 'oscillations loophole' has a counterpart in the mononotonicity assumption of the entropy argument.
- Given our limited understanding of dS entropy, this does not appear easy to close.
- Quite generally, even the most widely accepted Swampland conjectures are hard to defend rigorously.
- Much harder: Rule out dS also in the regime of 'large but not asymptotically large' volume.
- Alternative approach: Do not fight the landscape, but try to establish it by studying best concrete models.

## KKLT

Kachru/Kallosh/Linde/Trivedi '03

- KKLT is one of the leading concrete dS models in string theory (the other being the 'large volume scenario' or LVS).
  Balasubramanian/Berglund/Conlon/Quevedo '05
- The present 'no-dS' debate was sparked off (among others) by a concrete criticism of KKLT in Moritz/Retolaza/Westphal '17
- Before discussing the criticism, let us discuss the proposal.

# (2-slide reminder of) KKLT

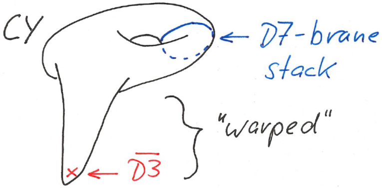
- CY with all complex-structure moduli fixed by fluxes;
  The only field left: Kahler modulus $T = \tau + ic$ with $\tau \sim \mathcal{V}^{2/3}$.

- $K = -3\ln(T + \overline{T})$ ;  fluxes give $W = W_0 =$ const.,

  $\Rightarrow \quad V \equiv 0 \quad$ ('no scale') .

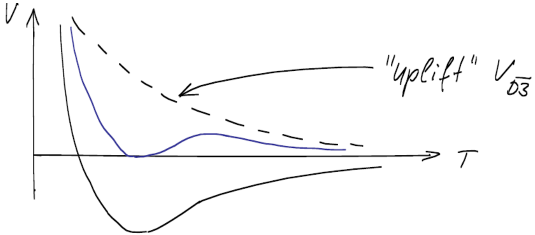
- Gaugino condensation on D7 brane stack: $W = W_0 + e^{-T}$.

- Small uplift by $\overline{\text{D3}}$-brane
  in a warped throat:
  $V \to V + c/\tau^2$.



# KKLT

- The scalar potential is changed first to SUSY-AdS, then to an 'uplifted' meta-stable de Sitter potential:




- A longstanding critical debate has targeted the metastability of the $\overline{D3}$ in view of flux-backreaction.

  (My take on this is that metastability remains plausible.)

Bena, Grana, Danielsson, Van Riet, ....

# KKLT under attack

Moritz/Retolaza/Westphal '17
Gautason/Van Hemelryck/Van Riet '18

- Recent criticism was rooted in a possibly too simplistic treatment of D7-gaugino–bulk-coupling:

$$\mathcal{L}_{10} \supset |G_3|^2 + G_3 \cdot \Omega_3 \langle \lambda\lambda \rangle \delta_{D7} \,.$$

Camara/Ibanez/Uranga '04, Koerber/Martucci '07
Baumann/Dymarsky/Klebanov/Maldacena/McAllister '06
Heidenreich/McAllister/Torroba '10

- It is clear what to expect:
$G_3$ backreacts, becoming itself singular at the brane.

- Plugging this back into the action,
one gets a divergent effect of type $(\delta_{D7})^2$.

- Now anything can happen....

# KKLT rescued

Hamada/AH/Shiu/Soler '18,'19; Kallosh '19; Carta/Moritz/Westphal '19

- Singular gaugino effects have been observed before, in other string models.

  Horava/Witten '96

- It has been shown that a highly singular $\langle\lambda\lambda\rangle^2$-term saves the day by 'completing the square'. Applied to our case:

$$\mathcal{L}_{10} \supset \left| G_3 + \Omega_3 \langle\lambda\lambda\rangle \, \delta_{D7} \right|^2 .$$

- Very roughly speaking, one now writes $G_3 = G_3^{flux} + \delta G_3$ and lets the second term cancel (most of) the $\delta$-function.

  The result is (**very** roughly):

$$\mathcal{L}_{10} \supset \left| G_3^{flux} + \langle\lambda\lambda\rangle \right|^2 \quad \rightarrow \quad \left| D_T W_0 + \partial_T e^{-T} \right|^2 .$$

## The perfect square structure in M-theory

- The established part of the story is in M-theory (with $x^{11}$ compactified on $S^1/\mathbb{Z}_2$). There, one has

$$S \sim -\int_{11} \left( G_4^2 \; - \; \delta(x^{11})(G_4)_{ABC\,11}\, j^{ABC} \right),$$

where $j^{ABC} \sim \overline{\lambda}\,\Gamma^{ABC}\lambda$.

- It is well-known that the divergence problem is resolved by the proposal (enforced by SUSY)

Horava/Witten

$$S \sim -\int_{11} \left( G_4 - \frac{1}{2}\delta(x^{11})\, j \right)^2 .$$

## Understanding the M-theory case in a toy model

- Let us first understand this better in a 5d toy-model, (with $x^5 \equiv y$ compactified on $S^1/\mathbb{Z}_2$):

(inspired by Mirabelli/Peskin '97)

$$S = -\int_5 (d\varphi - j\delta(y)\, dy) \wedge *(d\varphi - j\delta(y)\, dy)\,.$$

- The equation of motion is

$$d * (\, d\varphi - j\delta(y)\, dy) = 0\,,$$

which is solved by

$$d\varphi = j\delta(y) dy + \alpha_M\, dx^M\,.$$

- Crucially, $\alpha = \alpha_M\, dx^M$ is co-closed: $d * \alpha = 0$.

## Obtaining a finite action

- Excluding $x^\mu$-dependence, we can write the EOM as

$$\partial_y \left[ \partial_y \varphi - j\delta(y) \right] = 0$$

and the solution as

$$\partial_y \varphi = j\delta(y) + \alpha_5 \qquad \text{with} \qquad \alpha_5 = \text{const.}$$

- Flux quantization, $\int_{S^1} d\varphi \in \mathbb{Z}$, implies

$$\int dy\, \partial_y \varphi = j + \alpha_5 = n$$

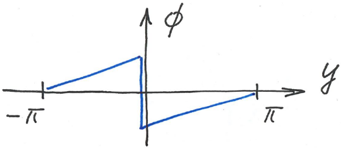
such that $\alpha_5 = n - j$. The resulting action is

$$S = -(n-j)^2\,.$$

- We see: $\partial_y \varphi$ cancels the singular term
  and develops a finite part $\sim (n-j)$.

# Obtaining a finite action (continued)

- Illustration for $n = 0$:




- The 'step' in $\partial_y \varphi$ cancels the source term $j\delta(y)$.

- Compactness and continuity of $\varphi$ ($\equiv$ flux quantization) enforce a non-trival slope proportional to this 'step'.

- If $n \neq 0$, continuity is replaced by an extra step of size $n$ at the boundary. Hence:

$$\mathcal{L} = \int_R |d\varphi - j\delta|^2 = -(n-j)^2/R\,.$$

- Crucial: Radius dependence of $j^2$ term.

## The co-dimension two case

- The case of interest is not co-dimension one but rather co-dimension two.

  $\Rightarrow$ Generalize our toy-model to 6d
  (equivantly, consider type IIB compactified to d=8)

- In principle, everything goes through as before.
  The lagrangian is:

$$\mathcal{L} = -\int d^2 z \left( |G_1|^2 - G_1 \cdot \bar{\jmath}_1 + \text{c.c.} \right) \quad \text{with} \quad \bar{\jmath}_1 = j\, dz\, \delta^2(z, \bar{z})\,.$$

- The naive perfect-square proposal would be

$$\mathcal{L} = -\int d^2 z \, |G_1 - \bar{\jmath}_1|^2 \,.$$

## The co-dimension two case (continued)

- But: The singular 'source-form' is not closed,

$$d\left(j\,dz\,\delta^2(z,\bar{z})\right) \neq 0\,.$$

To allow '$G_1$' (assumed to be closed) to compensate, we must project on the closed part using the unique decomposition

$$\omega = \alpha + d\beta + d^\dagger\gamma\,.$$

In other words, one drops '$d^\dagger\gamma$'. This does not change EOMs.

- Using indices $h$, $e$, $c$ for harmonic, exact and co-exact:

$$\mathcal{L} = \int_z -\left|\overline{G}_1^h + \overline{G}_1^e - j_1^h - j_1^e\right|^2\,.$$

Here $\overline{G}_1^e$ compensates $j_1^e$, so these terms drop out.

# From toy-model to D7 brane case

- We are left with:

$$\mathcal{L} = \int_z - \left| \overline{G}_1^h - j_1^h \right|^2 \ .$$

But $\overline{G}_1^h \equiv \overline{G}_1^{(0)}$ is the quantized flux,
so it can not compensate for the continuous $j_1^h \sim \lambda^2 \, dz / A_\perp$.

(Here $A_\perp$ is the 'brane-transverse' compact volume.)

- Thus, this perfect square of quantized flux and (finite) $\lambda^2$ term is the sole remainder of the calculation.

- Now the generalization to the realistic case is straightforward:

$$\mathcal{L} \supset \left| \overline{G}_3 - P\Big(\lambda\lambda \, \Omega_3 \, \delta_{D7}\Big) \right|^2 .$$

(Here $P$ is the closed-form projection, as before.)

## Cross checks / getting the KKLT-result

- As before, the singular parts cancel and, using $\int G_3^{(0)} \wedge \Omega \sim W_0$, one arrives at (after 4d-normalization of the gauginos)

$$K^{T\overline{T}} \left| e^{K/2} K_T W_0 + \lambda\lambda \right|^2$$

- This is precisely the perfect square structure that also appears in the SUGRA+gauge theory formulae of Wess/Bagger.

- With the substitution $e^{-K/2}\lambda\lambda \rightarrow e^{-T}$ one arrives at (pre-uplift) KKLT:

$$e^K K^{T\overline{T}} \left| D_T(W_0 + e^{-T}) \right|^2 .$$

## Recent related work by other groups

Bena/Grana/Kovensky/Retolaza

- Using Generalized Complex Geometry, the AdS parameter can be related to a parameter in 10d SUSY conditions.

  ⇒ fully 10d-local check of pre-uplift KKLT

Kachru/Kim/McAllister/Zimet

- Also use Generalized Complex Geometry, but try to go further towards a component-level check of KKLT
- However, non-local D7 action introduced ad hoc; divergence cancellation in $G_3$ kinetic term remains unclear.

# Back to our proposal

- While SUSY and Generalized Complex Geometry arguments may be elegant, having a down-to-earth 10d component analysis is also useful.

- The latter is obviously plagues by divergences in $|G_3|^2$.

- To me, our 'Horava-Witten-style' perfect-square singularity subtraction is still the leading candidate for this goal.

- It also has its troubles:

  When subtracting $|j_3|^2$, we left out $|j_3^c|^2 \supset \left(\frac{1}{z^2}\right)^2$.

- This last piece has a non-local tail.

- By contrast, the full source $j_3 = j_3^h + j_3^e + j_3^c$ is completely D7-localized.

## Electric-magnetic interpetation of $G_3\lambda^2$ coupling

- An unconventional re-interpetation of our perfect square action might hence start with the full source:

$$|G_3 + j_3|^2 \qquad \text{with} \qquad j_3 \sim \lambda^2 \delta_{D7}\overline{\Omega}\,.$$

- Observe that, in the term

$$G_3 \wedge *\bar{\jmath}_3 = G_3 \wedge *(\bar{\jmath}_3^h + \bar{\jmath}_3^e + \bar{\jmath}_3^c)\,,$$

  the sources $\bar{\jmath}_3^e$ and $\bar{\jmath}_3^c$ correspond precisely to electric and magnetic currents.

- For example:

$$G_3 \wedge *\bar{\jmath}_3^c \;\sim\; *G_3 \wedge \bar{\jmath}_3^c \;\sim\; G_7 \wedge \bar{\jmath}_3^c \;\sim\; dA_6 \wedge \bar{\jmath}_3^c \;\sim\; A_6 \wedge J_{mag}.$$

  Here, $\bar{\jmath}_3^e$ would not have contributed since it is exact.
  Vice versa, $\bar{\jmath}_3^e$ couples analogously to the 2-form potential.

## Electric-magnetic interpetation of $G_3\lambda^2$ coupling (continued)

- In summary, one would have

$$|G_3 + j_3|^2 \qquad \text{with} \qquad j_3 \sim \lambda^2 \delta_{D7} \overline{\Omega} \,.$$

and the EOMs

$$dG_3 = J_{mag.} \equiv d\bar{\jmath}_3^e \qquad \text{and} \qquad d * G_3 = J_{el.} \equiv d\bar{\jmath}_3^c \,.$$

In this way, the non-flux part of $G_3$ would cancel all but the harmonic part of $j_3$.

- As a result, one has added a completely local term $|j_3|^3$, and still finds the finite result:

$$|G_3^{(0)} + j_3^h| \sim |G_3^{(0)} + \lambda^2 \Omega / A_\perp|^2$$

- The details are still work in progress ...

## KKLT rescued

- Concerning KKLT, the above are fine points. In any case, one has in the end (possibly without the need for the '$P$'):

$$\mathcal{L} \supset \left| \overline{G}_3 - P\Big(\lambda\lambda\, \Omega_3\, \delta_{D7}\Big) \right|^2 .$$

- From this, one derives the 4d effective potential, without and with the $\overline{D3}$ brane uplift, in agreement with KKLT.

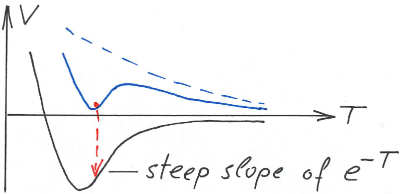
- One can plug this into the 10d Einstein equations and, again, obtain the expected 4d curvature (with or without uplift).

agreement with Carta/Moritz/Westphal,
still (partial) disagreement with Gautason/Van Hemelryck/Van Riet/Venken

## KKLT rescued ?

- Crucially, we know this must work out since 4d EOMs imply the integrated 10d Einstein eqs.

  ('$\Delta_{other}$' from steep slope)




cf. Hamada/AH/Soler/Shiu & Carta/Moritz/Westphal

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- However, a different group disagrees (with the treatment of the volume- or $T$-dependence in the 10d E-M-tensor).

  Gautason/Van Hemelryck/Van Riet/Venken '19

- Let us comment on this concern in more detail ......

## An aside on the E-M tensor of the gaugino condensate:

- Our approach:

$$g_{mn}\frac{\delta}{\delta g_{mn}}S_{eff} \quad\to\quad T\frac{\partial}{\partial T}S_{eff} \quad\to\quad T\frac{\partial}{\partial T}e^{-T}$$

- The derivative acting on $e^{-T}$ gives the crucial, dominant term stopping the runaway to large volume

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- The approach of Gautason et al. (disregarding the red part):

$$T\frac{\partial}{\partial T}S_{class.} \quad \text{with} \quad S_{class.}\supset T\,[G_3\,\lambda^2+(F_{\mu\nu})^2]$$

- Subsequent quantum averaging gives $\langle\lambda^2\rangle\sim e^{-T}$, but the $T$-derivative never gets to act on the exponential.

- We believe this is insufficient and the key effect (in this approach) will come from terms like $\langle G_3\lambda^2(F_{\mu\nu})^2\rangle$.

(for details on this point see added comment in v3 of our paper)

Furthermore:

- New concerns have been raised (about the large volume required to house the complicated topology needed for the D7-brane stack)

  Carta/Moritz/Westphal

- For further recent issues see...

  Das/Haque/Underwood,
  Bena/Dudas/Grana/Lüst,
  Blumenhagen/Kläwer/Schlechter
  ....

- Nevertheless, I believe one may be more optimistic about KKLT than last year.

## Summary / Conclusions

- One should certainly not simply believe in metastable stringy de Sitter but try to establish it.
- Concerning the recent '10d-line-of-attack', KKLT appears to in better shape now than a year ago.
- An interesting (partially open) issue in this context is the detailed structure of the D7-gaugino-bulk coupling.
- I view the a Horava-Witten-style divergence-cancelling $\lambda^4 \delta(z)^2$ term as a central and new feature.
- In parallel to establishing KKLT in more and more detail, getting stringy quintessence to work is the natural alternative.
- This is not easy....(cf. recent paper on the $F$-term problem)

## An Aside on Quintessence:

- Of course, in spite of all that's going to be said, KKLT (and other dS constructions) might in the end fail.

- Quintessence is a natural way out, but this is also difficult..

see e.g. Cicoli/Pedro/Tasinato '12
(also: Cicoli/Burgess/Quevedo '11)

- In particular, one faces an $F$-Term Problem:

AH/Skrzypek/Wittner

- Namely, one needs an extremely large volume, where phenomenological SUSY-breaking implies:

$$e^K |D_x W|^2 \qquad \gg \qquad \left| e^K (|D_T W|^2 - 3|W|^2) \right|$$

$\Rightarrow$ completely new scalar-potential term needed!

Selection of recent work: Cicoli/DeAlwis/Maharana/Muia/Quevedo; Acharya/Maharana/Muia; Emelin/Tatar; Hardy/Parameswaran; $\cdots$