The Higgs and other Thorns in the Side of the Swampland

Arthur Hebecker (Heidelberg)

including recent work with F. Denef / T. Wrase

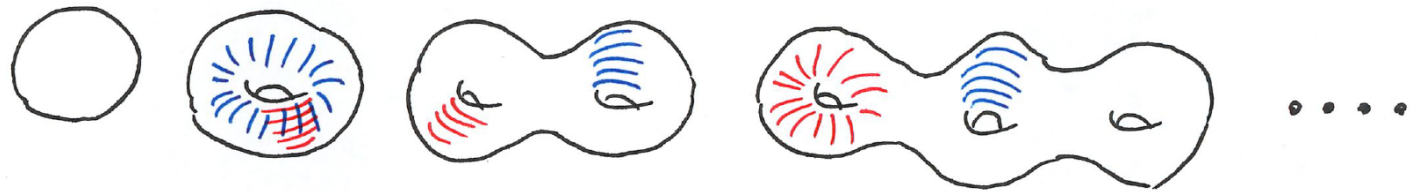
and work in progress with D. Junghans / E. Palti / A. Schachner

Outline

- The dS Swampland conjecture, the Higgs potential, and related issues.
- The Swampland Distance Conjecture and axionic field ranges (related to the axionic Weak Gravity Conjecture).

Landscape vs. Swampland

- String compactifications to $d = 4$ produce a flux-induced, exponentially large landscape of solutions (EFTs).



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

- While the simplest solutions are SUSY-Minkowski or -AdS, there is (in my opinion) strong evidence for meta-stable de-Sitter vacua.

Landscape vs. Swampland (continued)

- However, it is clearly important to keep questioning the constructions and scrutinizing the evidence.

  cf. talks and new papers by Danielsson, Van Riet, Bena, ...

- Recently, a stronger version of the doubts concerning metastable dS vacua has been put forward:

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

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

- Intriguingly, this does not imediately 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 $\Lambda_{cosm.}$.

There is unfortunately no time to do justice
to all the subsequent related papers...

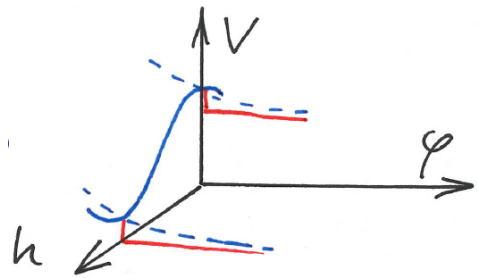
see, e.g.
Ghosh/Kiritsis/Nitti/Witkowski, Andriot, Roupec/Wrase, Ghalee,
Paban/Rosati, Brandenberger, Graef/Marozzi/Vacca,
Colgain/vanPutten/Yavartanoo, Denef/AH/Wrase,
Diaz/Frazer/Retolaza/Westphal, Kehagias/Riotto, Lehners,
Grag/Krishnan, Achucarro/Palma, Aalsma/Tournoy/Van der Schaar/Vercnocke
Banerjee/Danielsson/Dibitetto/Giri/Schillo, Dvali/Gomez, Conlon,
Bartelmann/Brandenberger/Heisenberg/Refregier, Murayama,
Kallosh/Linde/McDonough/Scalisi, Kallosh/Wrase, Kachru/Trivedi
Murayama/Yamazaki/Yanagida, De Alwis/Maharana/Muia/Quevedo,
.....
...

dS Swampland Conjecture vs. Higgs

- However, in the presence of the SM, an additive quintessence contribution is not sufficient to save the conjecture.
- Indeed,

$$V = \lambda(h^2 - v^2)^2 \; + \; \Lambda_{cosm.}$$

clearly violates the conjecture at $h = v$.



- An (apparent) remedy is also easily found:

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

- An immediate problem is that this is a coupled / interacting quintessence model – extreme tuning (of many operators) is now required.

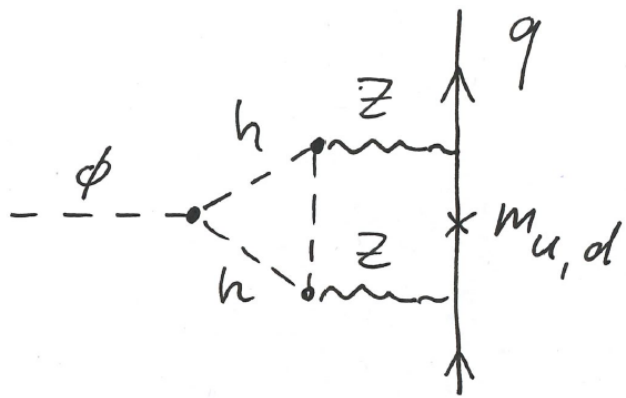
see also Marsh '18

dS Swampland Conjecture vs. Higgs (continued)

- Let us for the moment accept the tuning and press ahead.

  One has to check fifth force constraints.

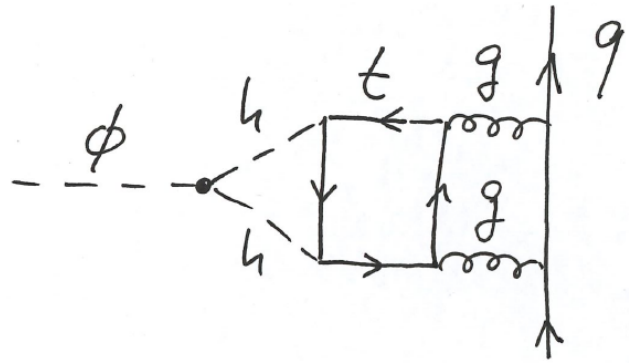
- Based on Equivalence Principle Violation from diagrams like



  we find significant but not (yet) critical constraints

  (with a factor of $\sim 10^4$ missing to rule out the model).

- Using nuclear binding energy effects and diagrams like



this has recently been strengthened. Choi/Chway/Shin '18

- As we also pointed out, one may consider the maximum at the perturbative vacuum of QCD (before chir.-symm.-breaking).

  Unlike the Higgs case, this maximum is very hard to remove by coupling to φ.

- This point has also been strengthened / made more quantitative by considering the potential in the pion sector.

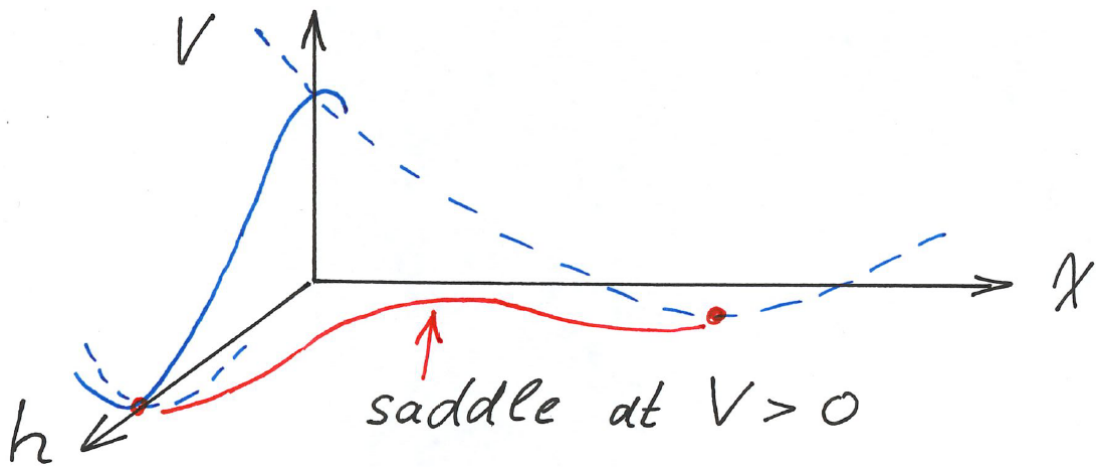
  Choi/Chway/Shin '18

  As a result, the authors claim $c \lesssim 10^{-2}$.

- Returning to the Higgs, one may try to solve the problem by introducing further (non-quintessence) scalars:

$$V = V_h(h) \; + \; \Lambda_{cosm.}\, e^{c\varphi} \qquad \rightarrow \qquad V_h(h,\chi) \; + \; \Lambda_{cosm.}\, e^{c\varphi}$$

- The idea would be to use χ to remove the maximum of $V_h(h)$.
  We have argued that this is fundamentally difficult due to unavoidable saddle points:



- The issue of designing suitable potentials $V_h(h, \chi)$ has recently been discussed in more detail...

  Cicoli/De Alwis/Maharana/Muia/Quevedo '18
  Murayama/Yamazaki/Yanagida '18

- On the one hand, the dangerous saddles may be avoided by cutting of the χ-field-space appropriately.

  Cicoli/De Alwis/Maharana/Muia/Quevedo '18

- On the other hand (dismissing the first option) a no-go theorem employing the saddle point idea has been proposed.

  Murayama/Yamazaki/Yanagida '18

- In any case, $V_h(h, \chi)$ with massive χ appears not to provide an easy way out.

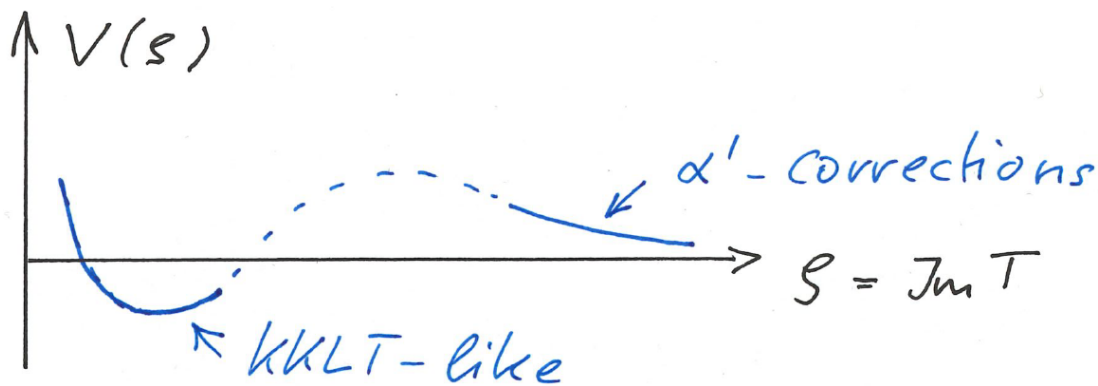
dS Swampland vs. Higgs – intermediate summary

- The $|V'|/V$ conjecture might fall 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, recall the potential..

Conlon '18



dS Swampland vs. Higgs – intermediate summary (continued)

- One may say 'the conjecture is *really* about forbidding metastable de Sitter' (sacrificing $|V'|/V$).
- But this puts us 'back to square one': The old debate about KKLT/LVS being controlled, calculating corrections etc. ...
- Such a critical debate is clearly needed, but at this time I do not see strong *new* reasons that the dS landscape must fall.
- In fact, the opposite:

  The dS maximum of the Higgs potential suggests that string theory has a way of realizing semi-classical dS solutions.

Field Ranges / Inflation

with Junghans / Palti / Schachner – to appear

- Apart from the dS Swampland Conjecture, a key phenomenol. reason for thinking about the Swampland is inflation

- The key constraints come from the axionic WGC

  Arkani-Hamed, Motl, Nicolis, Vafa, '06

  Cheung/Remmen; de la Fuente/Saraswat/Sundrum . . . '14
  Rudelius; Ibanez/Montero/Uranga/Valenzuela; Brown/Cottrell/Shiu/Soler/..
  ..Staessens/Ye; Bachlechner/Long/McAllister; AH/Rompineve/Witkowski;
  Junghans; Heidenreich/Reece/Rudelius; Kooner/Parameswaran/Zavala;
  Harlow; AH/Rompineve/Westphal; Kaloper/Kleban/Lawrence/Sloth . . . '15
  Conlon/Krippendorf . . . '16
  Dolan/Draper/Kozaczuk/Patel; AH/Henkenjohann/Witkowski/Soler . . . '17

  and Swampland Distance Conjecture

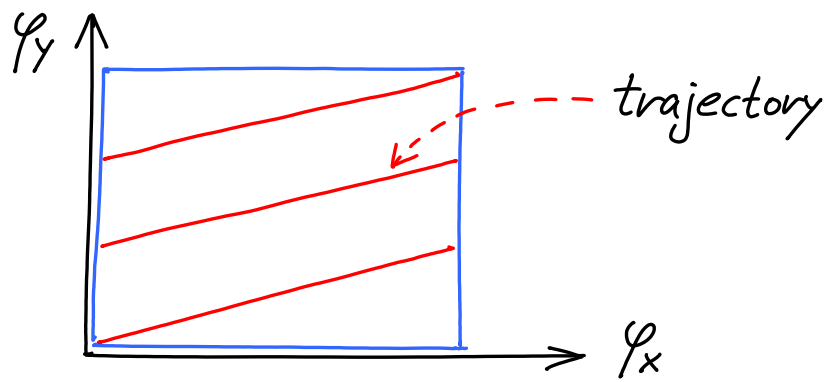
  Vafa, Ooguri/Vafa '05/06

  Palti/Baume/Klaewer '16, Blumenhagen/Valenzuela/Wolf/Grimm '17/18 ...

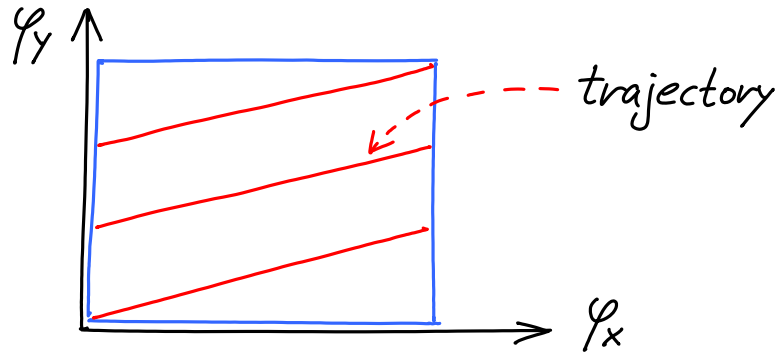
Field Ranges / Inflation (continued)

- As is well-known, the WGC statement $m < gM_P$ translates, in the axionic case, to $S < M_P/f$.
- This forbids transplanckian f-values (with important caveats...)
- One apparent loophole is to realize only an effective transplanckian axion.

Kim/Nilles/Peloso '04



Field Ranges / Inflation (continued)



- Concretely, this can be implemented using 3-form-higgsing à la Dvali:

AH/Mangat/Rompineve/Witkowski '16 ('Winding Inflation')

$$\mathcal{L} \supset (\partial\varphi_x)^2 + (\partial\varphi_y)^2 + (F_0 + \varphi_x + N\varphi_y)^2 +$$

see also Saraswat for the analogous trick in the U(1) WGC

see Shiu/Staessens/Ye for the 'inverse' higgsing idea

Concrete realization at (partially) large complex stucture

- Let $z_1, \cdots, z_n, u, v$ be complex structure moduli of a type-IIB orientifold, let $\mathrm{Im}(u) \gg \mathrm{Im}(v) \gg 1$.

$$K = -\log\left(\mathcal{A}(z, \overline{z}, u - \overline{u}, v - \overline{v}) + e^{2\pi i u} + e^{2\pi i v} + \text{c.c.}\right)$$

$$W = w(z) + f(z)(u + Nv) + e^{2\pi i u} + e^{2\pi i v}$$

- Without exponential terms, it is clear that W leaves one of the originally shift-symmetric directions $\mathrm{Re}(u)$ and $\mathrm{Re}(v)$ flat
- If $N \gg 1$, this direction is closely aligned with $\mathrm{Re}(u)$
- The exponentials induce cosine potential terms for this light field φ:

$$e^{2\pi i u} + e^{2\pi i v} \quad \rightarrow \quad \cos(2\pi\varphi) + \cos(2\pi\varphi/N)$$

Disclaimer

- I will not have time for inflation pheno and for how this model fits the famous 'mild WGC loophole'

  by Rudelius and Brown/cottrell/Shiu/Soler

- I will also not discus other interesting work using complex structure moduli to enhance field ranges

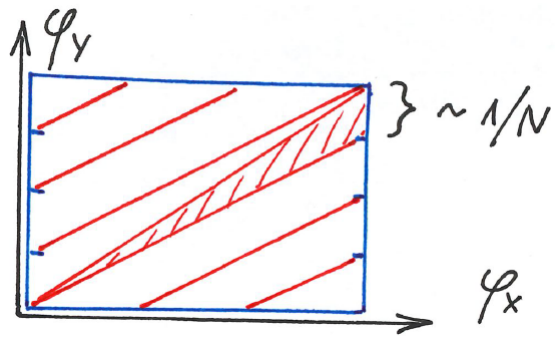
  e.g. by Palti, Blumenhagen, Ibanez, Landete, Marchesano, Regalado, Valenzuela, Wieck and many others....

The 'new twist' on Winding Inflation

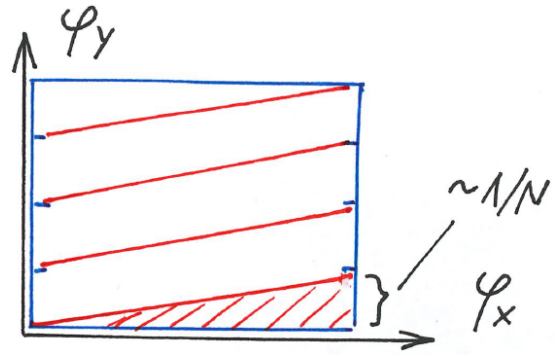
- Justified and very inspiring criticism has been raised by Palti:
- Indeed, the flux choice $N \gg 1$ may affect the stabilization of $\mathrm{Re}(u)$ and $\mathrm{Re}(v)$ in an adverse way (preventing $f_{eff} \gg 1$).
- One can show that, in the simplest setting, this is in fact deadly.
- We are still in the process of analyzing whether Large Field Inflation is nevertheless possible in more complicated (e.g. 3-moduli-mixing) scenarios.
- But, crucially, for (non-inflationary) large field ranges the situation looks promising!

The 'new twist' on Winding Inflation (continued)

- To see this, consider a 'misaligned' Winding trajectory:

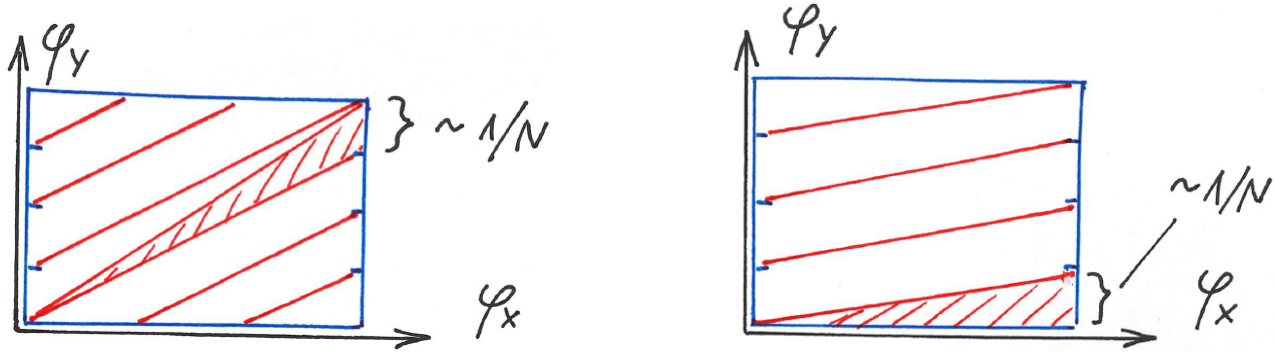


and compare it to the previously discussed 'aligned' case:



- The enhancement of the field range is similar: $f \rightarrow f_{eff} \sim Nf$.

The 'new twist' on Winding Inflation (continued)



- But, crucially, the flux-realization is through

$$W \supset (N-1)u + Nv \qquad \text{vs.} \qquad W \supset u + Nv\,.$$

- The corresponding stablization conditions for the saxions are

$$K_u/K_v = (N-1)/N \qquad \text{vs.} \qquad K_u/K_v = 1/N\,.$$

- Thus, misalignment allows us to be at a generic point ($K_u/K_v \sim \mathcal{O}(1)$) in moduli space and still have extended f !

Summary: Field Ranges / Swampland Distance Conjecture

- It appears possible/likely that large axionic field ranges can be realized with full moduli stabilization.
- This is not in conflict with the Swampland Distance Conjecture for moduli spaces. AH/Henkenjohann/Witkowski '17
- It would, however, be in conflict with a possible non-SUSY generalization to EFTs with very light scalar fields.
- Large Field Inflation would, in this approach, *not* yet be established (both cosine terms have short periods!)
- Progress along these line towards inflation is possible, but I have no definite expectation concerning the outcome.

Summary: $|V'|/V$ and dS Swampland Conjecture

- It is very interesting to explore the phenomenological (Higgs etc.) consequences of the $|V'|/V$ conjecture.
- Based on both the (developing) EPV constraints and the required tuning, I am skeptical. But surprises are of course possible...
- Independently of $|V'|/V$, it is interesting to imagine living in a non-fully-stablized comactification.
- But: The observed SUSY-breaking-energy can (presumably?) not be the allowed to drive the rolling of a modulus: This effect would be too strong (?)
- If so, why would an extra (very flat) scalar help?
  How does it overcome the problems of getting (approximate) Minkowski with strong SUSY-breaking?