The Ubiquitous Throat

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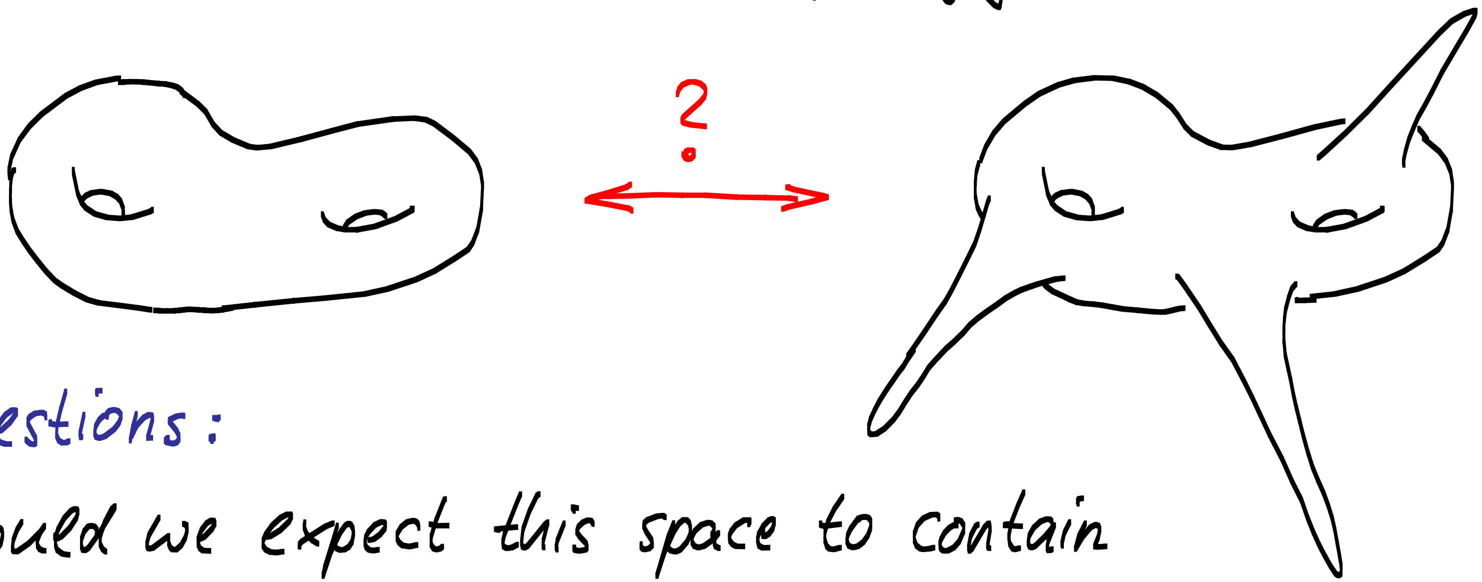
Outline

- Belief: Throats are a common feature of the type IIB landscape ($\Rightarrow$ large hierarchies are a common feature)
- Aim: Quantify the above statement
- Procedure: Which # of 3-cycles? How often do they shrink to a near-conifold geometry? What hierarchies are induced?
- Also: Stability issues; Phenomenological implications

Motivation

Assumption: The observed universe is based on a large-volume type IIB compactification with complicated topology



(RS, Verlinde, ... GKP ...)

Questions:

- Should we expect this space to contain strongly warped regions (Klebanov-Strassler-throats) ?
- How many of them ?
- Which warp factors ?

$\Rightarrow$ Important consequences for cosmology, SUSY-Breaking etc. may follow ...

Basic idea of analysis

- Expect orientifold with many 3-cycles (since otherwise the choice of fluxes will be too limited to allow for a sufficiently small cosm. constant Λ)
- Random flux numbers $\Rightarrow$ Some 3-cycles carry small flux numbers $\Rightarrow$ those cycles stabilized at small volume
- If the zero-volume limit of a cycle gives conifold point, then the small-volume case gives "throat"

$\Rightarrow$ Distribution of number & length of throats becomes a well-defined statistical question (→ Douglas et al.) (assuming no correlation with the fine-tuning of Λ)

- Result: Binomial distribution

The number of 3-cycles

- consider CY-orientifold with K 3-cycles
- flux vector: $N \in \mathbb{Z}^{2K}$
- tadpole condition: $$\underbrace{\frac{\chi_4}{24}}_{L_*} = \underbrace{\frac{1}{2} N^T \Sigma N}_{L} + N_{D3} \quad , \quad \Sigma = \begin{pmatrix} 0 & \mathbb{1} \\ \mathbb{1} & 0 \end{pmatrix}$$
- number of vacua: $$\boxed{\mathcal{N}_{SUSY} \sim L_*^K / K!}$$ (→ Denef, Douglas)
- uplifted vacua: (e.g. by $\overline{D3}$, as KKLT) $$\mathcal{N}_{uplift} \sim L_*^K / K!$$
- flat distribution of $-|W_0|^2$ $\Rightarrow$ need $\mathcal{N}_{uplift} \sim 10^{120}$

$$\Rightarrow \quad \boxed{K \sim \log(10^{120}) / \log(e L_* / \log(10^{120}))}$$

$\Rightarrow$ conservative estimate: choose L_* as large as possible ($L_* \sim 10^4$)

$\Rightarrow$ $\boxed{K \sim 60}$

alternative (less conservative) estimate:

- CYs with $h^{2,1} \sim 100 \cdots 200$ are "typical"
- large $h^{2,1}$ statistically preferred

$\Rightarrow$ $\boxed{K \sim 2 \cdot h^{2,1}_- \sim 2(h^{2,1}/2) \sim 200}$

Crucial assumption: Many of these $60 \cdots 200$ 3-cycles can shrink to conifold singularity

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- "Nodes" or "ordinary double points" are common in complex varieties
- 3-cycles of quintic ($h^{2,1} = 101$) have this feature $\Rightarrow$ expect the whole "Web of CYs" ($\to$ Candelas, Green, Hübsch) to inherit it.

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Stability issues

moduli: $\phi_a = (\tau, z_i)$ $\quad i = 1 \cdots K/2$

$$V = e^K \Big(\underbrace{K^{a\bar{b}} D_a W D_{\bar{b}} \bar{W}}_{\text{positive mass matrix}} - \underbrace{3|W|^2}_{\text{potentially negative terms}} \Big)$$

SUSY vacua:

$D_a W = 0$

(vanish for $W_0 \to 0$)

$\Rightarrow$ expect no stability problems after uplift

However: Denef/Douglas find stability problems in near conifold case for 1 compl. structure modulus

What is the reason? Are these problems generic?

Small W_0, Small $\delta\phi^a$

$$\Rightarrow \quad V \sim \delta\phi^a \underbrace{W_{ab}} K^{b\bar{c}} \underbrace{\bar{W}_{\bar{c}\bar{d}}} \delta\phi^{\bar{d}}$$

2nd derivative matrices

Recall: $W = A(z) + \tau B(z)$; $\int \Omega \sim z \ln z$

near conifold point

$$\Rightarrow \quad W_{ab} \sim \begin{pmatrix} 0 & \sim 1 \\ \sim 1 & 1/z \end{pmatrix} \quad \Rightarrow$$

1 small eigenvalue ; stability problem!

However: 2 compl. structure moduli

$$\Rightarrow \quad W_{ab} \sim \begin{pmatrix} 0 & \sim 1 & \sim 1 \\ \sim 1 & \sim 1 & \sim 1 \\ \sim 1 & \sim 1 & 1/z \end{pmatrix} \quad \Rightarrow$$

no small eigenvalue ;

<u>no stability problems!</u>

Distribution of throats

Denef/Douglas: probability for being near conifold point $z_i = 0$

(also: Giryavets, Kachru, Tripathy, Conlon, Quevedo ....)

$$p_i(|z_i|) \simeq \frac{1}{c_i \ln(1/|z_i|)}$$

$O(1)$ constant depending on moduli space away from $z_i = 0$

Giddings/Kachru/Polchinski:

warp factor (throat hierarchy) $\boxed{h_i \sim |z|^{-1/3}} \sim e^{2\pi P/3 g_s M}$

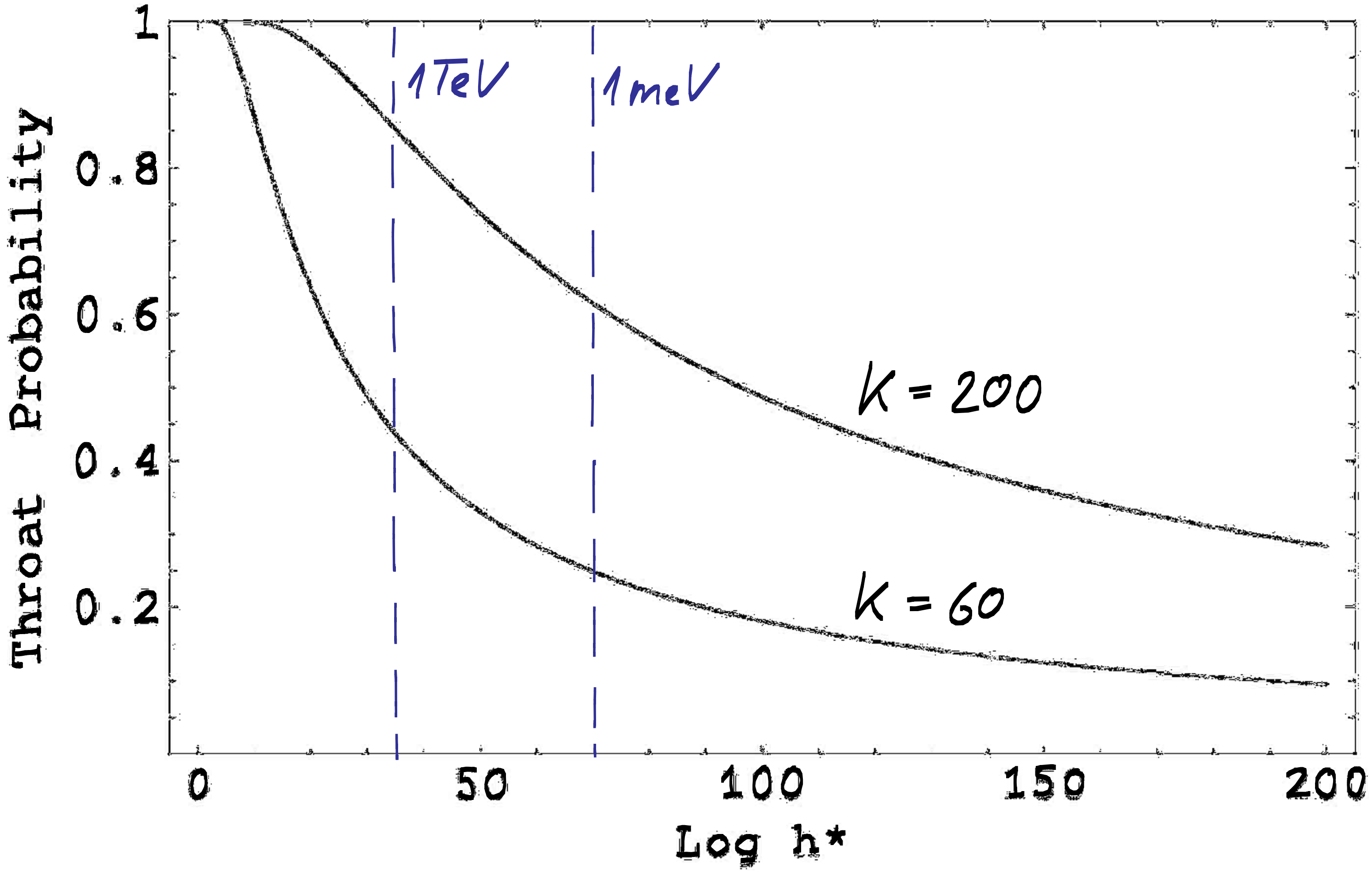
The various conifold points represent $O(K)$ subspaces of co-dimension one in the complex $K/2$-dimensional moduli space. Throats are in <u>slices</u> around them.

- Probability for creating hierarchy $> h_i$ at the $z_i \to 0$ conifold point is
$$p_i(h_i) \simeq \frac{1}{3 c_i \log h_i}$$

- Probability for creating n throats with hierarchy $h > h_*$ is
$$\boxed{p(n, h > h_* | K) \sim \binom{K}{n} p^n (1-p)^{K-n}} \quad ; \quad p \equiv \frac{1}{3c \log h_*}$$
(Binomial distribution)

$\Rightarrow$
- Throat # with $h > h_*$: $\quad \bar{n}(h > h_* | K) = \dfrac{K}{3c \log h_*}$
- Longest expected throat: $\quad h_1 \sim \exp(K/3c)$
- Probability for no throat with hierarchy $h > h_*$: $\quad p(0, h > h_* | K) \sim \exp\left(-\dfrac{K}{3c \log h_*}\right)$

Another interesting quantity: Probability $P(h > h_* | K)$ for having at least one throat with hierarchy $> h_*$



Both with $c = 1$

$\Rightarrow$ Very low "price" for having even a very long throat

Towards phenomenology

or: Are throats really ubiquitous?

Main problem: The parameters K and c are not known.

① Conservative scenario:

$K = 60$ (minimal value for cosm. constant) ; $c = 3$

$\Rightarrow$ crucial combination: $K/3c \sim 7$

$\rightarrow$ largest expected hierarchy: 10^3

$\rightarrow$ expect ~ 3 throats with hierarchy 10 or larger

(may be interesting for inflation etc., but no striking low-energy phenomenology)

$\rightarrow$ however: $\bar{n}\,(h > 10^{15}) \sim 0.2 \Rightarrow$ "electroweak hierarchy throat" in 1 out of 5 vacua.

② Favourable scenario: $K = 200$; $c = 1/3$

$$\Rightarrow K/3c = 200$$

→ largest expected hierarchy: 10^{80}

→ not having a throat with $h > 10^{30}$ (meV-scale!) has only 5% probability (such throats are a prediction!)

→ expect ~6 electroweak hierarchy throats

More specifically:

KKLT setup ; $\overline{D3}$ branes as only source of SUSY-breaking ; SM on D-branes in unwarped region

⇒ interesting modulus-anomaly-mediation phenomenology (→ talks of Nilles and Brümmer (competing "vector mediation"))

The required "10^7-throat" is present in 50% of vacua!

Conclusions / Outlook

- We have attempted to quantify the statement hat
  "throats are common in the type IIB landscape".
- Details of outcome depend on number of 3-cycles (K) and "bulk" of compl. structure moduli space (c)
- $K/3c$ → conservative: expect $h \sim 10^3$; $h \sim 10^{15}$ in 20% of vacua
  → favourable: expect $h \sim 10^{80}$;
  "meV-throats" are a firm prediction
- Need better understanding of geometry of CY 3-cycles and of compl. structure moduli space
- If "favourable case" confirmed, could throats rule out type IIB landscape via cosmological bounds?