CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

String defects, supersymmetry and the swampland

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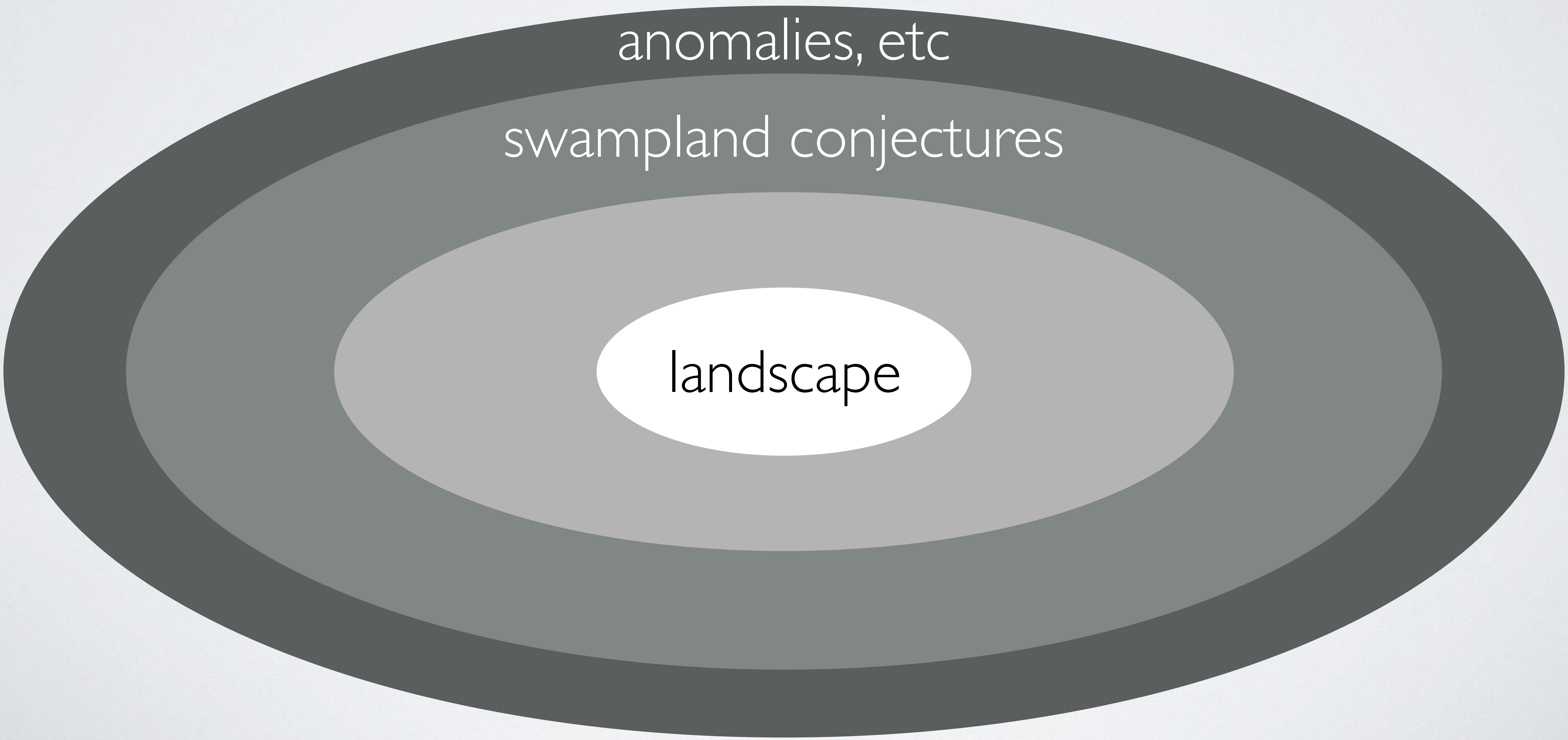
Based on arXiv:2007.12722 [hep-th] (JHEP)
with C. Angelantonj, C. Condeescu, E. Dudas

Swampland : constraints on effective theories of quantum gravity (beyond anomalies, unitarity, etc)

[Vafa '05, recent review: Palti '19]



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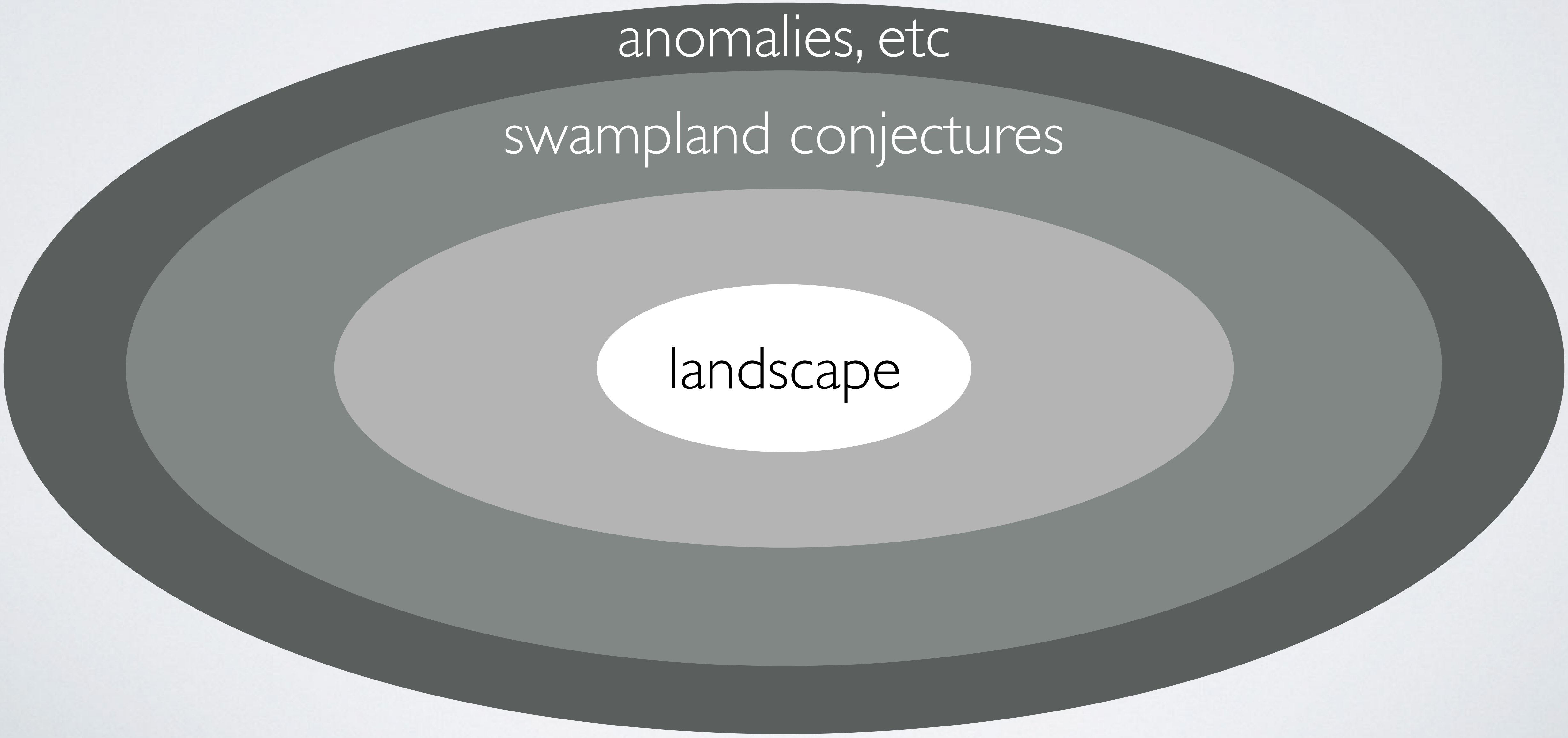

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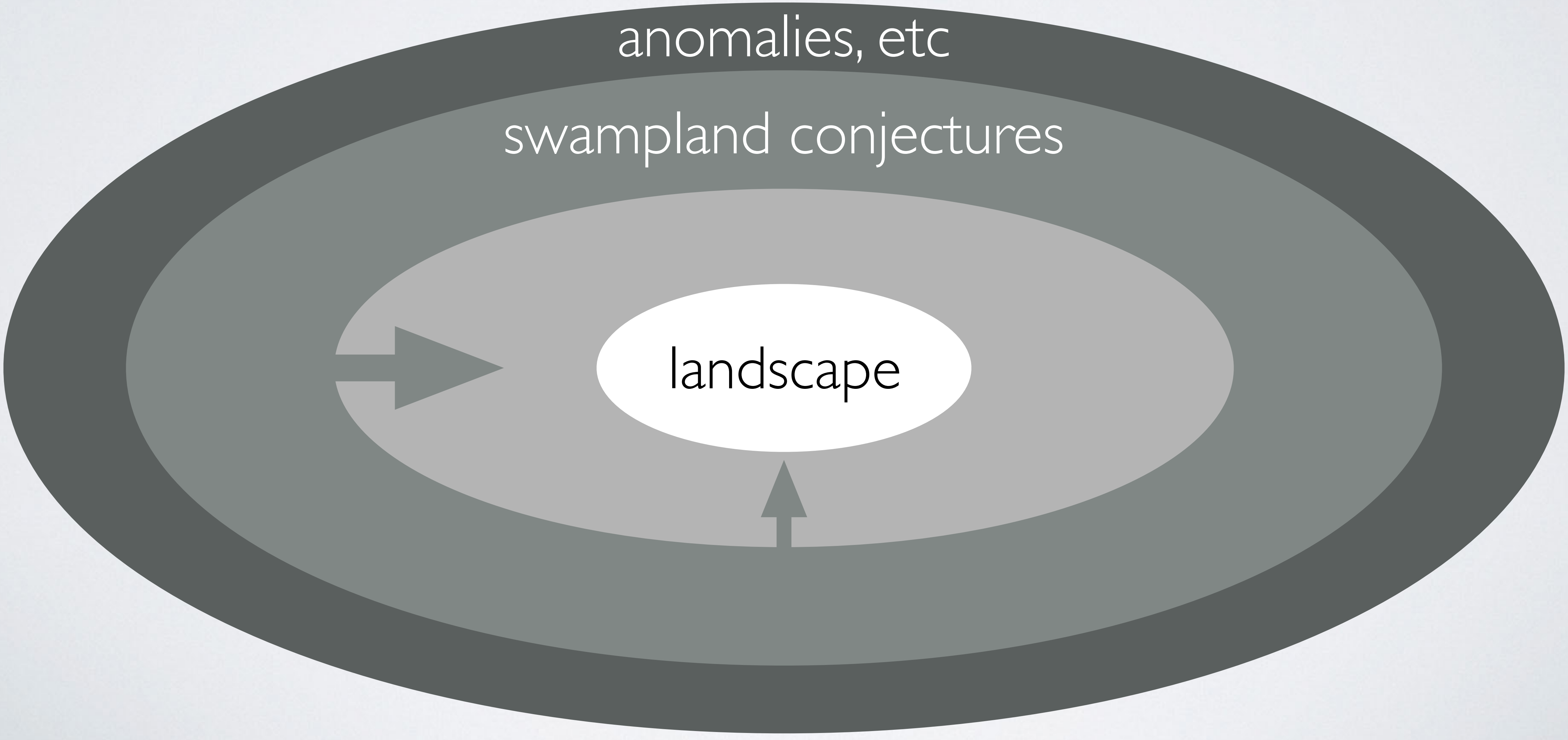

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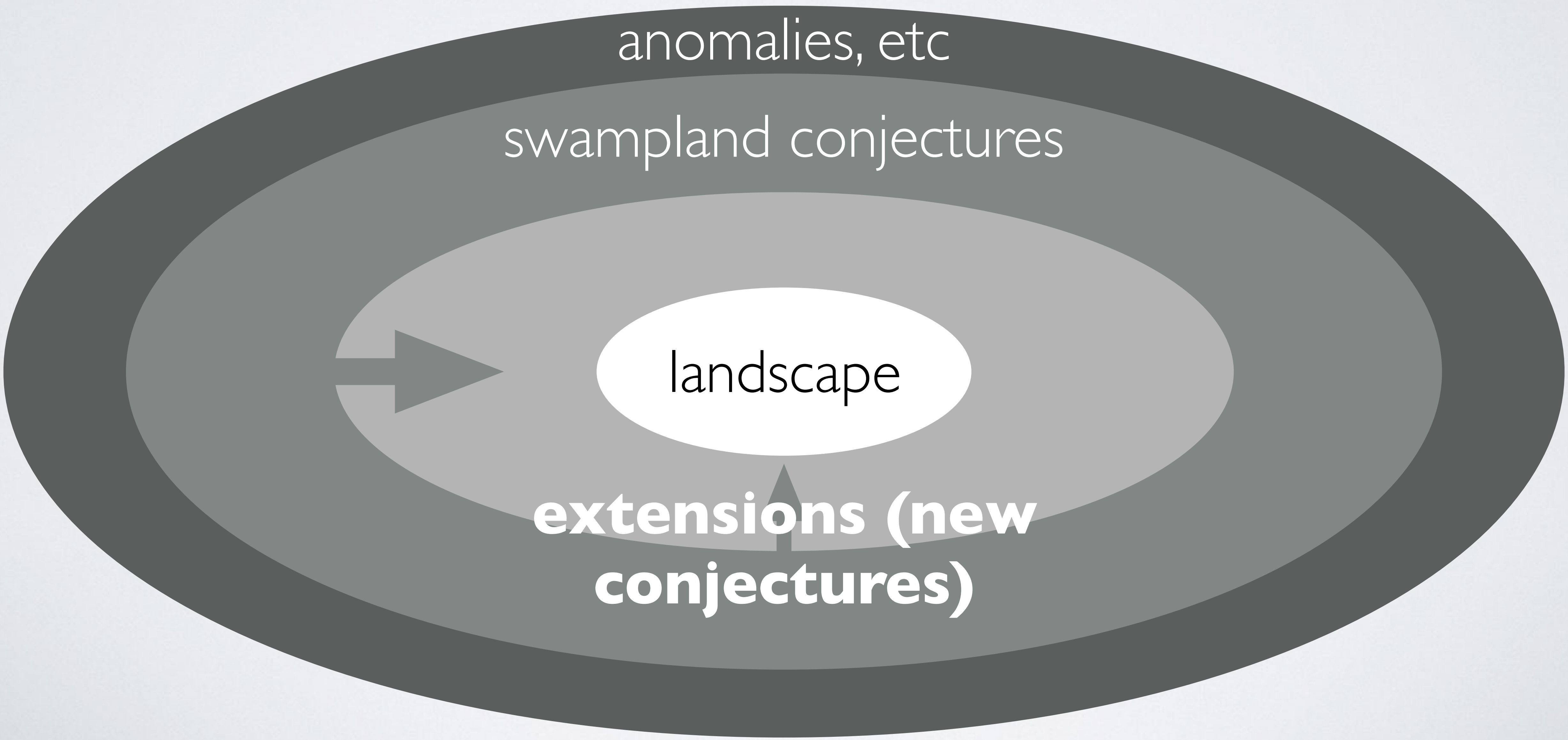

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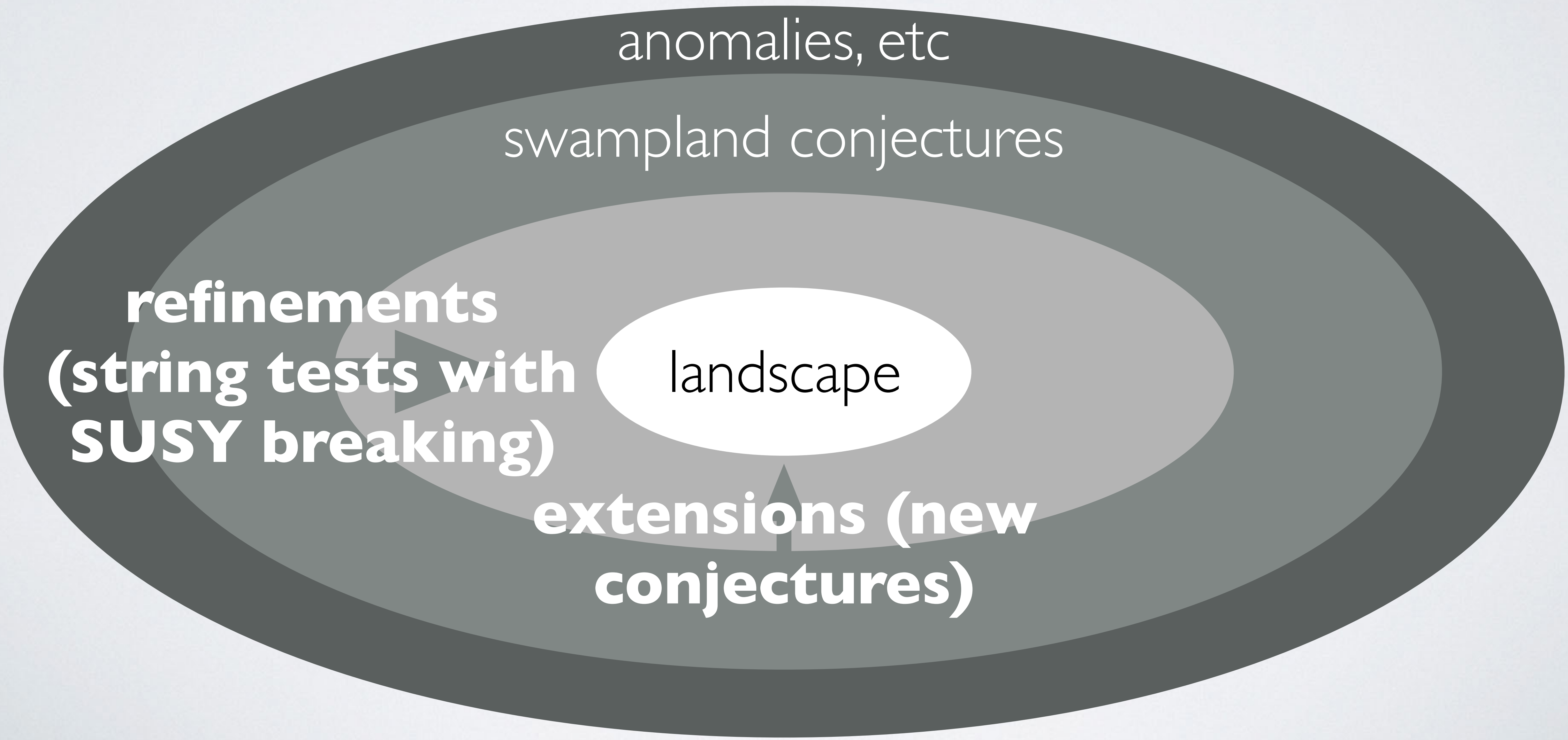

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A statement about the **deep IR**

Consistency of string defects from anomaly inflow

[KSV: Kim, Shiu, Vafa '19]

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Originally, in (10d and) 6d : start with a **N=1 SUGRA** with **anomaly cancellation à la Green-Schwarz-Sagnotti**

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$$I_8 = \frac{1}{2}\Omega_{\alpha\beta}\, X_4^\alpha\, X_4^\beta \qquad S_{GS} = \int \Omega_{\alpha\beta}\, C_2^\alpha \wedge X_4^\beta \qquad \delta_\theta\, C_2^\alpha = \ldots$$

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Use the completeness of the gauge spectrum : there exist **charged string defects**

[Polchinski '03]

$$S_{2d} \supset -\Omega_{\alpha\beta}\, Q^\alpha \int C_2^\beta$$

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Anomaly inflow on the defect :

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Consistency of the IR CFT constrains I_4 : compatibility ?

[KSV: Kim, Shiu, Vafa '19]

For **1/2-BPS string defects** :

$$Q \cdot J \geq 0 \qquad c_L = 3Q \cdot Q - 9Q \cdot a + 2 \geq 0 \qquad c_R = 3Q \cdot Q - 3Q \cdot a \geq 0$$

$$Q \cdot Q + Q \cdot a \geq -2 \qquad k_i \equiv Q \cdot b_i \geq 0 \qquad \sum_i \frac{k_i \dim G_i}{k_i + h_i^\vee} \leq c_L$$

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where the vectors a, b_i are defined from the 6d anomaly polynomial

$$I_8 = \frac{1}{2} \Omega_{\alpha\beta} X_4^\alpha X_4^\beta \qquad X_4^\alpha = \frac{1}{2} a^\alpha \mathrm{tr} R^2 + \frac{1}{2} \sum_i \frac{b_i^\alpha}{\lambda_i} \mathrm{tr} F_i^2$$

and all contractions are performed with $\Omega_{\alpha\beta}$

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Examples : N=1 SUGRA with gauge group $U(1)^{496}$ or $E_8 \times U(1)^{248}$ in 10d, N=1 SUGRA with 9 tensors and two bifundamentals of the gauge group $SU(N) \times SU(N)$ in 6d if $N > 9$, etc

[see also Lee, Weigand '19]

Tests in perturbative 6d orientifold models

A) examples from SUSY models

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Simplest example : Bianchi-Sagnotti-Gimon-Polchinski type I $T_4/\mathbb{Z}_2$ model

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Model of O9 and O5 planes, D9 and D5 branes, with gauge group

$$U(16)_9 \times U(16)_5$$

Spectrum :

Multiplicity	**Multiplet**	**Field Content**
1	Gravity	$(g_{\mu\nu}, C^{+}_{\mu\nu}, \psi_{\mu L})$
1	Tensor	$(C^{-}_{\mu\nu}, \phi, \chi_R)$
20	Hypers	$(4\phi_a, \psi_{aR})$
$(256, 1) + (1, 256)$	Vectors	(A_μ, χ_L)
$(120 + \overline{120}, 1) + (1, 120 + \overline{120}) + (16, 16)$	Hypers	$(4\phi, \chi_R)$

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$(120+\overline{120},1)+(1,120+\overline{120})+(16,16)$	Hypers	$(4\phi, \chi_R)$

Anomaly polynomial : $$I_8 = \left(\mathrm{tr}R^2 - \frac{1}{2}\mathrm{tr}F_1^2\right)\left(\mathrm{tr}R^2 - \frac{1}{2}\mathrm{tr}F_2^2\right)$$

String model : must be consistent

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String defects : **D1 branes**, or D1-like in 6d

Brane	0	1	2	3	4	5	6	7	8	9
D9	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$
D5	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$
$\mathrm{D}5'$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\times$	$\times$	$\times$	$\times$
D1	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$
$\overline{\mathrm{D}1}$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$

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D5	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$
D5$'$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\times$	$\times$	$\times$	$\times$
D1	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$
$\overline{\text{D1}}$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$

Landscape of defects by turning on magnetic fields on D5’

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D5$'$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\times$	$\times$	$\times$	$\times$
D1	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$
$\overline{\text{D1}}$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$

Landscape of defects by turning on magnetic fields on D5'

Focus on the **D1**

Two cases for the D1 branes

Brane	0	1	2	3	4	5	6	7	8	9
D5	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$
D1	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$

D1 brane at a fixed point

D1 brane in the bulk

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Brane	0	1	2	3	4	5	6	7	8	9
D5	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$
D1	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$

D1 brane at a fixed point

Representation	$SO(1,1) \times SU(2)_l \times SU(2)_R \times SO(4)$
$r\bar{r}$	$(0,1,1,1) + (\frac{1}{2},1,2,2')_L$
$r\bar{r}$	$(1,2,2,1) + (\frac{1}{2},2,1,2')_R$
$\frac{r(r+1)}{2} + \frac{\bar{r}(\bar{r}+1)}{2}$	$(1,1,1,4) + (\frac{1}{2},1,2,2)_R$
$\frac{r(r-1)}{2} + \frac{\bar{r}(\bar{r}-1)}{2}$	$(\frac{1}{2},2,1,2)_L$
$r\bar{n} + \bar{r}n$	$(\frac{1}{2},1,1,1)_L$
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$$I_4 = -\left(\mathrm{tr}R^2 - \frac{1}{2}\mathrm{tr}F_1^2\right) \Longrightarrow Q = \frac{1}{\sqrt{2}}(1,1)$$

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$$\implies c_L^{(\mathrm{KSV})} = 3Q\cdot Q - 9Q\cdot a + 2 = 20 \qquad c_R^{(\mathrm{KSV})} = 3Q\cdot Q - 3Q\cdot a = 6$$

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$$c_L = 4_{CM} + 20$$

$$c_R = 6_{CM} + 6$$

Two cases for the D1 branes

Brane	0	1	2	3	4	5	6	7	8	9
D5	×	×	×	×	×	×	•	•	•	•
D1	×	×	•	•	•	•	•	•	•	•

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D1 brane at a fixed point:

$$c_L=4_{CM}+20+6+96_{D5}$$
$$c_R=6_{CM}+6+6+96_{D5}$$

D1 brane in the bulk:

$$c_L=4_{CM}+20$$
$$c_R=6_{CM}+6$$

Two cases for the D1 branes

Brane	0	1	2	3	4	5	6	7	8	9
D5	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$
D1	$\times$	$\times$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$	$\bullet$

D1 brane at a fixed point

Representation	$SO(1,1)\times SU(2)_l\times SU(2)_R\times SO(4)$
$r\bar{r}$	$(0,1,1,1)+(\frac{1}{2},1,2,2')_L$
$r\bar{r}$	$(1,2,2,1)+(\frac{1}{2},2,1,2')_R$
$\frac{r(r+1)}{2}+\frac{\bar{r}(\bar{r}+1)}{2}$	$(1,1,1,4)+(\frac{1}{2},1,2,2)_R$
$\frac{r(r-1)}{2}+\frac{\bar{r}(\bar{r}-1)}{2}$	$(\frac{1}{2},2,1,2)_L$
$r\bar{n}+\bar{r}n$	$(\frac{1}{2},1,1,1)_L$
$rd+\bar{r}\bar{d}$	$(\frac{1}{2},1,1,2)_L$
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D1 brane in the bulk

Representation	$SO(1,1)\times SU(2)_l\times SU(2)_R\times SO(4)$
$\frac{r(r-1)}{2}$	$(0,1,1,1)+(\frac{1}{2},2,1,2)_L+(\frac{1}{2},1,2,2')_L$
$\frac{r(r+1)}{2}$	$(1,2,2,1)+(\frac{1}{2},1,2,2)_R$
$\frac{r(r+1)}{2}$	$(1,1,1,4)+(\frac{1}{2},2,1,2')_R$
$r(n+\bar{n})$	$(\frac{1}{2},1,1,1)_L$

$$I_4=-\left(\mathrm{tr}R^2-\frac{1}{2}\mathrm{tr}F_1^2\right)\Longrightarrow Q=\frac{1}{\sqrt{2}}(1,1)$$

$$\Longrightarrow\ c_L^{(\mathrm{KSV})}=3Q\cdot Q-9Q\cdot a+2=20 \qquad c_R^{(\mathrm{KSV})}=3Q\cdot Q-3Q\cdot a=6$$

$$c_L=4_{CM}+20+6+96_{D5}$$
$$c_R=6_{CM}+6+6+96_{D5}$$

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non-trivial CP factors

"accidentally" massless states

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I_4

$\Longrightarrow c_L^{(\mathrm{KSV})}$

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	$1,1)_L$

$R \quad - 3Q\cdot a = 6$

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BPS branes can have non-minimal central charges

Unitarity constraint ?

Tests in perturbative 6d orientifold models B) (brane) SUSY breaking

SUSY breaking in string theory : two examples

SUSY breaking in string theory : two examples

SUSY breaking **by deformation** of SUSY models (by compactification, Scherk-Schwarz) : KSV conditions expected to hold

SUSY breaking **at the string scale** (brane SUSY breaking) : KSV conditions expected to be violated, but SUSY breaking can be localised

Simplest example : type I $T_4/\mathbb{Z}_2$ model

[Antoniadis, Dudas, Sagnotti '99]

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Model of O9 and O5+ planes, D9 and anti-D5 branes, with gauge group

$$SO(16)_9^2 \times USp(16)_5^2$$

Spectrum :

Field/Multiplet	**Representation**
Gravity	1
Tensors	17
Hypers	4
A_μ	$(120,1;1,1)+(1,120;1,1)+(1,1;136,1)+(1,1;1,136)$
χ_L	$(120,1;1,1)+(1,120;1,1)+(1,1;120,1)+(1,1;1,120)$
Hypers	$(16,16;1,1)+(1,1;16,16)$
MW ψ_L	$(16,1;16,1)+(1,16;1,16)$
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Anomaly polynomial :

$$I_8 = \frac{1}{64}\left(\mathrm{tr}F_1^2+\mathrm{tr}F_2^2-\mathrm{tr}F_3^2-\mathrm{tr}F_4^2\right)^2 - \frac{1}{64}\left(-8\,\mathrm{tr}R^2+\mathrm{tr}F_1^2+\mathrm{tr}F_2^2+\mathrm{tr}F_3^2+\mathrm{tr}F_4^2\right)^2$$
$$-\frac{1}{128}\left(\mathrm{tr}F_1^2-\mathrm{tr}F_2^2+4\,\mathrm{tr}F_3^2-4\,\mathrm{tr}F_4^2\right)^2 - \frac{15}{128}\left(\mathrm{tr}F_1^2-\mathrm{tr}F_2^2\right)^2$$

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~~SUSY~~

Two cases for the D1 branes

Brane	0	1	2	3	4	5	6	7	8	9
$\overline{\text{D5}}$	×	×	×	×	×	×	•	•	•	•
D1	×	×	•	•	•	•	•	•	•	•

D1 brane at a fixed point

D1 brane in the bulk

Two cases for the D1 branes

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bulk CP factors

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KSV conditions apply !

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dm_1	
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Non-BPS stable branes generically violate the conditions

D1 branes "separated" from SUSY breaking do not

A « null charged string conjecture »

In both cases : **« bulk » branes** that verify the KSV constraints

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Null charged string conjecture

There must exist a consistent string with null charge (unless T=0)

When assumed, one can **exclude 6d SUSY models**

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[Kumar, Morrison, Taylor '10]

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$$\Omega = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \qquad a = (-3,1),\ b = (0,-1)$$

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- BPS branes can have non-minimal central charges
- Non-BPS stable branes generically violate the conditions
- D1 branes “separated“ from SUSY breaking do not
- Some anomaly polynomials cannot arise from a SUSY model

We proposed a **null charged string conjecture**, that allows to exclude models without known string theory realisation

THANK YOU