The Quantum Gravity Cut-Off in a (convex) Nutshell

String Pheno '23
Jul 2023

Based on [arXiv:2306.16450] and [arXiv: 2307. XXXXX]

Work with L. Ibáñez, A. Herráez and J. Calderón
and WIP with I. Valenzuela and I. Ruiz

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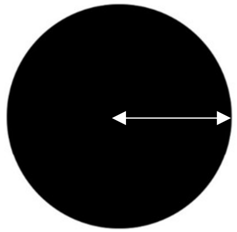
The Species Scale

- (Einstein) Gravity leads to some nice (and strange) solutions: Black Holes



$R_{\rm BH} \gg \ell_{\rm Pl}$

- E.g. Schwarzschild solution

$$ds^2 = -\left(1 - \frac{2GM}{r}\right) dt^2 + \left(1 - \frac{2GM}{r}\right)^{-1} dr^2 + r^2 d\Omega^2$$

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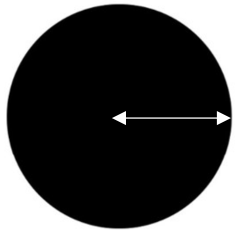

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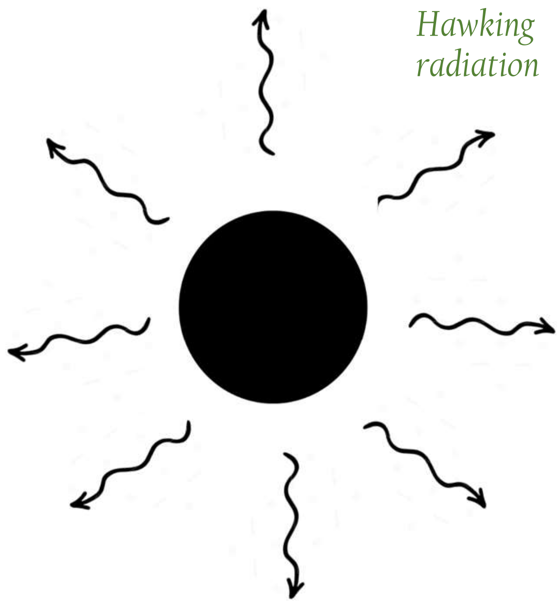
- General lore: ‘The smaller, the hotter’

$$T_{\mathrm{BH}} \sim \frac{1}{T_{\mathrm{BH}}} \sim \left(\frac{M_{\mathrm{Pl}}^{d-2}}{M_{\mathrm{BH}}}\right)^{\frac{1}{d-3}}$$



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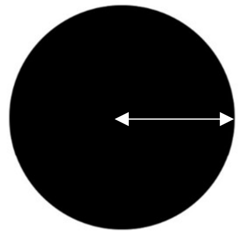

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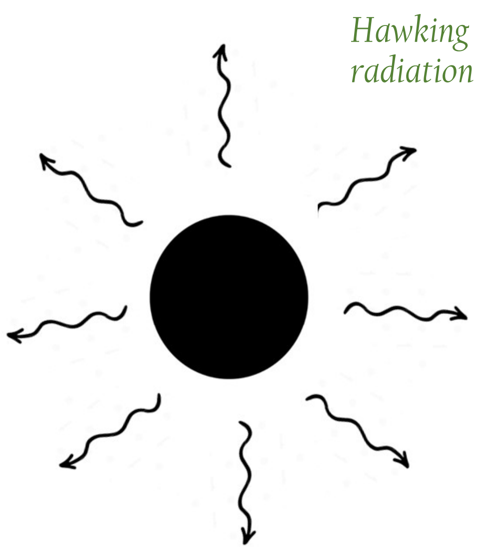

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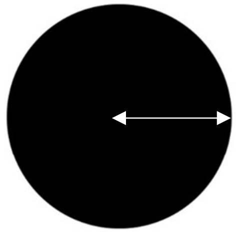

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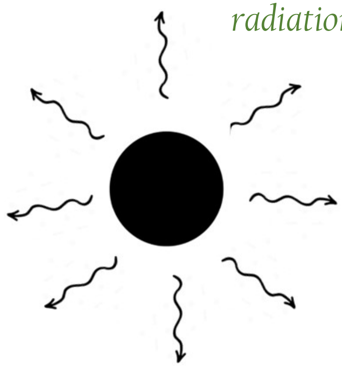
Hawking radiation



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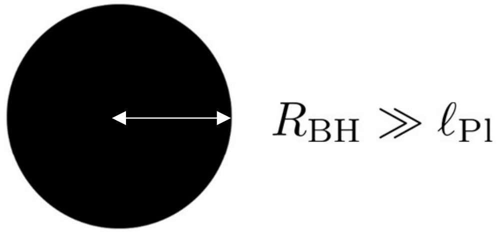

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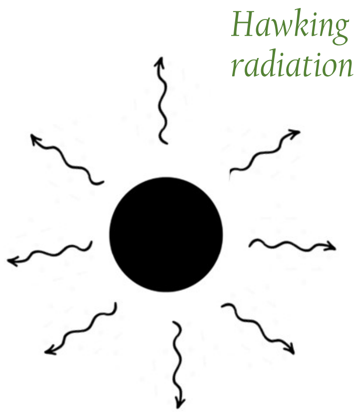


$$T_{\rm BH} \sim \frac{1}{T_{\rm BH}} \sim \left(\frac{M_{\rm Pl}^{d-2}}{M_{\rm BH}}\right)^{\frac{1}{d-3}}$$

- What is the minimum sized BH describable by our EFT?

The Species Scale

- A natural guess is to take it to be approx. of Planckian size

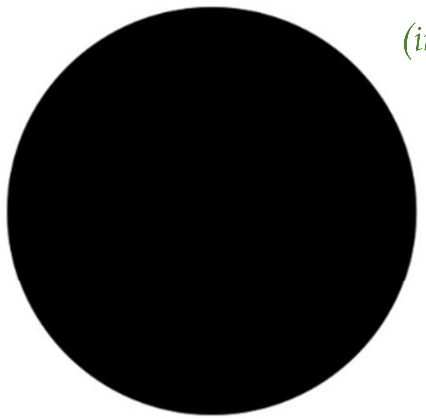
$$R_{\mathrm{BH}} \sim \mathcal{O}(\ell_{\mathrm{Pl}})$$

- It turns out that for theories with large number of species, this is an overestimate!
  (Problems with entropy, BH decay, ...)

- The correct QG scale is the Species Scale [Dvali, Redi, '07]

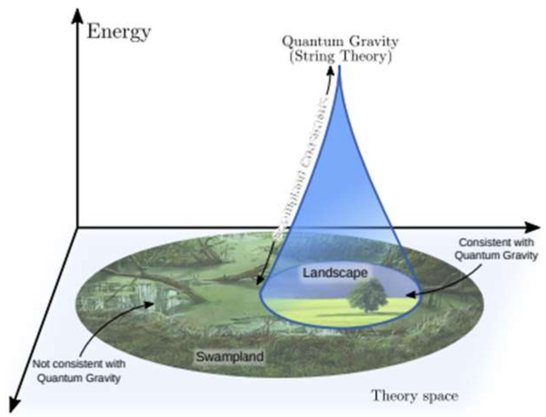
$$\ell_{\mathrm{sp}} \sim \ell_{\mathrm{Pl}}\, N^{\frac{1}{d-2}}$$

- Notice that for $N \gg 1$ one finds that $\ell_{\mathrm{sp}} \gg \ell_{\mathrm{Pl}}$



(in Planck units)

The Species Scale

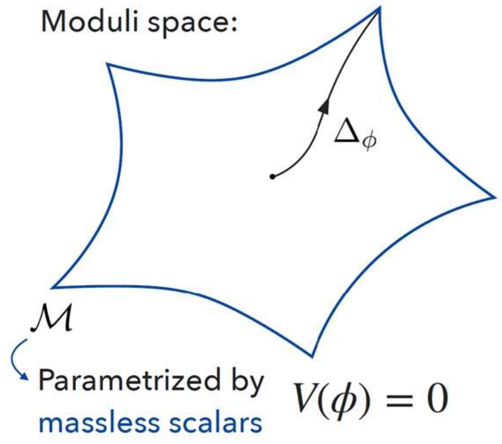


[van Beest, Calderón, Mirfendereski, Valenzuela, '21]

- The species scale plays a starring role in the Swampland Program

  Max. Validity of any Eff. Field Theory Description!!

- Natural question: Can we perametrically decouple such scale from the Planck mass? How low should it be when approaching infinite distance/weak coupling limits?



- Based on String Theory evidence and entropy bounds we propose:

$$\lambda_{\rm sp} \geq \frac{1}{\sqrt{(d-2)(d-1)}}$$

See A. Herráez Talk!!

- Where $\Lambda_{\rm sp} \sim e^{-\lambda_{\rm sp}\,\Delta_\phi}$

Outline

I. THE SPECIES SCALE DISTANCE CONJECTURE — The bound and its convex hull formulation

II. A SIMPLE EXAMPLE IN 9D — M-theory on T^2

III. A 'DUALITY' IN DISGUISE — A cute pattern between light towers and the QG cut-off

IV. SUMMARY & OUTLOOK — Open Questions. Future Directions

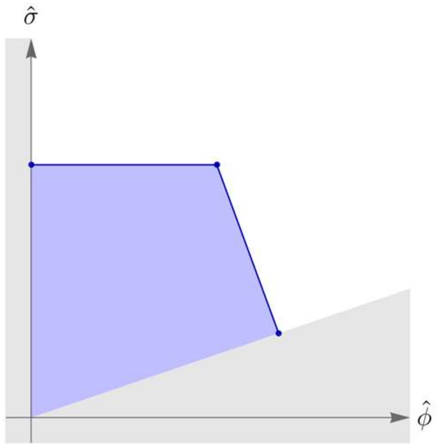
A Convex Hull condition

- In [Calderón, AC, Herráez, Ibáñez '23] we propose a bound for $\lambda_{\rm sp}$ in any inf. dist. limit
- In multi-moduli cases, what one defines is the charge-to-mass and species vectors

$$\zeta_{\rm t}^i \equiv -\partial^i \log m_{\rm tower} \qquad \mathcal{Z}_{\rm sp}^i \equiv -\partial^i \log \Lambda_{\rm sp}$$

- In analogy with the (Sharpened) Distance Conjecture, it is useful to define a convex hull [Calderón, Uranga, Valenzuela '20]

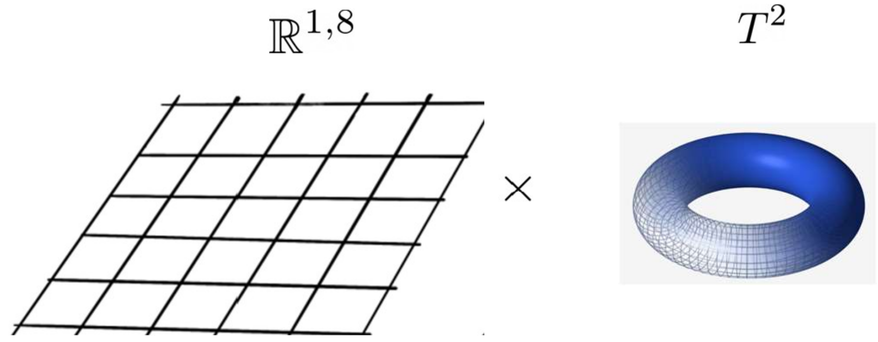
  → It gives us information about the nature of the inf. dist. limit



- This allows us to quickly visualize whether the SSDC holds or not for a given theory

$$\lambda_{sp} = \max\left\{\hat{n}\cdot\vec{Z}_{eff}\right\} \quad \Rightarrow \quad \textbf{SSDC: } \lambda_{sp} \geq \lambda_{sp,min}$$

A Simple Example in 9d

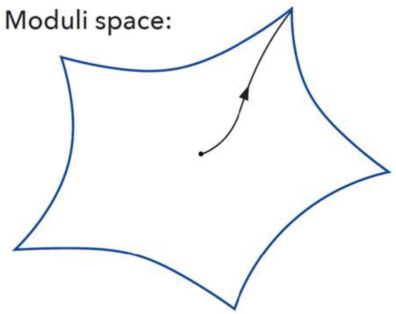


- Take M-theory on T^2 $\longrightarrow$ 9d N=2 SUGRA theory

- The theory has a classically exact moduli space

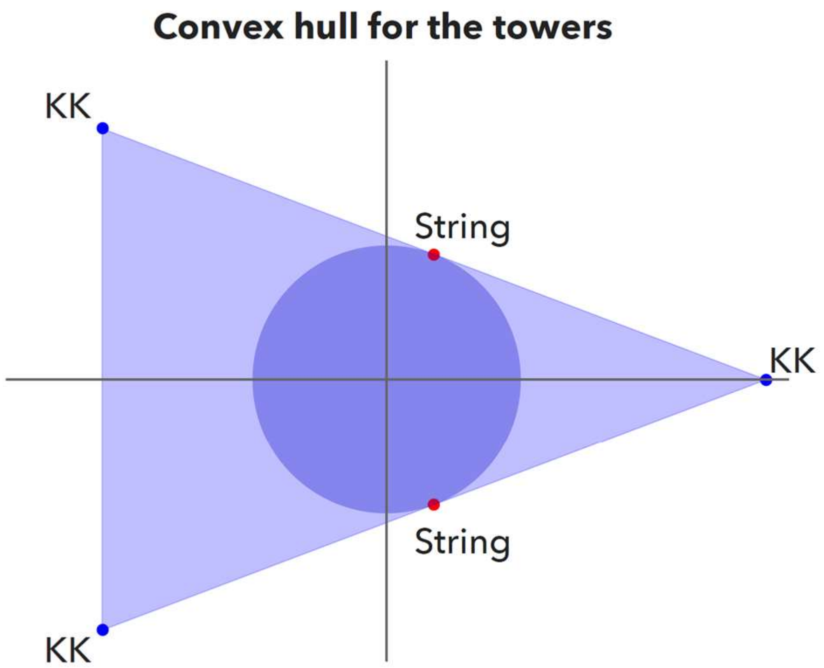
$$\mathcal{M}_{9\mathrm{d}} = \underbrace{SL(2,\mathbb{Z})\backslash SL(2,\mathbb{R})/U(1)}_{\textit{Complex Structure}} \times \underbrace{\mathbb{R}}_{\textit{Volume}}$$

- There are lots of towers and infinite distance limits… Each one of them characterized by some $\Lambda_{\rm sp}$



A Simple Example in 9d

- We compute the charge-to-mass vectors of the towers and from them we extract those of the species scale



[Etheredge, Heidenreich, Kaya, Qiu, Rudelius ‘22]

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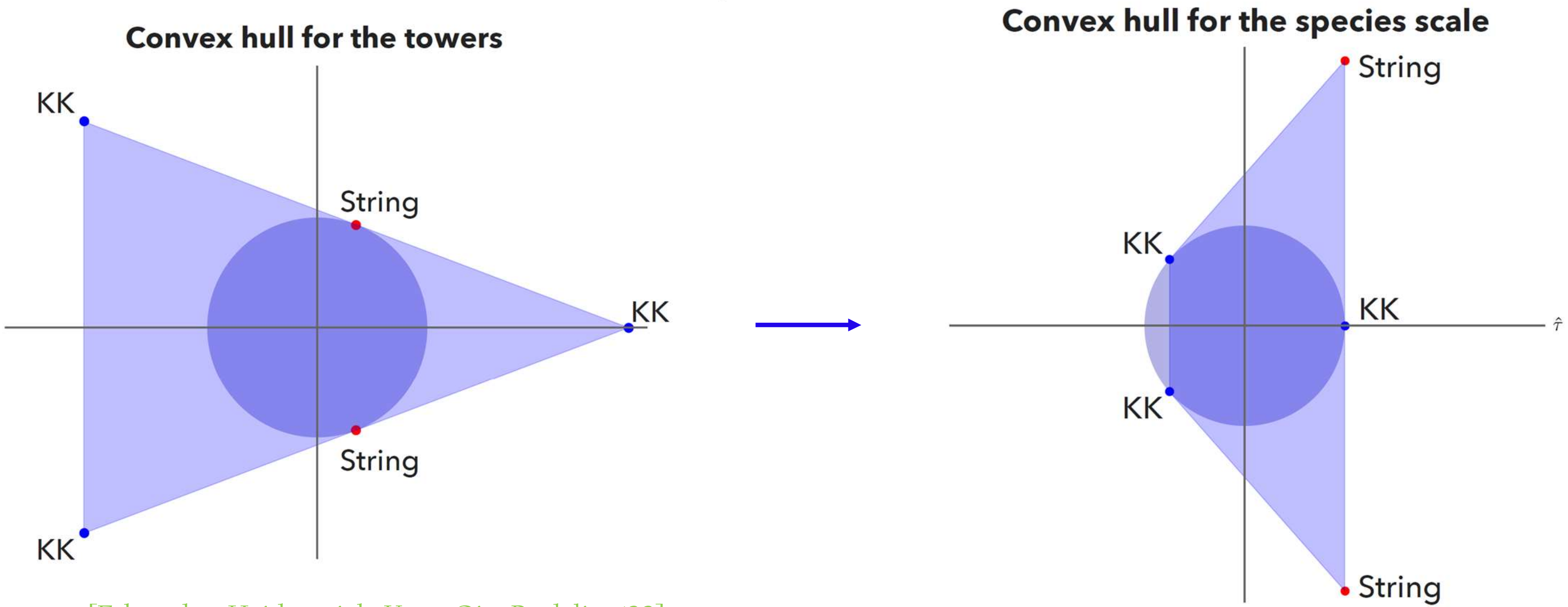

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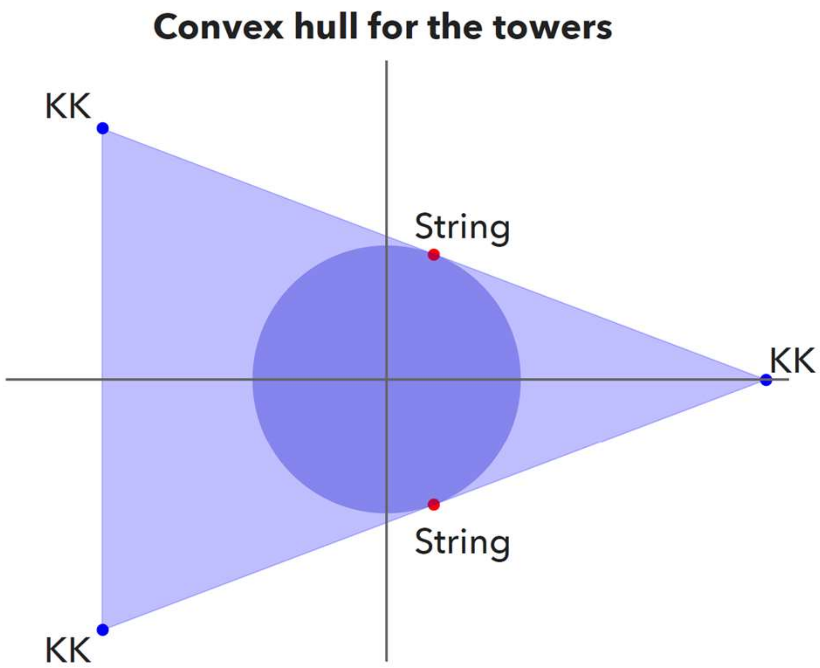

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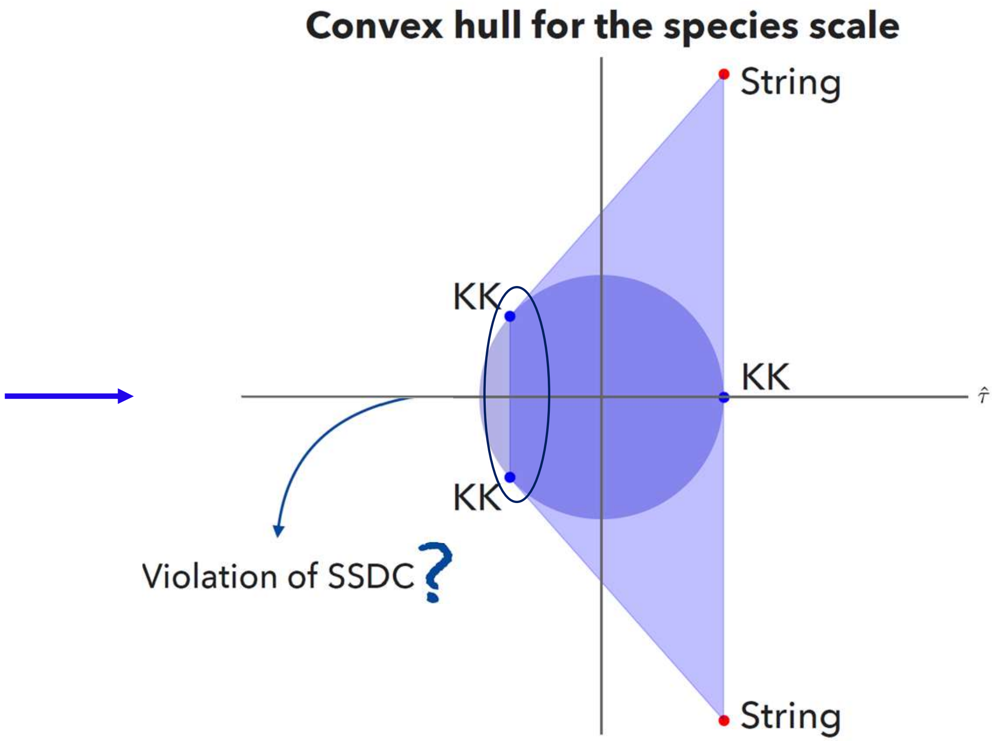

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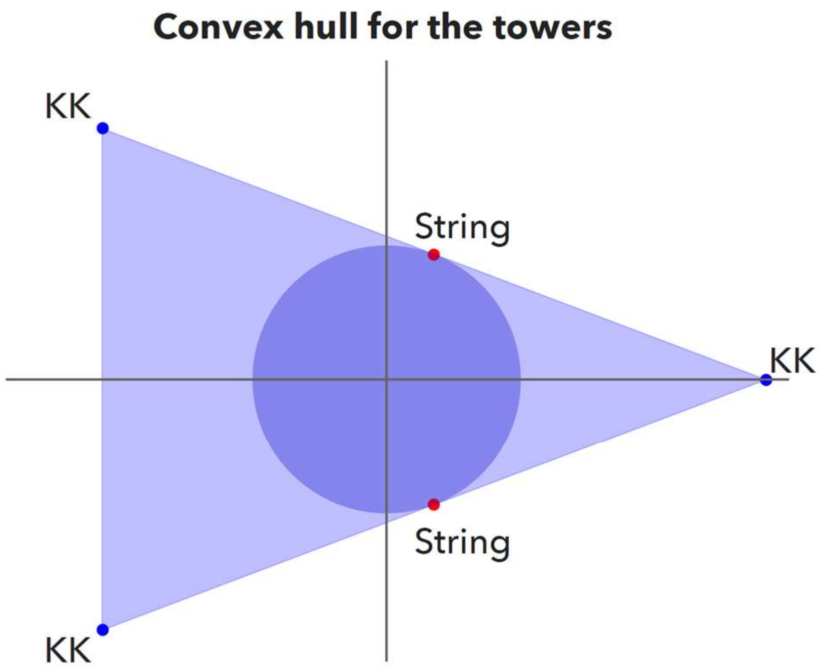

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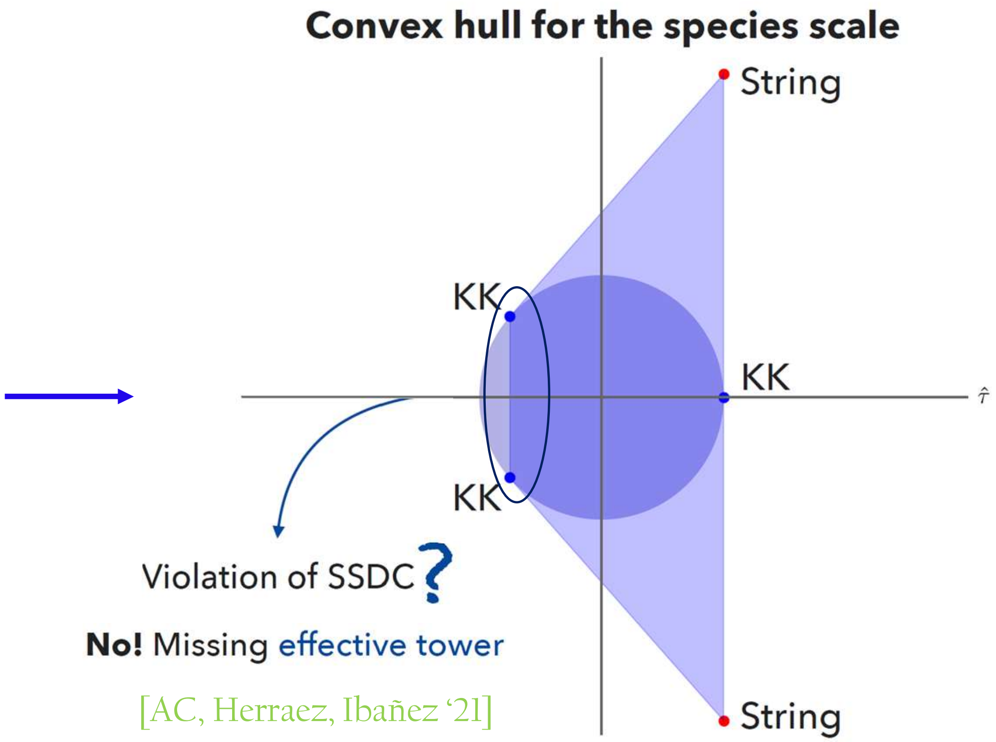

[AC, Herraez, Ibañez '21]

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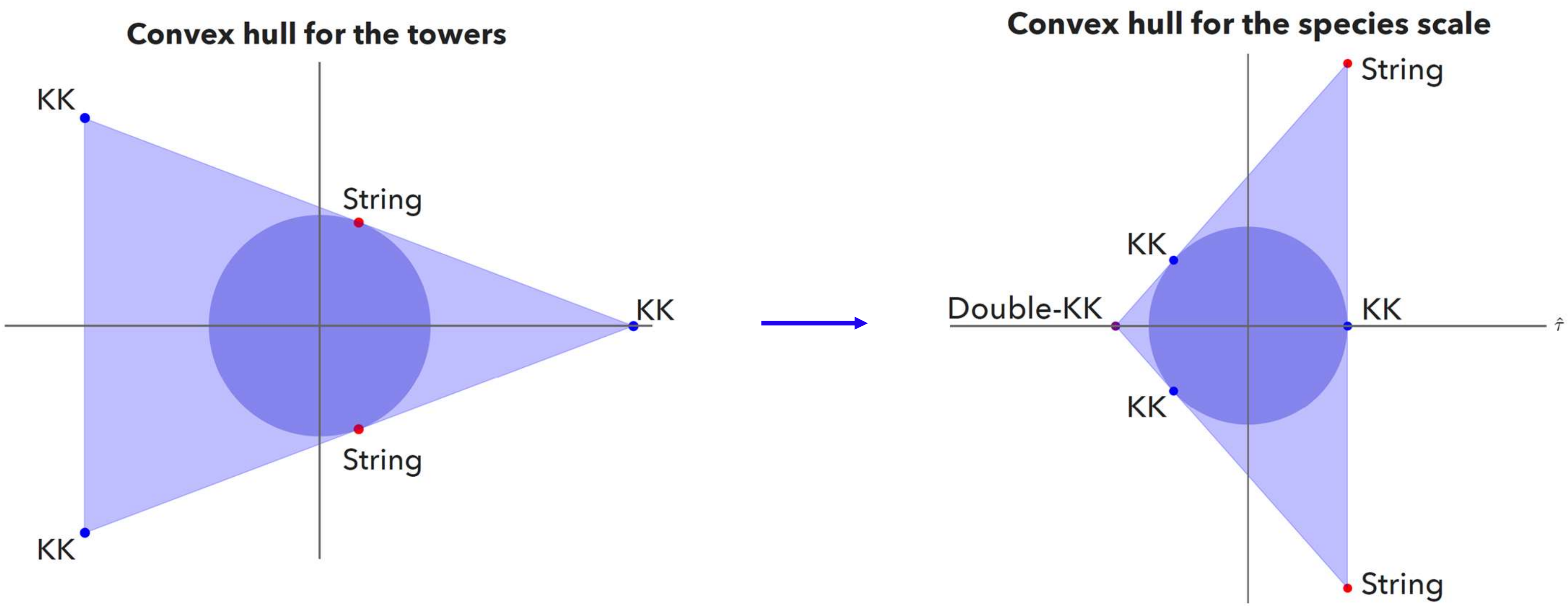
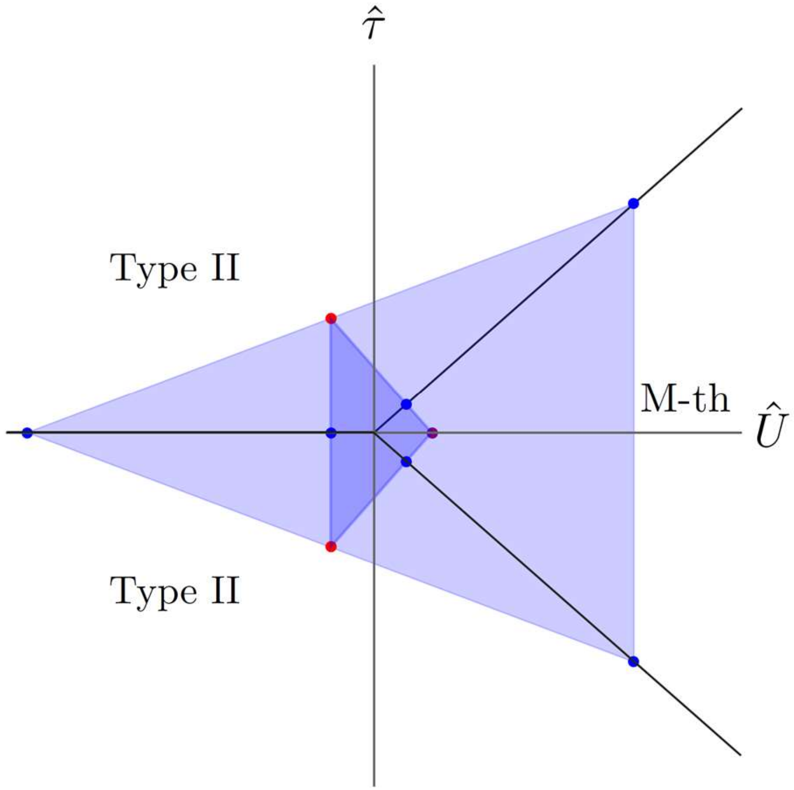


[Etheredge, Heidenreich, Kaya, Qiu, Rudelius '22]

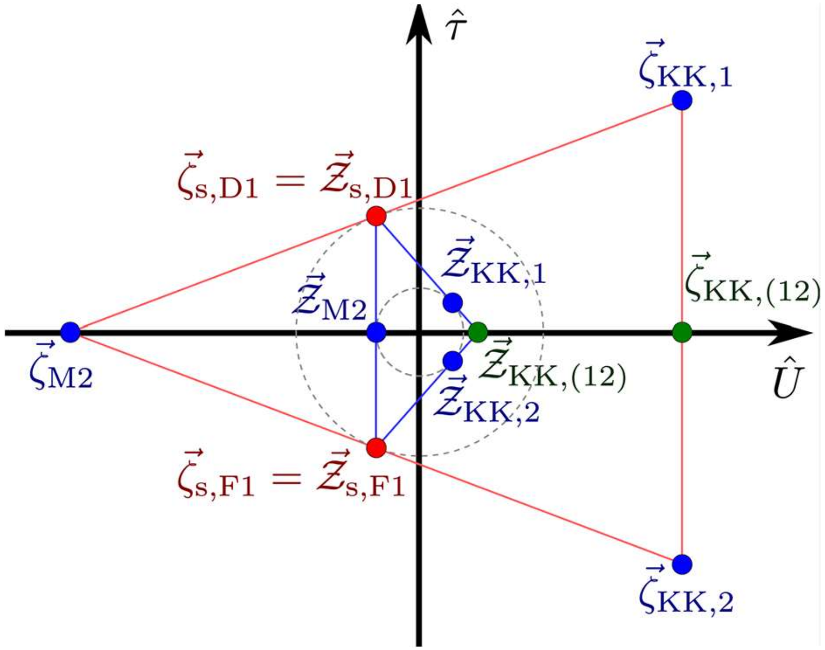
A Simple Example in 9d

- The Species Scale provides useful information: it tells us about duality frames!



A 'Duality' in disguise

- Let's have a closer look at the previous diagram
- Notice that the role between generating/saturating towers gets reversed!
- Moreover, strings are fixed under groing to one convex hull to the other
- In addition, the faces of one hull are orthogonal to the vertices of the other



$$\boxed{\vec{\zeta}_{\mathrm{t}} \cdot \vec{\mathcal{Z}}_{\mathrm{sp}} = G^{ij}\left(\partial_i \log m_{\mathrm{tower}}\right)\left(\partial_j \log \Lambda_{\mathrm{sp}}\right) = \frac{1}{d-2}}$$

A 'Duality' in disguise

- The proposal is that this pattern, namely

See I. Valenzuela's Talk!!

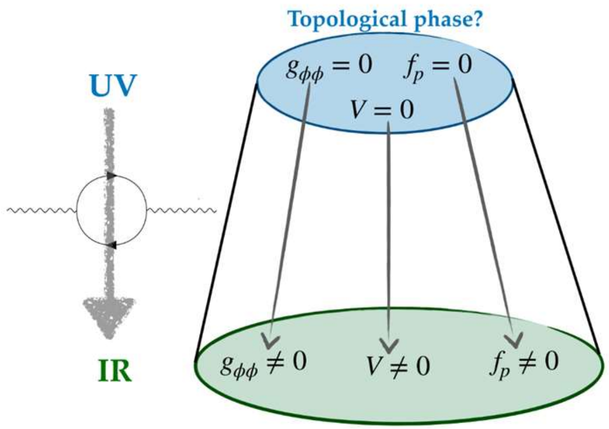
$$\vec{\zeta}_{\rm t} \cdot \vec{\mathcal{Z}}_{\rm sp} = G^{ij} \left(\partial_i \log m_{\rm tower}\right) \left(\partial_j \log \Lambda_{\rm sp}\right) = \frac{1}{d-2} \longrightarrow G^{ij} \left(\partial_i \log m_{\rm tower}\right) \left(\partial_j \log N\right) = -1$$

where one should take the lightest tower

- This seems to be non-trivially verified in all (to our knowledge) String Theory examples

- It implies the Sharpened Distance Conjecture and is related to the SSDC

See L. Ibáñez Talk!!



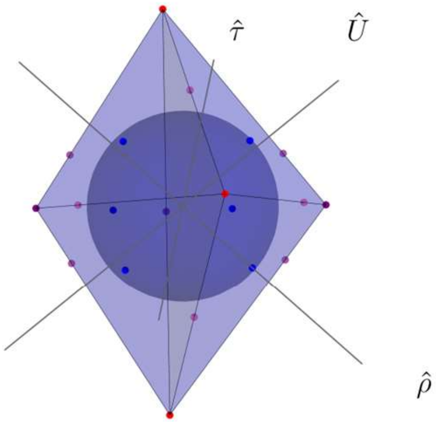
- Underlying reason? The Emergence Proposal? The Emergent String Conjecture?

[Blumenhagen, AC, Corvilain, Gligovich, Grimm, Heidenreich, Herraez, Heidenreich, Kawamura, Marchesano, Melotti, Paraskevopoulou, Rudelius, Seo Valenzuela]

Summary & Outlook

- There seems to be a lower universal bound for the exponential rate of the QG cut-off

$$\boxed{\lambda_{\rm sp} \geq \frac{1}{\sqrt{(d-2)(d-1)}}}$$



- This is satisfied in many string theory examples in a non-trivial way

  The concept of effective tower seems to be crucial

- There is moreover a pattern in string theory constructions relating the lightest towers of states to the QG cut-off

$$\boxed{\vec{\zeta}_{\rm t} \cdot \vec{\mathcal{Z}}_{\rm sp} = \frac{1}{d-2}}$$

- Is there any simple explanation for it? Perhaps Emergence?

Stay Tuned!!!

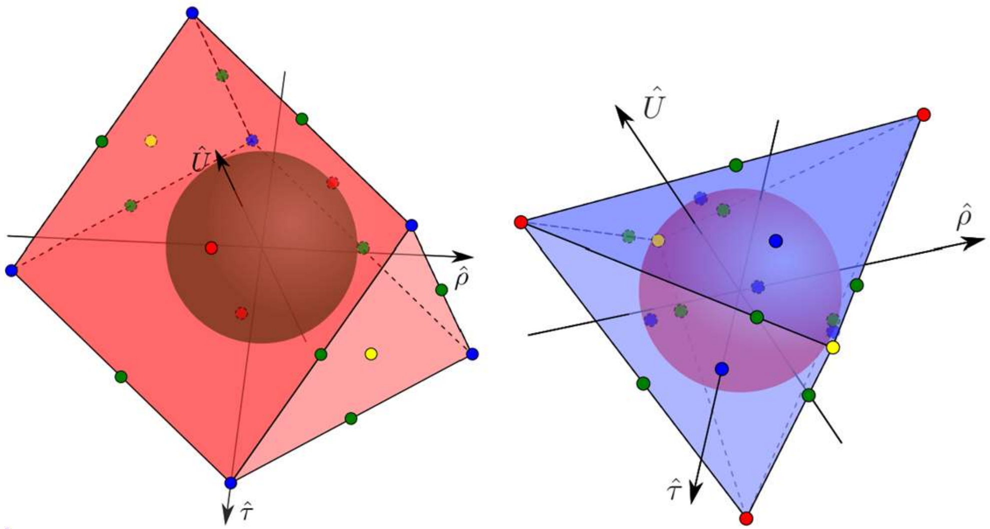
Thank you for your attention!

QUESTIONS?

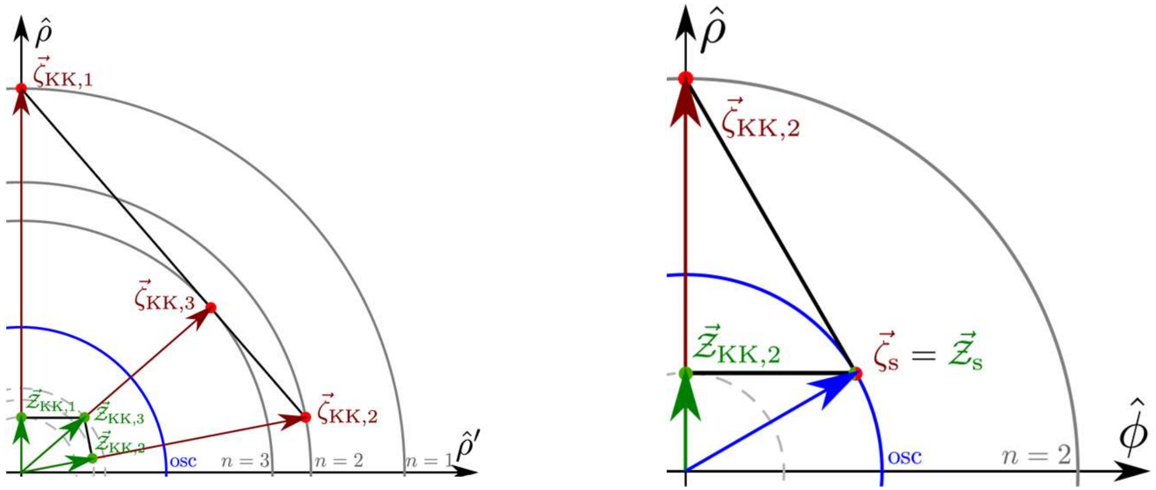
Contact: alberto.castellano@csic.es

8d Maximal SUGRA

- Again, BPS states generate both convex hulls



- One can choose a 'fundamental domain' and check the pattern
- There are essentially two possibilities: Decompactification or emergent strings [Lee, Lerche, Weigand '19]



Examples

- In the papers we discuss several examples of the SSDC and the pattern:

○ 4d N=2 and 4d N=1 vacua

i. Hypermultiplet moduli space

ii. Vector multiplet moduli space

○ Theories with 16 supercharges

i. Heterotic string theory on a circle

ii. M-theory on K3

○ Theories with maximal supersymmetry in $d \geq 4$