Entropy Bounds and the (Species Scale) Distance Conjecture

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IPhT CEA/Saclay

[arXiv:2112.10796] with A. Castellano and L.E. Ibáñez
[arXiv:2306.16450] with J. Calderón-Infante, A. Castellano and L.E. Ibáñez

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The Distance Conjecture

In a theory of QG, moving from a point P to a point Q an infinite distance away, an infinite tower of states become light **exponentially in the geodesic distance**

$$M(Q) \sim M(P)\ e^{-\alpha\,\Delta_\phi(P,Q)}$$

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- Top-down string constructions

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- Holography (AdS/CFT)

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- Bottom-up arguments

  {Montero, Vafa, Valenzuela '21][Stout '21 '22] {van de Heisteeg, Vafa, Wiesner '23] [Cribiori, Lüst, Montella ´23]

Bottom-up argument: Ingredients

Extensive Entropy in QFT

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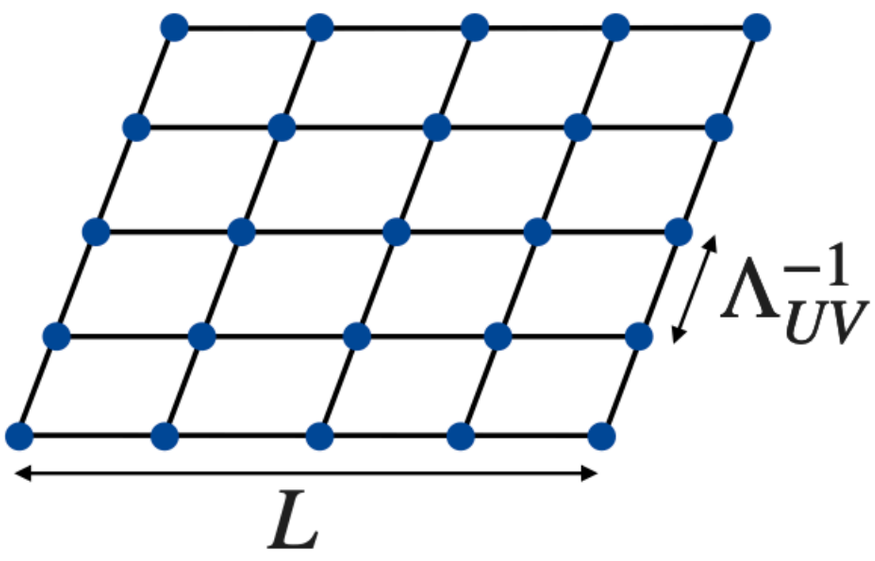
$$S \sim \Lambda_{\rm UV}^{d-1} \ \text{vol} \sim (\Lambda_{\rm UV}\, L)^{d-1}$$



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[Bousso´99]

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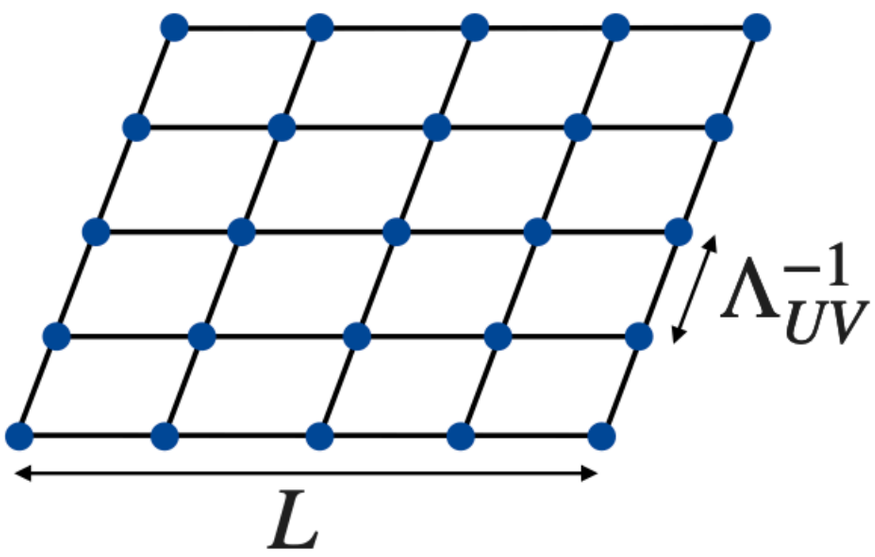

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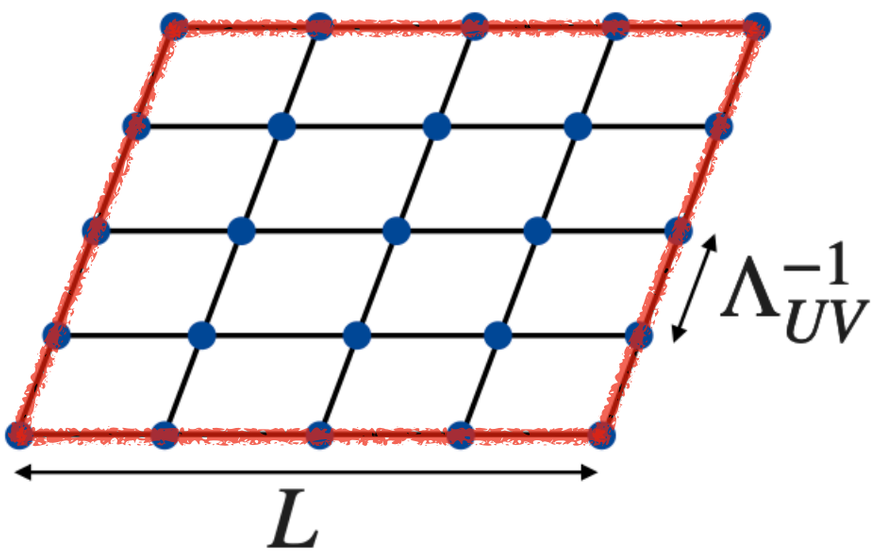

Covariant Entropy Bound

[Bousso´99]

$$S \leq \frac{A}{4G_{N,d}} \sim \frac{L^{d-2}}{4G_{N,d}}$$

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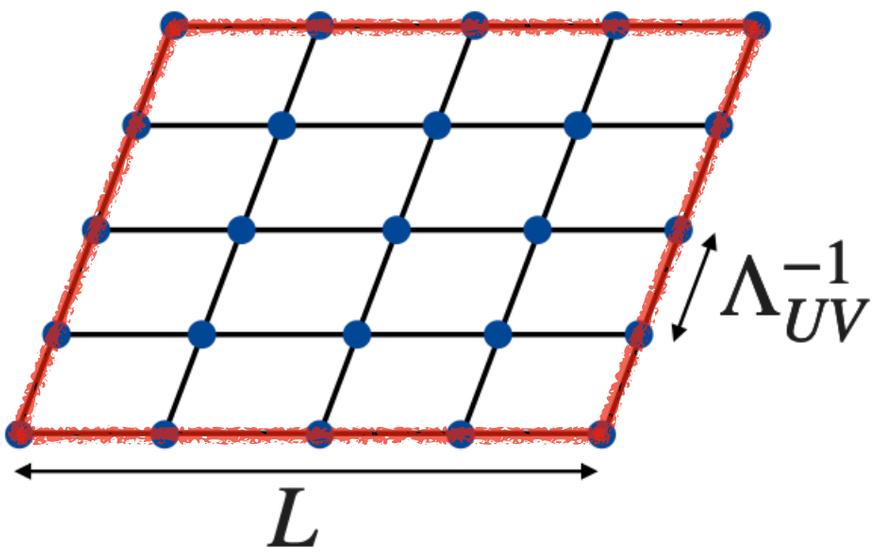

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[Dvali ´07]
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Species Scale (QG cut-off)

$$\Lambda_{\rm sp} \sim \frac{M_{{\rm pl},d}}{N_{\rm sp}^{\frac{1}{d-2}}}$$

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Appetizer: AdS Distance Conjecture

[Castellano, AH, Ibáñez '21]

For a family of AdS vacua with cosmological constant Λ_{AdS}, there exist a tower of states that becomes light in the limit $\Lambda_{\text{AdS}} \to 0$ as

$$m_{\text{tower}} \sim |\Lambda_{\text{AdS}}|^{\alpha}$$

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$$m_n = n^{1/p}\, m_{\rm tower} \longrightarrow \Lambda_{\rm sp} \simeq \frac{M_{{\rm pl},d}}{N_{\rm sp}^{\frac{1}{d-2}}} \simeq N_{\rm sp}^{1/p}\, m_{\rm tower} \longrightarrow \Lambda_{\rm sp} \sim m_{\rm tower}^{\frac{p}{d-2+p}}$$

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(+ Consistency of EFT. $\Lambda_{\rm UV} \geq L^{-1}$)

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$$\frac{d+p-2}{2p} \geq \alpha \geq \frac{(d-2+p)}{2p(d-1)}$$

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$$\frac{d-1}{2} \geq \alpha \geq \frac{1}{2\,(d-1)}$$

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Dynamical Cobordism

{Angius, Burrati, Calderón-Infante, Delgado, Huertas, Uranga ´21-'23]

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Running solutions in moduli space

- Gravity plus scalar sector

[Calderón-Infante, Castellano, AH, Ibáñez '23]

$$S = \frac{1}{\kappa_d^2}\int d^d x \sqrt{-g}\ \left[\frac{1}{2}R - \frac{1}{2}G_{ij}(\phi)\partial_\mu\phi^i\partial^\mu\phi^j\right]$$

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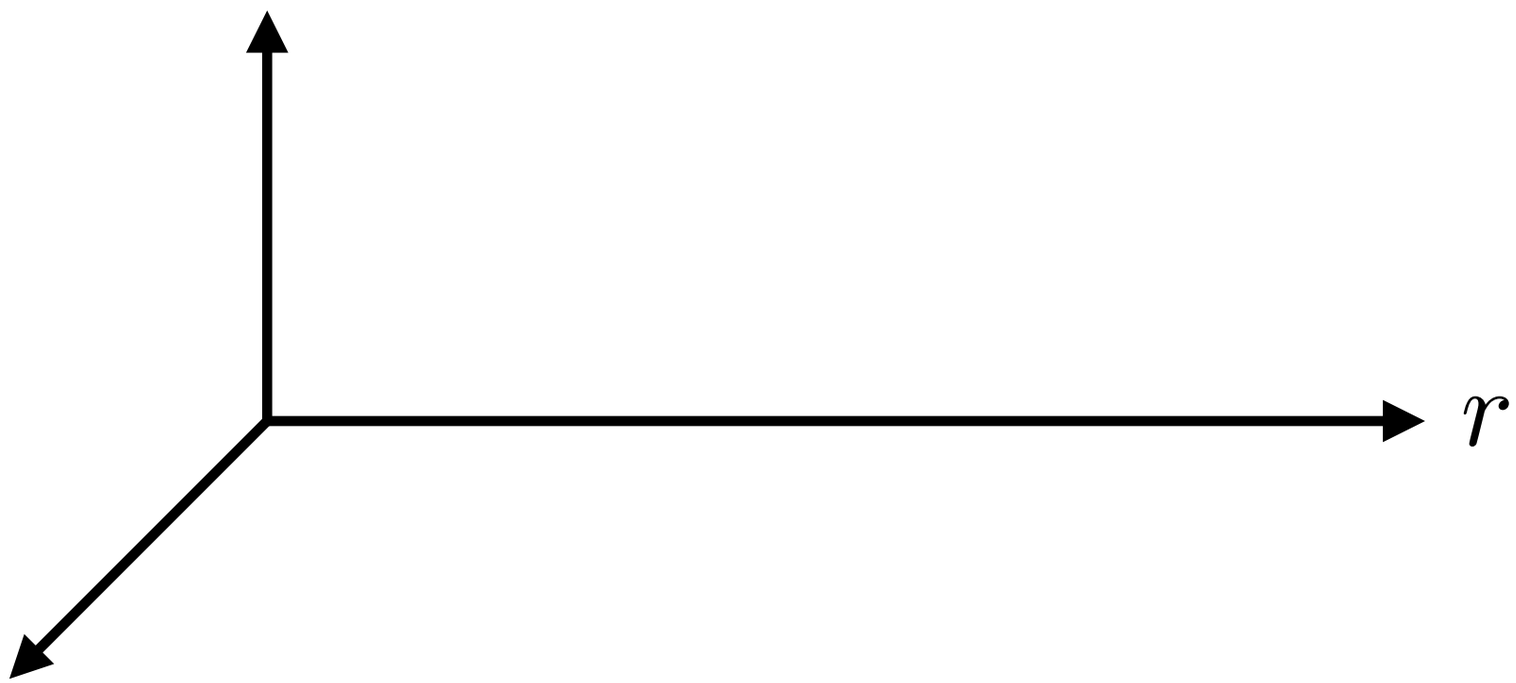

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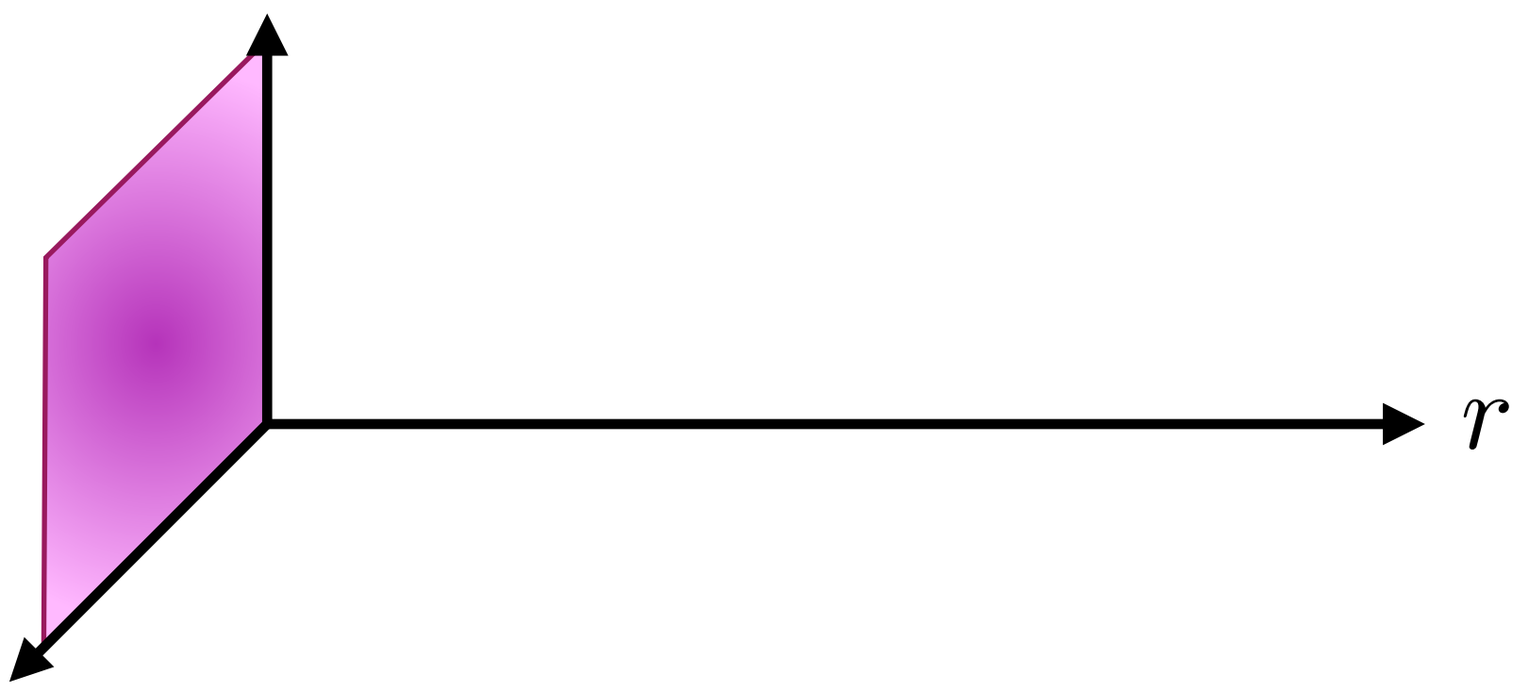

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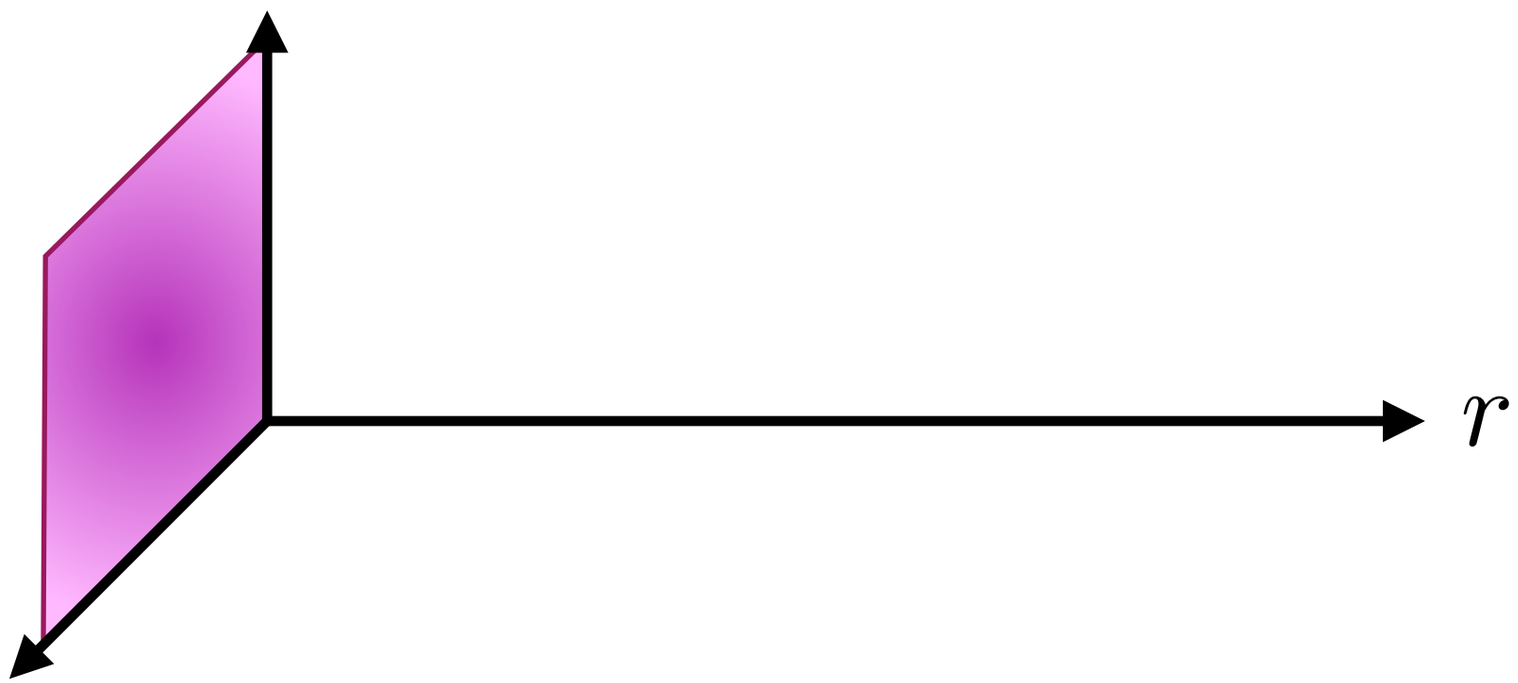

The Distance Conjecture: Bottom-up

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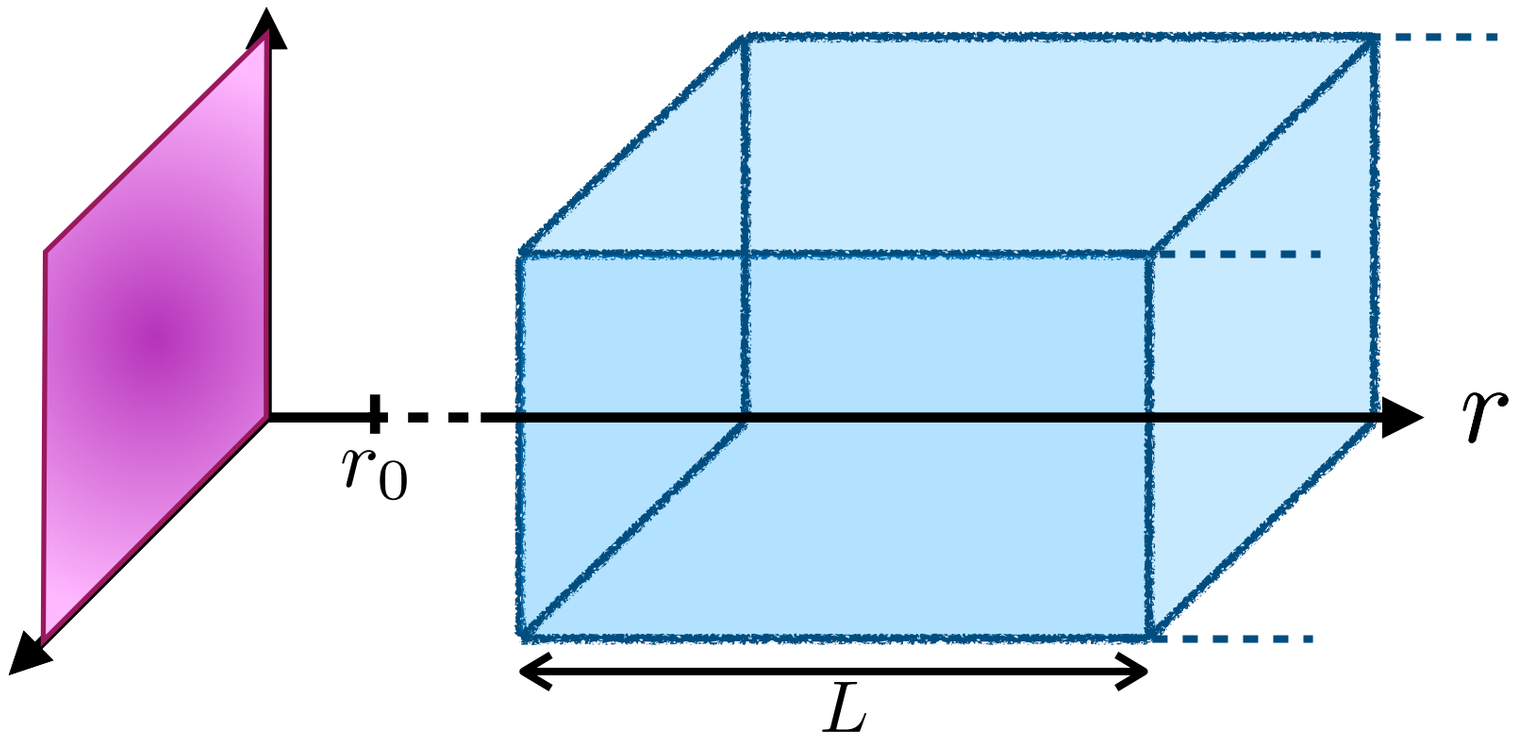

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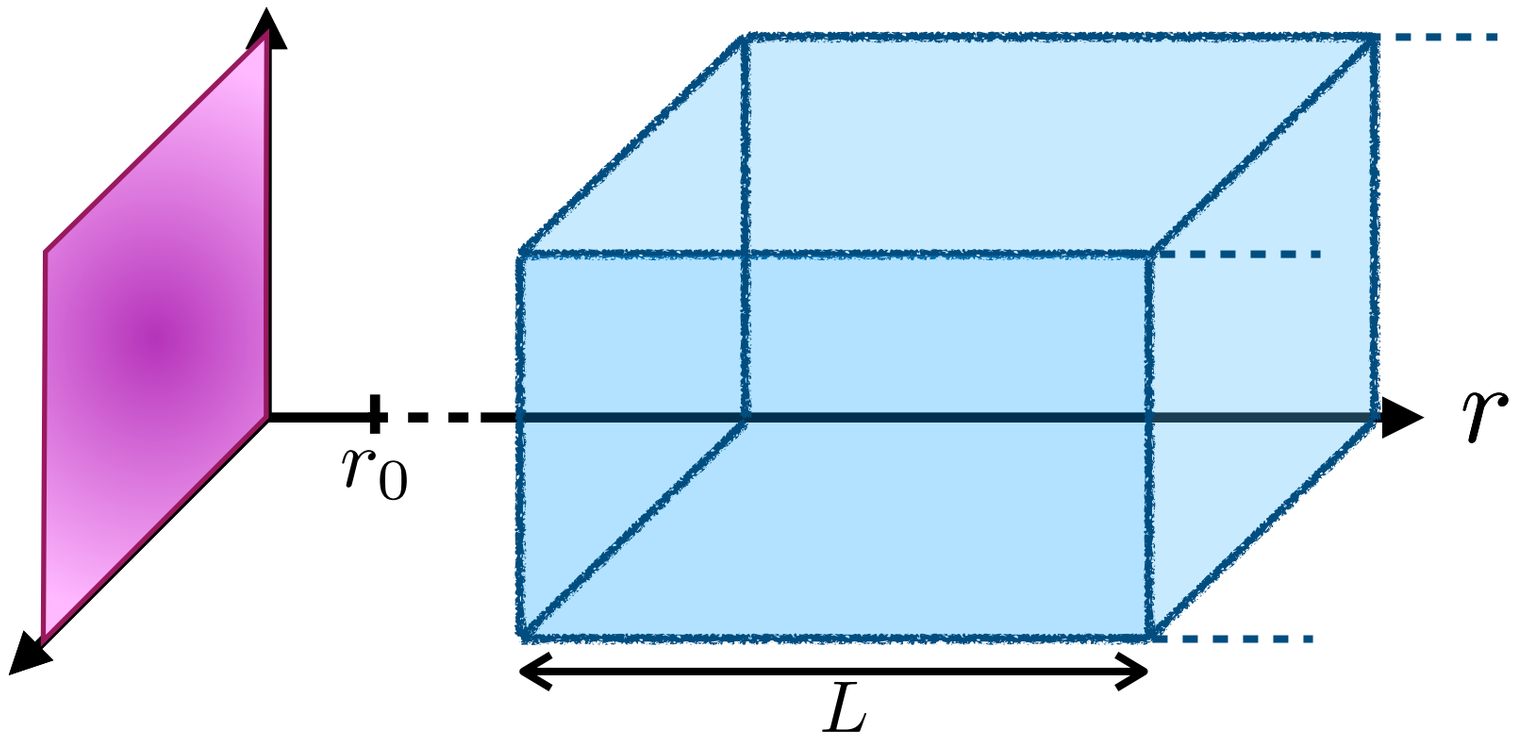

$$\Lambda_{\rm sp} \lesssim e^{-\lambda_{\rm sp,min}\,\Delta_\phi} \qquad\qquad \lambda_{\rm sp,min} = \frac{1}{\sqrt{(d-1)\,(d-2)}}$$

See also
[van de Heisteeg, Vafa, Wiesner '23]

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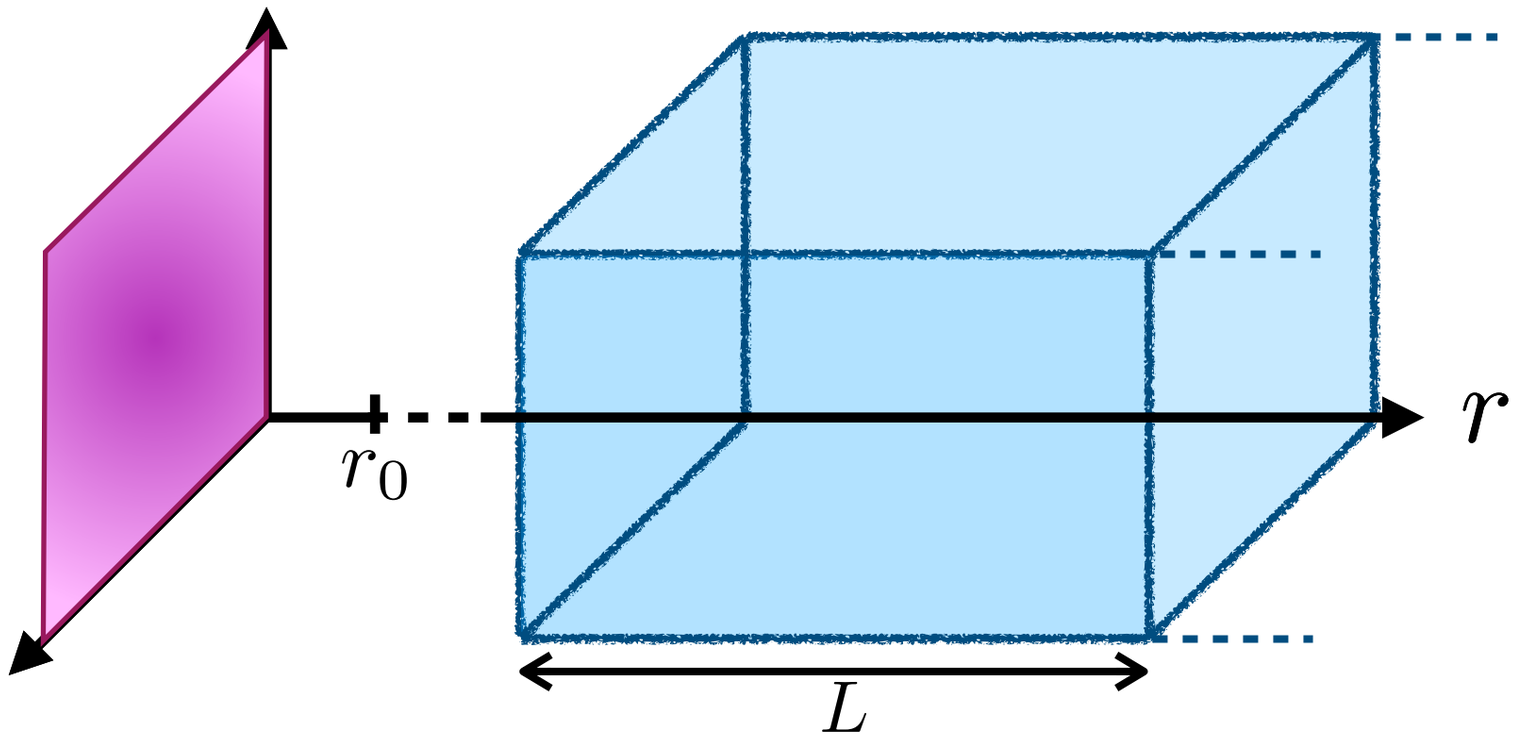

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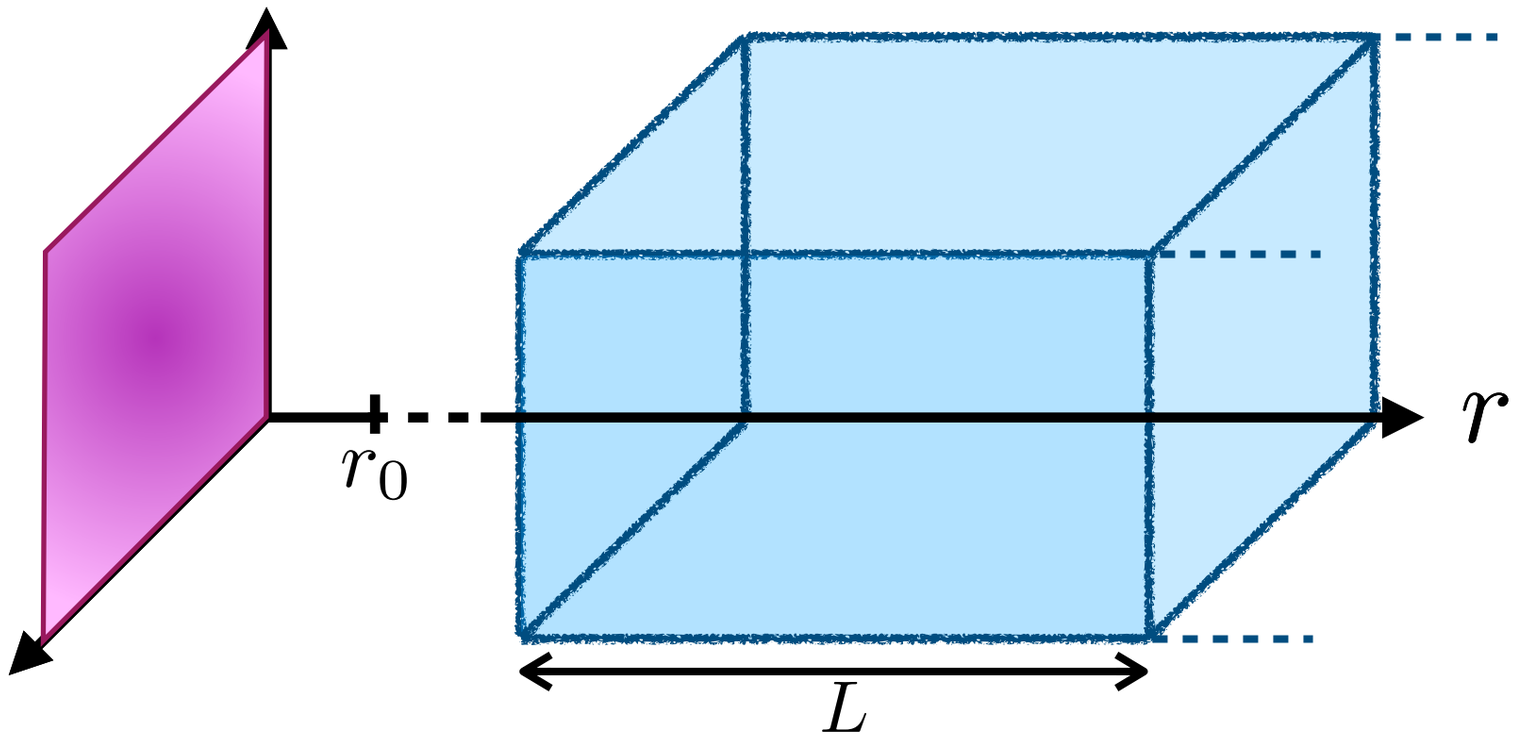

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- Species scale for a tower:

$$m_{\rm tower} \sim e^{-\lambda \Delta_\phi} \qquad \lambda \geq \lambda_{\rm min} = \frac{d+p-2}{p\sqrt{(d-1)(d-2)}}$$

  $p = 1 \longrightarrow$ Single KK tower
  $p \to \infty \longrightarrow$ String tower

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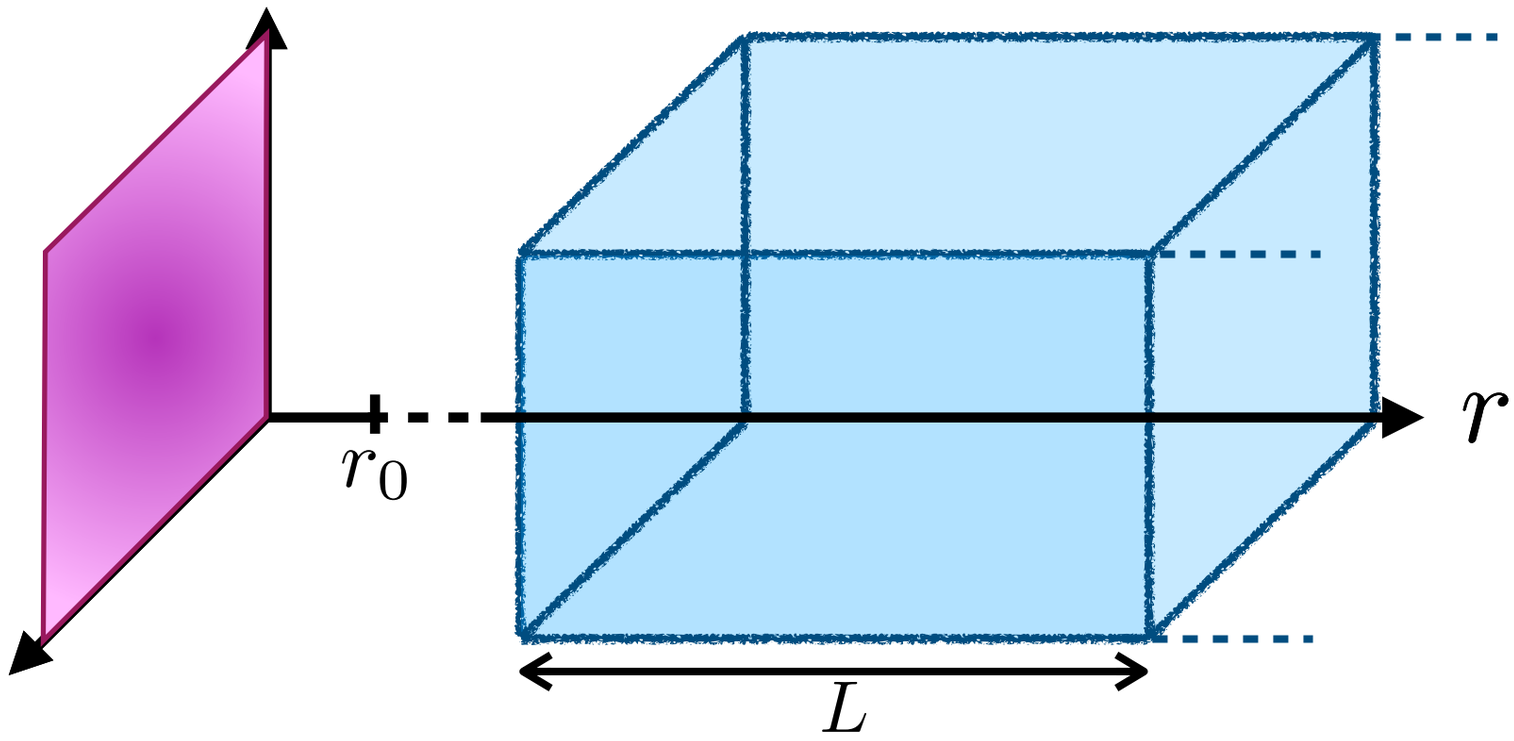

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[Etheredge, Heidenreich, Kaya, Qin, Rudelius '23] Single KK tower String tower

The Species Scale Distance Conjecture

Species Scale Distance Conjecture (SSDC): *the convex hull of species scale vectors* $\{\vec{z}_\beta\}$ *should contain the ball of radius* $\lambda_{\text{sp, min}} = \dfrac{1}{\sqrt{(d-1)(d-2)}}$.

[Calderón-Infante, Castellano, AH, Ibáñez ´23]

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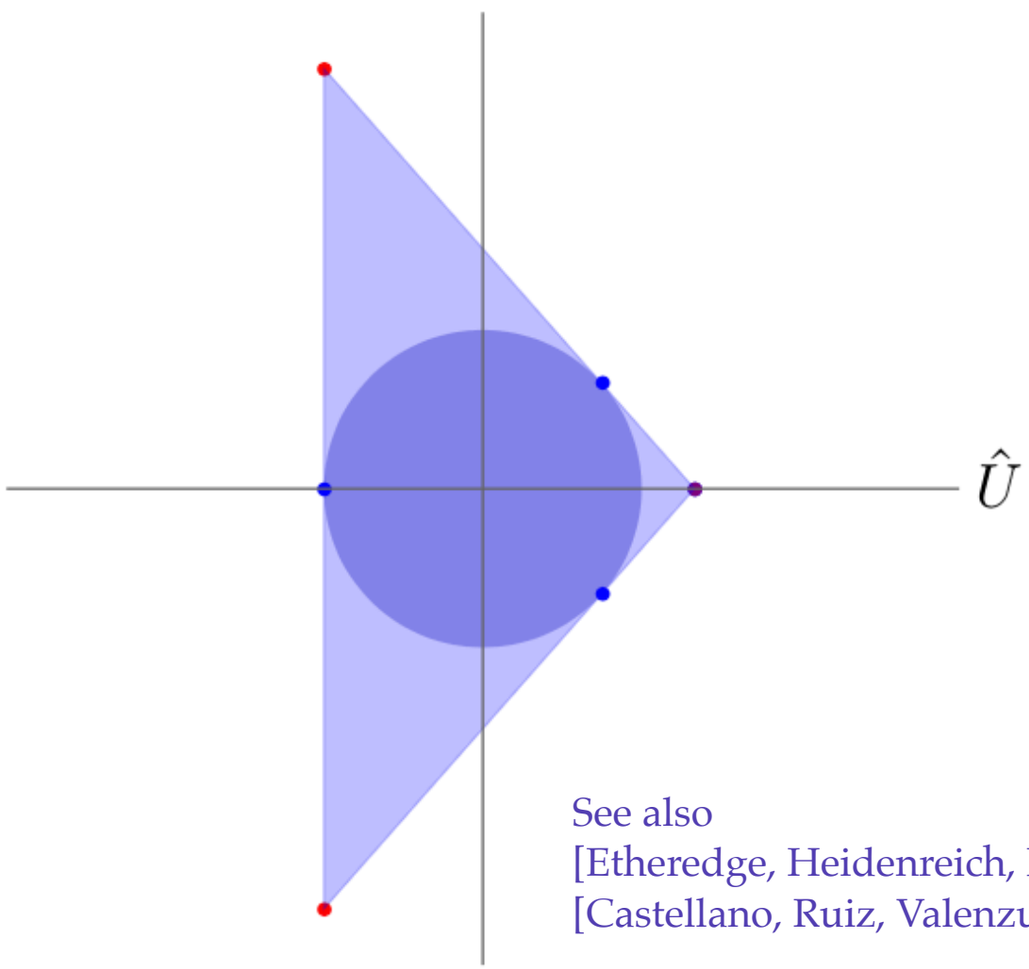

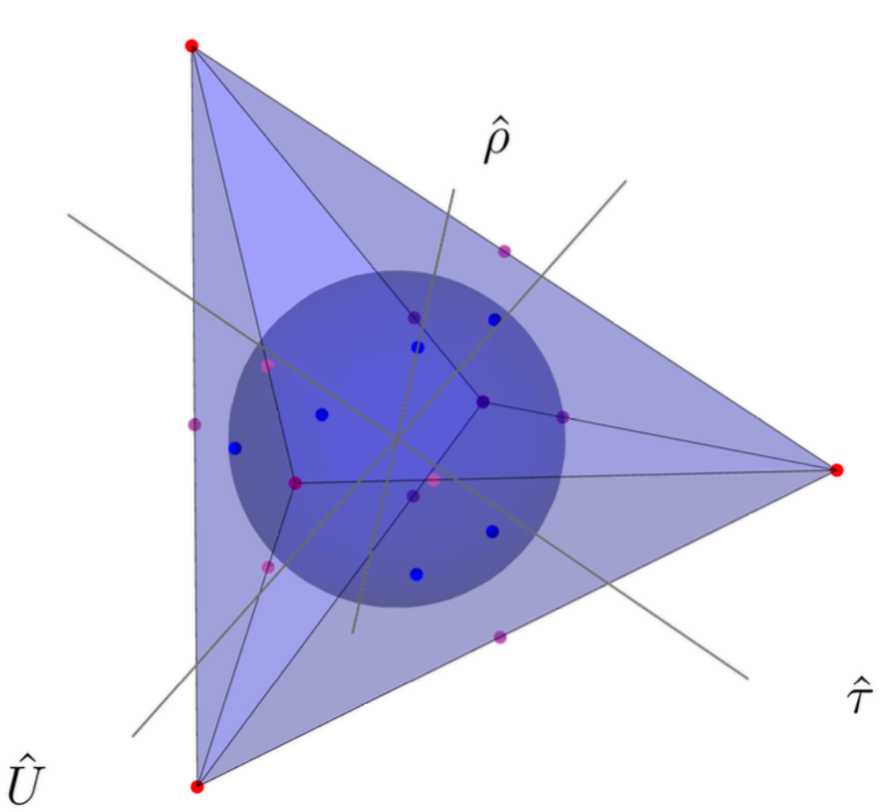

See also
[Etheredge, Heidenreich, McNamara, Rudelius, Ruiz, Valenzuela ´23]
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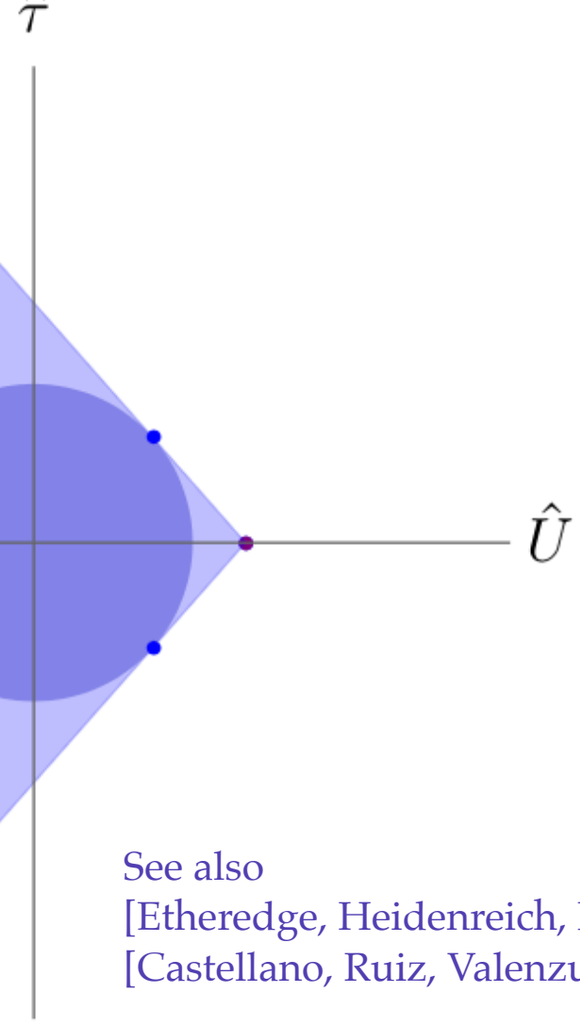

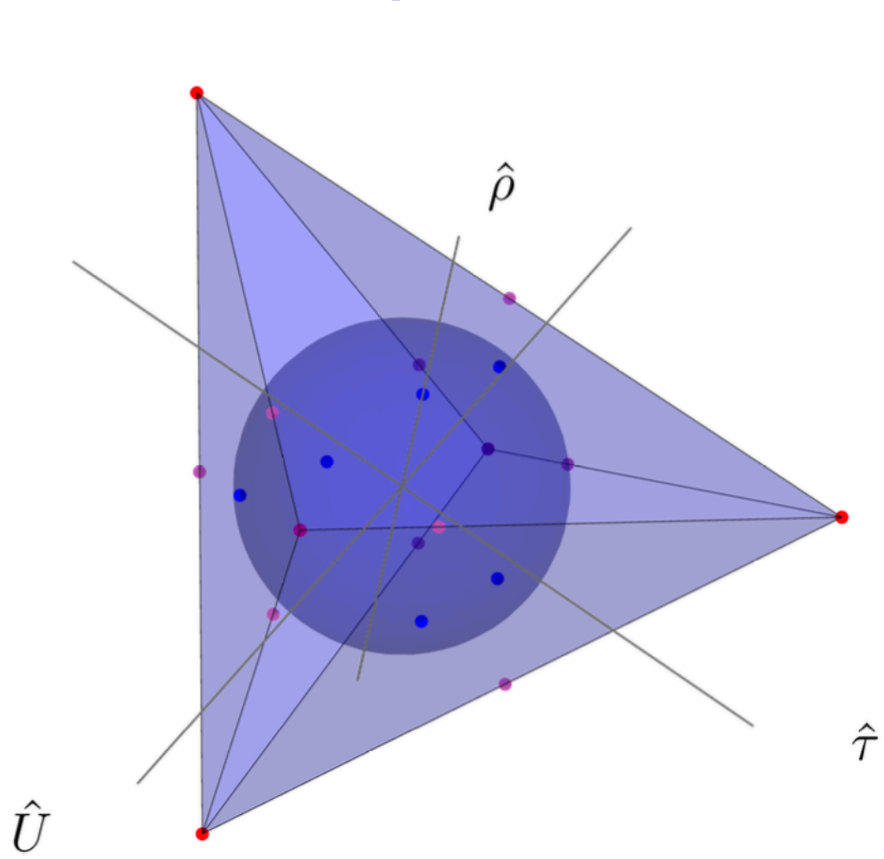

See also
[Etheredge, Heidenreich, McNamara, Rudelius, Ruiz, Valenzuela ´23]
[Castellano, Ruiz, Valenzuela WiP]

To be continued…

Summary and open questions

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Bottom-up argument for Distance Conjecture

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감사합니다
(Thank you!)