From towers to cut-offs: Black hole entropies from species

Alvaro Herraez
Max Planck Institute für Physik, München

Based on work with: A. Castellano, **A. Font,** L. E. Ibáñez, D. Lüst, J. Masías, M. Scalisi

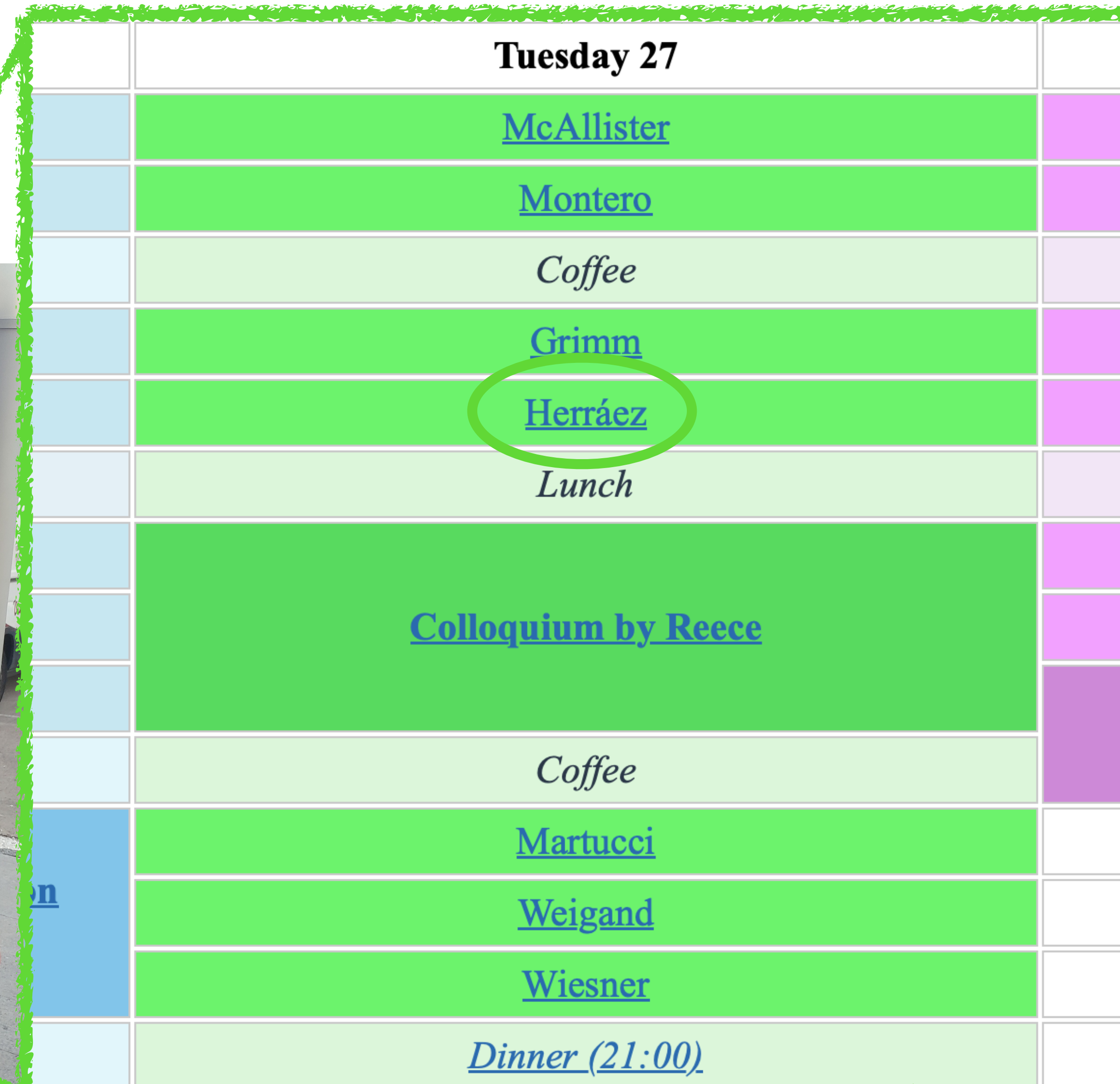
AnLy-Font Meeting

April 11th, 2024

ous voyez
es cordes ?
Pr. Font a vu
un moyen d'expliquer
les premiers instants
après le Big Bang.
POUR EN SAVOIR PLUS
Professeure Anamaría Font
Physicienne, Venezuela
Prix International L'Oréal-UNESCO
Pour les Femmes et la Science 2023
LE MONDE A BESOIN DE SCIENCE,
LA SCIENCE A BESOIN DES FEMMES.
unesco
FONDATION L'ORÉAL
For Women in Science


camarer


camarer


Tuesday 27
McAllister
Montero
Coffee
Grimm
Herráez
Lunch
Colloquium by Reece
Coffee
Martucci
Weigand
Wiesner
Dinner (21:00)

The Swampland Distance Conjecture
and Towers of Tensionless Branes

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

[1] *Facultad de Ciencias, Universidad Central de Venezuela, A.P.20513, Caracas 1020-A, Venezuela*

[2] *Departamento de Física Teórica and Instituto de Física Teórica UAM/CSIC, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain*

The Swampland Distance Conjecture and Towers of Tensionless Branes

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

[1] Facultad de Ciencias, Universidad Centra

Vene

[2] Departamento de Física Teórica and

Universidad Autónoma de Madrid,

On scale separation in type II AdS flux vacua

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

[1] *Facultad de Ciencias, Universidad Central de Venezuela, A.P.20513, Caracas 1020-A, Venezuela*

[2] *Departamento de Física Teórica and Instituto de Física Teórica UAM/CSIC, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain*

The Swampland Distance Conjecture and Towers of Tensionless Branes

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

[1] *Facultad de Ciencias, Universidad Centra*
Vene

[2] *Departamento de Física Teórica and*
Universidad Autónoma de Madrid,

On scale separation in type II AdS flux vacua

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

s, Universidad Central de Venezuela, A.P.20513,
Caracas 1020-A, Venezuela

Teórica and Instituto de Física Teórica UAM/CSIC,
a de Madrid, Cantoblanco, 28049 Madrid, Spain

A Gravitino Distance Conjecture

A. Castellano[1], A. Font[2,3], A. Herráez[4] and L.E. Ibáñez[1]

[1] *Departamento de Física Teórica and Instituto de Física Teórica UAM/CSIC, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain*

[2] *Facultad de Ciencias, Universidad Central de Venezuela, A.P.20513, Caracas 1020-A, Venezuela*

[3] *Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut 14476 Golm, Germany*

[4] *Institut de Physique Théorique, Université Paris Saclay, CEA, CNRS Orme des Merisiers, 91191 Gif-sur-Yvette CEDEX, France*

The Swampland Distance Conjecture and Towers of Tensionless Branes

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

[1] Facultad de Ciencias, Universidad Centra
Vene
[2] Departamento de Física Teórica and
Universidad Autónoma de Madrid,

On scale separation in type II AdS flux vacua

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

s, Universidad Central de Venezuela, A.P.20513,
Caracas 1020-A, Venezuela
Teórica and Instituto de Física Teórica UAM/CSIC,
a de Madrid, Cantoblanco, 28049 Madrid, Spain

A Gravitino Distance Conjecture

A. Castellano[1], A. Font[2,3], A. Herráez[4] and L.E. Ibáñez[1]

[1] Departamento de Física Teórica and Instituto de Física Teórica UAM/CSIC,
Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain
[2] Facultad de Ciencias, Universidad Central de Venezuela, A.P.20513,
Caracas 1020-A, Venezuela
[3] Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut
14476 Golm, Germany
[4] Institut de Physique Théorique, Université Paris Saclay, CEA, CNRS
Orme des Merisiers, 91191 Gif-sur-Yvette CEDEX, France

The Swampland Distance Conjecture
and Towers of Tensionless Branes

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

[1] *Facultad de Ciencias, Universidad Centra*
Vene
[2] *Departamento de Física Teórica and*
Universidad Autónoma de Madrid,

On scale separation in type II AdS flux vacua

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

s, Universidad Central de Venezuela, A.P.20513,
Caracas 1020-A, Venezuela
Teórica and Instituto de Física Teórica UAM/CSIC,
a de Madrid, Cantoblanco, 28049 Madrid, Spain

A Gravitino Distance Conjecture

A. Castellano[1], A. Font[2,3], A. Herráez[4] and L.E. Ibáñez[1]

[1] *Departamento de Física Teórica and Instituto de Física Teórica UAM/CSIC,*
Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain
[2] *Facultad de Ciencias, Universidad Central de Venezuela, A.P.20513,*
Caracas 1020-A, Venezuela
[3] *Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut*
14476 Golm, Germany
[4] *Institut de Physique Théorique, Université Paris Saclay, CEA, CNRS*
Orme des Merisiers, 91191 Gif-sur-Yvette CEDEX, France

The Swampland Distance Conjecture and Towers of Tensionless Branes

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

[1] Facultad de Ciencias, Universidad Centra
Vene
[2] Departamento de Física Teórica and
Universidad Autónoma de Madrid,

On scale separation in type II AdS flux vacua

A. Font[1], A. Herráez[2] and L.E. Ibáñez[2],

s, Universidad Central de Venezuela, A.P.20513,
Caracas 1020-A, Venezuela
Teórica and Instituto de Física Teórica UAM/CSIC,
a de Madrid, Cantoblanco, 28049 Madrid, Spain

A Gravitino Distance Conjecture

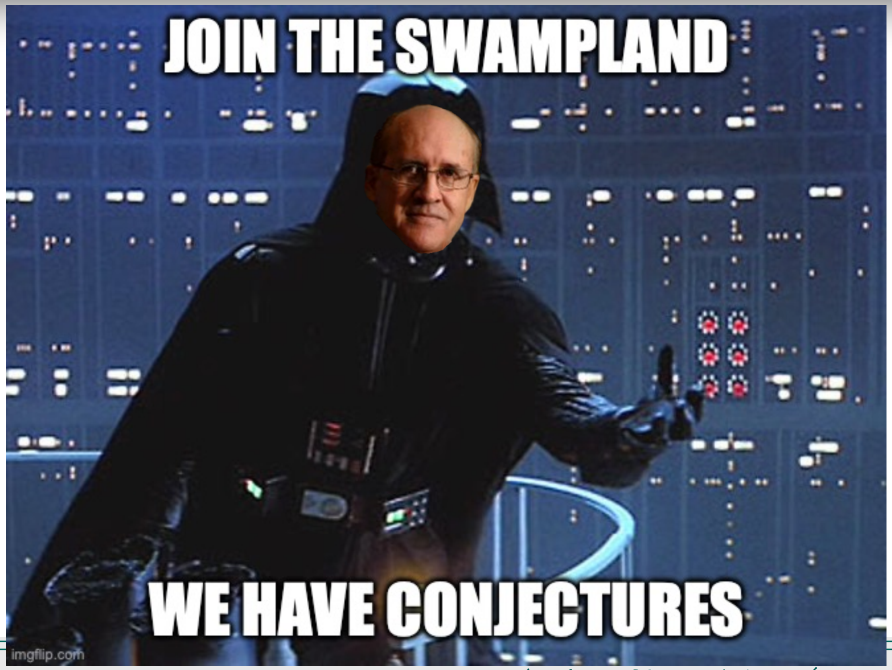
A. Castellano[1], A. Font[2,3], A. Herráez[4] and L.E. Ibáñez[1]

[1] Departamento de Física Teórica and Instituto de Física Teórica UAM/CSIC, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain

[2] Facultad de Ciencias, Universidad Central de Venezuela, A.P.20513, Caracas 1020-A, Venezuela

[3] Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut 14476 Golm, Germany

[4] Institut de Physique Théorique, Université Paris Saclay, CEA, CNRS Orme des Merisiers, 91191 Gif-sur-Yvette CEDEX, France



Outline

1. The Landscape vs. The Swampland
   (i) The Swampland Distance Conjecture
   (ii) Particles, Strings and Membranes in the infinite Distance Limits
2. The Species Scale and Minimal Black Hole Entropies
   (i) The Species Scale
   (ii) UV/IR Mixing, the Covariant Entropy Bound and Minimal black holes
   (iii) The Black Hole-String Correspondence
   (iv) The Black Hole-Species Tower Correspondence
3. Conclusions

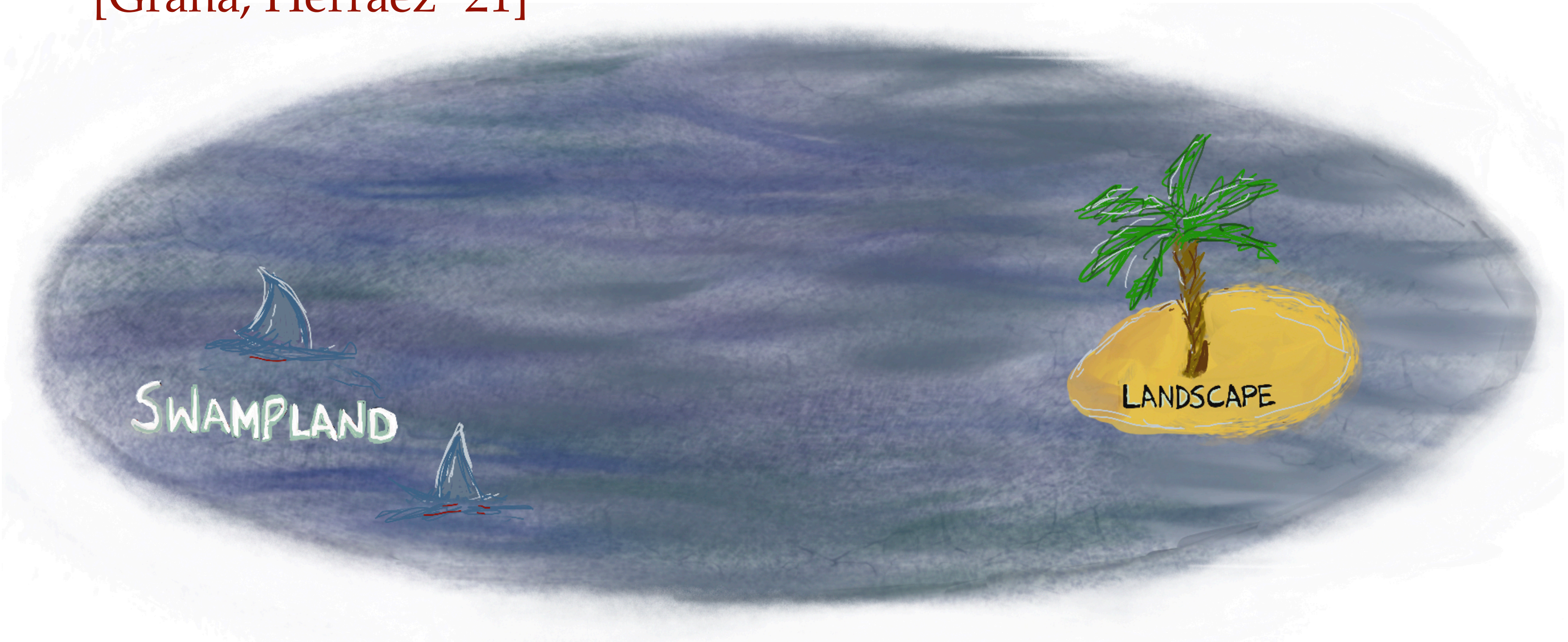
The Landscape vs the Swampland

- String Landscape ⟶ Naive expectation: Every EFT can be obtained from ST

- Swampland ⟶ Set of EFT that look consistent BUT cannot be consistently coupled to QG

[Vafa ’05]

Reviews: [Brennan, Carta, Vafa ’17] [Palti ’19]
[van Beest, Calderón-Infante, Mirfendereski, Valenzuela ’21]
[Graña, Herráez ´21]



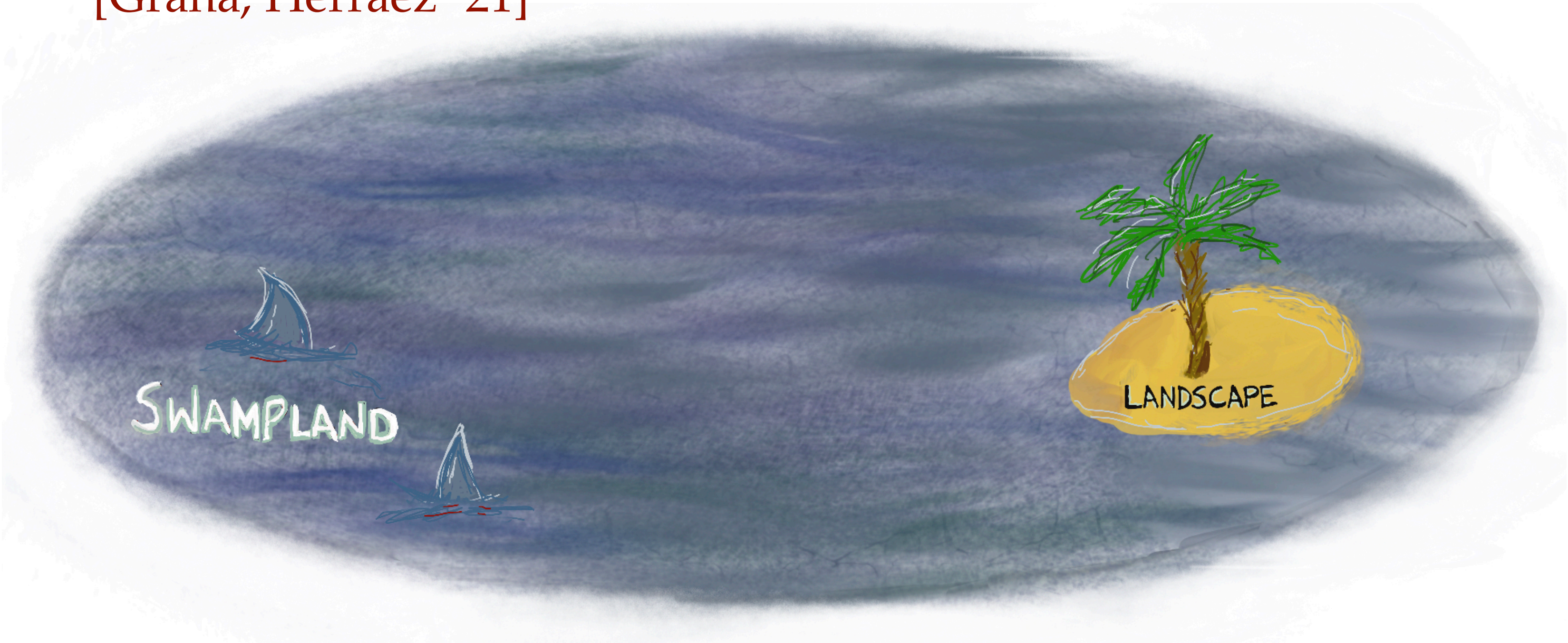
The Landscape vs the Swampland

- String Landscape ⟶ Naive expectation: Every EFT can be obtained from ST

- Swampland ⟶ Set of EFT that look consistent BUT cannot be consistently coupled to QG

[Vafa '05]

Reviews: [Brennan, Carta, Vafa '17] [Palti '19]
[van Beest, Calderón-Infante, Mirfendereski, Valenzuela '21]
[Graña, Herráez ´21]



QUESTION:
What are the general features of all QG EFT?

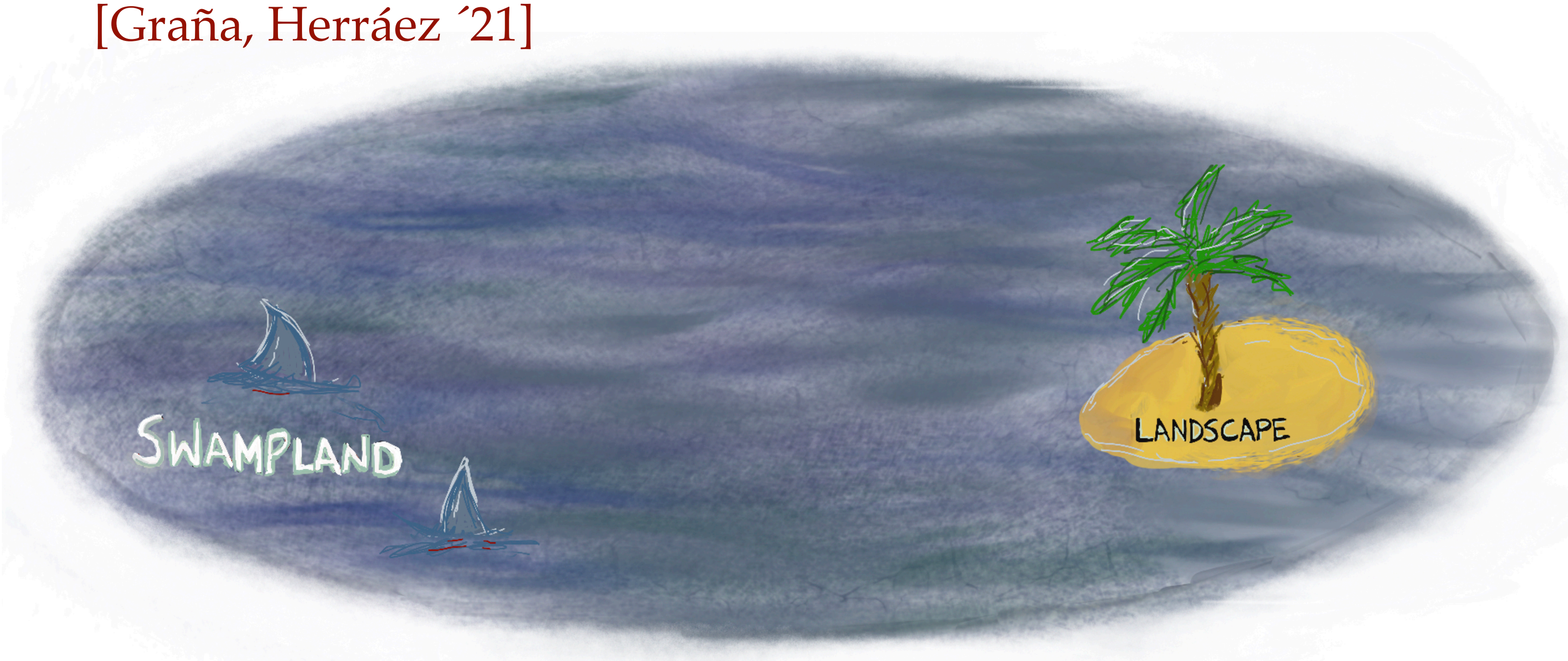
The Landscape vs the Swampland

- String Landscape ⟶ Naive expectation: Every EFT can be obtained from ST

- Swampland ⟶ Set of EFT that look consistent BUT cannot be consistently coupled to QG

[Vafa '05]

Reviews: [Brennan, Carta, Vafa '17] [Palti '19]
[van Beest, Calderón-Infante, Mirfendereski, Valenzuela '21]
[Graña, Herráez ´21]



QUESTION:
What are the general features of all QG EFT?

↕

Quantum Gravity Conjectures

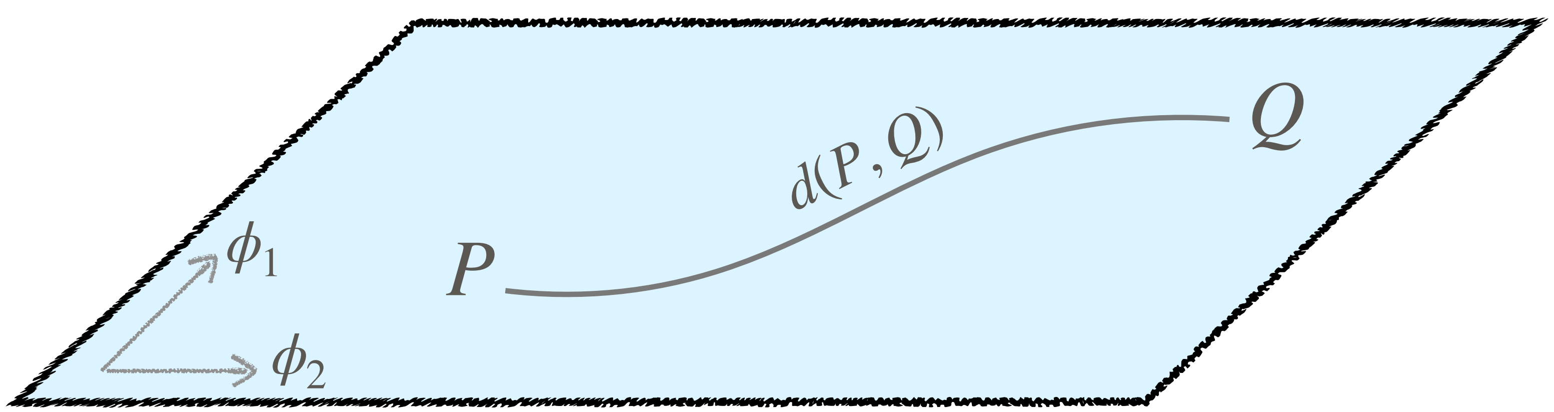
The Distance Conjecture

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

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

[Ooguri, Vafa ´06]

Scalar manifold with metric $g_{ij}(\phi_i)$ from kinetic terms



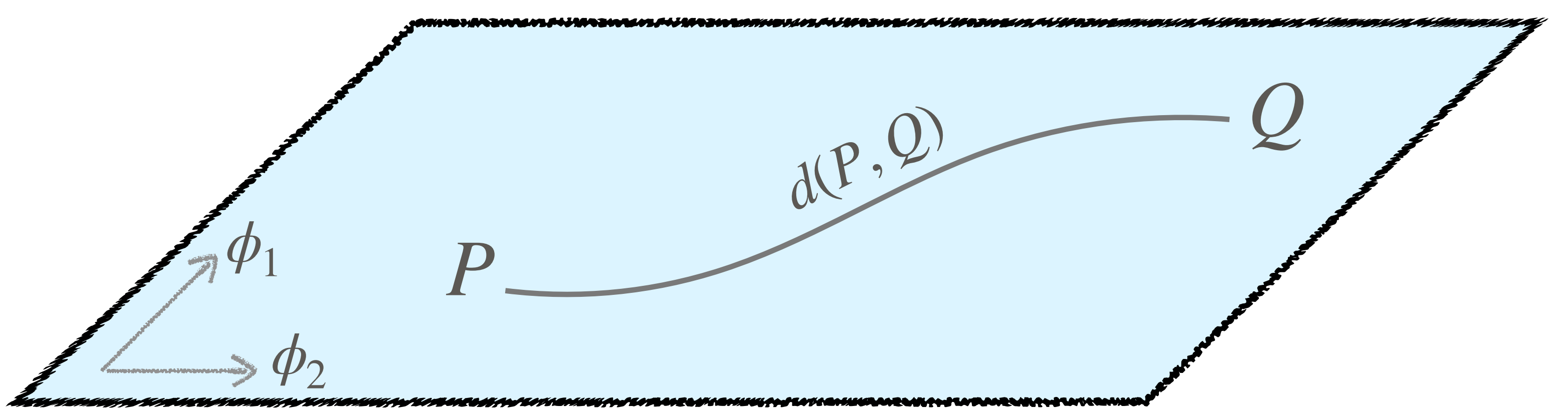
The Distance Conjecture

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

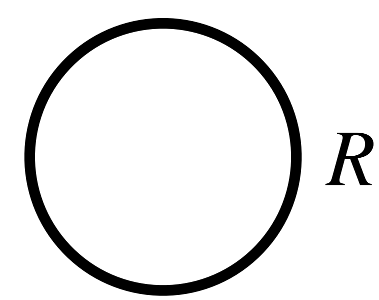
$$M(Q) \sim M(P)\ e^{-\alpha\, \Delta_\phi(P,Q)}$$

[Ooguri, Vafa ´06]

Scalar manifold with metric $g_{ij}(\phi_i)$ from kinetic terms



- <u>Example:</u> Compactification on a circle of radius



$R \to \infty$ Kaluza-Klein tower

$R \to 0$ Winding tower

The Distance Conjecture

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

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

[Ooguri, Vafa ´06]

- Top-down string constructions

  [Andriot, Baume, Blumenhagen, Buratti, Calderón-Infante, Castellano, Cecotti, Corvilain, Etheredge, Font, Gendler, Grimm, Heidenreich, AH, Ibáñez, Joshi, Kaya, Klaewer, Lanza, Lee, Lerche, Li, Lockhart, McNamara, Marchesano, Martucci, Ooguri, Palti, Qiu, Rudelius, Ruiz, Valenzuela, Vafa, Weigand, Wiesner, Wolf, Uranga…]

The Distance Conjecture

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

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

[Ooguri, Vafa ´06]

- Top-down string constructions

  [Andriot, Baume, Blumenhagen, Buratti, Calderón-Infante, Castellano, Cecotti, Corvilain, Etheredge, Font, Gendler, Grimm, Heidenreich, AH, Ibáñez, Joshi, Kaya, Klaewer, Lanza, Lee, Lerche, Li, Lockhart, McNamara, Marchesano, Martucci, Ooguri, Palti, Qiu, Rudelius, Ruiz, Valenzuela, Vafa, Weigand, Wiesner, Wolf, Uranga…]

- Holography (AdS/CFT)

  [Baume, Calderón-Infante'20 ´23] [Perlmutter, Rastelli, Vafa, Valenzuela '20]

The Distance Conjecture

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

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

[Ooguri, Vafa ´06]

- Top-down string constructions

  [Andriot, Baume, Blumenhagen, Buratti, Calderón-Infante, Castellano, Cecotti, Corvilain, Etheredge, Font, Gendler, Grimm, Heidenreich, AH, Ibáñez, Joshi, Kaya, Klaewer, Lanza, Lee, Lerche, Li, Lockhart, McNamara, Marchesano, Martucci, Ooguri, Palti, Qiu, Rudelius, Ruiz, Valenzuela, Vafa, Weigand, Wiesner, Wolf, Uranga…]

- Holography (AdS/CFT)

  [Baume, Calderón-Infante’20 ´23] [Perlmutter, Rastelli, Vafa, Valenzuela ’20]

- Bottom-up arguments

  {Montero, Vafa, Valenzuela ’21][Castellano, AH, Ibáñez ´21][Stout ’21 ’22][Calderón-Infante, Castellano, AH, Ibáñez ´23]
  {van de Heisteeg, Vafa, Wiesner ’23] [Cribiori, Lüst, Montella ´23] [Basile, (Cribiori), Lüst, Montella ´23 ’24]

The Distance Conjecture

[Ooguri, Vafa ´06]

- Infinite towers of particles at infinite distance points in IIB CS moduli space ⟶ D3-branes wrapping 3-cyles in the internal CY (and mirror in Kähler moduli space in IIA)

[Grimm, Palti, Valenzuela ’18]
[Grimm, Li, Palti ’18]
[Corvilain, Grimm, Valenzuela ’18]

The Distance Conjecture

[Ooguri, Vafa ´06]

- Infinite towers of particles at infinite distance points in IIB CS moduli space ⟶ D3-branes wrapping 3-cyles in the internal CY (and mirror in Kähler moduli space in IIA)

  [Grimm, Palti, Valenzuela '18]
  [Grimm, Li, Palti '18]
  [Corvilain, Grimm, Valenzuela '18]

- Motivation from preventing the appearance of a global symmetry in QG at the infinite distance point ~ Weak Gravity Conjecture

  - Instantons
    [Baume, Marchesano, Wiesner '18 '19]
  - Particles
  - Strings
    [Lee, Lerche, Weigand '18 '19]
  - Membranes
    [Lanza, Marchesano, Martucci, Valenzuela '20]

The Distance Conjecture

[Ooguri, Vafa ´06]

- Infinite towers of particles at infinite distance points in IIB CS moduli space ⟶ D3-branes wrapping 3-cyles in the internal CY (and mirror in Kähler moduli space in IIA)

  [Grimm, Palti, Valenzuela '18]
  [Grimm, Li, Palti '18]
  [Corvilain, Grimm, Valenzuela '18]

- Motivation from preventing the appearance of a global symmetry in QG at the infinite distance point ~ Weak Gravity Conjecture

  - Instantons
    [Baume, Marchesano, Wiesner '18 '19]
  - Particles
  - Strings
    [Lee, Lerche, Weigand '18 '19]
  - Membranes ⟵
    [Lanza, Marchesano, Martucci, Valenzuela '20]
    [Font, AH, Ibáñez ´19]

The Distance Conjecture

[Ooguri, Vafa ´06]

- Infinite towers of particles at infinite distance points in IIB CS moduli space ⟶ D3-branes wrapping 3-cyles in the internal CY (and mirror in Kähler moduli space in IIA)

  [Grimm, Palti, Valenzuela '18]
  [Grimm, Li, Palti '18]
  [Corvilain, Grimm, Valenzuela '18]

- Motivation from preventing the appearance of a global symmetry in QG at the infinite distance point ~ Weak Gravity Conjecture

  - Instantons
    [Baume, Marchesano, Wiesner '18 '19]
  - Particles
  - Strings
    [Lee, Lerche, Weigand '18 '19]
  - Membranes ⟵

  [Lanza, Marchesano, Martucci, Valenzuela '20]

  [Font, AH, Ibáñez ´19]

IMPORTANT REMARK

- In order for Quantum Gravity conjectures to be meaningful, we need to keep the Planck mass finite.
- The terms "massless/tensionless" = "massless/tensionless in Planck units".

Tensionless Membranes

[Font, AH, Ibáñez ´19]

Type IIA on CY (orientifolds) $\longrightarrow$ Dp-branes wrapping (p-2)-cycles

$\mathcal{N} = 2 \quad (\mathcal{N} = 1)$

$$T_{\mathrm{D}p}(\gamma_{p-2}) = \frac{M_P^3}{\sqrt{4\pi}} 4e^{K/2}\mathcal{V}_{p-2}$$

Tensionless Membranes

[Font, AH, Ibáñez ´19]

Type IIA on CY (orientifolds) $\longrightarrow$ Dp-branes wrapping (p-2)-cycles

$\mathcal{N} = 2 \quad (\mathcal{N} = 1)$

Brane	Cycle	Tension (in units of $M_P^3/\sqrt{4\pi}$)
$D2$	$-$	$2e^{K/2}$
D4	$P.D.\,[\tilde{\omega}^a]$	$2e^{K/2}\,\lvert T^a\rvert$
D6	$P.D.\,[\omega_a]$	$2e^{K/2}\left\lvert \frac{1}{2}\sum_{b,c}\kappa_{abc}T^bT^c\right\rvert$
$D8$	$\mathcal{M}$	$2e^{K/2}\left\lvert \frac{1}{6}\sum_{a,b,c}\kappa_{abc}T^aT^bT^c\right\rvert$
NS5	$P.D.\,[\beta^K]$	$2e^{K/2}\,\lvert N^K\rvert$

$$T_{\mathrm{D}p}(\gamma_{p-2}) = \frac{M_P^3}{\sqrt{4\pi}}\,4e^{K/2}\mathcal{V}_{p-2}$$

$$\left(\begin{aligned} \mathcal{V}_2^a &= \int_{\gamma_2^a} J = \int_{\mathcal{M}} J\wedge\tilde{\omega}^a \\ \mathcal{V}_{4,a} &= \frac{1}{2}\int_{\gamma_4^a} J\wedge J = \int_{\mathcal{M}} J\wedge J\wedge\omega_a \\ \mathcal{V}_6 &= \frac{1}{3!}\int_{\mathcal{M}} J\wedge J\wedge J \end{aligned}\right)$$

Tensionless Membranes

[Font, AH, Ibáñez ´19]

Type IIA on CY (orientifolds) ⟶ Dp-branes wrapping (p-2)-cycles

$\mathcal{N} = 2 \quad (\mathcal{N} = 1)$

Brane	Cycle	Tension (in units of $M_P^3/\sqrt{4\pi}$)
$D2$	$-$	$2e^{K/2}$
D4	$P.D.\,[\tilde{\omega}^a]$	$2e^{K/2}\,\lvert T^a\rvert$
D6	$P.D.\,[\omega_a]$	$2e^{K/2}\left\lvert \frac{1}{2}\sum_{b,c}\kappa_{abc}T^bT^c\right\rvert$
$D8$	$\mathcal{M}$	$2e^{K/2}\left\lvert \frac{1}{6}\sum_{a,b,c}\kappa_{abc}T^aT^bT^c\right\rvert$
NS5	$P.D.\,[\beta^K]$	$2e^{K/2}\,\lvert N^K\rvert$

$$T_{\mathrm{D}p}(\gamma_{p-2}) = \frac{M_P^3}{\sqrt{4\pi}}\,4e^{K/2}\mathcal{V}_{p-2}$$

$$\left(\begin{aligned} \mathcal{V}_2^a &= \int_{\gamma_2^a} J = \int_{\mathcal{M}} J\wedge\tilde{\omega}^a \\ \mathcal{V}_{4,a} &= \frac{1}{2}\int_{\gamma_4^a} J\wedge J = \int_{\mathcal{M}} J\wedge J\wedge\omega_a \\ \mathcal{V}_6 &= \frac{1}{3!}\int_{\mathcal{M}} J\wedge J\wedge J \end{aligned}\right)$$

Different infinite distance points

⟶ Different moduli diverge

⟶ **Always tensionless** membranes

Outline

1. The Landscape vs. The Swampland
   (i) The Swampland Distance Conjecture
   (ii) Particles, Strings and Membranes in the infinite Distance Limits
2. The Species Scale and Minimal Black Hole Entropies
   (i) The Species Scale
   (ii) UV/IR Mixing, the Covariant Entropy Bound and Minimal black holes
   (iii) The Black Hole-String Correspondence
   (iv) The Black Hole-Species Tower Correspondence
3. Conclusions

The species Scale

- Maximum UV cut-off in QG in the presence of N light species

$$M_{\mathrm{Pl,d}} \longrightarrow \Lambda_{\mathrm{QG}} = \frac{M_{\mathrm{Pl,d}}}{N^{\frac{1}{d-2}}}$$

[Dvali '07] [Dvali, Reedi '08]
[Dvali, Lüst '10] [Dvali, Gómez '10]

The species Scale

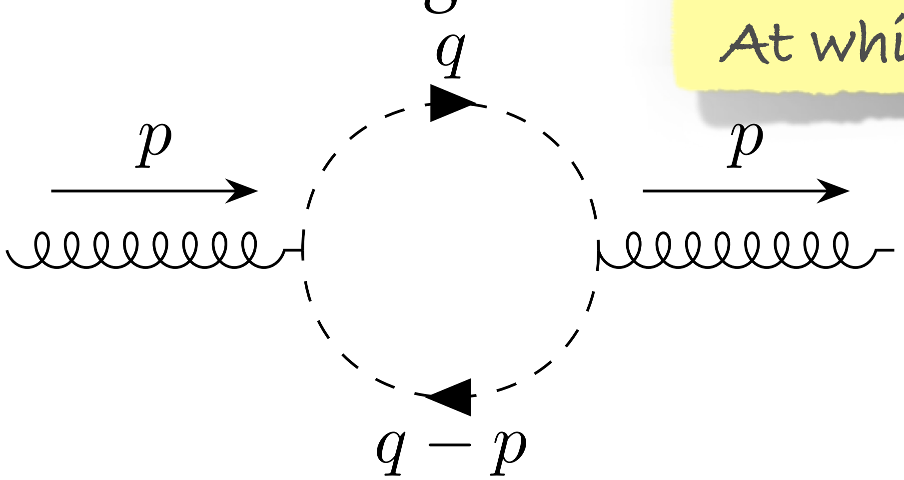
- Maximum UV cut-off in QG in the presence of N light species

$$M_{\mathrm{Pl,d}} \longrightarrow \Lambda_{\mathrm{QG}} = \frac{M_{\mathrm{Pl,d}}}{N^{\frac{1}{d-2}}}$$

[Dvali '07] [Dvali, Reedi '08]
[Dvali, Lüst '10] [Dvali, Gómez '10]

- **Perturbative** arguments

At which scale does the perturbative expansion break down?



$$\pi^{-1}\left(p^2\right) = 2p^2\left(1 - \frac{Np^2}{120\pi M_{\mathrm{pl},4}^2}\ln\left(-p^2/\mu^2\right)\right)$$

The species Scale

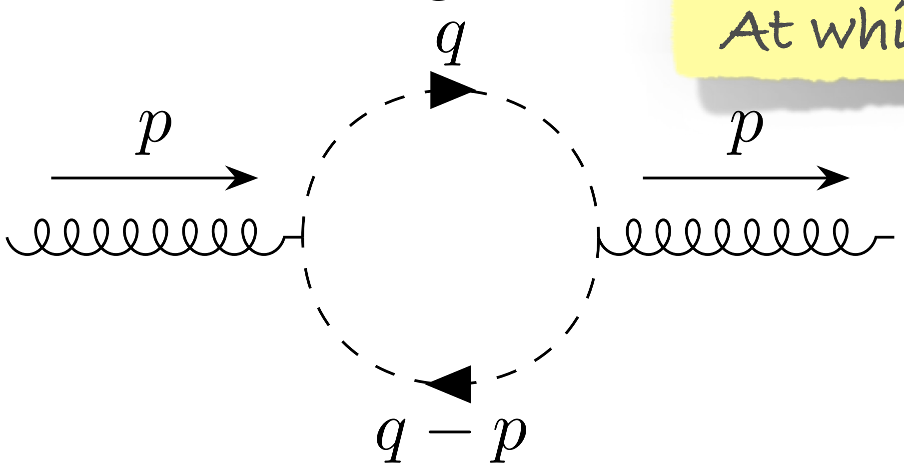
- Maximum UV cut-off in QG in the presence of N light species

$$M_{\text{Pl,d}} \longrightarrow \Lambda_{\text{QG}} = \frac{M_{\text{Pl,d}}}{N^{\frac{1}{d-2}}}$$

[Dvali '07] [Dvali, Reedi '08]
[Dvali, Lüst '10] [Dvali, Gómez '10]

- **Perturbative** arguments

At which scale does the perturbative expansion break down?



$$\pi^{-1}\left(p^2\right) = 2p^2\left(1 - \frac{Np^2}{120\pi M_{\text{pl},4}^2}\ln\left(-p^2/\mu^2\right)\right)$$

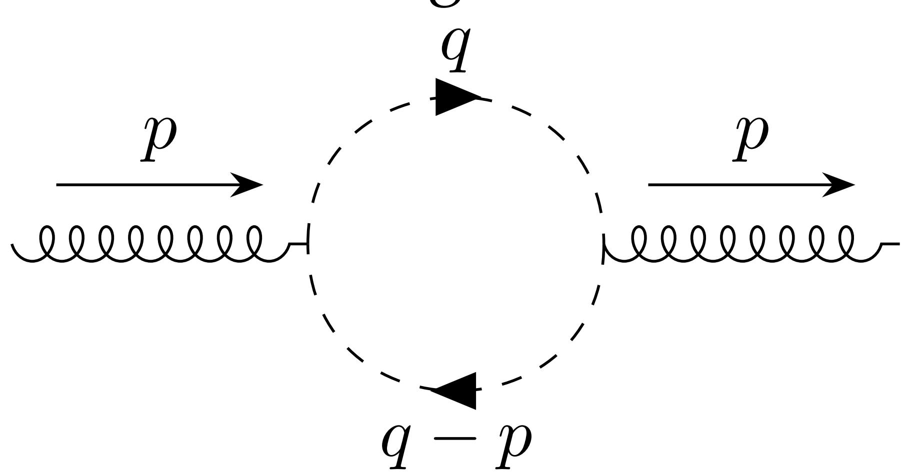
The species Scale

- Maximum UV cut-off in QG in the presence of N light species

$$M_{\text{Pl,d}} \longrightarrow \Lambda_{\text{QG}} = \frac{M_{\text{Pl,d}}}{N^{\frac{1}{d-2}}}$$

[Dvali '07] [Dvali, Reedi '08]
[Dvali, Lüst '10] [Dvali, Gómez '10]

- **Perturbative** arguments



$$\pi^{-1}\left(p^2\right) = 2p^2\left(1 - \frac{Np^2}{120\pi M_{\text{pl},4}^2}\ln\left(-p^2/\mu^2\right)\right)$$

- **Non-perturbative** arguments: Smallest semi-classical BHs have size $R \sim \Lambda_{\text{QG}}^{-1}$ since, in the presence of N species, its decay time can be estimated as $\tau \sim \Lambda_{\text{QG}}^{-1}$

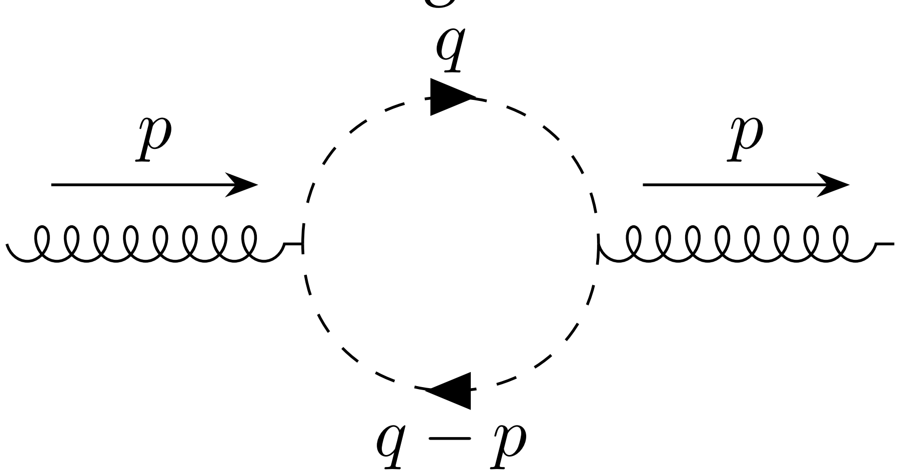
The species Scale

- Maximum UV cut-off in QG in the presence of N light species

$$M_{\text{Pl,d}} \longrightarrow \Lambda_{\text{QG}} = \frac{M_{\text{Pl,d}}}{N^{\frac{1}{d-2}}}$$

[Dvali '07] [Dvali, Reedi '08]
[Dvali, Lüst '10] [Dvali, Gómez '10]

- **Perturbative** arguments



$$\pi^{-1}\left(p^2\right) = 2p^2\left(1 - \frac{Np^2}{120\pi M_{\text{pl},4}^2}\ln\left(-p^2/\mu^2\right)\right)$$

- **Non-perturbative** arguments: Smallest semi-classical BHs have size $R \sim \Lambda_{\text{QG}}^{-1}$ since, in the presence of N species, its decay time can be estimated as $\tau \sim \Lambda_{\text{QG}}^{-1}$

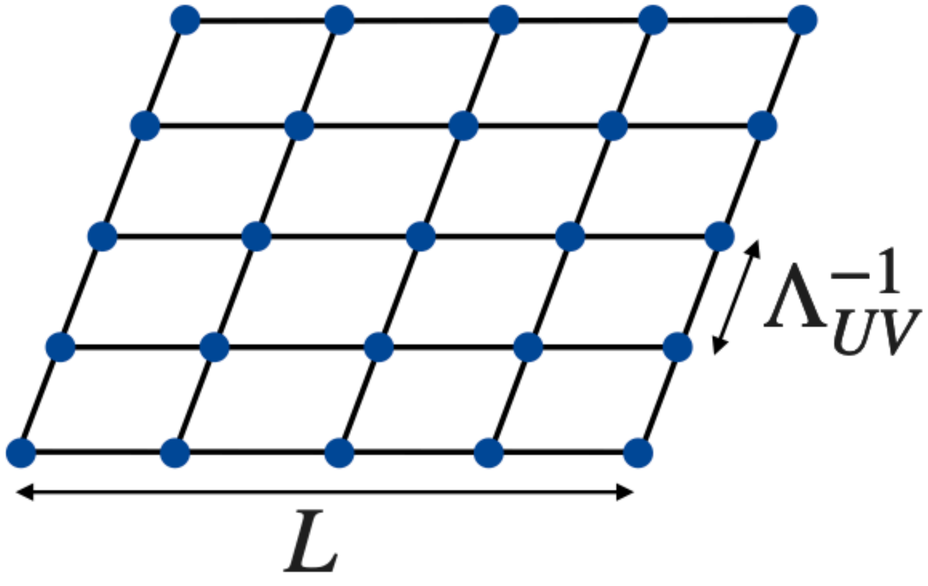
Species Scale of the d-dim EFT =
$M_{\text{Pl},\,d+p}$ (decompactification of p dimensions)
M_{str} (weakly coupled string limits)

UV/IR Mixing, the Covariant Entropy Bound and Minimal black holes

[Castellano, AH, Ibáñez ´21]
[AH, Lüst, Masias, Scalisi (WIP)]

Extensive Entropy in QFT

$$S \sim N_{\rm sp}\, T^{d-1}\ \text{vol} \sim N_{\rm sp}\,(T\,L)^{d-1}$$



UV/IR Mixing, the Covariant Entropy Bound and Minimal black holes

[Castellano, AH, Ibáñez ´21]
[AH, Lüst, Masias, Scalisi (WIP)]

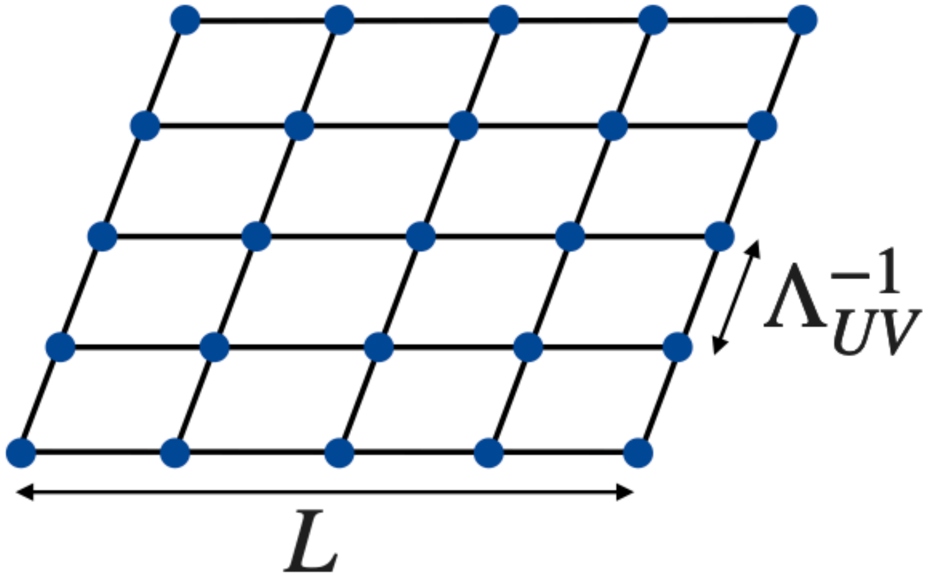
Extensive Entropy in QFT

$$S \sim N_{\text{sp}}\, T^{d-1}\ \text{vol} \sim N_{\text{sp}}\, (T\, L)^{d-1}$$

$$T \leq \Lambda_{\text{sp}}$$

Species Scale (QG cut-off)

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



UV/IR Mixing, the Covariant Entropy Bound and Minimal black holes

[Castellano, AH, Ibáñez ´21]
[AH, Lüst, Masias, Scalisi (WIP)]

Extensive Entropy in QFT

$$S \sim N_{\rm sp}\, T^{d-1}\ \mathrm{vol} \sim N_{\rm sp}\, (T\,L)^{d-1}$$
$$T \leq \Lambda_{\rm sp}$$

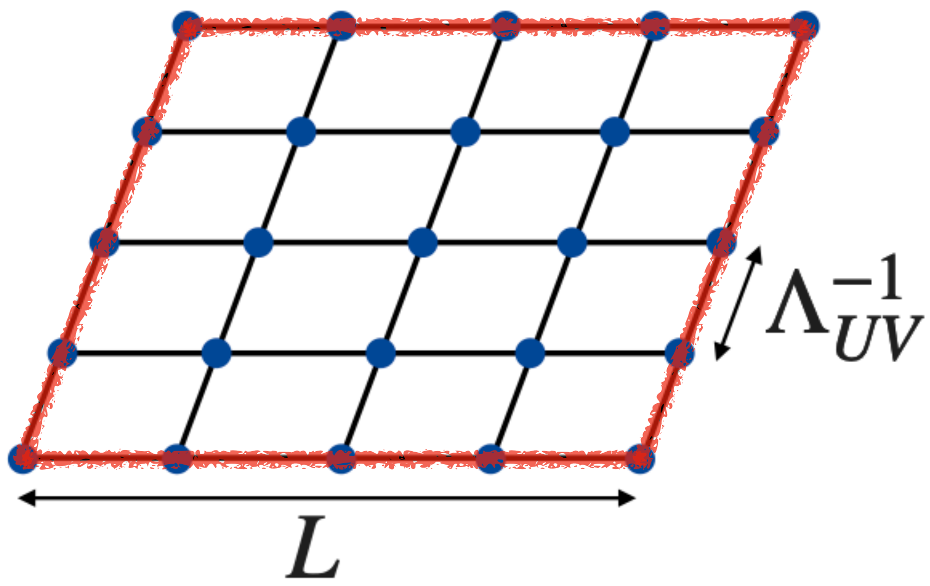
Covariant Entropy Bound

[Bousso´99]

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

Species Scale (QG cut-off)

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



UV/IR Mixing, the Covariant Entropy Bound and Minimal black holes

[Castellano, AH, Ibáñez ´21]
[AH, Lüst, Masias, Scalisi (WIP)]

Extensive Entropy in QFT

$$S \sim N_{\rm sp}\, T^{d-1}\ \mathrm{vol} \sim N_{\rm sp}\,(T\,L)^{d-1}$$
$$T \leq \Lambda_{\rm sp}$$

Covariant Entropy Bound

[Bousso´99]

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

Species Scale (QG cut-off)

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

Saturation of the bound at the scale of gravitational collapse

$$S \simeq N_{\rm sp} \qquad T = \frac{1}{L} \simeq \Lambda_{\rm sp}$$

UV/IR Mixing, the Covariant Entropy Bound and Minimal black holes

[Castellano, AH, Ibáñez ´21]
[AH, Lüst, Masias, Scalisi (WIP)]

Extensive Entropy in QFT

$$S \sim N_{\rm sp}\, T^{d-1}\ \text{vol} \sim N_{\rm sp}\,(T\,L)^{d-1}$$
$$T \leq \Lambda_{\rm sp}$$

Covariant Entropy Bound

[Bousso´99]

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

Species Scale (QG cut-off)

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

Saturation of the bound at the scale of gravitational collapse

$$S \simeq N_{\rm sp} \qquad T = \frac{1}{L} \simeq \Lambda_{\rm sp}$$

Species Entropy

[Cribiori, Montella, Lüst ´23]

Black Hole-String Correspondence

[Susskind ´93]
[Horowitz, Polchinski ’96 ’97]

[Chen, Maldacena, Witten ’21]
[Susskind ’21]
[Ceplack, Emparan, Puhm, Tomasevic ‘22]
[Bedroya, Vafa, Wang ‘23]

Black Hole-String Correspondence

[Susskind ´93]
[Horowitz, Polchinski ’96 ’97]

Black Hole

$$\ell_{\mathrm{Pl,d}}^{d-2} = g_{s,d}^2 \ell_{\mathrm{str}}^{d-2}$$

$$M_{\mathrm{BH}} \sim \frac{R_{\mathrm{BH}}^{d-3}}{\ell_{\mathrm{Pl,d}}^{d-2}} \sim \frac{R_{\mathrm{BH}}^{d-3}}{g_{s,d}^2 \ell_{\mathrm{str}}^{d-2}}$$

$$S_{\mathrm{BH}} \sim \left(R_{\mathrm{BH}}/\ell_{\mathrm{Pl,d}}\right)^{d-2} \sim g_{s,d}^{\frac{2}{d-3}} \left(M_{\mathrm{BH}} \ell_{\mathrm{str}}\right)^{\frac{d-2}{d-3}}$$

Black Hole-String Correspondence

[Susskind ´93]
[Horowitz, Polchinski ’96 ’97]

$$\ell_{\rm Pl,d}^{d-2} = g_{s,d}^2 \ell_{\rm str}^{d-2}$$

Black Hole

$$M_{\rm BH} \sim \frac{R_{\rm BH}^{d-3}}{\ell_{\rm Pl,d}^{d-2}} \sim \frac{R_{\rm BH}^{d-3}}{g_{s,d}^2 \ell_{\rm str}^{d-2}}$$

$$S_{\rm BH} \sim \left(R_{\rm BH}/\ell_{\rm Pl,d}\right)^{d-2} \sim g_{s,d}^{\frac{2}{d-3}} \left(M_{\rm BH}\ell_{\rm str}\right)^{\frac{d-2}{d-3}}$$

(Free) String

$$M_{\rm str} \sim \frac{L_{\rm str}}{\ell_{\rm str}^2}$$

$$S_{\rm str} \sim L_{\rm str}/\ell_{\rm str} \sim M_{\rm str}\ell_{\rm str}$$

Black Hole-String Correspondence

[Susskind ´93]
[Horowitz, Polchinski ’96 ’97]

$$\ell_{\mathrm{Pl,d}}^{d-2} = g_{s,d}^2 \ell_{\mathrm{str}}^{d-2}$$

Black Hole

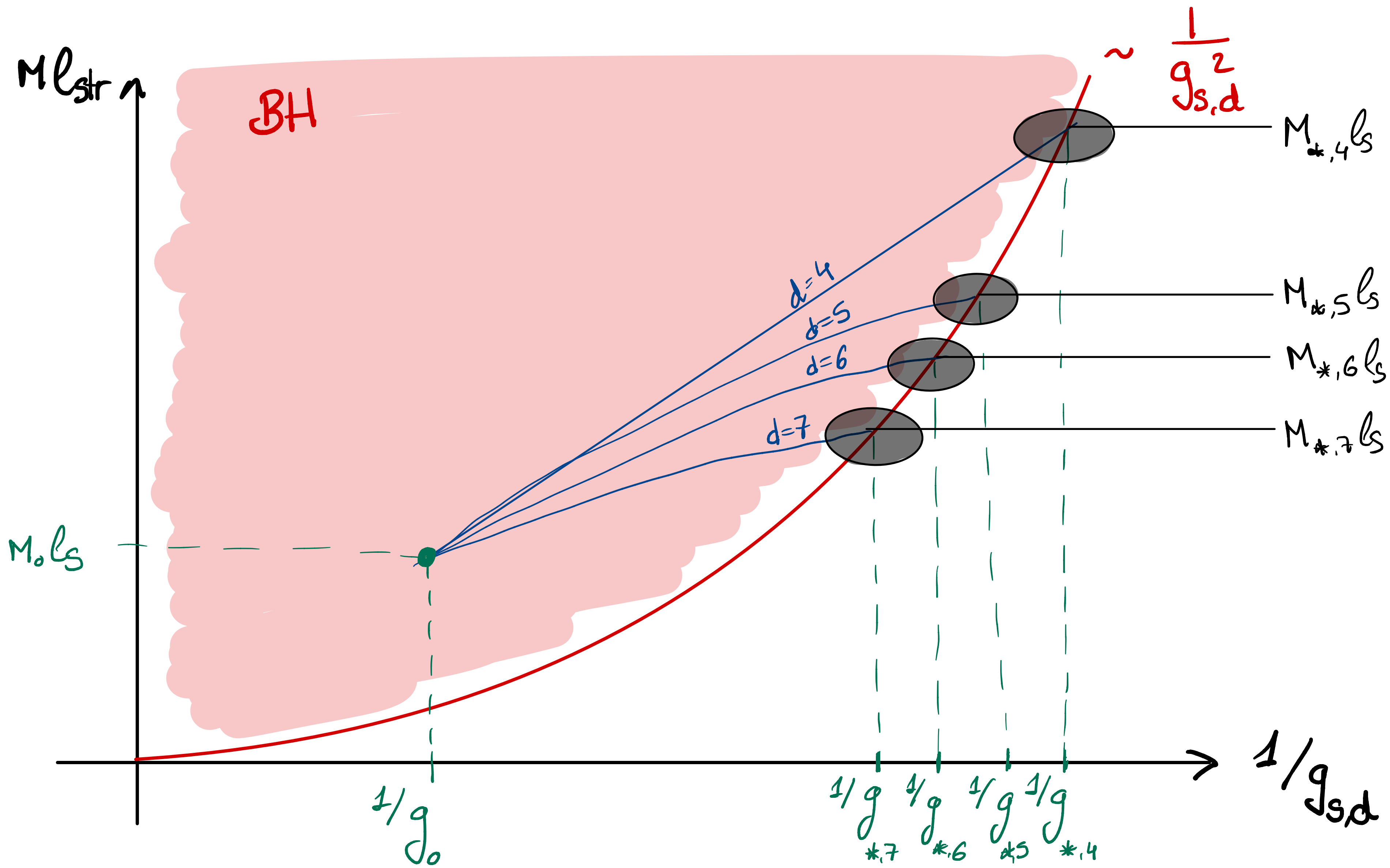
$$M_{\mathrm{BH}} \sim \frac{R_{\mathrm{BH}}^{d-3}}{\ell_{\mathrm{Pl,d}}^{d-2}} \sim \frac{R_{\mathrm{BH}}^{d-3}}{g_{s,d}^2 \ell_{\mathrm{str}}^{d-2}}$$

$$S_{\mathrm{BH}} \sim \left(R_{\mathrm{BH}}/\ell_{\mathrm{Pl,d}}\right)^{d-2} \sim g_{s,d}^{\frac{2}{d-3}} \left(M_{\mathrm{BH}}\ell_{\mathrm{str}}\right)^{\frac{d-2}{d-3}}$$

(Free) String

$$M_{\mathrm{str}} \sim \frac{L_{\mathrm{str}}}{\ell_{\mathrm{str}}^2}$$

$$S_{\mathrm{str}} \sim L_{\mathrm{str}}/\ell_{\mathrm{str}} \sim M_{\mathrm{str}}\ell_{\mathrm{str}}$$



[AH, Lüst, Masias, Scalisi (WIP)]

Black Hole-String Correspondence

[Susskind ´93]
[Horowitz, Polchinski ’96 ’97]

$$\ell_{\mathrm{Pl,d}}^{d-2} = g_{s,d}^2 \ell_{\mathrm{str}}^{d-2}$$

Black Hole

$$M_{\mathrm{BH}} \sim \frac{R_{\mathrm{BH}}^{d-3}}{\ell_{\mathrm{Pl,d}}^{d-2}} \sim \frac{R_{\mathrm{BH}}^{d-3}}{g_{s,d}^2 \ell_{\mathrm{str}}^{d-2}}$$

$$S_{\mathrm{BH}} \sim \left(R_{\mathrm{BH}}/\ell_{\mathrm{Pl,d}}\right)^{d-2} \sim g_{s,d}^{\frac{2}{d-3}} \left(M_{\mathrm{BH}} \ell_{\mathrm{str}}\right)^{\frac{d-2}{d-3}}$$

(Free) String

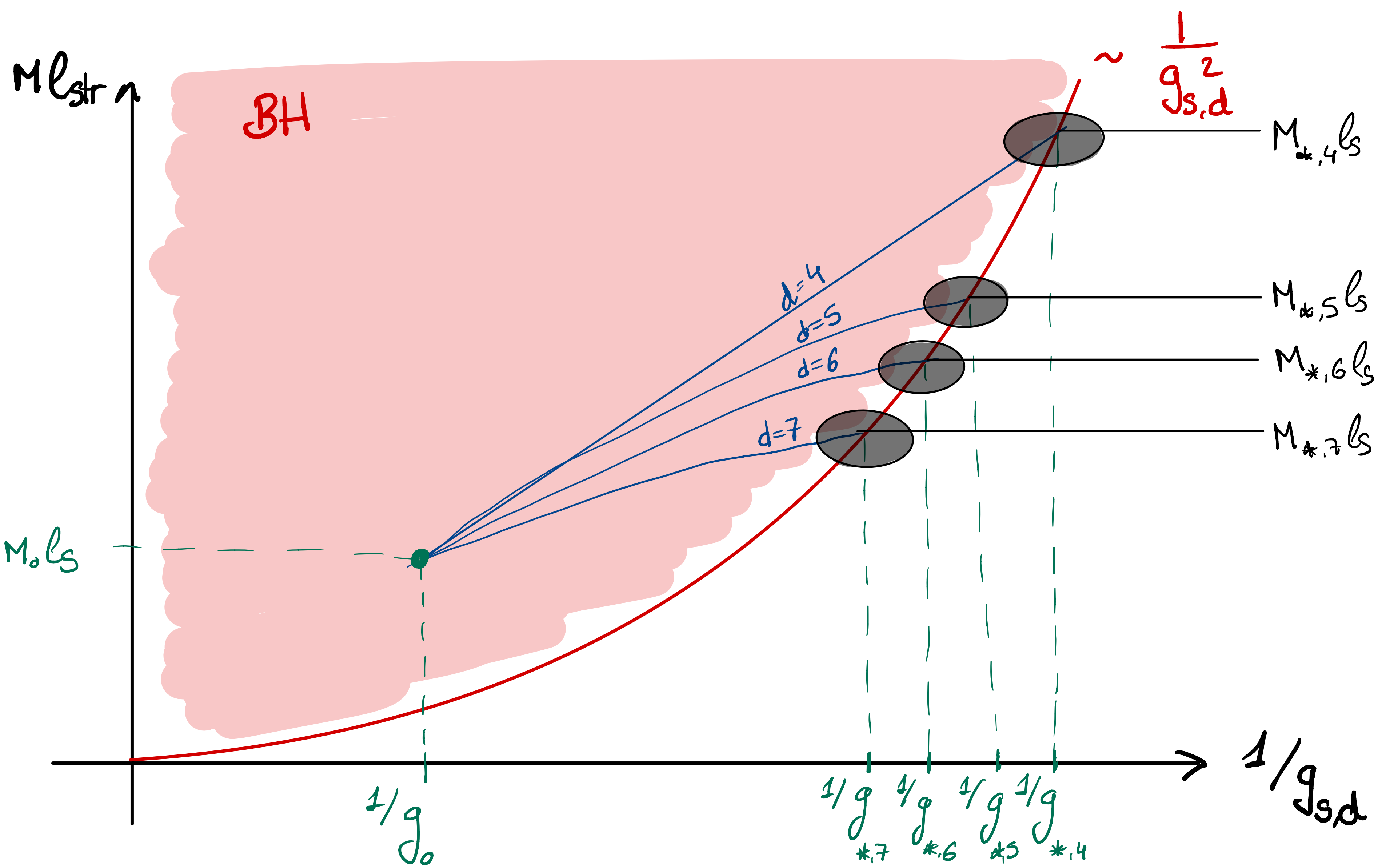
$$M_{\mathrm{str}} \sim \frac{L_{\mathrm{str}}}{\ell_{\mathrm{str}}^2}$$

$$S_{\mathrm{str}} \sim L_{\mathrm{str}}/\ell_{\mathrm{str}} \sim M_{\mathrm{str}} \ell_{\mathrm{str}}$$

Correspondence point (line)

$$R_{\mathrm{BH}} \sim \ell_{\mathrm{str}}$$

$$S = \frac{1}{g_{s,*}^2} = N_{\mathrm{sp}}$$



[AH, Lüst, Masias, Scalisi (WIP)]

Black Hole-Species Tower Correspondence

$$\ell_{\text{Pl,d}}^{d-2} = \frac{\ell_{\text{sp}}^{d-2}}{\mathscr{V}}$$

$$\ell_{\text{str}} \to \ell_{sp} = \Lambda_{\text{sp}}^{-1}$$
$$g_s^{-2} \to \mathscr{V}$$

Black Hole

$$M_{\text{BH}} \sim \frac{R_{\text{BH}}^{d-3}}{\ell_{\text{Pl,d}}^{d-2}} \sim \frac{R_{\text{BH}}^{d-3}\,\mathscr{V}}{\ell_{\text{sp}}^{d-2}}$$

$$S_{\text{BH}} \sim \left(R_{\text{BH}}/\ell_{\text{Pl,d}}\right)^{d-2} \sim \left(\frac{M_{\text{BH}}^{d-2}\ell_{\text{sp}}^{d-2}}{\mathscr{V}}\right)^{\frac{1}{d-3}}$$

Box of (free) species

$$L^{-1} = T \leq \Lambda_{\text{sp}}$$

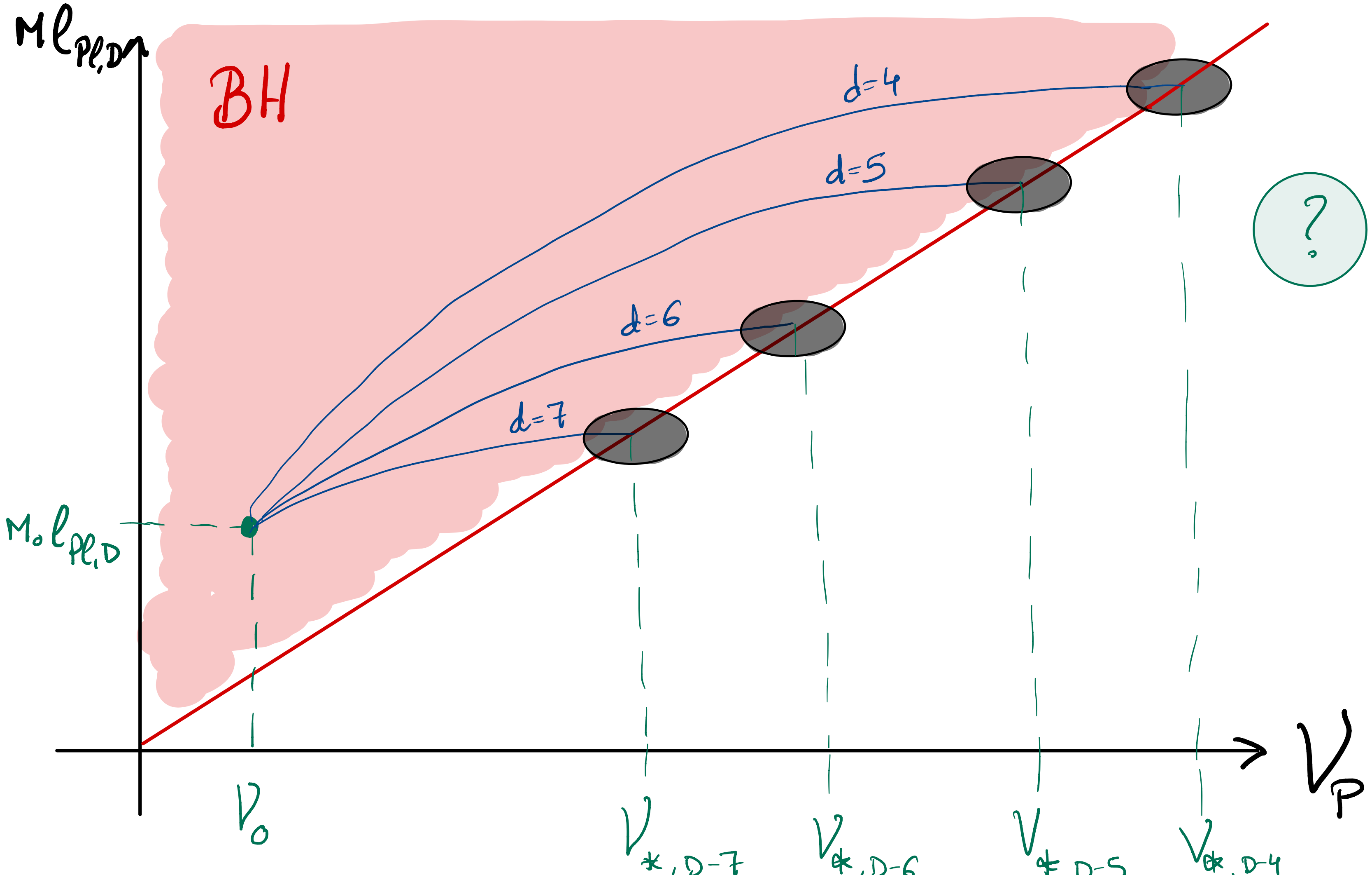
$$S \sim N_T\,(T\,L)^{d-1}$$

Correspondence point (line)

$$R_{\text{BH}} \sim \ell_{\text{sp}}$$

$$S = \mathscr{V}_* = N_{\text{sp},*}$$

[AH, Lüst, Masias, Scalisi (WIP)]



Black Hole-Species Tower Correspondence

$$\ell_{\mathrm{Pl,d}}^{d-2} = \frac{\ell_{\mathrm{sp}}^{d-2}}{\mathcal{V}}$$

$$\ell_{\mathrm{str}} \to \ell_{sp} = \Lambda_{\mathrm{sp}}^{-1}$$
$$g_s^{-2} \to \mathcal{V}$$

Correspondence point (line)

$$R_{\mathrm{BH}} \sim \ell_{\mathrm{sp}}$$

$$S = \mathcal{V}_* = N_{\mathrm{sp},*}$$

[AH, Lüst, Masias, Scalisi (WIP)]

Black Hole

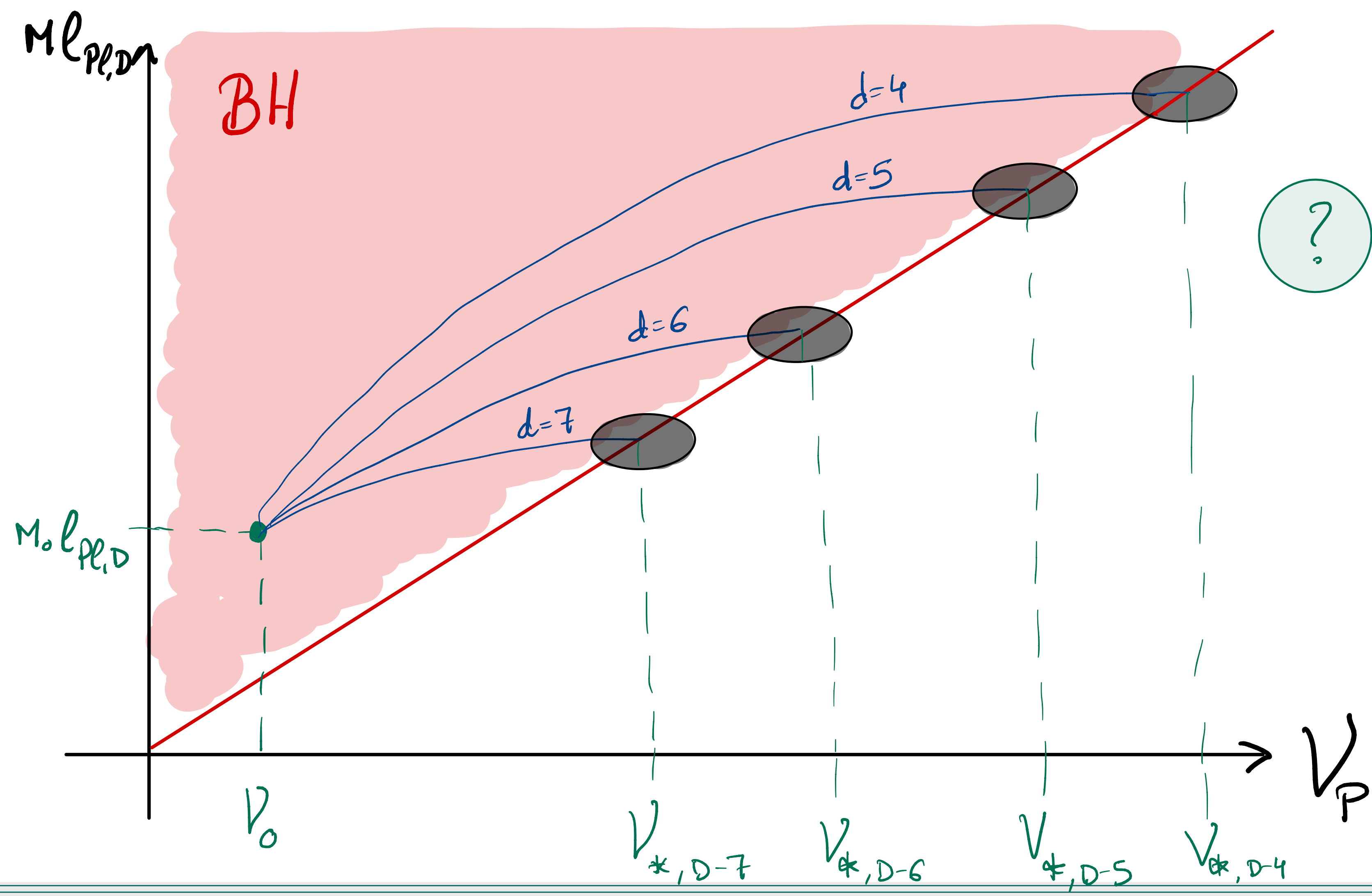
$$M_{\mathrm{BH}} \sim \frac{R_{\mathrm{BH}}^{d-3}}{\ell_{\mathrm{Pl,d}}^{d-2}} \sim \frac{R_{\mathrm{BH}}^{d-3}\,\mathcal{V}}{\ell_{\mathrm{sp}}^{d-2}}$$

$$S_{\mathrm{BH}} \sim \left(R_{\mathrm{BH}}/\ell_{\mathrm{Pl,d}}\right)^{d-2} \sim \left(\frac{M_{\mathrm{BH}}^{d-2}\ell_{\mathrm{sp}}^{d-2}}{\mathcal{V}}\right)^{\frac{1}{d-3}}$$

Box of (free) species

$$L^{-1} = T \leq \Lambda_{\mathrm{sp}}$$

$$S \sim N_T\,(T\,L)^{d-1} \sim N_{\mathrm{sp},*}$$



Summary

- Lots of light towers near infinite distance limits ⟶ Particles and extended objects

- Maximum cut-off for gravitational EFTs with such species ⟶ $\Lambda_{sp} = \frac{M_{Pl,d}}{N_{sp}^{\frac{1}{d-2}}} \geq m_{tower}$

- Entropy Bounds suggest smallest BH in the EFT has $R_{BH} \simeq \Lambda_{sp}^{d-1}$ and $M_{BH} \simeq \Lambda_{sp}^{3-d}\, M_{Pl,d}^{d-2}$

- Can compute the entropy (up to order one-factors, but recover area law) of semiclassical BHs from microstates of a free box of quantum relativistic species at $T = \Lambda_{sp,*}$ yielding $S = N_{sp,*} = N_T\,(TL)^{d-1}$

Thank you!

Gracias Anamaría!

Y mi más sincera enhorabuena por este merecidísimo premio!