Non-perturbative strings, asymptotic safety, and the swampland

Alessia Platania

Based on:

I. Basile, AP: 2101.02226, 2103.06276, 2107.06897

+ various wip with: I. Basile, J. Borissova, B. Knorr, M. Schiffer, et al

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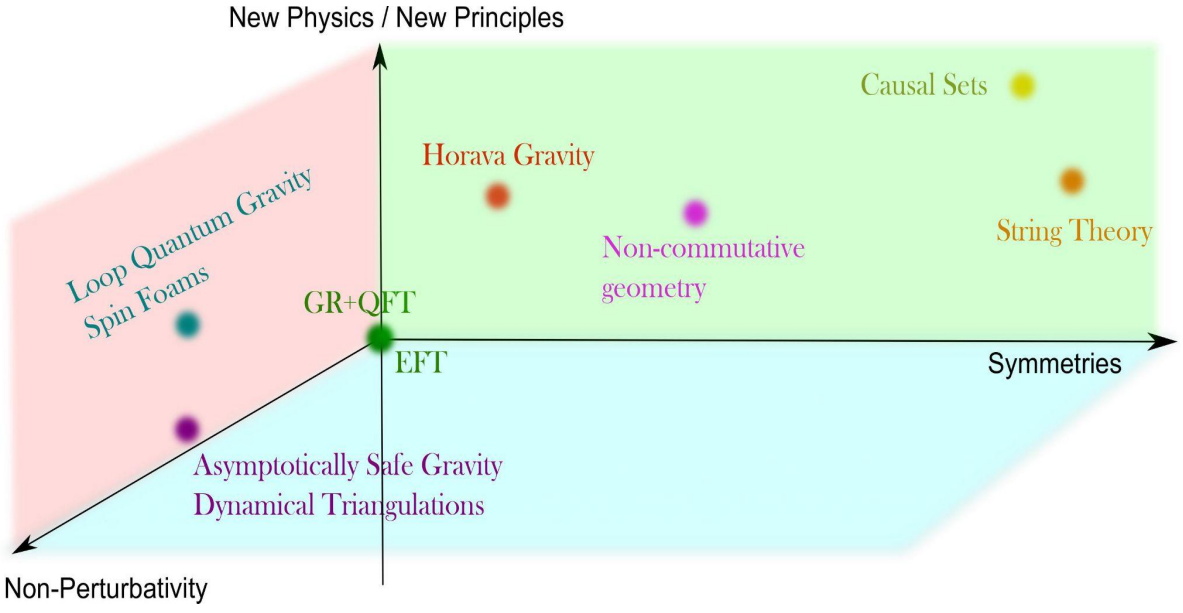
The realm of Quantum Gravity

Several approaches:

- String Theory
- Asymptotically Safe Gravity
- Dynamical Triangulation
- Non-local gravity
- Loop quantum gravity
- Group field theory
- Causal sets
- Horava gravity
- …



Goals/wishes:

- Consistency: Renormalizability, unitarity, compatibility with large scale physics & observations
- Predictions: quantum cosmology, quantum black holes, scattering amplitudes, grav. waves

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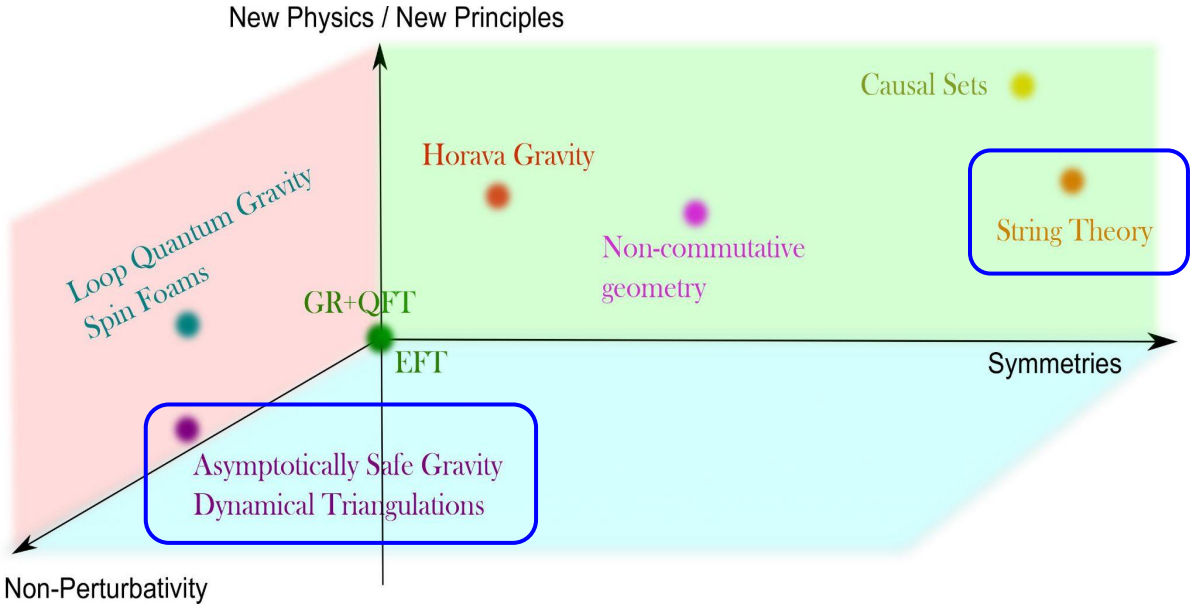

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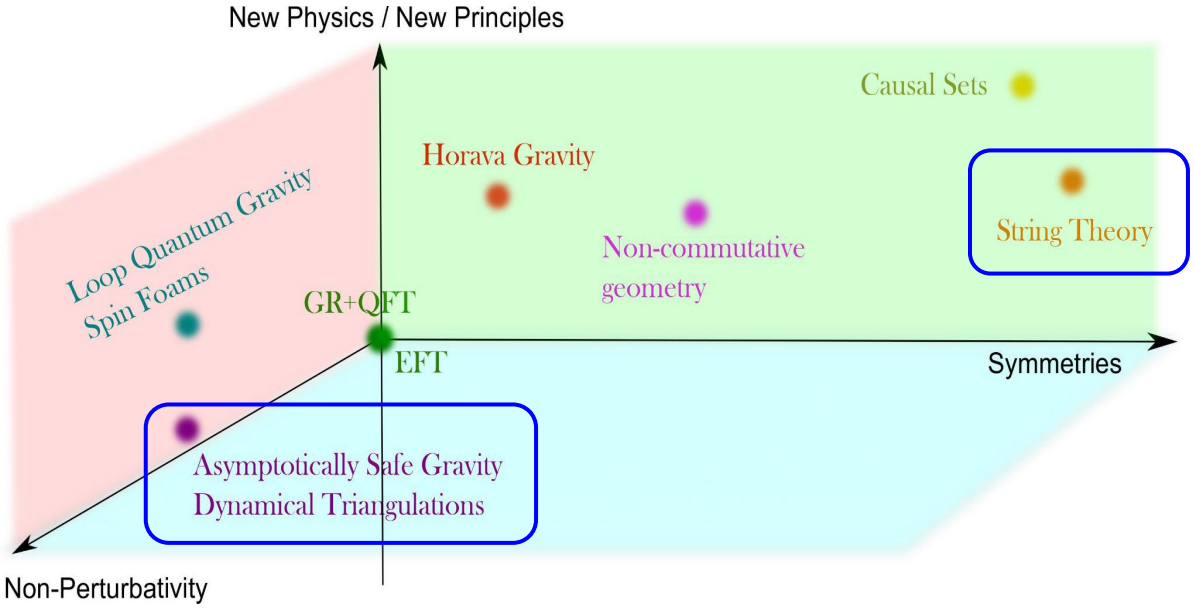


Motivation

- **<u>Similar language</u>: EFT, effective actions, scattering amplitudes**
- **<u>Is AS unitarity?</u>**

[Knorr, Pawlowski, Reichert, Ripken, Saueressig, Wetterich, AP…]+[talks by Knorr, Reichert]

- **<u>Eff-AS</u>: AS valid up to Planckian scales, then leave the stage to the stringy regime?**

[de Alwis et al 2019]

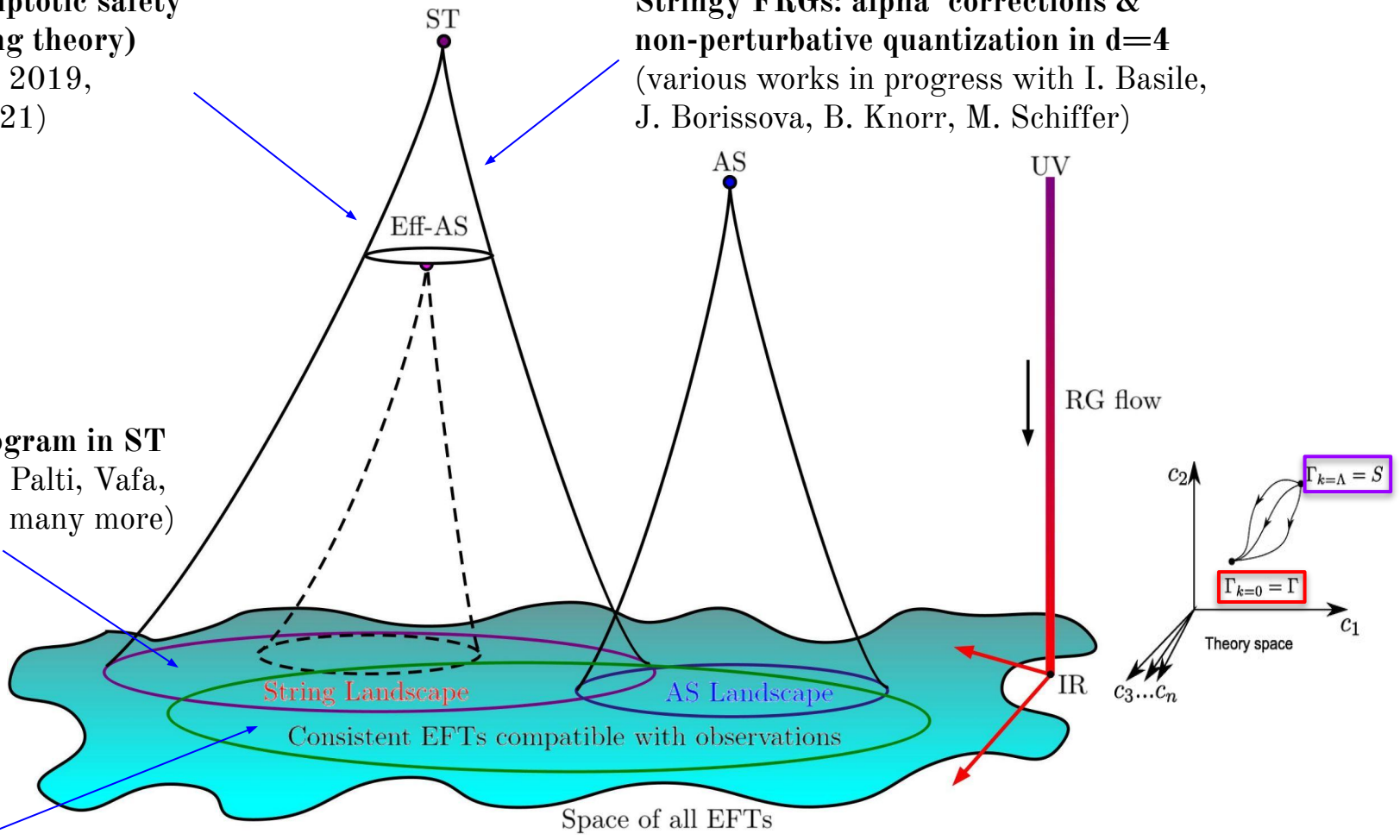
- **<u>Stringy problems</u>: moduli stabilizations, compactifications, broken supersymmetry, de Sitter ⇒ non-perturbativity needed!**
- **<u>AS/FRG+strings</u> = win-win scenarios?**

Effective asymptotic safety (AS from string theory)
(de Alwis et al 2019, Basile, AP, 2021)

Stringy FRGs: alpha' corrections & non-perturbative quantization in d=4
(various works in progress with I. Basile, J. Borissova, B. Knorr, M. Schiffer)

Swampland program in ST
(Lüst, Montero, Palti, Vafa, Valenzuela, and many more)

Swampland program in AS
(Basile, AP, 2021)



Quantum gravity phenomenology, positivity bounds, causality, unitarity, stability etc.
QG-model independent constraints on coefficients / form factors in the effective action (a lot of literature)

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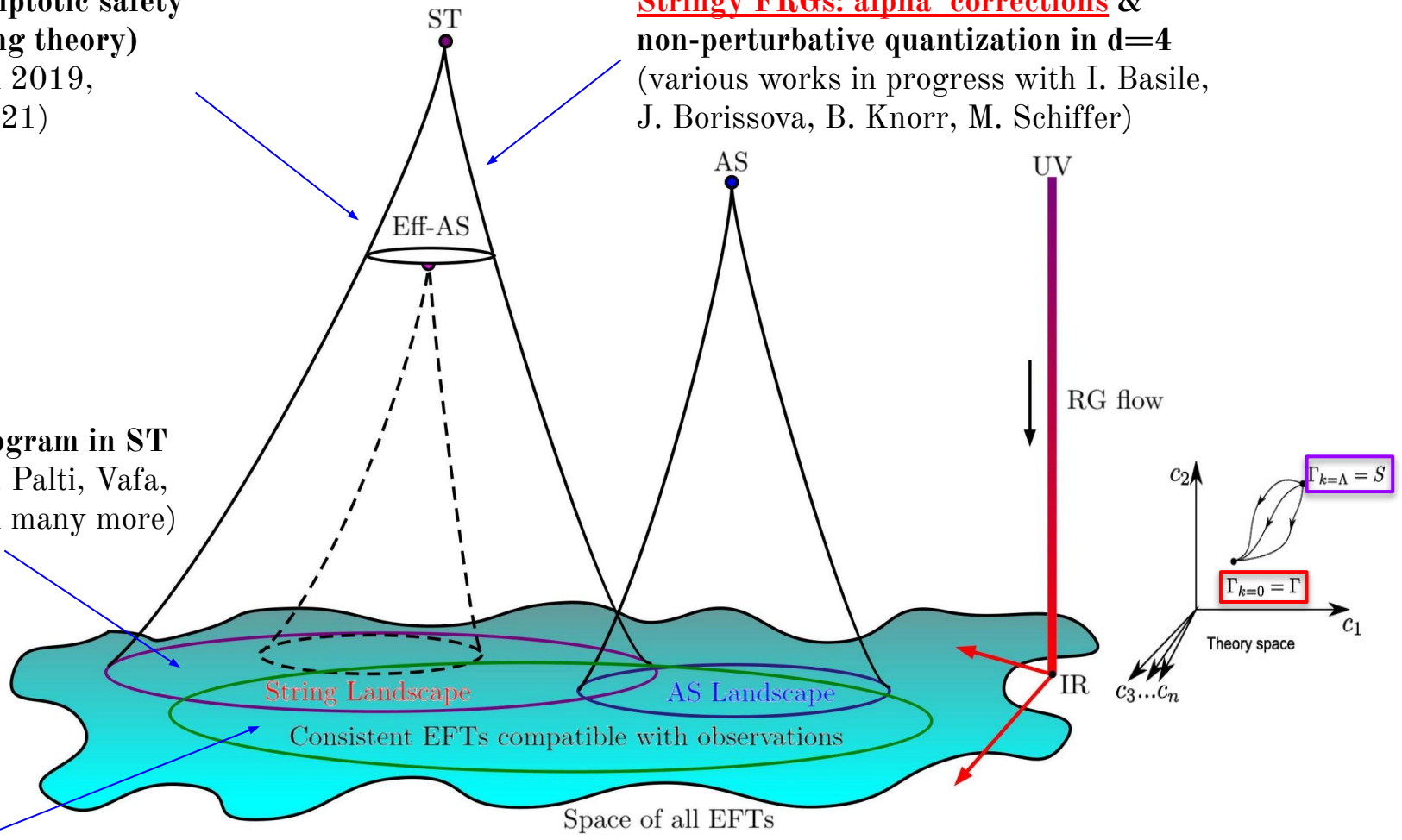

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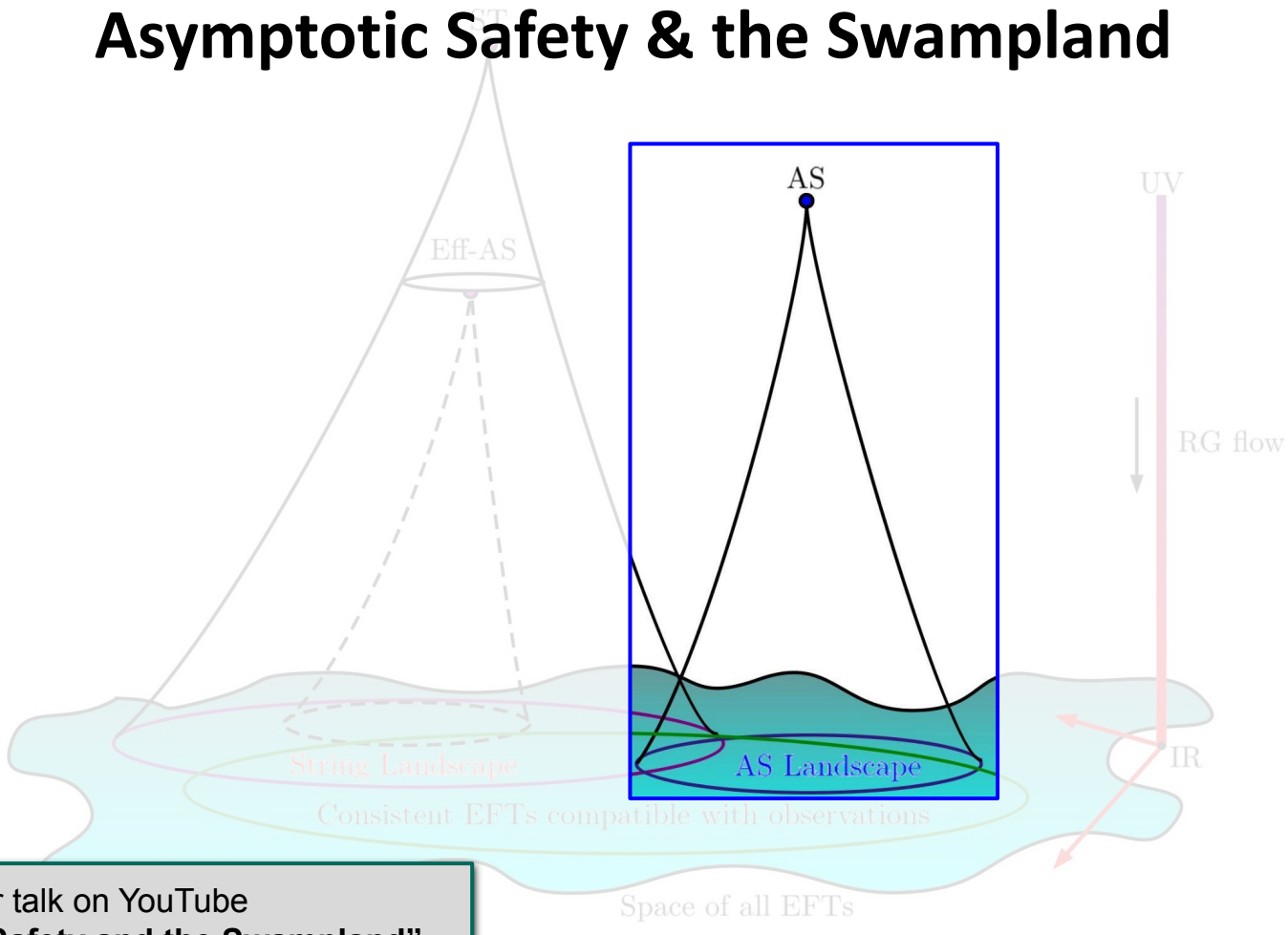
Asymptotic Safety & the Swampland

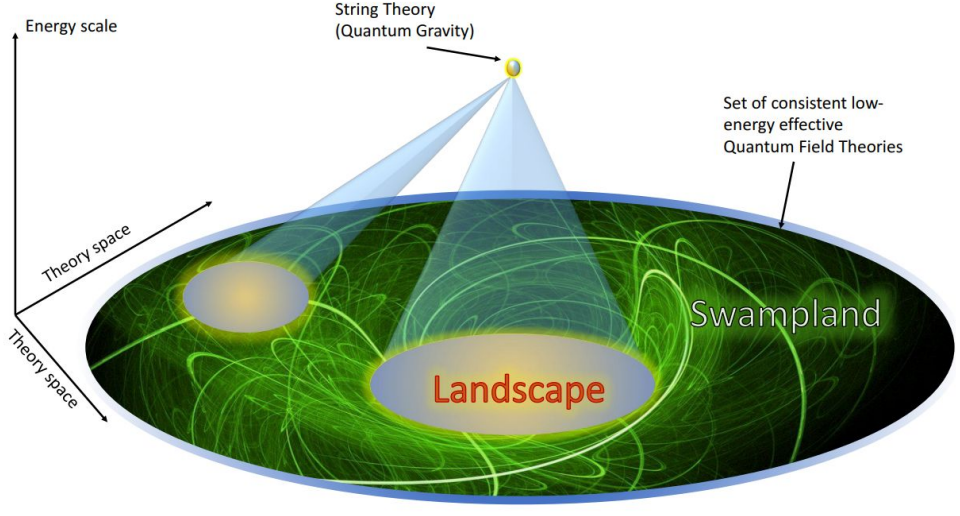


Detailed longer talk on YouTube
“Asymptotic Safety and the Swampland”
Seminar Series: **String Pheno Seminars**

The Swampland Program

The **Swampland** can be defined as the set of (apparently) consistent effective field theories that cannot be completed into quantum gravity in the ultraviolet.

E. Palti (2019)



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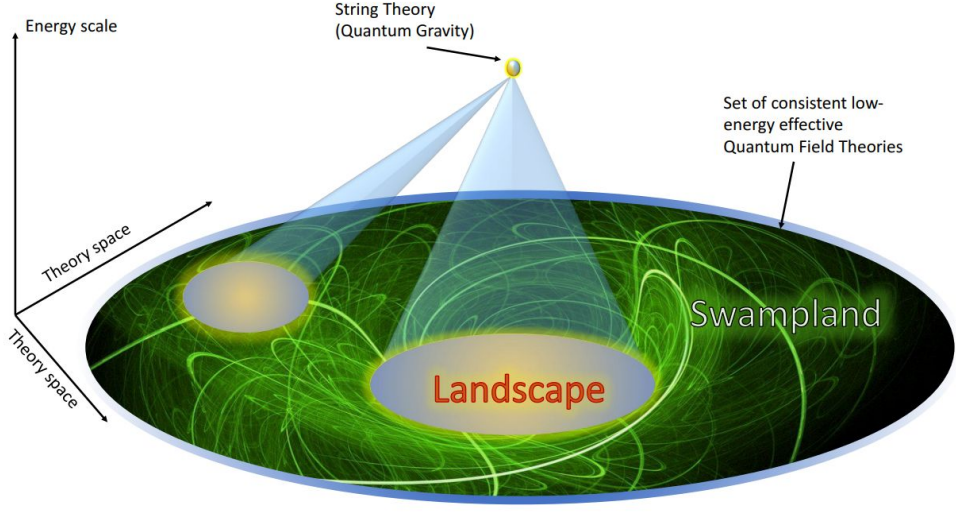
So string theory might lead to a large Landscape of effective low-energy theories, but there is an even larger Swampland of effective theories that cannot come from string theory. This is illustrated in figure 1. Note that we phrased the definition of the Swampland using a general notion of quantum gravity, rather than specifically string theory. For simplicity of notation, we will rarely distinguish between such a general quantum theory of gravity and string theory, but it is natural to define the Swampland in this more general sense. **E. Palti (2019)**



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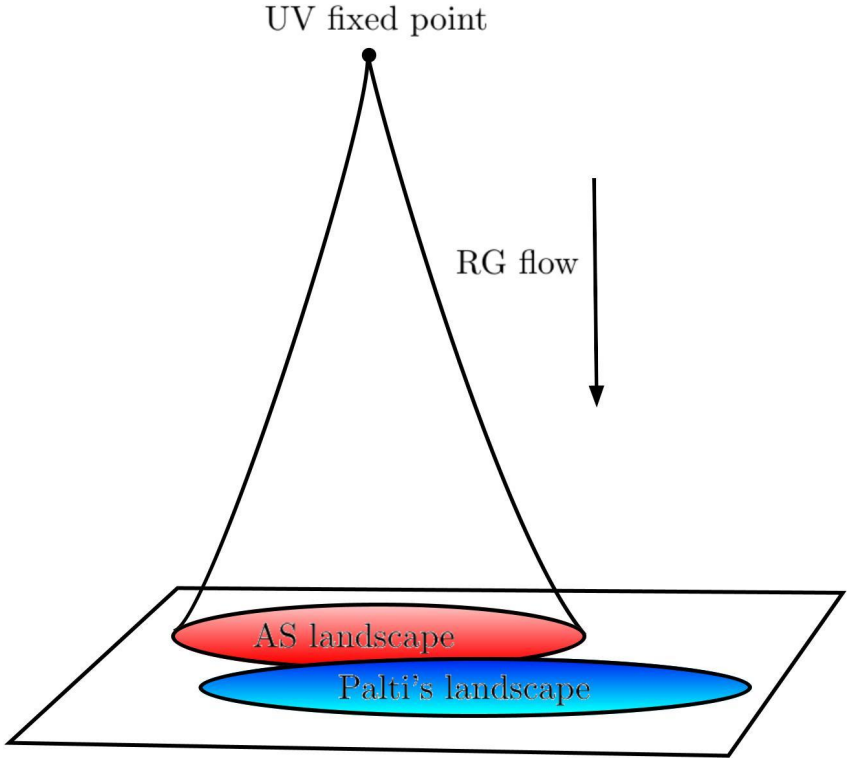
- **Idea**: test swampland conjectures within other approaches to quantum gravity
- **Our work [Basile, AP, 2107.06897]**:
  First computation in asymptotically safe gravity, within the simplest possible setup (proof of concept)
- **A lot to learn**: proper subsets vs disjoint sets, implications? Relations between approaches?
- **Non-trivial test of the "String Lamppost Principle"**
  "*All consistent quantum gravity theories are part of the string landscape*" [Montero, Vafa, '21]

Asymptotic Safety & the Swampland

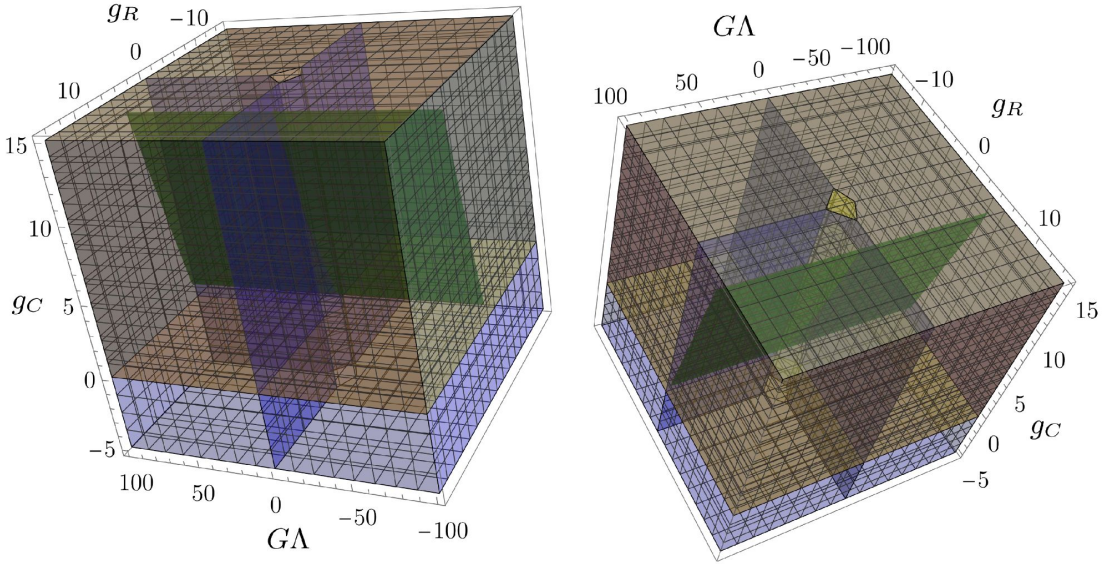
Recipe:

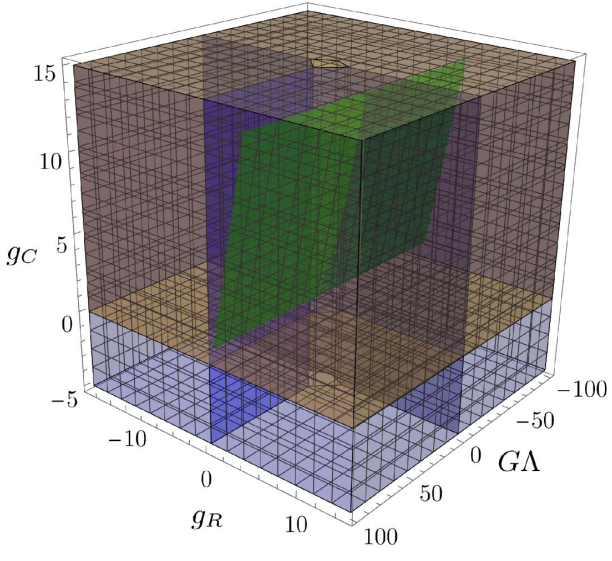
- **Consider a model of AS**
- **Run FRG machinery**: compute beta functions, solve beta functions for a sample of UV-complete trajectories, identify the "**AS landscape**" (AS-IR) in terms of Wilson coefficients in the effective action
- Use the same Wilson coefficients to identify the **region allowed by some swampland conjectures** (Palti's landscape)
- **Find the intersections** between the general landscape and the AS landscape



Ingredients:

- **AS toy model**: one-loop quadratic gravity [Codello, Percacci, '06]
- **Swampland conjectures**: de Sitter, trans-Planckian, weak gravity conjectures





Green plane: **AS landscape (one-loop quadratic gravity)**

$$\mathrm{EFT}_{\mathrm{AS}} \approx \{g_R = -0.74655 - \frac{2}{3}\,\omega_-\, g_C\}$$

Blue hyperplane: **trans-planckian cosmic conjecture**

$$M_{Pl}||\nabla V|| \leq cV \qquad \text{for } \Delta\phi \leq f M_{Pl} \qquad f, c \sim \mathcal{O}(1)$$

Yellow hyperplane: **weak gravity conjecture**

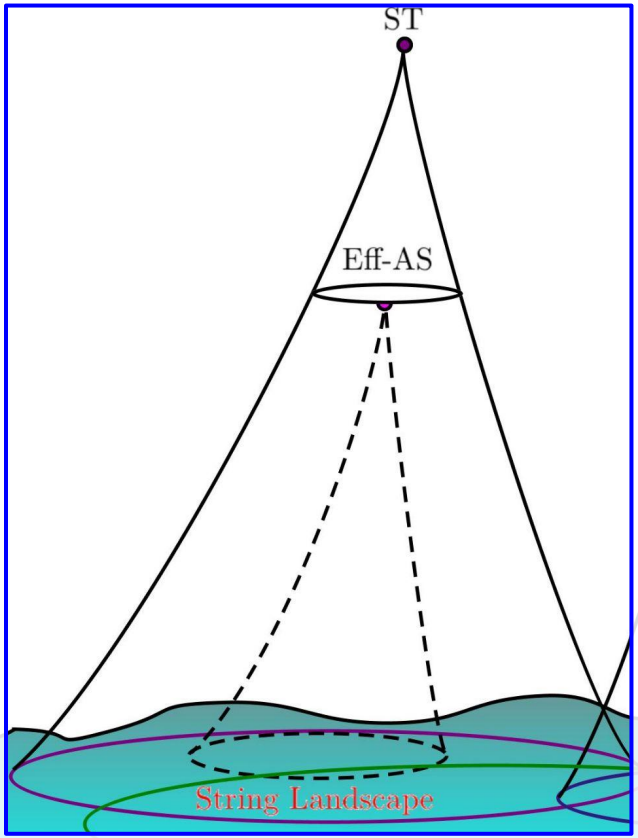
$$Q/M \leq (Q/M)_{extr}\left(1 - \frac{\Delta}{M^2}\right) \qquad \Delta \geq 0$$

Within this simple model of AS, and only some swampland conjectures

⇒ **non-trivial intersection**

[Basile, AP. 2107.06897]

Stringy FRGs



Detailed longer talk on YouTube
"String Tension between de Sitter vacua and Curvature Corrections"
Conference: **Corfu Summer Institute 2021**

Meissner-Hohm-Zwiebach effective action in string theory

Stringy higher-derivative terms = α' corrections

Cosmological backgrounds. Weyl anomaly cancellation + integration of all massive modes + cosmological backgrounds + T-duality ⇒

⇒ **Strong constraints on stringy cosmological effective action:**

$$S_{\rm MHZ} = \frac{{\rm Vol}_d}{16\pi G_{\rm N}} \int dt\, \frac{e^{-\Phi}}{n} \left[-\dot{\Phi}^2 + 2d\, n^2 \sum_{m=0}^{\infty} (-4)^m\, c_m\, \alpha'^{m-1} \left(\frac{H}{n} \right)^{2m} \right]$$

(Meissner, 1991)
(Hohm, Zwieback, 2015)

T-duality: cosmological Lagrangian has a single, even function of H + dilaton

Validity: no string loops, mini-superspace, bosonic string

Key Point: Computing all c-coefficients ⇒ access to **non-perturbative de-Sitter solutions** (if any)

Problem: Computation of the c-coefficients via perturbative stringy techniques (e.g., scattering amplitudes), one by one, is very hard. *Only the first few coefficients are known*!

Mini-superspace stringy effective actions from the FRG

[Basile, AP. 2101.02226]

- **Exact non-analytic solution valid in any spacetime dimension D**

  Same RG-running of G found in the context of asymptotic safety
  Incompatible with Einstein gravity

$$\Gamma_{\text{string}} = \frac{\text{Vol}_d}{16\pi G_{\text{N}}} \int dt\; n\, e^{-\Phi} \left[-\frac{\dot{\Phi}^2}{n^2} + \left(\Lambda + \tilde{c} \sqrt{\frac{H^2}{n^2 \Lambda}} \right) \right]$$

- **Analytic solution around two spacetime dimensions (leading order in epsilon)**

  Well-defined infrared limit, possible to compute effective action to leading order in epsilon
  Within truncations, no nice extension of this analytical solution to D=4 spacetime dimensions

$$\Gamma_{\text{string}} = \frac{\text{Vol}_{1+\epsilon}}{16\pi G_{\text{N}}} \int dt\; n\, e^{-\Phi} \left[\Lambda - \frac{\dot{\Phi}^2}{n^2} + \frac{H^2}{n^2} + \frac{8 G_{\text{N}} \Lambda}{3\pi} L\left(\frac{H^2}{n^2\, \Lambda} \right) \right]$$

String pheno application: [H. Bernardo, P. Chouha, G. Franzmann, ‘21]

$$L(s) \equiv -1 - \frac{23}{12}\, s + \left(\frac{3}{2} + s \right) \log\left(1 + \frac{s}{2} \right) + (1+s)^{\frac{3}{2}} \sqrt{\frac{2}{s}}\, \text{arctanh}\left(\sqrt{\frac{s}{2\,(1+s)}} \right) .$$

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No (non-perturbative) de Sitter solutions!

[Basile, AP. 2103.06276]

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Thank you!

Conclusions

- Proof of concept 1: **Testing swampland conjectures in other approaches to quantum gravity, e.g., AS**

- **Very clear recipe**:
  - Start from UV, integrate the RG flow down to the IR, identify **AS landscape**
  - Find **intersections** with the most commonly known Landscape, identified by swampland criteria

- **Results** (toy model, not full FRG computation, not all swampland criteria, electromagnetic duality assumed)
  - **Non-trivial intersection**
  - More refined computations needed

- Proof of concept 2: **Stringy FRGs and stringy alpha' corrections to all-order**

- **Combining the symmetries of string theory with the FRG, we derived cosmological stringy effective actions to all orders in alpha'**
  [minisuperspace, no string loops, but unfeasible using standard perturbative string theory]

- The resulting effective cosmological equations do not admit de Sitter solutions:
  Further evidence of the **no-de Sitter Swampland conjecture**