The predictive power of Asymptotically Safe Quantum Gravity: Can we test it?

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(UFF)

Witnessing Quantum Aspects of Gravity in a Lab
ICTP-SAIFR/Instituto Principia — September 2024

CNPq

Instituto de Física
Universidade Federal Fluminense

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Propaganda

BRINGING THE QUANTUM GRAVITY COMMUNITY TOGETHER

International Society for Quantum Gravity

http://isqg.org/

Members of the founding committee

Jan de Boer, Bianca Dittrich, Antonio D. Pereira, Astrid Eichhorn, Steve Giddings, Steffen Gielen, Stefano Liberati, Etera Livine, Dieter Lüst, Daniele Oriti, Kyriakos Papadodimas, Mairi Sakellariadou, Sumati Surya, Herman Verlinde

In this conference, we have seen lots of table-top experiments in order to probe the quantum nature of gravity. The laboratories (or devices) I will be considering in this talk are slightly bigger:

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LHC

Introduction

What do we actually know about the fundamental interactions?

3 + 1 interactions

gravitational - (General Relativity)

ElectroWeak + Strong

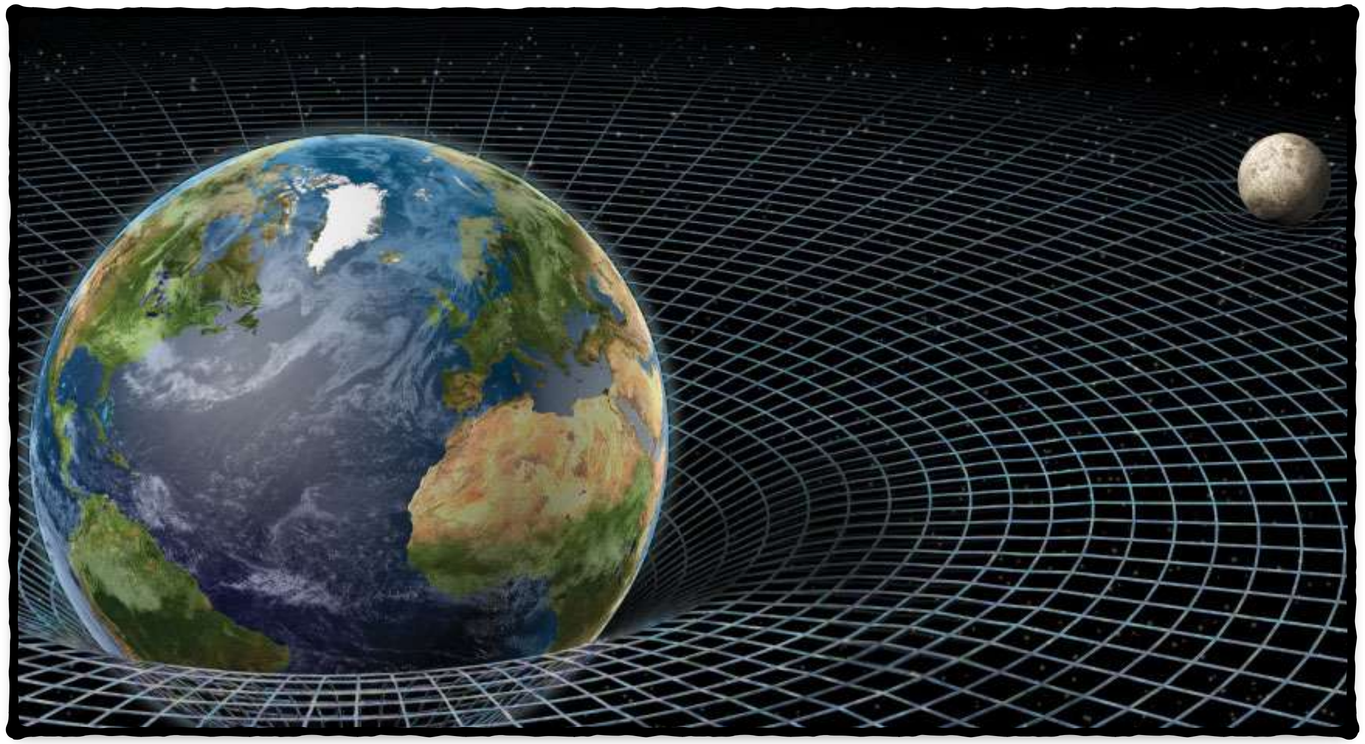
(Standard Model of Particle Physics)

Remarkable Theoretical Framework!

LHC, LIGO-VIRGO, EHT,…

General Relativity

Gravitational Interaction ⟷ Spacetime Geometry



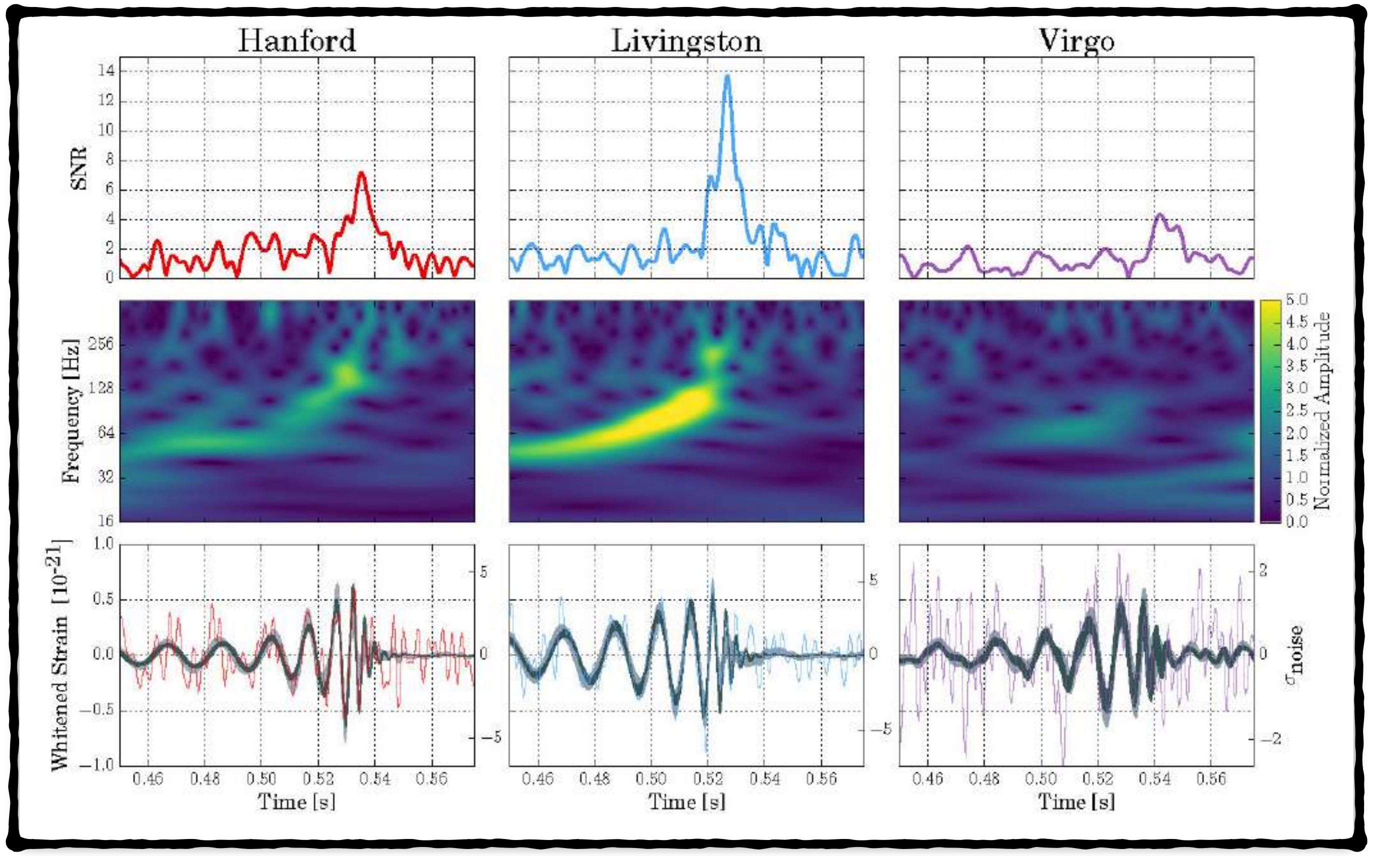
Energy&Matter deform spacetime geometry

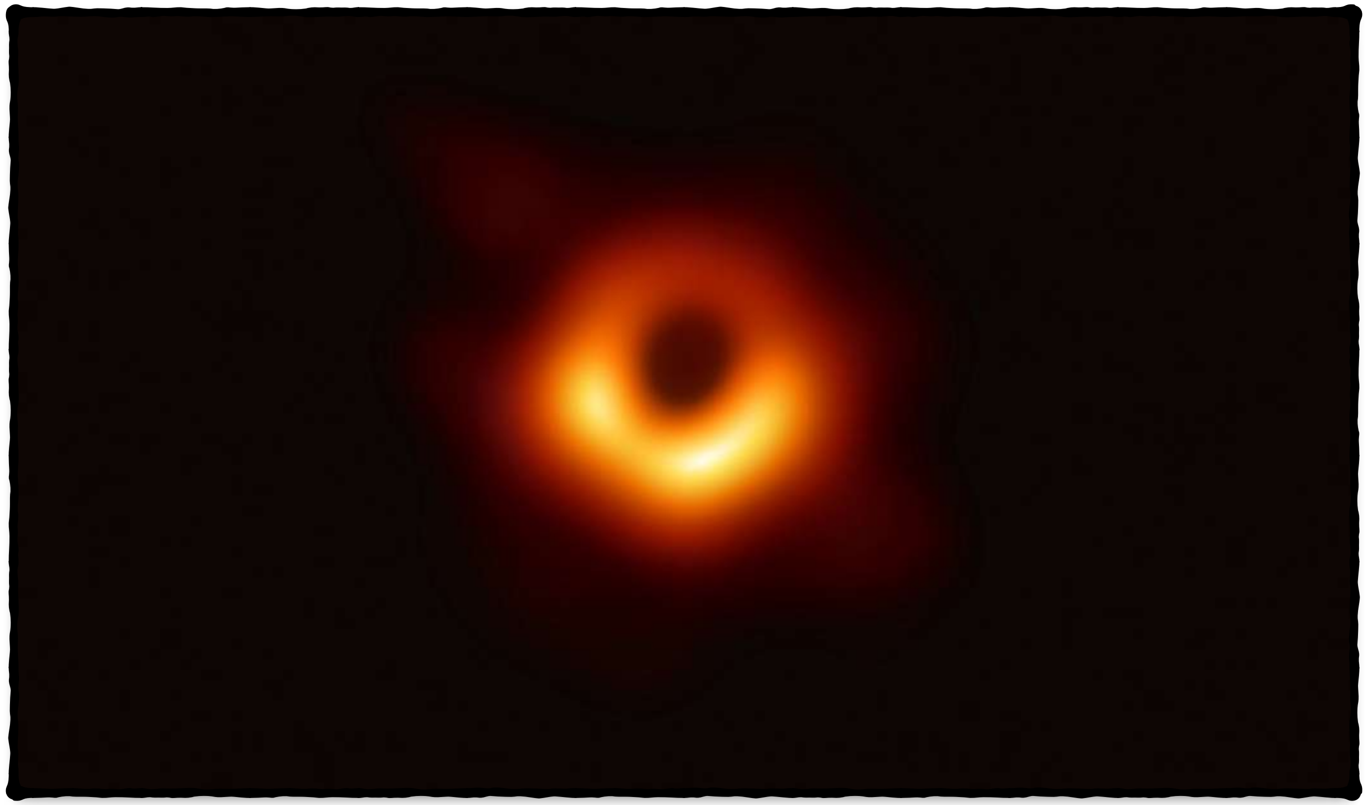
↓

GR predicts the existence of astonishing objects: Black Holes

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

Singularity at $r = 0$





We "see" black holes in the sky!

↓

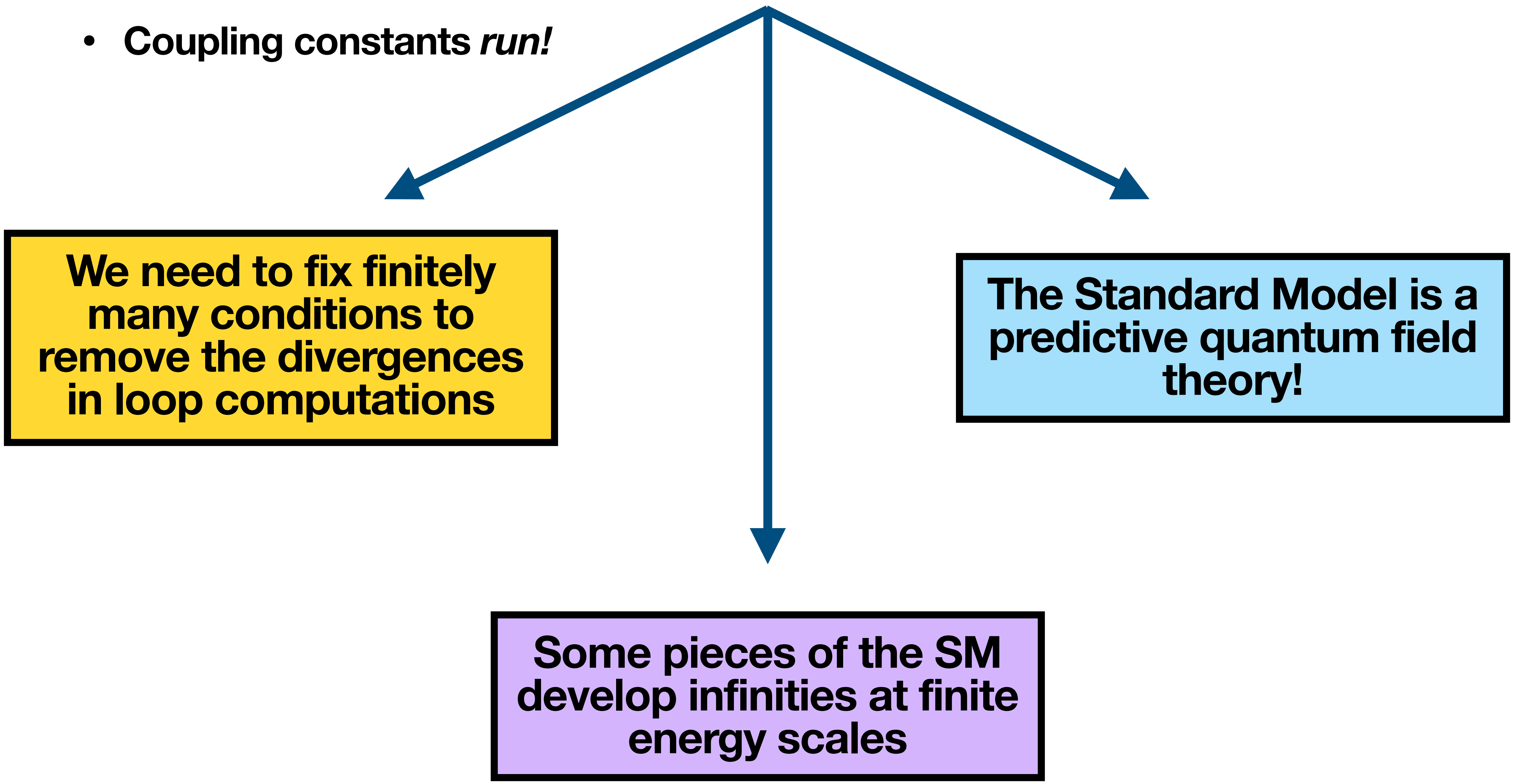
How to deal with the singularities?

↓

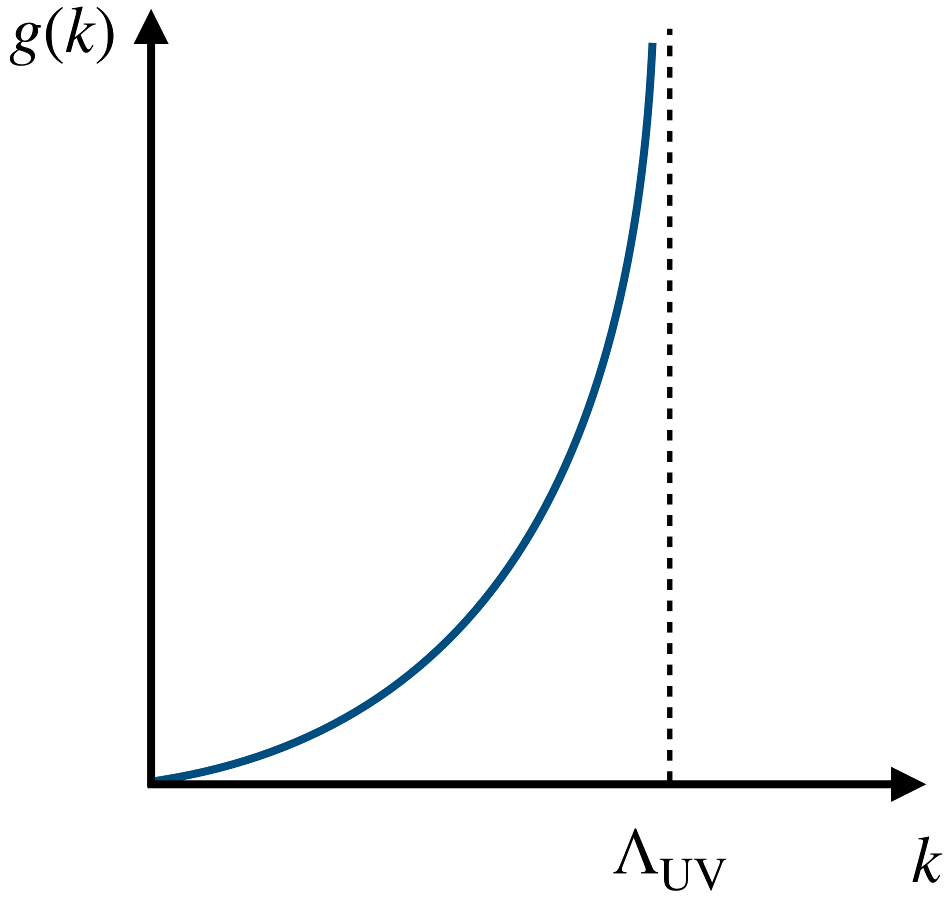
Initial singularity (*Big Bang*)?

Standard Model of Particle Physics

- It is a quantum field theory!
- Computations are typically divergent!
- However… the theory is perturbatively renormalizable!
- Coupling constants *run!*



Singularities in the SM as well…



Some couplings of the SM diverge at finite energy scales

↓

Landau Poles

↓

The SM also has its own singularities

Perturbative renormalizability is neither necessary nor sufficient to ensure that a QFT is valid across *all* energy scales

General Relavity & Standard Model

- Patches of our observed world
- Very successful descriptions but not complete
- There are known missing pieces (neutrino masses, dark universe,…)
- Structural problems: existence of singularities in both models

Quantum fields deform spacetime ⟷ Spacetime can also fluctuate quantum mechanically

(?)

- (Bold HOPE) Can the resulting theory of quantum gravity-matter resolve the singularities of GR and the SM?
- Immediate attempt: Implement a perturbative quantization of Gravity + SM

- The resulting theory is *perturbatively non-renormalizable!*

- This means that the theory requires infinitely many free parameters to absorb its divergences - *loss of predictivity*

Does it mean that there is an incompatibility between QFT and GR?

↓

NO!

Introduce a ultraviolet cutoff and do explicit (quantum) computations below the cutoff scale (as we do with the Standard Model!).

[See, e.g., works by Donoghue & Collaborators…]

Perturbatively non-renormalizable theories are perfectly valid descriptions up to some scale!

[see, e.g., talks by John Donoghue and Alessandro Codello]

We *do* have a theory of quantum gravity!

Brief Comment on Scales

One of the biggest challenges in quantum gravity is to detect direct effects arising from quantum spacetime fluctuations

$$\ell_p = \sqrt{\frac{\hbar G_N}{c^3}} \approx 10^{-35}\ m$$

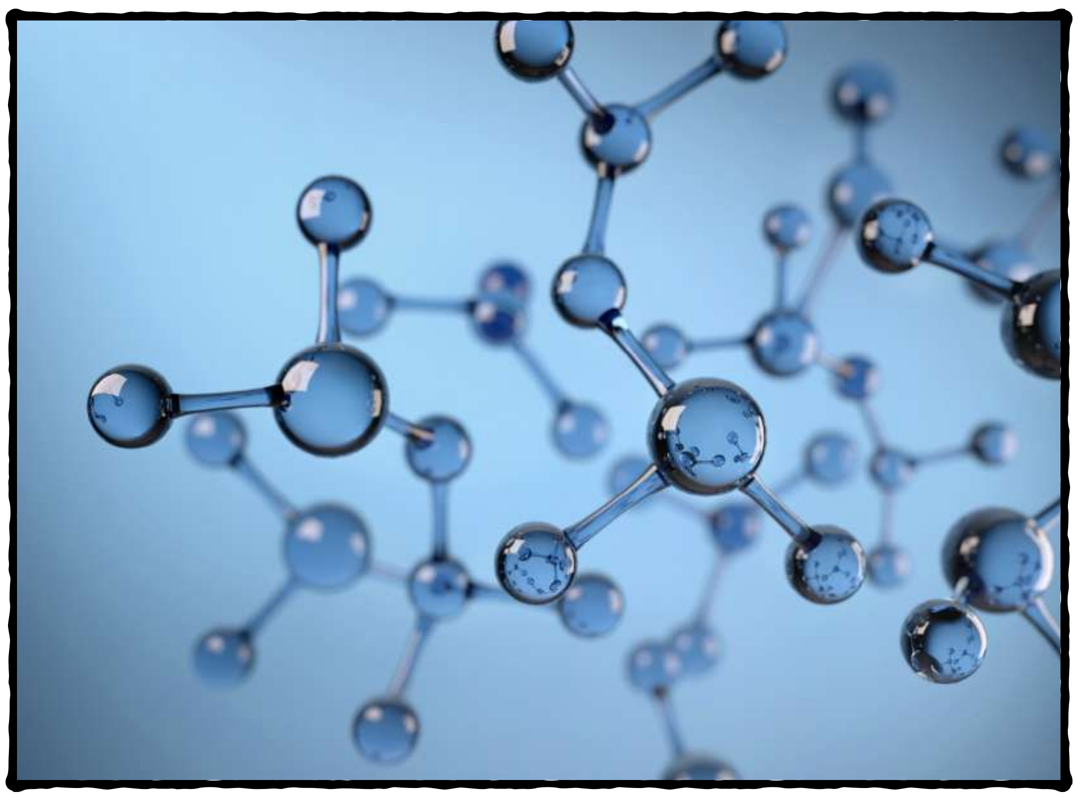
$$M_p \approx 10^{19}\ \mathrm{GeV}$$

$$E_{ew} \approx 10^{2}\ \mathrm{GeV}$$

- If we take seriously such dimensional analysis, quantum gravity effects take place at very (ridiculously) short distances or high energies.
- There is a huge gap between such a would-be quantum gravity scale and the most powerful colliders we have available at the moment (it varies from $10^{15} - 10^{17}$ orders of magnitude).
- Common lore: microscopic physics is completely washed out at large distances.

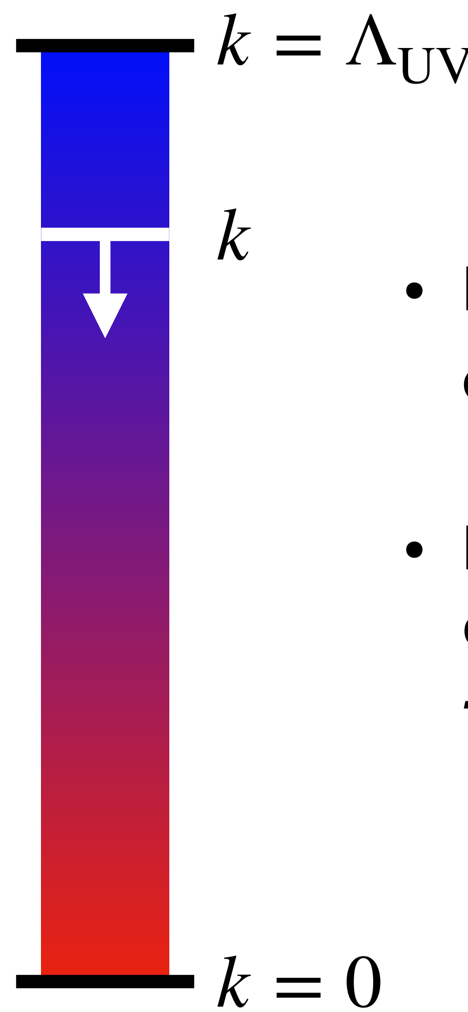
Is it meaningful to use Particle Physics knowledge to constrain quantum-gravity models?

Not *all* microscopic information is washed out: An instructive analogy



Bridging Scales

The mathematical tool that connects scales in quantum/statistical field theory is the renormalization group



- **Effective dynamics at scale k is encoded in the effective action S_k**
- **Lowering k establishes a sequence of effective actions and hence a *flow* - the *renormalization group flow***

Use the renormalization group as the bridge from quantum-gravity scales to Particle Physics - search for QG imprints

However…

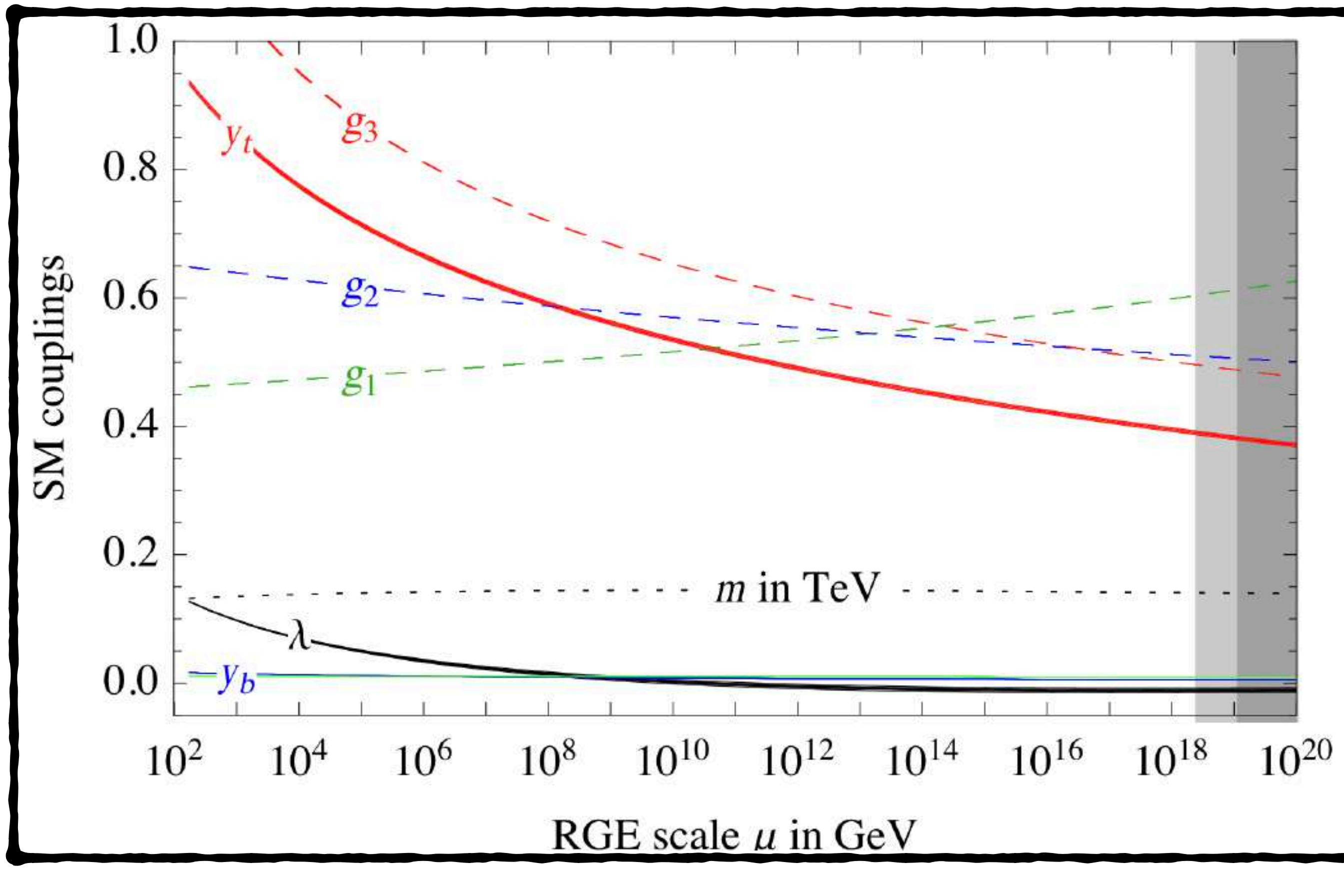
We would like to have a quantum gravity-matter theory that is valid across all energy scales

Effective Quantum Gravity is valid below the Planck scale

The Standard Model has its Landau poles at Transplanckian regimes

- **Aim: Construct a well-behaved theory of quantum gravity + matter at all energy scales**

- **Should we departure from standard field-theoretic methods in order to build up such a theory?**



[Buttazzo et al. 2013]

If such a *fundamental* quantum field theory of gravity + matter exists, how to test the quantum gravitational imprints using Particle Physics?

A Logical Possibility

The coupling constants of the full quantum field theory remain finite for arbitrarily large energy scales

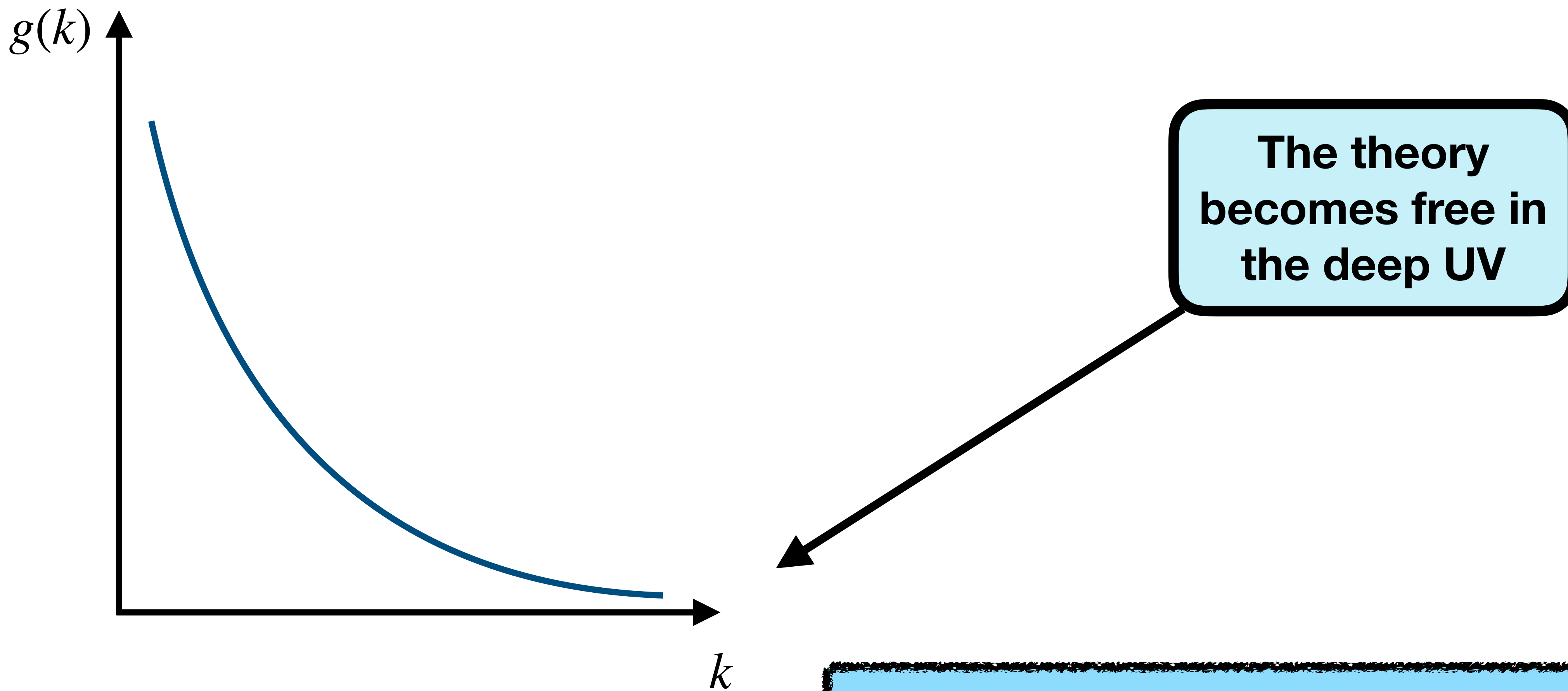
↓

This can be ensured by couplings reaching a renormalization group fixed point

At the RG fixed point, the theory becomes scale-invariant and a continuum limit can be *safely* taken

Paradigmatic example: QCD

Coupling runs to zero at arbitrarily large energy scales: Asymptotic Freedom



Perturbation theory is a good toolbox to probe such a fixed point

Paradigmatic example: QCD

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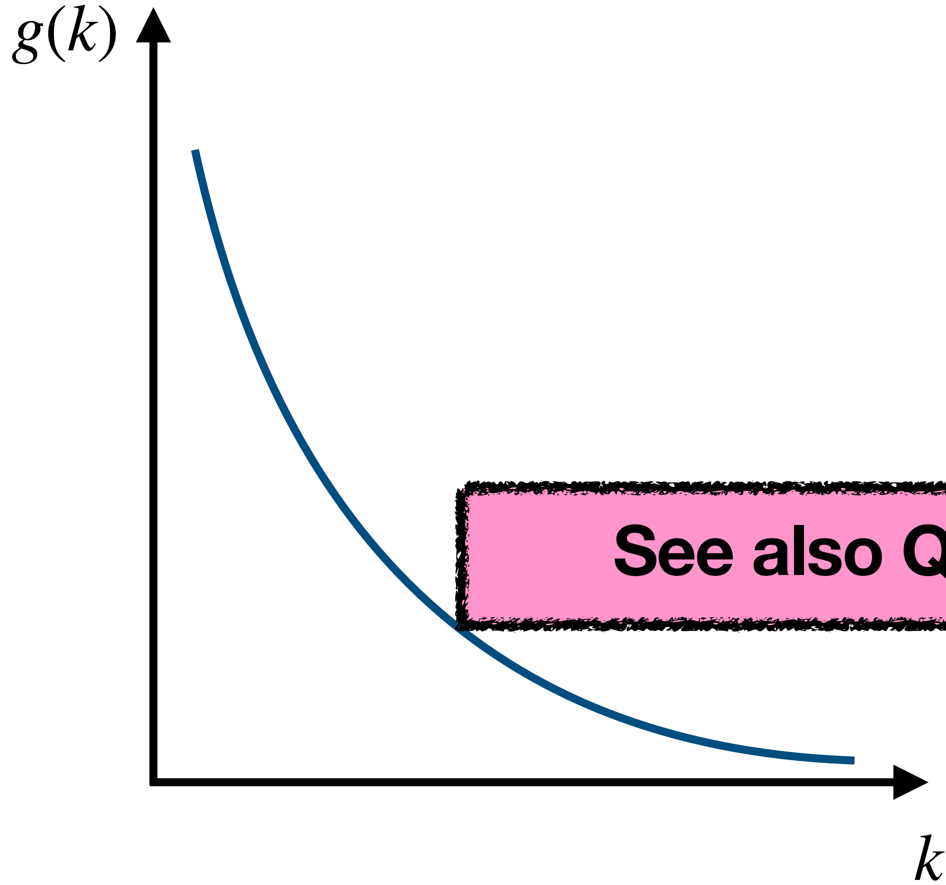


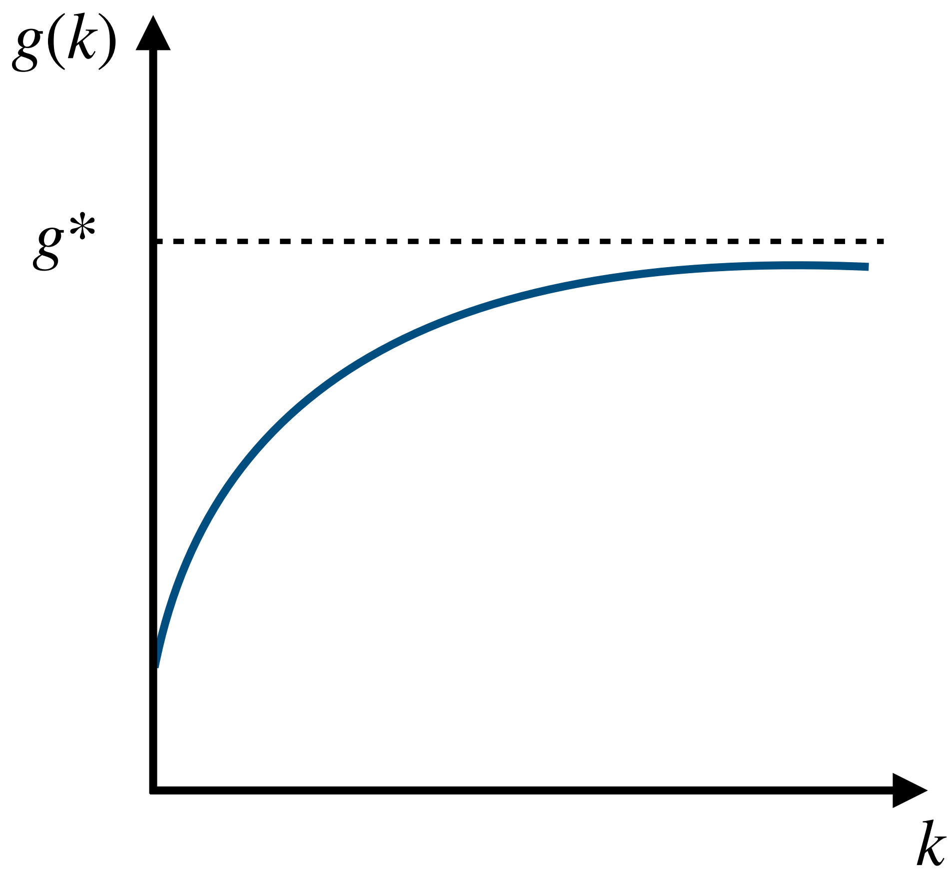
The theory becomes free in the deep UV

See also Quadratic Gravity!

Perturbation theory is a good toolbox to probe such a fixed point

Another possibility…

Coupling runs to finite value at arbitrarily large energy scales: Asymptotic Safety



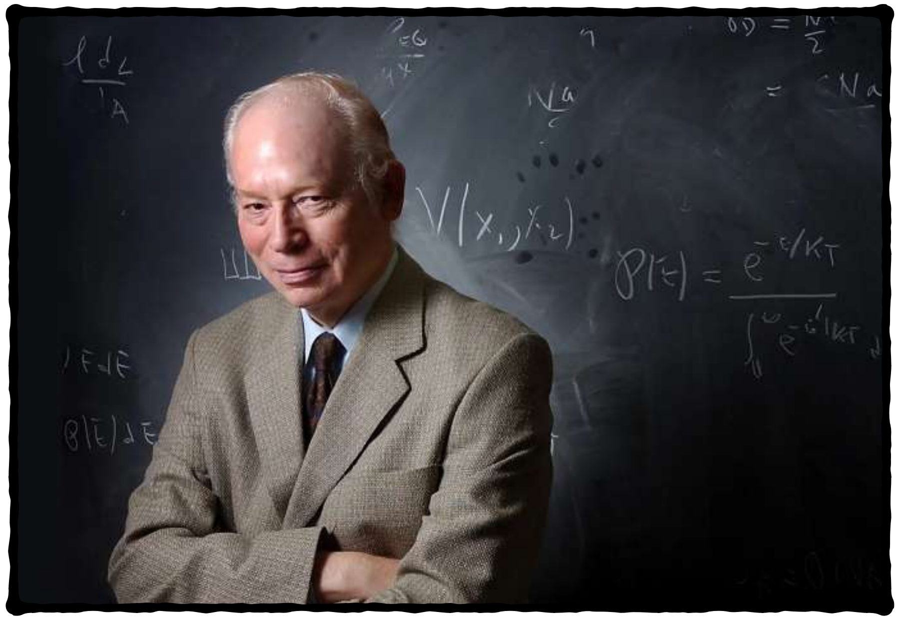
The theory remains interacting in the deep UV

Perturbation theory is NOT a good toolbox to probe such a fixed point

Could quantum gravity-matter system be asymptotically safe?

Weinberg

Go non-perturbative!



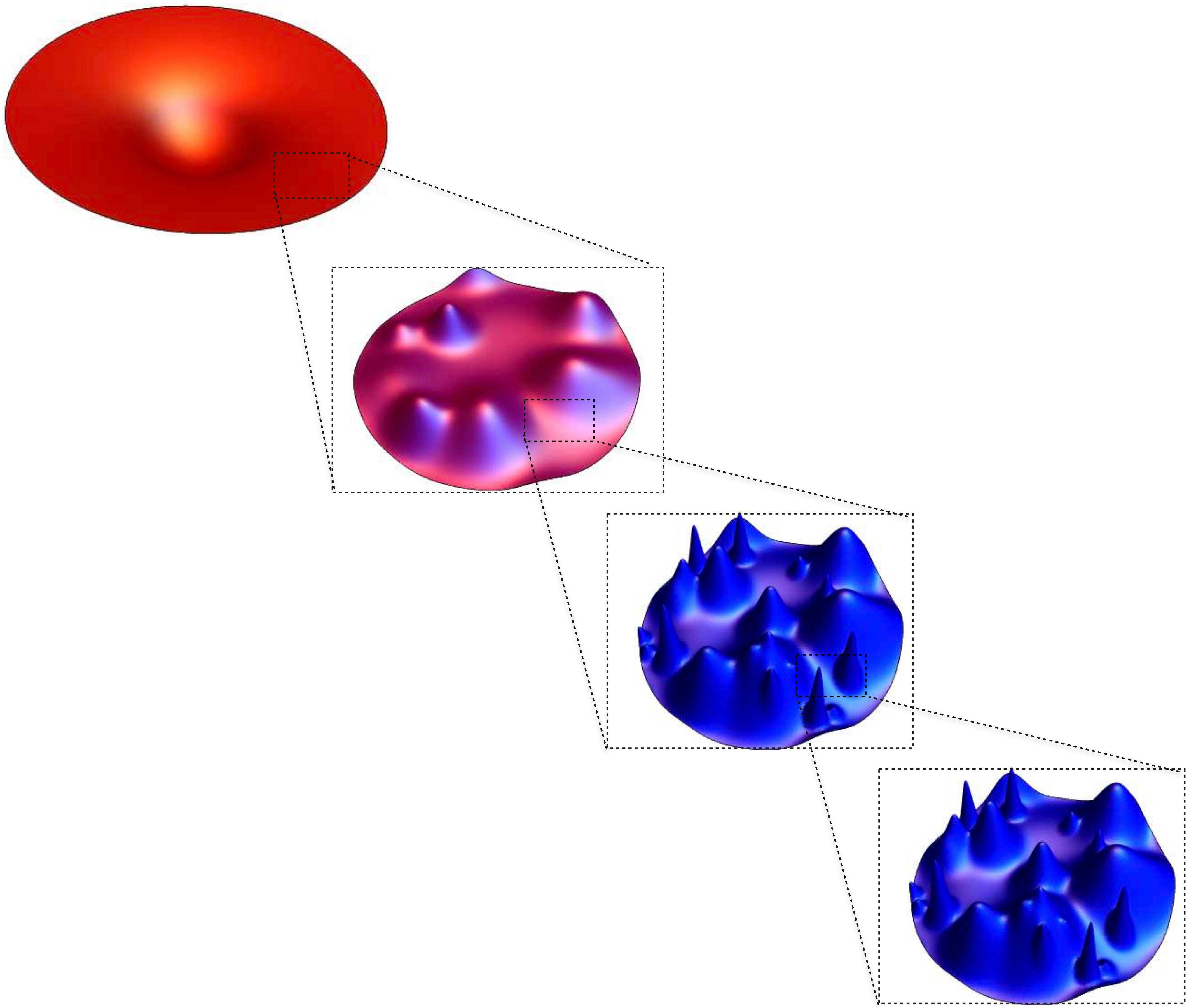
Steven Weinberg conjectured that Quantum Gravity could be an *asymptotically safe quantum field theory*

[“Ultraviolet divergences in quantum theories of gravitation” - S. Weinberg]
- *An Einstein centenary survey* edited by Israel and Hawking, 1979

“[…] this paper will be chiefly concerned with another possibility, that a quantum field theory which incorporates gravitation may satisfy a generalized version of the condition of renormalizability known as asymptotic safety.”

Asymptotic Safety Condition: the dimensionless counterparts of the *essential* couplings should reach a UV renormalization group fixed point

At the fixed point the couplings cease to run: *quantum scale invariance*



Different Strategies:

- Provide a lattice construction of quantum gravity-matter systems and perform Monte-Carlo simulations: Causal Dynamical Triangulations
- Use (semi-)analytical tools such matrix/tensor models in order to define a discretized path integral over geometries
- Look for a continuum limit!

- Use non-perturbative methods in the continuum to search for a non-trivial fixed point
- Functional Renormalization Group, Dyson-Schwinger equations, n-PI methods, ϵ-expansion,…
- Compute beta functions non-perturbatively

Most of the progress in Asymptotically Safe Quantum Gravity was achieved by the use of the FRG. This is by now called the Asymptotic Safety program for quantum gravity

Functional Renormalization Group

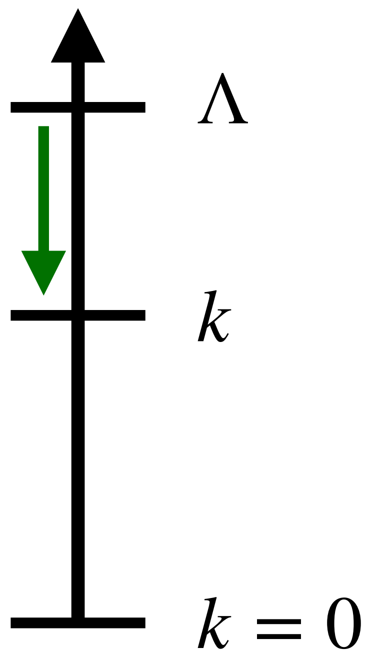
$$Z[J] = \int_\Lambda \mathscr{D}\phi \, \mathrm{e}^{-S[\phi] + \int \mathrm{d}^d x \, J(x)\phi(x)} \longrightarrow Z_k[J] = \int_\Lambda \mathscr{D}\phi \, \mathrm{e}^{-S[\phi] - \Delta S_k[\phi] + \int \mathrm{d}^d x \, J(x)\phi(x)}$$

Euclidean

regulator "action":

$$\Delta S_k = \frac{1}{2} \int \mathrm{d}^d x \, \phi(x) \, \mathscr{R}_k(-\partial^2) \phi(x)$$

gives a (large) mass to field modes with momentum lower than *k*



in flat space: Fourier modes

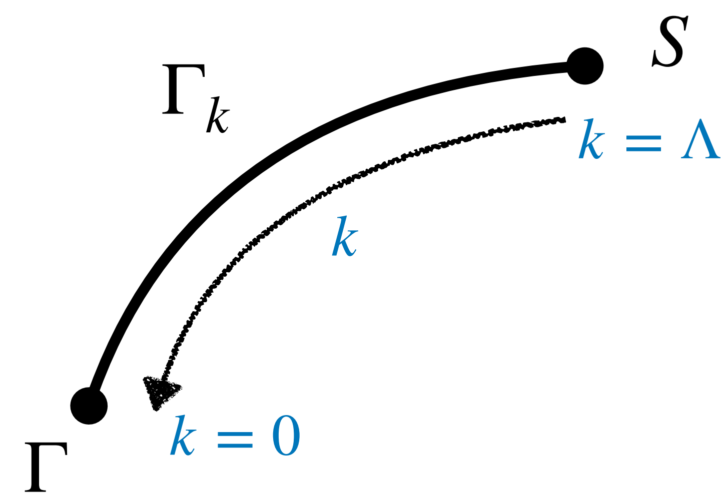
$$\phi(x) = \int_p \mathrm{e}^{ix\cdot p} \, \tilde{\phi}(p)$$

essentially

$$\mathscr{R}_k(p^2) \rightarrow \begin{cases} k^2 , & p^2 < k^2 \\ 0 , & p^2 > k^2 \end{cases}$$

Properties:

interpolates between full effective action and the “classical” one



satisfies an exact flow equation

$$\partial_t \Gamma_k = \frac{1}{2} \mathrm{STr} \left[\left(\Gamma_k^{(2)} + \mathscr{R}_k \right)^{-1} \partial_t \mathscr{R}_k \right]$$

$$\partial_t \equiv k \partial_k$$

(exact) flow equation - Wetterich equation

conversion of functional integral into functional differential equation

→

solving the flow equation

=

solving the functional integral

Theory Space

(Infinitely many)

Space of all (essential dimensionless couplings) functionals of the field which are compatible with the symmetries of the theory

the effective average action is expanded as $$\Gamma_k[\varphi] = \sum_i \bar{g}_i(k)\, \mathcal{O}_i[\varphi]$$

$$\partial_t \Gamma_k[\varphi] = \sum_i (\partial_t \bar{g}_i(k))\, \mathcal{O}_i[\varphi]$$

$$\bar{g}_i = k^{d_i} g_i$$

$$\partial_t \bar{g}_i = k^{d_i} (d_i\, g_i + \beta_i)$$

$$\beta_i = -\, d_i\, g_i + k^{-d_i} \partial_t \bar{g}_i$$

$$\partial_t \Gamma_k[\varphi] = \sum_i k^{d_i} (d_i\, g_i + \beta_i)\, \mathcal{O}_i[\varphi]$$

→ **extraction of beta functions**

suitable projection rule for the Wetterich equation

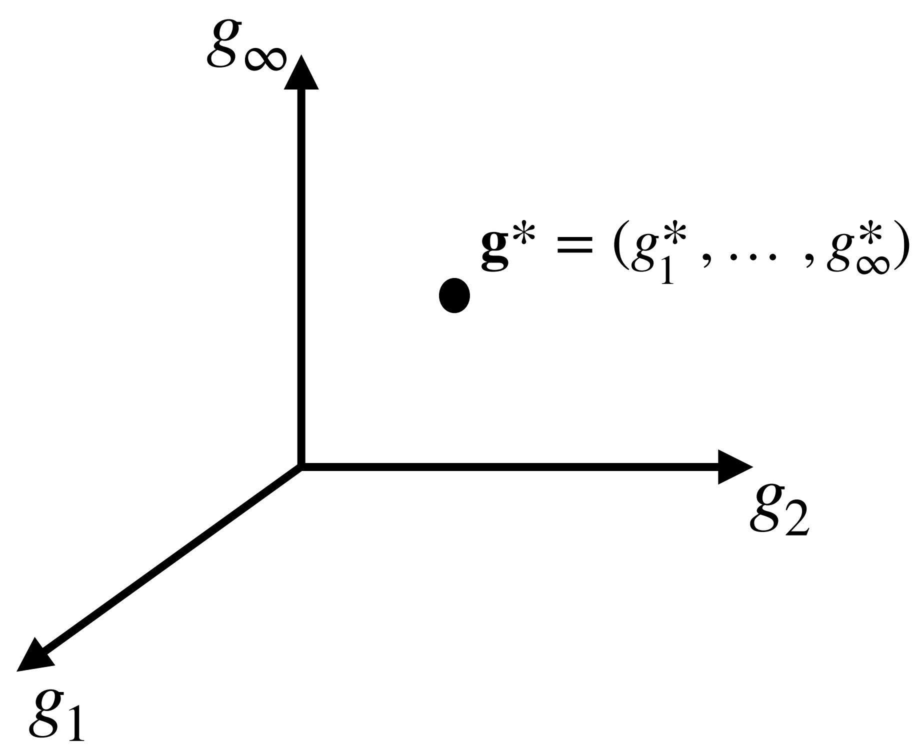
Approximations are necessary, but we don't need to use a perturbative scheme!

Looking for fixed points:

$$\beta_i(\mathbf{g}^*) = 0\,, \quad i = 1, \ldots, \infty$$

$$\mathbf{g}^* = (g_1^*, \ldots, g_\infty^*)$$

Theory Space



Linearized flow around the fixed point:

$$\partial_t (g_i - g_i^*) = \sum_j \frac{\partial \beta_i}{\partial g_j}(g_j - g_j^*)$$

diagonalize

$$\partial_t z_i = \lambda_i \, z_i$$

$$\downarrow$$

$$z_i(t) = C_i \left(\frac{k}{k_0}\right)^{-\theta_i}$$ **w/** $$\theta_i = -\lambda_i$$

In order to hit the fixed point:

$\theta_i < 0$ → z_i **grows towards de UV**

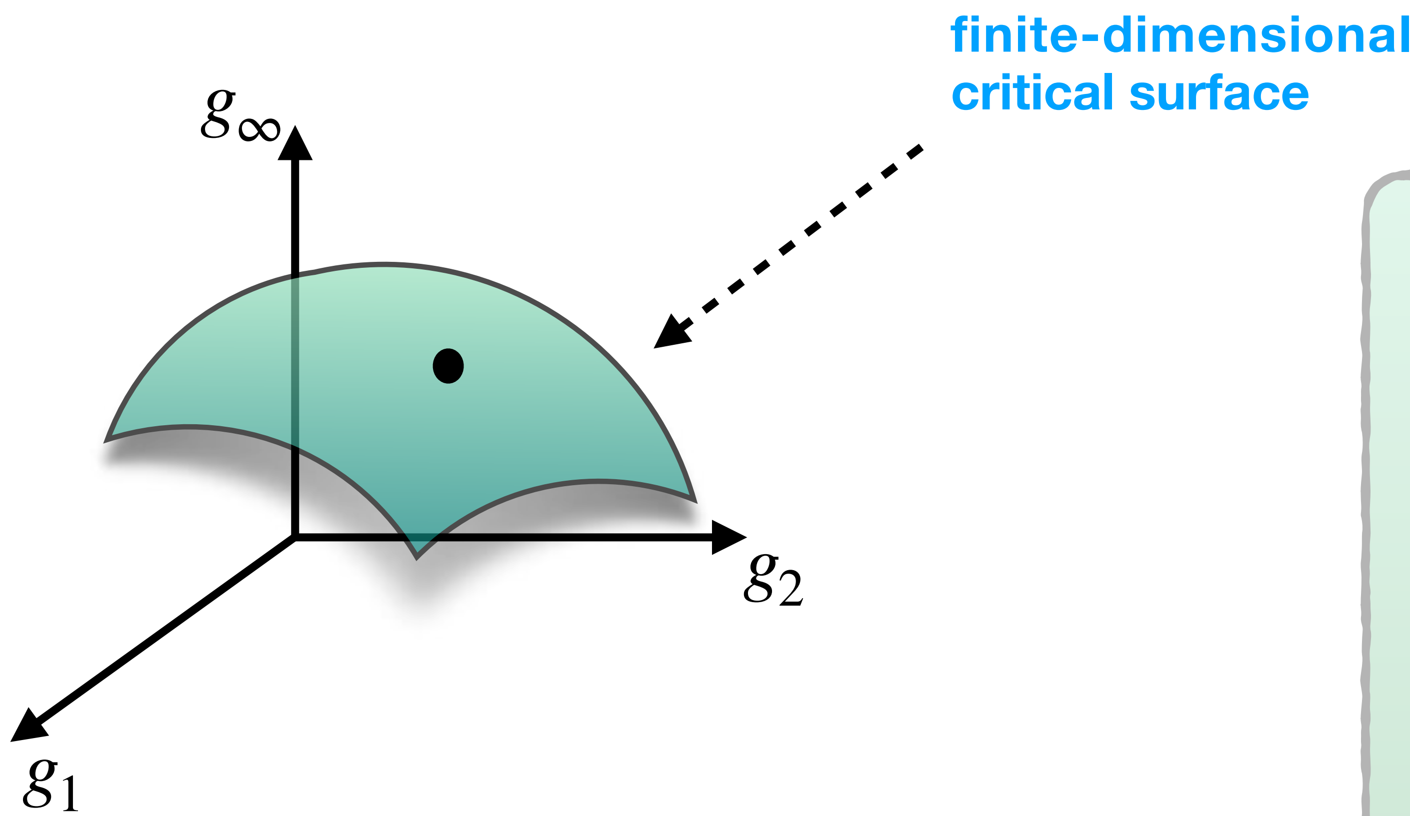
$C_i = 0$ **irrelevant direction**

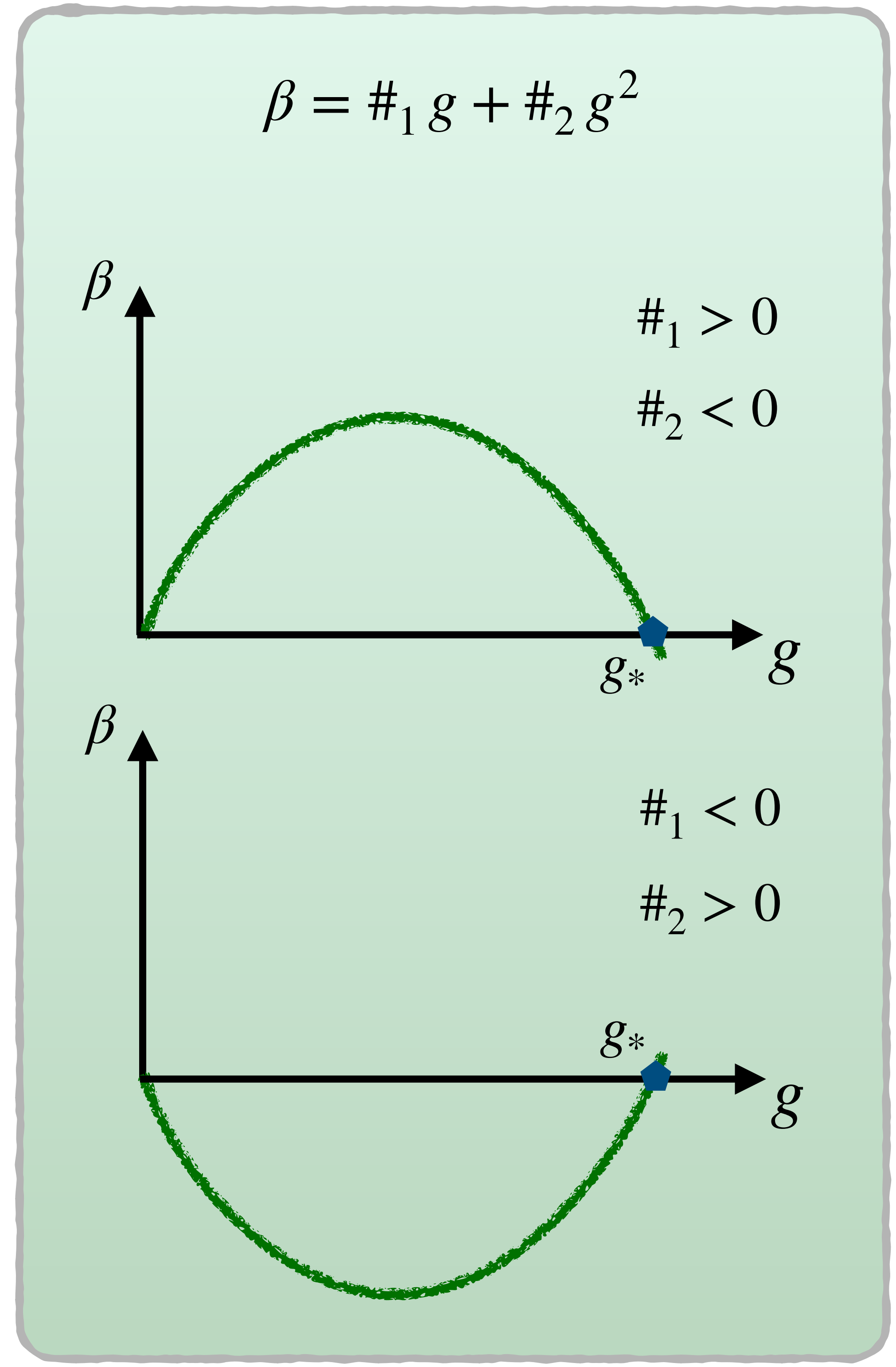
$\theta_i > 0$ → z_i **decreases towards de UV**

C_i **free parameter**

relevant direction

Predictivity requires that the number of relevant directions is finite





Asymptotic Safety:

Existence of a renormalization-group fixed point;

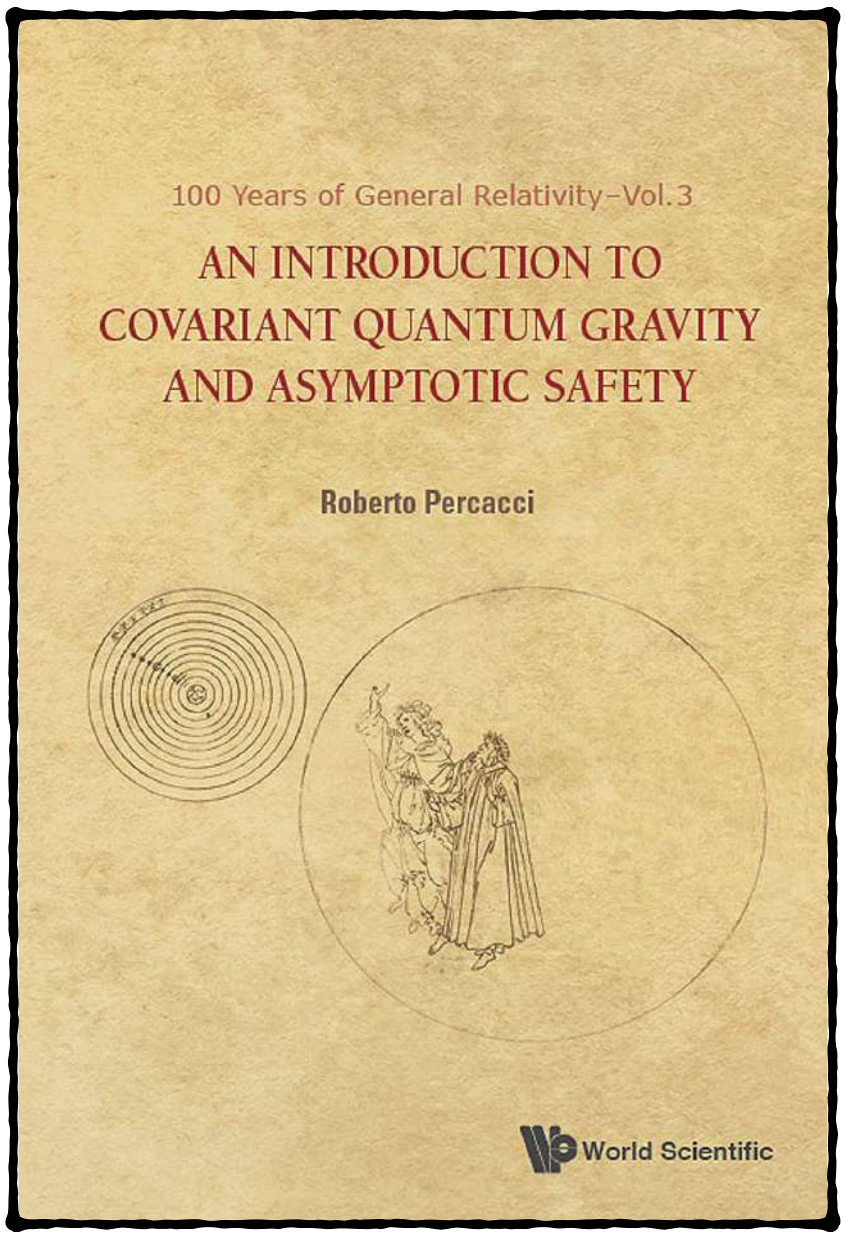
Fixed point features finitely many relevant directions;

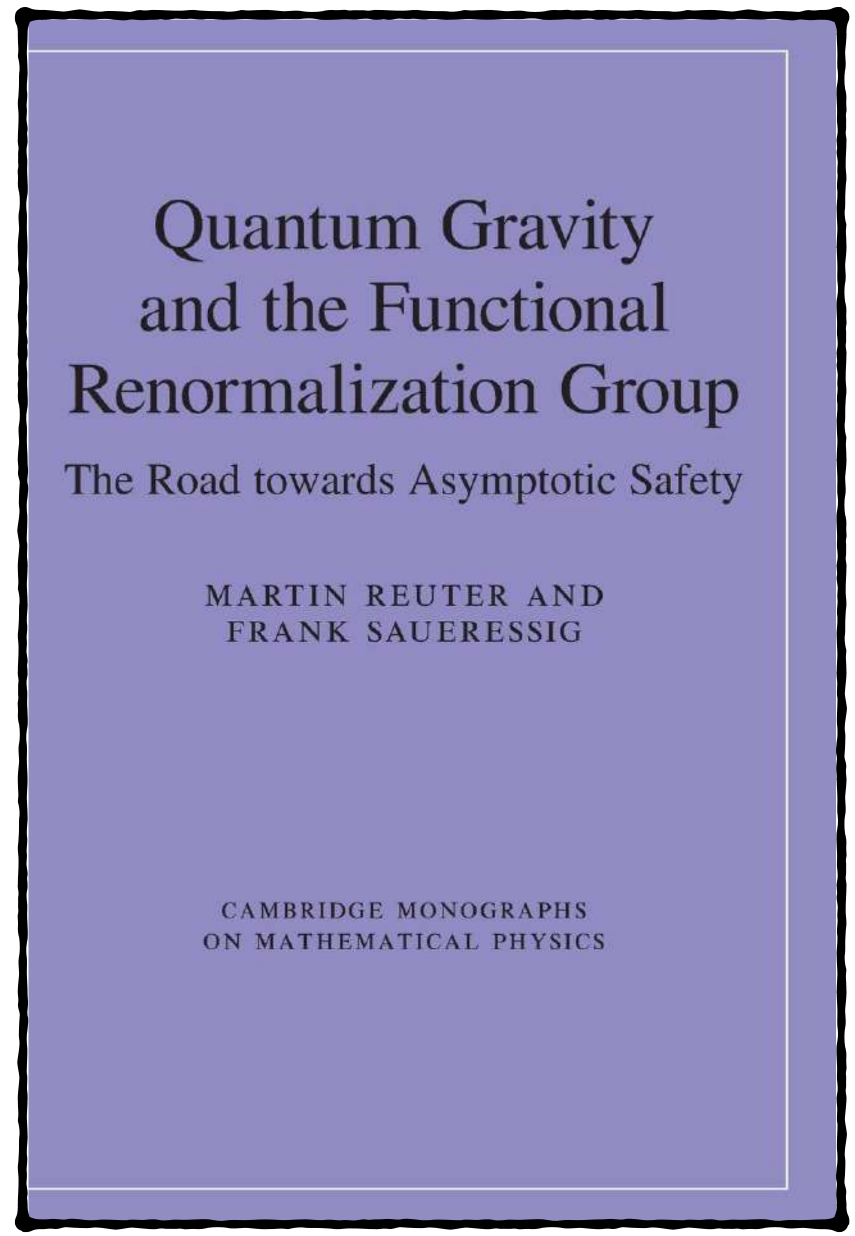
Asymptotically Safe Quantum Gravity

- the technical side -

Asymptotically Safe Quantum Gravity

- the technical side -





Asymptotically Safe Quantum Gravity

- the technical side -

But see also…

frontiers in Physics

ORIGINAL RESEARCH
published: 11 March 2020
doi: 10.3389/fphy.2020.00056

Check for updates

A Critique of the Asymptotic Safety Program

*John F. Donoghue**

Department of Physics, University of Massachusetts, Amherst, MA, United States

The present practice of Asymptotic Safety in gravity is in conflict with explicit calculations in low energy quantum gravity. This raises the question of whether the present practice meets the Weinberg condition for Asymptotic Safety. I argue, with examples, that the running of Λ and G found in Asymptotic Safety are not realized in the real world, with reasons which are relatively simple to understand. A comparison/contrast with quadratic gravity is also given, which suggests a few obstacles that must be overcome before the Lorentzian version of the theory is well behaved. I make a suggestion on how a Lorentzian version of Asymptotic Safety could potentially solve these problems.

Keywords: asymptotic safety, quantum gravity, effective field thoery, quadratic gravity, Lorentzian

Asymptotically Safe Quantum Gravity

- the technical side -

$$Z = \int \mathcal{D} g_{\mu\nu} \, \mathrm{e}^{-S[g_{\mu\nu}]}$$

Euclidean

No background to set a scale: *background field method*

$$g_{\mu\nu} = \bar{g}_{\mu\nu} + h_{\mu\nu}$$

The spectrum of the Laplacian of the background metric defines a scale

background independence is encoded in split symmetry

$$\bar{g}_{\mu\nu} \to \bar{g}_{\mu\nu} + \epsilon_{\mu\nu}$$
$$h_{\mu\nu} \to h_{\mu\nu} - \epsilon_{\mu\nu}$$

The gravitational action is invariant under general coordinate transformations: *gauge invariance*

→

Introduction of a gauge fixing term:

Faddeev-Popov procedure

$$Z_k[\mathcal{J}] = \int \mathcal{D}h_{\mu\nu}\mathcal{D}\bar{C}_\alpha \mathcal{D}C^\beta \, \mathrm{e}^{-S[\bar{g}+h]-S_{\mathrm{gf}}[\bar{g};h]-S_{\mathrm{gh}}[\bar{g};h,\bar{C},C]-\Delta S_k[\bar{\Phi};\Phi]+\int \mathrm{d}^d x\sqrt{\bar{g}}\,\mathcal{J}\cdot\Phi} \equiv \mathrm{e}^{W_k[\mathcal{J}]}$$

In complete analogy: construction of effective average action $\Gamma_k = \Gamma_k[\bar{\Phi};\Phi]$

$$\partial_t \Gamma_k[\bar{\Phi},\Phi] = \frac{1}{2}\mathrm{STr}\left[\left(\Gamma_k^{(0,2)}[\bar{\Phi},\Phi] + \mathbb{R}_k\right)^{-1}\partial_t \mathbb{R}_k\right]$$

The effective average action is a functional of two fields;

Integrating the flow and taking *k=0* leads to an effective action that depends on two fields, but background independence is guaranteed by BRST symmetry;

arXiv:2305.17453 (gr-qc)

[Submitted on 23 May 2023]

Nonperturbative Aspects of Quantum Field Theory in Curved Spacetime

Níckolas de Aguiar Alves

Pedagogical derivation of the flow equation for generic field content

...e action is a functional of two fields;

Integrati... 0 leads to an effective action that depends on two fie... endence is guaranteed by BRST symmetry;

Φ]

Choices…

Our starting point was a path integral over Riemannian metrics

However…

$h_{\mu\nu}$ can fluctuate widely

$$g_{\mu\nu} = \bar{g}_{\mu\nu} + h_{\mu\nu}$$

metric can be degenerate

metric can change signature

Such a linear split of the metric might introduce many spurious configurations in the non-perturbative realm!

Alternative: $g_{\mu\nu} = \bar{g}_{\mu\alpha}\left(\mathrm{e}^{\bar{g}^{-1}h}\right)^{\alpha}{}_{\nu}$ → avoid the previous problems + cover the space of Riemannian metrics

In the path integral, should we adopt different variables that lead to the same field equations in the case of GR?

Palatini $(g_{\mu\nu}, \Gamma^{\alpha}_{\beta\sigma})$ or pure e^{a}_{μ} or $(e^{a}_{\mu}, \omega^{bc}_{\nu})$

No *a priori* reason to choose one formulation instead of the other

En route to the Reuter fixed point

With the FRG equation, we are ready to compute the beta functions beyond perturbative schemes and look for fixed points

Practical Strategy

- **Choose an ansatz for the effective average action**
- **Compute the beta functions of the couplings present in the chosen truncation**
- **Look for suitable fixed-point solutions**
- **Enlarge the truncation following some ordering principle**
- **Investigate a possible (apparent) onset of stability of the results**

Einstein-Hilbert Truncation

$$\Gamma_k = \frac{1}{8\pi G_k}\int \mathrm{d}^d x\sqrt{g}\,\left(2\Lambda_k - R\right) + \mathrm{gauge-fixing\ sector}$$

In $d = 4$, a suitable fixed point for the dimensionless Newton constant and cosmological constant is found: $g_k = k^2 G_k$ and $\lambda_k = k^{-2}\Lambda_k$.

The fixed point has two relevant directions.

[Reuter, Saueressig 02]

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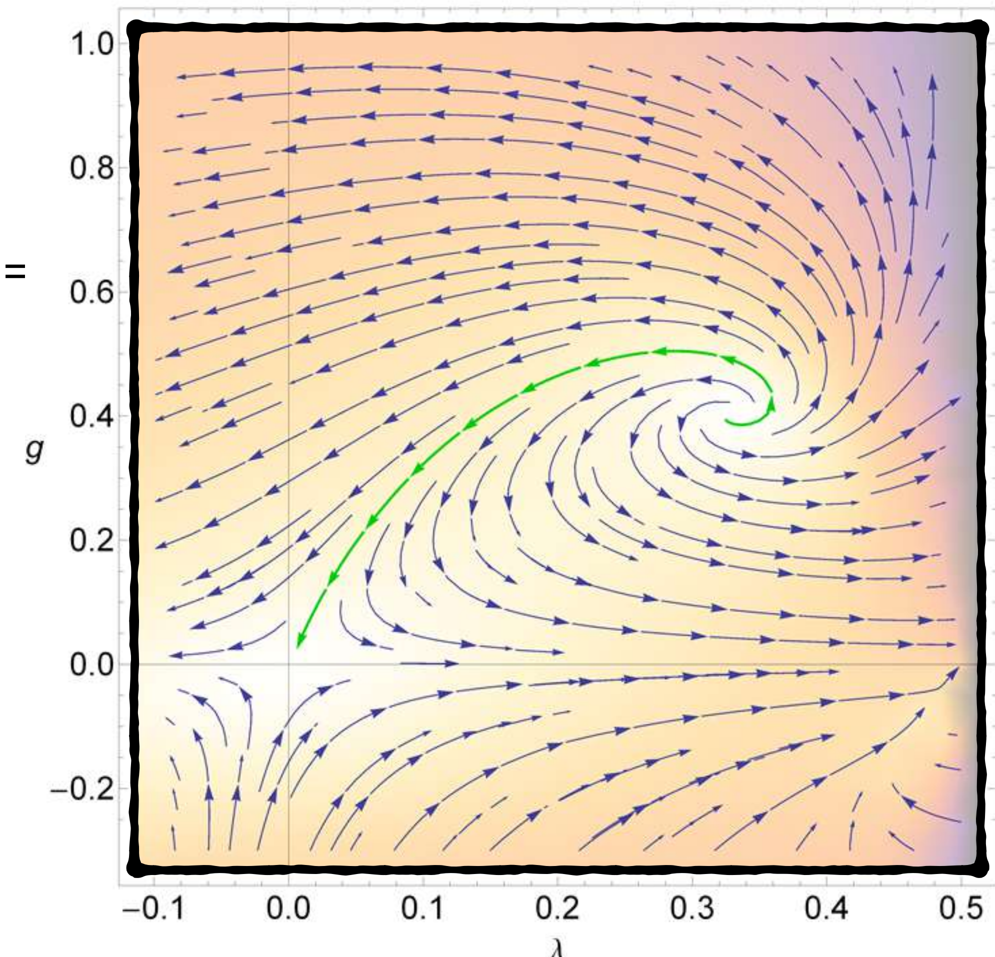
$\Gamma_k =$



tor

[Reuter, Saueressig 02]

Enlarging the truncation

$$\mathbf{1}$$

$$\sqrt{g}R$$

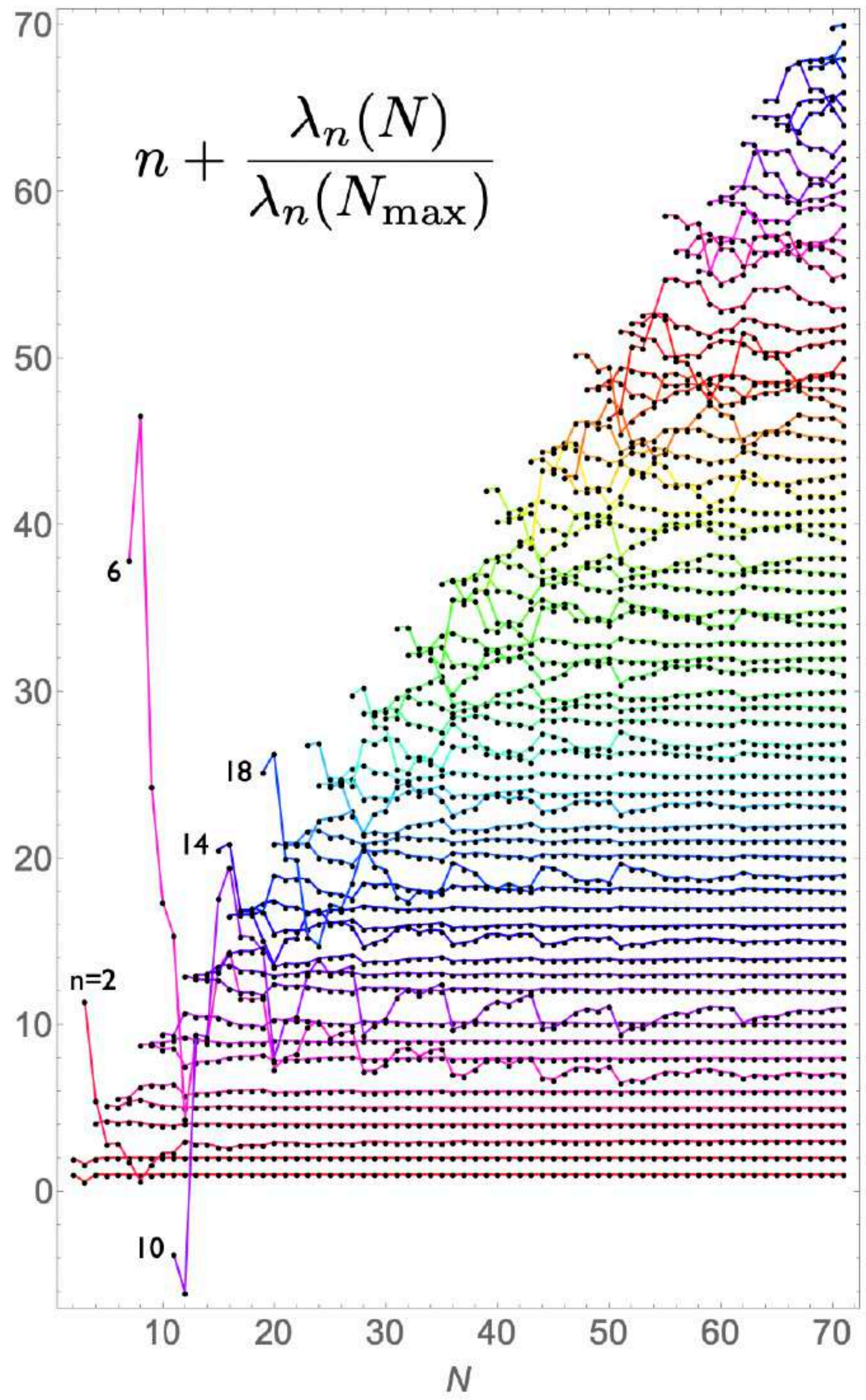
$$\sqrt{g}R^2 \qquad \sqrt{g}R_{\mu\nu}R^{\mu\nu} \qquad \sqrt{g}R_{\mu\nu}\, F_{\mathbf{Ric}}(\Delta)\, R^{\mu\nu} \qquad \sqrt{g}R\, F_{\mathbf{R}}(\Delta)\, R \qquad \cdots$$

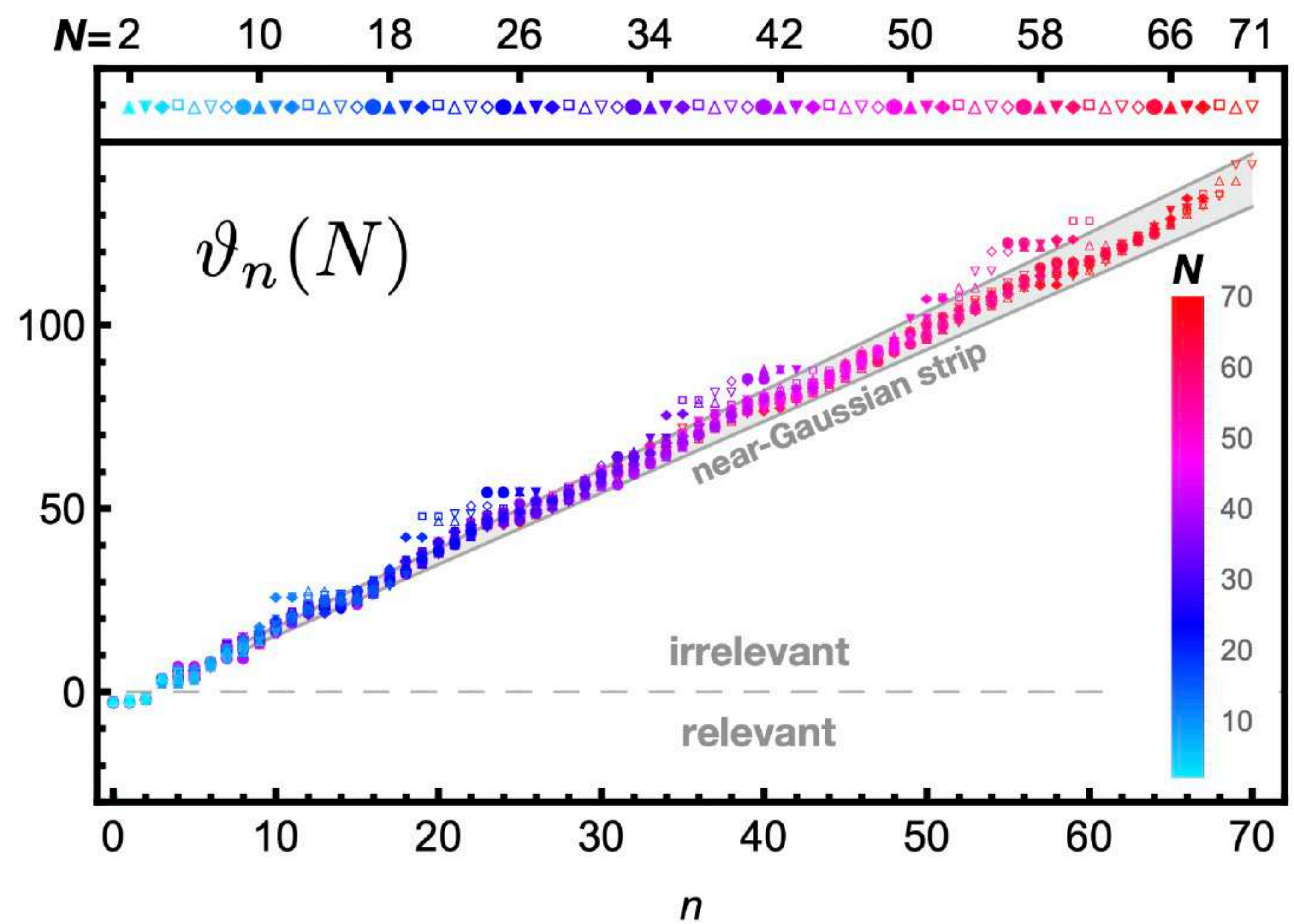
$$\sqrt{g}R^3 \qquad \sqrt{g}RR_{\mu\nu}R^{\mu\nu} \qquad \cdots$$

$$\vdots \qquad \vdots \qquad \ddots$$

By now, many different directions of the theory space have been explored. A suitable fixed point with rather stable properties persists against truncations enlargement.

Example: truncation of the $f(R)$ form [Falls, Litim, Schroeder 19]





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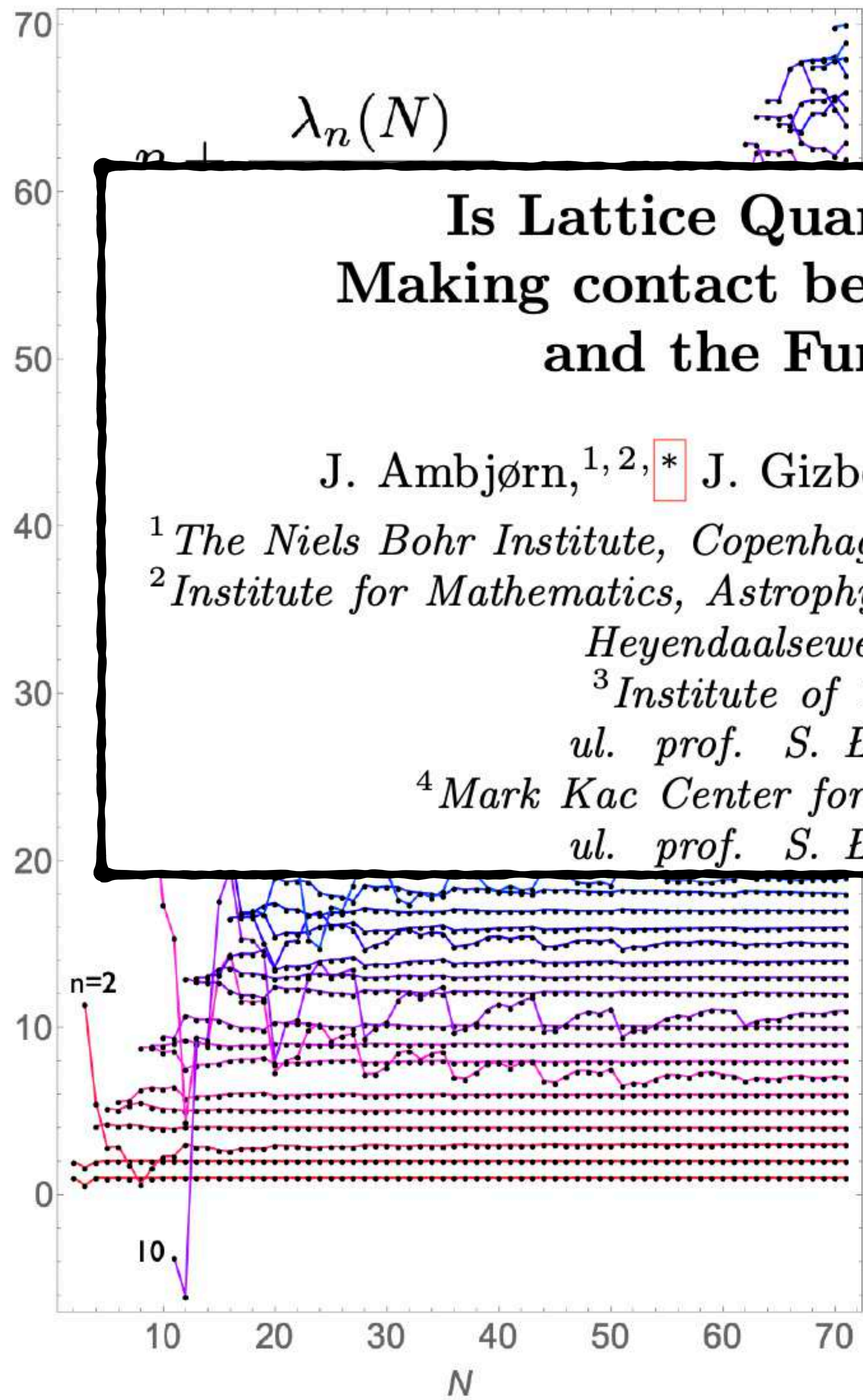

Is Lattice Quantum Gravity Asymptotically Safe ?
Making contact between Causal Dynamical Triangulations
and the Functional Renormalization Group.

[arXiv:2408.07808]

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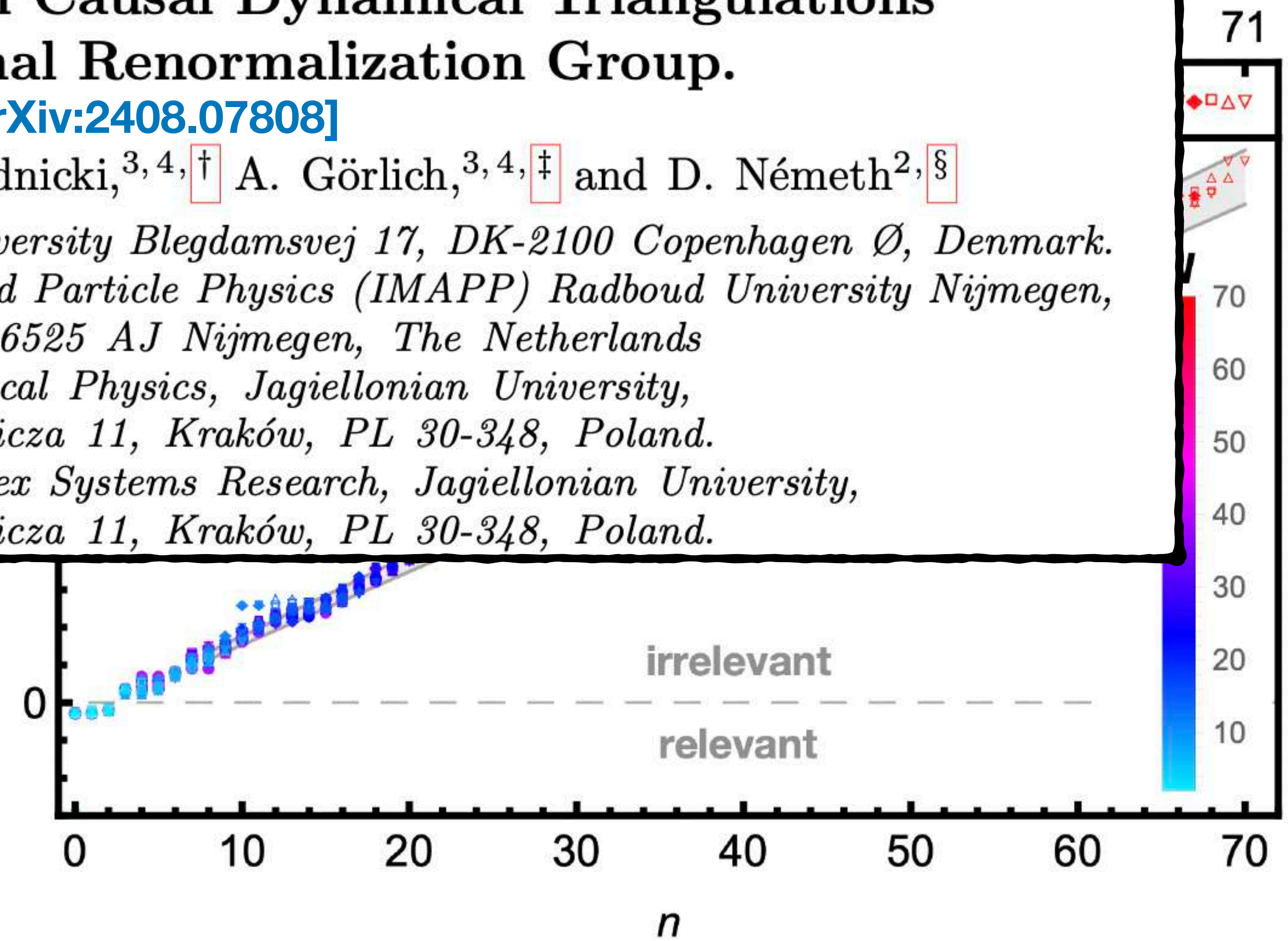


Towards phenomenology

In order to extract the effects of quantum-gravity fluctuations, one has to solve the “fully quantum equations of motion”

Interplay between Quantum gravity and Particle Physics

→ Quite active research topic in the field

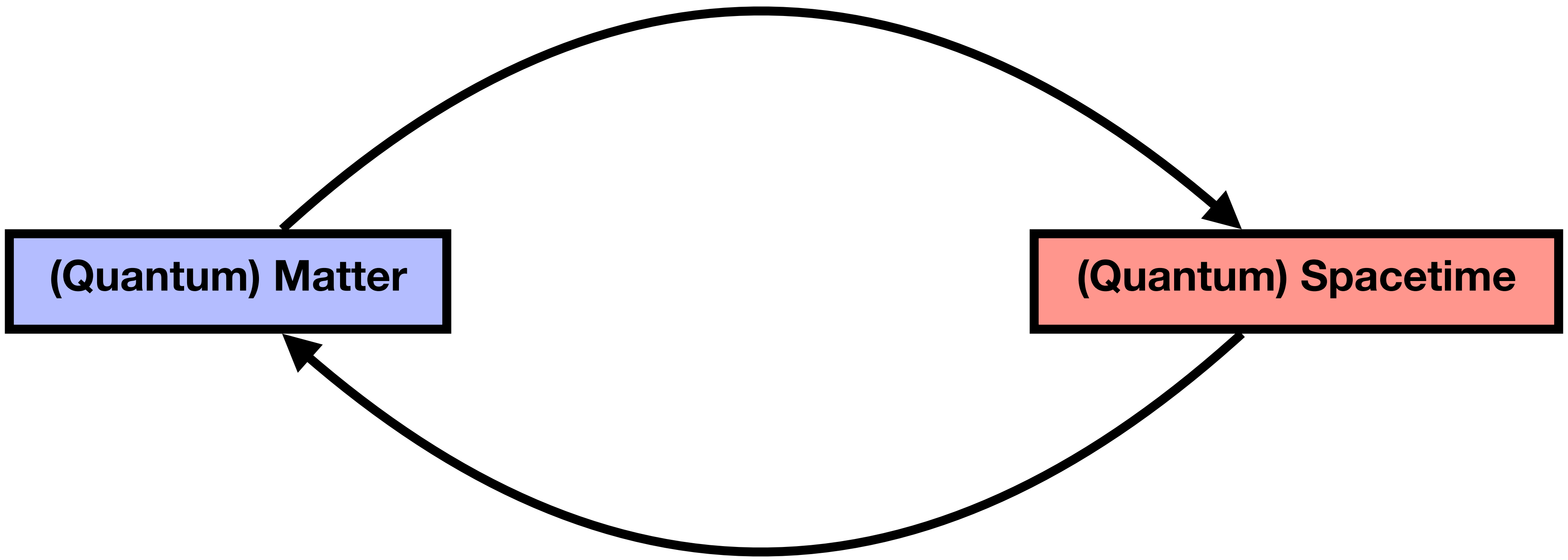
Cosmology and black holes

→ A first-principle analysis requires a well controlled knowledge of the effective action

→ **Classical cosmological and BH solutions are RG-improved**

Gravity-matter systems

[“Matter matters program”: Dona, Eichhorn, Percacci ‘14]



The gravitational fixed point should be consistent with matter coupling

Gravity-matter systems

[G. P. de Brito, *ADP*, A. F. Vieira '20]

Matter-fluctuations impact the running of gravitational couplings

Proof of principle example:

$$\Gamma_k = \Gamma_k^{\mathrm{grav}} + \Gamma_k^{\mathrm{matter}} + \Gamma_k^{\mathrm{gf}}$$

$$\Gamma_k^{\mathrm{grav}} = \frac{1}{16\pi G_{\mathrm{N},k}} \int \mathrm{d}^d x \sqrt{g}\, f_k(R, R_{\mu\nu}^2)$$

$$\Gamma_k^{\mathrm{matter}} = \frac{1}{2}\sum_{i=1}^{N_\phi} \int \mathrm{d}^d x \sqrt{g}\, g^{\mu\nu}\partial_\mu\phi_i\partial_\nu\phi_i + \sum_{i=1}^{N_\psi} \int \mathrm{d}^d x \sqrt{g}\, i\bar{\psi}_i \gamma^\mu \nabla_\mu \psi_i + \frac{1}{4}\sum_{i=1}^{N_A} \int \mathrm{d}^d x \sqrt{g}\, g^{\mu\alpha} g^{\nu\beta} F_{i,\mu\nu} F_{i,\alpha\beta}$$

Gravity-matter systems

[G. P. de Brito, ADP, A. F. Vieira '20]

Matter-fluctuations impact the running of gravitational couplings

Proof of principle example:

$$\ldots + \Gamma_k^{\text{matter}} + \Gamma_k^{\text{gf}}$$

$$\int \mathrm{d}^d x \sqrt{g}\, f_k(R, R_{\mu\nu}^2)$$

Faculty member at UNESP - Guaratinguetá

$$\Gamma_k^{\text{matter}} = \frac{1}{2}\sum_{i=1}^{N_\phi}\int \mathrm{d}^d x\sqrt{g}\, g^{\mu\nu}\partial_\mu\phi_i\partial_\nu\phi_i + \sum_{i=1}^{N_\psi}\int \mathrm{d}^d x\sqrt{g}\, i\bar{\psi}_i\gamma^\mu\nabla_\mu\psi_i + \frac{1}{4}\sum_{i=1}^{N_A}\int \mathrm{d}^d x\sqrt{g}\, g^{\mu\alpha}g^{\nu\beta}F_{i,\mu\nu}F_{i,\alpha\beta}$$

Gravity-matter systems

[G. P. de Brito, *ADP*, A. F. Vieira '20]

Stability of NGFP for some specific matter models							
Model	Matter content			Type I		Type II	
	N_ϕ	N_A	N_ψ	$f(R)$	$F(R^2_{\mu\nu}) + RZ(R^2_{\mu\nu})$	$f(R)$	$F(R^2_{\mu\nu}) + RZ(R^2_{\mu\nu})$
SM	4	12	45/2	✓(2)	✓(2)	✓(2)	✓(2)
SM + $3\nu_R$	4	12	24	✓(2)	✓(3)	✓(2)	✓(2)
MSSM	49	12	61/2	✖	✖	✖	✖
SU(5) GUT	124	24	24	✖	✖	✖	✖
SO(10) GUT	97	45	24	✓*(2)	✓*(3)	✓*(2)	✓*(2)

Matter content seems to matter!

Detection of matter fields that are incompatible with the fixed-point structure would correspond to inconsistency with the Asymptotic Safety scenario

Gravity-matter systems

- Quantum-gravity fluctuations can impact the running of matter couplings
- In the Standard Model: Abelian hypercharge and Higgs-Yukawa sectors feature a Landau pole
- Can quantum-gravity fluctuations "cure" such singularities?

- Consider a matter coupling g_i. In general, quantum-gravity contributions to the beta functions take the following form:

$$\beta_{g_i}|_{\text{grav}} = -f_{g_i} g_i + \ldots$$

- The function f_{g_i} is a function of the gravitational couplings

- The sign of f_{g_i} determines if the corresponding coupling features a fixed point (free or non-trivial) & its (ir)relevance

Gravity-matter systems

- Choose a symmetry group and define the operators compatible with such symmetries in the gravitational sector (within truncations)
- Choose the matter action (within truncations)
- Compute explicitly the values of f_{g_i}

- Suitable values of f_{g_i} can render a UV complete theory of gravity + matter
- This is not (necessarily) a unified theory in the grand unification sense
- Marginal couplings that are pushed towards irrelevance due to quantum gravitational contributions become predictions

Gravity-matter systems

Some exciting results were obtained in the Asymptotic Safety literature over the past two decades:

Prediction of the Higgs mass:

Asymptotic safety of gravity and the Higgs boson mass

Mikhail Shaposhnikov[a,*], Christof Wetterich[b]

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A B S T R A C T

There are indications that gravity is asymptotically safe. The Standard Model (SM) plus gravity could be valid up to arbitrarily high energies. Supposing that this is indeed the case and assuming that there are no intermediate energy scales between the Fermi and Planck scales we address the question of whether the mass of the Higgs boson m_H can be predicted. For a positive gravity induced anomalous dimension $A_\lambda > 0$ the running of the quartic scalar self-interaction λ at scales beyond the Planck mass is determined by a fixed point at zero. This results in $m_H = m_{\min} = 126$ GeV, with only a few GeV uncertainty. This prediction is independent of the details of the short distance running and holds for a wide class of extensions of the SM as well. For $A_\lambda < 0$ one finds m_H in the interval $m_{\min} < m_H < m_{\max} \simeq 174$ GeV, now sensitive to A_λ and other properties of the short distance running. The case $A_\lambda > 0$ is favored by explicit computations existing in the literature.

Gravity-matter systems

Some exciting results were obtained in the Asymptotic Safety literature over the past two decades:

Retrodiction of top mass:

Top mass from asymptotic safety

Astrid Eichhorn *, Aaron Held *

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ABSTRACT

We discover that asymptotically safe quantum gravity could predict the top-quark mass. For a broad range of microscopic gravitational couplings, quantum gravity could provide an ultraviolet completion for the Standard Model by triggering asymptotic freedom in the gauge couplings and bottom Yukawa and asymptotic safety in the top-Yukawa and Higgs-quartic coupling. We find that in a part of this range, a difference of the top and bottom mass of approximately 170 GeV is generated and the Higgs mass is determined in terms of the top mass. Assuming no new physics below the Planck scale, we construct explicit Renormalization Group trajectories for Standard Model and gravitational couplings which link the transplanckian regime to the electroweak scale and yield a top pole mass of $M_{\mathrm{t,pole}} \approx 171\,\mathrm{GeV}$.

Gravity-matter systems

Some exciting results were obtained in the Asymptotic Safety literature over the past two decades:

En route to test the compatibility of different mechanisms for neutrino masses in Asymptotic Safety [JHEP 08 (2019) 142]

On the impact of Majorana masses in gravity-matter systems

Gustavo P. de Brito,[a,b] Yuta Hamada,[c] Antonio D. Pereira[d,b] and Masatoshi Yamada[b]

Gravity-matter systems

Some exciting results were obtained in the Asymptotic Safety literature over the past two decades:

Asymptotically safe Standard Model + quantum gravity [SciPost Phys. 15, 105 (2023)]

The Asymptotically Safe Standard Model: From quantum gravity to dynamical chiral symmetry breaking

Álvaro Pastor-Gutiérrez[1,2], Jan M. Pawlowski[2,3] and Manuel Reichert[4]

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Gravity-matter systems

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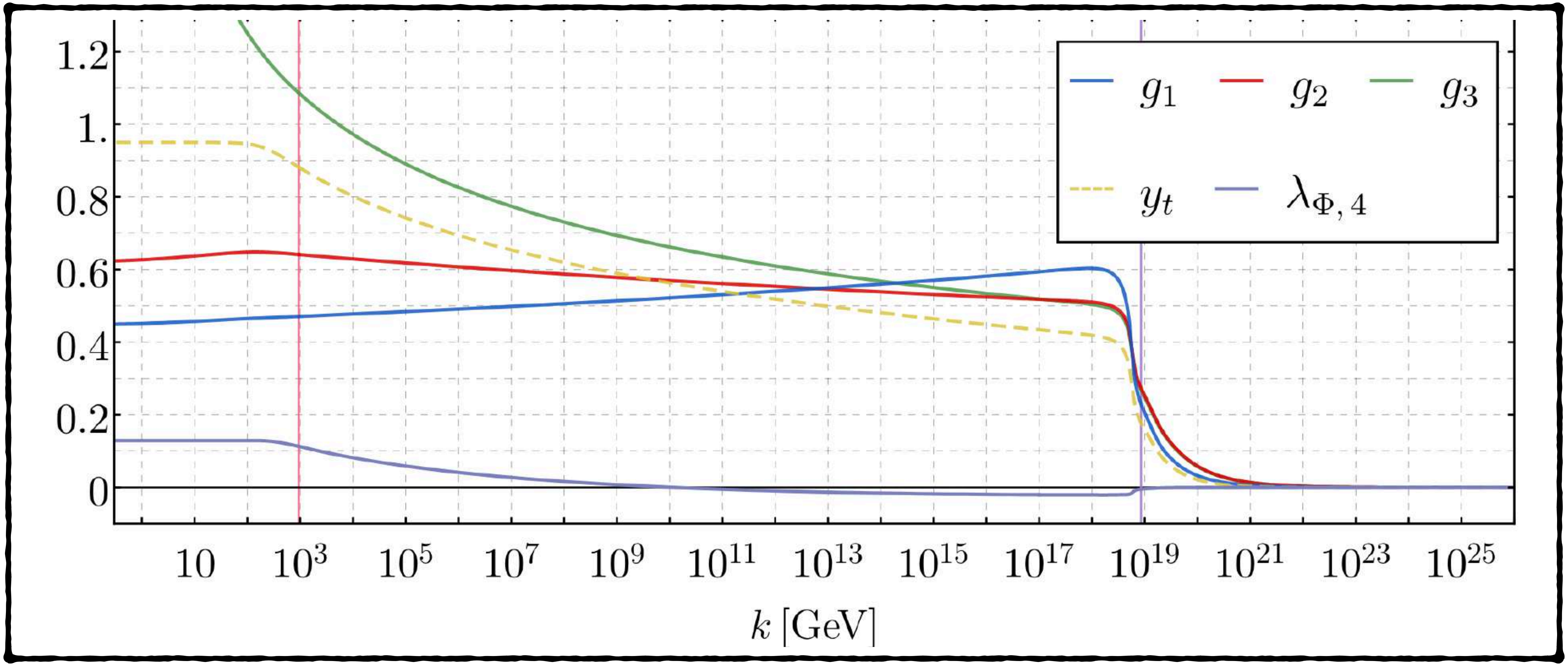

Gravity-matter systems

Some exciting results were obtained in the Asymptotic Safety literature over the past two decades:

No ALPs is Asymptotically Safe Quantum Gravity [JHEP 06 (2022) 013]

Are there ALPs in the asymptotically safe landscape?

Gustavo P. de Brito, Astrid Eichhorn and Rafael R. Lino dos Santos

Gravity-matter systems

Several other results were obtained by this interplay between quantum-gravity fluctuations and matter. See, e.g.,

[Submitted on 14 Dec 2022]

Asymptotic safety of gravity with matter

Astrid Eichhorn, Marc Schiffer

Gravity-matter systems

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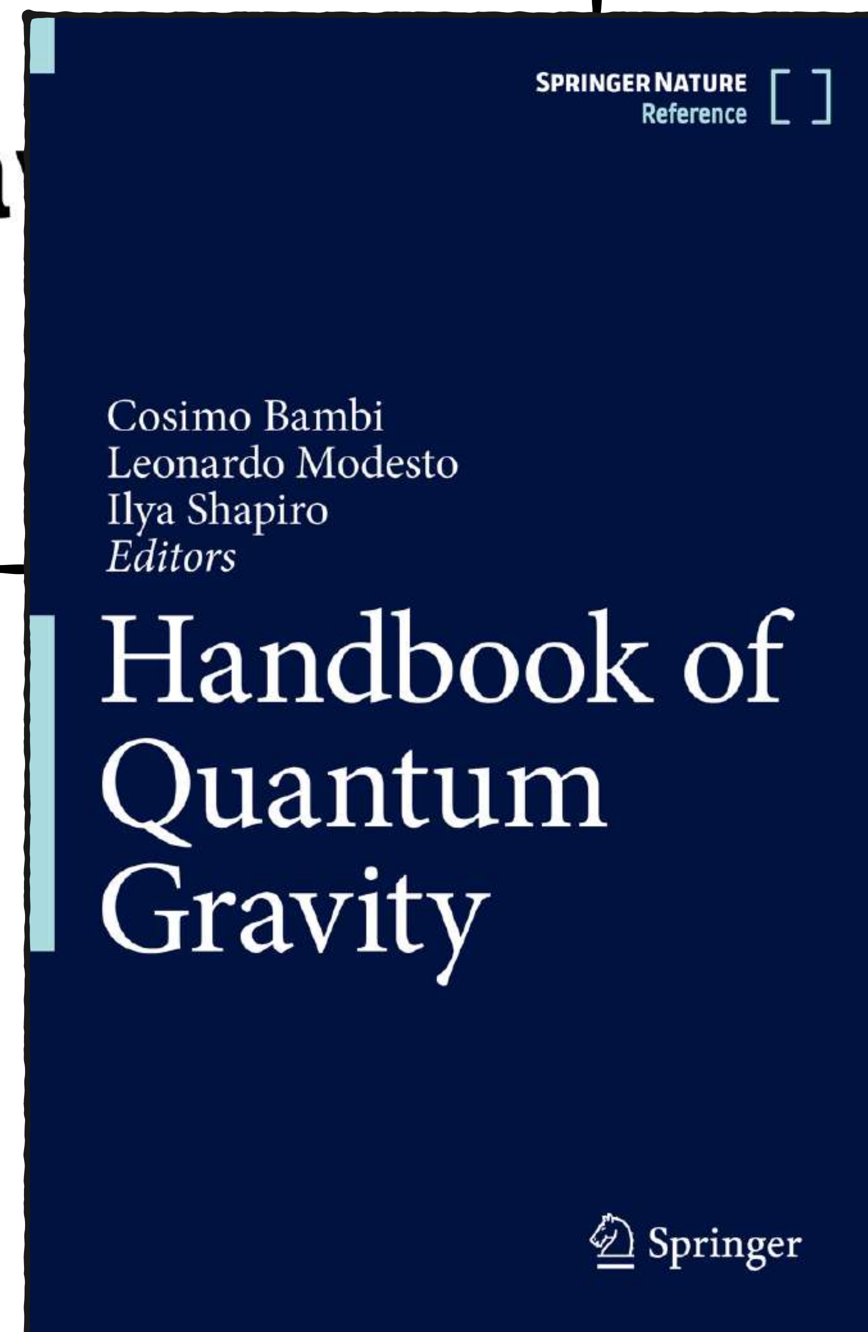

Final words

It seems that we cannot exclude the possibility of quantum gravity to be described by an asymptotically safe standard QFT

Non-perturbative tools are mandatory in this case - Big Challenge!

We have indications that the theory coupled to matter can produce consistency checks and even predictions

Many challenges ahead:

How to transport everything that we have learnt so far to the Lorentzian setting?

Is the theory unitary?

Do we have a complete RG-trajectory that emanates from the UV to our IR?

How to connect the results obtained with the FRG and other non-perturbative schemes?

Many of those questions have been under investigation over the past few years. Little time to tell details.

Thank you

Predictive Power

The existence of the UV-fixed point imposes severe constraints on the RG-flow

Quantum Scale Symmetry

↓

Finitely many free parameters

We have evidence for the necessity of 3 relevant directions

The theory is predictive

This is a hint for a fixed point that is not deeply non-perturbative

$G_k = k^{2-d} g_k$ $\qquad$ $\beta = (d-2) g_k + F_k(g)$

$d = 4$ $\qquad$ $\beta = 2 g_k + F_k(g)$

Perturbative calculations: asymptotic freedom ← $d = 2$ $\qquad$ $\beta = F_k(g)$

Asymptotic Safety can be established perturbatively ← $d = 2 + \epsilon$

This led Weinberg to conjecture the Asymptotic Safety scenario in four dimensions