Asymptotic Safety meets field redefinitions

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2204.08564
2312.03831 w/ A. Baldazzi, K. Falls, Y. Kluth
2311.12097

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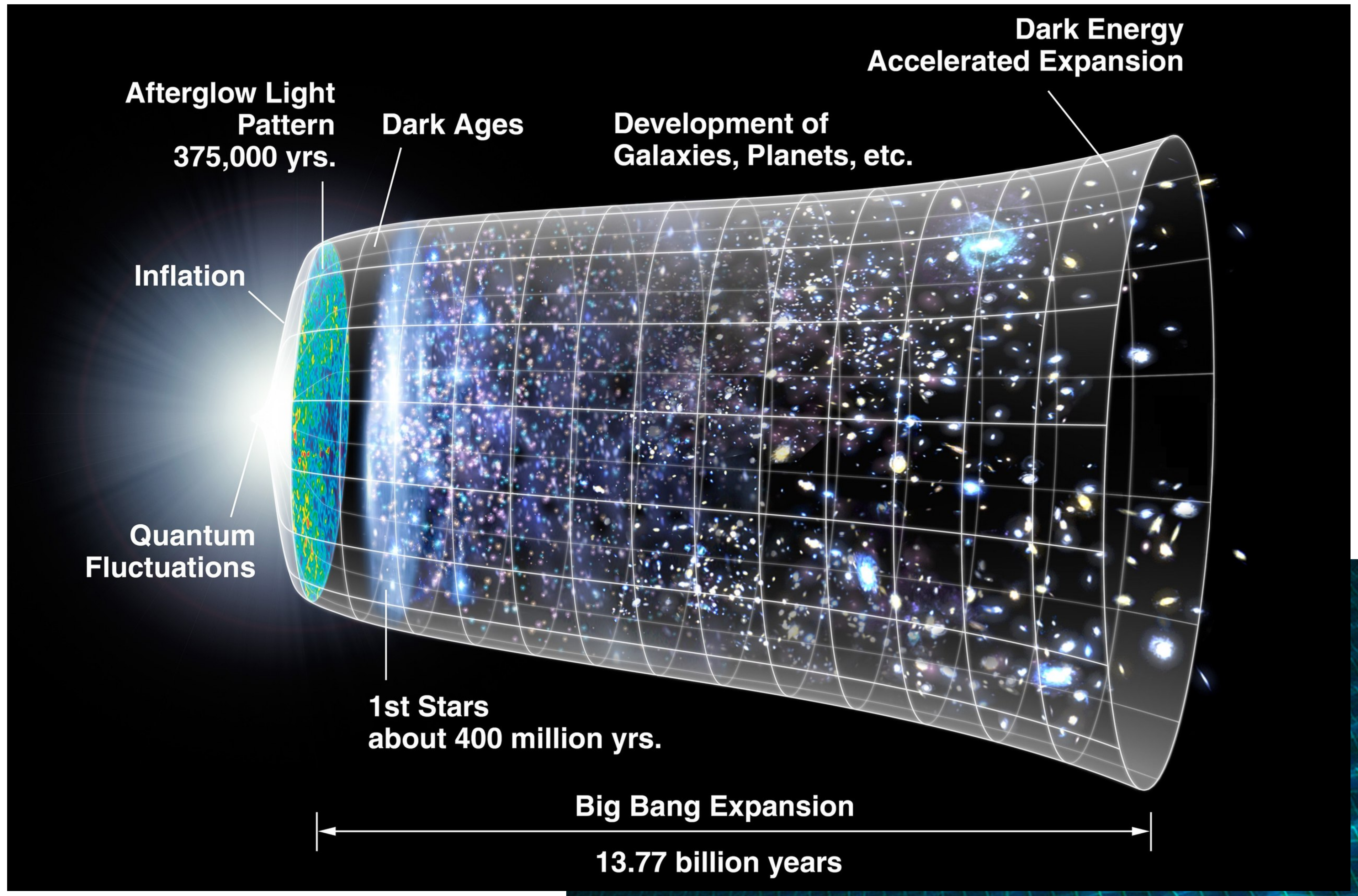
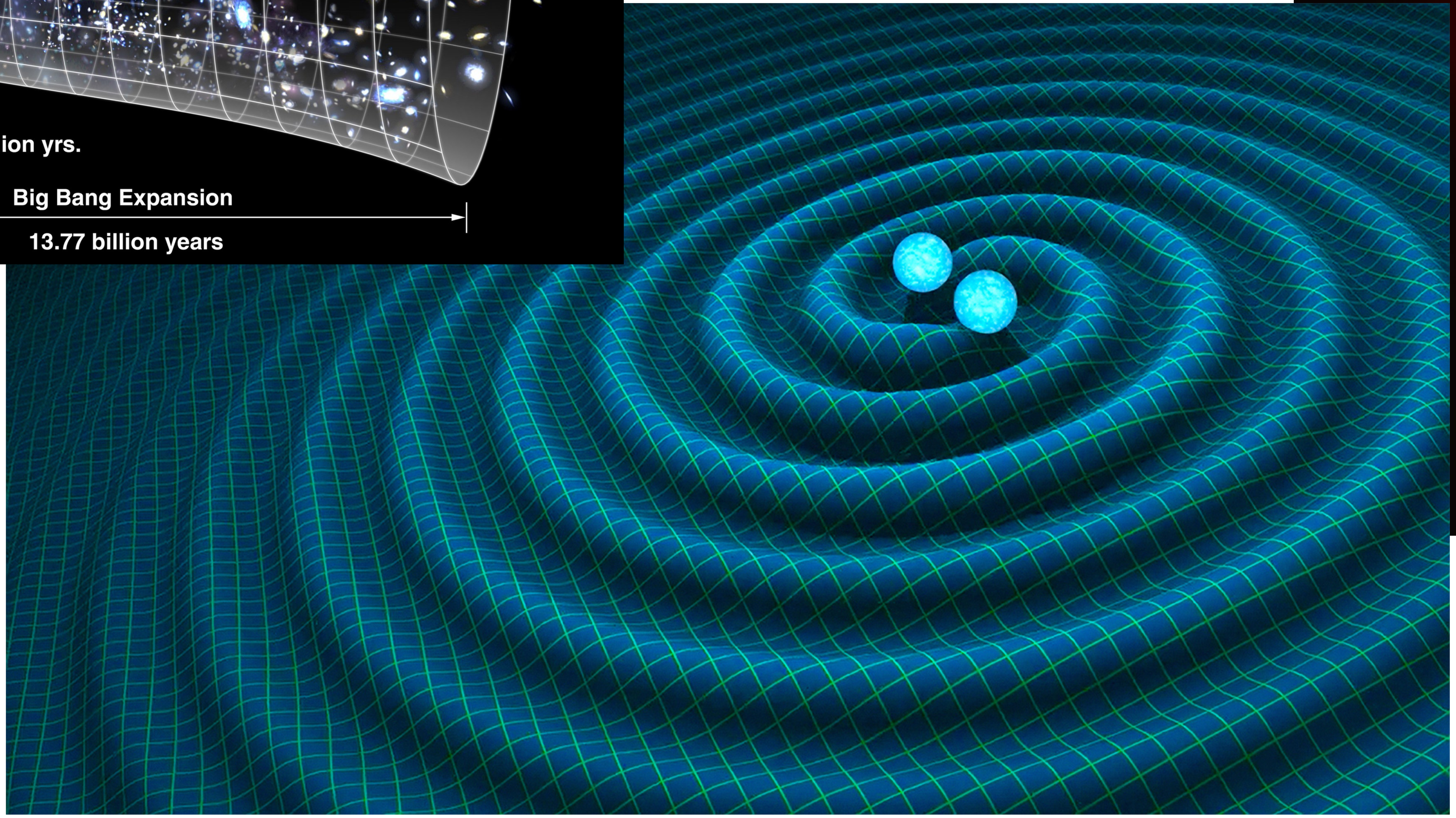
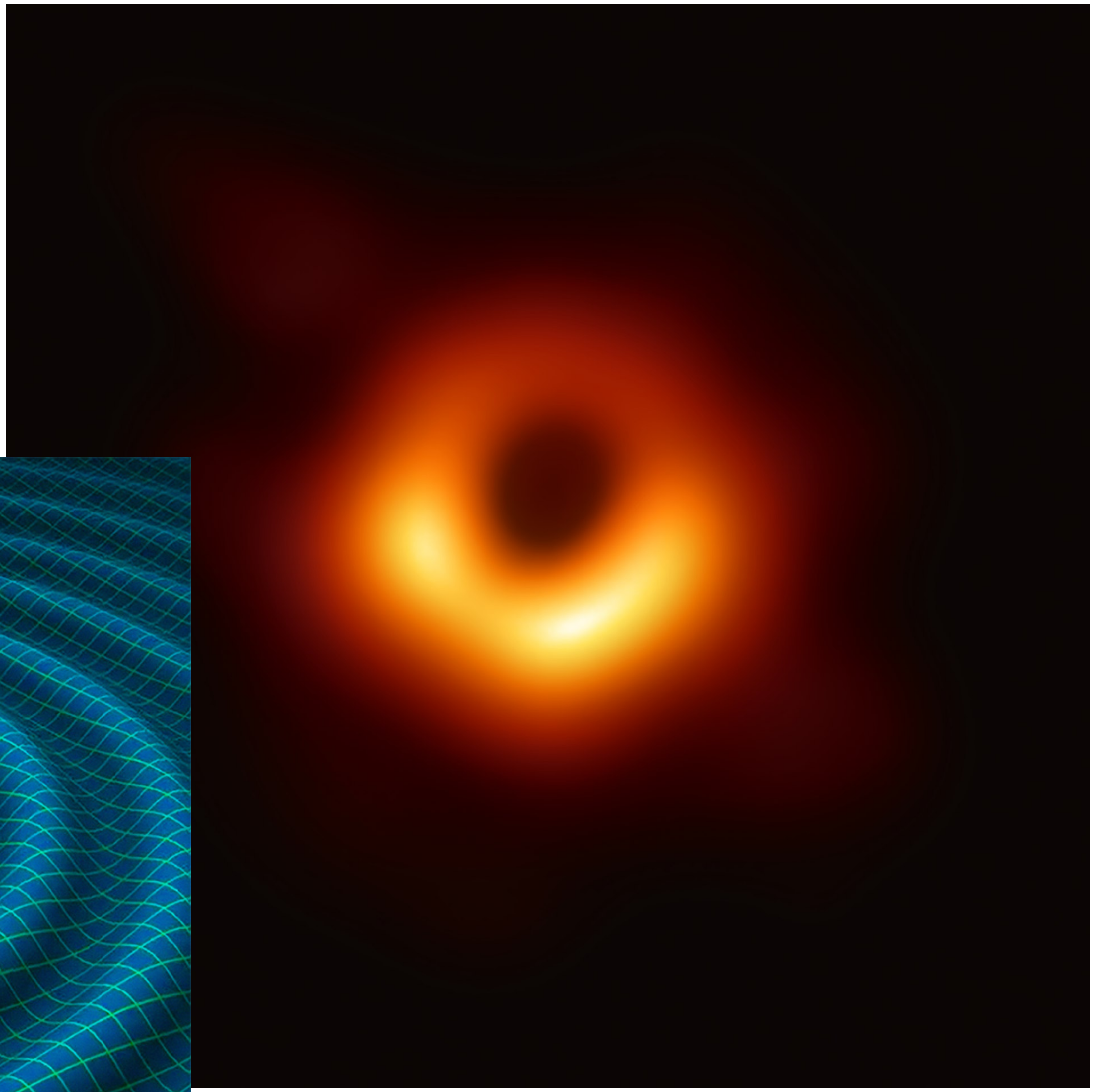
The Nordic Institute for Theoretical Physics

A Perspective on Quantum Gravity







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quantum gravity experiments

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**why trust any
approach in particular?**

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- today: focus on step 1a, be as conservative as possible

Outline

- Quantum Gravity as a QFT
- Asymptotic Safety
- Field redefinitions and essential couplings
- Results

Quantum Gravity as a QFT

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- established experimental fact: coupling constants “run with energy”

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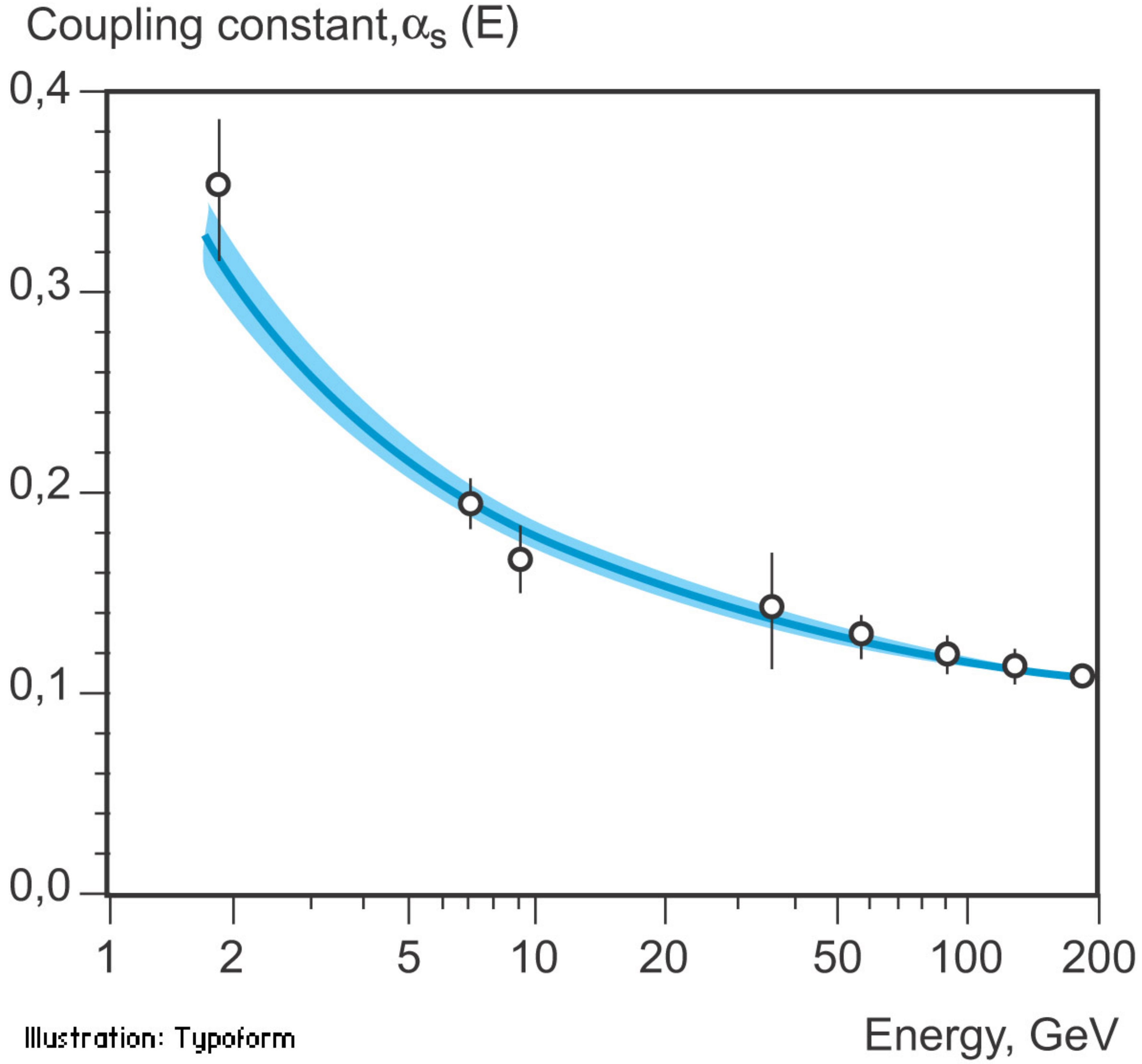

Nobel prize in Physics 2004
(Gross, Politzer, Wilczek)
“for the discovery of asymptotic freedom in the theory of the strong interaction”

nobelprize.org

Running coupling constants

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- measure scattering cross sections and compare them to theoretical predictions - coupling “constants” depend on energy scale dictated by their beta functions - **renormalisation group**

$$\beta_{\alpha_s} = -\left(11 - \frac{2}{3}N_f\right)\frac{\alpha_s^2}{2\pi} + \mathcal{O}(\alpha_s^3)$$

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- Quo vadis, quantum gravity?

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- the actual problem: **predictivity**

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vanish on-shell

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topological in d=4

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$$\Delta\Gamma^{\text{2-loops}}_{\text{div,OS}} \propto \frac{1}{\epsilon} \int \mathrm{d}^4x \sqrt{-g} \, \left[\tilde{a} \, C_{\mu\nu}{}^{\rho\sigma} C_{\rho\sigma}{}^{\tau\omega} C_{\tau\omega}{}^{\mu\nu}\right]$$

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$$\tilde{a} \neq 0$$

Goroff, Sagnotti '85, '86
van de Ven '92

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Is GR non-perturbatively renormalisable?

Asymptotic Safety

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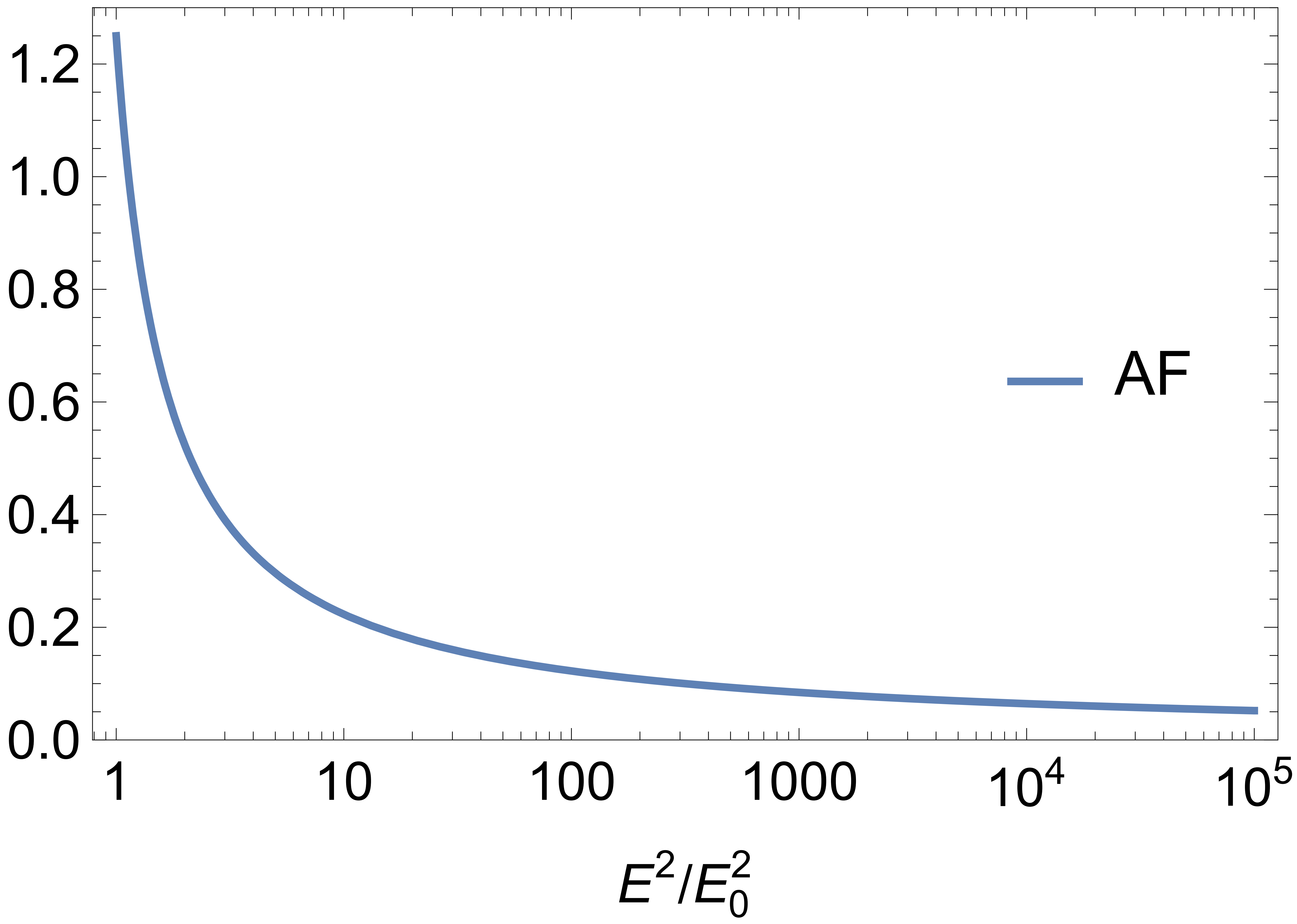
(aka non-perturbative renormalisability)

Asymptotic Safety in a plot



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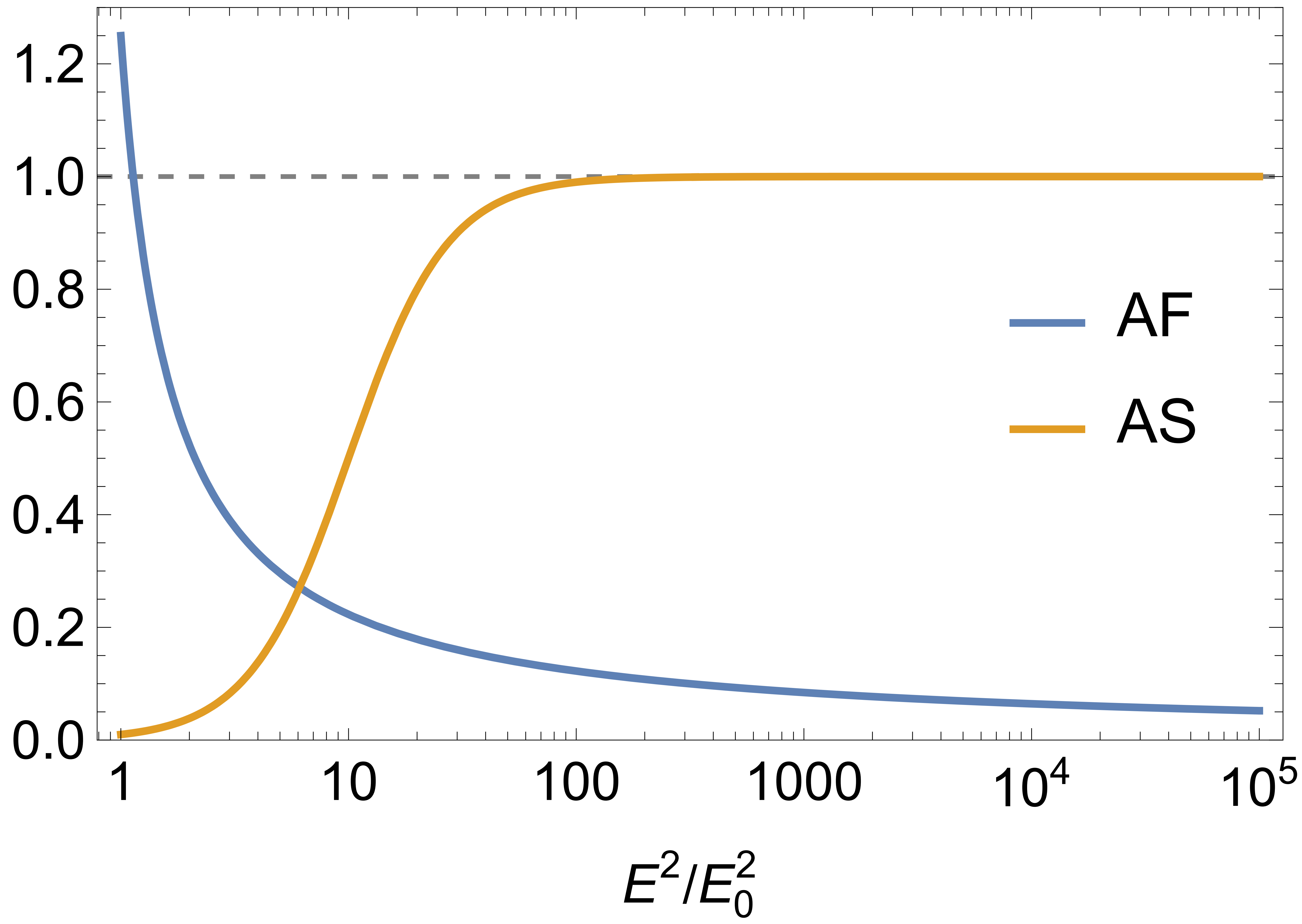

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    difficulty: generically have to include all operators consistent with symmetry

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critical exponents: positive is “bad” (“relevant”, needs measurement),
negative is “good” (“irrelevant”, fixed by fixed point)

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- tool: **F**unctional **R**enormalisation **G**roup (**FRG**)

Asymptotic Safety via FRG

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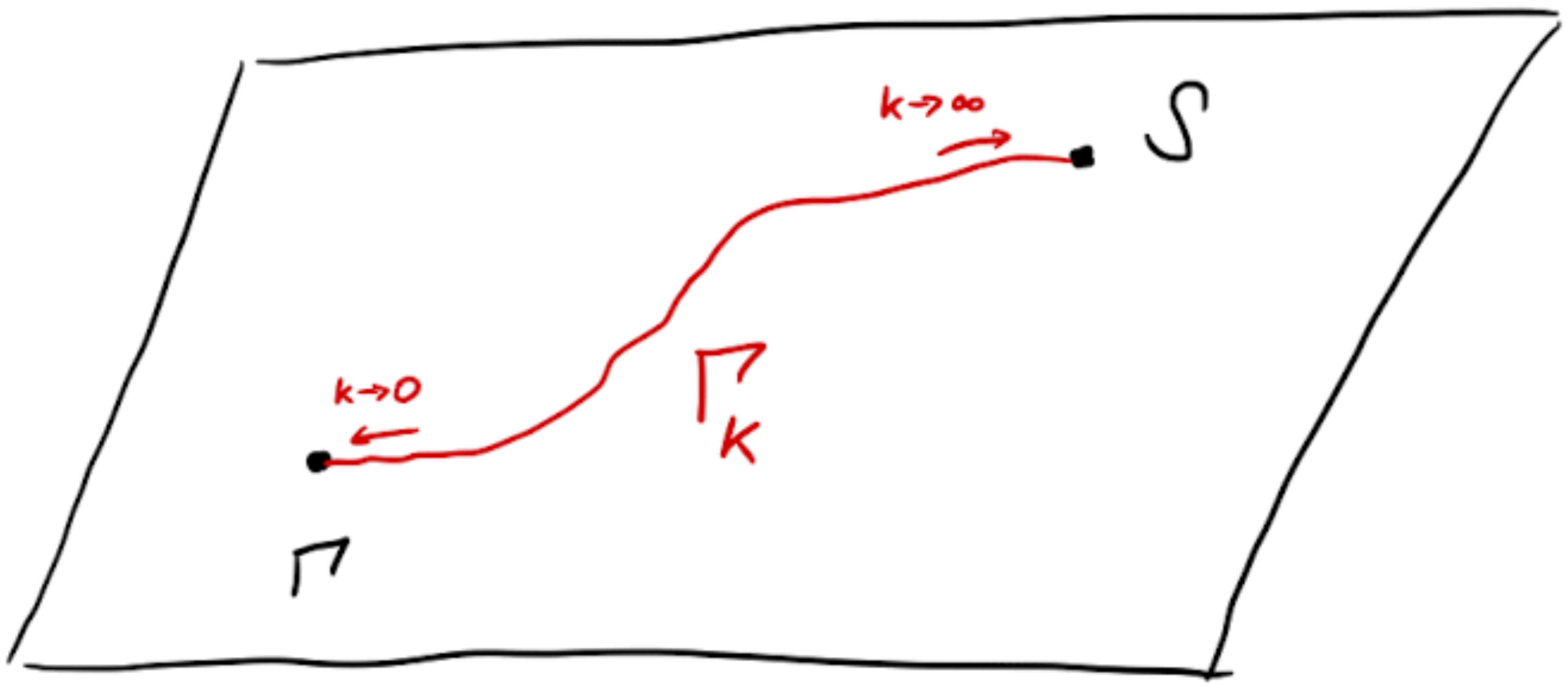

Asymptotic Safety via FRG

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- governed by **exact non-perturbative** RG equation:

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Wetterich '93

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- no free lunch: requires approximation

Field redefinitions and essential couplings

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- in particular: can redefine fields, but **conditions apply:**

    - don’t remove or introduce degrees of freedom

    - non-local redefinitions can be dangerous

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- different choices of field redefinitions give rise to different schemes, moves momentum dependence in scattering amplitude between different diagrams

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$$S = \int \mathrm{d}^4 x \, \frac{Z}{2} (\partial_\mu \phi)(\partial^\mu \phi) \,, \qquad \phi \mapsto \frac{1}{\sqrt{Z}} \phi$$

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Minimal essential scheme

- minimal essential scheme (MES): set everything to zero that you can set to zero by suitable field redefinition

Baldazzi, Ben Alì Zinati, Falls
2105.11482
Baldazzi, Falls
2107.00671

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- in theory with given spectrum, can put propagator into tree-level form

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- implication for Asymptotic Safety: only **essential** couplings need a fixed point!

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- running field redefinition - modification of flow equation

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Pawlowski hep-th/0512261; Baldazzi, Ben Alì Zinati, Falls 2105.11482

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$$\Psi_k = \langle \dot{\Phi}_k \rangle$$

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- plan for the rest of the talk: span action by essential operators only and investigate AS

AS in the MES - results

Two-loop counterterm

- approximation:

$$\Gamma_k = \frac{1}{16\pi G_N} \int \mathrm{d}^4x \, \sqrt{g} \, \left[2\Lambda_k - R + G_{C^3} \, C_{\mu\nu}{}^{\rho\sigma} C_{\rho\sigma}{}^{\tau\omega} C_{\tau\omega}{}^{\mu\nu} \right]$$

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- CC technically inessential, but needed for consistency at finite k

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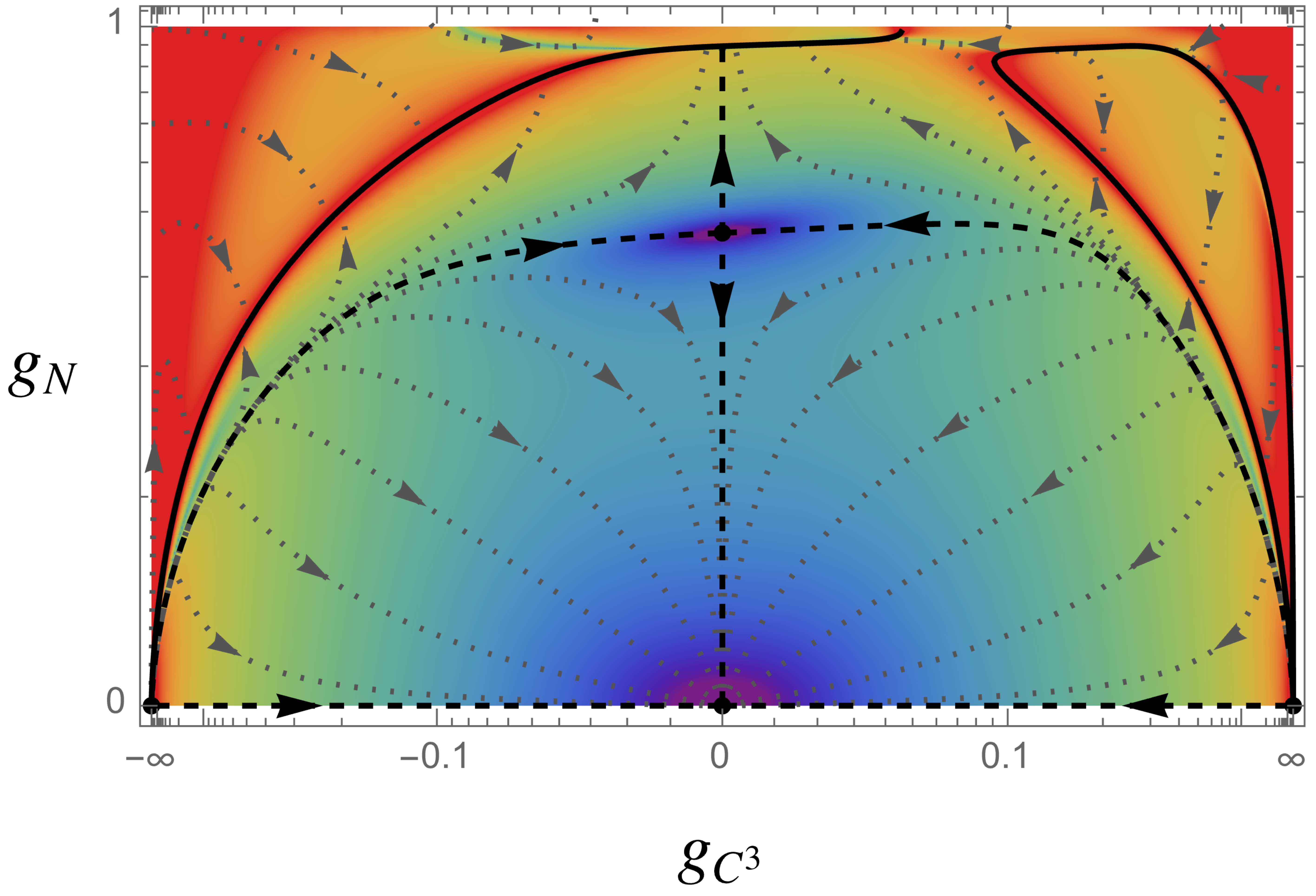

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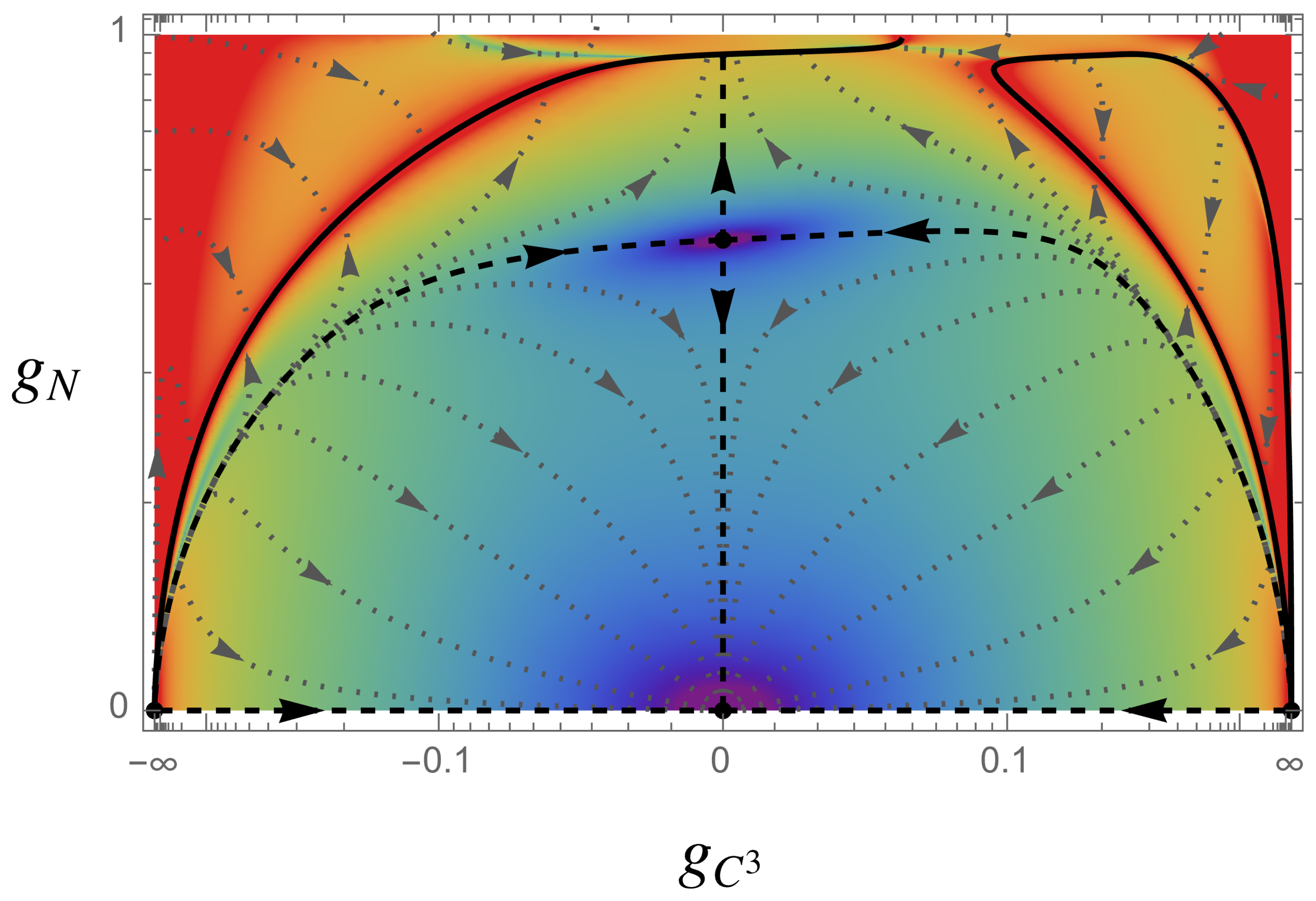

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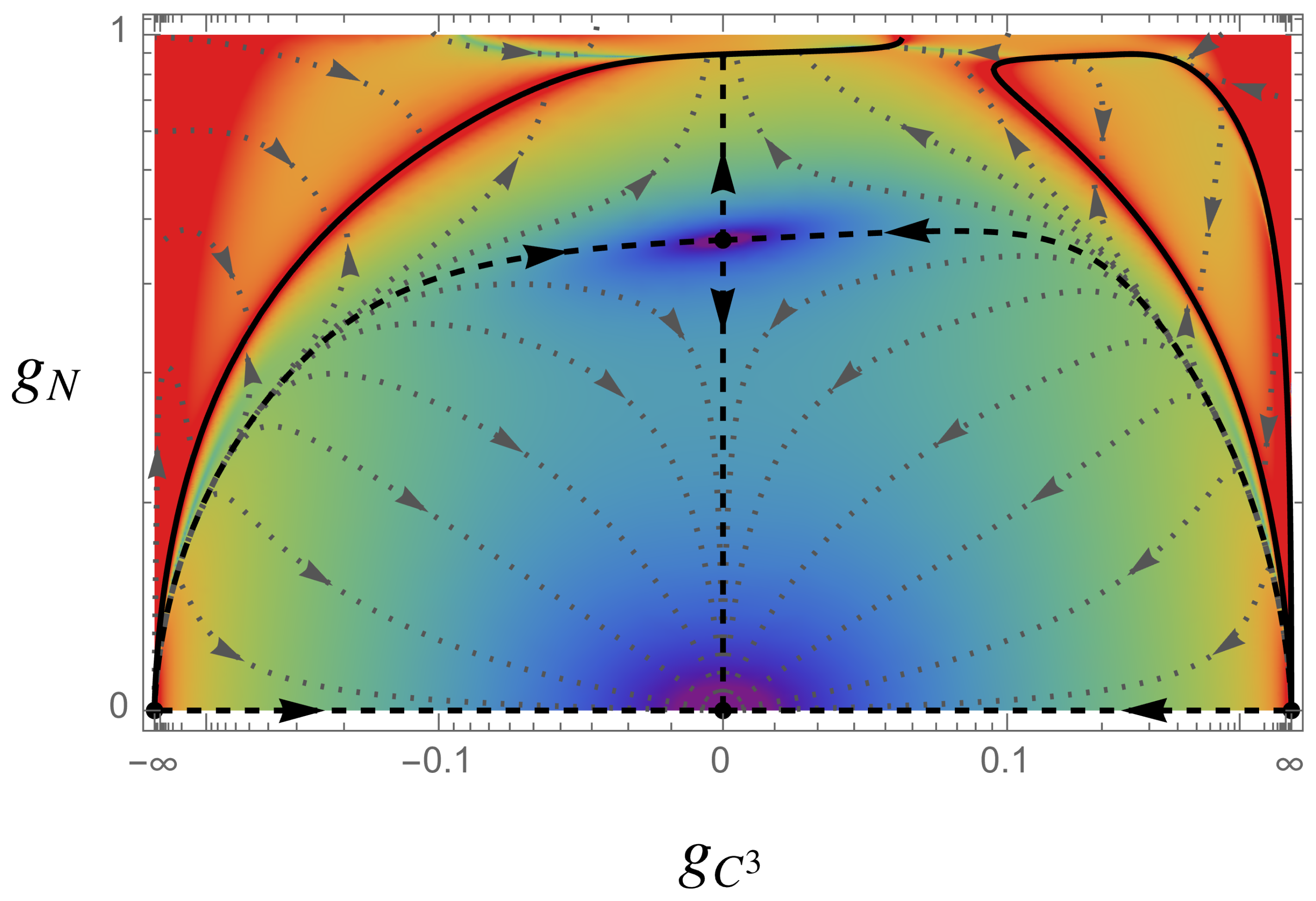

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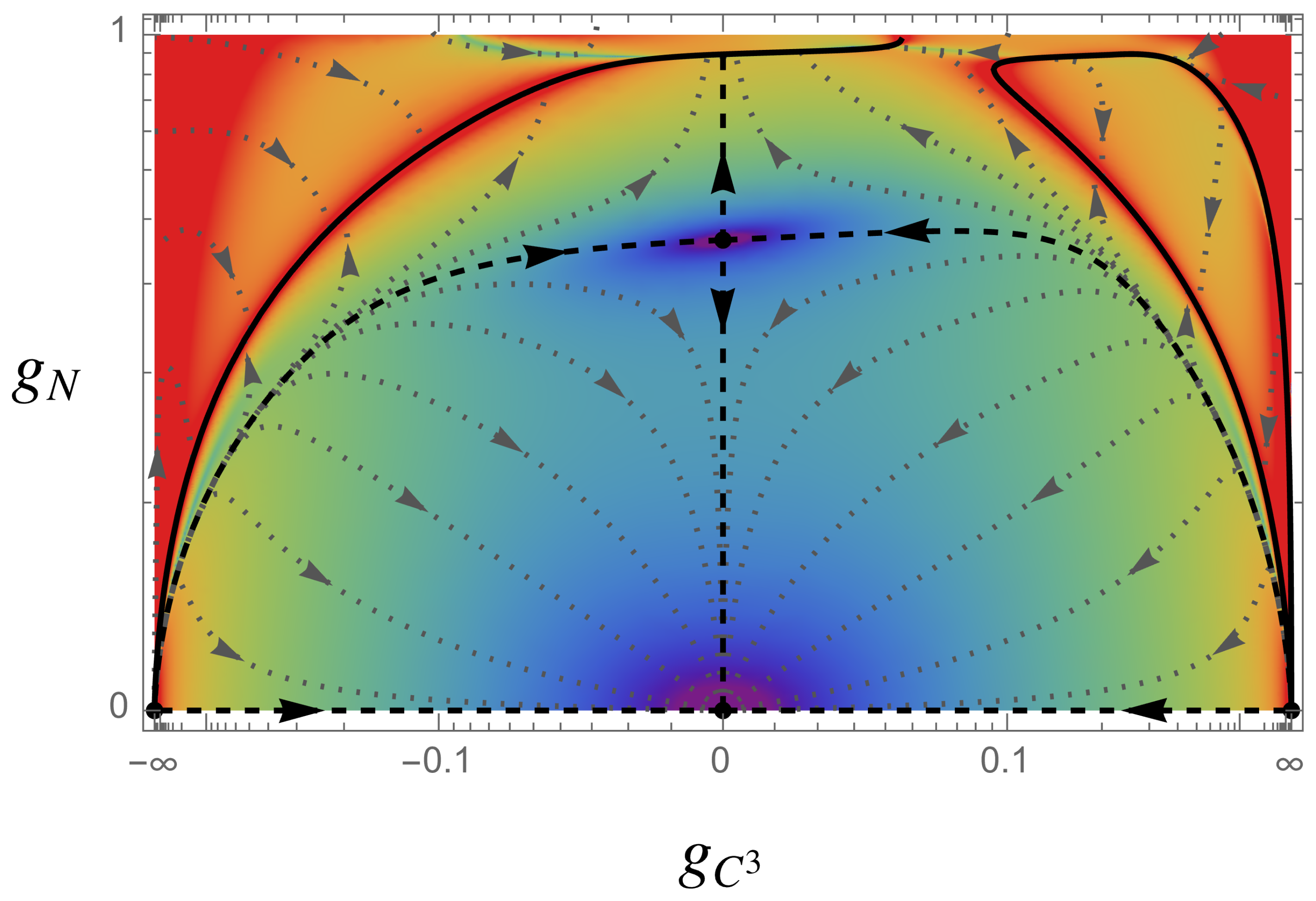

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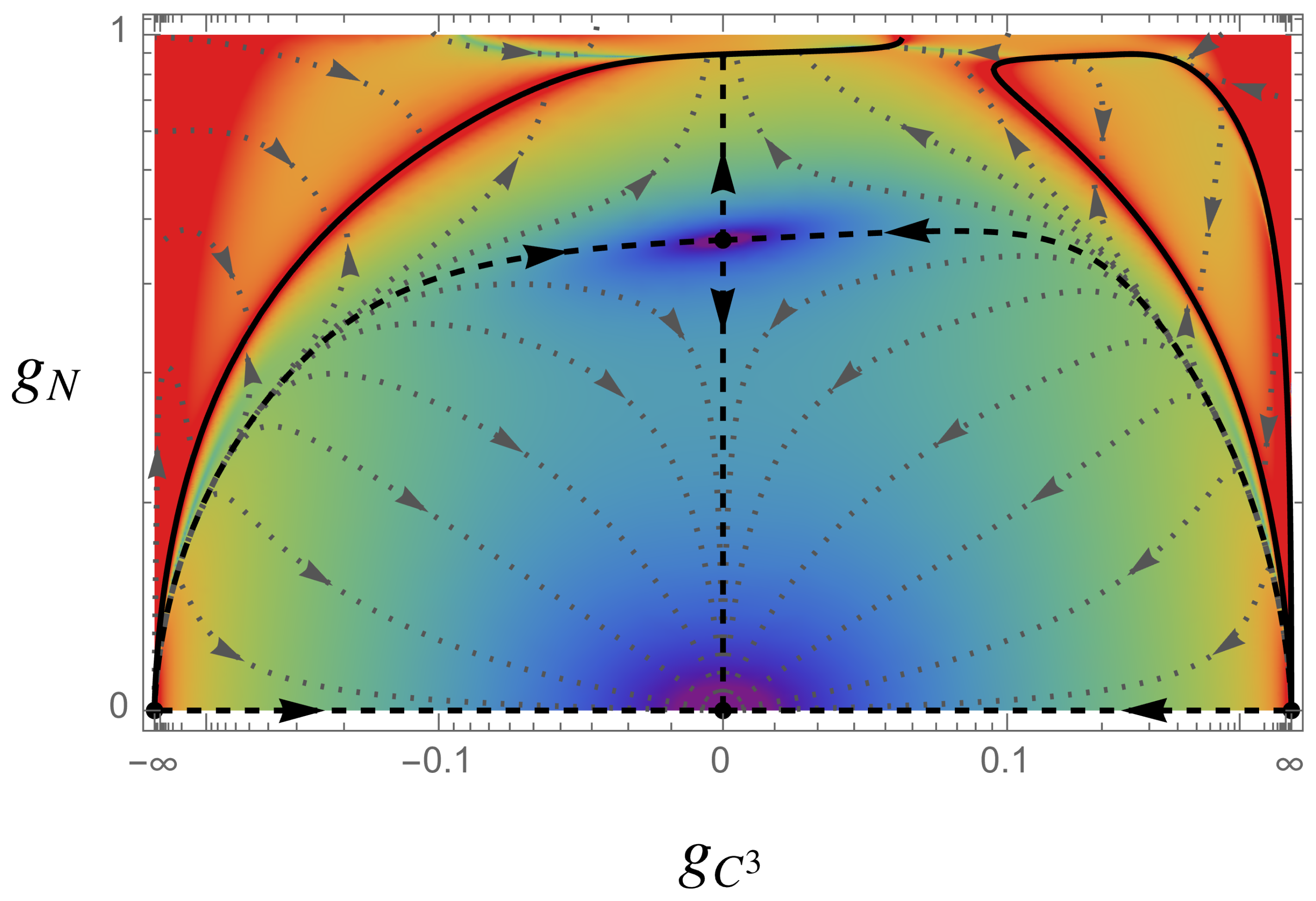

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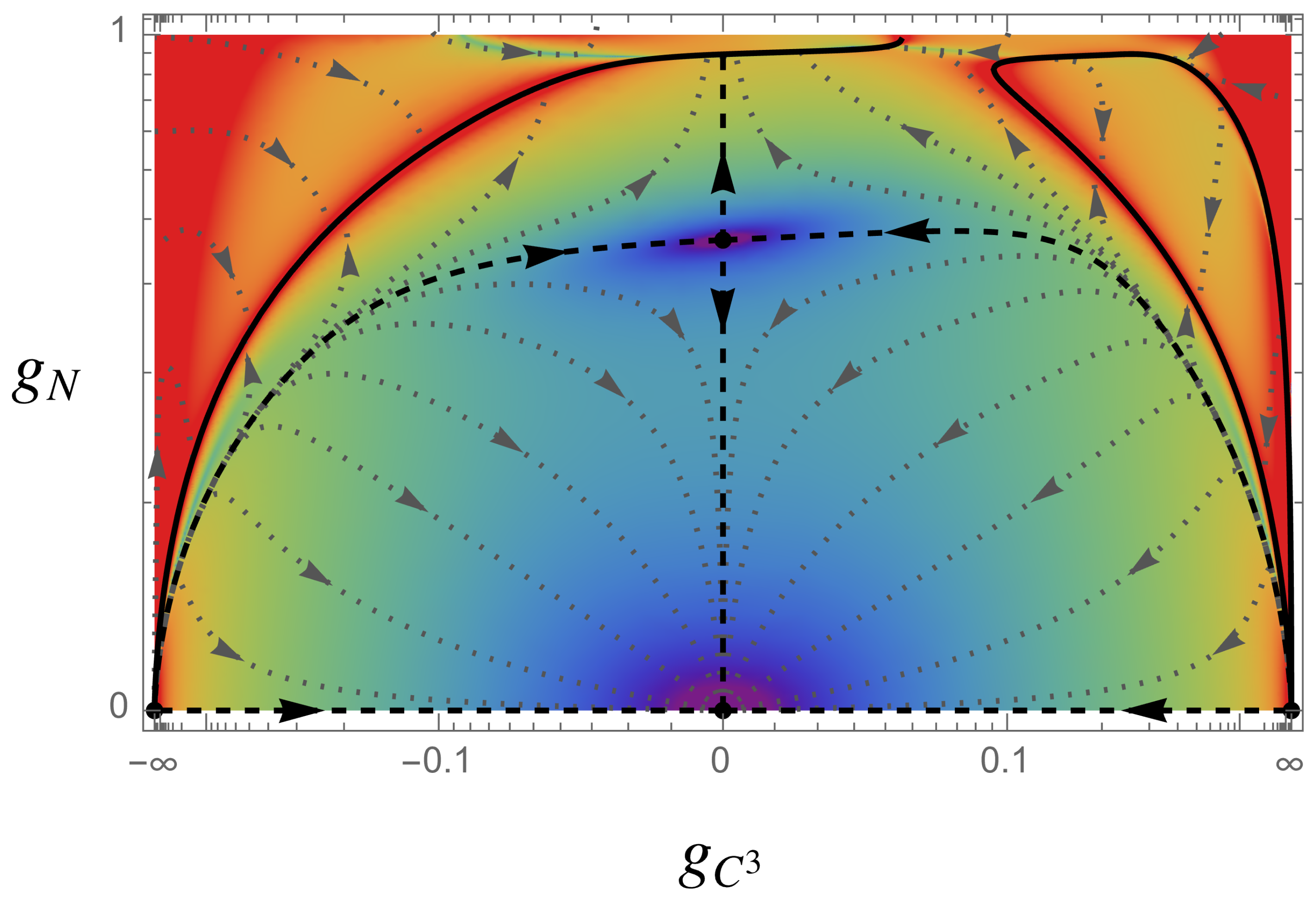

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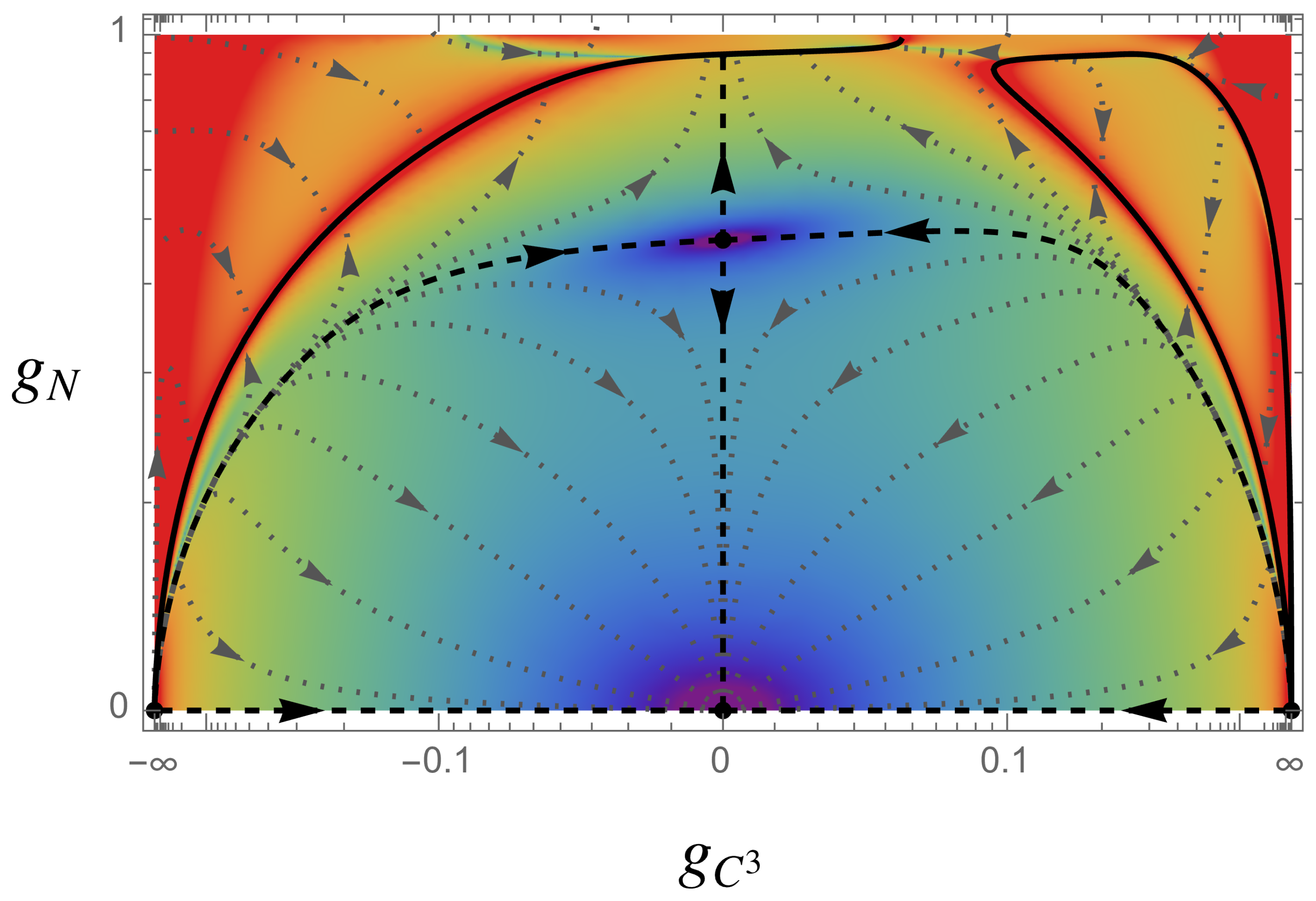

compatible with “standard” scheme

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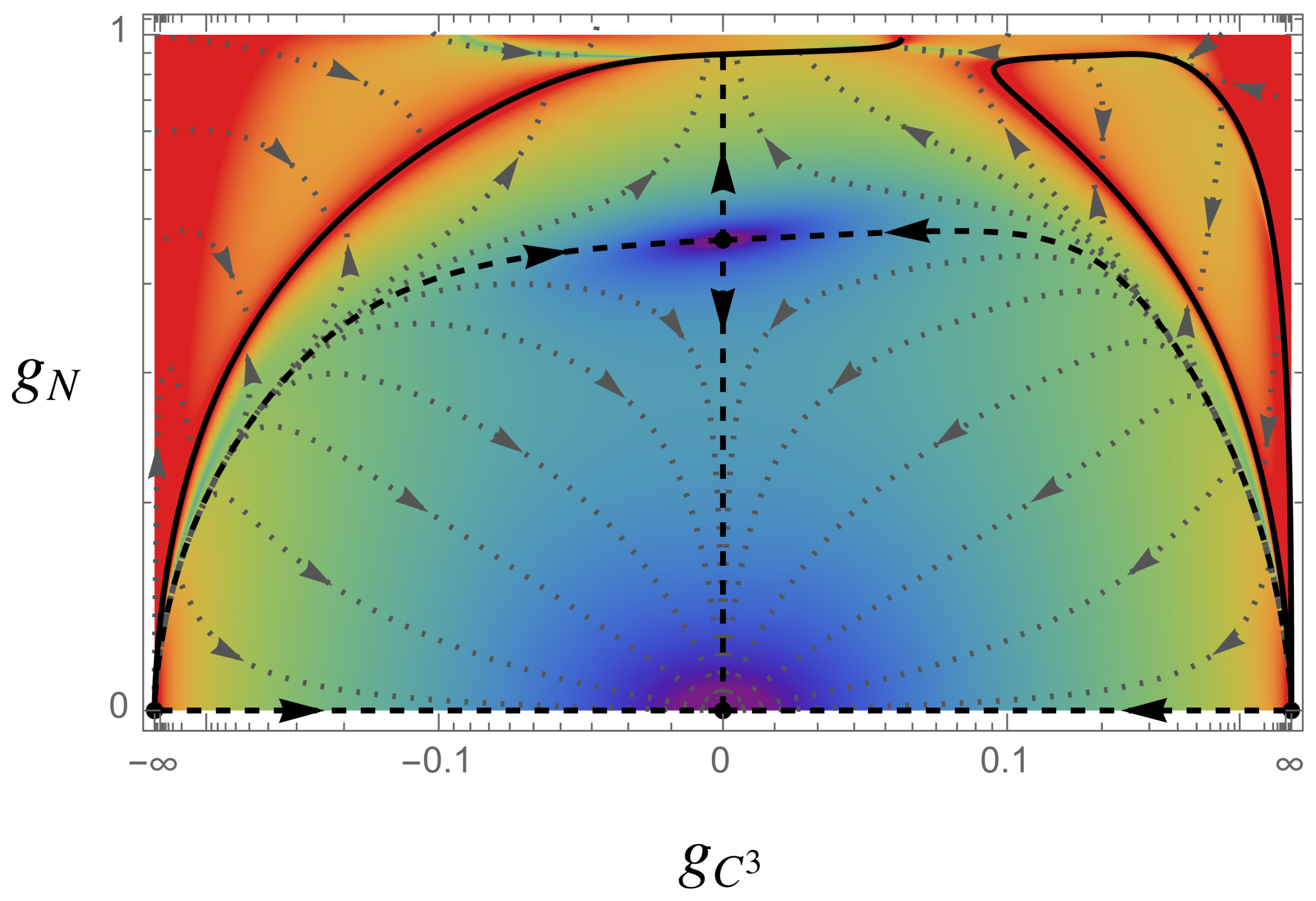

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AS tames the two-loop counterterm!

see also H. Gies, BK, S. Lippoldt, F. Saueressig 1601.01800

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Other results

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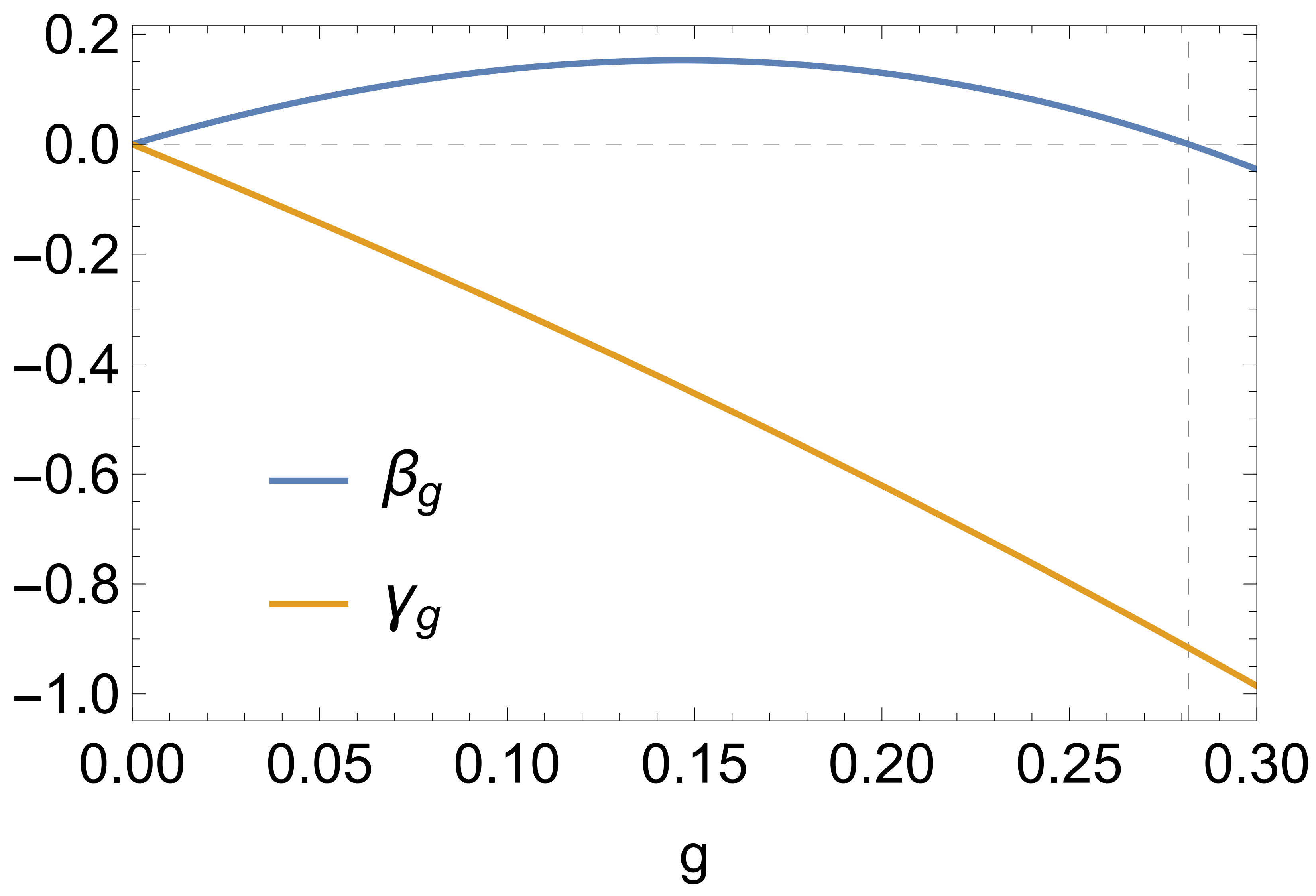

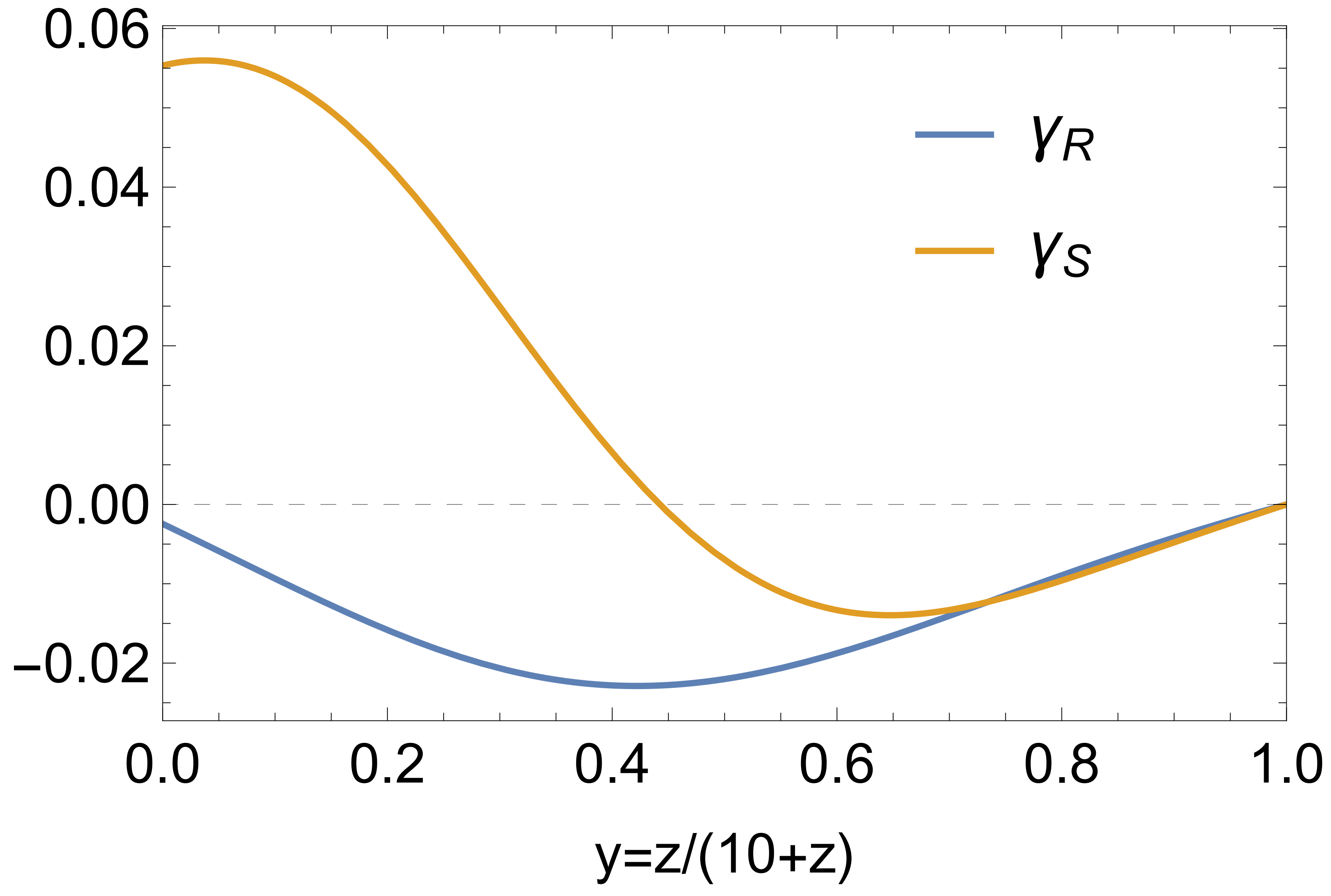

Other results

- graviton propagator

  BK 2311.12097

- gravity+shift-symmetric scalar

  BK 2204.08564

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$$\Gamma_k = \int \mathrm{d}^4x\,\sqrt{g}\,\left\{\frac{1}{16\pi G_N}\left[-2\Lambda + R + G_{\mathfrak{E}}\mathfrak{E}\right] + \frac{1}{2}D^\mu\phi D_\mu\phi + G_{D\phi^4}\left(\frac{1}{2}D^\mu\phi D_\mu\phi\right)^2\right\}$$

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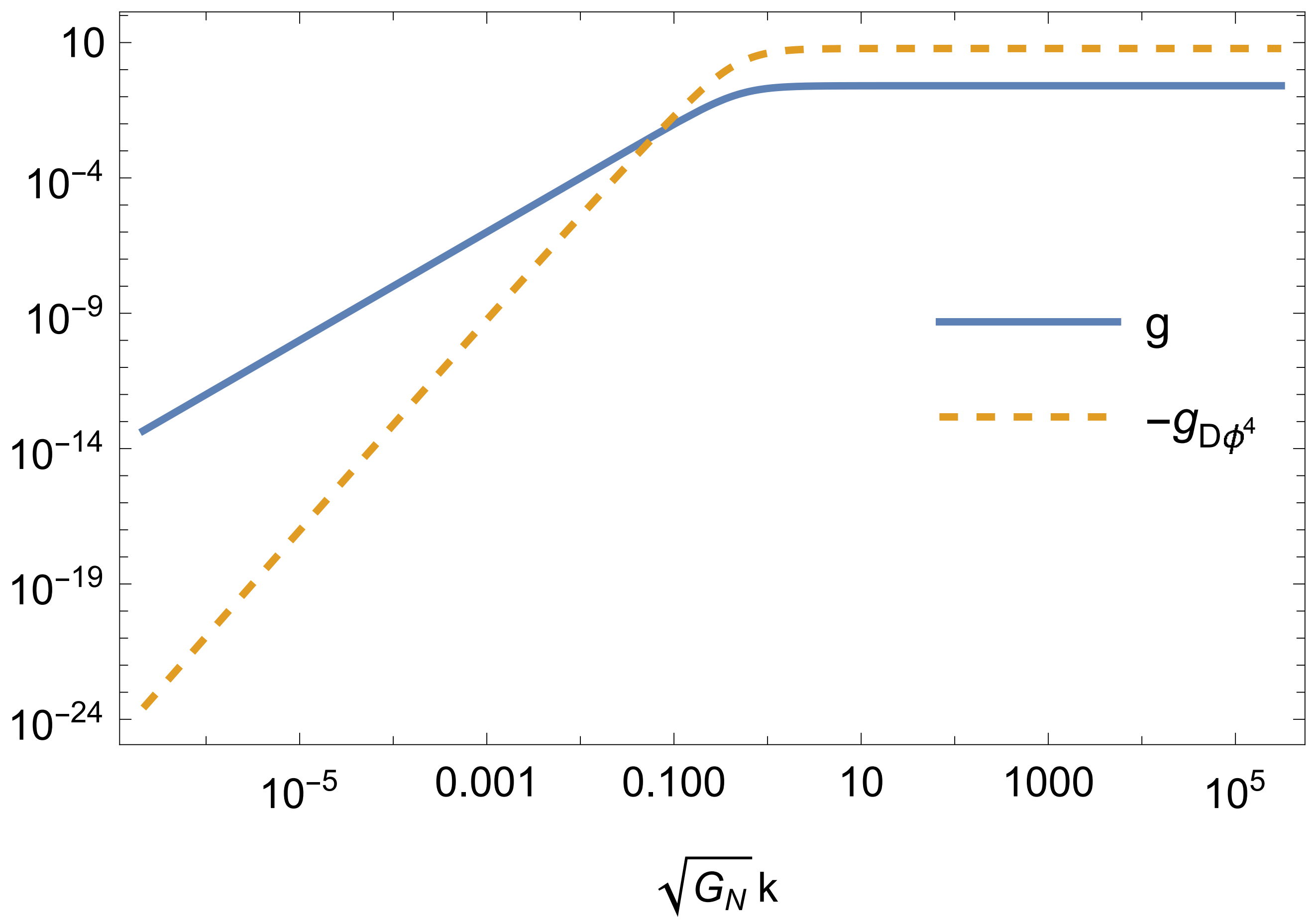

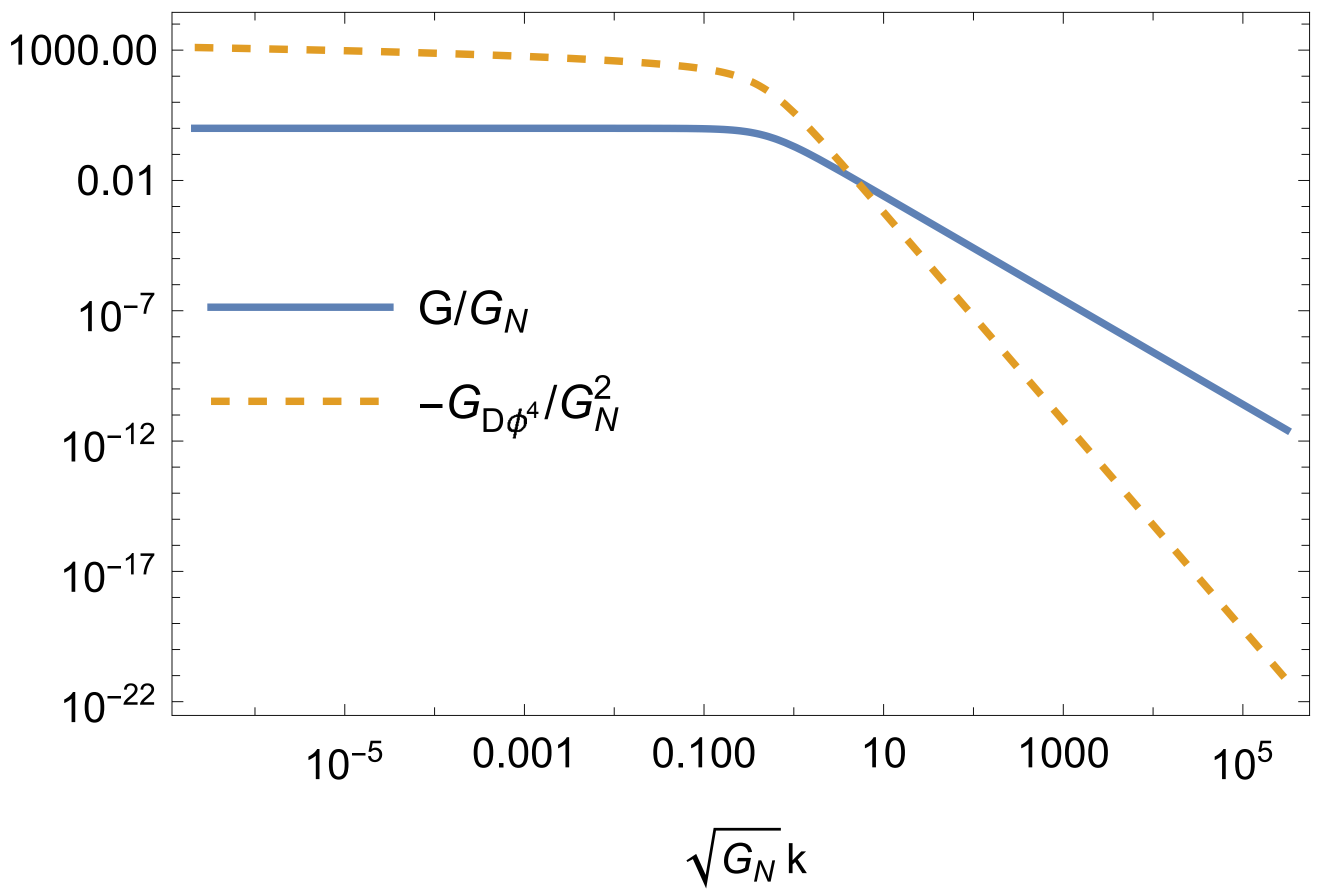

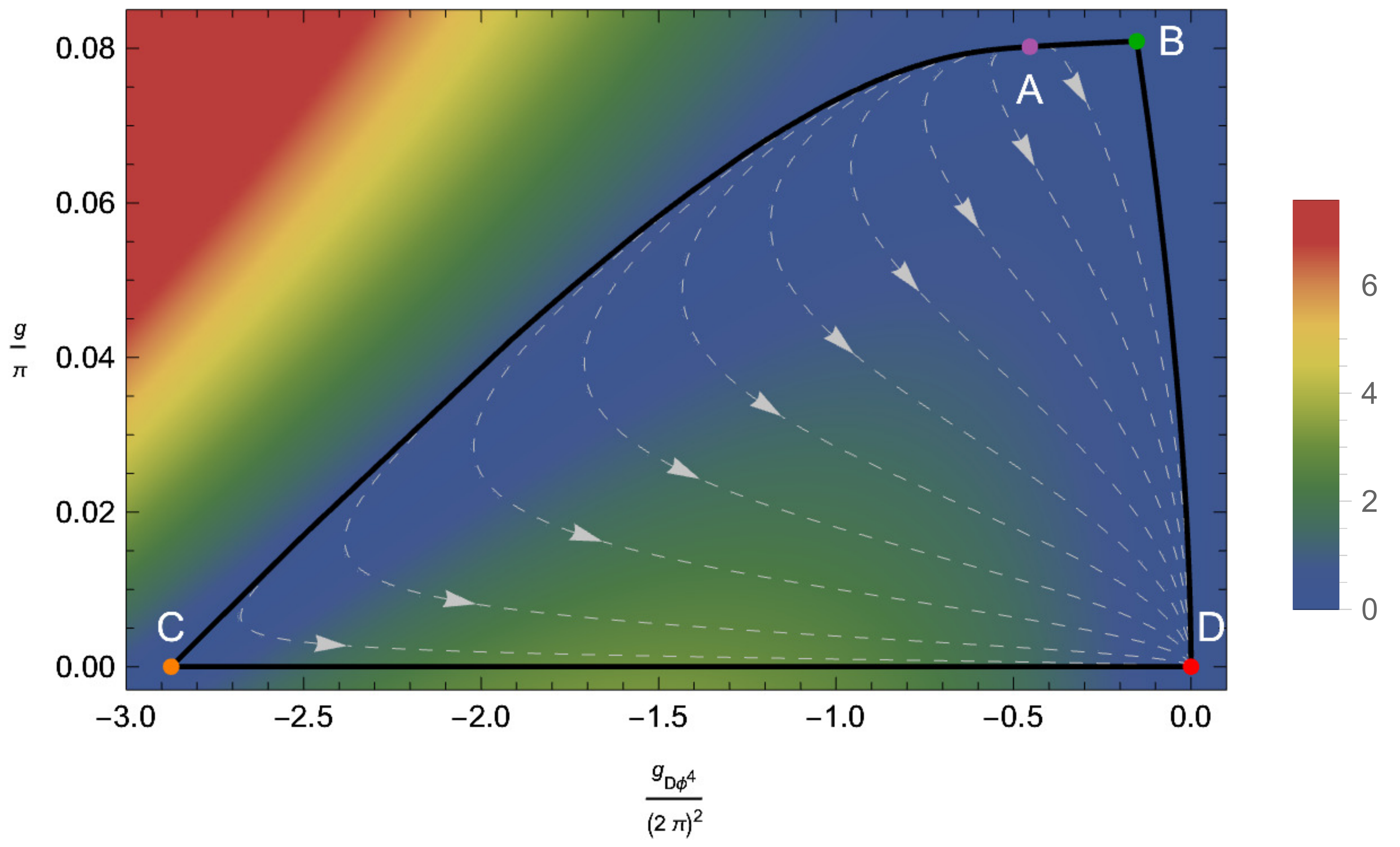

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- AS can tame the two-loop counterterm - non-trivial test

Quantum Gravity: From Gravitational Effective Field Theories to Ultraviolet Complete Approaches

29 July 2024 to 23 August 2024 — Albano Building 3

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Abstract and goal

The formulation of a consistent theory of quantum gravity is one of the most outstanding and pressing unsolved problems in theoretical physics, which has aroused interest since the middle of the last century. In the last decades, there have been several interesting developments, and promising novel ideas have been proposed, ranging from effective field theory approaches to ultraviolet complete theories. The main objective of this Nordita Scientific Program is to assess our current understanding of the interplay between gravity and quantum physics by addressing central questions, contrasting different approaches, and permitting a genuine exchange of ideas. In addition to focusing on formal aspects of several quantum gravity approaches, their applications in the context of cosmology and black hole physics will be discussed. The program is structured as follows:

- Week 1: PhD School "Towards Quantum Gravity" (topics: Perturbative quantum gravity, Effective field theory, Non-perturbative renormalisation group, String theory, Quantum cosmology, and Quantum black holes)
- Week 2: Workshop on Formal Aspects and Consistency of Quantum Gravity Approaches, part I
- Week 3: Workshop on Formal Aspects and Consistency of Quantum Gravity Approaches, part II
- Week 4: Workshop on Quantum Gravity Phenomenology

During the workshop, individual talks will be complemented by discussion sessions that will help to make the event more interactive and productive, so as to become the source of constructive debates and new insights towards a deeper understanding of gravitational physics at fundamental scales.

Talks are by invitation only.